Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation

Deliverable 4.1

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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

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Colophon

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Publishable executive summary

The target of this report is to define and verify the Baseline to compare the advancements of BIM-based renovation approach against the traditional renovation methods, as well as to detail Key Performance Indicators (KPIs) for measuring the achievement of EEB goals through renovation. Moreover, the Deliverable suggests Use Cases, that need to be detailed further during the BIM-Speed project to understand how to apply BIM-based tools and methodologies to support the renovation process.

This report is divided in three main sections. The first part of this deliverable consolidates the KPIs for EEB renovations, which referred to actual practice as well as recent EC studies addressing EEB, such as Level(s). The second part of this Deliverable describes the methodology for Baseline definition that, aligned with the Use Cases for BIM-based renovation, will serve as an objective reference to elaborate, execute and validate the impact of the renovation on building's performance. The KPIs cover almost all the key aspects linked to the renovation process (i.e. economy, energy, environment and comfort).

List of acronyms and abbreviations

DoA: Description of Action

BEM: Building Energy Model

BIM: Building Information Modeling

BS: BIM-SPEED

ECM: Energy Conservation Measure

EEB: Energy Efficient Buildings

EPBD: Energy Performance Buildings Directive

EPC: Energy Performance Contract

ESCO: Energy Services Company

GIS: Geospatial Information System

HVAC: Heating Ventilation Air Conditioning

IAQ: Indoor Air Quality

IEQ: Indoor Environmental Quality

IPMVP: International Performance Measurement and Verification Protocol

IPR: Intellectual Property Right

KPI: Key Performance Indicator

LCA: Life Cycle Analysis

LCC: Life Cycle Cost

MEP: Mechanical Electrical Plumbing

M&V: Measurement & Verification

nZEB: nearly-Zero Energy Buildings

PMV: Predicted Mean Vote

POE: Post Occupancy Evaluation

R&D: Research and Development

RES: Renewable Energy Source

RoI: Return on Investment

SME: Small and Medium-size Enterprise

TCP: Technology Commercialisation Platform

TRL: Technology Readiness Level

VR/AR: Virtual / Augmented Reality

UC: Use Case

Definitions

Not applicable.

Contents

1. Introduction

This report provides the identification, the definition and description of the Baseline, KPIs and Use Cases. The Deliverable summarises the activities carried out to define and verify the Baseline to compare the advancements of BIM-based renovation approach against the traditional renovation, as well as the Key Performance Indicators (KPIs) to measure the achievement of EEB goals through renovation.

The set of KPIs and the procedure to establish a Baseline reflect the current practice as confirmed by the European professional associations of all disciplines (design firms, HVAC firms, construction firms). The Baseline definition and KPIs need to directly lead to Use Cases for applying BIM-based tools for buildings' performance assessment useful for supporting the renovation process. The initially suggested Use Cases therefore provide input for the future activities for building energy modelling and performance assessment of the BIM-Speed project in detailing requirements in terms of data to be collected and measured and applying the performance assessment methodology with the necessary level of accuracy. The aim is that at the end of the project, the Use Cases investigate the entire aspects related to the building performance assessment, from comfort evaluation to energy performance with both real and simulated data, making use of BIM interoperability. They refer to the pre-renovation scenario as well as to the post-renovation condition. The key objective is to offer procedures to provide a complete overview of the building performance assessment.

The KPIs, covering the aspects of energy, environment and comfort, endorse the assessment of the building conditions pre and post-renovation. In addition, economic KPIs have been included to support the decision-making, avoiding the selection of unaffordable renovation scenarios. For each KPI, a concise benchmarking system is introduced for allowing comparison within different renovation strategies. The methodology for building performance benchmarking and energy efficiency assessment is developed based on common practices and references to standards (e.g. ISO 50001) and protocols (e.g. IPMVP). The KPIs will verified against the building data and external data (environment, GIS) collected in the context of WP1. Finally, the KPIs will be a key part of the holistic performance assessment and recommended for standardisation or normalisation.

The first section of this Deliverable consolidates the KPIs for EEB renovations referred to actual practice as well as recent EC studies addressing EEB KPIs, such as Level(s)[1]. The second part consists of the definition and development of Energy Baseline, which targets at providing a valuable benchmark for comparing pre- and post-renovation scenarios. The third section suggest the initial list of Use Cases for BIM-based renovation, which serve as an objective reference to elaborate, execute and validate the real demonstration cases.

[1] https://ec.europa.eu/environment/eussd/buildings.htm

2. Methodological approach

This Report defines the starting point of KPIs and Use Cases to build a workflow and provide information to the data acquisition phase: which data need to be acquired, how and for which BIM-SPEED phase (BIM Modelling, Energy Modelling...). Tracing the data and information flow envisioned on BIM-SPEED from the back to the front (Figure 1). In this way, the methodological approach for conducting performance simulations of renovation scenarios passes through a coordination with previous phases of the BIM-SPEED process defining a detailed flow of data.

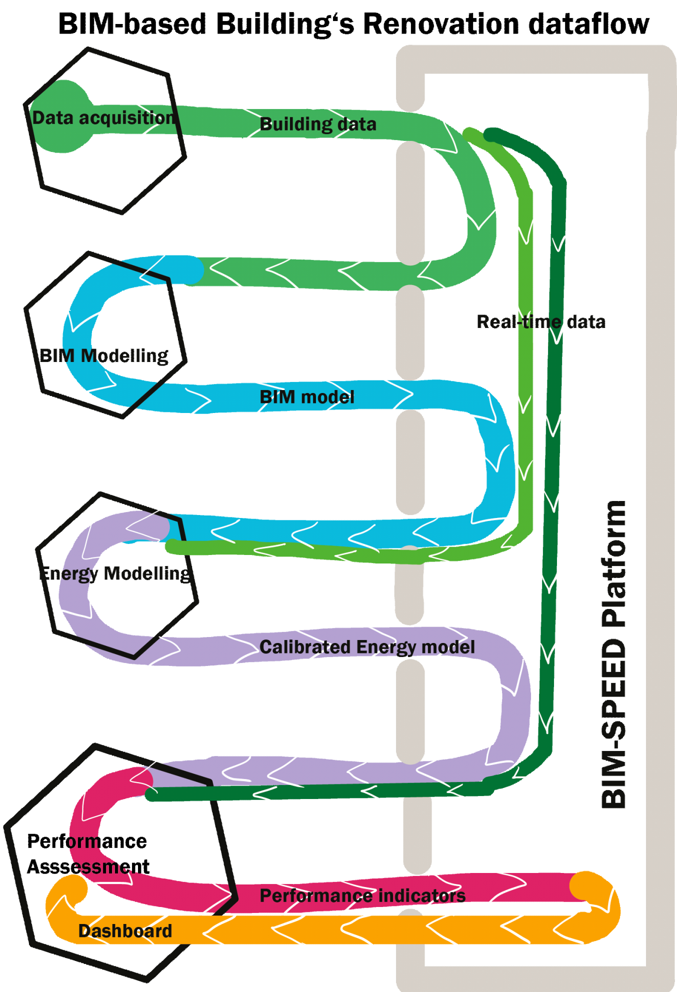

Figure 1 BIM-based Building's renovation dataflow for performance assessment

3. Definition of KPIs

Sustainability framework

The BIM-SPEED main target is to reach the "deep renovation level" according EU Energy–Efficiency Directive (EED) and EC SWD (2013 143 final), which results in more than 60% energy saving and CO_2 emission. The vision is to reach these levels by supporting the entire renovation process with BIM. These impacts need to be calculated based on a baseline defining the performance of the building before renovation. However, energy and CO2 savings are not the only goal during building renovation. Therefore, BIM-Speed envisions that impact calculation are carried out for a comprehensive set of Key Performance Indicators (KPIs) which have been defined and verified in various H2020 EEB research projects. The analysis of the building's performance will be based on a BEM approach that will be further elaborated during the BIM-SPEED project. The approach comprises energy modelling, indoor thermal comfort and financial/economic analysis. Therefore, the KPIs developed in BIM-SPEED cover the aspects of energy, environment, comfort and affordability. For each KPI, a concise benchmarking system is introduced which will allow for the comparative analysis during a building renovation project as well as between different projects. Thresholds from EU and national legal frameworks, building standards, sustainability labels and norms (EEB / nZEB / NZEB) have been considered. The methodology for building performance benchmarking and energy efficiency assessment has been developed based on common practices, references to standards such as ISO 50001 and protocols such as IPMVP, a thorough literature review and surveys among BIM-SPEED participants who are joining other EU H2020 projects. Moreover, most of the KPIs selected for BIM-SPEED are in line with the EU **Level(s) – A common EU framework of core sustainability indicators for office and residential buildings**[2]. The final set of KPIs has been verified against the building data and external data (environment, GIS) collected in WP1 and harmonized into a comprehensive KPI framework.

Key Performance Indicator definition and functions

A Key Performance Indicator (KPI) is:

- A **METRIC** to obtain a measurement on a scale.
- A **DESIGN SUPPORT TOOL** to provide the designer with quick feedback on the performance achieved and support design loops for performance optimisation.
- A **DECISION SUPPORT TOOL** to compare and identify the best option according to the stakeholder's preferences;
- A **COMMUNICATION TOOL** to summarise and explain the performance of a design choice to non-technical users.

[2] https://susproc.jrc.ec.europa.eu/Efficient_Buildings/docs/170816_Levels_EU_framework_of_building_indicators_Parts.pdf

In building renovation, a KPI is used to perform a **holistic building performance assessment and to measure the achievement of EEB goals through renovation and allows comparison analysis between pre and post-renovation as well as between different renovation options.**

The objective of BIM-SPEED is to develop a framework to compare building performance before and after renovation making use of both **measured** and **simulated data**. The output of this work package, “Conducting performance simulations of renovation scenarios” is to develop a dashboard for KPIs review (Holistic performance assessment). The dashboard’s target is to support the design team and the stakeholders to select the most optimal renovation solution.

The developed KPIs cover sustainability topics: Environment, Society and Economy. In particular:

1) **ENVIRONMENTAL KPIs**: consider building’s energy and environmental aspects, targeting at optimizing final energy demand and minimizing greenhouse effects.
2) **SOCIAL KPIs**: treat and optimize the aspects related to the needs of the occupants of a building: thermal comfort, acoustic comfort, indoor air quality, and visual comfort.
3) **ECONOMIC KPIs**: consider building’s cost related to operation, maintenance and renovation investment.

Key Performance Indicators in BIM-SPEED

This section briefly illustrates the KPIs developed for the BIM-SPEED project. Table 1 summarises the KPIs, reporting the ID and the responsible partner. Behind the responsible partners described in the table, all the partners involved in the project contributed to the definition of the KPIs. After summarizing the sources used for the development of the KPIs, the following sub-sections provide a concise description of each KPI. How to calculate each of the KPIs will be subject to future work on the BIM-Speed project, however, Appendix 1 already provides a summary of the current state of the art, providing some additional detail how to calculate the KPIs.

Table 1: KPIs list

Category	ID	Name	Responsible
ENVIRONMENT	BS.OPED	Operational Primary Energy Demand	CARTIF
	BS.TED	Total Energy Demand	CYPE
	BS.TEC	Total Energy Consumption **Sub-KPIs:** Energy Consumptions for Heating Energy Consumptions for Cooling Energy Consumptions for Lighting Energy Consumptions for DHW	CYPE
	BS.TES	Total Energy Savings	CYPE
	BS.EPS	Energy Performance Signature	STRESS

	BS.GWP	Global Warming Potential	CARTIF
SOCIAL	BS.TCWCS	Thermal Comfort Without Cooling system (Non-heating season)	UNIVPM
	BS.TC	Thermal Comfort (In the Heating Season & non-heating with cooling system)	UNIVPM
	BS.FP	Fuel Poverty	UNIVPM
	BS.VC	Visual Comfort	UNIVPM
	BS.IAQ	Indoor Air Quality	UNIVPM
	BS.AC	Acoustic Comfort	UNIVPM
ECONOMIC	BS.OEC	Operational Energy Costs	CARTIF
	BS.PP	Payback Period	CARTIF

3.1.1 Relation with other KPIs schemes

The selected KPIs derive from an investigation of the current activities in this field. In particular the Level(s) initiative has been considered, given its importance at EU level.

Level(s) is a shared EU framework of essential indicators for the analysis of buildings' sustainability. It works as a voluntary reporting scheme, connected to European policy objectives of building's performance assessment, to build a comparative library and enable design performance optimization though the use of each indicator in this structure. Level(s) aims at enhanced awareness about more efficient buildings and at improving effectiveness of resources in the built environment to support the parts engaged in the construction process. It defines a common language around sustainable buildings using indicators based on prominent tools and standards, shifting the main topic of sustainability in the built environment beyond merely energy consumption.

Along with the leading objective, which is about environmental impact, it implement the analysis of further complementary features of building performance through indicators for comfort, health, cost-analysis, and foreseeable performance compromise. This set of indicators and common metrics are defined in Level(s)' structure to support the measurement of buildings' efficiency in environmental impact through their life cycle. The definition of these indicators is meant to reach wider understanding of sustainable building's core principles, uphold decision-making along the design process, and generate performance data that are reliable and comparable; implementing the possibility to take meaningful actions at building level to uphold the European environmental policy objectives. Moreover, national and international certification schemes such as BREEAM (UK/NL/Spain/Norway/Sweden/Germany/ International), DGNB (Germany), HPI (Ireland), HQE (France) and Verde (Spain), stated their goal to define an alignment with Level'(s) criteria, highlighting the relevance of inscribing BIM-SPEED KPIs in its structure.

The introduced structure of Level(s)' framework develops around six all-encompassing leading fields or "macro-objectives", represented in **Errore. L'origine riferimento non è stata trovata.** among their subcategories and specifications. The KPIs selected in BIM-SPEED inherits features from Macro-objective 1 (energy/environment) and 4 (health and comfort). Furthermore, additional KPIs are included to provide a building performance assessment suitable for the stakeholders involved in the renovation process:

- Concerning energy, specific insights about the final energy use has been added with the KPIs: BS.TEC, BS.TES and BS.EPS. The report provided by these indicators collects information on how the energy is employed and how much energy is saved by a determined renovation intervention. Including these indicators is relevant when assessing the impact of a renovation scenario.

- Concerning comfort, the BIM-SPEED KPIs covers all the aspects depicted by Level(s), increasing the level of detail of thermal comfort, depending on the building typology and including visual and acoustic comfort (categorized as "Potential future Aspects" in Level(s)). In particular, for acoustic comfort, BIM-SPEED includes, BS.AC, a newly developed KPI recently published by UNIVPM [1]. In the future, the BIM-Speed team will further expand the KPI framework with more detailed subcategories for in-depth building performance assessment. Certain KPIs are macro descriptor of specific performance characteristics, providing an overall value, this could disguise the causes of the result obtained. They are useful as initial analysis to study the strong and weak points of the building. However, further investigation will be required to provide more information about each point of interest. The detailed investigation will be part of the future development in Tasks "Building Energy Performance Simulation based on BEM ", " Acoustic, thermal comfort, and indoor air quality assessment" and " Lighting and visual comfort assessment" of BIM-SPEED.

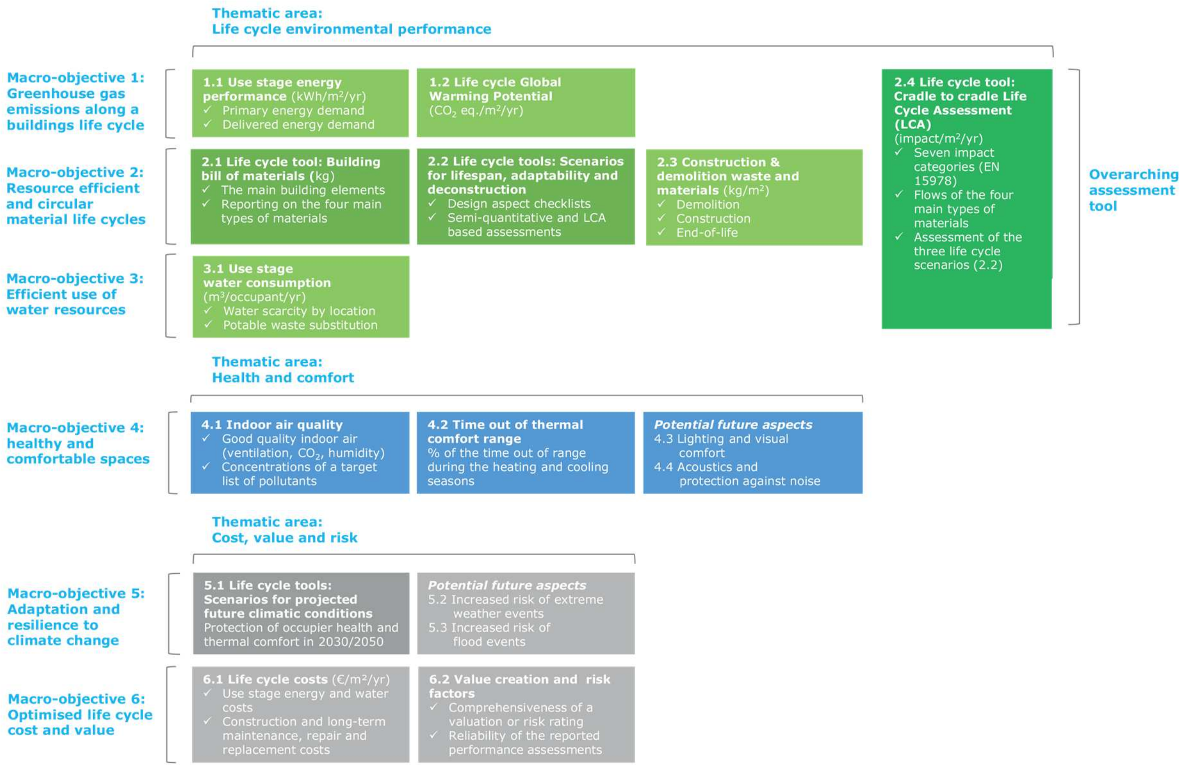

Figure 2 Thematic areas and KPIs from Level(s)

3.1.2 Relation with International benchmarking systems and certification protocols

A consistent number of benchmarking systems is operating, in the built environment, to assess the building environmental performance. Not only energy performance is assessed in these schemes, but also default parameters that consider building envelope components, indoor design conditions, ventilation and infiltration rates and services systems performance.

BIM-SPEED's KPIs are aligned to this context of international standards. The indicators used for comfort evaluation, adopt ISO 7730 [2] and ASHRAE 55 standards [3], that are the same used by the WELL Building Standard (https://www.wellcertified.com/). WELL Building Standard is one of the most advanced certification schemes for buildings; it is specialized in health and wellness interventions connecting them with construction and design's best practices. It considers a wide number of indicators for a very detailed wellbeing certification, in BIM-SPEED KPI some of these indicators are considered and accordingly benchmarked with standards, for example: ventilation effectiveness in BS.IAQ, Thermal comfort and Humidity control in BS.TC, Exterior noise intrusion, Internally generated noise and Reverberation time in BS.AC and Visual lighting design in BS.VC.

While for energy KPIs, a wide variety of certification protocols for buildings energy labelling provide thresholds to compare with in terms of Operational Primary energy (BS.OPED), Total Energy demand (BS.TED) and Total Energy consumption (BS.TEC).

3.1.3 Operational Primary Energy Demand (BS.OPED)

The aim of this KPI is the reduction of the primary energy consumptions promoting the integration of renewable energy sources and the improvement of the building's energy performance. The KPI is calculated in kWh/m^{2}year.

The term 'primary energy' indicates that the energy supplied to the building (from renewable and non-renewable sources) has not been subjected to any conversion or transformation process. The primary energy includes the energy necessary to generate the final energy consumed, comprising losses due to transformation, transportation to the building, etc. The losses are considered by means of primary energy factors which are nationally or even regionally defined.

This KPI is in line with Level(s) Macro Objectives 1 – Sub item 1.1.1.

3.1.4 Total Energy Demand (BS.TED)

This KPI targets at assessing the building energy use to investigate the amount of energy needed to maintain comfortable indoor conditions. The total energy demand is measured in kWh/m^{2}year.Total energy demand differentiates from the KPIs energy demand for cooling and heating as each of them appears at different times of the year and must be calculated separately.

In building renovation processes, it is crucial to know the energy demands of the building since they can support the team in the decision-making process. In fact, this KPI aids the designers in selecting the most energy-efficient systems to improve the overall building energy performance.

3.1.5 Total Energy Consumption (BS.TEC)

The objective of this KPI is to have an assessment of the building consumptions. Total Energy Consumption is the balance between the different energy sources needed to meet the energy demand of the building. The overall value includes the energy supplied for heating, cooling, ventilation, domestic hot water, lighting among others during a certain period (usually one year). The total energy consumption is measured kWh/m^{2}year.

The Total Energy Consumption KPI is the combination of different KPIs, that must be calculated separately. They are:

- Total Energy Consumption for Heating KPI;
- Total Energy Consumption for Cooling KPI;
- Total Energy Consumption for Domestic Hot Water KPI;
- Total Energy Consumption for Lighting KPI.

The achievement of detailed characterization profiles allows for a more reliable assessment of the energy efficiency of the building and for designing innovative control strategies based on real consumption patterns.

This KPI is in line with Level(s) Macro Objectives 1 – Sub item 1.1.2.

3.1.6 Total Energy Savings (BS.TES)

The Total Energy Savings is a KPI that provides the amount of energy that has been saved due to the renovation process. It is obtained calculating the difference between Total Energy Consumption before renovation (adjusted baseline – see section 0) and Total Energy Consumption after renovation. The total energy savings are measured in kWh/m^{2}year.

It is a crucial indicator for aiding designers and stakeholders in the decision-making process and in selecting the most suitable renovation strategy.

3.1.7 Energy Signature (BS.ES)

The Energy Signature KPI provides a straightforward way of estimating and comparing the performances of the buildings among different climatic contexts, allowing for a direct comparison between the calculated values with the actual consumption of the buildings and provides fast feedback on their performances. The Energy Signature is measured in kWh. The methodology is described in Annex B of EN 15603. The standard state that the energy consumption for heating, cooling and hot water are correlated with climatic data over a suitable period.

3.1.8 Global warming potential (BS.GWP)

The Global Warming Potential KPI represents the CO_2 emissions of a building caused by the different areas of application (heating, cooling, DHW, electrical appliances, etc.). This KPI encompasses the CO_2 emissions caused by the energy supply (thermal and electrical) for operating the building. It is calculated in $kgCO_{2eq}/m^2$year. The target of this KPI is the reduction of CO_2 emissions, for example, through the integration of renewable energy sources, the use of less polluting fuels and more energy-efficient systems. Global warming potential is necessary for calculating the environmental impact and the analysis of the CO_2 emissions can help in selecting equipment that uses sustainable fuels. This KPI is in line with Level(s) Macro Objectives 1 – Sub item 1.2.

3.1.9 Thermal Comfort (BS.TC)

Thermal Comfort is defined as the percentage of hours a building would be outside the comfortable PMV Range in buildings during the heating season or during the summer with the cooling system. According to EN 15251, an acceptable deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended. This KPI focuses on the evaluation of users' comfort using the PMV (Predicted Mean Vote) index. The PMV allows considering through a single parameter both building and system-related aspects such as the air and mean radiant temperature, the air speed and humidity, and user-related aspects such as clothing and activity types. The PMV model and its application for comfort measurement and verification are defined by the EN ISO 7730:2005 and ISO 7726.

This KPI is in line with Level(s) Macro Objectives 4 – Sub item 4.2.

3.1.10 Thermal Comfort Without Cooling System (BS.TCWCS)

Thermal Comfort without Cooling System is defined as the percentage of hours a building would be outside the comfortable temperature range (according to a predicted mean vote (PMV) for the occupants) assuming no mechanical cooling system (applicable during the non-heating season). According to EN 15251, an acceptable deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended. The aim of this KPI is the assessment of the thermal quality of the indoor environment. Its outcomes allows for investigating the possibility of avoiding the installation of cooling systems and the application of passive measures to guarantee both the users' well-being and the reduction of energy costs.

3.1.11 Acoustic Comfort (BS.AC)

The Acoustic Comfort KPI provides a measurement of the indoor acoustic comfort due to the noise coming from outside. The KPI is calculated at the building level but it is based on the evaluation of the indoor noise levels assessed for each room. The KPI is expressed as a percentage value from 0 % (minimum value) to 100 % (maximum value). The percentage value corresponds to an acoustic class, which ranges from A to E.

3.1.12 Fuel Poverty (BS.FP)

The Fuel Poverty KPI is defined as the percentage of Fuel Poverty status of households. It measures the percentage of the household income needed to pay the energy required to keep the house in comfortable conditions. This KPI allows for evaluating renovation options and their potential effect on the financial situation of a buildings occupants.

3.1.13 Visual Comfort (BS.VC)

The Visual Comfort KPI is defined as the percentage of hours during which a building is occupied and illuminance levels are below a standard threshold defined in EN 15251. According to EN 15251, an acceptable deviation is 5% of occupied hours. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

The aim of the KPI is to provide a comprehensive and straightforward way to measure the illuminance level of space and to assess if lighting requirements are matched.

3.1.14 Indoor Air Quality (BS.IAQ)

The Indoor Air Quality KPI is defined as the percentage of hours a building is outside the acceptable maximum CO_2 range defined in EN 15251. According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended. One of the key factors that affect indoor air quality is the presence of people in closed spaces. Occupants' breathing increases the CO_2 concentration with the concentration in the indoor air rising as the occupants exhaust the available air. The assessment of CO_2 presence in the indoor air covers the overall air quality, as the air changes required to contain the CO_2 levels guarantee a reduction of the concentration of other, more dangerous, pollutants, increasing the quality of the indoor air and thus providing a healthier environment for the occupants. The aim of the Indoor Air Quality KPI is to provide a comprehensive and straightforward way to assess and measure improvement in the building ventilation to guarantee the users' health and well-being.

3.1.15 Operational Energy Costs (BS.OEC)

The Operational Energy Costs KPI represents the total costs of the building spent on energy services (energy consumption, maintenance, etc.). It includes all the costs arising from the use of energy sources (oil, gas, solid fuels, district heating, electricity, etc.). The target of this KPI is the reduction of the operational energy costs by improving the building's energy performance, integrating renewable energies and changing the fuels.

3.1.16 Payback Period (BS.PP)

The Payback Period KPI compares the investment costs with the economic savings achieved from the energy conservation measures due to the retrofitting. This KPI refers to the period in years required to recover the funds expended in the investment. The analysis method has some limitations because it does not consider the time value of the money. The target of this KPI is to reduce the payback period by improving the building's energy performance and selecting cost-efficient solutions.

4. Definition of Baseline

The purpose of most of the above KPIs is to be able to compare existing building performance with the potential future performance of the building after defined renovations. However, a simple performance based on collected historical data that is aggregated across a previous time period, in most cases, cannot perform as well as a good comparative baseline. The improvement's results are not merely definable by the difference between the simulated future performance and the previous energy consumptions recorded. The performance of a building is not only influenced by its construction details but also by highly variable factors such as occupants' behaviour, weather conditions etc. that are not adjustable by renovation measures. If enough suitable historical information is available, statistical variations of these factors should be considered to establish baseline values for KPIs that normalize random effects of the non-influencing parameters. Such a Baseline then provides a fair benchmark and reference level for comparing an initial situation to the actual condition or to future scenarios. This general concept can be applied to many different aspects, such as comfort conditions or building energy use. In BIM-SPEED, working on renovation projects, the baseline definition is fundamental to determine the reference point of any performance assessment. Therefore, BIM-Speed submits a procedure to establish a clear normalized baseline to provide a comparison that allows to assess the impact of renovation measures on KPIs without influences that are beyond the control of the renovation designers.

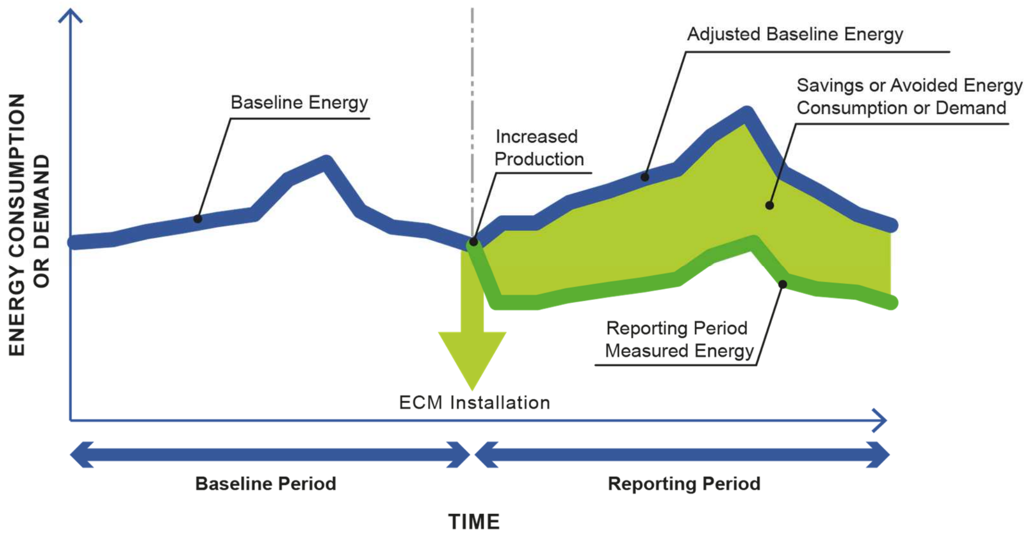

Figure 3. General principle of determining possible energy savings using establishing a baseline from a past reference period and comparing the baseline with the simulated effect of a possible renovation activity

The function of Baseline

The reference standards for the development of the Baseline are the UNI CEI EN ISO 50001:2018 [4] and the International Performance Measurement and Verification Protocol (IPMVP) [5]. The ISO 50001 specifies the requirements for creating, applying and enhancing an energy management system, which targets at providing continuous improvement of the energy performance (i.e. energy efficiency and energy use).

The ISO 50001 provides general guidance about the development of a Baseline with the following features:

- It is connected to a specific period of time (usually one year);
- It provides a quantitative reference which is a basis for comparing building energy performance;
- It can be normalized on factors which influence the energy use and/or the energy consumptions (e.g. production level, outdoor temperature, occupancy behavior);
- It can be used for evaluating the energy savings, as a reference before and after implementing renovation strategies.

According to paragraph 4.4.4 of ISO 50001, the organization should define the Energy Baseline fixing a period that is suitable to the aims and the purposes and considering the information in the initial energy review. Once these aspects have been defined, the Energy Baseline shall be maintained and recorded over the years. It can be adjusted in the case one or more features are subject to major changes (e.g. a change of the energy system). The ISO 50001 provides some suggestions, but it does not describe the method to normalize the Baseline. Further specifications are provided by the IPMVP, which is a framework of definitions and methods for assessing energy savings.

Most importantly, the IPMVP provides four options for determining energy savings:

A. **Retrofit Isolation: Key Parameter Measurement**. The savings are determined by field measurement of one or more relevant performance parameters defining the energy consumption of the system. The measurement frequency goes from short-term to continuous, depending on the expected changes in the measured parameter and the duration of the reporting period. The parameters that are not measured are estimated. Estimations can be based on historical data, manufacturer specifications or technical assessments. An error on the savings deriving from the estimations rather than the measurements should be evaluated. [*A typical application: the evaluation of the savings achieved by the retrofit of the lighting system where it is possible to measure the electric consumption of the lighting while the working hours can be estimated.*]

B. **Retrofit Isolation: All Parameter Measurement**. The savings are determined by real measurement of energy consumption derived by the system affected by the intervention. The measurement frequency goes from short term to continuous according to the variations foreseen in the savings and to the duration of the reporting period. [*A typical application: the evaluation of the savings achieved by the retrofit of the lighting system where it is possible to measure both the electric consumption of the lighting and the working hours.*]

C. **Whole Facility**. Energy savings are calculated by measuring energy consumption. Energy consumptions of the entire plant/facility are acquired for the entire reporting period through continuous measurements and regressive analysis is applied to consider the independent variables, which influence consumption (e.g. the outdoor air temperature).

D. **Calibrated Simulation**. The savings are determined by simulating the energy consumption of the whole building or part of it. This option requires skills in terms of calibration of the simulation models. This approach is used when the intervention(s) for efficiency has been applied but there is no historical data on energy consumption before the intervention (i.e. a baseline).

BIM-Speed will focus on developing the required procedures for the last option – **D. Calibrated simulation –** for the most important KPIs defined above. BIM-Speed will strongly focus on optimizing that procedure, exploiting the integration with the BIM platform.

Calculate the baseline

The baseline is established using a combination of measured and simulated data about the building. It requires the creation of building simulation models with the required level of detail and accuracy which requires a comprehensive interaction with BIM data.

The general procedure [6] for setting and applying a baseline is:

1) Define the physical boundaries of the case study (usually an entire building or a single apartment);
2) Select a previous reference year;
3) Collect data about the building energy performance for this year as it relates to the KPIs;
4) Establish the baseline by stochastically measuring the effect of uncontrollable factors, such as weather conditions or occupancy behaviour, on the performance of the building with respect to different KPIs
5) Simulate the effects of different building renovation measures using performance simulation methods and compare with the selected performance of the previous baseline period discounting for the effects of the uncontrollable factors.

According to this approach, the savings can be calculated with the following formula:

$$Energy\ Savings = (Baseline\ Energy - \ Reporting\ Period\ Measured\ Energy\ ) \mp Adjustments \qquad \text{Eq.1}$$

One important action is the definition of the ***Baseline period***. Since it represents the operating modes of the systems, the period should comprise an entire operating cycle including the maximum and minimum energy use, together with peak periods distribution. Moreover, it should be in a period near enough to the starting of the renovation works (preferably the period immediately before).

The ***Adjustments*** have the objective of bringing the energy use in the two periods to the same set of conditions. Weather, occupancy, plant throughput, and equipment operations are some of the aspects that commonly affect energy use. Adjustments are derived from identifiable physical facts and can be positive or negative.

One or more of the following techniques can measure the energy use in Eq. 1:

- Utility or fuel supplier invoices;
- Meters which can isolate a retrofit or portion of a facility from the rest of the facility. Measurements may be periodic for short intervals, or continuous throughout the post-retrofit period;
- Separate measurements of parameters used in computing energy use;
- Computer simulation, which is calibrated (e.g. DOE-2 or Energy Plus analysis for buildings);
- Agreed assumptions of ECM parameters that are well known. The boundaries of the savings determination, the responsibilities of the parties involved in project implementation, and the significance of possible assumption error will determine where assumptions can reasonably replace actual measurement.

The **Adjusted Baseline Energy** is calculated by first developing a mathematical model, which correlates the Baseline Energy data with the appropriate independent variable(s). These independent variables are included in the mathematical model to achieve the Adjusted Baseline Energy use. In this context, an **independent variable** is a parameter that is expected to change regularly and has a measurable impact on the energy use of a system or facility.

Common independent variables are weather-related parameters and occupancy. Weather is characterised by several aspects but for the building analysis, the most used variable is the outdoor temperature and, sometimes, the humidity. The significance of their impact on energy use can be assessed through mathematical models. Parameters found to have a significant effect on the baseline period should be included in the adjustments when applying Eq.1 for determining energy savings. The independent variables and the energy meters should be recorded at the same time. The number of independent variables to include in the model can be determined by regression analysis and other forms of mathematical modelling [7][8].

At least one year of data (i.e. daily or monthly energy data) during the baseline period and continuous data during the post-retrofit period are usually required to develop valuable models. In fact, models with fewer data can be affected by a statistical bias. Meter data can be hourly, daily or monthly whole-building data.

Many appropriate models are possible. To select the most suitable for the application, statistical evaluation indices should be considered, such as R^2 (coefficient of determination) or RMSE (Root Mean Square Error). Additional information concerning these selection procedures can be found in [7][9][10][11].

As an example, the following steps are needed to calculate the Adjustments term for Option C (whole facility):

1. Developing the appropriate model for the energy data related to the baseline period;
2. Inserting independent variables related to the post-retrofit period (e.g. ambient temperature) into the model from step 1. This process provides the energy use that would have happened under post-retrofit conditions if the ECM had not been realized;
3. Subtracting the baseline energy use from the result of step 2 for each month.

In general, the protocol can be implemented with a Measurement & Verification plan, which is founded on 13 key points:

1. Defining the target of the retrofit intervention;
2. Choosing the option of IPMVP and the boundaries in the building;
3. Creating the Baseline using audit and data collection (e.g. environmental parameters, occupancy patterns);
4. Identifying the reporting period;
5. Defining the correction factors for adjusting the energy consumptions or another KPI (e.g. outdoor air temperature);
6. Specifying the procedure for the data analysis;
7. Specifying the cost of the energy used in the calculation (according to energy carriers);
8. Determining the measurement specifications;
9. Assigning the responsibility for acquiring and reporting the measurement;
10. Estimating the expected accuracy of the measurement;
11. Defining a budget and the needed resources for the M&V process;
12. Determining how to present the data;
13. Specifying a quality assurance protocol for the steps of the procedure.

To recap the approach, the actions needed to obtain a correct Baseline are:

- Data acquisition of energy consumption or other operational parameters related to a specific KPI (e.g. climate conditions) both during the pre and post-renovation periods;
- Identification of operational parameters using a suitable regression method to establish the effects between KPI values and the parameters;
- Determination of the predicting curve using the consumption data in the Baseline period;
- Create the adjusted Baseline by applying to the predicting curve the operational parameters measured in the reporting period (i.e. post-retrofit).

In general, if it is possible to measure the performance of the building before and after a renovation intervention, the energy comparison should be done making the required adjustment to the Baseline (i.e. the pre-renovation situation). If real data can be measured only after the renovation and historical data are missing, Option D (calibrated simulation) should be followed, establishing the baseline through calibrated simulations. In the case that the energy performance needs to be simulated for both, the pre and post scenario, an adjustment using the baseline is not required since the boundary conditions between the two cases are exactly the same (e.g. same weather file and identical occupancy schedules). However, in most cases an entirely simulated comparison will not provide as accurate results as a comparison based on measurements.

5. Definition of Use Cases

Previous sections described the overall framework for building performance assessment, based on a set of KPIs and a procedure for baseline creation. Those elements are the basic tools for buildings renovations. Different data sources can be used for applying those tools. However, this is one of the actual barriers of enabling an accurate performance assessment to design and evaluate renovation measures. Having a unique, coherent and verified data source can provide a significant impact on renovation process efficiency. In BIM-SPEED the all-encompassing BIM platform is the only data source, continuously updated (e.g. digital twins). To support the future work of the BIM-Speed project to establish this platform, this section suggests Use Cases that need to be detailed further in the course of the project to understand how BIM can support the building performance assessment procedure based on the specified KPIs. To this end, the section can then serve as a first specification for the development of the required functionality on the BIM-Speed platform to support the holistic performance assessment of buildings.

Use Case definition

A Use Case is a list of actions that describes how a user achieves a goal by using software and system engineering. In particular, a Use Case defines the interactions between an actor and the system used to attain particulars targets. A Use Case is characterized by three elements:

- *Actor*: the type of users that interact with the system. The actor can be a human or external system;
- *System*: the mean used by the actor/s through which the goals are reached;
- *Goals*: the final scope such that the actor/s fulfils a list of actions.

The main steps required for the development of a Use Case are:

1. **Identify the actor/s**: The actors may be people or computer systems. A primary actor is one having a goal requiring the assistance of the system. A secondary actor is one from which the system needs assistance to satisfy its goal.
2. **Define what that Actor wants to do with the system**: The things that the actors want to do with the system become goals. From each goal, a Use Case is derived.
3. **For each of those Use Cases decide on the most usual course when that Actor is using the system**: A use case has one basic course and several alternative courses. The basic course is the simplest course, the one in which a request is delivered without any difficulty. There may be alternative courses that describe variants of the basic course and the errors that can occur. These are documented as extensions to the use case.
4. **Describe the basic course in the description for the use case:** The use scenario is written from the user's perspective in easy to understand language. This step is very similar to documenting a process flow. The steps necessary to achieve the identified goal are written out.

5. **Describe the alternatives and add those as extending use cases:** The extensions are written in the same manner as the original use case, but they provide alternatives to the simplest path.

Thus, a Use Case captures *who* (actor) does *what* (interaction) with the system, for what *purpose* (goal), without dealing with system internals. A complete set of Use Cases specifies all the different ways to use the system and therefore defines all behaviours required of the system, bounding the scope of the system. Generally, Use Case steps are written in an easy-to-understand structured narrative using the vocabulary of the domain. This is engaging for users who can easily follow and validate the Use Cases, and the accessibility encourages users to be actively involved in defining the requirements.

Use Cases in BIM-SPEED

The Use Cases developed within the BIM-SPEED Project follow the above-mentioned structure. They target at identifying the actors, the goals and systems, and, according to them, at illustrating which are the steps to be followed to reach the objectives. The UCs in this deliverable are focused on the building performance assessment, from the pre-retrofit situation to the operation conditions after the renovation interventions. Nineteen Use Cases have been developed to cover all the aspects of the building assessment. These identified use cases will become part of the larger total use case picture that will be developed in BIM-SPEED. As shown in Figure 4, five stages of the renovation process have been identified:

1. Existing building data acquisition
2. Renovation design
3. Performance analysis
4. Execution of renovation works
5. Occupation and maintenance

The Use Cases described in this report are linked with the stage N° 3 and 5 of the above list, but also interconnected with the Use Cases that will be developed for the other stages (e.g. data collection of WP1 that is linked with the stage N° 1 – Existing building data acquisition). Moreover, as visible in Figure 4 a second level of classification in the tree is defined and it includes the stages of the plan of work of RIBA. This deliverable’s UCs are inscribed in stage 3, “Development design” and stage 7 “Occupation and maintenance”, as respectively shown in Figure 5 and Figure 6.

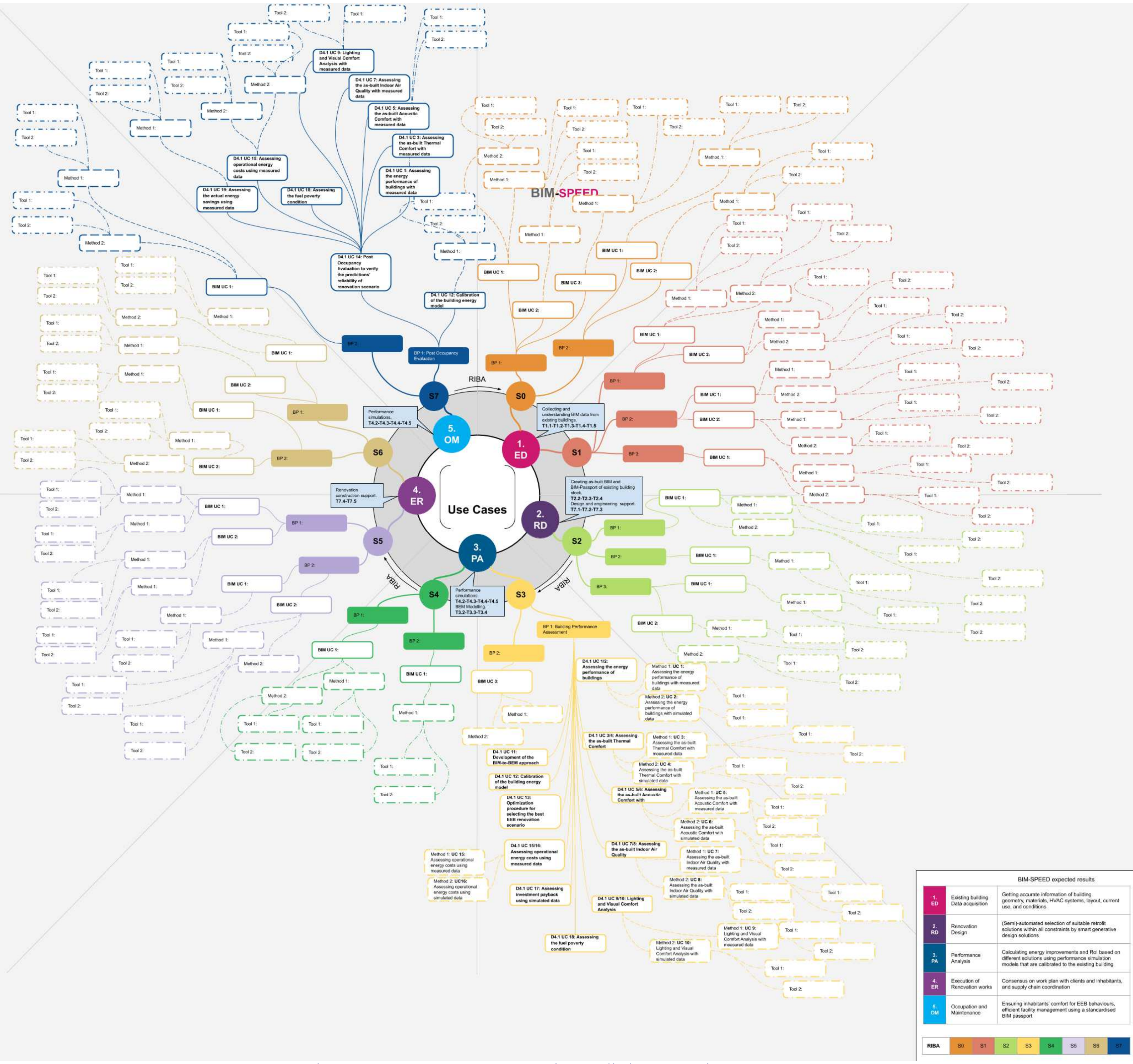

Figure 4 BIM-SPEED Use Cases tree view applied to renovation stages

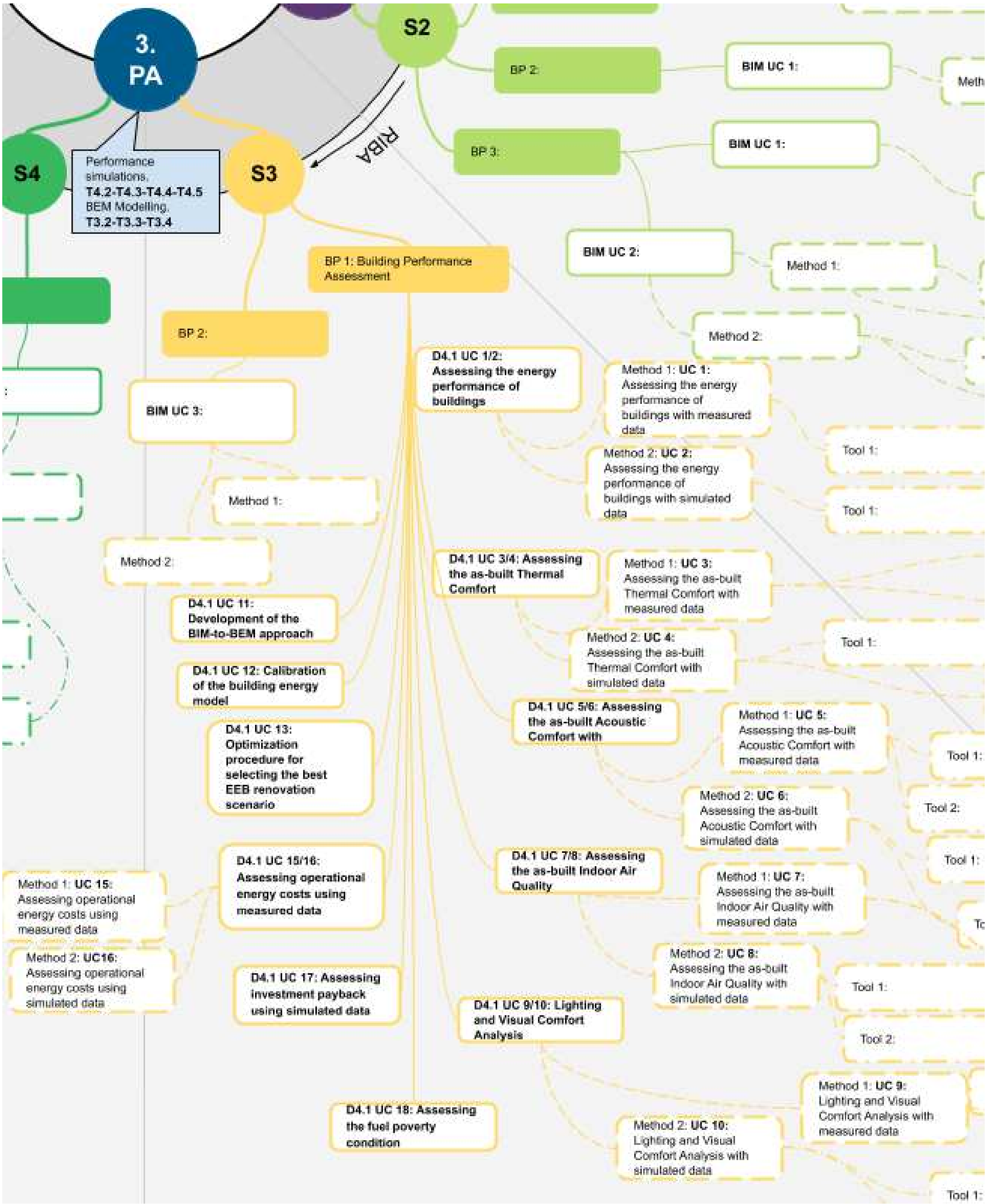

Figure 5 The stage 3 Use Cases developed in this deliverable

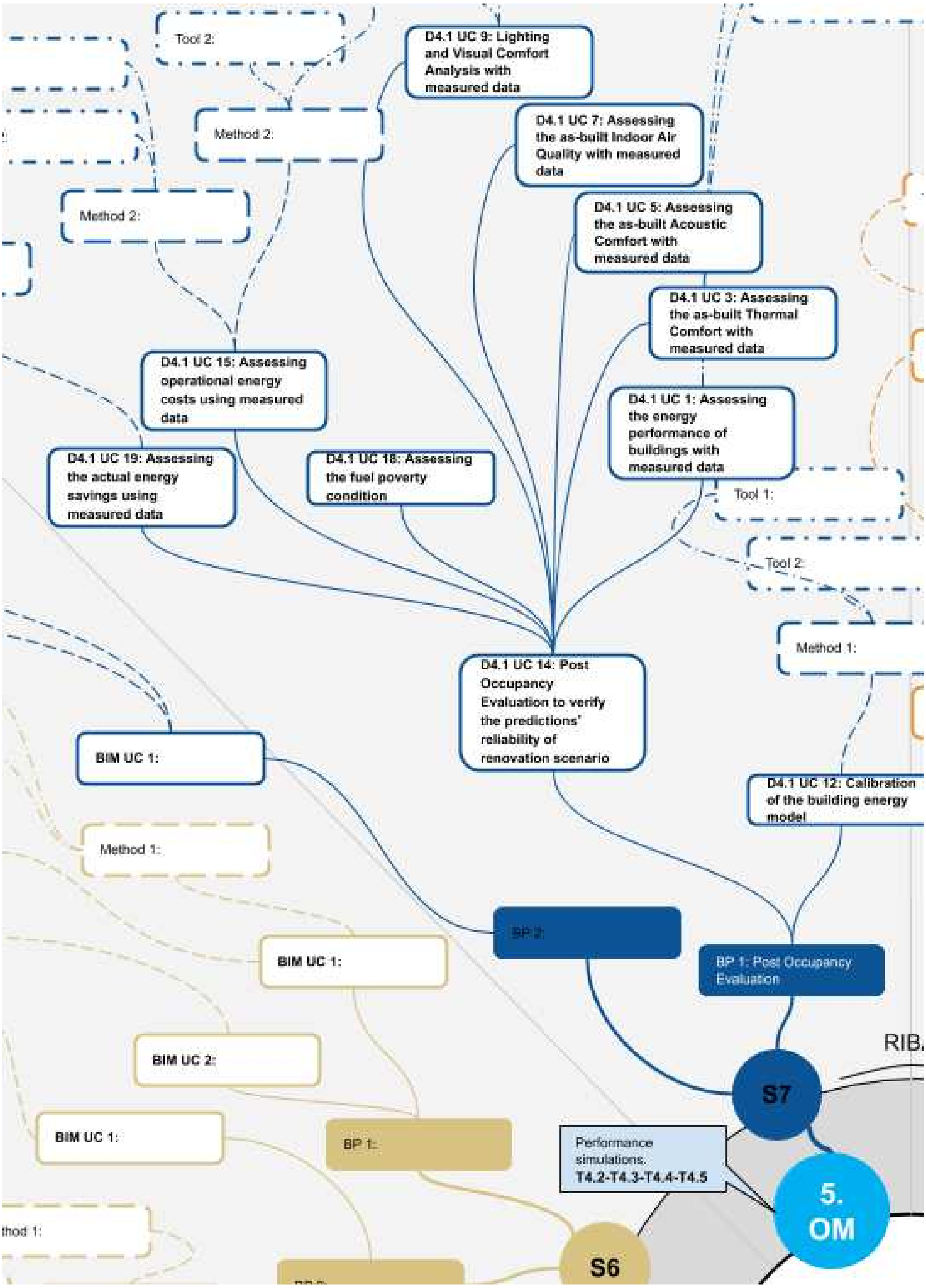

Figure 6 The stage 7 Use Cases developed in this deliverable

The Use Cases from UC1 to UC10 report how to use BIM to support the workflow to investigate the building performance according to different aspects. Energy performance, IAQ, thermal, acoustic and visual comfort can be investigated with precise procedures both using real and simulated data. UC11 and UC12 focus on using BIM for building performance simulations. The former presents the framework to perform the BIM-to-BEM process, which is an essential component when performing simulations. The latter is connected to the calibration procedures that should be applied to the energy model to fit the real building behaviour. UC13 has the objective of using BIM to present an optimization procedure for selecting the best EEB renovation scenario among a pool of possible solutions. The Use Cases from UC14 to UC19 are focused on the intervention impact, before and after renovation.

5.1.1 Overview of the Use Cases

This section provides an overview of the Use Cases developed for building performance assessment within the BIM-SPEED EU Project. Table 2 reports the list of the 19 UCs with the ID, the title, the goal and the involved partners. The following sub-sections briefly describe each UC, while the complete characterization is reported in Appendix 2.

Table 2. List of the Use Cases developed in the BIM-SPEED project

ID	USE CASE	GOAL	CONTRIBUTORS
UC1	Assessing the Energy Performance of buildings with measured data	Providing the building energy performance assessment using data measured in the demo cases.	UNIVPM, CARTIF
UC2	Assessing the Energy Performance of buildings with simulated data	Providing the building energy performance assessment using simulated data.	UNIVPM, CARTIF
UC3	Assessing the as-built Thermal Comfort with measured data	Assessing the occupants' thermal comfort before and/or after the renovation using measured data.	UNIVPM
UC4	Assessing the as-built Thermal Comfort with simulated data	Assessing the occupants' thermal comfort before and/or after the renovation using simulated data.	UNIVPM
UC5	Assessing the as-built Acoustic Comfort with measured data	Assessing the occupants' acoustic comfort before and/or after the renovation using measured data.	UNIVPM

UC6	Assessing the as-built Acoustic Comfort with simulated data	Assessing the occupants' acoustic comfort before and/or after the renovation using simulated data.	UNIVPM
UC7	Assessing the as-built Indoor Air Quality with measured data	Assessing the level of indoor air quality before and/or after renovation making use of measurements.	UNIVPM
UC8	Assessing the as-built Indoor Air Quality with simulated data	Assessing the level of indoor air quality before and/or after renovation making use of simulations.	UNIVPM
UC9	Lighting and Visual Comfort Analysis with measured data	Assess the occupants' Lighting and Visual comfort before and/or after the renovation using measured data.	UNS
UC10	Lighting and Visual Comfort Analysis with simulated data	Assessing the occupants' Lighting and Visual comfort before and/or after the renovation using simulated data	UNS
UC11	Development of the BIM-to-BEM approach	The use case provides an approach for BIM-to-BEM interoperability process, for performing energy performance analyses.	STRESS, CYPE
UC12	Calibration of the building energy model	Performing the calibration of the energy model according to a standardized approach.	UNIVPM
UC13	Optimization procedure for selecting the best EEB renovation scenario	Assessing the best renovation scenario with regard to energy, cost and comfort criteria from a pool of simulated alternatives	MTB, TUB, MOW
UC14	Post Occupancy Evaluation to verify the predictions' reliability of renovation scenario	Assessing the building performance using measured data in use on energy, indoor environmental quality (IEQ), well-being, carbon emissions, and cost of occupancy.	ACE, CYPE, FAS, DMO, TUB, UNIVPM
UC15	Assessing operational energy costs pre-renovation	Calculating the operational energy costs	ACE
UC16	Assessing operational energy cost and payback (simulated)	Calculating the operational energy cost and renovation payback using a simulated approach	ACE

UC17	Assessing operational energy cost post-renovation and actual payback	Calculating the actual operational energy cost and renovation payback.	ACE
UC18	Assessing the fuel poverty condition	Assessing the fuel poverty indicator.	ACE, UNIVPM
UC19	Assessing the actual energy savings	Assessing the actual energy savings by comparing pre and post-renovation data measured in the building	ACE

5.1.2 UC1: Assessing the energy performance of buildings with measured data

The UC provides a procedure to obtain a complete overview of the building energy performance, using BIM data to support the assessment based on measured data. The assessment is performed with the data collected in the demo cases. The main goal of the UC is to support the renovation design focusing on the reduction of the building energy consumptions. The renovation strategy should consider the output of the UC, which is implemented in five KPIs (i.e. BS.OPED, BS.TEC, BS.GWP, BS.FP, and BS.OEC). If real data from the building are not available, the energy assessment can be carried out according to UC2.

5.1.3 UC 2: Assessing the energy performance of buildings with simulated data

The UC aims at providing a methodology for the building energy performance assessment using simulated data starting from BIM data. UC2 reports a procedure for generating the energy model of the building (BEM) with which to simulate the building energy performance. The UC specifies the steps to move from the real building to the virtual one, also referring to UC11 for the BIM-to-BEM approach. It supports the renovation design and the reduction of the energy consumptions when real energy data from the building are missing. The output of the UC are obtained from the simulation process and they can be recapped into six KPIs (i.e. BS.OPED, BS.TED, BS.TEC, BS.GWP, BS.FP, and BS.OEC).

5.1.4 UC 3: Assessing the as-built Thermal Comfort with measured data

The UC provides a methodology for evaluating the thermal comfort using real data acquired through a monitoring campaign for a building. The procedure can be identically applied before and after the renovation process. The key target of the UC is the enhancement of the indoor comfort levels in all the possible situations. In fact, this UC explains the methodology for assessing the thermal comfort during the heating season and during the cooling season both with and without (i.e. free-running condition) cooling system. The outputs indicate the percentage of operating hours falling into each building category (i.e. cat. I is the best while cat. IV is the worst) and provide the comfort zones and sensitivity indices to highlight which parameters have the greatest influence on the thermal conditions. It also refers to two KPIs (i.e. BS.TCWC and BS.TC). If real data from the building are not available or monitoring campaign cannot be performed, the thermal comfort assessment can be carried out according to UC4.

5.1.5 UC 4: Assessing the as-built Thermal Comfort with simulated data

The UC provides a methodology for evaluating thermal comfort using simulated data. The procedure can be identically applied before and after the renovation process. This UC is used when the monitoring campaign for the data collection cannot be performed. Therefore, some connections with other UCs are needed (e.g. to UC11 for the BIM-to-BEM approach) for the creation of the BIM and BEM models. The key target of the UC is the enhancement of the indoor comfort levels in all the possible situations. In fact, the UCs contains the methodology for assessing the thermal comfort during the heating season and during the cooling season both with and without (i.e. free-running condition) cooling system. The outputs indicate the percentage of operating hours falling into each building category (i.e. cat. I is the best while cat. IV is the worst) and provide the comfort zones and sensitivity indices to highlight which parameters have the greatest influence on the thermal conditions. It also refers to two KPIs (i.e. BS.TCWC and BS.TC).

5.1.6 UC 5: Assessing the as-built Acoustic Comfort with measured data

The UC provides a methodology to obtain an overall assessment of the acoustic comfort of the building due to the surrounding noise using measured data. The procedure can be identically applied before and after the renovation process. The main target of the UC is the investigation and the optimization of the indoor acoustic comfort levels. The analysis is performed for each room that borders the external environment and then the overall value for the building is calculated. The key output is the acoustic classification of the building, which provides clear and simple identification of the acoustic status of the building. This outcome is also recapped in the BS.AC (Acoustic comfort) KPI. If real data from the building are not available or monitoring campaign cannot be performed, the acoustic comfort assessment can be carried out according to UC6.

5.1.7 UC 6: Assessing the as-built Acoustic Comfort with simulated data

The UC provides a methodology to obtain an overall assessment of the acoustic comfort of the building using simulated data. The procedure can be identically applied before and after the renovation process. The main target of the UC is the investigation and the optimization of the indoor acoustic comfort levels. The analysis is performed through a tool developed by UNIVPM. The procedure is carried out for each room that borders the external environment and then the overall value for the building is calculated. The key output is the acoustic classification of the building, which provides clear and simple identification of the acoustic status of the building. This outcome is also recapped in the BS.AC (Acoustic comfort) KPI.

5.1.8 UC 7: Assessing the as-built Indoor Air Quality with measured data

This UC provides the methodology to measure and assess the level of indoor air quality with respect to requirements suggested by actual standards. The procedure can be identically applied before and after the renovation process. The goal of the UC is the investigation and the enhancement of the indoor air quality levels through the renovation process. The outputs of the UC indicate the percentage of operating hours falling into each building category (i.e. cat. I is the best while cat. IV is the worst) and the BS.IAQ KPI. According to the outcome, the designers can understand which zones / areas need to be enhanced both at room and building level. If real data from the building are not available or monitoring campaign cannot be performed, the IAQ assessment can be carried out according to UC8.

5.1.9 UC 8: Assessing the as-built Indoor Air Quality with simulated data

This UC provides the methodology to simulate and assess the level of indoor air quality with respect to requirements suggested by actual standards. The procedure can be identically applied before and after the renovation process. The goal of the UC is the investigation and the enhancement of the indoor air quality levels through the renovation process. The outputs of the UC indicate the percentage of operating hours falling into each building category (i.e. cat. I is the best while cat. IV is the worst) and the BS.IAQ KPI. According to the outcome, the designers can understand which zones /areas need to be enhanced at both room and building level.

5.1.10 UC 9: Assessing the as-built Visual Comfort with measured data

This UC provides the methodology for assessing the occupants' Lighting and Visual comfort using measured data. The procedure can be applied both before and after the renovation process. The evaluation of the visual comfort is performed throughout a specific timeline (e.g. yearly, monthly, and daily), within a specific geo-location and considering physical constraints (e.g. window to wall ratio, spatial depth). The output of the UC presents a complete /data informative assessment of the Visual and Daylight comfort of the investigated building (to contrast with BREAM, LEED standard) to understand current building performance and determine the area of improvement through renovation. It is also linked to the BS.VC (Visual Comfort) KPI. If real data from the building are not available or monitoring campaign cannot be performed, the visual comfort assessment can be carried out according to UC10.

5.1.11 UC 10: Assessing the as-built Visual Comfort with simulated data

This UC provides the methodology for assessing the occupants' Lighting and Visual comfort using simulated data. The procedure can be applied both before and after the renovation process. The UC explains how to obtain the virtual model of the building and how to perform the lighting analysis with simulation software. The output of the UC presents a complete data informative assessment of the Visual and Daylight comfort of the investigated building (to contrast with BREAM, LEED standard) to understand current building performance and determine the area of improvement through renovation. It is also linked to the BS.VC (Visual Comfort) KPI.

5.1.12 UC 11: Development of the BIM-to-BEM approach

The UC explains the approach for the BIM-to-BEM interoperability process, which is used to perform building energy performance analyses. An efficient and practical BIM-to-BEM workflow supplies several benefits to the design process. It speeds up the renovation process while reducing the data losses and facilitating the correct flow of information from the geometrical model (i.e. the BIM) to the energy model (i.e. the BEM). The UC identifies the requirements of the BIM model to ensure the reliability and usability of the BIM-to-BEM workflow selected for the BIM-SPEED platform. The key output of the UC is the BEM model of the investigated building, which is the crucial component during the design process.

5.1.13 UC 12: Calibration of the building energy model

UC12 focuses on the definition of a standardized approach to perform the calibration of the BEM model. The UC 12 is directly connected to the previous one since the main input is the energy model realized according to UC11. The methodology for the calibration includes both manual and automated approaches to give a wider range of possibilities to execute the calibration. Investigating different design options with a well-calibrated energy model can reduce the energy performance gap since it provides strong and reliable outputs. Therefore, the building energy consumptions can be reduced through the identification of the most suitable interventions for the specific building.

5.1.14 UC 13: Optimization procedure for selecting the best EEB renovation scenario

The UC provides an optimization procedure to simulate and post-process a large number (i.e. hundreds to thousands) of different renovation scenarios for a project. The best scenarios according to energy, cost and comfort criteria are identified by the METABUILD tool. The main advantage of using this UC is the possibility to analyse a big amount of possible interventions and identify one or a set of optimal EEB renovation scenario(s). In particular, the evaluation process furnishes the energy, costs and comfort performance after the renovation and a complete overview of the savings obtained from the comparison to the “as-is” scenario. Therefore, UC13 speeds up the renovation process and reduces the building energy consumptions.

5.1.15 UC 14: Post Occupancy Evaluation to verify the predictions’ reliability of renovation scenario

The UC focuses on the assessment of predictions reliability of the adopted renovation solution. The building performance assessment is realized by using qualitative and quantitative data that concern energy aspects, the indoor environmental quality (i.e. IAQ, thermal, acoustic, and visual comfort), users’ well-being, systems’ carbon emissions and the cost of the occupancy (i.e. maintenance). Such Post Occupancy Evaluation (POE) can be used to validate and calibrate the analytic methods and/or simulation models developed in the course of the BIM-SPEED project. UC14 gives as output a complete assessment of the performance of the renovated building. Objective (e.g. total energy consumptions) and subjective (e.g. occupants’ interviews) data collected in the building are used to investigate the actual condition. In addition, the UC adopts KPIs (calculated before and after the renovation) to provide feedback on the extent to which the renovation objectives have been met.

5.1.16 UC 15: Assessing operational energy costs using measured data

The UC aims to calculate the flat the operational energy costs using measured data for the pre and post renovation scenario. The output of the UC supports the economic and the sustainability analysis since it highlights the actual costs (in €/m^2) faced by the occupants.

5.1.17 UC 16: Assessing operational energy cost using simulated data

The UC targets at assessing the operation energy costs for each of the evaluated renovation solutions using simulated data. The operational energy costs are derived from simulations in order to compare each design option proposal.

5.1.18 UC 17: Assessing the investment payback

The UC aims to provide an indicator to assess the investment payback for each design option. The output of the UC supports the economic and the sustainability analysis since it provides means to compare each design option for supporting investment decisions.

5.1.19 UC 18: Assessing the fuel poverty condition

The UC focuses on the assessment of the fuel poverty condition of the inhabitants. The energy consumption expenditure for the calculation is simulated, assuming the comfort levels are achieved throughout the year. If more than 10% of the household income is taken by the energy bill (keeping comfort levels), the fuel poverty is confirmed.

5.1.20 UC 19: Assessing the actual energy savings

The UC provides a procedure to obtain a complete overview of the actual building energy savings. The assessment is based on data collected in the demo case pre and post-renovation in order to calculate the actual energy savings.

6. Conclusions

This report presents the overall BIM-SPEED approach for building performance assessment based on the BIM. A set of KPIs has been developed, starting from previous experience of H2020 projects and literature analysis. That set has been harmonized to fulfil requirements derived from the development of the BIM-SPEED performance assessment and optimization platform. The scope of the platform is to get measured data together with BIM data so to create a reliable baseline of the building performance and calibrated models to be used for analysing the impact of renovation scenarios. To this aim, together with the KPIs, this report presented also the approach for creating the baseline, taking advantage of current standard and protocols (e.g. IPMVP).

To put in place the performance assessment approach, the overall renovation process has been divided in 5 stages to identify the required BIM-based tools required for overcoming the current barriers for the use of BIM in renovation projects. From the global picture, two stages of the renovation have been selected, where the performance assessment has been considered "relevant". Then, a set of initial Use Cases has been suggested to allow the implementation of the performance assessment platform. These Use Cases will be worked out in detail within the future work of the BIM-Speed project, leading to a description of the operations required to implement the entire assessment procedure. Future work will also detail which data is required, what calculation and operation methods need to be conducted with which tools, and what output data is required for a holistic performance assessment. developed in the other BIM-SPEED work packages. The outcome of this report will be the base of the next project phase, where the performance assessment tools will be developed. Once defined, these routines will be implemented in the BIM-Speed platform allowing for the streamlined storage of all required data, as well as, establishing the required interoperability between the different data and the different software tools required. In this sense, the KPIs and Use Cases will be living objects. When necessary, further KPIs will be included to improve the holistic platform and keep the pace of the state of the art in this field.

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APPENDIX 1 – KPIs Description

A1.1 Operational Primary Energy Demand

ID: BS.OPED [kWh/m^{2}year]

RESPONSIBLE PARTNER: CARTIF

DEFINITION: The primary energy is the energy supplied to the building (from renewable and non-renewable sources) that has not been subjected to any conversion or transformation process. It is the energy contained in fuels and other sources of energy and includes the energy necessary to generate the final energy consumed, including losses due to transformation, transportation to the building, etc. These losses are included in the primary energy factors. National or even regional conversion factors for calculating the primary energy consumptions from calculated or measured final energy consumption depend on the fuel and the fuel mix for generating electricity.

OBJECTIVE: The aim of this KPI is the reduction of the primary energy consumptions due to the integration of renewable energy sources and the improvement of the building's energy performance. The use of primary energy is required for calculating the environmental impact.

ASSESSMENT CRITERION: The primary energy demand is calculated from the final energy consumption (including renewable and non-renewable sources) and corresponding fuel-to-primary and electricity-to-primary conversion factors.

Data required: The input data required are related to the energy consumption of the building, the energy exported and the primary energy factors. They are recapped in Table 3.

Table 3: Data required for the BS.OPED KPI calculation

Input	Unit/Format
Final energy for energy carrier i	kWh
Primary energy factor (PEF) for final energy carrier i	-
Energy exported for energy carrier i	kWh
Primary energy factor (PEF) for exported energy carrier i	-
Size of the building (e.g. gross floor area, net floor area, conditioned floor area)	m^2

Calculation method: The final energy consumption can be directly measured onsite (monitoring systems), simulated (energy simulation tools) or directly derived from bills. To enable the comparability between buildings, the primary energy demand is related to the size of the building (e.g. conditioned area) and the considered time interval (e.g. year).

$$E_P = \frac{\sum(E_{F,i} \cdot fp_{F,i}) - \sum(E_{Exp,i} \cdot fp_{Exp,i})}{A_b} \qquad \left[\frac{kWh}{m^2}\right]$$

Where:

E_P: Operational Primary Energy Demand $\left[\frac{kWh}{m^2}\right]$;

$E_{F,i}$: Final energy for energy carrier I [kWh];

$fp_{F,i}$: Primary energy factor (PEF) for final energy carrier i [-];

$E_{Exp,i}$: Energy exported for energy carrier i [kWh];

$fp_{Exp,i}$: Primary energy factor (PEF) for exported energy carrier i [-];

A_b: Size of the building (e.g. gross floor area, net floor area, conditioned floor area) [m^2].

BENCHMARKS: Total annual primary energy demand for all end-uses in energy-efficient buildings does not usually exceed 120 kWh/m^2 (EPBD) [5]. Within the EPBD, the choice of values for primary energy factors (PEFs), which are used to calculate the primary energy content of energy delivered by different energy carriers, is at the discretion of Member States. In the following tables, Primary Energy Factors for some countries are reported:

Table 4: Primary Energy Factors for Spain [6]

Energy source	Factor $_{renewable}$	Factor $_{non-renewable}$	Factor $_{total}$
National conventional electricity	0.396	2.007	2.403
Peninsular conventional electricity	0.414	1.954	2.368
Diesel fuel for heating	0.003	1.179	1.182
LPG	0.003	1.201	1.204
Natural gas	0.005	1.190	1.195
Coal	0.002	1.082	1.084
Un-densified biomass	1.003	0.034	1.037
Densified biomass (Pellets)	1.028	0.085	1.113

The Primary Energy Factors for electricity generation as reported in the national standards on energy performance for buildings [7] and other conversion factors for different countries [8] are shown in the tables below.

Table 5: Primary Energy Factors for electricity generation for different countries [7]

	France	Germany	NL	Poland	Spain	Sweden	UK
PEF	2.58	2.6	2.56	3	2.6	2	2.92

Table 6: Primary Energy Factors for different energy carriers for specific countries [8]

Energy carrier	Metrics	Austria	Denmark	Finland	Germany	Italy	Sweden	Switzerland
Electricity	Non-renewable	1.3	-	1.7	2.6	2.18	-	2.53
	Total	1.91	2.5	1.7	3	-	1.5	2.97
Natural gas	Non-renewable	1.12	-	1	1.1	1	-	1.1
	Total	1.12	1	1	1.1	-	-	1.15
Oil	Non-renewable	1.11	-	1	1.1	1	-	1.15
	Total	1.13	1	1	1.1	-	1.2	1.24
Wood, pieces	Non-renewable	0.01	-	0.5	0.2	0	-	0.05
	Total	1.01	1	0.5	1.2	-	1.2	1.06
Wood, pellets	Non-renewable	0.14	-	0.5	0.2	0	-	0.3
	Total	1.16	1	0.5	1.2	-	1.2	1.22
District heat 70% CHP (fossil)	Non-renewable	0.76	-	-	0.7	-	-	0.81
	Total	0.77	1	0.7	0.7	-	0.9	0.8

The following table shows the interval of values of total PEF for the categories most frequently reported by the different member states [9].

Table 7: Interval of values of the total PEF for the different energy carriers reported by different member states [9]

Countries	Mains gas	LPG	Oil general	Diesel or heating oil	Fuel oil	Coal general	Biomass general	Wood general	Wood pellets	Grid Electricity	District heating general
EU countries in average	1.00 – 1.26	1.00 – 1.20	1.00 – 1.23	1.00 – 1.14	1.00 – 1.20	1.00 – 1.46	0.01 – 1.10	0.01 – 1.20	0.01 – 1.26	1.5 – 3.45	0.15 – 1.50
CEN (non-renewable) defaults	1.1	1.1	1.1	1.1	1.1	1.1	0.2	0.2	0.2	2.3	1.3

REFERENCES:

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[3] CITYFIED Project, “D2.2: Annex 1. Key Performance Indicators at project level”, December 2014.
[4] REMOURBAN Project,”D2.2: Evaluation protocols and indicators”, July 2016.
[5] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.
[6] Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España.
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[8] I. Satori, A. Napolitano, and K. Voss, “Net zero energy buildings: A consistent definition framework”, Energy and Buildings, vol. 48, pp. 220 – 232, May 2012.
[9] Roger Hitchin, Kirsten Engelund Thomsen, Kim B. Wittchen, “Primary Energy Factors and Members States Energy Regulations”.

A1.2 Total Energy Demand

ID: BS.TED [kWh/m^{2}year]

RESPONSIBLE PARTNER: CYPE

DEFINITION: The energy demand of the building is the total amount of energy the technical systems of the building (heating and cooling) have to provide to maintain its indoor environment in comfortable conditions. The calculation is usually performed for the period of one year. Total energy demand differentiates energy demand for cooling and heating as each of them appears at different times of the year and have to be calculated separately. The total energy demand is measured kWh/m^{2}year.

OBJECTIVE: The energy demand of a building states the quality of its envelope. For building renovation, it is crucial to know the energy demand of the building to be able to calculate its energy consumption and consequently to optimize its energy performance. It also supports the decision-making process, for example re-designing with passive house strategies to lower energy demand of the building before even installing any technical system.

The objective of this KPI is to have an assessment of building consumptions. This KPI aids the designers in selecting the most energy-efficient systems to improve the overall building energy performance.

ASSESSMENT CRITERION: Total Energy Demand KPI derives from the energy balance of the building calculated for each month. It takes into account the energy lost and gained due to thermal transmission via opaque and transparent elements, the energy interchange due to ventilation and infiltration, the gains due to occupancy, lighting and internal equipment as well as the required heating and cooling inputs.

Data required: The input data required are recapped in Table 8.

Table 8: Data required for the BS.TED KPI calculation

Input	Unit/Format
Weather Data File	.epw, .fwt
Conductivity of materials	W/(mK)
Thermal resistance of materials	$(m^2K)/W$
Thickness of materials	m
Density of materials	kg/m^3
Specific Heat of materials	J/(kgK)
Heat transfer of transparent elements	$W/(m^2K)$
Air permeability of transparent elements	$m^3/(hm^2)$
Solar factor of transparent elements	-
Heating set point temperatures of building zones	°C
Cooling set point temperatures of building zones	°C
Floor area of building zones	m^2
Room internal height	m
Volume	m^3

Calculation method: Total Energy Demand can be calculated through different methods. The most reliable ones are based on software simulation engines (e.g. EnergyPlus and TRNSYS). The core of the simulation is the model of the building that is based on fundamental heat balance principles.

The calculation of Total Energy Demand KPI can be performed using any simulation engine or equivalent simplified methods. Both the approaches must consider, either in detailed or in a simplified form, the following aspects:

a) Design, location and orientation of the building;

b) Evolution hour by hour in the transitory regime of the thermal processes;

c) Thermal coupling between adjacent areas of the building at different temperatures;

d) External conditions, internal conditions and operational conditions, taking into account the possibility that spaces behave in free oscillation;

e) Energy gains and losses for conduction through the thermal envelope (opaque enclosures, hollow and thermal bridges) taking into account the thermal inertia of the building;

f) The gains and losses produced by solar radiation passing through transverse transparent or semi-transparent elements and those related to the heating of opaque elements. Properties, orientation and inclination of the elements and the shadows of the building and other obstacles that can block radiation must be considered. In particular, it has to be evaluated:

- Gains and losses of energy produced by the exchange of air with the exterior due to ventilation and infiltration. Air quality requirements of the different spaces and the control strategies employed must be taken into account.
- Characterization of building envelope elements (opaque enclosures, transparent components and thermal bridges). Opaque enclosure features concern:

a) Geometric and constructive characteristics;

b) Boundary conditions (contact with air, terrain or adiabatic) and the thermal zone to which they belong;

c) Thermal properties: conductivity or thermal resistance, density, specific heat;

d) Air permeability.

Transparent component features include:

a) Geometric and constructive characteristics;

b) The opaque element where they are located;

c) Description and characterization of sunscreens and other elements that may produce shadows;

d) Thermal transmittance of the glazing and the frame;

e) The solar factor of the glazing;

f) Absorptivity of the outer face of the frames;

g) Air permeability.

Linear thermal bridges feature concern:

a) Type, description and location;

b) Linear thermal transmittance obtained in relation to the adjacent enclosures;

c) Length.

Calculation procedure: The energy demand is calculated through an energy balance in each of the thermal zones of the building, at least on an hourly basis.

$$Q_{z,i} + Q_{op,i} + Q_{w,i} + Q_{ve+inf,i} + Q_{equip,i} + Q_{light,i} + Q_{ocup,i} = 0$$

Where:

$Q_{z,i}$ = the amount of energy required to keep the temperature conditions in the zone “i”, given the contributions of the different elements of the building zone [kWh];

$Q_{op,i}$ = Energy transfer corresponding to the thermal transmission across opaque elements of the envelope, including thermal bridges [kWh];

$Q_{w,i}$ = Energy transfer corresponding to the thermal transmission across transparent elements of the envelope [kWh];

$Q_{ve+inf,i}$= Energy transfer corresponding to the thermal transmission due to ventilation and infiltration [kWh];

$Q_{equip,i}$ = Energy transfer corresponding to the internal heat gain due to internal equipment [kWh];

$Q_{light,i}$ = Energy transfer corresponding to the internal heat gain due to lighting [kWh];

$Q_{ocup,i}$ = Energy transfer corresponding to the internal heat gain due to internal occupancy [kWh].

Note:

- Heat gains are represented by positive amounts, while heat losses are represented by negative amounts.
- A positive value of $Q_{z,i}$ expresses a heating demand, while a negative value of $Q_{z,i}$ expresses a cooling demand.

The total heating energy demand is the sum of the heating demand of all the thermal zones in the building during a year, divided by the total surface of the building occupied zones.

$$Q_H = \frac{\sum_{z=1}^{n} Q_{H,i}}{\sum_{z=1}^{n} S_{z,i}} \qquad \left[\frac{kWh}{m^2 year}\right]$$

Where:

$S_{z,i}$ = Zone surface [m^2];

$Q_{H,i}$ = Total heating energy demand [kWh/m^{2}year];

Finally, the Total Energy Demand is calculated as the following:

$$Q = Q_H + Q_C \qquad \left[\frac{kWh}{m^2 year}\right]$$

Where:

$S_{z,i}$ = Zone surface [m^2];

Q_H = Total heating energy demand [kWh/m^{2}year];

Q_C = Total cooling energy demand [kWh/m^{2}year].

BENCHMARKS: The Energy Performance Directive requires all new buildings to be nearly zero-energy by the end of 2020. Member states are required to develop long-term renovation strategies to achieve energy-efficient a decarbonised European building stock by 2050. According to the Commission's impact assessment, renovation at an average rate of 3% annually is needed to accomplish the Union's energy efficiency ambitions in a cost-effective manner.

REFERENCES:

[1] 2010/31/UE - Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[2] 2018/844/UE - amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.
[3] EnergyPlus Manuals - https://energyplus.net/documentation
[4] ISO 12655:2013 - Energy performance of buildings -- Presentation of measured energy use of buildings.
[5] CTE – Technical Code for Edification of Spain.
[6] EN ISO 52016-1:2017 Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures.

A1.3 Total Energy Consumption

ID: BS.TEC [kWh/m^{2}year]

RESPONSIBLE PARTNER: CYPE

DEFINITION: The Total Energy Consumption is the balance between the energy necessary to meet the energy demand of the building, that includes the energy supplied for heating, cooling, ventilation, domestic hot water, lighting among others (equipment and appliances) and the energy generated by the building during a certain period (usually one year). The total energy consumption is measured kWh/m^{2}year.

Type of Energy Consumption: The calculation of the Total Energy Consumption KPI derives from the combination of different KPIs, that have to be calculated separately: Total Energy Consumption for Heating KPI, Total Energy Consumption for Cooling KPI, Total Energy Consumption for Domestic Hot Water KPI, Total Energy Consumption for Lighting KPI (Fig. 1). The achievement of detailed characterization profiles allows for a more reliable assessment of the energy efficiency of the building and for designing innovative control strategies based on consumption patterns.

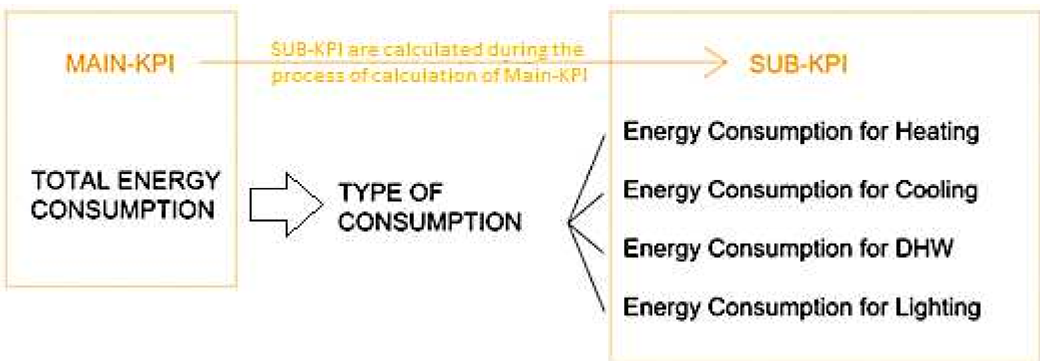


Figure 1 Type of energy consumptions

a) Total Energy Consumption for Heating: BS.ECH [kWh/m^{2}year].

Description: Energy consumption required to meet the reference for annual heating demand. Heat is the largest energy end-use. Heating for homes, industrial purposes and other applications account for around 50% of total energy consumption.

b) Total Energy Consumption for Cooling: BS.ECC [kWh/m^{2}year].

Description: Energy consumption required to meet the reference of annual cooling demand.

c) Total Energy Consumption for Domestic Hot Water: BS.DHWC [kWh/m^{2}year].

Description: Energy consumption required to meet the reference for annual DHW demand. Domestic how water (DHW) aggregates various uses in a household and accounts for a significant share of energy consumptions in a building.

d) Total Energy Consumption for Lighting: BS.ECL [kWh/m^{2}year]

Description: Energy consumption required to meet the reference annual Lighting demand. Electrical light sources are responsible for the energy consumption of around 1/6 to 1/5 of worldwide electricity production.

OBJECTIVE: Total Energy Consumption of the building has dramatically increased over the past decade where building energy use accounts for over 40% of total primary energy consumption in first world countries and the growing trend in building energy consumption will continue during the coming years due to the expansion of built area and its associated energy needs.

The objective of this KPI is to have an assessment of building consumptions. This KPI aids the designers in selecting the most energy-efficient systems to improve the overall building energy performance. Moreover, the Total Energy Consumption KPI is necessary for calculating the environmental impact and the CO_2 emissions indicators.

ASSESSMENT CRITERION: Total Energy Consumption is calculated taking into account the different fuel sources (e.g. oil, coal, solar…) in order to derive an appropriate energy performance indicator. For this calculation, energy conversion factors for each country are required.

Data required: The input data required are recapped in Table 9.

Table 9: Data required for the BS.TEC KPI calculation

Input	Unit/Format
Weather Data File	.epw, .fwt
Conductivity	W/(mK)
Thermal resistance	(m^{2}K)/W
Thickness	m
Density	kg/m^3
Specific Heat	J/(kgK)

Thermal bridges	W/(mK)
Heating setpoint temperatures	°C
Cooling setpoint temperatures	°C
Floor area	m^2
Room internal height	m
Volume	m^3
Internal gains due to occupancy, equipment, lighting	W
Ventilation needs	m^3/s
Energy Conversion Factors (solar, wind, natural gas, coal)	-
Rated Heating Power	kW
Rated Cooling Power	kW
Heating efficiency or Coefficient of Performance (COP)	-
Cooling efficiency or Energy Efficiency Ratio (EER)	-
Performance curves for correcting rated conditions depending on actual working conditions	-
DHW demand	m^3
Tap water temperature	°C

Calculation method: The Total Energy Consumption KPI can be calculated through different methods. The most reliable ones are based on software simulation engines, (e.g. EnergyPlus and TRNSYS). The core of the simulation is the model of the building that is based on fundamental heat balance principles. Calculation engines also include models of the building systems and are able to simulate the coupling between the building zones and the HVAC system. The changes in the systems working conditions are taken into account in the calculation of their actual capacities and power inputs, in most cases by using performance curves. Nowadays simulation engines are the most reliable way of making energy and thermal calculations.

The calculation of Total Energy Consumption KPI can be performed using any simulation engine or equivalent simplified methods. Both the approaches must consider, either in detailed or in a simplified form, the following aspects:

a) Design, location and orientation of the building.

b) Evolution hour by hour in the transitory regime of the thermal processes.

c) Thermal coupling between adjacent areas of the building at different temperatures.

d) External conditions, internal conditions and operational conditions, taking into account the possibility that spaces behave in free oscillation.

e) Energy gains and losses for conduction through the thermal envelope (opaque enclosures, hollow and thermal bridges) taking into account the thermal inertia of the building.

f) The gains and losses produced by solar radiation passing through transverse transparent or semitransparent elements and those related to the heating of opaque elements. Properties, orientation and inclination of the elements and the shadows of the building and other obstacles that can block radiation must be considered.

g) Gains and losses of energy produced by the exchange of air with the exterior due to ventilation and infiltration. Air quality requirements of the different spaces and the control strategies employed must be taken into account.

h) Needs of the heating, cooling, DHW and ventilation services, humidity control and lighting.

i) Sizing and performance of equipment and systems for cooling and heating energy production, DHW, ventilation, humidity control and lighting.

j) Use of different sources of energy, both generated in situ and remotely.

k) Energy conversion factors of final energy to primary energy from renewable and non-renewable sources.

l) Contribution of renewable energies produced in situ or in the proximity of the plot.

Calculation scheme: E_p= Primary energy consumption [kWh/m^{2}year] as defined in A1.1 Operational Primary Energy Demand.

Step 1: Calculate individual needs for each of the target building services.

- **Heating:** Heating demand per zone ($Q_{H,i}$), as detailed in Total Energy Demand KPI.
- **Cooling:** Cooling demand per zone ($Q_{C,i}$), as detailed in Total Energy Demand KPI.
- **DHW:** DHW energy demand is the amount of energy required to increase the temperature of the tap water to the setpoint temperature for domestic hot water.

$$Q_{DHW} = V_{DHW} \cdot \rho_w \cdot c_{p,w} \cdot (T_{DHW} - T_{tap})$$

Where:

Q_{DHW} = DHW energy demand [kWh];

V_{DHW} = DHW demand at the setpoint temperature [m^3];

T_{DHW} = Setpoint temperature for DHW [°C];

T_{tap} = Tap water temperature [°C];

ρ_w = Density of water (≈ 1000) [kg/m^3];

$c_{p,w}$ = Specific heat capacity of water ≈ 4180 [J/kg°C].

- **Lighting:** lighting energy demand [kWh] equals the installed lighting power of the building times the number of hours it is switched on depending on the building use.

Step 2: Calculate final energy consumption by each of the building systems to produce the energy needed.

$$E_{co,S} = \sum_{i=1}^{n} Q_{S,i} \cdot SP_{S,i} \Big/ \sum_{i=1}^{n} S_{z,i}$$

Where:

$E_{co,S}$ = Total energy consumption for the building service "S" [kWh/m^{2}year];

$Q_{S,i}$ = Total energy demand of zone "i", for service "S" [kWh/ year];

$SP_{S,i}$ = Seasonal performance factor of the system "S" that serves zone "i"[-];

$S_{z,i}$ = Zone "i" surface [m^2].

Note: calculation engines simulate the thermal building systems dynamically, taking into account the change in their performance with the working conditions hour by hour.

BENCHMARKS: The Energy Performance Directive requires all new buildings to be nearly zero-energy by the end of 2020, meaning each building will have to produce almost all of its energy consumption on-site, and take just short amount of energy from the grid.

Member states are required to develop long-term renovation strategies to achieve energy-efficient a decarbonised European building stock by 2050. According to the Commission's impact assessment, renovation at an average rate of 3% annually is needed to accomplish the Union's energy efficiency ambitions in a cost-effective manner.

REFERENCES:

[1] 2010/31/UE - Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[2] 2018/844/UE - amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

[3] EnergyPlus Manuals - https://energyplus.net/documentation

[4] ISO 12655:2013 - Energy performance of buildings -- Presentation of measured energy use of buildings.

[5] CTE – Technical Code for Edification of Spain.

[6] EN ISO 52016-1:2017 Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures.

A1.4 Total Energy Savings

ID: BS.TES [kWh/m^{2}year]

RESPONSIBLE PARTNER: CYPE

DEFINITION: The Total Energy Savings is a KPI that provides the amount of energy that has been saved due to the renovation process. It represents the difference between Total Energy Consumption before renovation and Total Energy Consumption after renovation. The total energy savings are measured in kWh/m^{2}year.

OBJECTIVE: Total Energy Savings KPI quantifies the savings due to the renovation interventions in the building. It is a crucial indicator for aiding users and stakeholders in the decision-making process and in selecting the most suitable renovation action.

ASSESSMENT CRITERION: Total Energy Savings KPI depends directly on the calculations of energy consumption before and after building renovation.

The approach for calculating energy savings is connected to the **Baseline** (Section **Errore. L'origine riferimento non è stata trovata.**). Three different circumstances can occur. In the first one, the building or the facility energy performance can be measured on-site both pre and post the renovation intervention. In this case, the total energy savings should be done calculated making the required adjustment to the Energy Baseline (i.e. the pre-renovation situation) in order to make the two time spans comparable. The second situation is when real energy data can be measured only after the renovation while the historical data are missing, In this circumstance, Option D should be followed since it provides the baseline through calibrated simulations. The last case is related to the unfeasibility of performing real measurements. If the energy performance needs to be simulated both in the pre and post scenario, the adjusted baseline is not required since the boundary conditions between the two situations are exactly the same (e.g. same weather file and identical occupancy schedules).

Data required: The input data required are recapped in Table 10.

Table 10: Data required for the BS.TES KPI calculation

Input	Unit/Format
Total Energy Consumptions before renovation	kWh/m^{2}year
Total Energy Consumptions after renovation	kWh/m^{2}year

Calculation method: Total Energy Savings KPI is given by the difference between Total Energy Consumptions of the building before and after renovation.

$$S_t = C_{br} - C_{ar} \quad \left[\frac{kWh}{m^2 year}\right]$$

Where:

S_t = Total Energy Savings [kWh/m^{2}year];

C_{br} = Total Energy Consumption before renovation [kWh/m^{2}year];

C_{ar} = Total Energy Consumption after renovation [kWh/m^{2}year].

BENCHMARKS: The Energy Performance Directive requires all new buildings to be nearly zero-energy by the end of 2020. Member states are required to develop long-term renovation strategies to achieve energy-efficient a decarbonised European building stock by 2050. According to the Commission's impact assessment, renovation at an average rate of 3% annually is needed to accomplish the Union's energy efficiency ambitions in a cost-effective manner. It does not exist a unique threshold, because the savings and the consideration about them are specific to each building (e.g. a building with a G label need higher savings than a B label one). Energy efficiency renovations are considered to have one of the highest paybacks relative to cost. The benchmark will be to provide enough energy savings to have a short return of investment for the renovation, from 2 up to 4 years.

REFERENCES:

[1] 2010/31/UE - Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[2] 2018/844/UE - amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

[3] EnergyPlus Manuals - https://energyplus.net/documentation

[4] ISO 12655:2013 - Energy performance of buildings -- Presentation of measured energy use of buildings.

[5] CTE – Technical Code for Edification of Spain.

[6] EN ISO 52016-1:2017 Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures.

A1.5 Energy Signature

ID: BS.ES [kWh]

RESPONSIBLE PARTNER: STRESS

DEFINITION: The Energy Signature (ES) of a building is a method of assessment, described in Annex B of EN 15603, in which the energy consumption for heating, cooling and hot water is correlated with climatic data over a suitable period.

OBJECTIVE: The Energy Signature KPI provides a straightforward way of estimating and comparing the performances of the buildings among different climatic contexts, allows a direct comparison between the calculated values with the actual consumption of the buildings and provides fast feedback on their performances.

In line with EN 15603 indications, the internal temperature is assumed as constant and it is useful in buildings with stable heat gains and relatively low passive solar gains.

The definition of Energy Signature assumes a hypothesis that external temperature is the most influential parameter related to energy consumption. During the winter season, the external temperature is actually the most influential parameter, but in summer, internal loads and solar gains could affect significantly the calculation results. This represents the main limit of this KPI.

ASSESSMENT CRITERION: Energy consumptions (heating, cooling, hot water), as well as average external temperature or accumulated temperature difference, are recorded at regular intervals and reported on a graphical representation that provides useful information on the energy performance. The assessment criterion proposed is based on the following assumptions:

- The presence of ongoing monitoring (based on hourly or sub-hourly measurements) common to all the demo sites, before and after the interventions;

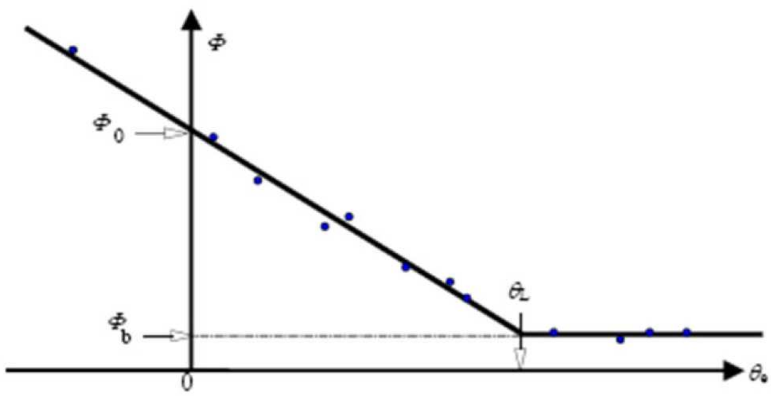
- All the KPIs calculations should be based on a predefined minimal data set (in some cases, the installation of additional sensors and meters should be necessary).

Data required: The input data required are recapped in Table 11.

Table 11: Data required for the BS.ES KPI calculation

Input	Unit/Format
Average power	kW
Power at 0 °C	kW
Base power	kW
Heating limit external temperature	°C
External average temperature	°C

Calculation method: The first step to define the Energy Signature KPI of a building is to collect the energy consumption data (heating, cooling, hot water) and the average external temperature at regular intervals (e.g. an hour is sufficient) over a certain period. The average external temperature can be measured directly or can be recovered from available neighbouring weather station data. Afterwards, it is necessary to obtain the average power by dividing the energy consumption by the duration of the time interval between successive records (e.g. hours). The average power and the average external temperature are plotted on a graph, like the one below (Fig.2). The diagonal line



is drawn using linear regression of the dots that represent the measurement campaigns conducted during the heating season.

Figure 2 Example of an Energy Signature (source: EN 15603)

The horizontal line (or with nearly-zero slope) represents the system loss and the energy services other than heating and cooling (e.g. hot water) independent of the outside temperature. The line drawn during the heating (or cooling) season is characterised by power, ϕ_0 at 0 °C, and a slope (or gradient), H:

$$\phi = \phi_0 - H\theta_e \quad [kW] \quad (eq. 1)$$

Where:

H is the slope of the diagonal line; it represents the sensitivity of the building to changes in external temperature;

$$H = {(\phi_0 - \phi_b)}\big/{\theta_l} \quad \left[\frac{kW}{°C}\right] \quad (eq. 2)$$

Where:

θ_e is the external average temperature between two successive records [°C];

ϕ_b is the base power, not dependant on external temperature (e.g. for system loss and hot water) [kW];

θ_l is the heating limit external temperature [°C];

The above equation (1) can be compared to the global, simplified average energy balance of the building:

$$\phi = H'(\theta_i - \theta_e) + \emptyset_a - \eta(A_e I_{sol}) \ [kW] \quad (eq. 3)$$

Where:

H' is the heat transfer coefficient of the building [W/K];

θ_i is the average internal temperature [°C];

$\emptyset_a$ includes system loss and average power for services other than heating. As a first approximation, this power does not depend on external temperature, and, if the pattern of use of the building is constant, this power can be assumed to be the average power measured during the intermediate season [kW];

η is the utilisation factor of solar gain [-];

A_e is the equivalent solar collecting area [m^2];

I_{sol} is the solar irradiance [W/m^2].

Comparing equation (1) and (3), H' is equal to H and:

$$\phi_0 = H\theta_i + \phi_a - \eta(A_e I_{sol}) \quad [kW] \quad (eq.4)$$

Seasonal energy use for heating can be estimated from the following equation:

$$Q_h = (\phi_0 - H\theta_e)t \quad [kW] \quad (eq.5)$$

Where:

Q_h is the seasonal energy use for the building [kW];
t is the duration of the heating season.

An estimate of the energy requirements can be obtained for a period less than the whole heating season. In any case, to obtain a good accuracy for H and ϕ_0, it is necessary for a large range of external temperatures θ_e.

An estimate of the confidence interval of the energy use for heating is calculated by:

$$\delta Q_h = \sqrt{\left[t^2\delta\phi_0{}^2 + \theta_e{}^2\delta H^2 + t^2 H^2 \delta\theta_e{}^2 + (\phi_0 - H\theta_e)^2\delta t^2\right]} \quad [kW] \quad (eq.6)$$

The energy signature, calculated as previously described, is able to provide a qualitative analysis on the evaluation of the energy consumption of a building.

The dispersion of the individual measurements above or below the line characterising can result from several causes:
- Variable solar or internal gains;
- Varying heat transfer coefficients, e.g. resulting from the effect of wind on a permeable building envelope, malfunctioning of the heating or cooling system.

BENCHMARKS: Daily energy signatures can generate more robust energy consumption benchmarks and provide additional information about the whole system composed by occupants-building envelope- HVAC plants.

REFERENCES:
[1] EN 15603:2008 Energy performance of buildings. Overall energy use and definition of energy ratings.

A1.6 Global warming potential

ID: BS.GWP [$kgCO_{2eq}/m^2year$]

RESPONSIBLE PARTNER: CARTIF

DEFINITION: This indicator represents the CO_2 emissions of a building caused by the different areas of application (heating, cooling, DHW, electrical appliances, etc.). This KPI encompasses the CO_2 emissions caused by the energy supply (thermal and electrical) for operating the building.

OBJECTIVE: The target of this KPI is the reduction of CO_2 emissions due to the integration of renewable energy sources, the use of less polluting fuels and more energy-efficient systems. Global warming potential is necessary for calculating the environmental impact. Comparing the CO_2 emissions may help in the selection of equipment which uses different fuels.

ASSESSMENT CRITERION: Global Warming Potential is expressed in CO_2 emissions (or equivalent) in kg per unit floor area of the building and depends on the specific primary fuel.

The input data required are related to the energy consumption of the building and the emission factors.

Data required: The input data required are related to the energy consumption of the building and the emissions factors. The input data required are recapped in Table 12.

Table 12: Data required for the BS.GWP KPI calculation

Input	Unit/Format
Final energy for energy carrier	kWh
Emission factor for final energy carrier i	$kCO_{2,eq}$/kWh
Size of the building	m^2

Calculation method: To calculate the direct CO_2 emissions, the energy consumption can be translated to CO_2 emissions figures by using conversion factors (emission factors) for different energy forms. The final energy consumption can be measured on-site (monitoring systems), simulated (energy simulation tools) or directly derived from bills. To enable the comparability between buildings, the emissions are related to the size of the building (e.g. gross floor area, net floor area, conditioned floor area) and the considered time interval (e.g. year).

$$Global\ Warming\ Potential\ = \frac{\sum(E_{F,i} \cdot fe_{F,i})}{A_b}\ [kgCO_2eq/m^2]$$

Where:

$E_{F,i}$: final energy for energy carrier i [kWh];

$fe_{F,i}$: emission factor for final energy carrier i [$kgCO_2$/kWh];

A_b: the size of the building (e.g. gross floor area, net floor area, conditioned floor area) [m^2].

BENCHMARKS: Some EU Member States have set minimum requirements on environmental emissions of new buildings, in accordance with EPBD [6]. Total annual primary energy demand for all end-uses in energy-efficient buildings does not usually exceed 120 kWh/m2 that corresponds to about 24.5 kgCO2/m2.

Standard emission factors are provided for European countries by Covenant of Mayor and internationally by IPCC. Emission factors used with reference to source and year should be accompanied by the assessment. Conversion factors for different forms are reported in the following table: National and European emission factors for consumed electricity (Covenant of Mayors). Standard Emission factors for fuel combustion – most common fuel types (IPCC, 2006).

Table 13: National and European emission factors [Covenant of Mayors]

Input	Unit/Format
Austria	0.209
Belgium	0.285
Germany	0.624
Denmark	0.461
Spain	0.440
Finland	0.216
France	0.056
United Kingdom	0.543
Greece	1.149
Ireland	0.732
Italy	0.483
Netherlands	0.435
Portugal	0.369
Sweden	0.023
Bulgaria	0.819
Cyprus	0.874
Czech Republic	0.950
Estonia	0.908
Hungary	0.566
Lithuania	0.153
Latvia	0.109
Poland	1.191
Romania	0.701
Slovenia	0.557
Slovakia	0.252
EU-27	0.460

Table 14: National and European emission factors [Covenant of Mayors]

Type	Standard emission factor (tCO_2/MWh)
Motor gasoline	0.249
Gasoil, diesel	0.267
Residual fuel oil	0.279
Anthracite	0.354
Other Bituminous coal	0.341
Sub-Bituminous coal	0.346
Lignite	0.364
Natural gas	0.202
Municipal wastes (non-biomass fraction)	0.330
Wood	0-0.403

Table 15: Emission factors for Spain [7]

Energy source	Emission factor
National conventional electricity	0.357
Peninsular conventional electricity	0.331
Diesel fuel for heating	0.311
LPG	0.254
Natural gas	0.252
Coal	0.472
Undensified biomass	0.018
Densified biomass (Pellets)	0.018

REFERENCES:

[1] Dr. Russell McKenna, Kilian Seitz, Michael Kleber, "CONCERTO Premium Indicator Guide", November 2012.

[2] Antonio Garrido Marijuán, Ghazal Etminan, Sebastian Möller, "Smart Cities Information System – Key Performance Indicators Guide", February 2017.

[3] CITYFIED Project, "D2.2: Annex 1. Key Performance Indicators at project level", December 2014.

[4] Peter Bosch et al, "CITYkeys list of project indicators", January 2017.

[5] REMOURBAN Project, "D2.2: Evaluation protocols and indicators", July 2016.

[6] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[7] Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España.

A1.7 Thermal Comfort Without Cooling System

ID: BS.TCWCS [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: Thermal Comfort KPI is defined as the percentage of Hours Outside Operative Temperature Range in buildings without mechanical cooling system (applicable to non-heating season). According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

OBJECTIVE: In buildings for dwelling and sedentary activities without cooling systems, where occupants have easy access to operable windows and can freely adapt their clothing to the thermal conditions, the thermal response differs from that of occupants of buildings with HVAC systems, and depends in part on the outdoor climate. The aim of this KPIs thus allows evaluating the thermal quality of the indoor environment and the possibility of avoiding the installation of cooling systems, and the performance of passive measures to guarantee the users' health and well-being and the reduction of energy costs to employ mechanical systems.

ASSESSMENT CRITERION: Thermal Comfort without mechanical cooling system KPI requires room-scale evaluations. The indoor operative temperatures are compared to the external running mean temperature, and the difference is assessed against a set limit to identify the number of days outside an acceptable comfort range; then the room values are aggregated through a floor-area weighted average. The temperatures can be obtained from simulations, as well as they can be acquired from on-site measurements.

Data required: The input data required are recapped in Table 16.

Table 16: Data required for the BS.TCWCS KPI calculation

Input	Unit/Format
Option 1: Indoor operative temperature Option 2: Air temperature Mean radiant temperature Option3: Air temperature Surfaces temperature Space geometry	°C
Daily average outdoor air temperature	°C

Start of cooling season (if simulation) or: Start of the monitoring period (if measurement)	[dd/mm/yy hh:mm] [dd/mm/yy hh:mm]
End of cooling season (if simulation) or: End of the monitoring period (if measurement)	[dd/mm/yy hh:mm] [dd/mm/yy hh:mm]
Occupied days	[d]
Room useful floor area	[m²]
Number of rooms	[-]

Calculation method: The Thermal Comfort without Cooling KPI can be calculated according to the following steps.

1° Method: temperatures are obtained from simulations.

- For each room in the building, calculate the daily average of hourly operative temperatures (To,i) [°C] through a simulation carried out on the entire cooling season.
- For each day j in the cooling season, calculate the running mean of the daily outdoor temperature (T_(rm,j)) [°C], as follows:

$$T_{rm,j} = \frac{T_{ed-1} + 0{,}8T_{ed-2} + 0{,}6T_{ed-3} + 0{,}5T_{ed-4} + 0{,}4T_{ed-5} + 0{,}3T_{ed-6} + 0{,}2T_{ed-7}}{3{,}8} \ [°C]$$

Where:

T_{ed-1} is the daily average of hourly external temperatures for the previous day (according to location weather data);

$T_{ed-2...7}$ are the daily averages of hourly external temperatures for the 2nd … 7th previous days (according to location weather data).

- For every room and every day, calculate the difference between operative and running mean temperature (ΔT_i) as follows:

$$\Delta T_i = T_{o,i} - 0{,}33T_{rm,j} - 18{,}8 \ [°C]$$

- Define the comfort limit ΔT_{lim} as follows:

Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): ΔTlim = ±2 °C;

Category II. New buildings and renovations: ΔTlim = ±3 °C;

Category III. Existing buildings: ΔTlim = ±4 °C;

Category IV. Acceptability for a limited part of the year: ΔTlim > ±4 °C.

- For every room in the building, calculate the number of occupied days outside the range ($d_{or,i}$) as the number of days when $|\Delta T_i| \geq |\Delta T_{lim}|$ and occupancy is above 0;
- For every room, calculate the percentage of occupied days outside the range (POR_i) [%], as follows:

$$POR_i = \frac{d_{or,i}}{d_{tot}} * 100 \ [\%]$$

Where:

d_{tot} = total occupied days during the cooling season [h].

- Calculate the average building percentage of occupied days outside the range, POR, as follows:

$$\Delta T = \frac{\sum_{i=1}^{n} POR_i * S_i}{\sum_{i=1}^{n} S_i} \; [\%]$$

Where:

n = total number of rooms in the building [-];

S_i = floor area of i^{th} room in the building [m^2].

2° Method: temperatures are acquired from on-site measurements.

- For every room in the building and for every day in the monitoring period, calculate the daily average of hourly operative temperatures ($T_{o,i}$) [°C] as follows:

  1) Measure the hourly air temperature ($T_{ah,i,j}$) [°C];

  2) Measure the hourly mean radiant temperature ($T_{ah,i,j}$) [°C];

  3) Calculate the hourly operative temperature

- For everyday j in the cooling season, calculate the running mean of the daily outdoor temperature ($T_{rm,j}$) [°C], as follows:

$$T_{rm,j} = \frac{T_{ed-1} + 0{,}8T_{ed-2} + 0{,}6T_{ed-3} + 0{,}5T_{ed-4} + 0{,}4T_{ed-5} + 0{,}3T_{ed-6} + 0{,}2T_{ed-7}}{3{,}8} \; [°C]$$

Where:

T_{ed-1} is the daily average of hourly external temperatures for the previous day (according to location weather data);

$T_{ed-2...7}$ are the daily averages of hourly external temperatures for the 2nd … 7th previous days (according to location weather data).

- For every room and every day, calculate the difference between operative and running mean temperature (ΔT_i) as follows:

$$\Delta T_i = T_{o,i} - 0{,}33T_{rm,j} - 18{,}8 \; [°C]$$

- Define the comfort limit ΔT_{lim} as follows:

  Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): ΔTlim = ±2 °C;

  Category II. New buildings and renovations: ΔTlim = ±3 °C;

  Category III. Existing buildings: ΔTlim = ±4 °C;

  Category IV. Acceptability for a limited part of the year: ΔTlim > ±4 °C.

- For every room in the building, calculate the number of occupied days outside the range ($d_{or,i}$) as the number of days when $|\Delta T_i| \geq |\Delta T_{lim}|$ and occupancy is above 0;

- For every room, calculate the percentage of occupied days outside the range (POR_i) [%], as follows:

$$POR_i = \frac{d_{or,i}}{d_{tot}} * 100\ [\%]$$

Where:

d_{tot} = total occupied days during the cooling season [h].

- Calculate the average building percentage of occupied days outside the range, POR, as follows:

$$\Delta T = \frac{\sum_{i=1}^{n} POR_i * S_i}{\sum_{i=1}^{n} S_i}\ [\%]$$

Where:

n = total number of rooms in the building [-];

S_i = floor area of i^{th} room in the building [m^2].

Note 1: Only the main rooms that are occupied for several hours and can be identified as "acoustically sensitive" (e.g. bedrooms, living rooms, offices, classrooms) are considered. Short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas, hallways) can be excluded from the analysis. Limit values are referred to as windows closed and shading systems (blinds, shutters, etc.) open. This configuration is supposed to be typical during daytime.

Note 2: As the KPI aggregates the values at the building level to provide an overall value, it can hide localised discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

Note 3: the method is valid only when 15 °C < T_{rm} < 30 °C. Days with T_{rm} values outside this range shall be excluded from the calculation, and the user advised that the outdoor conditions for that day do not allow thermal comfort without mechanical systems.

BENCHMARKS: According to EN 15251, an acceptable amount of deviation is 5% of occupied hours a year. The best performance is achieved when there are no deviations outside the PMV range. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

REFERENCES:

[1] ISO, ISO 7730 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, International Standardization Organization, Geneva (2005).

[2] ISO 7726 Ergonomics of the thermal environment - instruments for measuring physical quantities, International Standardization Organization, Geneva (2002).

A1.8 Thermal Comfort

ID: BS.TC [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: Thermal Comfort KPI is defined as the percentage of Hours Outside PMV Range in buildings in heating season or summer with the cooling system. According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit.

To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

OBJECTIVE: While optimising the heating/cooling systems is crucial to reduce the energy consumption, the comfort of users must be taken into account and guaranteed for most of the operative hours of the systems. Several parameters affect user comfort, and the PMV (Predicted Mean Vote) methodology allows to consider through a single parameter both building- and system-related aspects such as the air and mean radiant temperature, the air speed and humidity, and user-related aspects such as clothing and activity types. As the predicted quality of the indoor thermal environment increases, the PMV value gets closer to 0 (neutral thermal environment). The PMV model and its application for comfort measurement and verification are defined by the EN ISO 7730:2005 [1] and ISO 7726 [2].

ASSESSMENT CRITERION: The hourly PMV values have to be evaluated against a set limit to identify the number of occupied hours outside an acceptable comfort range, and the room values are aggregated through a floor-area weighted average.

Data required: The input data required are recapped in Table 17.

Table 17: Data required for the BS.TC KPI calculation

Input	Unit/Format
Air temperature	[°C]
Mean radiant temperature	[°C]
Air velocity	[m/s]
Relative humidity	[%]
Metabolic rate	[met]
Thermal resistance of clothing	[clo]
Start of the heating season (if simulation) or: Start of the monitoring period (if measurement)	[dd/mm/yy hh:mm] [dd/mm/yy hh:mm]
End of the heating season (if simulation) or: End of the monitoring period (if measurement)	[dd/mm/yy hh:mm] [dd/mm/yy hh:mm]

Occupied days	[d]
Room useful floor area	[m^2]
Number of rooms	[-]

Calculation method: The Thermal Comfort KPI can be calculated according to the following steps.

1° Method: PMV calculation.

- For every room in the building, calculate the hourly PMV ($PMV_{h,i}$) through a simulation carried out on the entire heating season according to the EN ISO 7730:2005 [1] methodology. the data required for the estimation of the PMV are the following: air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate and thermal resistance of the clothing
- Define PMV limit (PMV_{lim}) as follows:

  Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): $PMV_{lim} = \pm 0{,}2$;

  Category II. New buildings and renovations: $PMV_{lim} = \pm 0{,}5$;

  Category III. Existing buildings: $PMV_{lim} = \pm 0{,}7$;

  Category IV. Acceptability for a limited part of the year: $PMV_{lim} > \pm 0.7$.
- For every room in the building, calculate the number of occupied hours outside range $h_{or,i}$ as the number of hours when $|PMV_{h,i}| \geq |PMV_{lim}|$ and occupancy is above 0;
- For every room, calculate the percentage of occupied days outside the range (POR_i) [%], as follows:

$$POR_i = \frac{h_{or,i}}{h_{tot}} * 100\ [\%]$$

  Where:

  h_{tot} = total occupied hours during the heating season [h].
- Calculate the average building percentage of occupied days outside the range, POR, as follows:

$$\Delta T = \frac{\sum_{i=1}^{n} POR_i * S_i}{\sum_{i=1}^{n} S_i}\ [\%]$$

  Where:

  n = total number of rooms in the building [-];

  S_i = floor area of ith room in the building [m^2].

2° Method: PMV measurement.

- For every room in the building, measure the hourly PMV ($PMV_{h,i}$ [-]) for the entire monitoring period during the heating season according to the EN ISO 7726:1998 [3] measurement guidelines;
- Define the PMV limit (PMV_{lim}) as follows:

  Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): $PMV_{lim} = \pm 0{,}2$;

Category II. New buildings and renovations: PMV_{lim} = ±0,5;

Category III. Existing buildings: PMV_{lim} = ±0,7;

Category IV. Acceptability for a limited part of the year: PMV_{lim} > ±0.7.

- For every room in the building, calculate the number of occupied hours outside range $h_{or,i}$ as the number of hours when $|PMV_{h,i}| \geq |PMV_{lim}|$ and occupancy is above 0;
- For every room, calculate the percentage of occupied days outside the range (POR_i) [%], as follows:

$$POR_i = \frac{h_{or,i}}{h_{tot}} * 100\ [\%]$$

Where:

h_{tot} = total occupied hours during the heating season [h].

- Calculate the average building percentage of occupied days outside the range, POR, as follows:

$$\Delta T = \frac{\sum_{i=1}^{n} POR_i * S_i}{\sum_{i=1}^{n} S_i}\ [\%]$$

Where:

n = total number of rooms in the building [-];

S_i = floor area of i^{th} room in the building [m^2].

Note 1: Only the main rooms that are occupied for several hours and can be identified as "acoustically sensitive" (e.g. bedrooms, living rooms, offices, classrooms) are considered. Short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas, hallways) can be excluded from the analysis. Limit values are referred to as windows closed and shading systems (blinds, shutters, etc.) open. This configuration is supposed to be typical during daytime.

Note 2: As the KPI aggregates the values at the building level to provide an overall value, it can hide localised discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

BENCHMARKS: According to EN 15251, an acceptable amount of deviation is 5% of occupied hours a year. The best performance is achieved when there are no deviations outside the PMV range. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

REFERENCES:

[1] ISO, ISO 7730 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, International Standardization Organization, Geneva (2005).

[2] ISO 7726 Ergonomics of the thermal environment - instruments for measuring physical quantities, International Standardization Organization, Geneva (2002).
[3] ISO 7726:1998 Ergonomics of the thermal environment — Instruments for measuring physical quantities.

A1.9 Acoustic Comfort

ID: BS.AC [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: Acoustic Comfort KPI is assessed at building level and, through a single number, it provides a measurement of the indoor acoustic comfort due to the noise coming from outside. In particular, the Acoustic Comfort KPI is based on the evaluation of the indoor noise levels assessed for each room. These levels result from the quantity of the external noise which intrudes into the indoor environments, lowered by the acoustic abatement of the building envelope (according to ISO 12354 part 3).

The KPI is expressed as a percentage value from 0 % (minimum value) to 100 % (maximum value). The percentage value corresponds to an acoustic class, which ranges from A to E.

OBJECTIVE: The aim of the Acoustic Comfort KPI is to provide an assessment of the acoustic comfort of a building before and after renovation. Since it can be obtained from simulation, as well as from direct measurement, it works as a design and decision support tool, providing the designer with quick and clear feedback on the building's acoustic comfort. In particular, it assists during the decision-making process in renovation designs, since it makes it possible to rank and compare different renovation options, and therefore identify the best solution.

ASSESSMENT CRITERION: Acoustic Comfort KPI is calculated from the evaluation of the indoor A-weighted sound pressure level [dB(A)]. Indoor A-weighted sound pressure level within each room can be evaluated either from computation or from measurement (at the assessment position) of the outdoor sound pressure level, by using the sound level difference of the façade.

Data required: The input data required are recapped in Table 18.

Table 18: Data required for the BS.AC KPI calculation

Input	Unit/Format
The floor area of each room adjacent to the external environment	[m^2]
Room end-use	[-]
Indoor A-weighted equivalent sound pressure level (if simulation) or:	[dB(A)] [dB(A)] [dB]

Outdoor A-weighted equivalent sound pressure level (if measurement) Standardised sound level difference of the room façade (if measurement) Reverberation time (if measurement)	[s]

Calculation method: The Acoustic Comfort KPI can be calculated according to the following steps.

1° Method: Acoustic Comfort KPI calculation from the simulation of the indoor A-weighted equivalent sound pressure levels.

- Evaluate the outdoor sound pressure levels [dB(A)] at 2 meters in front of each room façade. External noise levels can be obtained from in situ measurements or deduced by strategic noise mapping data available for each specific area.
- Calculate the sound level difference of the façade through the calculation model proposed by the standard ISO 12354 part 3:

$$D_{2m,nT,w} = R'_w + \Delta L_{fs} + 10log\frac{V}{6T_0S} \quad [dB]$$

Where:

- R'_w is the apparent weighted sound reduction index of the façade [dB];
- V is the volume of the receiving room [m^3];
- T_0 is the reference reverberation time (for dwellings it is given as 0,5 s) [s];
- S is the total area of the façade as seen from the inside [m^2];
- ΔL_{fs} is the level difference due to façade shape [dB].

R'_w can be evaluated according to the following equation, in accordance with ISO 12354 part 3:

$$R' = -10log\left[\sum_{i=1}^{n}\frac{S_i}{S}10^{\frac{-R_{wi}}{10}} + \sum_{i=1}^{n}\frac{A_0}{S}10^{\frac{-D_{n,e,w,i}}{10}}\right] - K \ [dB]$$

Where:

A_0 is the reference equivalent sound absorption area (10 m^2);

$D_{n,e,w,i}$ is the weighted normalised sound level difference of each small element [dB];

R_{wi} is the sound reduction index of each element [dB];

S is the total area of the façade as seen from the inside [m^2];

S_i is the area of each element of the façade [m^2];

K is the correction due to the contribution of flanking sound transmission.

- Calculate the Indoor A-weighted sound pressure level of each room bordering to the external environment by the following formula, in accordance with ISO 12354 part 3:

$$L_{Aeq} = L_{Ext,2m} - D_{2m,nT} + 10\,log\left(\frac{T}{T_0}\right)\ \ [dB(A)]$$

Where:

L_{Aeq} is the average sound pressure level in the receiving room [dB];

$L_{Ext,2m}$ is the average sound pressure level at 2 m in front of the room façade [dB];

$D_{2m,nT}$ is the standardised sound level difference of the room façade [dB];

T_0 is the reference reverberation time [s] (0.5 s);

T is the reverberation time in the receiving room [s]. Reverberation time can be both measured, according to the standard EN ISO 3382 part 2 and calculated by means of predictive formula suggested in EN 12354 part 6.

For each room adjacent to the external environment, an acoustic class is assigned according to the calculated indoor A-weighted equivalent sound pressure level (L_{Aeq}). The acoustic class is defined by the design values of the L_{Aeq} for every type of space use (offices, bedrooms, living rooms, classrooms, etc.) (see Table 19). The L_{Aeq} thresholds and classification system have been defined within the European Project NewTREND, for which the methodology presented was developed, on the basis of acceptable noise limits from literature. The L_{Aeq} calculated is assessed against the set limit for each acoustic class, so as to evaluate how far it is from the values suggested in this research. The acoustic classification scheme above goes from class A (high level of acoustic comfort) to class E (very bad level of acoustic comfort) (see the following label system in Fig. 3). Assign a score to each room, ranging from 5 (Class A) to 1 (Class E).

Table 19: Acoustic class limits

Type of space	Class A	Class B	Class C	Class D	Class E
Bedroom	$L_{Aeq} \leq 30$	$30 < L_{Aeq} \leq 32.5$	$32.5 < L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 40$	$L_{Aeq} > 40$
Living room / kitchen	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$
Hotel bedroom	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$
Classroom	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$
Nursery school	$L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 42.5$	$42.5 < L_{Aeq} \leq 45$	$45 < L_{Aeq} \leq 50$	$L_{Aeq} > 50$
Office	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$
Conference room	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$
Hospital	$L_{Aeq} \leq 35$	$35 < L_{Aeq} \leq 37.5$	$37.5 < L_{Aeq} \leq 40$	$40 < L_{Aeq} \leq 45$	$L_{Aeq} > 45$

Retail shop	$L_{Aeq} \leq 45$	$45 < L_{Aeq} \leq 47.5$	$47.5 < L_{Aeq} \leq 50$	$50 < L_{Aeq} \leq 55$	$L_{Aeq} > 55$

Table 20: Score assigned to each acoustic class

Class	Score [-]
A	5
B	4
C	3
D	2
E	1

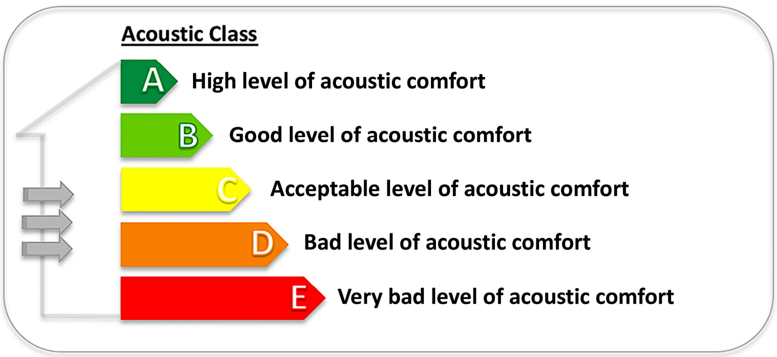


Figure 8 Acoustic class label

- Once assigned a score to each room, calculate the Acoustic Comfort KPI of the building:

$$KPI = \left(\frac{\sum_{i=1}^{n} A_i * RA_i}{A_{tot}}\right) \quad [-]$$

Where:
A_i is the reference floor area of each room adjacent to the external environment i [m^2];
RA_i is the score assigned to each room i [-];
A_{tot} is the total reference floor area of all the rooms adjacent to the external environment [m^2].

- Express the Acoustic Comfort KPI in a percentage value from 0 % to 100 %, through a linear interpolation from 1 to 5, where the score 1 corresponds to 0 % and the score 5 to 100 %.
- Assign an acoustic class from A to E to the building, based on the thresholds defined in Table 21.

Table 21: Building acoustic comfort classification thresholds

Class A	Class B	Class C	Class D	Class E
87.5%< KPI ≤ 100%	62.5%< KPI ≤87.5%	37.5%< KPI ≤62.5%	12.5%< KPI ≤37.5%	0%≤ KPI ≤12.5%

Note 1: Only the main rooms that are occupied for several hours and can be identified as "acoustically sensitive" (e.g. bedrooms, living rooms, offices, classrooms) are considered. Short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas, hallways) can be excluded from the analysis. Limit values are referred to as windows closed and shading systems (blinds, shutters, etc.) open. This configuration is supposed to be typical during daytime.

Note 2: As the KPI aggregates the values at the building level to provide an overall value, it can hide localised discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

2° Method: Acoustic Comfort KPI calculation from the measurement of the indoor A-weighted equivalent sound pressure levels.

- Measure the Indoor A-weighted sound pressure level of each room bordering to the external environment, according to EN ISO 16283 part 3.
- Continue with the step "d" to the end.

BENCHMARKS: Noise limit values vary from Country to Country and there is no uniform regulated classification of the sound pressure level within rooms due to sound coming from outside, for each specific use destination. According to the acoustic comfort classification proposed, which is based on acceptable noise limits from literature, if all the spaces in the building respect the minimum design value of indoor A-weighted sound pressure level (Class C), the Acoustic Comfort KPI of the building is between 37.5%< KPI ≤62.5%, that is the minimum acceptable level of acoustic comfort.

REFERENCES:

[1] ISO 12354 part 3, Building acoustics — Estimation of acoustic performance of buildings from the performance of elements —Airborne sound insulation against outdoor sound, 2017.

[2] ISO 16283 part 3, Acoustics — Field measurement of sound insulation in buildings and of building elements — Façade sound insulation, 2016.

[3] http://newtrend-project.eu

A1.10 Fuel Poverty

ID: BS.FP [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: Fuel Poverty KPI is defined as the percentage of Fuel Poverty status of households.

OBJECTIVE: The aim of the Fuel Poverty KPI is to evaluate the fuel poverty status of the building occupants. In particular, the main purpose is to assess if the Thermal Comfort KPI low value is associated with a fuel poverty condition of households or to poor building performance.

ASSESSMENT CRITERION: Fuel Poverty KPI is assessed at building scale.

Data required: The input data required are recapped in Table 22.

Table 22: Data required for the BS. FP KPI calculation

Input	Unit/Format
Energy costs (space heating, DHW, electricity)	[€]
Income per year	[€]

Calculation method: Fuel Poverty KPI can be calculated according to the following steps.

- Evaluate the energy costs for each domestic end-use (heating, DHW, electricity).
- Evaluate household income data per year (which can be collected via a survey)
- For every building, calculate the fuel poverty ratio as follows:

$$Fuel\ Poverty\ Ratio\ = \frac{EC}{I} \quad [-]$$

Where:

EC = energy costs (space heating + DHW + electricity) [€];

I = Household income per year [€].

- Calculate the percentage of fuel poverty status as follows:

$$\%\ of\ Fuel\ Poverty\ status\ =\ Fuel\ Poverty\ Ratio\ x\ 100 \quad [\%]$$

- Associate a Fuel Poverty condition to the calculated % of Fuel Poverty status, according to Table 23:

Table 23: Fuel Poverty condition

% of Fuel Poverty status	Fuel Poverty condition
< 10 %	Not in fuel poverty
10 – 15 %	Fuel poverty
15 – 20 %	Severe fuel poverty
20 – 25 %	Extreme fuel poverty
Over 25 %	Very extreme fuel poverty

A1.11 Visual Comfort

ID: BS.VC [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: Visual Comfort KPI is defined as the percentage of Occupied Hours Illuminance below the standard threshold. According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

OBJECTIVE: The aim of the Acoustic Comfort KPI is to provide a comprehensive and straightforward way to assess and measure the illuminance level of space, required to allow performing visual tasks efficiently and accurately.

ASSESSMENT CRITERION: Visual Comfort KPI requires room scale evaluations.

Data required: The input data required are recapped in Table 24.

Table 24: Data required for the BS. VC KPI calculation

Input	Unit/Format
Average illuminance level measured on the work-plane	[lx]
The minimum level of illuminance required by standards for the typical end-use of the room (if this value is not provided by local regulations, the thresholds provided by EN 15251 can be used)	[lx]
Total number of rooms investigated in the building	[-]
The floor area of ith room in the building	[m^2]

Calculation method: The Visual Comfort KPI can be calculated according to the following steps.

- Define the start and end times of the analysis period (yearly, heating, cooling, custom);
- For the selected rooms in the building, calculate the hourly average illuminance (L_i) [lx] from simulation or measured samples. Minimum sample time of 10 minutes is recommended;
- For every room and hourly value, calculate the room illuminance below threshold ($L_{thr,i}$) (given by local standards or taken from EN 15251) as follows:

$$L_{below,\mathrm{i}} = L_i - L_{thr,i} \quad [ppmm]$$

Where:

L_i is the hourly average illuminance [lx];

$L_{thr,i}$ is the minimum level of illuminance required by standards for the typical end use of the room [lx];

- For every room in the building, calculate the number of occupied hours outside the range $h_{or,i}$ as the number of hours when $L_{below,\mathrm{i}} \leq 0$;

- For every room in the building, calculate the percentage of hours below the threshold (BT_i) [%] as follows:

$$BT_i = \frac{h_{or,i}}{h_{tot}} * 100 \ \ [\%]$$

Where:

$h_{or,i}$ is the number of occupied hours outside range;

h_{tot} is the total occupied hours during the analysis period [h];

- Calculate the average building percentage of hours outside the range (BT_i) as follows:

$$\Delta\mathrm{T} = \frac{\sum_{i=1}^{n} BT_i * S_i}{\sum_{i=1}^{n} S_i} \ \ [\%]$$

Where:

n is the total number of rooms investigated in the building [-];

S_i is the floor area of ith room in the building [m2];

BT_i is the percentage of hours below the threshold [%].

BENCHMARKS: According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit.

REFERENCES:

[1] EN 15251. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Thermal Environment, Lighting and Acoustics. 2007, AFNOR: Paris, France.

A1.12 Indoor Air Quality

ID: BS.IAQ [%]

RESPONSIBLE PARTNER: UNIVPM

DEFINITION: The Indoor Air Quality KPI is defined as the percentage of Hours Outside CO2 range. According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit.

To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

OBJECTIVE: Indoor air quality depends on a variety of sources, such as occupants, finishing materials, cleaning products, installed equipment, and activities carried out in the spaces; these sources emit various types of pollutants that are difficult to forecast and complex to monitor. However, the presence of people guarantees the presence of CO_2 from breathing, with the concentration in the indoor air rising as the occupants exhaust the available air. The assessment of CO_2 presence in the indoor air is one of the indicators to evaluate the overall air quality, as the air changes required to contain the CO_2 levels guarantee a reduction of the concentration of other, more dangerous, pollutants, increasing the quality of the indoor air and thus providing a healthier environment for the occupants. Using only CO2 could not be exhaustive for indoor air quality in the case of having particular contaminants, however the CO2 is the most used indicator, available also into existing simulation engines (e.g. Energy plus), without the need of developing dedicated tools.

The aim of the Indoor Air Quality KPI is to provide a comprehensive and straightforward way to assess and measure improvement in the building ventilation to guarantee the users' health and well-being.

ASSESSMENT CRITERION: Indoor air quality KPI requires room-scale evaluations. The hourly CO_2 concentration values above outdoor are assessed against a set limit to identify the number of hours outside an acceptable comfort range, and the room values are aggregated through a floor-area weighted average. The CO_2 concentration values can be obtained from simulations, as well as they can be acquired from on-site measurements.

Data required: The input data required are recapped in Table 25.

Table 25: Data required for the BS. IAQ KPI calculation

Input	Unit/Format
Room CO_2 concentration	[ppm]
CO_2 concentration outdoor	[ppm]
Start of analysis period	[dd/mm/yy hh:mm]
End of analysis period	[dd/mm/yy hh:mm]
Occupied hours	[H]
Room useful floor area	[m^2]
Number of rooms	[-]

Calculation method: The Indoor Air Quality KPI can be calculated according to the following steps.

- Define the start and end times of the analysis period (yearly, heating, cooling, custom);
- For every room in the building, calculate the hourly average CO_2 concentration ($CO_{2,indoor,i}$) [ppm] through a simulation carried out on the entire analysis period. If measurements are possible, measure the hourly CO_2 concentration ($CO_{2,indoor,i}$) [ppm]. Contemporary, measure the hourly outdoor CO_2 concentration ($CO_{2,outdoor,i}$) [ppm].
- For every room and hourly value, calculate the room CO_2 concentration above outdoors ($CO_{2,above,i}$) as follows:

$$CO_{2,above,i} = CO_{2,indoor,i} - CO_{2,outdoor}\ [ppm]$$

If $CO_{2,above,i}$ is not measured, adopt the following formula:

$$CO_{2,above,i} = CO_{2,indoor,i} - 360 \ [ppm]$$

360 = average value, that depends on external climate. Generally, is between 350 and 410 ppm, so it is chosen 360 ppm.

- Define the CO_2 limit ($CO_{2,lim}$) as follows:

  Category I. Space with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): $CO_{2,lim}$ = 350 ppm;

  Category II. New buildings and renovations: $CO_{2,lim}$ = 500 ppm;

  Category III. Existing buildings: $CO_{2,lim}$ = 800 ppm;

  Category IV. Acceptability for a limited part of the year: $CO_{2,lim}$ > 800 ppm;

- For every room in the building, calculate the number of occupied hours outside the range ($h_{or,i}$) as the number of hours when $CO_{2,above,i} \geq CO_{2,lim}$;
- For every room, calculate the percentage of hours outside the range (POR_i) [%] as follows:

$$POR_i = \frac{h_{or,i}}{h_{tot}} * 100 \ \ [\%]$$

Where:

$h_{or,i}$ is the number of occupied hours outside range;

h_{tot} is the total occupied hours during the analysis period [h];

- Calculate the average building percentage of hours outside the range (BT_i) as follows:

$$\Delta T = \frac{\sum_{i=1}^{n} POR_i * S_i}{\sum_{i=1}^{n} S_i} \ \ [\%]$$

Where:

n is the total number of rooms investigated in the building [-];

S_i is the floor area of i[th] room in the building [m2];

POR_i is the percentage of hours outside the range [%].

Note 1: only consider main rooms that are occupied for several hours (e.g. bedrooms, offices, classrooms). Do not consider short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas).

Note 2: as the KPI aggregates the values at the building level to provide an overall value, it can hide localised discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

BENCHMARKS: According to EN 15251, an acceptable amount of deviation is 5% of occupied hours a year. The best performance is achieved when there are no deviations outside the CO2 concentration range.

REFERENCES:

[1] EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

[2] EN 13779:2007 Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems.

A1.13 Operational Energy Costs

ID: BS.OEC [€/m^{2}year]

RESPONSIBLE PARTNER: CARTIF

DEFINITION: The OEC KPI represents the total costs of the building spent on energy services (energy consumption, maintenance, etc.). It includes all the costs arising from the use of energy sources (oil, gas, solid fuels, district heating, electricity, etc.).

OBJECTIVE: The OEC KPI aims at reducing the operational energy costs by improving the building's energy performance, integrating renewable energies and changing the fuels.

ASSESSMENT CRITERION: The OEC KPI is assessed considering the parameters related to the building operational costs that can be derived from real data or analytical methods. In particular, there are two methods to calculate the operational energy costs KPI. The first method (method A) is the most accurate since it is based directly on energy bills. In case bills are not available, the other method (method B) is based on estimations considering the energy consumption of the building and the energy prices related to each specific location.

Data required: If real data are available, the calculation method (method A) needs the inputs recapped in Table 26. When analytical methods are used, input data from Table 27 are required.

Table 26: Data required for the BS. OEC KPI calculation method A

Input	Unit/Format
Electricity bills	[€]
Fuel bills	[€]
Maintenance Costs	[€]
Other costs for energy services	[€]
Size of the building	[m^2]

Table 27: Data required for the BS. OEC KPI calculation method B

Input	Unit/Format
Final energy consumption in electricity	[kWh]
Electricity price	[€/kWh]

Final energy consumption for the different fuels	[kWh]
Fuel price	[€/kWh]
Maintenance Costs	[€]
Other costs for energy services	[€]
Building plans	[m^2]

Calculation method: Following, methods A and B are detailed.

Method A: calculation based on Energy Bills.

The method provides the calculus of energy costs for electricity and for different fuels by using directly the information from real bills.

$$OEC = \frac{\sum(EB) + \sum(FB) + MC + Other}{A_b} \left[\frac{€}{m^2}\right]$$

- EB: Electricity Bills [€];
- FB: Fuel Bills (e.g. Natural gas, Gasoil, etc) [€];
- MC: Maintenance Costs [€];
- $Other$: include other costs for energy services [€];
- A_b: *the* size of the building (e.g. gross floor area, net floor area, conditioned floor area) [m^2].

Method B: calculation based on the determination of consumptions.

The calculation of the operational energy costs considers the energy consumption data (from any source) in kWh and the local unit costs (tariffs of energy suppliers) for every energy source in the specific location in €/kWh. To enable the comparability between buildings, the operational energy costs are related to the size of the building (e.g. gross floor area, net floor area, conditioned floor area) and the considered time interval (e.g. one year).

$$OEC = \frac{\sum(E_{F,el} \cdot P_{el}) + \sum(E_{F,f} \cdot P_f) + MC + Other}{A_b} \left[\frac{€}{m^2}\right]$$

- $E_{F,el}$: Final energy consumption in electricity [kWh];
- P_{el}: Electricity price [€/kWh];
- $E_{F,f}$: Final energy consumption for the different fuels [kWh];
- P_f: Fuel price [€/kWh];
- MC: Maintenance Costs [€];
- $Other$: include other costs for energy services [€];
- A_b: the size of the building (e.g. gross floor area, net floor area, conditioned floor area) [m^2].

BENCHMARKS: Table 28 reports the electricity prices for the different EU Member States in €/kWh [3], including taxes. The second column of Table 28 refers to electricity prices for the second semester of 2017, while the third one describes the first semester of 2018.

Table 28: Electricity prices for the different EU Member States [3]

Country	2017 second semester	2018 first semester
EU-28	0.2042	0.2053
Belgium	0.2877	0.2733
Bulgaria	0.0983	0.0979
Czech	0.1488	0.1573
Denmark	0.3010	0.3126
Germany	0.3048	0.2987
Estonia	0.1319	0.1348
Ireland	0.2355	0.2369
Greece	0.1620	0.1866
Spain	0.2177	0.2383
France	0.1756	0.1754
Croatia	0.1236	0.1311
Italy	0.2080	0.2067
Cyprus	0.1826	0.1893
Latvia	0.1582	0.1531
Lithuania	0.1107	0.1097
Luxembourg	0.1618	0.1671
Hungary	0.1134	0.1123
Malta	0.1298	0.1285
Netherlands	0.1556	0.1706
Austria	0.1978	0.1966
Poland	0.1451	0.1410
Portugal	0.2230	0.2246
Romania	0.1289	0.1333
Slovenia	0.1613	0.1613
Slovakia	0.1442	0.1566
Finland	0.1599	0.1612
Sweden	0.1993	0.1917
United Kingdom	0.1856	0.1839
Iceland	0.1518	0.1540
Liechtenstein	0.1618	-
Norway	0.1605	0.1751
Montenegro	0.1003	0.1024
North Macedonia	0.0811	0.0781
Albania	0.0856	-

Serbia	0.0695	0.0705
Turkey	0.0959	0.0904

Table 29 reports the natural gas prices for the different EU Member States in €/kWh [3], including taxes. The second column of Table 29 refers to gas prices for the second semester of 2017, while the third one describes the first semester of 2018.

Table 29: Natural gas prices for the different EU Member States [3]

Country	2017 second semester	2018 first semester
EU-28	0.0464	0.0431
Belgium	0.0437	0.0428
Bulgaria	0.0313	0.0316
Czech	0.0468	0.0475
Denmark	0.0387	0.0404
Germany	0.0453	0.0452
Estonia	0.0306	0.0287
Ireland	0.0535	0.0520
Greece	-	0.0458
Spain	0.0692	0.0526
France	0.0521	0.0481
Croatia	0.0293	0.0294
Italy	0.0558	0.0459
Latvia	0.0307	0.0301
Lithuania	0.0290	0.0285
Luxembourg	0.0357	0.0369
Hungary	0.0287	0.0282
Netherlands	0.0399	0.0379
Austria	0.0513	0.0488
Poland	0.0359	0.0343
Portugal	0.0585	0.0567
Romania	0.0175	0.0186
Slovenia	0.0369	0.0381
Slovakia	0.0371	0.0356
Sweden	0.0615	0.0632
United Kingdom	0.0438	0.0422
North Macedonia	0.0432	0.0345
Serbia	0.0308	0.0304
Turkey	0.0201	0.0178

Bosnia and Herzegovina	0.0279	0.0278
Moldova	0.0288	0.0235
Ukraine	0.0181	0.0174
Georgia	-	0.0129

REFERENCES:

[1] REMOURBAN Project,"D2.2: Evaluation protocols and indicators", July 2016.

[2] MOEEBIUS project, "D2.3 MOEEBIUS Energy Performance Assessment Methodology", June 2016.

[3] Eurostat [https://ec.europa.eu/eurostat]

A1.14 Payback Period

ID: BS.PP [%]

RESPONSIBLE PARTNER: CARTIF

DEFINITION: The PP KPI compares the investment costs with the economic savings achieved from the energy conservation measures due to the retrofitting. This KPI refers to the period of time in years required to recover the funds expended in the investment. The analysis method has some limitations because it does not consider the time value of the money.

OBJECTIVE: The target of this KPI is to reduce the payback period by improving the building's energy performance and selecting cost-efficient solutions. This leads to achieving lower operational energy costs.

ASSESSMENT CRITERION: The PP KPI is calculated considering the economic data related to the initial investment and to the economic savings reached from the retrofitting.

Data required: The input data required are recapped in Table 30.

Table 30: Data required for the BS. PP KPI calculation

Input	Unit/Format
Initial Investments Costs	[€]
Final energy consumption in electricity	[kWh]
Electricity price	[€/kWh]
Final energy consumption for the different fuels	[kWh]
Fuel price	[€]
Maintenance Costs	[€]
Other costs for energy services	[€]

Calculation method: The calculation method is based on the assessment of the payback period, defined as the time in which the initial investment is expected to be recovered from the savings generated.

$$Payback\ period\ [year] = \frac{IIC\ (€)}{ES\ (\frac{€}{year})}$$

Where:
IIC: Initial Investment Cost [€];
ES: Yearly economic savings [€/year] = Operational Energy costs baseline [€/year] – Operational Energy costs reporting [€/year].

BENCHMARKS: The length of the period to recover an investment is a key factor in deciding among different scenarios. A 4-5-year period is usually acceptable. Longer periods may be acceptable if there are considerable energy savings (reduced energy costs and operating expenses) over the long run.

REFERENCES:

[1] Dr. Russell McKenna, Kilian Seitz, Michael Kleber, "CONCERTO Premium Indicator Guide", November 2012.

[2] REMOURBAN Project,"D2.2: Evaluation protocols and indicators", July 2016.

[3] CITYFIED Project, "D2.2: Annex 1. Key Performance Indicators at project level", December 2014.

[4] Antonio Garrido Marijuán, Ghazal Etminan, Sebastian Möller, "Smart Cities Information System – Key Performance Indicators Guide", February 2017.

[5] MOEEBIUS project, "D2.3 MOEEBIUS Energy Performance Assessment Methodology", June 2016.

APPENDIX 2 – Use Cases Description

A2.1 UC1 - Assessing the energy performance of buildings with measured data

ID	UC 1
Name	**Assessing the energy performance of buildings with measured data**
Goal	The use case aims at providing the building energy performance assessment using measured data.
Supporting Business Process	Reducing building energy consumptions
Description	The use case provides a procedure to obtain a complete overview of the building energy performance. The assessment is performed with the data collected in the demo case.
Input data (linked with WP1)	- General information concerning the building (e.g. location, year of construction, floor area, number and type of occupants); - Energy consumptions for the different sources (e.g. natural gas, electricity, water): derived from bills, energy label, building energy audit, smart meters and surveys.
Sequence of actions	- Obtain the energy data measured in the demo cases according to different strategies (WP1/WP8); - Evaluate the energy performance a) calculating the building signature b) comparing the energy indicators with the reference building stock (this step aims at understanding the building energy behaviour) -Analyse the energy performance of the building (identification of the weak points to understand the key points for the interventions).
Output data	- Building final energy consumptions; - Building primary energy consumptions; - Building energy label; - KPIs: o BS.OPED (Operational Primary Energy Demand) o BS.TEC (Total Energy Consumption) o BS.GWP (Global Warming Potential) o BS.OEC (Operational Energy Costs)
Primary actor (and aims)	Energy experts, designers and all the figures involved in the renovation process (performing the energy assessment)
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use; - The building is identified in location and required information about building features are provided; - Real data are available or measurable.

Trigger	Building renovation
Extensions	- If the comparison with the most similar building stock is not available, the comparison target can be expanded (e.g. same climate but different building use); - If the data can be collected (or are available) only for a portion of the building, reference portion data will be used for the overall evaluation
Exceptions	
Post-conditions	POST-1. Identification of the energy weak points. POST-2. Identification of the zones to be enhanced.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM, CARTIF
Date of Last Update	26/08/2019
UC Approved By	

A1.15 UC2 - Assessing the Energy Performance of buildings with simulated data

ID	UC 2
Name	**Assessing the Energy Performance of buildings with simulated data**
Goal	The use case aims at providing the building energy performance assessment using simulated data.
Supporting Business Process	Reducing building energy consumptions.
Description	The use case presents a procedure to generate the energy model of the building (BEM) with which to simulate the building energy performance. In addition, the UC specifies the steps to move from the real building to the virtual building: 1) Geometrical and systems data; 2) BIM modelling; 3) BIM-to-BEM approach; 4) BEM modelling.
Input data (linked with WP1 and WP3)	The inputs are those needed to realize the energy model of the building (BEM). Some of them are the following: - General information concerning the building (e.g. plans, location, year of construction, floor area, number and type of occupants); - Loads and schedules (e.g. occupancy, lighting, appliance); - HVAC system and operation; - Construction materials (including thermal properties) and stratigraphy.
Sequence of actions	- Identify and collect the required input data for the BIM creation (location and building orientation, building geometrical and physical features, i.e. materials, stratigraphy, MEP). - Generate the BIM model of the demo cases (from WP2); - Execute the BIM-to-BEM approach (UC11); - Refine the BEM with missing or lacking information; -Calibrate the model with real energy data obtained in T1.3 (UC13); - Run the energy simulation (WP3); - Evaluate the energy performance a) calculating the building label b) comparing the energy indicators with the reference building stock (this step aims at understanding the building energy behaviour); - Analyse the energy performance of the building to identify possible improvements.
Output data	- Building final energy consumptions; - Building primary energy consumptions; -Building energy label; - KPIs: o BS.OPED (Operational Primary Energy Demand) o BS.TED (Total Energy Demand) o BS.TEC (Total Energy Consumption)

	o BS.GWP (Global Warming Potential) o BS.OEC (Operational Energy Costs)
Primary actor (and aims)	Energy simulation experts, designers and all the figures involved in the renovation process (performing the energy assessment).
Secondary actor (and aims)	Final user (helping in the data collection) and building owner.
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use. - The building is identified in location and required information about building features are provided.
Trigger	Building renovation
Extensions	If the comparison with the most similar building stock is not available, the comparison target can be expanded (e.g. same climate but different building use). If the data can be collected (or are available), only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the energy weak points. POST-2. Identification of the zones to be enhanced.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM, CARTIF
Date of Last Update	26/08/2019
UC Approved By	

A1.16 UC3 – Assessing the as-built Thermal Comfort with measured data

ID	UC 3
Name	**Assessing the as-built Thermal Comfort with measured data.**
Goal	Assess the occupants' thermal comfort before and/or after the renovation using measured data.
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology for evaluating thermal comfort under different conditions: 1) During the heating season; 2a) During the cooling season with the cooling system; 2b) During the cooling season without the cooling system.
Input data (linked with WP1)	Some data are mandatory regardless of the thermal comfort condition (i.e. 1, 2a and, 2b) while other variables depend on the surveyed condition. The mandatory data are the following: - Start of monitoring period; - End of monitoring period; - Occupied days; - Net floor area; - The number of rooms. For calculating the thermal comfort during the heating season (condition 1) and during the cooling season with the cooling system (condition 2a) the following further variables are needed: - PMV index (which can be obtained with the following variables: Air Temperature, Mean Radiant Temperature, Air Velocity, Relative Humidity, Metabolic Rate and, Clothing Level). For calculating the thermal comfort during the cooling season without cooling system (condition 2b) the following further variables are needed: - Air Temperature; - Mean Radiant Temperature; - Outdoor Temperature.
Sequence of actions	- Identify and collect the required input data; - Identify the season of the year to apply the correct thermal model (1, 2a or 2b); - Apply the thermal comfort calculation model: the calculus is firstly applied to each room and then to the whole building; - Analysis of the thermal comfort results under the different conditions and the worst situations.
Output data	- Percentage of operating hours falling into each building category; - Sensitivity indices; - Comfort zones; - KPIs:

	o BS.TCWC (Thermal Comfort Without Cooling system) o BS.TC (Thermal Comfort)
Primary actor (and aims)	Architect, HVAC engineer, energy experts, thermal comfort experts
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use. - The building is identified in location and required information about building features are provided. - Access to at least one zone of the building to get input data.
Trigger	Building renovation, comfort concerns from occupants
Extensions	Some measured data (outdoor air temperature) can be obtained from external sources (e.g. public weather stations). Some measured data (clothing, metabolic rate) can be assumed (EN ISO 7730:2006). If the data can be collected (or are available), only for a room of the building, reference room data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the thermal worst situations. POST-2. Identification of the zones to be enhanced both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	28/08/2019
UC Approved By	

A1.17 UC4 – Assessing the as-built Thermal Comfort with simulated data

ID	UC 4
Name	**Assessing the as-built Thermal Comfort with simulated data**
Goal	Assess the occupants' thermal comfort before and/or after the renovation using simulated data.
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology for evaluating thermal comfort under different conditions: 1) During the heating season; 2a) During the cooling season with the cooling system; 2b) During the cooling season without the cooling system.
Input data	Some data are mandatory regardless of the thermal comfort condition (i.e. 1, 2a and, 2b) while other variables depend on the surveyed condition. The mandatory data are the following: - Start of heating season; - End of heating season; - Start of cooling season; - End of cooling season; - Occupied days; - Net floor area; - The number of rooms. For calculating the thermal comfort during the heating season (condition 1) and during the cooling season with the cooling system (condition 2a) the following further variables are needed: - PMV index (which can be obtained with the following variables: Air Temperature, Mean Radiant Temperature, Air Velocity, Relative Humidity, Metabolic Rate and, Clothing Level). For calculating the thermal comfort during the cooling season without cooling system (condition 2b) the following further variables are needed: - Data to realize the BEM model (see UC2); - Air Temperature; - Mean Radiant Temperature; - Outdoor Temperature.
Sequence of actions	- Identify and collect the required input data for the BIM creation (as-built location and building orientation, overshadowing, building geometrical and physical features, i.e. materials, build-ups, hygroscopes of material build-ups, thermal mass, opening types, sizes and locations, shading, albedo, stratigraphy, MEP, risers, control set-points and profiles). - Generate the BIM model of the demo cases (WP2/WP8); - Execute the BIM-to-BEM approach (UC11); - Refine the BEM with missing or lacking information; - Perform the energy simulation (WP3);

	- Extract the required input data from the simulation; - Identify the season of the year to apply the correct thermal model; - Apply the thermal comfort calculation model: the calculus is firstly applied to each room and then the whole building; - Analysis of the thermal comfort results under the different conditions and the worst situations, including overheating Analysis of overheating under future climate scenarios 2030 & 2050.
Output data	- Percentage of operating hours falling into each building category; - Sensitivity indices; - Comfort zones; - KPIs: o BS.TCWC (Thermal Comfort Without Cooling system) o BS.TC (Thermal Comfort)
Primary actor (and aims)	Energy simulation experts, designers and all the figures involved in the renovation process (performing the energy assessment), thermal comfort experts.
Secondary actor (and aims)	Final user (helping in the data collection) and building owner.
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use. - The building is identified in location and required information about building features are provided.
Trigger	Building renovation
Extensions	If the data are available only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the thermal worst situations. POST-2. Identification of the zones to be enhanced both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019
UC Approved By	

A1.18 UC5 – Assessing the as-built Acoustic Comfort with measured data

ID	UC 5
Name	**Assessing the as-built Acoustic Comfort with measured data**
Goal	Assess the occupants' acoustic comfort before and/or after the renovation using measured data
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology to obtain an overall assessment of the acoustic comfort of the building due to the surrounding noise. The key output is the acoustic classification of the building.
Input data (linked with WP1)	- The floor area of each room adjacent to the external environment; - Room end use; - Indoor sound pressure level measured in each room; - Standardised sound level difference of the room façade; - Reverberation time measured in each room. N.B. The analysed rooms are only those bordering to the external environment.
Sequence of actions	- Identify and collect the required input data; - Apply the acoustic comfort calculation model: the calculus is firstly applied to each room and then the whole building; - Analysis of the acoustic comfort results (Acoustic Comfort KPI), with the identification of the building acoustic class.
Output data	- Acoustic class of the building; - Sensitivity indices; - KPI: o BS.AC (Acoustic Comfort)
Primary actor (and aims)	Acoustic experts, designers and all the figures involved in the renovation process (performing the energy assessment).
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use. - The building is identified in location and required information about building features are provided.
Trigger	Building renovation Acoustic complaints from the occupants
Extensions	If the data are available only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the rooms with the worst noise situations.

	POST-2. Identification of the rooms, which require an improvement of room façade insulation.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019
UC Approved By	

A1.19 UC6 – Assessing the as-built Acoustic Comfort with simulated data

ID	UC 6
Name	**Assessing the as-built Acoustic Comfort with simulated data**
Goal	Assess the occupants' acoustic comfort before and/or after the renovation using simulated data.
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology to obtain an overall assessment of the acoustic comfort of the building. The key output is the acoustic classification of the building.
Input data (linked with WP1)	- The floor area of each room adjacent to the external environment; - Room end use; - Indoor A-weighted equivalent sound pressure level. N.B. The analysed rooms are only those bordering to the external environment.
Sequence of actions	- Identify and collect the required input data (outdoor A-weighted sound pressure level in front of each room bordering to the external environment, the total number of investigated rooms in the building, floor area of each room). - Apply the acoustic comfort calculation model: the calculus is firstly applied to each room and then the whole building. - Analysis of the acoustic comfort results (Acoustic Comfort KPI), with the identification of the building acoustic class.
Output data	- Acoustic class of the building; - Sensitivity indices; - KPI: o BS.AC (Acoustic Comfort)
Primary actor (and aims)	Acoustic experts, designers and all the figures involved in the renovation process (performing the energy assessment).
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use. - The building is identified in location and required information about building features are provided.
Trigger	Building renovation Acoustic complaints from the occupants
Extensions	If the data are available only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the rooms with the worst noise situations.

	POST-2. Identification of the rooms, which require an improvement of room façade insulation.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019
UC Approved By	

A1.20 UC7 – Assessing the as-built Indoor Air Quality with measured data

ID	UC 7
Name	**Assessing the as-built Indoor Air Quality with measured data.**
Goal	To assess the level of indoor air quality before and/or after renovation making use of measurements.
Supporting Business Process	Increase the comfort level.
Description	This use case provides the methodology to measure and assess the level of indoor air quality with respect to requirements suggested by actual standards.
Input data (linked with WP1)	- Indoor CO_2 concentration measured in the selected room [ppm] - Outdoor average CO_2 concentration [ppm] - Geometrical data of the building
Sequence of actions	- Identify the most relevant room suitable for the measurement campaign; - Define the measurement periods and tools required; - At the starting day of the monitoring campaign, make spot measurements of outdoor CO_2 concentration; - Acquire CO_2 data in the selected rooms; - Apply the calculation method.
Output data	- Percentage of operating hours compliant with buildings' categories - KPI: o BS.IAQ (Indoor Air Quality)
Primary actor (and aims)	Architect, HVAC engineer, Energy experts, IAQ experts.
Secondary actor (and aims)	Final user (helping in the data collection) and building owner.
Preconditions	Building typology cannot be different from residential, office, commercial and public.
Trigger	Building renovation IAQ complaints from the occupants
Extensions	If the data are available only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed. If outdoor CO_2 data are not available, values from nearby stations can be used.
Post-conditions	POST-1. Identification of the worst situations. POST-2. Identification of the zones to be enhanced both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	

Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019
UC Approved By	

A1.21 UC8 – Assessing the as-built Indoor Air Quality with simulated data

ID	UC 8
Name	**Assessing the as-built Indoor Air Quality with simulated data**
Goal	To assess the level of indoor air quality before and/or after renovation making use of simulations
Supporting Business Process	Increase the comfort level.
Description	This use case provides the methodology to simulate and assess the level of indoor air quality with respect to requirements suggested by actual standards
Input data (linked with WP1)	- Data to realize the BEM model (see UC2); - Indoor CO_2 concentration simulated in all rooms [ppm] - Outdoor average CO_2 concentration [ppm] (the value can be achieved also from a local weather station) - Geometrical data of the building.
Sequence of actions	- Retrieve the CO2 data from BEM results; - Define the measurement periods and tools required; - Evaluate the average outdoor CO_2 concentration where the building is located; - Apply the calculation method.
Output data	- Percentage of operating hours compliant with buildings' categories - KPI: o BS.IAQ (Indoor Air Quality)
Primary actor (and aims)	Architect, HVAC engineer, Energy experts
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	Building typology cannot be different from residential, office, commercial and public.
Trigger	- Building renovation; - IAQ complaints from the occupants.
Extensions	
Exceptions	If the preconditions are not satisfied, the use case is not employed. If outdoor CO_2 from UC7 is not available, a fixed value can be used.
Post-conditions	POST-1. Identification of the worst situations. POST-2. Identification of the zones to be enhanced both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	

Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019
UC Approved By	

A1.22 UC9 – Lighting and Visual Comfort Analysis with measured data

ID	UC 9
Name	**Lighting and Visual Comfort Analysis with measured data**
Goal	Assess the occupants' Lighting and Visual comfort before and/or after the renovation using measured data.
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology for evaluating Visual comfort under different conditions: 1) Throughout specific/determined timeline (yearly, monthly, daily); 2) Within a specific geo-location; 3) Physical constraints (window to wall ratio, spatial depth, interior lighting, shading, material passport etc.).
Input data (linked with WP1)	- Detailed information concerning the building (e.g. geolocation, building plan, Interior/surface illuminance (table heights, surface materials, window to wall ratio); - Artificial lighting Analysis data: Spatial Activity-based illumination levels (e.g. work area vs lounge area vs meeting room), Intensity of Light flux based on artificial light type, life span, and intensity of its lux. - Natural Lighting Analysis data: spatial depth measurements, glare control measurements, handheld, network Sensors
Sequence of actions	- Placement of sensors (network and or Handheld) for light/ lux level assessment; - Identify optimal time frame and space for observation in correspondence to building intended function; - Photometric & sensor data analysis; - Review and assessment of areas of opportunities for optimization.
Output data	- A Complete /data informative assessment of the Visual and Daylight comfort of the investigated building (to contrast with BREAM, LEED standard) to understand current building performance and determine the area of improvement through renovation; - KPI: o BS.VC (Visual Comfort)
Primary actor (and aims)	Energy experts, designers and all the figures involved in the renovation process (performing the energy assessment).
Secondary actor (and aims)	Final user (helping in the data collection) and building owner.
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use; - The building is identified in location and required information about building features are provided; - A reconstructed clean 3D model with material tags;

	- Real data are available or measurable.
Trigger	Building renovation.
Extensions	Some measured data (weather/EnergyPlus data) can be obtained from external sources (e.g. EnergyPlus). If the data can be collected (or are available) only for a room of the building, reference room data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the Lighting & Visual Comfort's worst situations. POST-2. Identification of the areas of opportunities to be optimized both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNS
Date of Last Update	26/08/2019
UC Approved By	

A1.23 UC10 – Lighting and Visual Comfort Analysis with simulated data

ID	**UC 10**
Name	**Lighting and Visual Comfort Analysis with simulated data**
Goal	Assess the occupants' Lighting and Visual comfort before and/or after the renovation using simulated data.
Supporting Business Process	Increase the comfort level.
Description	The use case provides a methodology for evaluating Visual comfort under different conditions: 1) Throughout specific/ determined timeline (yearly, monthly, daily); 2) Within specific geo-location; 3) Within physical constraints (window to wall ratio, spatial depth, interior lighting, shading, material passport etc.).
Input data (linked with WP1)	- Digital model of the Building with context, surface definition and material, topography, and geographic coordinate (for solar analysis accuracy) - Fully integrated Light sources and intensity levels (in 3D model matching the analysed building conditions) - Sensors, and site analysis data definition in the 3D model for the focus area of investigation.
Sequence of actions	- Identify and collect the required input data for the BIM creation (location and building orientation, building geometrical and physical features, i.e. materials). - Generate the BIM model of the demo cases; - Run the sensor data simulation to perform the Lighting analysis of the current condition in contrast to the proposed concept; - Check the simulation results: evaluate the energy outcomes to understand their reliability; - Calibration procedure by contrasting visual comfort analysis from the sensors in the building to the Digital twin readings. (if needed); - Extract the required input data from the simulation (solar analysis, light/lux levels, spatial depth, wall to window ratio, material passport); - Identify the season of the year to apply the correct lighting analysis model; - Analysis of the Lighting & Visual comfort results under the best conditions and the worst situations. Keeping the industry standards LEED, BREEAM standards guidelines as a reference.
Output data	- Digital Twin of the Building with design implementations enabling an optimal and up-to-industry standard (LEED, BREAM) for Visual and Daylight comfort metrics. (informing/ supporting design decisions for the renovation); - KPI: o BS.VC (Visual Comfort)
Primary actor (and aims)	Energy experts, designers and all the figures involved in the renovation process (performing the energy assessment)

Secondary actor (and aims)	Final user (helping in the data collection) and building owner.
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use; - The building is identified in location and required information about building features are provided; - A reconstructed clean 3D model with material tags; - Real data are available or measurable.
Trigger	Building renovation
Extensions	If the data are available only for a portion of the building, reference portion data will be used for the overall evaluation.
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1. Identification of the worst situations of Lighting & Visual Comfort in the pre-renovation scenario. POST-2. Identification of the areas of opportunities to be optimized both at room and building level.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNS
Date of Last Update	26/08/2019
UC Approved By	

A1.24 UC11 – Development of the BIM-to-BEM approach

ID	UC 11
Name	**Development of the BIM-to-BEM approach**
Goal	The Use Case aims at providing an approach for BIM-to-BEM interoperability process, for performing energy performance analyses.
Supporting Business Process	Speed up the renovation process.
Description	The BIM federated model can be the information base or the main database allowing designers to perform structural, MEP, energy analyses. An effective BIM to BEM workflow reduces the data losses and facilitates the correct flow of information to simulate energy performance. Different BIM to BEM workflows, with commercially available software, can be used to perform an energy assessment of a building. The use case provides the requirements of the BIM model to ensure the reliability and usability of the selected BIM to BEM workflow for the BIM-SPEED platform.
Input data (linked with WP1)	- General information concerning the building (e.g. location, floor area, construction year, building orientation, building type[1], geometry, number of occupants, space type (e.g. occupancy/lighting schedule), heated/non-heated zones, cooled/non-cooled zones, occupied/non-occupied zones, opaque and transparent enclosures (including thermal properties for each material)); - Information about the energy systems: HVAC and Hot Water Production systems typologies defined by zones. [1] Structural typology (e.g. Reinforced Concrete, Masonry, Steel) and building category (e.g. detached, duplex, apartment)
Sequence of actions	- In order to perform an energy assessment of a building, a BIM model can be firstly developed by means of a BIM authoring tool (as Autodesk Revit, ArchiCAD, and others); - The data included in the BIM model are mapped to a BIM file, in gbXML or IFC format; - The BIM file can be read by the GUI of a BEM tool (such as OpenStudio, Design Builder and others) and then sent to Simulation Engine (such as EnergyPlus or DOE-2); - The software maps output to the GUI; This procedure could raise some issues related to transfer from BIM tools to BIM files; file conversion from BIM to BEM formats; importing of BIM files in energy simulation tools; data loss; and others. Several solutions can be adopted for solving these issues.
Output data	- BEM (Building Energy Model)
Primary actor (and aims)	BIM designer and Energy Analyst who collaborate for BIM-to-BEM interoperability. - Knowledge of basic building energy systems - Knowledge of compatible building energy standard - Knowledge and experience of building system design - Ability to manipulate, navigate, and review a 3D Model

	- Ability to assess a model through engineering analysis tools
Secondary actor (and aims)	Energy manager and owners.
Preconditions	- Building Energy Simulation and Analysis Software(s) and tool(s). - Well-adjusted Building 3D-BIM Model.
Trigger	Energy performance monitoring; Building renovation
Extensions	
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1: Save time and costs by obtaining building and system information automatically from the BIM model instead of inputting data manually. POST-2: Improve building energy prediction accuracy by auto-determining building information such as geometries, volumes precisely from the BIM model. POST-3: Help with building energy code verification. POST-4: Optimize building design for better building performance efficiency and reduce building life-cycle cost.
Frequency of Use	Every time the energy performance monitoring or the building renovation (for example, when HVAC system is replaced, windows are replaced, envelope characteristics changes ...) is settled.
Other Information	
Support planned for	BIM-SPEED
UC Created By	STRESS, CYPE
Date of Last Update	26/08/2019
UC Approved By	

A1.25 UC12 – Calibration of the building energy model

ID	UC 12
Name	**Calibration of the building energy model**
Goal	Perform the calibration of the energy model according to a standardized approach.
Supporting Business Process	Reducing the building energy consumptions.
Description	The Use Case aims at providing a methodology to perform the calibration of the building energy model by using both manual and automated approaches.
Input data (linked with WP1)	- BEM model (for the data necessary to create the BEM model see UC2); - Real energy consumptions of the investigated building; - When possible, actual data from the demo case (e.g. loads, and schedules).
Sequence of actions	- Realize the BEM of the demo case; - Collect the energy consumptions of the demo case; - Compare the real and the simulated data to evaluate the energy performance gap; - Apply iterative adjustments on the most sensitive parameters of the energy model until the discrepancy becomes lower than a predetermined value (e.g. 5%).
Output data	- Calibrated BEM (Building Energy Model)
Primary actor (and aims)	Building energy experts, designers, energy managers.
Secondary actor (and aims)	The figure involved in the renovation process.
Preconditions	- The BEM is available; - Real building energy consumptions are available.
Trigger	- Building renovation - Energy assessment.
Extensions	
Exceptions	If the preconditions are not satisfied, the use case is not employed.
Post-conditions	POST-1: Identification of the incorrect or inaccurate input data of the BEM model.
Frequency of Use	Every time a building renovation process starts.
Other Information	
Support planned for	BIM-SPEED
UC Created By	UNIVPM
Date of Last Update	26/08/2019

UC Approved By	

A1.26 UC13 – Optimization procedure for selecting the best EEB renovation scenario

ID	**UC 13**
Name	**Optimization procedure for selecting the best EEB renovation scenario**
Goal	Assess the best renovation scenario with regard to energy, cost and comfort criteria from a pool of simulated alternatives.
Supporting Business Process	Speed up the renovation process and reducing the building energy consumptions.
Description	The use case provides an optimization procedure to simulate and post-process a large number (hundreds to thousands) of different renovation scenarios for a project. The best scenario(s) with regard to energy, cost and comfort criteria is/are identified by the METABUILD tool.
Input data	The optimization procedure uses the calibrated building energy models (BEM) of the project (see UC12).
Sequence of actions	- Use existing input or run the simulation for building as-is; - Set constraints for scenario alternatives with regard to design options (e.g. HVAC system, materials, window sizes); - Guarantee that input into optimization (performance and cost data of the different renovation measures) is accurate and has a similar degree of detail for all examined building elements and technologies; - Run simulations of hundreds to thousands of possible renovation scenarios; - Compare alternatives with regard to defined goals (energy, comfort, cost).
Output data	One (or a set of) optimal EEB renovation scenario(s), including: - proposed renovation measures; - energy, cost and comfort performance after renovation; - overview of savings as compared to the “as-is” situation.
Primary actor (and aims)	Owners, designers and planners to define goals and constraints for the renovation project
Secondary actor (and aims)	Final user to be involved with regards to comfort goals and constraints
Preconditions	- Calibrated building energy model (BEM) - Performance and cost data of high quality of the possible building elements and technologies that are evaluated in the optimization process.
Trigger	Building renovation.

Extensions	Different economic, occupancy and climate change scenarios can be taken into account during the optimization process, in order to guarantee the robustness of the chosen renovation scenario(s).
Exceptions	In the case that only a limited number of renovation alternatives is considered, automated simulations of every single alternative can be conducted instead of optimization. The METABUILD tool can be applied for the conduction of these automated simulations.
Post-conditions	- Assessment of the requirements for the practical implementation of the renovation measures suggested by the METABUILD optimization tool. - Interaction with the actors: Information and feedback on acceptance of the suggested renovation.
Frequency of Use	Once for every renovation project
Other Information	
Support planned for	BIM-SPEED
UC Created By	MTB, TUB, MOW
Date of Last Update	23/08/2019
UC Approved By	

A1.27 UC14 – Post Occupancy Evaluation to verify the predictions' reliability of renovation scenario

ID	**UC 14**
Name	**Post Occupancy Evaluation to verify the predictions' reliability of renovation scenario**
Goal	The use case aims at providing the building performance assessment using qualitative and quantitative data in use on energy, indoor environmental quality (IEQ) (thermal, acoustic, air, lighting comfort), well-being, carbon emissions and cost of occupancy (i.e. maintenance). POE will be used to validate and calibrate the analytic methods and/or simulation models developed in the course of the BIM-SPEED project.
Supporting Business Process	Reducing the building energy consumptions and increasing the comfort level.
Description	The use case provides a procedure to obtain a complete overview of the built result in use and provides feedback on the extent to which the renovation objectives have been met. The assessment is performed based on the data collected in the demonstration cases.
Input data	- General information concerning the building (e.g. location, year of construction, floor area, number and type of occupants); - Total Energy consumptions (derived from bills, energy label, building audit, smart meters and surveys) ideally to the granularity of main energy end uses (heating, HW, cooling, ventilation, lighting, appliance loads, IT); - Annual total and daily profiles of usage; - Daily profiles for IEQ data from monitors, including temperature, lighting levels, VOCs, CO_2 levels from key spaces; - Occupants well-being assessment from surveys/ interviews including BUS standard questions; - External weather data; - Results of simulations before renovation – full prediction as well as calculations for asset ratings/regulatory compliance; - Water consumption; - Other information in sufficient detail to satisfy Level(s) questionnaire L3 at the minimum; -Actual maintenance costs.
Sequence of actions	- Obtain the energy data measured in the demo cases after retrofitting/ in use; efficiency of renovated HVAC systems to the same or better granularity as stated above; - Collect data on IEQ and carbon footprint after retrofitting/ in use; - Conduct surveys/ interviews with occupants; - Collect data on actual maintenance costs; - Analyse data; - Evaluate results;

	- Validate and calibrate the analytic and simulation models.
Output data	- Complete assessment of the performance of the renovated building in use: resources consumed, indoor environmental quality and, the achieved occupant satisfaction. - Comparison between KPIs calculated from measurement before renovation and after renovation.
Primary actor (and aims)	Final user inhabitant and building owner (data collection).
Secondary actor (and aims)	Energy experts, architects, designers.
Preconditions	- Buildings under investigation have been renovated and they are in use for 1-3 years. Data from year 1 of occupation can also be helpful for addressing issues during the defects liability period. - Building occupants are willing to participate in surveys/ interviews/ provide performance data (consent in relation to GDPR). - Real data are available or measurable. - Sample size determination (ensuring that a sufficient number of occupants participate in the surveys). - Defining targeted thresholds (above x %) to conclude the satisfaction of the occupants about a matter in question.
Trigger	Building renovation completed
Extensions	
Exceptions	
Post-conditions	
Frequency of Use	Every time a building renovation process is completed, and the building is in use/ has been in use for 1-3 years.
Other Information	
Support planned for	BIM-SPEED
UC Created By	ACE, CYPE, FAS, DMO, TUB, UNIVPM
Date of Last Update	25/0/2019
UC Approved By	

A1.28 UC15 – Assessing operational energy costs using measured data

ID	UC 15
Name	**Assessing operational energy costs using measured data**
Goal	The UC aims to assess the flat operational energy cost using measured data
Supporting Business Process	Sustainability analysis Economic parameter
Description	The UC aims to collect the flat operational energy cost before and after renovation and calculate the operational energy cost per square meterage of the flat.
Input data	- Energy bills collected on-site; - The net floor area (in m^2) of the surveyed apartment.
Sequence of actions	1) Request the needed information from the residents: energy bill paid in the last year. 2) Surveyed Information on-site: apartment net floor area (m^2). 3) Calculate the indicators.
Output data	- KPI: o BS.OEC (Operational Energy Cost)
Primary actor (and aims)	- Residents (provide the information) - Energy Expert (calculate the indicators and evaluate the energy impact)
Secondary actor (and aims)	Stakeholders
Preconditions	Residents are willing to share their energy bills. Residents have the above information available. Residents agree upon the access to their apartment by the site surveyor.
Trigger	Site survey works approval
Extensions	
Exceptions	If real energy bills are not available or residents do not want to share such information, the operational energy costs can be estimated considering the energy consumptions of the building and the energy prices related to each specific nation.
Post-conditions	
Frequency of Use	Before and after renovation
Other Information	
Support planned for	BIM-SPEED
UC Created By	ACE
Date of Last Update	23/08/2019
UC Approved By	ACE / CARTIF

A1.29 UC16 – Assessing operational energy using simulated data

ID	UC 16
Name	**Assessing operational energy cost using simulated data**
Goal	The UC aims to assess the flat operational energy cost using simulated data
Supporting Business Process	Sustainability analysis Economic parameter
Description	The UC aims to calculate and compare the simulated operational energy cost per square meter for different renovation scenarios.
Input data	- Architect's design options modelled in 3D - Energy cost - The net floor area (in m2) of the surveyed apartment. - Measured data for model calibration - Renovation budget (in €)
Sequence of actions	1) Architect's design options for renovation available in BIM 2) Generate and calibrate BEM (UC12) 3) Simulate the operational energy consumption for each design option 4) Calculate Operational Energy Costs for each option; 5) Calculate the KPI 6) Compare KPI for different design option
Output data	KPIs: o BS.OEC (Operational Energy Costs)
Primary actor (and aims)	Energy expert (Run the simulation and calculate the KPI for each option) Quantity surveyor (Define the renovation budget) Architects (Provide different design options)
Secondary actor (and aims)	Residents and stakeholders
Preconditions	Design options presented to the client As surveyed 3D BIM model
Trigger	Client commissioning the Architect and the energy expert for the renovation design.
Extensions	
Exceptions	
Post-conditions	
Frequency of Use	Once per each design option
Other Information	

Support planned for	BIM-SPEED
UC Created By	ACE / CARTIF
Date of Last Update	23/08/2019
UC Approved By	

A1.30 UC17 – Assessing investment payback

ID	UC 17
Name	**Assessing investment payback using simulated data**
Goal	The UC will provide an indicator to assess the investment the period of time required to recover the investment for each design option
Supporting Business Process	Sustainability analysis Economic parameter
Description	The UC aims to calculate the actual renovation payback. The UC aims to calculate and compare the investment payback in years for different renovation scenarios, using simulated data to calculate the energy consumption
Input data	- Architect's design options - Total energy consumption before the renovation - Measured Data for BEM calibration (UC12)- The apartment area after renovation - Renovation cost per each design option - Simulated energy consumption for each design option per year
Sequence of actions	1) Architect's design options for renovation available in BIM 2) Generates and calibrate BEM (UC12) 3) Simulate the energy consumption for each option 4) Calculate the energy savings for each option (energy consumption before renovation – simulated energy consumption) 5) Renovation cost (€) 6) Calculate the KPI BS.PP
Output data	KPIs: o BS.PP (Payback Period)
Primary actor (and aims)	Architects to provide the design option Residents (provide energy consumption before renovation) Energy Expert (simulate the energy consumption and calculate energy savings).
Secondary actor (and aims)	Stakeholders
Preconditions	- Client requirements presented - Architect and energy expert commissioned by the client - Residents willing to share the energy consumption information
Trigger	Design option assessment

Extensions	
Exceptions	
Post-conditions	
Frequency of Use	Once for every design op
Other Information	
Support planned for	BIM-SPEED
UC Created By	ACE/CARTIF
Date of Last Update	23/08/2019
UC Approved By	

A1.31 UC18 – Assessing the fuel poverty condition

ID	UC 18
Name	**Assessing the fuel poverty condition**
Goal	The UC aims at assessing the fuel poverty indicator
Supporting Business Process	Sustainability analysis Social and economic parameters
Description	The UC provides a procedure to assess the household fuel poverty status before and after the renovation in case that the thermal comfort KPI provides a very low value.
Input data	- Simulated operational energy cost to keep the indoor environment in comfortable conditions. (Assuming building performance before and after renovation) - Residents annual income (€)
Sequence of actions	1) Collect all the input data; 2) Calculate the fuel poverty KPI.
Output data	KPI: o BS.FP (Fuel Poverty)
Primary actor (and aims)	Energy Expert – calculate the indicator and make it available to all stakeholders. Residents – provide the annual income
Secondary actor (and aims)	Stakeholders
Preconditions	The Thermal Comfort KPI (BS.TC) returns a value of 0%. Occupants are willing to share information about their income.
Trigger	Very low level of thermal comfort condition.
Extensions	
Exceptions	
Post-conditions	POST-1: a clear indication of the poverty status of the occupants
Frequency of Use	Twice – before and after renovation
Other Information	
Support planned for	BIM-SPEED
UC Created By	ACE, UNIVPM
Date of Last Update	23/08/2019
UC Approved By	

A1.32 UC19 – Assessing the actual energy savings

ID	UC 19
Name	**Assessing the actual energy savings using measured data**
Goal	The UC targets at assessing the actual energy savings by comparing pre and post-renovation data measured in the building
Supporting Business Process	Reducing the building energy consumptions Energy Performance assessment
Description	The use case provides a procedure to obtain a complete overview of the actual building energy savings. The assessment is based on data collected in the demo case pre and post-renovation.
Input data	- All input data from UC1
Sequence of actions	- Obtain the energy data measured in the demo cases before and after renovation - Evaluate the energy performance by calculating and compare the KPIs before and after renovation. - Assessing energy savings and provide feedback to designers.
Output data	- Output KPIs from UC1 before and after renovation
Primary actor (and aims)	Energy experts performing the energy assessment.
Secondary actor (and aims)	Final user (helping in the data collection) and building owner
Preconditions	- The buildings under investigation are classified as residential or have a comparable end-use; - The building is identified in location and required information about building features are provided; - Real data are available or measurable.
Trigger	One year of building operation at least to provide enough data for pre and post-renovation performance
Extensions	
Exceptions	
Post-conditions	POST-1: Provide feedback to future architectural design in new renovations
Frequency of Use	Every time a building renovation is finished and has at least one year of operation.
Other Information	
Support planned for	BIM-SPEED

UC Created By	ACE
Date of Last Update	23/08/2019
UC Approved By	