GUIDELINES FOR ENERGY EFFICIENCY HBIM DEVELOPMENT OF EXISTING BUILDINGS

Date: 29/07/2021

Authors: Elena Gigliarelli, Filippo Calcerano, Letizia Martinelli (ISPC-CNR) - Stavroula Thravalou, Kristis Alexandrou, Georgios Artopoulos (CI-EEWRC)

This project is funded by the EU under the ENI CBC Med Programme

Index

1 INTRODUCTION

1.1 Document purpose

This document provides a technical guideline for an energy audit of a historical building to support its energy and environmental improvement (as shown in the Energy Audit Process Flow schema based on the EN 16247-2:2014, see par 1.4), from the analyses to the design stage up to the Energy Performance Contracting implementation.

Each section of the guideline can also be used as technical specification for tender activities, along with the related template Annex.

1.2 General Project Information

This guidelines' document was developed within the ENI CBC Med BEEP project and aims to enhance the capacity of public local administrations to design, and realise innovative energy and environmental improvement on historic public buildings, through a multidisciplinary and integrated digital approach (using Building Information Modelling and performance-based design to develop an Energy Efficient Heritage Building Information Model - EE-HBIM). The guideline is based on the testing of this emerging technology on built heritage in eight different EU and non EU Mediterranean countries to demonstrate its scalability to the entire building stock of the Med area. The project will provide public administrations with a powerful method for the energy rehabilitation of public buildings to be supported with private funds through the Energy Performance Contracting.

The HBIM model should integrate previously collected information on the building (geometric, diagnostic, environmental data), to create a comprehensive documentation of the building's current state. Moreover, the HBIM model will be used as a basis to inform the subsequent simulation-based energy-environmental improvement concept, through energy renovation scenarios that are both compatible with the identified historic buildings and capable to enhance its energy and environmental performance.

1.3 Energy and Environmental Performance Improvement of Built Heritage: a framework

On this very subject it should be remembered that any protection order placed on cultural assets must be accepted as one of the many limitations (economic, respect of norms, functional, energy usage etc.) which an architectural design is constantly held to abide by and resolve. It is an arduous and stimulating, but by no means impossible, challenge.(G Carbonara 2017)

The construction sector plays a decisive role in the challenge for sustainable development: in Europe and the US, it is responsible for a final energy consumption of around 40%, which drops below 20% in China and is slightly above 30% as the world average (Belussi et al. 2019). The low cost of energy, together with the development of modern air conditioning systems for indoor spaces, has led in the last century to the overshadowing of investments in the energy efficiency of buildings. The situation began to change with the oil crisis of 1973 and the rise in energy prices after 2000, which made the investment in energy efficiency more convenient and demonstrated how the strong dependence on imports of fossil sources from external countries could pose a threat to a country's political independence and prosperity (Troi, Zeno, and Wedebrunn 2015). In parallel, awareness has also grown on the devastating risks associated with human-caused climate change (IPCC 2014). This has triggered a series of international actions that started with the Earth Summit in Rio de Janeiro in 1992, continued with the Kyoto protocol of 1997 and reached the Paris agreement of 2015. Sustainability has thus become a central pillar in contemporary life (Laine et al. 2019) from which derives the key role of energy efficiency in the 2030 Agenda for Sustainable Development (UN 2015), and its sub-theme related to improvement of the energy performance of buildings which is now a central aspect in energy policies around the world. In this framework the EU released in December 2019 the European Green Deal, capturing its commitment to tackle climate change. Among other actions, it prioritises energy efficiency in the building sector, as the largest single energy consumer (European Commission 2020).

The energy retrofit of a building refers to the set of actions needed in order to improve its energy and environmental performance. The challenge of the energy retrofit of a building consists in applying the most profitable set of technologies to obtain an improved energy performance, while maintaining satisfactory levels of service and internal thermal comfort under a given set of operating constraints (Ma et al. 2012). The heterogeneity of the existing building stock, the continuous evolution of technologies and markets and the variability of the actors are responsible for the complexities linked to the decision-making process concerning energy retrofits (De Boeck et al. 2015; Murto et al. 2019). Despite the numerous actions taken at the public level, the energy retrofit rate is still lower than expected (Friege and Chappin 2014), to the point that in order to achieve the 2050 objectives the pace should be doubled if not tripled (BPIE 2019).

1.3.1 Energy improvement of built heritage

Although Europe is one of the "early mover" markets for energy retrofit of buildings, the built heritage is still substantially exempt from the Energy Building Performance Directives because of the difficulties in finding energy efficiency solutions compatible with historical and architectural values. As stated in the EBPD (EP 2010), "*Buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic merit, where compliance with the requirements would unacceptably alter their character or appearance*" may in fact be excluded from attaining energy performance requirements. Moreover, historical buildings are usually protected both by national regulation and international conventions, which introduces additional levels of protection that hinder energy retrofit interventions. Historic buildings are neither the largest portion of buildings (Economidou et al. 2011) in the European building stock, nor the most energy-intensive (Martínez-Molina et al. 2016; Historic England 2018; Pretelli and Fabbri 2016). Thus, the concerns that potential measures for energy efficiency would damage the historical building, have slowed down the disciplinary integration process between conservation and sustainable design.

1.3.2 Approach to energy improvement of the built heritage

A key element in drafting an energy improvement process of a historic building is the search for the right balance between interventions and building context, historical-artistic values, passive behaviour and energy use, which requires a holistic view (Historic England 2018; G Carbonara 2017). This approach allows the creation of a shared knowledge framework between the actors involved in the process (Historic England 2018) and guarantees that the chosen solutions are appropriate for the historic building framework.

In dealing with a historical building, we can make at least two fundamental clarifications regarding the energy retrofit approach and the guiding principles of restoration:

1. According to the current Italian debate on the topic (de Santoli 2015; Giovanni Carbonara 2015), the concept of "energy improvement intervention" is to be preferred to "energy regulatory compliance/ adjustment/ adaptation". The Architectural Restoration scholar Giovanni Carbonara argues that the concept of "improvement" is antithetical to the one of "adjustment" that refers to regulatory compliance, including safety and comfort. The "improvement concept" has been firstly introduced in the field of structural consolidation of the built heritage with excellent results, i.e. without losing the general scope of an intervention on the built heritage that is its preservation for the future generation (or the ones related to the concept of "Integrated conservation" expressed in the Declaration of Amsterdam (AA. VV. 1975). In the same way, the concept of improvement can also be applied to energy efficiency and historical buildings as the energy and environmental behaviour of an historical building (both active and passive), can be improved through appropriate and well-balanced solutions without leading to a disruption of the building, which would be the case should one wrongly assume that the building has to be "adjusted" to current legislations and requirements, as if it were the case of a new or recent construction. If the "adjustment" can change the building and make it unrecognizable, destroying or impairing its cultural values (Giovanni Carbonara 2015), the improvement can help rebuild the natural functioning processes of historical and architectural structures, enhancing at the same time their distinctive characteristics and identities linked to the local microclimate (Gigliarelli, Calcerano, and Cessari 2017; GBC 2017a). The conflict between environmental design and heritage conservation is finally over and energy efficiency measures are now fully recognised as a key protection tool to support the conservation process (Giovanni Carbonara 2015).
2. The solutions adopted must be in line with the guiding principles introduced by the international restoration charters. These are universally recognised principles produced by the critical debate on restoration, starting around the nineteenth century and developed through the international restoration charters. A brief summary of these principles is given below (G Carbonara 2017):

a) *minimum intervention:* the energy improvement design should aim at preserving the original material as much as possible and avoid unnecessary interventions;
b) *reversibility:* the interventions must be reversible in the future, whenever possible;
c) *distinguishability:* new works should be distinguishable against the existing one;
d) *physical-chemical and figurative compatibility:* the interventions must guarantee compatibility between ancient and new materials, new design solution and historical and architectural features. This applies also to energy improvement project (for example, understanding the building's bioclimatic functioning - also through historical and architectural insights on the technologies used - is vital to reconstruct and optimise its passive behaviour);
e) respect for the material and figurative authenticity of the building.

Further references on can be found in Annex **Error! Reference source not found.** and EEP Deliverable 3.1 (Gigliarelli et al. 2020).

1.4 Energy Audit Process Flow of historical buildings - BEEP Project

The energy audit is one of the fundamental process of the energy upgrade of a building (de Santoli 2015). The EN 16247 defines the Energy Audit as a "systematic inspection and analysis of energy use and energy consumption of a site, building, system, or organization with the objective of identifying energy flows and the potential for energy efficiency improvements and reporting them" (CEN 2012). This guideline is based on the Energy Audit process of the EN 16247-2:2014 and introduces some adjustments in order to tackle the specificity of historical buildings, capitalise on the potential of new digital technologies applied to the construction sector for the built heritage (mainly, Heritage Building Information Modelling and Numerical Simulation of the energy and environmental performance of buildings), and promote the use of the Energy Performance Contracting scheme.

The results of the analysis of the innovative energy rehabilitation intervention will be incorporated into a Heritage Building Information Modelling (HBIM) environment that is the digital representation of physical and functional characteristics of a historical building, creating a shared knowledge resource for information about it.

Environmental and energy analysis will help to develop the historical building energy audit, as well as the three energy-environmental improvement scenarios. The passive behaviour of the building will be taken into consideration, in order to enhance its distinctive features and embedded passive strategies, closely linked with its climate and microclimate context, and also increase its energy performance and comfort conditions.

The proposed process flow is shown below. Each step is further analysed in the following Chapters. Each activity can be outsourced following the description and the corresponding reference template if the case may be. The BIM model outsourcing has been described in more detail because it should follow a specific regulation (ISO 19650-1 2018).

Analysis of the innovative energy rehabilitation intervention

pre-planning (also energy performance indicators);

technical documentation survey;

field analyses

→ to go into EE-HBIM model

Design of intervention, energy simulation and assessment

Development of energy model, input data verification and calibrated dynamic energy simulation of the existing building (ante-operam)

Design, simulation and evaluation of the energy and environmental improvement intervention and scenarios (post-operam)

→ to go into WP4 HBIM model

Final technical report on the Energy Audit

Energy Performance Contracting implementation

1.5 Glossary

AEC	*Architecture, Engineering and Construction*
BCF	*BIM Collaboration Framework*
BEP	*BIM Execution Plan. Plan that explains how the information management aspects of the appointment will be carried out by the delivery team.*
BI-EM	*Building Information-Energy Model. A BIM-based energy model that automates the energy modelling process within the BIM software (Revit Energy Model)*
BIM	*Building Information Modelling. Use of a shared digital representation of a built* asset *to facilitate design, construction and operation processes to form a reliable basis for decisions.*
BIM-BEM **BIM-BPS**	*Building Information Model to Building Energy Model. A converted energy model using exported information from a BIM model*
BPS or BEM	*Building Performance Simulation or Building Energy Modelling (generally used as synonyms)*
bSDD	*buildingSMART Data Dictionaries*
CDE	*Common Data Environment. Agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process*
CFD	*Computational Fluid Dynamic*
COBie	*Construction Operations Building Information Exchange. International standard for information Exchange about construction data focused from a BIM methodology point of view*
DTV	*Design Transfer View*
DES	*Date Exchange Schema*
FM	*Facility Management*
GBS	*Green Building Studio*
gbXML	*Green Building eXtensible Markup Language. A format used in order to allow a smooth transfer of BIM model properties to energy calculation applications.*
HVAC	*Heating, Ventilation and Air Conditioning*
IAI	*International Alliance for Interoperability*
IDM	*Information Delivery Manual*
IFD	*International Framework for Dictionaries*
IFC	*Industry Foundation Class. A neutral, non-proprietary data format used to describe, exchange and share information, smoothing the information exchange and interoperability between software applications in a BIM workflow*
Information	*Reinterpretable representation of data in a formalized manner suitable for communication, interpretation or processing*
Information model	*Set of structured and unstructured information containers, that is named persistent set of information retrievable from within a file, system or application storage hierarchy*
ISO	*International Organization for Standardization*
LCC	*Life cycle costs*
LOD	*Level of Development LOD. It defines the development level of information that a BIM model has, and this one is the composing part,*

	constructive system or assembly of the building.
Level of Information Need	*Extent and granularity required for a particular information deliverable at a particular plan of work stage. According to ISO 19650 it should substitute LOD.*
MEP	*Mechanical, Electrical, and Plumbing*
MVD	*Model View Definitions*
Plenum	*A plenum is a non-occupiable space between a ceiling and the floor above specifically intended for mechanical systems and other systems that require ceiling space*
Point cloud	*The result of a data collection of a building or object by laser scanner of photogrammetry, consisting in a set of points in the space that reflect its surface.*
R-value	*Thermal Resistance*
RV	*Reference View*
SHGC	*A value describing the solar heat gain coefficient in a glazing (window) material*
Space	*A space is defined as a building volume enclosed by ceilings, floor, walls or by another space's boundary. Space has a plethora of properties assigned to it to describe its energy resources, such as loads from people, lighting and equipment*
U-value	*Heat Transfer coefficient or Thermal Transmittance*
Weather File (epw)	*A single file in a format called an .epw that contains a collection of information to describe the environment of a location for each hour of the year, supplying data such as temperatures, luminescence data for sunlight, heating, and more*
XML	*eXtensible Markup Language*
XSD	*XML Schema Definition*

2 ANALYSIS PHASE FOR THE INNOVATIVE ENERGY REHABILITATION INTERVENTION

The activities shown below encompass the analysis phase following the energy and environmental improvement approach on historical buildings (see §1.3):

2.1 Preliminary analysis;

2.2 Historical and architectural analysis;

2.3 Geometric survey;

2.4 Energy and environmental analysis;

2.5 General conservation state.

2.1 Preliminary analysis for the energy rehabilitation intervention

This paragraph describes the preliminary analysis as intended to support the energy audit process of a historical building, as well as the historical and architectural analysis.

2.1.1 Purpose of the analysis

The first activity to be performed is the preliminary analysis. The aim of this activity is to establish a first contact with the historic public building, its owner and occupants, in order to plan the subsequent analyses. The first step is the documentation analysis and the photographic and visual survey, that will provide an overview of the building. Establishing contact with the building's occupants is also essential to start analysing the building's key features in terms of environmental and energy performance.

2.1.2 Pre-planning

Pre-planning in this activity should be very lean and allow to optimise the first field surveys and the first contacts with the involved stakeholders

2.1.3 Data acquisition

The analyses should gather general data of the building, information on recent works (if any), its use and current condition, as well as a brief overview of its active systems (HVAC, DHW, etc. .)

The main tasks to be performed during the preliminary analysis are:

- to identify the contact people for maintenance, facility management, design, documentation;
- to verify the availability of the building for surveys and diagnostics, depending on the building usage (for example, environmental monitoring can be disrupting for the normal building usage and requires at least one year of continuous measurements);
- to carry out preliminary surveys and photographic report of the building.

The main information to be retrieved includes:

- city planning regulation – urban plans - cadastral documentation – building prescriptions;

- drawings (plans, sections, elevations) (in printed and digital form: .dwg, .pdf, BIM models);
- documentation for the historical analysis: bibliographical and archival documentation, maps and historical cartography, studies on similar and/or coeval buildings;
- information from the occupants concerning comfort conditions (interviews);
- documentation on previous interventions on the building: maintenance, renovations, diagnostics;
- documentation on HVAC and installations: functional schemes, technical documentations, security documentation, plans;
- documentation on maintenance and facility management (maintenance plan, etc.);
- energy bills (electricity and gas) for at least one year operation;
- energy contracts.

2.1.4 Output

Al the data collected must be organised in minutes, reports and digital folders to support the subsequent analyses.

2.2 Historical and architectural analysis

The following paragraphs describe the historical and architectural analysis as intended to support the energy audit process of an historical building.

2.2.1 Purpose of the analysis

The activity will perform onsite study and archival research that are the fundamental core of the historic building analysis, as they provide a first understanding of the changes that the building went through over time and constitute a historical-critical guideline for subsequent analyses and intervention.

2.2.2 Pre-planning

Pre-planning activities to support historical and architectural analyses are already tackled in the preliminary analyses (§ 2.1), as among the main information that should be retrieved are: bibliographical and archival documentation, maps and historical cartography and studies on similar and/or coeval buildings. Subsequent meetings with the building owner and scholars who might have already studied the building, could provide access to additional documentation.

2.2.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;

- updated time schedule of activities.

2.2.3 Data acquisition

The analysis path to be followed in order to determine the characteristics of the building from a historical and architectural point of view, consists of a series of actions that involve different skills and disciplinary areas.

The first cognitive approach concerns the analysis of historical, textual, archival and image-based data in order to acquire meaningful data regarding:

- pre-existing building fabrics on the site;
- purposes, methods, phases and timing of projects and transformations;
- intended use of the building;
- any constraints and problems in the implementation of interventions or transformation phase; and also,
- to identify clients, architects, workers and the organization of the site whenever possible;
- to understand the functional, visual and conceptual relationships with the neighbourhood, the city and the territory.

The survey should also be conducted in specific archives and libraries, as well as digital databases and repositories, where it is possible to retrieve useful information about the building phases (and other changes occurred over time).

Data from the available historical sources (such as bibliographic, archival, cadastral, cartographic, images) require appropriate interpretation. Through a critical interpretative analysis of the gathered material, the building's historical transformations and stratifications will be identified. This process allows to retrace the history of the building starting from the first building nucleus, to all subsequent transformations, with particular attention to the modifications, restorations and partial destructions that might have occurred over time. The interpretation of the building's construction phases and modifications should also be achieved through the interpretation of the materials and construction techniques used, as they are often indicative of the succession of interventions that have been stratified on the building.

The information deriving from the historical-architectural analysis should then be comparatively assessed with the ones of the geometric survey (§ 2.3) in order to conclude on the morphological and geometrical aspects of the building. This integrated approach allows a) to determine the presence of one or more buildings and therefore the construction units, b) to distinguish the original structures from those added and c) to understand the construction features in order to identify the structural functions and the masonry stratigraphy. Furthermore, from the comparative analysis of the results it is possible to make an initial diagnosis of the actual state of the artefact and to direct the research towards other fields of investigation through the use of field and laboratory analyses, if needed.

2.2.4 Output

The analyses aimed at identifying the main features of the architectural complex should be organised in the form of a report describing the main characteristics of the architectural complex and the building transformations that the building has undergone over time.

The analysis on the building site must include:

- Geographical and territorial framework
- Topography and climate
- Location, (urban or rural or other context) urban transformations, access, orientation, etc.

The analysis on the regulatory framework of the building must include a list of the main urban regulations, listed building national and local regulations, heritage conservation national and local regulation and specific regulation on the building as for example any regulatory constraints on the intervention.

The historical and architectural analysis must describe main historical and architectural features of the building including:

- its historical context and local architecture background,
- the analysis and assessments of changes undergone by the building over time,
- a brief analysis of the existing geometric dimensional knowledge of the building,
- typological, architectonic and decorative characters,
- restoration or structural reinforcement interventions

For a reference template on this analysis see Annex 8.1.

2.2.5 BIM integration

The information collected and organised provides the basis for the modeling activities of the building's construction elements in both geometric and informative representation, based on the dimensional data collected in the geometric survey.

2.3 Geometric survey

The following paragraphs describe the geometric survey, as intended to support the energy audit process of a historical building, as well as the BIM modelling.

2.3.1 Purpose of the analysis

The activity regards the integration of traditional and innovative techniques (topographical, terrestrial laser scanner, photogrammetry) in the survey phase will supply an accurate representation of the building, and will provide the basis for geometric modelling of the HBIM model and hence of the energy model for energy and environmental simulation.

The following information are absolutely needed in order to develop a robust HBIM model of the building, with a detail accuracy that can be compared to a 1:20 drawing scale (as a general reference, LOD 500 of the American Institute of Architects 2013):

- a georeferenced geometric survey with topographical information of the exterior and interior of the building.

If planned accordingly, the geometric survey can also provide an invaluable source of information for the general conservation state analysis (see §2.5)

2.3.2 Pre-planning

Prior to data acquisition in the field, it is critical to conduct pre-planning meetings with the involved stakeholders (i.e. building owner representatives, building technical and management staff, occupants representatives, consultants, service providers) to discuss:

- measurement objectives: a clear and concise scope of the geometrical survey effort should be established in this stage with a detailed list of the measurements to be taken, the measurement resolution and level of detail, the required accuracy for each (which may not be the same), and the required file format for deliverables (if relevant);
- security and access constraints: ensuring unhindered access is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- mobilisation strategy.

2.3.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.3.3 Data acquisition

Regarding the geometric survey, the type of survey techniques to prefer depend on the current information already available on the building, linked to the building complexity. Therefore, this guideline foresees two different path of survey-analysis for two extreme cases that are proposed below:

- **CASE 1** if geometric information is almost complete
- **CASE 2** if no geometric information is available.

Depending on their particular case, the actors involved can develop middle ground strategy.

2.3.3.1 CASE 1

If robust information on the geometric characteristics of the building is available (e.g. digital drawings or paper-based survey documentation at scale 1:50, including plans of all floors, all elevations and at least 3-4 sections in both axes), the activities should focus on:

- a measurement verification of the existing information, and
- if needed, geometric data integration to attain the required survey accuracy,
- integration of image-based survey information (e.g. photogrammetry) on the external building elevation and the main internal elements

Recommended instruments for improving this type of geometric survey could be total station, photogrammetry with calibrated camera and/or laser scanner.

2.3.3.2 CASE 2

If there is no reliable geometric information of the building available, the activities should provide:

- a complete georeferenced geometric survey of the exterior and interior of the building using:
    - traditional-direct survey methods and,
    - photogrammetry or laser scanner data, with RGB information.

In both cases, georeferencing the building and the topographical network is recommended (although not strictly necessary for the building's energy modelling using BIM and BPS), as it can improve the overall documentation of the building and may also be used in subsequent activities/interventions. Ground and/or aerial scans could also be performed in order to obtain a complete representation of the building.

2.3.4 Output

2.3.4.1 CASE 1

For the verification and completion of the existing information, the activity should reproduce and integrate the existing drawings in digital vector-based files, covering (at least) the following:

- plans of all the floors;
- all elevations;
- 3-4 main sections in different axis;
- significant details.

The plans must show the main linear dimensions of each room, the thickness of internal and external walls, fenestrations, and the main dimensions of the entire building. The elevations (referring to a single dimensioned plan common to all vertical representations), the internal heights and the surfaces of the single rooms should also be indicated. The representation scale should be 1:50 or less, for the plans, sections, and elevations, and 1:20 for the details.

For the integration of the existing geometric data with photogrammetric survey on the external building facades and specific internal elements, the activity should produce at least the rectified photography of the external building elevation and the main internal elements as coordinate-controlled imagery or scaled rectified imagery or other controlled method. A resolution of 300 dpi is generally recommended as appropriate.

It is strongly suggested, when performing a photogrammetric survey, to also produce a point-cloud of the building (at least of the exterior) because it can be really useful in the modelling HBIM activities. In fact, technological developments in the involved equipment (cameras) and software are facilitating the process of extracting photogrammetry data to point cloud, which is becoming increasingly easy to develop, less time consuming and expensive.

2.3.4.2 CASE 2

The activity should produce the registered 3D point cloud of the building exterior and interior. Data exchange format and non-proprietary format should be preferred to streamline the importing process in the most widespread BIM authoring software. In addition to the laser intensity value, RGB colour information, acquired on a per point basis at each scan position, is required.

Normally point clouds that are very detailed can be very large in file size, resource demanding and difficult to manage with current IT workstations in the subsequent phases of the process. Within the current workflow, the point cloud should convey the geometric base data for BIM modelling activities; therefore, attention must be paid to the trade-off between accuracy and feasibility in the use of files.

There are many workflows to help solving this issue. For example, the raw point cloud acquired can be decimated (reduced in file size) to a given level of detail. The surveyor could also perform a differentiated survey of exterior (more detailed to capture decorations) and interior (less detailed, just to define spaces and building envelope thicknesses). Moreover, the whole point cloud file could be divided into portions of a fixed file size, corresponding to specific building sections, that can be differently integrated, in the BIM model, making all the process smoother and less demanding in terms of IT resources.

Within this guideline the suggested accuracy for the laser scanner survey is:

- The required maximum tolerance for precision of detail is: 1:20 +/- 6mm - 1:50 +/- 15mm
- The required point density/rate of capture of measured points is: 1:20 ≤2.5mm - 1:50 ≤5mm

For a reference template on this analysis see Annex 8.2.

2.3.5 BIM integration

Usually geometric survey information, either 2D vectorial data file or 3D point clouds can be imported in the most common BIM Authoring tool and used as a base to model building elements. Point clouds in particular can be used to discretise and acquire the main geometric configuration of the building and the single measures of external and internal elements.

2.4 Energy and environmental analyses

The following paragraphs describe the energy and environmental analyses as intended to support the energy audit process of a historical building.

1.1.1 Purpose of the analysis

The environmental and energy analyses described in this technical guideline document will serve, along with the other (historical, geometric, etc.) analyses, to define the thermophysical characteristics of the opaque and transparent envelope. The environmental monitoring part, if present, will help calibrating the building model used for the dynamic energy simulation (see § 4.1) and the subsequent drafting of the energy retrofit scenarios (see § 4.2). The energy Auditor (whose services may be outsourced) is the figure who follows the entire process from the data collection phase, to the development of the energy audit. For the aforementioned purposes, the following data need to be obtained:

- climatic data;
- building occupancy profiles;
- thermophysical characteristics of the opaque and transparent envelope;
- building systems and operation profiles;
- building energy consumption and energy bills;
- indoor environmental and comfort conditions in the spaces [not mandatory];

2.4.1 Pre-planning

Prior to data acquisition in the field, the energy Auditor should conduct pre-planning meetings with technical representatives of the building owner and interested parties (e.g. occupants' representatives), to discuss the environmental and energy analyses objectives, security or access constraints, mobilisation strategy, details about the involvement of building occupants and to agree on all the operating procedures for carrying out the analyses.

During the meetings, the service provider (i.e. the energy Auditor) agrees with the organization on how to access the building, how to gather the available technical documentation, how to access its energy systems, the data to be provided at the end and the analysis execution program. The aspects covered in the meeting are:

- Purposes and measurement objectives: a clear and concise scope of the analyses effort should be established in this stage with a detailed list of the measurements to be taken, the measurement resolution and level of detail, and the required file format of the deliverables;
- Clear definition of each building structure to be surveyed with the appropriate tools;
- Verification of existing technical documentation;
- Mobilisation strategy – The expertise of the service provider is essential for establishing the mobilisation strategy: how many survey points, timing of field surveys during the year or the day, delivery deadlines, etc.;
- Level of involvement of the building occupants
- Security and access constraints: Ensuring unhindered access for service providers is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- Health and safety.

All investigations and tests of any kind must be agreed in advance with the competent local Heritage Conservation Authority.

2.4.1.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

1.1.2 <u>Data acquisition</u>

The first part for the energy and environmental analysis to be conducted by the energy Auditor, is the collection of the existing technical documentation concerning the energy behaviour of the building. The second part concerns a set of environmental field analysis (i.e. mandatory environmental monitoring and optional analyses).

2.4.1.2 Technical documentation

An indicative and non-exhaustive list of the technical documentation survey part, that the energy Auditor shall collect (according to EN 16247) contains:

- Energy Management Service or/and Energy Supply contracts;
- Energy related data (mainly through the Energy Bills of the last three years, or from individual metering, if available) such as: energy and water consumption

data, delivered, produced and exported energy per energy source (if available) and short-interval (e.g. hourly) energy demand (if available);

- Climatic data for energy simulation purposes (see Annex 8.3)
- Any changes that have occurred in the building in the last three years (change in the use of the spaces, in the set-points of the environmental parameters, management interventions on the systems, energy improvement interventions, etc.);
- Any previous energy analyses performed on the building, if present;

2.4.1.2.1 Deliverables

The deliverable of the technical documentation survey is a technical report containing all the documentation found on the building and an outline of the key data contained (see ANNEX 8.4).

2.4.1.3 Field analyses

Regarding the field analyses survey, a mandatory and an additional data set of measurements are described below. The mandatory analyses are necessary to provide robust information on the building use, the thermophysical properties of opaque and transparent envelope and the building's systems. Additional field analyses are strongly recommended as they allow stakeholders to attain a better and more accurate analysis of the building performance, and define the interventions strategies and the related Return of Investments in a more efficient way. The type of survey techniques to be performed depends on three key factors:

- the tool/approach selected to perform energy simulations, that also depends on the country regulation;
- the current information already available on the building, and the building's complexity;
- the available budget and timeframe of the retrofit process.

2.4.1.3.1 A. Mandatory analysis (data verification through visual and heat flux meter analysis)

Integrating the data collected so far by the actors involved (following the required verification), the energy Auditor shall provide the following information through site visits and heat flux meter analysis:

- Existing technical documentation on building geometry and confirmation of the provided data deriving from the geometric survey (floor area and building volume as-built); record of any external factor that may influence the energy performance of the building (e.g. shading by adjacent trees or buildings);
- Building occupancy patterns (intended use of spaces and occupancy schedules):

- Occupancy schedule;
- Window opening patterns (time schedule for each window operation time schedule and percentage of opening), (*These data are gathered through frequent visual inspection or occupant survey);*

- Building systems information, including:
  - Heating system and cooling system (overall typology, generation characteristics, terminals position and characteristics, etc.);
  - Domestic Hot Water system;
  - Forced ventilation system (typology, Air Handling unit, terminals);
  - Lighting systems (lighting position and characteristics);
  - Other equipment (other specific systems, building automation systems…);
  - Control diagrams and settings (e.g. heating and cooling setpoint and setback temperatures);
  - Air changes per hour of every space *(if the building has no forced ventilation, the value can be estimated or it can be detected in detail with an indoor environmental monitoring – see additional analysis B3*);
  - Heating and cooling operation schedules;
  - Hourly internal gains due to people, appliances, equipment, and all the heat sources in the area;
  - Hourly indoor water vapour production;
  - Minimum and maximum relative humidity set point (if a humidity control system is present);

- Opaque envelope information (referring to any thermal frontier with the outside environment or with unheated rooms, e.g. perimeter walls characterized by different stratigraphy, roofing, floors, slab on ground, etc.):
  - Thermal conduction resistance [m^2K/W];
  - Heat capacity [J/m^2K];
  - Hypothesis on the detailed stratigraphy of the structure with thickness, conductivity and thermal capacity of each layer (including internal partitions, box awnings (if present) and portion of opaque wall under the window);
  - Presence of condensation and surface or interstitial humidity;
  - Increase in the thickness of the masonry (if any);
  - Degradation, swelling, detachment or cracking of the plaster and surface finishes;

  - Bacteriological germination, surface efflorescence, mould and fungi;

- Transparent envelope information, including:
  - Geometry;
  - Frame materials;
  - Glass type and materials;
  - Thermal transmittance [W/m^2K];
  - Usage profile and shading devices (if present);
  - General conservation state of the windows (crack analyses, air tightness, water sealing).

2.4.1.3.2 Deliverables

The deliverable on the mandatory field analysis is a technical report on the analyses performed that contains the aforementioned data regarding the opaque and transparent structures. The deliverable also consists of technical floor plans and technical data sheets showing in detail the data collected on the building systems (see ANNEX 8.4).

2.4.1.3.3 B. Additional field analyses

When information on the thermophysical properties of opaque and transparent envelope is incomplete or there is a need to collect more information on their properties in order to formulate a solid hypothesis on the stratigraphy, additional field analyses are recommended. The analyses are also relevant to provide further data to help defining input data of dynamic energy simulation to be performed at later stages and calibrating it. Such additional analyses are the following:

- IR thermographies (B1);
- Simplified indoor environmental monitoring (B2);
- Air flow rate measurements and complete environmental monitoring (B3);
- Occupant thermal comfort assessment (B4)

2.4.1.3.4 B1. IR Thermographies

IR thermographies analyses shall be performed according to local technical regulation or following international guidelines. If carried out, they should precede the heat flux meter analyses in order to help defining the measuring spots of the heat flux measurements.

Additional data to be reported are:

- Thermal bridges;
- Air cracks;
- Materials emissivity;
- Capillary rise of water (estimated);
- Irregularities in the installation of the materials, any infrared visible degradation in the internal layers.

2.4.1.3.5 Deliverables (B1):

The additional deliverable on the thermophysical characteristics of the opaque and transparent envelope is a technical report on the analyses performed that contains thermograms and photographs shoots taken during the analyses pointing out the temperature levels and the building parts where defects or irregularities were found.

2.4.1.3.6 B2. Simplified indoor environmental monitoring

A short monitoring campaign of the indoor environmental indicators of air temperature and relative humidity shall be conducted for selected, characteristic thermal zones of the building. The suggested monitoring period is 2 - 3 weeks (20 days) during winter, summer and mid-season (if possible). Access to the exterior weather data during the monitoring period is strongly recommended (through a credible local meteorological station or in-situ monitoring through the installation of a portable weather station in the vicinity). These data shall be used for the calibration of the digital model and the dynamic energy performance simulation. Additional data to be reported are:

- Time series of indoor Dry Bulb Temperature (°C) in each selected zone
- Time series of indoor Relative Humidity (%) in each selected zone
- Time series of exterior Dry Bulb Temperature (°C) (strongly recommended)
- Time series of exterior Relative Humidity (%) (strongly recommended)

2.4.1.3.7 Deliverables (B2):

The additional deliverable of the indoor environmental monitoring is a technical report that presents the location of the data logger, the selection of the characteristic thermal zones to be monitored, the timeseries of the results for each zone and each monitoring period.

2.4.1.3.8 B3. Air flow rate measurements and complete environmental monitoring

The estimation of the air flow rate and air tightness of the building envelope shall be performed according to local technical regulation or following international guidelines. For the determination of air permeability of the building, the fan pressurization method (blower door) (ISO 9972:2015) or the tracer gas dilution method (e.g. monitoring the concentration of carbon dioxide CO2) (ISO 12569_2017) may be used. Additional data to be reported is:

- Air permeability (ach)

Additional data to be monitored, if possible, are:

- Air velocity (m/s)
- Illuminance (lx)
- Surface temperatures (°C)
- Concentration of polluting agents in the air (e.g. CO2)

2.4.1.3.9 Deliverables (B3):

The additional deliverable of the air flow measurement is a technical report that describes the method that was followed and the results obtained.

2.4.1.3.10 B4. Occupant thermal comfort assessment

A questionnaire survey shall be conducted in order to highlight potential issues in terms of usage profile of the building and occupants' comfort. The questionnaire shall contain a simple checklist to collect information on the occupants (and the space in which they work) concerning:

- Thermal comfort assessment and thermal preference (too cold, too hot, etc.) during: a) winter and b) summer;
- Overall thermal comfort (general acceptance, complaints);
- Visual comfort assessment (for the visual task or for glare)

The sampling rate of the occupants' responses should be defined by the researchers, depending on the level of in-depth analysis required, the availability of the monitoring equipment and the occupants' commitment (e.g. seasonal distribution of the questionnaire with simultaneous monitoring of the indoor thermal environment is an option for insightful thermal comfort assessment, yet it requires more resources).

2.4.1.3.11 Deliverables (B4):

The additional deliverable of the thermal comfort assessment is a technical report that describes the method that was followed, presents the questionnaires and the results obtained.

2.4.2 Output

All the deliverables produced within these analyses should be organised in a specific report that takes into account also the EE-HBIM Model approach (see §2.4.3).

For a reference template on this analysis see Annex 8.4.

2.4.3 BIM integration

The data from Energy and Environmental analyses should be funnelled into the HBIM model. The organization of collected data can support both a check of the completeness of the data collected for the energy analysis, and a library of the functional data for insertion in the simulation software.

To allow this transfer from field analysis to model, data should be consistent with the BIM Model Element Table (see Annex 8.7) if any or BIM model parameters. Any definition of property set (Pset) for the chosen file format export (IFC, gbXML etc.) should take the issue into account.

To be identified inside the model, all objects must be referenced with a unique alphanumeric identification code, that must be consistent with the BIM model identification system.

As stated throughout the report template (see Annex 8.4), all these data should be integrated in the HBIM model: depending on the case study specifics, software used for BIM modelling and simulation and data integration process, it is paramount to define a coherent data input strategy.

2.5 General conservation state

The following paragraphs describe the general conservation state analyses as intended to support the energy audit process.

2.5.1 Purpose of the analysis

The general conservation state analysis is considered as a preliminary visual analysis useful for the building knowledge and, mainly, to support energy analysis and the selection of energy improvement technologies capable also of reducing possible decay causes while being compatible with international restoration charts. A preliminary detection and mapping of the various alteration and decay patterns found on the exposed surfaces and macroscopic elements of criticality affecting the structures, should be developed with a particular consideration for factors (for example, a very significant humidity problem in the basement, or the exceptional lack of air tightness of a window, etc.) that can strongly affect energy efficiency. Of course, if the buildings present particular criticality that cannot be enough understood with preliminary analyses and can affect the intervention strategies, further diagnostics analyses should be planned and executed.

The minimum information needed is the visual detection and mapping of the materials and the various alteration and decay patterns found on the exposed surfaces (external and internal), with elaboration of technical sheets.

2.5.2 Pre-planning

Prior to data acquisition in the field, it is critical to conduct pre-planning meetings with the involved stakeholders (i.e. building owner representatives, building technical and management staff, occupants representatives, consultants, service providers) to discuss:

- analysis objectives: a clear and concise scope of the general conservation state analysis should be established with the required deliverables (see Annex 8.5);
- security and access constraints: ensuring unhindered access is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- mobilisation strategy

Any supplementary in-depth investigations that could involve destructive analyses of any kind must be agreed in advance with the competent local Heritage Conservation Authority.

2.5.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.5.3 Data Acquisition

The following visual analysis and investigations relating to the general conservation state should be performed:

- material analysis: survey and mapping of structural and finishing materials and thematic mapping of existing finishes (including windows and external doors, surfaces, stone or wooden artefacts);
- decay and deterioration pattern and crack pattern analysis;
- identification and graphic representation of the building elements construction phases.

The analysis shall follow the local national and international regulation requirements on General conservation state analysis (see Annex 8.5).

2.5.4 Output

The analysis must include:

- technical report on the analysis findings;
- technical data sheets consisting of descriptive, graphic (thematic maps) and photographic sections, on the architectural surface analysis, material analysis, decay and deterioration pattern and crack pattern analysis, following the local national and international regulation requirements;
- if relevant, description and explanation of the annexes schemes, legends, etc.

The documents described above can be produced in pdf format for the descriptive and photographic section and .dxf format scale 1:50-1:20 for the thematic maps, if not differently specified by the local regulation.

If there are no local regulation available, the following international regulations are suggested:

- ICOMOS. Principle for the Analysis, Conservation and Structural Restoration of Architectural Heritage; International Council on Monuments and Sites: Paris, France, 2003.
- ICOMOS. Illustrated Glossary on Stone Deterioration Patterns; International Council on Monuments and Sites: Paris, France, 2008
- EN 16096:2012. Conservation of Cultural Property—Condition Survey and Report of Built Cultural Heritage; European Committee for Standardization, 2012.

For a reference template on this analysis see Annex 8.5.

2.5.5 BIM integration

The general conservation state analysis does not have to go directly in the BIM model: to the best of our knowledge, up to know, there is no defined way to represent decay in a BIM model as a property of the element it belongs to (for example, a moist area as belonging to the wall it is on), primarily for limitations of BIM software; there are several workarounds, but, for us, none is, up to know, a real improvement in the building information process from the traditional thematic maps referred to the building elevations.

Therefore, the general idea is to integrate the General conservation state report as an external link to the model. For specific issues it would be possible to link more detailed analysis, if performed, or to add specific information to given building elements, but this is not a primary goal of the process.

3 ENERGY EFFICIENCY HERITAGE BUILDING INFORMATION MODEL (EE-HBIM)

The following paragraphs describe the Energy Efficient Heritage Building Information Modelling activities as intended to support the energy audit process.

3.1 Purpose of the EE-HBIM modelling

The purpose if the EE-HBIM model is to act as a centralized repository to optimize the management of the large amount of information (geometrical, alphanumerical and documents) deriving from the analysis and simulation process for the energy amelioration of built heritage. The advantages of the model will be the simplification and effectiveness in ensuring the permanence, consultation and implementation of data, accessible and understandable by different stakeholders.

The model should be developed in two different stages. Within Stage 1, corresponding to the ex-ante building state, the EE-HBIM model will integrate the previously collected information deriving from the performed analysis (geometric, diagnostic, energy and environmental data, see § 2.2, 2.3, 2.4, 2.5) to create a comprehensive documentation of the building's current state.

The EE-HBIM model of Stage 1 will be used as a basis to inform a subsequent energy-environmental improvement concept, through energy renovation scenarios that are both compatible with the identified historic buildings and capable of enhancing their energy and environmental performance. Scenarios' energy performance will be evaluated with specific dynamic energy simulation software (to be described in the next release of this guideline – Output 4.5).

In Stage 2 (to be described in the next release of this guideline – Output 4.5), the technical characteristics of each scenarios and its energy performance will be integrated within the EE-HBIM model (4D - 5D – 6D – 7D), in order to facilitate a ROI analysis and the drafting of the Energy Performance Contracting.

3.2 Pre-Planning

3.2.1 <u>BIM Execution Plan (BEP)</u>

Before starting the modelling process, it is critical to develop a BIM Execution Plan (BEP). In line with the definition of ISO 19650, the BEP defines the methodologies, requirements and timeframe on which the information modelling will be carried out. A BEP should detail not only how information is created and delivered, but also the 'why' (defining the BIM use), and the 'who' (assigning responsibility for it). It specifies the management, technical, commercial and project information and deliverables required for the project in a way that is specific, measurable, achievable and realistic. All stakeholders involved must adhere to and follow the BEP.

There are numerous templates for BEP following ISO 19650 requirements; based on those documents, the actors should adapt BEP to buildings' peculiarity, model uses, data available and stakeholders' skills and tools.

The BEP describes models federation, model uses, naming convention, LOD and modelling strategy, providing a flexible overall methodology for EE-HBIM. The main topics of a BEP are provided below.

3.2.1.1 Roles and responsibilities

The BEP shall indicate the Project Team Members carrying the following roles, indicating their capability and experience to fulfil the requirements of the roles: BIM Manager, whose function is to manage the whole information process; CDE manager, whose function is to manage the Common Data Environment; BIM Coordinator, whose function is to manage each discipline model; BIM Specialist (generally more than one), whose function is to model the model containers. The same person can fulfil different roles.

3.2.1.2 Model uses

Model uses must be defined as they direct the main modelling approaches. Within Stage 1 and Stage 2 of the modelling process, the main objectives and their corresponding model uses are:

Phase	**Objectives**	**Uses**
Stage 1	Constructive HBIM model definition	Integration and representation of building geometrical and technical information according to the documentation provided by the Employer (geometric survey, drawings, etc.) Definition of building elements Space, areas and volumes analysis
	Management of the knowledge documentation on the historical building	Integration of historical documentation provided by the Employer (information sheets, links, etc.) Integration of diagnostic information provided by the Employer (materials and structure survey, etc.)
	Management of the environmental-energy analysis	Integration of energy and environmental analyses developed by the Employer.
Stage 2	Support of three energy intervention scenarios and of choice of adapted	Integration of three energy improvement intervention

	renovation strategies and technologies	scenarios (short/medium/long term) provided by the design activity of the Employer with data concerning Time, Costs and management (4D, 5D, 6D, 7D)
	Assessment of ROI of the environmental-energy intervention scenarios	Integration of Return of Investment evaluation method based on the intervention costs and energy saves of the interventions

3.2.1.3 Level of Information Need

When modelling geometrically complex objects, typical of historical buildings, it is paramount a clear specification of the Level of Information Need (ISO 19650-1 2018; EN 17412 2020), that expresses the level of maturity required for a particular information deliverable at a particular plan of work stage. It is important to avoid the delivery of too little information, which increases risk, and the delivery of too much information, which is wasteful.

Depending on the model uses, the necessary information should therefore be balanced between geometrical correspondence and alphanumeric data. The perceived benefits (in terms of information quality and completeness, visualisation requirements, etc.) should be carefully weighed against model functionality, file restrictions and time–effort. In order to be cost-effective, the minimum level of graphical detail sufficient for the purpose of the model should be specified.

The development of an EE-HBIM model requires to articulate in a shared definition the content and detail of model objects: for instance, the clear description of which building elements to model, their standard classification, the Level of Information Need for each modelled element, including both their geometrical information and alphanumerical information provided through model parameters.

An effective way to organize this information is using the Model Element Table (BIMForum 2019), that is a table in which a building is decomposed into modelling elements (walls, floors, etc.) according to a breakdown structure, following Omniclass classification (Construction Specifications Institute 2019). Each modelling element is associated to a Relevant Attribute Table, that are tabs containing attribute information for the associated model objects to be inserted in the BIM model using specific parameters. Relevant Attribute Tables, therefore, condensed the required alphanumeric information for any given model object. An explanation on how to use the Model Element Table is provided in Annex 8.7.

The main issues in the use of the Model Element Table, and therefore the OmniClass classification for historical building arise from the fact that all building classifications based on ISO 12006 have been developed for the contemporary industrial process of the construction sector and the most widespread construction systems and technologies; so they may not be appropriate to include the complex, not standard elements and technologies of built heritage. For example, the definition of structural element reflects the separation between structural frame and enclosures that is normally not applicable to historical buildings. Top levels may still work well, as they indicate in broad terms the object type, while detail that is introduced in lower levels can be misleading. A lite classification (top of pyramid) with additional commentary is the likely way (Brookes 2017).

3.2.1.4 Model federation and data segregation

The BEP shall indicate a federated model strategy, depending on the historic building dimension and on the energy simulation process. It is recommended to separate at least the architectural model and the MEP model, including terminals and heating and cooling production system– useful for the energy analysis. A separated structural model is more useful with a frame concrete or wood structure.

3.2.1.5 Data sharing and collaboration

A Common Data Environment (CDE) complying with ISO 19650 and ISO 27001, must be used for the management or sharing of data, in order to facilitate collaboration and information sharing between members of the project team. It is essential that common BIM standards are established and agreed in advance.

3.2.1.5.1 Naming convention

It is paramount to define naming specification to be used for all document types uploaded to a CDE, in line with IEC 82045-1 and BS 1192:2007(A2) 2016. For the object naming convention, an existing standard can be applied; when using the Model Element Table, that is based on Omniclass classification, Omniclass standard could be applied, keeping in mind its limits when describing historic buildings (see § 3.2.1.3)

3.2.1.5.2 Modelling strategy

A description of the modelling strategy, data exchange formats, common coordinate system should be provided.

For an example of the BEP for energy and environmental improvement of historical buildings, please refer to Annex 8.6.

3.2.2 <u>Outsourcing of the EE-HBIM model - tender process</u>

If the BIM modelling activity is outsourced, the actors involved in the tender process shall follow the bidding procedure defined by ISO 19650. The Employer shall define an Exchange Information Requirements (EIR), that is a tender document setting out the information to be delivered, and the standards and processes to be adopted by the Consultant as part of the project delivery process, outlining the Employer strategic approach and specifying the management, technical, commercial and project information and deliverables required for the project.

The Consultant shall deliver a Pre-contract BIM Execution Plan (BEP) for the project as a direct response to the EIR. If selected, The Consultant shall deliver a Post-contract BEP and review their BEP regularly and additionally when there is any change to their contract.

3.3 Output: EE-HBIM Modelling

The modelling process should be based on the geometric and technical information (geometric survey, drawings, etc.) collected during the analysis phase (see § 2). Based on the collected information, the model will represent the constructive system and technological characteristics of the building (vertical and horizontal structural system, materials, etc.) as accurately as possible within the Level of Information Need. The walls, roofs and floors will be modelled with their stratigraphy (know or assumed). Decorative elements can have a simplified representation, as long as their constructive system is detailed.

The HBIM model development will take advantage of the parametric tools of native software (e. g. system families) as much as possible, avoiding non-parametric tools such as mass modelling. The correct representation of the building technical, constructive and environmental features is paramount, even when leading to simplification of uneven features, typical of historical buildings (e.g. assuming planarity of walls), if needed.

Historical and diagnostic information (materials and structure survey, energy analyses, etc.) collected during historical and architectural analysis (see § 2.2) and general conservation state analysis (see § 2.5) should be incorporated in the model. If the information cannot be directly integrated in the elements, it can be linked using reports, sheets, drawings, etc.

In order to support environmental-energy intervention scenarios, the energy information collected in energy and environmental analyses (e.g. transmittance values for walls and windows, occupancy data, etc., see § 2.4) should be integrated in the model. Occupancy and uses profiles for each room and/or thermal zones, if not included in the model, should be linked as external files (reports, sheets, etc.).

Regarding MEP system, HVAC systems terminals and plants should be represented. If no specific MEP system is modelled, room/areas information could include data on plants and terminals.

Regarding object insertion and constraints, all objects (walls, roofs, ceilings, floors, HVAC systems, structures, windows, etc.) must be constrained to the corresponding lower and upper level.

If a federated model strategy is developed, all models should be geo-referenced according to the same absolute origin established in the union file. The reference grids of the federated files may refer to a relative origin, suitably identified due to the geometric and disciplinary complexity of the work, but these grids must conform to the georeferencing of the absolute origin.

4 DESIGN OF INTERVENTION, ENERGY SIMULATION AND ASSESSMENT

The activities described below encompass the processes of developing the energy model and assessing the energy performance of the existing building; analyse passive and active technologies employed by the building and the market maturity; design the energy and environmental improvement intervention assessing their technical feasibility and then group them in one or more energy and environmental intervention scenario to be evaluated with post-operam building performance simulation and Payback time calculations.

The above are outlined in the following paragraphs:

4.1 Development of energy model, input data verification and calibrated dynamic energy simulation of the existing building (ante-operam);

4.2 Design, simulation and evaluation of the energy and environmental improvement intervention and scenarios (post-operam).

Dynamic simulation are considered a requirement in this process due to the complexities involved in historical buildings energy and environmental performance assessments (see Annex 8.8 and Annex 8.14). Country-specific regulation on energy-audits and energy efficiency of buildings should guide the selection of the simulation typology to be performed, between at least the simple hourly method of EN ISO 52016-1 or a detailed dynamic model. For more information on the two approaches please refer to the study of Ballarini et al. (2020).

4.1 Development of energy model, input data verification and calibrated dynamic energy simulation of the existing building (ante-operam)

Although the calibrated dynamic energy simulation of the existing building could still be part of an analysis phase, given its strong connection with the design activities (it provides the performance indicator benchmarks and the starting model for the post-operam ones) it was deemed more practical to include it in this phase also to foster a joint reflection with the involved actors on simulation as a whole.

4.1.1 Purpose of the analysis

This section provides technical specifications for the activities of modelling, data verification and the development of the dynamic energy simulation of the historic building to be retrofitted. The Simulation Expert (whose services may be outsourced) is the figure who follows the entire process from the data verification phase, to the development of the energy model and the dynamic energy simulation. The dynamic simulations along with any necessary analyses and modelling to be carried out by the Consultant will help evaluate the energy and environmental performance of the existing case-study building along with the following environmental and energy improvement scenarios (see § 4.2).

4.1.2 Pre-planning

Prior to performing the dynamic energy simulations, pre-planning meeting should be conducted the Simulation Expert to discuss the activity objectives, security or access constraints, mobilisation strategy and more details regarding (as described in EN 16247-2):

- Activity objectives: A clear and concise scope of the activities should be established at this stage, compiling a detailed list of the simulations to be performed, the results' accuracy, the performance indicators, as well as the required format of the deliverables. Also, the interventions' objectives (design limitations etc.) should be clearly stated.

- Data availability: Clear definition of the available data (historical and architectural, geometric, diagnostic, energy and environmental data, see § 2.2, 2.3, 2.4, 2.5) regarding the current state of the building. Availability of ante-operam EE-HBIM file to streamline energy modelling activites and planning of interoperability workflow (see Annex 8.9 for the State of the Art on BIM and BPS interoperability and 8.10 for the feasibility studies conducted during BEEP project with best modelling practices on two different software combinations). Discussion regarding the available climate file (see Annex 8.3) and the energy simulation software to be used. It is noted that the simulation software should comply with ISO 52016 and provide hourly or sub-hourly calculation options.

- Security and access constraints: Ensuring unhindered access for service providers is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas.

- Mobilisation strategy.

4.1.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;

- activity and mobilisation plan specification;

- updated time schedule of activities.

4.1.3 Data acquisition

4.1.3.1 Input data verification

The available building information should be provided to the Simulation Expert. The HBIM digital model may be used as a basis for drafting the digital energy model (to be used for the simulations, for more information on the interoperability process refer to Annex 8.9). The environmental monitoring, if present, as well as the energy analyses data will be used for the calibration of the digital model.

During the pre-planning activities, the Simulation Expert should receive the following data in the respective forms:

- All the energy and environmental-related data in the form of spreadsheets (.xls or other database file format) and reports. These data concern: the technical documentation survey performed in the framework of the preliminary analysis (historical and architectural, geometric, diagnostic, energy and environmental data, see § 2.2, 2.3, 2.4, 2.5), robust information on the thermophysical properties of opaque and transparent envelope, previous analyses and monitoring performed, existing building design sheet and thematic maps, energy bills, occupancy schedules, HVAC systems etc.;
- the geometry of the building in CAD format or the native EE-HBIM model, with the complete energy-related metadata integration (e.g. all the single instances of walls with their thermophysical characteristics, the windows, generators, terminals, etc. in specific schedules in which each single object is defined).

The Simulation Expert shall then verify the data with in-situ survey and collect further information, if deemed necessary, in order to complement the input data required for the drafting of the energy model.

The strategy for obtaining a valid climate file to be used for the simulation is to be discussed in the pre-planning activities. The file should represent the long-term average climatic conditions of the buildings' location (e.g. Typical Meteorological Year 2 - TMY2, Weather Year for Energy Calculations 2 - WYEC2 etc.). It can be either extracted from national databases or online weather data repositories or generated based on detailed outdoor environmental monitoring according to EN ISO 15927-4. Its final compatibility with the Simulation Software should be confirmed by the Simulation Expert (see Annex 8.3).

4.1.3.2 Model calibration

<u>In case the historic building(s) is in use and employ HVAC systems</u>, the prime calibration parameter may be the energy consumption (kWh) on an annual and monthly basis. For this purpose, the current Energy Bills, or data deriving from energy meters shall be used. The tolerance range proposed by the ASHRAE Guideline 14 (2014) or relevant literature will be accepted. An overview of the existing literature is provided in the ANNEX 8.8.

If additional analyses are available, particularly the "Simplified indoor environmental monitoring (B2)" (described in § 2.4.1.3.3), an enhanced calibration based on the environmental parameters of air temperature and relative humidity is recommended. In this case, the calibration process shall be also based on the comparison of simulated and measured data (i.e. data recorded during the monitoring period in specific, indicative thermal zones).

The statistical indicators of mean absolute error (MAE), and root mean square error (RMSE), shall be used. The first indicator represents the standard deviation of the differences between measured and simulated data, while the second one takes into account the average absolute error of the differences between measured and simulated values. Two different accuracy levels LV 1 (high accuracy) and LV 2 (low accuracy) are suggested. The tolerance range for temperature and relative humidity of the narrower range of accuracy (Lv. 1) and the wider range of accuracy (Lv. 2) are:

- Lv. 1: Temperature: ± 1 °C and Relative Humidity: ± 5%.

- Lv. 2: Temperature: ± 2 °C and Relative Humidity: ± 10%

Additional **optional** uncertainty indices that can be used and their corresponding threshold of accuracy, according to the literature[3], are:

- Coefficient of determination, R^2, where $R^2 > 0.75$
- Inequality coefficient, IC, where IC < 0.25

More references regarding the calibration processes are provided in the ANNEX 8.8.

<u>In case the historic building(s) is not in use</u> due to abandonment or partial collapse, or/and no energy consumption data can be retrieved, instead of the existing building, the modelling of a base-case model will be performed. The base-case model will correspond to an airtight building and assumptions regarding the operation schedules will be made, based on the proposed use after restoration. Typical schedules and design values shall be used, unless indicated differently by the building owners and the future use of the building.

4.1.3.3 Dynamic simulation

For the performance of the dynamic energy simulation the following specifications can be used as a reference notwithstanding the accordance with the country-specific regulation and the guideline recommendation on using at least the simplified dynamic hourly simulation method of EN ISO 52016:

- Natural ventilation and infiltration shall be calculated based on dynamic modelling (infiltration calculated based on window openings, cracks, buoyancy and wind driven pressure differences). In case of lacking data, tabular information from regulation on air changes per hour can be used.
- Simulations shall be calculated based on the amount of solar radiation falling on each surface of the building zone including the floor surface and walls and windows, while accounting for direct solar and light transmission through internal windows and taking into account the effect of exterior shadowing surfaces (e.g. surrounding buildings) and window shading devices (e.g. “full interior and exterior” solar distribution should be employed allowing for the EnergyPlus check for non-convex zones).
- The simulation should be based on a minimum of 15 min step (i.e. 4 timesteps per hour, or more).
- In case of complex fenestrations, calculations should be carried out more often than the default 20 days.

4.1.4 <u>Output</u>

This part of the analysis should include:

- a technical report that presents:
    - the input data (focus on potential deviations from the data received);

- the methodology that was adopted regarding the modelling of the building, i.e. the reasoning behind the thermal zones definition and the source of occupancy schedules, adopted modelling process (e.g. simplification of complex or mass elements, etc.) and analysis settings applied for the simulation;
- the results of the validation indicators and documentation on the overall accuracy of the model.

- an .XML file (exported from the simulation software or any other exchange format) to be used for the CDE (Common data environment);
- the digital file of the validated model of the existing building or the equivalent base-case model.

For a reference template on this analysis see Annex 8.11 (Chapter 1-4)

4.1.5 BIM Integration

The results of the energy simulation should be exported in a compatible to BIM authoring software document format (i.e., PDF, XML, XLS, IFC, etc.). This information can be assigned directly to BIM 'spaces' and MEP systems' analytical properties/attributes or attached to the BIM model in the form of a linked report document for each design intervention respectively.

If the Energy model has been modelled in the Energy Simulation Software from scratch, the naming convention for the building spaces should be identical to that of the BIM model to ensure the proper integration of the analysis results to the BIM model.

If the Energy model is generated based on a draft BIM model export, the building spaces' naming conventions included within the imported file should be maintained.

4.2 Design, simulation and evaluation of the energy and environmental improvement intervention and scenarios (post-operam)

The following paragraphs describe the design activity as intended to support the energy audit process of a historical building and is structured in three main steps.

4.2.1 Purpose of the activity

The purpose of this activity is to develop the energy and environmental improvement interventions and then assembly them into energy and environmental improvement scenarios for the analysed building for improving its energy performance and indoor comfort conditions. This will be based on the following design process:

- Part A: based on Chapter 2 findings (see § 2.2, 2.3, 2.4, 2.5), this part entails the analysis of a) the passive design strategies for the analysed building, and b) the maturity of the market regarding the passive and active technologies in each partner country. The understanding and appropriate interpretation of climate limitations and potentials, as well as the passive design elements embedded in the historic building under study, is a crucial step in designing the energy improvement strategy. Available passive strategies and active energy systems should be considered with the objective to lower energy consumption while enhancing the comfort of occupants. An insightful overview of the state of the art regarding the compatibility of passive and active technologies in historic buildings is provided in Annex 8.12, while a reference template for the analysed building is provided in Annex 8.13.

- Part B: based on Chapter 2 analyses and the “ante operam” simulation results (see § 4.1.3.3), a number of energy and environmental improvement interventions will be designed. The development of these interventions will consider a number of parameters and criteria (current state of the involved part, compatibility and heritage significance, technical compatibility and feasibility check, environmental sustainability, other design criteria, technical characteristics, estimated cost and time of the intervention1) and will rely on passive and active technologies. A comprehensive overview of the methodology approaches and the decision-making process for developing the energy concept for retrofitting the analysed building is provided in the Annex 8.14, while a reference template for the interventions is provided in Annex 8.15.
- Part C: this phase involves the grouping of energy and environmental improvement interventions into one or more intervention scenarios, evaluated and tuned thanks to the results of post-operam building performance simulation and further calculation of pay-backtime based on intervention cost estimation and simulation results. By assembling the interventions into three scenarios (short, middle and long term) it is possible to cover a wide range of possibilities according to the funding strategies. All the scenarios should ensure indoor comfort according to local and/or international regulations. The short-term scenario corresponds to more cost-effective interventions from energy efficiency and payback-period point of view. The middle-term scenario will focus on a deeper renovation. Finally, the long-term scenario will pursue the best available technologies that are compatible with the building and allow the best energy and environmental improvement in the long run, resulting in an even greater payback period. Following the creation of the EE-HBIM model (see § 4.1.5) and the dynamic energy simulation of each scenario, final adjustments might be necessary for the definition of each scenario.

It is important to highlight that all assessment activities during intervention and scenarios development receive feedback from each other up to the final definition (and tuning) of the scenarios.

4.2.2 Pre-planning

Pre-planning activities need to be performed with the Simulation Expert and any other involved expert for the design of the intervention (MEP experts, Restoration experts, building owner representatives). For the definitions of the energy and environmental improvement intervention and subsequent scenarios, consultation between the Energy Auditor and the Simulation Expert (if different) is paramount. Preliminary

1 These last two commonly addressed in a BIM process as 5D and 4D respectively.

simulation results of particular zones will be discussed in order to assist in the definition of the design proposals (e.g. indicators of indoor thermal comfort, energy consumption rate and savings etc.). Final adjustments in the energy and environmental improvement intervention and scenarios will be made according to the simulation results in each case.

4.2.3 Energy and Environmental improvement design process

4.2.3.1 Part A: Analysis of passive and active technologies

The relevant passive strategies employed in heritage buildings across the Mediterranean basin and the complementary active energy systems available for integration in heritage buildings are outlined in Annex 8.12. In this document, an overview of the passive design analysis tools and methods is presented, and the potential integration challenges and opportunities of active systems in heritage buildings are outlined. This Annex presents also the country-specific findings of the partners involved in BEEP Project.

The data to be obtained for developing a background on the compatible active and passive energy efficient technologies are:

- Overview of the environmental responsiveness of built heritage (brief and general overview of the main passive techniques that are employed by vernacular heritage in the country - through relevant bibliography);
- Identification of the recommended passive design strategies according to local climatic conditions (use of bioclimatic charts and climate analysis tools);
- Opportunities, impediment and challenges in applying passive design strategies in the case-study building;
- Outline of the current situation, trends and challenges (market maturity) regarding the implementation of innovative RES or building envelope technologies, for application in existing buildings; accounting for compatibility issues in heritage buildings.
- Opportunities, impediment and challenges regarding active systems integration in the case-study building.

4.2.3.2 Part B: Design and assessment of energy and environmental improvement intervention

A number of assessment criteria and methodologies are developed to assess the energy and environmental improvement interventions. These are outlined in the reference Annex 8.14. Reflecting on the existing methodologies, the following assessment criteria are suggested for the development of the design process:

- compatibility and heritage significance: i.e. compatibility with a) the guiding principles of restoration, as expressed through the International Charters of Restorations (§ 1.3), and b) the national regulatory framework; potential risks of architectural, aesthetic or visual impact, or risks regarding the building's setting;

- technical compatibility and feasibility check; i.e. description of the technological and mechanical compatibility with the other systems and components of the building; potential hygrothermal risks; structural risks; corrosion risks; salt reaction risks; biological risks; and reversibility;
- environmental sustainability of the intervention; i.e. description of whether the intervention is characterised by specific environmental sustainability principles. i.e. whether the intervention minimises environmental pollution and emission of substances in the indoor environment, whether it uses as much as possible renewable resources, recyclable/reused materials, low embodied energy etc.;
- other design criteria i.e. technical characteristics to be evaluated in the materials and components to be used, methods of carrying out the intervention and laying of materials, possible instrumental checks to be performed before and after the intervention, possible problems to be taken into account in the design and execution of the intervention;
- technical characteristics i.e. description of the technical characteristics of the intervention and comparison with the existing technologies through table, images and schemes, section plan etc;
- estimated cost and timing of the intervention (usually referred to as 5D and 4D of a BIM process). Data acquisition should be achieved based on previous work experience / similar projects or by requesting quotation from companies (as suggested in the Annex 8.15). Time and cost estimation should contain the following information:
    - Intervention name and code.
    - Quantity related to the intervention, per unit or per measure.
    - Measuring unit.
    - Estimated cost of the intervention as per unit or measure.
    - Estimated amount of time of the intervention realisation.

  The above data should take the form of a table as shown in Annex 8.15 Chapter 3.

4.2.3.3 Part C: Design, simulation and assessment of energy and environmental improvement scenarios

Energy and environmental improvement scenarios (one or more) are developed by grouping selected energy and environmental interventions based on a first estimation of the most cost-effective or urgent interventions to be done. A suggestion could be to group interventions into three scenarios (namely short medium and long term), in order to be able to address a wide range of possibilities and allow for a greater design flexibility based on the available funding strategies. On average a short term scenario should have a payback time between 5 and 10 years, a middle term scenario should have a payback time between 10 and 20 years and a long term scenario should have a payback time over 20 years2. For the economic evaluation of the energy retrofit

2 Still, if the funding schema is clearly identified the team could aim for a single best available scenario saving simulation effort on the other two possible solutions.

scenarios, the indicator of payback time is suggested. The use of this indicator is widespread as it is easy to understand by non-experts and require simple calculations. More information can be retrieved in the Annex 8.17. The assessment of the scenario is based on the post-operam simulation results of the selected scenarios ad described in Annex 8.11 (post-operam energy consumption and related post-operam energy bills).

4.2.4 Output

4.2.4.1 Part A: Analysis of passive and active technologies

The output of this part of the analysis is a thorough report discussing the parameters mentioned in par. 4.2.3.1. A template for reporting the above data is provided in Annex 8.13.

4.2.4.2 Part B: Design and assessment of energy and environmental improvement intervention

The output of this part is a report describing the energy and environmental improvement intervention designed and their assessment according to the assessment criteria mentioned in par. 4.2.3.2. A template for reporting the above data is provided in Annex 8.15.

4.2.4.3 Part C: Design, simulation and assessment of energy and environmental improvement scenarios

The output of this part can be divided in a dedicated post-operam simulation results report and in an energy and environmental improvement scenario synthesis report (including the main simulation results from the previous report). The latter can be very effective to discuss the assessment with non experts stakeholders.

The post-operam simulation results report should include:

- a technical report that presents:
  - a brief description of the input data with a reflection on their uncertainties;
  - a comparative analysis of the results on a monthly and yearly basis (graphs and comparative tables summarising the results of the energy and environmental improvement scenarios and the existing base-case model) The indicators to be reported for the existing building (or the base-case scenario) and the retrofit scenarios are:
    a) final & primary energy demand per scenario (kWh/m^2 yearly),
    b) energy consumption per energy source (on at least monthly steps) (kWh/m^2 annual), and

c) energy use or/and production from Renewable Energy Sources (RES) per system (on a monthly basis).

- the .XML files (exported from the simulation software) of the three retrofit scenarios, to be used for the CDE (Common Data Environment);
- the digital files of the three models that correspond to the energy retrofit scenarios.

For a reference template on this analysis see Annex 8.11 (Chapter 4).

The energy and environmental improvement scenario synthesis report should include a brief description of the building with an overview of the energy consumption from § 2.4 and also a comparative analysis of the energy and environmental intervention scenarios proposed in which:

- the interventions involved in each scenario should be clearly stated;
- each scenario with the involved interventions should be briefly described highlighting the related synergies between the foreseen interventions;
- for each scenario, a selection of the most important parameters should be presented in a comparative assessment with the existing building conditions (i.e. the energy consumptions and energy bills, the expected energy production from RES, the expected cost and timing of implementation the intervention) and the payback time.

A template for reporting the above data is provided in Annex 8.11. Annex 8.17 describes the calculation of the payback time. Based on the timing of interventions acquired in § 4.2.3.2. Simplified GANT chart for scenario implementation can be added as shown in Annex 8.16 chapter 2.2.

4.2.5 BIM Integration

Similarly to the 4.1.5 BIM integration paragraph, all energy intervention scenarios results should be exported in a data format compatible to the BIM authoring software, i.e., PDF, XML, XLS or IFC. This information can be assigned directly to BIM 'spaces' and MEP 'systems' analytical properties/attributes (using global project parameters) or attached to the BIM model in the form of a linked report document for each design intervention respectively.

If the energy intervention scenario involves the creation of new additional elements, i.e., construction of new interior walls and ceilings, or suggests the construction of new building spaces/MEP systems, all of the affected building components and spaces should be assigned to different construction phase ID. Using the construction phase filters, energy simulation results of the particular intervention scenario may be assigned to affected spaces and MEP systems only. In the case of a high complexity retrofit intervention scenario in which a great proportion of the building undergo excessive modification, a replica of the BIM model should be made and all BIM elements should be assigned to the new construction phase. In this respect, energy simulation results should be assigned to the BIM model in a similar manner to the existing building case. In any case depending on the analysed building, specific BIM modelling strategies can be deployed.

If the energy intervention scenario involves the modification of existing building envelope or the upgrade of MEP systems only, i.e., thickness differentiation caused by thermal insulation layer addition, the phasing mechanism for assigning energy simulation results should be adopted.

4.2.5.1 4D and 5D implementation

4D and 5D implementation should be conducted for each energy and environmental improvement intervention separately. The integration of this information can aid the design process assessment of the energy intervention scenarios. If third party 4D or 5D simulation software will be used, the sorting of information and subsequently the methodology for implementing the 4D and 5D in the EE-HBIM model should be formulated prior to the activity. 4D and 5D intervention data can be added to the BIM model through the use of unique construction phase ID to the respective BIM objects modifications/additions. If the 4D and 5D simulation is implemented in third-party software, the results should be exported in universal format, i.e., PDF, XML or XLS and linked to the EE-HBIM model.

5 POST OPERAM ENERGY EFFICIENCY HERITAGE BUILDING INFORMATION MODEL (EE-HBIM)

The following paragraphs describe the development of the Stage 2 of the Energy Efficient Heritage Building Information Modelling activities, in order to integrate the renovation scenarios of the building, as well as the corresponding 4D and 5D BIM dimensions of time and costs.

5.1 Purpose of EE-HBIM modelling

As described in § 3.1, the purpose of the EE-HBIM model is to act as a centralised repository of the information on the building obtained from analysis, simulation, intervention scenarios' planning.

Stage 1 (see § 3) corresponds to the ex-ante model of the building. Stage 2, outlined in this chapter, focuses on integrating, in the previously developed EE-HBIM model, the intervention scenarios designed, simulated and assessed in § 4. The technical characteristics and energy performance of each scenario are modelled to facilitate a ROI analysis and the drafting of the Energy Performance Contracting.

5.2 Pre-planning

5.2.1 Update of the BIM Execution Plan

After the simulation phase and intervention scenarios development phase, the Building Execution Plan prepared for the ante-operam EE-HBIM model (see § 3.2.1) may need revising, to illustrate how interoperability between the BIM authoring software and the energy simulation software has been handled and to explain how to the three intervention scenarios will be represented. Moreover, BEP shall reflect any adjustment in the workflow and any modification needed to accommodate specific requirements.

5.2.2 Outsourcing of the EE-HBIM model - tender process

If the BIM modelling activity is outsourced, the tender should generally comprise both Stage 1 and Stage 2 of the EE-HBIM model. In this case, the BEP adjustement shall be defined by the consultant.

If, however, the is a different consultant for Stage 1 and 2 or only Stage 2 is outsourced, the actors involved in the tender process shall follow the bidding procedure defined by ISO 19650, as described in § 3.2.2. The Employer shall define an Exchange Information Requirements (EIR), that is a tender document setting out the information to be delivered, and the standards and processes to be adopted by the Consultant as part of the project delivery process, outlining the Employer strategic approach and specifying the management, technical, commercial and project information and deliverables required for the project.

The Consultant shall deliver a Pre-contract BIM Execution Plan (BEP) for the project as a direct response to the EIR. If selected, The Consultant shall deliver a Post-contract BEP and review their BEP regularly and additionally when there is any change to their contract.

5.3 Output: updated EE-HBIM Modelling

The intervention scenarios modelling represents an update of the ante-operam EE-HBIM model (see § 3); this previous model, therefore, shall be the basis of any further development. All modelling principles and guidelines presented for the ante-operam EE-HBIM model (see § 3.3) apply to this update as well.

The actors involved shall define specific strategies to implement intervention scenarios within the ex-ante model, integrating all the relevant information produced, such as simulation data, time, costs, technical specifications, etc. The strategies depend on model uses, building characteristics, type of intervention, BIM authoring tool selected. Some typical methods involve the use of different linked models, the use of design options, the revision of existing elements; the modelling of new additional elements, etc.; different methods can be combined as appropriate. Cost and time considerations shall be added, also with reference to other phases (see 4.2.3.2 and 4.2.3.3) where the scenarios are described. To enhance clarity and consistency, if a coding convention was developed for the interventions, it shall be used in the modelling phase as well.

The intervention scenarios shall be represented with the same level of information, to facilitate comparisons: geometrical modelling of the interventions (architectural objects, MEP objects, either revised from the existing one or newly modelled), non geometrical data integration (simulation data, time, costs, technical specifications, etc.), compromises between geometrical accuracy and parametric object definition, use of constraints, etc. shall be consistent.

6 ENERGY PERFORMANCE CONTRACTING IMPLEMENTATION

The recent change in the European and national regulatory framework on energy efficiency has led to a review of the performance standards and procedures. The transposition of Directive 31/2010/EU, Directive 27/2012/EU and Directive 844/2018/EU does not only concern the areas of energy efficiency of buildings from a technical and technological point of view, but also proposes the development of models and tools for the financing of interventions and for the development of Energy Performance Contract (EPC). The main activity in this domain is the definition of guidelines for the creation of new formats for the EPC contract, based on technological innovations in the field of energy efficiency. The European Commission has been working closely with the Member States for the development of an application model for Public Administration (PA), in order to involve private operators and encourage the aggregation of demand, generate economies of scale and use EPC, also with the involvement of private operators (ESCO). In the following paragraph, the state of the art in European countries working in BEEP project are synthesized.

The objective of the guidelines for EPC contracts is to provide an easy and quick tool of use and consultation for the experienced public manager, preparing and managing energy performance contracts, and for the public administrator who is entrusted with the political choice of activation of such contracts. EPC contracts are atypical, as their content is highly technical; in fact, in addition to the legal content (guarantees, jurisdiction, security rules, etc.), they have also an economic content (financing arrangements, calculation of performance, etc.) and a technical-engineering content (energy audits, redevelopment and plant engineering).

6.1 What is EPC

Energy Performance Contracting (EPC) is a financing mechanism used to support energy efficiency measures and renewable energy installations without worrying about the financial barriers. The Energy Efficiency Directive 2012/27/EC (EED) defines EPC as follows:

''*energy performance contracting* means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings;”. (DIRECTIVE 2012/27/EU, 2012)

Thus, in an EPC contract the energy service company (ESCO) is committed to provide guaranteed energy improvements to the customer’s territory while the finances are covered from the achieved energy savings. The concept of EPC is illustrated in Figure 1.

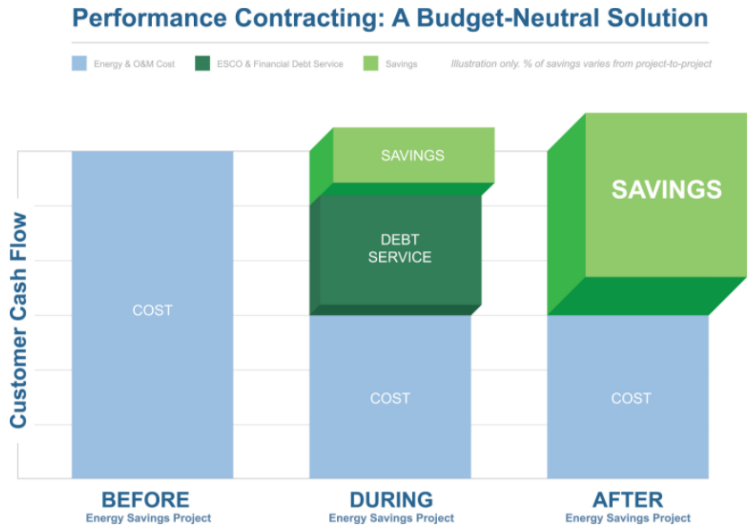


Figure 1: EPC contracts cash flow. (ESPC – ENERGY SAVINGS PERFORMANCE CONTRACT, 2020)

The EPC foresees that the investments made by third parties are repaid with the energy savings obtained during the contract through a link between ESCO remuneration and performance (e.g. financial savings).

Some of the main advantages of such contracts are:

- Overpassing financial barriers
- No risk at the customer side
- Improving energy consumption
- Integrating new technologies in buildings
- Promoting green buildings
- Contributing in reaching national energy goals

There are many models of EPC contracts, however the most famous models are as follows:

Shared Savings: In this model, the ESCO does not guarantee to reach a certain amount of savings. However, both the client and the ESCO share a predefined percentage of the savings as agreed in the contract. If no savings are achieved, the client pays the energy bill while the ESCO must pay for the financial obligations associated with equipment purchases.

Guaranteed Savings: In this model, the ESCO guarantees a certain amount of energy savings each year of the contract. If the agreed amount of savings is not reached, the ESCO shall pay the shortage to the client. However, if the savings exceed the agreed amount, the excess is divided between the customer and the ESCO according to the particular contract.

The EPC contract can be financed either by the client, the ESCO or a third-party financer. However, the most famous method is a bank loan with low interest value. In an EPC, the ESCO can provide the following services:

- Energy audit
- Design engineering
- Construction management
- Arrangement of long-term financing
- Commissioning

- Operation and maintenance
- Measuring and verification

It is important to note that the level of measurement and verification depends on the scale of the project. The International Performance Measurement and Verification Protocol (IPMVP) is adopted in EPC contracts, where the ESCO chooses the convenient option that best fits the particular case between options A, B, C & D.

6.2 EPC in the European Context

The European Union has set ambitious targets to increase energy efficiency. As part of the Europe 2020 Strategy, Member States have agreed to reduce greenhouse gas emissions by at least 20%, increase the share of renewable energy to at least 20% of consumption, and achieve energy savings of 20% or more. The energy savings target was translated in the Energy Efficiency Directive from 2012 and 2018. According to the burden-sharing principle, Member States were free to choose individual national targets, as long as the general EU-wide target would be reached. The European Commission is tracing periodically the progress towards this target, through specific reports. The latest of such assessment document, launched in November 2015, noted that, according to a Commission evaluation from 2014, the level reached by 2020 would fall below the 20% by 1-2%. Currently, the national indicative targets of Member States fall short of the collective 20% by 2.4%[3]. The European Commission, upon analyzing the financing market for energy investment across Europe, concluded that "energy efficiency market has strong investment potential, but is still small, fragmented, risky, and relies predominantly on direct or indirect subsidies".

European Union set more ambitious goals with the Clean energy for all Europeans package (finished adopting in 2019), with at least 40% cuts in greenhouse gas emissions (compared to 1990 levels); at least 32% share for renewable energy (with an upward revision clause by 2023); at least 32.5% improvement in energy efficiency (with an upward revision clause by 2023).

With the Green New Deal, European Union promotes the new target of 55% greenhouse gas emissions by 2030, presenting a Target Plan 2030[4], proposing a renovation wave to improve housing quality in the EU, also including innovative financing schemes under InvestEU. These could target housing associations or ESCOs that could roll out renovation, including through EPC[5].

While developed countries may easily achieve results with regular ESCOs, a government-led so-called "super ESCO" is needed in developing countries, due to weak institutions. In particular, while Germany, France, UK, and Austria have a large energy services market, other countries lack policy effectiveness and have weak inter-institutional cooperation, where decision-making is not based on impact studies, and ineffective

[3] European Commission, 2015, COM(2015) 574 final, https://ec.europa.eu/transparency/regdoc/rep/1/2015/EN/1-2015-574-EN-F1-1.PDF

[4] See https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en#:~:text=The%20Commission's%20proposal%20to%20cut,becoming%20climate%20neutral%20by%202050%20.

[5] See https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2, § 2.1.4.

communication between public authorities, energy companies, and consumers occurs (Murafa 2017).

The EPC status in Europe depends mainly on the ESCO market. The development of the ESCO market in Europe was studied and disseminated in the Energy Service Market in the EU report. The results are shown in table 1.

Table 1: ESCO market development between 2015 and 2018 (Boza-Kiss, Toleikyté, and Bertoldi 2019)

Austria	→	Italy	↑
Belgium	↑	Latvia	↗
Bulgaria	→	Lithuania	↗
Croatia	↑	Luxembourg	○
Cyprus	○	Malta	○
Czech Republic	→	the Netherlands	↗
Denmark	↑	Poland	↗
Estonia	→	Portugal	↗
Finland	↗	Romania	↗
France	↗	Slovak Republic	↗
Germany	↗	Slovenia	↑
Greece	→	Spain	↗
Hungary	↗	Sweden	↓
Ireland	↗	the UK	↗

Note that the green arrow refers to the growth of the market, with fast increase (point upwards), or slow increase (pointing halfway), while the yellow arrow signifies no change or stable market, and red arrow shows a decrease in the market. The donut shape refers to countries with low ESCO market.

Also, according to the same report issued in 2019, it was found that France and Germany have the largest markets, followed by Italy. The biggest Energy Performance Contracting market in terms of the number of companies, projects and market volume is led by Germany (Boza-Kiss, Toleikyté, and Bertoldi 2019).

The European Parliament and the Council of the European Union assured the importance of developing the market for energy services to ensure the availability of both the demand for and the supply of energy services by promoting energy performance contracting in (DIRECTIVE 2012/27/EU, 2012). Capacity building workshops were then organized during the EPC campaign done in 2013.

The current status of the EPC market in Europe differs from one country to another. Some countries are advanced (Germany) where as others are still in their earlier stages. The main barriers facing the implementation of EPC contracts include:

- Lack of awareness from the demand side of the market for energy services
- Poor understanding of energy efficiency and EPC by financial institutions
- Small size of projects
- Incompatibility of legal and regulatory frameworks
- Low understanding of Measurement and Verification protocols
- Administrative hurdles
- Lack of motivation
- Limited government support

The introduction of the EPC Code of Conduct in 2015 has helped to increase knowledge and grow the ESCO market in some countries (Bulgaria, Boza-Kiss, Toleikyté, and Bertoldi 2019).

6.3 BIM for EPC

The Table below shows how BIM could improve EPC essential tasks:

Table 2: BIM advantages in improving EPCs

EPC essential tasks	Problems/issues	Possible solutions with BIM
Involvement of owners / tenants	It is difficult to communicate technical solutions to non-technical final users	BIM allow for simplified visualization of technical data (3D, render, etc.).
Energy refurbishment	The refurbishment project is done in successive phases and often architects, structural engineers and HVAC engineers experience difficulties in interacting with each other, with subsequent interferences/ problems up to the implementation phase.	Design is done in a shared environment (Common Data Environment) where it is possible to coordinate the different models coming from the different professionals contributing to the refurbishment.
Construction phase	Construction is a complex phase that is hard to efficiently manage.	BIM can help manage the construction phase.

Expected budget	The construction sector has a chronic problem of price uncertainties.	BIM can help manage prices and quantity take-offs.
Evaluation of the refurbishment project(s)	It is difficult to evaluate different options.	BIM can help simulate different design scenarios, assisting also decision support systems.
Facility management costs	Facility management (when present) often relied on traditional, not parametric technologies, leading to redundancies and inconsistencies.	BIM promotes facility management implementation and facilitates integrated control of information and operation.
Public tenders	Public tenders often lack complete, reliable documentation.	BIM can provide a robust data repository with all the tender information, constraints, and requirements.
Tenders assignments	Tenders are usually assigned through the examination of paper-based documents.	BIM model must represent the entire building in all these parts, proving more susceptible to detailed assessment. Code checking and clash detection on BIM models can be successfully used to evaluate bidders.
Project life-cycle	The presence of several stakeholders is prone to inconsistencies during planning, design, implementation and operation phases.	BIM can promote a life cycle approach in the construction sector
Evaluation of return of Investment (RoI)	RoI is inherently uncertain	BIM allow for a better evaluation of costs and time by making the construction workflow more reliable and robust.

7 REFERENCES

AA. VV. 1975. 'Declaration of Amsterdam'. https://www.icomos.org/en/and/169-the-declaration-of-amsterdam.

American Institute of Architects. 2013. 'AIA Document E203-2013 Building Information Modeling and Digital Data Exhibit'. American Institute of Architects.

ASHRAE Guildeline 14. 2014. 'Guideline 14, Measurement of Energy and Demand Savings'. ASHRAE.

Ballarini, I., A. Costantino, E. Fabrizio, and V. Corrado. 2020. 'A Methodology to Investigate the Deviations between Simple and Detailed Dynamic Methods for the Building Energy Performance Assessment'. *Energies*. https://www.mdpi.com/1996-1073/13/23/6217/pdf.

Belussi, Lorenzo, Benedetta Barozzi, Alice Bellazzi, Ludovico Danza, Anna Devitofrancesco, Carlo Fanciulli, Matteo Ghellere, et al. 2019. 'A Review of Performance of Zero Energy Buildings and Energy Efficiency Solutions'. *Journal of Building Engineering* 25 (September): 100772. https://doi.org/10.1016/j.jobe.2019.100772.

BIMForum. 2019. 'LOD Spec 2019 Part I For Building Information Models'. Associated General Contractors of America (AGC).

BPIE. 2019. 'Towards a Decarbonised EU Building Stock: Expert Views on the Issues and Challenges Facing the Transition - Factsheet'. Building Performance Institute Europe. http://bpie.eu/wp-content/uploads/2018/10/NZE2050-factsheet_03.pdf.

Brookes, Carl. 2017. 'The Application of Building Information Modelling (BIM) within a Heritage Science Context'. 29. Research Department Reports. Historic England.

Carbonara, G. 2017. 'Cultural Heritage and Retrofit of Historical Buildings Evaluations of Restoration Issues'. In *Keynote Speech Climamed 2017 – Mediterranean Conference of HVAC Historical Buildings Retrofit in the Mediterranean Area 12-13 May 2017 - Matera, Italy*. Matera.

Carbonara, Giovanni. 2015. 'Energy Efficiency as a Protection Tool'. *Energy and Buildings*, Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, 95 (May): 9–12. https://doi.org/10.1016/j.enbuild.2014.12.052.

CEN. 2012. *EN 16247 Energy Audit*.

Construction Specifications Institute. 2019. 'OmniClass® Introduction and User's Guide'. Construction Specifications Institute.

De Boeck, L., S. Verbeke, A. Audenaert, and L. De Mesmaeker. 2015. 'Improving the Energy Performance of Residential Buildings: A Literature Review'. *Renewable and Sustainable Energy Reviews* 52 (December): 960–75. https://doi.org/10.1016/j.rser.2015.07.037.

Economidou, M., B. Atanasiu, C. Despret, J. Maio, I. Nolte, and O. Rapf. 2011. 'Europe's Buildings under the Microscope. A Country-by-Country Review of the Energy Performance of Buildings'. *Buildings Performance Institute Europe (BPIE)*.

EN 17412. 2020. *Building Information Modelling. Level of Information Need. Concepts and Principles*.

EP. 2010. *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings*.

European Commission. 2020. 'Renovation Wave'. 2020. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en.

Friege, Jonas, and Emile Chappin. 2014. 'Modelling Decisions on Energy-Efficient Renovations: A Review'. *Renewable and Sustainable Energy Reviews* 39 (November): 196–208. https://doi.org/10.1016/j.rser.2014.07.091.

GBC. 2017. 'GBC Historic Building'. Green Building Council Italia. http://gbcitalia.org/documents/20182/157656/Sistema+di+verifica+GBC+HB_2016-mag17.pdf/7d185808-b994-45fe-a6af-218e81a8fe27.

Gigliarelli, Elena, Filippo Calcerano, and Luciano Cessari. 2017. 'Heritage Bim, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit'. *Energy Procedia*, Climamed 2017 – Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area 12-13 May 2017 - Matera, Italy, 133 (October): 135–44. https://doi.org/10.1016/j.egypro.2017.09.379.

Gigliarelli, Elena, Filippo Calcerano, Letizia Martinelli, and Leo Lorenzi. 2020. 'A3.1.1 - State of the Art Analysis on HBIM and Interoperability - ENICBCMed BEEP Project Delivereable'. http://www.enicbcmed.eu/sites/default/files/2021-07/31_Output.pdf.

Historic England. 2018. *Energy Efficiency and Historic Buildings, How to Improve Energy Efficiency*. Historic England.

IPCC. 2014. '2014: Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change e [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (Eds.)]'. Cambridge University Press, NY, USA. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.

ISO 19650-1. 2018. *ISO 19650-1:2018 Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM) — Information Management Using Building Information Modelling — Part 1: Concepts and Principles*.

Laine, A., J. Davies, K. Buchanan, K. Warren, and J. Turtinen. 2019. *Heritage Research Matters. Case Studies of Research Impact Contributing to Sustainable Development*. http://jpi-ch.eu/wp-content/uploads/Heritage-Research-Matters.pdf.

Ma, Zhenjun, Paul Cooper, Daniel Daly, and Laia Ledo. 2012. 'Existing Building Retrofits: Methodology and State-of-the-Art'. *Energy and Buildings* 55 (December): 889–902. https://doi.org/10.1016/j.enbuild.2012.08.018.

Martínez-Molina, Antonio, Isabel Tort-Ausina, Soolyeon Cho, and José-Luis Vivancos. 2016. 'Energy Efficiency and Thermal Comfort in Historic Buildings: A Review'. *Renewable and Sustainable Energy Reviews* 61 (August): 70–85. https://doi.org/10.1016/j.rser.2016.03.018.

Murto, P., M. Jalas, J. Juntunen, and S. Hyysalo. 2019. 'Devices and Strategies: An Analysis of Managing Complexity in Energy Retrofit Projects'. *Renewable and Sustainable Energy Reviews* 114 (October): 109294. https://doi.org/10.1016/j.rser.2019.109294.

Pretelli, Marco, and Kristian Fabbri. 2016. 'New Concept of Historical Indoor Microclimate - Learning From the Past for a More Sustainable Future'. *Procedia Engineering*, World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium 2016, WMCAUS 2016, 161 (January): 2173–78. https://doi.org/10.1016/j.proeng.2016.08.811.

Santoli, Livio de. 2015. 'Reprint of "Guidelines on Energy Efficiency of Cultural Heritage"'. *Energy and Buildings*, Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, 95 (May): 2–8. https://doi.org/10.1016/j.enbuild.2015.02.025.

Troi, Alexandra, Bastian Zeno, and Ola Wedebrunn. 2015. *Energy Efficiency Solutions for Historic Buildings. A Handbook - Introduction*. Basel: Birkhäuser.

UN. 2015. 'Transforming Our World: The 2030 Agenda for Sustainable Development'. United Nations. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf.

8 ANNEXES

8.1 Reference template for historical and architectural analysis

8.2 Reference template for geometric survey

8.3 Reference on climate data

8.4 Reference template for energy and environmental analyses

8.5 Reference template for Conservation State Analysis

8.6 Reference template for the BIM Execution Plan

8.7 Explanation and use of Model Element Table

8.8 State of the art analysis on building performance simulation on historic buildings

8.9 State of the art analysis on BIM and numerical simulation interoperability

8.10 Feasibility study interoperability of different software used for the simulation

8.11 Reference template for dynamic energy simulation

8.12 State of the art analysis of active and passive energy efficiency technologies compatible with built heritage

8.13 Reference template of compatible active and passive energy efficiency technologies report

8.14 Reference on the methodological approach for the development of the energy and environmental improvement intervention and scenarios

8.15 Reference template for the development of the energy and environmental improvement interventions

8.16 Reference template for the comparative analysis of energy and environmental improvement scenarios.

8.17 Reference for the economic evaluation of the proposed energy retrofit scenarios - payback time indicator

8.18 EPC format (Guaranteed savings model)

8.19 EPC format (Shared savings model)

ANNEX 8.1 REFERENCE TEMPLATE FOR HISTORICAL AND ARCHITECTURAL ANALYSIS

Index

1. GENERAL INFORMATION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

2. SITE ANALYSIS

Description of the historical building site, including:

1. Geographical and territorial framework
2. Topography and climate
3. Location, (urban or rural or other context) urban transformations, access, orientation, etc.

3. REGULATORY FRAMEWORK

List of the main urban regulations, listed building national and local regulations, heritage conservation national and local regulations, etc. concerning the historical building.

4. HISTORICAL AND ARCHITECTURAL ANALYSIS

Description of the main historical and architectural features of the building, including:

1. Historical context, local architecture background (Coeval historical main events, history of the owner/architect/builder, if relevant, similarities – differences with local architecture, coeval constructive techniques, etc.)
2. Analysis and assessment of the changes undergone by the building over time (historical analysis, historical building phases and transformations, bibliographic and records searches, mapping, iconographic and eventually stratigraphic analysis)
3. Brief analysis of the existing geometric-dimensional knowledge of the building (to be integrated with geometric survey, see Annex 5.2)
4. Typological, architectonic and decorative characters (determination of the formal structure of the building, analysis of building constructive techniques, decoration elements, details)
5. Restauration or structural reinforcement interventions.

5. CURRENT USE OVERVIEW

Description of the building current use, including:

1. Functions, space organization, levels, floor plans, internal circulation.
2. Occupancy of the building by personnel or other users

6. ANNEXES

Tentative list of possible annexes, depending on the case study.

1. Historical and archival sources (*e.g. iconographic sources such as historical cartography, retrospective graphic records (drawings, photos, prints), artistic representations, plans, maps; text sources such as letters, documents, newspapers; material sources such as buildings, works of art, coins, etc.);*
2. Photographic documentation with location diagram;
3. Site plan and cadastral map;
4. Drawings (plans, sections, elevations, etc.).

ANNEX 8.2 REFERENCE TEMPLATE FOR GEOMETRIC SURVEY

Index

1. GENERAL INFORMATION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

2. INTRODUCTION

Brief introduction of the geometric survey activities connected to BEEP project.

2.1. Existing geometrical documentation on the building

Brief description (with images) of the existing geometrical documentation on the building, if any, its completeness and accuracy, and the subsequent choice of a survey methodology (measurement verification and integration if existing documentation is robust and accurate, complete survey with different technique if the documentation is lacking).

2.2. Type of survey adopted

Brief description of the survey type adopted: reasons for the choice, methodologies, positions, how the activities were tailored to the specific features of building, etc.

3. SITE CONDITIONS

Description of the building and its state encountered during the survey activities that have influenced the work at hand (if relevant).

4. PRE PLANNING ACTIVITIES

4.1. Pre planning activities description

Description of the pre-planning activities including (briefly) any tender activities performed, the first contacts with the consultant and the owner related to the survey, and the planning of the activities.

Depending on the type of survey adopted, some description include, but are not limited to:

1. measurement objectives (detailed list of the measurements to be taken, the measurement resolution and level of detail, the required accuracy, etc.);
2. security and access constraints, if relevant;
3. mobilisation strategy.

4.2. Equipment

Brief description of the equipment used.

4.3. Personnel

Brief description of the personnel used.

5. DATA ACQUISITION

5.1. Description of the performed data acquisition activities

Description of the field activities with text and photos, detailing the survey development, issues encountered, main marked points and control points (for linear measurements), photos, target and network location diagram and 3D coordinates of all control points/targets (for photogrammetry and laser scanning), survey accuracy, need for unplanned complementary methods, etc.

6. POST PROCESSING

Description of the post processing of acquired data (development of drawings from acquired measurements or post-processing of photogrammetry and/or laser scanner data to compute point clouds).

Main data management issues to describe: information subject to errors, low degree of computerisation depending on the method used, etc.

Description of the software used, formats, methodologies, etc.

7. RESULTS

7.1. Overview of the survey activities

Brief description of the main findings of the activities (referencing the annexes). Depending on the type of survey adopted, the results may vary.

7.2. Integration of survey results in the BIM process

Description of the technical documentation developed: drawings produced (if any), photogrammetry information (resolution, format), point cloud (format, accuracy), etc.

Description (with images) of the integration of the survey information within the BIM authoring software chosen. Depending on the type of survey adopted, the integration may vary. Possible integration include:

1. drawings integration on the model layer system and grid system;
2. rectified photography integration on the model elevation;
3. point cloud import and positioning in the model.

8. ANNEXES

Tentative list of possible annexes (to be reproduced in low resolution format, or as an extract, with photos, etc.), depending on the survey methodology adopted:

8.1. Technical documentation of the building

(for traditional survey)

Drawings with linear dimensions, representation scales at least 1:50, comprehending at the minimum:

1. the plans of all the floors;
2. all elevations;
3. at least 3-4 main sections in both directions;
4. significant details, if needed.

8.2. Photogrammetric documentation

(for photogrammetry survey)

Photogrammetry information integration of geometric data, comprehending the rectified photography of the external building elevation and the main internal elements as coordinate-controlled imagery or scaled rectified imagery or other controlled method.

8.3. Point cloud of the building exterior and interior

(for laser scanning survey)

Images representing the georeferenced and registered versions of the point cloud, with laser intensity value and RGB colour information.

Registration report showing the overall accuracy of the laser scan survey; etc.

8.4. Complementary means

A “Complementary means” annex could be added, in which other material such as video or manual measurements/sketches could be included if needed.

ANNEX 8.3 REFERENCE ON CLIMATE DATA

Index

1. INTRODUCTION

Climate data on an hourly basis for an entire year is needed for dynamic building energy simulation, to be used in order to estimate the energy and environmental performance of the case study building. The selection of relevant weather inputs that represent accurately the conditions is crucial to limit the global uncertainty of building energy simulation results. Their use is related to the stage of a) the calibration of the energy model of the existing building (current state) and b) the simulation of the energy retrofit scenarios. The following paragraphs aim to provide an overview of technical characteristics of weather files, and briefly outline workflows regarding the creation of climate files new, from the very beginning, or the modification of existing climate files.

2. CLIMATE DATA REQUIREMENTS

Based on a single-year data set, the “Test Reference Year” (TRY) was from the earliest attempts to create weather data files (NCDC 1976). The use of TRY is strongly discouraged, as it does not support solar data and no single year can represent the typical weather patterns (Crawley 1998). Thus, the climate data to be used for the dynamic energy simulation should represent long-term average climatic conditions of the building’s location. In this aim, "typical-year" weather files have been developed that are extracted from many years of historical weather data, often from the most recent 15-30 years of historical weather data.

The Typical Meteorological Year (TMY) that was released by the National Renewable Energy Laboratory (NREL), uses a multi-year weather data series of around 27 years, and the TMY2 approximately 30 years. The TMY considers 9 climatic parameters, i.e. minimum, mean and maximum daily dry bulb temperature, minimum, mean and maximum daily dew point, mean and maximum daily wind velocity and daily global horizontal radiation. In the TMY2 the weather quantities are 10, since it also incorporates the parameter of direct solar radiation (Hensen and Lamberts 2011). TMY3 files have also been developed, following a similar approach (Wilcox and Marion, 2008).

The “Weather Year for Energy Calculations 2” (WYEC2) was developed by ASHRAE on the basis of TRY format, but it includes solar data (measured where available, otherwise calculated based on cloud cover and type) and also represents long-term average climatic conditions (ASHRAE 1985).

Depending on the Building Performance Simulation (BPS) software selected, different file formats for climate data may be required. Specific information should be retrieved from the user documentation manual of the selected BPS software. The most widespread file formats for weather data are:

- EPW (EnergyPlus Weather Format)
- TRNSYS (Transys energy file)
- TMY3 (Typical Meteorological Year 3)
- IWEC2 (International Weather for Energy Calculations 2)
- CLM (ESP-r weather format)
- WEA (Daysim weather format)

- DDY (ASHRAE Design Conditions or "file" design conditions in EnergyPlus format)
- STAT (expanded EnergyPlus weather statistics)

2.1. Climate data sources

Most BPS software usually contain features for easy access and selection of a compatible weather file through available built-in weather data repositories. In this case, the selection is usually automatic, based on the building's location.

If this option is not available, a climate file can be either extracted or purchased from national databases or online weather data repositories. Some of the available sources are outlined below:

- Free climate data can be downloaded from the repository: http://climate.onebuilding.org/
  The TMY that are provided derive from a variety of organizations. The prime file format is .epw. Additional file formats that can be retrieved are: .clm, .wea, .ddy as well as .stat.

- Free climate data can be downloaded from the repository: https://energyplus.net/weather
  Weather data for more than 2100 locations are available in .epw format. Additional file formats that can be retrieved are: .txt, .ddy and .stat.

- ASHRAE Weather Year for Energy Calculations 2 (IWEC 2) can be purchased from:
  http://ashrae.whiteboxtechnologies.com/IWEC2
  The database contains weather observations on average at least four times per day of wind speed and direction, sky cover, visibility, ceiling height, dry-bulb temperature, dew-point temperature, atmospheric pressure, liquid precipitation, and present weather for at least 12 years of record up to 25 years. No measured solar radiation data are available, yet, the hourly total horizontal solar radiation is calculated using an empirical model based on the sun-earth geometry, reported cloud cover, temperature difference from three hours previously, relative humidity, and wind speed.

- A wide set of environmental parameters and whether files can be purchased from: https://meteonorm.com/en/meteonorm-version-8

  Meteonorm generates representative typical years for any place on earth based on real data sources and sophisticated calculation tools. It may contain more than 30 different weather parameters. The radiation database includes long term monthly averages. Daily, hourly or minute values are generated stochastically. In addition to global radiation. Hour-to-Hour and day-to-day variability and distributions are modelled as realistic as possible – but may include deviations from measured data. Various file formats are available, e.g.: .EPW, .TMY2, .TMY3 .CSV, PVSol, etc.

In case climate data for the particular building location are not available or the location is too far away from a weather station, there is no generally accepted procedure for the selection of a suitable weather data source. One option is to use a weather generator tool (e.g. Meteonorm) that can extrapolate weather data from weather stations in the vicinity. An alternative option is to identify some candidate sources with approximately the same latitude and elevation as the site (within 30-50 km and a few hundred meters of elevation). Then comparison of monthly statistics derived from candidate files (using a simulation program weather utility[1]) to climatological summaries for the project location will generally allow the selection of an acceptable match. If no similar source is found, data synthesis or adjustment procedures should be considered (Hensen and Lamberts 2011).

2.2. Creation and modification of climate files

Climate data files can be generated, based on detailed outdoor environmental monitoring as described in EN ISO 15927-4:2005. ISO 15927-4 specifies a method for constructing a reference year of hourly values of appropriate meteorological data suitable for assessing the average annual energy for heating and cooling. A thorough analysis and improvement suggestion of the Standard is provided by Pernigotto et al. (2014).

Given the fact that the above procedure requires meticulous calculations and skills, along with a very detailed climate data set, which is not always readily available, adopting adjustment processes by modifying an existing climate file (with the use of file-converter applications) is often opted instead.

The following steps provide an example of the process summarising the modification of an EnergyPlus weather file (*.epw). The steps 1 to 7 may be followed when a candidate climate files from a location close to the site (approximately the same latitude and elevation) is available but need to be modified by available long-term climate data of the site's location; steps 3 to 7 may be followed when available long-term data from the site location are available in spreadsheet format.

1. Select the existing – candidate weather file .epw (of the near location),
2. Export the file in .csv format or spreadsheet and use it as a template,
3. Replace the data of the template (the nearby location) that need to be modified, by copy-pasting the new data column-by-column. In this process, the physical relationships between the variables should be maintained[2],
4. Ensure the year is set to 2002 in all rows,
5. Save the new file as .cvs file,
6. Use a weather file translator (file-converter applications) to convert the template .csv file to .epw format. Many BPS software incorporate easy-to-use,

[1] e.g. the .epw viewer: https://mdahlhausen.github.io/epwvis/

[2] This can be done by using the free tool "Elements" which is used to alter spreadsheet-type weather data. When changing a parameter (e.g. dry-bulb, wet-bulb, etc.), the tool asks the user to define what other parameters to hold constant in order not to violate physics (e.g. >100% RH). This is also applied to solar radiation data (beam, diffuse, and total).

file-converter applications (e.g. Design Builder can convert . tmy2, .iwec, .csv, .fmt, .clm files into .epw[3])

7. Rename the .epw file as required.

It is noted that for the conversion/modification of other file formats, specific technical guidelines have to be collected by online sources and technical documentation of the selected BPS software.

3. REFERENCES

ASHRAE. 1985. 'Weather Year for Energy Calculations.' Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

CEN. 2005. 'ISO 15927-4:2005'. European Committee for Standardization. https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/04/13/41371.html.

Crawley, Drury B. 1998. 'Which Weather Data Should You Use for Energy Simulations of Commercial Buildings?' ASHRAE TRANSACTIONS. Part 2. Atlanta: ASHRAE.

'Elements | Big Ladder Software'. n.d. Accessed 11 July 2021. https://bigladdersoftware.com/projects/elements/.

Hensen, Jan, and Roberto Lamberts, eds. 2011. *Building Performance Simulation for Design and Operation*. London; New York: Spon Press.

NCDC. 1976. 'ASHRAE Test Reference Year Reference Manual (TD9706)'.

Pernigotto, Giovanni, Alessandro Prada, Andrea Gasparella, and Jan L.M. Hensen. 2014. 'Analysis and Improvement of the Representativeness of EN ISO 15927-4 Reference Years for Building Energy Simulation: Journal of Building Performance Simulation: Vol 7, No 6'. *Journal of Building Performance Simulation* 7 (6): 391–410. https://doi.org/10.1080/19401493.2013.853840.

'Weather Data for Simulation | EnergyPlus'. n.d. Accessed 11 July 2021. https://energyplus.net/weather/simulation.

Wilcox, S, and W Marion. 2008. 'Users' Manual for TMY3 Data Sets'. NREL/TP-581-43156. Colorado: National Renewable Energy Laboratory (NREL).

[3] https://designbuilder.co.uk/helpv4.2/Content/_Edit_hourly_weather_data.htm

ANNEX 8.4 REFERENCE TEMPLATE ENVIRONMENTAL AND ENERGY ANALYSIS

Index

1 INTRODUCTION

The template provides a workflow for the environmental and energy analysis, to be integrated it the EE-HBIM guideline.

The data from the operators interviewed, from the documents found and from the field analyses are funnelled into this document. In a traditional Energy Audit, this organization can support both a check of the completeness of the data collected for the energy analysis, and a library of the functional data for insertion in the simulation software.

To allow this transfer from field analysis to model, data within the Annexes of this template must be consistent with the BIM Element Table section on parameters, if any, and therefore BIM model parameters. Any definition of property set (Pset) for open format export should take the issue into account.

To be identified, all objects must be referenced with a unique alphanumeric identification code, that must be consistent with the BIM model identification system (for example Revit software use the parameters Mark and Type Mark to identify this type of unique coding). Depending on the type of object, the code can be an instance code for individual objects like rooms, or a type code, for repeating objects such as constructions.

Within the template, rooms will be identified with a 3 digit number (see § 3.1.2), objects types with a capitalized letter representative of the category and a 2 digit number (for example W01 for windows), object instances (if relevant) with the same letter lowercase and digit number. Examples of coding will be given throughout this document. Other coding system are also possible, internal coherence is anyway paramount.

In Blue are the fields of all the codes to be inputted

in Red are example data as reference

2 GENERAL INFORMATION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

3 COLLECTED DATA

3.1 General information on the spaces

3.1.1 Building(s)

The table should be filled in for each building of the case study.

Building A (if there are more than one building)

[the table is just a reference, please adapt to the case study's specificities, levels and spaces]

NAME		
LOCATION		
COORDINATES		
IMAGE	Insert an orthophoto or other plan image of the analysed site with orientation and highlight each audited building (by contour, fill, etc.).	
FUNCTION		
NUMBER OF FLOORS		
NUMBER OF BUILDING UNITS	In order to understand if the property is splitted	
NET HEATED SURFACE	M^2	
NET HEATED VOLUME	M^3	
V: GROSS HEATED VOLUME	M^3	
A: BUILIDING ENVELOPE SURFACES (ADJACENT TO THE GROUND, TO HEATED OR/AND NON-HEATED SPACES, TO THE EXTERNAL AIR)	M^2	
C=A/V COMPACTNESS RATIO (THE AREA OF A BUILDING'S EXTERNAL ENVELOPE TO ITS HOSTED INNER VOLUME)		
YEAR OF CONSTRUCTION		
PREVIOUS INTERVENTIONS	Year	

	Description	
PREVIOUS INTERVENTIONS	Year	
	Description	

3.1.2 Rooms/Spaces

This section defines, for each floor of each building, the rooms/spaces present with their use and for each of them a unique 3 digit identification code is assigned. The code will be used to identify the room in the data sheets that contain information about it and to indicate the room in other sheets, if necessary. The code is unique, there shall not be rooms with the same code even if they belong to different building units or floors.

The coding must be verified together with the BIM coding for the rooms and, if present, the room coding of the building management system. The sheet describing the floor plan (room schedule and thematic plans) should be directly extracted from the HBIM model.

COD.	**FUNCTION**	
		Please insert a level plan with a thematic map of the rooms of the level with the various rooms defined graphically (graphically represented by contour, fill colour, etc.) with the code tag. The plan should be extracted from the model and applied on a sheet with the corresponding rooms schedule

3.2 Energy consumption

This section describes the energy and other utilities' contracts information and the building's consumption of thermal energy, electricity and water.

3.2.1 Contracts

The following tables should be filled in with information of energy and other utilities' contracts.

3.2.1.1 Management service contracts

CONTRACT/CERTIFICATION	DESCRIPTION
Facility/Maintenance Management	
Energy Management System (EnMS)	

3.2.1.2 Energy supply contracts

TYPE	DATA ACCESSIBILITY[1]	NOTES
Methane (1)	Yes / No / online	
Methane (2)	Yes / No / online	
Diesel fuel	Yes / No / online	
LPG	Yes / No / online	
Wood	Yes / No / online	
Pellet	Yes / No / online	
Heat networks (District heating)	Yes / No / online	
Electrical energy (1)	Yes / No / online	
Electrical energy (2)	Yes / No / online	
Onsite produced energy		

3.2.2 Fuel, electricity and water consumption[2]

Energy consumption data collected from general meters and/or dedicated meters (if available) and/or energy supply bills. Describe the energy meters (heat and electricity) and water meters present if relevant. Monthly (or at more frequent intervals) consumption data should be obtained for at least the last three years filling the

---

[1] [The energy auditor should verify the possibility to access an online energy contract management of the building on the energy supplier website, if present]

[2] The information presented in the consumption tables can also be monthly and seasonal; please add to the attachment any measurements with such frequencies. It is paramount to have at least seasonal measurements, in order to decouple the different energy uses to be shown in the table FUEL, ELECTRICITY AND WATER CONSUMPTION PER USE (Year 2019) (e.g. if the boiler is responsible for both heating and DHW, the summer gas consumption shows the share of consumption for non-heating uses and allows to assume the winter gas share for heating).

following table, if data is not available at monthly intervals fill in the yearly table below.

Monthly table

FUEL, ELECTRICITY AND WATER CONSUMPTION (Year 2019)														
Type	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**TOTAL**	**Annual costs**
Electricity (kWh)														
Diesel (Lt)														
Methane gas (Nm^3)														
LPG (kg)														
Wood (ton)														
Other														
Water (lt)														

Yearly table (alternative to the monthly table)

ENERGY SOURCE	2016-2017		2017-2018		2018-2019	
	quantity	annual cost	quantity	annual cost	quantity	annual cost
Methane gas (1)	m^3	€	m^3	€	m^3	€
Methane gas (2)	m^3	€	m^3	€	m^3	€
diesel fuel	l	€	l	€	l	€
LPG	l	€	l	€	l	€
Wood	Kg	€	Kg	€	Kg	€
Pellet	Kg	€	Kg	€	Kg	€
Heat networks (District heating)	Mj	€	Mj	€	Mj	€
Electrical energy (1)	kWh	€	kWh	€	kWh	€
Electrical energy (2)	kWh	€	kWh	€	kWh	€
water(1)	l	€	l	€	l	€
water(2)	l	€	l	€	l	€

Consumption per use

FUEL, ELECTRICITY AND WATER CONSUMPTION PER USE (Year 2019)						
ENERGY USE	**Electricity**	**Diesel fuel**	**Methane gas**	**LPG**	**Wood / Pellets**	**other**
Heating						
Cooling						
Lighting						
Office equipment						
Other special equipment						
..						
DHW						

3.3 Climate Data

Please describe the type source of climate data sets, indicate, if possible, the position and altitude of the meteorological station used as reference and the distance from the case study site (also with an orthophoto or plan).

Please identify the available data, i.e tabular hourly or a weather file in international standard format containing:

- external air temperature
- air humidity,
- wind velocity,

- average solar irradiance on the horizontal plane
- other (depending on the specific calculation methods chosen).

3.4 Usage profile schedules

3.4.1 System usage profile schedules

Please briefly describe the usage profiles schedules of the systems.

If control systems are present, please indicate the controlled parameters (temperature, air exchange, humidity, illuminance) and their settings in winter, summer and other periods.

Describe the control and automation systems that may be present (Building Energy Management Systems BEMS, Building Automated Control Systems BACS).

The data of the usage profiles of the systems will be specified in detail in the attachments (see § 5.2.1) by filling in the relevant information in the corresponding sheet. In addition, the annexes also contain information sheets on the control systems.

3.4.2 Rooms occupancy schedules

Please briefly describe the rooms/spaces usage profiles schedules depending on the rooms/spaces function.

The data of the usage profiles of the rooms/spaces will be specified in detail in the attachments (see § 5.2.2) by filling in the corresponding sheet.

All the sheets should be extracted, with drawing and schedules combined, from the EE-HBIM model.

3.4.3 Equipment usage profile schedules

Please indicate if there is equipment with an extremely high energy consumption, highly affecting the energy balance of the building, its use profiles can be described here (e.g. a data room with server).

3.4.4 Usage profile Thematic plans

Please provide thematic plans of usage profile for each level, with suitable graphical representation (fill colour map, contour maps, etc.), should be extracted from the EE-HBIM model.

3.4.5 Opaque envelope

Please provide an overview of the various types of opaque envelope in the building.

The data of the structures will be specified in detail in the annexes by filling in the corresponding sheet. All the sheets should be extracted, with drawing and schedules combined, from the EE-HBIM model: the model is particularly suited to produce opaque and transparent envelope schedules (see § 5.3.1 and 5.3.2).

3.4.6 Transparent envelope

Please provide an overview of the various types of transparent envelope elements in the building. The data on the transparent envelope elements of the rooms/spaces will be specified in detail in the attachments (see § 5.3.2) by filling in the corresponding sheet.

3.5 Systems

3.5.1 Heating system, Cooling system, Domestic Hot Water (HVAC and DHW)

Please fill in the following table for each heating, cooling and domestic hot water production system, detailing the types of generators, distribution systems, terminal units, storage tanks and rooms served by the system. The same information should be provided in the HBIM model.

The unique codes for each component and progressive for each type of component will allow to both identify the relative data sheet in the attachment and to indicate the component in other technical sheets if needed. This coding system should be consistent with the BIM coding system for objects. The sheets should be extracted from the schedules EE-HBIM model. As stated in the Introduction, all the columns of the first rows correspond to parameters of the BIM model that should be integrated in the BIM Element Table and any Pset.

[the table content is just a reference, please adapt to the case study's systems]

Please describe the system (or systems) layout for heating, cooling and domestic hot water production. Describe the individual components that constitute each system and their connection type (series and parallel): generators, distribution system and related circulation pumps, terminals, control system, storage and on-site power generation systems used (such as solar thermal and photovoltaic systems). The data on each individual component will be specified in detail in the attachments (see § 5.4) by filling in the corresponding sheet.

If possible, please insert an image of the system diagram.

SYSTEM	GENERATOR OF THE THERMAL POWER PLANT (COD.)	DISTRIBUTION (COD.)	TERMINAL UNITS (COD.)	ENERGY STORAGE (COD.)	CODES OF THE ROOMS SERVED BY THE SYSTEM
Heating	Heat generator (G01) + Heat generator(G02) / Cogeneration (G10)	Hydronic (D01)	Radiant heating (T01) / Radiators (T06)	Puffer (S01)	001, 002, 003, 004, 005….
Heating	Heat networks	Hydronic (D02)	Radiators (T02)		

+ Domestic Hot water	(district heating) + Heat exchanger (G03)	+ open Hydronic (D03)			
Cooling	Heat pump (G04) + Heat generator (G05)	Hydronic (D04)	Radiators (T02)		
HVAC	Heat pump (G06) + Generator (G07) + AHU(G08)	Hydronic (D05) + Aeraulic(D06)	Wall mounted air diffuser (T03) + Fan coil (T04)		
Domestic Hot Water	Heat generator (G08) + Solar thermal collector (G01)	open Hydronic (D07)		Water storage(S02)	
Heating and Cooling (no air treatment)	Heat pump (G09)	Direct (D08)	Split (T05)		

3.5.2 Mechanical ventilation

Please briefly describe the mechanical ventilation system (if present); the specific data will be reported in detail in the attachments (see § 5.4.2) by filling in the corresponding sheet.

3.5.3 Lighting

Please briefly describe the lighting system by detailing the type, state of maintenance, control system and estimating the visual comfort related to the activities performed in the space. The data on individual appliances type will be specified in detail in the attachments (see § 5.4.7) by filling in the corresponding sheet and the Rooms/Spaces sheets (see § 5.1).

3.5.4 Equipment

If there is equipment with an extremely high energy consumption, highly affecting the energy balance of the building, they can be briefly described here, while the specific data will be reported in detail in the attachments (see § 5.4.8) by filling in the corresponding sheet.

3.5.5 Onsite energy production systems

Please briefly describe the onsite energy production systems, if present (Solar thermal energy systems, photovoltaic system or any other system), the technology used and the percentage of building energy demand they can cover. The data on each system will be specified in detail in the attachments (see § 5.4.9) by filling in the corresponding sheet.

3.5.6 Room by dedicated system thematic maps

Thematic plans depicting the rooms served by each system, with suitable graphical representation (fill colour map, contour maps, etc.), should be extracted from the EE-HBIM model.

4 ADDITIONAL FIELD ANALYSES

Please briefly describe the outcome of the additional suggested field analyses.

4.1 IR thermographies (B1)

Please briefly describe the obtained methods and results.

4.2 Simplified indoor environmental monitoring (B2)

Please briefly describe the obtained methods and results.

4.3 Air flow rate measurements and complete environmental monitoring (B3)

Please briefly describe the obtained methods and results.

4.4 Occupant thermal comfort assessment (B4)

Please briefly describe the obtained methods and results.

5 ANNEXES

The annexes present a list of sheets describing in detail all the building systems that were briefly described before.

All these data will be implemented in the HBIM model: therefore, the coding system should correspond to the model naming system and the data structure should correspond to a set of parameters in the model, as detailed in the Model Element Table, if any (see Introduction). Whichever the data transferring method from field analysis to HBIM model (even if data are collected with pen and paper), please keep in mind this correspondence as you fill in the data and give a name to each parameter.

Please add to the Annexes also all the reports on specific field analysis listed in § 5.5.

5.1 Rooms Annexes

The detailed sheets represent the data that shall be collected in the field analysis and technical documentation survey. As stated throughout the report template, all these data should be integrated in the HBIM model: depending on the case study specifics, software used for BIM modelling and simulation and data integration process, it is paramount to define a coherent data input strategy. Probably, these data should be inputted in the HBIM model partly in the "Room" properties, partly in the HVAC object properties, partly on construction elements and materials, and then from the BIM model being exported, as much and as smoothly as possible, to the simulation software. Part of BEEP project is to define and test this type of workflow.

As stated in the Introduction, all elements of the sheet correspond to parameters of the BIM model that should be integrated in the BIM Element Table and any Pset.

ROOM CODE (INSTANCE)	006		
FUNCTION	Office		
ROOM OCCUPANCY SCHEDULE CODE (cfr. § 3.4.2)	U01		
HEATING, COOLING AND VENTILATION (HEATING AND COOLING EMISSION SYSTEM)			
GENERATOR CODE SERVING THE ROOM	G01, G03...		
TERMINALS TYPE CODE	NUMBER OF TERMINALS	CONTROL SYSTEM	**SYSTEM USAGE PROFILE CODE**
Radiators (T01)		Thermostatic Radiator Valves (D01)	U01

Radiators (T01)		Centralised (D02)	U01
Radiators (T02)		Zone thermostat (D03)	U01
Split (T03)		Single space (D04)	User defined
Fan coil (T04)		Single space (D05)	User defined
TRANSPARENT ENVELOPE			
TRANSPARENT ENVELOPE TYPE CODE	DIMENSIONS (width - length) cm		
W01	cm x cm		
W02	cm x cm		
W03	cm x cm		
LUMINAIRES (replicate for each luminaire type if there are more than one)			
LUMINAIRE TYPE CODE	NUMBER OF ITEM		
L01	4		
L02	2		
VISUAL COMFORT	Please provide a qualitative assessment of the appropriateness of illuminance level for different uses, possible glaring, differences in lighting levels, presence of additional table lighting		
ROOM LUMINAIRE STATE OF MAINTENANCE	Please briefly describe the state of maintenance of lightings: if they are dirty, if there are any lamps or appliances to be substituted, etc.		
CONTROL SYSTEM (**CODE**)	Please indicate if there is a lighting control system (for instance, dimmer, general automatic shut off system, movement sensors) or they are needlessly left on.		
OTHER EQUIPMENT			
TYPE	n°	Energy efficiency	Reference

PC	1	W/m^2[3]	ASHRAE 1997...
CONTROL SYSTEM	Please indicate if there is an automatic control system to turn the equipment on and or they are always needlessly left on.		

5.2 Usage profile schedules annexes

5.2.1 System usage schedule annexes

Each schedule indicate the usage period of the systems belonging to each room and the settings for heating, cooling and air exchange temperature.

A distinction is made between system usage profiles in winter and summer; if there other periods of system usage profiles are relevant please add additional sections to the schedule as needed. The same system usage profile can refer to different rooms; it could be possible to have a single system usage profile for the entire building.

These system profile schedules shall be integrated in the HBIM model, for example as a linked pdf to the corresponding elements in the HBIM model.

SYSTEM USAGE PROFILE CODE			
ROOM CODE (of the rooms where the profile is set up)			
WINTER HEATING PERIOD			
DAYS OF THE WEEK		For instance, Monday, Tuesday, Wednesday, Thursday, Friday	
HOURS INTERVALS OF USE PER DAY	HEATING SETPOINT	COOLING SETPOINT	ESTIMATED AIR CHANGES PER HOUR
08.30 - 13.30	°C	°C	volume/h; m^3/h;
14.30 - 18.30	°C	°C	volume/h; m^3/h;
DAYS OF THE WEEK		For instance, Saturday, Sunday	
HOURS INTERVALS OF USE PER DAY	HEATING SETPOINT	COOLING SETPOINT	ESTIMATED AIR CHANGES PER HOUR[4]

[3] usually taken by ASHRAE tables (1997 ASHRAE Fundamentals Handbook - Chapter 28)

[4] give an estimate/tabular value if possible.

8.30 - 18.30	°C	°C	volume/h; m^3/h;
1° HOLIDAY PERIOD			
2° HOLIDAY PERIOD			

SYSTEM USAGE PROFILE CODE			
ROOM CODE (of the rooms where the profile is set up)			
DAYS OF THE WEEK		For instance, Monday, Tuesday, Wednesday, Thursday, Friday	
HOURS INTERVALS OF USE PER DAY	HEATING SETPOINT	COOLING SETPOINT	ESTIMATED AIR CHANGES PER HOUR
08.30 - 13.30	°C	°C	volume/h; m^3/h;
14.30 - 18.30	°C	°C	volume/h; m^3/h;
DAYS OF THE WEEK		For instance, Saturday, Sunday	
HOURS INTERVALS OF USE PER DAY	HEATING SETPOINT	COOLING SETPOINT	ESTIMATED AIR CHANGES PER HOUR
8.30 - 18.30	°C	°C	volume/h; m^3/h;
1° HOLIDAY PERIOD			
2° HOLIDAY PERIOD			

5.2.2 Room occupancy schedules annexes

Each schedule indicate the occupancy period of each room. The same room usage profile can refer to different rooms; it could be possible, in theory, to have a single room usage profile for the entire building.

The activity taking place in the rooms is not specified, as it can be deduced from the room code definition, that is based on the room use (see § 3.1.2)

These room occupancy schedules shall be integrated in the HBIM model, for example as a linked pdf to the corresponding elements in the HBIM model.

ROOM OCCUPANCY SCHEDULE CODE	U01
ROOM CODE where the usage profile is set up	
DAYS OF THE WEEK	For instance, Monday, Tuesday, Wednesday, Thursday, Friday
HOURS INTERVALS OF USE PER DAY	NUMBER OF PEOPLE
08.30 - 13.30	2
14.30 - 18.30	1
DAYS OF THE WEEK	For instance, Saturday, Sunday
HOURS INTERVALS OF USE PER DAY	NUMBER OF PEOPLE
08.30 - 18.30	1
1° Holiday period	from DD/MM, to DD/MM
2° Holiday period	from DD/MM, to DD/MM

5.2.3 Equipment usage schedule annexes

If there is equipment with an extremely high energy consumption, highly affecting the energy balance of the building, its use profiles can be described here. For everyday equipment the simulation strategy will define the way their internal gain is calculated (they could be linked to the room occupancy schedule with an estimated value W/per person)

EQUIPMENT USAGE SCHEDULE CODE	U01
ROOM CODE where the usage profile is set up	
EQUIPMENT CODE	
DAYS OF THE WEEK	For instance, Monday, Tuesday, Wednesday, Thursday, Friday

HOURS INTERVALS OF USE PER DAY	8:30 - 13:30 / 14.30 - 18.30
DAYS OF THE WEEK	For instance, Saturday, Sunday
HOURS INTERVALS OF USE PER DAY	8:30 - 18:30
1° Holiday period	from DD/MM, to DD/MM
2° Holiday period	from DD/MM, to DD/MM

5.3 Construction annexes

5.3.1 Opaque envelope annexes

5.3.1.1 Walls annexes

As for Rooms schedules, the opaque schedules should be directly extracted from the HBIM model and extract a section representation of the wall stratigraphy as image.

As stated in the Introduction, most elements of the sheet correspond to parameters of the BIM model that should be integrated in the BIM Element Table and any Pset.

[the table is just a reference, please adapt to the case study's specificities, levels and spaces]

TYPE OF OPAQUE ENVELOPE	(Wall, floor, roof)
WALL/FLOOR/ROOF CODE	C01 Each envelope category shall have its coding number, referring to the category (walls C01, floors F01, roofs R01).
DESCRIPTION	For instance: stone masonry with plaster on both sides, fair faced brick wall, composite concrete-brick floor, slabs on grade, masonry vault, wood pitched floor, etc.
IMAGE (SECTION WITH STRATIGRAPHY)	
THICKNESS	cm
HEAT FLUX METER MEASUREMENTS	Yes (please indicate value) /No Please indicate if this opaque envelope typology was selected for heat flux meter analyses. In the final audit report, specific energy software technical sheets of all opaque envelope typology will contain all the data (estimated and measured) including thermophysical properties.

TENTATIVE STRATIGRAPHY	
LAYER (from external to internal layer)	THICKNESS (cm)
External layer. For instance: plaster, stone cladding, metal cladding, stone, brick, fair faced concrete, roof tiles	cm
For instance: air, stone, bricks, hollow bricks, concrete, rock wool, fibreglass, polyurethane, screed, planking, vapour barrier	cm
For instance: air, stone, bricks, hollow bricks, concrete, rock wool, fibreglass, polyurethane, screed, planking, vapour barrier	cm
...	cm
Internal layer. For instance: plaster, stone cladding, stone, brick, fair faced concrete, tiles, false ceiling.	cm
BRIEF DESCRIPTION BASED ON THE FIELD SURVEY	
Please briefly present any relevant information gathered from visual analysis, thermographic analysis and any other analyses carried out to define the type of structure, its state of conservation and its thermo-hygrometric characteristics. The information may concern the type of structure, presence of subsidence or structural lesions, material discontinuity in the structure, state of conservation, swelling and detachment of the plaster and surface finishings, condensation and interstitial and surface humidity, infiltration and capillary action of water, presence of biopathogenic agents, air infiltration, water infiltration (for example in roofing).	

5.3.1.2 Flooring annexes

Please fill in the same sheet presented above for the walls for each flooring element (code F01).

5.3.1.3 Roofing annexes

Please fill in the same sheet presented above for the walls for each roofing element (code R01).

5.3.1.4 External doors annexes

Please define a specific schedule for external doors if they are relevant for the energy and environmental behaviour of the building. If so fill the same sheet presented for the opaque envelope also for these doors (code E01).

5.3.2 Transparent envelope annexes

As for opaque envelope schedules, the transparent envelope schedules should be directly extracted from the HBIM model and extract a section representation of the wall stratigraphy as image.

[the table is just a reference, please adapt to the case study's specificities, levels and spaces]

5.3.2.1 Windows annexes

TYPE OF TRANSPARENT ENVELOPE	(Window, skylight, curtain wall)	
WINDOW TYPE CODE	W01 Each transparent envelope category, if more than one exist, shall have its coding number, referring to the category (for instance: window W01, skylight A01, curtain wall B01).	
DESCRIPTION	For instance: double-glazed 2 panel wooden frame, double-glazed skylight PVC frame, single-glazed curtain wall with aluminium frame, ribbon window.	
IMAGE	Schematic drawing of the window and frame geometry with dimensions and thicknesses of glass and frames. Alternatively, photographic images.	
NUMBER OF PANELS AND TYPE OF MOVEMENT	For instance: 2 panels shutters window, 1 panel bottom-hung casement window, 1 panel horizontal pivot window,2 panels vertical sliding sash window, 2 panels horizontal sliding window. Double windows (used in heritage buildings).	
CONSTRUCTION TRANSMITTANCE	Please indicate only if it is indicated in the product sheet.	
GLASS		
SOLAR FACTOR	Please indicate only if it is indicated in the product sheet.	
LAYER		THICKNESS (mm)
For instance: float glass, low-emissivity glass, laminated glass		mm
For instance: air, argon, kripton		mm
For instance: float glass, low-emissivity glass, laminated glass		mm

For instance: air, argon, kripton	mm
For instance: float glass, low-emissivity glass, laminated glass	mm
FRAME	
MATERIAL	For instance: hardwood, softwood, aluminum, PVC
INSULATION CHAMBERS	Not present, 1, 2 ...
SPACER	
SPACER TYPE	In the case of insulating glass, describe the spacer (if present) and its material.
SHADING SYSTEM	
TYPE	For instance: external / internal louvers, venetian blinds, sunshades, shutters, curtains etc.
IMAGE	Schematic drawing or photo of the louvers and/or roll box enclosure
ROLL BOX ENCLOSURE	Please describe, if present, the material, isolation (if present) infiltration of the roll box enclosure.
CONTROL SYSTEM	For instance: manual, electric with manual control, electric with automatic control, programmable, with sensor (actuators) of presence, illuminance, temperature, solar radiation direction
BRIEF DESCRIPTION BASED ON THE FIELD SURVEY	
Please briefly present any relevant information gathered from visual analysis, thermographic analysis and any other analyses carried out to define the type of structure, its state of conservation and its thermo-hygrometric characteristics. The information may concern the type of structure, state of conservation and maintenance, installation errors, air infiltration, water infiltration, usage and state of conservation of louvers	

5.3.2.2 Skylights annexes

Please fill in the same sheet presented above for the windows for each skylight element, if present (code A01).

5.3.2.3 Curtain wall annexes

Please fill in the same sheet presented above for the windows for each curtain wall, if present (code B01).

5.4 Systems annexes

5.4.1 Generators annexes

As for opaque construction schedules, generators schedules should be directly extracted from the HBIM model.

As stated in the Introduction, all the elements of the sheet correspond to parameters of the BIM model that should be integrated in the BIM Element Table and any Pset.

[the tables are just a reference, please adapt to the case study's equipment]

5.4.1.1 Heat generators annexes

HEAT GENERATOR TYPE CODE	G01
ROOM CODE served by the generator	001, 002, 003, 004...
IMAGE	
MANUFACTURER AND MODEL	
PURPOSE	For instance: heating, domestic hot water
FUEL	
HEATING RECOVERY	For instance: standard, condensing.
OPERATION PROFILE	For instance: single stage, multi-stage, modulating
TYPE OF DRAFT	For instance: sealed, open vented
TYPE OF INSTALLATION	For instance: wall mounted, floor standing
HEATING INPUT	kW
HEATING OUTPUT	kW
EFFICIENCY OF NOMINAL HEAT INPUT (LAST SURVEY DATE)	% (DD/MM/YYYY)
INSTALLATION DATE	DD/MM/YYYY
POSITION	For instance: exterior, Technical room
CONSERVATION/MAINTENANCE STATE	good, medium, scarce
DIMENSIONS	cm x cm x cm

BURNER	
BURNER MANUFACTURER AND MODEL	
MODALITÀ IMMISSIONE ARIA	For instance: Venturi burners, blown-air burners
INSTALLATION DATE	DD/MM/YYYY
BURNER CONSERVATION/MAINTENANCE STATE	good, medium, scarce

5.4.1.2 Electric boiler annexes

BOILER TYPE CODE	G01
ROOM CODE served by the generator	001, 002, 003, 004...
IMAGE	
MANUFACTURER AND MODEL	
ELECTRIC POWER	kW
INSTALLATION DATE	
STORAGE CAPACITY	
CONSERVATION/MAINTENANCE STATE	good, medium, scarce
DIMENSIONS	cm x cm x cm

5.4.1.3 Heat pump annexes

HEAT PUMP TYPE CODE	G02
ROOM CODE served by the generator	001, 002, 003, 004...
IMAGE	
MANUFACTURER AND MODEL	
POWER SUPPLY TYPE	For instance: compression heat pumps, absorption heat pumps, combustion heat pumps
OUTDOOR THERMAL SOURCE	For instance: Air, water, ground

INDOOR THERMAL SOURCE	For instance: Air, water			
REFRIGERANTS	For instance: R22, R407C, R410A, R600, altro.			
INSTALLATION DATE				
POSITION	For instance: External, Technical room			
CONSERVATION/MAINTENANCE STATE	good, medium, scarce			
DIMENSIONS	cm x cm x cm			
HEATING				
COOL SOURCE/SINK	°C	°C	°C	°C
HEAT SOURCE/SINK	°C	°C	°C	°C
HEATING CAPACITY	kW	kW	kW	kW
POWER INPUT	kW	kW	kW	kW
COP - COEFFICIENT OF PERFORMANCE/GAS UTILIZATION EFFICIENCY - GUE				
COOLING				
COOLING CAPACITY	kW			
POWER INPUT	kW			
EFFICIENCY ENERGY RATIO (EER)	%			

5.4.1.4 AHU (Air-handling unit) annexes

AHU TYPE CODE	G03
ROOM CODE served by the	001, 002, 003, 004...

generator		
IMAGE		
MANUFACTURER AND MODEL		
AIR SYSTEM	For instance: Single duct, multiple zone, dual duct.	
SUPPLY AIR FLOW RATE	For instance: Constant Air Volume (CAV), variable air volume (VAV)	
SUPPLY AIR TEMPERATURE	For instance: Constant Air Temperature, variable air temperature.	
TYPE OF TREATED AIR	For instance: outside air, air mixed in the AHU, air mixed in room terminals (FAT, Fan Assisted Terminal).	
HEAT/COOLING RECOVERY EXCHANGER	Yes, No, type	
INSTALLATION DATE		
POSITION	Roof	
CONSERVATION/MAINTENANCE STATE	good, medium, scarce	
DIMENSIONS	cm x cm x cm	
VENTILATION		
MAXIMUM AIRFLOW	m^3/h	
MINIMUM AIRFLOW	m^3/h	
FILTER DESCRIPTION		
HEATING		
FLOW RATE	m^3/h	m^3/h
HEATING CAPACITY	kW	kW

COOLING		
FLOW RATE	m^3/h	m^3/h
COOLING CAPACITY	kW	kW

5.4.1.5 Cogeneration plant annexes

HEAT EXCHANGER TYPE CODE	G03			
IMAGE				
MANUFACTURER AND MODEL				
FUEL				
PURPOSES				
TYPE OF ENGINE				
TOTAL EFFICIENCY	%			
ELECTRICAL EFFICIENCY	%			
HEATING OUTPUT	kW			
WATER TEMPERATURE	T in min	T in max	T out	T out max
	°C	°C	°C	°C
ELECTRICAL OUTPUT	kW			
POTENTIAL DIFFERENCE	V			
INSTALLATION DATE				
POSITION				
CONSERVATION/MAINTENANCE STATE	good, medium, scarce			

5.4.1.6 Heat exchanger of the district heating/cooling system annexes

HEAT EXCHANGER TYPE CODE	G03		
IMAGE			
MANUFACTURER AND MODEL			
ENERGY SOURCE PRIMARY CIRCUIT	For instance: urban district heating/cooling, neighborhood district heating/cooling		
MEDIUM FOR HEAT/COOLING DISTRIBUTION	For instance: hot water, superheated water, steam	T in	T out
		°C	°C
SECONDARY CIRCUITS	Water	T in	T out
		°C	°C
HEATING/COOLING OUTPUT	kW		
INSTALLATION DATE			
POSITION			
CONSERVATION/MAINTENANCE STATE	good, medium, scarce		

5.4.2 Controlled mechanical ventilation annexes

VENTILATION SYSTEM	exhaust-only, supply-only, balanced with or without energy recovery
TYPE OF SENSING SYSTEM	automatic control, hygro-regulable.
HEAT RECOVERY SYSTEM	nor present, cross-flow heat exchanger, other heat exchanger (specify).
SENSIBLE HEAT EXCHANGE EFFICIENCY	%
ENTHALPIC EXCHANGE EFFICIENCY - HEATING	% (se presente)
ENTHALPIC EXCHANGE EFFICIENCY - COOLING	% (se presente)
ESTIMATED AIR CHANGES	m^3/h

5.4.3 Distribution system annexes

DISTRIBUTION SYSTEM CODE	D001		
HEAT TRANSFER FLUID FOR DISTRIBUTION	For instance: hot water, superheated water, air, etc.		
DISTRIBUTION	To the various users with a single circuit, to the various users with autonomously adjustable circuits (by zones), other.		
MAIN PIPE SIZE	length (m) per dimension		
MAIN PIPE INSULATION	Present, good, medium, scarce.		
CIRCULATING PUMPS			
MANUFACTURER AND MODEL	INSTALLATION DATE	FLOW RATE Q (m^3/h)	PUMP HEAD (m)
EXPANSION TANKS			
MODEL	CAPACITY (l)	OPEN/CLOSED	PRE-CHARGED PRESSURE (bar)

5.4.4 Heating, cooling, ventilation terminals typologies annexes

TERMINAL TYPE CODE	T01
TYPOLOGY	For instance: radiators, radiant panel, fan coil, split, wall inlet, chilled beams...
IMAGE	
TECHNICAL CHARACTERISTICS (dimensions and heating/cooling capacity)	For , for radiators the heat output of the typology, the water in/out temperature.
CONSERVATION/MAINTENANC	

E STATE	

5.4.5 Control system annexes

CONTROL SYSTEM TYPE CODE	E01
CONTROLLED FUNCTION/PROPERTIES	heating, domestic hot water, cooling, ventilation and air-conditioning, lighting, building management system (BMS), building energy management system (BEMS)
IMAGE	
DESCRIPTION	The EN 15232: 2012 for a classification of control systems may be useful.

5.4.6 Heat storage systems annexes

COLLECTOR TYPE CODE	
IMAGE	
MANUFACTURER AND MODEL	
PURPOSE	For instance: domestic hot water, heating, cooling.
CAPACITY (l)	
INSULATION	Present, efficient, not efficient
INSTALLATION DATE	

5.4.7 Lighting - Luminaire typologies annexes

LUMINAIRE TYPE CODE	L01
GROUP	For instance: recessed, pendant, wall mounted, spot
TYPOLOGY	For instance: incandescent, halogen, fluorescent, LED.
IMAGE	
MANUFACTURER AND MODEL	
EQUIPMENT	for instance 2 x LED 4100 lm, 36 W, 4000 K
OTHER TECHNICAL CHARACTERISTICS	for instance if the light is dimmable

TOTAL POWER CONSUMPTION	for instance 72 W
OVERALL CONSERVATION/MAINTENANCE STATE	

5.4.8 Equipment

If there are equipment with an extremely high energy consumption highly affecting the energy balance of the building (e.g. a server room), they can be briefly described here.

EQUIPMENT TYPE CODE	E01
TYPOLOGY	
IMAGE	
TECHNICAL CHARACTERISTICS	
POWER	KW
USAGE PROFILE	
CONSERVATION/MAINTENANCE STATE	

5.4.9 Onsite energy production systems

5.4.9.1 Solar thermal collector

COLLECTOR TYPE CODE	
TYPOLOGY	For instance: Flat plates, selective surface, Evacuated tube
IMAGE	
MANUFACTURER AND MODEL	
PURPOSE	For instance: domestic hot water, heating integration, other.
STORAGE TYPE	Traditional, integrated
COLLECTOR EFFICIENCY	%

COLLECTOR SURFACE	m^2
COLLECTORS NUMBER	
TILT ANGLE	°
AZIMUTH	°
INSTALLATION DATE	
POSITION	
CONSERVATION/MAINTENANCE STATE	good, medium, scarce
HEAT STORAGE SYSTEM CONNECTED (CODE)	001 (2), 002 (3)

5.4.9.2 Photovoltaic panels system

MODULE TYPE	
TYPOLOGY	For instance: monocrystalline silicon, polycrystalline silicon, thin film, hybrid, photovoltaic tile.
IMAGE	
MANUFACTURER AND MODEL	
GRID CONNECTION	For instance: grid connected, stand alone.
MODULE EFFICIENCY	%
ACTIVE SURFACE/TOTAL SURFACE	m^2
NUMBER OF MODULES	
TILT ANGLE	°
AZIMUTH	°
KILOWATT-PEAK	kWp
INSTALLATION DATE	

POSITION	
CONSERVATION/MAINTENANCE STATE	good, medium, scarce
MANUFACTURER AND MODEL OF THE INVERTER	
POWER STORAGE SYSTEM	
TYPE	not present, battery, fuel cell
IMAGE	
MANUFACTURER AND MODEL	
BATTERY CAPACITY	kWh
INSTALLATION DATE	
CONSERVATION/MAINTENANCE STATE	

5.5 Field Analysis annexes

The full report on field analyses performed should be provided The following organisation is just a schema.

5.5.1 IR thermographies (B1)

5.5.2 Simplified indoor environmental monitoring (B2)

5.5.3 Air flow rate measurements and complete environmental monitoring (B3)

5.5.4 Occupants thermal comfort assessment (B4)

ANNEX 8.5 REFERENCE TEMPLATE FOR GENERAL CONSERVATION STATE ANALYSIS

Index

1. GENERAL INFORMATION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

2. INTRODUCTION

Brief introduction of the general conservation state analysis activities.

2.1. Description of existing sources of information

Description, if present, of any technical documentation used already available on the building.

2.2. Type of analysis adopted

Brief description of the type of general conservation state analyses adopted. They should comprise, but not be limited to:

1. material analysis: survey and mapping of structural and finishing materials and thematic mapping of existing finishes (including windows and external doors, surfaces, stone or wooden artefacts);
2. decay and deterioration pattern and crack pattern analysis;
3. identification of the building elements construction phases.

3. SITE CONDITIONS

Description of the building and its state encountered during the general conservation state analysis activities that have influenced the work at hand (if relevant).

4. PRE PLANNING ACTIVITIES

Description of the pre-planning activities including (briefly) any tender activities performed, the first contacts with the consultant and the owner related to these analyses, and the planning of the activities.

5. DATA ACQUISITION

5.1. Description of methodologies used

Description of the visual field survey, any non-destructive analysis if performed, any previous documentation already available, etc.

5.2. Description of the performed data acquisition activities

Description of the field activities with text and photos. According to the complexities of analyses (e.g. specific non-destructive analyses), issues encountered, etc., the description could be more or less detailed.

6. POST PROCESSING

Description of the post processing of acquired data (development of thematic maps): software used, formats, methodologies, etc.

If complex field analyses have been carried on, please provide a detailed description of the data post processing, if relevant.

7. RESULTS

7.1. General conservation state overview

Introduction and synthesis of the main findings of the activities, highlighting the general conservation state overview of the building referencing to the annexes, and focusing on specific issues.

7.2. Material analysis

Brief description of the material analysis findings (with images), referencing the corresponding annexes. If relevant, description and explanation of the annexes schemes, legends, etc.

7.3. Decay and deterioration pattern and crack pattern analysis

Brief description of the decay and deterioration pattern and crack pattern analysis (with images), referencing the corresponding annexes. If relevant, description and explanation of the annexes schemes, legends, etc.

7.4. Identification of the building elements construction phases

Brief description of building elements construction phases analysis (with images), referencing the corresponding annexes. If relevant, description and explanation of the annexes schemes, legends, etc.

8. ANNEXES

Tentative list of possible annexes (to be reproduced in low resolution format, or as an extract, with photos, etc. with photos, etc., depending on the type and quantity of information).

8.1. Technical sheets of building elevation with decay and deterioration pattern and crack analysis

Technical data sheets consisting of descriptive, graphic (thematic maps) and photographic sections, on the architectural surface analysis, material analysis, decay and deterioration pattern and crack pattern analysis, following the local national and international regulation requirements (both in .pdf and .dxf format scale 1:50 and 1:20 for thematic maps, if not differently specified by the local regulation).

If there are no local regulation available, we suggest to indicate at least the following international regulations:

1. *ICOMOS. Principle for the Analysis, Conservation and Structural Restoration of Architectural Heritage; International Council on Monuments and Sites: Paris, France, 2003;*
2. *ICOMOS. Illustrated Glossary on Stone Deterioration Patterns; International Council on Monuments and Sites: Paris, France, 2008;*
3. *EN 16096:2012. Conservation of Cultural Property—Condition Survey and Report of Built Cultural Heritage; European Committee for Standardization, 2012.*

8.2. Complementary means

A “Complementary means” annex could be added, in which other material such as video or manual measurements/sketches could be included if needed.

ANNEX 8.6 REFERENCE TEMPLATE FOR THE BIM EXECUTION PLAN (BEP)

Index

1. GENERAL INFORMATION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

2. INTRODUCTION

This document provides a framework Building Execution Plan (BEP) for the development of a virtual model, using the Heritage Building Information Modelling (HBIM) process.

In line with the definition of ISO 19650, the BEP (intended in the regulation as BIM Execution Plan), defines the methodologies, requirements and timeframe on which the information modelling will be carried out. A BEP should detail not only how information is created and delivered, but also the 'why' (defining the BIM use), and the 'who' (assigning responsibility for it). It specifies the management, technical, commercial and project information and deliverables required for the project in a way that is specific, measurable, achievable and realistic. All parties must adhere to and follow the BEP.

3. PROJECT PHASES / MODIFICATIONS / MILESTONES:

Identification of project construction phases, milestones, modifications, etc.:

[the table is a possible reference, please adapt to the building's specificities]

Project Construction Phases	**Date**	**Collapsed / Demolished / addition / Temporary**
Building A *(Space 0.1-0.8)*	*1830*	*Existing*
Auxiliary Space - GF *(Space 0.8)*	*1964*	*Demolished*
Storage Room - GF *(Area 0.11)*	*1973*	*Addition*

4. EE-HBIM MODEL SPECIFICATIONS REQUIREMENTS

4.1. Roles and responsibilities

Brief description of the roles and responsibilities of operators carrying the following roles, indicating their capability and experience to fulfil the requirements of the roles. The same person can fulfil different roles:

Function	Role	Name	Title
Management of the information process	BIM Manager		
Management of the CDE	CDE manager		
Management of the asset	BIM Coordinator		
Information modelling	BIM Specialist		

4.2. Hardware and software infrastructure

Brief description of the hardware and software infrastructure implemented for the EE-HBIM model.

4.3. Model Uses

Brief description of the model Uses of EE-HBIM model, including, but not limited to the ones necessary for the proposed energy Audit of historical buildings, presented below:

Phase	**Objectives**	**Uses**
Stage 1	Constructive HBIM model definition	Integration and representation of building geometrical and technical information according to the documentation provided by the Employer (geometric survey, drawings, etc.) Definition of building elements Space, areas and volumes analysis
	Management of the knowledge documentation on the historical building	Integration of historical documentation provided by the Employer (information sheets, links, etc.) Integration of diagnostic

		information provided by the Employer (materials and structure survey, etc.)
	Management of the environmental-energy analysis	Integration of energy and environmental analyses developed by the Employer.
Stage 2	Support of three energy intervention scenarios and of choice of adapted renovation strategies and technologies	Integration of three energy improvement intervention scenarios (short/medium/long term) provided by the design activity of the Employer with data concerning Time, Costs and management (4D, 5D, 6D, 7D)
	Assessment of ROI of the environmental-energy intervention scenarios	Integration of Return of Investment evaluation method based on the intervention costs and energy saves of the interventions

4.4. Naming conventions

File naming convention should be in line with IEC 82045-1 and BS 1192:2007(A2) 2016.

The model should be developed according to a clear breakdown structure, reflected in the objects constituting the model, organized in single elements and/or parts, groups, blocks and systems, and structured according to appropriate grouping codes, for a unique classification and naming. A brief description of the naming convention of model objects should be provided, with examples, if relevant.

4.5. Model structure definition: model federation

Brief description of the model federation, if any, indicating a federated model strategy, depending on the building dimension and on the energy simulation process. According to the model uses of the energy Audit process proposed, the separation of disciplinary models: architectural model and MEP (mechanical, electrical, plumbing, including terminals and heating and cooling production system– useful for the energy analysis) model is considered ideal. Diagram should be used how the model is separated, i.e. by building, zone, spaces, floors, and/or discipline and define the union file of the federation.

If a federation of models is required, each federated model should be geo-referenced based on a master model (see § 4.6). Please describe the layers/workset into which each federated model has been organized, if relevant.

4.6. Measurement and coordinate systems

Describe the measurement system (Imperial or Metric) and coordinate system (geo-referenced) used.

If a federated model strategy is developed (see § 4), all models should be geo-referenced according to the same absolute origin established in the union file. The reference grids of the federated files may refer to a relative origin, suitably identified due to the geometric and disciplinary complexity of the work, but these grids must conform to the georeferencing of the absolute origin.

The origin point of the coordinate system and the project system can be indicated using a table, like in the reference table below:

Coordinates case study name				
	East	*North*	*Altitude terrain (m.s.l.m.)*	*Altitude project (m)*
Survey Origin				
Project origin				
Project North angle				

Table 1: Coordinates origin.

4.7. Worksharing strategy (if any)

Description of the worksharing strategy implemented (if any) for collaboration among different operators on the same BIM model at the same time: type of server used (internal server, BIM cloud computing server), central/local model strategy (depending on the authoring software), etc.

4.8. Level of Information Need

The Level of Information Need defines the level of maturity required for a particular information deliverable at a particular plan of work stage. It provides a framework that defines the extent and granularity of information and helps to prevent the delivery of too much information.

The level of information needs for the project could be defined using the Model Element Table, which is a key document as it both allocates responsibility for preparation of the models and identifies the Level of Information Need and the properties by Uniformat/OmniClass classification for model elements.

Please provide a brief description of Level of Information Need, with reference to the Model Element Table or to any other standard system used to define it for each model element.

4.9. Model accuracy and tolerance

Models should include all appropriate dimensioning as needed for design intent, analysis, and construction. Level of detail and model elements properties are provided in the BIM Model Element Table.

4.10. Modelling strategy

Please provide a description of the proposed model strategy, tackling the modelling strategy as a whole (for example, the use of scan to BIM strategies, the relationship between survey information and modelling, the simplification strategy of the building, the geometrical constraints used, et.c), as well as the specific definition of single model elements (such as walls of windows). This specific definition can be provided as plain text or with a table.

Object insertion specifics

Please specify, together with the modelling strategy, also the insertion strategy and/or constraints for the main building elements, with respect to the main coordinate reference systems defined in the model.

As a reference, the table below defines the most common insertion strategies and constraints for most building elements; please adapt to the case study and its elements, indicate if other strategies are used and why and complete with the building elements missing.

Object insertion specifics	
Building element	Insertion/constraints strategy
Roofing	All roofing elements shall be constrained to the corresponding horizontal level
Flooring	All flooring elements shall be constrained to the corresponding horizontal level
Horizontal finishes (if separated from roofing and/or flooring)	All horizontal finishes elements (if separated from roofing and/or flooring) shall be constrained to the horizontal level /space directly above them
Ceilings	All ceiling elements shall be constrained to the horizontal level /space directly below them
Exterior walls	All exterior wall elements must have a lower and an upper constraint. They shall be constrained to the corresponding horizontal level below; there must also be a superior constraint, depending however on the type of structure and the necessity of

	the energy analysis model: for instance, constraint to the lower/upper part of the above (if the exterior wall is divided into levels), or constraint to the roofing level (if a continuous exterior wall from terrain to roof is most suitable)
Interior walls	All interior walls shall be constrained to the corresponding horizontal level below and limited at the top by the extrados of the flooring above.
Vertical structural elements (if different from walls)	All vertical structural elements (if different from walls) shall be constrained to the corresponding horizontal level below and limited at the top by the extrados of the flooring above.
Horizontal structural elements (if separated from flooring and/or roofing and finishes)	All horizontal structural elements (if separated from flooring and/or roofing and finishes) shall be constrained to the corresponding horizontal level and limited at the top by the extrados of the flooring above.
Vertical equipment and systems	All vertical equipment and systems shall be constrained to the corresponding horizontal level and limited at the top by the extrados of the flooring above.
Horizontal equipment and systems	All horizontal equipment and systems shall be constrained to the corresponding horizontal level.
Furniture (if relevant)	All furniture (if relevant) and systems shall be constrained to the corresponding horizontal level

Table 2: Object insertion specifics.

4.11. Non-geometrical information implementation

Brief description of the implementation strategy of non-geometrical information: parameters definition (with reference to the Model Element Table, if any), linked information from reports, drawings, etc.

For the linked files, please prefer open formats wherever possible. For CAD linked files, please refer to adopted CAD standards, if relevant, such as ISO 13567.

4.12. Modelling content and reference information

Identify items such as families, workspaces and databases (if relevant).

[the table is a possible reference, please adapt to the case study's specificities]

BIM use	Discipline	Modelling content / Reference Info	Version
Interior stone artefact	*Arch*	*XYZ Application family*	*Ver. 20.0.0.377*

Table 3: Modelling content.

5. ELEMENTS AND SPACES CLASSIFICATION

This classification is extremely important for interoperability to open standards, which are currently not suited to export some of the features of historical building within HBIM.

As a reference for .ifc export, the table below presents the most common correspondence between elements categories and IFC classes.

ELEMENT CATEGORY	CLASSI IFC
Furniture	IfcFurniture
Caseworks (fixed furniture)	IfcFurniture
Shaft	IfcOpeningElement
Ceilings	IfcCovering
Windows	IfcWindow
Foundation	IfcSlab, IfcFooting, IfcPile
Spaces/Rooms	IfcSpace
Courtain walls structure	IfcMember, IfcPlate
Walls	IfcWall, IfcCurtainWall
Courtain walls panels	IfcPlate, IfcDoor, IfcMember
Flooring	IfcSlab
Columns	IfcColumn
Structural Columns	IfcColumn
Doors	IfcDoor

Ramps	IfcRamp, IfcRampFlight, IfcSlab
Railings	IfcRailing, IfcMember
Stairs	IfcStair
Stairs - landing	IfcStair, IfcSlab
Stairs - flight	IfcStairFlight
Stairs - structure	IfcMember
Curtain wall systems	IfcCurtainWall
Structural beam system	IfcElementAssembly
Structural grid	IfcBeam, IfcMember
Roofing	IfcRoof
Roofing – drain pipe	IfcPipeSegment
Slabs	IfcSlab
Trusses	IfcElementAssembly

Table 4: Elements classification corresponding to IFC classes.

ANNEX 8.7 THE MODEL ELEMENT TABLE EXPLANATION AND USE

Index

1. INTRODUCTION

1.1. Overview of the Model Element table

When modelling geometrically complex objects, typical of historical buildings, it is paramount a clear specification of the Level of Information Need (ISO 19650-1 2018), defined to enable the right level of information to be provided to satisfy the information related purposes at each information exchange. It is important to avoid the delivery of too little information, which increases risk, and the delivery of too much information, which is wasteful (Churcher and Davidson 2019).

Depending on the model uses, the necessary information should therefore be balanced between geometrical correspondence and alphanumeric data. The perceived benefits (in terms of information quality and completeness, visualisation requirements, etc) should be carefully weighed against model functionality, file restrictions and time–effort. In order to be cost-effective, the minimum level of graphical detail sufficient for the purpose of the model should be specified. (Antonopoulou and Bryan 2017)

The development of EEHBIM models requires to articulate in a shared definition the content and detail of model objects: for instance, the clear description of which building elements to model, their standard classification, the Level of Information Need for each modelled element, including both their geometrical information and alphanumerical information provided through model parameters (UNI EN 17412 2020).

The *Level of Development (LOD) Specification* from BIMforum, the American chapter of buildingSMART internation, has been selected for this purpose. The Specification is widely used as a standard reference, enabling practitioners in the AEC Industry to define what their models can be relied on for, and allows downstream users to clearly understand the usability and the limitations of models they are receiving. (BIMForum 2019)

The required information for each modelled object is organized within the Model Element Table.

2. MODEL ELEMENT TABLE USE

2.1. Omniclass Classification of BIM Objects within the Model Element Table

The Model Element Table is organized by Omniclass classification (Construction Specifications Institute 2019), a comprehensive classification system for the construction industry, mainly used in the USA and Canada, to classify and order the built environment within digital projects, based on *ISO 12006* (2015). For more information on the Omniclass classification, please refer to CSI website https://www.csiresources.org/standards/omniclass.

In particular, the Model Element Table mirrors the Omniclass Element Table 21, corresponding to CSI Uniformat 2010, so each row represents a Building Element according to Omniclass. An Element is a major component, assembly, or “constituent of a construction entity with a characteristic function, form, or position”(ISO 12006 2015). Predominating functions include, but are not limited to, supporting, enclosing, servicing, and equipping a facility. Functional descriptions can also include a process or an activity. Examples: Structural Floors, Exterior Walls, Storm Sewer Utility, Stairs, Roof Framing, Furniture and Fittings, HVAC Distribution.

Within the Model Element Table, each row also coincides with a BIM model object or part of a BIM model object (for example, in the case of composite model objects comprehending structural element and finishes that are modelled as a single object). Therefore, the Element Table offers users the possibility to classify and define properties for all of model objects considered separately. It is then possible to differentiate information and detail for each of them, while maintaining clarity and consistency.

The individual tables in OmniClass are organized in a hierarchy with 4 levels (in some cases, the levels can be up to 7), with increasing detail: broad-based concepts are at the top level and the most detailed concepts are at the bottom level. The concepts at each level are indicated by a number with two digits. Within the classification, each object can therefore be represented, according to the required detail, with a code with an identifier for the table (the table number and -) and a minimum of two digits (level 1) to a maximum of 8 digits (level 4). The choice of the detail level for each object is discretionary

For example, within Table 21 Elements that corresponds to the Model Element Table, Interior Operating Windows can be represented as *21-03* (Interiors) or *21-0310* (Interiors - Interior Construction) or *21-031020* (Interiors - Interior Construction – Interior Windows) or, finally, 21-*03102010* (Interiors - Interior Construction – Interior Windows - Interior Operating Windows).

In the Model Element Table, each OmniClass level is associate to a colour and organized in rows in a way as to show the hierarchical structure of the classification: level 1 is orange, level 2 is blue, level 3 is purple, level 4 is green and, when present, level 5 is red.

The main issues in the use of OmniClass classification for historical building arise from the fact that all building classifications based on ISO 12006 have been developed for the contemporary industrial process of the construction sector and the most widespread construction systems and technologies; so they may not be appropriate to include the complex, not standard elements and technologies of built heritage. For example, the definition of structural element reflect the separation between structural frame and enclosures that is normally not applicable to historical buildings. Top levels may still work well, as they indicate in broad terms the object type, while detail that is introduced in lower levels can be misleading. Heritage involves often unique things and systemising to cover everything explicitly could never be justified as there will be no repeats. A lite classification (top of pyramid) with additional commentary is the likely way (Brookes 2017).

Therefore, the developed Model Element Table within BEEP Project is limited to level 2-3 of OmniClass classification, only rarely rely on the level 4 and 5, namely to better highlight the notable structural specification of historical buildings. In some cases (for example, exterior walls 21-022010), not all the elements are specified at the lower level, but only some specific elements that it was useful to point out and differentiate (for example, parapets). It is recommended to use the higher OmniClass level suitable to differentiate a given model object and its required information. If an object is not present as specific element, please refer to the higher level within the corresponding element category.

To enhance clarity, some elements not applicable to historical buildings have been removed from the table. The Omniclass classification is periodically updated to tackle the construction sector development; it does not however allow users for directly adding new element, in order to avoid discrepancies.

In the case of historical buildings, many elements are not present in the classification and in its adaptation in the Model Element Table; within the scope of BEEP project, the possibility to add new elements to the Model Element Table is admissible, as long as it is motivated and shared among partners. Any time there is the need of an Element addition, please refer first to the complete Omniclass Table 21 and the original Model Element Table, to prevent redundancies.

The Model Element Table should provide an overview of most common building elements within BEEP project case studies; obviously, not all model objects coincide with rows of the Model Element Table (especially in the case of services and equipment); only the row of the table and the corresponding Relevant Attribute Tables appropriate for each case study should be used.

2.2. Milestones and Level of Information Need within the Model Element Table

For each row of model object (Element), the Model Element Table includes Milestone columns, referring to the most relevant Milestones of the project (generally corresponding to Design and Construction Phases and Deliverables, often requiring administrative verifications and authorizations). Each milestone column has three subcolumns: Level of Development (LOD), Model Element Author (MEA), and Notes.

According to the proposed approach, the Milestones are the two Stages of the EEHBIM model: Stage 1 *EE-HBIM model development* and Stage 2 *4D and 5D EE-HBIM model implementation*.

The Model Element Author (MEA) refers to the entity (or individual) responsible for managing and coordinating the development of a specific model object (Element) to the Level of Information Need required for an identified Project milestone (American Institute of Architects 2013b).

The Level of Development (LOD) of the Model Element Table agrees with the definition of the American Institute of Architects AIA (American Institute of Architects 2013a):

LOD100: LOD 100 elements are not geometric representations. Examples are information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD 100 elements must be considered approximate.

LOD200: At this LOD elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Any information derived from LOD 200 elements must be considered approximate.

LOD300: The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs. The project origin is defined and the element is located accurately with respect to the project origin

LOD350: Parts necessary for coordination of the element with nearby or attached elements are modeled. These parts will include such items as supports and connections. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs.

LOD400: An LOD 400 element is modeled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension call-outs.

The proposed approach follows the ISO 19650 definition of Level of Information Need, which underlies the possible diverse deepening of geometric detail and alphanumeric information. However, the Level of Information Need is a broad concept and the method for defining it is established by the appointing party as part of the project's information standard, based on EN regulation (UNI EN 17412 2020).

Therefore, to enhance consistency, this document will adhere to the AIA LOD definition, especially referring to geometric detail, while alphanumeric information will be outlined using the Relevant Attribute Tables.

2.3. Relevant Attribute Tables

Model object (Element) are associated to Relevant Attribute Tables, that are tabs containing attribute information for the associated model objects to be inserted in the BIM model using specific parameters. Relevant Attribute Tables, therefore, condensed the required alphanumeric information for any given model object.

Relevant Attribute Table is normally defined at level 2 of the OmniClass classification and is considered applicable to all the following levels. In case a more relevant specification is needed, a Relevant Attribute Table has been be applied to lower levels. When an upper level of the OmniClass classification is preferred for an object, even when lower levels are available, the higher level Relevant Attribute Table should be referred to. Each element row at level 2 can be associated to more than one Relevant Attribute Table; please select among the proposals the one that better suits you needs.

The Attribute Description lists Attributes (parameters) relevant to the associated model objects (Elements). The way information is implemented in the BIM model depends on the BIM authoring software; some attributes could be inherent to the modelling process (for example, wall layers thickness) or can already be part of the software basic parameters. What is important is to provide the required information, following the BIM software specificities; if needed, new parameters should be added.

Attributes are grouped into two categories: Baseline and Additional. The Baseline is the suggested list of attributes to be defined within the BIM model and populated. If the data is not available or the information is not applicable (for example, there is no deterioration or decay pattern, or no previous known intervention on the model object element), it can be left blank; however, the attribute (generally in the form of an object parameter) should be present

The Additional category is a list of possible attributes that may be relevant for the given project, but are not necessary (therefore, the corresponding parameters can be added or not to the model). For example, in the case of structural elements, most of the parameters concerning material characteristics and bearings are additional, because BEEP project does not focus on structural analysis and, for historical buildings, many of the parameters would need a specific intense diagnostics campaign. However, if the information on structural characteristic is know for a given case study, it can be added to the model object. The same goes for fire, acoustic and security rating.

Attributes depend on the model uses and the level of granularity of the BIM model (see 3). As the main model uses entail a limited model granularity (for example, walls should be modelled as single composite objects whenever possible), some information, that would require a more detailed modelling to be properly represented within the model (e.g. general conservation state), are represented through the use of synthetic, descriptive parameters and external link to traditional analysis, when existing. In this way, the information can nonetheless be retrieved within the BIM model and possibly used to enhance future, more detailed modelling processes.

3. MODELLING SPECIFICATIONS

Depending on model uses, Level of Information Need for the model objects can vary and affect modelling strategies and best practices. Sometimes, different model uses can point out to contradictory modelling strategies, e.g. a high level of granularity (high differentiation of objects) for a model used for a project process involving various operators (architects, engineers) with a high detail, or a lower level of granularity (elements represented as single composite objects) for a model used for energy analysis and simulation or facility management. In order to avoid redundancies and errors deriving from model duplication, a balance between conflicting model uses should be investigated.

One of the main model uses of Stage 1 is the management of energy analysis. To enhance interoperability between BIM authoring software and energy simulation software, it would be advisable to represent enclosure elements, structural or not, defining the limit between indoor and outdoor and dividing thermal zones (e.g. walls, roofs, floors), as single, composite model objects.

For reasons of consistency, when not in contrast with other model uses that require a higher granularity, it is therefore recommended to model all extensive model object such as walls, roofs, floors), as single, composite model objects.

As the separation between bearing elements and finishing is fundamental for OmniClass classification, in the case of a single object comprising more Omniclass element, the OmniClass code for all the elements, separated by a +, should be indicated.

Regarding services and MEP (mechanical, electrical, plumbing) systems, within the proposed energy Audit, it is fundamental to model at least terminals and generators of HVAC systems and lighting; more detailed modelling, especially in Phase 2 of design alternative, is permitted and advisable, if relevant. The whole service section of the Model Element Table can be used to this end.

4. BIBLIOGRAPHY

American Institute of Architects. 2013a. 'AIA Contract Document G202-2013, Building Information Modeling Protocol'. American Institute of Architects.

———. 2013b. 'AIA Document E203-2013 Building Information Modeling and Digital Data Exhibit'. American Institute of Architects.

Antonopoulou, Sofia, and Paul Bryan. 2017. *BIM for Heritage: Developing a Historic Building Information Model*. Swindon.: HISTORIC ENGLAND.

BIMForum. 2019. 'LOD Spec 2019 Part I For Building Information Models'. Associated General Contractors of America (AGC).

Brookes, Carl. 2017. 'The Application of Building Information Modelling (BIM) within a Heritage Science Context'. 29. Research Department Reports. Historic England.

Churcher, David, and Sarah Davidson, eds. 2019. 'Information Management According to BS EN ISO 19650 - Guidance Part 1: Concepts'. UK BIM Alliance.

Construction Specifications Institute. 2019. 'OmniClass® Introduction and User's Guide'. Construction Specifications Institute.

ISO 12006. 2015. *ISO 12006:2015 Building Construction — Organization of Information about Construction Works*.

ISO 19650-1. 2018. *ISO 19650-1:2018 Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM) — Information Management Using Building Information Modelling — Part 1: Concepts and Principles*.

UNI EN 17412. 2020. *Building Information Modelling. Level of Information Need. Concepts and Principles*.

ANNEX 8.8: STATE OF THE ART ANALYSIS ON BUILDING PERFORMANCE SIMULATION ON HISTORIC BUILDINGS

Index

1 INTRODUCTION

Building Performance Simulation (BPS[1]) allows the study and optimisation of energy performance in an interrelated way, through the creation of a behavioural model of a given historical urban fabric, building or wall element, reduced to a certain level of abstraction (Augenbroe 2002). The main innovation introduced by the simulations, with respect to previous methodologies of analysis and evaluation of the energy-environmental performance of buildings, is the possibility of treating them as an integrated system of related elements that can be optimized and not as the sum of elements designed and optimised separately (Hensen 2004). The purpose of simulations is not only to reveal the interactions between the building, occupants, HVAC systems and the outdoor climate, but also to facilitate the use of environmentally and energy-efficient design solutions (Hong, Chou, and Bong 2000). The simulations, in fact, support users in understanding complex phenomena by providing relatively rapid feedback on the performance implications of the design hypotheses (Clarke and Hensen 2015). Yet, the application of these tools on historic buildings is still in an experimental phase and subject to certain challenges. In this document, various cases of this integration will be presented.

2 ADVANTAGES OF USING BUILDING PERFORMANCE SIMULATION ON THE BUILT HERITAGE

In the field of historical built heritage, building performance simulation are particularly interesting because they guarantee innovative non-destructive applications in both pre-diagnostic and diagnostic terms (E. Gigliarelli et al. 2017). These tools in fact:

- facilitate the understanding and analysis of complex phenomena, dynamically studying the exchange of energy between the building and the surrounding environment including biophysical (water, soil, vegetation) and bioclimatic (solar radiation and ventilation) factors. This allows for innovative applications also in non-destructive analysis techniques;
- provide retroactive feedback on the evolution of decay phenomena and on energy and environmental implications of conservation interventions. We refer to specific heat, air and moisture transport software for predictive analysis in building envelopes, or to the possibility of dynamically studying the trend of physical quantities related to comfort (but also to the possible formation of degradation phenomena) within each single room;
- allow, through the methods of environmental analysis, to investigate the constructive events of ancient architecture in ways so far completely unexplored, that are halfway between virtual and experimental archaeology, reconstructing models to be studied (e.g. allowing to study how the spaces were probably used in a building or how back in the day devices were used to improve comfort of occupants, provide further elements to a historical analysis).

[1] Also referred to as Building Energy Modelling – BEM, Building Energy Simulation –BES.

Moreover, the simulation-based study of the bioclimatic behaviour of historic fabrics provides an added knowledge value to the explorative process of the building itself, allowing the possibility to model its natural functioning processes, paving the way for design solutions capable of enhancing its distinctive characteristics and identities linked to the local microclimate (GBC 2017; E. Gigliarelli, Calcerano, and Cessari 2016).

3 ENERGY MODELLING TOOLS USED IN THE CASE OF HISTORIC BUILDINGS

Currently, several simulation software are available for the evaluation of energy performance of buildings. These tools can be classified as static, semi-dynamic and dynamic. Stationary and semi-dynamic approaches are simplified methods that consider a limited number of factors. They are more related to the evaluation of energy performance in standard conditions of use and usually input data are provided by standard references from national databases, used for energy labelling. In particular, results from static tools are simplified as they do not consider the periodic trend of temperature and do not take into consideration thermal inertia of the structures. Semi dynamic software (also called sketch design software) take this parameter under consideration, yet they require simplified inputs for climatic data and building description. On the contrary, dynamic simulation software are able to evaluate accurately all factors but they need detailed input data for climatic conditions and building properties.

Calzolari (2016) studied the criticalities of applying BPS, generally used for new or existing buildings, to the built heritage. Pracchi (2014) and Heath et al. (2010) each simulated a historic building using multiple BPS software programs and found large discrepancies between results from the different programs, illustrating the ways in which these limitations (§ Chapter 5) can have downstream effects on retrofit decision-making. Despite the complexity of whole building, i.e. dynamic software tools, they are acknowledged as more suitable for the modelling of historic buildings due to their flexibility and capacity to produce more accurate results (Adhikari et al. 2013).

Simulation software is extremely useful in calculating environmental conditions and energy consumption in buildings prior to intervention, as it allows the behaviour of the different climate conditioning systems and installations to be predicted (Webb 2017). The capacity of numerical tools to minimise the computational time for evaluating finite set of alternatives based on various criteria is extremely valuable for the development of multiple criteria decision analysis tools. The project Climate for Culture has coupled climate modelling with whole building simulation tools. The project scope was to provide information on future indoor climate change and address the risks for cultural heritage. Various online tools were produced, as well as a Decision Making Support System providing general information for stakeholders. Similar tools were also developed through several projects focusing on retrofitting historic buildings, such as SECHURBA[2] (AA. VV. 2011; E. Gigliarelli, Calcerano, and Cessari 2018) and EFFESUS[3].

A thorough review of studies regarding historic buildings employing numerical tools (CFD[4] or BPS) is provided in the work of Martínez-Molina et al. (2016). The studies are grouped per building use and method of analysis (i.e. monitoring, simulation, CFD, etc.). In the case of museums, libraries and theatres, most of the studies focus on the regulation of the microclimatic environment; an important aspect in order to minimize the ageing and degradation of the materials and artworks (Muñoz-González et al. 2018). Tronchin and Fabbri (2017) used Building Performance Simulation to optimise energy consumption and ancient manuscripts conservation in the Malatestiana Library in Cesena (Italy). A methodology for microclimatic qualification assessment is described in the study of Corgnati, Fabi, and Filippi (2009), which is based on medium/long field monitoring of environmental parameters and a microclimatic quality evaluation in museums. Silva, Coelho, and Henriques (2020) discussed the indoor microclimatic monitoring of a church in Lisbon (Portugal) and compared the results with other case studies in different European geographical areas, to propose a new method of analysis specifically dedicated to temperate climates (Silva and Henriques 2014). The work of Camuffo et al. (2010), Schellen and Neuhaus (2010), Muñoz González et al. (2020), Varas-Muriel, Martínez-Garrido, and Fort (2014) focus on simulating active environmental conditioning systems such as heating, ventilation, air-conditioning and cooling (HVAC) in churches. In the recent work of de Rubeis et al. (2020), an extensive review of similar studies is provided, reporting the results of reseaches employing air-to-air heat pumps, adaptive ventilation (Napp and Kalamees 2015) or variable heating and cooling setpoints (H. L. Schellen and van Schijndel 2011).

Different indoor conditions, such as natural lighting, were analysed in other studies employing whole building simulation tools. Balocco and Calzolari (2008) performed a natural lighting design research in a medieval church in Florence, Italy. A solar radiation control showed that the installations ensured energy savings for cooling and lighting and as well as guaranteeing users' lighting comfort. Michael et al. (2017) coupled natural lighting field measurements with numerical simulations in vernacular buildings in Cyprus in order to assess lighting comfort. Nocera et al. (2018) developed a calibrated model based on the Radiance software to improve daylight performance in a classroom of the Caserma Gaetano Abela in Sicily (Italy).

Additional analysis and uses of numerical tools concern the estimation of air quality and the use of innovative materials. Cataldo et al. (2005) studied air quality in a cultural heritage building by integrating different non-destructive methods, such as microclimatic and ground penetrating radars. Bernardi et al. (2014) showed the efficacy of phase change materials when used as thermal energy storage units in heritage buildings. The study revealed, that direct contact between phase change materials and heritage objects is not recommended, as mechanical damage could result.

---

[2] SECHURBA Research Project: Sustainable Energy Communities in Historic Urban Areas'. 2011 https://ec.europa.eu/energy/intelligent/projects/en/projects/sechurba

[3] EFFESUS Research Project: Energy Efficiency for EU Historic Districts' Sustainability'. 2016 https://www.effesus.eu/

[4] Computational fluid dynamics, another branch of numerical analyses, addressed later in the paragraph.

A numerical tool used for predicting indoor and outdoor airflow, heat transfer and indoor thermal comfort, that is gaining ground over the last decades, is Computational Fluid Dynamics (CFD). There are a few applications of CFD in the sector of building conservation. Balocco and Grazzini (2009) investigated the ancient natural ventilation system inside a historical building in Palermo, Italy, and analysed a simple cooling technique. Papakonstantinou, Kiranoudis, and Markatos (2000) modelled thermal comfort conditions in the Hall of the National Archaeological Museum of Athens, while D'Agostino and Congedo (2014) investigated the adequacy of natural ventilation in a historical building located in the South of Italy. The model determined a great variability of the thermo-hygrometric parameters among the ventilation solutions. Kristianto, Utama, and Fathoni (2014) investigated the thermal comfort conditions in the Minahasa Traditional House, suggesting greater silts height and roof openings for enhanced airflow in indoor spaces. Finally, Du, Bokel, and van den Dobbelsteen (2014) coupled field measurements and dynamic thermal and CFD simulation through the platform of Design Builder in order to investigate the thermal performance of the vernacular Chinese house.

Pisello et al. (2014) used BPS to support the energy refurbishment of Palazzo Gallenga Stuart in Perugia (Italy) estimating a 50% reduction in energy consumption, Cellura et al. (2017) for a rural building in Sicily (Italy).

Gigliarelli, Calcerano, and Cessari (2017), focused on a multiscalar approach supported by a HBIM platform and further analysed the BIM to BPS interoperability on historical buildings applications (Gigliarelli et al. 2017; 2019).

Despite the extensive use of numerical tools and particularly whole building energy modelling and CFD software, a number of researchers have expressed concerns regarding the predictive accuracy of such tools. Huerto-Cardenas et al. (2020) reviewed the main approaches used by researchers for BPS model validation with special reference to historical buildings through microclimatic parameters, highlighting the main issues and advantages of the different methods reviewed and defining suitable validation thresholds.

4 MODEL CALIBRATION APPROACHES

The use of dynamic simulation tools represents a great opportunity to predict the behaviour of extremely dynamic systems such as buildings. However, as models always represent a simplification of real cases, the reliability of predictions provided by simulation models requires a thorough calibration process. The ASHRAE Guildeline 14: 2014 defines calibration as "..*the process of reducing the uncertainty of a model by comparing the predicted output of the model under a specific set of conditions to the actual measured data for the same set of conditions*". Therefore, in-situ experimental data acquisition (e.g. energy consumption data or environmental conditions) is imperative in order to compare the predicted output of the model to the actual measured data.

In the case of historic buildings for which building construction is often little known, the calibration phase is of particular importance (Roberti, Oberegger, and Gasparella 2015). However, there is no established methodology or indicators for estimating the level of accuracy of models. Huerto-Cardenas et al. (2020) who reviewed the challenges regarding validation of dynamic hygrothermal simulation models for historical buildings, report the increasing use of microclimatic parameters for calibration and validation purposes in heritage BPS. This is mainly related to the availability of environmental data that are acquired through high-accuracy measurement equipment for occupants' thermal comfort assessment or risk-assessment of building materials and objects. An additional reason for using microclimatic parameters is the lack of energy consumption data, generally adopted in the model validation. This latter issue can be attributed to the absence of heating/cooling systems, which is often the case for many historic buildings, or due to difficulties in retrieving the energy consumption data. The following are often used to provide more accurate model inputs and help calibrate the model: whole building energy consumption, indoor air temperatures, in situ material properties, laser scanning of building geometry and blower door pressurization tests of airtightness (Webb 2017). Yet, the most frequently used microclimatic variables involved in model calibration are: indoor dry-bulb air temperature (Ta) and Relative Humidity (RH) (Huerto-Cardenas et al. 2020). In the study of Rajčić, Skender, and Damjanović (2018), three categories are used for the estimation of the prediction accuracy: excellent, acceptable and low. The difference between simulated and measured data is interpreted as "excellent" when it lies within ± 1 °C and ± 5% from the median for temperature and relative humidity respectively, "acceptable" when values fall within ±3 °C and ±10% from the median, while "low" when both values are out of these ranges.

A summary of the main uncertainty indices for estimating a model accuracy is provided in Table 1. ASHRAE Guildeline 14: 2014 recommends the use of the following indicators for calibrated simulations: Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) and the Normalized Mean Bias Error (NMBE). The monthly thresholds are ±5% and 15% for NMBE and CVRMSE respectively. The hourly ones are ±10% and the 30%.

Table 1: Main uncertainty indices used to evaluate the accuracy of BPS model, based on the statistical analysis of measured (m) and simulated (s) data. Source: Huerto-Cardenas et al. (2020)

Index	Name	Formula
% error	Percent error/difference	$\% error = \left(\frac{m-s}{m}\right) \times 100 = \left(1-\frac{s}{m}\right) \times 100$
MBE	Mean bias error	$MBE = \frac{\sum_{i=1}^{n}(m_i - s_i)}{n}$
MAE	Mean absolute error	$MAE = \frac{\sum_{i=1}^{n}\lvert m_i - s_i\rvert}{n}$
RMSE	Root mean square error	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n}}$
NMBE	Normalized mean bias error	$NMBE = \frac{1}{\bar{m}} \times \frac{\sum_{i=1}^{n}(m_i - s_i)}{n} \times 100$
CVRMSE	Coefficient of variation of the RMSE	$CVRMSE = \frac{1}{\bar{m}} \times \sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n}} \times 100$
RN_RMSE or NRMSE	Range normalized RMSE or normalized RMSE	$RN\_RMSE = \frac{1}{(max_m - min_m)} \times \sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n}} \times 100$
r	Pearson correlation coefficient	$r = \frac{\sum_{i=1}^{n}(m_i - \bar{m}) \times (s_i - \bar{s})}{\sqrt{\sum_{i=1}^{n}(m_i - \bar{m})^2} \times \sqrt{\sum_{i=1}^{n}(s_i - \bar{s})^2}}$
R^2	Coefficient of determination	$R^2 = 1 - \frac{\sum_{i=1}^{n}(m_i - s_i)^2}{\sum_{i=1}^{n}(m_i - \bar{m})^2}$
IC	Inequality coefficient	$IC = \frac{\sqrt{\frac{1}{n} \times \sum_{i=1}^{n}(m_i - s_i)^2}}{\sqrt{\frac{1}{n} \times \sum_{i=1}^{n}s_i^2} + \sqrt{\frac{1}{n} \times \sum_{i=1}^{n}m_i^2}}$

Roberti, Oberegger, and Gasparella (2015) proposed a calibration methodology based on the minimization of Root Mean Square Error (RMSE) through particles warm optimization algorithms implemented in the Genopt software and apply it to a medieval building located in the historic centre of Bolzano (Italy). The results obtained a remarkable accuracy of the model, that was validated on hourly indoor air and surface temperatures in winter. Coelho, Silva, and Henriques (2018) discussed a validation process of historic building simulation models by comparing measured and simulated temperature and water-vapour pressure quantifying Coefficient of Determination (R^2), coefficient of variation of the root mean square error, normalized mean bias error and goodness of fit. They case-study that was presented is a 13th century church in Lisbon (Portugal), whose indoor conditions were monitored over a year. The authors conducted a sensitivity analysis for three parameters; namely, air change rate, solar heat gain coefficient and short-wave radiation absorption coefficient. They concluded that the best results are obtainable by considering monitored weather file rather than data provided from databases, and that the parameters of soil and slab interface temperature have a significant role.

Cornaro, Puggioni, and Strollo (2016) suggested retrofit solutions for a complex historic building in Italy by using numerical tools coupled with data obtained through a short term monitoring campaign. Pigliautile et al. (2019) discussed an innovative methodology based on experimental monitoring and dynamic simulation, in order to assess the impact of passive solutions on occupants' thermal comfort and artworks preservation. The case-study considered was the castle of Pieve del Vescovo, located near Perugia (Italy). The simulation model was performed via DesignBuilder software and EnergyPlus engine. The iterative calibration process involved the modification of the external wall materials' width and the internal thermal gains. The statistical analysis of the calibration phase considered mean bias error and root mean square error.

De Rubeis et al. (2020) analysed the thermo-hygrometric conditions of the church of Santa Maria Annunziata of Roio in L' Aquila (Italy), both for artworks preservation and occupants' comfort. The analysis was carried out by means of EnergyPlus coupled with Design Builder software. In this case, the weather file used for the simulation was created using the data measured by a nearby weather station (i.e. dry bulb temperature, wind speed, atmospheric pressure, relative humidity, and solar radiation). The approach employed in their work is divided into two steps: The first calibration phase of the model was performed by comparing measured and experimental indoor air temperature, and manually and iteratively varying parameters of the model, namely temperature setpoints and air leakage, to improve its accuracy. In the second phase, the ability of the calibrated model to predict the behaviour of the building was assessed through the statistical indicators of Mean Bias Error (MBE), Coefficient of Variation of the Root Mean Square Error (CV(RMSE)), the deviation between simulated and measured indoor air temperature trends and the Coefficient of Determination (R^2).

An additional parameter with significant impact on potential differences between the modelled (theoretical) and the actual energy performance of buildings, in general, is occupant behaviour. While this parameter has been studied (Brohus et al. 2010), in the case of historic buildings user-driven energy efficiency remains problematic (Berg et al. 2017). Research and empirical data remain insufficient, while the existing methodologies assessing occupant behaviour are predominately qualitative. Certain interplays between user-related energy consumption and awareness of a buildings' cultural heritage values are reported, calling for more quantitative approaches regarding the occupant behaviour in heritage buildings (Berg et al. 2017; Kavgic et al. 2010).

5 OPEN ISSUES REGARDING THE APPLICATION OF A SIMULATION-BASED DESIGN APPROACH IN HISTORIC BUILDINGS

The term simulation-based design refers to a process, in which simulations are the main tool for evaluation and verification, aimed at eliminating inefficient design scenarios with the least possible waste of resources (Mefteh 2018). Given that the impact of strategic decisions on the energy and environmental characteristics of buildings, simulation-based design should be a fully integrated tool in the decision-making process regarding architecture (Reiser et al. 2008; Lechner 1991). In order to apply a simulation-based design approach to the built heritage, several points still need to be thoroughly addressed. Among these are:

1. The uncertainty of the data measured on site for the characterisation of the building materials to be used in the energy modelling;
2. Simplifications and assumptions, mainly referring to:

- complex and irregular geometries (most modelling software require simplifications of the building shape, that sometimes fail to adequately represent the complexity of heritage buildings and the number of surfaces, and consequently accurately calculate the energy flow between them);
- the lack of homogeneous and standardized construction elements (this might correspond either to the case of complex façades with several historical phases, or the case of a single wall with irregularities (Roberti, Oberegger, and Gasparella 2015), which often may be deteriorated or partly damaged and therefore may have variable thermophysical properties);
- the inertial behaviour of the building mass, which requires specific corrections and precautions in order to be adequately simulated by software created to simulate buildings constructed based on other structural systems than massive load bearing elements (Mazzarella and Pasini 2017);
- important envelope moisture buffering and related complexities to its calculation (Paolini et al. 2016);
- thermal stratification in large spaces (Webb 2017);
- occupant behaviour that is subject to social, economic and cultural values and insufficiently documented in the case of historic buildings (Berg et al. 2017);

3. The need to build a "critical" database of case studies, and of historical wall stratigraphies with thermophysical characteristics to help energy modellers with the definition of those charcteristics where desctructive tests are not available, and more in general to help consolidate the energy modelling approach on historical buildings, in order to identify “groups” of particularities (if any), tendencies and reverse “*the lack of publicly available detailed data relating to inputs and assumptions*“ (Kavgic et al. 2010);
4. The need for a reflection on the limits of a deterministic approach (deriving from simulation tools) applied to naturally heterogeneous cases, such as the ones of historic buildings. The above challenge calls for an approach that is tolerant to the ambiguities / limits of knowledge, inherent in the input data of the modelling of a historic building (with reference also to a possible probabilistic approach). Knowledge transfer from the diagnostic phase of the conservation process where there is a strong link between hard science specialists, humanities and conservation experts would also be beneficial, to help finding a compromise between different analysis systems approaches, to be used in parallel for the reconstruction and the energy and environmental behaviour of the built heritage. Simulation-based design on built heritage should follow therefore the path of other disciplinary field such as the structural diagnosis (Croci 2000), that was capable to find a methodological compromise between procedures that despite their uncertainties represent to date the best possible formulation of a problem based on data, hypothesis and interpretation (Gigliarelli et al. 2019);
5. The need to develop an interdisciplinary debate on the subject, allowing for the integration of different views and competences;
6. The need to create a set of guidelines based on the existing literature on the calibration and validation of energy models of historic buildings (Roberti, Oberegger, and Gasparella 2015; Huerto-Cardenas et al. 2020), while respecting the "case by case" approach according to the complexity of each case. This is important in order to identify the best energy diagnosis path to use (including not only application but also economic and time constraints), according to the principle of gradual complexity of the analyses performed in relation to the gradual deepening of the level of information required for a specific purpose.

6 REFERENCES

AA. VV. 2011. ‘SECHURBA Sustainable Energy Communities in Historic Urban Areas’. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/sechurba_guide_en.pdf.

Adhikari, R.S., Elena Lucchi, Valeria Pracchi, and Elisabetta Rosina. 2013. ‘Static and Dynamic Evaluation Methods for Energy Efficiency in Historical Buildings’. In *PLEA 2013: Sustainable Architecture for a Renewable Future*, 8.

ASHRAE Guildeline 14. 2014. ‘Guideline 14, Measurement of Energy and Demand Savings’. ASHRAE.

Augenbroe, Godfried. 2002. ‘Trends in Building Simulation’. *Building and Environment* 37 (8–9): 891–902. https://doi.org/10.1016/S0360-1323(02)00041-0.

Balocco, Carla, and Rachele Calzolari. 2008. ‘Natural Light Design for an Ancient Building: A Case Study’. *Journal of Cultural Heritage* 9 (2): 172–78. https://doi.org/10.1016/j.culher.2007.07.007.

Balocco, Carla, and Giuseppe Grazzini. 2009. ‘Numerical Simulation of Ancient Natural Ventilation Systems of Historical Buildings. A Case Study in Palermo’. *Journal of Cultural Heritage* 10 (2): 313–18. https://doi.org/10.1016/j.culher.2008.03.008.

Berg, Fredrik, Anne-Cathrine Flyen, Åsne Lund Godbolt, and Tor Broström. 2017. ‘User-Driven Energy Efficiency in Historic Buildings: A Review’. *Journal of Cultural Heritage* 28 (November): 188–95. https://doi.org/10.1016/j.culher.2017.05.009.

Bernardi, Adriana, Francesca Becherini, Maria Dolores Romero-Sanchez, Angel Lopez-Buendia, Arianna Vivarelli, Luc Pockelé, and Sandro De Grandi. 2014. ‘Evaluation of the Effect of Phase Change Materials Technology on the Thermal Stability of Cultural Heritage Objects’. *Journal of Cultural Heritage* 15 (5): 470–78. https://doi.org/10.1016/j.culher.2013.11.002.

Brohus, Henrik, Per Heiselberg, Allan Simonsen, and Kim C Sørensen. 2010. ‘Influence of Occupants’ Behaviour on the Energy Consumption of Domestic Buildings’. In *10th Rehva World Congress: Sustainable EnergyUse in Buildings*, 9. Antalya, Turkey.

Calzolari, Marta. 2016. *PRESTAZIONE ENERGETICA DELLE ARCHITETTURE STORICHE: SFIDE E SOLUZIONI Analisi Dei Metodi Di Calcolo per La Definizione Del Comportamento Energetico*. Franco Angeli.

Camuffo, Dario, Emanuela Pagan, Sirkka Rissanen, Łukasz Bratasz, Roman Kozłowski, Marco Camuffo, and Antonio della Valle. 2010. ‘An Advanced Church Heating System Favourable to Artworks: A Contribution to European Standardisation’. *Journal of Cultural Heritage* 11 (2): 205–19. https://doi.org/10.1016/j.culher.2009.02.008.

Cataldo, Rosella, Antonella De Donno, Giorgio De Nunzio, Gianni Leucci, Luigia Nuzzo, and Stefano Siviero. 2005. ‘Integrated Methods for Analysis of Deterioration of Cultural Heritage: The Crypt of “Cattedrale Di Otranto”’. *Journal of Cultural Heritage* 6 (1): 29–38. https://doi.org/10.1016/j.culher.2004.05.004.

Cellura, Maurizio, Giuseppina Ciulla, Francesco Guarino, and Sonia Longo. 2017. ‘Redesign of a Rural Building in a Heritage Site in Italy: Towards the Net Zero Energy Target’. *Buildings* 7 (3): 68. https://doi.org/10.3390/buildings7030068.

Clarke, J. A., and J. L. M. Hensen. 2015. ‘Integrated Building Performance Simulation: Progress, Prospects and Requirements’. *Building and Environment*, Fifty Year Anniversary for Building and Environment, 91 (September): 294–306. https://doi.org/10.1016/j.buildenv.2015.04.002.

‘Climate for Culture Research Project’. n.d. Climate for Culture. https://www.climateforculture.eu/.

Coelho, Guilherme B. A., Hugo Entradas Silva, and Fernando M. A. Henriques. 2018. ‘Calibrated Hygrothermal Simulation Models for Historical Buildings’. *Building and Environment* 142 (September): 439–50. https://doi.org/10.1016/j.buildenv.2018.06.034.

Corgnati, Stefano Paolo, Valentina Fabi, and Marco Filippi. 2009. ‘A Methodology for Microclimatic Quality Evaluation in Museums: Application to a Temporary Exhibit’. *Building and Environment* 44 (6): 1253–60. https://doi.org/10.1016/j.buildenv.2008.09.012.

Cornaro, Cristina, Valerio Adoo Puggioni, and Rodolfo Maria Strollo. 2016. ‘Dynamic Simulation and On-Site Measurements for Energy Retrofit of Complex Historic Buildings: Villa Mondragone Case Study’. *Journal of Building Engineering* 6 (Journal Article): 17–28. https://doi.org/10.1016/j.jobe.2016.02.001.

Croci, Giorgio. 2000. ‘General Methodology for the Structural Restoration of Historic Buildings: The Cases of the Tower of Pisa and the Basilica of Assisi’. *Journal of Cultural Heritage* 1 (1): 7–18. https://doi.org/10.1016/S1296-2074(99)00119-3.

D’Agostino, Delia, and Paolo Maria Congedo. 2014. ‘CFD Modeling and Moisture Dynamics Implications of Ventilation Scenarios in Historical Buildings’. *Building and Environment* 79 (Journal Article): 181–93. https://doi.org/10.1016/j.buildenv.2014.05.007.

Du, Xiaoyu, Regina Bokel, and Andy van den Dobbelsteen. 2014. ‘Building Microclimate and Summer Thermal Comfort in Free-Running Buildings with Diverse Spaces: A Chinese Vernacular House Case’. *Building and Environment* 82 (Journal Article): 215–27. https://doi.org/10.1016/j.buildenv.2014.08.022.

‘EFFESUS Research Project: Energy Efficiency for EU Historic Districts’ Sustainability’. 2016. 2016. https://www.effesus.eu/.

GBC. 2017. ‘GBC Historic Building’. Green Building Council Italia. http://gbcitalia.org/documents/20182/157656/Sistema+di+verifica+GBC+HB_2016-mag17.pdf/7d185808-b994-45fe-a6af-218e81a8fe27.

Gigliarelli, E., F. Calcerano, M. Calvano, F. Ruperto, M. Sacco, and L. Cessari. 2017. ‘Integrated Numerical Analysis and Building Information Modeling for Cultural Heritage’. In *Proceedings of 3rd IBPSA Italy Conference 8-11 February, BSA 2017, Bozen/Bolzano, Italy.* Bolzano.

Gigliarelli, E., F. Calcerano, and L. Cessari. 2016. 'Implementation Analysis and Design for Energy Efficient Intervention on Heritage Buildings'. *Ioannides M. et al. (Eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2016. Lecture Notes in Computer Science. Springer, Cham* 10058. https://doi.org/10.1007/978-3-319-48496-9_8.

———. 2018. 'Analytic Hierarchy Process. A Multi-Criteria Decision Support Approach for the Improvement of the Energy Efficiency of Built Heritage'. In *3rd International Conference on Energy Effiiciency in Historic Buildings 2018, EEHB2018 Edited by Tor Broström, Lisa Nilsen and Susanna Carlsten*. Visby, Sweden, September 26-28, 2018: Uppsala University, Department of Art History. http://www.iea-shc.org/Data/Sites/1/publications/Energy-efficiency-in-historic-buildings_preliminary-conference-report.pdf.

Gigliarelli, E., F. Calcerano, F. D'Uffizi, C. Di Biccari, G. Mangialardi, and M. Campari. 2019. 'From Heritage BIM to BPS, a Computational Design-Based Interoperability Approach'. In *Building Simulation 2019, Rome*. Rome.

Gigliarelli, Elena, Filippo Calcerano, and Luciano Cessari. 2017. 'Heritage Bim, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit'. *Energy Procedia*, Climamed 2017 – Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area 12-13 May 2017 - Matera, Italy, 133 (October): 135–44. https://doi.org/10.1016/j.egypro.2017.09.379.

Heath, Nicolas, Gary Pearson, Bob Barnham, and Richard Atkins. 2010. 'Technical Paper 8: Energy Modelling of the Garden Bothy, Dumfries House'. Technical paper 8. Historic Scotland.

Hensen, J.L.M. 2004. 'Towards More Effective Use of Building Performance Simulation in Design'. *In Leeuwen, J.P. van & Timmermans, H.J.P. (Eds.). Proceedings of the 7th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, 2-5 July. Eindhoven: Eindhoven University of Technology.*

Hong, Tianzhen, S. K Chou, and T. Y Bong. 2000. 'Building Simulation: An Overview of Developments and Information Sources'. *Building and Environment* 35 (4): 347–61. https://doi.org/10.1016/S0360-1323(99)00023-2.

Huerto-Cardenas, H.E., F. Leonforte, N. Aste, C. Del Pero, G. Evola, V. Costanzo, and E. Lucchi. 2020. 'Validation of Dynamic Hygrothermal Simulation Models for Historical Buildings: State of the Art, Research Challenges and Recommendations'. *Building and Environment* 180 (August): 107081. https://doi.org/10.1016/j.buildenv.2020.107081.

Kavgic, Miroslava, Anna Mavrogianni, D. Mumovic, A.J. Summerfield, Zarko Stevanovic, and Maja Đurović-Petrović. 2010. 'A Review of Bottom-up Building Stock Models for Energy Consumption in the Residential Sector'. *Building and Environment* 45 (July): 1683–97. https://doi.org/10.1016/j.buildenv.2010.01.021.

Kristianto, Mandau A., N. Agya Utama, and Andhy Muhammad Fathoni. 2014. 'Analyzing Indoor Environment of Minahasa Traditional House Using CFD'.

Procedia Environmental Sciences 20: 172–79. https://doi.org/10.1016/j.proenv.2014.03.023.

Lechner, Norbert. 1991. *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*. Hoboken, N.J.: John Wiley & Sons.

Martínez-Molina, Antonio, Isabel Tort-Ausina, Soolyeon Cho, and José-Luis Vivancos. 2016. 'Energy Efficiency and Thermal Comfort in Historic Buildings: A Review'. *Renewable and Sustainable Energy Reviews* 61 (August): 70–85. https://doi.org/10.1016/j.rser.2016.03.018.

Mazzarella, Livio, and Marina Pasini. 2017. 'Integration Time Step Issue in Mediterranean Historic Building Energy Simulation'. *Energy Procedia*, Climamed 2017 – Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area 12-13 May 2017 - Matera, Italy, 133 (October): 53–67. https://doi.org/10.1016/j.egypro.2017.09.371.

Mefteh, Wafa. 2018. 'Simulation-Based Design: Overview about Related Works'. *Mathematics and Computers in Simulation* 152 (October): 81–97. https://doi.org/10.1016/j.matcom.2018.03.012.

Michael, A., C. Heracleous, S. Thravalou, and M. Philokyprou. 2017. 'Lighting Performance of Urban Vernacular Architecture in the East-Mediterranean Area: Field Study and Simulation Analysis'. *Indoor and Built Environment* 26 (4): 471–87. https://doi.org/10.1177/1420326X15621613.

Muñoz González, C.M[a], A.L. León Rodríguez, R. Suárez Medina, and J. Ruiz Jaramillo. 2020. 'Effects of Future Climate Change on the Preservation of Artworks, Thermal Comfort and Energy Consumption in Historic Buildings'. *Applied Energy* 276 (October): 115483. https://doi.org/10.1016/j.apenergy.2020.115483.

Muñoz-González, Carmen Ma, A.L. León-Rodríguez, M. Campano-Laborda, C. Teeling, and R. Baglioni. 2018. 'The Assessment of Environmental Conditioning Techniques and Their Energy Performance in Historic Churches Located in Mediterranean Climate'. *Journal of Cultural Heritage* 34 (November): 74–82. https://doi.org/10.1016/j.culher.2018.02.012.

Napp, Margus, and Targo Kalamees. 2015. 'Energy Use and Indoor Climate of Conservation Heating, Dehumidification and Adaptive Ventilation for the Climate Control of a Mediaeval Church in a Cold Climate'. *Energy and Buildings* 108 (December): 61–71. https://doi.org/10.1016/j.enbuild.2015.08.013.

Nocera, Francesco, Alessandro Lo Faro, Vincenzo Costanzo, and Chiara Raciti. 2018. 'Daylight Performance of Classrooms in a Mediterranean School Heritage Building'. *Sustainability* 10 (10): 3705. https://doi.org/10.3390/su10103705.

Paolini, Riccardo, Maryam Meshkin Kiya, Elisabetta Rosina, Lavinia C. Tagliabue, and Enrico De Angelis. 2016. 'Application of Biological Growth Risk Models to the Management of Built Heritage'. *TECHNE - Journal of Technology for Architecture and Environment* 0 (12): 207–13. https://doi.org/10.13128/Techne-19354.

Papakonstantinou, K.A., C.T. Kiranoudis, and N.C. Markatos. 2000. 'Computational Analysis of Thermal Comfort: The Case of the Archaeological Museum of

Athens'. *Applied Mathematical Modelling* 24 (7): 477–94. https://doi.org/10.1016/S0307-904X(99)00049-9.

Pigliautile, Ilaria, Veronica Lucia Castaldo, Nastaran Makaremi, Anna Laura Pisello, Luisa F. Cabeza, and Franco Cotana. 2019. 'On an Innovative Approach for Microclimate Enhancement and Retrofit of Historic Buildings and Artworks Preservation by Means of Innovative Thin Envelope Materials'. *Journal of Cultural Heritage* 36 (March): 222–31. https://doi.org/10.1016/j.culher.2018.04.017.

Pisello, Anna Laura, Alessandro Petrozzi, Veronica Lucia Castaldo, and Franco Cotana. 2014. 'Energy Refurbishment of Historical Buildings with Public Function: Pilot Case Study'. *Energy Procedia*, International Conference on Applied Energy, ICAE2014, 61 (January): 660–63. https://doi.org/10.1016/j.egypro.2014.11.937.

Pracchi, Valeria. 2014. 'Historic Buildings and Energy Efficiency'. *The Historic Environment: Policy & Practice* 5 (2): 210–25. https://doi.org/10.1179/1756750514Z.00000000052.

Rajčić, Vlatka, Ana Skender, and Domagoj Damjanović. 2018. 'An Innovative Methodology of Assessing the Climate Change Impact on Cultural Heritage'. *International Journal of Architectural Heritage* 12 (1): 21–35. https://doi.org/10.1080/15583058.2017.1354094.

Reiser, Claudius, Ruth David, Markus Faigl, and Oliver Baumann. 2008. 'Accounting for Primay Energy New Code Requires Dynamic Simulation'. *Proceedings of Building Simulation 2008: 3rd Conference of International Building Performance Simulation Association, Berkley, California, July 30, August 1*.

Roberti, Francesca, Ulrich Filippi Oberegger, and Andrea Gasparella. 2015. 'Calibrating Historic Building Energy Models to Hourly Indoor Air and Surface Temperatures: Methodology and Case Study'. *Energy and Buildings* 108 (December): 236–43. https://doi.org/10.1016/j.enbuild.2015.09.010.

Rubeis, Tullio de, Iole Nardi, Mirco Muttillo, and Domenica Paoletti. 2020. 'The Restoration of Severely Damaged Churches – Implications and Opportunities on Cultural Heritage Conservation, Thermal Comfort and Energy Efficiency'. *Journal of Cultural Heritage*, 18.

Schellen, H., L., and E. Neuhaus. 2010. 'Conservation Heating in a Historical Building: Results from an Experimental and Simulation Study'. In *Developments in Climate Control of Historic Buildings*, edited by T. Kilian, T. Vyhlídal, and Tor Broström, Stuttgart, 21–27. Stuttgart: Fraunhofer.

Schellen, Henk L., and A. W. M. van Schijndel. 2011. 'Setpoint Control for Air Heating in a Church to Minimize Moisture Related Mechanical Stress in Wooden Interior Parts'. *Building Simulation* 4 (1): 79–86. https://doi.org/10.1007/s12273-011-0026-7.

Silva, Hugo Entradas, Guilherme B.A. Coelho, and Fernando M.A. Henriques. 2020. 'Climate Monitoring in World Heritage List Buildings with Low-Cost Data Loggers: The Case of the Jerónimos Monastery in Lisbon (Portugal)'. *Journal of*

Building Engineering 28 (March): 101029. https://doi.org/10.1016/j.jobe.2019.101029.

Silva, Hugo Entradas, and Fernando M. A. Henriques. 2014. 'Microclimatic Analysis of Historic Buildings: A New Methodology for Temperate Climates'. *Building and Environment* 82 (December): 381–87. https://doi.org/10.1016/j.buildenv.2014.09.005.

Tronchin, Lamberto, and Kristian Fabbri. 2017. 'Energy and Microclimate Simulation in a Heritage Building: Further Studies on the Malatestiana Library'. *Energies* 10 (10): 1621. https://doi.org/10.3390/en10101621.

Varas-Muriel, M.J., M.I. Martínez-Garrido, and R. Fort. 2014. 'Monitoring the Thermal–Hygrometric Conditions Induced by Traditional Heating Systems in a Historic Spanish Church (12th–16th C)'. *Energy and Buildings* 75 (June): 119–32. https://doi.org/10.1016/j.enbuild.2014.01.049.

Webb, Amanda L. 2017. 'Energy Retrofits in Historic and Traditional Buildings: A Review of Problems and Methods'. *Renewable and Sustainable Energy Reviews* 77 (September): 748–59. https://doi.org/10.1016/j.rser.2017.01.145.

ANNEX 8.9: STATE OF THE ART ANALYSIS ON BIM AND NUMERICAL SIMULATION INTEROPERABILITY

Index

1. INTRODUCTION

3.1 Background

The building sector is responsible for contributing up to 30% of the global greenhouse gas emissions (GHG) and for consuming almost 40% of the total energy production. The implementation of Energy Efficiency (EE) in the built environment is one of the principal objective of the European Union's (EU) action plan for sustainable development (EBPD 2010). For restraining the energy consumption and environmental footprint of the building stock, EU and various International institutions formulated a series of policies and regulations, which lead to the establishment of new standards around energy rehabilitation strategies and the promotion of smart technology solutions (see BEEP Output 3.1 § 2.2, AA. VV. 2020). In addition, these directives set a new reference point for energy performance requirements and consequently bring forward the concept of nearly zero energy buildings (nZEB). The realization of Energy Efficiency objectives within tight financial budgets and durable result expectations stress the need for advanced control over the life cycle costs (LLC) of buildings (Liu, Xianhai, and Chiming 2015). The impact of design decision on the energy and environmental performance of a building is much higher as these decision are closer to the early design stages (Lechner 1991). Under these lines, the early involvement of MEP engineer, the need for early energy-related insights as well as the continuous monitoring of the buildings' energy performance responses are becoming essential key aspects for the entire building planning and asset management process.

The tight interrelation of these objectives points out the importance of a well-formulated approach of rapid deployment, which requires collectiveness and collaboration among the involved professionals. The necessity for shifting over to a renewed, integrated planning practice is commonly considered as a step forward to better deal with cost-effective energy saving developments (Ryan and Sanquist 2012).

In the last decade, Building Information Modelling (BIM), defined as the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions (ISO 19650-1 2018), became a popular approach which encapsulates the above capacity for sustainable building development. BIM puts in place all the necessary tools for activating an integrated design and planning workflow. This is accomplished through the embodiment of building information within the geometrical model itself. Hence, a native BIM software acts as a core database of information of multiple dimensions, classifying the building's operational, financial, managerial, ecological and maintenance attributes and functions. However, exporting BIM data for Building Performance Simulation (BPS) applications depends on data exchange formats and their subsequent file standards compatibility. When information is fully defined and appropriately registered, a single export can save a significant amount of time, effort and potential error occurrences, as compared to reproducing the respective Energy Model in a native BPS environment (Pinheiro et al. 2016).

The transferring of information between BIM and BPS software is carried out under Open BIM standards, through the data exchange schema (DES) of Industry foundation Class (IFC) or Green Building eXtensible Markup Language (gbXML) (Augenbroe 2002; Pinheiro et al. 2016; Kamel and Memari 2019). Amongst the majority of BPS software packages, gbXML is considered a more straight forward option for use with many BPS software packages, since the schema output is lighter in size and dedicated to energy-related information exchange (for a comparison of the two file formats see §3.10). However, despite the potential of BIM technology for generating a collective and automated design and planning workflow, the interoperability of BIM to BPS is yet not fully functional nor effortless (Rahmani Asl et al. 2015; Kamel and Memari 2019; Hijazi, Kensek, and Konis 2015; E. Gigliarelli et al. 2019). An exported BIM model may result into decomposed or unjustifiably interpreted geometry, with numerous incidences of improper or inadequate data conversion.

3.2 Glossary

AEC	*Architecture, Engineering and Construction*
BCF	*BIM Collaboration Framework*
BI-EM	*Building Information-Energy Model. A BIM-based energy model that automates the energy modelling process within the BIM software (Revit Energy Model)*
BIM	*Building Information Modelling*
BIM-BPS	*Building Information Model to Building Energy Model. A converted energy model using exported information from a BIM model*
BPS	*Building Performance Simulation*
bSDD	*buildingSMART Data Dictionaries*
CFD	*Computational Fluid Dynamic*
DTV	*Design Transfer View*
DES	*Date Exchange Schema*
FM	*Facility Management*
GBS	*Green Building Studio*
gbXML	*Green Building eXtensible Markup Language*
HVAC	*Heating, Ventilation and Air Conditioning*
IAI	*International Alliance for Interoperability*
IDM	*Information Delivery Manual*
IFD	*International Framework for Dictionaries*
IFC	*Industry Foundation Class*
ISO	*International Organization for Standardization*
LCC	*Life cycle costs*
MEP	*Mechanical, Electrical, and Plumbing*
MVD	*Model View Definitions*
Plenum	*A plenum is a non-occupiable space between a ceiling and the floor above specifically intended for mechanical systems and other systems that require ceiling space*
R-value	*Thermal Resistance*
RV	*Reference View*
SHGC	*A value describing the solar heat gain coefficient in a glazing (window) material*
Space	*A space is defined as a building volume enclosed by ceilings, floor, walls or by another space's boundary. Space has a plethora of properties assigned to it to describe its energy resources, such as loads from people, lighting and equipment*
U-value	*Heat Transfer coefficient or Thermal Transmittance*
Weather File (epw)	*A single file in a format called an .epw that contains a collection of information to describe the environment of a location for each hour*

	of the year, supplying data such as temperatures, luminescence data for sunlight, heating, and more
XML	*eXtensible Markup Language*
XSD	*XML Schema Definition*

3.3 Document Purpose

The purpose of this document is to explore and address the current state of BIM to BPS Interoperability development, its causes, challenges and current workflow approaches in AEC daily practice. It seeks to provide critical insights of the current obstacles the AEC industry is facing around this subject, in order to allow the Project partners to select and implement the most efficient semi-automatic workflow available.

A brief introduction and a schematic representation of the problem formulation is documented in Section 2. The current level of BIM and BPS integration, BIM and BPS information requirements and the importance of an effective BIM to BPS conversion is described in Section 3. Interoperability and data exchange schemas of IFC and gbXML are presented in Section 4. Currently available solutions are offered in Section 5, while Section 6 concludes with the exchange process limitations and future research description.

3.4 Project Scope

The scope of this document is outlined in the table below:

In scope of this Document	Out of scope of this document
- Describe the problem formulation - Literature review of existing BIM to BPS workflows/conversions - Comparison of IFC and gbXML data schema - Provide guidance for an effective BIM to BPS Interoperability - Provide advice on establishing a successful semi-automatic workflow - Provide advice on avoiding/reducing parallel modelling between the two software environments	- Provide advice on IT solution - Provide software or scripts - Suggest the use of specific software packages or versions - Explain Energy Simulation Models

Table 1: Document scope

2. SCHEMATIC REPRESENTATION OF PROBLEM

The need of the AEC industry to engage in a more collaborative design and planning practice is commonly considered as a great development for enhancing the final resolution (richness and accuracy) of a building outcome in all its critical aspects. BIM technology provides a complete digital solution for modelling, storing, editing and managing building information, while promoting a clear role designation to the involved professionals. During a project's development, the engagement of project engineers with numerical simulations at different project phases, is of primary importance. For this reason, BIM authoring software should be able to exchange model information seamlessly. From research literature and professional practice reports, the interaction of the two is still away from being smooth and error-less (Rahmani Asl et al. 2015; Kamel and Memari 2019; GSA 2015; Hijazi, Kensek, and Konis 2015).

Currently, AEC firms rely on a plethora of design and simulation software, when it comes to explicit tools and services for project collaboration. Communication and interoperability between these tools depend on data exchange formats and their compatibility (Augenbroe 2002), which within the BIM pipeline is typically ensured by a Common Data Environment (CDE). A CDE represents the agreed source (and repository) for collecting, managing and disseminating information for any given project (ISO 19650-1 2018). It aligns the process of model collaboration with the established industry collaboration protocols to enable multiple users to perform collaboration operations on model content management, content creation, viewing and reporting and system administration. In particular, the exchange of digital models should be filtered in order to map only the segment of data that is essential for the particular numerical simulation, i.e., in the case of BPS, simplified building geometry and thermal data. Currently, project files exported from BIM software are usually too condensed in information and too large in size for the basic needs of simulation software to operate correctly. Therefore, project professionals are often called to manually remodel and reregister the information before executing the building numerical simulation. This lack of compatibility leads to increased time-consuming processes which are also prone to human error, inconsistencies and redundancies, especially in large construction projects, with multiple planning and design phases. Approximately 80% of the total resources needed to perform a building simulation are consumed on unnecessary replicating actions (Ryan and Sanquist 2012).

Despite the aforementioned workflow obstacles found in process of the model data transfer from BIM to numerical simulation software, in the case of BIM to BPS conversion, the level of complexity becomes even higher. Contrary to a native BIM model, BPS input data are much more abstract
, in terms of the building's geometrical input as well as of the alphanumerical information. Therefore, the transfer of information from BIM to BPS demands serious simplification of the building geometry from 3D objects to 2D surfaces. For this reason, the exporting process is also subjected to geometric computational conversion processes, also known as 'healing computations'. Current efforts occupied with the BIM to BPS interoperability issue utilise both the IFC and gbXML data schemas. Specifically, a schematic representation of the interoperability problem is presented in Figure 1.

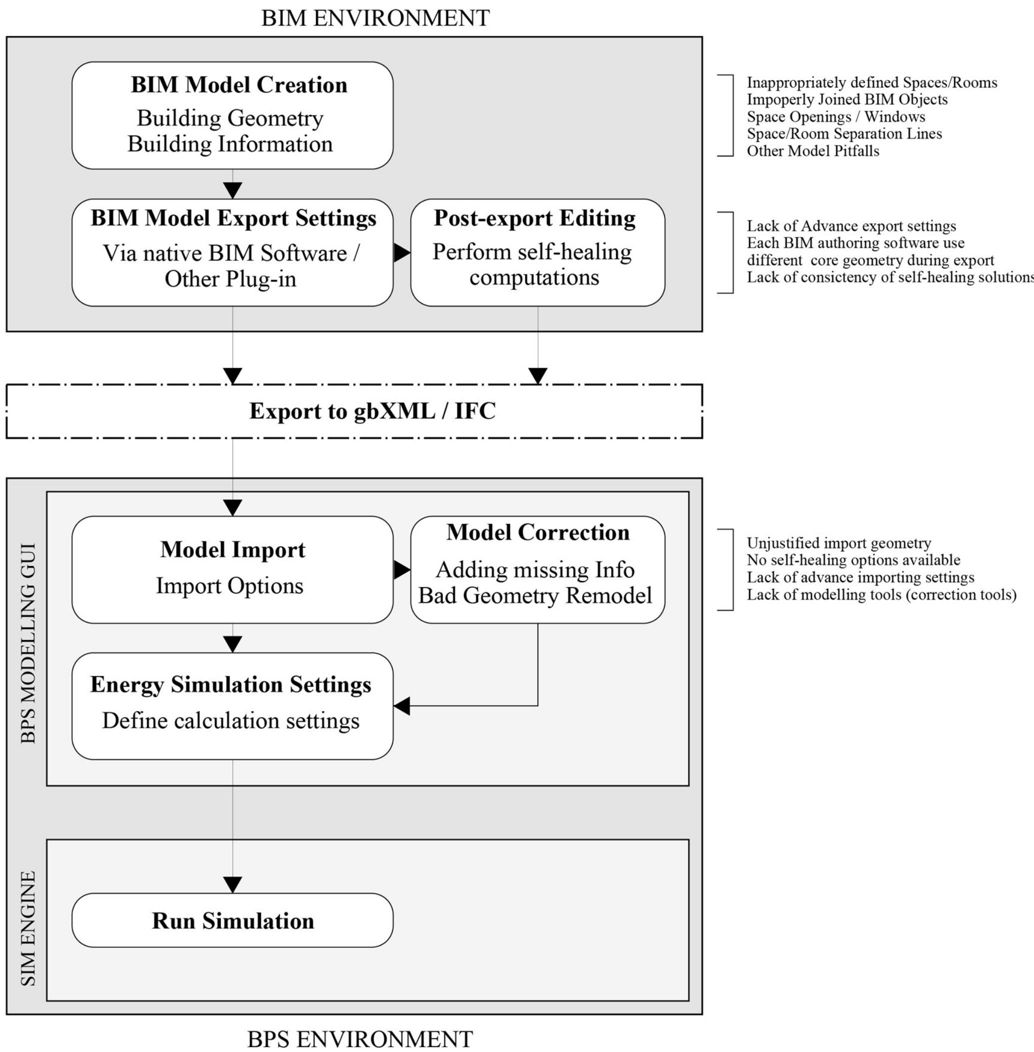


Figure 1: Schematic representation of BIM to BPS Interoperability problem

3. BIM FOR BPS

3.5 Building Information Modelling

A Building Information Model refers to the digital model of a building that contains a wide spectrum of information from a variety of construction industry fields. This model includes input from all construction stakeholders, including the architect, structural engineer, mechanical engineer, energy engineer, and others, that defines building attributes from the beginning of its lifecycle until its demolition (Sacks et al. 2018). According to literature, the majority of BIM definitions refer to the model as a series of actions of broad changes in design, construction and facility management, instead of a digital object in itself. In particular, BIM is described as a set of policies, processes and technologies, which set the standards for a holistic collaborative methodology for building design and construction (Succar 2009). BIM technology is described as one of the most promising developments happening in the AEC industry which enables and integrate design and construction workflow.

3.1.1 BIM maturity levels

The level of implementation of BIM technology depends on the level of complexity of a building Project but more importantly on how the model will be used (Jayasena and Weddikkara 2013). For scalability reasons, this characteristic is formally described as BIM maturity. In short, the level of maturity defines the level of collaboration between industry professionals. In Figure 2 the schema of BIM maturity levels developed by the BIM Industry Working Group is presented (BIM Industry working group (BIWG) 2011). The diagram was developed for the British Government Construction Client Group and is rapidly adopted throughout Europe. These levels are formulated based on industry standards of the disciplines involved.

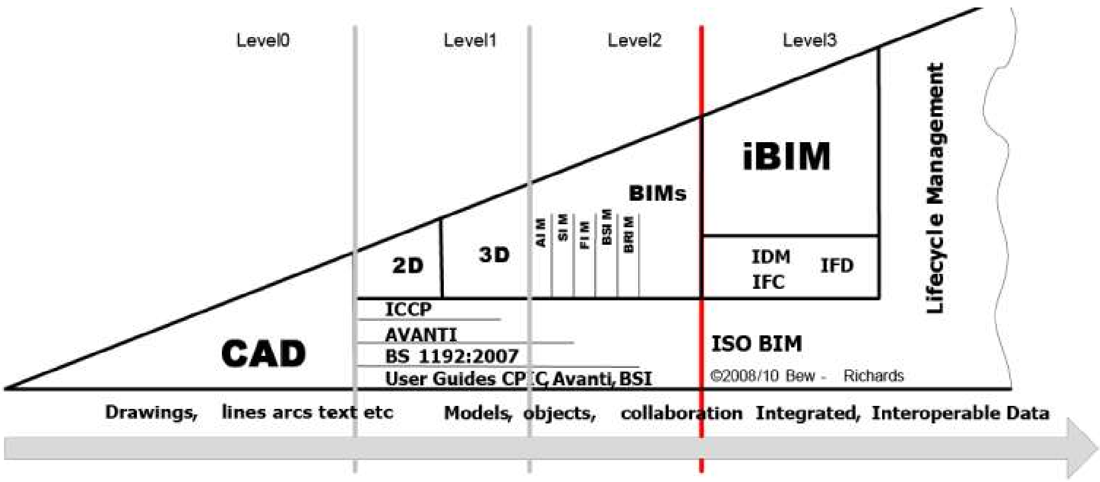


Figure 2: Maturity scheme – BIM Industry Working Group (BIM Industry working group (BIWG) 2011).

The implementation of a BIM model at maturity level 3 means that all previous levels' requirements are fully respected and realised. At level 0, only CAD drawings and spreadsheet calculations are executed. This level includes no digital models and is commonly referred to as the document-oriented level. Level 1 is the first step towards a basic BIM model. At this stage, a 3D model of the building is developed, however, it still cannot be used for cost, operations or other calculations. This option can be achieved at maturity level 2, where building information is assigned to the building objects. At final stage 3, building information is shared between the involved professional through open BIM standards. Level 3 provides a full utilisation of BIM technology and ideally sets the standards for a seamless collaboration.

Facilitating a frequent and structured collaboration between the involved parties is boosted at BIM maturity levels 2 and 3. Consequently, the interoperability between native BIM software and other numerical simulation packages becomes critical. A seamless exchange of information between the two software environments may accelerate the building development workflow or even enable automation.

3.1.2 Level of Development (LOD) and Level of information Need

Another important aspect of BIM implementation is the definition of the level of information, both geometrical and alphanumerical, within a BIM model and its elements. A very common term to express this concept is the Level of Development (LOD). This term is used to describe both the geometrical and alphanumerical level of information incorporated in a model for each and every modelling phase of a project's development (Boton, Kubicki, and Halin 2015). Level of Development is divided in a scale of 5 levels, namely, in the US version, L100, L200, L300, L400 & L500 (Choi, Kim, and Kim 2015). L100 represents the level of information of a conceptual design, whereas, L500 indicates a geometry at an as-built level, with information reaching the operation and maintenance level. Similarly to level of maturity, the decision of LOD for a BIM model is directly related to its purpose and uses.

ISO 19650 (2018) introduces the corresponding concept of Level of Information Need, that defines the extent and granularity of information to be provided to satisfy the information related purposes of each model element. Compared to LOD, it stressed the importance of the "right" amount of information to be delivered, to avoid redundancy and waste (Churcher and Davidson 2019). Moreover, it is intended as a general framework to be adapted to the specific BIM process, without providing a strict template, but leaving a lot of flexibility to implementation; therefore, it is well suited for interoperability workflows, that require ad-hoc solutions.

When it comes to BIM for BPS interoperability, Level of information Need becomes probably the most important aspect for consideration, in avoiding convergence issues (Sacks et al. 2018). While a L500 (that could correspond to a specifically defined, very high Level of Information Need) model creates the best conditions for the ultimate control and management of a construction project when a very high detail is required, it makes things difficult for the energy professionals involved. Due to the fact that BPS environment support only simplified geometry of single surfaces for each room/space face, a L500 BIM model carries unnecessary information for the former. In geometrically heavy models, the establishment of a proper and automated conversion/simplification of the geometry is constantly at risk. Although the data schema of gbXML may manage better the transition of only energy-related alphanumerical information, the conversion/simplification of the model geometry remains an unsolved process of the export workflow; for a comparison of approaches see (Guzmán Garcia and Zhu 2015; Dong et al. 2007; Lam et al. 2012; Hijazi, Kensek, and Konis 2015; Garwood et al. 2018; Pinheiro et al. 2016).

3.6 Building Performance Simulation (BPS)

The design of the built environment is a complex task involving the interaction among technical domains, diverse performance expectations and emerging uncertainties. Building Performance Simulations provide a means to deal with these complexities allowing the exploration of design solutions and their impacts (Clarke and Hensen 2015), mainly in terms of environmental and energy performance. Despite the impact of strategic decisions on the energy and environmental characteristics of a building is much higher when these decisions are close to the early design stages (Lechner 1991), BPS are mainly used as a performance confirmation at later stages of design instead of a design support through the whole design process starting from the early design stages (Morbitzer 2003; Bambardekar and Poerschke 2009). While the implementation of Energy and Environmental Simulation at a later stage of the design process will impact only the few design parameters that are still flexible (Morbitzer 2003), resolving usually in a fine tuning of the HVAC systems, and having a less meaningful impact upon the quality of the building design, an early energy simulation engagement will instead affect the design trajectory, in terms of the building's shape, form and size (Morbitzer 2003). Therefore, to design high performance buildings it is important to assure informed decision making during the early design phases and this also includes the use of BPS tools (Attia et al. 2012). BPS can also contribute positively during the building's operation stage, by determining the optimum operational schedule of the HVAC systems, dynamic shading systems and other technical services. An effective utilisation of BPS can achieve an optimum balance between cost, comfort and energy efficiency.

3.3.1 The importance of an effective BIM to BPS interoperability

The sustainable development of a building project requires an iterative energy analysis that starts from conceptual design phase to the detailing and finally the operation stages. This iterative process, enhanced by the BIM technology advantages, may enable reaching the full potential of sustainable building design (Pinheiro et al. 2016). An effective BIM to BPS interoperability solution can enable the following advantages:

- Time saving for unnecessary remodelling processes and reduce error-prone manual re-input of data.
- Facilitate energy engineers perform energy simulations using the updated version of the model at every design or operation phase of the project.
- Automatically implement changes of the model between phase A and B.
- Take advantage of BIM parametric modelling tools to test new design ideas or perform optimization techniques based on energy-related criteria, in a short amount of time.
- Bridge the gap between BIM professionals and energy engineers, by providing energy analysis feedback back into BIM model.

3.3.2 BPS Information Requirements

Figure 3 provides an overview of the input data necessary to perform an Energy analysis. Input data differ in case of a static or a dynamic simulation. The classification of data is based on the four following categories: Environmental Data, Building Data, Occupants Data, Heating & cooling loads and Building service systems & operational schedules. The scope of this section is to provide a basic understanding of the level of information needed to be registered in a BIM model before exchanging with BPS software. For BEEP project, all necessary BPS information requirements are described in *A.3.2.5 Environmental and Energy analyses*.

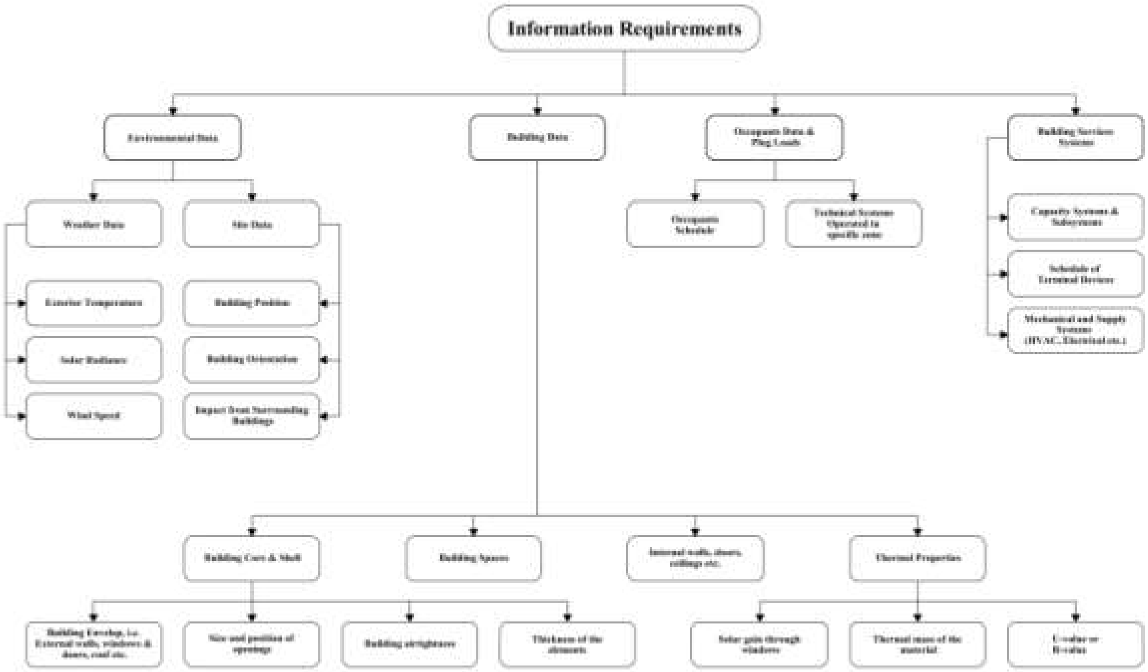


Figure 3: BPS Information Requirements (Karlapudi 2018).

4. INTEROPERABILITY AND DATA EXCHANGE SCHEMAS

3.7 Interoperability

The term interoperability is used here to describe the process of data sharing or exchange between a BIM software and a numerical simulation software, in order to remove the need for data model regeneration (Sacks et al. 2018). According to literature, one of the biggest obstacles in solving current interoperability misfunctioning and enabling the wider adoption of BIM-based energy analysis is the data exchange between the BIM and BPS models (Costa and Madrazo 2015). The problems generally arise from the different logic with which the two software environments evolved (Hijazi, Kensek, and Konis 2015; E. Gigliarelli et al. 2019), which reduced the possibility for simulation software to exploit the potential offered by object-oriented programming of BIM software (Abanda, Vidalakis, and Tah 2015; Jeong et al. 2014). The difficulties in a seamless conversion of BIM-based data into coherent BPS-model depend on simplifications and assumptions required for making the energy simulation models (Ahn et al. 2014), and the relative need to convert/transform data in the process. The lack of a standardised process in building energy modelling (E. Gigliarelli et al. 2017; Hitchcock and Wong 2011; Guruz, Katranuschkov, and Scherer 2016) and the gap still present between design and energy modelling are the main limitations that impede the process (Wilkins and Kiviniemi 2008). The transfer of both geometric and informative data between software is still imprecise (Lam et al. 2012; Pinheiro et al. 2016) and requires a strong supervision/manual intervention, thus reducing the main benefits of an exchange process that is as automated as possible. Another typical problem occurs when modelling strategies optimised for other model uses, i.e., architectural or structural optimisation, are in conflict and do not allow an orderly division of the objects modelled for exchanges between disciplines, as it usually occurs between Architectural, Structural and MEP BIM (Tchouanguem Djuedja et al. 2019). A seamless exchange of data between the two (BIM software and a numerical simulation software) heavily depends on the proper filtering of the data, i.e., eliminate redundancy and maintain a simplified exchange process.

3.4.1 Open Standard Exchange Schemas

Software interoperability between BIM and other simulation software is achieved through digital format exchange using common proprietary or open standards. The following open and neutral file exchange formats are currently being used to enable interoperability between BIM and BPS:

IFC: Industry Foundation Class

This is a global standard file format mostly used for solving interoperability between different native BIM software. IFC is designed to store information of geometry, including its respective classification, properties and quantities.

gbXML: Green building eXtensible Markup Language

This industry supported file format is tailored to make the exchange of information from a CAD-based BIM environment to a BEM environment. gbXML is dedicated to store element attributes that are dominantly energy related.

Each data schema has its own advantages and disadvantages when it comes to BIM for BPS conversion. In literature there are many comparisons of the above exchange languages (Hijazi, Kensek, and Konis 2015; Lam et al. 2012; Pinheiro et al. 2016; Dong et al. 2007), however, errors still occur irrespective of the file format that is used (Kamel and Memari 2019). Manual adjustments are still necessary to resolve incorrect or improper conversion/translation or storing of the information. In order to improve interoperability, the developers of IFC and gbXML continue to work on updates of the exchange schemas. However, the lack of knowledge about different native BIM software is considered a major obstacle for reaching and providing a solid interoperability solution to the market today (NBS 2014; 2015), and the same is true also for the lack of knowledge about different BPS software and their heterogeneity in addressing the simulation tasks (input data needed, approach etc.). Currently, there many research efforts on providing native BIM plug-in tool for model correction or stand-alone post export editing tool for solving the interoperability problem. More information about current solutions is provided in Section 5.

3.8 Industry Foundation Class (IFC)

IFC[1] is an open meta-data schema used to transfer building information from one software to another among all professionals of a design, construction and facility management project. IFC is developed by buildingSMART and its formulation is based on open International standards. The purpose of buildingSMART is to deliver a good quality data exchange schema in order to match the information needs of the entire building industry, hence IFC include terms, concepts and specifications from the involved disciplines. IFC has been structured in a four conceptual layer, Resource layer, Core layer, Interoperability layer and domain layer (Figure 4) with a total of approximately 800 entity definitions, thousands of data attributes and much more standardised object properties.

Resource Layer: is the lowest layer in the IFC data schema architecture and provides commonly used resources. It can be used or referred by classes in the other layers.

Core Layer: consists the elementary structure of the IFC and defines most abstract generic concepts. Further dedicated input is handled by the following layers of the IFC object model.

Interoperability Layer: This is specialized information added to core layer objects. This info is shared among multiple model domains.

Domain Layer: layer responsible for additional information to model objects that will be used by domain experts.

[1] For more information see https://technical.buildingsmart.org/standards/ifc/

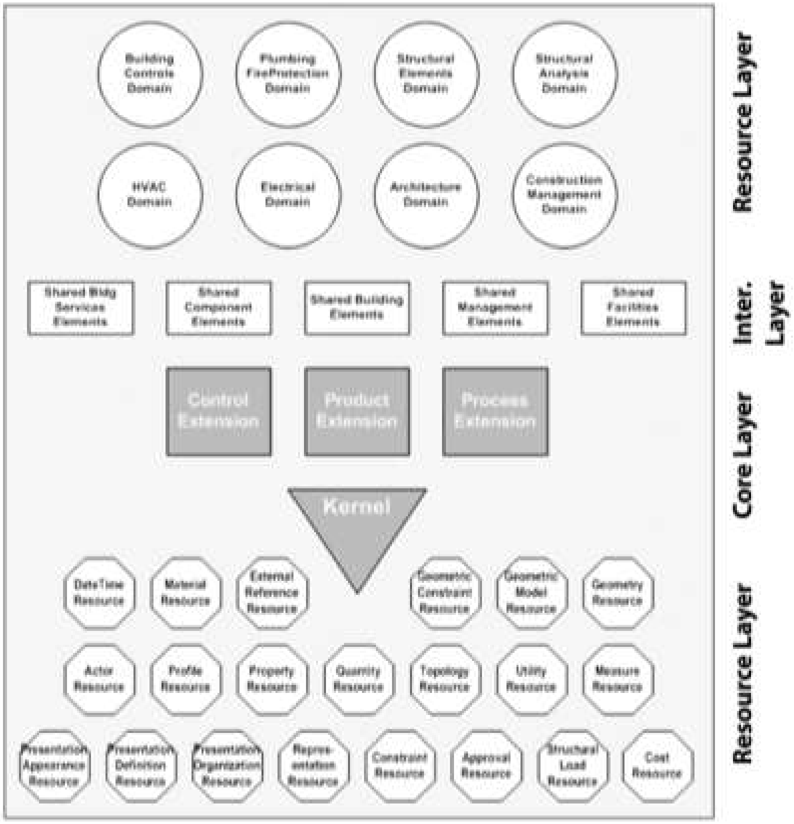


Figure 4: IFC Data schema with four conceptual layers (buidingSMART 2020).

The official latest IFC version currently in use is IFC4.1, released in 2018 (buidingSMART 2020). Compare to its previous versions, IFC4.1 can define a model at higher level of detail. In the context of building energy analysis, IFC 4.x can describe different building boundaries and store additional HVAC information. Extensions made to the IFC4.1 schema include:

- Description of alignment as a combination of horizontal and vertical alignment;
- Linear Placement according to ISO 19148;
- IfcSectionedSolidHorizontal as a new geometry representation particular useful for describing infrastructure facilities.

3.9 Green building eXtensible Markup Language (gbXML)

The gbXML[2] schema is developed by Green Building Studio (GBS) in 1999. The schema stores data in the form of eXtensible Markup Language (XML) language, turning it into machine and human readable language. XML enables users to modify the language and thus, it allows for customization on data domain exchange. Specifically, its use and purpose can be greatly differing according to its semantic structuring. gbXML facilitates the exchange of explicit building information, such as weather data, building geometry, HVAC systems, lighting and thermal zones, thermal loads, schedules, etc., making it more appropriate for supporting interoperability between BIM native software and engineering tools (Ham and Golparvar-Fard 2015a). The gbXML schema is rich in data and can store up to 500 types of building elements and attributes. Each building

[2] For more information see https://www.gbxml.org/About_GreenBuildingXML_gbXML

component, from architectural to MEP model, holds its own information and has its own reference ID. The following figure shows the hierarchy of information organisation of the schema (Figure 5).

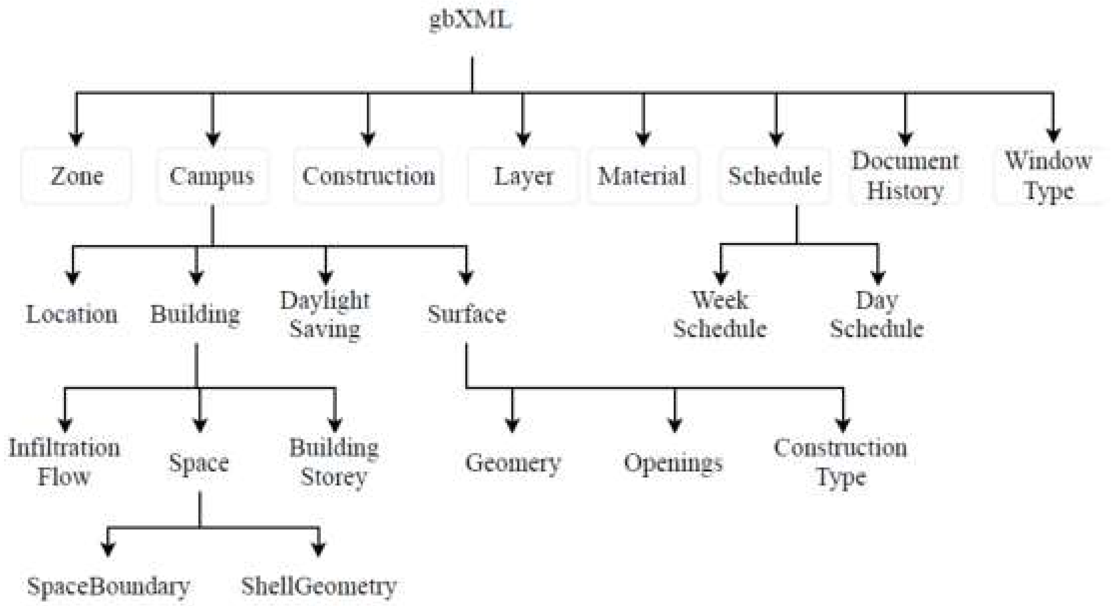


Figure 5: Simplified hierarchy of information organisation in gbXML schema (Ham and Golparvar-Fard 2015).

The concept of reference ID is to form necessary relationships between other components. For example, a wall, roof or slab component is defined as surface, which in turn defines the geometry, construction information and information about the opening on that surface. The construction information includes all wall layers; within each layer it stores the material and thermal information separately and linked to the construction type. The details of the type on opening are linked to the actual components using reference ID.

The primary ''Building'' component of gbXML defines the building, including information of the different storey levels, which further defines space types included in it. The ''Space'' component is assembled by ''Room binding elements'', such as wall, roof, floor etc. Bounding elements consist of two nodes, ''Shell Geometry'' and ''Space Boundary''. Shell Geometry defines the inner surface of the adjacent wall, while space boundary defines the coordinates of the centreline of the Bounding Element. In case of an internal wall, which is separated by two consecutively located spaces, the centreline and both faces of the wall are defined. ''Operating schedule'' and ''Occupants' schedule'' are defined separately and linked to the space thought the reference ID mechanism.

3.10 Data exchange schemas comparison

Data exchange schemas are constantly under development and they are increasing their added-value on dealing with interoperability improvement. This is acknowledged by many researchers, i.e., (Guzmán Garcia and Zhu 2015; Ham and Golparvar-Fard 2015b; Cemesova, Hopfe, and Mcleod 2015; Cheng and Das 2014). Each schema carries its own advantages and drawbacks. According to Moon et al. 2011, the gbXML schema is more dedicated to BIM for BPS exchange operations, officially supported by many BIM software providers. However, the IFC schema is more developed data model for buildings in the AEC industry, able to transfer all building information data (Sacks et al. 2018). In this context, IFC may provide an interoperability solution for all types of numerical simulation interoperability needs. In the case of BIM to BPS however, IFC causes time consuming simulation runs or even software crashes. gbXML on the other hand may be more compact and more popular in the AEC industry, although still it does not allow to perform a complex geometry exchange between a native BIM software and a BPS. This is because the gbXML schema can only accept rectangular planar shapes. Compared to the ''top-down'' approach of the IFC, the gbXML employs a ''bottom-up'' process, which makes it more accessible and flexible to handle.

3.11 Conversion from BIM to BPS

Currently, the conversion of a BIM model to a BPS model could be achieved in a fully automated, semi-automated or non-automated (manual) fashion.

- The fully-automated concept refers to the idea of automatically and instantly generating a fully-defined BPS model from a BIM model. This idea is currently being promoted by Autodesk seeking to create a fully-automated BIM to BPS exchange between *Revit* and *Green building studio*, via gbXML exchange schema. Today, this approach can be applied only in the case of small-scale buildings of conventional rectangular shape, and in any case it does not take into consideration the need of the energy modeller to design his own simulation by making simplifications or modifications compared to the starting BIM model (such as for example for the definition of thermal zones).
- The semi-automatic concept refers to the idea of exporting only the necessary (and/or possible to transfer) data from a BIM model, i.e., building geometry, spaces, material thermal properties, etc. The exported file is then imported into third party BPS software to further execute the simulation. Depending on the complexity of the export BIM model, additional modelling or information registration work in the BPS software may be necessary.
- The non-automatic, or manual conversion, process is the case that is usually being followed today by the energy modelling industry. In this case the user is required to remodel the building in the BPS modelling environment before running the analysis.

3.12 The 'H' factor in BIM to BPS Interoperability

Heritage buildings add an extra layer of complexity in both geometry and information data implementation. This complexity adds extra difficulty to the issues that stem from the application of the energy simulation methods to historical buildings (A.4.3.2 paragraph 2.3), partly because of data transfer/exchange. Regarding the geometric aspects, the process for converting geometry from walls with thicknesses in the BIM environment to the two-dimensional surfaces of the walls in the energy model (BPS) is challenged by the particularities of built heritage. Specifically, historic buildings frequently have walls with variable thickness, floor height changes (E. Gigliarelli et al. 2019), while they typically feature complex geometric shapes, such as vaults or domes, that cannot be easily modelled in BIM and then converted into the energy model.

Moreover, heritage buildings usually necessitate additional consideration on the way their thermophysical behaviour and the relation between surfaces can be adequately represented in the energy model. In the representation of a historic building envelope, even the transfer of information data can encounter specific problems, as it is substantially dependent on the heterogeneity of the layers and the properties of the materials (also due to variable patterns of decay on the same type of wall), as well as the considerable lack of standardisation. There do exist solutions towards the right direction, which usually need extension to fit the specificities of heritage buildings, for example, the COBie Information Delivery Manual (IDM) for historical buildings[3].

4 INTERNATIONAL GUIDELINES

Even though the topic of BIM and BEM interoperability is still in its infancy, research has started more than ten years ago. The following table lists the documents which attempt to systematise this transfer of data, highlighting the critical aspects of both the process and operation:

Table 1: International Guidelines

Title	Author-year	Main Topics covered
GUIDELINES for OptEEmAL BIM Input Files.	(Giannakis et al. 2019)	The guidelines develop a IFC BIM-based building energy model generation methodology to streamline the process and reduce errors. The BIM authoring tool investigated is Autodesk Revit, and the consortium also produced a dedicated IFC exporter.
Project Execution Planning guide, version 1.2.	(Computer Integrated Construction Research Group, PENN State University 2019)	The guide contains a flowchart for BIM-based energy analyses highlighting the information exchanges and the stakeholders involved.
A study of national BIM guidelines from around the world determining what future Swedish national BIM guidelines should contain.	(Kralsson and Rönndahl 2018)	A comparative study of BIM guidelines from ten countries (Australia, Belgium, Canada, Finland, Hong Kong, New Zeland, Norway, Singapore, UK and US), containing an appendix on the simulation and energy analysis.

[3] https://technical.buildingsmart.org/standards/information-delivery-manual/idm-database/

IBPSA Project 1 - BIM/GIS and Modelica Framework for building and community energy system design and operation.	(IBPSA 2017)	The project focuses on the creation of new computational tools based on Modelica to build the basis of the next generation computing tools focusing on open standards IFC and CityGML.
EDSL Guide for Revit gbXML Files	(Cadline 2016)	The guide focuses on the creation of a useable Revit model for gbXML exporting for EDSL TAS Engineering simulation software.
BIM Guide 05 Energy Performance, version 2.1	(GSA 2015)	The guide aims at helping the US General Service Administration in the development of their BIM execution plans, also taking into account the energy modelling. The guide contains insights on the role of BIM within the energy modelling process and case studies.
RP-1468 -- DEVELOPMENT OF A REFERENCE BUILDING INFORMATION MODEL (BIM) FOR THERMAL MODEL COMPLIANCE TESTING	(Clayton et al. 2013)	The report contains guidelines for mapping a Revit BIM model into a description (the most relevant subset of information) for energy modelling in DOE-2 simulation software.
Task 2.2.12 – CMU Report 02: Identification and Analysis of Interoperability Gaps between Nbims/Open Standards and Building Performance Simulation Tools.	(Lam et al. 2012)	The report focuses on interoperability gaps between IFC and gbXML open standards and energy modelling. IFC and gbXML are also compared.
HESMOS - Deliverable D2.1: BIM Enhancement Specification	(Liebich et al. 2011)	The project developed an Information Exchange Requirement for an Information Delivery Manual for a BIM to simulation process.
Implementation guide:	(Weise et al. 2011)	The guide is addressed to

space boundaries for energy analysis		software developers for supporting the exporting of space boundaries in IFC format also tackling the issue of the specific Model View Definition.
Information Delivery Manual (IDM) for BIM Based Energy Analysis as part of the Concept Design BIM 2010.	(Weise et al. 2011)	The guide addresses the data flow between BIM and simulation workflows, stressing the need for energy analyses from the conceptual design phase.
An automated IFC-based workflow for building energy performance simulation with Modelica	(Andriamamonjy, Saelens, and Klein 2018)	This paper describes the essential elements of this an integrated workflow, achieved with the already available technology, Information Delivery Manual (IDM) and a newly developed Model View Definition. This MVD is tailored to the needs of Building Energy Performance Simulation (BEPS) that uses the Modelica language together with a specific library (IDEAS) and can easily be adapted to other libraries.

For a selection of recent European Research Projects on BIM to BPS interoperability please refer to (AA. VV. 2020, para. 6.2)

5 LIMITATIONS & ONGOING RESEARCH

5.1 Limitations

The principal obstacles in the conversion process from BIM to BPS environment lie mainly in the quality of data, already existing in the BIM model as well as the exporting data schema translation. These limitations cause the following issues:

- Inadequate or fragmented spaces and thermal zones;
- Missing (mainly lost during the improper translation) or additional (result for example of an incorrect translation of the three-dimensional envelope into surfaces) building components;
- Wrongly placed walls and openings;
- Misinterpreted wall to wall or wall to window joint conditions
- Wrong boundary conditions
- Wrong conversion of informative data.

These errors are generated mainly due to the modelling process followed in the native BIM software, in conjunction with the inability of the exchange schemas to interpret the geometry in a solid and comprehensible manner. Another contributing aspect to the complications above is the immense level of data currently incorporated in a BIM model, such as furniture, architectural ornaments, mechanical systems, electrical and plumbing objects, etc.

5.2 Ongoing Research

The joint application of BIM and numerical simulations of building energy performance on historic buildings (i.e., Energy Efficient Heritage BIM) is still not widespread in professional practices. Even the conversion of BIM or the application of energy simulation to the case of heritage constructions, entails additional methodological considerations[4]. The application of these methodologies to historic buildings aims at maximising the potential offered by new technologies. The application of Energy Efficient Heritage BIM constitutes a complex variant (E. Gigliarelli et al. 2017; 2019) of the studies that currently address the issue of interoperability between BIM and simulations in the case of new constructions (Senave and Boeykens 2015; Maile et al. 2013; GSA 2015; Kamel and Memari 2019). One of the most significant case study in terms of joint use of the two technologies can be found in the Italian industrial research project METRICS Management and Requalification of Historic Centres and Buildings, funded by the PON Research and Competitiveness 2007-2013 (Gigliarelli, Calcerano, and Cessari 2017). The objective of METRICS was the development of innovative approaches and methodologies for the energy improvement of historic centres. The project addressed the issue with a multiscale, multidisciplinary and holistic approach, which involved the use of HBIM technology as a basis for the environmental energy analysis of buildings and the development of intervention strategies both on the urban scale and on the individual building. Among other objectives, this project focused on the interoperability between HBIM and dynamic simulations software ecologies (E. Gigliarelli et al. 2017; 2019) (Elena Gigliarelli et al. 2017; E. Gigliarelli et al. 2019).

[4] For more information see chapter 4 and par 5.3 of (AA. VV. 2020)

6 REFERENCES

AA. VV. 2020. 'A3.1.1 STATE OF THE ART ANALYSIS ON HBIM AND INTEROPERABILITY - ENICBCMed BEEP Project'.

Abanda, F H, A H Oti Vidalakis, and J H M Tah. 2015. 'A Critical Analysis of Building Information Modelling Systems Used in Construction Projects'. *Advances in Engineering Software* 90: 183–201. https://doi.org/10.1016/j.advengsoft.2015.08.009.

Ahn, Ki-Uhn, Young-Jin Kim, Cheol-Soo Park, Inhan Kim, and Keonho Lee. 2014. 'BIM Interface for Full vs. Semi-Automated Building Energy Simulation'. *Energy and Buildings*, The 2nd International Conference on Building Energy and Environment (COBEE), 2012, University of Colorado at Boulder, USA, 68, Part B (January): 671–78. https://doi.org/10.1016/j.enbuild.2013.08.063.

Andriamamonjy, Ando, Dirk Saelens, and Ralf Klein. 2018. 'An Automated IFC-Based Workflow for Building Energy Performance Simulation with Modelica'. *Automation in Construction* 91 (July): 166–81. https://doi.org/10.1016/j.autcon.2018.03.019.

Attia, Shady, Elisabeth Gratia, André De Herde, and Jan L. M. Hensen. 2012. 'Simulation-Based Decision Support Tool for Early Stages of Zero-Energy Building Design'. *Energy and Buildings* 49 (June): 2–15. https://doi.org/10.1016/j.enbuild.2012.01.028.

Augenbroe, Godfried. 2002. 'Trends in Building Simulation'. *Building and Environment* 37 (8–9): 891–902. https://doi.org/10.1016/S0360-1323(02)00041-0.

Bambardekar, Suhas, and Ute Poerschke. 2009. 'The Architect as Performer of Energy Simulation in the Early Design Stage.' *Proceedings of Building Simulation 2001: 1st Conference of International Building Performance Simulation Association, Glasgow, Scotland, July 27-30,2009*.

BIM Industry working group (BIWG). 2011. 'A Report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper, Available on-Line at Http://Www. Bimtaskgroup. Org/Wp-Content/Uploads/2012/03'. URN 11. Innovation and Skills. Department of Business.

Boton, Conrad, Sylvain Kubicki, and Gilles Halin. 2015. 'The Challenge of Level of Development in 4D/BIM Simulation Across AEC Project Lifecyle. A Case Study'. *Procedia Engineering* 123: 59–67. https://doi.org/10.1016/j.proeng.2015.10.058.

buidingSMART. 2020. 'Industry Foundation Classes 4.0.2.1 - Reference View 1.2'. BuildingSMART. https://standards.buildingsmart.org/MVD/RELEASE/IFC4/ADD2_TC1/RV1_2/HTML/.

Cadline. 2016. 'EDSL Guide for Revit GbXML Files'.

Cemesova, Alexandra, Christina J. Hopfe, and Robert S. Mcleod. 2015. 'PassivBIM: Enhancing Interoperability between BIM and Low Energy Design Software'.

Automation in Construction 57 (September): 17–32. https://doi.org/10.1016/j.autcon.2015.04.014.

Cheng, Jack C P, and Moumita Das. 2014. ‘A BIM-Based Web Service Framework for Green Building Energy Simulation and Code Checking’. *Journal of Information Technology in Construction* 19: 150–68.

Choi, Jungsik, Hansaem Kim, and Inhan Kim. 2015. ‘Open BIM-Based Quantity Take-off System for Schematic Estimation of Building Frame in Early Design Stage’. *Journal of Computational Design and Engineering* 2 (1): 16–25. https://doi.org/10.1016/j.jcde.2014.11.002.

Churcher, David, and Sarah Davidson, eds. 2019. ‘Information Management According to BS EN ISO 19650 - Guidance Part 1: Concepts’. UK BIM Alliance.

Clarke, J. A., and J. L. M. Hensen. 2015. ‘Integrated Building Performance Simulation: Progress, Prospects and Requirements’. *Building and Environment*, Fifty Year Anniversary for Building and Environment, 91 (September): 294–306. https://doi.org/10.1016/j.buildenv.2015.04.002.

Clayton, M, J. Haberl, W. Yan, S. Kota, F. Farias, W. Jeong, J. Kim, and J.L.B. Alcocer. 2013. ‘RP-1468 -- DEVELOPMENT OF A REFERENCE BUILDING INFORMATION MODEL (BIM) FOR THERMAL MODEL COMPLIANCE TESTING’.

‘Collaboration and Interoperability’. 2018. In *BIM Handbook*, by Rafael Sacks, Charles Eastman, Ghang Lee, and Paul Teicholz, 85–129. Hoboken, New Jersey: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119287568.ch3.

Computer Integrated Construction Research Group, PENN State University. 2019. ‘Project Execution Planning Guide’. https://www.bim.psu.edu/bim_pep_guide/.

Costa, G, and L Madrazo. 2015. ‘Connecting Building Component Catalogues with BIM Models Using Semantic Technologies: An Application for Precast Concrete Components’, 10.

Dong, B., K. P. Lam, Y. C. Huang, and G. M. Dobbs. 2007. ‘A Comparative Study of the IFC and GbXML Informational Infrastructures for Data Exchange in Computational Design Support Environments’. In *Proceedings: Building Simulation 2007*.

EBPD. 2010. ‘Directive 2010/31/EU of the European Parliament and the Council of 19 May 2010 on the Energy Performance of Buildings’. *Official Journal of the European Union*, 12–35.

‘Facilitators of BIM Adoption and Implementation’. 2018. In *BIM Handbook*, by Rafael Sacks, Charles Eastman, Ghang Lee, and Paul Teicholz, 2018th ed., 323–63. Hoboken, New Jersey: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119287568.ch8.

Garwood, Tom Lloyd, Ben Richard Hughes, Dominic O’Connor, John K. Calautit, Michael R. Oates, and Thomas Hodgson. 2018. ‘A Framework for Producing GbXML Building Geometry from Point Clouds for Accurate and Efficient Building Energy Modelling’. *Applied Energy* 224 (August): 527–37. https://doi.org/10.1016/j.apenergy.2018.04.046.

Giannakis, G I, K Katsigarakis, G N Lilis, and S Álvarez-Díaz. 2019. 'GUIDELINES for OptEEmAL BIM Input Files', 18.

Gigliarelli, E., F. Calcerano, M. Calvano, F. Ruperto, M. Sacco, and L. Cessari. 2017. 'Integrated Numerical Analysis and Building Information Modeling for Cultural Heritage'. In *Proceedings of 3rd IBPSA Italy Conference 8-11 February, BSA 2017, Bozen/Bolzano, Italy.* Bolzano.

Gigliarelli, E., F. Calcerano, F. D'Uffizi, C. Di Biccari, G. Mangialardi, and M. Campari. 2019. 'From Heritage BIM to BPS, a Computational Design-Based Interoperability Approach'. In *Building Simulation 2019, Rome*. Rome.

Gigliarelli, Elena, Filippo Calcerano, and Luciano Cessari. 2017. 'Heritage Bim, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit'. *Energy Procedia*, Climamed 2017 – Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area 12-13 May 2017 - Matera, Italy, 133 (October): 135–44. https://doi.org/10.1016/j.egypro.2017.09.379.

GSA. 2015. 'BIM Guide 05 Energy Performance'. U.S. General Services Administration.

Guruz, R., P. Katranuschkov, and R. J. Scherer. 2016. 'EeBIM LAB – TOWARDS A COHERENT GREEN BUILDING DESIGN PROCESS'. In *Proceedings of Central European Symposium on Building Physics CESBP 2016 / BauSIM*. https://www.researchgate.net/publication/310450225_eeBIM_LAB_-_TOWARDS_A_COHERENT_GREEN_BUILDING_DESIGN_PROCESS.

Guzmán Garcia, Elizabeth, and Zhenhua Zhu. 2015. 'Interoperability from Building Design to Building Energy Modeling'. *Journal of Building Engineering* 1 (March): 33–41. https://doi.org/10.1016/j.jobe.2015.03.001.

Ham, Youngjib, and Mani Golparvar-Fard. 2015a. 'Mapping Actual Thermal Properties to Building Elements in GbXML-Based BIM for Reliable Building Energy Performance Modeling'. *Automation in Construction* 49 (January): 214–24. https://doi.org/10.1016/j.autcon.2014.07.009.

———. 2015b. 'Mapping Actual Thermal Properties to Building Elements in GbXML-Based BIM for Reliable Building Energy Performance Modeling'. *Automation in Construction*, 30th ISARC Special Issue, 49 (January): 214–24. https://doi.org/10.1016/j.autcon.2014.07.009.

Hijazi, Mohammad, Karen Kensek, and Kyle Konis. 2015. 'Bridging the Gap: Supporting Data Transparency from BIM to BEM'. In *ARCC 2015 Conference – The FUTURE of Architectural Research (Chicago, IL)*, 8.

Hitchcock, R. J., and J. Wong. 2011. 'Transforming Ifc Architectural View Bims for Energy Simulation'. *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November*.

IBPSA. 2017. 'IBPSA Project 1 - BIM/GIS and Modelica Framework for Building and Community Energy System Design and Operation'. 2022 2017. https://ibpsa.github.io/project1/index.html.

ISO 19650-1. 2018. *ISO 19650-1:2018 Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information*

Modelling (BIM) — Information Management Using Building Information Modelling — Part 1: Concepts and Principles.

Jayasena, Himal Suranga, and Chitra Weddikkara. 2013. 'ASSESSING THE BIM MATURITY IN A BIM INFANT INDUSTRY'. *Sri Lanka*, 8.

Jeong, WoonSeong, Jong Bum Kim, Mark J. Clayton, Jeff S. Haberl, and Wei Yan. 2014. 'Translating Building Information Modeling to Building Energy Modeling Using Model View Definition'. *The Scientific World Journal* 2014. https://doi.org/10.1155/2014/638276.

Kamel, Ehsan, and Ali M. Memari. 2019. 'Review of BIM's Application in Energy Simulation: Tools, Issues, and Solutions'. *Automation in Construction* 97 (January): 164–80. https://doi.org/10.1016/j.autcon.2018.11.008.

Karlapudi, Janakiram. 2018. 'A Methodology to Classify and Determine Data Sharing Requirements between OpenBIM Models and Energy Simulation Models'. In , 112.

Kralsson, I. T., and C. Rönndahl. 2018. 'A Study of National BIM Guidelines from around the World Determining What Future Swedish National BIM Guidelines Ought to Contain'. Bachelor Thesis, Jönköping University - School of Engineering. https://bimalliance.se/library/4352/isak-karlsson-christoffer-roenndahl.pdf.

Lam, K. P., O. Karaguzel, R. Zhang, and J. Zhao. 2012. 'Identification and Analysis of Interoperability Gaps between Nbims/Open Standards and Building Performance Simulation Tools'. Task 2.2.12 – CMU Report 02: Center for Building Performance and Diagnostics. http://www.andrew.cmu.edu/user/okaraguz/TechnicalWritingSamples/Interoperability_Identification.pdf.

Lechner, Norbert. 1991. *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*. Hoboken, N.J.: John Wiley & Sons.

Liebich, T., K. Stuhlmacher, P. Katranuschkov, R. Guruz, N. Nisbet, J. Kaiser, B. Hensel, R. Zellner, T. Laine, and M.-C. Geißler. 2011. 'HESMOS Deliverable D2.1: BIM Enhancement Specification',. http://e2b.ectp.org/fileadmin/user_upload/documents/E2B/HESMOS/HESMOS_WP02_D02_1__Final.pdf.

Liu, Sha, Meng Xianhai, and Tam Chiming. 2015. 'Building Information Modeling Based Building Design Optimization for Sustainability'. *Energy and Buildings* 105: 139–53. https://doi.org/10.1016/j.enbuild.2015.06.037.

Maile, T., J. O'Donnell, V. Bazjanac, and C. Rose. 2013. 'BIM-Geometry Modelling Guidelines for Building Energy Performance Simulation'. *Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28*.

Moon, Hyeun Jun, Min Seok Choi, Sa Kyum Kim, and Seung Ho Ryu. 2011. 'Case Studies for the Evaluation of Interoperability between a BIM Based Architectural Model and Building Performance Analysis Programs'. In *Proceedings of 12th Conference of International Building Performance Simulation Association*, 12:p326-328.

Morbitzer, C. 2003. 'Towards the Integration of Simulation in the Building Design Process'. Strathclyde: PHD thesis, Energy System Research Unit, University of Strathcylde.

NBS. 2014. 'NBS National BIM Report 2014'. https://www.thenbs.com/knowledge/nbs-national-bim-report-2014.

———. 2015. 'NBS National BIM Report 2015'. https://www.thenbs.com/knowledge/nbs-national-bim-report-2015.

Pinheiro, Sergio, J Donnell, Reinhard Wimmer, Vladimir Bazjanac, S Muhic, Tobias Maile, Jérôme Frisch, and Christoph Treeck. 2016. 'Model View Definition for Advanced Building Energy Performance Simulation'. In .

Rahmani Asl, Mohammad, Saied Zarrinmehr, Michael Bergin, and Wei Yan. 2015. 'BPOpt: A Framework for BIM-Based Performance Optimization'. *Energy and Buildings* 108 (December): 401–12. https://doi.org/10.1016/j.enbuild.2015.09.011.

Ryan, Emily M., and Thomas F. Sanquist. 2012. 'Validation of Building Energy Modeling Tools under Idealized and Realistic Conditions'. *Energy and Buildings* 47 (April): 375–82. https://doi.org/10.1016/j.enbuild.2011.12.020.

Sacks, Rafael, Charles Eastman, Ghang Lee, and Paul Teicholz. 2018. 'Introduction'. In *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*, Third Edition, 1–31. John Wiley & Sons.

Senave, M., and S. Boeykens. 2015. 'Link between BIM and Energy Simulation'. *WIT Transactions on The Built Environment, Vol 149, © 2015 WIT Press*. https://doi.org/10.2495/BIM150291.

Succar, Bilal. 2009. 'Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders'. *Automation in Construction*, 357–75. https://doi.org/0.1016/j.autcon.2008.10.003.

Tchouanguem Djuedja, Justine Flore, Mohamed Hedi Karray, Bernard Kamsu Foguem, Camille Magniont, and Fonbeyin Henry Abanda. 2019. 'Interoperability Challenges in Building Information Modelling (BIM)'. In *Enterprise Interoperability VIII*, edited by Keith Popplewell, Klaus-Dieter Thoben, Thomas Knothe, and Raúl Poler, 9:275–82. Proceedings of the I-ESA Conferences. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-13693-2_23.

Weise, M., T. Liebich, R. See, V. Bazjanac, T Laine, and B. Welle. 2011. 'Implementation Guide: Space Boundaries for Energy Analysis'.

Wilkins, Chris, and Arto Kiviniemi. 2008. 'Engineering-Centric BIM'. *ASHRAE Journal December 2008*.

ANNEX 8.10: FEASIBILITY STUDY INTEROPERABILITY OF DIFFERENT SOFTWARE USED FOR THE SIMULATION

1 GENERAL INTRODUCTION

This deliverable is part of the BEEP Project WP4, Energy rehabilitation design scenarios within the EE-HBIM approach, and describes the feasibility study performed by the consortium on the interoperability between a BIM approach and the software chosen for dynamic simulation of the energy improvement scenarios BEEP case studies.

1.1 Framework of the tools used by the consortium and their integration

Each partner has chosen both the BIM and simulation software on the basis of a series of considerations depending for the BIM software:

- on the context of the country also from the regulatory point of view,
- on the skills within the partnership or of the consultants employed
- on the dissemination of these tools.

For the dynamic simulation software:

- on the context of the country also from the regulatory point of view,
- on the skills within the partnership or of the consultants employed
- to embed in the project progressive levels of complexity in the tools used for energy simulation

Here is a brief summary of the tools used by each partner:

Partner	**BIM authoring tool**	**Dynamic simulation software**	**Exchange file format**
BEN – ISPC CNR	Graphisoft ArchiCAD	Logicalsoft Thermolog	IFC
PP1 – MASI			
PP2 – IVE	Autodesk Revit	Cypertherm He Plus	IFC
PP3 – CyI-EEWRC	Autodesk Revit	DesignBuilder	gbXML
PP5 – CCHP			
PP6 – LCEC			
PP7 – E-JUST			
PP4 - NERC	Graphisoft ArchiCAD	TRNSYS	IFC

1.2 Description of Tools used

1.2.1 BIM Authoring Tools

Autodesk Revit

Autodesk Revit is a multidisciplinary Building Information Modelling software for Architects, engineers, contractors, asset management, manufacturers and other AEC industry professionals. The software enables the creation of 3D objects and the subsequent recording/registration of their alphanumerical property characteristics, depending on the model use. Revit is capable to track various stages in the building's lifecycle, from concept to construction up to the stage of maintenance and management. Modelling in Revit follows a parametric associative design logic enabling in this way a clear modelling process with errors/warnings tracking notifications.

The first version of Revit was launched on April 2000 and today it is considered as one of the most popular design software worldwide. Revit is only available for Windows computers and since 2016, it is only available in 64-bit version.

Autodesk's BIM 360 for Revit enables multidisciplinary teams to co-author a central Revit model in the cloud using granular access permissions.

Graphisoft ArchiCAD

ArchiCAD is a professional Building Information Modelling (BIM) software by Graphisoft, complying with common digital-delivery requirements, offering an intuitive design environment, accurate building information management, open collaboration and automated documentation. Combining ease of use with advanced modelling capabilities, it can integrate architecture processes from the initial concept and sketch to documentation, detail and construction.

After its launch in 1987, ArchiCAD became one of the first commercial BIM software specific for architecture-engineering-construction (AEC) industry. It works on two platforms: macOS and Windows.

While it is a standalone software, it is integrated with specific cloud solutions for team working. It has stressed the optimization of open format exporting, especially .IFC, for collaboration among different stakeholders.

1.2.2 Dynamic Simulation software

Cypertherm He Plus

CYPETHERM EPlus and CYPETHERM HE Plus are tools for energy modelling and simulation of buildings with EnergyPlus™. They are integrated into the Open BIM workflow through the BIMserver.center platform, which allows the import of BIM models (IFC4 and IFC2x4), generated by CAD/BIM programs such as IFC Builder. CYPETHERM EPlus is mainly used to determine the energy performance of HVAC systems through the energy consumption per system and energy vector used. CYPETHERM HE Plus is a free application designed for the justification of the regulations limiting energy demand in Spain and a tool recognized by the Government of Spain for the calculation of the energy performance certification. CYPE is a Spanish developer and marketer of technical software for Architecture, Engineering and Construction professionals.

Design Builder (GUI) and Energy Plus (engine)

DesignBuilder is a front-end platform for EnergyPlus simulation engine. Models either imported from BIM or built within DesignBuilder provide fully-integrated performance analysis including: energy and comfort, HVAC, daylighting (Radiance engine), multi-objective optimisation tools for advanced cost-benefit analysis, Computational Fluid Dynamics (SIMPLER algorithm), and reports complying with several national building regulations and certification standards (e.g. BREEAM/LEED). Additional available reports are uncertainty analysis and sensitivity analysis. A large number of occupancy, lighting, HVAC templates and material libraries are available for the user.

Logicalsoft Thermolog

Termolog is a software by Logicalsoft for the numerical analysis of energy and environmental performance of a building. The Termolog simulation engine (developed in collaboration with Politecnico di Milano) runs the hourly dynamic analysis according to the procedure set out in the UNI EN ISO 52016: 2018 standard to perform the hourly energy balance and the response of the building to the climate and internal condition of use. The software includes an archive of materials and the climatic data of all the Italian municipalities and is able to import the data of any location in the world. The dynamic calculation of Termolog allows to obtain: hourly value of the indoor air temperature, of the indoor operating temperature, of the mean radiant temperature; sensible and latent thermal load per hour for heating and cooling; sensible and latent energy needs; thermohygrometric conditions of the inlet air to ensure the necessary humidification or dehumidification.

TRNSYS

TRNSYS is a software environment for the simulation of transient systems (systems whose behaviour is dependent on the passage of time) available for more than 40 years. Although it is mainly used for energy analysis, the software is also suitable for modeling other dynamic systems such as traffic flows and biological processes.

TRNSYS consists of two parts, the calculation engine and the component library. The standard library includes about 150 models (multizone buildings, HVAC equipment, meteorological data) that can be modified by the user. The software structure is modular: the user specifies the components that make up the system and the way in which they are connected.

2 Methodology and description of the experimentation performed

2.1 Project Methodology

The present feasibility study utilises a methodological workflow of experimental development and qualitative research. A series of BIM model sample exports has been carried out and subsequently investigated in the respective BPS software for examining the nature and reversibility of the occurred errors, i.e., geometric model inconsistencies, gbXML schema limitations, data conversion issues, data redundancy, etc. Each of the interoperability test is analysed and recorded, both in terms of the accuracy and adequacy of their geometrical and alphanumerical attributes. Therefore, the logic for selecting each successive test model was based on the purposive sampling for avoiding previously experienced error-prone BIM model settings or export configurations. The selected methodology pursues to secure a clear understanding of the BIM to BPS exchange capabilities in the current stage of BIM model development.

2.2 Description of the experimentation performed

The feasibility study experimentation uses the BIM models developed for the BEEP project (pilot building). BEN and PP1 were involved in the experimentation using Graphisoft Archicad (BIM) and Logitalsoft Thermolog (BPS) software. PP3 and PP7 were involved in the experimentation using Autodesk Revit (BIM) and DesignBuilder (BPS) software.

3 ARCHICAD TO TERMOLOG WORKFLOW

This chapter describe a best modelling practice to address the data flow from the BIM Environment of Graphisoft Archicad to the BPS environment of Logicalsoft Termolog and is the results of the tests performed to develop the model of Palazzo Maffei-Borghese (Clementino) described in par 3.7. This Chapter is divided into paragraph according to the steps needed for the data flow from the BIM to the BPS environment. The document is designed to provide a concise indication of what to do at each point of the index, leaving the explanation of the proposed solution to the notes. This way the document can be consulted quickly during modelling operation or studied in-depth.

3.1 Data mapping and construction of a shared knowledge framework among experts involved;

The modelling activities should start from data gathered according to a specific protocol that allows both BIM and BPS modelling to go smoothly. This process is described in the BEEP guideline, at Chapter 2.4 and 2.4.5 specifically. To start the process, a series of meetings among the experts involved to create a shared knowledge framework is suggested and this document can represent the outline of the points to be discussed together.

3.1.1 Data definition and mapping, planning of the tests

This first step of the process require the collection of the data necessary for the entire energy audit workflow, and subsequently, starting from the software chosen for the simulations, a first definition and mapping of the input data for the simulation. The task should be performed by conservation expert, BIM experts and BPS experts to check the correspondence between data needed by the energy software and data to be inputted in the BIM software. This data mapping process should closely follow the indication of the BEP and of the Model Element Table if present. In this phase tests should also be performed to check the feasibility of the process as developed in the Italian case study experience (*§* 3.7).

3.2 Graphisoft ArchiCAD Model preparation

This paragraph describes the best modelling practices on the BIM environment end using the software Graphisoft Archicad.

3.2.1 Elements that can be imported into Termolog

The main elements that Termolog imports from an IFC file are as follows[1]:

IfcElement	Element in Termolog
ifcWall/ifcWallStandardCase	Walls (Pareti)

1

ifcSlab	Floors, ceilings, Roofs (Pavimenti, soffitti, coperture)
ifcRoof	Roofs (Coperture)
ifcWindow	Glasses (Finestre)
ifcDoor	Doors (Porte)
ifcSpace	Room (Locali)

Termolog can import also levels (that however in Archicad are managed differently and must be remodelled in Termolog in case of complex buildings with slabs at different heights) and obstructions, moreover if a complex element e.g. a window with its whole decoration and architectural aedicule is assigned the ifcWindows ifcElement it will not be imported in Termolog. For all the elements that should be filtered during the export-import process, the ifcProxy element can be assigned to all archicad objects that we don't want to be imported in Termolog

3.2.2 Elements that are not imported in Termolog

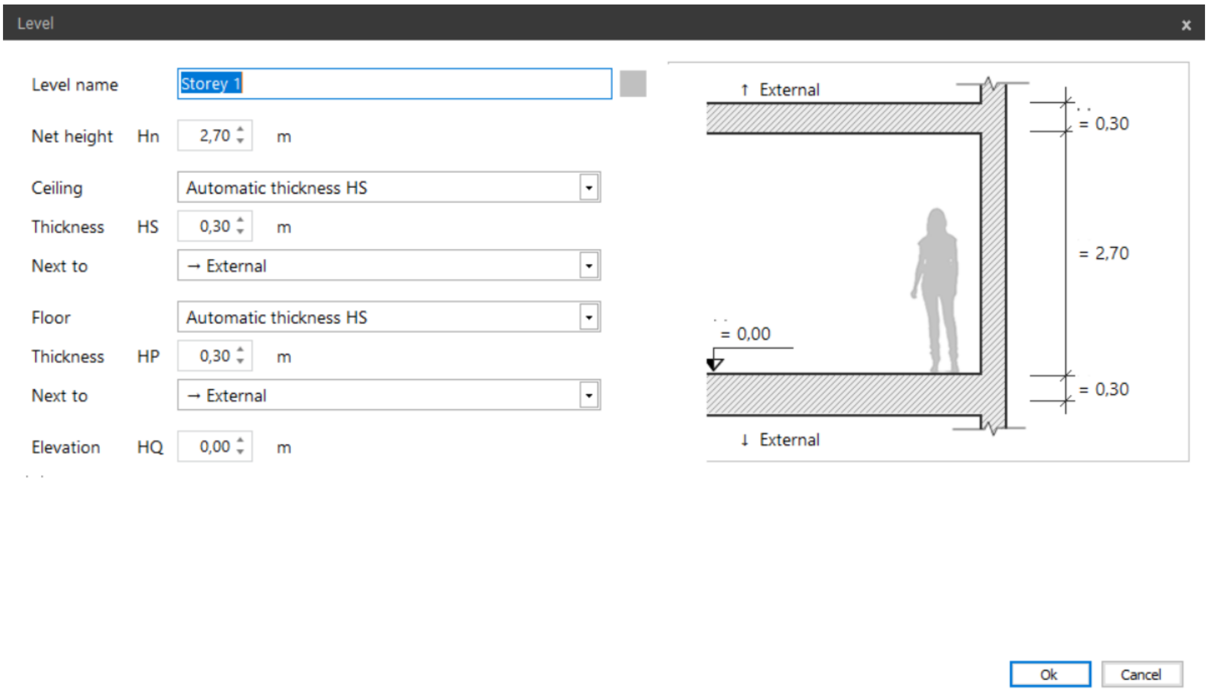
The elements that will not be included in the import into Termolog are:

1) Elements that have no role in the energy calculation carried out by Termolog:
   - Stairs
   - Railings
   - Pillars (represented in Termolog by thermal bridges)
   - Beams (represented in Termolog by thermal bridges)
2) Elements modeled with special tools in Archicad which, although required in the Termolog model, would not be recognized once imported:
   - Mesh
   - Shapes
   - Shell
   - GDL objects

   These objects if possible should be modeled with other tools even if this would require simplifications of their geometry..
3) Elements for which Termolog does not foresee a geometric modeling but a tabular data entry:
   - systems

3.2.3 Levels

The image shows the pop-up with which Termolog allows the definition of level parameters.



The following table shows the parameters that in Termolog define the geometry of the layers and how they are read from the imported IFC file

TERMOLOG PARAMETERS	ARCHICAD PARAMETERS	IMPORTED VALUES
Level Height HQ (Quota livello HQ)	Elevation (Elevazione)	The value is always imported correctly*
Ceiling thickness HS (Spessore soffitto HS)		The value of the thickness of the ceiling associated with that level or of the floor associated with the upper level is entered**
Spessore pavimento HP		Viene inserito il valore il valore dello spessore del pavimento associato a quel piano. **
Altezza netta		HQ Piano superiore - HQ Piano considerato - HS Piano considerato

* Within the importing process, Termolog has set the "Free plan dimensions (Quote dei piani liberi)" option by default. This means that the heights of the different floors will not be linked to each other by the measure that in Archicad is given by the “Difference (Dislivello)” parameter (which in Termolog corresponds to HQ + HS).

**In the automatic recognition of these values during import, there may be errors due for example to an incorrect assignment of the structure to the imported slabs or the presence of floors of different thickness on the same floor. Furthermore, Termolog provides two methods for filling in the thickness of the floors:

1. HS / HP thickness from user value (Spessore HS/HP da valore utente)
2. Automatic HS / HP thickness (Spessore HS/HP automatica)

When importing, Termolog sets the first option as default. The second option, which provides for automatic recognition of the thickness of the slabs of that floor, has the advantage of allowing an automatic update of the value of this field in the event of a modification of the slab structure. This option is recommended unless there are special cases such as the presence of two floors of different thickness on the same floor (see section 3.6.1B).

A. Level selection

It is advisable to create the levels foreseen by the Architectural BIM model in Archicad.

NOTE
Termolog requires additional levels to handle special situations such as different floor heights (see section 3.6.1A and 3.6.1B). Although an Archicad model that has already correctly set all the plans required by Termolog would guarantee a much better result in importing the latter, this setting would go against the logic with which Archicad uses the levels within the model organization.

B. Level elevation

It is advisable to set the elevation of the floors to the finished floor level, in order to have consistency with the setting of the level heigths in Thermolog (which for Termolog area always finished floor level).

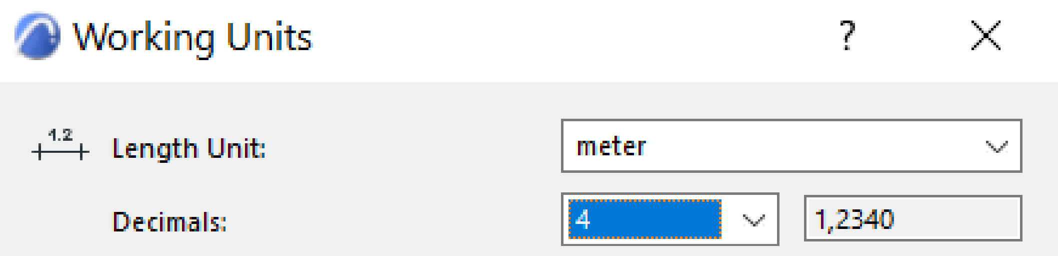
3.2.4 Composite structure and materials

3.2.4.1 Graphic design

A. Layer thickness of the structures

The thickness of the layers is defined/hypothesized for the energy analysis.

Before setting the thickness of the layers of the composite structures, it is necessary to make the measurements readable to the tenth of a millimeter. For example, if working in meters, in the "work units (unità di lavoro)" tab, set 4 decimal digits in the "unit of measure (unità di misura)" field. In this way you can be sure of the data entered in Archicad and that imported into Termolog.



NOTE

It is important to check the thicknesses of the layers of the Archicad structures up to the tenth of a millimeter because both Termolog and Archicad foresee that level of detail. The risk is that, working in Archicad in meters and not displaying all four decimals, non-zero values of tenths of a millimeter present in the default Archicad layers used as a basis for modeling new structures are transferred from one software to another (for example in plaster layers).

3.2.4.2 Properties

A. Material name

The material name must be the same as that of the materials used in Termolog, preferably giving information on the real material (Plaster, Gypsum, Tuff, Concrete) to facilitate the matching of the materials during import into Termolog and to maintain consistency of the coding between the two environments.

B. Material properties

The material properties entered will only be those required by the architectural BIM model (thus excluding any other thermophysical properties required by the energy analyses).

3.2.5 Walls

A. Walls structures (strutture delle pareti) that Termolog imports from an IFC file

Within Termolog the name of the structures of the imported IfcWall elements is assigned automatically and corresponds to the Archicad name of the structure (compound or base) followed by the thickness of the structure in mm (e.g. “402 sack wall”). This means that for wall elements created in Archicad with the same structure but different value of the "Position (posizione)" parameter, Thermolog will import just one structure, thus not taking into account the different values of the "Position" parameter.

For example, in the case of historical load-bearing masonry present both as external and internal masonry, it is recommended to create two different distinct structures for a probable different thickness of one of the layers of plaster (in this way also Termolog will directly create two structures with different names and different “position” parameters).

3.2.5.2 Graphic design

A. Walls height

Excluding special cases, the walls must be connected to the floor immediately above the host one, for example avoiding walls that extend over several floors or walls with the al grezzo"upper link (collegamento superior)" parameter set to "not connected (non collegato".

B. Offset walls with respect to the home and upper floors (Offset muri rispetto piano ospite e piano superior)

The offsets of the walls to the host floor(piano ospite) and the connected upper floor (piano superiore collegato) will have to be set as required by the architectural BIM model.

NOTE
In section 3.2.3B it is recommended to set the Archicad floors(piani) at the height level of the finished floor. However, this choice is not linked to that concerning the definition of the base and upper level of the walls, which depending on the case could for example also refer to the level of the rustic height level of the floor or its intrados.

NOTE
In a note of section 3.2.3A it was mentioned how in the presence of height differences along a floor of the building it is preferable not to create two distinct floors in Archicad but a single floor with respect to which a part of the building will be "offset". The walls of this part of the building will therefore have offsets with respect to the home floor and the upper floor. Care must therefore be taken in setting these offsets to ensure that the base and the top of all the "staggered" walls are actually at the required heights (for example, the finished or rustic "staggered" floors).

C. Reference line – external face (Linea di riferimento – faccia esterna)

In all walls (not just the external ones) it is advisable to always keep the “reference line” parameter set to “external face”.

NOTE
The walls imported from Termolog maintain the position they have in Archicad but their reference line, while maintaining the same length, is sometimes placed on a face of the wall other than that one set in Archicad (nevertheless never inside the structure).

This modification does not affect the value of the dispersing area of the wall (the length of the wall being correctly imported) but having the same positioning of the reference line both in Archicad and Termolog can help in the verification of the imported geometries and facilitate the operation of the Termolog command which allows you to create a room by clicking on any of its internal points. Termolog seems to keep the position of the reference line if this is set in Archicad at the external face of the wall.

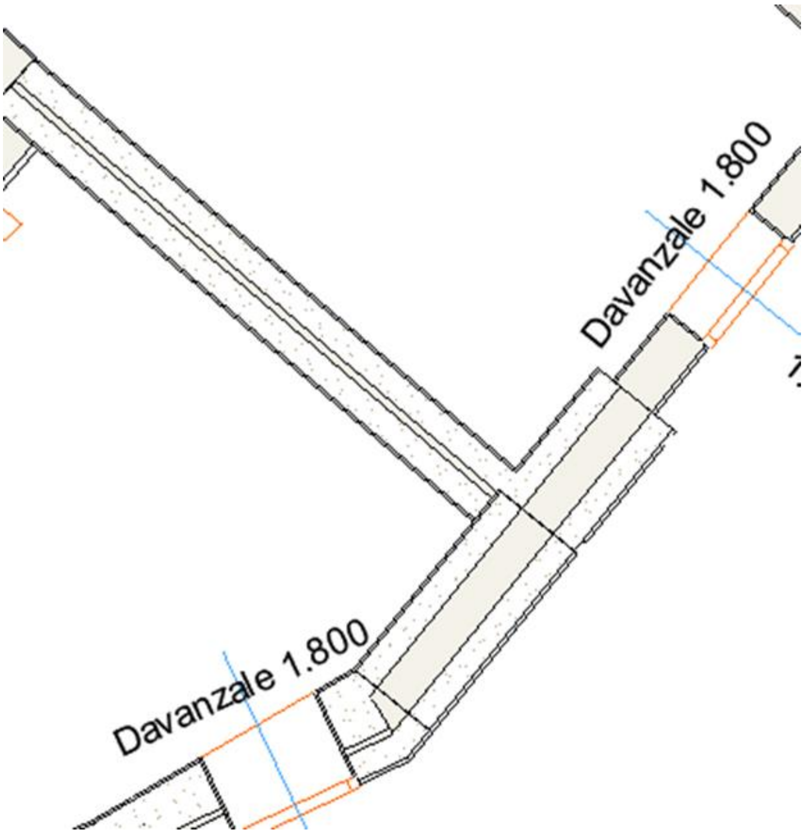
D. Reference line – wall intersection (Linea di riferimento – intersezione tra i muri)

At the junctions between two or more walls, connect reference lines whenever possible.

NOTE
In Termolog the correct junction of the walls is important for several aspects such as the length assigned to each wall (avoiding, for example, overlapping of external walls) and the correct perimeter of the rooms. If in Archicad the reference lines are connected at the junctions between different walls, it is easier for Termolog to import correctly the model.

E. Juction between external wall and internal wall

In correspondence of the junction between an internal wall and an external wall it would be preferable for the latter to be continuous and not broken into two elements as in the following figure.



NOTE
As described in section 3.5.3A, when importing the IFC file into Termolog we will use the option "Break overlapping walls (spezza le pareti in corrispondenza di sovrapposizioni)" which, in the case of insertions between internal and external walls, breaks the latter into two distinct walls in order to assign to each room the part of the external wall that delimits it. If in Archicad the external wall is already broken at the joint, it is likely that during the import phase in Termolog it will be further broken in another point, creating a small part of the external wall that risks not being assigned to any room.

F. Non-constant thickness walls

For the modeling of the walls it is advisable to use the "Straight(Dritto)" option as "Geometry Method (Metodo Geometria)" in order to create flat walls of constant thickness unless this involves geometric approximations incompatible with the intended use of the architectural BIM model. In case of irregular walls, the use of non-costant thickness walls (Trapezoid option in Geometry Method) should be evaluated on a case-by-case basis.

NOTE

The preference for using the "Straight (Dritto)" option derives from the fact that the variable thickness walls present in an IFC file are imported into Termolog with the wrong geometry and must therefore be eliminated and remodelled. Therefore, in the case of historic buildings with many walls of irregular thickness (in plan or section), before starting the modeling it would be advisable to establish the right compromise between the level of accuracy that the architectural BIM model requires for modeling the geometry of the walls, and the additional work required in the energy software for verification and correction of the imported model.

G. Building parts not taken into account for the energy analyses

If the requirements of the architectural BIM model require it, it is advisable to model the unheated areas and those heated by another system (for example, apartments in the analysed building not subject to analysis).

If the stratigraphies of the walls of these areas had not been detected, create structures that have:

1. Base structure (Struttura base)
2. Thicknesses surveyed or compatible with known neighboring walls
3. External appearance surveyed

NOTE
Dynamic calculation according to ISO 52016 does not require the modeling of neighboring areas not heated or heated by another system. However, the architectural BIM model often requires an even simplified modeling of these areas.

3.2.5.3 Properties

A. Property "Position (Posizione)

The "Position (Posizione)" parameter must be filled in according to the meaning it has in Archicad, that is, to indicate whether the element is internal or external, without worrying about the direction of dispersion it will assume in Thermolog.

NOTE
In Archicad the "Position (Posizione)" property refers to the IFC IsExternal property. This property is available for various elements (walls, floors, roofs, doors, windows, acc.) And is used to indicate whether the element is external or not. Termolog uses the value of the IsExternal property of the elements imported from an IFC file to compile the value of the "direction of dispersion" of the element according to the scheme shown in the following table:

Position (Posizione) Archicad	IsExternal (IFC)	Direction (Verso) Termolog[2]
External (Esterno)	True	External (Esterno)
Internal (Interno)	False	Room inside the zone (Locale interno alla zona)
Undefined (Non definito)		Room inside the zone (Locale interno alla zona)

It should also be noted that if several different positions are associated with the same Archicad structure, when importing it, Termolog will create only one considering only one of the detectable dispersion directions (thus combining all the others, § 3.2.5A).
Since this IFC parameter is not designed to indicate the direction of dispersion, it does not represent all the possible directions of dispersion of the structures envisaged by Termolog.
For this reason it will in any case be necessary to check and correct the direction of dispersion of the structures imported into Termolog, creating a dedicated structure for each combination of wall stratigraphy and dispersion directions.

3.2.6 Slab

3.2.6.1 Graphic design

A. Profile of the slab

The profile of the floor must be traced as required by the architectural BIM model.

B. Balcony

In Archicad the balconies will be modeled according to the Architectural BIM model (so it will probably be a different element from the floor slab, if only for the fact that it has a different finish than the internal flooring).

NOTE
For the energy calculation, the balconies must be considered only as shading elements, while the floors to which they are connected will be included in the calculation of the thermal capacity and possibly of the dispersions of the rooms they delimit. Therefore it would be useful for exporting to a generic energy analysis software, to separate the balcony from the rest of the floor to prevent the first from being computed in the area of the second. Termolog automatically manages to exclude from the calculations the floor surfaces that do not delimit the rooms, therefore the balconies will still be considered correctly only for their behavior as a shading element, both if modeled in continuity with the rest of the floor and if made as a separate element.

[2] Currently the English version of Thermolog do not have a translation for the Direction of the dispersion values, therefore the translation in English was made by the authors

C. False Ceilings

- Model the ceilings as a separate element from the slab.
- Classify suspended false ceilings as ifcCovering
- Enter a " false ceiling height" parameter in an abacus of the rooms which reports the value of the distance between the intrados of the slab and the intrados of the ceiling to facilitate data input in Termolog.

NOTE
For rooms with a closed false ceiling, Termolog requires to input the "Hc False ceiling height (Hc Altezza controsoffitto)" present in the room data sheet, which requires the value of the distance between the intrados of the false ceiling and the intrados of the floor. Graphic modelling of the false ceilings is not foreseen by Termolog.

NOTE
It is advisable to also associate graphic drawings (false ceiling plans) with the abacus in order to facilitate the work of the energy modellers. The use of plans and any sections of the rooms is also useful in cases of false ceiling with variable height within the same room (for example lower on the sides and higher in the center), in which the energy modeler energy is called to define a fictitious average height representative of the real volume.

D. Internal vaults

For vaults that separate internal rooms (and therefore do not fall within the calculation of the dispersions), follow the instructions below:

- Model the vaults as an element separated from the floor (both if they are separated by a void or if they are a single continuous construction element)
- Classify the vaults as ifcCovering
- Report the following two parameters referring to any vaults present in a room schedule:
    - Keystone vault thickness: distance between the intrados of the keystone and the level of the finished slab above.
    - Thickness of vault on the springer plane: distance between the springer of the vault and the level of the finished slab.
- If compatible with the modeling work required for the architectural BIM model, create any graphic drawings that can support the energy modeler to understand the geometry of the vaults (for example, schematic sections of the vaults that indicate the respective room).

NOTE
Termolog does not allow the modelling of curved geometries. When importing the Ifc file, only the floors without the vaults will be imported. The energy modeler will eventually have to modify the stratigraphy of the floor so that it takes into account the thermal capacity of the entire ceiling-vault system. Furthermore, in the event of a gap between the vault and the floor, the “Hc False ceiling height” parameter must be filled in the room sheet in order to take into account the real volume subtracted from the vault to the room.

E. E. Vaults with the dispersing intrados towards the outside (for example on arcades), vaults and complex roofing shapes (domes) dispersing towards the outside

In Archicad the vaults will be modeled according to the Architectural BIM model, and classified as ifcCovering in order to be filtered upon export to Termolog. In Termolog the vaults will then be remodelled case by case in an attempt to represent their thermal behavior with the right degree of approximation.

3.2.6.2 Properties

A. Property "Position(Posizione)"

The "Position (Posizione)" parameter must be filled in according to the meaning it has in Archicad, that is, whether the element is internal or external, without worrying about the direction of dispersion it will assume in Termolog.

3.2.7 Roofing

3.2.7.1 Graphic design

A. General indications

The roofs must be modelled as foreseen by the architectural BIM model (preferably with Archicad slab(Solaio) and roof(Falda).

3.2.7.2 Properties

A. Position "Properties"

The "Position (Posizione)" parameter must be filled in according to the meaning it has in Archicad, that is, whether the element is internal or external, without worrying about the direction of dispersion it will assume in Termolog.

B. Archicad classification

The elements of the roofs will be assigned to the Archicad class required by the architectural BIM model.

NOTE
Termolog sometimes has problems importing geometries classified as IfcRoof elements, so it is preferable to assign roofing elements to the IfcSlab category. This classification can be obtained through the IFC translator settings indicated in this guide, allowing the possible assignment of roofing elements to the Archicad "Roof(Tetto)" class.

3.2.8 Windows

A. Types windows that Termolog imports from an IFC file

Do not assign the same Archicad ID to windows with different sizes.

NOTE
Termolog considers as different "types" of window frames that have any difference in one or more of the following aspects:

1. Frame: the characteristics to be taken into account are both geometric (shown in the table below) and non-geometric (materials, number of air chambers, thermal insulation).
2. Glass: number and treatment of layers, thickness, thermophysical characteristics.
3. Shading: Type, material, color, air permeability, hourly use profile.
4. Window box(Cassonetto): Presence or not, dimensions (width and height as indicated in the following table) stratigraphy of the wall section with the window box.
5. Sub-window(Sottofinestra): Presence or not of the sub-window, dimensions (width and height as indicated in the following table) stratigraphy of the wall section of the sub-window.
6. Direction of dispersion.

However, when importing an IFC, Termolog automatically generates different types of doors and windows only if they have different size of the cutout, and therefore there is a risk of combining two types that should remain separate (for example, same width and height of the cutout but different frame material). To these types, Termolog will assign the Archicad ID of the first window encountered during the importing process as a name. If several windows have different dimensions of the cutout but the same Archicad ID, Termolog will create only one type of window structure with that name and will assign it to the corresponding window while it will not assign any window structure to the others.

ID – Archicad	Name – IFC	Windows name (Nome Serramento) - Termolog

3.2.8.2 Graphic modelling

Termolog will only import the width and height of the cutout of the geometry of the windows present in an IFC file, and its position with respect to the wall that hosts it (these parameters will in any case have to be checked in Thermolog due to the simplification that the program brings to the imported cutout).

To simplify the geometric modeling of fixtures that for some reason have not been imported into Termolog, it is advisable, together with the IFC file, to extract simplified plans from the Archicad model in which the labels of the fixtures, doors and the coding of the rooms are legible .

A. Schedules and drawings

Create a schedule (and / or graphic drawings) in Archicad with the geometric parameters of the doors and windows required by Termolog (indicated in the following table) that can support their subsequent input in the energy model. In this case it is important to insert the values of these parameters in Archicad with an adequate precision (indicatively with errors lower than one cm) for subsequent energy calculations.

TERMOLOG PARAMETERS	ARCHICAD PARAMETERS	DESCRIPTION
Floor Height H (Altezza H da terra)	Sill to story 0 (Davanzale dal piano)	Dimension of the lower side of the fixed frame with respect to the base of the wall that hosts the frame.
Frame Width (Larghezza)	Window dimension -> Width (Dim. Infisso --> Larghezza)	Window width (with respect to the external sides of the fixed frame)
Height (altezza)	Window dimension -> Height (Dim. Infisso --> Altezza) – Transom – lower transom	Window height (with respect to the external sides of the fixed frame) less the height of lower and upper transom if present
Frame thickness (Spessore trasversale)	Frame thickness (Spessore Telaio)	Fixed frame thickness
Frame thickness (Spessore trasversale)	Sash frame thickness (Spess. Telaio Battente)	Mobile frame thickness
Top (Telaio superiore)	(Upper frame width + Sash frame width + Rebate width) (Larg. Telaio Sup. + Larg. Telaio Battente - Larg. Incavo)	Width of the upper side of the frame **
Bottom (Telaio inferiore)	Bottom frame width + Sash frame width + Rebate width (Larg. Telaio Inf. + Larg. Telaio Battente - Larg. Incavo)	Width of the lower side of the frame **

Left (Telaio lato sx)	Frame width side 2 + Sash frame width + Rebate width (Larg. Telaio Lato 2 + Larg. Telaio Battente - Larg. Incavo)	Width of the left side of frame**
Right (Telaio lato dx)	Frame width + Sash frame width + Rebate width (Larg. Telaio + Larg. Telaio Battente - Larg. Incavo)	Width of the right side of the frame **
N° horizontal (Div. orizzontali numero)		Number of horizontal dividing elements (spacing)***
Thickness (Div. orizzontali spessore)	Division width (Larg. Divisione)	Average thickness of horizontal dividing elements (spacing)***
N° vertical (Div. verticali numero)		Number of vertical dividing elements (spacing)***
Thickness (Div. verticali spessore)	Mullion Width (Larg. Traversine)	Average thickness of vertical dividing elements (spacing)***
Transom window shape (Sopraluce forma)		If an upper transom is present, one of the following shapes must be indicated: rectangle, triangle, semicircle.
Transom window height (Sopraluce Altezza)	Window dimension height – Height of Up Horizontal division - (Upper frame width/2) (Dim. Infisso Altezza - Alt. Divisioni Sup. Oriz. - (Larg. Telaio Sup./2))	Dimension including the height of the upper transom mirror and the height of the upper frame.
Opaque (Sopraluce Opaco)		Indicate if the upper transom is an opaque element (yes / no)
Lower transom height (Sottoluce Altezza)	Height of Lower Horiz. Division – (Lower Frame width/2) (Alt. Divisioni Inf. Oriz. -	Dimension including the height of the lower transom and the height of the lower frame.

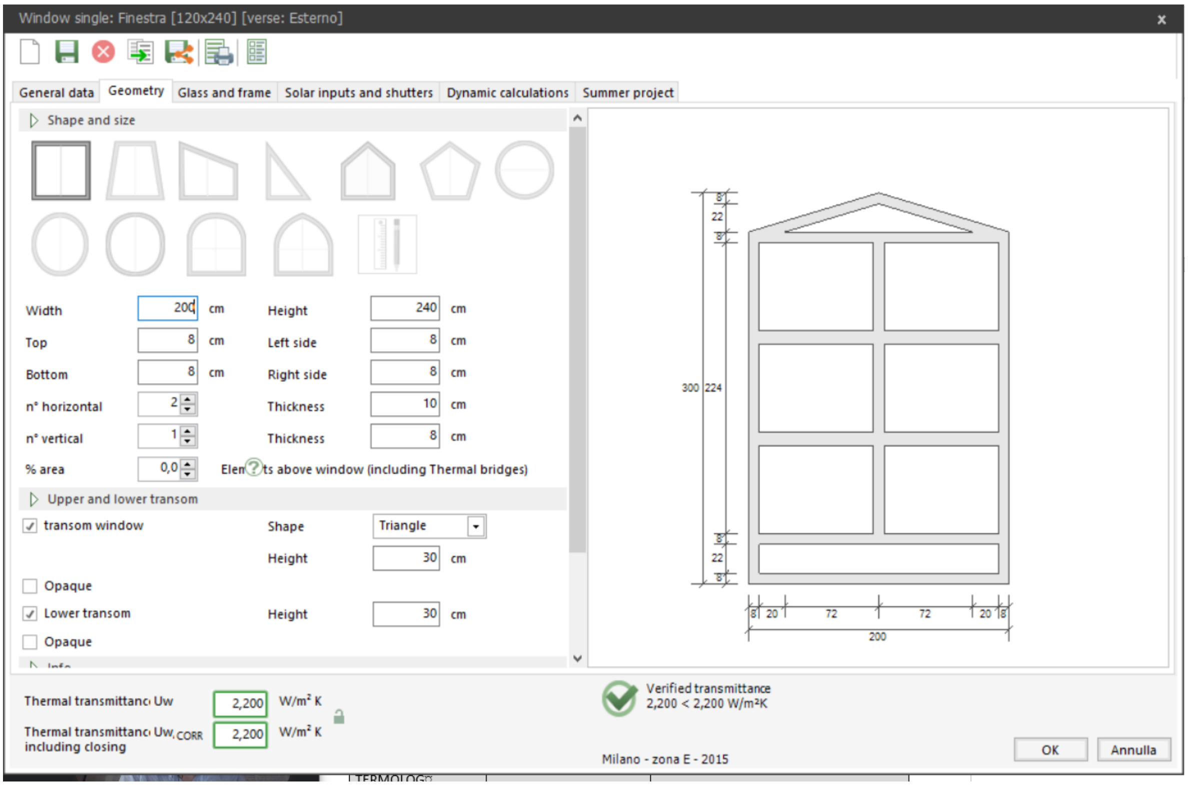
	(Larg. Telaio Inf./2))	
Opaque (Sottoluce Opaco)		Indicate if the lower transom is an opaque element (yes / no)
Box Width	Wallhole width + Box offset left + Box offset Right (Larg. Foro Muro + Offset SX Cassonetto + Offset DX Cassonetto)	Width of the window box
Box height	Box Height (Alt. Cassonetto)	Height of the window box
Wall inset width	Width of wall Inset (Larg. Nicchia)	Width of the windowsill
Wall inset height	Height of wall Inset (Alt. Nicchia)	Height of the windowsill

* In Termolog there is only one parameter for the thickness of the window that indicates an average between the thickness of the fixed and mobile frame. In Archicad there is a parameter for the thickness of the fixed frame and one for the thickness of the mobile frame.

** By frame we mean the structure including fixed frame and mobile frame.

*** Both the door shutter and the spacing between two panels are considered dividing elements.

The picture shows the input data sheet of Termolog



B. Wallhole dimensions (Apertura muro) Parameters

Set the wallhole dimensions (Apertura muro) parameters as required by the Archictural BIM Model.

NOTE

In Termolog the geometry of the cutout will always be generated as a simple extrusion of the external profile of the window frame.

C. Elements inside the window system

Elements that are modelled in Archicad within the window tool (such as platbands, sills, benches, frames, shading) even if exported to IFC will not be imported into Termolog, as the software does not provide for a graphic modelling. The modelling of these elements in Archicad can therefore freely follow the provisions of the architectural BIM model.

D. External elements attributable to the window system

If other elements referable to a window are modeled in Archicad, they will not be assigned to one of the IFC classes that can be imported in Termolog (such as IfcWall or IfcWindow). For example, it is advisable to classify the decorative system of an aedicula as IfcProxy.

3.2.8.3 Properties

A. "Position (Posizione)" Property

The "Position (Posizione)" parameter must be filled in according to the meaning it has in Archicad, that is to indicate whether the element is internal or external, without worrying about the direction of dispersion it will assume in Termolog.

B. Window thermal transmittance

The thermal transmittance of the window is a property that can be imported into Termolog. However, if its value is not known, it is advisable to carry out its calculation directly in Termolog (facilitating the process of manual data entry in Termolog by creating a specific abacus in Archicad § 3.2.8.2A) in order to maintain trace of this operation and to facilitate any subsequent changes. If, on the other hand, this value is provided by a product data sheet, it is possible to evaluate the advisability of inserting it directly into Archicad.

C. Other non geometric properties

Any other non-geometric properties entered will only be those required by the architectural BIM model (thus excluding any other thermophysical properties required by the energy analyses).

3.2.9 Doors

Do not assign the same Archicad ID to doors with different dimensions. For the doors it is advisable to follow the same indications relating to the windows regarding ID and cutout (width and height of the door) in order to export the elements and then import them into Termolog where they will then be refined in terms of thermophysical properties by type.

3.2.10 Zones

3.2.10.1 Graphical design

A. General indications

The zones in Archicad must be modeled as required by the architectural BIM model.

3.2.10.2 Properties

Termolog will not import the properties of the Archicad zones, it is therefore advisable to enter these parameters as required by the architectural BIM model.

3.2.11 Shading elements

3.2.11.1 Graphical Design

A. Context – surrounding buildings

For subsequent energy analyses in Termolog, the modelling of the external envelope of the surrounding buildings is required with the use of walls, floors and pitches in order to simulate the shading effects of the surrounding context on the building.

Walls of the surrounding buildings:

- It is preferable that the walls are not divided between one floor and another but that they extend over the entire height of the building. The choice of the guest floor is irrelevant (you can choose the most suitable one and if necessary assign an offset) while for buildings with several floors it is necessary to set "Upper connection (collegamento superiore)" to "Not Connected (non collegato)".
- Since the stratigraphy of the context walls is not relevant for energy analyses, a basic structure can be used rather than a composite one. It is preferable to give the structure a name that indicates its use for context buildings.
- These walls must also be modeled by setting the reference line on the “external face (faccia esterna)” (section 3.2.5.2C) and using the “straight(dritto)” one as the “geometry method(metodo di geometria)” (section 3.2.5.2F).
- Modeling of internal walls is not required for energy analysis purposes. On the contrary, parapets and other elements that can generate shadow on the studied building should be modeled.

Roofing of the surrounding buildings:

- The roofs of the surrounding buildings will be modeled like those of the building to be analysed.
- Since roof stratigraphy is not relevant for energy analyses, a basic structure can be used rather than a composite one. It is preferable to give the structure a name that indicates its use for context buildings.

NOTE
Modeling of other elements such as windows, intermediate floors or rooms is not required. While any modeling of the first two categories of elements would not create problems for the imported model, the premises could generate errors in the calculations if not deleted after importing into Termolog.

NOTE
As for the roofs of the building analysed, by setting the translator correctly, the roofs of the surrounding buildings will be translated into ifcSlab, keeping their correct height also in Termolog.

3.3 Export towards IFC file format

Termolog imports both IFC2x3 and IFC4 schema files.

In Archicad it is possible to export in IFC model from File Menu> Save As.

When selecting “IFC file” in “Save as” tab, in addition to the file name, it is possible to set which elements to export in “Export(Esporta)” and the translator to use in “Translator(Traduttore)”.

The "Export" field can be used as follows:

•select “Entire project” to export all the elements of the project;

• select "Visible elements (on all floors) to export only the currently selected elements.

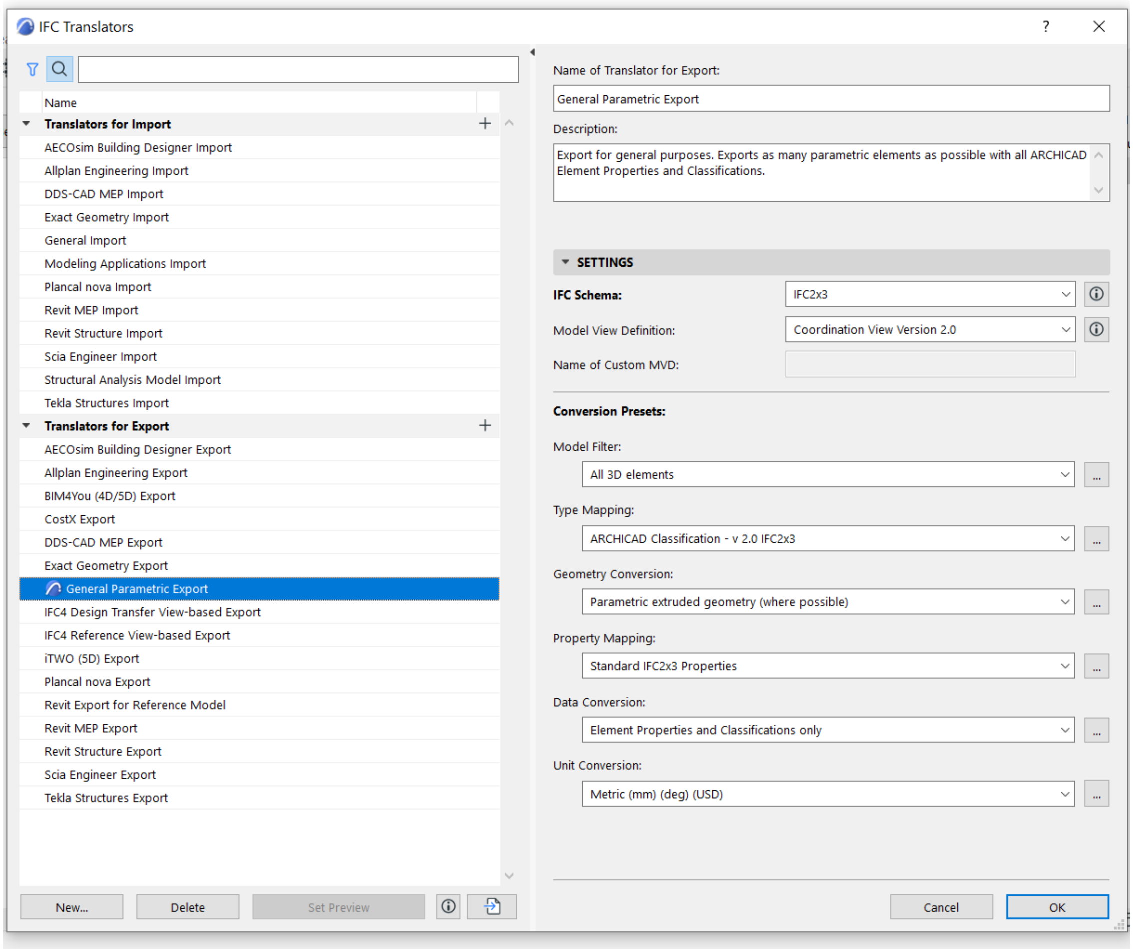
If necessary, further filters can be added in the "Model Filter for Export" window.

In the "Translator" field, the specific translators from those in the "IFC Translators" window can be selected. The translators will be discussed in section , which we will discuss in section 3.3.1. The chosen translator will indicate the IFC scheme, the MVD and all the other settings that will be used in the export phase.

3.3.1 <u>Translator settings</u>

In Archicad you can check the configurations of the pre-set translators or create your own from the “IFC Translators” window, which can be accessed from the File menu, then Interoperability> IFC> IFC Translators.

To set up a new translator for data transfer in Termolog, it is recommended to start from the "General Parametric Export" translator configuration, one of the export translators already present in Archicad. This translator uses the IFC2x3 schema with the MVD (Model View Definition) “Coordination View 2.0”.



Here are some tips on setting up the translator for Termolog starting from the "General Parametric Export(Esportazione Parametrica Generale) configuration.

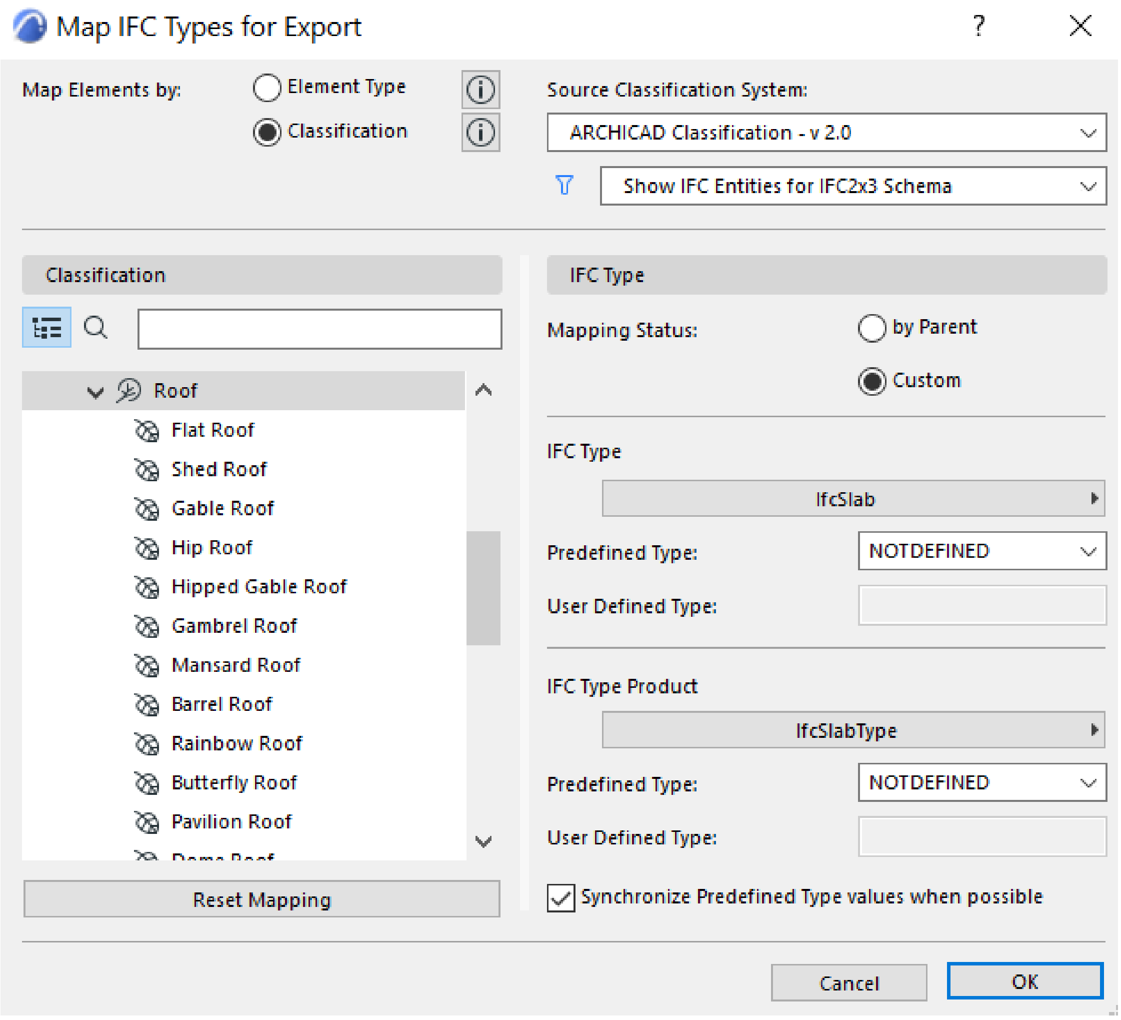
3.3.1.1 Type mapping

Within the settings “Type Mapping”, click on “Map IFC Types for Export”. Then set “Map Elements by”: “Classification”. Then it is recommended to enter the following settings for the "Roof" class:

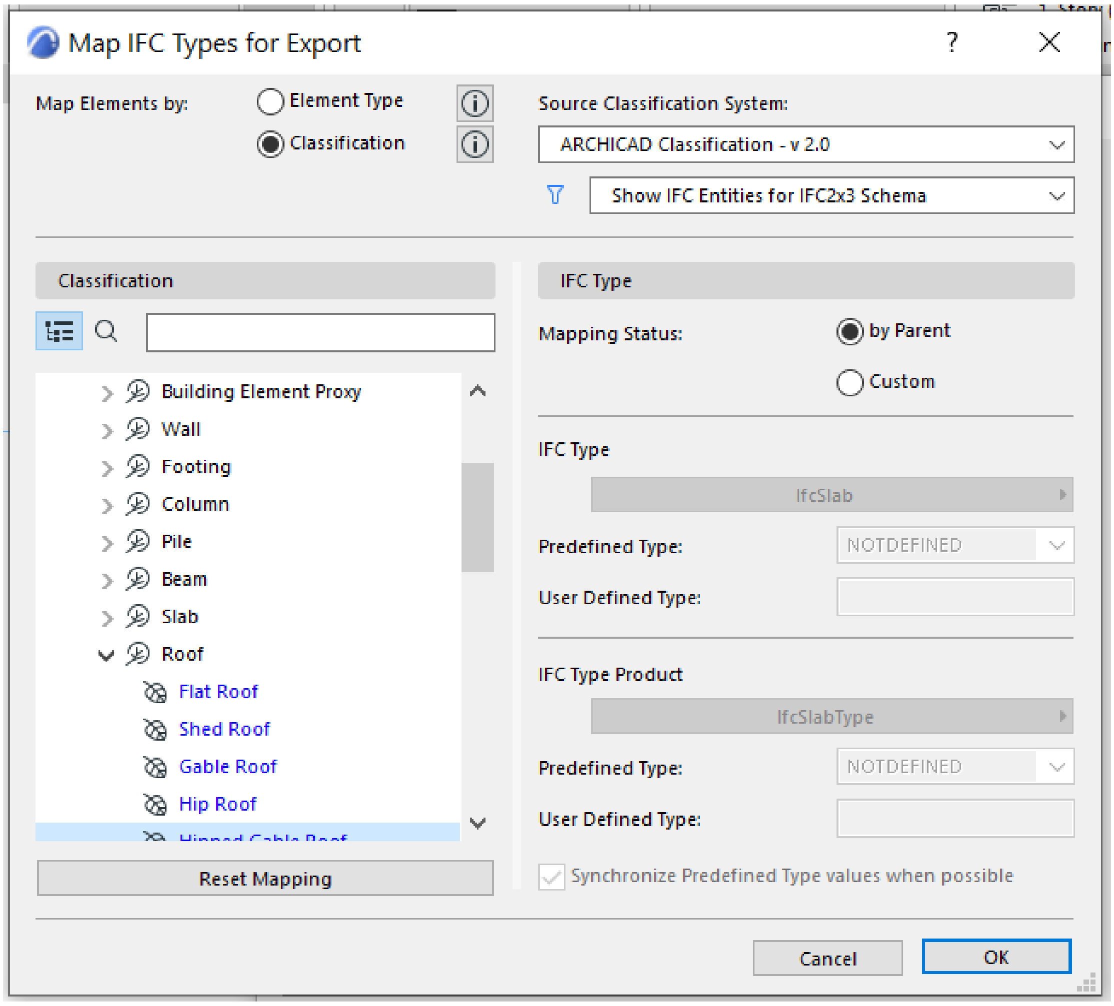
• Mapping status: Custom

• IFC type: ifcSlab

• Predefined Type: The setting is not relevant for the purpose of importing the IFC into Thermolog.



For all “Roof” subclasses, set "by Parent" as the "Mapping Status". So that the subclasses set this way should be highlighted in blue.



NOTE

As mentioned in section 3.2.7.2B, Termolog sometimes has problems importing geometries of ifcRoof classification. The mapping just described allows you to assign the Archicad class "Roof", or one of its subclasses, to a roofing element, but to export it to ifc as ifcSlab.

3.4 Check of the exported file

For a first check of the exported IFC file, it is recommended to use an IFC viewer capable of allowing an analysis of the file created by the BIM software even before importing it into the BPS environment and therefore before any import operation can modify the created information.

As software we recommend an IFC (and gbXML) viewer that has dedicated features for energy analysis. In this case, Logicalsoft's free software was chosen, called Logical BIM viewer, which, compared to a normal IFC viewer, allows direct access to some specific parameters of energy analysis through clear and tidy preset tab.

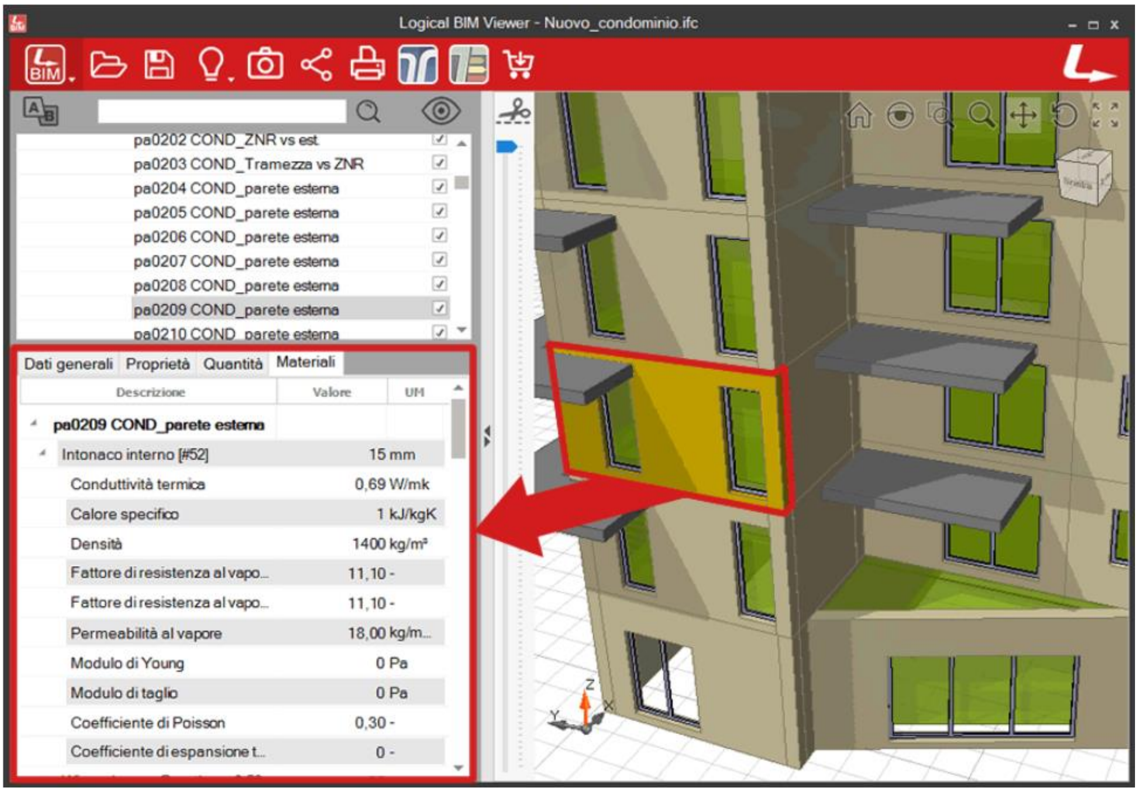


Figure 1: Logicalsoft, Logical BIM viewer

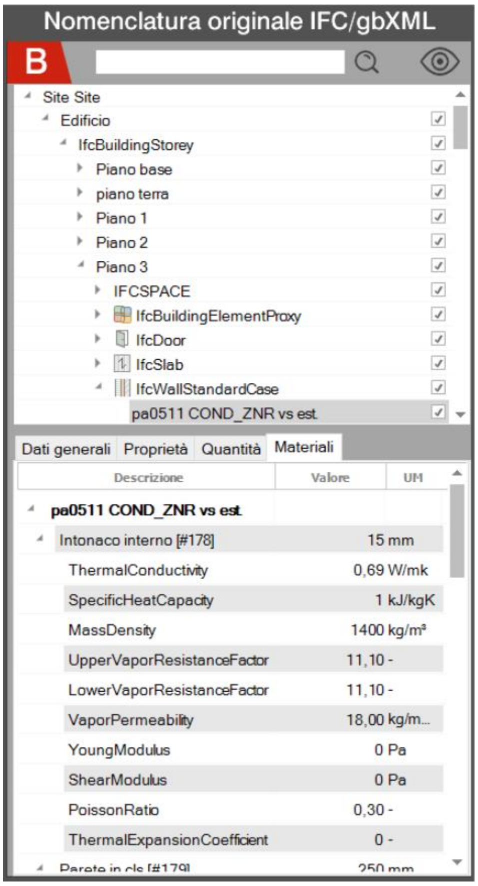


Figure 2: Logical BIM Viewer example of elements classification and property schedule

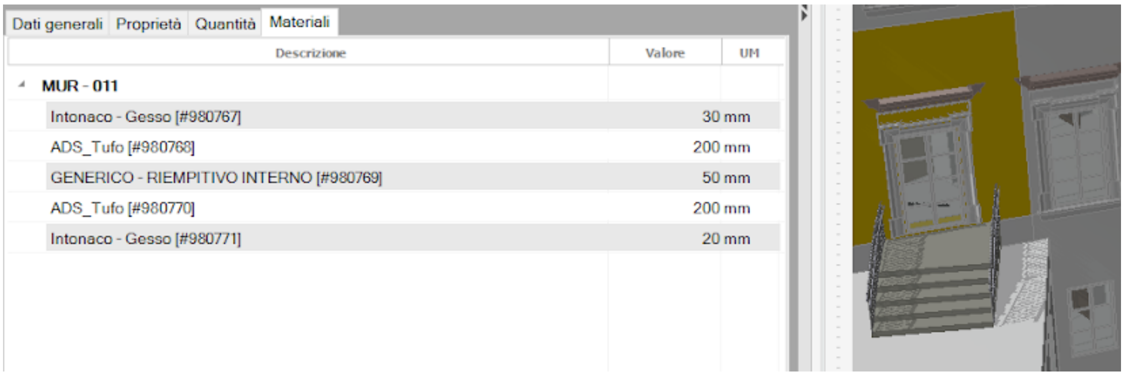
This interface allows a quick check on the IFC file exported by Archicad, of the energy parameters, along with an immediate understanding of which are the parameters that will be recognised by Termolog for import.

3.4.1 <u>Walls</u>

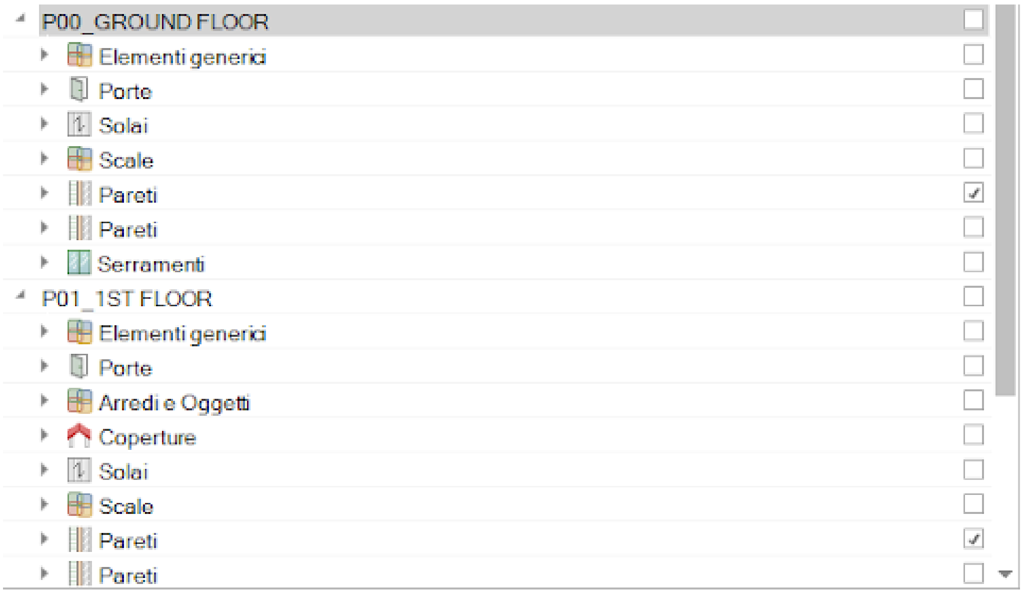
A. Walls with irregular thicnkess

The walls modelled in Archicad with a non-constant thickness, if exported to IFC following the indications of this guide, should have a correct 3D geometry representation (as modeled in Archicad) but should lose the information on the wall stratigraphy.

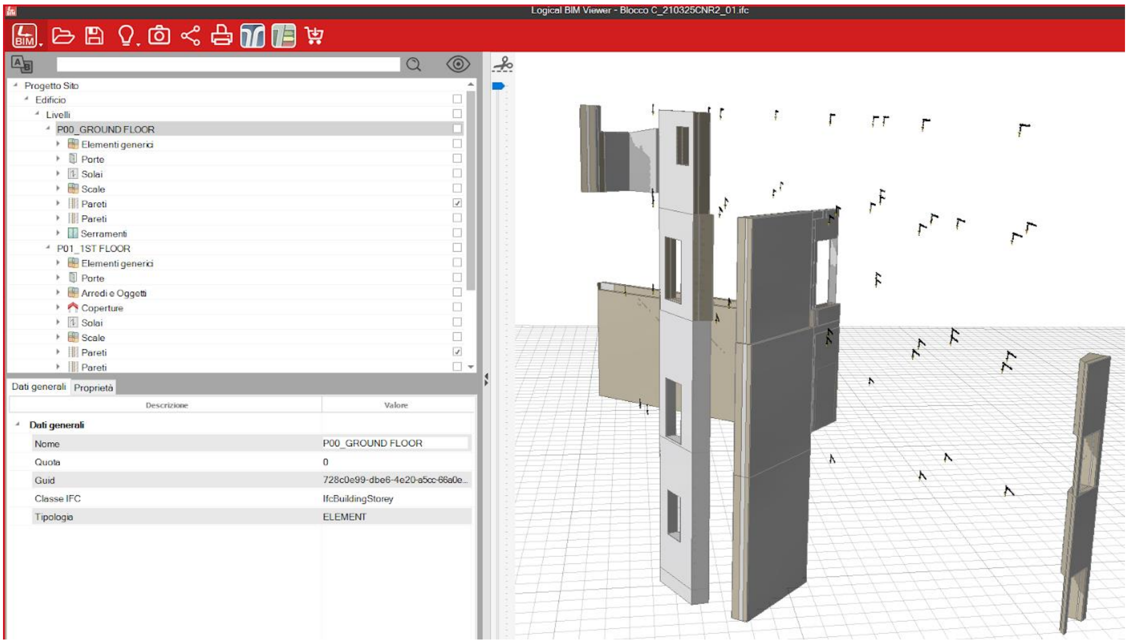
The first figure shows the correct display of layers and materials for wall with constant thickness; the second figure shows instead the wall with irregular thickness (non-parallel faces) for which the viewer does not indicate layers and materials.

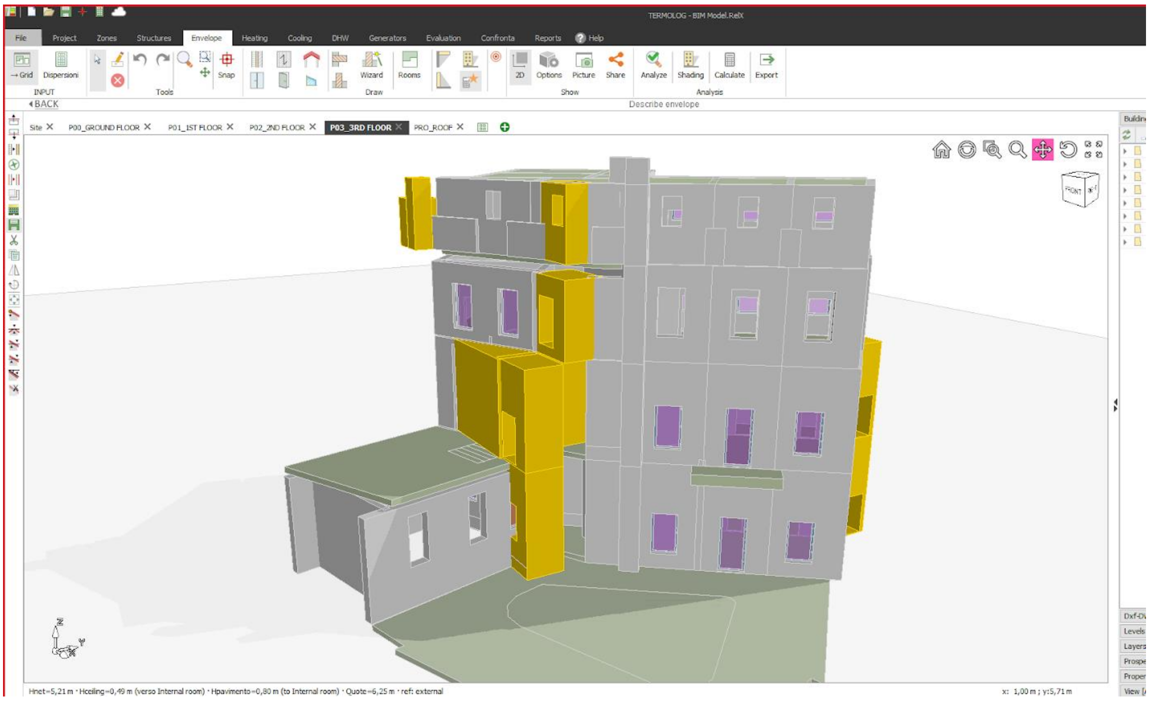


The LogicalBIMviewer viewer classifies these irregular walls into a specially created wall category. The following figure shows how each floor hosting these irregular walls has two categories of walls: the "standard" wall category and the one created for irregular walls that facilitates their identification.



The following images show the irregular walls as they appear in the ifc file (set in the viewer as the only visible elements of the model) and how they are modified after importing into Termolog (elements highlighted in yellow).

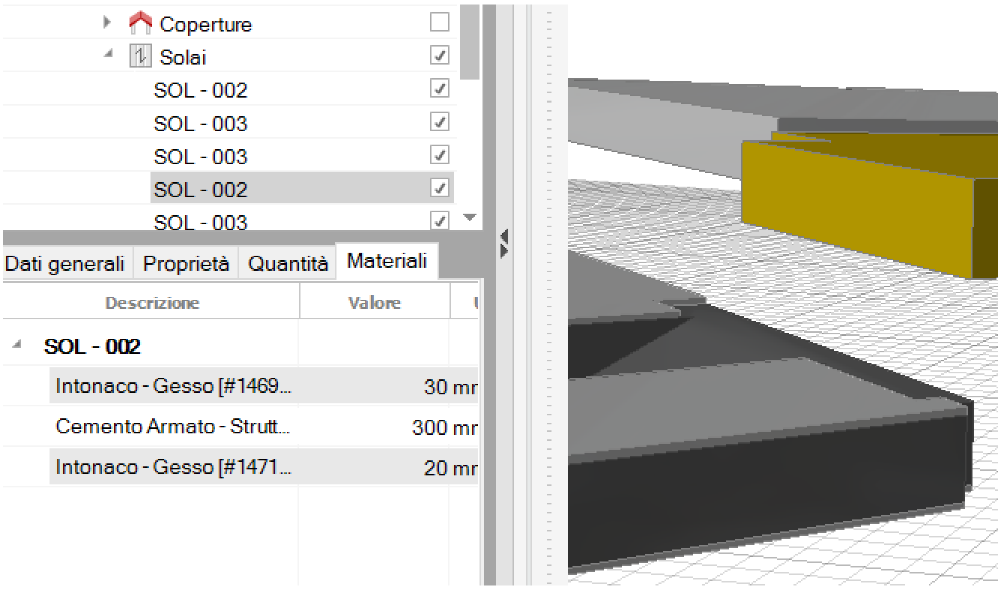




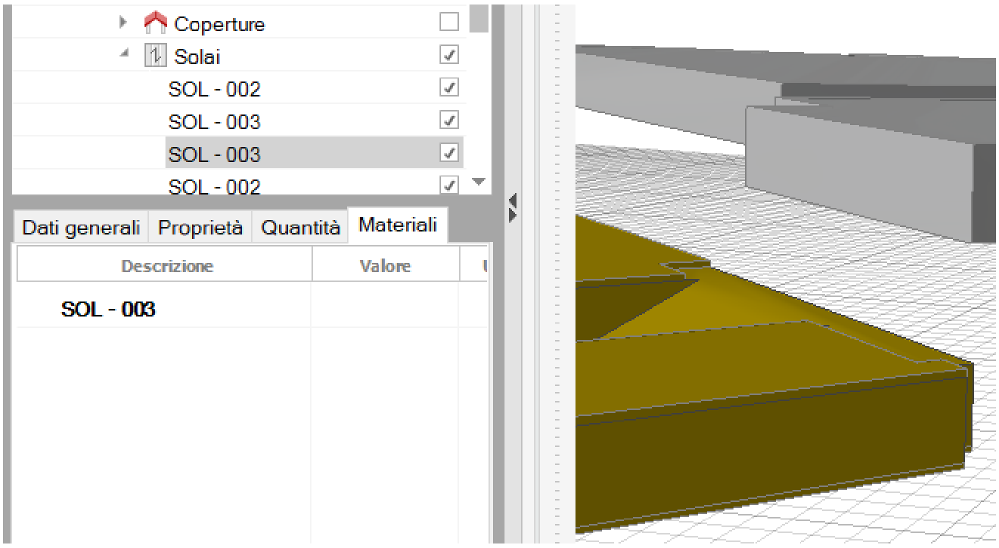
3.4.2 <u>Slabs</u>

A. Information on stratigraphy exported to the IFC

The slabs exported to IFC following the instructions of this guide, should keep information on the materials of the layers and their thickness in the dedicated sheet, and be displayed in LogicalBIMviewer as a single component, similar to the floor highlighted in yellow in the image below.



In some cases, however, the exported floors may not report the information on the materials of the layers and their thickness in the dedicated tab and, on the contrary, display these layers in the 3D element shown in the viewer, similarly to the floor highlighted in yellow in the image below.



Each of these floors will not be imported into Termolog as a single floor element but will generate as many floor elements as there are layers. In addition, each of these floors will have no associated structure.

3.5 IFC import in Logicalsoft Termolog

3.5.1 Before importing the file

A. Insert project materials in the Termolog archive

During the import phase, the materials of the IFC file assigned to the layers of walls, floors, roofs and doors must be replaced with homonymous material previously entered in the Termolog archive. These can be created as new materials or from materials already in the archive using the duplicate command. In both cases these materials will be automatically placed in the "User Materials(Materiali Utente)" directory.

B. Reference (Filo di riferimento)

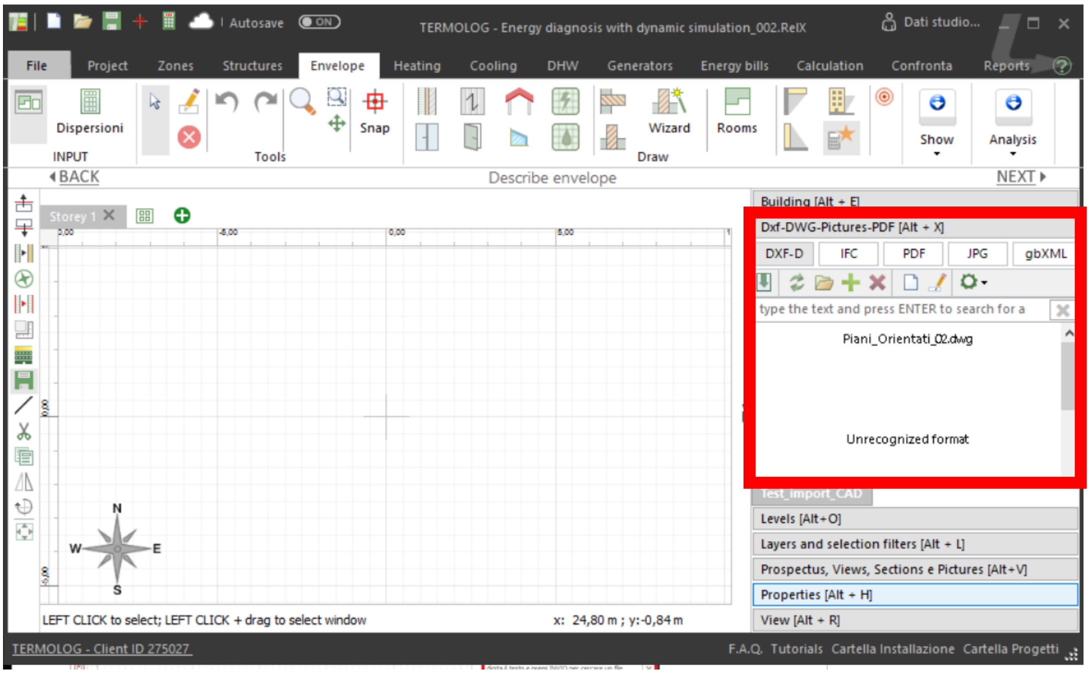
Within the Project menu (first tab) within the settings sub-tabset “Reference” to “External(Esterno)”.

C. Zone definition

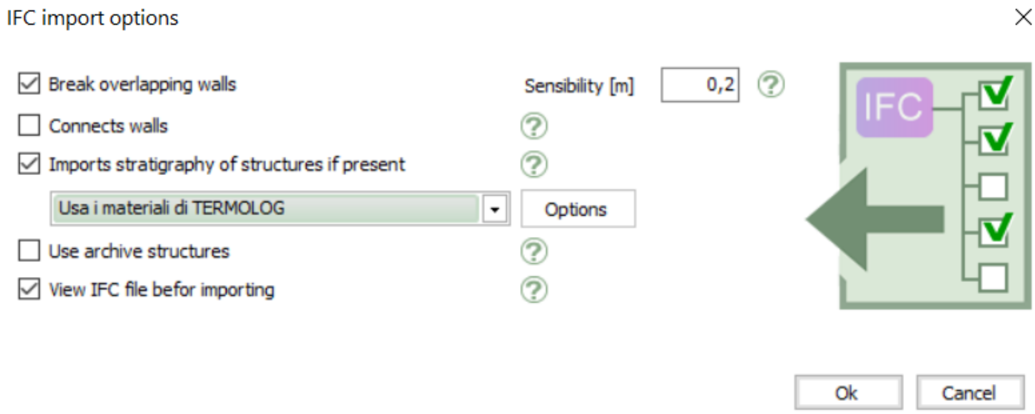
Before importing the IFC file, it is possible to create the air-conditioned zones in the appropriate TERMOLOG menu, to which the rooms designed in the BIM model will be associated during the import phase.

3.5.2 Import procedure

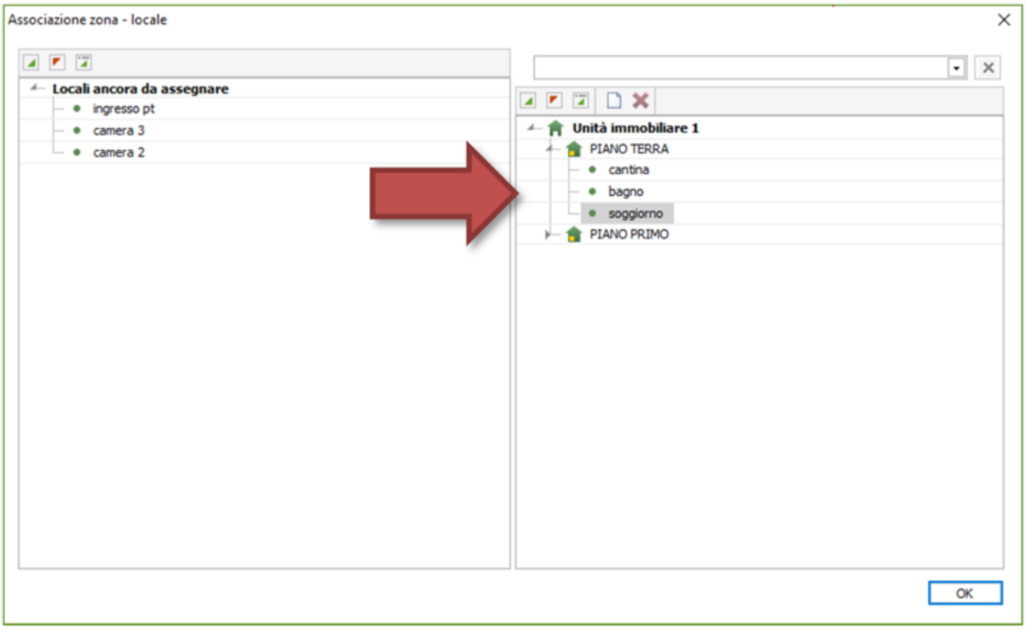
1. Access the graphical input of the Envelope menu and in the Import Panel (Dxf-DWG-Picture-PDF (Alt + x) view the folder containing the IFC file to import. Drag the file to the screen.



2. Select the import options (see section 3.5.3).



3. Associate the rooms created in the BIM model to the zones created in TERMOLOG by dragging the elements from left to right..
   NOTE
   If only one air-conditioned zone has been created, all the rooms in the IFC file will be automatically assigned to that zone, therefore the dialog screen for the association of rooms-zones will not appear..



In the figure PIANO TERRA (Ground floor) is a thermal zone created in TERMOLOG to which the cellar, bathroom and living room imported from IFC have been associated.

NOTE
If the same IFC file or files containing the same elements are imported again, TERMOLOG automatically associates the structures already modified and saved.

The association is made by name, it is therefore necessary to keep the same name for the elements to be reused in other imports.

3.5.3 Import options

Non selezionando alcuna Opzione TERMOLOG importerà solo la geometria dell'involucro presente all'interno del file IFC, lasciando all'utente l'associazione successiva delle strutture disperdenti agli elementi geometrici importati.

In alternativa è possibile selezionare le seguenti Opzioni di Importazione:

A. Break overlapping walls

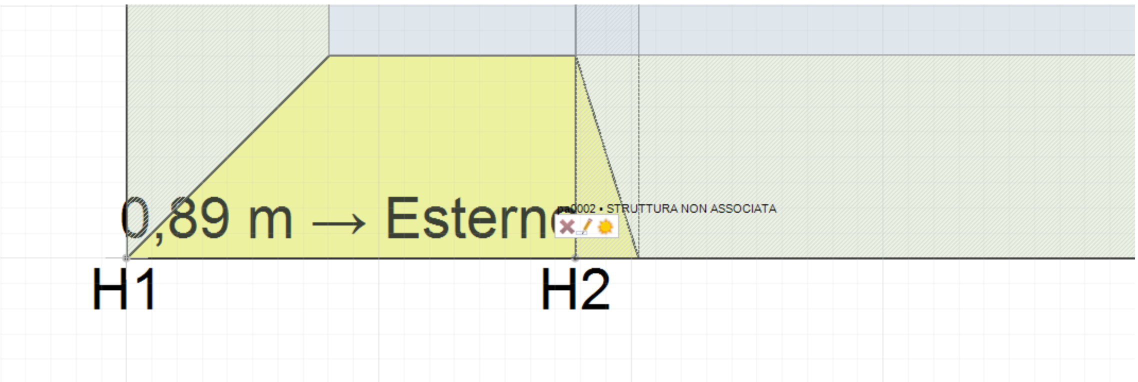
Check this option.

With this command TERMOLOG breaks the walls in correspondence with partitions that delimit different rooms.

NOTE
Termolog does not recognise the portion of the area of a wall in contact with a room but assigns the entire wall and its total area to one or more rooms in contact with it. For this it is necessary that the walls are divided in such a way as to allow this logic of allocation.

NOTE

By checking the result obtained by setting this option in the import phase in Termolog, it may happen that you see an overlap of the broken wall parts in the plan. In the two images that follow, the wall has been broken at the coinciding points H1 and H2 and the right part (first image) and the left part (second image) seem to overlap.



The problem is related only to an incorrect display in Termolog. The length of the wall in the analytical model is given by the distance of the two points H1 and H2 of the reference line of the wall. In the previous images it is therefore noted that the wall was broken correctly, since the point H2 of the left wall coincides with the point H1 of the right wall. For further verification, you can also check the length of the two portions of the wall in the relative cards.

B. Connect walls

Uncheck this option.

The command allows TERMOLOG to automatically fillet the intersecting walls.

NOTE

It is recommended not to use this command to avoid the risk that the length of the reference line of the walls can be changed without adequate control.

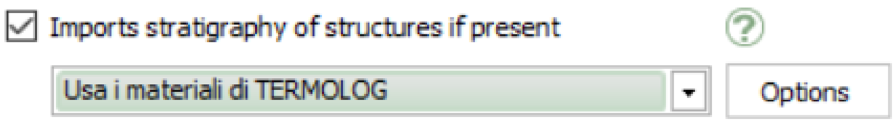
C. Sensibility [m]

The Sensibility value can be left as default 0,2 m. It is the maximum length within which TERMOLOG tries to break or connect the incident structures.

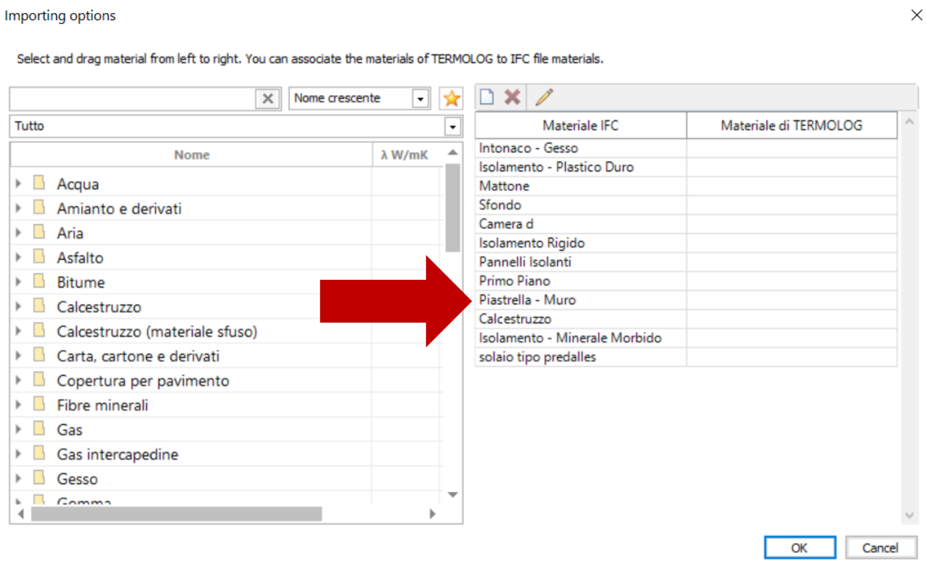
D. Import the stratigraphies of the structures if present

Select this option and proceed as follows::

1. From the drop-down menu set "Use the materials of Termolog"



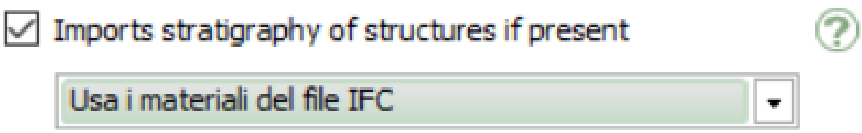
2. Click on options
3. In the window that opens, associate each IFC material with the material of the same name previously created in the "User materials" directory of the Termolog archive.



NOTE

This semi-automatic procedure has the advantage of allowing the compilation of the thermophysical properties of the materials directly in Termolog. Instead, if these properties had already been correctly entered in Archicad, it would be possible to import these characteristics with the following alternative procedure:

1. Select “Import stratigraphy of structures if present”



2. From the drop-down menu select “Use IFC materials”(Usa i materiali del file IFC)”

E. Associate the imported structures with the archive elements

Uncheck this option.

This command allows an alternative procedure for importing stratigraphies to the one recommended in the previous point.

NOTE

By selecting this option, Termolog automatically replaces the structures present in the IFC file (doors, windows, walls, floors, roofs) with those inserted before importing into the Archive of the current Termolog Report. Termolog matches structures of the IFC file to those of the archive by comparing the value of some of their dimensions. The use of this option is not recommended especially in cases of complex buildings with many structures because it can lead to errors in the replacement. For example, the replacement of wall structures takes place only in consideration of their thickness; this means that if the IFC file contains two walls 20 cm thick but one of tuff and the other of brick, they could be re-associated with the same 20 cm thick structure present in the Thermolog archive.

F. View IFC before importing

This option allows you to view the file within the Logical Soft IFC viewer before starting the import.

3.6 Checks of the imported file in Termolog and post-processing

For a smoother work in Termolog it is recommended to install the add-ons from the Help > Install add-ons home screen. Also it is important that, if the operator is using a PC with a dedicated graphics card, Termolog is set to use it. For the setting, right-click on the desktop and select the installed graphics card (for example: “Control panel XXX…”. Select the item “manage 3D settings”. Access the program settings tab and select Termolog as the program to customise. At that point set the graphics card and conclude with "apply".

3.6.1 Levels

A. Create new levels

Termolog requires the creation of multiple levels to manage some particular situations for energy calculation, for example:

- differences in height among two adjacent floors
- Rooms spanning several floors
- Floor with slabs of different thickness or direction of dispersion

Since for these situations the imported BIM models will often have only one level, in this case it will be necessary to create a new level and move some parts of the imported model to it. To do this you can follow the following procedure:

1. Create a new level
2. Set the level parameters
3. Move the layer above (or below) the layer from which you want to copy the imported items
4. Select the items to move to the new layer
5. Use the command "Move selected objects to the upper (or lower) level"

B. Floor with slabs of different in thickness or different direction of dispersion

This situation leads to a problem in setting the height of the walls when using "Automatic Height H (Altezza H struttura automatica)” setting. This setting calculates the height of a wall using a constant value of the thickness of the floor and ceiling of the level to which it belongs (as indicated in section 3.6.3A). If on a level there are two or more slabs that have different in thickness or direction of dispersion, if using “Automnatic Height H” setting, the most correct solution would be to create several levels at the same height, one for each different slab (as indicated in the section 3.6.1A).

3.6.2 Wall, floor, ceiling and roof structures

A. Check of the structures imported from the IFC file

The operator must check in the structures menu that the structures are present for walls, floors, ceilings and roofs:

1. At least one structure for each type of stratigraphy foreseen by the model;
2. For each stratigraphy it is important to check which direction of dispersion has been imported and possibly create duplicates in order to model all the structures with different direction of dispersion required.

If there were no errors in the import procedure, the first check should not detect any problems, instead it is likely that errors are found in the second check (due to the fact that the IFC IsExternal parameter does not take into account the many directions of dispersion that would be needed).

To create structures with the same stratigraphy but a different direction of dispersion than an already imported one, it is advisable to:

1. Check that all the parameters of the imported structure are correct and, if necessary, modify them
2. Duplicate the structure by giving it a new name
3. Correct the direction of dispersion in the new structure

This way the structures should have been correctly compiled and it is possible to check in the envelope tab to correct any errors in assigning structures to the imported elements.

NOTE

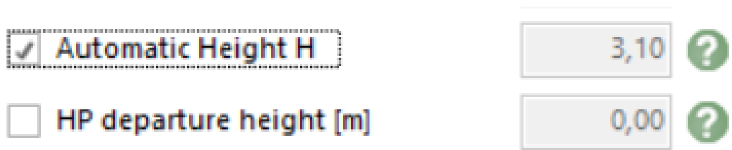
In the Envelope tab to make a change to all the elements of a floor that have the same structure, it is possible to select them all together with Ctrl + left mouse click on one of them.

3.6.3 <u>Walls</u>

A. Altezza pareti

Excluding exceptions that require special configurations of the height of the walls, in the Envelope:

1. Select one or more walls (with Ctrl + left mouse click on one of them)
2. Right click on one of the selected walls → Modify
3. Select the parameter "Automatic Height H”
4. Deselect the parameter “HP departure height” parameter



NOTE

It is necessary to repeat the procedure for each single type of structure.

NOTE

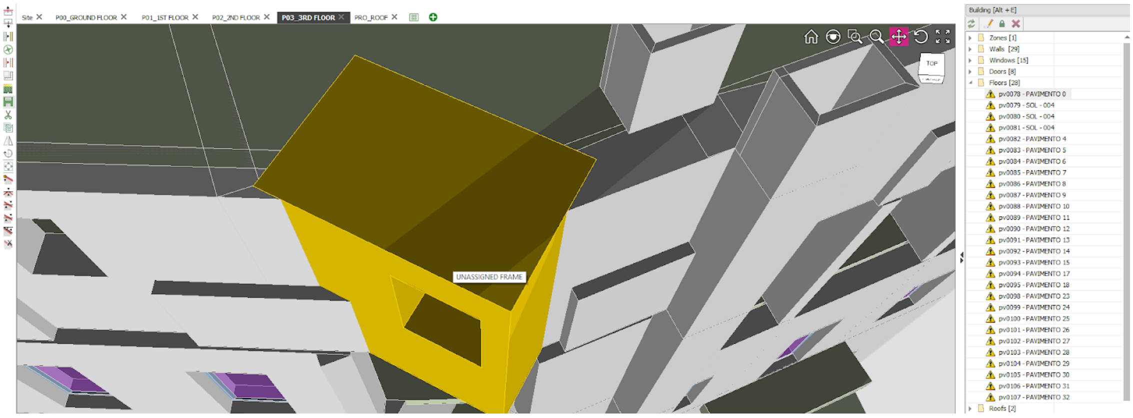
If in Termolog the reference line was set to external, within the graphic input the height of the walls must be set to include half or the entire thickness of the slab to which it belongs (depending on the direction of dispersion of the attics).

When importing walls from an IFC file, Termolog does not change the height of the imported walls. Therefore, for example, in the case of importing an architectural BIM model, these heights should not coincide with those required by Termolog.

With the " Automatic Height H " command, Termolog recalculates the height of a wall starting from the data entered in the level to which it belongs: level net height + half or entire lower slab thickness + half or entire upper slab thickness.

B. Wall with irregular thickness

If in the IFC file there are walls with irregular thickness (with non parallel faces), these will be imported into Termolog without an associated structure, rotated and translated with respect to their correct position on the plan and with incorrect values of length and thickness. In Termolog you will then have to proceed with the elimination and remodeling of these walls and the creation of a structure to be associated with them.



These walls can be identified in several ways:

- from the 3D model or from the 2D plans of Termolog in which the positioning and size errors of the walls are usually evident;
- in LogicalBIMViewer these walls are classified in a category of walls distinct from the others (see dedicated section);
- in the "Envelope" menu of Termolog, "Building" tab, "Walls" folder, these elements are among those without an assigned structure (they have the Archicad ID rather than the name of the structure).

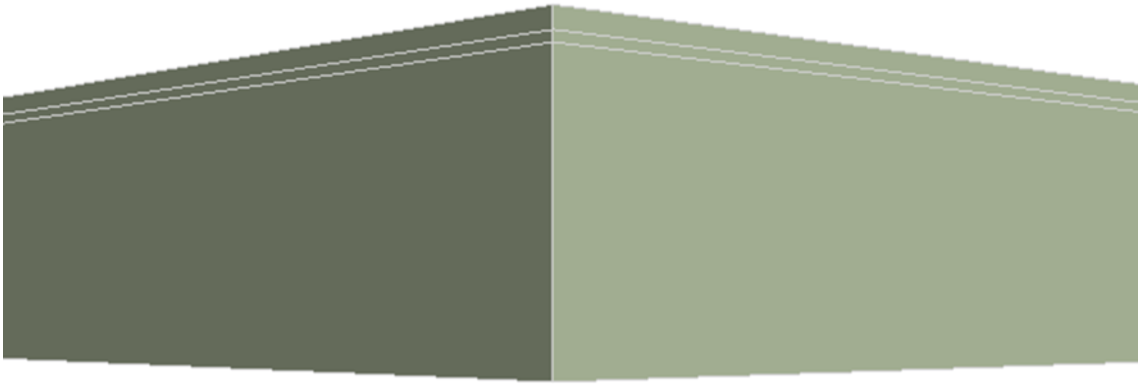
NOTE

It is possible that in the import process Termolog mistakenly creates hundreds of duplicates of a single wall. It is therefore advisable to check the number of walls present in each imported floor in the envelope tab and in the building sub-tab as the first check to be done on the imported file. If there are floors with a very high number of walls (they could be over a thousand), it will be necessary to search in the structures displayed in the tab a structure that is repeated a lot of times, then left click on any of it to identify it within the model and then Ctrl + left click on it and delete it to delete all togheter all the duplicates. It is key to perform this check at the beginning of the imported file check because the presence of these "exploded" walls in hundreds of copies makes the navigation of the model particularly cumbersome and can lead to crashes.

3.6.4 Slabs (Floors and Ceilings)Pavimenti/Sofitti

A. Excess slabs generated during the import process.

As described in section 3.4.2A some types of slabs are not imported into Termolog as a single slab element but instead generate as many slab elements as their layers (as in the image below). Furthermore, each of these slabs lack an associated structure



In Termolog only one slab will be kept for each of these imported slabs, eliminating those in excess. The structure for each of the remaining slabs will then be created and associated.

There are several ways to identify these excess slabs, for example:

- in the "Envelope" menu of Termolog, "Building" tab, "Floors" folder, these elements are among those without an assigned structure (they have the ID Archicad rather than the name of the structure);
- in the "Envelope" menu of Termolog, "Layers and Selection Filters" tab, make only the floors visible and more easily identify the excess slabs from the 3D model

B. Suspended ceilings

In the room tabs, if there are closed suspended ceilings, fill in the parameter "Hc False ceiling height". To carry out this operation, it is advisable to make use of schedules and/or drawings specifically created in Archicad.

C. Internal vaults

The geometry of the vaults will not be imported from the Ifc file but only of the slabs. For the vaults that separate internal rooms (and therefore do not fall within the calculation of the dispersions) the energy modeller will have to evaluate whether:

• modify the stratigraphy of the slab so that it takes into account the thermal capacity of the entire floor-vault system.

• In the event of a gap between the vault and the floor, the “Hc False ceiling height” parameter must be filled in in the room card in order to take into account the real volume subtracted from the vault to the room.

To carry out these assessments, it is advisable to make use of abacuses and/or drawings specifically created in Archicad.

D. Vaults with the dispersing intrados towards the outside (for example on arcades), vaults and complex roofing shapes (domes) dispersing towards the outside

In Termolog the vaults are remodelled case by case in an attempt to represent their thermal behavior with the right degree of approximation.

3.6.5 Windows and doors

A. Check of the transparent windows and doors imported from the IFC file

The operator will have to create the different types of windows required by the model in the Structures menu.

To carry out this operation, it is advisable not to modify the imported windows but to create new ones either from scratch or starting from those contained in the archive.

NOTE

This way a trace of the replacement is kept as the imported elements are stored in the Structures menu in a dedicated directory called "IFC".

For the input of the parameters of the different types of doors and windows, it is advisable to use abacuses and/or graphic drawings specifically created in Archicad.

Once the required structures have been created, it is possible to go on the envelope tab to assign the correct type of transparent window or door structure to each element.

NOTE

To change all the windows of a same type within a floor, in the graphic select one of them with Ctrl + left mouse click.

NOTE

If, as soon as the import has been carried out, some structures are not associated with their geometric element in the model, try to save and reopen the file or change the menu to allow a model refresh.

3.6.6 Rooms

A. Rooms spanning over two ore more levels

There are two cases:

1. Rooms that span over several floors but are included between two levels already defined in the model (for example a room that goes from the ground floor level to the second floor)
2. Rooms that span between two levels, one of which is not defined in the model (for example a room that goes from the ground floor level to the middle of the first floor).

In both cases, it can be created an additional level to those already imported, move the related structures to this level and finally create a single room. Depending on the complexity of the case, the procedure will not always be decisive, for example it could not allow the modeling of any walkway included in the room (whose useful surface could in any case be added to the room using the "mezzanine" command in the Room tab). A recommended alternative for the first case is to divide the room by creating one room for each level and then grouping them with a single thermal zone. This way it will be possible both to exploit imported levels and structures without the need for specific modifications, and to consider any slabs between one floor and another (as in the case of walkway).

3.6.7 Shading elements

A. Imported structures referring to rooms not subject to calculation

The dynamic calculation does not require the modeling of unheated areas, heated by another system or of solar greenhouses. Structures of these areas (such as walls, floors, windos, roofs) may be modeled in the imported model. To exclude them from the calculation, just check that these structures have not been assigned by Termolog to any room. The structures will instead correctly fit into the shading calculation.

B. Shading elements not imported

Some shading elements may be excluded from the import in Termolog because they are classified in categories not imported by the program. It will therefore be necessary to remodel these elements in Termolog as obstructions, vertical or horizontal overhangs. One example is railings that could be modeled as obstructions.

3.7 Report on the tests

The feasibility study process of Palazzo Maffei-Borghese (Clementino) was planned in three steps:

- Data mapping and construction of a shared knowledge framework among experts involved;
- Interoperability tests phase 1: tests on simplified models to address generic interoperability issues;
- Interoperability tests phase 2: tests on a portion of the case study to address case-study specific issues.

Each test (Interoperability tests phase 1 and 2) involved a basic workflow as follows:

- BIM modelling of the element(s) to be exported
- File export from BIM to IFC
- Data check in IFC viewer
- Data import in BPS
- Data check in BPS

The guiding principle of the feasibility study, already used in (Gigliarelli et al. 2019), was to keep every experts within their working "comfort zone" without forcing processes in the BIM environment. Logicalsoft Termolog was involved in the study and is currently signing a Memorandum of Understanding with BEN-CNR to further study the workflow.

The stakeholders involved where BIM experts from PP1 MASI, BIM, BPS and interoperability experts from BEN CNR, interoperability and BPS expert from Logicalsoft Termolog.

The first step of data mapping highlighted the data flows between the two environment and identified the focus of the study on the data flow of both geometric and alphanumeric data of walls, windows, rooms, materials, levels, slabs, roofing and shading surfaces. CNR developed a first draft of best modelling practices from which the phase 1 of tests started.

To test data flows of walls, windows, rooms, materials, levels, slabs, roofing and shading surfaces, a series of extremely simplified model were developed and shared in a folder (§ Figure 3 Figure 4Figure 5) with the aim of:

- easily isolate any interoperability issue;
- being able to perform additional tests to develop a modelling best practice.

The results of the tests were noted on a shared document and then discussed in plenary meetings among the experts.

In some cases, the development of the solution for an issue suggested to Logicalsoft further development of the software, that even if not readily available for the BEEP project modelling will help further streamline specific processes.

Below there is a selection of images from one of the test model in the three environments, the Archicad BIM environment in Figure 3, the IFC viewer environment in Figure 4, and the Termolog BPS environment in Figure 5

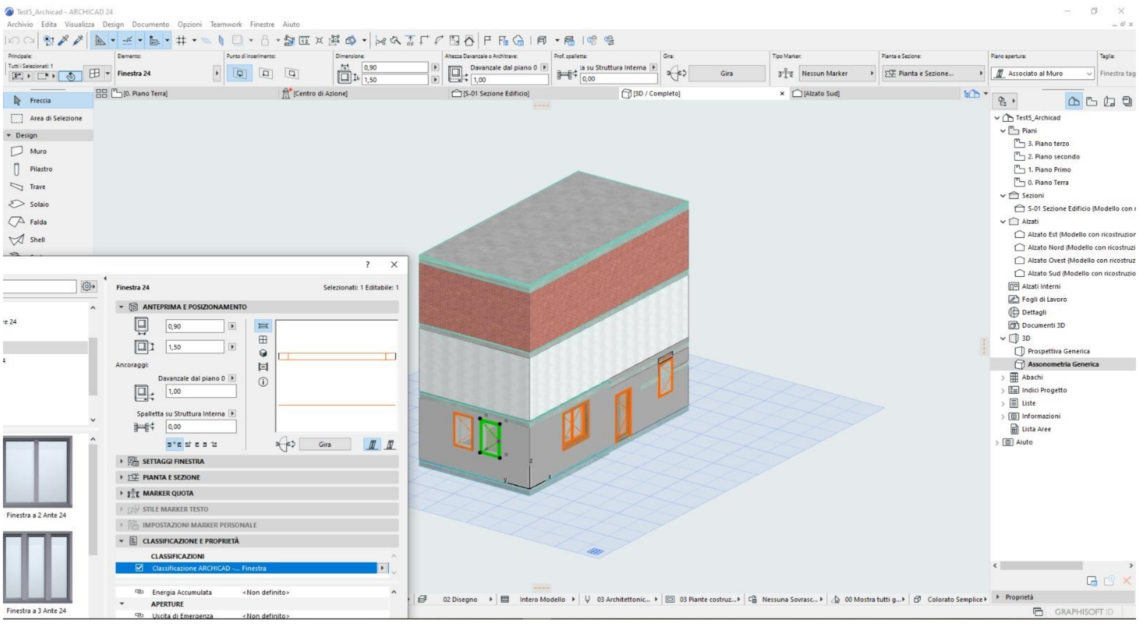


Figure 3: Archicad environment, test model with a focus on windows

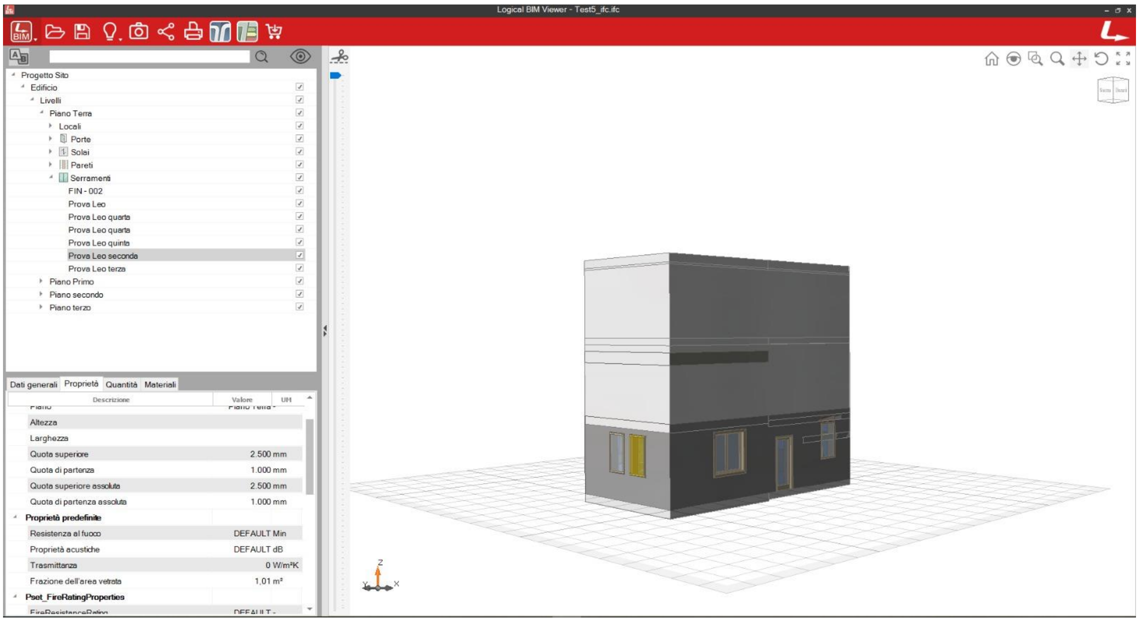


Figure 4: Logicalsoft IFC Viewer (Logical BIM Viewer), to check exported data from Archicad

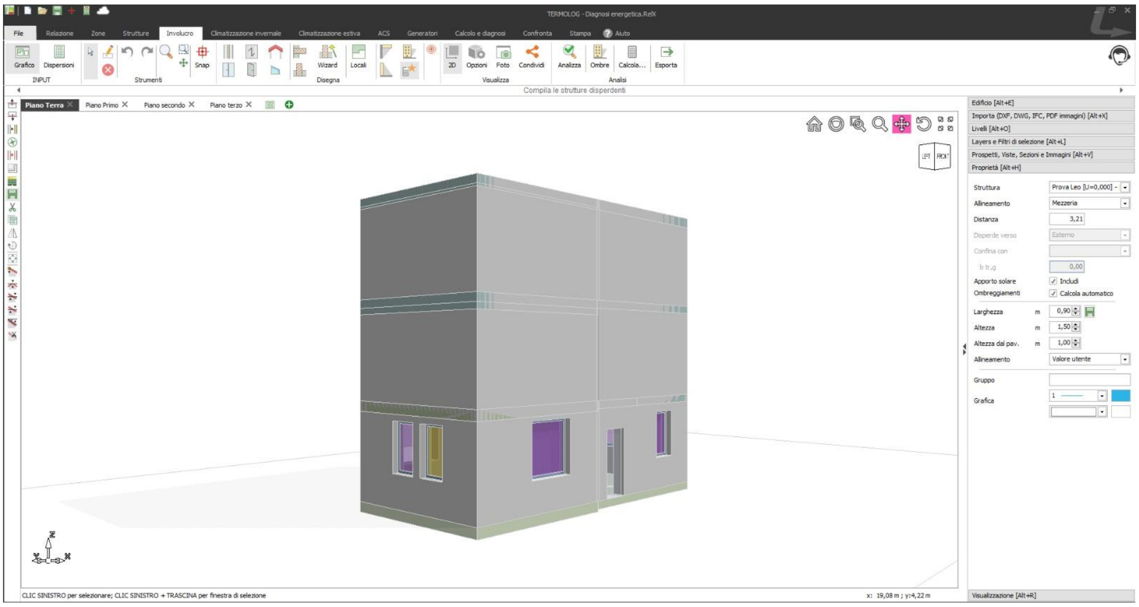


Figure 5: Termolog environment, imported IFC Model to be checked

Once addressed the main issues in phase 1, the team developed a modelling strategy for phase 2 which involved:

- the definition of construction elements;
- the modelling strategies for the building parts which are not occupied from the Avvocatura Generale di Stato;
- the definition of levels in Archicad
- The definition of schedule to streamline windows data flow between the two environment
- The definition of a schedule to streamline ceiling and vault data flow between the two environments.

For the construction elements the team decided to define its characteristics in order to be able to integrate the results of environmental analyses (HFM measurements) into the model during its modelling and before final export (§ Figure 6).

Tabella 3. Sintesi delle tipologie costruttive individuate in fase di rilievo (colori) e con indagine termografica (lettere). Le lettere in bianco indicano le zone selezionate per la misura termoflussimetrica. La zona I, in rosso, si riferisce alla misura della muratura della chiostrina interna.¶

	Localizzazione									
	Vicolo del Divino amore				Via del Clementino				Via di Pallacorda	
Piano	Sezione 1	Sezione 2	Sezione 3	Sezione 4	Sezione 5	Sezione 6	Chiostrina interna	Sezione 7	Sezione 8	Sezione 9
copertura	K	J	FALDA	FALDA	FALDA	X	Y	FALDA	Y	W
terzo	A						I		G	
secondo	A	B	D	G	G	G	G	G	G	
primo	A	A	C	F	F	F	F	F	F	
terra	A	A	C	E	E	E	E	E	E	L

¶

Figure 6: Breakdown of one of the elevation into sections and management scheme of the heat flow meter analyses

For modelling strategy, the team used the previous A3.2.5 activity results to define every room to be modelled for the Energy model of Palazzo Maffei-Borghese used by Avvocatura Generale di Stato.

For the Level the team studied Termolog Level definition (§ Figure 7) and then planned Archicad level accordingly also taking into account a specific rigidity of Archicad that does not recommend creating additional levels in case of height differences inside the floors as instead would suggest a Termolog optimised approach.

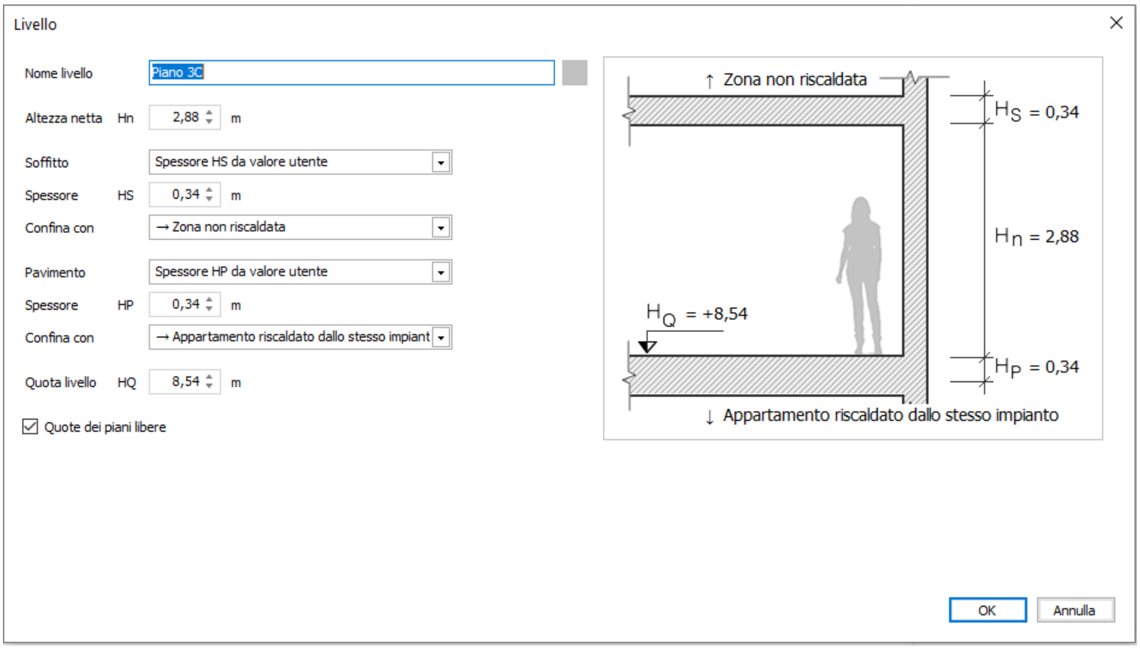


Figure 7: Termolog level definition

The Termolog definition of windows (§ Figure 8) was used to extract the parameters to be represented in a specific Archicad schedule, and then manually modelled in Termolog, as Termolog cannot import all the data needed to calculate the thermophysical properties of a window and therefore it is better to model them in the BPS environment to reduce parallel modelling.

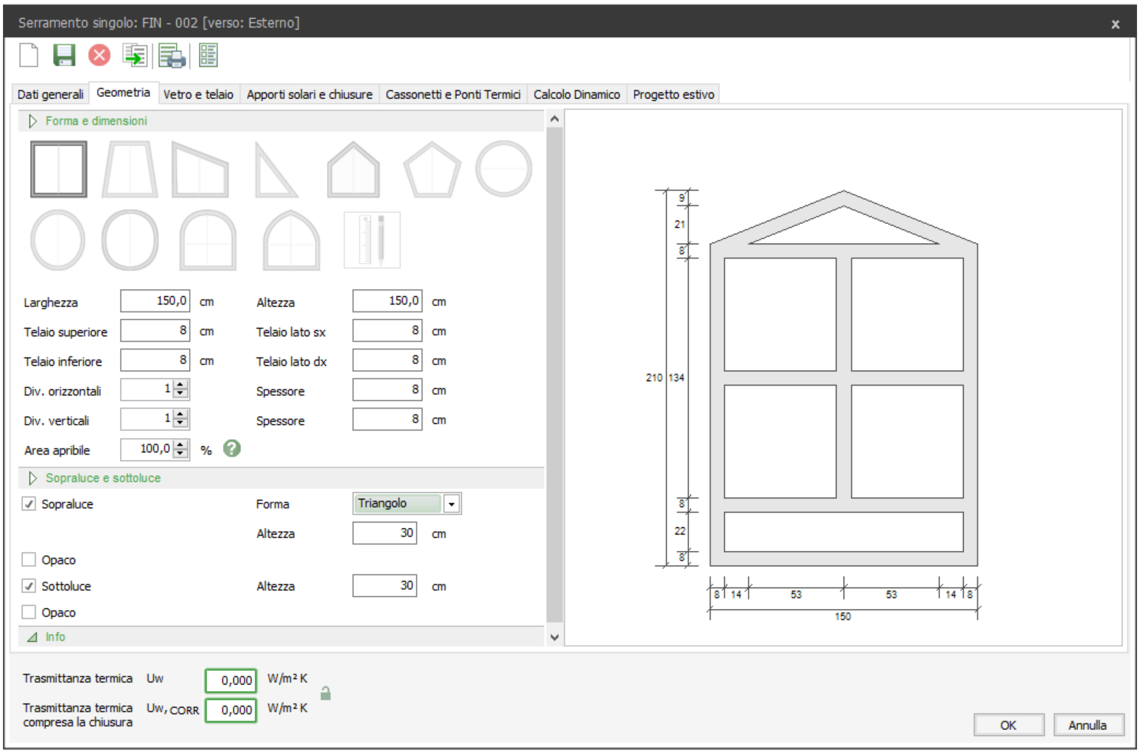


Figure 8: Termolog window properties to be extracted from a schedule in Archicad

Also to streamline ceiling and vault modelling in Termolog a dedicated schedule was developed in Archicad containing the information needed to allow the energy modeller to correctly represent the two elements in the Energy model.

3.8 Main findings

The structure of Termolog allows to keep a large part of the structure by types and instances of the BIM software and therefore facilitates the post-processing of data in the BPS environment.

The first step of data mapping and the creation of a shared knowledge framework among experts, before starting the BIM modelling brought all the experts on the same level of understanding of the process and, through a fruitful exchange of knowledge allowed to solve a series of problems in short, thanks to the possibility to appeal each time to the the specific skills of a different expert on the same issue.

3.9 Limitations

Even if Termolog has proved flexible in its ability to acquire BIM data, some steps still require heavy manual intervention by the energy modeller, both in terms of BPS modeling and data check, with an increased risk of errors in the process.

4 REVIT TO DESIGN BUILDER WORKFLOW

4.1 Data definition and organisation, planning of the tests

The BIM model used for the feasibility study was initially checked in terms of its geometrical consistency, i.e., all major components were modelled and categorized properly, and its energy related data comprehensiveness, i.e., dynamic energy simulation requirements.

The energy performance data were collected from A3.2.5 and registered to BIM materials and object families respectively. The following measures are registered:

For opaque envelop:

- Thermal conductivity W/(m·K)
- Specific heat capacity J/(g·°C)
- Density Kg/m^3

For transparent envelop:

- Visual Transmittance (VT)
- Solar Heat Gain Coefficient (SHGC)
- Thermal Resistance (R)
- Heat Transfer Coefficient W/(m^2°C)

GbXML has over 500 different type of elements, attributes and innemirations to depict building components aspects for the purpose analysis objectives. According to the gbXML schema hierarchy (Table 1), all necessary information for the export is summarised below:

- 3D and 2D planar polygonal surfaces (Space boundaries)
- Opaque construction and materials
- Thermal and emission properties
- HVAC equipment
- Glazing and shading surfaces (including their operation)
- Energy, power, efficiencies, water use and physical characteristics
- Lighting and control
- Schedules
- Internal and external equipment
- Costs, including LCA

The task was performed together by the building conservation expert, BIM experts and dynamic simulation experts to check the correspondence between country-specific regulatory framework in relation to the building condition data needed by the energy software and data to be input in the BIM software.

4.2 Autodesk Revit Model preparation

4.2.1 Modelling rules

Table 1: gbXML schema hierarchy[3]

Level	Modelling rules
Location	Provide climate zone, weather data and project location information.
Building	Provide project-specific occupancy and internal gains schedules. Provide project-specific thermostat and HVAC set-back schedules.
Spaces	Space is the most critical component for a decent BIM model export to gbXML. Revit can define spaces using the 'Room bounding' option found in all elements involved. A space can only be placed in fully enclosed voids. Space boundaries are automatically traced in planar view. Space upper and lower limits should be carefully set either by dragging these from the section view or by defining them according to model levels using the respective property dialogue. Check 'Areas and Volumes' under 'Volume Computations' tabs in the ribbon bar to properly bound spaces.
Surfaces	2D or 3D planar surfaces are used to define a bounded room, i.e., wall, roofs, ceilings etc. Surfaces for primary building elements are generated based on the building elements' centreline by default. For this reason, it is very important to use the 'wall joints' tool in Revit to apply the appropriate wall joint configuration before the export. It is advised that walls are drawn using the centreline reference in the first place. Wall surfaces are also categorized into internal and external wall surfaces based on element adjacencies. For example, a wall surface is categorised to external wall surface when the particular surface is adjacent to a single room only. The Adjacency tolerance can be updated once the import is made. It can be accessed from the Advanced tab of the Model options dialog.

[3] https://www.gbxml.org/Schema_Current_GreenBuildingXML_gbXML

	BIM model elements such as roofs, slabs, model in place system family or mullion family which do not form a 'closed' space are automatically defined as shading surfaces and are visualised with green colour in the gbXML import dialogue box (DesignBuilder).
Openings	Openings refer to all kind of building opening surfaces such as doors, windows and skylights and are in their majority hosted components on primary building elements, i.e., walls, slabs, roofs etc. Window families which are modelled with additional openings to the initial opening default parameters will not be recognised during the export and it is advised to use separate families for the creation of each opening. Glass doors do not export as glass. Project-specific glazed door properties should be defined and assigned to the door once imported into DesignBuilder. The type and performance of all glazing elements should be verified once imported to DesignBuilder.

4.2.2 Elements to be excluded in the export

- Elements that are not relevant in the energy simulation (stairs, beams, railings, stone pediments, ornamenting elements, etc.)
- Particular geometries not foreseen by the simulation software (mesh, etc.)

'Room binding' option should be disabled for these elements.

4.2.3 Elements to be included in the export: modelling rules

Revit export to gbXML necessitates the selection of the construction phase to be prepared for export, i.e., Existing building/New Construction/All construction phases. Make sure that all elements to be exported have the same construction phase ID.

4.3 gbXML Export Category

The gbXML export category used for this report is 'Room/Space Volumes'.

Revit 'Spaces' can transfer MEP object's information to the gbXML file during export. 'Rooms' attain only construction and thermal properties.

4.4 Export Settings

The following exporting settings should be set according to the special characteristics of the building model spatial configuration and peculiarities[4].

[4]https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/Revit-DocumentPresent/files/GUID-89B09D35-4CDE-458C-AFBD-492FCDB66E9A-htm.html

Building Type: Type of building according to the gbXML schema version 0.37.

Location: Location of the building which defines the climate and temperatures used in loads calculation.

Ground Plane: Ground plane of the building model.

Export Category: The gbXML export category used for this report based is 'Room/Space Volumes'.

Export Complexity: This setting refers to the level of detail provided for openings, and whether shading surface information will be exported. Depending on the project features the 'Complex with Mullions and Shading Surfaces' option may create a huge number of shading surfaces that will significantly slow down the export process. For typical building projects, this option is not recommended. However, mullions can be modelled once imported into the energy simulation software. They do not affect the energy simulation results.

Detailed Elements: This setting should be active. It enables the export to contain the thermal properties of Revit materials (associated with building elements).

Project Phase: This option has been mentioned in Section 3.2, under the 'Elements to be included in the export'.

Sliver Space Tolerance: The distance tolerance for area to be considered as sliver spaces.

Building Envelope: Specifies the method to use to determine the building envelope.

Option 1: Use Function Parameter: This method uses the Function type parameter of walls, floors, and building pads to determine the building elements considered to be part of the building envelope.

Option 2: Identify Exterior Elements: This method uses a combination of ray-casting and flood-fill algorithms to identify the building elements that are exposed to the outside of the building, the building envelope. Analytical surfaces originating from the building elements in the envelope are classified as exterior or shading surfaces.

Building Service: Specifies the heating and cooling system for the building.

Schematic Types: Specifies the constructions type for the building. Click to open the Schematic Types dialog, where you can enter the materials and insulation (U-values) for the building.

Building Infiltration Class: Specifies an estimate of outdoor air that enters the building through leaks in the building envelope.

Infiltration can be specified as:

Loose - 0.076 cfm/sqft for tightly constructed walls.

Medium - 0.038 cfm/sqft for tightly constructed walls.

Tight - 0.019 cfm/sqft for tightly constructed walls

None - infiltration is excluded from the calculation of loads.

Export Default Values: Exports user-specified values as well as default values for People, Electrical Loads, Occupancy, Lighting, Power Schedules, and Construction Types. Clear this option to export only user-specified values.

4.5 Checking the exported gbXML file

gbXML viewing software such as Spider Web (online platform) can accelerate the process of the gbXML file evaluation since they can provide an easy to use and fast loading interface for checking the exported gbXML file and tracking possible errors or lack of information exchange. At this stage, the gbXML model should contain all spaces already defined in Autodesk Revit (geometric information) and additional check should be made on the level of information transfer, as mentioned in the following section 3.6.

4.6 gbXML properties

The following properties should be successfully assigned to the gbXML model surfaces:

<table>
<tr><th colspan="8">Visibility</th></tr>
<tr><td colspan="2">Surface ID</td><td colspan="2">Space Name</td><td colspan="4">Storey Level</td></tr>
<tr><td colspan="8">Selected Surface Attributes</td></tr>
<tr><td>Surface Type</td><td colspan="2">Construction Reference</td><td>Exposed to Sun</td><td>ID</td><td colspan="2">CAD object ID</td><td>Name</td></tr>
<tr><td colspan="8">Adjacent Spaces</td></tr>
<tr><td colspan="5">Space ID Reference 1</td><td colspan="3">Space ID Reference 2</td></tr>
<tr><td colspan="8">Planar Geometry</td></tr>
<tr><td colspan="2">Cartesian Point</td><td colspan="2">Cartesian Point</td><td colspan="2">Cartesian Point</td><td colspan="2">Cartesian Point</td></tr>
<tr><td colspan="8">Rectangular Geometry</td></tr>
<tr><td>ID</td><td colspan="2">Azimuth</td><td>Tilt</td><td colspan="2">Width</td><td colspan="2">Height</td></tr>
<tr><td colspan="8">Opening</td></tr>
<tr><td>Window Type</td><td>Opening Type</td><td>ID</td><td colspan="2">CAD Object ID</td><td>Name</td><td>Width</td><td>Height</td></tr>
<tr><td colspan="8">Construction</td></tr>
<tr><td colspan="2">ID</td><td colspan="2">U-Value</td><td colspan="2">Absorptance</td><td colspan="2">Name</td></tr>
</table>

4.7 gbXML import in Design Builder

4.7.1 The DesignBuilder gbXML import function operates by simply mapping the gbXML space surface geometry to building blocks. The following options are available.

4.7.2 Import options

View: This option is for selecting the thumbnail viewpoint of the gbXML file selected for the import. Plan view, elevation view or axonometric view.

Import priority:

Adjacency separation tolerance: Adjacency tolerance between two surfaces. Increase this number in cases where building spaces are separated by large gaps due to thick walls or partitions.

Create storey blocks: Storey blocks option enables the creation of a single block using the spaces within the same storey level. This has the advantage of making it much easier to modify internal layouts at a later stage[5].

Import thermal properties: This option will enable materials, constructions and glazing systems' thermal properties already defined in the BIM model to remain as gbXML surfaces and windows attributes.

Allow open manifold building blocks: Open manifold building blocks are spaces with one or more surfaces missing. If this kind of space is not intended then this option should be kept active in order to evaluate the export quality. If activated this option can determine which spaces are problematic.

Import as building blocks: This option should be turned on in order for the imported building model to be ready for use on the DesignBuilder. If unchecked the building geometry will arrive as outline block.

Import shade surfaces: This option should be enabled for importing shading surfaces.

Merge co-planar surfaces: If the above Import shading surfaces option is enabled, then you can choose to either merge any such co-planar surfaces or not.

4.8 Check of the imported file in Design Builder

Once imported, the building model should be thoroughly examined in terms of the level of information successfully exchanged. At this stage, the geometry of spaces should be imported correctly as these have been previously checked in the online platform of Spider Web.

4.9 Conclusions of the testing process

The geometric information contained in the exported gbXML file includes a collection of surfaces derived from corresponding BIM walls, slabs and roofs centrelines. These surfaces represent the inner and outer volumes of spaces predefined in the Revit software. The surface objects contain information of the parent space as well as information of adjacent surfaces and spaces. By extend, surfaces also contain information of the openings for windows and doors. Spaces and subsequently surface objects are identified by users through a manual or semi-automatic process. This methodology involves several loop cycles to be conducted before the under-examination BIM model is exported into a good quality gbXML file.

It is important to understand that the success of the BIM model to DesignBuilder data transfer process critically depends on how well the spatial identification process has

[5] https://designbuilder.co.uk/helpv4.5/Content/Import_3-D_CAD_Data.htm

been conducted in the BIM system. Intersecting or missing spaces in the BIM model will result into a problematic gbXML import.

4.10 Reports on the tests on 'The British Cavalry Club' case study by PP3

This section presents the final model produced through a series of tests performed by the application of the proposed methodology. The BIM model of PP3's pilot building has been used to illustrate the steps of the process.

Figure 9: The British Cavalry Club BIM model.

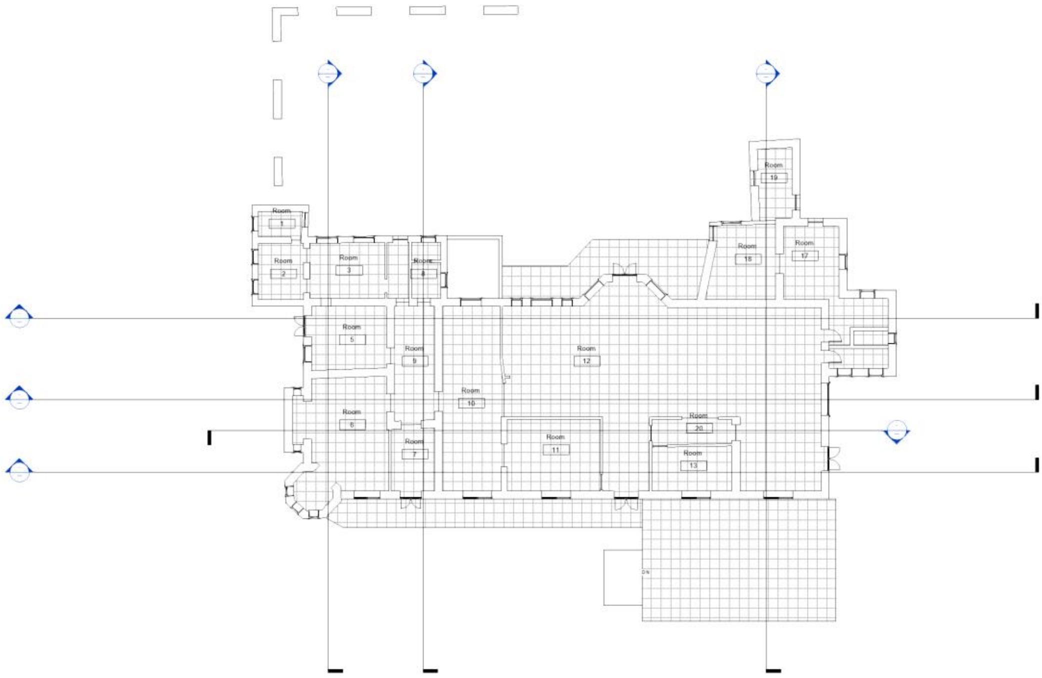


Figure 10:The British Cavalry Club BIM model – Plan view (Ground Floor)

The following thermal characteristics have been registered to the BIM Model:

For opaque envelope:

- Thermal conductivity W/(m·K)
- Specific heat capacity J/(g·°C)
- Density Kg/m^3

For transparent envelop:

- Visual Transmittance (VT)
- Solar Heat Gain Coefficient (SHGC)
- Thermal Resistance (R)

- Heat Transfer Coefficient W/(m^2°C)

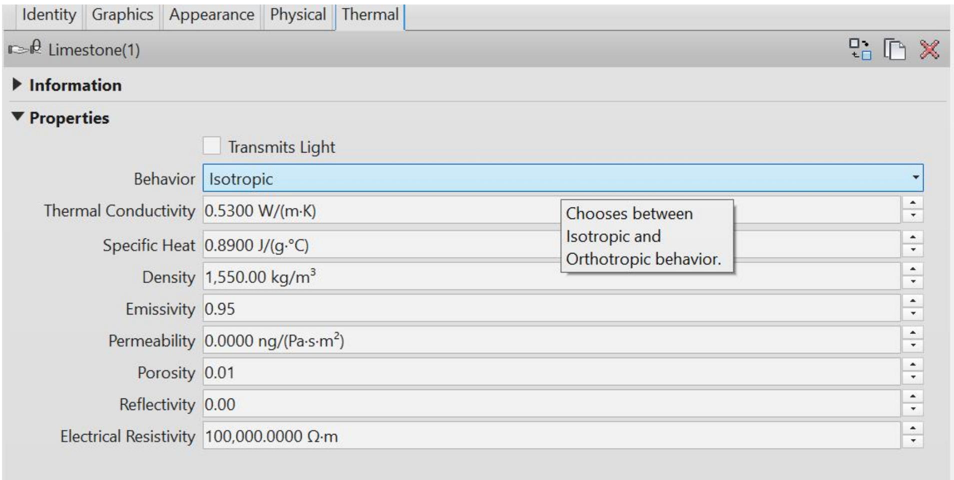


Figure 11: Thermal Properties of materials used

The model has been exported using 'Room/spaces Volumes' default export option in Revit. The test building model contains 23 rooms (picture 4).

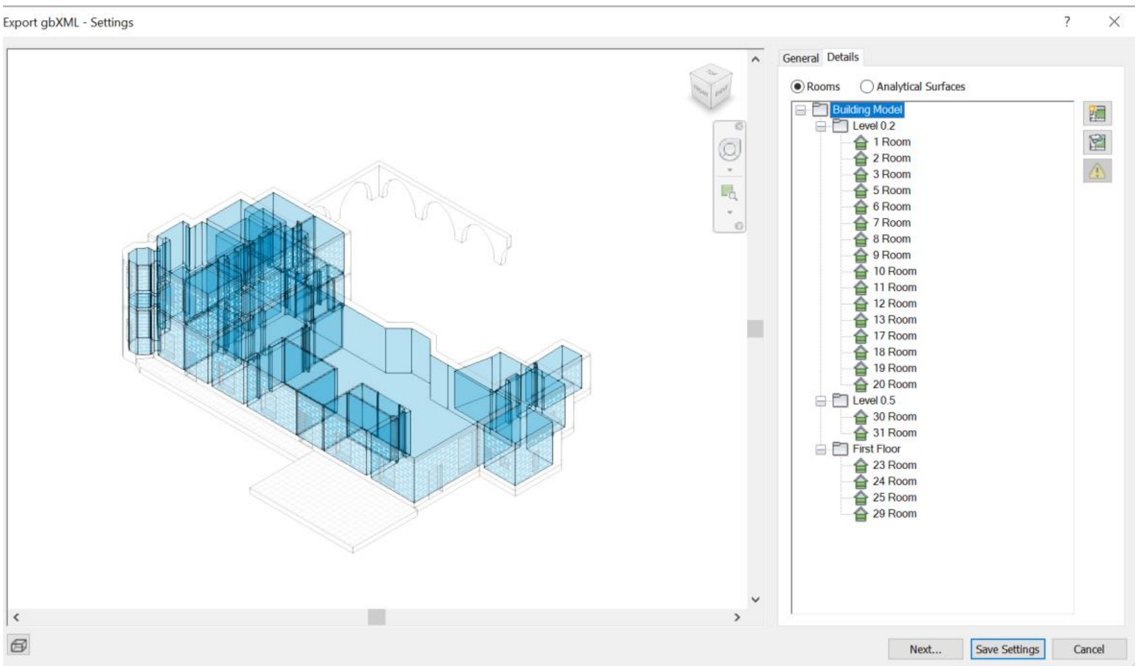


Figure 12:Room/space Volumes dialogue box.

The model is exported using the following settings:

Building Type: Office

Export Category: Rooms

Export Complexity: Complex with mullions and shading surfaces

Detailed Elements: Enabled

Sliver Space Tolerance: 100.00

Project Phase: New Construction

Building Envelop: Use Functional Parameters

The model was then checked on Spider Web platform to check both for geometrical errors as well as the level of information transferred.

Figure 13: gbXML Check – Spider Web.

Finally, the gbXML model was imported to DesignBuilder using the following options:

View: 6-Axonometric

Adjacency separation tolerance: 0.010

Create storey blocks: Enabled

Import thermal properties: Enabled

Allow open manifold building blocks: Disabled

Import as building blocks: Enabled

Import shade surfaces: Enabled

Merge co-planar surfaces: Enabled

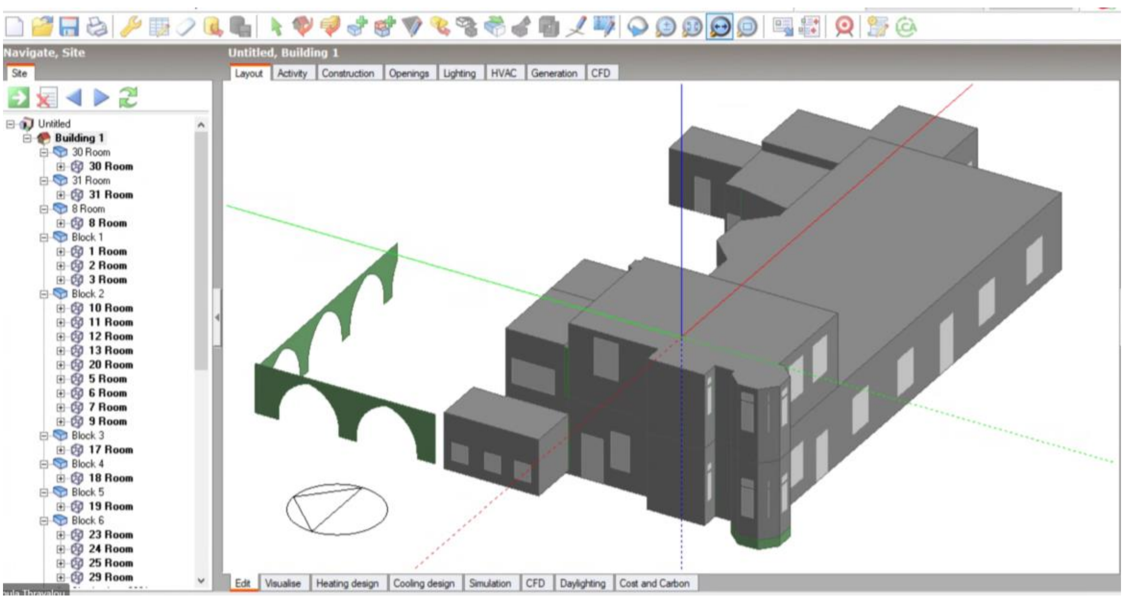


Figure 14: gbXML import to DesignBuilder

Although thermal properties were effectively transferred to primary opaque building components such as walls, roofs and slabs, some geometrical details were not exported properly. These are presented below (see Figure 15 to Figure 17– 10). The reasons for these errors are described in sections 4.13 Main Findings and 4.14 Limitations.

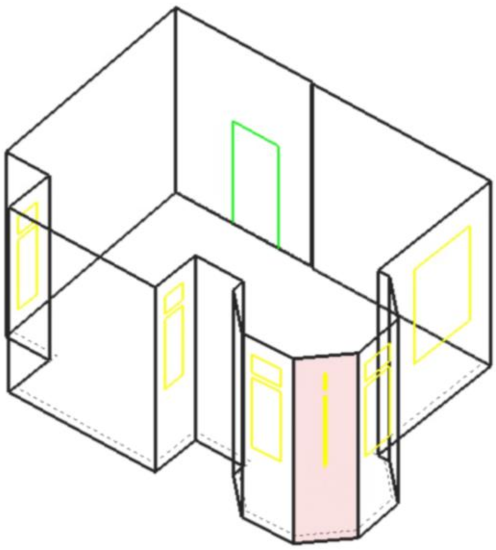


Figure 15: False window width dimension

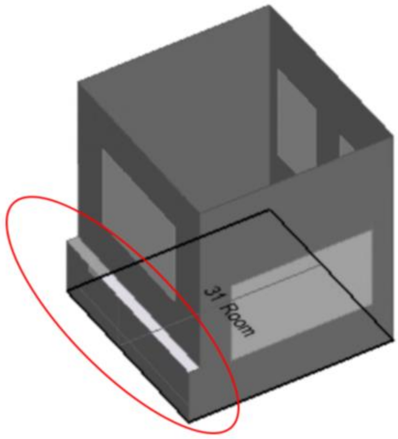


Figure 16: Gap created due to different wall families used.

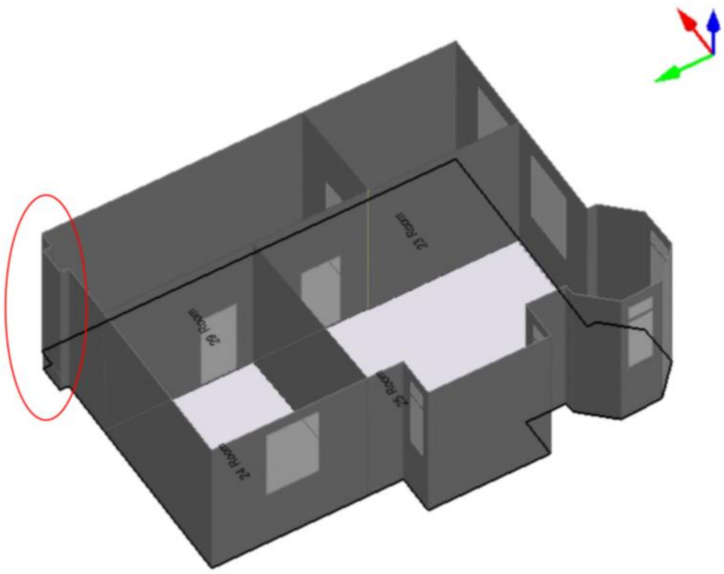
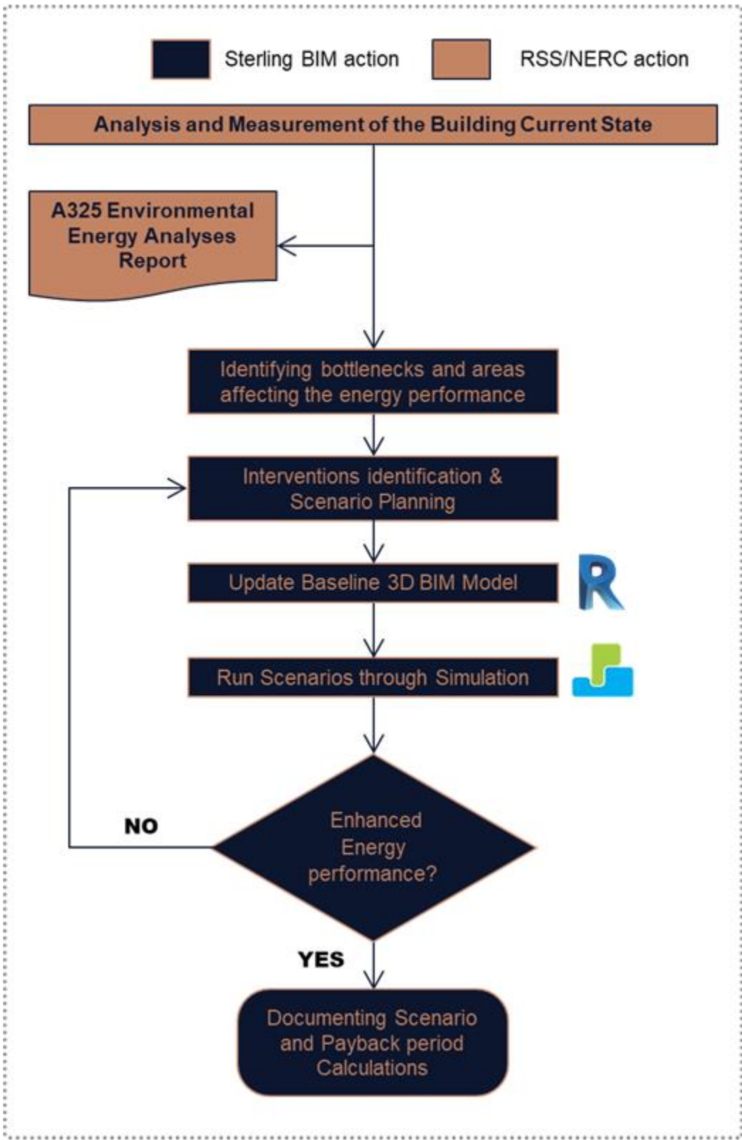


Figure 17: False wall extrusion due to wall joint type defined in BIM model.

4.11 Reports on the tests on 'Al Karak Municipality guest house' case study by PP4

Measurement and verification of the current state of the building, in terms of thermal flow and energy performance was performed.



4.11.1 Description of the experimentation performed

RSS/ NERC team conducted several site visits for Al-Karak Municipal Guest House in order to carry out the required heat flux measurements for the building's opaque envelope. GreenTEG tool kit was installed to record the thermal flow on an hourly basis and for 72 hours to measure the U-value of walls, thereby, evaluate the thermal transmittance of the walls.

The U-value was analyzed according to ISO 9869-1:2014. It was found that the U-value is equal to (3.8 W/m^2K) and average heat flux of about 38 W/m2. Referring to the Jordanian Codes, this U-value is considered higher than the recommended value which should be less than 1.0 W/m^2K. Therefore, it is recommended to add thermal insulation.

4.11.2 Joint study of the input parameters

In order to start with the model, several site visits were essential in order to specify materials and verify building geometry and element dimensions.

A geographical survey was performed in order to start model production. Considerable amounts of information were missing, taking into consideration the age and poor as-built documentation of the historic building. Therefore, we had to predict and assume some of the information such as the external wall layers, depending on common construction methods employed in that period.

Using the information provided by the first survey, we were able to model the exterior façade and surrounding elements. A second site visit was necessary to capture all internal building elements and onsite dimensions.

Depending on the historical data, we predicted the missing information and we continued with the model to increase the level of details to the required level.

4.11.3 Data definition and organisation, planning of the tests

In this first phase the data to be collected necessary for the entire energy diagnosis workflow was defined, and subsequently, starting from the software chosen for the simulations, a first definition of the input data for the simulation was performed. The task was performed by conservation expert, BIM experts and dynamic simulation experts to check the correspondence between data needed by the energy software and data to be inputted in the BIM software.

4.11.4 Autodesk Revit Model preparation

When creating objects/assets within models it is important to ensure that they are created in a manner that integrates with the other solutions that will be employed later in the project. This relates to the dimensions and properties that are allocated to an object/asset, as well as the method used in its construction. It also involves how an object/asset is named and what layer/family/type it resides on in the BIM authoring tool.

Objects/assets should be modelled in line with appropriate guidance given for each modelling solution used, each being specific to that solution, with naming following BS EN ISO 19650-2:2018 to an agreed Level of Information Need for the project's stage gate.

It is also critical that the model represents how the project is to be estimated and constructed. Objects/assets must be modelled as they will be constructed (i.e. in an as-built state), not in an analytical state.

Objects/assets should never overlap. If elements overlap they will cause clashes and also generate false quantities during take-off.

Elements to be excluded in the export:

- Internal staircase and balcony railings
- Plumbing fixtures
- Mechanical equipment
- Electrical elements

Elements to be included in the export: modelling rules:

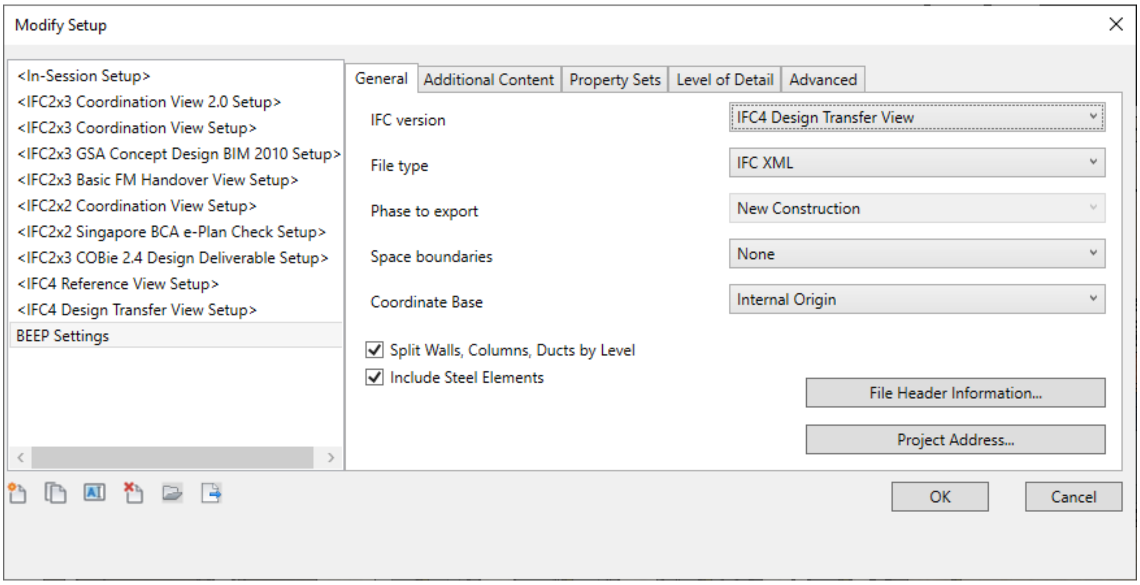
Project Phase to export: New Construction

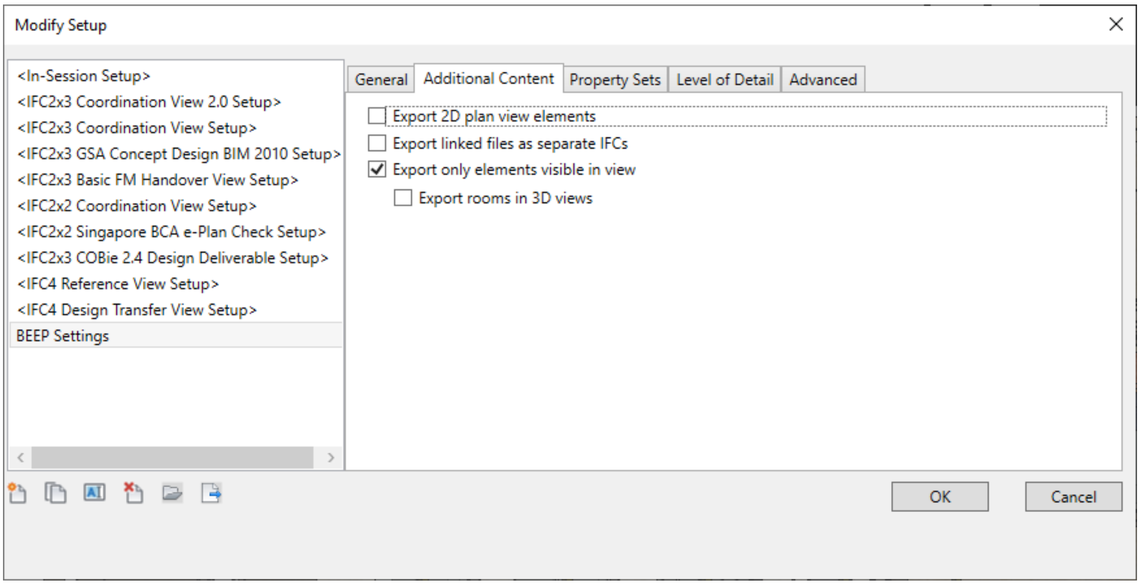
IFC model includes: Project, Site, Building, Building Storeys (i.e., Floors), Space, Zone, Type Product, Product and associated Properties for each required level of the schema.

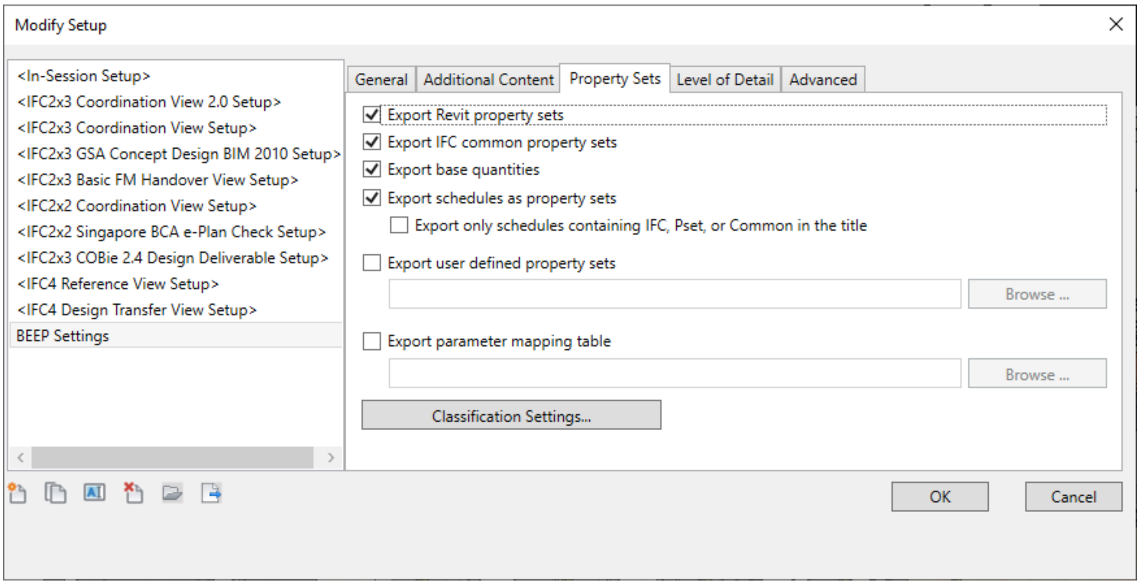
4.11.5 IFC Export

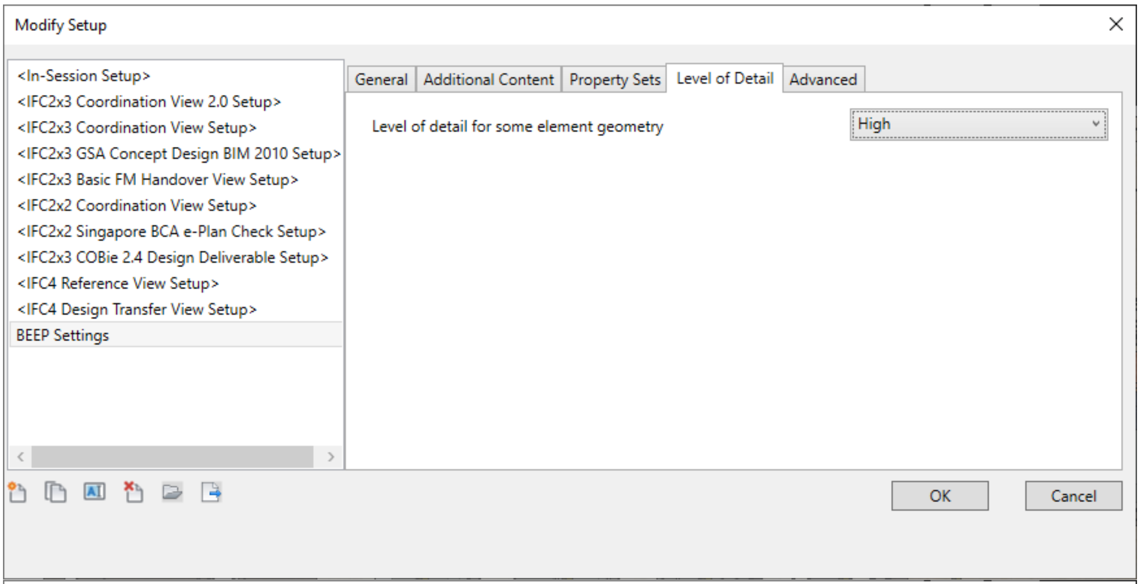
We have provided our own IFC settings to export to IFC format, depending on the way we modelled the project and expected outcomes.

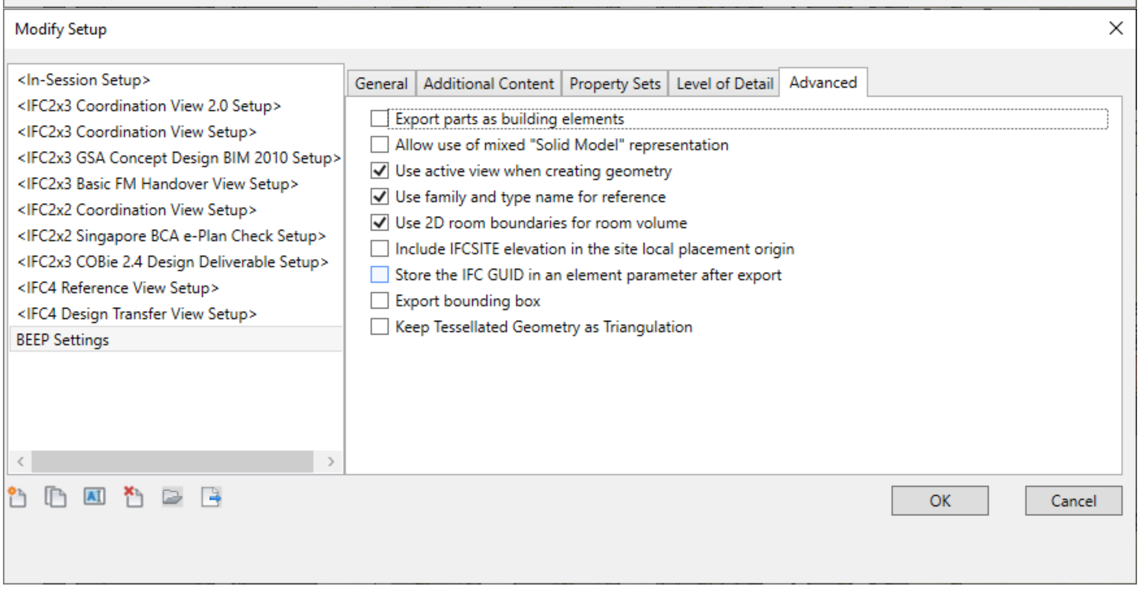
For BEEP project we used the following export settings:











IFCxml file format - gbxml

Green Building XML (gbXML) is the language of buildings, allowing disparate building design software tools to all communicate with one another.

The Green Building XML schema (gbXML) is an open schema developed to facilitate transfer of building data stored in Building Information Models (BIM) to engineering analysis tools. gbXML is being integrated into a range of software CAD and engineering tools and supported by leading 3D BIM vendors. gbXML is streamlined to transfer building properties to and from engineering analysis tools to reduce the interoperability issues and eliminate plan take-off time.

.ifcXML: XML representation of IFC data

IFC Version

IFC4 Design Transfer View: The purpose of this version is to provide building information with support for editing of interconnected elements. It enables inserting, deleting, moving, and modifying physical building elements and spaces.

Table 1: IFC Mapping table

Native BIM Category/Sub-category	IFC Class Name	IFC Type
Floors	IfcSlab	Floor
Slab Edges	IIfcBuildingElementProxy	SlabEdge
Wall/Exterior	IfcWall	StoneWALL
Roofs	IfcRoof	Roof
Door	IfcDoor	Door
Windows	IfcWindow	Window
Walls/Interior	IfcWall	InteriorWall
Stairs	IfcStairs	Stairs
Curtain Panels	IfcCurtainWall	CurtainPanels
Curtain Wall Mullions	IfcCurtainWall	CurtainWallMullions

Technical documentation for IFC:

IFC4: https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/

IFC properties

Properties used:

- Version: IFC 4 Design Transfer view
- File type: IFCXML

- Walls, columns and ducts to be split by level.
- Elements exported: Only visible in view.
- Property Sets to be exported: Revit property sets, IFC property sets, Base quantities, Schedules
- Level of details: High
- Naming Conventions: use family and type naming

IFC exporter

The IFC for Autodesk Revit 2020 contains up-to-date improvements on the default IFC import and export capabilities of Revit contributed by Autodesk and our Open Source contributors. Therefore, IFC in Revit 2020 was used for exporting.

Native BIM software: Revit 2020

Exporter: Native IFC Exporter from Revit

Exported IFC check

Asite Adoddle was used as a common data environment to upload all project documents and models for sharing and reviewing.

Asite Adoddle has the functionality to view and check different model file types including Revit and IFC format.

4.11.6 IFC IMPORT in Design builder

Revit 2020 allows exporting gbxml files directly with Energy Settings.

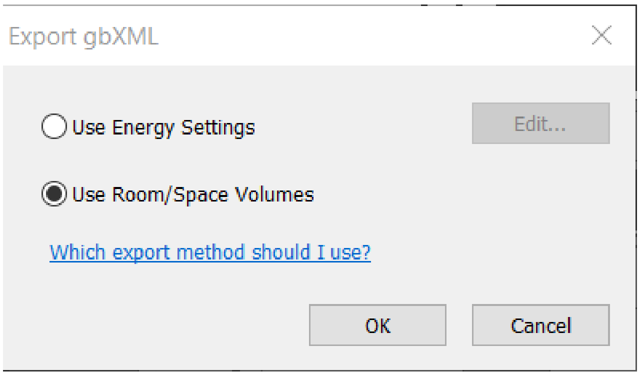


Figure 18 gbXML file Export from Revit 2020

Design Builder

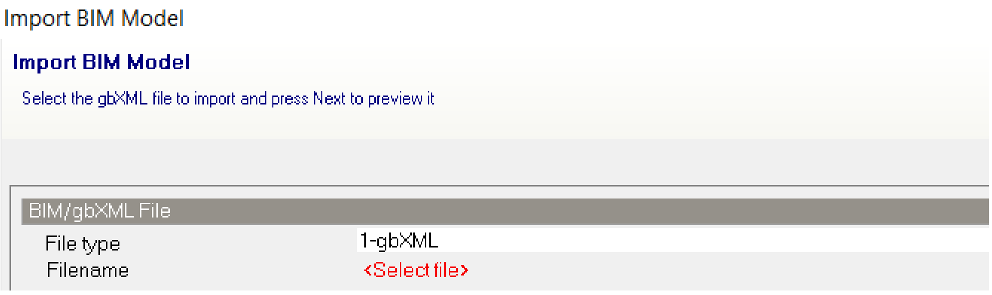


Figure 19 BIM model import – Design Builder

Import check in Design Builder

Manual checks were performed for the following:

- Taking random dimensions in the model to make sure all model elements and model location were correct.
- Checking all imported element properties against actual object parameters.
- Location accuracy for the imported model
- Orientation for the imported model.

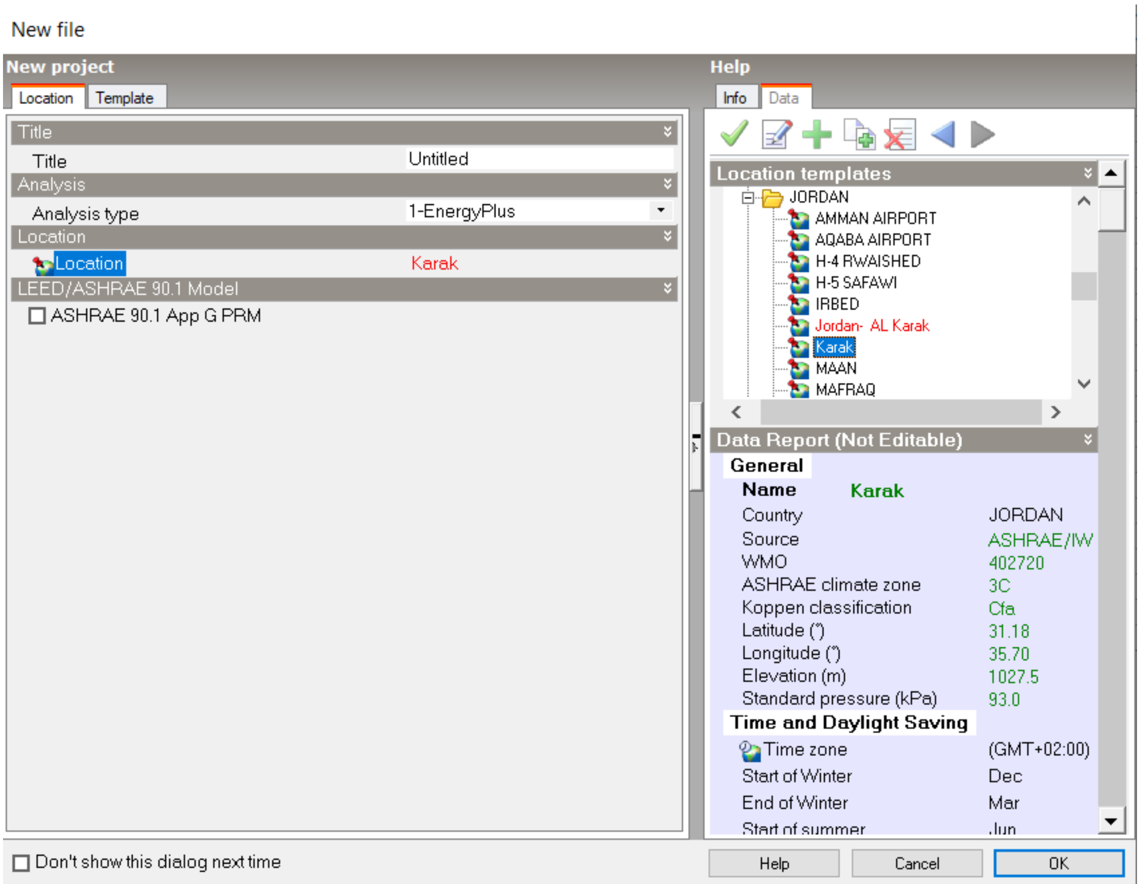
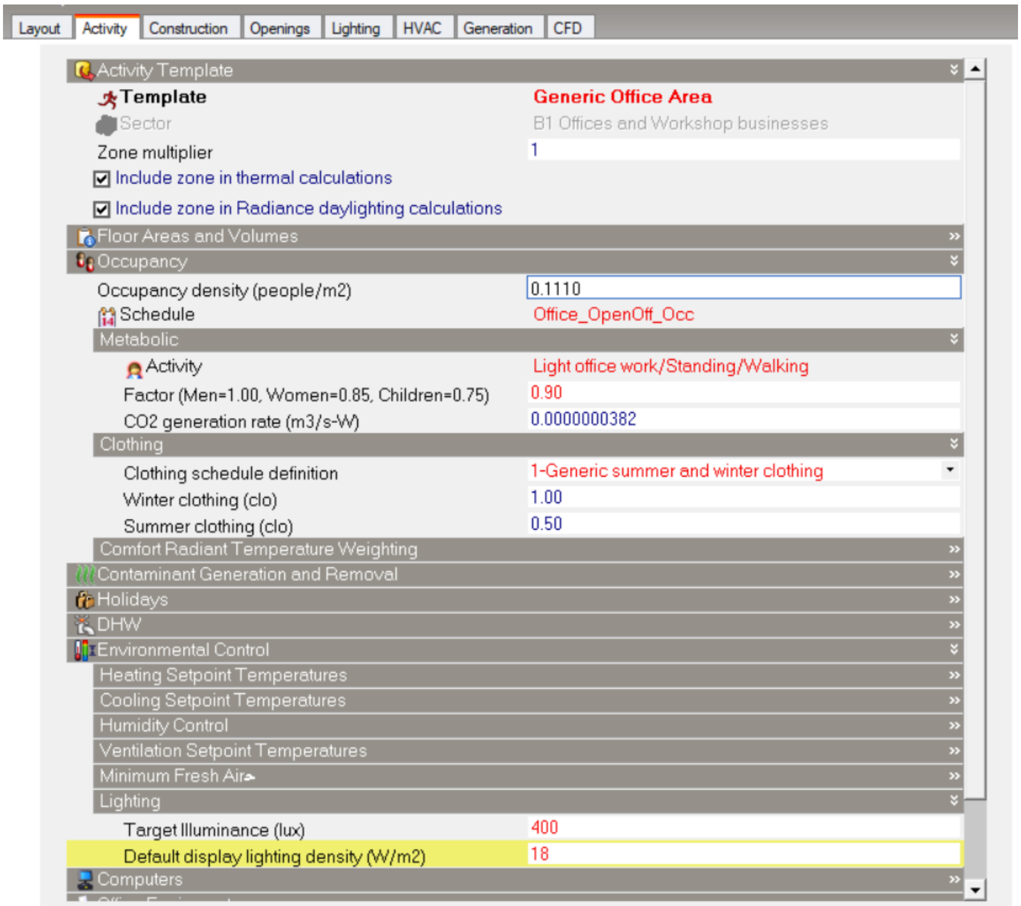
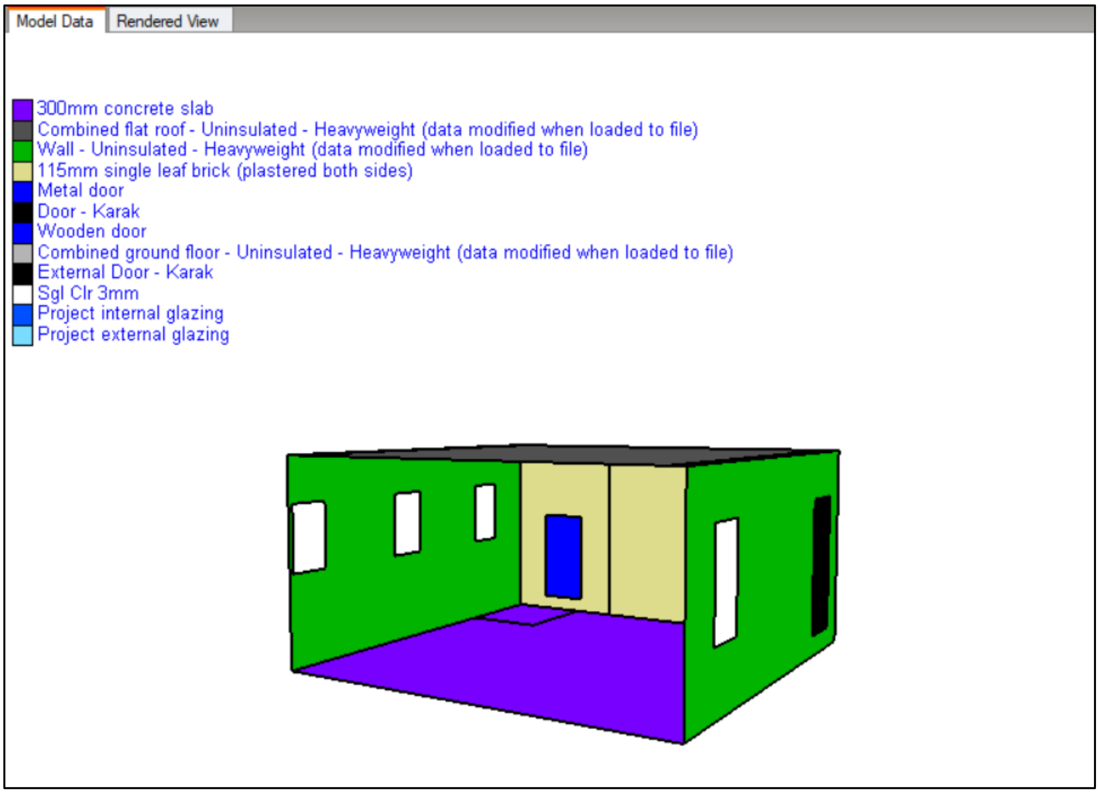
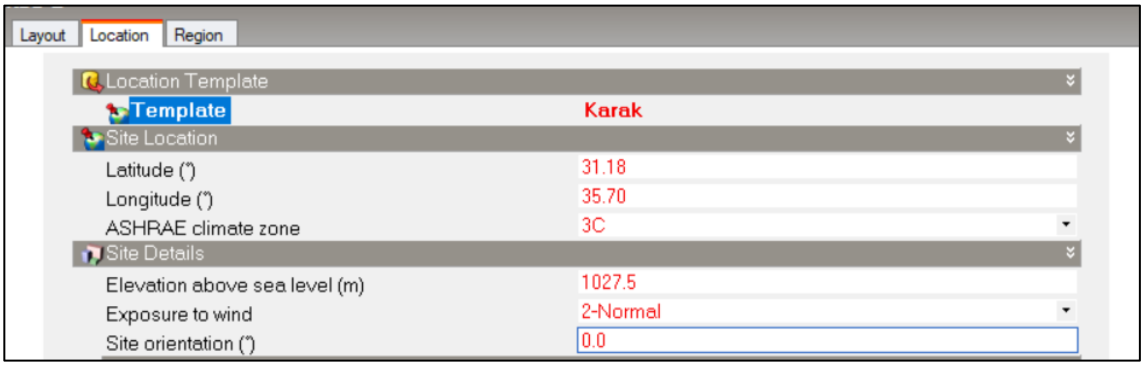


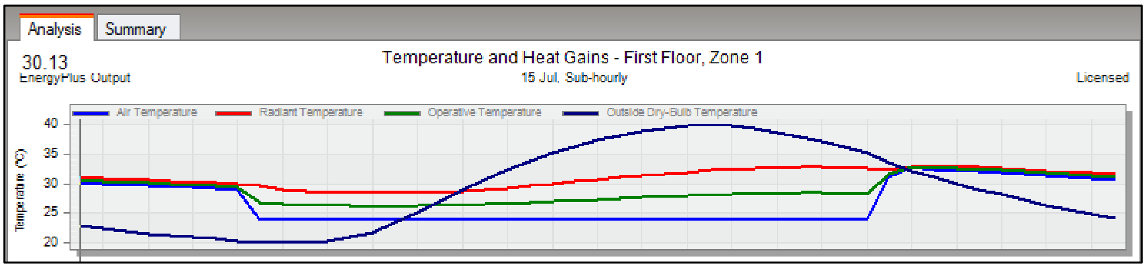
Figure 20: New Project settings - Design Builder

Report on the tests









4.12 Reports on the tests on PP7 case study (Cordahi Building)

Name of Building: Cordahi Building

Location: Alexandria City Centre

Floor area: 6000 m^2

Volume: 25000 m^3

Original use – present or future use: Original use was Mixed use commercial, administrative and residential. Current use has additional small low budget hotel and a bank. Future use Food & Beverage hub in additional to retail areas, a bank and a concept hotel.

Year: 1921

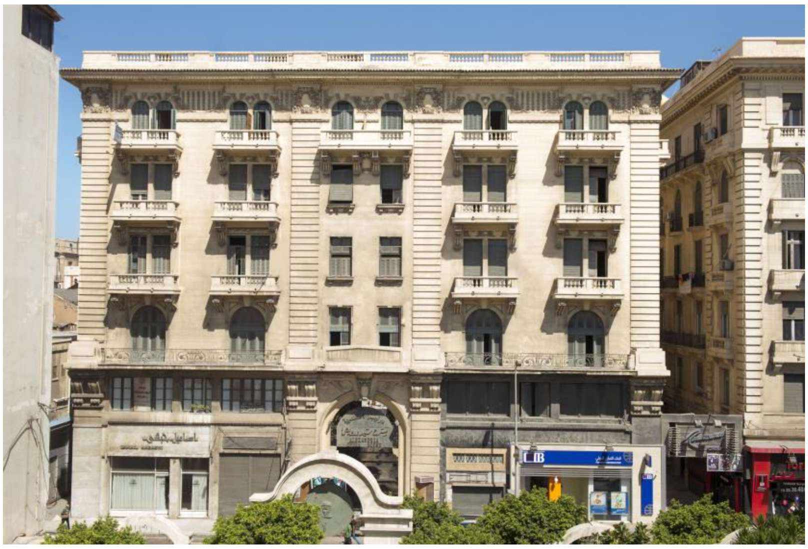


Figure 21: The Cordahi Building

Software Tools: namely, Autodesk Revit 2020, as native BIM software, and Design Builder, as Building Performance Simulation (BPS)

4.12.1 Data definition and organisation, planning of the tests

All 2D plans were reviewed in order to start work on a comprehensive 3D BIM model on Autodesk Revit.

All PC's or laptops were reviewed and checked for compatibility and Autodesk Revit 2019 for education was downloaded and set up on 2 separate machines in order to go through the modelling process.

All geometric survey drawings were prepared and reviewed as well as site verification of measurements to start modelling.

Previously prepared Cad drawings, including plans and elevations, are checked by the team members, modified and updated to match the real current state of the building, then inserted into REVIT project to start the modelling procedure.

In this project, The REVIT architecture template is used (version 2019), and the units are in meters. Also, any family creation is based on the REVIT family templates (version 2018 & 2019).

Then the strategy is as follow:

4. After the adjustments of levels, The CAD drawings are inserted in REVIT for modelling in refer to each level, followed by the creation of walls, floors, columns and ceiling.
5. Families are created and loaded into the project file, and finally placed.

6. Also, model in place is used in different parts of the buildings, especially decorative details along facades.

4.12.2 Check of the imported file in Design Builder

In the imported model to Design Builder, the floors and the stairs spaces were imported as separated rooms which will result in inaccuracy in the energy simulation results.

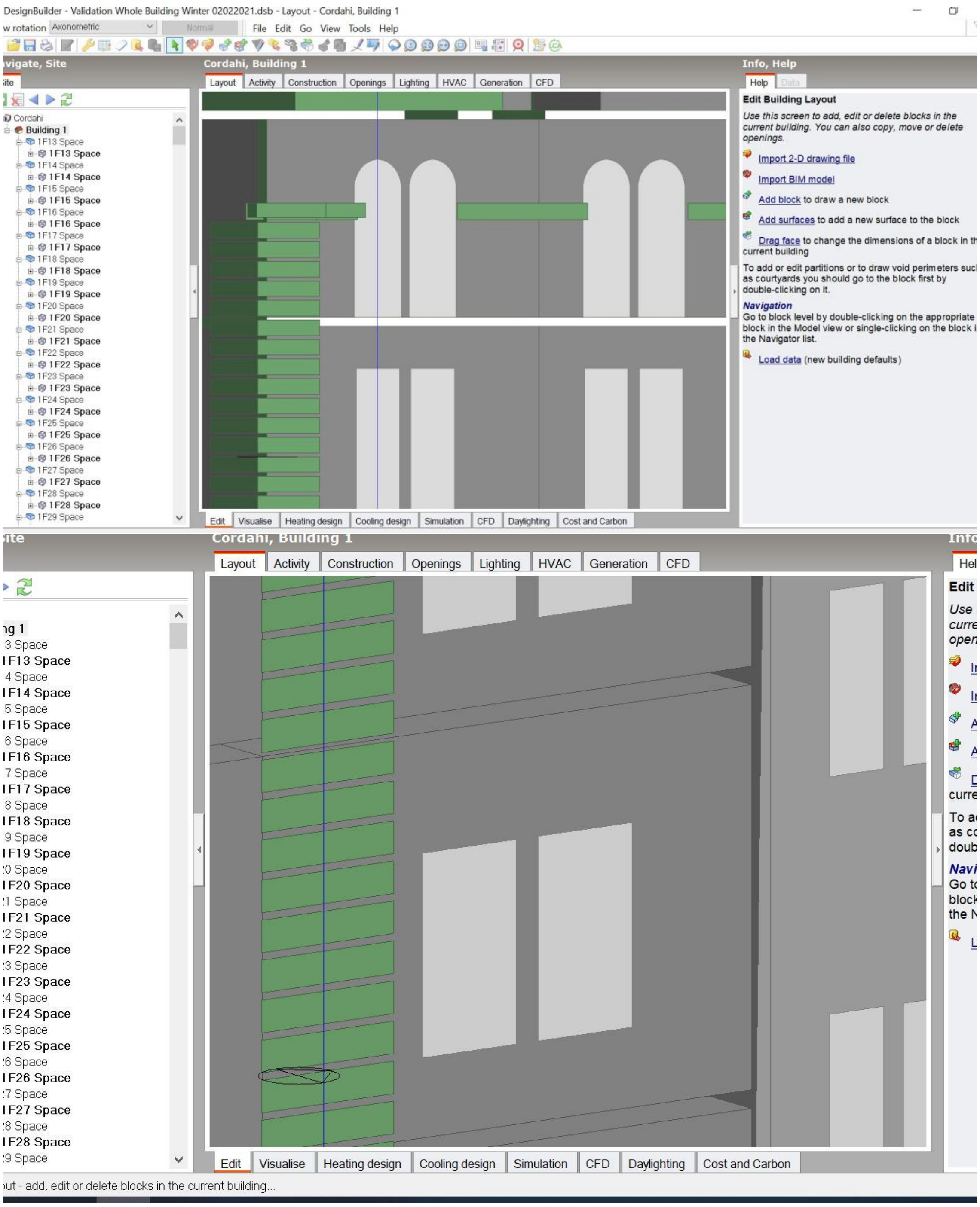


Figure 22:gbXML import to DesignBuilder

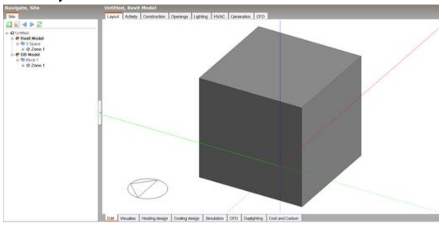
4.12.3 <u>Conclusions of the testing process</u>

There were some trials performed to ensure the accuracy of the model exported from Revit to Design Builder as follows:

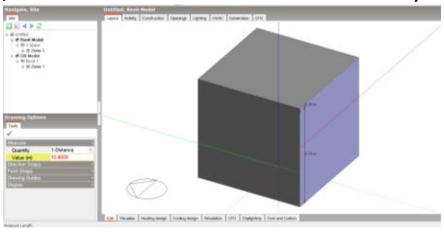
When the model was exported from Revit to DesignBuilder, the dimensions of the space changed, half (1/2) the width of the wall is subtracted from the space dimensions. Therefore, the following trials were performed:

- Find the factor for the difference of energy simulation of a modeled box in Revit then exported to DB, and a box modeled in DB.
  <u>Steps</u>:

1. Box with dimensions of (Outer dimensions: 10.8X10.8X10.4 m^3, net dimensions: 10X10X10 m^3) is modeled in Revit and then exported to DB. (Revit Model) - The outer dimensions of the exported box to DB changed to be (10.4X10.4X10 m^3)



2. Model another box with the same dimensions in DB. (Outer dimensions: 10.8X10.8X10.4 m3, net dimensions: 10X10X10 m3)

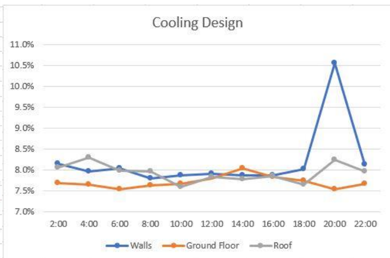


3. Assign the same material to both boxes. (Limestone- 0.4 m thickness)
4. Run energy simulation. (Heating and cooling design)
5. Comparing the results for the walls, Floor, and roof of the two modeled boxes.
6. Calculating the factor.

	Cooling Design (KW) (15th of July)											Heating Design (KW)
Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00	
	Walls											Walls
Revit Model	2.21	2.26	9.08	7.44	6.98	6.96	6.99	7.11	7.48	1.99	1.97	-10.36
DB Model	2.39	2.44	9.81	8.02	7.53	7.51	7.54	7.67	8.08	2.2	2.13	-11.2
Factor	0.081	0.080	0.080	0.078	0.079	0.079	0.079	0.079	0.080	0.106	0.081	0.081
	Ground Floor											Ground Floor
Revit Model	-4.29	-4.05	-2.52	-2.62	-2.61	-2.69	-2.86	-3.06	-3.23	-4.38	-4.56	0.64
DB Model	-4.62	-4.36	-2.71	-2.82	-2.81	-2.9	-3.09	-3.3	-3.48	-4.71	-4.91	0.69
Factor	0.077	0.077	0.075	0.076	0.077	0.078	0.080	0.078	0.077	0.075	0.077	0.078
	Roof											Roof
Revit Model	2.36	2.05	3.13	2.51	2.24	2.3	2.7	3.31	3.92	3.03	2.89	-3.06
DB Model	2.55	2.22	3.38	2.71	2.41	2.48	2.91	3.57	4.22	3.28	3.12	-3.3
Factor	0.081	0.083	0.080	0.080	0.076	0.078	0.078	0.079	0.077	0.083	0.080	0.078

Room Geometry Dimensions m2			
Revit Model	92.16		9.6X9.6
DB Model	100		10X10
Factor	0.085	8.5%	

	Cooling Design (KW) (15th of July)											Heating Design (KW)
Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00	
Walls	8.1%	8.0%	8.0%	7.8%	7.9%	7.9%	7.9%	7.9%	8.0%	10.6%	8.1%	8.1%
Ground Floor	7.7%	7.7%	7.5%	7.6%	7.7%	7.8%	8.0%	7.8%	7.7%	7.5%	7.7%	7.8%
Roof	8.1%	8.3%	8.0%	8.0%	7.6%	7.8%	7.8%	7.9%	7.7%	8.3%	8.0%	7.8%



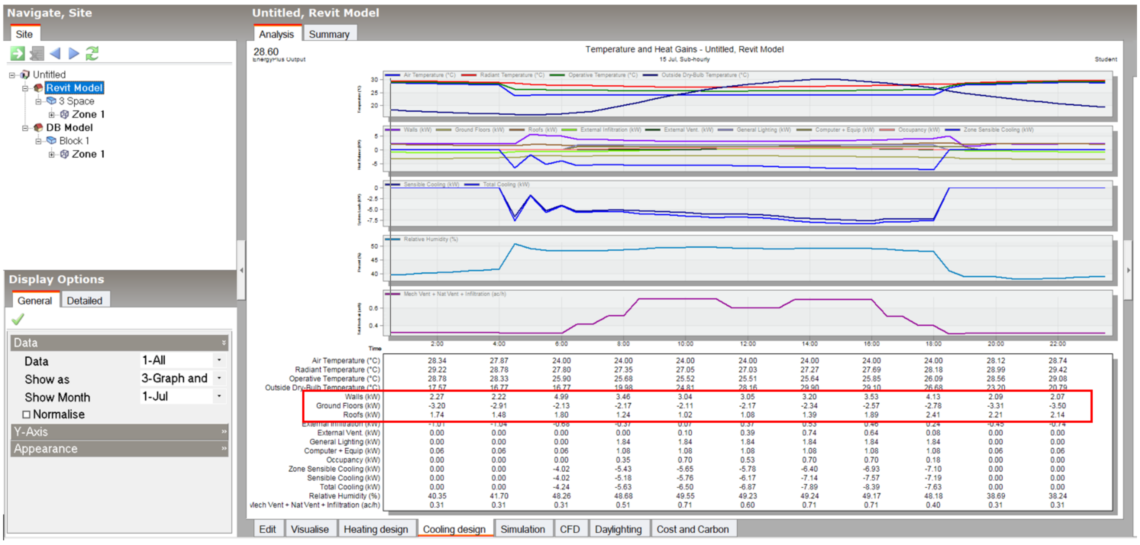
<u>Results:</u> The difference in the results of the energy simulation is similar to the difference in the dimensions.

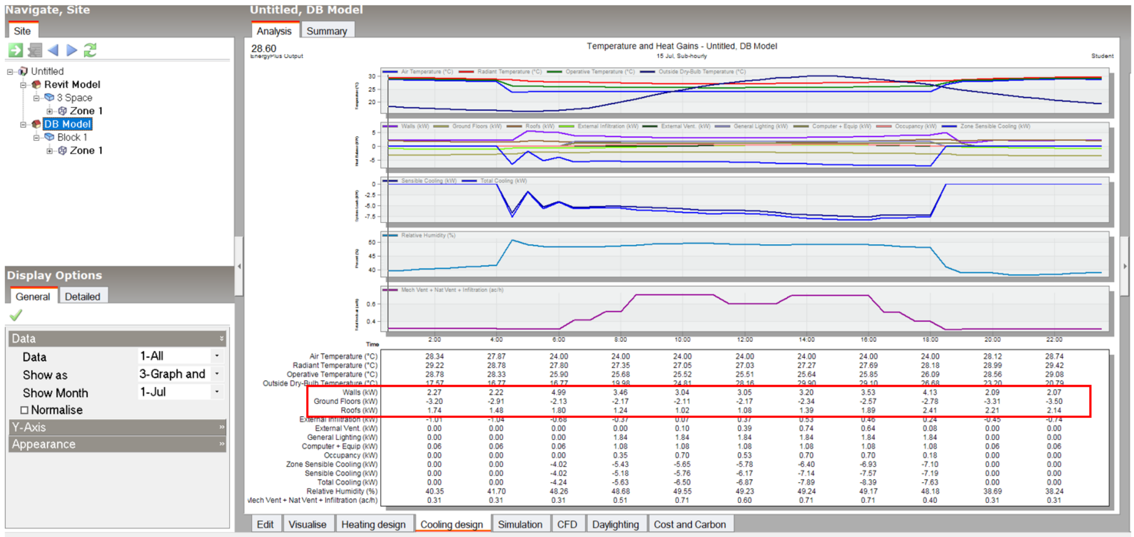
- Assigning materials in DB for both the modelled geometry in Revit and in DesignBuilder.

  <u>Steps</u>:

  1. Box with dimensions of (10X10X10 m3) is modelled in Revit and then exported to DB.
  2. Measure the dimensions of the imported box in DB to model another box with the same measured dimensions.
  3. Assign the same material to both boxes. (Limestone- 0.4 m thickness)
  4. Run energy simulation. (Heating and cooling design)

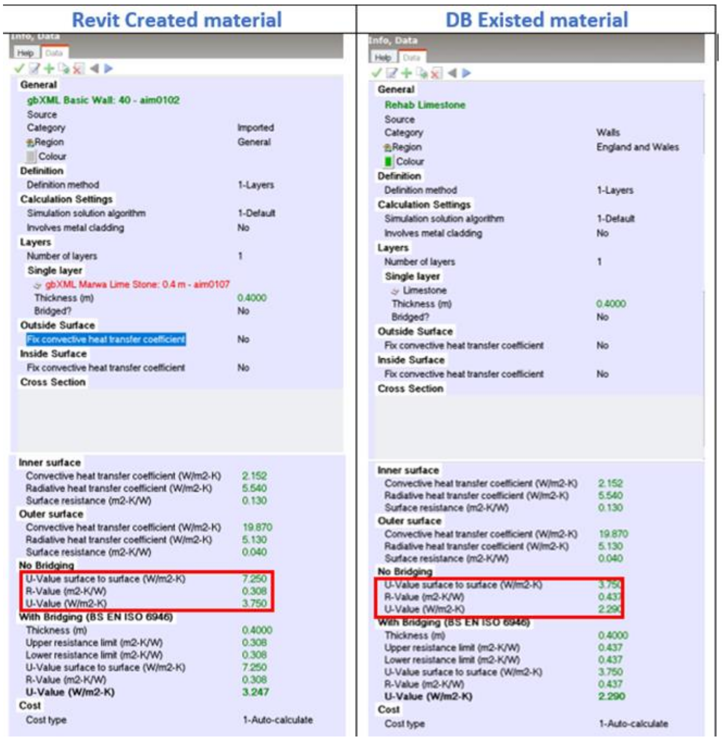
5. Comparing the results for the walls, Floor, and roof of the two modelled boxes





<u>Results</u>: Both have the same energy simulation results in DB.

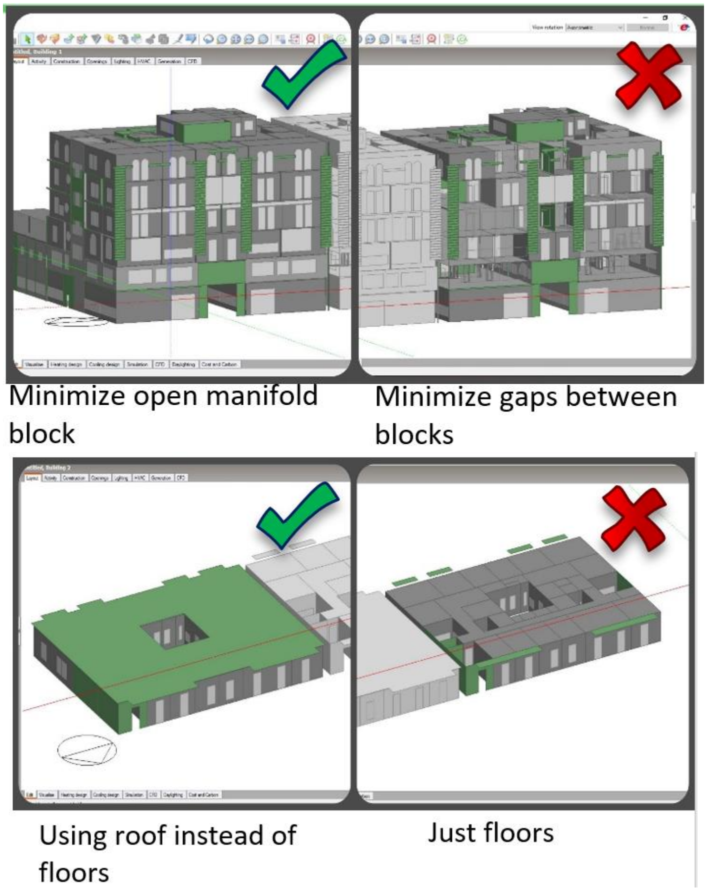
- Creating a new material (Limestone) in Revit, similar to an existing material in DesignBuilder (Limestone) with the same thermal properties.
  <u>Steps</u>:
  1. Choose a material in DB (Limestone) and find its thermal properties.
  2. Create a new material (Limestone) in Revit with the same thermal properties of the DB material.
  3. Build a model and assign the new material to the model in Revit.
  4. Export the model to DB.
  5. Check the U-value of the new material (created in Revit) and the basic material existed in DB.



Results: The same material existed in DB and the new material created in Revit have different U-values despite the fact that they both have the same thermal properties The box Geometry.

- Steps taken to try to seamlessly integrate BIM and DB
  - Exported BIM Model to Design Builder
  - Solved a lot of errors that occurred from the export procedure (as shown in the example figures down below)
  - Ran the simulation successfully

Using floors as balconies for shading | Using roof as balconies for shading



4.13 Main findings

- A good gbXML model can be achieved through several export test and respective BIM model correction.
- Wall join types and geometrical constraints of the involved building objects play a key role for avoiding open manifold blocks.
- All hosting elements with multiple number of openings, i.e., glass door with glass transom and additional narrow side windows should be modelled as separate family objects.
- Use ‘space’ elements instead of ‘rooms’ when exporting a BIM model which contains MEP objects.
- Pay close attention to ‘analytical tab’ dialogue box of the Revit gbXML exporter before exporting to gbXML.
- Automatic calculation of U-value from imported thermal properties is not always correct.
- The materials and activities properties should be rechecked in Design Builder as they are not correctly imported from Revit.

4.14 Limitations

- DesignBuilder does not support the IFC schema for importing a BIM model.
- The generated gbXML surface objects are by default computed based on walls, roofs, and slabs centrelines. This option may cause the creation of space dimensions out of scale.
- Walls composed of two separate wall families result as a spited gbXML surface with a narrow gab separating the two. This limitation disables the exporting of

unique architectural configurations, especially those usually encountered in heritage buildings.

5 REFERENCES

Gigliarelli, E., F. Calcerano, F. D'Uffizi, C. Di Biccari, G. Mangialardi, and M. Campari. 2019. 'From Heritage BIM to BPS, a Computational Design-Based Interoperability Approach'. In *Building Simulation 2019, Rome*. Rome.

Chen, Shisheng & Jin, Ruoyu & Alam, Mahmood. (2018). Investigation of Interoperability between Building Information Modelling (BIM) and Building Energy Simulation (BES). 9. 137-144. 10.1556/1848.2018.9.2.9

ANNEX 8.11: REFERENCE TEMPLATE FOR DYNAMIC ENERGY SIMULATION ANALYSIS

Index

1. GENERAL INTRODUCTION

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

1.1. General introduction of the software and the calculation method

Brief description of the chosen software and its main features like calculation method and regulatory compliance.

2. Model input data (ante-operam)

2.1. Introduction

Brief description of the input data used by the software.

2.2. Weather data

Brief description of the weather data, the data present, data format, source of data, choice of data and related reasoning.

2.3. Thermal zones and user schedule

Brief description of the thermal zone definition of the building and of the occupancy schedules used with highlights of the reasoning behind the thermal zones definition and the source of occupancy schedules.

2.4. Envelope and Interiors parameters

Brief description of the parameters of the envelope (exterior vertical and horizontal enclosures - opaque and transparent), interiors (if relevant) with reference to the Model Element Table (see Annex 7.7), and highlighting thermal bridges (if any) and how they are calculated (if they are).

2.5. Building Geometry

Brief description of how the abstract geometry of the energy model was reached from the real geometry of the building, also including specific reflections relating to the thermal representation of the historic building (simplification of complex elements, methods of working with the masses, etc.).

2.6. Building Systems

Brief description of the modelled systems (heating, cooling, lighting, ventilation, RES, storage etc..) and their modelling strategy.

3. Ante-operam Energy Model calibration

Description of the energy calibration strategy and of all the calculation, trial and errors, performed.

4. Ante-operam Energy simulation results

Description of the results of the ante-operam model including free running simulation results to help comprehend and evaluate the passive behaviour of the building including:

- comfort (just to check country regulatory compliance);
- global primary energy demand Ep,gl;
- energy performance consumption for each sources involved in the scenarios or for energy use;
- energy production from renewable energy sources (RES);
- Free running analysis of temperature and relative humidity in specific thermal zones (useful for the design of the intervention scenarios)]

5. Energy modelling and simulation results of the scenarios (post-operam)

Description of the input data for each energy and environmental improvement scenarios and of the yearly energy simulation results (and monthly - if useful) in terms of:

- comfort (just to check country regulatory compliance);
- global primary energy demand Ep,gl;
- energy performance consumption for each sources involved in the scenarios or for energy use (keep in mind to obtain data to ease the calculation of the related energy bills);
- energy production from renewable energy sources (RES).

5.1. Scenario n°1 (Short term) modelling and results

Description of the simulation results of the scenario[1].

[1] The number of the scenarios can vary, the short, medium and long term layout is just a reference

5.2. Scenario n°2 (Middle term) modelling and results

Description of the simulation results of the scenario.

5.3. Scenario n°3 (Long term) modelling and results

Description of the simulation results of the scenario.

6. Annexes

Depending on the software output: spreadsheets and the calculation performed

ANNEX 8.12 ANALYSIS OF ACTIVE AND PASSIVE ENERGY EFFICIENCY TECHNOLOGIES COMPATIBLE WITH BUILT HERITAGE

Index

1 Introduction

The reuse of historic buildings for public purposes is currently being increasingly encouraged by city authorities across Europe (Philokyprou 2014). Specifically, the reuse and adaptation of heritage buildings as museums and office spaces for the public administration is a very common practice in many European countries. For these architectural functions, the indoor microclimate is highly important (Jeong and Lee 2006) and recently became the focus of research in preservation of built heritage and retrofit interventions. Many strategies for the enhancement of the indoor comfort and the energy efficiency of buildings of these uses are developed and explored internationally (Pavlogeorgatos 2003; La Gennusa et al. 2008), in addition to the conservation of the building.

The European Green Deal, released in December 2019, captures the commitment of the EU to tackling climate change and among other actions, it prioritises energy efficiency in the building sector, as the largest single energy consumer (European Commission 2020). In this respect, EU has highlighted the importance of the digitalisation of the building retrofitting process – see European Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EC). In addition, the EU Green Deal highlights the need to boost renovation in order to meet the agreed energy efficiency and climate objectives, because of the very low annual rates of renovation of the building stock in Member States. Specifically, the annual renovation rate of the building stock varies from 0.4% to 1.2% in Member States. This rate will need to at least double to reach the EU's energy efficiency and climate objectives (European Commission 2019). As a consequence, to the above today, there is clearly a direction by all countries to reduce energy use in the existing building stock. The project EFFESUS (2016) reported that in Europe the percentage of buildings built before 1945 varies between 6.1% (Turkey) and 47.4% (Luxembourg), with a mean average value of 23.1%. Therefore, the impact of the historic building stock in terms of energy consumption and CO_2 emissions can be significant.

However, heritage buildings that are considered to have important architectural and cultural qualities worthy of preservation, are usually excluded from legislation regarding minimum energy performance requirements. The potential for retrofit of cultural heritage buildings is significant due to the current composition of the building stock in Europe and the preferred attitude of the public towards the older stock (Sodagar 2013). Over the last decades, there is a growing interest on the energy retrofit of historic buildings, as they do not always comply with contemporary concepts regarding thermal comfort (Martínez-Molina et al. 2016) and face the challenge of resilience in the light of climate change (Košir 2019a). Therefore, as entirely passively conditioned buildings are rarely attainable, a balanced interplay between passive and active building elements is often the final goal of an efficient retrofit strategy. *Passive systems* collect and transport heat by non-mechanical means, and operate on the energy available in the immediate environment. In contrast, *active systems* import energy, such as electricity, to power mechanical systems (e.g. heat pumps). Buildings that incorporate passive features combined with basic low tech active elements, e.g. fans, are termed *hybrid* buildings. Older buildings are capable of adapting to the new energy efficiency (EE) norms; therefore, the challenge is to achieve the desired effect without damaging the architectural and historical value of buildings, while retaining the feasibility of the investment (Ding 2013). The preliminary evaluation of the climatic potential of a buildings' location is a key tool for planning both the enhancement of passive design aspects and the effective upgrade of the insulation capacity of the building envelope. The incorporation of active systems or energy microgeneration systems are also gaining ground over the last years, yet integration issues may arise in the case of heritage buildings (Historic England, 2018).

Available design strategies and active energy systems should be considered with the objective to lower energy consumption while enhancing the comfort of occupants, although comfort is very difficult to quantify in exact values that satisfy everyone (Hegger et al. 2012). Indoor comfort includes a number of parameters of the indoor environment, such as temperature humidity, air quality, lighting and noise levels, as presented below. In this context, there have been attempts to study the indoor environment holistically (Bluyssen 2009). In BEEP, all aspects of comfort that can be improved should be considered by the designer when selecting scenario for implementation (as described in A_4.3.4). According to the ISO 7730 (2005) standard, thermal comfort is described as being "that condition of mind which expresses satisfaction with the thermal environment". Factors of thermal environment according to ASHRAE (2019) are metabolic rate, depending of the activity, clothing insulation, air temperature, radiant temperature, air speed and humidity.

Drawing on the above, and given the particularities and uses of the BEEP pilot buildings, this document presents in a comprehensive way, the relevant passive strategies employed in heritage buildings across the Mediterranean basin and the complementary active energy systems available for integration in the BEEP pilot buildings. In this aim, an overview of the passive design analysis tools and methods is presented; the potential integration challenges and opportunities of active systems in heritage buildings are outlined; and a number of cases of integration of active systems in heritage buildings are presented. County-specific reviews follow in the annexes. Particularly, each partner report expands in two chapters presenting: a) the potential of enhancing the passive design strategies in every case-study location and pilot building and b) an overview of the maturity of the market regarding active technologies applicable in the heritage building sector.

2 Passive design strategies

2.1 Tools and methods for passive design analysis

The understanding and appropriate interpretation of climate limitations and potentials, is a crucial step in the design of the energy retrofit process. The most widely used approach to analysing climate data with respect to the passive design of buildings is to assess the indoor environmental conditions that should be achieved in order to obtain occupants' comfort (Givoni 1969; Olgyay 1963; Szokolay 2014). The analytical method for climate analysis was introduced in the early 60s by the pioneers of the field, Olgyay (1963) and Givoni (1969). Olgyay (1963) was the first to attempt to devise the bioclimatic chart. In his bioclimatic chart, Olgyay related relative humidity (RH) with the dry bulb temperature (DBT), taking into consideration the impact of the solar irradiance and air movement. However, Olgyays' chart was suggested for lightweight buildings located in humid regions where indoor and outdoor temperatures are close, therefore its applicability is limited.

Givoni (1969) and Milne and Givoni (1979) proposed a chart that adopts the psychometric format, overlaying it with hourly weather data of a location. Designated ranges of temperature and relative humidity mark the "comfort zone", where most of people would feel comfortable. If local outdoor temperatures and humidity fall outside the "comfort zone", the potential applicability of selected bioclimatic measures (e.g. passive solar heating, natural ventilation, high thermal mass, etc.) is recommended. The particular chart has been modified though the years in order to incorporate additional insights and improvements. However, it should be noted that it provides a partial description of conditions required for comfort, neglecting other environmental variables (e.g. radiant temperature and airflow rate), as well as clothing and activity (metabolic rate). While environmental based criteria describe relatively universal requirements in which all humans feel "comfortable" (rational or heat balance approach – Fanger (1970)), a varying tolerance for discomfort is noted, depending on age, sex, health, cultural conditioning, and expectations (adaptive thermal comfort approach – de Dear and Brager (2002)). The latest revision of the chart by Givoni himself (1998) extends the acceptable indoor comfort parameters in regions where due to economic, social and/or climatic circumstances a larger range of temperatures are acceptable by the occupants (Figure 1). This version is the one most often used today (Desogus, Felice Cannas, and Sanna 2016; Manzano-Agugliaro et al. 2015; Katafygiotou and Serghides 2015).

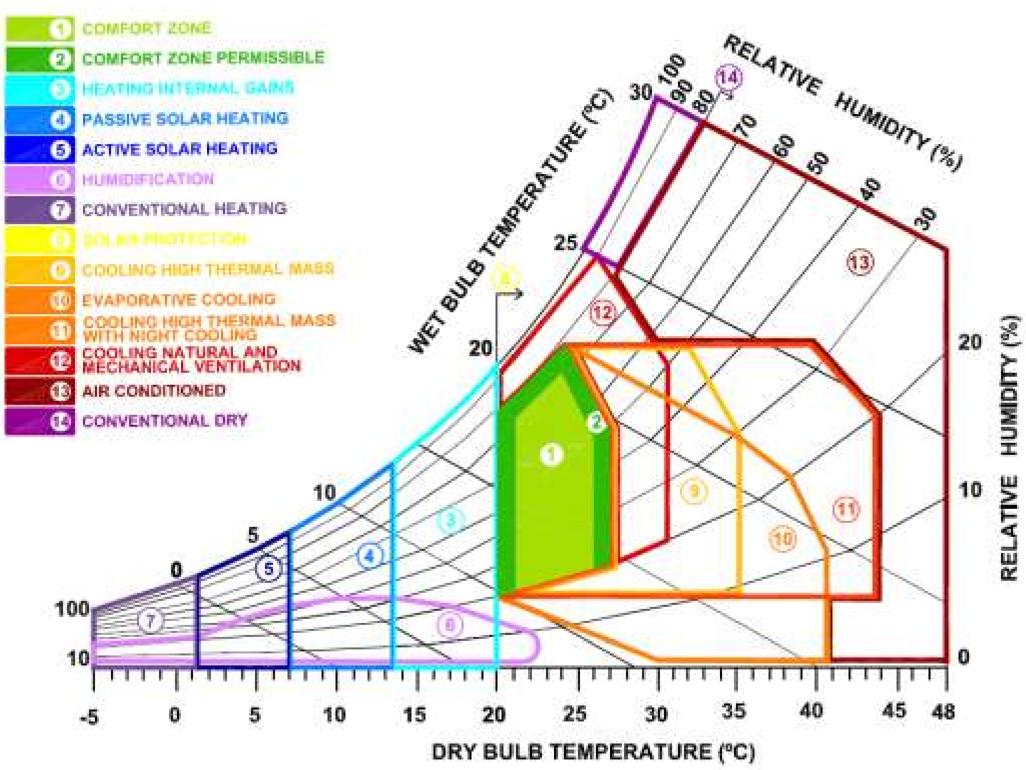


Figure 1: The Givoni chart as presented in Manzano-Agugliaro et al. (2015).

Computer-based simulation and energy design tools make it possible to utilise site-specific hourly weather data to analyse data for bioclimatic design. Climate Consultant 6.0 (University of California 2017) is a digital tool for analysing locations' climate characteristics, which uses a Givoni's chart as a basis. In order to address the solar irradiation parameter in the calculation, it overlays the values of received irradiation onto the displayed data points in the psychrometric diagram. By plotting minimum and maximum daily temperatures on Givoni's chart (or Olgyay's) an evaluation of the diurnal temperature variation is possible. This is a valuable information regarding the applicability of various passive strategies (e.g. night cooling). A more effective solution on how to incorporate this aspect in a bioclimatic chart was provided by Evans (2003). Evans introduced the comfort triangles bioclimatic chart, which is a quasi-dynamic evaluation of climate parameters based on the relationship between the average temperature and the average diurnal temperature variation.

Concluding on the outlined limitations and virtues of the bioclimatic potential analysis, it is highlighted that the use of the bioclimatic charts should be viewed primarily as a climate evaluation tool and not as a building design tool (Košir 2019b). However, the results of this analysis are extremely valuable if implemented appropriately, and may influence substantially decisions regarding the energy retrofit approach.

2.2 Main passive design strategies across the Mediterranean region

The term *passive system* was adopted in the early 1970s to describe thermal delivery systems that are driven by natural phenomena and without power-driven mechanical devices. Edward Mazria, in his Passive Solar Energy Book (Mazria 1979), defines a passive solar heating or cooling system as 'a system in which the thermal energy flows naturally by means of radiation, conduction and convection'. In temperate climates passive design aims at providing heating during the heating period (winter), whilst avoiding overheating during the cooling period (summer). Passive heating involves the distribution, storage and conservation of collected solar energy. Accordingly, passive cooling involves overheating prevention, mainly through shading and ventilation (Norton 2014). These processes are illustrated in Figure 2.

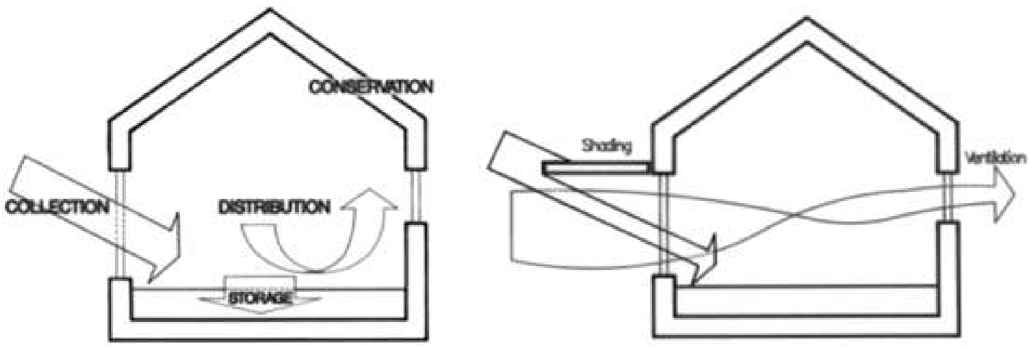


Figure 2: Passive solar energy collector (left) and overheating avoidance (right) in temperate climates. Source: Norton, 2014.

2.2.1 Natural ventilation

Built vernacular architecture incorporates numerous possibilities for enhancing natural airflow. This is achieved by exploiting wind and buoyancy-driven pressure differences, which often have a combined effect (Gładyszewska-Fiedoruk and Gajewski 2012). The wind induces a pressure distribution on the building envelope, which is determined by wind speed and direction, the building shape and nearby obstructions. Apart from wind, differences in temperature and hence air density create an imbalance in the pressures of interior and exterior air masses, thus creating a vertical pressure gradient.

Passive solar buildings with conservatories or atria often ultimately rely upon ventilation and infiltration to provide the medium of heat transfer. Ventilation and infiltration are both dependent upon a) the wind speed and direction, b) the temperature difference between the building and the ambient environment, c) the aerodynamic shape of the building, d) overall building airtightness (type and position of openings) and e) surrounding topography and obstructions. A designer may, given appropriate analytical tools, use these effects to optimise air flow (Allard 1998; Aynsley 2007; Grosso 1997; Asimakopoulos 1996; Lechner 1991).

2.2.2 Thermal mass

The transient characteristics of thermal response of the building and its envelope is crucial for appropriate evaluation of the building's energy balance. In fact, a number of passive design strategies such as passive solar heating and night-time ventilation, are based on the transient behaviour of buildings (DeKay and Brown 2014). The employment of thermal mass can reduce the peak heating or cooling load (Ahmad et al. 2006), and subsequently the building energy consumption of buildings.

In order to evaluate the thermal inertia effect, two dynamic indicators are widely used: the time lag and the decrement factor (Asan 2006; Kontoleon and Eumorfopoulou 2008). The time lag depicts the heat transmission delay, i.e. the time needed for the heat wave of a specific period to propagate from the outdoor to the indoor surface of a wall. Figure 3 shows the benefit of a massive building compared to a lightweight one in terms of potential reduction of cooling and heating loads (Asimakopoulos 1996).

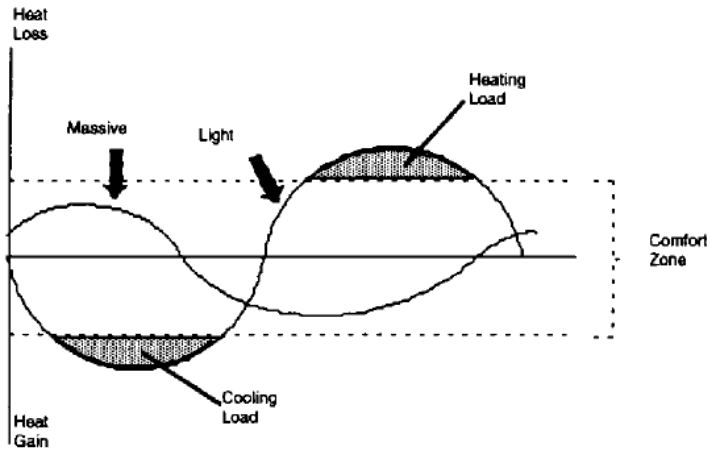


Figure 3: Daily Building heating and cooling loads for buildings of massive and light construction. Source: Asimakopoulos, 1996.

The decrement factor defines the reduction of indoor temperature oscillations in comparison to the external temperatures – Figure 4 (Košir 2019a). Heavy mass buildings exhibit large thermal lag (i.e. 8–12 h) and substantial decrement factor resulting in relatively constant and comfortable indoor temperatures (Ogoli 2003).

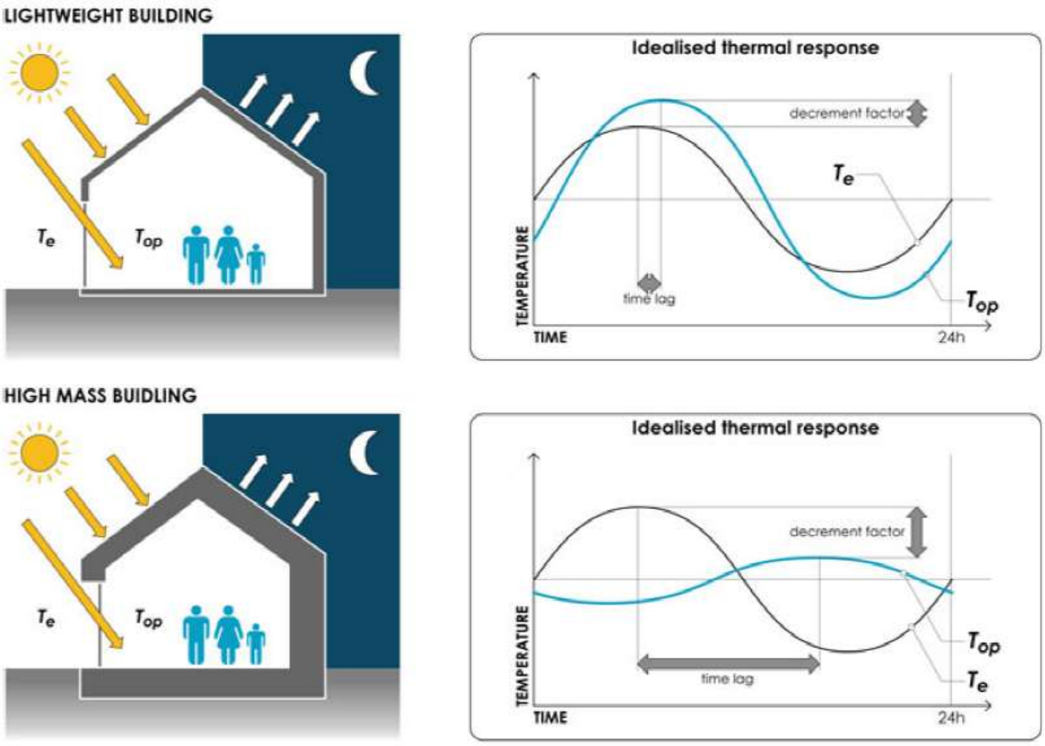


Figure 4: Idealised thermal diurnal performance of extremely lightweight (top) and high mass (bottom) building. Te and Top correspond to outdoor and indoor temperature respectively. Source: Košir 2019.

Contrary to high mass buildings, an extremely lightweight building with an envelope composed of materials with high thermal conductivity (λ in W/(mK)) and low density (ρ in kg/m^3) and specific heat (Cp in J/(kgK)) would represent almost no obstruction to the transmission of heat. Therefore, indoor temperature during the day would be expected to be higher than the external air temperature due to the added effect of solar radiation (Haggard, Bainbridge, and Aljilani 2010). The situation would be reversed during the night because of radiative losses of the building envelope to the night sky. The application of thermal insulation to a lightweight building results in a considerable improvement of the thermal performance and consequential energy use. However, the time lag and decrement factor are less affected by the addition of an insulation layer. Consequently, a lightweight insulated building envelope will provide inferior indoor thermal conditions comparing to a high mass insulated building (Košir 2016).

2.2.3 Reduction of thermal losses

In order to reduce thermal losses during the heating period, the following measures are suggested:

- Minimize conductive heat flow. This strategy is achieved by using insulation (further in chapter 4).
- Minimize infiltration. "Infiltration" refers to uncontrolled air leakage around doors and windows and through joints, cracks, and faulty seals in the building envelope. Infiltration (and the resulting "exfiltration" of heated or cooled air) is

considered the largest and potentially the most intractable source of energy loss in a building, given that insulation measures have been taken (Donald Watson 1989).

- Creation of buffer zones: Additional measures inhibiting thermal losses is the proper distribution of low-use or auxiliary spaces in order to provide climatic buffers and subdivide the interior creating separate heating and cooling zones (Donald Watson 1989).
- Minimize winter wind exposure: Winter winds increase the rate of heat loss from a building through accelerating the cooling of the exterior envelope surfaces by conduction, and also by increasing infiltration (or more properly, exfiltration) losses (Donald Watson 1989). The use of windbreaks is commonly used reduce the impact of such winds. Two design techniques serve this function (Allard 1998):
  a) the use of neighbouring landforms, structures, or vegetation as a physical barrier for winter wind protection, and
  b) proper building form and orientation that minimizes winter wind turbulence.

2.2.4 Internal gains:

Internal gains are provided by people who occupy the space, artificial lighting, any machinery that generates heat energy and any process that might also generate heat. All humans emit heat to their surroundings due to their metabolic activity, which is related to the activity that is performing (i.e. sedentary, sleeping, etc.). The heat can be released as sensible or latent heat. Accordingly, the electrical energy used by lighting or equipment (computers or other domestic appliances) is ultimately released as heat. The energy is emitted by means of conduction, convection or radiation. Internal gains are important in order to modify the indoor temperature and provide comfort, especially during mid-seasons.

2.2.5 Passive Heating

- Direct solar gains. Early approaches of passive design concerned primarily direct solar radiation harvesting (beam radiation). The strategy of direct solar gain in its simplest form, refers to the practice of orientating windows, sunspaces or other integral conservatories towards the south (in northern hemisphere) (Norton 2014). The ancient Greeks were aware of the principles of passive solar design, while the Romans enacted laws to protect a building's access to the sun (Hakim 2008) that are accessible in actual technical treatises (Xenophon IV sec B.C.; Vitruvius Marcus Pollio 15AD). Passive heating from direct solar gain incurs little or no extra cost and it is a simple, self-functioning operation.

  Passive solar features on buildings are frequently at ground level. In urban locations exhibiting high housing densities, a dwelling may often experience levels of over shading at lower sun angles by neighbouring buildings. In this way, ground-floor passive solar elements may often prove ineffective. On the contrary, roof-space windows do not cause loss of privacy as can be the case with the large glazed areas. However, in this case, there is a high risk of overheating, not only in the summer but also towards the end of the heating season (Givoni 1998a). With fixed shading devices, the seasonal geometry of solar radiation permits some control of unwanted solar radiation. However, care must be given to the orientation, inclination and the geometry of fixed overhangs and fins.

- Indirect solar gains: Besides the impact of direct solar radiation, heat can be stored in building elements when: a) they accept radiant heat emitted by the building space which has direct solar gains, e.g. the ceiling of a room whose floor accepts direct solar radiation, or b) when the elements are heated by heat transfer through the movement of the hot air. The last method is less efficient; however, it consists the main heat transfer method to remote building places (e.g. isolated gains form a sunspace)(Donald Watson 1989). Energy storage in the walls, ceilings and floors of buildings can be enhanced by encapsulating suitable phase change materials (PCMs) within these surfaces (Saffari et al. 2017) (further in chapter 4).

2.2.6 Passive cooling

The term 'passive cooling' was defined by (Cook 1989) as any building design technique that not only combats outdoor heat, but also transfers indoor heat to natural heat sinks such as the sky (upper atmosphere), the atmosphere (ambient air) and the earth without the use of motorised mechanical components (Cook 1989). By contrast, (Givoni 1994) puts more emphasis on the architectural and climatic issues involved in the utilisation of the same natural heat sinks. According to Mathaios Santamouris and Asimakopoulos (2013), passive cooling broadly covers all the measures and processes that contribute to the natural control and reduction of the cooling needs of buildings. It includes all the preventive measures to avoid overheating in the interior of buildings, as well as strategies for the transfer of internal heat to the external environment, whether generated within the interior or entering through the envelope of the building. The fundamental strategies for enhancing passive cooling are outlined below:

- Ensure shading. As midday solar altitude angles are much higher in summer than in winter, it is possible to shade windows during the summer period, without preventing winter solar heat gain. Widespread shading techniques refer to the following:
  a. Minimize reflectivity of ground and building surfaces outside windows facing the summer sun.
  b. Use neighbouring landforms, structures, vegetation or special architectural elements such as semi-open spaces (porches and galleries).
  c. Shape and orient the building envelope accordingly, in order to minimize exposure to the summer afternoon sun (West).
  d. Provide seasonally operable shading, including deciduous trees.

- Promote ventilation. Cooling by air flow is succeeded by two natural processes, cross-ventilation (wind driven) and stack-effect ventilation (driven by the buoyancy of heated air, even in the absence of external wind pressure (Allard 1998; Aynsley 2007). Key points and architectural elements can be noted regarding this strategy:

a) Occupant interaction with the building envelope: Given that the temperatures of the external environment during noon and afternoon are higher than the ones of the indoor environment in the summer, it can be deduced that applying day-time ventilation is not beneficial in terms of heat exchange. Yet, it might be associated with the preference of increased air movement or a series of driving forces regarding physiological, psychological, social, environmental and contextual background (Fabi et al. 2012). Thus, having energy-aware occupants is a great asset in the management of various passive design strategies, ventilation being the most important one. As Berg et al. (2017) point out, users should be involved in actions aiming to raise awareness regarding the values of the historic buildings; which in turn, may be a driver for raising awareness also in terms of energy. In this way, they can actively become part of the energy improvement decision-making process.
b) Solar chimneys: Solar chimneys are passive solar thermosyphonic systems enhancing natural ventilation in buildings removing indoor air by stack-effect. Besides day-time use, a solar chimney with massive heat storage walls is a natural ventilation device able to extend operation long after sunset, or exclusively be used for night cooling of internal environments (Koronaki 2013). Such a cooling operation scheme is particularly effective in hot and dry places. Calcerano et al. (2017), investigated the potential of coupling natural ventilation and thermal storage systems to improve hygrothermal comfort and reduce energy consumption during summer season in an existing building in the Mediterranean. For the thermal chimney the study estimated a discomfort hours reduction potential between 61,5% and 26,20% and an energy reduction potential between 58,28% and 6,36% depending on the thermal mass of the simulated building and the climate context.
c) Windcatchers: A windcatcher is a roof-mounted device that supplies fresh airflow into a room and expels indoor air under the action of wind pressure and buoyancy forces. During the daytime, by the movement of external wind at roof level, a positive pressure on the windward side of the structure and at the same time, negative pressure on the leeward side are produced. This pressure difference is highly sufficient to deliver fresh air to indoor space and extract stale and warm air out. During night-time, in the absence of air movement or in low wind conditions, the windcatcher device operates using the natural buoyancy of thermal forces like a chimney (Jomehzadeh et al. 2017). (Ghadiri, Ibrahim, and Dehnavi 2011) found that a vernacular windcatcher with height of 6 m has potential to decrease the air temperature from 25 °C to 21 °C in hot and dry region of Yazd. Jomehzadeh et al. (2020) provides a recent review of the impacts of geometry, microclimate and macroclimate on the performance of a windcatcher. According to their results, windcatchers with a square cross-section and curved roof demonstrate better ventilation in the room compared to other configurations. It is also highlighted that the integration of a windcatcher with other natural ventilation systems such as solar chimney and wing wall has a

considerable effect on the ventilation efficiency (Jomehzadeh et al. 2020) (further in chapter 4).

- Enhance radiant cooling (night-time ventilation): The effectiveness of night ventilation consists in the circulation of colder nocturnal air in the building which removes excessive heat and consequently reduces the rate at which the internal temperature rises during the following day (Givoni 1998b). The suitability of this strategy is attributed to climates with high daily air temperature fluctuations and relatively low night temperatures (Mat Santamouris 2006; Givoni 1994; Shaviv, Yezioro, and Capeluto 2001). Blondeau, Spérandio, and Allard (1997) analysed experimental results and showed that night ventilation succeeded in decreasing the diurnal indoor air temperatures from 1.5 to 2°C, even when the average daily air temperature fluctuation was 8.4°C. Similar results were derived from the analysis of raw data collected in a traditional dwelling in Cyprus, with the external air temperature fluctuating about 8°C (Michael, Demosthenous, and Philokyprou 2017).

  An extensive review of night ventilation research undertaken in the last 20 years is provided by Solgi et al. (2018). According to the reviews' conclusions, it is highlighted that in order to optimize night ventilation systems, coupling with other passive or active systems is of paramount importance. Such systems are wind-catchers (Jomehzadeh et al. 2017), earth to air heat exchange systems, atriums or other novel thermal energy storage like phase change materials (PCMs) (Saffari et al. 2017) (further in chapter 4).

- Promote evaporative cooling. Water utilization as a heat sink in evaporative cooling technique has been applied for centuries in the Middle Eastern countries such as Iran, Egypt and Jordan (Saadatian et al. 2012). The main concept is providing evaporating moisture into the incoming air through various means:
  a) Evaporative cooling towers: This element works well in arid conditions enhancing the mechanism of natural ventilation, by using gravity to drive air flow without wind or fans in order to cool and humidify air(DeKay and Brown 2014). The cooling tower can also operate as updraft shafts for stack-ventilation during the day when outdoor air is cooler than indoor air or at night while employing night-time ventilation (Ford et al. 2012).
  b) The use of underground water canal known as Qanat is another traditional technique used for evaporative cooling. This is integrated with windcatcher design to decrease the air temperature and to humidify the indoor environment. Warm dry air enters the underground water channel and travels distance to reach the building. During this passage, the interaction between warm air and cool water causes the evaporation of water which leads to decreasing in air temperature. On the other side, wind blowing around the windcatcher causes a negative pressure on the leeward side of the opening which exhaust the warm indoor air and replace with fresh cooled air coming from Qanat (Hughes, Calautit, and Ghani 2012).
  c) Humidification can be achieved using exterior vegetation, water ponds or fountains), patios complemented by the presence of water and vegetation

that help to reduce the temperature and increase the relative humidity by conducting an evapotranspiration process.

2.3 Lessons learned from vernacular architecture

Indigenous and long-established building practices employed by vernacular architecture have slowly been perfected in traditional societies (Yannas and Weber 2013; Noble 2007; Rapoport 1980). Indeed, vernacular forms incorporate passive design strategies that are specific to a given climate, site, building function and use. Yet, they were also shaped according to prevailing cultural and architectural preferences (Rapoport 1980). The elevated degree of climatic adaptability of vernacular heritage has been documented in various studies (Zhai and Previtali 2010; Cook 1997; Vellinga, Oliver, and Bridge 2008) among which the emblematic work of Oliver (1997) and Coch (1998) who describe the interrelation of vernacular forms and climate worldwide.

Building orientation and compactness is a prime consideration in order to reduce its exposure to the intensity of the sun (Fathy 1986). Earth sheltering (or earth-contact) techniques such as banking earth against the walls of a building or covering the roof, have a number of climatic advantages; e.g. thermal storage and attenuating indoor temperature fluctuations (daily and seasonally), wind protection and reduction of envelope heat loss or gain (winter and summer). Examples of vernacular subterranean settlements can be found from Matmata in Tynisia, Matera in Italy, Guadix in Spain and Cappadocia in Turkey (Vegas et al. 2014).

The courtyard has been among the most prevalent architectural typological elements in the Mediterranean and the Middle East (Dipasquale, Mecca, and Picone 2014). Besides the socio-cultural value of this space, many studies confirm that the presence of the courtyard contributes to a significant reduction in the cooling load during the warm months (Almhafdy et al. 2015; Ghaffarianhoseini, Berardi, and Ghaffarianhoseini 2015). Courtyard houses prevail in temperate and hot climates. The prime bioclimatic virtues of this typological element concern the enhancement of natural ventilation, shading through the seasonal vegetation and evaporative cooling employed through the watering of plants and the common practice of wetting outdoor floor surfaces (Philokyprou et al. 2017). During summer nights, cool air descends into the courtyard and the surrounding rooms. The building structure is therefore cooled, ensuring lower temperature levels during the next day. Proper vegetation in the courtyard prevents the sun from reaching the building envelope and the courtyard floor. Thus, heat flow from the exterior to the interior is retarded, also depending on the thermal mass of the walls. By late afternoon, the courtyard floor and the indoor rooms become warmer, as most of the trapped air escapes by sunset. After sunset, the air temperature drops rapidly and the courtyard begins to radiate heat to the clear night sky. Cool night air then begins to descend into the courtyard, completing the diurnal cycle.

Several studies focus on environmental design strategies applied in Mediterranean vernacular architecture (Correia, Dipasquale, and Mecca 2014). (Cañas and Martín 2004) state that the main strategy adopted in the Mediterranean coast of Spain was protection against solar radiation through proper orientation of the building, shading systems, small openings, light colouring of the façades and use of proper vegetation.

Bioclimatic design strategies, and respective guidelines for regions in Greece with dominant Mediterranean climatic conditions were drafted reported by Kolokotroni and Young (1990). According to this study, the proposed strategies for areas located in the Mediterranean basin included the southern orientation of buildings, compact building form, movable shading devices and light-coloured external surfaces. A series of alternative scenarios for heat capacity, insulation protection level and size of openings were also presented in the aforementioned study. According to (Imessad et al. 2014), in Mediterranean climates like northern Algeria, the combination of different passive cooling techniques such as insulation, thermal mass, window shadings and night ventilation is the most effective practice from both the points of view of energy savings and indoor thermal comfort.

In the hot and arid regions of Iran the main domestic vernacular passive cooling systems are: thick adobe walls, semi open spaces (iwans and loggias), underground rooms, windtowers, domes, and air vents; all indicating an intimate knowledge of the environment, as well as a sophisticated indigenous building technology. The seasonal use of rooms, the feature of courtyard and vegetation as well as the extensive utilization of the roof (e.g. for sleeping) are simple solutions to the extremes of a hot (and cold) arid climate (Foruzanmehr 2018). Schoenauer (2000), suggests common passive cooling methods in the Middle East: water features and plants in the courtyard, semi-open living spaces, wind-catchers, high ceilings, shading devices and compact houses. Semi-open spaces, such as porticos or eyvan[1], verandas and galleries, were oriented to take advantage of the climate. Wind traps, equipped with cooling jars and linked to a vertical air duct, brought fresh and humidified air into the dwelling and helped in general to create better air circulation in the house. A disproportionately high ceiling in the living rooms enhanced air circulation. By sitting at floor level, the occupants enjoyed the coolest indoor environment.

Summarising the strategies employed by vernacular architecture in the wider Mediterranean region:

Building Geometry and layout- B

1. central courtyards with greenery, vegetation and water features;
2. underground living spaces;
3. semi-open living spaces (e.g. talars, eyvans, loggias);
4. high thermal mass (e.g. thick stone or adobe masonry);
5. domes and vaulted roofs;
6. wind-catchers[2];
7. vertical air vents;
8. building form that reduces wind turbulence;
9. distribution of interior rooms in order to create buffer zones.

Occupant behavior - O

1. sleeping on rooftops;
2. seasonal use of rooms (i.e. different summer and winter living spaces);
3. watering of courtyards or/and outdoor paving surfaces

[1] recessed porticos with open arches facing the courtyard or the interior patio
[2] e.g. “Badgir” in Iran, “Malqaf” in Egypt, “Barjeel” in Iraq and the Gulf, “Bating” in Syria (Jomehzadeh et al. 2017)

Microclimate – M

1. Use of vegetation as a) wind barrier, b) shading element, or c) buffer zone;
2. Use of water elements;
3. Finishing flooring materials with low reflectivity and high thermal mass (e.g. earth, stone)

Urban design - U

1. proper building orientation;
2. compact urban texture/fabric;
3. twisting and covered streets.

3 Contemporary challenges in the integration of active systems in heritage buildings - international restoration framework.

Energy efficiency refurbishments of historic buildings began to emerge in the late 1970s' and early 1980s', as a consequence of the two oil crises, which created an unprecedented interest in energy retrofit (Martínez-Molina et al., 2016). A more global approach, through the scope of sustainability, was introduced through the proceedings of the Faro Convention, released in 2005 (COE 2005) and marked the time when reducing energy consumption in built heritage, during conservation process, became a challenge for researchers (Vieites, Vassileva, and Arias 2015). However, until today, historic buildings and monuments that are officially protected due to their special architectural or historic merits, are excluded from attaining energy performance requirements ('Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast)' 2010). Despite the lack of a regulatory framework for minimum energy performance requirements in historic dwellings, the potential of energy savings and emissions' reduction by retrofitting the particular building stock has been widely acknowledged. This is achieved through the work of several research programs (e.g. SECHURBA, CLIMATE FOR CULTURE, 3ENCULT, RIBUILD, EFFESUS) and studies (Historic England 2018; Gigliarelli, Calcerano, and Cessari 2017; AA. VV. 2020; MIBACT 2015; GBC 2017; A. (EURAC research) Troi and Bastian 2014) that have been carried out over the last years (see also the selection of recent European research project in the 3.1 BEEP Output, par 6.1, AA. VV. 2020).

The use of contemporary materials and techniques, such as steel and glass, is often adopted in architectural intervention and energy retrofit projects. This practice is in line with international principles on conservation as the new additions differ from the original fabric, and, at the same time, establish an interesting impact in the aesthetic value of the existing structure. Universally recognised principles on conservation promote changes with reversibility and minimum impact on the authentic fabric (the Burra chapter - ICOMOS (1999)). Emphasis is given in preserving the morphology and typology of heritage buildings and thus highlighting the principle of integrity in terms of material selection (The Venice Charter - ICOMOS (1964)). Environmental and social aspects in conservation are highlighted in the Declaration of Amsterdam (ICOMOS 1975), as well as in more recent documents, such as Faro Convention (COE 2005). Critical views regarding authenticity and cultural values embayed on the material expression of heritage artefacts are discussed in the Nara document (1994). A brief summary of the principles outlined in the main conservation charters is provided by Carbonara (2017). As mentioned, energy improvements in historic dwellings should cater for:

a) *minimum intervention:* the energy improvement design should aim at preserving the original material as much as possible and avoid unnecessary interventions;
b) *reversibility:* the interventions must be reversible in the future, whenever possible;
c) *distinguishability:* new works should be distinguishable against the existing one;
d) *physical-chemical and figurative compatibility:* the interventions must guarantee compatibility between ancient and new materials, new design solution and historical and architectural features. This applies also to energy improvement project (for example, understanding the building's bioclimatic functioning - also through historical and architectural insights on the technologies used - is vital to reconstruct and optimise its passive behaviour);
e) respect for the material and figurative authenticity of the building.

The challenge of integrating Renewable Energy Sources (RES) technologies in a sensitive historic context consists in promoting reversible and compatible technologies that will increase the economic value and avoid any kind of damage. The installation of solar panels e.g. is critical as their presence is not always coherent with the historical building in terms of aesthetics, colours, shapes, dimensions and surfaces (Lucchi et al. 2014). According to the Washington Charter of ICOMOS (1987) (Article 8), "*new functions and activities should be compatible with the character of historic town or urban area*". Furthermore, "*adaptation of these areas to contemporary life requires the careful installation or improvement of public service facilities*". Active solar systems are considered as contemporary elements. Thus, according to Article 10 of the same charter, these "*should be in harmony with the surroundings*" and should not be discouraged since (they) can "*contribute to the enrichment of an area*"(ICOMOS 1987; Bougiatioti and Michael 2015).

4 Active technologies & innovative materials for heritage building integration

According to the EU Strategy on Heating and Cooling (European Commission 2016), the two main pillars for integrating efficient heating and cooling into EU energy policies are: a) the prevention of energy leakage from buildings, and b) the maximisation of the efficiency of heating and cooling systems. A third pillar, which is a key point in reaching nearly zero energy consumption in buildings is the incorporation of innovative technologies for the production of energy from renewable sources. The groups of relevant technologies and solutions that can contribute to this aim are summarised below:

- ***Energy management;***

  This is mainly a diagnostic tool as actions can easily be taken, when the energy production and the technical systems are identified and quantitative information about the energy use of the different energy consumers, e.g. heating, cooling, *lighting, domestic hot water, ventilation systems, is available. The best option for achieving high level energy management is through performing energy monitoring and energy audits and also raising awareness of the occupants' impact in energy consumption.*

- ***Reduction of heating and cooling demands;***

  The most relevant retrofitting solutions for ensuring lower heating and cooling demands (kW) are improving thermal insulation of the building's envelope and enhancing the passive strategies for heating, cooling and ventilation (either through interventions on the building envelope e.g. installing solar shading devices, or the surrounding environment e.g. the use of vegetation).

- ***Equipment efficiency;***

  High energy efficiency equipment is an important asset. One of the least difficult technologies to apply is energy saving light bulbs, which provide the same lighting conditions with less electrical power input. The considered energy efficient equipment may also include: efficient boilers and cooling equipment, heat recovery system in the air handling units and water efficient measures to reduce domestic hot water consumption and its energy need.

- ***System efficiency;***

  Implementing smart controls of the technical systems can increase their overall performance, therefore considerable energy savings may occur. Regarding the lighting system, the simple energy saving solution is the control of the lighting with movement sensors or dimming possibilities regarding the outdoor lighting levels.

- ***Renewable energy.***

  The renewable energy sources are 'clean' energies; thus, they ensure the sustainability of the energy production and the lowest primary energy use. The relevant energy production equipment from renewable energy sources include: heat pumps, geothermal systems, solar thermal panels and photovoltaic panels, solar powered absorption chiller and biomass boiler.

4.1 Reduction of heating and cooling demands

<u>Humidity control and pathology</u>

Decay and failure issues that mainly refer to humidity patterns, surface deterioration, condensation, plaster decay, etc. are linked with energy performance aspects, therefore, the improvement of the building pathology is an imperative step towards its energy retrofit. Wetness conditions in the basement or foundation area will need particular attention in buildings seeking to reduce energy consumption. Besides the integrity of the building fabric, the relative humidity of indoor air influences the health and wellbeing of building occupants (Park 1996). Treatment interventions should mainly focus on the rising damp, through separation of the structures from the wet soil by implementing a horizontal non-ventilated cavity that reduce the abutting surfaces, while the indoor spaces may still benefit from the thermal inertia of the soil (De Fino et al.

2017). Additional measures aiming at controlling moisture migration are: a) the application of vapor barriers to the warm side of building envelope, that however introduces drastic changes in the hygrothermal behaviour of the historic walls, b) the use of vapour open insulation materials without vapour barrier to keep the original vapour transport of the walls and enable summer drying potential (Andreotti et al. 2020) c) the replacement of the waterproof membrane on the roof and d) the implementation of hydroscopic materials in plasters used for finishing internal spaces, as they have the ability to passively buffer moisture through adsorption and desorption of vapour (Maskell et al. 2018).

4.1.1 Improvement of airtightness

Improving the airtightness of buildings is a cost-effective means of reducing space-conditioning energy consumption. Air tightness is the fundamental building property that impacts infiltration. Infiltration, or air leakage, is the movement of air through leaks, cracks, or other adventitious openings in the building envelope (Sherman and Chan 2004). Air leakage occurs at joints of the building fabric, around doors and windows, cracks in masonry walls etc., as well as where pipes and cables pass through the building (Hall 2008). However, in old buildings, infiltration is the primary source of outdoor air to control adequate indoor air quality (IAQ). Improving air tightness will need to be coupled with a ventilation system in order to provide sufficient airflow (Sherman and Chan 2004), and the thermohygrometric behaviour of the walls should be understood and taken into account when increasing the air tightness of the building to anticipate any possible side effect. Spray-applied foam is commonly used to block air leakage at holes and cracks; when used in small quantities, is reversible with little impact on the surfaces to which it is applied (ASHRAE Guildeline 34 2019).

4.1.2 Thermal inertia

Utilizing short-term Thermal Energy Storage (TES) is a key ingredient in strategies used to control energy demand. The ability of TES materials to absorb excess energy, and to store and release it at a later time is known as thermal inertia (see paragraph 2.2), and when such heat transfer is timed correctly, thermal inertia can be used to improve thermal comfort and reduce auxiliary energy demand (Farid et al. 2004). The simplest method to store thermal energy is in the form of sensible heat storage, which stores thermal energy by increasing the temperature of a solid or liquid. The main downside of this method is the volume of space occupied by the SHS material for the amount of stored energy needed (Ahmad et al. 2006). When reducing material usage and reducing the weight of the construction are important, latent heat thermal energy storage techniques may be preferred.

- Phase change materials (PCMs) are well known examples of materials using latent heat thermal storage. PCMs are substances with high heat of fusions, melting and solidifying at predictable temperatures (Zalba et al. 2003). The use of PCMs is also recommended in order to improve the performance of lightweight building elements, where the latent heat stored during the melting process performs a similar function to the thermal mass in high mass buildings (Košir 2019b). Nevertheless, the amount of incorporated PCMs must be substantial in order to have a noticeable effect. At the same time, care must be taken that PCM re-solidifies in diurnal cycle in order to be ready for melting the next day (Košir 2019b).

Another technique for enhancing passive solar heating gains through exploiting the benefits of thermal mass is the incorporation of solar spaces or the element of a Trombe wall.

- The classical Trombe wall is a massive wall covered by exterior glazing with an air channel between the layers; the glass is located at a short distance from the wall leaving no habitable space between the two layers. This massive wall absorbs and stores the solar energy through the glazing. Some of this energy is transferred through the wall into the indoor area of the building (the room) by conduction. Meanwhile, the colder air enters the air channel from the room through a lower wall vent, is heated by the wall and flows upward due to buoyancy (Manzano-Agugliaro et al. 2015). A review of the opportunities and challenges of this element is provided in the work of (Saadatian et al. 2012). A new technical scheme to apply Trombe wall technology for wall conservation in modern historic buildings was recently suggested by (Du and Jia 2019).
- Glazed galleries are architectural elements that capture solar radiation during cold seasons and maintain the energy by using enclosures, floors and generally capacitive materials, which later return the energy with a phase difference (Manzano-Agugliaro et al. 2015). The conversion of semi-open spaces into indoor spaces with extended frameless glazed surfaces is a commonly used practice in heritage buildings. Besides the extension of valuable living spaces, this practice is in line with the creation of buffer zones and/or solar spaces. In the case of south adjacent spaces, it is important to assure that the glazed surfaces are operable or removable, in order to enable the seasonal use of such a solar space and avoid overheating during the summer (Thravalou, Philokyprou, and Michael 2018).

4.1.3 Addition of thermal insulation

The position of the thermal insulation in relation to the thermal mass of the building envelope plays an important role (Asan 2000). Exterior insulation is generally recommended as it consists the least expensive and technically least demanding solution (A. Troi and Bastian 2015). However, in half-timbered or decorated stucco facades, or in case there is insufficient space for exterior insulation, interior insulation is advisable. In this case, a complete interior insulation system is required, involving the integration of moisture management and careful design of details such as window reveals and internal wall connections. Internal insulated high mass buildings will basically perform as lightweight buildings, because the mass of the envelope is effectively excluded from the internal environment by the thermal insulation (Hudobivnik et al. 2016). Even relatively small thicknesses (e.g. ≈20 mm) of thermal insulation will substantially reduce the convective and radiative interactions between the indoor environment and the envelope's thermal mass. Also, placing the thermal insulation layer towards the warmer side of the wall (i.e. the interior) will eventually cause greater temperature difference between the exterior and interior environment, that might lead to condensation within the wall, especially at the former interior layer, which will be covered by the insulation (A. Troi and Bastian 2015). In order to prevent accumulation of moisture in the wall cross-section, the use of vapour retardant foils, dense interior transpirant plaster, or vapour-resistant insulating layers can be used (A. Troi and Bastian 2015). Andreotti et al. 2020, studied also the solution of vapour open insulating materials to preserve the original vapour transport within the envelope. Furthermore, the use of internal insulation (where possible due to a lack of both materic and pictorial internal decorations) alters the comfort conditions of the internal space by modifying the radiative exchange between the occupants and the surrounding surfaces. In the absence of other massive elements (floors) this aspect should also be considered. Another problem could arise from the creation of new thermal bridges in the envelope.

In addition to the reduction of the conductive heat losses, the use of efficient insulation materials is important to also reduce the impact of urban noise. Unfortunately, the use of natural or recycled materials is not particularly widespread. According to a 2017 analysis report, the plastic foam segment accounts for the largest share, among all material type segments, in the world thermal insulating materials market (Building Thermal Insulation Market 2016). Their use can cause environmental issues due to the use of non-renewable materials and to the disposal phases of end-of-life products, in particular for plastics.

Latest research advances (e.g. research projects AERCOINS, HIPIN, NANOINSULATE, FOAMBUILD) focus on insulation technologies that do not only possess very high thermal insulation capacity, but also are thinner, lighter, non-flammable, and with lower CO2 and Volatile Organic Compound (VOC) emissions (Quenard 2014). Two types of materials are now available on the market: a) Vacuum Insulation Panels (VIP), with a large number of manufacturers around the world, and b) Advanced Porous Materials (APM), such as aerogel or other porous materials (porous silica etc.). These materials have thermal conductivity values, λ, below 15 $mWm^{-1}K^{-1}$ (and may reach up to 5 $mWm^{-1}K^{-1}$), as opposed to common insulating materials that reach minimum λ values of 29 $mWm^{-1}K^{-1}$. A Vacuum Insulation Panel can be considered as an “opaque glazing” element with similar handling & installation constraints to a window system. Therefore, such materials still remain difficult to handle and to install on-site, while they are also more expensive than common insulation materials (e.g. mineral, expanded perlite or PUR foam boards); yet they are often the most attractive solution if the cost of reduced floor area is taken into account.

De Fino et al. (2017) proposed a number of energy retrofit interventions in the case of the historic districts of Monopoli and Maglie in Italy. For plastered walls, the addition of high performing insulation panels on the external facade was suggested e.g. aerogel, VIPs, multi-layer reflective boards, including a thermo-insulating plaster coating (e.g. hydraulic lime with EPS additives). For exposed walls with an interior cavity, the suggested intervention concerned the filling of the inner cavity with high performing insulation mixtures (e.g. hydraulic lime with nanoparticles). In their study, the insulation on the internal facade of the walls was not considered, in order to keep the thermal inertia of the building components and prevent interstitial condensation. Regarding the thermal upgrade of the roof component, the following measures were suggested: a) the replacement of the inclined screed above the slab with high performing insulation lightweight concrete (e.g., with expanded clay, pumice, expanded glass); b) the addition of a high performing insulation panel above the screed (e.g. aero-gel, VIPs, multi-layer reflective boards); and finally, c) the addition of coatings or boards with phase changing materials (PCMs) on the internal side to enhance the attenuation and time shift of the summer temperature peaks through controlled latent heat storage and release (e.g. pre-cast PCM boards or PCM-embedded thermal plaster).

4.1.4 Windows & fenestration:

In the framework of the research project 3ENCULT, the two-layer concept regarding the upgrade of historic windows was introduced. In this case, a box-type window and a casement window were installed, separating the outer layer of the original 'historic' window from a new inner layer (A. Troi and Bastian 2015). The secondary glazing approach is also suggested in the English Heritage guide on energy Conservation in traditional Buildings (AA.VV. 2008) and in the energy efficiency guidelines of the Italian Ministry of Cultural Heritage and Activities (MIBACT 2015).

Nowadays, dynamic tintable and smart windows are available, that can alter the solar factor and/or the transmittance of the glazing. Chromogenic glasses refer to glazing in which transmission properties are variables. Four modes of switchable effect can be employed; a) Electrochromic, b) Gasochromic, c) Photochromic, that contains a coating of silver halide, which changes form clear to dark in the sunlight, and d) Thermochromic, which has a coating of vanadium oxides, which exhibit a reversible semiconductor-to-metallic phase transition when temperature rises (Soltani et al. 2008). Electrochromics and gasochromics enable control of transmittance independent of both insulation or ambient temperature. Low heat loss through windows may be achieved, via using multiple panes, low long-wave emittance coatings and the inclusion between panes of inert gases, aerogels or a vacuum either singly or in combination (Kubie, Muneer, and Abodahad 2000). Vacuum glazing comprises two contiguously sealed glass panes with low emittance films on one or both glass surfaces with the vacuum gap, separated by an array of tiny support pillars to maintain the glass separation under atmospheric pressure (Fang and Eames 2006). The thinness of vacuum glazing and its excellent thermal performance make it highly suited to retrofit in buildings having the potential to significantly reduce heating (Eames 2008). A recent study explores the potential of phase change material (PCM) placed in a glass container; particularly, a triple glazed window which outer cavity was filed with paraffin (Wieprzkowicz and Heim 2020). According to the results, windows with liquid PCM can assure good sky view and visual comfort, while PCM in solid state negatively influences these conditions. Nevertheless, lower light transmittance contributed to the limitation of the glare effect. The most effective utilisation of PCM properties was obtained by combining different paraffins in one window, dividing it to sections (Wieprzkowicz and Heim 2020). However, it should be emphasized that the intervention on windows and fenestration should be planned in tight collaboration with the conservator. Reflections on the historical and aesthetic compatibility may concern not only the shape and appearance of the frame, but also the window typology, the surrounding framing, the window to wall connection, fittings and additional equipment as window shutter and the glass itself. This is the case of the replacement of the fixtures in the Waaghaus in Bozen (another 3ENCULT case study), where the original proportion between glass area and sash bars and windows frame and the optic appearance of original historic glazing were identified as one of the elements to be preserved (Exner et al. 2010).

4.1.5 Hybrid heating and cooling systems:

Hybrid ventilation systems combine mechanical and natural forces in a two-mode system where the operating mode differs according to the season and daily fluctuations (Lomas, Cook, and Fiala 2007).

Ventilation systems with heat recovery are gaining ground in energy retrofit projects of existing buildings, including heritage buildings (Pukhkal et al. 2014; Passive House). A Heat Recovery system efficiently pre-warms fresh filtered air drawn into a building with the heat extracted from stale air leaving the building, using a heat exchanger.

Modern windcatchers have been developed to take the advantages of traditional windcatcher and eliminate their limitations to adopt them with advanced building principals and technologies. Contemporary versions of windcatchers consist in the commercial four-sided windcatcher with solar panel, louvers, solar powered fan and adjustable dampers (Jomehzadeh et al. 2020). The louvers in commercial windcatchers are designed not only to direct the external air into the occupied space but also prevent penetration of rainwater and other objects entering the building. Dampers and diffusers are employed to control the air flow rate through windcatchers with respect to external wind speed (Hughes, Calautit, and Ghani 2012).

Mechanically assisted evaporative cooling is achieved with an economizer-cycle evaporative cooling system, instead of, or in conjunction with, refrigerant air-conditioning. The spraying of water on the roof (if the existing roof has little insulation) and the spraying of water indoors to reduce the temperature of the overhead air are contemporary techniques involving low tech mechanisms. Care must be taken in dimensioning the system properly, as air that is saturated with water vapour can create a problem; it lacks the ability to absorb any additional amount of humidity, which can cause condensation when the temperature falls (Erell, Pearlmutter, and Williamson 2011). In 2010 Solar Decathlon competition, Nottingham's team presented a hybrid downdraught cooling system installed in a central lightwell and ventilation shaft located on the roof (Ford et al. 2012). Eight misting nozzles were incorporated in the skylight, providing evaporatively cooled air into the central double-height space, which in turn promoted the air flow to first-floor (Ford et al. 2012).

4.2 System efficiency

4.2.1 Lighting

The restoration of the natural lighting and daylighting harvesting systems originally included in the historic building is generally recommended. However, in many cases, additional illumination might be required to showcase architectural elements or to provide increased ambient illumination or higher lighting levels for art and tasks. With the introduction of LED lighting or miniature LED downlights, luminaires have been reduced in size to the extent that they are better integrated into architectural elements and concealed from the occupants - installed in cornices, purlins, narrow and shallow soffits, window casements, etc. (ASHRAE Guideline 34 2019). LED light sources offer high-efficacy, low operating costs, and a wide range of control options (including changing the colour emitted by an LED lamp, light outputs, and colour temperature *choices). LED lighting equipment often requires remote control gear (LED drivers, transformers, power supplies, etc.) and often more specialized dimming equipment. This can raise the initial cost of the lighting system, but this premium is rapidly paid back through reduction in energy use and maintenance costs.*

Where dimming is required or desired for energy efficiency or function, the options vary from fluorescent, compact fluorescent, to LED lamps, ensuring that compatible dimmable luminaires and controls are specified. Where dimming is not necessary, lower-wattage ceramic metal halide (CMH) lamps are recommended as they are particularly well suited for building facade lighting. In areas where significant natural light (daylight) is available, daylight harvesting can be accomplished with the use of light sensors coupled with controls that will balance daylight and electric light once set to a specific light level requirement. Coordination for daylight harvesting works best if sets of luminaires are on separate switches to permit controlled partial electrical lighting to supplement daylighting (ASHRAE Guideline 34 2019).

4.2.2 Controls (lighting, temperature and humidity)

Dimming and automatic switching controls will maximize energy savings and, in many cases, extend the life of lighting and HVAC equipment. Controls include wall box dimmers, wired and wireless lighting control systems, occupancy sensors, and door jamb switches. Wireless systems are particularly suitable for historic buildings, as they are much less invasive and do not require cutting and patching of wall, ceiling, and floor surfaces for wire runs. Many advances in controls have been made recently that permit both programming and remote control online through smart phones, tablets, and computers (ASHRAE Guideline 34 2019).

The seasonal adjustment of temperature set points is recommended in historic buildings in order to control relative humidity and maintain its levels within the limits necessary for sustaining thermal comfort and indoor air quality for building occupants. Allowing for seasonal adjustment and unoccupied setbacks for temperature and humidity set points is an energy conservation measure, which when applied it should reduce energy consumption by the HVAC systems in the building (ASHRAE Guideline 34 2019). In museum environments especially, consideration for the artefacts and interior building fabric should also be considered when determining the most appropriate set points and setbacks.

4.3 Renewable energy

Heritage buildings may often have limited potential for renewable energy systems integration, due to legislative protection status or dense urban surrounding. Thus, the enhancement of energy optimization should not only focus at the building level, but also at the urban fabric in proximity. Recent studies (Jansen, Mohammadi, and Bokel 2020) have proven the importance of decentralised heat production from PV-thermal (PVT) collectors and collective seasonal underground storage.

Agugliaro et al. (2015) have examined the concept of modern strategies applied in Mediterranean buildings, referring to the most prominent technologies: thin building *integrated photovoltaic films on buildings; spraying of water on roofs; placement of buried pipes as heat exchangers, for preheating and cooling the ventilation air.*

A Building Integrated Photovoltaics (BIPV) system is a PV system integrated into the building envelope (e.g. roof, façade, window, etc.). Thus, it replaces a building element i.e. a conventional construction material. Technologies that are available for building integration (BIPV) are among others the following:

- Flexible (foil) BIPV: Flexible BIPV is a relatively new product that allows for attractive integration options in a building as it is lightweight and flexible, which is beneficial to its ease of installation (Jelle and Breivik 2012). Photovoltaic cells are often made of thin-film cells to maintain flexibility and to be effective in high temperatures (e.g. in non-ventilated roofs). Flexibility is achieved mainly due to its very thin structure, combined with its ability to be installed on flexible substrates (stainless steel sheets or polymer film), giving it a handy and compact form (Chopra, Paulson, and Dutta 2004).
- BIPV tiles are photovoltaic modules (without a metal frame), usually integrated with the same logic and properties of conventional roof tiles, thus allowing easy roofing to be reconstructed (Heinstein, Ballif, and Perret-Aebi 2013). BIPV tile products may cover the entire roof or selected parts of the roof.

5 References

AA. VV. 2020. 'A3.1.1 STATE OF THE ART ANALYSIS ON HBIM AND INTEROPERABILITY - ENICBCMed BEEP Project'.

AA.VV. 2008. 'Energy Conservation in Traditional Buildings'. English heritage. https://www.ciob.org/sites/default/files/English%20Heritage%20Energy%20Conservation.pdf.

Ahmad, Maha, André Bontemps, Hébert Sallée, and Daniel Quenard. 2006. 'Experimental Investigation and Computer Simulation of Thermal Behaviour of Wallboards Containing a Phase Change Material'. Energy and Buildings 38 (4): 357–66. https://doi.org/10.1016/j.enbuild.2005.07.008.

Allard, Francis. 1998. Natural Ventilation in Buildings: A Design Handbook. London: James & James Ltd.

Almhafdy, Abdulbasit, Norhati Ibrahim, Sabarinah Sh Ahmad, and Josmin Yahya. 2015. 'Thermal Performance Analysis of Courtyards in a Hot Humid Climate Using Computational Fluid Dynamics CFD Method'. Procedia - Social and Behavioral Sciences 170 (January): 474–83. https://doi.org/10.1016/j.sbspro.2015.01.012.

Andreotti, Mirco, Dario Bottino-Leone, Marta Calzolari, Pietromaria Davoli, Luisa Dias Pereira, Elena Lucchi, and Alexandra Troi. 2020. 'Applied Research of the Hygrothermal Behaviour of an Internally Insulated Historic Wall without Vapour Barrier: In Situ Measurements and Dynamic Simulations'. Energies 13 (13): 3362. https://doi.org/10.3390/en13133362.

Asan, H. 2000. 'Investigation of Wall's Optimum Insulation Position from Maximum Time Lag and Minimum Decrement Factor Point of View'. Energy and Buildings 32 (2): 197–203. https://doi.org/10.1016/S0378-7788(00)00044-X.

Asan, H. 2006. 'Numerical Computation of Time Lags and Decrement Factors for Different Building Materials'. Building and Environment 41 (5): 615–20. https://doi.org/10.1016/j.buildenv.2005.02.020.

ASHRAE Guildeline 34. 2019. 'Guideline 34, Energy Guideline for Historic Buildings'. ASHRAE.

Asimakopoulos, D. 1996. Passive Cooling of Buildings. Edited by M. Santamouris. 1st edition. London: Routledge.

Aynsley, Richard. 2007. 'Natural Ventilation in Passive Design'. BEDP ENVIRONMENT DESIGN GUIDE.

Berg, Fredrik, Anne-Cathrine Flyen, Åsne Lund Godbolt, and Tor Broström. 2017. 'User-Driven Energy Efficiency in Historic Buildings: A Review'. Journal of Cultural Heritage 28 (November): 188–95. https://doi.org/10.1016/j.culher.2017.05.009.

Blondeau, P., M. Spérandio, and Francis Allard. 1997. 'Night Ventilation for Building Cooling in Summer'. Solar Energy 61 (5): 327–35. https://doi.org/10.1016/S0038-092X(97)00076-5.

Bluyssen, Philomena. 2009. The Indoor Environment Handbook. 1st ed. Routledge. https://doi.org/10.4324/9781849774611.

Bougiatioti, Flora, and Aimilios Michael. 2015. 'The Architectural Integration of Active Solar Systems. Building Applications in the Eastern Mediterranean Region'. Renewable and Sustainable Energy Reviews 47 (July): 966–82. https://doi.org/10.1016/j.rser.2015.03.030.

Building Thermal Insulation Market. 2016. 'Building Thermal Insulation Market by Material (Glass Wool, Stone Wool, Polystyrene), Application (Flat Roof, Pitched Roof, External Wall, Internal Wall, Cavity Wall, Floor), Building Type (Residential, Non-Residential) - Global Forecast to 2022.' 2016. https://www.marketsandmarkets.com/Market-Reports/building-insulation-materials-market-510.html.

Calcerano, Filippo, Carlotta Cecchini, and Letizia Martinelli. 2017. 'Numerical Analysis of Passive Strategies for Energy Retrofit of Existing Buildings in Mediterranean Climate: Thermal Mass and Natural Ventilation Combination'. Sustainable Buildings 2: 4. https://doi.org/10.1051/sbuild/2017003.

Cañas, Ignacio, and Silvia Martín. 2004. 'Recovery of Spanish Vernacular Construction as a Model of Bioclimatic Architecture'. Building and Environment 39 (12): 1477–95. https://doi.org/10.1016/j.buildenv.2004.04.007.

Carbonara, Giovanni. 2017. 'Cultural Heritage and Retrofit of Historical Buildings Evaluations of Restoration Issues.' Presented at the Keynote speech Climamed 2017 –Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area, Matera, Italy, May 12.

Chopra, K. L., P. D. Paulson, and V. Dutta. 2004. 'Thin-film Solar Cells: An Overview'. Progress in Photovoltaics: Research and Applications. John Wiley & Sons, Ltd. 1 March 2004. https://onlinelibrary.wiley.com/doi/abs/10.1002/pip.541.

Coch, Helena. 1998. 'Chapter 4—Bioclimatism in Vernacular Architecture'. Renewable and Sustainable Energy Reviews 2 (1–2): 67–87. https://doi.org/10.1016/S1364-0321(98)00012-4.

COE. 2005. 'Council of Europe Framework Convention on the Value of Cultural Heritage for Society (Signed in Faro Convention)'. Faro, Portugal: COE.

Cook, Jeffrey. 1989. Passive Cooling. Cambridge: MIT Press.

———. 1997. 'Climate'. In Encyclopaedia of Vernacular Architecture of the World., edited by Paul Oliver, 127–29. Cambridge: Cambridge University Press.

Correia, Mariana, Letizia Dipasquale, and Saverio Mecca. 2014. VERSUS. HERITAGE FOR TOMORROW: Vernacular Knowledge for Sustainable Architecture. Book, Edited. Firenze: Firenze University Press.

De Fino, Mariella, Alba Scioti, Elena Cantatore, and Fabio Fatiguso. 2017. 'Methodological Framework for Assessment of Energy Behavior of Historic Towns in Mediterranean Climate'. Energy and Buildings 144 (June): 87–103. https://doi.org/10.1016/j.enbuild.2017.03.029.

Dear, Richard J. de, and Gail S. Brager. 2002. 'Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55'. Energy and Buildings 34 (6): 549–61. https://doi.org/10.1016/S0378-7788(02)00005-1.

DeKay, M., and GZ Brown. 2014. Sun, Wind and Light: Architectural Design Strategies. 3rd ed. Hoboken: Wiley.

Desogus, Giuseppe, Leonardo Giuseppe Felice Cannas, and Antonello Sanna. 2016. ‘Bioclimatic Lessons from Mediterranean Vernacular Architecture: The Sardinian Case Study’. Energy and Buildings 129 (October): 574–88. https://doi.org/10.1016/j.enbuild.2016.07.051.

Ding, Grace. 2013. ‘Demolish or Refurbish – Environmental Benefits of Housing Conservation’. Construction Economics and Building 13 (2): 18–34. https://doi.org/10.5130/AJCEB.v13i2.3322.

Dipasquale, Letizia, Saverio Mecca, and Adelina Picone. 2014. ‘Courtyard Houses’. In Versus. Heritage For Tommorrow, edited by Mariana Correia, Letizia Dipasquale, and Saverio Mecca, 151–63. Firenze: Firenze University Press.

‘Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast)’. 2010. Vol. L 153/13. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32010L0031.

Du, Xiaohui, and Bei Jia. 2019. ‘Discussion on Applying Trombe Wall Technology for Wall Conservation and Energy Saving in Modern Historic Buildings’ 13 (4): 537–48. https://doi.org/10.1080/15583058.2018.1440029.

Eames, Philip C. 2008. ‘Vacuum Glazing: Current Performance and Future Prospects’. Vacuum, The World Energy Crisis Part 2: Some More Vacuum-based Solutions, 82 (7): 717–22. https://doi.org/10.1016/j.vacuum.2007.10.017.

EFFESUS. 2016. ‘Research Project: Energy Efficiency for EU Historic Districts’ Sustainability’. 2016. https://www.effesus.eu/.

Erell, Evyatar, David Pearlmutter, and T. J. Williamson. 2011. Urban Microclimate: Designing the Spaces between Buildings. 1st ed. London ; Washington, DC: Earthscan.

European Commission. 2016. ‘An EU Strategy on Heating and Cooling’. Vol. COM/2016/051. Brussels: European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1456485641537&uri=CELEX:52016DC0051#footnoteref19.

———. 2019. ‘The European Green Deal’. 2019. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2.

———. 2020. ‘Renovation Wave’. 2020. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en.

Evans, John Martin. 2003. ‘Evaluating Comfort with Varying Temperatures: A Graphic Design Tool’. Special Issue on Urban Research 35 (1): 87–93. https://doi.org/10.1016/S0378-7788(02)00083-X.

Exner, D., F. Roberti, A. Troi, E. Lucchi, T. Caprioli, and R. Lollini. 2010. ‘D 6.2 Documentation of Each Study Case CS1 Public Weigh House, Bolzano (Italy) Delivered at M42’.

http://www.3encult.eu/en/casestudies/Documents/3ENCULT_Case%20Study%201.pdf.

Fabi, Valentina, Rune Vinther Andersen, Stefano Corgnati, and Bjarne W. Olesen. 2012. 'Occupants' Window Opening Behaviour: A Literature Review of Factors Influencing Occupant Behaviour and Models'. Building and Environment 58 (December): 188–98. https://doi.org/10.1016/j.buildenv.2012.07.009.

Fang, Yueping, and Philip C. Eames. 2006. 'The Effect of Glass Coating Emittance and Frame Rebate on Heat Transfer through Vacuum and Electrochromic Vacuum Glazed Windows'. Solar Energy Materials and Solar Cells 90 (16): 2683–2695.

Fanger, Poul, O. 1970. Thermal Comfort. Analysis and Applications in Environmental Engineering. Thermal Comfort.Analysis and Applications in Environmental Engineering. Book, Edited. Copenhagen: Danish Technical Press.

Farid, Mohammed M., Amar M. Khudhair, Siddique Ali K. Razack, and Said Al-Hallaj. 2004. 'A Review on Phase Change Energy Storage: Materials and Applications'. Energy Conversion and Management 45 (9): 1597–1615. https://doi.org/10.1016/j.enconman.2003.09.015.

Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture, Principles and Examples with Reference to Hot Arid Climates. Book, Edited. Chicago: The United Nations University.

Ford, Brian, Robin Wilson, Mark Gillott, Omar Ibraheem, Jose Salmeron, and Francisco Jose Sanchez. 2012. 'Passive Downdraught Evaporative Cooling: Performance in a Prototype House'. Building Research & Information 40 (3): 290–304. https://doi.org/10.1080/09613218.2012.669908.

Foruzanmehr, Ahmadreza. 2018. Thermal Comfort in Hot Dry Climates. 1st ed. Book, Edited. London: Routledge. https://doi.org/10.4324/9781315527130.

GBC. 2017. 'GBC Historic Building'. Green Building Council Italia. http://gbcitalia.org/documents/20182/157656/Sistema+di+verifica+GBC+HB_2016-mag17.pdf/7d185808-b994-45fe-a6af-218e81a8fe27.

Ghadiri, Maryam Hossein, N Lukman Ibrahim, and Mahmud Dehnavi. 2011. 'The Effect of Tower Height in Square Plan Wind Catcher on Its Thermal Behavior'. Australian Journal of Basic and Applied Sciences 5 (9): 381–85.

Ghaffarianhoseini, Amirhosein, Umberto Berardi, and Ali Ghaffarianhoseini. 2015. 'Thermal Performance Characteristics of Unshaded Courtyards in Hot and Humid Climates'. Building and Environment 87 (Journal Article): 154–68. https://doi.org/10.1016/j.buildenv.2015.02.001.

Gigliarelli, Elena, Filippo Calcerano, and Luciano Cessari. 2017. 'Heritage Bim, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit'. Energy Procedia, Climamed 2017 – Mediterranean Conference of HVAC Historical buildings retrofit in the Mediterranean area 12-13 May 2017 - Matera, Italy, 133 (October): 135–44. https://doi.org/10.1016/j.egypro.2017.09.379.

Givoni, Baruch. 1969. Man, Climate and Architecture. Book, Edited. Amsterdam/London/New York: Elsevier Publishing Co. Ltd.

———. 1994. Passive and Low Energy Cooling of Buildings. Book, Whole. Canada: John willy & Sons.

———. 1998a. Climate Considerations in Building and Urban Design. Book, Whole. John Wiley & Sons.

———. 1998b. 'Effectiveness of Mass and Night Ventilation in Lowering the Indoor Daytime Temperatures. Part I: 1993 Experimental Periods'. Energy and Buildings 28 (1): 25–32. https://doi.org/10.1016/S0378-7788(97)00056-X.

Gładyszewska-Fiedoruk, Katarzyna, and Andrzej Gajewski. 2012. 'Effect of Wind on Stack Ventilation Performance'. Energy and Buildings 51 (August): 242–47. https://doi.org/10.1016/j.enbuild.2012.05.007.

Grosso, Mario. 1997. Il Raffrescamento Passivo Degli Edifici. Ambiente Territorio Edilizia Urbanistica. Maggioli.

Haggard, Ken, David A. Bainbridge, and Rachel Aljilani. 2010. Passive Solar Architecture Pocket Reference. 1st edition. London? Routledge.

Hakim, Besim S. 2008. 'Mediterranean Urban and Building Codes: Origins, Content, Impact, and Lessons'. URBAN DESIGN International 13 (1): 21–40. https://doi.org/10.1057/udi.2008.4.

Hall, Keith. 2008. Green Building Bible Vol.1. 4 th. Vol. 1. Green Building Press.

Hegger, Manfred, Matthias Fuchs, Thomas Stark, and Martin Zeumer. 2012. Energy Manual: Sustainable Architecture. Walter de Gruyter.

Heinstein, Patrick, Christophe Ballif, and Laure-Emmanuelle Perret-Aebi. 2013. 'Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths'. Green 3 (2): 125–56. https://doi.org/10.1515/green-2013-0020.

Historic England. 2018. Energy Efficiency and Historic Buildings, How to Improve Energy Efficiency.

Hudobivnik, Blaž, Luka Pajek, Roman Kunič, and Mitja Košir. 2016. 'FEM Thermal Performance Analysis of Multi-Layer External Walls during Typical Summer Conditions Considering High Intensity Passive Cooling'. Applied Energy 178 (September): 363–75. https://doi.org/10.1016/j.apenergy.2016.06.036.

Hughes, Ben Richard, John Kaiser Calautit, and Saud Abdul Ghani. 2012. 'The Development of Commercial Wind Towers for Natural Ventilation: A Review'. Applied Energy 92 (April): 606–27. https://doi.org/10.1016/j.apenergy.2011.11.066.

ICOMOS. 1964. 'International Charter for Conservation and Restoration of Monuments and Sites (The Venice Charter)".'

———. 1975. 'Congress on the European Architectural Heritage, Declaration of Amsterdam'.

———. 1987. 'Charter for the Conservation of Historic Towns and Urban Areas (The Washington Charter)'. https://www.icomos.org/charters/towns_e.pdf.

———. 1999. 'The Australia ICOMOS Charter for the Conservation of Places of Cultural Significance (The Burra Charter)'.

Imessad, K., L. Derradji, N. Ait Messaoudene, F. Mokhtari, A. Chenak, and R. Kharchi. 2014. ‘Impact of Passive Cooling Techniques on Energy Demand for Residential Buildings in a Mediterranean Climate’. Renewable Energy 71 (Journal Article): 589–97. https://doi.org/10.1016/j.renene.2014.06.005.

Jansen, Sabine, Saleh Mohammadi, and Regina Bokel. 2020. ‘Developing a Locally Balanced Energy System for an Existing Neighbourhood, Using the “Smart Urban Isle” Approach’. Sustainable Cities and Society, no. Journal Article: 102496. https://doi.org/10.1016/j.scs.2020.102496.

Jelle, Bjørn Petter, and Christer Breivik. 2012. ‘State-of-the-Art Building Integrated Photovoltaics’. Energy Procedia, Technoport 2012 - Sharing Possibilities and 2nd Renewable Energy Research Conference (RERC2012), 20 (January): 68–77. https://doi.org/10.1016/j.egypro.2012.03.009.

Jeong, Jae-Hoon, and Kyung-Hoon Lee. 2006. ‘The Physical Environment in Museums and Its Effects on Visitors’ Satisfaction’. Building and Environment 41 (7): 963–69. https://doi.org/10.1016/j.buildenv.2005.04.004.

Jomehzadeh, Fatemeh, Hasanen Mohammed Hussen, John Kaiser Calautit, Payam Nejat, and M. Salim Ferwati. 2020. ‘Natural Ventilation by Windcatcher (Badgir): A Review on the Impacts of Geometry, Microclimate and Macroclimate’. Energy and Buildings 226 (November): 110396. https://doi.org/10.1016/j.enbuild.2020.110396.

Jomehzadeh, Fatemeh, Payam Nejat, John Kaiser Calautit, Mohd Badruddin Mohd Yusof, Sheikh Ahmad Zaki, Ben Richard Hughes, and Muhammad Noor Afiq Witri Muhammad Yazid. 2017. ‘A Review on Windcatcher for Passive Cooling and Natural Ventilation in Buildings, Part 1: Indoor Air Quality and Thermal Comfort Assessment’. Renewable and Sustainable Energy Reviews 70 (April): 736–56. https://doi.org/10.1016/j.rser.2016.11.254.

Katafygiotou, M. C., and D. K. Serghides. 2015. ‘Bioclimatic Chart Analysis in Three Climate Zones in Cyprus’. Indoor and Built Environment 24 (6): 746–60. https://doi.org/10.1177/1420326X14526909.

Kolokotroni, M., and A.N. Young. 1990. ‘Guidelines for Bioclimatic Housing Design in Greece’. Building and Environment 25 (4): 297–307. https://doi.org/10.1016/0360-1323(90)90003-A.

Kontoleon, K.J., and E.A. Eumorfopoulou. 2008. ‘The Influence of Wall Orientation and Exterior Surface Solar Absorptivity on Time Lag and Decrement Factor in the Greek Region’. Renewable Energy 33 (7): 1652–64. https://doi.org/10.1016/j.renene.2007.09.008.

Koronaki, I.P. 2013. ‘The Impact of Configuration and Orientation of Solar Thermosyphonic Systems on Night Ventilation and Fan Energy Savings’. Energy and Buildings 57 (February): 119–31. https://doi.org/10.1016/j.enbuild.2012.10.054.

Košir, Mitja. 2016. ‘Adaptive Building Envelope: An Integral Approach to Indoor Environment Control in Buildings.’ Automation and Control Trends. https://doi.org/10.5772/64951.

———. 2019a. ‘Bioclimatic Design—Where to Start?’ In Climate Adaptability of Buildings., edited by Mitja Košir, 33–65. Springer. https://doi.org/10.1007/978-3-030-18456-8_2.

———. 2019b. Climate Adaptability of Buildings: Bioclimatic Design in the Light of Climate Change. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-18456-8.

Kubie, J., Tariq Muneer, and N. Abodahad. 2000. Windows in Buildings. Oxford ; Boston: Architectural Press.

La Gennusa, Maria, Giovanni Lascari, Gianfranco Rizzo, and Gianluca Scaccianoce. 2008. ‘Conflicting Needs of the Thermal Indoor Environment of Museums: In Search of a Practical Compromise’. Journal of Cultural Heritage 9 (2): 125–34. https://doi.org/10.1016/j.culher.2007.08.003.

Lechner, Norbert. 1991. Heating, Cooling, Lighting: Sustainable Design Methods for Architects. Hoboken, N.J.: John Wiley & Sons.

Lomas, Kevin J., Malcolm J. Cook, and Dusan Fiala. 2007. ‘Low Energy Architecture for a Severe US Climate: Design and Evaluation of a Hybrid Ventilation Strategy’. Energy and Buildings 39 (1): 32–44. https://doi.org/10.1016/j.enbuild.2006.03.032.

Lucchi, E., G. Garegnani, L. Maturi, and D. Moser. 2014. ‘Architectural Integration of Photovoltaic Systems in Historic Districts. The Case Study of Santiago de Compostela.’ In International Conference in Energy Efficiency in Historic Buildings. Madrid, Spain.

Manzano-Agugliaro, Francisco, Francisco G. Montoya, Andrés Sabio-Ortega, and Amós García-Cruz. 2015. ‘Review of Bioclimatic Architecture Strategies for Achieving Thermal Comfort’. Renewable and Sustainable Energy Reviews 49 (September): 736–55. https://doi.org/10.1016/j.rser.2015.04.095.

Martínez-Molina, Antonio, Isabel Tort-Ausina, Soolyeon Cho, and José-Luis Vivancos. 2016. ‘Energy Efficiency and Thermal Comfort in Historic Buildings: A Review’. Renewable and Sustainable Energy Reviews 61 (August): 70–85. https://doi.org/10.1016/j.rser.2016.03.018.

Maskell, Daniel, Andrew Thomson, Pete Walker, and Manfred Lemke. 2018. ‘Determination of Optimal Plaster Thickness for Moisture Buffering of Indoor Air’. Building and Environment 130 (Journal Article): 143–50. https://doi.org/10.1016/j.buildenv.2017.11.045.

Mazria, Edward. 1979. The Passive Solar Energy Book. Book, Edited. Emmaus: Rodale Press.

MIBACT. 2015. ‘Linee Di Indirizzo per Il Miglioramento Dell’efficienza Energetica Nel Patrimonio Culturale. Architettura, Centri e Nuclei Storici Ed Urbani’. Ministero dei beni e delle attività culturali e del turismo Direzione generale Belle Arti e Paesaggio. http://www.beap.beniculturali.it/opencms/multimedia/BASAE/documents/2015/10/27/1445954374955_Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf.

Michael, Aimilios, Despina Demosthenous, and Maria Philokyprou. 2017. 'Natural Ventilation for Cooling in Mediterranean Climate: A Case Study in Vernacular Architecture of Cyprus'. Energy and Buildings 144 (June): 333–45. https://doi.org/10.1016/j.enbuild.2017.03.040.

Milne, Murray, and Baruch Givoni. 1979. 'Architectural Design Based on Climate'. In Energy Conservation Through Building Design, edited by D. Watson, 96–113. New York: McGraw- Hill.

Noble, Allen G. 2007. Traditional Buildings: A Global Survey of Structural Forms and Cultural Functions. London: I. B. Tauris & Company.

Norton, Brian. 2014. 'Passive and Hybrid Solar Design of Buildings.' In Harnessing Solar Heat. Lecture Notes in Energy, Vol. 18, 213–44. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-7275-5_12.

Ogoli, David Mwale. 2003. 'Predicting Indoor Temperatures in Closed Buildings with High Thermal Mass'. Energy and Buildings 35 (9): 851–62. https://doi.org/10.1016/S0378-7788(02)00246-3.

Olgyay, Victor. 1963. Design with the Climate: Bioclimatic Approach and Architectural Regonalism. Book, Edited. New Jersey: Princeton University Press.

Oliver, Paul. 1997. Encyclopedia of Vernacular Architecture of the World. Book, Edited. Cambridge: Cambridge University Press.

Park, S. C. 1996. 'Holding the Line: Controlling Unwanted Moisture in Historic Buildings.' Vol. 39. Washington, DC: U.S. Department of the Interior, National Parks Service. Heritage Preservation Services.

Pavlogeorgatos, G. 2003. 'Environmental Parameters in Museums'. Building and Environment 38 (12): 1457–62. https://doi.org/10.1016/S0360-1323(03)00113-6.

Philokyprou, Maria. 2014. 'Adaptation of New University Uses in Old Buildings: The Case of Rehabilitation of Listed Buildings in Limassol Cyprus for University Purposes'. International Journal of Architectural Heritage 8 (5): 758–82. https://doi.org/10.1080/15583058.2012.738282.

Philokyprou, Maria, Aimilios Michael, Stavroula Thravalou, and Ioannis Ioannou. 2017. 'Thermal Performance Assessment of Vernacular Residential Semi-Open Spaces in Mediterranean Climate'. Indoor and Built Environment 27 (8): 1050–68. https://doi.org/10.1177/1420326X17699037.

Pukhkal, Viktor, Nikolay Vatin, Murgul, and Vera. 2014. 'Central Ventilation System with Heat Recovery as One of the Measures to Upgrade Energy Efficiency of Historic Buildings'. Applied Mechanics and Materials 633–634 (Journal Article): 1077–81. https://doi.org/10.4028/www.scientific.net/amm.633-634.1077.

Quenard, Daniel. 2014. 'OVERVIEW - Superinsulating Materials: A New Era of Insulation Technologies'. BUILD UP. https://www.buildup.eu/en/news/overview-superinsulating-materials-new-era-insulation-technologies.

Rapoport, Amos. 1980. 'Vernacular Architecture and the Cultural Determinants of Form'. Buildings and Society: Essays on the Social Development of the Built Environment, no. Journal Article: 283–305.

Saadatian, Omidreza, K. Sopian, C. H. Lim, Nilofar Asim, and M. Y. Sulaiman. 2012. 'Trombe Walls: A Review of Opportunities and Challenges in Research and Development'. Renewable and Sustainable Energy Reviews 16 (8): 6340–51. https://doi.org/10.1016/j.rser.2012.06.032.

Saffari, Mohammad, Alvaro de Gracia, Svetlana Ushak, and Luisa F. Cabeza. 2017. 'Passive Cooling of Buildings with Phase Change Materials Using Whole-Building Energy Simulation Tools: A Review'. Renewable and Sustainable Energy Reviews 80 (Journal Article): 1239–55. https://doi.org/10.1016/j.rser.2017.05.139.

Santamouris, Mat. 2006. Building Ventilation: The State of the Art. 1st ed. Routledge. https://doi.org/10.4324/9781849770620.

Santamouris, Mathaios, and D. Asimakopoulos N. 2013. Passive Cooling of Buildings. Book, Whole. New York: Earthscan.

Schoenauer, Norbert. 2000. 6,000 Years of Housing. 3rd ed. New York: W. W. Norton & Company, Inc.

Shaviv, Edna, Abraham Yezioro, and Isaac G Capeluto. 2001. 'Thermal Mass and Night Ventilation as Passive Cooling Design Strategy'. Renewable Energy 24 (3–4): 445–52. https://doi.org/10.1016/S0960-1481(01)00027-1.

Sherman, M. H., and R. Chan. 2004. Building Airtightness: Research and Practice. Berkeley: Lawrence Berkeley National Laboratory.

Sodagar, Behzad. 2013. 'Sustainability Potentials of Housing Refurbishment'. Buildings 3 (1): 278–99. https://doi.org/10.3390/buildings3010278.

Solgi, Ebrahim, Zahra Hamedani, Ruwan Fernando, Henry Skates, and Nnamdi Ezekiel Orji. 2018. 'A Literature Review of Night Ventilation Strategies in Buildings'. Energy and Buildings 173 (August): 337–52. https://doi.org/10.1016/j.enbuild.2018.05.052.

Soltani, M., M. Chaker, E. Haddad, and R. Kruzelecky. 2008. 'Thermochromic Vanadium Dioxide (VO2) Smart Coatings for Switching Applications.' Applied Physics in the 21st Century.

Szokolay, Steven. 2014. Introduction to Architectural Science: The Basis of Sustainable Design. Book, Edited. Oxford: Routledge.

Thravalou, Stavroula, Maria Philokyprou, and Amilios Michael. 2018. 'The Impact of Window Control on Thermal Performance. Investigating Adaptable Interventions in Vernacular Mediterranean Heritage'. Journal of Architectural Conservation 24 (1): 41–59. https://doi.org/10.1080/13556207.2018.1456058.

Troi, Alexandra, and Zeno Bastian. 2015. Energy Efficiency Solutions for Historic Buildings. A Handbook. Book, Edited. Basel: Birkhauser.

Troi, Alexandra (EURAC research), and Zeno (Passive House Institute) Bastian. 2014. Energy Efficiency Solutions for Historic Buildings. A Handbook. Berlin, Boston: Birkhäuser. https://doi.org/10.1515/9783038216506.

University of California. 2017. Climate Consultant Software. (version 6). http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

Vegas, Fernando, Camilla Mileto, Valentina Christini, and Jose Ramon Ruiz Checa. 2014. ‘Underground Settlements’. In Versus. Heritage For Tommorrow, edited by Mariana Correia, Letizia Dipasquale, and Saverio Mecca, 115–23. Firenze: Firenze University Press.

Vellinga, Marcel, Paul Oliver, and Alexander Bridge. 2008. Atlas of Vernacular Architecture of the World. 1st ed. Book, Edited. London: Routledge.

Vieites, Esteban, Iana Vassileva, and Juan E. Arias. 2015. ‘European Initiatives Towards Improving the Energy Efficiency in Existing and Historic Buildings’. Energy Procedia 75 (Journal Article): 1679–85. https://doi.org/10.1016/j.egypro.2015.07.418.

Vitruvius Marcus Pollio. 15AD. De Architettura Libri Decem.

Watson, Donald. 1989. ‘Bioclimatic Design Research’. In Advances in Solar Energy. Advances in Solar Energy (An Annual Review of Research and Development), edited by K. W. Böer, 402–38. Boston: Springer. https://doi.org/10.1007/978-1-4613-0837-9_6.

Wieprzkowicz, Anna, and Dariusz Heim. 2020. ‘Modelling of Thermal Processes in a Glazing Structure with Temperature Dependent Optical Properties - An Example of PCM-Window’. Renewable Energy 160 (November): 653–62. https://doi.org/10.1016/j.renene.2020.06.146.

Xenophon. IV sec B.C. Oeconomicus.

Yannas, Simos, and Willi Weber. 2013. Lessons from Vernacular Architecture. Book, Edited. New York: Routledge.

Zalba, Belén, José M. Marín, Luisa F. Cabeza, and Harald Mehling. 2003. ‘Review on Thermal Energy Storage with Phase Change: Materials, Heat Transfer Analysis and Applications’. Applied Thermal Engineering 23 (3): 251–83. https://doi.org/10.1016/S1359-4311(02)00192-8.

Zhai, Zhiqiang (John), and Jonathan M. Previtali. 2010. ‘Ancient Vernacular Architecture: Characteristics Categorization and Energy Performance Evaluation’. Energy and Buildings 42 (3): 357–65. https://doi.org/10.1016/j.enbuild.2009.10.002.

5.1 Auxiliary references

BPIE. (2013). Boosting building renovation: An overview of good practices. Brussels: Building Performance institute Europe.

EST. (2005). Improving airtightness in dwellings (Vol. CE137/GPG224). London: Energy Saving Trust.

EST. (2006). Practical refurbishment of solid-walled houses (Vol. CE184). London: Energy Saving Trust.

EST. (2007). Cavity wall insulation in existing dwellings: A guide for specifiers and advisors (Vol. CE252). London: Energy Saving Trust.

RICS (2009). Historic Building Conservation, Vol. 7, Crown Copyright, Coventry.

Young, R. (2011). “Historic preservation and adaptive use: a significant opportunity for sustainability”, in Plowright, P. (Ed.), Considering Research: Reflecting upon current themes in Architecture Research hosted by the Lawrence Technological University, MI, 20-23 April, pp. 569-580.

5.2 Main Restoration Charters

- The Athens Charter for the Restoration of Historic Monuments –1931

  https://www.icomos.org/en/167-the-athens-charter-for-the-restoration-of-historic-monuments

- INTERNATIONAL CHARTER FOR THE CONSERVATION AND RESTORATION OF MONUMENTS AND SITES (The Venice Charter 1964)

  https://www.icomos.org/charters/venice_e.pdf

- The Declaration of Amsterdam -1975

  https://www.icomos.org/en/and/169-the-declaration-of-amsterdam

- European Charter of the Architectural Heritage -1975

  https://www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/170-european-charter-of-the-architectural-heritage

- Charter for The Conservation of Historic Towns and Urban Areas (Washington Charter 1987)

  https://www.icomos.org/charters/towns_e.pdf

- The Nara Document on Authenticity (1994)

  https://www.icomos.org/charters/nara-e.pdf

- The Aalborg Charter (1994)

  http://www.sustainablecities.eu/fileadmin/repository/Aalborg_Charter/Aalborg_Charter_English.pdf

- The Faro Convention (2005)
  https://rm.coe.int/16800837463

6 Annexes

6.1 Passive strategies employed by heritage buildings in Italy

6.1.1 Overview of the environmental responsiveness of built heritage in Italy

The geographical characteristics of the Italian peninsula give Italy a great climatic variability, from the Mediterranean subtropical climate in the South (with summer temperatures even above 40° C), to the temperate continental climate of the northern regions (with winter temperatures that can reach -20° C).

According to the climatic classification used to support bioclimatic design of V. Olgiay (1963), Italy falls within the temperate climate area with average temperature of the coldest months between -3 and 18°C, with both daily and yearly thermal range and great variability of weather and precipitation, and requires a seasonal approach capable to deal with both winter and summer season and to take advantage of daily thermal range, and natural ventilation, while keeping relative humidity under control (Calcerano 2015).

Köppen-Geiger climate classification (Köppen 1918; Kottek et al. 2006) positions the Italian territory, of coastal and inland medium altitudes, mainly within the C group of temperate climates, while parts of the Apennine mountain range and the Alps fall within the cold climates of group D. According to more detailed development of Köppen-Geiger classification for Italy made by Pinna (1977), the Italian territory can be divided as follows (Blasi and Michetti 2005):

1. a tundra climate (EF), with average temperature of all the months < 10 °C, on the Alpes above 3500 m altitude.
2. a cold continental climate (Df), with average temperature of the coldest month < -6 °C, average of the warmest month < 10 °C and annual average < 0 °C, on the Alpes between 2000 m and 3500 m altitude;
3. a cool continental climate (Df), with average temperature of the coldest month < -3 °C, average of the warmest month between 10 °C and 15 °C and annual average between 3 °C and 6 °C, on the Alpes below 2000 m altitude;
4. an oceanic climate (Cf), with average temperature of the coldest month between -3 °C and 0 °C, average of the warmest month between 15 °C and 20 °C and annual average between 6 °C and 10 °C, on Prealps and high altitude Appenines;
5. a temperate continental climate (Cf), with average temperature of the coldest month between -1.5 °C and 3 °C, annual average between 9 °C and 15 °C and 3 months with average > 20 °C, on the major part of Po Valley;
6. a temperate subcontinental climate (Cf), with average temperature of the coldest month between -1 °C and 4 °C, annual average between 10 °C and 14 °C and 2 months with average > 20 °C, which includes high Po Valley, Venetian Plain, Adriatic high coastal line and medium altitude Appenine peninsula;
7. a subcoastal climate (Cs), with average temperature of the coldest month between 4 °C and 6 °C, annual average between 10 °C and 14.5 °C and 3 months with average > 20 °C, which interests inlands and medium elevation areas of Central and Southern Italy;

8. a temperate-hot climate (Cs), with average temperature of the coldest month between 6 °C and 10 °C, annual average between 14.5 °C and 17 °C and 4 months with average > 20 °C, which comprehends most of the low elevation coastal areas of Tyrrhenian, Ionian and south Adriatic line;
9. a subtropical climate (Cs), with average temperature of the coldest month > 10 °C, annual average > 17 °C and 5-6 months with average > 20 °C, along part of the southern and insular coastal line (Figure 5).

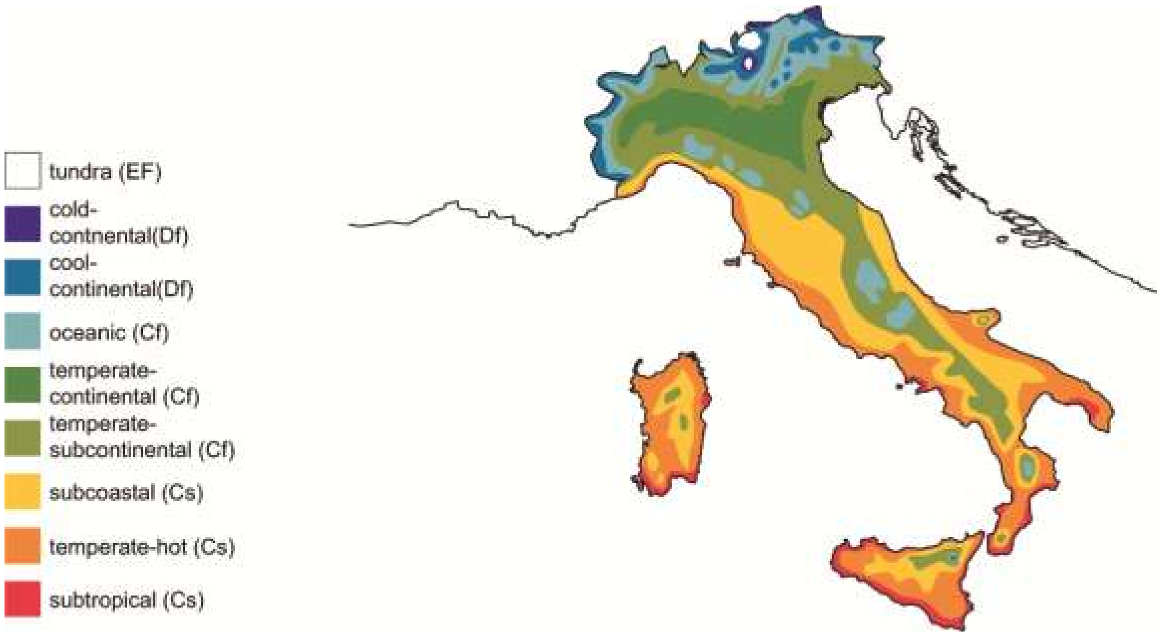


Figure 5: Italian climate zones according to Pinna classification.

Italian regulation (P.R. 1993; ISO 2008; UNI 2016, 10349) divides the territory in six climate zones (from A to F) according to the parameter of Heating Degree Day (HDDs), which are proxies for the energy demand needed to heat a home or a business (European Environment Agency 2019) of a typical year (ISO 15927-4:2005).

For each municipality, belonging to a climatic zone determines the period of the year and the number of daily hours in which the heaters can be switched on. The HDD of Italian municipalities range from 568 in Lampedusa (Agrigento) to 5,165 in Sestriere (Turin).

Climate Zone	Degree Day (DD)	Number of municipalities	Residential population	% Residential population
A	DD≤ 600	2	22.989	0,04%
B	600 <GG ≤ 900	157	3.176.382	5,33%

C	900 <GG ≤ 1.400	989	12.657.407	21,25%
D	1.400 <GG ≤ 2.100	1611	14.970.952	25,13%
E	2.100 <GG ≤ 3.000	4271	27.123.848	45,53%
F	DD>3.000	1071	1.619.003	2,72%

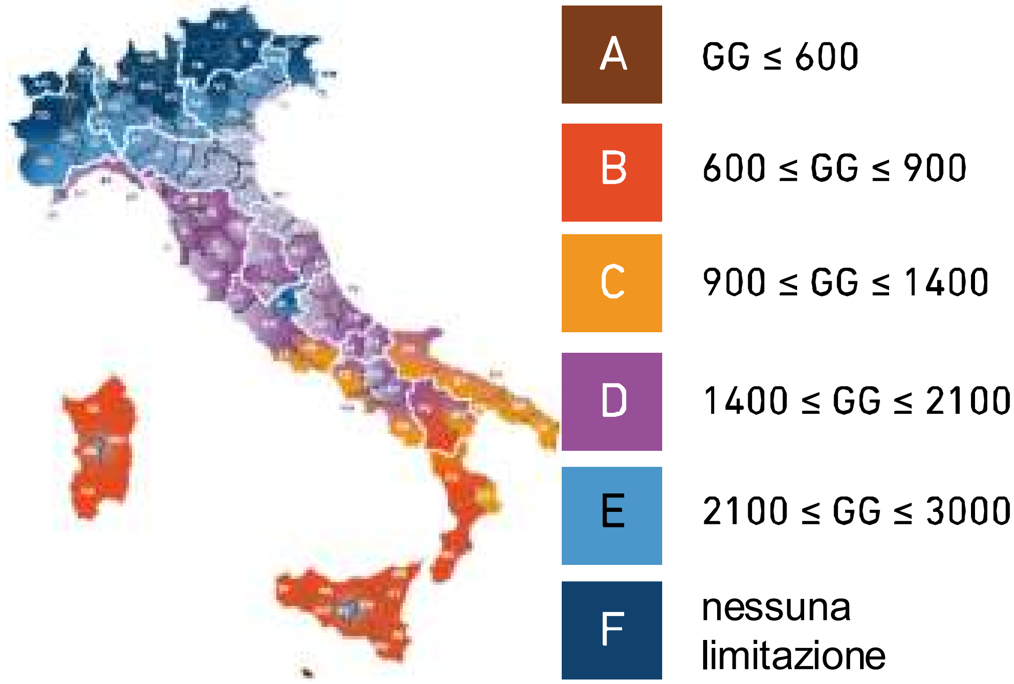


Figure: Graphic display of the subdivision of Italian municipalities into climatic zones of Annex A of Presidential Decree 412 of 1993, updated and supplemented by Presidential Decree n ° 74/2013 (Corrado, Ballarini, and Corgnati 2012).

National energy consumption for winter heating can be considered proportional to the degree days and the population (ISO 15927-6:2008 and UNI 10349-3:2016), therefore the climatic zone E, the most populated, has higher consumption, while climatic zones A and B have little impact on national consumption. The latitude difference between North and South also involves large differences in the values of global solar radiation on the horizontal surface ranging from 1.214 kWh/m² in Ahrntal (Bolzano) to 1.679 kWh/m² in Pachino (Syracuse), with an average of 1.471 kWh/m² (0,127 toe/m²). The UNI 10349 series of standards reports the values of the climatic monthly data of the various Italian municipalities that can be used for the energy performance calculations of buildings.

Heritage buildings in temperate climate areas tend to develop housing solutions capable of managing the radical seasonal change in atmospheric conditions, preferring massive external walls, pitched roofs (with heavy roofing) limited openings in the northern elevations and reduced openings on the east and west ones in contrast with large openings to the south, making extensive use in particular on this orientation of balconies and loggias, porches and projecting roofs in a range of solutions that finds perhaps the most significant expression in the typology with arcaded courtyard (Novi 1999).

According to F. Butera (AA. VV. 1979), as regards Italy, the mildness of the climate has led to a characterization of the architecture which, while not neglecting the climatic factor, was mainly determined by other factors, above all cultural or linked to the dominations of different cultures.

In the Italian regions with a mountain climate, an example of local architecture are the alpine huts, which generally exploit the difference in height by partially burying the rear part of the building generally exposed to the north and thus able to exploit the insulation and thermal stability of the land being the settlements mainly built on the south-facing slopes. Often in these houses the barn, generally made of wood on the upper floors and the stables on the lower ones, constitute insulating buffer spaces or, in the case of the stables, also heated by the presence of animals. The masonry of considerable thickness is not tampered and the ventilation openings are small and with splayings that allow better lateral penetration of the light radiation (Davoli 1993). The buildings are often characterized by wooden balconies on all sides except the north one. The roofs mainly pitched and with heavy roofing (and therefore of good thermal inertia) are characterized by accentuated projections to protect balconies and walls from the snow that melting would wet the walls compromising their insulating power (Los and Pulitzer Los 1985).

In the regions with a hot and dry climate, on the other hand, we find examples of particularly compact and massive architectures with minimized openings and stormwater collection management systems which in special underground tanks further increase the thermal flywheel action of the ground. This typology of buildings like the trullo is capable of guaranteeing excellent conditions of comfort throughout the whole year.

The Italian region with a mild climate is instead characterized by a vast multitude of building types, from which some recurring elements can be summarized, common to Roman villas such as convent buildings or city arcades (Monti et al. 2001). A central role in buildings whose attention is paid to the interior of the courtyards, is played precisely by the intermediate spaces such as courtyards and arcades that guarantee shaded internal areas sheltered from the winds and capable of supplying fresh air and light to the internal environments always of limited depth (Martinelli and Matzarakis 2017). The massive wall faces and attics are made with vaults that provide thermal stability, the underground rooms provide a reserve of fresh air for the natural air conditioning of the upper rooms and are often in synergy with the presence of tanks inside the courtyards or below the buildings for the collection of rain water.

6.1.2 Available active energy systems for heritage building integration in Italy

6.1.2.1 Existing available active systems and technologies for building integration in Italy – Compatibility with built heritage.

In Italy from 1 January 2018, new buildings and those subjected to a deep renovation (for existing buildings with surfaces exceeding 100sqm and subject to complete renovation of the building elements making up the envelope or in case of demolition and reconstruction) must satisfy at least 50% of the energy needs calculated during the design phase with renewable energy (D.Lgs 2011; 2016). More specifically, the obligation rises to 55% for public works outside historic centers, and to 25% and 27.5% for private and public properties in historic centers (defined urban zones A in D. M. 1968). However, the rule excludes listed heritage buildings (protected by the Code of Cultural Heritage and urban planning instruments), or if the designer demonstrates that the introduction of renewables involves an alteration incompatible with the historical and artistic value of the building (Table 1).

Building typology	**Heating + DHW + Cooling**	**DHW**
Private buildings	50%	50%
Private buildings in historical centres	25%	25%
Public buildings	55%	55%
Public buildings in historical centre	27,5%	27,5%

Table 1: Minimum percentage of RES in Italy fro new building and deep renovated buildings starting from 1 January 2018

The regulation obliges to integrate photovoltaic production with solar collectors and heat pumps and also introduces a minimum electrical power to be installed as a function of the footprint of the building according to the formula:

P(kW) for private buildings = surface on the ground floor of the building (sqm) / 50

P(kW) for public buildings = surface on the ground floor of the building (sqm) / 55

The Decree 26 June of 2015, defines what sources are to be considered Renewable Energy Sources and to what extent: for each energy source (methane, pellets, etc.), the regulation defines the portion of consumption to be considered as renewable (REN) and, vice versa, what it is to be considered non-renewable (NREN). For example, according to this regulation, methane is 100% non renewable while 80% of energy produced by solid biomass is considered renewable (Table 2).

Energy carrier	Fp, nren	fp,ren	Fp,tot
Natural Gas	1,05	0	1,05
GPL	1,05	0	1,05
Diesel and fuel oil	1,07	0	1,07
Coal	1,10	0	1,1
Solid biomass	0,2	0,8	1
Liquid and gaseous biomass	0,4	0,6	1
Electricity from grid	1,95	0,47	2,42
District heating	1,5	0	1,5
Urban solid waste	0,2	0,2	0,4
District cooling	0,5	0	0,5
Thermal energy from solar collectors	0	1	1
Electricity from photovoltaics panel, mini-wind turbine, mini-hydro power	0	1	1
Thermal energy from external environment (free cooling)	0	1	1
Thermal energy from external environment (heat pump)	0	1	1

Table 2: Primary energy conversion factors of energy carriers (D. 2015)

Solar cooling & heating technologies

Active solar systems harvest, accumulate and use solar radiation to produce electrical or thermal energy. The most problematic aspect of these systems is the impact on the image of the building in terms of volume, materials and surfaces (MIBACT 2015; Lucchi and Pracchi 2013).

Photovoltaics

As for photovoltaics, the greater yield of a continuous surface compared to the use of smaller elements and the need to apply these systems on the roof respecting the existing slope of the pitches rarely allow an optimized situation from an energy point of view.

The MIBACT guidelines (2015) suggest the relocation of photovoltaic energy production outside the historic centres. With regard to the integration on the roofs of historic buildings, the indication is to exploit as much as possible the roofs of the annexed buildings and secondly, the integrated solutions over the replacement of the roof. It is also important to study the arrangement of the panels in a continuous way and on the pitch with better characteristics to reduce the visual fragmentation of the pitches and the choice of compatible colour solutions. Moreover, as a general rule the principles of reversibility and non-invasiveness of the interventions are to be used as a guide for defining the interventions through a mitigation of the impacts by studying the type and arrangement of the panels most compatible with the historic building. An interesting reflection and a tool on defining the minimal local levels of integration quality can be found in the LESO-QSV method developed by the University of Lausanne[3].

Solar collectors

For solar collectors, the reflections already addressed for photovoltaics are still valid, with the difference that, due to the characteristics of the storage tanks and the minimization of system heat losses, installation on annexed buildings as in the case of photovoltaics is not recommended (MIBACT 2015; Lucchi and Pracchi 2013). The guidelines in this case therefore recommend the use of panels with an internal storage tank.

Geothermal energy

The use of geothermal exchangers to support heat pumps can provide a large contribution of renewable energy to a building system, including historic buildings. The characteristics of historic buildings, generally inserted in dense urban fabrics, do not generally allow the exploitation of horizontal ground heat exchangers, unless there is free land available beyond the footprint of the building, while the realization of borehole geothermal heat exchangers involves all the risks related to drilling in highly stratified historical areas of archaeological interest.

As part of the European project Horizon 2020 Cheap and Efficient APplication of reliable Ground Source Heat exchangers and PumpS, these systems were however theoretically studied also in application to historic buildings such as the church of S. Croce in Florence and the Murano Glass Museum[4].

Biomass energy

Biomass are substances of biological origin linked to forests, crops and residues of the agri-food industry from which it is possible to obtain fuels (solid, liquid or gaseous) that can be exploited with technologies that are currently already mature. Biomasses are considered partially renewable (§ **Error! Reference source not found.**), and do not contribute with their emissions to the formation of acid rain and in the neutral balance of CO2 in the atmosphere (provided that they are actually local). On the other hand,

[3] https://www.epfl.ch/labs/leso/research/domains/renewables_integration/leso-qsv/
[4] https://cheap-gshp.eu/

their reduced presence on the Italian territory and the low energy density combined with their seasonality and other factors such as humidity content and mechanical resistance lead to logistical problems associated with relative cost increases (MIBACT 2015).

Lighting

In the field of artificial lighting, the historical-critical interpretation of the building is an effective guide to understand what the lighting of the asset was originally and then define the colour and intensity of the light to be used or its extension by surfaces, lines or spot inside the historic building, without prejudice to the “right to being dark” of some historic architectures (MIBACT 2015). The technological evolution of LEDs today offers great design flexibility and reduced consumption along with advanced control possibilities that should always be considered as a potential source of energy and economic savings in interventions on historic buildings.

Building automation

A Building Automation and Control System (BACS) is made up of one or more sensors that measure the parameters required for the implementation of the control strategy, such as the external and internal temperature, the presence of pollutants in the air, the speed and direction of the wind or the presence and direction of rain, one or more actuators operating on the openings, and a control and supervision system that induces the actuator to operate on the openings based on a programmed algorithm (Levermore 1989). Attention has also recently shifted from controlling the active systems to managing passive behaviour of buildings, for example by acting on the opening parts, on the shading systems, on specific bioclimatic technologies or on adaptive materials (Pierucci 2015). Conventional internal environment control systems are "reactive" in the sense that they react based on sensor detections for feedback, but this relationship has certain times and levels of interrelation (Calcerano 2015). More advanced systems add a virtual simulation model that runs in parallel to the measurements on the building by simulating potential alternatives in advance of the real model so as to be able to direct it towards resource optimization (Mahdavi and Pröglhöf 2005). BACS introduce the concept of responsive architecture, a rather of complex systems that make the building capable of modifying its behaviour and performance in relation to environmental conditions or the needs of users (Pierucci 2015). UNI EN 15232:2012 defines 4 classes of BACS efficiency depending on the automation systems specs within seven fields (heating, DHW, cooling, ACH, lighting, shading, technical home and building management) with two calculation methods to estimate the possible savings depending on the efficiency class. This strategy is particularly interesting when integrated in historical buildings given its low impacts thanks to the new technologies. This systems are reversible thanks to the small dimension of the physical parts needed, they are characterised by a low impact on the building, they are quick to install and flexible in terms of further possible evolution of the need of the building and its occupants (Pierucci 2015).

6.1.2.2 Compatibility issues with heritage buildings

In historic buildings, the systems are generally needed to address two types of problems, that of the thermohygrometric comfort of the occupants and its compatibility with the conservation of the historic building, to which a third order of problems can be added, in the case of archival or exhibition use in which the conservation of movable cultural heritage also takes over (Lucchi and Pracchi 2013; De Santoli 2007).

The MIBACT guidelines (2015) provide an in-depth framework on system integration on historic buildings, from which it is possible to extract some general indications:

- the first concerns the implementation of "dry construction" interventions as far as possible, to avoid masonry interventions. A preventive survey of the state of the building is therefore a key analysis to be performed in order to accurately predict holes and housings for cables and pipes, and it is important to use of core drills in order to avoid manual demolition of the walls that involve further intervention with mortar, a source of potential subsequent complications and cost increases;
- system adaptations must always be calibrated on the existing building, without giving in to the temptation of super-automation, and preferring quality and simplicity both in construction and in management and maintenance phases, the latter particularly important to avoid that repairs on the plants require destructive interventions.
- particular attention should be paid to plant engineering works in seismic areas such as the opening of conduits that can weaken the walls or the integration of concrete structures for the lifts that can instead stiffen the structural behaviour of the building;
- for air conditioning systems it is recommended to use single-pipe systems, preferably in copper, the use of radiant floor panels and the recovery through jacketing or intubation of old flues;
- for the integration of renewable energy sources, the focus is on making the system intervention as part of the design solution in terms of compatibility, comparison and optimization between project requirements and requirements offered by the historic building, to minimise their impact. The guideline reports examples of this "integrated" design as responses to the particular needs of a historic building that could lead to the use of special flexible pipes for access to certain rooms, or high pressure to be able to reduce the pipe sections, the use of visible system solutions given the prohibitions to execute wall conduits and therefore the need to design the solution in terms of materials, colors and design, up to the study of the possible recovery of existing systems for their reuse or for the simple preservation of their historical value.

6.1.3 Existing examples of active systems integration in heritage buildings in Italy.

Below it is reported a selection of case studies of active systems integration in Italy that can be connected also to the Italian case study

6.1.3.1 Palazzo Santander

Name of Building: Palazzo Santander

Location: Corso Massimo D'Azeglio 33/E - Torino

Coordinates: 45°02'48.0"N 7°40'45.2"E

Floor area: 7.000,00 m^2

Original use – present use: Original use: Headquarter of training offices for the Fiat automotive industry; Present use: Headquarters of Banco Santander Bank.

Year: Late 19th century Early 20th century

Picture:

Figure 6: Plan view Palazzo Santander

Figure 7: Palazzo Santander. Source: https://citynews-torinotoday.stgy.ovh/~media/original-hi/9040049169856/palazzo-santander-2.jpg

Climate Characteristics:

Figure 8: Turin, Climate characteristics and wind rose (source: https://www.windfinder.com/windstatistics/tornino_aeroporto)

Palazzo Santander is located in Turin, Piedmont, Northern Italy. The local climate is characterised by mild springs and autumns on average, summers on average hot with maximum daytime temperatures, recorded in July and August, equal to 36 ° C and average daytime temperatures of 26 ° C. Winter, on the other hand, is quite harsh with average daytime temperatures, recorded between December and January, equal to 4 - 5 °C and minimum night temperatures that can reach peaks of even -13 ° C.

Characteristics of the building:

The building was built between the end of the nineteenth century (1899) and the early twentieth century and housed the Isvor Fiat headquarters, a company training center owned by the Fiat industries. It is currently inserted in a multifunctional space resulting from the recovery of the area and the building, evidence of early 19th century industrial architecture, and new interventions on public spaces, green and otherwise. Among the new constructions there are also two new buildings located on the north-east side of the existing structure, with a mainly residential function.

Although the building presents materials that are typical of the transition between the nineteenth and twentieth centuries, and a different size, orientation and original use, from an aesthetic point of view we do not have a strong formal detachment of the architectures designed 50 years earlier, and therefore we find references to arches, pilasters, cornices and mouldings as in the Italian case study of BEEP Palazzo Maffei-Borghese (Clementino). The number of floors (three, to which a new roofing has recently been added) is also comparable. Both buildings are also inserted in an urban context and close to a river. The main facades of the building overlook Corso Massimo d'Azeglio to the west and Corso Dante, to the south, which leads to the river. To the north of the building there is also a sort of courtyard, delimited by the L-shaped plan of the structure.

Brief description of the intervention:

The intervention is part of a set of actions that involved the whole neighbourhood. In particular, the Palazzo Santander undergo a retrofit intervention (with GBC historic building certification) after the building was abandoned in 2008. The activities aimed at improving the energy efficiency were implemented during the works for the creation of offices for the new headquarters of Banco Santander. The aim was to create innovative and comfortable spaces for workers from all points of view, from the visual to the thermal one. The interior spaces have been redesigned paying attention to the inclusion of vegetation. And the same attention can be seen in the courtyard. Among the interventions carried out there are: the provision of bicycle stations and the use of green public or private transport to reach the building in order to limit emissions; the recovery of outdoor spaces with vegetation and an attention to the heat island effect, the reduction of water consumption; the control of waste management during construction and throughout the life cycle of the building; the building and its surroundings is also a smoke-free area.

In order to obtain certification it is necessary to guarantee a reduction in energy consumption. This was achieved in two ways: by reducing consumption related to the artificial lighting of indoor environments thanks to a sensor system that allows the environments to be illuminated only when the building is used and using renewable energies for energy production.

Active systems employed

Energy efficiency has been achieved through the use of renewable energy for HVAC systems as the building reached the maximum score (6/6) for the use of renewable sources as energy supply. A complex system for summer cooling and winter heating with a heat pump, powered by geothermal energy, is able to guarantee thermal comfort throughout the year, while keeping energy consumption levels low. The system works by exploiting the constant and relatively high temperatures of the groundwater, which are introduced into the pipes as a heat conducting liquid and then returned to the outlet.

Sources:

https://gbcitalia.org/web/guest/gbc-hb-progetti

https://www.gbcitalia.org/documents/20182/86368/GBC+Italia+Scheda+punteggio+Palazzo+Santander.pdf/7e927d3f-07d2-4c11-a088-086aa2711967

https://www.quotidianopiemontese.it/2018/04/13/inaugurato-palazzo-santander-torino/

https://torino.diariodelweb.it/torino/articolo/?nid=20180413-503005

https://www.torinotoday.it/economia/palazzo-santander-corso-dante.html

https://citynews-torinotoday.stgy.ovh/~media/original-hi/9040049169856/palazzo-santander-2.jpg

https://www.rottasutorino.it/2018/05/verde-e-vetrate-per-la-nuova-sede-di-santander-a-torino.html

http://www.comune.torino.it/cgi-bin/cittagora/exec/view.cgi/1/8542

6.1.3.2 Palazzo Gulinelli

Name of Building: Palazzo Gulinelli

Location: Corso d'Ercole I d'Este - Ferrara

Coordinates: 44°50'24.8"N 11°37'13.4"E

Floor area: Edificio 3.850,00 m^2 - Giardino storico annesso 10.000m^2

Volume: -

Original use – present or future use: Public international school Smiling, Offices of the Canonici Mattei Foundation.

Year: First phase XIV sec. Second phase: XIX sec.

Picture:

Figure 9: Plan view, Palazzo Gulinelli

Figure 10: Prospetti Principali Sud ed Est di Palazzo Gulinelli a Ferrara. Source: https://gbcitalia.org/documents/20182/1263963/gbc_progettomese_gulinelli_02.jpg/7bf9ef66-0cd9-4c5c-ad34-5ea75b6a3ce2?t=1580297096503

Climate Characteristics:

Figure 11: Bologna, climate characteristics and wind rose. Source: https://it.windfinder.com/windstatistics/bologna_borgo_panigale

The city of Ferrara is located in Emilia-Romagna near the River Po, in a flat area and not in direct contact with the Adriatic Sea. The territory has mild and not particularly hot springs and autumns, cold winters with average daytime temperatures between 4 and 7 ° C with maximum peaks of 22 ° C and minimums of -13 ° C. Summers are hot, with average daytime temperatures around 28 ° C and maximum diurnal peaks that can reach 39 - 40 ° C.

Characteristics of the building:

The building is the result of several construction phases. The first phase dates back to the end of the 14th century and beginning of the 15th as the first two distinct nuclei are witnessed since 1508. The nineteenth-century intervention gives the current character to the facade and provided for the unification of the two initial nuclei in a single block. The current structure has an L-shaped plan, around the historic garden. The two main facades overlook Via Armari to the South and Corso Ercole I d'Este to the East. The building is located in the historic center of Ferrara, close to the Burana Canal on the South.

Despite the planimetric and climatic diversity, from a formal point of view the building is similar to the case study of Rome, linked to the Italian construction tradition of palaces spread from the fourteenth century. until the nineteenth century. For both structures the maximum height does not exceed 3 floors. Both have formal features on the façade relating to the nineteenth-century phase with a noble ground floor, framed by a high base and an upper string course frame, to which the two upper floors, the first, patronal, overlap, with important openings (characterized by elements architectural decorations such as tympanums, pilasters and capitals) and a second floor characterized by smaller openings with more measured decorative elements. Both structures are in load-bearing masonry, with decorative elements on the façade, such as corner bosses and molded friezes.

Both structures have a public function with spaces used as offices and have a tree-lined courtyard. A characterising aspect of Palazzo Gulinelli is the presence of an original ventilation system of Victorian origin.

Brief description of the intervention:

Following the earthquake that hit Emilia in 2012, Palazzo Gulinelli required consolidation and restoration. This intervention introduced passive and active systems for the energy efficiency of the restricted building. The building has been certified LEED GBC Historical building gold.

The intervention was designed in BIM. The intervention involved the consolidation of the structure starting from the foundations, damaged by the earthquake, up to the complete recovery of the original roofs. In the same way, according to the restoration criteria, all the original parts that could be recovered have been recovered, from the wooden beams to the flooring. Promoting not only historical preservation but also the GBC principle of sustainable materials recovery. The removal of architectural barriers was achieved through the demolition of a structure from the 1980s, replaced by an X-Lam structure in which elevators were inserted.

The interventions on improving the passive behavior of the building made it possible to reduce consumption by 30%. The insertion of an internal insulation along the facades reduced heat dispersion, avoiding altering the external appearance of the façades. The replacement of a structure added in the 1920s to the guesthouse floor, not valuable and damaged, with a light X-Lam structure, equipped with a roof garden, has allowed a further improvement in energy performance. The original nineteenth-century internal ventilation system was also recovered which reached the various rooms through internal ventilation ducts (similar to flues) and allowed the hot air, coming from an underground boiler, to heat the rooms. The intervention also affected the windows where a double glazing was inserted.

Active systems employed:

The "proto-Victorian" micro-ventilation system for heating was implemented by an active system for heating and cooling with radiant panels. The intervention involved the use of renewable sources for lighting and heating, in particular, to avoid damage to the rooms, dry-mounted and removable radiant panels were inserted. The panels were positioned on the floor or ceiling depending on the needs related to the building.

Sources:

https://gbcitalia.org/web/guest/palazzo-gulinelli

https://gbcitalia.org/documents/20182/1263963/gbc_progettomese_gulinelli_02.jpg/7bf9ef66-0cd9-4c5c-ad34-5ea75b6a3ce2?t=1580297096503

https://gbcitalia.org/documents/20182/1921325/recmagazine158_GBC+Italia_Palazzo+Gulinelli.pdf/f8d08307-f89c-4fd8-b287-a5ff90e88d81

https://www.gbcitalia.org/web/guest/-/palazzo-gulinelli-gbc-historic-building-oro-riceve-il-premio-bim-digital-award20

https://www.palazzogulinelli.com/il-progetto/sistema-energetico/

https://www.palazzogulinelli.com/il-palazzo/condotti-di-ventilazione/

6.1.3.3 Waaghaus

Name of Building: Casa della pesa, Waaghaus

Location: Kornplatz-Piazza del Grano, 2, 39100 Bolzano BZ

Coordinates: 46°29'57.88"N 11°21'18.9"E

Floor area: *843,5 m^2 heated area*

Original use – present or future use: In the past the building served as a public weighing office, today after the intervention it is the office of a cultural association called Waag

Year: XII century followed by slight changes in the Baroque period and in the early 1900s

Picture:

Figure 12 : Plan view Waaghaus


Figure 13: Principal facade on Kornplatz, Waaghaus. Source http://www.3encult.eu/en/project/welcome/PublishingImages/Waaghaus%20copy.jpg

Climate Characteristics:

Figure 14 : Bozen/Bolzano, climate characteristics, wind rose. Source: https://www.windfinder.com/windstatistics/bolzano

Bolzano is located in Trentino - Alto Adige, a mountainous region of Northern Italy, characterized by low temperatures, especially in mid-seasons and in winter, when the greatest concentrations of snowfall are concentrated. Autumn and spring are mostly characterised by mild daytime temperatures, nonetheless low compared to the national average. Summers are characterized by average daytime temperatures not exceeding 27 ° C in the hottest months (July - August) with maximum peaks of 38 ° C and minimum even of -2 ° C. Winters are notoriously cold with average daytime temperatures between December and January equal to 3 ° C, with minimums of -11 ° C and maximums no higher than 18 ° C. Average night temperatures drop considerably, hovering between 0 and -1 ° C.

Characteristics of the building:

The first nucleus of the building dates back to the 12th century and still today has the Romanesque characteristics of the Alpine imprint on the facade. Its former use was of the public weighing office of cereals and liquids and only later, towards the end of the 1800s, it became the Cassa di Risparmio di Bolzano. After the energy improvement intervention (2018-2020) the building was transformed into a cultural center.

The structure is made of stone masonry, about 60 cm thick, and wooden roof, with a high slope due to the heavy winter snowfalls. Two facades have important decorations from an artistic point of view, in particular the facade that connects, through the arcades, the building to the neighboring one, is decorated with a fresco depicting the crucifixion by Silvester Müller, from the sixteenth century.

The building is located in the heart of the city, in the historic centre of Bolzano. Also in this case, the building is located near rivers and streams. In particular, two canals cross the historic center, the first is the Talvera torrent to the west of the building and the second is the Rio Rivellone to the south.

The main facade faces south, onto Piazza del Grano, which also extends to the east of the building. To the north, the structure overlooks via del Portici, characterized precisely by the characteristic arcades typical of the entire historic centre to protect the inhabitants from the elements, which also connect the building to the west with its neighbouring building. The building extends over three main levels, with a fourth floor derived from the high roof. Like all structures in the historic centre, it has underground spaces often dedicated, in the past, to the storage of food.

The building undergo an intervention in the Baroque period with some fixtures that still today date back to this period. Others were replaced in the 1900s with elements of scarce value. Among the fixtures, a box type was recognized, from the 1950s-1960s which allowed the addition of a second frame, in winter, to better defend against the cold.

Brief description of the intervention:

The intervention was carried out as part of the FP7 3encult Project, as one of the eight case studies. The study was supported by environmental analyses and energy simulations which, after several monitoring and calibration cycles, made it possible to arrive at optimized design solutions[5].

The study focused on the material composition of the envelope to identify the thermophysical characteristics and on the air infiltration due to the fixtures, the two major issues related to the building. The original heating system was made of carbon ovens located in the rooms, today it is heated with radiators supplied by a gas-fired boiler with no mechanical ventilation and cooling system.

Based on the analyses, several strategic intervention were planned including:

the joint use of the thermal mass of stone walls in combination with natural ventilation;

the usage of existing chimneys as solar chimneys;

the exploit of the stable temperature of the underground spaces (10 ° C less in summer and 10 ° C more in winter);

the installation of collectors both in the roof and in the cellars.

[5]http://www.eurac.edu/en/research/technologies/renewableenergy/publications/Documents/EURAC_RenEne_AICARR2014_FRoberti-UFilippiOberegger-DExner-AGasparella.pdf

As regards the passive actions aimed at reducing heat loss, the project proposed the following interventions[6], up to a reduction of ca. 50% of energy consumption:

The installation of a removable internal insulation to avoid damage on the internal walls and external decorated, also applicable on the roof and on the floor.

Replacement of the box windows of the mid-1900s of little historical value

Recovery of the original Baroque windows with conservation and limitation of air infiltrations.

Internal ventilation system with heat recovery.

Active systems employed:

On the active systems a heat recovery ventilation system with an efficiency of 05%, was aimed at avoiding heat dispersion and external air infiltrations.

Sources:

https://www.wikizero.com/it/Waaghaus

http://www.eurac.edu/en/research/technologies/renewableenergy/publications/Documents/EURAC_RenEne_AICAR R2014_FRoberti-UFilippiOberegger-DExner-AGasparella.pdf

http://www.3encult.eu/en/casestudies/default.html#CS01

http://www.3encult.eu/en/casestudies/Documents/3ENCULT_Case%20Study%201.pdf

https://www.infobuildenergia.it/casa-della-pesa-a-bolzano-riqualificazione-energetica-di-un-edificio-antico/

6.1.3.4 Basilica di Santa Maria di Collemaggio.

Name of Building: Basilica di Santa Maria di Collemaggio

Location: Piazzale Collemaggio, 67100 L'Aquila AQ

Coordinates: 42°20'33.9"N 13°24'18.0"E

Floor area: 2140,5 m^2

Volume: -

Original use – present or future use: Basilica

Year: XII sec.

Picture:

[6] http://www.3encult.eu/en/casestudies/Documents/3ENCULT_Case%20Study%201.pdf

Figure 15 : Plan view of the Basilica di Santa Maria di Collemaggio

Figure 16 : Main facade of the Basilica. Source https://www.hiberatlas.com/smartedit/projects/39/POLIMI_Collemaggio_Exterior%20Construction%20Photo_002.jpg

Climate characteristics:

Fig. 3 Temperatura e velocità dei venti Scoppito https://www.windfinder.com/windstatistics/scoppito

The city of L'Aquila is located in the Abruzzo region, a predominantly mountainous region of central Italy. Despite being in a central position, the city is located at an altitude of 715 m above sea level with generally lower temperatures compared with other areas in central Italy.

In autumn and spring the average daytime temperatures vary from 9 to 14 ° C, which can however reach minimum temperatures as low as -6 ° C. In winter, average daytime temperatures drop between 4 to 7 ° C. In winter, night peaks of even -15 ° C can be reached. Summers are on average hot with average daytime temperatures between 22 and 24 ° C, with maximum peaks between 35 and 38 ° C.

Characteristics of the building:

The Basilica of Santa Maria di Collemeggio is a religious building dating back to the 12th century. The basilica is part of a religious complex located outside the historic city walls, in an area with low population density, and is surrounded by a large green area belonging to the countryside and the Botanical Garden of the University of L'Aquila. The ecclesiastical building has the structural conformation typical of the medieval church, with an elongated plan, however without a transept, divided into three naves by columns. The structure consists of a single, compact environment, characterized by apsidal terminations, on the east side, and with no openings except for the three front entrance doors. The main façade, oriented to the West, has the characteristics of the Abruzzo Romanesque-Gothic style and is made up of stones with white and pink veins, which denote its formal uniqueness. The structure is in load-bearing masonry, of considerable size, and on the internal walls there are frescoes of particular historical-artistic importance. Functionally and contextually, the building of Santa Maria di Collemaggio presents itself in total diversity with respect to the Italian case study, however, like this one, it has stone masonry and artistic peculiarities to safeguard.

Brief description of the interventions:

The aim of the intervention was to recover and safeguard the structure from the damage suffered during the violent earthquake of 2009, which caused extensive damage both to the structure and the wall paintings. The starting point was the construction of an HBIM model which supported the whole process up to the design of the heating and cooling system.

Active systems employed:

The intervention is particularly interesting because it is based on the achievement of local thermal comfort which allows for significant energy savings. The heating system is targeted to the occupants and is not aimed at raising the whole indoor airtemperature of the church. Drastic and significant variations in temperature could have irremediable consequences on the stone walls and in particular on the wall paintings also dating back to the 12th century. This is why a special system has been devised that uses the same pew that host the occupants during the celebrations as radiant hydronic terminals. The water is heated by a water to water heat pump and then distributed through small pipes to the benches and the heated footboards. The pew integrate specifically designed radiant panels optimised to maximize the view factors of the seated people. The system is also supported by a borehole geothermal heat exchanger (4 borehole 150m deep each) placed on the back of the Basilica, and is turned on 1 hour before each celebration and then turned off. The team employed CFD simulation(Aste et al. 2016) to design the system and verify that while active, the rise of environmental temperature in the whole church is only 2.5 °C this not causing abrupt changes that could damage the paintings.

Sources:

https://www.hiberatlas.com/en/basilica-di-santa-maria-di-collemaggio--2-39.html

Aste, Niccolò, Stefano Della Torre, Rajendra S. Adhikari, Michela Buzzetti, Claudio Del Pero, Fabrizio Leonforte, and Massimiliano Manfren. 2016. 'Sustainable Church Heating: The Basilica Di Collemaggio Case-Study'. Energy and Buildings 116 (March): 218–31. https://doi.org/10.1016/j.enbuild.2016.01.008.

6.1.4 Refenreces

AA. VV. 1979. La Progettazione Dell'architettura Bioclimatica. Franco Muzzio Editore.

Aste, Niccolò, Stefano Della Torre, Rajendra S. Adhikari, Michela Buzzetti, Claudio Del Pero, Fabrizio Leonforte, and Massimiliano Manfren. 2016. 'Sustainable Church Heating: The Basilica Di Collemaggio Case-Study'. Energy and Buildings 116 (March): 218–31. https://doi.org/10.1016/j.enbuild.2016.01.008.

Blasi, Carlo, and Leopoldo Michetti. 2005. 'Biodiversità e clima'. In Stato della biodiversità in Italia, edited by Carlo Blasi. Roma: Palombi.

Calcerano, Filippo. 2015. 'Progettazione Tecnologica per l'architettura Bioclimatica. Strategie e Sistemi Di Ventilazione Naturale per Il Raffrescamento Passivo Nella Riqualificazione Energetico-Ambientale in Clima Mediterraneo'. Tesi di dottorato, Roma: La Sapienza.

Cerroni, Federica. 2010. Progettare il costruito. Tecnologie per la riqualificazione sostenibile dei siti ad elevata qualità storica e ambientale. Roma: Gangemi.

Coch, Helena. 1998. 'Chapter 4—Bioclimatism in Vernacular Architecture'. Renewable and Sustainable Energy Reviews 2 (1–2): 67–87. https://doi.org/10.1016/S1364-0321(98)00012-4.

Corrado, Vincenzo, Ilaria Ballarini, and Stefano Paolo Corgnati. 2012. 'Project Tabula - Typology Approach for Building Stock Energy Assessment - ITALIA'. UE nell'ambito del programma Intelligent Energy Europe 2009-2012.

D. 2015. Applicazione Delle Metodologie Di Calcolo Delle Prestazioni Energetiche e Definizione Delle Prescrizioni e Dei Requisiti Minimi Degli Edifici. https://www.gazzettaufficiale.it/eli/id/2011/03/28/011G0067/sg.

D. M. 1968. Limiti Inderogabili Di Densita' Edilizia, Di Altezza, Di Distanza Fra i Fabbricanti e Rapporti Massimi Tra Spazi Destinati Agli Insediamenti Residenziali e Produttivi e Spazi Pubblici o Riservati Alle Attivita' Collettive, al Verde Pubblico o a Parcheggi Da Osservare Ai Fini Della Formazione Dei Nuovi Strumenti Urbanistici o Della Revisione Di Quelli Esistenti, Ai Sensi Dell'art. 17 Della Legge 6

Agosto 1967, n.765. https://www.gazzettaufficiale.it/eli/id/2011/03/28/011G0067/sg.

Dall'Ò, Giuliano. 2011. Green energy audit: manuale operativo per la diagnosi energetica e ambientale degli edifici. Milano: Edizioni Ambiente.

Davoli, P. 1993. Architettura Senza Impianti: Aspetti Bioclimatici Dell'architettura Preindustriale. Firenze: Alinea.

De Santoli, L. 2007. Gli Aspetti Energetici Nella Conservazione Dei Beni Culturali in G. Carbonara, Trattato Di Restauro. Vol. IX. Utet Scienze Tecniche.

D.Lgs. 2011. Attuazione Della Direttiva 2009/28/CE Sulla Promozione Dell'uso Dell'energia Da Fonti Rinnovabili, Recante Modifica e Successiva Abrogazione Delle Direttive 2001/77/CE e 2003/30/CE. (11G0067). https://www.gazzettaufficiale.it/eli/id/2011/03/28/011G0067/sg.

———. 2016. Proroga e Definizione Di Termini. https://www.gazzettaufficiale.it/eli/id/2011/03/28/011G0067/sg.

European Environment Agency. 2019. 'Heating and Cooling Degree Days'. https://www.eea.europa.eu/data-and-maps/indicators/heating-degree-days-2.

Historic England. 2018. Energy Efficiency and Historic Buildings, How to Improve Energy Efficiency. Historic England.

ISo. 2005. ISO 15927-4:2005. https://www.iso.org/standard/41371.html.

ISO. 2008. ISO 15927-6:2008. http://store.uni.com/catalogo/uni-en-iso-15927-6-2008?josso_back_to=http://store.uni.com/josso-security-check.php&josso_cmd=login_optional&josso_partnerapp_host=store.uni.com.

Köppen, Wladimir. 1918. 'Koppen Climate Classification (Climatology)'. Encyclopedia Britannica. 1918. http://www.britannica.com/EBchecked/topic/322068/Koppen-climate-classification.

Kottek, Markus, Jürgen Grieser, Christoph Beck, Bruno Rudolf, and Franz Rubel. 2006. 'World Map of the Köppen-Geiger Climate Classification Updated'. Meteorologische Zeitschrift 15 (3): 259–63. https://doi.org/10.1127/0941-2948/2006/0130.

Levermore, G. J. 1989. Staff Reaction to Building Energy Management Systems. Bracknell, Berks.: BSRIA.

Los, Sergio, and Natasha Pulitzer Los. 1985. L'architettura del regionalismo: guida alla progettazione bioclimatica nel Trentino. Trento: Provincia Autonoma di Trento, Servizio Energia.

Lucchi, E., and V. Pracchi. 2013. Efficienza Energetica e Patrimonio Costruito. Maggioli Editore.

Mahdavi, A., and C. Pröglhöf. 2005. 'A Model-Based Method for the Integration of Natural Ventilation in Indoor Climate Systems Operation'. Proceedings of 9th International IBPSA Conference, BS 2005; Montreal; Canada; 15 August 2005 through 18 August 2005.

Martinelli, Letizia, and Andreas Matzarakis. 2017. 'Influence of Height/Width Proportions on the Thermal Comfort of Courtyard Typology for Italian Climate Zones'. Sustainable Cities and Society 29 (February): 97–106. https://doi.org/10.1016/j.scs.2016.12.004.

MIBACT. 2015. 'Linee Di Indirizzo per Il Miglioramento Dell'efficienza Energetica Nel Patrimonio Culturale. Architettura, Centri e Nuclei Storici Ed Urbani'. Ministero dei beni e delle attività culturali e del turismo Direzione generale Belle Arti e Paesaggio. http://www.beap.beniculturali.it/opencms/multimedia/BASAE/documents/2015/10/27/1445954374955_Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf.

Monti, Carlo, Riccardo Roda, Maria Rosa Ronzoni, Pietro Andreotti, and SAIE. 2001. Costruire sostenibile: il Mediterraneo, 2001. Firenze; Bologna: Alinea ; Fiere internazionali di Bologna-Ente autonomo.

Novi, Fausto. 1999. La riqualificazione sostenibile: applicazioni, sistemi e strategie di controllo climatico naturale. Firenze: Alinea.

Olgyay, Victor. 1963. Design With Climate: Bioclimatic Approach to Architectural Regionalism. First Edition edition. Princeton University Press.

Pierucci, Alessandra. 2015. 'Building Automation e Risparmio Energetico Nel Recupero Edilizio'. INGENIO. https://webapi.ingenio-web.it/immagini/file/byname?name=PIERUCCI_ALESSANDRA_Building_Automation_e_risparmio_energetico_nel_recupero_edilizio_qowK.pdf.

Pinna, M. 1977. Climatologia. Torino: Utet.

P.R. 1993. Regolamento Recante Norme per La Progettazione, l'installazione, l'esercizio e La Manutenzione Degli Impianti Termici Degli Edifici Ai Fini Del Contenimento Dei Consumi Di Energia. https://www.gazzettaufficiale.it/eli/id/1993/10/14/093G0451/sg.

Tubi, Norberto, Maria Pia Silva, and Federica Ditri. 2009. Gli Edifici in Pietra - Recupero e Costruzione - Murature, Solai - Analisi Bioclimatica e Ambientale. Sistemi Editoriali.

UNI. 2016. UNI 10349-3:2016. http://store.uni.com/catalogo/uni-10349-3-2016.

UNI EN. 2012. UNI EN 15232:2012 - Prestazione Energetica Degli Edifici - Incidenza Dell'automazione, Della Regolazione e Della Gestione Tecnica Degli Edifici.

6.2 Passive strategies employed by heritage buildings in Spain

6.2.1 Overview of the environmental responsiveness of built heritage in Spain

Fig. 01: Spanish climatic zones. Source: ISFTIC images bank

Spain has several diverse climatic zones throughout its territory:

- Coastal Mediterranean climate (on the southern and eastern coasts), with mild temperatures and abundant rainfall except in summer.
- Continental Mediterranean climate (in the interior, in almost all the peninsula), with low winter temperatures and high and irregular rainfall in summer.
- Oceanic climate (in Galicia and Cantabria) characterized by abundant rainfall throughout the year, especially in winter, and cool temperatures.
- Mountain climate (in the highlands), with very cold winters and abundant rainfall.
- Subtropical climate (in the Canary Islands), with warm temperatures throughout the year and low rainfall.
- Arid or semi-arid climate (in some parts of the eastern peninsular: Almería, Granada, Murcia or Alicante), with relatively mild temperatures throughout the year and more abundant rainfall than in the Canary Islands.

Vernacular architecture has tried to respond to these different zones, offering solutions adapted to the climatic characteristics of the site, considering other aspects beyond the use of orientations and thermal mass for regulation and/or insulation. While in the case of continental, oceanic and mountain climate zones, the most common vernacular solutions have taken into account controlled or restricted ventilation, surfaces that capture or absorb sunlight for passive heating, as well as hermetic and protected openings, in the case of zones with more temperate climates other considerations seem to have been taken into account, such as natural cross ventilation, solar protection of openings, creation of shading and interior-exterior transition spaces for passive cooling, with more open floor plans being designed in general.

6.2.2 Available active energy systems for heritage building integration in Spain

6.2.2.1 Existing available active systems and technologies for building integration in Spain– Compatibility with built heritage.

Although new Spanish buildings have a regulatory framework that guarantees a certain energy efficiency, the Spanish building stock is obsolete and half of the buildings are more than 40 years old, having been built without considering any energy efficiency standard. Due to this context, measures such as the incorporation of insulation in the building envelope, the replacement of the old frames of the façade openings for new ones with better thermal performance, also substituting single glazing with double glazing, are quite popular when undertaking an energy rehabilitation.

Already in 2012, a catalogue of energy solutions applicable to heritage buildings was developed within the framework of the RENERPATH project (part of the Spain-Portugal POCTEC Cross-Border Cooperation Operational Programme 2007-2013). The proposed solutions were mainly related to the building envelope, lighting and cooling/heating technologies:

- In the case of solutions related to the envelope, new enclosure concepts such as cBloco -ceramic masonry blocks- and solar tiles -photovoltaic solar systems on roofs and ceramic coverings- were proposed.
- In the case of lighting, emphasis was placed on lighting regulation and control systems as the key element in the energy improvement.
- In the case of heating/cooling technologies, some solutions for the integration of renewable generation elements (solar collectors, photovoltaic modules and biomass boilers) were proposed.

According to the IDAE's Renewable Energy Statistical Report (with data updated as of March 2020), this was the primary consumption of renewables in the heating and cooling sector in 2018:

	Surface (m^2)	Primary Energy Production (ktoe)
Biomass and waste		4,130
Biogas		55
Low temperature solar thermal	4,202,770	324
Geothermal		19
TOTAL THERMAL AREAS		**4,528**

Fig.08: Primary consumption of renewable energy 2018. Sectors: heating and cooling. Source: http://informeestadistico.idae.es/t4.htm

The heating and cooling sectors accounted for a quarter of the nearly 18 million toe of primary renewable energy consumption in 2018.

According to the aforementioned report, the solar thermal surface area installed in Spain during 2018 increased by 2% compared to that installed the previous year, and the market associated with the Technical Building Code grew by 4% with respect to 2017. The accumulated solar surface area at the end of 2018 reached 4.2 million square meters.

As stated in the update of the “Long-term strategy for energy retrofitting in the building sector” (ERESEE, June 2020), Spain is one of the EU countries with the greatest potential for the use of renewable energies in buildings, particularly solar energy, due to the hours of sunshine and the remarkable development of this business and industrial sector in Spain. In addition, and increasingly so, there is also great potential for other renewable sources such as aerothermal, geothermal or biomass.

According to the latest studies on heating and cooling carried out in Spain (such as the report on HVAC market data in 2019 by AFEC -Association of HVAC Equipment Manufacturers), the highest growth in sales of machines in 2019 was in those of aerothermal heat pumps up to medium capacity.

In the case of geothermal energy, Ground Source Heat Pumps (GSHP) represent an attractive alternative to Air Source Heat Pumps (ASHP) since the outdoor unit is buried underground, removing one of the main barriers regarding building integration compatible with heritage protection; namely, the visual impact of equipment placed in the envelope.

As for biomass, according to the report "Biomass in Spain. Generation of added value and prospective analysis" (FEDEA -Fundación de Estudios de Economía Aplicada-, 2020), the production of thermal energy from biomass for building and industry has been progressing slowly in Spain and currently consumes around 4,000 ktoe, a figure significantly lower than that of other European countries. The latest report of the Biomass Observatory for 2020 complies 433 biomass heat networks, representing some 383 MW of installed thermal power. Three quarters of the existing heat networks in the country operate with biomass. Most of the biomass heat networks are in rural areas, although the most powerful ones are in cities with between 50,000 and 300,000 inhabitants. According to the use of the connected buildings, 75% of the inventoried networks supply energy to public buildings and 22% to private buildings, mainly dwellings. Half of the private networks connect blocks of apartments, most of them in neighbourhoods that are more than 40 years old and which already had central heating.

In the industrial sector, cogeneration became in 2019 a key energy tool for more than 600 Spanish industries, supporting 200,000 direct jobs and contributing 20% of the country's industrial GDP, generating 11% of national electricity and 20% of gas demand. There is no specific data on this system for the building sector -micro-cogeneration-, beyond some cases in which it has been successfully implemented and the possible benefits it could have in the residential or tertiary sector.

6.2.2.2 Compatibility issues with heritage buildings

In 2018 an update of the “Energy Saving Basic Document” (Documento Básico de Ahorro de Energía, DB-HE) of the “Technical Building Code” (Código Técnico de la Edificación, CTE) was approved, with new requirements to comply with Directive 2010/31/EU (EPBD). This regulation updated the energy performance requirements for both new buildings and existing one, firstly applying to public buildings. No special mention was made of heritage buildings, which were included in the category of existing buildings. The regulations therefore excluded from compliance buildings with recognised heritage values.

The latest update of the same document (CTE DB-HE, 2019) excludes from compliance with the limitation of energy consumption and demand, "buildings that are officially protected as part of a declared environment or because of their particular architectural or historical value, insofar as compliance with certain energy requirements could unacceptably alter their character or appearance, being the authority dictating official protection in charge of determining the unalterable elements". The same exemption applies to the conditions of the lighting installations and the minimum generation of electric power, indicating for the latter case that "in those buildings in which, for urban or architectural reasons, or because they are officially protected buildings (being the authority that dictates the official protection the one that determines the unalterable elements), it is not possible to install the required power, it is mandatory to justify this impossibility by analysing the different alternatives and the solution closest to the maximum production conditions will be adopted".

The deadline for the transposition of EU Directive 2018/844 into Spanish national law was 10 March 2020. Spain missed the deadline. The ERESEE 2020 (presented in July 2020), with milestones, indicators, and intermediate targets up to 2030 and 2040, makes the following specific considerations about protected buildings:

- They are not included in the public energy inventory of buildings belonging to the General State Administration (published annually since 2013, in compliance with Article 5 of Directive 2012/27/EU, on the web portal of the Ministry for Ecological Transition and Demographic Challenge).
- Although not included in the public inventory, these protected buildings have also been energetically inventoried following the same methodology and may be the object of specific energy efficiency improvement action programs, taking into consideration their architectural peculiarities.
- Protected buildings of the General State Administration, which represent a considerable number of the total public buildings and given that their particularities and different degrees of protection make it difficult to implement standard measures, should be the object of a specific analysis to study their possible energy rehabilitation.

It is worth mentioning the exclusive competences of the autonomous communities and city councils in urban planning and housing, which allow them to apply specific regulations and ordinances.

6.2.3 Existing examples of active systems integration in heritage buildings in Spain

Considering the previously explained context, the integration of active and/or hybrid systems in heritage buildings is far from being a common practice in Spain. However, there are examples such as the following:

- Real Colegiata de San Isidoro (León). The existing obsolete heating system was replaced with one based on biomass boilers, incorporating radiators inside all the wooden benches:

Fig.09: Biomass heating system at the Real Colegiata de San Isidoro (León). Sources: https://www.diariodeleon.es/articulo/cultura/san-isidoro-estreno-pionero-sistema-calefactor-biomasa/200912180332001072894.html - https://decoracion.trendencias.com/varios/la-novedosa-calefaccion-de-san-isidoro-de-leon-eficiencia-y-diseno

- Protected Palace for State Administration Offices (C/ Manuel Silvela, 4. Madrid). It is the first refurbishment case in Spain incorporating geothermal and thermoactive HVAC. The building is a mansion from the beginning of the last century with a high degree of protection:

Fig.10: Refurbishment with a geothermal and thermoactive HVAC system (Madrid). Sources: http://www.eneres.es/es/manuel-silvela/ - https://inarquia.es/wp-content/uploads/2014/06/k2_attachments_556ebf1d071be-Proyectos-Emblematicos-en-el-ambito-de-la-geotermia-2010.pdf - https://www.construction21.org/espana/data/sources/users/330/proceso-constructivo-forjados-inerciales-y-geotermia.pdf

Although these two cases are rather anecdotal, the most popular technology seems to be rooftop photovoltaic panels. In Valencia itself, as examples, we could name the modernist building "Punt de Ganxo", close to the case study, and the City Hall headquarters in the Tabacalera building.

6.2.4 <u>References</u>

AFEC. 2020. “Estadísticas de Mercado 2019.” AFEC: Asociación de Fabricantes de Equipos de Climatización. https://www.afec.es/es/mercado-2019

Coch, H. 1998. “Bioclimatism in vernacular architecture”. Renewable and Sustainable Energy reviews, 2 (1-2), 67-87. DOI: 10.1016/S1364-0321(98)00012-4

Cristini, V., Ruiz-Checa, J., Higón Calvet, J., Palmero Iglesias, J. 2015. “Passive energy saving strategies in vernacular architecture: parameterization of resources applied to a case study”. Structural Studies, Repairs and Maintenance of Heritage Architecture XIV. C.A. Brebbia, Wessex Institute of Technology, UK y S. Hernández, Universidad de La Coruña.

Feduchi, L. 1976. “Itinerarios de arquitectura popular española”. Barcelona: Blume.

Ferreira Vaz, J., Fernandes, S., Luso, E., Ferreira, D. 2015. “Bioclimatic solutions in vernacular architecture: transition spaces”. European Scientific Journal.

Flores López, C. 1974. “Arquitectura popular española”. Madrid: Aguilar.

Gregorio, M. 2020. “Estudios sobre la Economía Española – 2020/01. Biomasa en España. Generación de valor añadido y análisis prospectivo”. FEDEA: Fundación de Estudios de Economía Aplicada.

https://documentos.fedea.net/pubs/eee/eee2020-01.pdf

IDAE. 2020. “Informe Estadístico de Energías Renovables”. IDAE: Instituto para la Diversificación y Ahorro de la Energía. http://informeestadistico.idae.es/

INTBAU España. 2020. “Journal of Traditional Building, Architecture and Urbanism. 1-2020”. https://www.traditionalarchitecturejournal.com/

IVE. 2011. “Use of Building Typologies for Energy Performance Assessment of National Building Stock. Existent Experiences in Spain”. Valencia: Instituto Valenciano de la Edificación.

IVE. 2014. “Guía de estrategias de diseño pasivo para la edificación”. Valencia: Instituto Valenciano de la Edificación.

https://www.five.es/tienda-ive/guia-de-estrategias-de-diseno-pasivo/

Manzano-Agugliario, F., Montoya, F., Sabio-Ortega, A., García-Cruz, A. 2015. “Review of Bioclimatic Architecture Strategies for Achieving Thermal Comfort”. Renewable and Sustainable Energy Review, 49, 736-755.

Mencías Carrizosa, D., Arroba Fernández, M., Meneses Navarro, J.A., De Andrés Marcos, J. 2014. “Integración de las energías renovables en los edificios con valores patrimoniales arquitectónicos”. II Congreso Edificios Energía Casi Nula.

Ministerio de Educación, Cultura y Deporte. Gobierno de España. 2015. “Plan Nacional de Arquitectura Tradicional”. IPCE: Instituto del Patrimonio Cultural de España. http://www.culturaydeporte.gob.es/planes-nacionales/planes-nacionales/arquitectura-tradicional.html

Ministerio de Transportes, Movilidad y Agenda Urbana. Gobierno de España. 2020. “Actualización 2020 de la Estrategia a largo plazo para la rehabilitación energética en el sector de la edificación en España”.

https://www.mitma.es/recursos_mfom/paginabasica/recursos/es_ltrs_2020.pdf

Ministerio de Transportes, Movilidad y Agenda Urbana. Gobierno de España. “Código Técnico de la Edificación”. https://www.codigotecnico.org/

Olgyay, V. 2002. “Arquitectura y clima”. Barcelona: Gustavo Gili.

REHABEND. 2016-2020 “Construction pathology, rehabilitation technology and heritage management”. Books of abstracts of the 6th, 7th and 8th REHABEND Congresses.

https://www.rehabend.unican.es/

RENERPATH. 2012. “Guía de aplicación para la rehabilitación energética de edificios patrimoniales”. RENERPATH Project (POCTEP 2007-2013)

RENERPATH-2. 2018. “Pre-Standard Application at European Level”. RENERPATH-2 Project (POCTEP 2014-2020).

http://www.renerpath2.eu/documentacion.html

6.3 Passive strategies employed by heritage buildings in Cyprus

6.3.1 Overview of the environmental responsiveness of built heritage in Cyprus

According to Köppen-Geiger climate classification, Cyprus has a subtropical climate, i.e. combination of Mediterranean and semiarid type (Csa and BSh) (Peel, Finlayson, and Mcmahon 2007). However, Cypriot climate varies according to the altitude and the distance from the sea. Figure 17 presents the distribution of the climatic zones of the island, i.e. Costal (CZ1), Lowlands (CZ2), Semi-mountainous (CZ3) and Mountainous (CZ4). Figure 18 presents, in more detail, the climate zones per administrative sector.

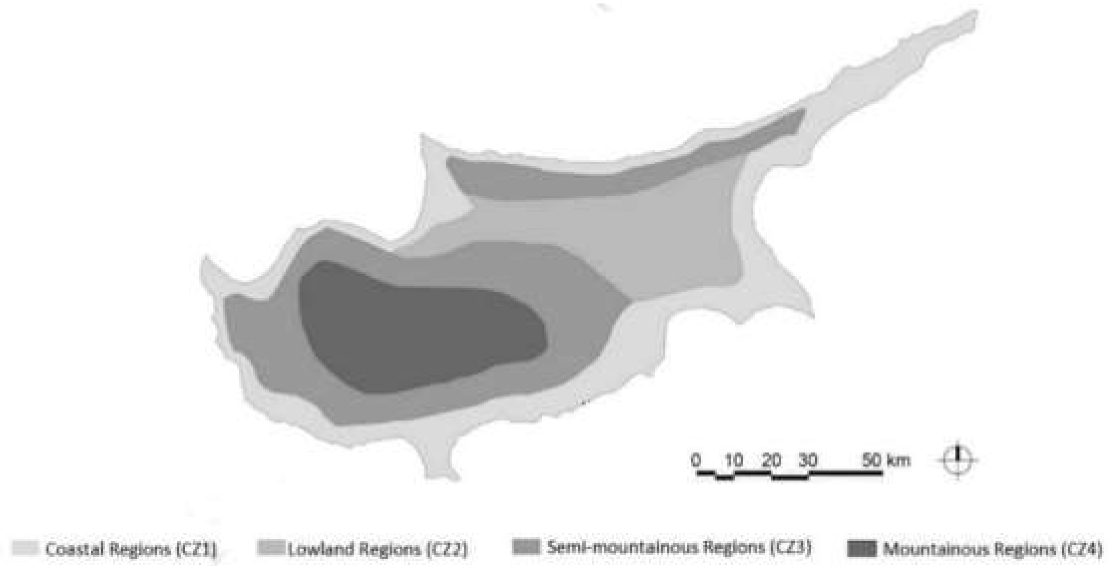


Figure 17: The Climatic Zones of Cyprus (Ministry of Energy, Commerce, Industry and Tourism 2015).

Climatic conditions in zones CZ1, CZ2 and CZ3 are similar, yet, CZ4 is characterized by high altitude (regions above 600 m), therefore has very distinctive characteristics. Specifically, according to their study, the cooling demands of mountainous areas of Cyprus are negligible; in lowland regions cooling demands could be covered through evaporative cooling and thermal mass in combination with night ventilation, whereas in coastal zones mechanical dehumidification is required (Katafygiotou and Serghides 2015). Accordingly, passive means are deemed insufficient to cover the heating demands of winter period, in all the climate zones and particularly in the mountainous zone CZ4 (Katafygiotou and Serghides 2015). Another study regarding different types of residential buildings (single-storey and multi-storey buildings in continuous building system or detached) indicate that the heating demands in CZ4 are deemed three times higher than other zones and the cooling demands are deemed seven times lower (Ministry of Energy, Commerce, Industry and Tourism 2015). In the lowlands cooling energy demands account for 51% of the total energy demands in residential buildings as opposed to heat demands which are responsible for 23% of the total (Menicou et al. 2015).

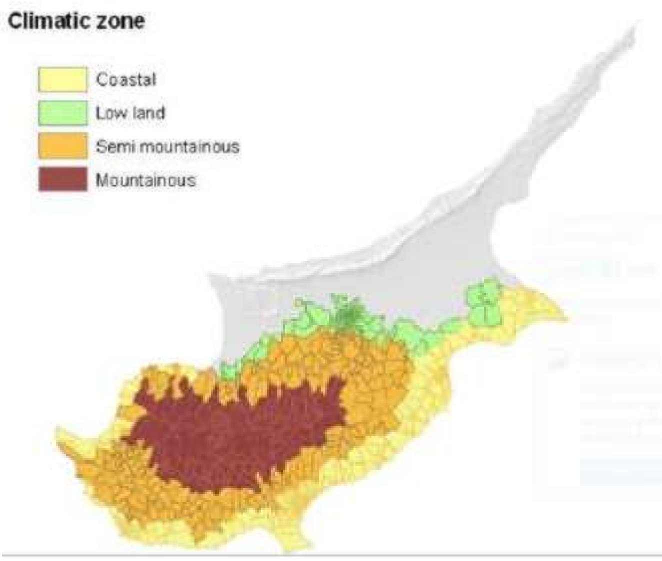


Figure 18: The Climatic Zones of Cyprus – per administrative border (EXERGIA S.A. 2012).

Vernacular architecture varies in built form and construction materials used across lowland, coastal, semi-mountainous and mountainous regions. Characteristic examples of vernacular dwellings are presented in Figure 19,Figure 20 andFigure 21. A comparative assessment of the passive design techniques of vernacular dwellings from different regions of Cyprus is provided by Philokyprou, Michael, Malaktou, et al. (2017). As stated in their study, in all the climate zones, dwellings are built with high-mass walls, i.e. stones and adobes, maximizing thus, the heat storage capacity of the building envelope which contributes to passive cooling. Due to the large diurnal temperature fluctuations of the lowland region, the effectiveness of thermal mass as a passive cooling design strategy is maximized in this area, compared to coastal and mountainous regions where smaller diurnal temperature fluctuations occur.

In terms of building form, the lowland settlements are mainly semi-compact built forms, in order to mitigate high summer temperatures and reduce the exposure to outdoor climatic conditions. High ceilings also prevail in the lowland regions, contributing to the cooling of the interior of the dwellings. Settlements in lowland regions are compact and usually have small internal courtyards (with rectangular or irregular shape in plan). The smaller courtyards of the lowland areas with their high boundary walls, contrary to the more spacious courtyards in the coastal regions, ensure adequate shading and mitigate high summer temperatures (Philokyprou, Michael, and Thravalou 2013; Philokyprou, Michael, Malaktou, et al. 2017). The preference for light-coloured plaster, mainly observed in lowland areas, reflects high percentage of incident solar radiation and thus significantly reduces solar heat gains. Vernacular dwellings in the mountainous regions have more compact built forms with lower ceiling height, in order to reduce the thermal losses. Partially subterranean spaces, which are widely integrated in the design of vernacular dwellings in the mountainous region, provide thermal buffering, shielding from cold winter winds and regulation of outdoor temperature extremes. The vertical development of buildings into multiple floor levels, which is a special design aspect of mountainous regions as a result of the topography, offers thermal buffering to the intermediate floor level spaces (Philokyprou, Michael, Malaktou, et al. 2017).

The semi-open spaces are more widely applied in the lowland regions, compared to coastal and mountainous regions, ensuring suitable outdoor living spaces during the hot summer period (Philokyprou, Michael, Thravalou, et al. 2017). In addition, the cross arrangement of the openings, as well as smaller high-positioned openings of the wall (as in Figure 19 – right), enhance the air flow in the interior space through cross-ventilation and stack effect, respectively. These design strategies are mainly observed in coastal regions and to a lesser degree in lowland regions. In addition to natural ventilation, the above mentioned design strategies contribute to the improvement of indoor daylighting conditions. It is noted that the openings of the building envelope are rather limited and small in all climatic regions in the country and often include external timber shutters or lattices for shading (e.g. Figure 20). The courtyards are usually surrounded by one or two storey buildings and high perimeter boundary walls (e.g. **Error! Reference source not found.** – middle) which block undesirable cold winter winds (Philokyprou, Michael, Malaktou, et al. 2017).

Figure 19: Urban Settlements in the lowlands and the coastal zones. Serial-type housing (left), courtyard-type house (middle), the pass-through central space of portico (right).

Figure 20: Double storey buildings in urban Settlements in the lowlands and the coastal zones. House with closed timber projection locally called sachnisi (left), covered alley (middle), residences with balconies and cantilevered windows (middle and right).

Figure 21: Rural settlements in mountainous and semi-mountainous regions. Typical stone-built dwelling (left), stone-paved

alleys (middle), adobe buildings with earth plasters (middle), open space with deciduous plants for shading purposes (right).

6.3.2 Available active energy systems for heritage building integration in Cyprus.

6.3.2.1 Existing available active systems and technologies for building integration in Cyprus– Compatibility with built heritage.

Regarding buildings' envelope energy performance, barely half of the existing household stock has not taken any energy savings measures and only 12% have used some form of heat insulation on the building envelope. The situation is slightly better in terms of door and window frames, as 38% of the homes have used double glazing (Economidou, Zangheri, and Paci 2017). Insulation materials are widespread in the market, with mineral wool and expanded polystyrene boards being the most widespread practice for buildings' envelope renovation projects. PCM coatings have very limited and mainly experimental applications so far.

As far as the end uses energy sources is concerned, Cyprus is currently dependent on imported oil to meet most of its energy needs (IRENA 2015). In the households, gas oil systems dominate space heating equipment, while solar water heaters are dominant in water heating systems. Electricity is the second most widely used energy form for space heating, water heating and cooking. The maximum net generating capacity of power plants and other installations that use renewable energy sources to produce electricity in Cyprus is shown in Figure 22 (IRENA 2019). The prime renewable sources of energy are solar (deriving mainly from photovoltaic) and wind, while a limited portion of the production derives from biogas. Geothermal energy for space cooling in residences is still very limited (Michopoulos et al. 2016).

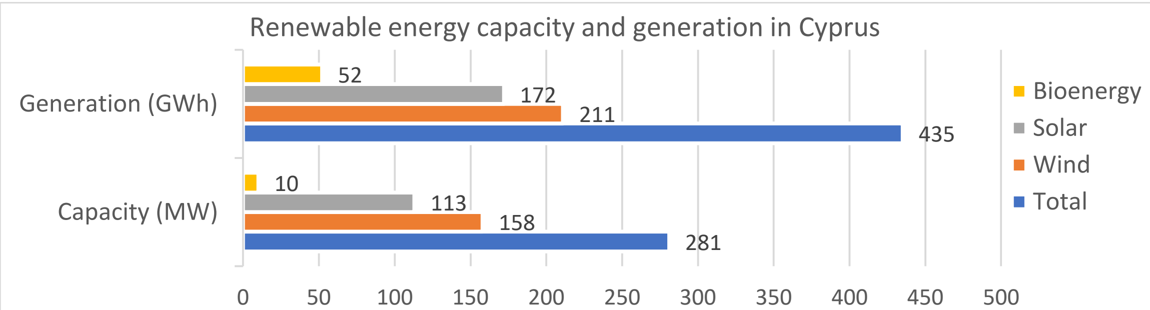


Figure 22: Renewable energy capacity and generation in Cyprus, in 2018. Source: (IRENA 2019)

In conclusion, the potential of energy savings associated with the Cypriot building sector is acknowledged. However, the need for more market action, enhanced private sector involvement and a smooth transition towards nearly zero energy buildings (nZEBs) are increasingly highlighted (Economidou, Zangheri, and Paci 2017).

6.3.2.2 Compatibility issues with heritage buildings

The regulatory framework for the protection of the traditional character of buildings in Cyprus prohibits the installation of RES on the roof of (declared) heritage buildings. Nonetheless, RES can be installed on the roof of building extensions (newly constructed or not declared sections of the original building). In most cases, solar thermal panels for hot water are installed and in few occasions, there are examples of PV installation. Also, the installation of HVAC or other technical systems in heritage buildings should be minimal. Their external units should be hidden from the main view and ensure that they will not affect the microclimate of the building. To avoid the installation of big systems, which usually demand large spaces for maintenance works, fans are usually preferred for cooling purposes and eco-friendly fireplaces for heating purposes. In the case of lighting systems, the installation of energy efficient lights is usually easier and have no major implications for the building's fabric. Overall, apart from electro-mechanical installations, interventions that can be made without compromising the original building's fabric are: installation of double glazing or internal glazing, roof insulation, reconstruction or maintenance of windows/doors/shutters/shades, and the placement of thermal plaster or internal insulation under specific considerations (VIOLET 2020).

6.3.2.3 Existing legislative framework & incentives regarding energy retrofit interventions in heritage buildings in Cyprus

A significant change regarding the energy performance of listed buildings has been made recently in Cyprus. The Amendment of the Law on the Regulation of the Energy Efficiency of Buildings, has been officially published on the 13th of November 2020 (Law 155(I)/2020). According to the new regulatory document:

a) Buildings that have been declared as listed buildings or as ancient monuments cease to be exempted from the obligation to have an Energy Performance Certificate (EPC), when sold or rented.
b) Buildings that have been declared as listed buildings or as ancient monuments can be exempted from the minimum energy efficiency requirements only if their owners present the proposed energy upgrade interventions and supply adequate documentation for exemption, to the Competent Departments [to the Director of the Department of Town Planning and Housing, to the Director of the Department of Antiquities, or the Competent Local Authority].

In the previous legislation, no documentation was needed for these buildings to get exemption, therefore, in most cases no energy upgrade measures were implemented (Cyprus Energy Agency 2020).

An additional reason for limited progress on the energy upgrade of heritage buildings at a national level, has been the lack of financing schemes and incentives. All the incentives provided up-to-day from the Energy Service Department, concerned the energy upgrade of residential buildings. Energy upgrade interventions were not excluded in heritage buildings (as long as they were compatible), however, the set criteria and technical requirements for a holistic energy improvement, proved to be very difficult to reach for these buildings. This resulted to their -indirect- exclusion from the available incentives. Likewise, the existing incentives address particularly to buildings under protection status (direct grants, tax incentives and the transfer of development rights), have as main target the protection of the cultural and architectural aspects. These incentives are very important for essential restoration activities, yet they do not clearly address energy performance interventions. In fact, energy upgrade interventions are not excluded, but the overall financing is considered too low to include these as well (Cyprus Energy Agency 2019).

Considering the recent amendment of the legislative framework regarding the energy performance certification and the minimum energy performance requirements of listed buildings, financing schemes are expected to be harmonised in the following years.

6.3.3 Existing examples of active systems integration in heritage buildings in Cyprus.

There are a few examples of heritage buildings, which incorporated energy improvement measures and active systems (Figure 23). Yet, as this practice was not regulated by national legislation, it remains far from common and depends mainly on private initiatives (owner's and/or the architect's intentions).

Figure 23: Left: Listed building in Kato Arodes, Paphos, Cyprus. During restoration, a PV system was installed. Right: Listed building in the walled city of Nicosia, Cyprus. During restoration, thermal insulation was installed. An extension was also added with a PV system on its roof [Ms Antonia Theodosiou, Architect, Environmental Engineer] Source:(Cyprus Energy Agency 2019)

In the framework of the ongoing research programme HYBUILD ('HYBUILD' n.d.), a pilot hybrid electrical-thermal storage system will be installed in a historic building in Nicosia. The proposed system will be installed on a vernacular dwelling located in the historic core of Aglantzia, which will be used as a Renewable Energy and Smart Solution Center by the municipality (Figure 24). The RES systems will be enhanced with enabling technologies offering the benefits of smart digitalised home solutions that can seamlessly be integrated in the neighbouring community / district to form energy communities (Heracleous et al. 2019). Due to a number of aesthetical and regulatory issues, the hybrid systems will be installed on a free-standing iron construction of the square that will also serve as a shelter. On the roof of the building photovoltaic panels with increased integration possibilities will be installed.

Figure 24: The pilot case study building of HYBUILD project in Nicosia. Source: (Heracleous et al. 2019).

6.3.4 References

Chrysochou, Nasso. 2014. Vernacular Architecture of Cyprus. The Development and Influences from the Rural to the Urban Fabric. Nicosia: Εντυποι.

Cyprus Energy Agency. 2019. ‘Action Plan for Cyprus - VIOLET Project’. VIOLET Interreg Europe Project [2017 – 2021]. https://www.interregeurope.eu/violet/library/.

———. 2020. ‘Action Plan & Regional Update: Cyprus Energy Agency’. VIOLET Interreg Europe Program. 2020. https://www.interregeurope.eu/violet/news/news-article/10980/action-plan-regional-update-cyprus-energy-agency/.

Demi, Danilo. 1997. The Walled City of Nicosia, A Typology Study. Nicosia Master Plan. Book, Edited. Nicosia: UNDP United Nations Development Programme.

Economidou, Marina, Paolo Zangheri, and Daniele Paci. 2017. ‘Long-Term Strategy for Mobilizing Investments for Renovating Cyprus National Building Stock.’ Vol. D1.8. http://www.mcit.gov.cy/mcit/EnergySe.nsf/All/7E8188C6CD612FB5C22581C4002CD533/$file/Study%20Results%20Final%20Report%20Long%20trem%20strategy%20for%20mobilizing%20investments%20for%20renovating%20Cyprus%20national%20building%20stock.pdf.

EXERGIA S.A. 2012. ‘Provision of Consulting Services for the Definition of Nearly Zero Energy Residential Buildings in Cyprus’. Contract agreement MCIT/ES/01/2011.

Florides, G. A, S. A Tassou, S. A Kalogirou, and L. C Wrobel. 2001. ‘Evolution of Domestic Dwellings in Cyprus and Energy Analysis’. Renewable Energy 23 (2): 219–34. https://doi.org/10.1016/S0960-1481(00)00160-9.

Georghiou, Costas. 2013. BRITISH COLONIAL ARCHITECTURE IN CYPRUS: The Architecture of the British Colonial Administration, 1878-1960. Nicosia: En Tipis Publications. https://www.nasisbooks.com/shop/english-books/architecture/architectural-theory-history/british-colonial-architecture-in-cyprus/.

Heracleous, Chryso, Chrysanthos Charalambous, Aimilios Michael, Athena Yiannaka, and Venizelos Efthymiou. 2019. 'Development of an Innovative Compact Hybrid Electrical-Thermal Storage System for Historic Building Integrated Applications in the Mediterranean Climate.' In Comfort at the Extremes 2019 : Energy, Economy and Climate. Dubai.

'HYBUILD'. n.d. HYBUILD. Accessed 14 January 2021. http://www.hybuild.eu/.

Ionas, Ioannis. 1988. La Maison Rurale de Chypre (XVIIIe-XXe Siècle): Aspects et Techniques de Construction. XII. Vol. 12. Book, Whole. Nicosia: Centre de recherche scientifique de Chypre.

IRENA. 2015. 'Renewable Energy Roadmap for the Republic of Cyprus'. https://www.irena.org/publications/2015/Jan/Renewable-Energy-Roadmap-for-the-Republic-of-Cyprus; International Renewable Energy Agency.

———. 2019. 'Renewable Energy Statistics 2019'. Abu Dhabi.: The International Renewable Energy Agency. www.irena.org/Publications.

Kalogirou, Soteris A., George Florides, and Savvas Tassou. 2002. 'Energy Analysis of Buildings Employing Thermal Mass in Cyprus'. Renewable Energy 27 (3): 353–68. https://doi.org/10.1016/S0960-1481(02)00007-1.

Katafygiotou, M. C., and D. K. Serghides. 2015. 'Bioclimatic Chart Analysis in Three Climate Zones in Cyprus'. Indoor and Built Environment 24 (6): 746–60. https://doi.org/10.1177/1420326X14526909.

Marangou, Anna, and Andreas Koutas. 2009. Nicosia. The History of the City. Book, Whole. Nicosia: I.G.Kasoulides and Son Ltd.

Menicou, M., P. Exizidou, V. Vassiliou, and P. Christou. 2015. 'An Economic Analysis of Cyprus' Residential Buildings' Energy Retrofits Potential'. International Journal of Sustainable Energy 34 (3–4): 166–87. https://doi.org/10.1080/14786451.2013.873800.

Michael, Amilios, Maria Philokyprou, Stavroula Thravalou, and Ioannis Ioannou. 2016. 'The Role of the Thermal Mass of Adobe Walls in the Thermal Performance of Vernacular Dwellings'. In XIIth World Congress on Earthen Architectures Terra. Lyon, France. https://craterre.hypotheses.org/1827.

Michaelides, Demetrios. 2012. Historic Nicosia. Book, Edited. Nicosia: Rimal Publications.

Michopoulos, A., V. Voulgari, A. Tsikaloudaki, and Th. Zachariadis. 2016. 'Evaluation of Ground Source Heat Pump Systems for Residential Buildings in Warm Mediterranean Regions: The Example of Cyprus'. Energy Efficiency 9 (6): 1421–36. https://doi.org/10.1007/s12053-016-9431-1.

Milne, Murray, and Baruch Givoni. 1979. 'Architectural Design Based on Climate'. In Energy Conservation Through Building Design, edited by D. Watson, 96–113. New York: McGraw- Hill.

Ministry of Energy, Commerce, Industry and Tourism. 2015. Technical Guidelines for Nearly Zero Energy Buildings. Nicosia, Cyprus. www.mcit.gov.cy.

———. 2020. Law 155/2020 Regulation of the Energy Efficiency of Buildings. Degree 121/2020. Nicosia: MECIT.

Papacharalambous, G. 1968. The Cypriot Dwelling (Η Κυπριακή Οικία). Book, Edited. Nicosia: Center of Scientific Researches.

Passiardis, Stilianos. 1995. Statistical Analysis of Wind Speed in Cyprus. Meteorological Notes No 14, Book, Whole. Nicosia: Republic of Cyprus.

Peel, M C, B L Finlayson, and T A Mcmahon. 2007. 'Updated World Map of the Köppen-Geiger Climate Classification'. Hydrol. Earth Syst. Sci., 13.

Philokyprou, Maria, Aimilios Michael, Eleni Malaktou, and Andreas Savvides. 2017. 'Environmentally Responsive Design in Eastern Mediterranean. The Case of Vernacular Architecture in the Coastal, Lowland and Mountainous Regions of Cyprus'. Building and Environment 111 (January): 91–109. https://doi.org/10.1016/j.buildenv.2016.10.010.

Philokyprou, Maria, Aimilios Michael, Stavroula Thravalou, and Ioannis Ioannou. 2017. 'Thermal Performance Assessment of Vernacular Residential Semi-Open Spaces in Mediterranean Climate'. Indoor and Built Environment 27 (8): 1050–68. https://doi.org/10.1177/1420326X17699037.

Philokyprou, Maria, Amilios Michael, and Stavroula Thravalou. 2013. 'Assessment of the Bioclimatic Elements of Vernacular Architecture. The Historic Centre of Nicosia, Cyprus'. In Le Vie Dei Mercanti XI Forum: Heritage, Architecture, Landesign. Focus on Conservation, Regeneration, Innovation, 666–75. Aversa, Capri: La scuola di Pitagora editrice.

Philokyprou, Maria, Amilios Michael, Stavroula Thravalou, and Chryso Heracleous. 2014. Bioclimatic Approach of Vernacular Architecture of Cyprus. Book, Whole. Nicosia: Research Programme BIOVERNACULAR. www.biovernacular.ac.cy.

Philokyprou, Maria, Amilios Michael, Stavroula Thravalou, and Ioannis Ioannou. 2013. 'Evaluation of Sustainable Design Elements in the Historic Centre of Nicosia, Cyprus'. In Vernacular Heritage and Earthen Architecture, edited by Mariana Correia, Gilberto Carlos, and Sandra Rocha, 631–37. London: Taylor & Francis Group.

Sinos, S. 1976. A Review of the Vernacular Architecture of Cyprus. Book, Whole. Athens.

Thravalou, Stavroula, and Maria Philokyprou. 2020. 'Urban Design Considerations in the Environmental Assessment of Vernacular Buildings with Timber Projections (Sachnisi): The Case of Nicosia's Historic Center'. Frontiers of Architectural Research. https://doi.org/10.1016/j.foar.2020.11.001.

Thravalou, Stavroula, Maria Philokyprou, and Amilios Michael. 2016. 'Natural Ventilation Performance of Heritage Buildings in the Mediterranean Climate. The Case of a Two-storey Urban Traditional Dwelling in Nicosia, Cyprus.' In Proceedings of 9th Windsor Conference:Making Comfort Relevant, 328–39. Windsor, UK. http://nceub.org.uk/W2016/W2016_index.html.

VIOLET. 2020. 'Policy Recommendations to Promote the Inclusion of Standards for Heritage Buildings in EU Regulations'. VIOLET Interreg Europe Project [2017 – 2021]. https://www.interregeurope.eu/violet/library/.

Zachariadis, Theodoros. 2016. Climate Change in Cyprus: Review of the Impacts and Outline of an Adaptation Strategy. SpringerBriefs in Environmental Science. Springer. https://doi.org/10.1007/978-3-319-29688-3.

6.4 Passive strategies employed by heritage buildings in Jordan

6.5 Passive strategies employed by heritage buildings in Palestine

6.5.1 Overview of the environmental responsiveness of built heritage in Palestine

The climate of the Palestinian Territories is influenced by the Mediterranean climate where long, hot, dry summer and short, cool, rainy winter climate conditions prevail. Climatic variations occur in the different topographical regions. Though relatively small in area, the West Bank enjoys diverse topography, soil structure and climate conditions (ARIJ 1994).

There are seven climate zones in Palestine: (Energy Efficeint Building Code, Ministry of Local Government 2004)

1. Zone one: Hot dry summer, warm winter.
2. Zone two: Hot dry summer, mild winter.
3. Zone three: Hot semidry summer, temperate winter.
4. Zone four: Warm sub-humid summer, cold winter.
5. Zone five: Warm sub-humid summer, temperate winter.
6. Zone six: Partially Humid.
7. Zone seven: Semi dry, it has properties similar to those of the third zone.
8. First 5 zones prevail in the West Bank while the last two in Gaza Strip.

It is well known that most of the Palestinian modern buildings consist of walls constructed from stones, concrete, bricks and plaster with a total thickness exceeding 25 cm. Flat roofs are constructed of concrete , hollow bricks and plaster.

There are many features that describes the heritage building and the modern buildings; the percentage of openings area is 10-15% of the wall area in desert regions, while in mountainous areas it reaches 20%, people used the small size and number of openings in the northern façades in the cold regions of northern Palestine, in order to reduce thermal leakage outside and energy loss in the winter season. In addition to the use of openings in the longitudinal direction, the small width of the openings and the increase in the thickness of the walls, would work to break the solar rays and reduce amount reaching inside space in the various climatic regions of Palestine.

6.5.2 Available active energy systems for heritage building integration in Palestine

6.5.2.1 Existing available active systems and technologies for building integration in Palestine – Compatibility with built heritage.

Solar cooling & heating technologies

The photovoltaic systems implementation has increased in the last decade, due to the effort provided on the awareness of the benefits of photovoltaic systems implementation and due to its cost decrease with a payback period of few years. A photovoltaic system is already installed on roof of the building, roof space availability limits size of addition systems to be installed on the roof.

In addition, domestic solar water heating (SWH) is widely used in Palestine where almost 70% of houses and apartments have such systems. In fact, Palestine is one of the leading countries in the field of SWH for domestic purpose. A typical thermosiphon solar heating system is already installed on the roof for domestic water heating.

Geothermal energy

The utilization of geothermal technology as a source of energy for heating and cooling has been started in Palestine during the MED-ENEC project in one of the ITEHAD subdivision villas in Ramallah city and with the establishment of the first company in the region to utilize the geothermal energy in residential and commercial sectors called MENA Geothermal.

Geothermal technology was implemented in the UCI Headquarters Building in Ramallah, Palestine, which is considered the largest geothermal heating and cooling project in the Middle East and North Africa. To reach the maximum benefit of this technology and make it more feasible, buildings should be efficiently improved in terms of energy efficiency, such as improving the building insulation thereby reducing the total heating and cooling energy requirement and the total required geothermal ground loop. Higher cost is anticipated for installing the ground loop heat exchanger due to the rocky nature of ground in West Bank.

Biomass energy

Biomass energy is predominantly used for heating purposes and constitutes approximately 15% of Palestinian energy supply. Being an agrarian economy, Palestine has a strong potential for biomass energy. There is good potential for biogas generation from animal manure, poultry litter and crop wastes. In addition, organic fraction of municipal solid wastes is also represents a good biomass resource in Palestine with few pilot projects installed in Palestine. Agricultural residue and could be important source of biomass such as olive mills waste knowns as jift (pomace). Boiler burning biomass are employed by household for space and domestic water heating in Palestine.

Cogeneration systems

Cogeneration power systems are still not used in Palestine through good potential exist for combine heat and power CHP for hospitals, hotels and for some industries.

Compatibility issues with heritage buildings

After referring to the legal framework in Palestine that applies to the case study which are; Antiquates law 1966, Cultural heritage protection law 2018, Bylaws for the protection of the heritage culture and traditional buildings in Bethlehem 2014, we selected the previous mentioned technologies to be compatible with the laws and to integrate them with the building without affecting it.

6.5.3 Existing examples of active systems integration in heritage buildings in Palestine

Rehabilitation Of Maqam An-Nabi Mosa in Jericho

Maqam Al Nabi Musa is one of the important sites in Palestine with precious religious, cultural and historical dimensions, which dates back to the Mamluk era. Over time the building developed as many additions were built, forming the complex it is today.

The shrine of the Prophet Musa is located 11 km south of Jericho, and 20 km east of Jerusalem. It has an area of about 5,000 square meters, as it consists of 3 floors surrounded by a stone wall on all sides, and in the centre of it is a mosque and surrounded by courtyards surrounded by colonial rooms open to the central square.

Due to its exceptional importance, the Centre for Cultural Heritage Preservation, in cooperation with the United Nations Development Program (UNDP), with funding from the European Union (EU), and in partnership with restoration expert Dr. Paolo Viti, is working on the restoration and rehabilitation of the shrine of the Prophet Musa and the provision of a revival plan for the region.

The restoration process focuses on preserving the spiritual, religious, historical and cultural value of the shrine and highlighting it through educational spaces (Virtual Reality) so that the visitor can gain knowledge when visiting the site. It also includes an area for the traditional market and traditional crafts, through which the visitor can experience the atmosphere of ancient Arab gatherings. It will also contain a sleeping section and a restaurant to complement the traditional image of the shrine, when families would gather there to spend the season period (the season of Nabi Musa) and enjoy the simple atmosphere, cooking and eating together.

The project includes design work and supervision of restoration and rehabilitation works, In the current stage, work is being done on the internal shrine, and in the coming stages, the focus will be on the restoration of the mosque, which is the centre of importance in the shrine, and in what follows, the revival of the natural landscape surrounding the shrine.

Also installed HVAC system (Water Chiller) for the heating system of the rooms and for the domestic water usage.

6.5.4 References

Energy Efficeint Building Code, Ministry of Local Government (2004)

Applied Research Institute – Jerusalem (ARIJ – 2004)

Construction Materials & Local Market Survey in Palestinian Territories (August – 2002)

Architectural Styles Survey in Palestinian Territories (August – 2002)

6.6 Passive strategies employed by heritage buildings in Lebanon

6.6.1 Overview of the environmental responsiveness of built heritage in Lebanon

Lebanon is characterized by 4 climatic zones: the coastal zone, the medium altitude western mountain zone, the continental shelf zone and the high mountain zone. Each of these zones has an architecture specific to its own climate variations, manifested through various design strategies ranging from perfect adaptation to site and intelligent use of local resources to the employment of energy efficient structures and adaptation to the climate.

In the coastal climatic zone, where solar gain and humidity are factors to consider, typologies of buildings were caractarized by a relatively thin layer of walls (25 to 30 cm) made of lime or sand stone, 3 bay-windows oriented to the west (windows are places where maximum ventilation can occur in contrast to the highmountain region where window size and number is kept to a minimum) and a central hall plan. Walls contained oriculars that allowed air inside the house, thus creating a natural ventilation system. Overhangs were later introduced as shading devices in the hot summer and to keep rain water away from the walls and windows.

In the medium altitude western mountain zone, where it is relatively cold with low humidity, buildings were constucted with thick walls made of two ashlar stone faces and a rubble core measuring a total of 60 to 100 cm in thickness. This enveloppe helped maintain a controlled interior comfort. The thick massive walls served as a shading device from high summer exposure; but even with limited size, the openings allowed the winter sun to enter.

In the continental shelf zone, known as arid and hot areas during summer, buildings' walls were made of local materials, mainly earth-packed blocks, but sometimes made of stone that was white washed to preserve the thermal comfort on the inside and reduce the thermal bridges. Shading was insured by the addition of outer galleries that limited the sun exposure on the inner living areas. Other typologies prevailed in this climtic zone, such as the U-shaped buikdiings having a central fountain that humidifies the living spaces.

As for the high mountain zone, liwan typologies were developed. The liwan is a space that opens to the outside and continues by connecting to the space in front of it. Cross-ventilation was achieved by internal windows or vents between the rooms and the central space, which originally was permanently open. Furthermore, the very position of the central living space, be it the liwan or the central hall, ensured that it is the coolest space during hot daytime. Shielded on its long sides by the adjacent rooms, the open end of the hall was either turned to the north or to the south in order to avoid deep penetration of the sun's rays. Color played an important role in the cooling of structures. Light color material was applied on exterior surfaces reflecting excessive heat during the hot season as well as on interior barriers in order to maximize the usage of natural lighting. Other criteria that played a role in selecting the position of the openings were: views, natural lighting and privacy requirements.

6.6.2 Available active energy systems for heritage building integration in Lebanon

6.6.2.1 Existing available active systems and technologies for building integration in Lebanon – Compatibility with built heritage.

The active systems and technologies integrated in heritage buildings in Lebanon can be classified into 2 categories:

First with energy efficient active systems which include highly efficient boilers, VRV systems and ACs with inverters which demand less energy to function.

Second, on the renewable energy aspect, Lebanon is currently witnessing a remarkable increase in the installation of solar PV distributed generation. In fact, the Ministry of Energy and Water has pushed through LCEC for the development of distributed solar PV generation mainly through the National Energy Efficiency and Renewable Energy Action (NEEREA) financing mechanism that was setup by the Central Bank of Lebanon and LCEC back in 2012.

Rooftop solar photovoltaic applications in Lebanon exceeded 22 MW in 2019 according to the latest "2019 Decentralized Solar PV Status Report for Lebanon" to reach a total of 78.54 MWp installed in 2019.

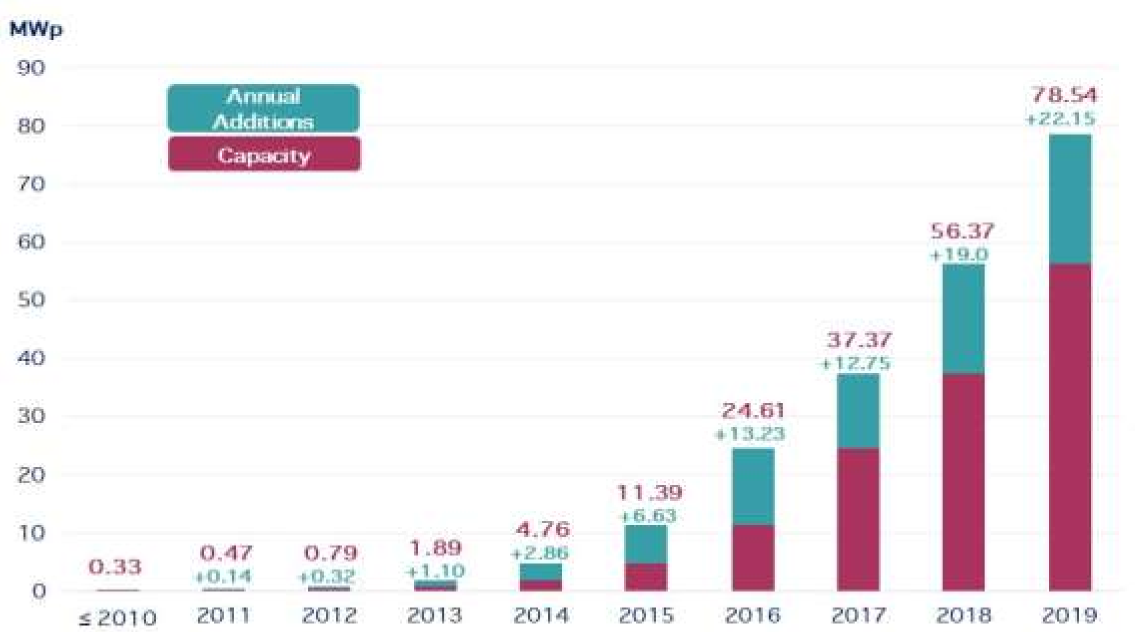


Figure 7: Rooftoop solar photovoltaic applications in Lebanon. Source: LCEC

Solar cooling & heating technologies

Solar Water Heaters (SWH) technology is by far the most developed RE technology in Lebanon. Currently, more than 688,356 m^2 of solar collector area was installed in the country by the end of 2019. The demand for SWHs is still on the rise.

Geothermal energy

The geothermal technology in Lebanon is still limited with only few projects implemented notably a geothermal cooling facility in the Four Seasons hotel in Beirut, and a geothermal ground source heat pump project in the MEDRAR project with a total capacity of 3.1 MW installed. The main constraint is related to the needed authorization and permission for drilling specifically with vertical systems as well as the cost.

Biomass energy

Currently, the size of bioenergy in Lebanon is still modest and limited and the sector is still far from reaching a maturity level. Bioenergy targets in Lebanon were set based on two different but complementary outputs: heat and electricity.

The use of biomass to generate electricity has been validated by the implementation of the Naameh and Saida power plants which extract biogas from municipal solid waste to drive a gas turbine which generates electricity with a total capacity of 7.0 MW installed.

Cogeneration systems

This technology is not applied in Lebanon on a small scale at the end-use level.

6.6.2.2 Compatibility issues with heritage buildings

In the context of decree 1057 issued on 27/11/2007 (إحالة مشروع قانون إلى مجلس النواب يتعلق بحماية الأبنية التراثية, 2007), which aims to protect, revive and highlight monuments, buildings and establishments that are isolated or that form between them an urban fabric in cities, villages and towns and which, due to the characteristics of their architecture, or their integration into their natural or civil surroundings, have a distinct historical, artistic, scientific or heritage value, it is important to state that the owner of the protected property can benefit from the bids of the fund established under the 2003 budget law in order to carry out restoration work and other works that should be carried out so that the building conforms to the specifications required by the special regime for the protection zone imposed by the decree of the final arrangement.

However, due to the absence of legal texts to justify preventing the demolition of groups of heritage buildings, the owners of some influential heritage buildings have filed appeals on the side of the State Council and were able to liberate their properties due to the unsound legal situation that arose. Nevertheless, after the explosion of Beirut port on the 4th of August, 2020 a decree preventing the sale of any historic building without getting a permission form the ministry of culture was issued by the finance minister Ghazi Wazni.

It is worth mentioning that there is no legal framework to lead the integration of active or hybrid systems in heritage buildings.

6.6.3 Existing examples of active systems integration in heritage buildings in Lebanon

The main active systems incorporated in heritage buildings in Lebanon are:

- HVAC systems (split systems) (example: Ministry of Foreign Affairs and Emigrants)
- LED Lighting (Example: Municipality of Tripoli, Rashid Karami Municipal Building)
- Central heating and cooling systems, motion detectors to control lighting in the West Hall, Main Hall at the American University of Beirut.
- Centralized chillers and motion detectors in Sage Hall at the Lebanese American University.

6.6.4 References

Corpus Levant. 2004. Rehabilitation: Traditional Lebanese Architecture, Leogravure, Beirut.

Kassatly, Houda, 2000. "Terres de Bekaa", Geuthner.

Liger-Belair, Jacques, 2000. "L'habitation au Liban / The dwelling in Lebanon", Geuthner.

Ragette, Friedrich, "Architecture in Lebanon", Caravan Books_Delmar, New York, 1980.

Sehnaaoui, Nada, 2002. L'occidentalisation de la vie quotidienne à Beyrouth: 1860 – 1914. Dar An Nahar. Beirut.

UNDP Project LEB/99/G35, 2005. Climate and Comfort: Passive Design Strategies for Lebanon.

6.7 Passive strategies employed by heritage buildings in Egypt

6.7.1 Overview of the environmental responsiveness of built heritage in Egypt

The climate in the northern part of Egypt is a hot Mediterranean climate that is quite different from the climate in the rest of desert areas of Egypt (mostly in upper Egypt). Prevailing winds from the Mediterranean Sea greatly moderate the temperatures of the northern coastal line, making the summers moderately hot and humid, while the winters moderately wet and mild.

- Building’s form is compact and the presence of patios in urban areas is frequent. On orientation, buildings seek the south quadrant to maximize solar gains in winter and to reduce them during summer.
- Proper shading for windows using screens (mashrabiya) or vegetation when heat gains are not desired. The use of grids aims to foster cross air circulation in the building, ensuring privacy and thermal comfort. Minimizing the size and number of openings reduces heat gains.
- The use of local materials, mainly earth and stone, is perfectly suited to local climate. Their good heat storage capacity stabilizes indoor temperature (that remain cooler during the day and warm at night).

Figure 25: Left: the used screens (Mashrabiya), right: a building facade with small openings[7].

The climate in the Nuba, Aswan in upper Egypt is a hot-dry climate, exceed-ing the thermal comfort during day and night. Construction Materials are red brick 25–40 cm for walls and reinforced concrete for the roofs. The building includes a large courtyard that is covered with palm leaves (jareed), and all rooms are opened to the courtyard. These new buildings are not responsive to climate considerations (no good positioning of openings in accordance to orientation) leads to thermal discomfort.

[7] Fernandes, J. E. P., Dabaieh, M., Mateus, R., & Bragança, L. (2014). The influence of the Mediterranean climate on vernacular architecture: a comparative analysis between the vernacular responsive architecture of southern Portugal and north of Egypt.

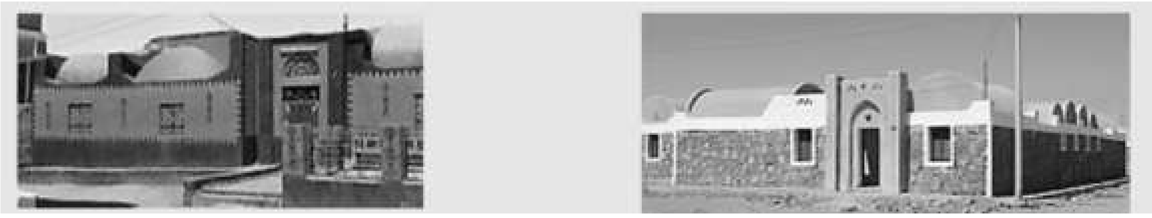


Figure 26: Left: old Nubian houses, right: new nubian houses.

Unlike the old nubian buildings, its construction materials were stone, clay and sand for the walls, palm leaves (jareed) and grain stalks for the flat roofs, and clay brick for the arched domes. The architecture of the old buildings made it thermally comfortable with the existence of local building materials and the use of openings in the domes and the courtyards that allowed the cross ventilation, as shown in the following Figure.

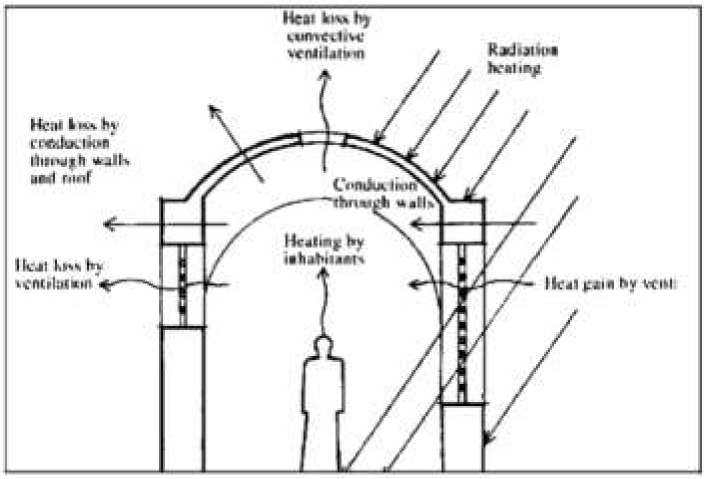


Figure 27: Ventilation systems through cross ventilation, stack effect[8].

6.7.2 Examples of intervention of energy improvement of historic buildings in Egypt

Villa Antoniadis in Alexandria, Egypt

Villa Antoniadis is a heritage building built in the mid-nineteenth century and it is listed as historic monument number 1250 at a national level, as a significant architectural style building.

8

Bayoumi, O. A. M. (2018). Nubian Vernacular architecture & contemporary Aswan buildings' enhancement. Alexandria Engineering Journal, 57(2), 875-883.

Figure 28: Villa Antoniadis and its Garden before renovation. (By Ahmed Khalil in 2008) (Khalil et.al,2018)

The building was in a process of a restoration and adaptive-reuse project by its new owner (The Bibliotheca Alexandrina) from 2011 till 2018, which aimed to use the building as the premises for the Alexandria and Mediterranean Research Centre in addition to other cultural purposes to ensure that the building is well restored and provided with ongoing maintenance.

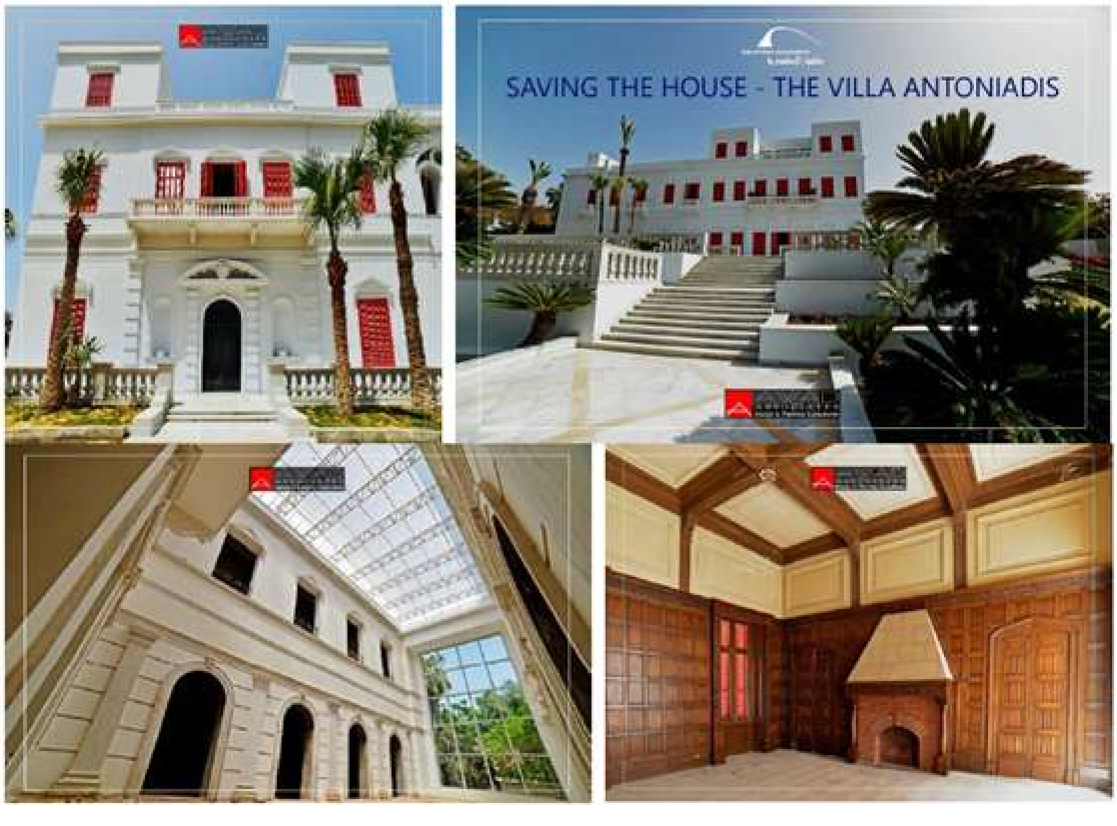


Figure 29: The Villa after renovation by Ahmed Khalil in 2017 (Khalil et.al,2018)

A simulation was applied to the renovation project using the DesignBuilder energy modelling software to determine the project's thermal behaviour, energy consumption, and energy use intensity. The project was also simulated with six introduced interventions to achieve more energy efficiency when compared to the base case: (1) adding thermal insulation; (2) exterior openings with double glazing; (3) adding shading to the atrium; (4) internal lighting control; (5) using natural ventilation; and (6) adding photovoltaic panels on the roof to analyze their potentials and benefits.

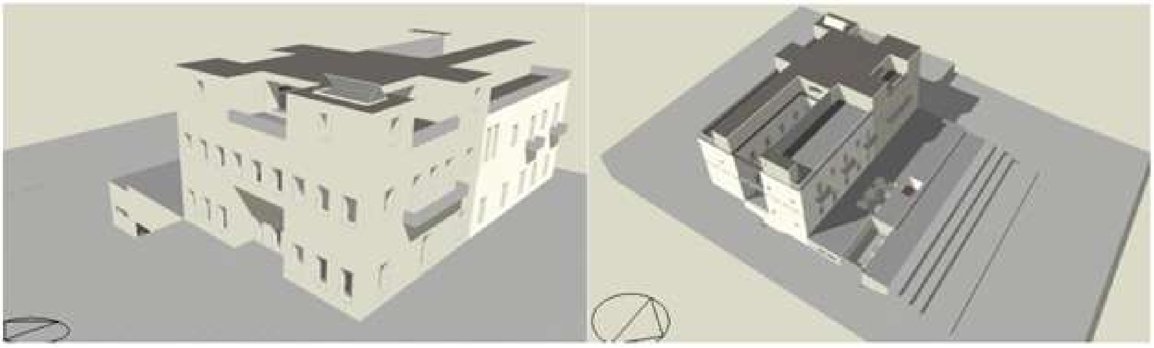


Figure 30: The Base case simulation model. (Khalil et.al,2018)

The simulation proved a possible reduction of 36.5% in the cooling, heating and lighting energy consumption as well as generated 74.7% of the energy required for cooling, heating and lighting from renewable energy sources.

On the other hand, due to the moderate climate of Alexandria city, passive treatments such as wall insulation and double glazing had a minimal benefit (in this case 0.4% and 5% savings, respectively) as the building does not rely on relatively high cooling loads (compared to other cities within the hot arid climate zone) or heating loads, while active treatments such as lighting control and solar energy generation (in this case 23.9% and 48.1% energy use savings, respectively) can have the upper hand in energy consumption reduction[9].

Residential Heritage Building in Alexandria, Egypt

This residential building is a heritage building built in the nineteenth-century and it is listed as a historical monument with its eclectic Italian style that is located in the heritage business district of Alexandria, it is typical of the major part of the city's conservation area.

[9] Ahmed M. R. Khalil,Naglaa Y. Hammouda, Khaled F. El-Deeb. 2018. Implementing Sustainability in Retrofitting Heritage Buildings. Case Study: Villa Antoniadis, Alexandria, Egypt. Heritage, 1(1), 57-87. https://www.mdpi.com/2571-9408/1/1/6

Figure 31: Picture of the Residential Heritage Building. (Taher et.al, 2019).

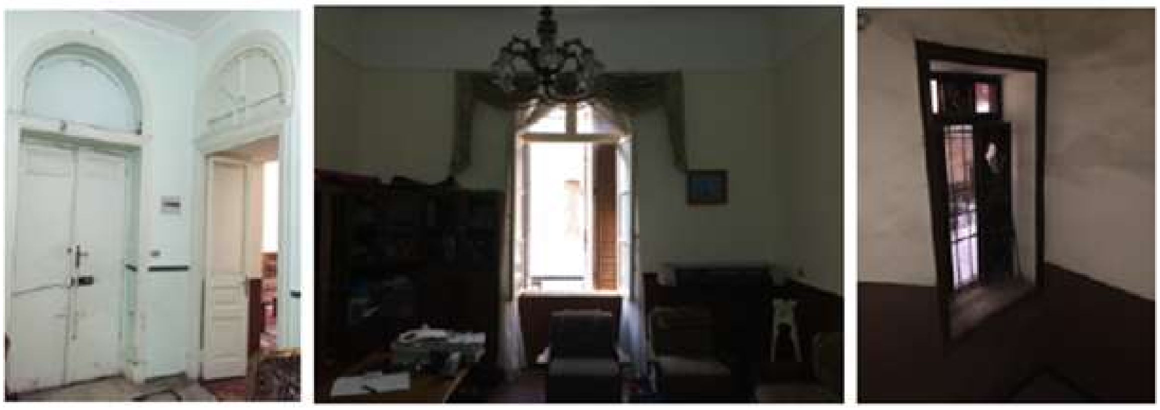


Figure 32: Pictures of the interiors of the Residential Heritage Building. (Taher et.al, 2019).

Taher et.al (2019) presented an assessment of wind driven natural ventilation performance in this the European style courtyarded heritage building that was designed for passive energy use, yet it is observed that its occupants currently rely on mechanical ventilation (air conditioning). It was assumed that the energy consumption and thermal performance of the heritage building can be improved if it performs as it was originally designed.

The assessment was conducted in two parts; (a) a detailed physical monitoring was conducted to measure air speed inside and outside the case study building. (b) Steady RANS CFD (computational fluid dynamics) simulation was conducted for the same building to expand on the measurement’s findings. Simulations were validated against air speed measurements in parts of the building.

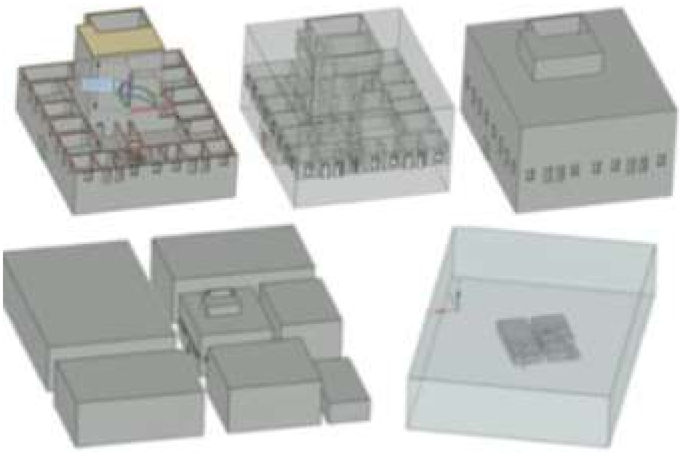


Figure 33: CFD Model of the Residential Building. (Taher et.al, 2019).

Modelling and measuring the current occupation of the building, the results obtained demonstrated unacceptable conditions for indoor comfort. This failure was evidently due to a combination of factors including occupants' behavior and modifications to the functional environmental principles of the building's original design. Alterations included the blockage of upper openings which have negatively affected the induction of cross ventilation and the stack effect throughout the building. Results showed a detailed example of how a deficiency of performance in natural ventilation is created in the case study building as modified today, and indicated potential for future improvement[10].

(3) Wekalet El-Ghouri Heritage Building in Cairo, Egypt

Among Islamic Cairo Heritage buildings, Wekalet El-Ghouri is located in Al-Azhar area, was built in 1504 by the Memluk Sultan Qunsuwah El Ghouri.

Figure 34: Central courtyard of Wekalet El-Ghouri.(Wikipedia,2020).

[10] Ahmed K Taher, Oriel Prizeman, Bakr Gomaa, Simon Lannon. 2019. Case study assessment for natural ventilation performance of heritage buildings in the Mediterranean city of Alexandria (Egypt). In IOP Conference Series: Materials Science and Engineering (Vol. 609, No. 3, p. 032012). IOP Publishing. https://iopscience.iop.org/article/10.1088/1757-899X/609/3/032012/meta

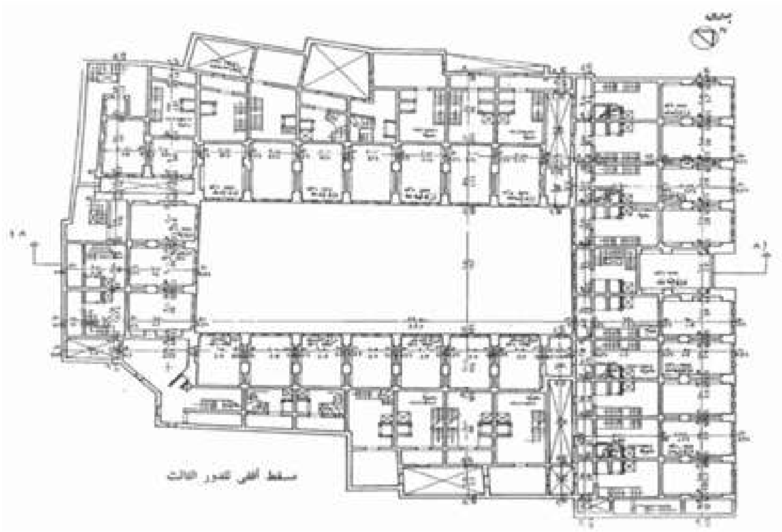


Figure 35: Wekalet El-Ghouri typical floor plan. (Fahmy et.al,2019).

Fahmy et.al (2019) used three steps in the methodology to prove the efficiency of the passive design of one of the heritage buildings, which is Wekalet El-Ghouri. These steps are 1) the overview of the proposed generic energy criterion and its related factors and sub-factors; 2) the simulation procedures using the eQuest software, and 3) sustainability indexing and the assessment procedures. Simulations were divided into three parts; 1) as built limestone material of thicknesses 40 cm and 60 cm; 2) contemporary materials, which are 12 cm and 25 cm brick blocks; and 3) modified contemporary material in which insulating boards are added.

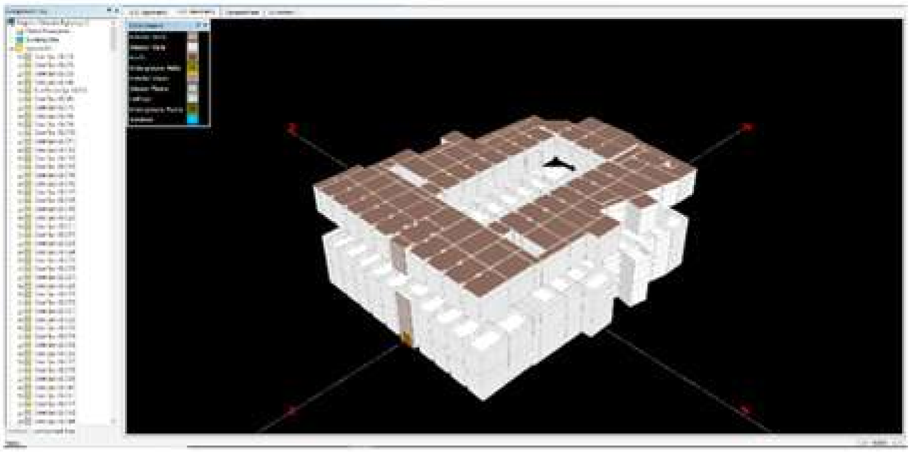


Figure 36: The graphical user interface of eQuest having the simulation model of the case study. (Fahmy et.al,2019).

The Results showed the superiority of the as-built used construction material (limestone masonry blocks) over several contemporary construction blocks (12 cm and 25 cm concrete masonry units)[11].

[11] Mohammad Fahmy, Sherif Mahmoud, Marwa Abdelalim, Mohammad Mahdya. 2019. Generic Energy Efficiency Assessment for heritage buildings; Wekalat El-Ghouri as a case study, Cairo, Egypt. Energy Procedia, 156, 166-171.

6.7.3 References

Fernandes, J. E. P., Dabaieh, M., Mateus, R., & Bragança, L. (2014). The influence of the Mediterranean climate on vernacular architecture: a comparative analysis between the vernacular responsive architecture of southern Portugal and north of Egypt.

Bayoumi, O. A. M. (2018). Nubian Vernacular architecture & contemporary Aswan buildings' enhancement. Alexandria Engineering Journal, 57(2), 875-883.

Ahmed M. R. Khalil,Naglaa Y. Hammouda, Khaled F. El-Deeb. 2018. Implementing Sustainability in Retrofitting Heritage Buildings. Case Study: Villa Antoniadis, Alexandria, Egypt. Heritage, 1(1), 57-87. https://www.mdpi.com/2571-9408/1/1/6

Ahmed K Taher, Oriel Prizeman, Bakr Gomaa, Simon Lannon. 2019. Case study assessment for natural ventilation performance of heritage buildings in the Mediterranean city of Alexandria (Egypt). In IOP Conference Series: Materials Science and Engineering (Vol. 609, No. 3, p. 032012). IOP Publishing. https://iopscience.iop.org/article/10.1088/1757-899X/609/3/032012/meta

Mohammad Fahmy, Sherif Mahmoud, Marwa Abdelalim, Mohammad Mahdya. 2019. Generic Energy Efficiency Assessment for heritage buildings; Wekalat El-Ghouri as a case study, Cairo, Egypt. Energy Procedia, 156, 166-171.

ANNEX 8.13: REFERENCE TEMPLATE OF COMPATIBLE ACTIVE AND PASSIVE ENERGY EFFICIENCY TECHNOLOGIES REPORT

Index

1. Passive strategies employed by heritage buildings in [*country*]

1.1 Overview of the environmental responsiveness of built heritage in [*country*]

Brief description of the main features of vernacular architecture in various climatic zones in the country. Basic differences noted in various climatic zones. A strategy that is used in another climate zone may have been neglected in the particular zone of the building for cultural or historic reasons, yet it can still be effective. So, this section aims to provide a brief and general overview of the main passive techniques that are employed by vernacular heritage in the country – through relevant bibliography (for a reference see the country-specific chapters of Annex 8.12).

1.2 Passive design practices employed by the built heritage in [*building region/city*]

Focusing on the region where the building is located, description of the following: main building layout/form, main construction materials, existence/absence of thermal mass and semi-open spaces, presence and type of shading elements, an approximation of window to wall ratio per orientation, urban geometry (what is the architecture of the surrounding buildings in the wider neighbourhood context - if there is any particularity or urban-scale strategy applied that is worth mentioning). Annex 8.12 can be used as a reference for the description of main passive design strategies.

1.3 Recommended passive design strategies in [*building region/city*]

Charts for the building location(as a basic documentation of the bioclimatic analysis):

- annual Dry Build Temperature (DBT) and Relative Humidity (RH) chart,
- average hourly distribution of DBT per month,
- annual or seasonal windrose,
- the Givoni comfort chart with the hourly distribution of temperature per month.

Examples of the charts and usefull links are provided below.

Example of average hourly distribution of Dry Bulb Temperature per month. On the website https://weatherspark.com can be used to obtain this image inserting the building city and extracting the third image of the page (Average Hourly Temperature).

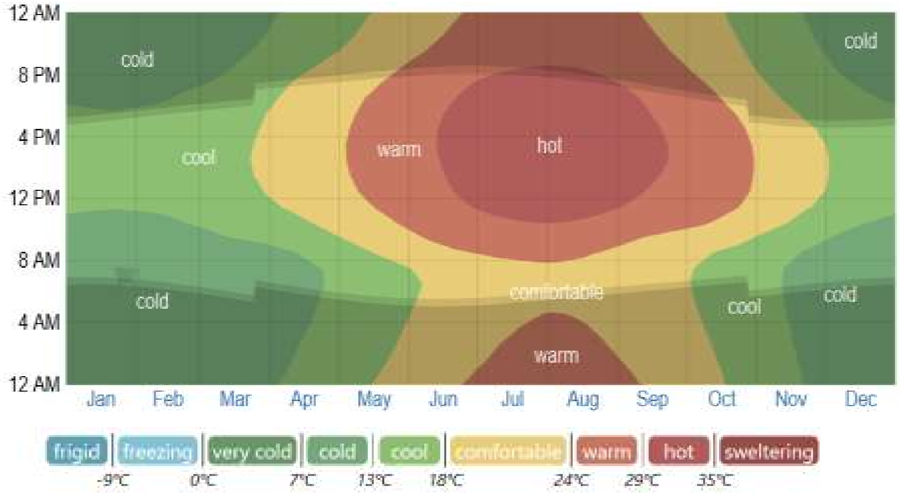
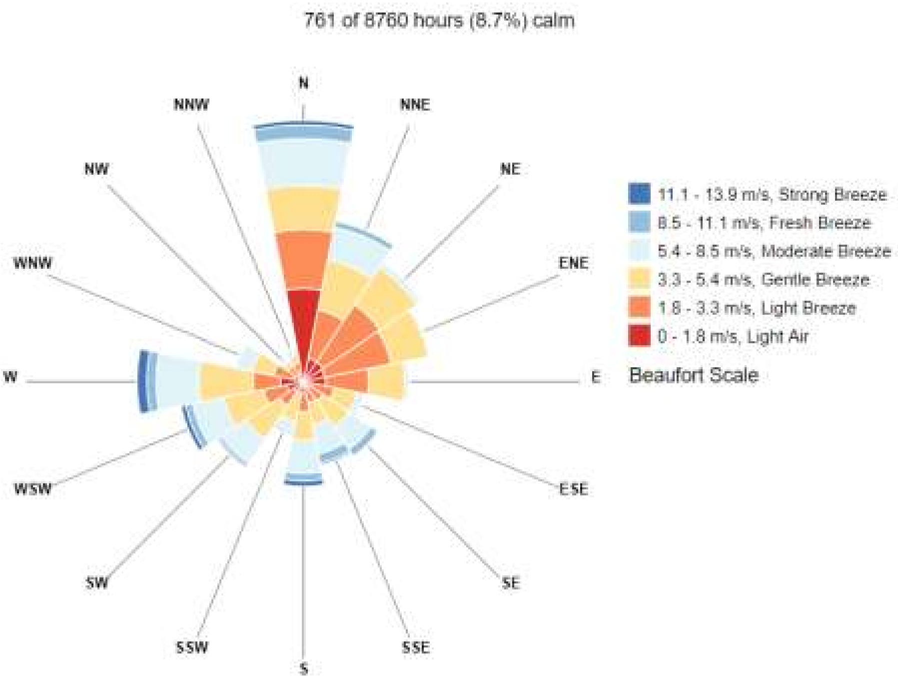


Fig. X: The average hourly temperature in Nicosia, colour coded into bands. The shaded overlays indicate night and civil twilight. Source: https://weatherspark.com/y/97684/Average-Weather-in-Nicosia-Cyprus-Year-Round

Example of the annual or seasonal wind rose: monthly wind Rose of Rome. On the website https://mdahlhausen.github.io/epwvis/ it is possible to upload *.epw file, search for the windrose and extract it. To have m/s as wind speed measure check the SI measrurements units up on the right of the screen.

Alternative source: www.windfinder.com



Example of Givoni comfort diagram in Nicosia. On the website https://drajmarsh.bitbucket.io/psychro-chart2d.html it is possible to click on the world icon and load the weather file for the building area, go to data mapping, select show monthly ranges, go to comfort overlay and select Givoni bioclimatic chart and click on EXP and export the image.

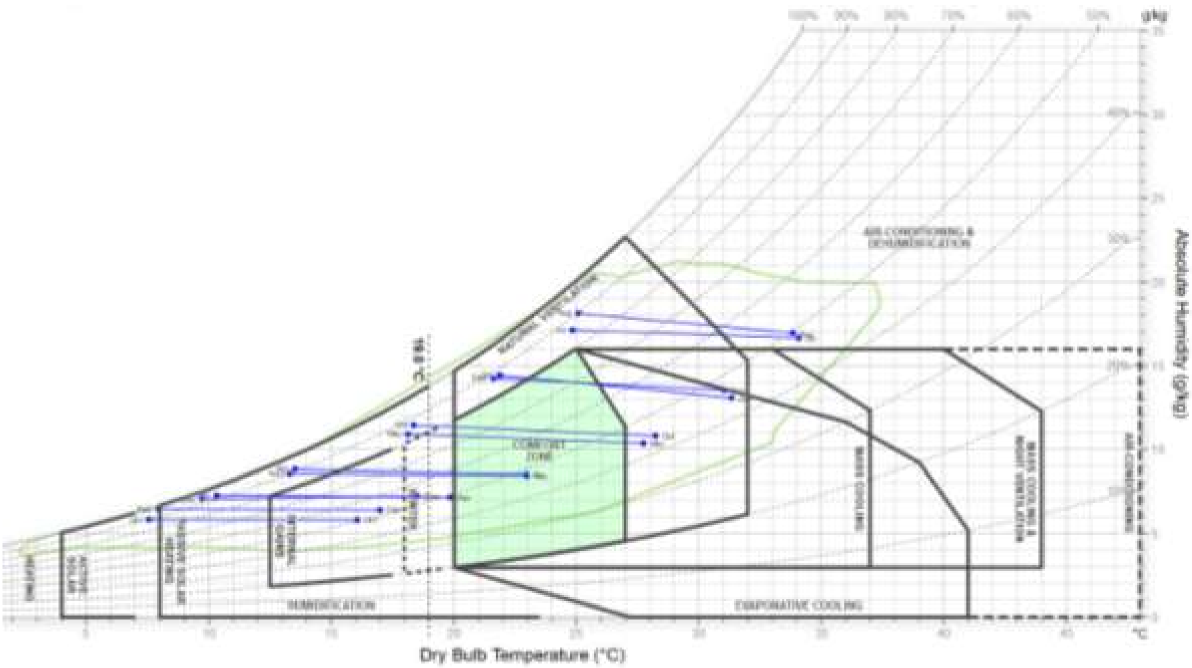


Fig.X: Givoni comfort diagram for Nicosia. Source: https://drajmarsh.bitbucket.io/psychro-chart2d.html

The use of the online applications provided by http://andrewmarsh.com/software/ is recommended as it is possible to import the actual climate file *.epw to be used for the simulation and provide a visualisation of the climate data.

Additional tool for the creation of the psychrometric chart: Climate consultant 6.0 software. Available: http://www.energy-design-tools.aud.ucla.edu/

Synthesis table, based on the above analysis. When the background colour of each cell is grey it means that the strategy applies, if it's light grey it means that the strategy only partly applies, if it's white the strategy doesn't apply.

Table X: Recommended passive strategies per month in [building location/city (e.g. Nicosia)]

Month	Reduction of heat loss	Passive Solar heating	Internal gains	Natural ventilation	Thermal mass	Thermal mass combined with night-ventilation	Evaporative cooling
1							
2							
3							

4							
5							
6							
7							
8							
9							
10							
11							
12							

Brief comments on the appropriate and recommended passive strategies for the particular area.

1.4 Opportunities, impediment and challenges in applying passive design strategies in the case-study building.

A more specific analysis of the solar incidence, the shading and the ventilation potential of the building according to the surrounding built environment is required (i.e. assessment of how the wind affects the case-study building, whether the surrounding building density or other physical obstacles prevent/inhibit the ventilation potential/shading potential etc., whether the building layout or the arrangement of the windows favours or not cross-ventilation/buoyancy driven ventilation etc).

A basic documentation should comprise the following:

- a 3D representation or/and 2D sections of solar incidence during winter and summer solstice,
- sun-path diagrams (e.g. a solar shading mask on a stereographic chart)

Example of solar shading mask (created through the application: https://drajmarsh.bitbucket.io/shading-box.html)

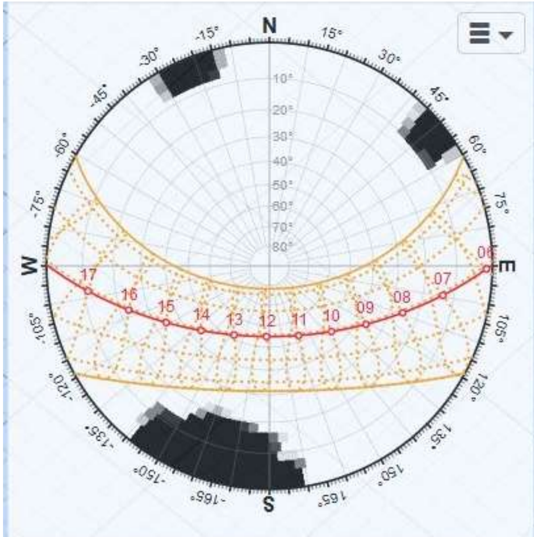


Fig.X: Solar shading mask in the location of the building in Nicosia (at the buildings' main entrance). Created through the application: https://drajmarsh.bitbucket.io/shading-box.html

Additional tool for the creation of sun-path diagrams (cartesian or stereographic): https://drajmarsh.bitbucket.io/sunpath2d.html

Alternative sources for sun shading analysis: http://andrewmarsh.com/software/app-shading/, http://andrewmarsh.com/software/sunpath3d-web/

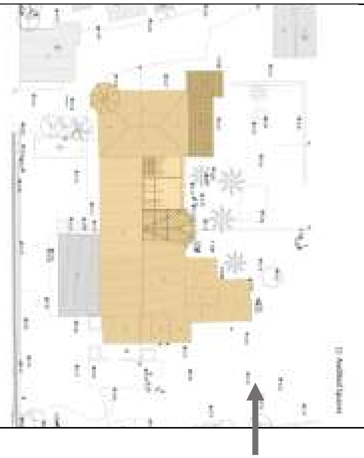
1.5 Evaluation of the passive performance of the building:

Based on the overall environmental analysis (including data reported in Annex 8.4), table descripting the applied passive design strategies in the building.

The table should start describing the existing passive strategies implemented in the building, then elaborating whether the performance of some of them could be further enhanced and whether additional passive strategies could be introduced. Insights on impediments and challenges regarding the implementation of these strategies in the specific building.

The aim is to highlight how traditional solutions (in vernacular architecture / urban fabric design) can support active systems (and therefore are worthy partners in the mitigation strategy), to account for their compatibility with the proposed active systems, and their contribution to the overall performance.

Table X: Passive design strategies employed in the building, *[building name]*

	Technique *Indication of the techniques through which each passive strategy is accomplished (see Annex 8.12)*	**Photograph or sketch** *Photo of the building element that describes the technique or a sketch/conceptual diagram of how it works.*	**Comments** *Assessment of the technique, if it is working sufficiently and how could it be enhanced.*
Passive Solar heating	*Example: Glazed surfaces on the East*		*Example: The main axis of the building is North-South, so due to limited wall surface on the South and less window surfaces on the West (main façade), direct solar gains derive primarily from East. The building shape and orientation favours cooling design strategies rather than heating design. Potential redistribution of uses in the interior of the building might benefit the heat transfer from the south orientated rooms towards the rest of the building.*
	Example: Indirect solar gains through high thermal mass building elements.		*Example: The surroundings do not limit the potential of indirect solar gains through the envelope.*
Reduction of heat loss			

Internal gains			
Natural ventilation			
Thermal mass	*Example: Local limestone with high thermal capacity*		*Example: The building employs great thermal mass. A great part of the building envelope is plastered, so the use of latent heat storage through PCMs coatings could enhance the transient capacity of the envelope.*
Evaporative cooling			
...			

1. Available active energy systems for heritage building integration in [*country*]

2.1. Existing available active systems and technologies for building integration in [*country*] – Compatibility with built heritage.

Description of the current situation, trends and challenges in the country (market maturity) regarding the implementation of innovative RES or building envelope technologies, for application in existing buildings (for a reference see the country-specific chapters of Annex 8.12).

Building materials and shading elements

…

Solar cooling & heating technologies

…

Geothermal energy

…

Biomass energy

…

Cogeneration systems

…

1.6 Compatibility issues with heritage buildings

Legal framework and current conservation policy in the country. Comment on compatibility issues of the aforementioned technologies regarding heritage building integration.

2.2. Existing examples of active systems integration in heritage buildings in [*country*].

Example(s) of active or/and hybrid systems incorporated in heritage buildings in the country.

2.3. Opportunities, impediment and challenges regarding active systems integration in the case-study building.

Impediments and challenges regarding the implementation of active or/and hybrid systems in the specific case-study building., also referring to the capacity of BIM in representing said active or/and hybrid systems. Description of how easy it is to upgrade existing legacy equipment/infrastructure in the specific heritage building.

2. References

…

ANNEX 8.14 REFERENCE ON THE METHODOLOGICAL APPROACH FOR THE DEVELOPMENT OF THE ENERGY AND ENVIRONMENTAL IMPROVEMENT INTERVENTION AND SCENARIOS

Index

1. Introduction

1.1. Document purpose

This document provides an overview of the methodological approach and the decision-making process for developing the energy and environmental improvement intervention and scenarios on historical buildings. Its aim is to present a performance-based design workflow that will consider various criteria in order to obtain the most efficient retrofit solutions, through a retroactive feedback process.

1.2. Background on energy retrofit evaluation criteria

A balanced interplay between passive and active building elements is often the final goal of an efficient retrofit strategy. However, in the case of historic buildings, the challenge is to achieve the desired effect while respecting the architectural and historical value of the built heritage and retaining the feasibility of the investment (Ding 2013). Over the last decades, numerous guidelines and methodologies have been developed, outlining the procedure of decision-making for historic buildings refurbishment (Webb 2017). According to Webb (2017), retrofit guidance and decision making tools are under an ongoing development and aim to bridge the gap of regulatory exemptions regarding energy performance of heritage buildings. While energy retrofits were previously seen as a potential threat to the character and fabric of historic and vernacular buildings, recent research presents a considerable shift of this viewpoint; treating energy retrofits as an opportunity to protect these buildings (Carbonara 2015), and respond to global environmental concerns (Webb 2017).

European Standard EN 16883

In this framework, the European Standard EN 16883:2017 "*Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings*" was developed in 2017. The standard presents a methodology for selecting and integrating measures for energy performance improvements and reduction of greenhouse gas emissions. An imperative first step of this process is the building survey that includes the assessment of the heritage significance of the building, its present and historic uses and structural capacity, as well as the buildings' energy and indoor environmental performance. A set of assessment criteria are proposed, not only of technical and economic aspects, but also of the impact on the buildings' physical and heritage significance. The method is based on tabular risk-benefit scheme with a 5-scale rating system (ranging from *high risk, low risk, neutral, low benefit* and *high benefit*). The assessment categories are the following:

- Technical compatibility: hygrothermal risks; structural risks; corrosion risks; salt reaction risks; biological risks; and reversibility.
- Heritage significance of the building and its settings: Risk of material, constructional or structural impact; risk of architectural, aesthetic or visual impact; risk of spatial impact.
- Economic viability: Capital costs; operating costs including maintenance costs; economic return; economic savings.
- Energy: Energy demand in terms of primary energy rating (total, non-renewable and renewable energy); Life cycle demand in terms of use of renewable primary

energy and non-renewable primary energy (including the concept of embodied energy).

- Indoor environmental quality: building content preservation; building fabric preservation; occupant comfort levels; emission of substances.
- Impact on the outdoor environment: greenhouse gas emissions from measures implemented and operation; emissions of harmful substances; natural resources use.
- Aspects of use: Influence on the use and the users of the building; consequences of change of use; consequences of adding new technical room; ability of building users to manage and operate control systems.

ASHRAE Guideline 34-2019

ASHRAE Guideline 34 describes a similar process regarding the methodological step of building documentation and survey. However, in addition to indoor monitoring and walk-through energy audits, the importance of whole-building energy simulation is highlighted; as a tool for estimating the energy performance of the building. According to the standard, the project team is required to use a critical approach in order to select appropriate energy savings measures and balance between three main factors: heritage value, energy efficiency goals and budget. The evaluation criteria are not specified any further per category, yet, the overall potential impact of each energy retrofit measure is characterized as *beneficial, benign, detrimental* or *to be further studied* (in case the impacts are unclear).

GBC Historic Building

A more integrated approach on energy refurbishment criteria and rating tools is adopted by the World Green Building Council (World GBC), a global network with approximately 70 participating countries ('World Green Building Council. Annual Report 2018/19.' n.d.). The particularities of historic buildings were recently addressed by the Italian GBC, which has promoted and implemented the protocol *GBC Historic Building* (GBH HB) certification ('Green Building Council Historic Buildings' n.d.). This rating system aims to adapt the LEED international protocols and aspects of sustainability, to the evaluation of heritage buildings' restoration and refurbishment. It evaluates the sustainability of the overall refurbishment activities from the design phase, the construction phase, as well as the operation and the maintenance of the building. In this approach, energy efficiency and retrofit process are considered as a form of protection of the historic building and not necessarily a change in the building's original material consistency. The rating system and evaluation criteria are organized into the following categories:

- Historic Value: Preliminary and advanced investigative analysis (energetic, diagnostic on materials and forms of degradation, diagnostics on structures and monitoring); project reversibility; compatible end-use; chemical and physical compatibility and integrated materials; sustainable restoration site; scheduled maintenance plan; involvement of specialist in restoration of architectural heritage and landscape.
- Sustainability of the Site: This category concerns the environmental aspects related to the place where the historical building is situated, with particular

reference to the relationship between the building itself, the surrounding environment and the potential impacts that the building is capable of generating (e.g. heat island effect or light pollution reduction).

- Water efficiency: Through the credits of this category, in addition to the reduction of water consumption, credits are granted for potential storm water collection and management.
- Energy and Atmosphere: Compliance with the minimum energy performance regulation is mandatory. Additional credits concern the incorporation of renewable energy technologies, enhanced commissioning and refrigerant management, as well as monitoring and verification.
- Materials and Resources: The Materials and Resources thematic area aims to ensure that the design intervention is in continuity with the existing building, preserving as much as possible the historical material, in compliance with the principles of sustainability linked to the reduction of the extraction of materials virgin and land consumption.
- Indoor Environmental Quality: This thematic area gives emphasis on the fulfilment of occupants' comfort conditions and indoor air quality. This approach encourages the respect of the historic environment by protecting surfaces and high-quality materials while achieving the highest levels of comfort and indoor air quality attainable, by taking advantage of the boundary conditions.
- Innovation in Design: This thematic area rewards aspects that are excellence in design in case of performance that greatly exceed those required by the protocol itself or the particular characteristics of the project which, although not related to any prerequisite or credit, guarantee documented benefits in terms of sustainability.
- Regional Priority: This credit area aims to enhance the environmental aspects regarding the locality in which the building is situated. Also, it encourages design teams to focus on the aspects of regionalism.

Other European Research Projects

The research programme 3ENCULT, that focused on best practice solutions for cultural heritage buildings, based the assessment criteria on the Sustainability Triangle: *Ecology –Economy – Society*. A number of assessment criteria were defined and associated with different compatibility aspects, ranging from ecological, over economic, constructional and functional to conservation compatibility (3 ENCULT 2011). More specifically, the criteria were:

- Energy: CO_2 balance over whole life-cycle; Resource consumption; Primary energy saving potential; Final energy cost reduction;
- Economy: Enhancement of indoor comfort; Recoverability; Damage risk; Utilisation value;
- Social: Loss of substance; Disturbance of appearance; Reversibility.

The SECHURBA project had set a target for the buildings audited to identify how they could achieve a minimum 40% reduction in energy use. The proposed interventions were categorised as low/medium/high cost and low/medium/high impact and priority was given to energy efficiency interventions. To aid with decision-making about such interventions, a software system was developed, to be used in conjunction with a database of indicative technologies and materials for heritage buildings' retrofits. A Multi-Criteria Analysis (MCA) was developed to address aesthetic and historic features, energy saving systems, financial and administrative frameworks. Specifically, the 4 categories of the assessment criteria were (Gigliarelli, Calcerano, and Cessari 2018):

- Assess Against International Conventions of Conservation: assessment of the interventions' compatibility with the main principles of the European Charters of Restoration;
- Energy Efficiency: energy use performance indicators;
- Environmental Sustainability: assessment of whether the intervention minimises environmental pollution and uses as much as possible renewable resources;
- Economic Feasibility: assessment in order to achieve low cost and to maximize return capital in relation to costs.

Akande et. al. (2016) provides an overview of the existing approaches in determining the energy use capacity of an existing building. Their study emphasises in the importance of post-occupancy monitoring and managing of the energy use pattern in heritage building refurbishment projects.

In conclusion, the prime stages of the energy audit for defining energy improvement interventions in heritage buildings according to the existing literature (and also incorporated in BEEP's Project methodology), include: a) building survey and analysis covering also the buildings' historical and aesthetical significance, b) indoor environmental monitoring, and c) dynamic simulation. A far as the assessment criteria of the potential interventions is concerned, the literature reveals the intention of balancing multiple criteria, among which conservation and energy consumption prevail. The needs of the building fabric and occupants have emerged as important additional criteria, as well as economic, embodied energy, and climate change considerations. Beyond these, there is a lack of definitive consensus about precisely which criteria should be considered, and how they should be categorized. Also, the accessibility to funds is not covered by most methodology approaches, omitting a decisive factor in the implementation of the project.

2. REFERENCES

3 ENCULT. 2011. 'Position Paper on Criteria Regarding the Assessment of Energy Efficiency Measures Regarding Their Compatibility with Conservation Issues.' Deliverable D2.2=D3.2.

Carbonara, Giovanni. 2015. 'Energy Efficiency as a Protection Tool'. *Energy and Buildings*, Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, 95 (May): 9–12. https://doi.org/10.1016/j.enbuild.2014.12.052.

Ding, Grace. 2013. 'Demolish or Refurbish – Environmental Benefits of Housing Conservation'. *Construction Economics and Building* 13 (2): 18–34. https://doi.org/10.5130/AJCEB.v13i2.3322.

EN 16883. 2017. 'Conservation of Cultural Heritage - Guidelines for Improving the Energy Performance of Historic Buildings'. CEN/TC 346 - Conservation of cultural property.

Gigliarelli, E., F. Calcerano, and L. Cessari. 2018. 'Analytic Hierarchy Process. A Multi-Criteria Decision Support Approach for the Improvement of the Energy Efficiency of Built Heritage'. In *3rd International Conference on Energy Effiiciency in Historic Buildings 2018, EEHB2018 Edited by Tor Broström, Lisa Nilsen and Susanna Carlsten*. Visby, Sweden, September 26-28, 2018: Uppsala University, Department of Art History. http://www.iea-shc.org/Data/Sites/1/publications/Energy-efficiency-in-historic-buildings_preliminary-conference-report.pdf.

'Green Building Council Historic Buildings'. n.d. GBC Italia. Accessed 20 November 2020. https://www.gbcitalia.org/historic-building.

Webb, Amanda L. 2017. 'Energy Retrofits in Historic and Traditional Buildings: A Review of Problems and Methods'. *Renewable and Sustainable Energy Reviews* 77 (September): 748–59. https://doi.org/10.1016/j.rser.2017.01.145.

'World Green Building Council. Annual Report 2018/19.' n.d. Accessed 20 October 2020. https://www.worldgbc.org/news-media/world-green-building-council-annual-report-201819-report-download.

ANNEX 8.15 REFERENCE TEMPLATE FOR THE DEVELOPMENT OF THE ENERGY AND ENVIRONMENTAL IMPROVEMENT INTERVENTIONS

Index

1. GENERAL INTRODUCTION

This document present in a comprehensive way, the adopted methodology approach for defining proper energy and environmental improvement interventions, for historical building.

1.1. Current state of the building

Brief overview of the case study, the stakeholders involved, and the activities performed, summarising the main findings, giving also an overview of the building in terms of energy use and bills.

Name of Building:

Location:

Floor area:

Volume:

Original use – present use:

Year of construction:

Picture:

Brief description of the buildings' construction phases, significance, construction materials and conservation state, use, etc.

2. DESCRIPTION OF THE PROPOSED INTERVENTIONS

2.1. Intervention category and code

For each energy and environmental improvement intervention described it is suggested to adopt the following identification code:

COUNTRY[1]_BUILDING_INTERVENTIONCATEGORY_NUMBEROFMEASURE

- In the field *COUNTRY* two letters should be adopted e.g: IT for Italy or JO for Jordan;
- In the field BUILDING two letters for identification or a number if buildings are more than one should be adopted;
- In the field *INTERVENTION CATEGORY* the letter in *Table 1* describes only the category (not the detailed numbering) of the intervention: P for Passive Systems, A for Active systems and R for Renewable Systems.
- The field *NUMBER OF MEASURE* is a progressive number of two digits for each INTERVENTION CATEGORY (P, A, or R) of each building (please note that this number do not refer to the detailed numbering of the intervention category in *Table 1*).

For example, IT1P01 is the first intervention regarding passive systems to be proposed in the analysed building n°1 in Italy.

The detailed numbering of the intervention category (i.e 1.1.1) will be used for further defining the intervention in each case study annex.

Table 1: Intervention categories

Intervention category code	**Intervention category**
P	1. **Passive Systems**

[1] Country code can be avoided if there is no risk of confusion among stakeholders.

	1.1. Reduction of thermal losses through insulation of the building envelope 1.1.1. External walls 1.1.2. Roofs 1.1.3. Slabs (on basement, pilotis or attic) 1.1.4. Windows and fenestration 1.2. Enhancement of thermal inertia and envelopes' time lag 1.3. Improvement of airtightness[2] 1.4. Humidity control[1] 1.5. Creation of buffer zones 1.6. Protection from wind exposure[1] 1.7. Shading systems 1.7.1. Interior shading (e.g. blinds etc.) 1.7.2. External shading systems adjacent to the envelope (e.g. pergolas, overhangs, shutters etc.) 1.7.3. External shading systems in the buildings' surroundings (e.g. vegetation, proper finishing material selection with lower reflectivity etc.) 1.8. Natural ventilation 1.8.1. More efficient schedules and window operation patterns (e.g. application of night-time ventilation etc.) through the empowerment of energy-aware occupant behaviour 1.8.2. Building management systems and controls of window operation (e.g. temperature or glare control for operation schedules, see also 2.2.3) 1.8.3. Special building features enhancing crossed-ventilation or/and buoyancy driven ventilation (e.g. windcatchers, solar chimneys, cross-arrangement of openings and establishment of un-obstructed airflow path etc.) 1.9. Evaporative cooling 1.10. Daylighting and natural lighting surfaces (e.g. additional skylight or lighting shelve etc.)
A	**2. Active Systems**
	2.1. HVAC Systems 2.1.1. Generation (heat/cool) 2.1.2. Distribution (hydraulic/aeraulic) 2.1.3. Control and regulating systems and terminals 2.1.4. Mechanical ventilation and air handling systems 2.1.5. Building management systems and remote controls

[2] Although difficult to quantify and consequently simulate, it is included for completeness of discussion and to maintain the link with Annex 8.11 to provide an holistic approach in the retrofit concept.

	2.2. Electrical Systems 2.2.1. Generation, Distribution and Use 2.2.2. Lighting 2.2.2.1. General lighting 2.2.2.2. Desk lighting 2.2.3. Building management systems and remote controls (e.g. glare or thermal control of glazing) 2.3. Plumbing and DHW Systems 2.3.1. Efficiency of DHW Systems 2.3.2. Reduction of Water Consumption 2.3.3. Building management systems and remote controls
R	**3. Renewable Energy Sources**
	3.1. Generation, Distribution and Use 3.2. Building management systems and remote controls

Example of intervention list:

Assuming that an Italian analysed building has four interventions in the category of passive systems, three in active systems and one in renewables, their coding would be:

IT1P01, IT1P02, IT1P03, IT1P04, IT1A01, IT1A02, IT1A03, IT1R01

2.2. Description of the interventions

The following paragraphs include the description of the characteristics of the proposed interventions for the energy and environmental improvement of the analysed building.

2.3. IT1P01 [name of the intervention i.e. *Window replacement of the west wing*]

General description of the intervention, highlighting the building parts involved and referring also to the intervention subcategories related to the proposed intervention (an intervention measure may involve more than one category).

For example:

Window replacement of west wing of the building.

Intervention subcategories: 1.1.4 Windows and fenestration, 1.7.2 external shading

Replacement of existing windows of the west wing of the building with insulated wooden frame double pane windows…

<u>Description of the current state of the involved parts</u>

Description of the current state of the parts involved by the intervention using also schemes, images schedules.

For example:

The windows of the south and west elevations are in precarious conditions with poor performance of thermal insulation, air tightness and control of thermal radiation. On the north elevation they have recently been replaced and do not require any intervention. The East front has a heterogeneous situation with some fixtures in poor condition and others in still acceptable conditions.]

<u>Compatibility and heritage significance</u>

Brief overview of the compatibility with a) the guiding principles of restoration, as expressed through the International Charters of Restorations, and b) the national regulatory framework, outlining potential risks of architectural, aesthetic or visual impact, or risks regarding the building’s setting. It is important to highlight how this specific intervention is compatible.

For example:

The current fixtures are not original, they have already been replaced and some of them are not in good condition. It was decided to opt for a substitution keeping the same materials and the same glass colour, to avoid altering the aesthetic appearance of the elevations. Particular attention is also to be paid to the handles and hinges that must be in ...

Techinical compatibility and feasibility check

Brief description of the technological and mechanical compatibility with the other systems and components of the building, outlining potential hygrothermal risks; structural risks, corrosion risks, salt reaction risks, biological risks, and reversibility.

For example:

The substitution of the fixtures will involve the replacement of the fixed frame in some fixtures, and the addition of vapour barrier in order to prevent condensation the sun shading elements must be light enough to be supported by the structure of the current opening. The marble window sill will be preserved...

Environmental sustainability of the intervention

Brief description of whether the intervention is characterised by specific environmental sustainability principles. For example whether the intervention minimises environmental pollution and emission of substances in the indoor environment, whether it uses as much as possible renewable resources, recyclable/reused materials, low embodied energy etc….

Other design criteria

Here should be added any other useful information for planning the intervention (i.e. technical characteristics to be evaluated in the materials and components to be used, methods of carrying out the intervention and laying of materials, possible instrumental checks to be performed before and after the intervention, possible problems to be taken into account in the design and execution of the intervention.

Technical characteristics

Brief description of the technical characteristics of the intervention and comparison with the existing technologies through table, images and schemes, section plan etc.

If the intervention foresees substituting or changing a single element (for example a window or a wall) it is important to check that code of the new substituted or changed element is univocal and related to the previous element modified. In this example of a windows substitution it is suggested to add the description, some images and a synthesis table with the most important technical parameters related to the intervention comparing current state and proposed intervention.

For example:

Window code	Thermal Transmittance window, Uw (W/m^2K)	Thermal Transmittance glass, Ug (W/m^2K)	Thermal Transmittance frame, Uf (W/m^2K)	Solar heat gain coefficient, SHGC	Visible transmittance of glazing (Tv)
W01					
W01_new					

<u>Estimated cost of the intervention</u>

Brief description of the methodology used for the estimated cost of implementation of each intervention (usually referred to as 5D of a BIM process); for example the sorting of information, how the quantities of each intervention were calculated, if they were extracted from the BIM model, if cost estimation was derived from local price list or by requesting quotation from companies etc.

Cost estimation should contain the following information:

- Intervention name and code.
- Quantity related to the intervention, per unit or per measure.
- Measuring unit.
- Estimated cost of the intervention as per unit or measure.

Timing of implementation estimation

Description of how the timing of implementation of each intervention was estimated. For example if it was derived from similar works or by requesting quotation from companies.

2.4. IT1P02 ….

Same as above…

3. Table on main interventions

Synthesis table of the interventions described above.

Intervention Code	**Name of Intervention**	**Quantity**	**Unit of Measurement**	**Cost**	**Total cost**	**Timing of implementation**
Number of the intervention.	*Name of intervention*	*Estimate of the quantity relating to the intervention, per unit or per measure. The measurements can also be extracted directly from the ante operam HBIM model*	*Unit of Measurement*	*Estimate of the cost based on the works, i.e. add scaffolding costs to a thermal insulation of the opaque envelope. The data can be derived either from local price lists or by requesting quotations from companies*	*Total cost*	*Estimate of the times of realisation, based on similar works or on the same quotations requested from the companies*
IT1P01	*Window replacement of west wing of the building*	*40*	*m^2*	*600 €/m^2*	*24.000 €*	*4 weeks*
IT1P02	*…*	*…*	*…*	*…*	*…*	*…*

4. REFERENCES

3 ENCULT. 2011. 'Position Paper on Criteria Regarding the Assessment of Energy Efficiency Measures Regarding Their Compatibility with Conservation Issues.' Deliverable D2.2=D3.2.

Carbonara, Giovanni. 2015. 'Energy Efficiency as a Protection Tool'. *Energy and Buildings*, Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, 95 (May): 9–12. https://doi.org/10.1016/j.enbuild.2014.12.052.

Ding, Grace. 2013. 'Demolish or Refurbish – Environmental Benefits of Housing Conservation'. *Construction Economics and Building* 13 (2): 18–34. https://doi.org/10.5130/AJCEB.v13i2.3322.

EN 16883. 2017. 'Conservation of Cultural Heritage - Guidelines for Improving the Energy Performance of Historic Buildings'. CEN/TC 346 - Conservation of cultural property.

'Green Building Council Historic Buildings'. n.d. GBC Italia. Accessed 20 November 2020. https://www.gbcitalia.org/historic-building.

Webb, Amanda L. 2017. 'Energy Retrofits in Historic and Traditional Buildings: A Review of Problems and Methods'. *Renewable and Sustainable Energy Reviews* 77 (September): 748–59. https://doi.org/10.1016/j.rser.2017.01.145.

'World Green Building Council. Annual Report 2018/19.' n.d. Accessed 20 October 2020. https://www.worldgbc.org/news-media/world-green-building-council-annual-report-201819-report-download.

ANNEX 8.16 REFERENCE TEMPLATE FOR THE COMPARATIVE ANALYSIS OF ENERGY AND ENVIRONMENTAL IMPROVEMENT SCENARIOS

Index

1. GENERAL INTRODUCTION

This document presents in a comprehensive way, a comparative analysis of the energy and environmental improvement scenarios developed on the basis of the improvement interventions designed. Three energy and environmental improvement intervention scenarios are envisaged in this document.

1.1. Current state of the building

Brief description of the building giving also an overview of the building in terms of energy use and bills.

Name of Building:

Location:

Floor area:

Volume:

Original use – present use:

Year of construction:

Picture:

Brief description of the buildings' construction phases, significance, construction materials and conservation state, use, etc.

Overview of the energy consumption (see Annex 8.4).

Table 1: Annual table of final energy consumption and cost

ENERGY SOURCE	2016-2017		2017-2018		2018-2019	
	quantity	**annual cost**	**quantity**	**annual cost**	**quantity**	**annual cost**
Methane gas (1)	m^3	€	m^3	€	m^3	€
Methane gas (2)	m^3	€	m^3	€	m^3	€
diesel fuel	*l*	€	*l*	€	*l*	€

LPG	*l*	€	*l*	€	*l*	€
Wood	*Kg*	€	*Kg*	€	*Kg*	€
Pellet	*Kg*	€	*Kg*	€	*Kg*	€
Heat networks (District heating)	*Mj*	€	*Mj*	€	*Mj*	€
Electrical energy (1)	*kWh*	€	*kWh*	€	*kWh*	€
Electrical energy (2)	*kWh*	€	*kWh*	€	*kWh*	€
water(1)	*l*	€	*l*	€	*l*	€
water(2)	*l*	€	*l*	€	*l*	€

According to ISO/DIS 52000-1:2017 the energy performance is expressed as the building's total primary energy demand (EP_{tot}) divided by the conditioned area (kWh/m^2yearly). The primary energy factors (PEF) that are applied to convert Final Energy into Primary Energy, subject to country-specific characteristics. The total primary energy, EP_{tot} (kWh), is the sum of both non-renewable (EP_{nren}) and renewable (EP_{ren}) energy sources (if any) and refers to all the energy services (heating, cooling, DHW, ventilation, lighting).

Total cost of the energy bills and the building's total primary energy consumption, EP_{tot} (kWh/m^2yearly). EP_{tot} can derive from aggregating the above mentioned energy consumptions (converted from the energy bills) or from the results of the simulation of the calibrated model (ante operam), performed in the activity 4.1 (see Annex 8.12). Data coming from real consumptions is preferable.

2. COMPARATIVE ANALYSIS OF INTERVENTION SCENARIOS

2.1. Description of the three scenarios

Summary table of the interventions and their involvement in each scenario as per the example below. A tick in the scenario column means that the scenario involves that intervention, i.e. Short term scenario is made of IT1P02 IT1A01, IT1A02 and IT1R01, the middle term is IT1P01… …]

On average:

- a short term scenario should have a payback time between 5 and 10 years
- a middle term scenario should have a payback time between 10 and 20 years
- a long term scenario should have a payback time over 20 years

Intervention	Short term scenario	Middle term scenario	Long term scenario
IT1P01 Windows replacement of the west wing….		***X***	***X***
IT1P02 ….	***X***	***X***	***X***
IT1P03		***X***	***X***
IT1P04			***X***
IT1A01	***X***	***X***	
IT1A02	***X***	***X***	
IT1A03			***X***
IT1R01	***X***	***X***	***X***

Short term scenario

I.e. Intervention involved: IT1P02 + IT1A01 + IT1A02 + IT1R01

<u>Description of the scenario</u>

Description of the scenario with the interventions involved and the related synergies between the interventions foreseen in the scenario.

Energy simulation results, expected energy production from RES, expected cost and timing of implementation the intervention as per cost and time estimation on activity 4.1 (see Annex 8.15), and the Simple payback time (see Annex 8.17).

Middle term scenario

I.e. Intervention involved: IT1P01 + IT1P02 + IT1P03 + IT1A01 + IT1A02 + IT1R01

Description of the scenario

Description of the scenario with the interventions involved and the related synergies between the interventions foreseen in the scenario.

Energy simulation results, expected energy production from RES, expected cost and timing of implementation the intervention as per cost and time estimation on activity 4.1 (see Annex 8.15), and the Simple payback time (see Annex 8.17).

Long term scenario

I.e. Intervention involved: IT1P01 + IT1P02 + IT1P03 + IT1P04 + IT1A03 + IT1R01

Description of the scenario

Description of the scenario with the interventions involved and the related synergies between the interventions foreseen in the scenario.

Energy simulation results, expected energy production from RES, expected cost and timing of implementation the intervention as per cost and time estimation on activity 4.1 (see Annex 8.15), and the Simple payback time (see Annex 8.17).

2.2. Comparative assessment of the proposed energy retrofit scenarios

Table with the key data of each scenario: EP_{tot} for each scenario, energy production from RES, investment cost of each scenario (sum of the cost of each intervention involved in the scenario). Calculation of: estimate of the new energy bills starting from the consumption calculated in the scenarios, simple payback time and payback time (see Annex 8.17).

Parameters	Existing building	Short Term	Middle Term	Long Term
Total Primary Energy EP_{tot} [kWh/annual]	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Total Primary Energy EP_{tot} [kWh/m^{2}annual]	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Primary Energy consumption percentage reduction		*%*	*%*	*%*
Final Energy use per energy source [kWh/m^{2}annual]				

1. Electricity 2. Diesel oil 3. Natural Gas 4. LPG 5. District Heating 6. District Cooling 7. Other (please define)		*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Final Energy use and production from RES				
1. Heat pumps [kWh_{th}/annual] 2. PV [kWh_{el}/annual]] 3. Solar thermal system [kWh_{th}/annual] 4. Wind turbines [kWh_{el}/annual]] 5. Biomass [kWh_{th}/annual] 6. CHP (Combined Heat and Power) [kWh_{th}/annual, kWh_{el}/annual] 7. Other (please define)	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Total Energy Production from RES (normalised to electrical energy) kWh/annual				
Overall Investment Cost [€]	/	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Energy cost [€]	*Xxxxxxx*	/	/	/
Average annual Energy cost over the project's life span (30 years) [€/annual]	/	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*
Simple payback time	/	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*

[year]				
Payback time	/	*Xxxxxxx*	*Xxxxxxx*	*Xxxxxxx*

Simplified GANNT on scenario implementation

Synthesis of the timing of implementation related to the scenarios.

Short term scenario simplified GANNT									
Scenario	**Weeks**								
	1	2	3	4	5	6	7	8	9
IT1P02									
IT1A01									
IT1A02									
IT1R01									

Middle term scenario simplified GANNT												
Scenario	**Weeks**											
	1	2	3	4	5	6	7	8	9	10	11	12
IT1P01												
IT1P02												
IT1P03												
IT1A01												
IT1A02												
IT1R01												

Long term scenario simplified GANNT												
Scenario	**Weeks**											
	1	2	3	4	5	6	7	8	9	10	11	12

IT1P01												
…												
…												
…												
…												
…												

3. REFERENCES

3 ENCULT. 2011. 'Position Paper on Criteria Regarding the Assessment of Energy Efficiency Measures Regarding Their Compatibility with Conservation Issues.' Deliverable D2.2=D3.2.

Carbonara, Giovanni. 2015. 'Energy Efficiency as a Protection Tool'. *Energy and Buildings*, Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality, 95 (May): 9–12. https://doi.org/10.1016/j.enbuild.2014.12.052.

Ding, Grace. 2013. 'Demolish or Refurbish – Environmental Benefits of Housing Conservation'. *Construction Economics and Building* 13 (2): 18–34. https://doi.org/10.5130/AJCEB.v13i2.3322.

EN 16883. 2017. 'Conservation of Cultural Heritage - Guidelines for Improving the Energy Performance of Historic Buildings'. CEN/TC 346 - Conservation of cultural property.

'Green Building Council Historic Buildings'. n.d. GBC Italia. Accessed 20 November 2020. https://www.gbcitalia.org/historic-building.

Webb, Amanda L. 2017. 'Energy Retrofits in Historic and Traditional Buildings: A Review of Problems and Methods'. *Renewable and Sustainable Energy Reviews* 77 (September): 748–59. https://doi.org/10.1016/j.rser.2017.01.145.

'World Green Building Council. Annual Report 2018/19.' n.d. Accessed 20 October 2020. https://www.worldgbc.org/news-media/world-green-building-council-annual-report-201819-report-download.

ANNEX 8.17: Reference for the economic indicators of the proposed energy retrofit scenarios

Index

1. Wider Vision of the Return of Investment

The Return of Investment is a financial ratio used to calculate the benefit an investor (in our case the ESCOs) will receive in relation to their investment cost. It is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of a number of different investments.

RoI is commonly measured as a ratio of the net income over the capital cost of the investment. The higher this ratio is, the higher the benefit. It acts as an indicator which can separate low-performing investments from high-performing ones.

Although RoI gives an indication of the of the profitability of an investment, it does not take into consideration the time factor. For example, a return of 25% over 5 years is expressed the same as a return of 25% over 5 days. But obviously, a return of 25% in 5 days is much better than 5 years!

Thus the return of investment must be accompanied by the payback period of each intervention.

2. RoI Formula

The return of Investment can be obtained simply through the following formula:

$$RoI = \frac{Net\ Income}{Cost\ of\ Investment}$$

Where the net income considers the revenue from the energy savings with the operation and maintenance costs considered.

3. Payback Period Calculation Methodology

For the economic evaluation of the proposed energy retrofit scenarios, the economic indicator of **payback time (PBT)** will be used. The use of this indicator is widespread as it is easy to understand by non-experts and require simple calculations. The information provided by PBT is the time in which the investment can be paid off, corresponding to the number of years in which the benefits equal the costs of its implementation. PBT is defined as the smallest value of time, T (months or years)*, for which:

$$I_o - \sum_{n=0}^{T} \frac{B_n - C_n}{(1+r)^n} = 0$$

Where:

- $\boldsymbol{I_o}$ **is the initial investment**, i.e. the sum of all the costs to be sustained for the integration and final delivery of a given retrofit action. These costs include design, purchase of systems and components, connection to suppliers, installation and the commissioning process. The initial investment costs are the costs presented to the owner.
- **Cn** are the **costs** deriving from an intervention over time T, for example, any maintenance and repairs costs that are expected in the period considered.
- **Bn** are the obtainable **benefits** following an intervention, for example, the benefits in terms of savings on the energy bill in the period considered.
- The **discount rate**, **r**, is the parameter (%) indicating the value of money at different periods. It is used to determine how much something in the future

would be worth in the present. In energy efficiency projects, the discount rate is defined as: $r = i + f - f'$, where i is the inflation rate (%), f the real cost of money gross of the direct taxes (e.g. the interest rate charged by a bank for borrowing money), and $f'$is the annual rate of change in the energy price (equals inflation rate, it can be a negative or positive value).
The higher the discount rate, the lower the value we assign to future savings in today's decisions.

A simplified method for the economical assessment of the investment can be considered, if the annual savings, A, are constant. In this case, the **simple payback time (SPT)** can be easily calculated as the ratio of the initial investment, I_o, to the annual net saving, A (i.e. the net annual cash flow between costs and benefits, i.e. benefits minus costs):

$$SPT = \frac{I_o}{A}$$

4. Country Example

The National Energy Efficiency and Renewable Energy Action (NEEREA) is a national financing mechanism that allows private sector entities to get subsidized loans for any type of energy efficiency and renewable energy projects. NEEREA is active through all Lebanese commercial banks under the leadership and management of BDL.

By January 2015, more than 200 projects were approved under the NEEREA financing mechanism with a total amount of more than 250 million USD. NEEREA is the first green financing mechanism in the Arab Region that finances renewable energy, energy efficiency projects and green buildings.

The loan is eligible to private, existing and newly built facilities. It has a ceiling of 10 million USD and is offered at a low interest rate for a maximum of 14 years including a grace period of up to 6 months to 4 years.

The green loans are provided by Lebanese commercial banks to the private sector. The most important aspect of NEEREA is that it links the commercial banks to private companies to ensure a sustainable development of the socio-economic framework.

4.1. How it works

Clients interested in implementing green energy projects through NEEREA should follow the specific process:

1. Prepare a technical report (as per the reports' templates prepared by the LCEC) either by the client himself or by the appointed energy company including a full feasibility study with full financial and technical analysis. The report should also include the total amount of the requested loan. This report contains all the needed information of all interventions including the energy savings, payback period and CO_2 saved. These factors would help the bankers to issue the loan or not.
2. Pick a commercial bank where the loan is then studied.
3. The report, once studied by LCEC, is re-sent to the commercial bank or to BDL to review and send the results to the commercial bank.
4. The commercial bank informs the client whether the loan is granted or rejected. If granted, the client can then implement the technical solutions.

This process takes around three months based on the quantity of applications and availability of information. Disciplinary action will be taken if the final execution diverges from the original plans.

4.2. NEEREA Results

By June 2020, more than 1,000 projects were approved by the NEEREA financing mechanism with a total amount of more than 600 Million USD. Results show that around 76% of the projects were for solar photovoltaic while 42% of loans amount were for green buildings. These projects all together contribute to an annual saving of 73,253,210 USD. Until today, NEEREA has achieved to reduce yearly energy consumption by 260,163,325 kWh and 281,245 tons of CO_2.

Annex 8.18 EPC FORMAT (GUARANTEED SAVINGS MODEL)

1 Definitions

Actual Energy Consumption during the Monitoring Period: Energy consumption within the Monitoring Period, which results from measurements and calculations, based on the Measurement and Verification Program.

Actual Energy Savings of the Monitoring Period: The reduction of energy consumption resulting from the implementation of activities within the Monitoring Period.

Actual Financial Benefit of the Monitoring Period: The financial benefit resulting from the Actual Energy Savings of the Monitoring Period.

Actual Financial Compensation: The attributed energy services fee for the services provided by the ESCO within a Monitoring Period, as shown by the Monitoring Period Report.

Baseline Energy Consumption: Energy consumption in the Premises during the Reporting Period.

Baseline Energy Cost: the amount in euros identified as the "Baseline Energy Cost" in Annex 3 (*BASELINE ENERGY CONSUMPTION*), based on:

(a) the annual energy and water consumption levels ***[CHOICE: (i) [at the Premises] or (ii) [in respect of the Systems]]*** prior to the implementation of the energy savings mechanisms by the ESCO; and
(b) the applicable unit rates

Business Day: means a day (other than a Saturday or a Sunday or a public holiday).

Business Hours: means the hours between 8.00 am and 6.00 pm on a Business Day.

Completion Report: The report prepared by the ESCO upon completion of a task or a group of tasks performed under the Project.

Contract Period: The time period from the entry into force until the termination of the Contract.

Contract: This Energy Savings Performance Contract and all annexes attached hereto.

Effective Date: The date this Contract is signed, or if counterparts of this Contract are signed, the date the last counterpart is signed.

Energy Prices of the Monitoring Period: Average unit energy values of the Monitoring Period, which are used for the calculation of the energy cost and the financial benefit from energy savings.

Equipment: The goods, materials, and equipment to be installed by the ESCO at the Premises as more particularly described in Annex 9 (*List of Measures and Equipment*), including any additions and modifications made to such goods, materials or equipment during the Term.

ESCO: Energy service companies (ESCOs) develop, design, build, and arrange financing for projects that save energy, reduce energy costs, and decrease operations and maintenance costs at their customers' facilities.

Financial Compensation: The fee provided by the Contract to the ESCO for the services provided within of a Monitoring Period.

Guaranteed Energy Saving for the Monitoring Period: The reduction of energy consumption within the Monitoring Period guaranteed by the ESCO that will result from the implementation of the actions of the Project.

Guaranteed Financial Benefit of the Monitoring Period: The financial benefit within the Monitoring Period guaranteed by the ESCO that will result from the implementation of the actions of the Project.

Implementation Plan: The project execution plan, with an extensive description of activities, resources, and annexes of each Measure.

List of Measures and Equipment: Table containing basic information on the Measures, the new equipment as well as the upgraded equipment under the contract.

Measure for improving energy efficiency: The supply and installation of new equipment, the upgrade or replacement of existing equipment, as well as any work or service provided by the ESCO under the Contract in order to reduce energy consumption at the Contract Facility.

Monitoring Period Report: The report prepared by the ESCO at the end of each Monitoring Period and includes measurements and calculations made to determine the Actual Energy Savings, the Actual Financial Benefit, as well as the Actual Financial Compensation for the Monitoring Period.

Monitoring Period: Each time period within the Contract Period, after which the Actual Energy Consumption and the Actual Financial Benefit are calculated.

Predicted Baseline Energy Consumption during the Monitoring Period: The energy consumption in the Premises within the Monitoring Period, which is calculated based on the Baseline Energy Consumption methodology described in the Measurement and Verification Program.

Premises: means the Customer's premises in which the Works are to be performed as more particularly described in Annex 1(Premises).

Reporting Period: The time period for performing the calculations to determine the Actual Energy Saving and the Actual Financial Benefit of the Monitoring Periods.

Supplementary Work Program: The plan for the execution of the actions required to ensure compliance with the performance guarantees.

Total Actual Energy Savings: The overall reduction in energy consumption resulting from the Project.

Total Actual Financial Benefit: The total financial benefit that results from the Total Actual Energy Savings.

Total Guaranteed Energy Savings: The reduction of energy consumption guaranteed by the ESCO that will occur as a result of the Project.

Total Guaranteed Financial Benefit: The financial benefit guaranteed by the ESCO that will arise as a result of the Project.

Works: Collectively, the Equipment, professional services, and project construction related to the project.

2 Subject of the Contract

2.1 Under the Contract, the ESCO implements the Project that aims to save energy and improve the degree of energy efficiency in the premises. The financial consideration of the ESCO comes from the energy savings achieved by the implementation of the Project.

2.2 The Project will be implemented in the Premises, which is described in Annex 1.

2.3 The Customer undertakes the financing, with own and/or foreign funds, of the Equipment.

2.4 The Project consists of all activities and services provided by the ESCO (List of Measures and Equipment) and concerns the selection and supply of new equipment, the installation of new equipment, the upgrade of existing equipment as well as activities and interventions aimed at improving the degree of energy efficiency and energy savings in the Premises.

2.5 Prior to the signing of the Contract, The ESCO has prepared and completed an Energy Savings Report in respect of the [CHOICE: (i) [Premises] or (ii) [Systems]], as included in Annex 4 (Energy Savings Report) and that the Energy Savings Report has been approved and accepted by the Customer.

2.6 Any payments to be made by the Customer to the ESCO in respect of the preparation of the Energy Savings Report shall be separately itemized in Annex 8 (Contract Price and Payment Schedule). If Annex 8 (Contract Price and Payment Schedule) is silent on the payments to be made in respect of the Energy Savings Report, the cost of such works shall be deemed to have been included within the Contract Price.

2.7 The Works undertaken by the ESCO in respect of the preparation of the Energy Savings Report have been undertaken prior to the Effective Date. The preparation of the Energy Savings Report is a part of the scope of work to be performed by the ESCO under this Contract. The Parties agree that the ESCO shall be bound by the terms and conditions of this Contract with respect to the preparation of the Energy Savings Report.

2.8 The Customer represents and warrants that, to the best of its knowledge and belief, the Information provided to the ESCO for the purpose of the Energy Savings Report is complete and accurate and is not misleading in any material respect. If at any time the Customer becomes aware of any material omission or inaccuracy in any such information, the Customer shall promptly notify the ESCO in writing and provide the ESCO with such missing or accurate information that may be in its possession. In such circumstances, the ESCO shall also be entitled to adjust the Baseline Energy Cost to reflect the revised Information provided by the Customer.

3 Duration of the Contract

3.1 The agreement enters into force on the date of its signing by the parties. This date is the date of commencement of the Contract.

3.2 The expiration date of the Contract is defined as ___________________.

3.3 Contract Period is the period from the start date to the end date of the Contract.

3.4 In case of achieving the Total Guaranteed Financial Benefit in a period of less than the Contract Period, the Contract is terminated automatically. The Contracting Parties may in this case agree to an extension of their cooperation, on the same or different financial terms, either by amending the contract or by concluding a new contract.

4 Monitoring Periods

4.1 The Contract Period is subdivided into Monitoring Periods.

4.2 The Monitoring Period is the basic time unit for monitoring the execution of the Contract. At the end of each Monitoring Period, the ESCO performs the planned measurements and calculations to determine the Actual Energy Savings of the Monitoring Period and the corresponding Actual Financial Benefit of the Monitoring Period (according to the Program of Measurement and Verification).

4.3 The Monitoring Periods are detailed in Annex 2.

5 Reporting Period, Baseline Energy Consumption, Energy Prices

5.1 The Reporting Period is used as the time period for performing the calculations to determine the Actual Energy Saving and the Actual Financial Benefit of the Monitoring Periods.

5.2 The consumption of each system within the Reference Period (Baseline Energy Consumption), is the starting point for determining the Actual Energy Saving of each Monitoring Period. Based on the development scenario described in the Measurement and Verification Program, the Predicted Baseline Energy Consumption is determined for each Monitoring Period, which is the basis for comparison with the Actual Energy Consumption of the Monitoring Period.

5.3 The Baseline Energy Consumption of the Monitoring Periods are listed in Annex 3.

5.4 For the cost of energy and the conversion of energy benefit into financial benefit, the parties agree on the use of energy prices for each Monitoring Period (Energy Prices of Monitoring Period), which resulted from the implementation of an energy price evolution scenario.

5.5 For each system, the Energy Price for the Monitoring Period is considered to be its average value.

5.6 The Energy Prices for the Monitoring Periods are listed in Annex 3.

6 Guaranteed Energy Savings and Guaranteed Financial Benefit

The ESCO provides the Customer with guarantees regarding the energy savings and the financial benefit from the implementation of the project, as follows:

6.1 Total Guaranteed Energy Savings broken down by energy product as follows:

- electricity ....kWh,
- natural gas ....
- oil ....
- LPG ....
- Thermal energy ....
- other energy product ....

These values are based on the performed energy simulation describing three retrofit scenarios (see Annex 6: Environmental and Energy Simulation for the EE-HBIM Design of Energy Rehabilitation), which are derived after the development of the HBIM model (see Annex 5: EE-HBIM Model Development Report).

6.2 Total Guaranteed Financial Benefit .... euros,

6.3 Guaranteed Energy Savings and Guaranteed Financial Benefits of Monitoring Periods, according to the tables listed in Annex 7.

6.4 The calculation of the Guaranteed Financial Benefit (in total as well as for each Monitoring Period) is based on the respective Guaranteed Energy Savings and Energy Prices of the Monitoring Period. The calculation of the financial benefit also considers the reduction of operating and maintenance costs in the premises.

7 List of Measures and Equipment

7.1 The Contracting Parties have drawn up a List of Measures and Equipment, which lists all the measures implemented by the ESCO as well as the equipment that is installed or upgraded under the Contract.

7.2 The List of Measures and Equipment includes a list of Measures, a list of New Equipment and a list of Upgraded Equipment and is detailed in Annex 9.

8 Financial Compensation of the ESCO

8.1 The Financial Compensation of the ESCO for the services provided under the Contract is agreed to an amount of _______ euros for each Monitoring Period. This is the Actual Financial Compensation paid to the ESCO, provided that the Actual Financial Benefit of the Monitoring Period is not less than its Guaranteed Financial Benefit.

8.2 In the event that at any Monitoring Period the Actual Financial Benefit falls short of the Guaranteed Financial Benefit, the Actual Financial Compensation of the ESCO arises from the Actual Financial Compensation, less any amount of the difference. If the Actual Financial Compensation is negative, the difference is paid by the ESCO to the Customer as compensation.

8.3 The Actual Financial Compensation of the ESCO is determined at the end of each Monitoring Period and summarized in Annex 10.

8.4 In case of automatic termination of the Contract due to the achievement of the Total Guaranteed Financial Benefit in a period of less than the Contract Period (as provided in paragraph3.4), the remaining difference of the total financial exchange is paid by the Customer to the ESCO.

9 Periodic Clearance

9.1 At the end of each Monitoring Period, the ESCO performs measurements and calculations, according to the procedures provided in the Measurement and Verification Program, in order to determine the Actual Energy Consumption of the Monitoring Period and compare it with the Predicted Baseline Energy Consumption for the calculation of the Actual Energy Saving of the Monitoring Period and the resulting Actual Financial Benefit of the Monitoring Period.

9.2 Within _______ calendar days from the end date of the Monitoring Period, the ESCO prepares and submits to the Customer the Monitoring Period Report (Annex 10), which includes

9.2.1 Detailed calculations and measurement results for the determination of energy consumption within the Monitoring Period, according to the Measurement and Verification Program.

9.2.2 Tables for determining the energy and financial benefit of the Monitoring Period (Actual Energy Saving and Actual Financial Benefit).

9.2.3 Financial Clearance Table, which includes the deviations from the Guaranteed Energy Saving and the Guaranteed Financial Benefit of the Monitoring Period, as well as the determination of the Financial Compensation of the ESCO for the Monitoring Period.

9.3 The monitoring of the Monitoring Period Report is based on the Measurement and Verification Program, which describes all the procedures for determining the energy and financial benefit of the Monitoring Period, based on the provisions of article 8 regarding the Financial Compensation of the ESCO.

9.4 After the approval of the Monitoring Period Report by the Customer, it is signed by the contracting parties and, in case of a positive Actual Financial Compensation, an invoice is issued by the ESCO for the Monitoring Period, with this amount, while in case of a negative Actual Financial Compensation, the ESCO pays the difference to the Customer.

9.5 The payment of the invoice for the Monitoring Period is done within _______ days from its receipt.

9.6 The payment of any resulting compensation from the ESCO to the Customer is done within a period of _______ days from the signing of the Monitoring Period Report.

10 Implementation Plan

10.1 Description

The project implementation plan, with a detailed description of activities, resources and schedules is reflected in the Implementation Plan (Annex 11).

10.2 Start of execution of the Project

The ESCO, within a period of _______ from the date of signing the Contract, must start the execution of the Project based on the Implementation Plan.

10.3 Legal compliance

The Project must be implemented in accordance with the requirements of the _______ law legislation.

10.4 Quality check

The ESCO is responsible for quality control of the measures throughout their implementation. The ESCO must inspect and control any work performed to meet the requirements under the Contract.

10.5 Timetable

10.5.1 The ESCO must perform the Works for the implementation of the measures according to the schedule included in the implementation plan.

10.5.2 The modification of the implementation schedule is not allowed, except in cases of emergency/force majeure. The modification of the time period of implementation of the Measures in these cases is allowed by an additional agreement, which is signed by the contracting parties and annexed to the Contract. In this case, the period of implementation of the Measures is extended not more than that attributed to the emergency/force majeure, which results from an appropriate confirmation document.

10.6 Self-supervision - Subcontracting

10.6.1 The Project implementation is done through the ESCO itself.

10.6.2 The ESCO may outsource the implementation of specific tasks that fall within the scope of the Contract to third parties. In this case, the ESCO bears full responsibility to the Customer for the consequences of non-fulfillment or insufficient fulfillment of the obligations of third parties. The scope and type of work assigned to third parties are annexed to the Contract.

10.7 Access to the Premises

10.7.1 The ESCO has inspected the Premises and acknowledges and accepts that there is sufficient space and access to and within the Premises for the installation and operation of the Equipment.

10.7.2 The Customer shall give the ESCO, its employees, Sub-Contractors, agents and representatives a right of access to and non-exclusive possession of the Premises for the performance of the Works during Business Hours or during such hours as may be agreed by the Parties in writing.

10.7.3 The Parties acknowledge that the ESCO may need to access the Premises to undertake emergency repairs or corrections. In such circumstances, the ESCO shall immediately notify the Customer, which notification shall be confirmed in writing no later than three (3) Business Days after the emergency event arose (in circumstances where written notice is not provided in the first instance) and the Customer shall not unreasonably restrict or prevent the ESCO from accessing the Premises to undertake such Works.

10.8 Equipment and Materials used

10.8.1 The ESCO undertakes the obligation to ensure that the execution of the Works and provision of services under the Contract is carried out with the same means and materials.

10.8.2 When performing the Works and providing services, the ESCO must use the materials and equipment provided in the List of Measures and Equipment (Annex 9) and in accordance with the applicable technical regulations.

10.8.3 The ESCO may, after written approval by the Customer, use similar materials and equipment, having similar technical characteristics, to those provided in the List of Measures and Equipment.

10.8.4 The materials and equipment used must be accompanied by a technical file with all the necessary elements (technical characteristics, operating conditions, etc.). The ESCO must provide copies of the above upon request by the Customer.

10.8.5 During the execution of the Works, the ESCO must comply with the technical instructions of the manufacturers/suppliers for the installation of the equipment as well as the quality control procedures provided by them.

10.9 Approval and Acceptance Procedures

10.9.1 The ESCO must inform the Customer in writing about the completion of each task or group of tasks.

10.9.2 The ESCO, within the deadline _______ calendar days after the completion of the Measure, sends to the Customer the Completion Report (Annex 12).

10.9.3 The Customer checks the Completion Report based on the Implementation Plan.

10.9.4 If deviations from the provisions of the Implementation Plan are found in the Completion Report, the parties draw up and co-sign a Supplementary Work Program, which includes the necessary actions to remove the discrepancies and their implementation schedule. The ESCO must, with its own means and expenses, proceed with the implementation of the Supplementary Work Program within a period of _______ calendar days from the date of its signing, unless a different deadline is provided in it.

10.9.5 If the Works have been implemented in accordance with the Implementation Plan, the Completion Report is signed by the contracting parties.

10.9.6 The signing of the Completion Report by the contracting parties certifies the successful completion of the activities. These tasks include those described in the Implementation Plan.

10.10 Prerequisite Measures

The ESCO may not initiate the implementation of the Measures, for which there are, under the Implementation Plan, prerequisite Measures that have not been completed, as certified by the Completion Report. Otherwise, the ESCO must, at its own expense, carry out all the necessary remedial actions, in accordance with the requirements and instructions of the Customer.

10.11 Instructions - Training

10.11.1. The ESCO must provide the Customer with instructions for the operation and maintenance of the Equipment, as well as a complete list of its spare parts.

10.11.2 Within a period of _______ calendar days from the completion of the installation of each component of the Equipment, the ESCO must proceed to the training of the personnel that will be indicated by the Customer regarding the operation and maintenance of this equipment.

10.12 Performance Guarantees and Insurance

10.12.1 The ESCO must perform the tasks provided in the Implementation Plan by providing the quality guarantees described for each task in it (guarantees of good execution).

10.12.2 The validity of the performance guarantee is the date of signing by the contracting parties of the Completion Report.

10.12.3 The ESCO must enforce professional liability insurance and any other type of insurance agreed in the Contract.

10.13 Supplementary Work Program

10.13.1 If, during the period of validity of the performance guarantee, deficiencies or defects are found in the work performed or in the installed Equipment, the Contracting Parties draw up and co-sign a Supplementary Work Program (Annex 13).

10.13.2 The Supplementary Work Program, after being signed by parties, is annexed to this Contract and constitutes an integral part of it.

10.13.3 The Supplementary Work Program includes the necessary remedial actions required and their implementation schedule.

10.13.4 The ESCO must, at its own expense and means, implement the Supplementary Work Program. In this case, the period of validity of the performance guarantee is extended accordingly.

11 3.4 Measurement and Verification Program

11.1 The parties have agreed that all procedures for measuring and calculating the energy and financial benefit from the implementation of the Project will be based on the Measurement and Verification Program (Annex 14).

11.2 During the preparation of the Measurement and Verification Program, various factors shall be taken into account, such as the type of energy-saving measures, the projected energy savings and the implied financial benefit, the degree of uncertainty regarding the savings, as well as the intended risk sharing.

11.3 The Measurement and Verification Program is a reference point for the parties during the preparation and control of the Monitoring Period Reports.

11.4 The Measurement and Verification Program defines the procedures and methodology of measurement and verification of each Measure. The measurement procedures and methodology are described in Annex 14 and are in accordance with the International Performance Measurement & Verification Protocol (IPMVP).

12 Substantial Changes

12.1 Substantial change is any change in the Customer's facilities that is expected to result in an increase or decrease in energy consumption by at least _______%.

12.2 The substantial changes include the following:

- Changes in the use of the installation
- Changes in the operating hours of the installation
- Changes in standard operating and comfort levels
- Changes/additions of equipment of the installation
- Renovations in the installation
- Misuse of installation equipment
- Failure to perform maintenance and repairs of equipment
- Change of supplier or method of energy pricing
- Restriction or suspension of operation after a court decision
- Closing the installation
- Any change other than weather conditions that affects the energy consumption of the installation

12.3 The Contracting Parties agree that any substantial change constitutes a reason for amendment of the Contract, as it makes necessary the revision of the technical parameters and calculations of the Project.

12.4 The Customer must inform the ESCO in writing for any substantial change in its facilities at least _______ days prior to that change.

13 Obligations and Rights of the Contracting Parties

13.1 For the improper execution of the Contract, the contracting parties are responsible according to the current legislation and the terms of the Contract.

13.2 In case of delay by the Customer in fulfilling the payment obligations of the Actual Financial Compensation, the ESCO has the right to request a clause amounting to ____% of the amount due for each day of delay.

13.3 The Customer is exempted from the clause mentioned in paragraph 13.2 if he proves that the inability to fulfill the obligations of payment of the Actual Financial Compensation is due to reasons of force majeure or to the fault of third parties.

13.4 The ESCO is liable to the Customer for any deviations from the requirements of the Contract as well as for any violations of applicable laws and regulations.

13.5 The ESCO is responsible for the quality of the Equipment, materials and Works performed during the warranty period and within the Contract Period.

13.6 In case of delay in the fulfillment of the obligations of the ESCO provided in the Contract, including the delay in the execution of the works and in the correction of identified weaknesses and/or deficiencies, the Customer is entitled to demand compensation.

13.7 The payment of compensation or any other liability does not release the parties from fulfilling their obligations under the Contract.

13.8 The parties are not responsible for the partial or complete failure to fulfill their obligations under the Contract in case of force majeure. In this case, the provisions of article 15 apply.

13.9 The ESCO shall be liable for compensation for damages caused by third parties as a result of works under the Contract unless it proves that they are due to the fault of the third parties.

13.10 If during the execution of works it becomes ESCO the correction of deficiencies and imperfections, setting a reasonable period of time for this, and, in case of non-fulfillment by the ESCO of this claim, to unilaterally terminate the Contract and demand compensation.

14 Ownership Rights

14.1 The Customer owns any equipment installed by the ESCO at the Contract Facility (Premises).

15 Force Majeure

15.1 Incidents of Force Majeure shall mean in particular floods, lightning, earthquakes, fires, explosions, wars, national emergencies, and any unforeseen similar occurrences if they are outside the scope of any degree of fault on the part of the parties.

15.2 If either Party is prevented or delayed in the performance of any of its obligations under this Contract (save for any obligation to make payment) by a Force Majeure Event, then:

15.2.1 the affected Party's obligations under this Contract shall be suspended for so long as the Force Majeure Event continues and to the extent that the affected Party is so prevented, hindered or delayed;

15.2.2 within ______ Business Days after commencement of the Force Majeure Event the affected Party shall notify the other Party in writing of the occurrence of the Force Majeure Event, the date of commencement of the Force Majeure Event and the effect of the Force Majeure Event on its ability to perform its obligations under this Contract;

15.2.3 the affected Party shall use all reasonable efforts to mitigate the effects of the Force Majeure Event upon the performance of its obligations under this Contract; and

15.2.4 immediately after the cessation of the Force Majeure Event the affected Party shall notify the other Party in writing of the cessation of the Force Majeure Event and shall resume performance of its obligations under this Contract.

15.3 If either Party is prevented from the performance of all or substantially all of its obligations for a period exceeding _____________ consecutive Days, the other Party may terminate this Contract by giving not less than _________ Business Days' notice in writing to the other Party, in which case neither Party shall have any liability to the other except that rights and liabilities which accrued prior to such termination shall continue to subsist.

16 Settlement of Disputes

16.1 If a dispute or difference arises under or in connection with this Contract (including a dispute relating to the existence, validity or termination of this Contract or any obligation arising out of or in connection with this Contract), then either Party shall provide the other Party with a written notice of dispute ("Notice of Dispute").

16.2 Upon receiving a Notice of Dispute in accordance with clause 16, such dispute shall be referred in writing to the senior members of each of the Customer and the ESCO who shall endeavor to resolve the dispute amicably, in good faith, within twenty (20) Business Days of such referral.

16.3 If the Parties are unable to resolve the dispute within the twenty (20) Business Day period referred to in clause 16.2, the Parties hereby agree that the dispute shall be subject to the exclusive jurisdiction of the courts of _________.

16.4 Pending final resolution of any court proceedings under this Contract, the ESCO shall continue performing its duties and obligations under this Contract without delay and the Customer shall continue to pay all undisputed sums in accordance with the terms of this Contract.

17 Notices

17.1 Any notice or other communication pursuant to or in connection with this Contract shall be in writing in the English language and may be delivered personally or sent by:

17.1.1 post (air mail if overseas); or

17.1.2 by email,

to the address for that Party set out in clause 17.2.

17.2 Each Parties' address for service is as follows:

17.2.1 Customer:

Address: [insert address]

Attention: [insert]

Email: [insert email address]

17.2.2 ESCO

Address: [*insert address*]

Attention: [*insert*]

Email: [*insert email address*]

17.3 Any notice or other communication shall be deemed to have been served:

17.3.1 At the address or email referred to in clause 17.2 within Five (5) Business Days;

18 Amendments

18.1 The Contract is amended only by written and explicit agreement between the parties.

19 Termination of the Contract

19.1 Termination of the Contract can be done either by agreement of the parties or by a court decision.

19.2 In case of termination of the Contract by agreement of the parties, it must be done in written form, with a special termination agreement.

19.3 The termination of the Contract by a court decision is based on civil law and the terms of the Contract.

19.4 Reasons for termination of the Contract by a court decision constitute in particular

- Breach of essential terms of the Contract
- Delays in the execution of the Project in relation to the schedule by the ESCO, without any fault on the part of the Customer
- Inability to secure the necessary permits and approvals for the execution of the Project
- Failure of the ESCO to comply Services to the specifications and quality requirements of the Project
- Bankruptcy of one of the Contracting Parties

20 Final Provisions

20.1 The Contract as well as the rights and obligations of the contracting parties are governed by and construed in accordance with ________law.

20.2 The Contract consists of _______ pages. It is signed by the parties in _______ copies.

Annex 1: Premises

- Project Details

Name		
Location		
Coordinates		
Image		
Function		
Number Of Floors		
Number Of Building Units		
Net Heated Surface		
Net Heated Volume		
V: Gross Heated Volume		
A: Building Envelope Surfaces (Adjacent To The Ground, To Heated Or/And Non-Heated Spaces, To The External Air)		
C=A/V Compactness Ratio (The Area Of A Building's External Envelope To Its Hosted Inner Volume)		
Year Of Construction		
Previous Interventions	Year	
	Description	
Previous Interventions	Year	

	Description	

- General Description of the Current State of the Facility

[This section should offer a short description of the facility (residential building, commercial building, industry, house, etc.) including location, architecture, number of floors, and other useful information]

[This Section contains basic information about the condition of the premises at the time of contract execution. Such information would include facility area, construction type, use, occupancy, hours of operation, and any special conditions that may exist]

[Include photos and drawings if needed]

Annex 2: Monitoring Periods (MP)

CODE	Start Date	End Date
MP1		
MP2		
MP3		
MP4		
MP5		
MP6		

Annex 3: Baseline Energy Consumption

[Parties to describe for each Monitoring Period the Baseline Energy Consumption, Energy Price and Baseline Energy Cost.]

This annex is used as a basis to compare the Baseline consumption with the Actual consumption of the Monitoring Period to determine the energy savings as well as the financial benefits.

Monitoring Period		***Type of Consumption***	***Baseline Energy Consumption***	***Energy Price (Euro/energy unit)***	***Baseline Energy Cost (Euro)***
Code	***Time period***				
MP1		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP2		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP3		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP4		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			

Annex 4: Energy Savings Report

[This annex should include a detailed feasibility study of the different components of the project]

[The technical feasibility should check every condition for the realization, the installation and maintenance of the system, so the technical feasibility study considers the technical features of the proposed system]

- Energy Consumption:

[As the first step in the technical analysis is to perform the full load inventory with the real time measurements, this section of the proposal is dedicated to analyze the present situation and to introduce the main energy use of the facility]

Month	Electrical Energy (kWh)	Thermal Energy (kWh)	Total (kWh)	Total Cost (euro)
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				
Total				

- Description of Measures:

This section describes the measures to be installed in the premises. Please insert all calculation done to deduce the energy savings for each measure. Add additional sub-sections for additional measures as needed

- Measure 1:

Measure Code:

Measure Description:

[General description of the measure, highlighting the building parts involved. Please add also the intervention subcategories related to the proposed measure]

Description of the current state of the involved parts

[Describe the current state of the parts involved by the measure.]

Feasibility check

[Briefly describe the technological and mechanical compatibility with the other systems and components of the building].

Environmental sustainability of the intervention

[Briefly describe whether the intervention is characterised by specific environmental sustainability principles.]

Other design criteria

[add any other useful information for planning the measure]

Technical characteristics

[briefly describe the technical characteristics of the measure and compare it with the existing technologies through table, images and schemes, section plan etc.

Technical characteristics [current state]

…….

…….

Technical characteristics proposed [measure]

- …….
- …….

.

Estimated cost of the measure

…

Implementation time

- …….
- …….

Energy Savings

- …….
- …….

- Summary:

Measure Code	Savings (kWh/year)	Savings (euro/year)	Simple payback	Annual Costs (euro)	Payback Period(years)	Return of Investment	Annualized RoI
e.g. LB7P01							
…..							
…..							
Total							

Annex 5: EE-HBIM Model Development Report

1. General Information

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

2. Introduction

Brief introduction of the BIM model development activities connected to BEEP project.

3. Pre Planning Activities

Description of any pre-planning activities concerning the BIM model development: software or hardware purchase, organization and management phase, etc.

Reference to the geometric survey activity and its integration strategy within the model (if relevant).

3.1. BIM Tender development (if any)

Brief description of any tender activities performed (for the subcontracting of the whole service as external service, for the hiring of a consultant, etc.), the first contacts with the contractors (if any), the work organization, etc.

3.2. BIM Execution Plan development

Brief description of the BIM Execution Plan, provided by the Consultant in case of tender activities and/or developed internally.

4. EE-HBIM Model Development Workflow

4.1. Modelling workflow general strategy

Brief introduction of the general modelling strategy adopted.

4.2. Template selection

Description of the template selection or implementation for the different disciplinary models.

4.3. Modelling environment definition

Description of the modelling environment development: grids structure - levels - sharing coordinates system, etc.

4.4. Integration of geometrical survey documentation

Description of the strategy to integrate geometrical survey documentation in the model, in the form of point clouds import, CAD drawings import referred to model levels, etc. This integration should be connected to modelling strategy (for example, scan to BIM in the case of point clouds).

5. EE-HBIM Modelling Current Status

Brief description, with images, of the current status of the model: what has been already modelled, how, problems encountered, modifications, adjustments, etc.

5.1. EE-HBIM Modelling of architectural elements

Brief description of the modelling implementation of architectural elements, as they were encountered within the modelling process up to the current state (second semester, first semester of reporting on the model): compromises between geometrical accuracy and parametric object definition, scan to BIM strategies (if a point cloud laser scanner survey of the building is available), use of constraints, etc.

5.2. Modelling spaces

Modelling definition of the architectural spaces up to the current state of the model (second semester, first semester of reporting on the model).

5.3. Modelling strategy of MEP objects

Brief description of the modelling implementation of MEP elements (with reference to BEP): which elements have been modelled (generally, terminals and boilers), up to the current state of the model (second semester, first semester of reporting on the model).

5.4. Non geometrical information implementation

Brief description of the implementation of non geometrical information: parameters definition (with reference to the Model Element Table), linked information from reports, drawings, etc. up to the current state of the model (second semester, first semester of reporting on the model).

Annex 6: Environmental and Energy Simulation for the EE-HBIM Design of Energy Rehabilitation

1. General introduction of the software and the calculation method

[briefly describe the chosen software and its main features like calculation method and regulatory compliance]

2. Model input data (ante-operam)

2.1. Introduction

[brief description of the input data used by the software]

2.2. Weather data

[brief description of the weather data, the data present, data format, source of data, choice of data and related reasoning]

2.3. Thermal zones and user schedule

[brief description of the thermal zone definition of the building and of the occupancy schedules used. Highlight the reasoning behind the thermal zones definition and the source of occupancy schedules]

2.4. Shell and Interiors parameters

[brief description of the parameters of the envelope (exterior vertical and horizontal enclosures - opaque and transparent), interiors (if relevant), please refer to the model element table. Highlight thermal bridges (if any) and how they are calculated (if they are)]

2.5. Building Geometry

[brief description of how the abstract geometry of the energy model was reached from the real geometry of the building. Also include specific reflections relating to the thermal representation of the historic building (simplification of complex elements, methods of working with the masses, etc.)]

2.6. Building Systems

[brief description of the modelled systems (heating, cooling, lighting, ventilation, RES, storage etc..) and their modelling strategy]

3. Ante-operam Energy Model calibration

[description of the energy calibration strategy and of all the calculation, trial and errors, performed]

4. Ante operam Energy simulation results

[description of the results of the ante-operam model including free running simulation results to help comprehend and evaluate the passive behaviour of the building including:

- *comfort (just to check country regulatory compliance);*
- *global primary energy demand Ep,gl;*
- *energy performance consumption for each sources involved in the scenarios or for energy use;*
- *energy production from renewable energy sources (RES);*
- *Free running analysis of temperature and relative humidity in specific thermal zones (useful for the design of the intervention scenarios)]*

5. Energy modelling and simulation results of the scenarios (post-operam)

[description of the input data for each energy improvement scenarios and of the yearly energy simulation results (and monthly - if useful) in terms of:

- *comfort (just to check country regulatory compliance);*
- *global primary energy demand Ep,gl;*
- *energy performance consumption for each sources involved in the scenarios or for energy use (keep in mind to obtain data to ease the calculation of the related energy bills);*
- *energy production from renewable energy sources (RES).*

5.1. Short term scenario modelling and results

5.2. Middle term scenario modelling and results

5.3. Long term scenario modelling and results

Annex 7: Guaranteed Energy Savings and Guaranteed Financial Benefits of Monitoring Periods

Monitoring Period		***Type of Consumption***	***Guaranteed Energy Savings***	***Energy Price (Euro/energy unit)***	***Guaranteed Financial Benefit (Euro)***
Code	***Time period***				
MP1		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP2		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP3		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP4		***Electricity (kWh)***			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			

Annex 8: Contract Price and Payment Schedule

Measures

Give an example or a form to be filled

- All payments under the contract will be made in Euro.
- The customer shall effect payments to the ESCO after acceptance by the customer of the invoices submitted by the ESCO, upon achievement of the corresponding energy savings for each monitoring period as per the following table.

CODE	Date	Payment (Euro)
MP1		
MP2		
MP3		
MP4		
MP5		
MP6		

- The payment amount should in accordance to the amount calculated in the monitoring period report. If the amount is negative, the ESCO shall pay this amount to the customer.

Annex 9: List of Measures and Equipment

Measure Code	Description	Implementation Start Date	Operation Start Date	Cost (Euro)
LB7A01	*Replacement of CFL lighting wilt LEDs*	*February 2022*	*March 2022*	*600*

New Equipment

Code	Description	Measure Code	Installation place	Quantity	Technical Characteristics	Cost (Euro)
LB7A01-E1	*LED lamps*	*LB7A01*	*Ground Floor*	*65*	*1600 lumen*	*465*

Upgraded Equipment

Code	Description	Measure Code	Type of Intervention	Technical Characteristics	Cost (Euro)
LB7A02-E1	*Chiller*	*LB7A02*	*Fixing HVAC system*	*120,000 BTU/hr*	*13,000*

Annex 10: Monitoring Period Report

A- Detailed calculations and measurements results:

B- Actual Energy Savings of the Monitoring Period:

Monitoring Period		Type of Consumption	Baseline Energy Consumption	Actual Energy Consumption	Actual Energy Savings	Guaranteed Energy Savings(from Annex 7)	Deviations from Guaranteed Energy Savings
Code	Time period		1	2	3=1-2	4	5=3-4
		Electricity (kWh)					
		Natural Gas					
		LPG					
		Thermal Energy					
		Others					
		Total					

C- Actual Financial Benefit of the Monitoring Period:

Monitoring Period	Type of Consumption	Actual Financial Benefit from energy savings (Euro)	Actual Financial Benefit from Operation and Maintenance (Euro)	Total Actual Financial Benefit (Euro)	Guaranteed Financial Benefits (Euro) (from Annex 7)	Deviations from Guaranteed Financial Benefits (Euro)

Code	Time period		1	2	3=2+1	4	5=3-4
		Electricity (kWh)					
		Natural Gas					
		LPG					
		Thermal Energy					
		Others					
		Total					

D- Summary Table for determining the ESCO's compensation:

Monitoring Period		Financial Compensation of the ESCO (Euro)	Total Deviation of the Financial Benefits (Euro)	Actual Financial Compensation (Euro)
Code	Period	1	2	3=2+1 if 2<0 3=1 if 2>0

- Total Deviation of the Financial Benefits: the total deviation resulting from Table C.
- For the determination of the Actual Financial Compensation of the ESCO, the Financial Compensation is reduced by the sum of the negative financial benefit variances identified in Table C.
- Positive financial benefit deviation does not enter the process of determining the Actual Financial Compensation, as the additional financial benefits from over-coverage of the guaranteed belong to the Customer.
- In case the total of the negative financial benefit deviations exceeds the Financial Compensation of the ESCO, the resulting difference is determined as a debt compensation of the ESCO to the Customer.

Annex 11: Implementation Plan

Project execution plan with full analysis by measure, activities and tasks. Please use the same codes as Annex 9.

- Measure
  - Code*: LB7R01*
  - Category: *Renewables*
  - Installation point: *Roof*
  - Detailed description*: Installing PV panels*
  - Start date
  - Completion date
  - List of activities
  - Cost budget
  - Expected energy and economic benefit
  - Implementation monitoring (progress reports, completion report)

- Work
  - Code: *LB7R01-1*
  - Detailed description: *Fixing the panels on the roof.*
  - Technical specifications, standards Execution procedures
  - Licensing, approvals
  - Resources required
  - Start date
  - Completion date
  - Cost budget
  - Implementation monitoring (progress reports, completion report)

Annex 12: Completion Report

This report is made and entered into as of this day of ______________________(Date), at ________________(Place), by and between ___________("ESCO"), having its principal offices at __________________, and ___________ ("Owner") having principal offices at ______________________, for the purpose of installing certain energy, water and operating cost saving equipment, described in **Annex 9 (LIST OF MEASURES AND EQUIPMENT)**, and providing other services designed to save energy for the Owner's property and buildings, known as___________, located at _____________ (the "Project Site(s)").

1. List of completed tasks

Work Code	Work Description	Measure Code	Start Date	Operation Start Date	Cost (Euro)

2. Deviations of the completed tasks

<table>
<tr><th>Work Code</th><th>Work Description</th><th>Deviations</th></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td>Schedule Deviation:</td></tr>
<tr><td>Budget Deviation:</td></tr>
<tr><td>Quantity Deviation:</td></tr>
<tr><td>Quality Deviation:</td></tr>
<tr><td>Justification:</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td>Schedule Deviation:</td></tr>
<tr><td>Budget Deviation:</td></tr>
<tr><td>Quantity Deviation:</td></tr>
<tr><td>Quality Deviation:</td></tr>
<tr><td>Justification:</td></tr>
</table>

Annex 13: Supplementary Work Program

This Supplementary Work Program was drafted and agreed in the framework of the contract for energy services (hereinafter referred to as the Contract) between ____________("ESCO"), having its principal offices at ____________________, and ____________ ("Owner") having principal offices at ________________________, in order to fully comply with the provisions of the Implementation Plan of the Contract.

Work Code	Work Description	Measure Code	Start Date	Operation Start Date	Cost (Euro)

Annex 14: Measurement and Verification Program

1. **Risk-taking, obligations**

Summary of commitment and risk allocation for the main elements of the Measurement and Verification Program (risk sharing matrix).

2. **Schedule of reports**

	Submission Date	Approval Date
Periodic measurement and verification reports		
Other measurement and calculation reports		

3. **Format and content of reports and reports**
   3.1. Periodic measurement and verification reports
   3.2. Other measurement and calculation reports
4. **Summary of methodology**
   4.1. Brief description of the project's Premises and equipment and how to achieve energy and cost savings.
   4.2. Guidelines and options for measurement and verification procedures (A, B, C, D) from those provided by the International Performance Measurement & Verification Protocol (IPMVP).
   4.3. A brief description of the measurement and verification activities for each energy saving measure.
   4.4. A brief description of the methods of calculating the savings for each energy saving measure
5. **Baseline Energy Consumption**
   5.1. Description of all parameters that determine the Baseline Energy Consumption such as weather conditions, operating hours, etc. The way of determining each parameter (measurement, monitoring, calculation, manufacturer data, etc.) is clearly described.
   5.2. Detailed report of the data for the determination of the baseline energy consumption:
   - Monitored parameters
   - Details of the monitored equipment (location, type, model, etc)
   - Sampling and measurement schedule
   - Measurement and monitoring equipment (description, calibration procedures, errors)
   - Data collection format
   - Measurement results
6. **Methodology for calculating energy savings**
   6.1. Detailed description of the data analysis methodology before the energy saving calculations.
   6.2. Sources of data and assumptions.
   6.3. Types and technical details of energy saving calculations.

6.4. Adjustments and corrections to the reference levels of energy consumption

6.5. Energy rates used to calculate cost savings as well as their adjustment process.

7. **Operating and maintenance cost savings**

7.1. Description of how to achieve operating and maintenance cost savings.

7.2. Description of the process of calculating operating and maintenance cost savings.

8. **Measurement and verification procedures**

8.1. Description of the parameters that affect energy consumption. For each parameter, the method of quantification is described (measurement, monitoring, calculations, etc.)

8.2. Detailed report of the collected data

- Monitored parameters
- Details of the monitored equipment ((location, type, model, etc)
- Sampling and measurement schedule
- Measurement and monitoring equipment (description, calibration procedures, errors)
- Data collection format
- Measurement results

8.3. Description of the data analysis process

Annex 8.18: EPC format (GUARANTEED SAVINGS MODEL)

Annex 8.19 EPC FORMAT (SHARED SAVINGS MODEL)

1 Definitions

Actual Energy Consumption during the Monitoring Period: Energy consumption within the Monitoring Period, which results from measurements and calculations, based on the Measurement and Verification Program.

Actual Energy Savings of the Monitoring Period: The reduction of energy consumption resulting from the implementation of activities within the Monitoring Period.

Actual Financial Benefit of the Monitoring Period: The financial benefit resulting from the Actual Energy Savings of the Monitoring Period.

Baseline Energy Consumption: Energy consumption in the Premises during the Reporting Period.

Baseline Energy Cost: the amount in euros identified as the "Baseline Energy Cost" in Annex 3(*BASELINE ENERGY CONSUMPTION*), based on:

(a) the annual energy and water consumption levels ***[CHOICE: (i) [at the Premises] or (ii) [in respect of the Systems]]*** prior to the implementation of the energy savings mechanisms by the ESCO; and

(b) the applicable unit rates

Business Day: means a day (other than a Saturday or a Sunday or a public holiday).

Business Hours: means the hours between 8.00 am and 6.00 pm on a Business Day.

Completion Report: The report prepared by the ESCO upon completion of a task or a group of tasks performed under the Project.

Contract Period: The time period from the entry into force until the termination of the Contract.

Contract: This Energy Savings Performance Contract and all Annexes attached hereto.

Effective Date: The date this Contract is signed, or if counterparts of this Contract are signed, the date the last counterpart is signed.

Energy Prices of the Monitoring Period: Average unit energy values of the Monitoring Period, which are used for the calculation of the energy cost and the financial benefit from energy savings.

Equipment: The goods, materials, and equipment to be installed by the ESCO at the Premises as more particularly described in Annex 9 (*List of Measures and Equipment*), including any additions and modifications made to such goods, materials or equipment during the Term.

ESCO: Energy service companies (ESCOs) develop, design, build, and arrange financing for projects that save energy, reduce energy costs, and decrease operations and maintenance costs at their customers' facilities.

Financial Compensation: The fee provided by the Contract to the ESCO for the services provided within of a Monitoring Period.

Implementation Plan: The project execution plan, with an extensive description of activities, resources, and Annexes of each Measure.

List of Measures and Equipment: Table containing basic information on the Measures, the new equipment as well as the upgraded equipment under the contract.

Measure for improving energy efficiency: The supply and installation of new equipment, the upgrade or replacement of existing equipment, as well as any work or service provided by the ESCO under the Contract in order to reduce energy consumption at the Contract Facility.

Monitoring Period Report: The report prepared by the ESCO at the end of each Monitoring Period and includes measurements and calculations made to determine the Actual Energy Savings, the Actual Financial Benefit, as well as the Actual Financial Compensation for the Monitoring Period.

Monitoring Period: Each time period within the Contract Period, after which the Actual Energy Consumption and the Actual Financial Benefit are calculated.

Operating Period: The main part of the Contract Period, which follows the Preliminary Period.

Percentage of Financial Compensation: The percentage applied to the Actual Financial Benefit for determining the Financial Compensation of a Monitoring Period.

Predicted Baseline Energy Consumption during the Monitoring Period: The energy consumption in the Premises within the Monitoring Period, which is calculated based on the Baseline Energy Consumption methodology described in the Measurement and Verification Program.

Preliminary Period: The phase of supply, installation, upgrade and modernization of equipment under the Contract.

Premises: means the Customer's premises in which the Works are to be performed as more particularly described in Annex 1 (Premises).

Reference Period: The period of time in which energy consumption is deemed representative by the Contracting Parties.

Start Date: The start date of the Operating Period.

Supplementary Work Program: The plan for the execution of the actions required to ensure compliance with the performance guarantees.

Total Actual Energy Savings: The overall reduction in energy consumption resulting from the Project.

Total Actual Financial Benefit: The total financial benefit that results from the Total Actual Energy Saving.

Works: Collectively, the Equipment, professional services, and project construction related to the project.

2 Subject of the Contract

2.1 Under the Contract, the ESCO implements the Project that aims to save energy and improve the degree of energy efficiency in the premises. The financial consideration of the ESCO comes from the energy savings achieved by the implementation of the Project.

2.2 The Project will be implemented in the Premises, which is described in Annex 1.

2.3 The Project will be implemented with its own means and resources by the ESCO, which undertakes its full financing, with its own and/or foreign funds, in accordance with the financing scheme described in Annex 8 (Investment Cost and Financing of the Project).

2.4 The Project consists of all activities and services provided by the ESCO (List of Measures and Equipment) and concerns the selection and supply of new equipment, the installation of new equipment, the upgrade of existing equipment as well as activities and interventions aimed at improving the degree of energy efficiency and energy savings in the Premises.

2.5 Prior to the signing of the Contract, the ESCO has prepared and completed an Energy Savings Report in respect of the [CHOICE: (i) [Premises] or (ii) [Systems]], as included in Annex 4 (Energy Savings Report) and that Energy Savings Report has been approved and accepted by the Customer.

2.6 Any payments to be made by the Customer to the ESCO in respect of the preparation of the Energy Savings Report shall be separately itemized in Annex 8 (Investment Cost and Financing of the Project). If Annex 8 (Investment Cost and Financing of the Project) is silent on the payments to be made in respect of the Energy Savings Report, the cost of such works shall be deemed to have been included within the Contract Price.

2.7 The Works undertaken by the ESCO in respect of the preparation of the Energy Savings Report have been undertaken prior to the Effective Date. The preparation of the Energy Savings Report is a part of the scope of work to be performed by the ESCO under this Contract. The Parties agree that the ESCO shall be bound by the terms and conditions of this Contract with respect to the preparation of the Energy Savings Report.

2.8 The Customer represents and warrants that, to the best of its knowledge and belief, the information provided to the ESCO for the purpose of the Energy Savings Report is complete and accurate and is not misleading in any material respect. If at any time the Customer becomes aware of any material omission or inaccuracy in any such information, the Customer shall promptly notify the ESCO in writing and provide the ESCO with such missing or accurate information that may be in its possession. In such circumstances, the ESCO shall also be entitled to adjust the Baseline Energy Cost to reflect the revised Information provided by the Customer.

3 Duration of the Contract

3.1 The agreement enters into force on the date of its signing by the parties. This date is the date of commencement of the Contract.

3.2 The expiration date of the Contract is defined as ___________________.

3.3 Contract Period is the period from the start date to the end date of the Contract.

4 Preliminary Period and Monitoring Periods

4.1 The Contract Period consists of the Preliminary Period and the Monitoring Periods.

4.2 The Preliminary Period is the phase of supply, installation and upgrade of equipment.

4.3 The Monitoring Period is the basic time unit for monitoring the execution of the Contract, starting from the Start Date. At the end of each Monitoring Period, the ESCO performs the planned measurements and calculations to determine the Actual Energy Savings of the Monitoring Period and the corresponding Actual Financial Benefit of the Monitoring Period (according to the Program of Measurement and Verification).

4.4 The Monitoring Periods are detailed in Annex 2.

5 Reference Period, Baseline Energy Consumption, Energy Prices

5.1 For the calculation of the Actual Energy Savings and the Actual Financial Benefit of the Monitoring Periods, the calendar year preceding the year of the commence of the contract (Reference Period) is used as the base time period.

5.2 The consumption of each system within the Reference Period (Baseline Energy Consumption), is the starting point for determining the Actual Energy Saving of each Monitoring Period. Based on the development scenario described in the Measurement and Verification Program, the Predicted Baseline Energy Consumption is determined for each Monitoring Period, which is the basis for comparison with the Actual Energy Consumption of the Monitoring Period.

5.3 The Baseline Energy Consumption of the Monitoring Periods are listed in Annex 3. The energy consumption and savings are based on the performed energy simulation describing three retrofit scenarios (see Annex 6: Environmental and Energy Simulation for the EE-HBIM Design of Energy Rehabilitation), which was derived after the development of the HBIM model (see Annex 5: EE-HBIM Model Development Report).

5.4 For the cost of energy and the conversion of energy benefit into financial benefit, the parties agree on the use of energy prices for each Monitoring Period (Energy Prices of Monitoring Period), which resulted from the implementation of an energy price evolution scenario.

5.5 For each system, the Energy Price for the Monitoring Period is considered to be its average value.

5.6 The Energy Prices for the Monitoring Periods are listed in Annex 3.

6 List of Measures and Equipment

6.1 The Contracting Parties have drawn up a List of Measures and Equipment, which lists all the measures implemented by the ESCO as well as the equipment that is installed or upgraded under the Contract.

6.2 The List of Measures and Equipment includes a list of Measures, a list of New Equipment and a list of Upgraded Equipment and is detailed in Annex 9.

7 Financial Compensation of the ESCO

7.1 The Financial Compensation of the ESCO for the services provided under the Contract is agreed to be calculated as a percentage of the Actual Financial Benefit for each Monitoring Period.

7.2 The Contracting Parties, taking into account the desired depreciation rate of the ESCO, have agreed on the benefit-sharing model set out in the Annex of Energy Savings and Financial Benefit of Monitoring Periods in Annex 7.

7.3 The Actual Financial Compensation of the ESCO is determined at the end of each Monitoring Period and summarized in Annex 10.

8 Periodic Clearance

8.1 At the end of each Monitoring Period, the ESCO performs measurements and calculations, according to the procedures provided in the Measurement and Verification Program, in order to determine the Actual Energy Consumption of the Monitoring Period and compare it with the Predicted Baseline Energy Consumption for the calculation of the Actual Energy Saving of the Monitoring Period and the resulting Actual Financial Benefit of the Monitoring Period.

8.2 Within _______ calendar days from the end date of the Monitoring Period, the ESCO prepares and submits to the Customer the Monitoring Period Report (Annex 10), which includes

8.2.1 Detailed calculations and measurement results for the determination of energy consumption within the Monitoring Period, according to the Measurement and Verification Program.

8.2.2 Tables for determining the energy and financial benefit of the Monitoring Period (Actual Energy Saving and Actual Financial Benefit).

8.2.3 Financial Clearance Table, which includes the deviations from the Guaranteed Energy Saving and the Guaranteed Financial Benefit of the Monitoring Period, as well as the determination of the Financial Compensation of the ESCO for the Monitoring Period.

8.3 The monitoring of the Monitoring Period Report is based on the Measurement and Verification Program, which describes all the procedures for determining the energy and financial benefit of the Monitoring Period, based on the provisions of article 7 regarding the Financial Compensation of the ESCO.

8.4 After the approval of the Monitoring Period Report by the Customer, it is signed by the contracting parties and, in case of a positive Actual Financial Compensation, an invoice is issued by the ESCO for the Monitoring Period, with this amount, while in case of a negative Actual Financial Compensation, the ESCO pays the difference to the Customer.

8.5 The payment of the invoice for the Monitoring Period is done within _______ days from its receipt.

9 Implementation Plan

9.1 Description

The project execution plan, with a detailed description of activities, resources and schedules is reflected in the Implementation Plan (Annex 11).

9.2 Start of execution of the Project

The ESCO, within a period of _______ from the date of signing the Contract, must start the execution of the Project based on the Implementation Plan.

9.3 Supply and installation of equipment

9.3.1 The Equipment will be installed by the ESCO in the Premises.

9.3.2 The method of financing the Equipment is described in Annex 8 (Investment Cost and Financing of the Project).

9.3.3 All legal permits and approvals required for the installation and operation of the Equipment must be obtained in accordance with the law. The contractors will cooperate to obtain the licenses and approvals and, if legally provided, the Customer will submit and process in his name the relevant applications and other supporting documents.

9.3.4 The cost of obtaining the required permits and approvals shall be borne by the ESCO unless otherwise agreed.

9.3.5 The ESCO is obliged to provide the Customer with copies of all required permits and approvals for the Equipment to be installed before the start of the installation works.

9.3.6 The installed Equipment must meet all the specifications and safety requirements.

9.3.7 The ESCO oversees all work and is responsible for construction methods, techniques and processes. It is also responsible for paying for the cost of materials necessary for the supply and installation of the Equipment.

9.3.8 For the execution of any work that affects the smooth operation of the installation, the ESCO must obtain from the Customer written permission to perform works.

9.3.9 The ESCO must ensure that there is sufficient space at the Customer's premises for the installation and operation of the equipment.

9.3.10 The Customer is obliged to take all necessary measures for the protection of equipment from wear, theft and misuse. The Customer must also allow the ESCO free access to the premises for works related to the Contract during working hours, as well as at any other time period requested by the ESCO and accepted by the Customer. The Customer must also allow the ESCO direct access to the facility for the purpose of performing repair and restoration works, upon a written request stating in detail the type of works to be performed, the reason and the consequences that will have on the operation of the facility.

9.4 Trial operation and start-up

9.4.1 The ESCO performs a complete operation audit in accordance with the procedures and instructions of the manufacturers, before the approval and receipt by the Customer. The purpose of the inspection is to ensure that the equipment operates in accordance with the specifications contained in the Contract and that any modifications or changes to systems or equipment components have been made in such a way as not to disrupt the smooth operation of the installation.

9.4.2 The ESCO must notify the Customer in writing of the schedule inspections and tests it intends to perform, and the Customer has the right to appoint persons who can attend all the inspections/tests performed by the ESCO or the manufacturers of the Equipment.

9.4.3 The ESCO is responsible for repairing all deficiencies and dealing with malfunctions that occur during testing and start-up.

9.5 Legal compliance

The Project must be implemented in accordance with the requirements of the _______ law legislation.

9.6 Quality check

The ESCO is responsible for quality control of the measures throughout their implementation. The ESCO must inspect and control any work performed to meet the requirements under the Contract.

9.7 Timetable

9.7.1 The ESCO must perform the Works for the implementation of the measures according to the schedule included in the implementation plan (Annex 11).

9.7.2 The modification of the implementation plan is not allowed, except in cases of emergency/force majeure. The modification of the time period of implementation of the Measures in these cases is allowed by an additional agreement, which is signed by the contracting parties and annexed to the Contract. In this case, the period of implementation of the Measures is extended not more than that attributed to the emergency/force majeure, which results from an appropriate confirmation document.

9.8 Subcontracting

9.8.1 The Project implementation is done through the ESCO itself.

9.8.2 The ESCO may outsource the implementation of specific tasks that fall within the scope of the Contract to third parties. In this case, the ESCO bears full responsibility to the Customer for the consequences of non-fulfillment or insufficient fulfillment of the obligations of third parties. The scope and type of work assigned to third parties are annexed to the Contract.

9.9 Access to the Premises

9.9.1 The ESCO has inspected the Premises and acknowledges and accepts that there is sufficient space and access to and within the Premises for the installation and operation of the Equipment.

9.9.2 The Customer shall give the ESCO, its employees, Sub-Contractors, agents and representatives a right of access to and non-exclusive possession of the Premises for the performance of the Works during Business Hours or during such hours as may be agreed by the Parties in writing.

9.9.3 The Parties acknowledge that the ESCO may need to access the Premises to undertake emergency repairs or corrections. In such circumstances, the ESCO shall immediately notify the Customer, which notification shall be confirmed in writing no later than three (3) Business Days after the emergency event arose (in circumstances where written notice is not provided in the first instance) and the Customer shall not unreasonably restrict or prevent the ESCO from accessing the Premises to undertake such Works.

9.10 Equipment and Materials used

9.10.1 The ESCO undertakes the obligation to ensure that the execution of the Works and provision of services under the Contract is carried out with the same means and materials.

9.10.2 When performing the Works and providing services, the ESCO must use the materials and equipment provided in the List of Measures and Equipment (Annex 9) and in accordance with the applicable technical regulations.

9.10.3 The ESCO may, after written approval by the Customer, use similar materials and equipment, having similar technical characteristics, to those provided in the List of Measures and Equipment.

9.10.4 The materials and equipment used must be accompanied by a technical file with all the necessary elements (technical characteristics, operating conditions, etc.). The ESCO must provide copies of the above upon request by the Customer.

9.10.5 During the execution of the Works, the ESCO must comply with the technical instructions of the manufacturers/suppliers for the installation of the Equipment as well as the quality control procedures provided by them.

9.11 Approval and Acceptance Procedures

9.11.1 The ESCO must inform the Customer in writing about the completion of each task or group of tasks.

9.11.2 The ESCO, within the deadline _______ calendar days after the completion of the Measure, sends to the Customer the Completion Report (Annex 12).

9.11.3 The Customer checks the Completion Report based on the Implementation Plan.

9.11.4 If deviations from the provisions of the Implementation Plan are found in the Completion Report, the parties draw up and co-sign a Supplementary Work Program, which includes the necessary actions to remove the discrepancies and their implementation schedule. The ESCO must, with its own means and expenses, proceed with the implementation of the Supplementary Work Program within a period of _______ calendar days from the date of its signing, unless a different deadline is provided in it.

9.11.5 If the Works have been implemented in accordance with the Implementation Plan, the Completion Report is signed by the contracting parties.

9.11.6 The signing of the Completion Report by the contracting parties certifies the successful completion of the activities. These tasks include those described in the Implementation Plan.

9.12 Prerequisite Measures

The ESCO may not initiate the implementation of the Measures, for which there are, under the Implementation Plan, prerequisite Measures that have not been completed, as certified by the Completion Report. Otherwise, the ESCO must, at its own expense, carry out all the necessary remedial actions, in accordance with the requirements and instructions of the Customer.

9.13 Instructions - Training

9.13.1 . The ESCO must provide the Customer with instructions for the operation and maintenance of the Equipment, as well as a complete list of its spare parts.

9.13.2 Within a period of _______ calendar days from the completion of the installation of each component of the Equipment, the ESCO must proceed to the training of the personnel that will be indicated by the Customer regarding the operation and maintenance of this equipment.

9.14 Performance Guarantees and Insurance

9.14.1 The ESCO must perform the tasks provided in the Implementation Plan by providing the quality guarantees described for each task in it (guarantees of good execution).

9.14.2 The validity of the performance guarantee is the date of signing by the contracting parties of the Completion Report.

9.14.3 The ESCO must enforce professional liability insurance and any other type of insurance agreed in the Contract.

9.15 Supplementary Work Program

9.15.1 If, during the period of validity of the performance guarantee, deficiencies or defects are found in the work performed or in the installed Equipment, the Contracting Parties draw up and co-sign a Supplementary Work Program (Annex 13).

9.15.2 The Supplementary Work Program, after being signed by parties, is annexed to this Contract and constitutes an integral part of it.

9.15.3 The Supplementary Work Program includes the necessary remedial actions required and their implementation schedule.

9.15.4 The ESCO must, at its own expense and means, implement the Supplementary Work Program. In this case, the period of validity of the performance guarantee is extended accordingly.

10 **Errore. L'origine riferimento non è stata trovata.** Measurement and Verification Program

10.1 The parties have agreed that all procedures for measuring and calculating the energy and financial benefit from the implementation of the Project will be based on the Measurement and Verification Program (Annex 14).

10.2 During the preparation of the Measurement and Verification Program, various factors shall be taken into account, such as the type of energy-saving measures, the projected energy savings and the implied financial benefit, the degree of uncertainty regarding the savings, as well as the intended risk sharing.

10.3 The Measurement and Verification Program is a reference point for the parties during the preparation and control of the Monitoring Period Reports.

10.4 The Measurement and Verification Program defines the procedures and methodology of measurement and verification of each Measure. The measurement procedures and methodology are described in Annex 14 and are in accordance with the International Performance Measurement & Verification Protocol (IPMVP).

11 Substantial Changes

11.1 Substantial change is any change in the Customer's facilities that is expected to result in an increase or decrease in energy consumption by at least _______%.

11.2 The substantial changes include the following:

- Changes in the use of the installation
- Changes in the operating hours of the installation
- Changes in standard operating and comfort levels
- Changes/additions of equipment of the installation
- Renovations in the installation
- Misuse of installation equipment
- Failure to perform maintenance and repairs of equipment
- Change of supplier or method of energy pricing
- Restriction or suspension of operation after a court decision
- Closing the installation
- Any change other than weather conditions that affects the energy consumption of the installation

11.3 The Contracting Parties agree that any substantial change constitutes a reason for the amendment of the Contract, as it makes necessary the revision of the technical parameters and calculations of the Project.

11.4 The Customer must inform the ESCO in writing for any substantial change in its facilities at least _______ days prior to that change.

12 Obligations and Rights of the Contracting Parties

12.1 For the improper execution of the Contract, the contracting parties are responsible according to the current legislation and the terms of the Contract.

12.2 In case of delay by the Customer in fulfilling the payment obligations of the Actual Financial Compensation, the ESCO has the right to request a clause amounting to ____% of the amount due for each day of delay.

12.3 The Customer is exempted from the clause mentioned in paragraph 12.2 if it proves that the inability to fulfill the obligations of payment of the Actual Financial Compensation is due to reasons of force majeure or to the fault of third parties.

12.4 The ESCO is liable to the Customer for any deviations from the requirements of the Contract as well as for any violations of applicable laws and regulations.

12.5 The ESCO is responsible for the quality of the Equipment, materials and Works performed during the warranty period and within the Contract Period.

12.6 In case of delay in the fulfillment of the obligations of the ESCO provided in the Contract, including the delay in the execution of the works and in the correction of identified weaknesses and/or deficiencies, the Customer is entitled to demand compensation.

12.7 The payment of compensation or any other liability does not release the parties from fulfilling their obligations under the Contract.

12.8 The parties are not responsible for the partial or complete failure to fulfill their obligations under the Contract in case of force majeure. In this case, the provisions of article 15 apply.

12.9 The ESCO shall be liable for compensation for damages caused by third parties as a result of works under the Contract unless it proves that they are due to the fault of the third parties.

12.10 If during the execution of works it becomes obvious that it is not performed properly, the Customer has the right to demand from the ESCO the correction of deficiencies and imperfections, setting a reasonable period of time, and, in case of non-fulfillment, the Customer has the right to terminate the Contract and to demand compensation.

13 Ownership Rights

13.1 Title to the Equipment installed at the Premises shall not pass to the Customer until the Customer has paid the ESCO all Shared Savings Payments and all Charges in full, at which time title shall pass to the Customer.

13.2 The ESCO shall maintain ownership of all Equipment and other property brought onto the Premises by the ESCO for the purposes of this Contract and title in the Equipment shall only pass in accordance with clause 13.1.

13.3 Until title passes to the Customer in accordance with clause 13.1, the Customer shall not remove the Equipment from the Premises and shall ensure the Equipment is not damaged and no serial numbers, name plates or other means of identification are removed or obscured. The Customer shall be liable for any such removal or damage to the Equipment during this period and any remedial or repair costs incurred by the ESCO arising from a breach by the Customer of this clause 13.3 shall be charged on a cost reimbursable basis to the Customer. Such payments shall be due within ________ Business Days of the ESCO sending the Customer a written demand for payment.

13.4 Notwithstanding that any Equipment may have been affixed to the Premises, until title in the Equipment passes to the Customer in accordance with clause 13.1, the ESCO shall be entitled to remove any Equipment from the Premises at any time, provided that the ESCO shall only exercise such right where the Customer is in default of its obligations to pay the ESCO in accordance with this Contract and after giving the Customer at least ________Business Days written notice of its failure to make payment and the ESCO's intention to remove the Equipment from the Premises.

13.5 Risk in the Equipment shall pass to the Customer upon its installation at the Premises.

13.6 The ESCO shall assign to the Customer any and all manufacturer warranties relating to the Equipment (including warranties relating to spare parts used and installed when repair is necessitated by malfunction) as soon as is reasonably practicable upon title in the Equipment passing to the Customer in accordance with clause 13.1.

13.7 If any defect or fault occurs in the Equipment during the Contract period, the ESCO shall make all necessary manufacturer warranty claims in relation to the Equipment in order to rectify or replace the defective Equipment.

14 Equipment Maintenance and Operation

14.1 The ESCO is responsible for the maintenance, repairs and adjustments of the Equipment, in accordance with the terms and procedures of the manufacturers.

14.2 The costs for the maintenance, repairs and adjustments of the Equipment are borne exclusively by the ESCO.

14.3 In the event that the need for maintenance or repair of the Equipment arises from the mismanagement of the Customer, the relevant costs are borne by the Customer to the extent that there is no warranty or insurance coverage.

14.4 The Customer must immediately inform the ESCO or its authorized subcontractors about:

- any malfunction of the Equipment that may affect the energy savings.
- any interruption or modification of the power supply at the Customer's Premises.
- any modification, replacement or change of equipment mode that affects the execution of the project.

14.5 The Customer must also immediately inform the ESCO of any emergency that comes to his knowledge and that affects the equipment. In this case, the ESCO must respond immediately and take care of all necessary corrective actions. Any verbal notification of the ESCO from the Customer must be accompanied by a corresponding written notice. In case of unjustified delay on the part of the Customer to notify the ESCO of a malfunction or emergency, the ESCO is entitled to claim compensation from the Customer for the damage incurred in connection with the energy savings.

14.6 The Customer may not remove, modify, replace, move or change the mode of operation of the Equipment without the prior written consent of the ESCO.

14.7 The Customer must keep the installation site of the Equipment in good condition and assures that there are no conditions that adversely affect its operation.

15 Force Majeure

15.1 Incidents of Force Majeure shall mean in particular floods, lightning, earthquakes, fires, explosions, wars, national emergencies, and any unforeseen similar occurrences if they are outside the scope of any degree of fault on the part of the parties.

15.2 If either Party is prevented or delayed in the performance of any of its obligations under this Contract (save for any obligation to make payment) by a Force Majeure Event, then:

15.2.1 the affected Party's obligations under this Contract shall be suspended for so long as the Force Majeure Event continues and to the extent that the affected Party is so prevented, hindered or delayed;

15.2.2 within __________Business Days after commencement of the Force Majeure Event the affected Party shall notify the other Party in writing of the occurrence of the Force Majeure Event, the date of commencement of the Force Majeure Event and the effect of the Force Majeure Event on its ability to perform its obligations under this Contract;

15.2.3 the affected Party shall use all reasonable efforts to mitigate the effects of the Force Majeure Event upon the performance of its obligations under this Contract; and

15.2.4 immediately after the cessation of the Force Majeure Event the affected Party shall notify the other Party in writing of the cessation of the Force Majeure Event and shall resume performance of its obligations under this Contract.

15.3 If either Party is prevented from the performance of all or substantially all of its obligations for a period exceeding ____________ consecutive Days, the other Party may terminate this Contract by giving not less than ___________ Business Days' notice in writing to the other Party, in which case neither Party shall have any liability to the other except that rights and liabilities which accrued prior to such termination shall continue to subsist.

16 Settlement of Disputes

16.1 If a dispute or difference arises under or in connection with this Contract (including a dispute relating to the existence, validity or termination of this Contract or any obligation arising out of or in connection with this Contract), then either Party shall provide the other Party with a written notice of dispute ("Notice of Dispute").

16.2 Upon receiving a Notice of Dispute in accordance with clause 16.1, such dispute shall be referred in writing to the senior members of each of the Customer and the ESCO who shall endeavor to resolve the dispute amicably, in good faith, within twenty (20) Business Days of such referral.

16.3 If the Parties are unable to resolve the dispute within the twenty (20) Business Day period referred to in clause 16.2, the Parties hereby agree that the dispute shall be subject to the exclusive jurisdiction of the courts of _________.

16.4 Pending final resolution of any court proceedings under this Contract, the ESCO shall continue performing its duties and obligations under this Contract without delay and the Customer shall continue to pay all undisputed sums in accordance with the terms of this Contract.

17 Notices

17.1 Any notice or other communication pursuant to or in connection with this Contract shall be in writing in the English language and may be delivered personally or sent by:

17.1.1 post (air mail if overseas); or

17.1.2 by email,

to the address for that Party set out in clause 17.2.

17.2 Each Parties' address for service is as follows:

17.2.1 Customer:

Address: [insert address]

Attention: [insert]

Email: [insert email address]

17.2.2 ESCO

Address: [*insert address*]

Attention: [*insert*]

Email: [*insert email address*]

17.3 Any notice or other communication shall be deemed to have been served:

17.3.1 At the address or email referred to in clause 17.2 within Five (5) Business Days;

18 Amendments

18.1 The Contract is amended only by written and explicit agreement between the parties.

19 Termination of the Contract

19.1 Termination of the Contract can be done either by agreement of the parties or by a court decision.

19.2 In case of termination of the Contract by agreement of the parties, it must be done in written form, with a special termination agreement.

19.3 The termination of the Contract by a court decision is based on civil law and the terms of the Contract.

19.4 Reasons for termination of the Contract by a court decision constitute in particular

- Breach of essential terms of the Contract
- Delays in the execution of the Project in relation to the schedule by the ESCO, without any fault on the part of the Customer
- Inability to secure the necessary permits and approvals for the execution of the Project

- Failure of the ESCO to comply Services to the specifications and quality requirements of the Project
- Bankruptcy of one of the Contracting Parties

20 Final Provisions

20.1 The Contract as well as the rights and obligations of the contracting parties are governed by and construed in accordance with ________law.

20.2 The Contract consists of _______ pages. It is signed by the parties in _______ copies.

Annex 1: Premises

- Project Details

Name		
Location		
Coordinates		
Image		
Function		
Number Of Floors		
Number Of Building Units		
Net Heated Surface		
Net Heated Volume		
V: Gross Heated Volume		
A: Builiding Envelope Surfaces (Adjacent To The Ground, To Heated Or/And Non-Heated Spaces, To The External Air)		
C=A/V Compactness Ratio (The Area Of A Building's External Envelope To Its Hosted Inner Volume)		
Year Of Construction		
Previous Interventions	Year	
	Description	

Previous Interventions	Year	
	Description	

- General Description of the Current State of the Facility

[This section should offer a short description of the facility (residential building, commercial building, industry, house, etc.) including location, architecture, number of floors, and other useful information]

[This Section contains basic information about the condition of the premises at the time of contract execution. Such information would include facility area, construction type, use, occupancy, hours of operation, and any special conditions that may exist]

[Include photos and drawings if needed]

Annex 2: Preliminary Period and Monitoring Periods (MP)

- Preliminary Period

Phase Description	Start Date	End Date

- Monitoring Periods

CODE	Start Date	End Date
MP1		
MP2		
MP3		
MP4		
MP5		
MP6		

Annex 3: Baseline Energy Consumption

[Parties to describe the Baseline Energy Consumption, Baseline Unit Rates and Baseline Energy Cost.]

Monitoring Period		*Type of Consumption*	*Baseline energy consumption*	*Energy Unit Rate (Euro/energy unit)*	*Baseline Energy Cost (Euro)*
Code	*Time period*				
MP1		*Electricity (kWh)*			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP2		*Electricity (kWh)*			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP3		*Electricity (kWh)*			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
MP4		*Electricity (kWh)*			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			

Annex 4: Energy Savings Report

[This annex should include a detailed feasibility study of the different components of the project]

[The technical feasibility should check every condition for the realization, the installation and maintenance of the system, so the technical feasibility study considers the technical features of the proposed system]

- Energy Consumption:

[As the first step in the technical analysis is to perform the full load inventory with the real time measurements, this section of the proposal is dedicated to analyze the present situation and to introduce the main energy use of the facility]

Month	**Electrical Energy (kWh)**	**Thermal Energy (kWh)**	**Total (kWh)**	**Total Cost (euro)**
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				
Total				

- Description of Measures:

This section describes the measures to be installed in the premises. Please insert all calculation done to deduce the energy savings for each measure. Add additional sub-sections for additional measures as needed

  - Measure 1:

<u>Measure Code:</u>

Measure Description:

[General description of the measure, highlighting the building parts involved. Please add also the intervention subcategories related to the proposed measure]

Description of the current state of the involved parts

[Describe the current state of the parts involved by the measure.]

Feasibility check

[Briefly describe the technological and mechanical compatibility with the other systems and components of the building].

Environmental sustainability of the intervention

[Briefly describe whether the intervention is characterised by specific environmental sustainability principles.]

Other design criteria

[add any other useful information for planning the measure]

Technical characteristics

[briefly describe the technical characteristics of the measure and compare it with the existing technologies through table, images and schemes, section plan etc.

Technical characteristics [current state]

…….

…….

Technical characteristics proposed [measure]

- *…….*
- *…….*

.

Estimated cost of the measure

…

Implementation time

- …….
- …….

Energy Savings

- …….
- …….

- Summary:

Measure Code	Savings (kWh/year)	Savings (euro/year)	Simple payback	Annual Costs (euro)	Payback Period(years)	Return of Investment	Annualized RoI
e.g. LB7P01							
…..							
…..							
Total							

Annex 5: EE-HBIM Model Development Report

1. General Information

Name of Building: name

Location: location

Floor area: m^2

Volume: m^3

Original use – present or future use: use

Year: year

Picture: a picture of the building

2. Introduction

Brief introduction of the BIM model development activities connected to BEEP project.

3. Pre Planning Activities

Description of any pre-planning activities concerning the BIM model development: software or hardware purchase, organization and management phase, etc.

Reference to the geometric survey activity and its integration strategy within the model (if relevant).

3.1. BIM Tender development (if any)

Brief description of any tender activities performed (for the subcontracting of the whole service as external service, for the hiring of a consultant, etc.), the first contacts with the contractors (if any), the work organization, etc.

3.2. BIM Execution Plan development

Brief description of the BIM Execution Plan, provided by the Consultant in case of tender activities and/or developed internally.

4. EE-HBIM Model Development Workflow

4.1. Modelling workflow general strategy

Brief introduction of the general modelling strategy adopted.

4.2. Template selection

Description of the template selection or implementation for the different disciplinary models.

4.3. Modelling environment definition

Description of the modelling environment development: grids structure - levels - sharing coordinates system, etc.

4.4. Integration of geometrical survey documentation

Description of the strategy to integrate geometrical survey documentation in the model, in the form of point clouds import, CAD drawings import referred to model levels, etc. This integration should be connected to modelling strategy (for example, scan to BIM in the case of point clouds).

5. EE-HBIM Modelling Current Status

Brief description, with images, of the current status of the model: what has been already modelled, how, problems encountered, modifications, adjustments, etc.

5.1. EE-HBIM Modelling of architectural elements

Brief description of the modelling implementation of architectural elements, as they were encountered within the modelling process up to the current state (second semester, first semester of reporting on the model): compromises between geometrical accuracy and parametric object definition, scan to BIM strategies (if a point cloud laser scanner survey of the building is available), use of constraints, etc.

5.2. Modelling spaces

Modelling definition of the architectural spaces up to the current state of the model (second semester, first semester of reporting on the model).

5.3. Modelling strategy of MEP objects

Brief description of the modelling implementation of MEP elements (with reference to BEP): which elements have been modelled (generally, terminals and boilers), up to the current state of the model (second semester, first semester of reporting on the model).

5.4. Non geometrical information implementation

Brief description of the implementation of non-geometrical information: parameters definition (with reference to the Model Element Table), linked information from reports, drawings, etc. up to the current state of the model (second semester, first semester of reporting on the model).

Annex 6: Environmental and Energy Simulation for the EE-HBIM Design of Energy Rehabilitation

1. General introduction of the software and the calculation method

[briefly describe the chosen software and its main features like calculation method and regulatory compliance]

2. Model input data (ante-operam)

    2.1. Introduction

[brief description of the input data used by the software]

    2.2. Weather data

[brief description of the weather data, the data present, data format, source of data, choice of data and related reasoning]

    2.3. Thermal zones and user schedule

[brief description of the thermal zone definition of the building and of the occupancy schedules used. Highlight the reasoning behind the thermal zones definition and the source of occupancy schedules]

    2.4. Shell and Interiors parameters

[brief description of the parameters of the envelope (exterior vertical and horizontal enclosures - opaque and transparent), interiors (if relevant), please refer to the model element table. Highlight thermal bridges (if any) and how they are calculated (if they are)]

    2.5. Building Geometry

[brief description of how the abstract geometry of the energy model was reached from the real geometry of the building. Also include specific reflections relating to the thermal representation of the historic building (simplification of complex elements, methods of working with the masses, etc.)]

2.6. Building Systems

[brief description of the modelled systems (heating, cooling, lighting, ventilation, RES, storage etc..) and their modelling strategy]

3. Ante-operam Energy Model calibration

[description of the energy calibration strategy and of all the calculation, trial and errors, performed]

4. Ante operam Energy simulation results

[description of the results of the ante-operam model including free running simulation results to help comprehend and evaluate the passive behaviour of the building including:

- *comfort (just to check country regulatory compliance);*
- *global primary energy demand Ep,gl;*
- *energy performance consumption for each sources involved in the scenarios or for energy use;*
- *energy production from renewable energy sources (RES);*
- *Free running analysis of temperature and relative humidity in specific thermal zones (useful for the design of the intervention scenarios)]*

5. Energy modelling and simulation results of the scenarios (post-operam)

[description of the input data for each energy improvement scenarios and of the yearly energy simulation results (and monthly - if useful) in terms of:

- *comfort (just to check country regulatory compliance);*
- *global primary energy demand Ep,gl;*
- *energy performance consumption for each sources involved in the scenarios or for energy use (keep in mind to obtain data to ease the calculation of the related energy bills);*
- *energy production from renewable energy sources (RES).*

5.1. Short term scenario modelling and results

5.2. Middle term scenario modelling and results

5.3. Long term scenario modelling and results

Annex 7: Energy Savings and Financial Benefits of Monitoring Periods

Monitoring Period		Type of Consumption	Energy Savings	Energy Price (Euro/energy unit)	Percentage of Finance Exchange (%)	Financial Benefits (Euro)
Code	Time period					
MP1		Electricity (kWh)				
		Natural Gas				
		LPG				
		Thermal Energy				
		Others				
MP2		Electricity (kWh)				
		Natural Gas				
		LPG				
		Thermal Energy				
		Others				
MP3		Electricity (kWh)				
		Natural Gas				
		LPG				
		Thermal Energy				
		Others				
MP4		Electricity (kWh)				
		Natural Gas				
		LPG				
		Thermal Energy				
		Others				

Annex 8: Investment Cost and Financing of the Project

To be filled by the ESCO. It should mention the costs of the equipment and installations to be installed in the premises.

If the project is financed through a loan, the details of the loan must be added.

Annex 9: List of Measures and Equipment

Measures

Measure Code	Description	Implementation Start Date	Operation Start Date	Cost (Euro)
LB7A01	Replacement of CFL lighting wilt LEDs	February	March	600

New Equipment

Code	Description	Measure Code	Installation place	Quantity	Technical Characteristics	Cost (Euro)

Upgraded Equipment

Code	Description	Measure Code	Type of Intervention	Technical Characteristics	Cost (Euro)

Annex 10: Monitoring Period Report

A- Detailed calculations and measurements results:

B- Actual Energy Savings of the Monitoring Period:

Monitoring Period		Type of Consumption	Baseline Energy Consumption	Actual Energy Consumption	Actual Energy Savings
Code	Time period		1	2	3=1-2
		Electricity (kWh)			
		Natural Gas			
		LPG			
		Thermal Energy			
		Others			
		Total			

C- Actual Financial Benefit of the Monitoring Period:

Monitoring Period		Type of Consumption	Actual Financial Benefit from energy savings (Euro)	Actual Financial Benefit from Operation and Maintenance (Euro)	Overall Actual Financial Benefit (Euro)
Code	Time period		1	2	3=2+1
		Electricity (kWh)			
		Natural Gas			

		LPG			
		Thermal Energy			
		Others			
		Total			

D- Summary Table for determining the ESCO's compensation:

Monitoring Period		Percentage of Finance Exchange (Euro)	Total Actual Financial Benefit (Euro)	Financial Compensation of the ESCO (Euro)
Code	Period	1	2	3=1x2

The Financial Compensation is determined by applying the Percentage of Finance Exchange (%) on the Total Actual Financial Benefit of the Monitoring Period (shared savings model).

Annex 11: Implementation Plan

Project execution plan with full analysis by measure, activities and tasks. Please use the same codes as Annex 9.

- Measure
  - Code: *LB7R01*
  - Category: *Renewables*
  - Installation point: *Roof*
  - Detailed description*: Installing PV panels*
  - Start date
  - Completion date
  - List of activities
  - Cost budget
  - Expected energy and economic benefit
  - Implementation monitoring (progress reports, completion report)

- Work
  - Code: *LB7R01-1*
  - Detailed description: *Fixing the panels on the roof.*
  - Technical specifications, standards Execution procedures
  - Licensing, approvals
  - Resources required
  - Start date
  - Completion date
  - Cost budget
  - Implementation monitoring (progress reports, completion report)

Annex 12: Completion Report

This report is made and entered into as of this day of _______________________(Date), at _________________(Place), by and between ____________("ESCO"), having its principal offices at ____________________, and ____________ ("Owner") having principal offices at ________________________, for the purpose of installing certain energy, water and operating cost saving equipment, described in **Annex 9 (List Of Measures And Equipment)**, and providing other services designed to save energy for the Owner's property and buildings, known as____________, located at ______________ (the "Project Site(s)").

1. List of completed tasks

Work Code	Work Description	Measure Code	Start Date	Operation Start Date	Cost (Euro)

2. Deviations of the completed tasks

<table>
<tr><th>Work Code</th><th>Work Description</th><th>Deviations</th></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td>Schedule Deviation:</td></tr>
<tr><td>Budget Deviation:</td></tr>
<tr><td>Quantity Deviation:</td></tr>
<tr><td>Quality Deviation:</td></tr>
<tr><td>Justification:</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td>Schedule Deviation:</td></tr>
<tr><td>Budget Deviation:</td></tr>
<tr><td>Quantity Deviation:</td></tr>
<tr><td>Quality Deviation:</td></tr>
<tr><td>Justification:</td></tr>
</table>

Annex 13: Supplementary Work Program

This Supplementary Work Program was drafted and agreed in the framework of the contract for energy services (hereinafter referred to as the Contract) between ____________("ESCO"), having its principal offices at ___________________, and ____________ ("Owner") having principal offices at _______________________, in order to fully comply with the provisions of the Implementation Plan of the Contract.

Work Code	Work Description	Measure Code	Start Date	Operation Start Date	Cost (Euro)

Annex 14: Measurement and Verification Program

1. **Risk-taking, obligations**

Summary of commitment and risk allocation for the main elements of the Measurement and Verification Program (risk sharing matrix).

2. **Schedule of reports**

	Submission Date	Approval Date
Periodic measurement and verification reports		
Other measurement and calculation reports		

3. **Format and content of reports and reports**
   - 3.1. Periodic measurement and verification reports
   - 3.2. Other measurement and calculation reports
4. **Summary of methodology**
   - 4.1. Brief description of the project's Premises and equipment and how to achieve energy and cost savings.
   - 4.2. Guidelines and options for measurement and verification procedures (A, B, C, D) from those provided by the International Performance Measurement & Verification Protocol (IPMVP).
   - 4.3. A brief description of the measurement and verification activities for each energy saving measure.
   - 4.4. A brief description of the methods of calculating the savings for each energy saving measure
5. **Baseline Energy Consumption**
   - 5.1. Description of all parameters that determine the Baseline Energy Consumption such as weather conditions, operating hours, etc. The way of determining each parameter (measurement, monitoring, calculation, manufacturer data, etc.) is clearly described.
   - 5.2. Detailed report of the data for the determination of the baseline energy consumption:
     - Monitored parameters
     - Details of the monitored equipment (location, type, model, etc)
     - Sampling and measurement schedule
     - Measurement and monitoring equipment (description, calibration procedures, errors)
     - Data collection format
     - Measurement results
6. **Methodology for calculating energy savings**
   - 6.1. Detailed description of the data analysis methodology before the energy saving calculations.
   - 6.2. Sources of data and assumptions.
   - 6.3. Types and technical details of energy saving calculations.
   - 6.4. Adjustments and corrections to the reference levels of energy consumption
   - 6.5. Energy rates used to calculate cost savings as well as their adjustment process.
7. **Operating and maintenance cost savings**

7.1. Description of how to achieve operating and maintenance cost savings.

7.2. Description of the process of calculating operating and maintenance cost savings.

8. **Measurement and verification procedures**

8.1. Description of the parameters that affect energy consumption. For each parameter, the method of quantification is described (measurement, monitoring, calculations, etc.)

8.2. Detailed report of the collected data

- Monitored parameters
- Details of the monitored equipment ((location, type, model, etc)
- Sampling and measurement schedule
- Measurement and monitoring equipment (description, calibration procedures, errors)
- Data collection format
- Measurement results

8.3. Description of the data analysis process

Annex 8.19 EPC format (SHARED SAVINGS MODEL)