GUIDELINES FOR ENERGY EFFICIENCY HBIM DEVELOPMENT OF EXISTING BUILDINGS

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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 Data acquisition

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^{2}K];
  - 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 BIM Execution Plan (BEP)

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 Outsourcing of the EE-HBIM model - tender process

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

In case the historic building(s) is in use and employ HVAC systems, 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.

In case the historic building(s) is not in use 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 Output

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

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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

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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

[to be filled in after the final reporting phase]

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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 indicators of the proposed energy retrofit scenarios

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,

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[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).

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[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

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[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

<table>
<tr><td>Radiators (T01)</td><td></td><td>Centralised (D02)</td><td>U01</td></tr>
<tr><td>Radiators (T02)</td><td></td><td>Zone thermostat (D03)</td><td>U01</td></tr>
<tr><td>Split (T03)</td><td></td><td>Single space (D04)</td><td>User defined</td></tr>
<tr><td>Fan coil (T04)</td><td></td><td>Single space (D05)</td><td>User defined</td></tr>
<tr><td colspan="4">TRANSPARENT ENVELOPE</td></tr>
<tr><td>TRANSPARENT ENVELOPE TYPE CODE</td><td colspan="3">DIMENSIONS (width - length) cm</td></tr>
<tr><td>W01</td><td colspan="3">cm x cm</td></tr>
<tr><td>W02</td><td colspan="3">cm x cm</td></tr>
<tr><td>W03</td><td colspan="3">cm x cm</td></tr>
<tr><td colspan="4">LUMINAIRES (replicate for each luminaire type if there are more than one)</td></tr>
<tr><td>LUMINAIRE TYPE CODE</td><td colspan="3">NUMBER OF ITEM</td></tr>
<tr><td>L01</td><td colspan="3">4</td></tr>
<tr><td>L02</td><td colspan="3">2</td></tr>
<tr><td>VISUAL COMFORT</td><td colspan="3">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</td></tr>
<tr><td>ROOM LUMINAIRE STATE OF MAINTENANCE</td><td colspan="3">Please briefly describe the state of maintenance of lightings: if they are dirty, if there are any lamps or appliances to be substituted, etc.</td></tr>
<tr><td>CONTROL SYSTEM (CODE)</td><td colspan="3">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.</td></tr>
<tr><td colspan="4">OTHER EQUIPMENT</td></tr>
<tr><td>TYPE</td><td>n°</td><td>Energy efficiency</td><td>Reference</td></tr>
</table>

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 °C	T out °C
SECONDARY CIRCUITS	Water	T in °C	T out °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.

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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).

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[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.

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[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.

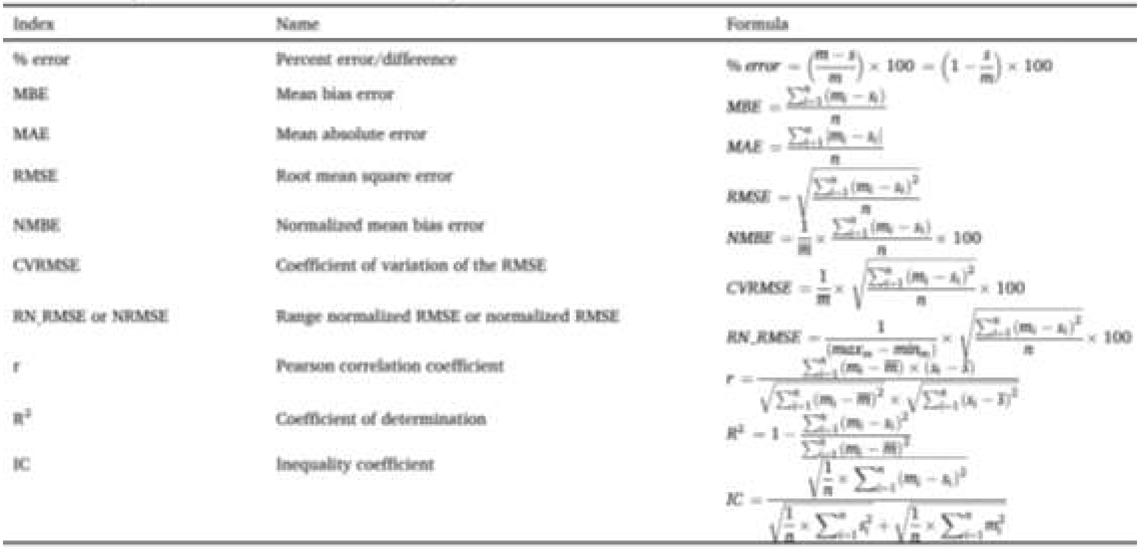
4 MODEL CALIBRATION APPROACHES

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	$NMBE = \frac{1}{\overline{m}} \times \frac{\sum_{i=1}^{n}(m_i - s_i)}{n} \times 100$
CVRMSE	Coefficient of variation of the RMSE	$CVRMSE = \frac{1}{\overline{m}} \times \sqrt{\frac{\sum_{i=1}^{n}(m_i - s_i)^2}{n}} \times 100$
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	$r = \frac{\sum_{i=1}^{n}(m_i - \overline{m}) \times (s_i - \overline{s})}{\sqrt{\sum_{i=1}^{n}(m_i - \overline{m})^2} \times \sqrt{\sum_{i=1}^{n}(s_i - \overline{s})^2}}$
R^2	Coefficient of determination	$R^2 = 1 - \frac{\sum_{i=1}^{n}(m_i - s_i)^2}{\sum_{i=1}^{n}(m_i - \overline{m})^2}$
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.

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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.

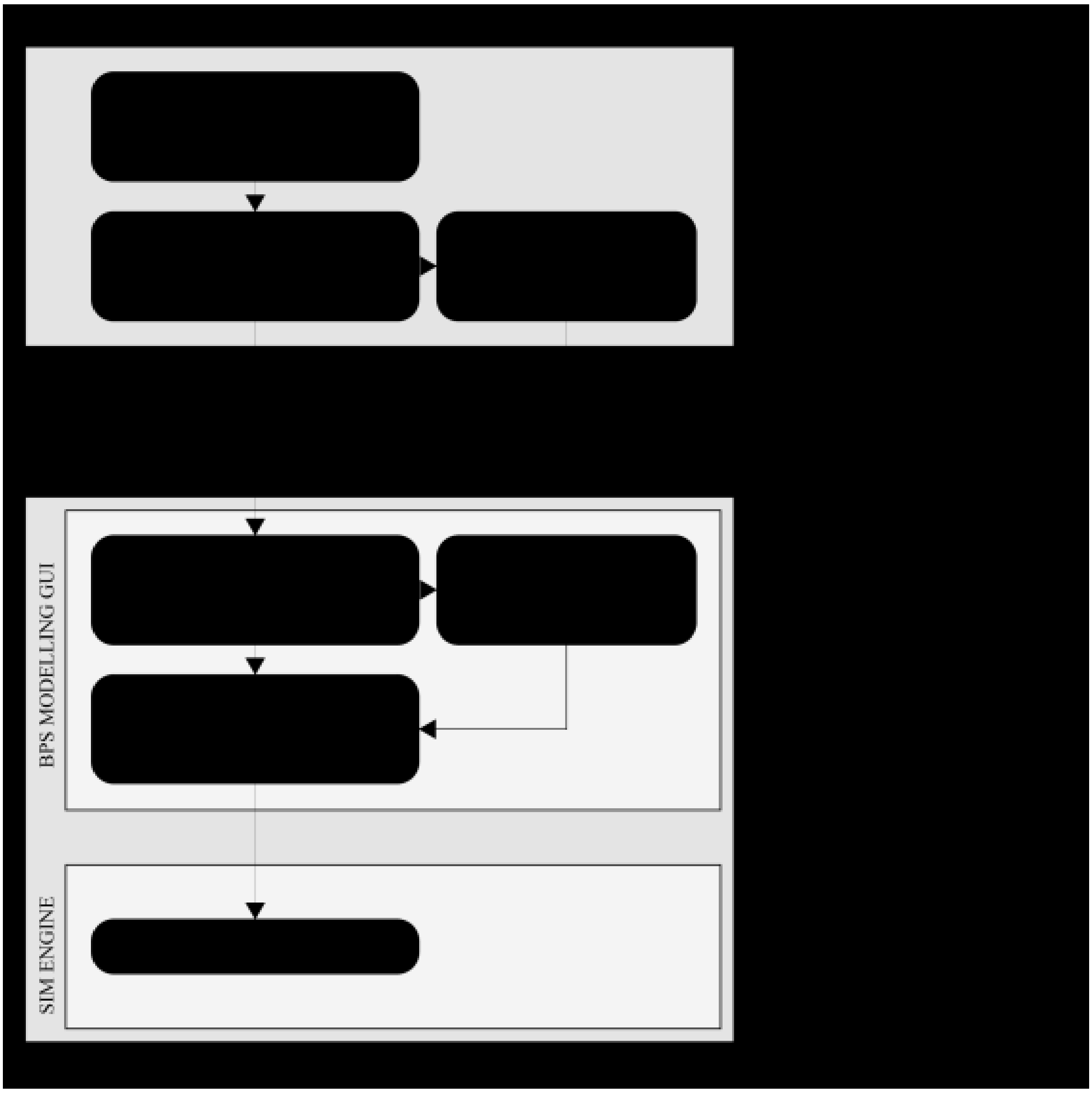

Figure 1: Schematic representation of BIM to BPS Interoperability problem

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.

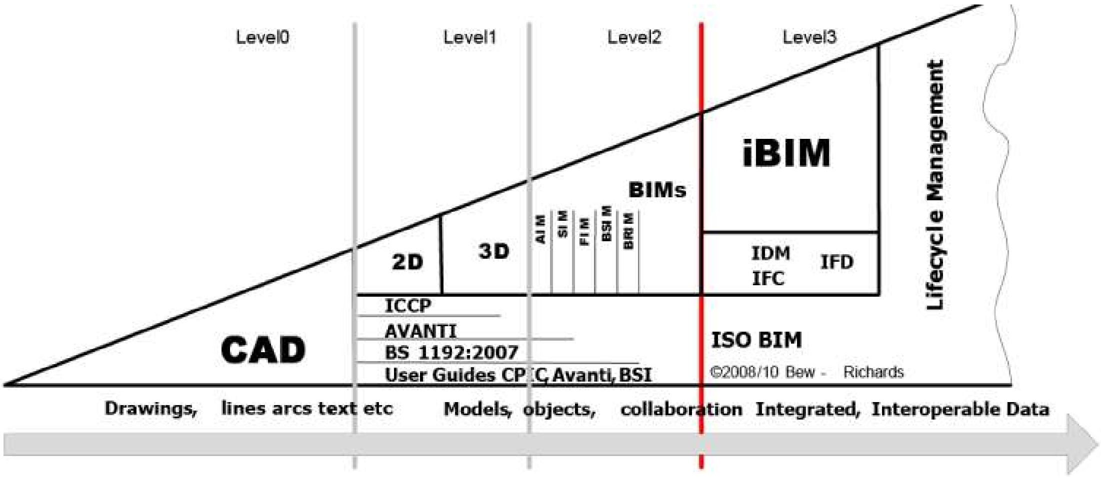

Figure 2: Maturity scheme – BIM Industry Working Group (BIM Industry working group (BIWG) 2011).

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*.

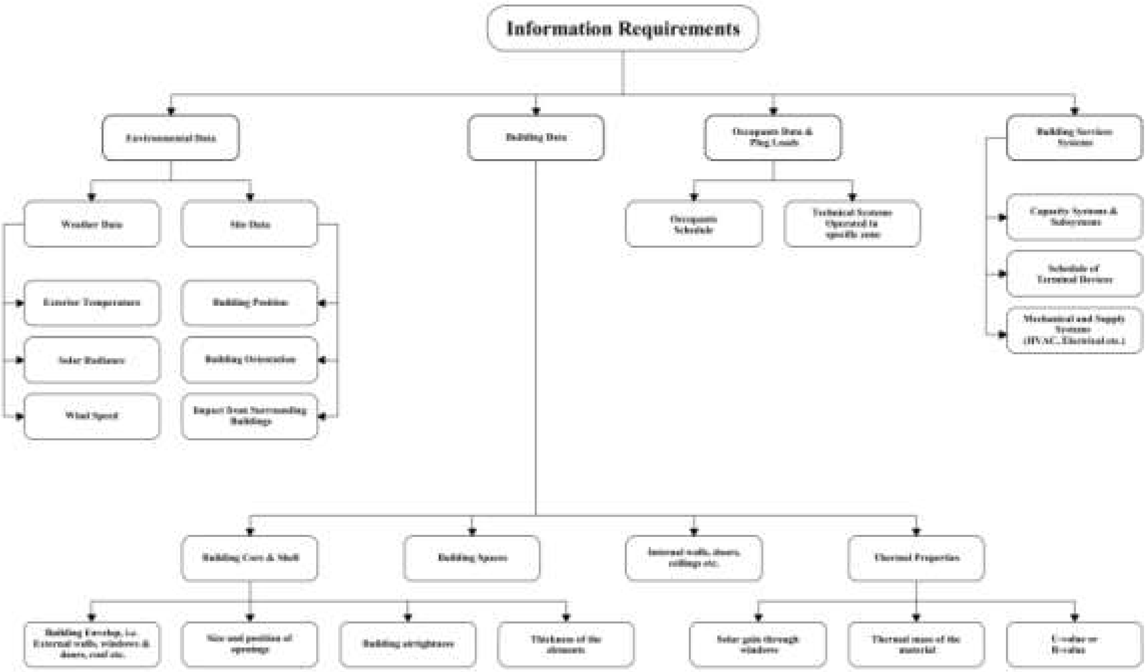

Figure 3: BPS Information Requirements (Karlapudi 2018).

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.

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

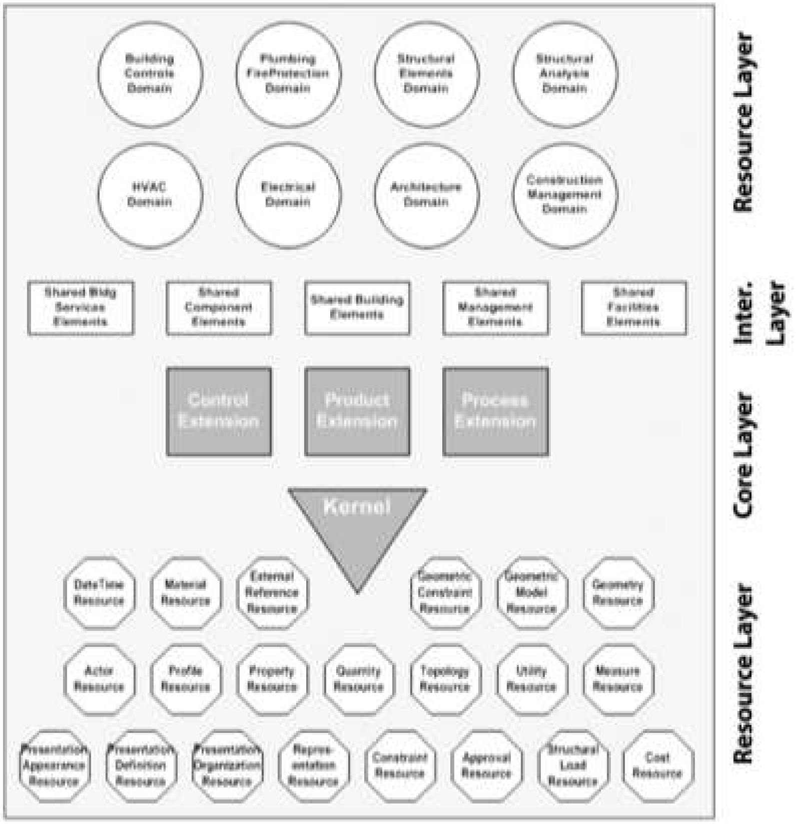

Figure 4: IFC Data schema with four conceptual layers (buidingSMART 2020).

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

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[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).

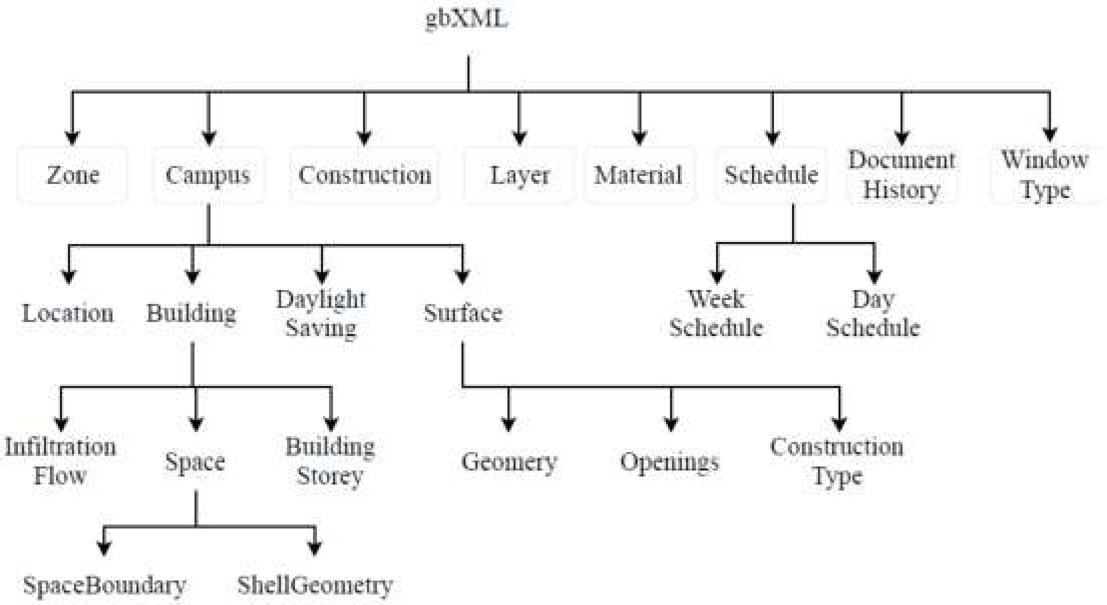

Figure 5: Simplified hierarchy of information organisation in gbXML schema (Ham and Golparvar-Fard 2015).

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.

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[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).

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

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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].

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[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).

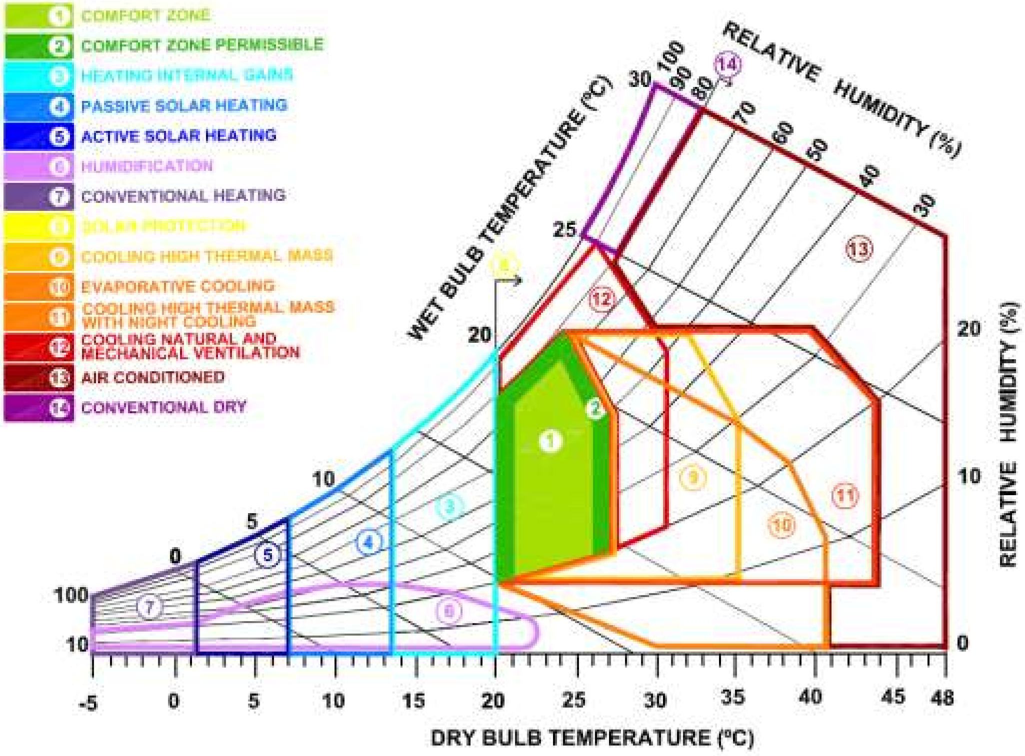

Figure 1: The Givoni chart as presented in Manzano-Agugliaro et al. (2015).

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.

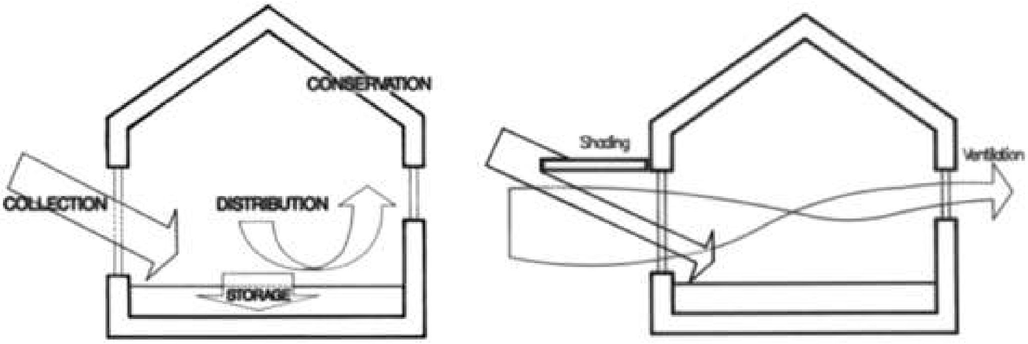

Figure 2: Passive solar energy collector (left) and overheating avoidance (right) in temperate climates. Source: Norton, 2014.

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).

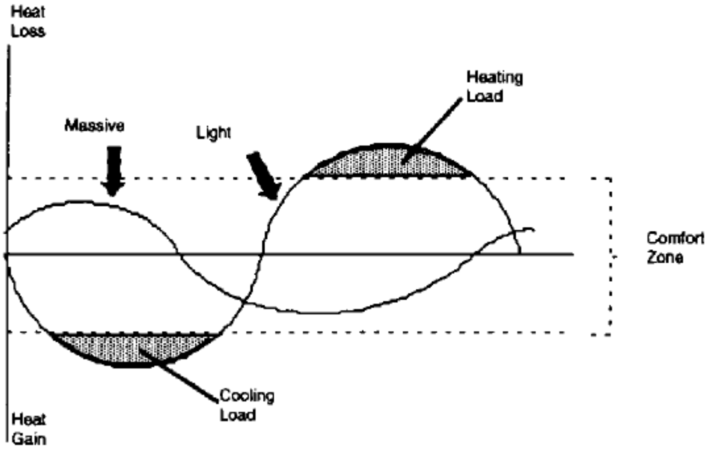

Figure 3: Daily Building heating and cooling loads for buildings of massive and light construction. Source: Asimakopoulos, 1996.

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).

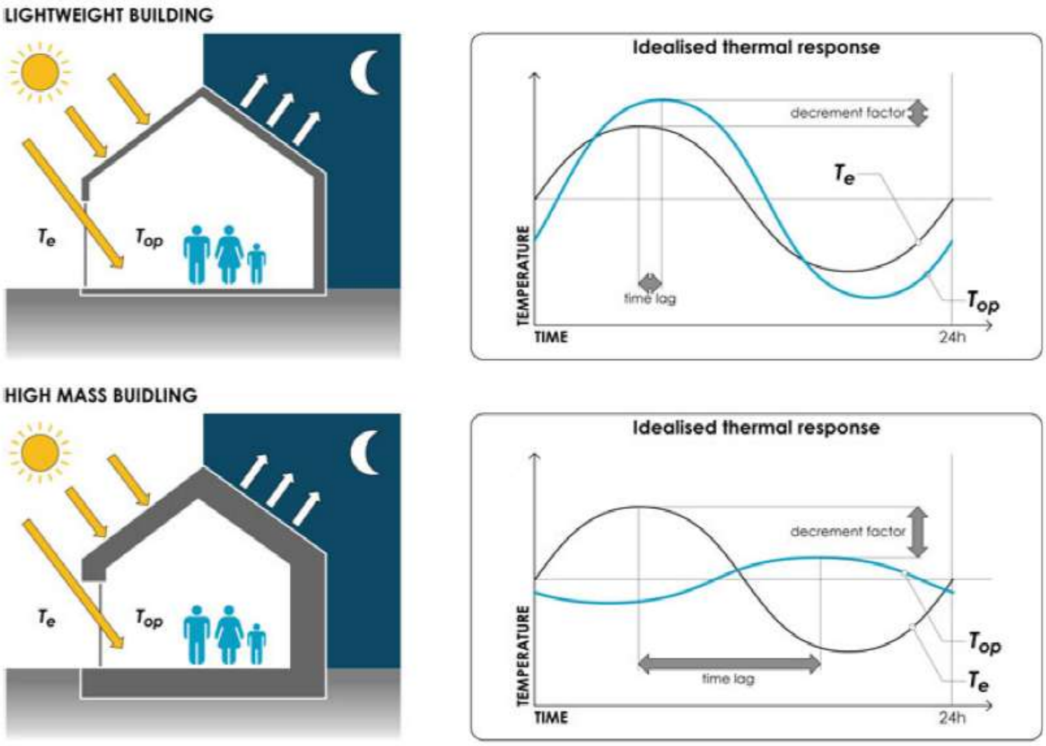

Figure 4: Idealised thermal diurnal performance of extremely lightweight (top) and high mass (bottom) building. Te and Top correspond to outdoor and indoor temperature respectively. Source: Košir 2019.

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

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[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

Humidity control and pathology

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. precast 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.

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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).

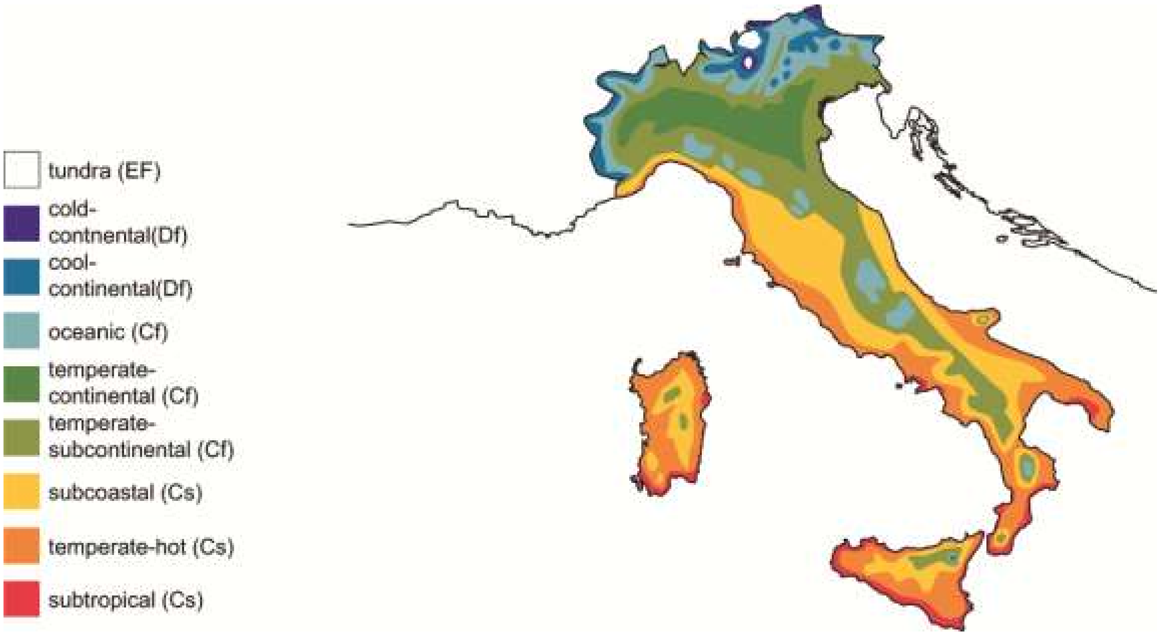

Figure 5: Italian climate zones according to Pinna classification.

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%

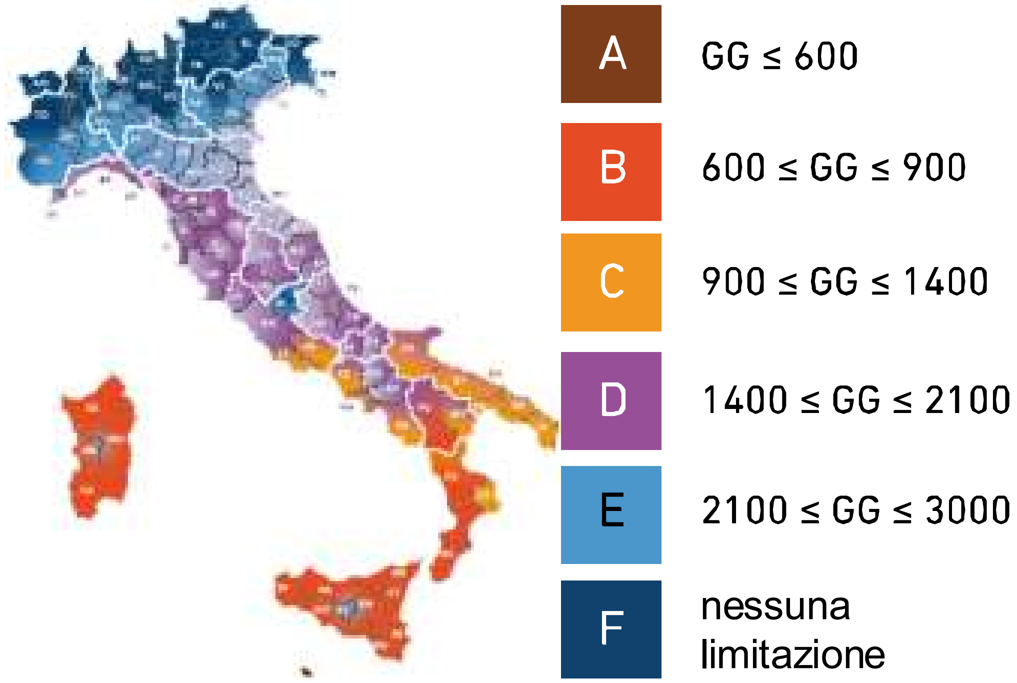

Figure: Graphic display of the subdivision of Italian municipalities into climatic zones of Annex A of Presidential Decree 412 of 1993, updated and supplemented by Presidential Decree n ° 74/2013 (Corrado, Ballarini, and Corgnati 2012).

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,

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[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.

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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.

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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.

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[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.

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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:

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[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:

AVERAGE DAYTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	18	22	33	40	33	34	35	38	31	26	24	18
AVG	1	7	9	14	16	22	24	24	18	14	10	1
MIN	-12	-15	-5	-6	[illegible]	[illegible]	9	[illegible]	[illegible]	[illegible]	-7	-8

AVERAGE NIGHTTIME TEMPERATURES (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX	13	15	[illegible]	30	28	28	31	33	25	22	17	13
AVG	1	1	1	5	11	15	17	17	14	10	1	2
MIN	-11	-15	-6	-5	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-7	-8

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.

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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.

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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.

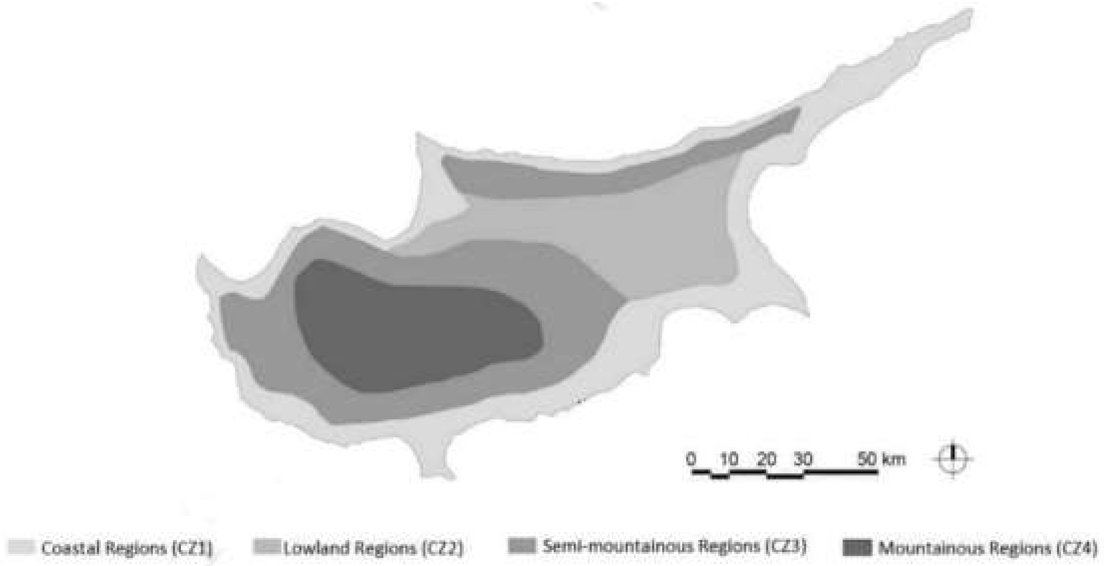

Figure 17: The Climatic Zones of Cyprus (Ministry of Energy, Commerce, Industry and Tourism 2015).

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).

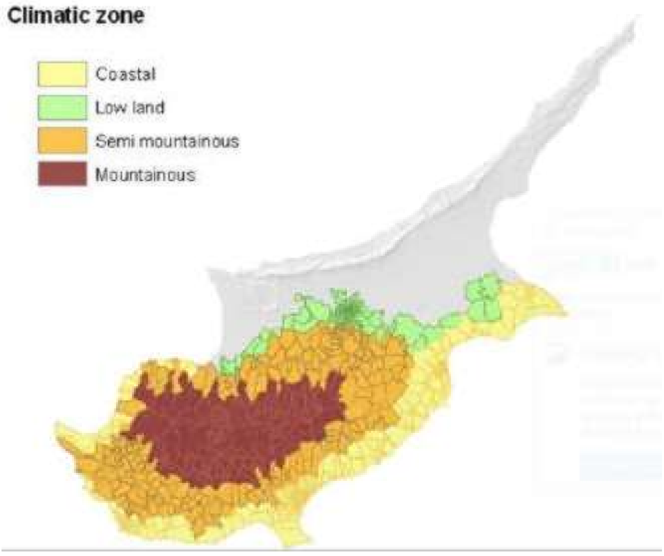

Figure 18: The Climatic Zones of Cyprus – per administrative border (EXERGIA S.A. 2012).

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).

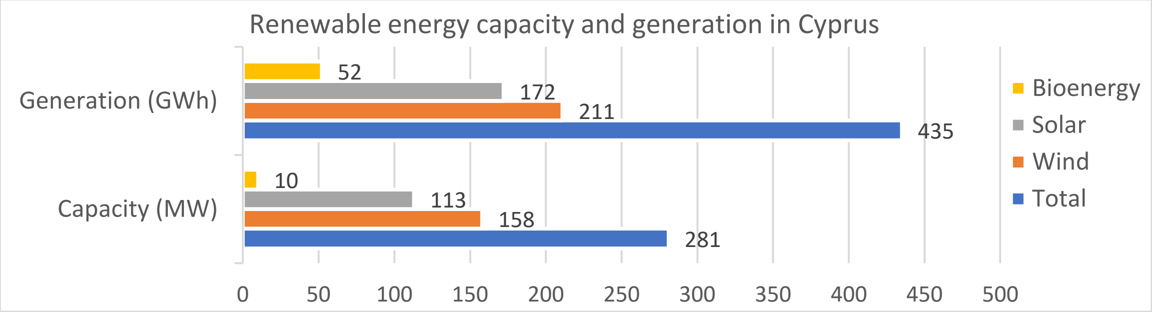

Figure 22: Renewable energy capacity and generation in Cyprus, in 2018. Source: (IRENA 2019)

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).

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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.

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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.

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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.

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[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.

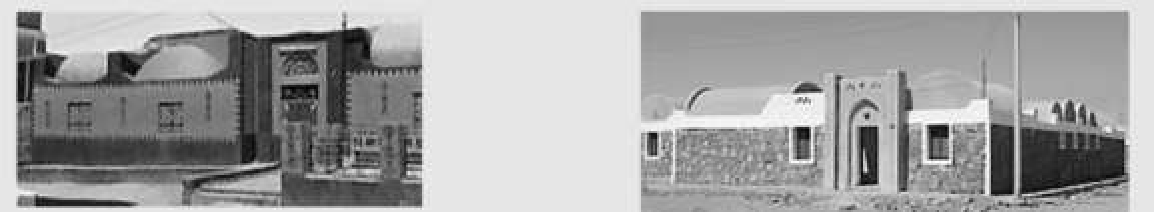

Figure 26: Left: old Nubian houses, right: new nubian houses.

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.

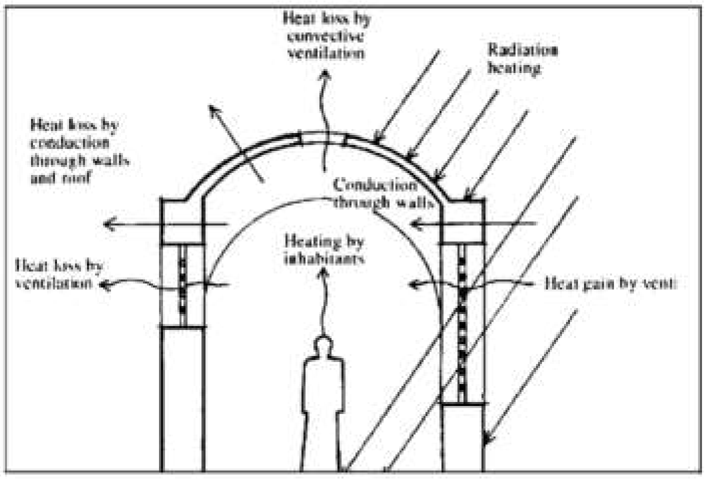

Figure 27: Ventilation systems through cross ventilation, stack effect[8]*.*

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.

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[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.

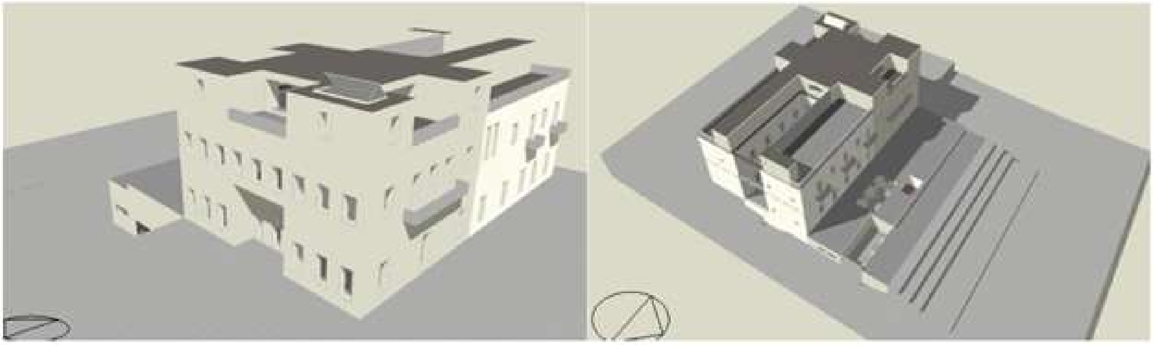

Figure 30: The Base case simulation model. (Khalil et.al,2018)

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.

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[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).

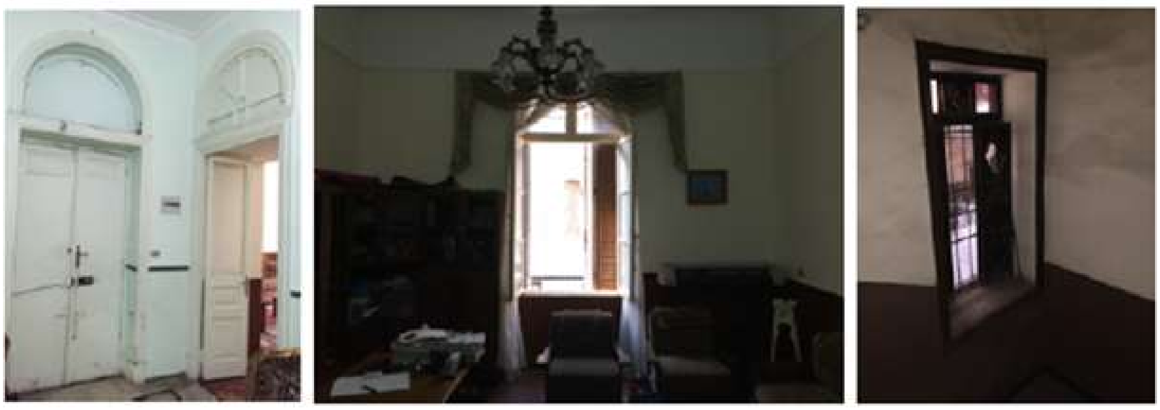

Figure 32: Pictures of the interiors of the Residential Heritage Building. (Taher et.al, 2019).

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.

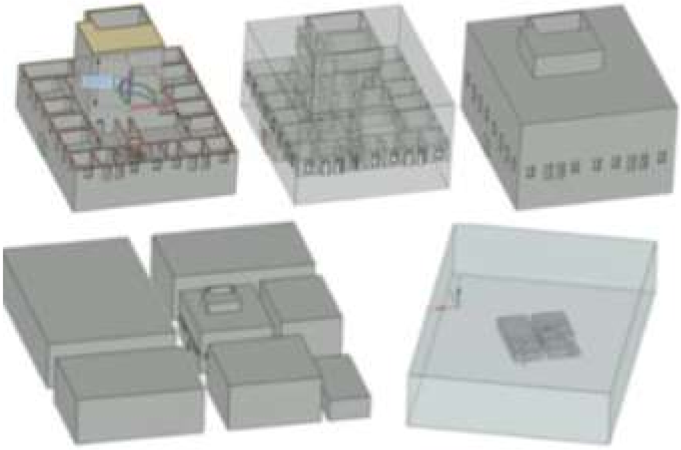

Figure 33: CFD Model of the Residential Building. (Taher et.al, 2019).

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).

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[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

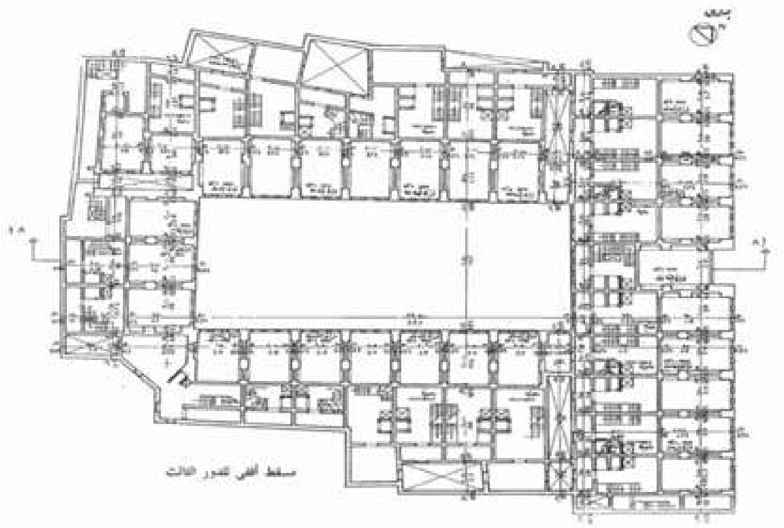

Figure 35: Wekalet El-Ghouri typical floor plan. (Fahmy et.al,2019).

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.

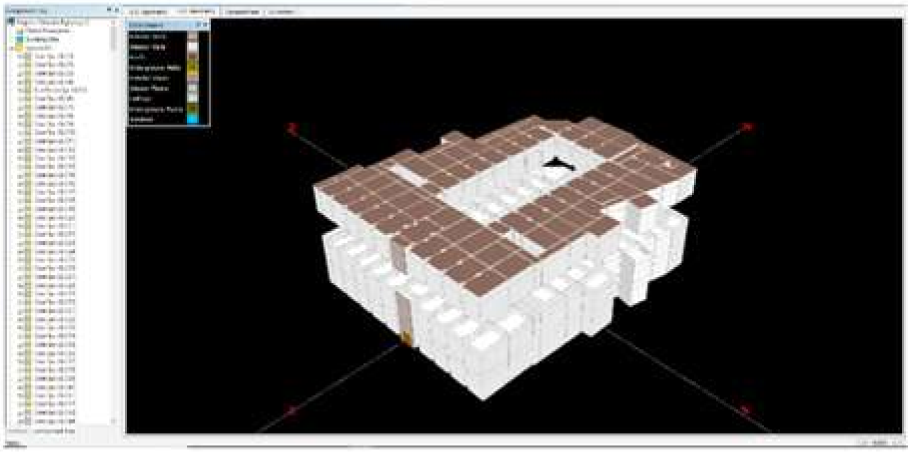

Figure 36: The graphical user interface of eQuest having the simulation model of the case study. (Fahmy et.al,2019).

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].

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[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.

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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).

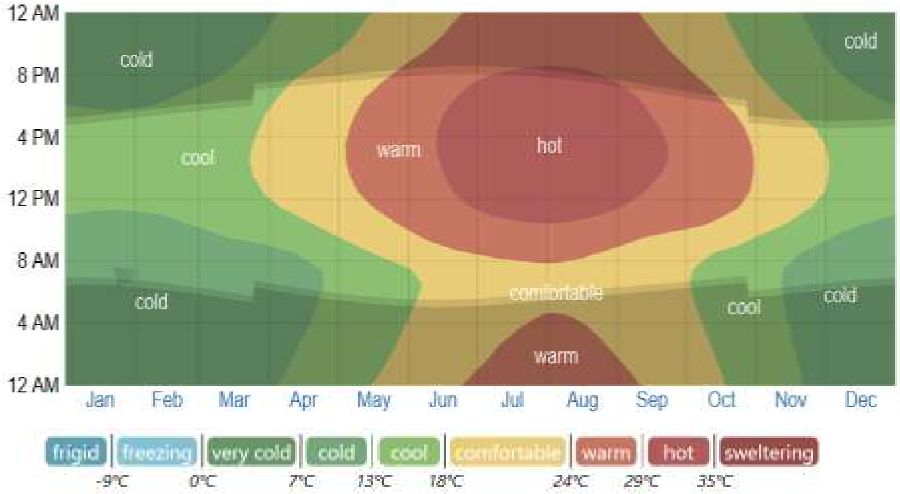
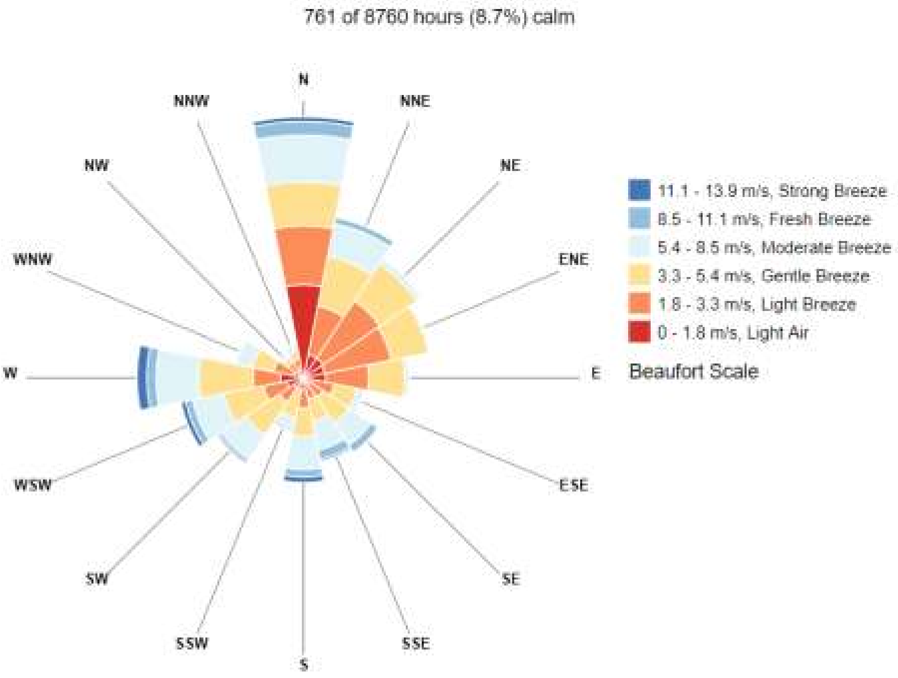


Fig. X: The average hourly temperature in Nicosia, colour coded into bands. The shaded overlays indicate night and civil twilight. Source: https://weatherspark.com/y/97684/Average-Weather-in-Nicosia-Cyprus-Year-Round

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.

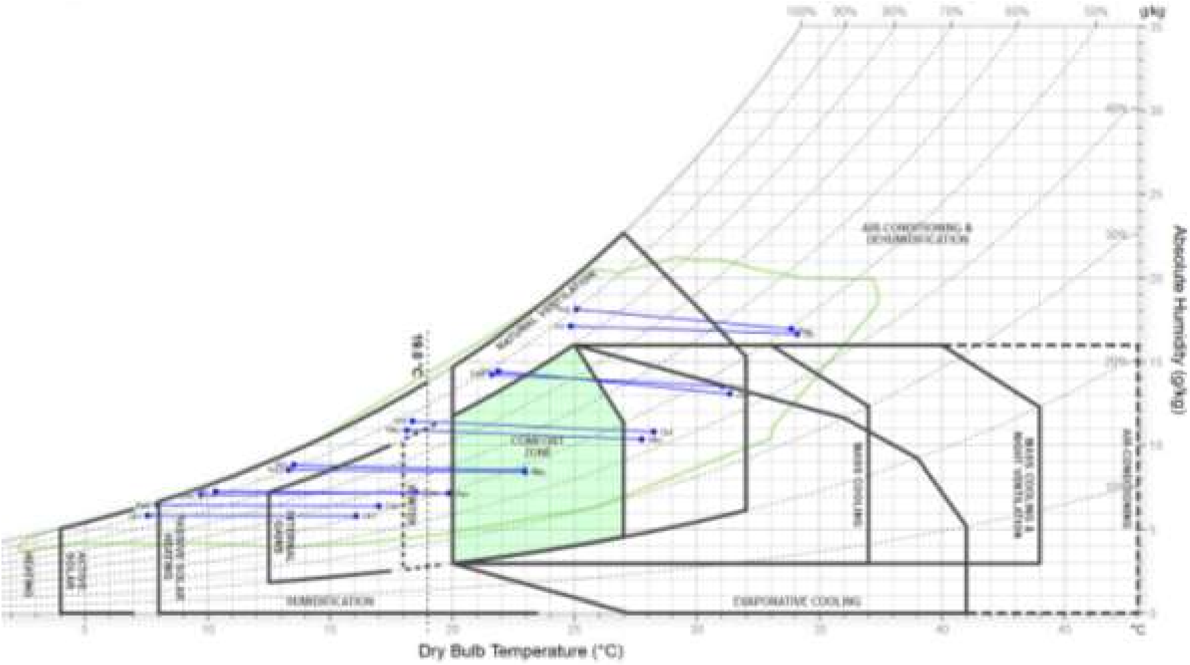


Fig.X: Givoni comfort diagram for Nicosia. Source: https://drajmarsh.bitbucket.io/psychro-chart2d.html

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)

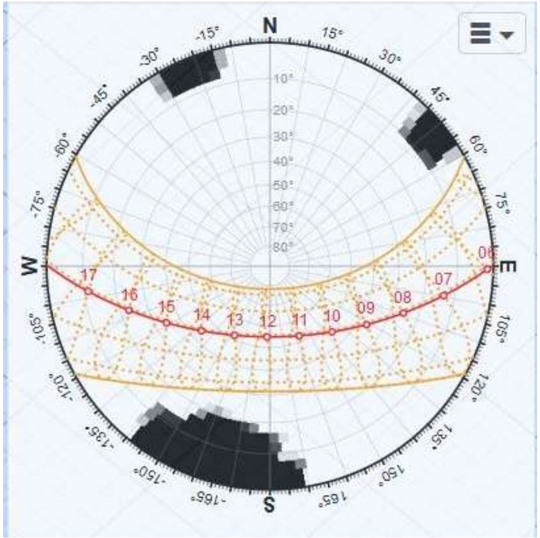


Fig.X: Solar shading mask in the location of the building in Nicosia (at the buildings' main entrance). Created through the application: https://drajmarsh.bitbucket.io/shading-box.html

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

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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…

Description of the current state of the involved parts

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.]

Compatibility and heritage significance

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^{2}K)	Thermal Transmittance glass, Ug (W/m^{2}K)	Thermal Transmittance frame, Uf (W/m^{2}K)	Solar heat gain coefficient, SHGC	Visible transmittance of glazing (Tv)
W01					
W01_new					

Estimated cost of the intervention

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.

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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

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).

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.

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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.