Real demonstration results of BEM performance simulation using BIM-SPEED Toolset

Deliverable 4.2

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

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Real demonstration results of BEM performance simulation using BIM-SPEED Toolset

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Colophon

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Publishable executive summary

The purpose of this report is to collect and summarise the results of the building energy performance simulations of the BIM SPEED demonstration cases. The activities performed includes the development of BEM models of the actual state of the buildings, the assessment of the energy performance and the evaluation of the renovation scenarios. All the energy models have been collected in an OpenData repository on DepositOnce available at the following URL: https://doi.org/10.14279/depositonce-16386.

The following different tools and procedures have been applied to the BIM SPEED democases:

- the BIM-to-BEM procedures and tools created within BIM SPEED;
- the calibration procedure developed by Università Politecnica delle Marche;
- the optimization tool developed by Metabuild.

Moreover, the deliverable suggests a way to include real-time data coming from monitoring and weather forecast data into the energy simulations in order to increase BEM reliability and have more precise prediction of building energy consumption.

In general, the activities carried out constitutes an important step to consolidate the use of BIM in the building renovation process and check the developments achieved in BIM SPEED.

The report provides an introduction about the methods, tools and processes adopted, an overview of the process applied in each democase, a qualitative assessment of the time reduction related to the adoption of the BIM-to-BEM workflow for the energy simulations and specific energy Reports, one for each demo.

List of acronyms and abbreviations

BEM: Building Energy Model

BIM: Building Information Model

DIYEPW: Do-It-Yourself EnergyPlus weather

EEB: Energy-efficient Building

EED: Energy Efficiency Directive

EPW: EnergyPlus Weather

EPBD: Energy Performance Buildings Directive

GbXML: Green building XML

GIS: Geospatial Information System

HVAC: Heating Ventilation Air Conditioning

IDF: Input Definition Format

IEQ: Indoor Environment Quality

IFC: Industry Foundation Classes

KPI: Key Performance Indicator

LAF: Localized Actual meteorological year File

MEP: Mechanical Electrical Plumbing

nZEB: Nearly Zero-Energy Buildings

RES: Renewable Energy Source

TRL: Technology Readiness Level

XML: Extensible Markup Language

Definitions

BIM-to-BEM interoperability

BIM-to-BEM interoperability is the ability of BIM and BEM tools to communicate and exchange data correctly.

Open BIM

Open BIM is a universal approach for collaborative design, realization and operation of buildings based on open standards and workflows. Open BIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model.

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1. Introduction

1.1 Description of the deliverable content and purpose

The main goal of this deliverable is to provide practical examples for designers, energy modelers, and building owners in order to increase the know-how and the awareness on the potential benefits due to the adoption of the BIM-to-BEM procedures, the calibration process, and the use of optimization processes for defining renovation interventions on existing buildings.

The document provides information on the activities carried out on each BIM SPEED pilot regarding the building energy simulations, informing on the current energy performance of the buildings and on expected energy savings of each renovation proposed.

In general, the scope of work was to test and check the procedures developed in WP3 on real cases, consolidate the use of BIM in the building renovation process also for the energy assessments, accelerating the energy analysis and therefore, enhancing the energy efficiency of the proposed interventions.

Deliverable type is “other” and summarising Task 4.2 activities, 3 main practical assets can be identified:

Activity 1: Oversee running the building energy simulations

The building energy simulations have been carried out in conjunction with WP3 and WP8 activities. Different tools and procedures have been used, according to pilots’ responsible needs and expertise. A general coordination of activities and results have been performed within task 4.2 as well as a technical support related the new procedures developed in WP3.

Chapter 2 provides the methodology and the workflow adopted to perform the Building Energy Performance simulations on the BIM SPEED democases.

The energy models, complete with building elements, layout, topology, systems and occupancy patterns, were collected in an OpenData repository on DepositOnce, together with complete Energy Reports summarizing features and results.

Activity 2: Conduct various simulations for building renovation

For each pilot various simulations for building renovations were performed according to the inputs coming from Task 7.1 activities comprising energy, thermal load and HVAC performance analyses. In particular, two different approaches were used. One following a more traditional process and with a limited number of solutions evaluated and one based on an automated optimization process capable of evaluating multiple simulations of varying renovation solutions in search of the optimal energy performance. For this purpose, an automated optimization tool was developed by Metabuild. Chapter 3 provides the methodologies and the workflow adopted to evaluate the renovation scenarios.

Activity 3: Automatic parametrisation of the simulation model with real-time data and weather forecast

A way to include real-time data coming from monitoring and weather forecast data into the energy simulations was investigated in order to increase BEM reliability and have more precise prediction of building energy consumption. Chapter 4 summarises a few feasible approaches to include real time data and weather forecast into the Energy simulations.

To conclude, a qualitative assessment of the time reduction related to the adoption of the BIM-to-BEM workflow for the energy simulations has been provided within Chapter 5.

All the BIM SPEED pilots, expect for Varna and Malko Tarnovo, have been included int the BEM performance simulation activities. The two Bulgarian demos have been used to test other BIM SPEED tools.

1.2 Contributions of partners

All the partners assigned to Task 4.2 have contributed to the development of this report. More specifically, partners' contribution to the deliverable can be divided as follows:

Table 1: Contribution of partners

#	Partner	Contribution
1	**STRESS**	Leader of the deliverable, coordination of the overall task activity, direct BEM creation for Vitoria and Frigento democases, oversee all the other BEM development, investigation of automatic parametrization with real-time data and weather forecast.
2	**CYPE**	Overseeing BEM development and evaluation of the renovation scenarios applying the CYPETHERM Procedure and tools.
3	**UNIVPM**	Investigation of automatic parametrization with real-time data and weather forecast.
4	**MTB**	Development of an automatic optimization tool to assess multiple renovation scenarios.

1.3 Target group and relations to other activities

The main target group of this deliverable are designers, energy modelers and building owners.

Task 4.2 activities are directly linked to:

- WP2: from which the BIM models are derived;
- WP3: Task 3.2 concerning the BIM-to-BEM procedures, Task 3.3 for the integration of weather file data into BEM models and Task 3.4 for the calibration process;
- WP4: Task 4.1 concerning the Energy KPIs to be calculated and the use Cases and Task 4.5 to which Energy KPI are provided;
- WP7: Task 7.1 for the renovation scenarios options;
- WP8: Task 8.1 for the activities carried out on each demonstration case.

2. Building energy performance evaluation workflow

This section provides an overview of the workflow adopted for the assessment of the energy performance of buildings and renovation scenarios on the BIM SPEED democases with simulated data. It corresponds to the Use Case UC 2, specifies the steps to move from the real building to the virtual one and supports the renovation design and the reduction of the energy consumptions when real energy data from the building are missing.

As shown in the figure below, the workflow starts with the creation of the Energy Model called "Baseline model", that corresponds to the actual state of the building, then the BEM, to be reliable, has to be calibrated using the energy consumption (from energy bills or direct monitoring) and the energy performance of the building are evaluated according to the Energy KPIs defined in Deliverable 4.1 (i.e. BS.OPED, BS.TED, BS.TEC, BS.GWP, BS.FP, and BS.OEC). Once the BEM of the baseline has been created, calibrated and assessed, it is possible to define and model the renovation scenarios, run the simulations and compare the results.

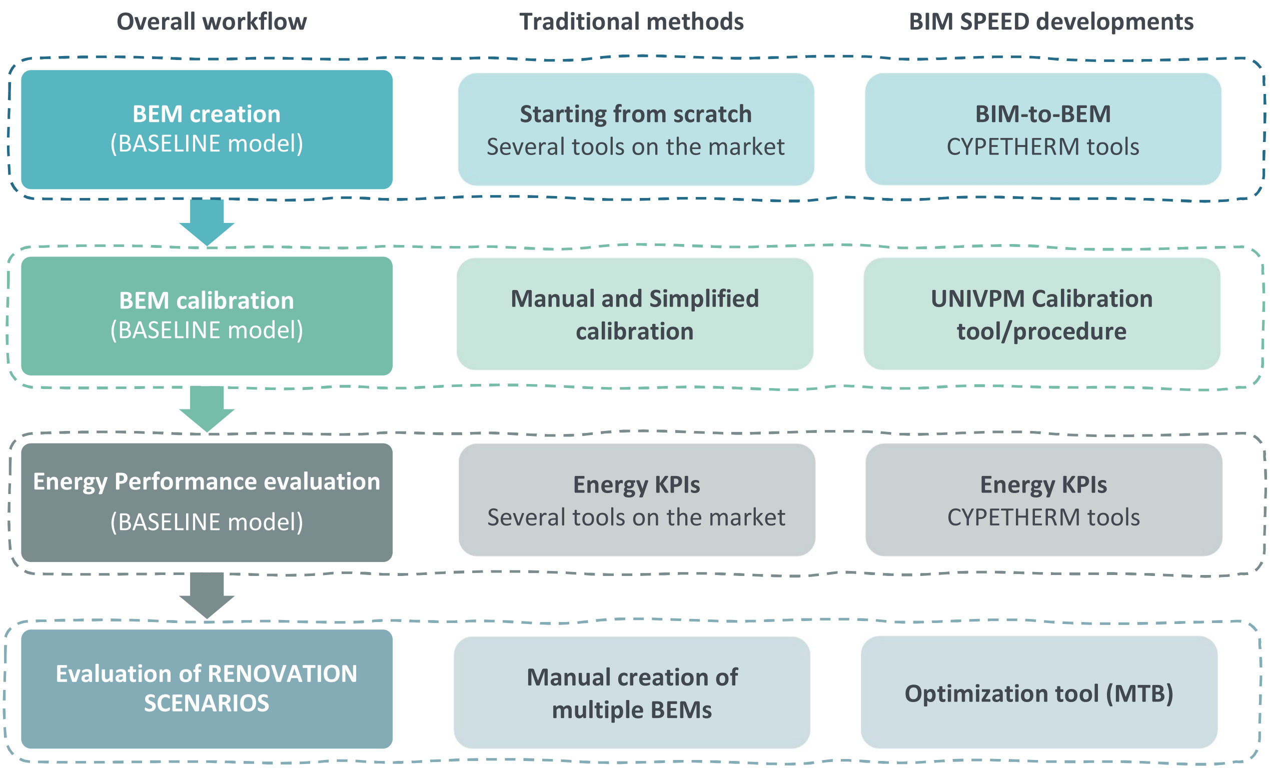


Figure 1: Task 4.2 Energy assessment workflow

The overall process, starting from the creation of the BEM and ending with the evaluation of the renovation scenarios, can be implemented through:

- traditional methods and tools (middle column);
- tools and procedures developed in BIM SPEED (right column);
- a mix of both (e.g. BEM created in the traditional way and calibrated with the tool developed in BIM SPEED).

The following paragraphs detail the process step-by-step. Practical examples of different combination of procedures and tools that can be adopted for the energy assessments have been documented within each Energy Report included in an OpenData repository on DepositOnce available at the following URL: https://doi.org/10.14279/depositonce-16386.

2.1 BEM creation methodology

The creation of a detailed BEM is a very lengthy, laborious and resource consuming process. In general, it starts with an energy audit, requires specific tools and ends with the calibration of the model.

The methodological approach adopted in BIM SPEED for the creation of the BEMs passes through a coordination with previous phases of the BIM-SPEED process, starting from the data acquisition methods provided in WP1 and the creation if as-built BIMs as defined in WP2.

2.1.1 Auditing procedures and data collection

Deliverable 1.1 “Methods for architectural, structural, thermal 3D data acquisition of existing buildings” and Deliverable 1.2 “Methods for surveying and diagnostics of HVAC systems in existing buildings” provided guidelines and methods for data acquisition of existing buildings.

The auditing procedure consists of an initial phase of preliminary data collection, a site survey to define the process and the retrieval of technical and energy-related information. In general, the energy audit is needed to collect the following data (in addition to the geometrical information):

- thermo-physical characteristics of the envelope (materials properties);
- specification of the energy performance of windows;
- space use and features to identify homogeneous thermal zones;
- thermal loads due to the specific use of the different thermal zones;
- ventilation rates of the thermal zones (per occupant or space size);
- set point temperatures of each thermal zone;
- HVAC systems for the building and for each thermal zone (sub-systems).

Some of this information may already be included in BIM models.

Following the methodology for the energy audit process in line with the standard EN 16247-2:2022 “Energy Audit Part 2: Buildings” is summarized.

Table 2: Steps in the energy audit process

#	Steps	Purpose and characteristics
A	**Preliminary contacts**	a. Definition of the needs of the client b. Definition of the scope of intervention, degree of accuracy and objectives of the DE c. Definition of the type of audit and energy system

		d. Preliminary information on the operations to be carried out pe the DE e. Preliminary information on strategic programs, building energy management systems, constraints on potential energy saving measures f. Definition of building contact person and figures to be involved in all phases g. Definition of report deliverables to be submitted
B	**Preliminary meeting**	a. Defining the boundaries of the energy system and operational modes of access b. Definition of resources and data to be provided c. Definition of safety and security standards for the execution of DE d. Informing the client of the process steps, execution scheme, and mode of operation e. Acquisition of preliminary and significant data on the building, past events, recent maintenance works, special constraints f. Definition of the schedule of inspections with relevant priorities
C	**Data collection**	a. Data collection of the energy system b. Retrieval of design, operation and maintenance documents c. Current and projected prices and costs d. Relevant energy, economic and environmental data e. Review and possible integration of data collected f. Preliminary analysis of the energy system
D	**On site activities**	a. Inspection of various aspects of the energy system and its behavior based on the preliminary meeting and data collected b. Evaluate the significant energy aspects c. Identify operating modes, user behavior and their influence on energy consumption d. List areas and processes that need data integration to support analysis
E	**Analysis**	a. Construction of the energy model based on the data and information collected b. Budget analysis and diagram of energy flows broken down by end use, plant system and supply c. Definition and calculation of energy performance indicators, comparison of actual, operational and benchmark indices d. Identification and evaluation of energy saving opportunities ORE, intervention scenarios
F	**Report**	a. Development of the contents of the energy diagnosis report according to the scope, objectives and level of detail
G	**Final Meeting**	a. Delivery of the diagnosis report b. Presentation of results and verification of supplementary vc investigation c. Analysis and preliminary planning of interventions

Within the BIM SPEED Project, the Energy Audits have been performed by the pilots' responsible. Results and information have been documented within the energy reports included within an OpenData repository on DepositOnce available at the following URL: https://doi.org/10.14279/depositonce-16386.

After a framing of the site, of the activities boundaries and the actors involved, an inventory of the main energy data was carried out through the compilation of a special check-list (excel file circulated among all partners for the data collection).

2.1.2 BEM creation: tools and procedures used

To create BEM models, according to each democase needs, two different approaches were adopted:

- the BIM-to-BEM approach developed in BIM SPEED: the CYPETHERM Procedure has been fully detailed within D3.2 "A set of support tools and standardized procedures for BEM creation", it allows both to use a simple approach and a full BIM-BEM advanced approach according to the expertise of the energy modeler and the data available.
- a traditional approach using different tools already available on the market: since the BIM-to-BEM process might require a few manual adjustments, simplifications and corrections that could be extremely time-consuming especially for large and complex buildings, a few democases adopted a traditional process for the BEM creation, choosing to test other BIM SPEED tools.

To support the BEM creation following the CYPETHERM Procedure a dedicated webinar has been carried out with specific training (25th February 2021).

2.2 BEM calibration

Since a significant discrepancy is found between simulated results coming from BEM and measured energy consumption, reaching values up to 250%, it is important calibrate the models. Deliverable 3.4 "A set of calibrated BEM for real demo" provides details on the calibration methodologies and on the BEM-Calibration Tool developed by UNIVMP within the framework of task 3.4 activities, including both manual and automated approaches to give a wider range of possibilities to execute the calibration.

In general, to calibrate a BEM model all the parameters that influence the energy performance of a building must be accurately collected during the period of interest. In particular, to complete a calibration, energy consumptions (utility bills spanning at least 1 year and comprising at least 12 valid meter readings, according to ASHRAE 14 standard) must be available.

To support pilots' activities, a "BEM-Calibration: data collection guideline" (included within Appendix 1) had been developed to collect data and set BEM models compliant with the BEM-Calibration Tool requirements. The purpose is to avoid the gap between predicted and real energy consumptions.

2.3 Energy performance evaluation

Deliverable 4.1 identified the energy KPIs to be assessed in order to evaluate the energy behavior of the building conditions pre and post-renovation. There are different simulation engines that can be used to calculate the energy performance of a building starting from a compatible energy model. Many available tools already implement their simulation algorithms.

The information gathered during the energy audits, the energy modeling performed using dedicated software, and the technician's experience enabled the characterization of energy consumption for the different BIM SPEED democases.

Table 3 briefly summarises the Energy KPIs calculated for the BIM SPEED democases in order to evaluate the energy performance of the actual state of the buildings (baseline models). Additionally, the CYPETHERM Procedure allows to export an .idf file compatible with Energy Plus, a simulation tool which leads to more accurate predictions of various additional parameters.

Table 3: Energy KPIs evaluated for the actual state of the BIM SPEED democases

#	KPIs	Definition
BS.OPED	**Operational Primary Energy Demand**	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. 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.
BS.TED	**Total Energy Demand**	The energy demand of a building states the quality of its envelope. It 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.
BS.TEC	**Total Energy Consumption**	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/m2year. 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.

2.4 Real demonstration results

All the BIM SPEED pilots, expect for Varna and Malko Tarnovo, have been involved in task 4.2 activities.

The following paragraph 2.4.1 provides an overview of the methodologies and the tools adopted for the BEM creation. All the BEM models of the actual state of the buildings, and the Energy Reports have been collected in an OpenData repository on DepositOnce available at the following URL: https://doi.org/10.14279/depositonce-16386.

2.4.1 Summary of the methodologies and tools applied

The following table summarises the procedures and the tools adopted in each democase to perform the energy assessment. Not all the BIM SPEED democases tested a BIM-to BEM procedure, for some democases, due to the complexity of the existing BIM models that would have required much more effort and manual adjustments rather than starting from the scratch, the BEM creation was aimed to test other BIM SPEED tools (e.g. the Calibration tool, the Optimization tool and the multi decision-making tool).

Table 4: Summary of the procedures and tools for the BEM creation

#	PILOT	BEM creation Process/Tools	CALIBRATION Process
1	**Vitoria**	**BIM-to-BEM** CYPE's Procedure	**COMPLETED** UNIVPM tool
2	**Lichtenrade**	**Traditional Process** IDF Editor EPlus	No calibration tested
3	**Warsaw I**	**BIM-to-BEM** CYPE's Procedure	Only a **simplified validation** process completed
4	**Warsaw II**	**BIM-to-BEM** CYPE's Procedure	No calibration tested
5	**Barlad**	**BIM-to-BEM** CYPE's Procedure	No calibration tested
6	**M. Tarnovo**	no energy assessment	
7	**Varna**	no energy assessment	

8	**Frigento**	**BIM-to-BEM** CYPE's Procedure	Only a **simplified validation** process completed
9	**Gdynia**	**BIM-to-BEM** CYPE's Procedure	Only a **simplified validation** process completed
10	**Warmond**	**Traditional Process** Rhino + Grasshopper + EnergyPlus	**COMPLETED** UNIVPM tool
11	**Tempelhof**	**BIM-to-BEM** CYPE's Procedure	No calibration tested
12	**Antony**	**Traditional Process** Design Builder	No calibration tested
13	**Massy**	**Traditioanl Process** Design Builder	No calibration tested

Out of 13 demonstrators, 7 tested the BIM-to-BEM procedure developed in WP3, while 4 demonstrators used, for the creation of BEM models, a traditional approach starting the energy model development for the scratch.

The Calibration tool developed by UNIVPM was tested in 2 democases: Vitoria and Warmond. For the other democases it was not possible to test the tool as not all the required data (monitoring data, energy bills) were available with a proper level of detail.

3. Building renovation scenarios evaluation

To evaluate various renovation scenarios two different approaches were adopted according to the BEM features and the pilots' needs:

- an automated optimization procedure based on the use of the Optimization tool developed by Metabuild;
- a manual procedure involving the manual configuration of multiple BEMs.

Both approaches, detailed within the following paragraphs, allow the evaluation of the energy savings that a specific renovation can provide.

The identification of the renovation scenarios to be assessed under the energy point of view was provided, for each democase, by the multi decision-making tool (task 7.1) based on the specific issues and suitable areas of improvements identified in each building.

The approach for calculating energy savings is connected to the current state of the building (baseline) and to the comparison between the energy consumption of the baseline and the expected energy consumption as calculated for the specific renovation.

The following Energy KPIs have been evaluated for each renovation scenarios.

Table 5: Energy KPIs evaluated for the renovation scenarios of the BIM SPEED democases

#	KPIs	Definition
BS.OPED	**Operational Primary Energy Demand**	As in previous table 3
BS.TED	**Total Energy Demand**	As in previous table 3
BS.TEC	**Total Energy Consumption**	As in previous table 3
BS.TES	**Total Energy Savings**	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.

The Total Energy Savings KPI is a crucial indicator for aiding users and stakeholders in the decision-making process and in selecting the most suitable renovation action.

3.1 Automated optimization procedure for the assessment of renovation scenarios

An optimization procedure to simulate and post-process a large number of different renovation scenarios in search of the optimal solution has been developed by Metabuild.

3.1.1 Brief overview of the tool

Metabuild is a future cloud platform that enables real estate developers and architects to create better buildings using artificial intelligence commanded by a unique optimization algorithm. It was created within 8 years of research and development, initially for new buildings and now being extended for building renovation projects. It enables building owners to reduce life cycle costs of their real estate projects by up to 30%.

The optimization process, for the time being, is not yet fully automated in all its steps and the tool is still being further developed. Basically, the procedure is characterised, whether it is done manually or automatic, by three main steps:

1. Input data and set-up of the optimization process;
2. Calculation of the optimization;
3. Output data and report generation.

3.1.2 Input data and set-up of the optimization process

The first step corresponds to preparation and adaptation of the data to be introduced in the calculation engine. This phase can be divided in the following subtasks:

- BEM model adaptation: it might be necessary to simplify or adapt the BEM in order to complete the optimization process;
- Identification of a list of options to be tested in the optimization process;
- Definition set of constructions data, economic data, finance data to be used in the process.

This step is not fully automatic and requires manual input from an energy expert.

3.1.3 Input data and set-up of the optimization process

The second step corresponds to launching of simulations and calculations according to the configuration defined previously and based on an optimization algorithm. Once the optimization is launched, the search of a range of optimal renovation scenarios is fully automatic and controlled by an AI algorithm. The calculation time depends on many factors such as building size number of thermal zones, number of different options included in the optimization, number of servers available, number of simulations to be proofed for obtaining the optimal solution.

In general, optimization processes last averagely at least 3 days, but they could require up to 10 days for larger and complex buildings, and the number of simulations for reaching the goal optimal are 4.000.

3.1.4 Output data and report generation

The last step concerns the data processing. The step is almost automatic. The optimal solutions are shown within a diagram “the pareto front” where a range of solutions are identified as optimal. It is possible then to select manually one or more optimal solutions for the automatic generation of the report.

The main advantage of using this approach is the possibility to analyse automatically a big amount of possible interventions and identify one or a set of optimal EEB renovation scenario(s) according to energy and cost criteria or other KPIs that are decisive for the project.

Once scenarios are identified, the evaluation can be enriched with comparative calculations e.g. energy savings and CO_2 savings with regard to the baseline.

3.2 Manual procedure for the assessment of renovation scenarios

To evaluate different renovation scenarios and assess the expected energy savings also a manual and more “traditional” procedure has been proposed to the democases. The approach can be completed using several tools already available on the market and allow to evaluate a limited number of interventions since thein needs to be modelled by the users manually.

Starting from the BEM of the baseline, the interventions are manually completed modifying those parameters representative of the renovations (e.g. adding a layer of external insulation to the existing stratigraphies of the external walls or changing the efficiency of a boiler).

3.3 Real demonstration results

All the BIM SPEED pilots, expect for Varna and Malko Tarnovo, have been involved in task 4.2 activities.

The following paragraph 3.3.1 provides an overview of:

- the procedure applied for the evaluation of the renovation scenarios;
- the summary of the expected energy savings.

For each demo, details on processes and the energy results have been included in the Energy Reports available, together with the BEMs of the renovated scenarios, at the following URL: https://doi.org/10.14279/depositonce-16386.

3.3.1 Summary of the renovation scenarios process

The following table summarises the procedures and the tools adopted in each democase to assess the renovation scenarios. The different interventions proposed were identified in the framework of task 7.1 activities.

As shown, the automated optimization process developed by Metabuild to search a set of optimal renovation solutions among a large number of possible configurations has been applied in 4 democases (Frigento, Warmond, Antony and Massy) while the other democases adopted a traditional process assessing a more limited number of scenarios.

Table 6: Summary of the procedures and tools for the assessment of the renovation scenarios

#	PILOT	BEM Interventions Process/Tool	Number of renovation scenarios assessed
1	**Vitoria**	**COMPLETED** - CYPETHERM EPlus	3
2	**Lichtenrade**	**COMPLETED** - IDF Editor EPlus	3
3	**Warsaw I**	**COMPLETED** - CYPETHERM EPlus	3
4	**Warsaw II**	**COMPLETED** - CYPETHERM EPlus	1
5	**Barlad**	**COMPLETED** - CYPETHERM EPlus	3
6	M. Tarnovo	no energy assessment	
7	Varna	no energy assessment	
8	**Frigento**	**COMPLETED** - MTB Optimization tool	4000
9	**Gdynia**	**COMPLETED** - CYPETHERM EPlus	4
10	**Warmond**	**COMPLETED** - MTB Optimization tool	4000
11	**Tempelhof**	**COMPLETED** - CYPETHERM EPlus	3
12	**Antony**	**COMPLETED** - with MTB Optimization tool	4000
13	**Massy**	**COMPLETED** - with MTB Optimization tool	4000

3.3.2 Summary of the expected energy savings

The following table summarises the energy savings expected in each democase with the adoption of the best renovation scenario according to the assessment done and documented within the Energy Reports.

Table 7: Summary of the expected energy savings

#	PILOT	BASELINE EP_{TOT}[kWh/m²]	BEST SCENAIO EP_{TOT}[kWh/m²]	Energy SAVING	BIM SPEED process adopded
1	**Vitoria**	272.7	13.9	95%	BIM-to-BEM
2	**Lichtenrade**	47.81	43.12	10%	NO
3	**Warsaw I**	234.6	92.4	60%	BIM-to-BEM
4	**Warsaw II**	no energy assessment of the baseline			BIM-to-BEM
5	**Barlad**	762.8	578.8	24%	BIM-to-BEM
6	Malko Tarnovo	no energy assessment			
7	Varna	no energy assessment			
8	**Frigento**	102.6	51.30	50%	BIM-to-BEM Optimization process
9	**Gdynia**	233.8	75.9	68%	BIM-to-BEM

10	**Warmond**	61.93	18.18	71%	Optimization process
11	**Tempelhof**	162.9	83.4	49%	BIM-to-BEM
12	**Antony**	58.66	2.64	95%	Optimization process
13	**Massy**	21.54			Optimization process

The results indicate that by adopting the BIM SPEED procedures (BIM-to-BEM and/or the Optimization process) the expected energy savings range from 24% (Barlad demo, which has low savings due to the limited proposed interventions) to 95% (Vitoria demo, where the very high energy saving is due to the installation of a very efficient PV system able to provide a large amount of electricity throughout the year and Antony where the very high energy saving is due to an extremely performing insulation). On average, the expected savings range from 49% to 71%.

For the Lichtenrade demo, the expected energy savings are very low (only 10%), a traditional BEM creation process and a traditional selection of renovation scenarios were adopted for the demo without specific energy expertise.

4. Automatic parametrisation with real-time data and weather forecast

In this chapter, to complement the analyses performed on the demos and processes developed in BIM SPEED, possible processes for automatic parameterization of the simulation models with real-time data and weather forecasts were analyzed. Within the framework of BIM SPEED, any new tools have been developed and the processes have not been tested on demonstrators, the topic was introduced as it represents a very promising aspect to be further developed to enrich dynamic simulations, extract results and calculate KPIs.

4.1 Current Approach

BEM simulations carried out with EnergyPlus involve two types of data:

- building model with IDF input data files (geometry, building materials, and HVAC system);
- climatic factors in .epw format (EnergyPlus weather) including humidity, temperature, solar radiation, wind speed, and precipitations.

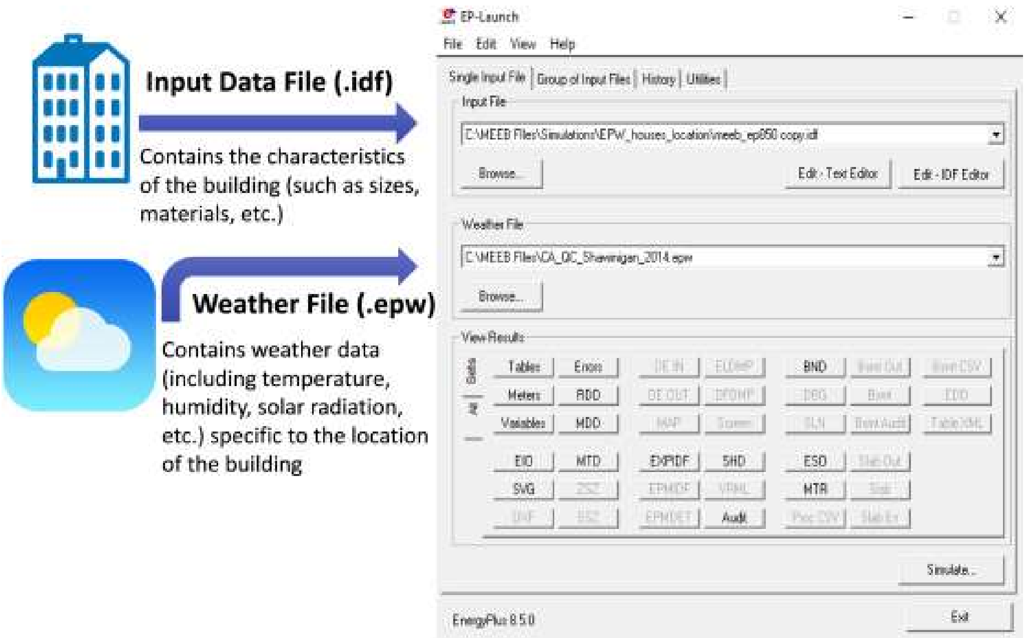


Figure 2: Energy Plus main interface

The EPW files contain the weather data, including temperature, humidity, temperature, solar radiation, wind speed and rainfall and they are freely available from the MEREEN weather service, the BIM SPEED GID data provider service or from https://energyplus.net/weather for different locations around the world.

It is evident how the meteorological parameters above can affect energy-building simulations, and, for this reason, they must be as accurate as possible.

However, all types of weather files, in general, show some critical issues such as:

- reliability of the source: even small variations have a strong impact on the simulations
- availability: for example, EnergyPlus often provides TMY files from airport meteorological stations that can report huge differences with respect to the building's geographical location. Different studies report that microclimate conditions are important in terms of energy building consumption so it would be a plus to gain local weather data.
- modifiability: for an inexperienced user it is difficult to use available climatic data associated with measured ones with a suitable format for EnergyPlus.

Currently, it is possible to refer to two approaches: one analyzes real-time data as a modification of statistical ones and the other is investigating how to forecast weather data locally, working on real-time data, from other locations. The first method is supported by two software DIYEPW and LAF that are going to be illustrated.

4.2 Practical approaches to implement real-time data into the energy simulations

Two practical approaches to implement real-time data into the energy simulations have been investigated.

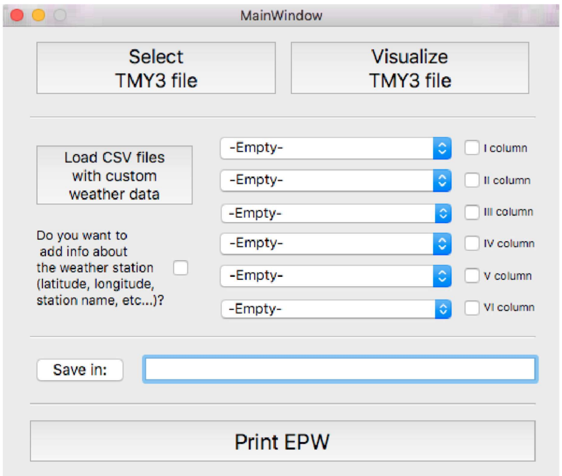
DIYEPW

DIYEPW, acronymous for Do-It-Yourself EnergyPlus weather file generation, is a Python tool that allows to the creation of AMY files. AMY files, or actual meteorological years, are files that contain hourly meteorological data and are specific to a given geographical location. They differ from the TMY, typical meteorological year data, which instead are created on a statistical part of a block of years. For building energy models, AMY files are more useful, even though, it is advisable to integrate specific local variables (dry bulb, dew point, pressure, wind direction, wind speed). DIYEPW allows for the addition of these variables using the same TMY template and therefore in .epw format (usable in EnergyPlus). Furthermore, it supplies solutions to problems related to missing data (a situation frequented in this field of data collection). It is possible to get started by clicking the following website:
https://diyepw.readthedocs.io/en/latest/

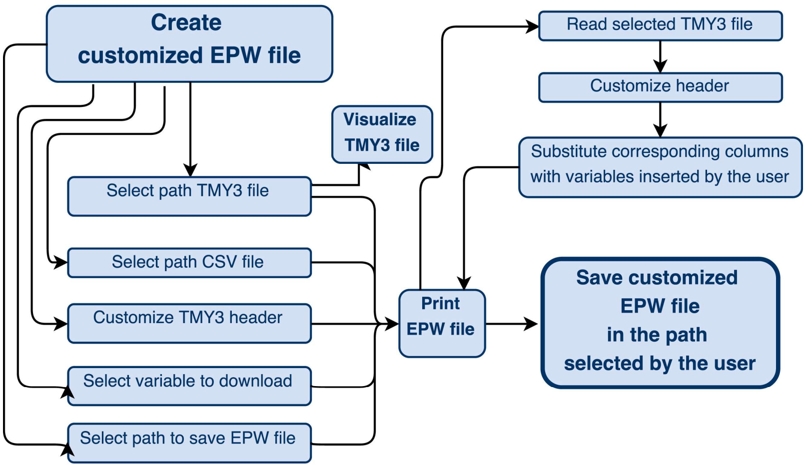
LAF

LAF, the acronym for Localized Actual Meteorological Year File Creator, is a Phyton tool too, for using locally observed weather data in building energy simulations. The software is composed of three separate modules three modules: the TMY3 module, the MesoWest module, and the EPW module.
First, the TMY3 module provides the data schema at a general level; by using its format data are collected using the MesoWest module. MesoWest is a database that allows you to know variables such as temperature, humidity, and wind speed, of specific stations in the USA. This module permits the selection of the variables of interest from the processing of different files of climate control units, returning the averages for each location, and interpolating the data to extract the missing ones.

Finally, the EPW module allows you to change the header of the TMY3 file by replacing the local variables entered by the user. In this way, it is possible to enter real-time variables of a specific site minimizing affections on building energy simulation.



(a)



(b)

Figure 3: Interface and representation of the EPW module

4.3 Practical approaches to implement weather forecast data into the energy simulations

Because of the impact of climate variations on HVAC parameters, taking care of forecasting hour by hour is a matter of big interest.

For this reason, artificial intelligence is gaining ground in the sector. Particularly, scientists are trying to use neural networks to predict hourly local temperatures, for example on an outside wall, by using both recent data from nearby meteorological stations and from the place of interest itself.

It is possible that these data would then be useful as input to create real-time AMY files.

The methods and developments described above represent a starting point for new research toward a user-friendly automatic parametrization of a simulation model able to use .epw files created with data strictly related with the building of interest and so particularly accurate.

5. Real demonstration results

All the BIM SPEED pilots, expect for Varna and Malko Tarnovo, have been involved in task 4.2 activities.

For each demo, details on processes and results have been included in the Energy Reports available at the following URL: https://doi.org/10.14279/depositonce-16386.

5.1 Open Data Repository

The following table summarises the features of the OpenData repository created on DepositOnce.

Table 8: OpenData Repository information

BIM-Speed Demonstration Projects - Energy Performance Reports

dc.contributor.author	Raggi, Eva	
dc.date.issued	2022-10-26	
dc.description.abstract	The reports here summarize the results of the building energy performance simulations of the BIM SPEED demonstration cases. Activities reported upon include the development of BEM models of the actual state of the buildings, the assessment of the energy performance and the evaluation of the renovation scenarios. The following tools and procedures have been applied to generate the reports: • the BIM-to-BEM procedures and tools created within BIM SPEED; • the calibration procedure developed by Università Politecnica delle Marche; • the optimization tool developed by Metabuild. The reports provide examples for the outputs of an important step to consolidate the use of BIM in the building renovation process: The detailed performance analysis of buildings and renovation options.	en
dc.description.sponsorship	EC/H2020/820553 /EU/Harmonised Building Information Speedway for Energy-Efficient Renovation/BIM-SPEED	
dc.language.iso	en	
dc.rights.uri	https://creativecommons.org/licenses/by/4.0/	
dc.subject.ddc	DDC::600 Technik, Medizin, angewandte Wissenschaften::620 Ingenieurwissenschaften::620 Ingenieurwissenschaften und zugeordnete Tätigkeiten	
dc.subject.other	BIM-Speed	en
dc.subject.other	Building Performance Simulation	en
dc.subject.other	Building Energy	en
dc.subject.other	Building Information Modeling	en
dc.subject.other	Renovation	en
dc.title	BIM-Speed Demonstration Projects - Energy Performance Reports	en
dc.type	Textual Data	
tub.affiliation	Technische Universität Berlin::Verbundforschung::EU Verbundprojekte::BIM-SPEED	

The repository can grow also after the end of the BIM SPEED Project with additional demos. Its structure makes it easy to add additional Energy Reports and BEM models (adopting the procedure developed in BIM SPEED) once available.

5.2 Format of the Energy Reports

A common structure for the Energy Reports has been provided to standardize the process and the results.

The following figure shows the Table of Content of the Energy Reports.

Contents

Figure 4: Table of Content of the Energy Reports

Basically, the reports were structured around 6 main sections:

1) General information

The section introduces the building. A general description of the main features of the building is provided together with the information on the building location and the weather data

2) Energy Modelling

This section introduces the process and the tools adopted for the BEM creation and describes the BEM's technical features including information on the envelope components, HVAC systems and occupancy, lighting, equipment and operating patterns.

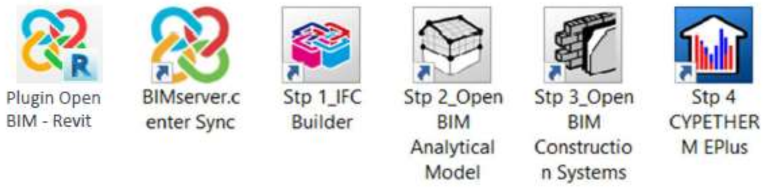


Figure 5: Example of tools used for the BIM-to-BEM process (from Vitoria Energy Report)

3) BEM Calibration

Information on the Calibration methodology and the results of the process, if performed, are provided. The following table shows and example of the calibration results.

Table 9: Example of calibration results (from Vitoria Energy Report)

Reporting period and CV(RMSE)	Experimental	Original BEM	Phase 1 Calibration	Phase 2 Calibration
from 21/11/2019 to 13/03/2020	6604 kWh	8256 kWh	5531 kWh	6482 kWh
from 14/03/2020 to 20/05/2020	1475 kWh	2855 kWh	1724 kWh	2020 kWh
CV(RMSE)	-	37.7%	19.3%	9.8%

4) Building Energy Performance Simulation results

This section documents the results of the energy simulations carried out on the BEM baseline models (actual state of the building). The Energy KPIs (BS.OPED: Operational Primary Energy Demand, BS.TED: Total Energy Demand and BS.TEC: Total Energy Consumption) are provided in order to characterise the energy behaviour of the building before the renovations.

5) Building renovation scenarios

This section introduces the process and the tools adopted for the assessment of the renovation scenarios. If the Optimization process was adopted, details on the Optimization set-up and on the planning variants considered have been provided. The assessment ends with the evaluation of the energy performance and the calculation of the Energy KPIs of each renovation scenario.

6) Time reduction evaluation

The final section provides a qualitative analysis to demonstrate the time reduction for the BIM-to-BEM process. A summary of the results is provided in the following section 5.3.

5.3 Summary of the Energy Reports provided

The following Energy Reports have been provided and are available within the dedicated Repository:

- Vitoria Energy Performance Report
- Lichtenrade Energy Performance Report
- Warsaw I Energy Performance Report
- Warsaw II Energy Performance Report
- Frigento Energy Performance Report
- Gdynia Energy Performance Report
- Warmond Energy Performance Report
- Tempelhof Energy Performance Report
- Massy Energy Performance Report
- Antony Energy Performance Report

Additional demos can be included and added to the Repository also after the end of the BIM SPEED project.

5.4 Summary of the Time reduction results

A qualitative strategy to demonstrate the time reduction for the BIM-to-BEM process compared to current practice has been set and adequately verified in most of the pilots based on the expertise of the energy modeler. As shown in the following figure, the process for the BEM creation was divided into 4 different main steps:

- Phase 1: Building data collection;
- Phase 2: Building geometry creation;
- Phase 3: Building thermal characterization;
- Phase 4: HVAC characterization.

	Workflow required for the BEM creation
1	**BUILDING DATA COLLECTION (site inspection, document/drawing analysis,..), specific data for the thermal chatacterisation are needed**
	a) direct geometrical measurments (needed if detailed and reliable technical drawings are not available)
	b) collection and detection of the thermal characteristics of building components (mapping of windows type, wall type...)
	c) collection and identification of relevant HVAC characteristics (installed power, type of terminals, ...)
	d) data on building operational uses
2	**Building geometry creation**
	a) 2D floorplans reconstruction from on site measurements (needed if detailed and reliable technical drawings are not available)
	b) creation of the 3D geometry of the building directly with specific Building Energy Simulation tools
3	**Building thermal characterisation**
	a) creation of the building components and related libraries (e.g. materials, stratigraphies..)
	b) definition of the thermal zones (uses, internal gains - occupancy, lighting, equipment schedules - temperatures..)
4	**HVAC characterisation**
	a) creation of the HVAC components (and related libraries)
	b) definition of the systems

Figure 6: Workflow adopted for the time reduction evaluation

The following table summarises for each democase in which the BIM-to-BEM process has been adopted, the results of the time reduction evaluation.

Table 10: Summary of the time reduction of the BIM-to-BEM processes

#	PILOT	BIM-to-BEM process	% of time reduction
1	**Vitoria**	YES	42%
2	**Warsaw I**	YES	43%
3	**Warsaw II**	YES	39%
4	**Barlad**	YES	38%
5	**Frigento**	YES	44%
6	**Gdynia**	YES	40%
7	**Tempelhof**	YES	41%
AVERAGE			**41%**

The average result demonstrates that the BIM-to-BEM procedure can provide an average 41% of time reduction compared to current and traditional process showing the convenience of adopt this kind of approach to create reliable BEM models.

6. Conclusions

The use of BIM open standards, allowed with the use of CYPETHERM Suite tools, has been prioritised for interoperability with the BIMSPEED Platform for the BEM creation. Seven pilots tested the BIM-to-BEM procedure developed in WP3 while six pilots, based on the own available expertise, adopted a more traditional process, testing not the BIM-to-BEM process and tools but providing energy simulations and testing others BIM SPEED tools as the Calibration tool (Task 3.4) and/or the MTB optimization tool for the identification of optimal renovation scenarios.

The following different tools and procedures have been applied to the BIM SPEED democases:

- the BIM-to-BEM procedures and tools created within WP3;
- the calibration procedure developed by UNIVPM;
- the optimization tool developed by Metabuild.

The activities performed includes the development of BEM models of the actual state of the buildings, the assessment of the energy performance and the evaluation of the renovation scenarios (deliverable type is “other”).

All the energy models have been collected within a dedicated Repository available at the following URL: https://doi.org/10.14279/depositonce-16386.

As a results, it has been experienced that a complete interoperability process between BIM and BEM is still not completely possible, but the developments achieved in BIM SPEED represent a good starting point for full compatibility between BIM ad BEM models.

Multiple limitations exist due to lack of:

- Adequate knowledge on the tools/process
- Existing issues/limitation of tools and procedures

In general, the activities carried out constitutes an important step to consolidate the use of BIM in the building renovation process and regarding the time-reduction evaluation, the average result demonstrates that the BIM-to-BEM procedure can provide an average 41% of time reduction compared to current and traditional process showing the convenience of adopt this kind of approach to create reliable BEM models.

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Appendix 1:

BEM-CALIBRATION
Data collection guidelines

Issue Date	31 May 2021
Produced by	UNIVPM

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Contents

1. Introduction

In building energy renovation, it is fundamental to determine energy savings of different Energy Conservation Measures (ECM) to define the most advantageous ECM from the energy/economic/environmental points of view. To compute savings, both pre-retrofit and post-retrofit building energy data measurements are needed, which, however, are usually not available at the same time. Moreover, even when both before and after retrofit measurements are present, they would not necessarily yield an accurate representation of savings, since taken under different weather conditions that strongly affect energy consumptions.

Numerical simulations can be used to estimate energy consumption in a pre-retrofit and a post-retrofit scenario under the same conditions. However, due to the uncertainties in physical models and Building Energy Model (BEM) input assumptions, the accuracy of numerical simulation outcomes is usually poor, obtaining high discrepancy between numerical results and measured building performance (performance gap).

To increase simulation accuracy, a Building Energy Model (BEM) calibration is generally proposed (calibrated simulation). A BEM calibration allows increasing the BEM accuracy by fine-tuning uncertain input values to match the predicted energy consumption obtained under a specific set of conditions, with the actual measured data for the same set of conditions. A BEM calibration generally consists of four steps:

1. Data collection;
2. Model enrichment with collected data and simulation;
3. Comparing the simulation model output to measured data;
4. Model refinement until an acceptable calibration is achieved.

In building energy renovation, the BEM adopted for calibration is generally that representing the building in a pre-retrofit condition (baseline model), and is typically calibrated against real measured energy consumption data for space heating (baseline data). However, if baseline data do not exist, the BEM can be calibrated considering the post-retrofit condition.

Once a calibrated BEM is obtained, the BEM in the post-retrofit (or pre-retrofit) scenario is created from the calibrated model, and energy savings are computed. The differences between the baseline and the post-retrofit models are limited to the ECM. All other factors, such as weather and occupancy, are instead uniform between the two models (unless a specific difference has been observed that must be accounted for) to ensure saving calculation reliability.

The BIM-SPEED BEM-calibration procedure is based on ASHRAE 14 [1] and IPMVP [2] Standards, which define the procedures and requirements for calibrating building energy models to be used for energy savings calculation in building energy retrofit projects.

The developed calibration procedure differs from the traditional, time-consuming, manual calibration approaches due to the adoption of an automated calibration tool, which assists the building energy modelers in the model refinement iterative process (step 4) without requiring high BEM expertise.

In particular, the tool only requires that the modeler defines the range of variation of most relevant uncertain input data. Then, the tool takes advantage of artificial intelligence algorithms to search for the best model configuration (set of input values) that better matches measured energy consumption or other output variables.

Despite automatic, however, the developed tool does not substitute a correct data collection (step 1), which is still fundamental for the success of whatever model refinement process. Indeed, even when all the data are adequately collected, a high gap of performance is still usually present, making the model refinement still needed. Moreover, even when a reasonable match is developed between the modeled and measured outputs, e.g. energy flows, it is not certain that the model is a good representation of the building. Data collection must be then carried out to ensure that the calibrated BEM reflects as much as possible the actual building operation, performance, and characteristics.

In this brief guideline, the minimum requirements for BEM calibration are briefly summarized with a specific focus on the data collection for Building Energy Performance Simulation (BEPS) according to ASHRAE 14 and IPMVP requirements. This guide is intended to be neither a guideline on how to collect data nor a building energy modeling guide. For these activities, the energy modeler may refer to the dedicated tasks in the BIMSPEED project. The guide has instead the main aim to stress the importance of data collection as a necessary (but not sufficient) condition for the success of the BEM calibration process.

2. Data collection

To calibrate a BEM, all the parameters that influence the energy performance of a building must be accurately collected during the period of interest (see Section 2.1). These parameters can be subdivided into the following three categories:

- Outdoor factors, which consider the surrounding environment (buildings and vegetation) of the case study, the weather conditions, and the location;
- Indoor factors, which are the parameters mainly related to the user occupancy, i.e. the interaction between users and building technologies (e.g. windows opening, HVAC activation schedule, heating set-point, etc.), and internal thermal loads;
- Envelope factors, i.e. those related to the building envelope, such as dimensions and properties of building surfaces.

These data can be further distinguished in:

- Quantitative data (building characteristics);
- Qualitative data (user's habits and customs).

Among all these parameters, those that may change during the baseline and those that are constant during the baseline period but may change in the post-retrofit scenario (i.e. mainly weather data and occupancy-related data) should be always accurately identified and quantified to obtain a reliable calibrated BEM and to verify savings with an acceptable level of uncertainty.

Concerning weather conditions, outside air temperature, humidity, solar radiation, and wind speed, and direction should be measured over the same period the indoor measurements and the utility data are measured (see Section 2.3).

Concerning occupancy-related data, all the operating schedules of each system affecting energy use data should be defined, such as HVAC, lighting, and equipment operation, and windows opening. Also, the nameplate and performance data of each system should be collected (see Section 2.5). Occupants' presence schedules should be also collected, including occupancy population levels or density, operating hours, etc (see Section 2.5). Spot measurements of selected HVAC and other building system components, including interior temperature and humidity data, airflow, electric utility data, can also be used to define internal schedules (see Section 2.6).

Finally, utility data for space heating should be collected to allow the comparison between actual and simulated building energy performance and then to evaluate the accuracy of the model (see Section 2.2).

Methods to be followed and suggestions according to the ASHRAE 14 and IPMVP Standards to collect some of these data are briefly described in the following subsections. However, other methods can be followed if justified. It should be noted that sensitivity analysis can be carried out with the developed BIMSPEED Calibration tool before data collection (assuming a reasonable range of variation) to determine which parameters are the most influencing on the model prediction (and thus requiring higher accuracy) and those that do not affect model prediction (and thus that can be excluded from the data collection plan).

2.1 Baseline period

Data can be collected from the building during the baseline period, the post-retrofit period, or both. The baseline period must include data across the full range of expected operating conditions, modes, and independent variables. Typically, the baseline period is the period immediately before the retrofit and should represent one or more complete operating cycles to minimize bias. For weather-dependent loads, the baseline period should be a full year. If data cannot be obtained for a full cycle of operation, shorter periods that are representative for each operating mode (e.g. one month in each season) may be acceptable if the data collection interval is reduced (e.g. from monthly to hourly). In all cases, care must be taken to ensure that the baseline period is representative of typical conditions and does not over- or underemphasize specific operating conditions.

2.2 Utility Data

According to ASHRAE 14, utility bills spanning at least 1 year and comprising at least 12 valid meter readings should be collected. Hourly or smaller interval meter data should be also collected if available. If hourly data are not available from the utility but are needed for calibration, equipment to collect such data should be installed.

Energy consumption data for space heating should be determined from bills since needed for comparing the predicted and actual building energy performance. If both space heating and domestic hot water (DHW) energy consumption are reported in the same bill, DHW energy consumption should be modeled assuming a constant DHW energy consumption equal to that obtained in summer if constant. Alternatively, the energy consumption for space heating can be obtained by subtraction making the same assumption or measured.

Energy demand data for space heating can be also determined and used for calibration if available. Demand energy data for space heating could be also useful when energy consumption data for space heating are not available from meters (e.g. in the case of district heating). In the latter case, equipment to collect such data should be installed.

Electric energy consumption data from bills or submeters (monthly or hourly) should be also collected, useful to determine internal thermal loads and occupancy schedules.

Information regarding the dates of meter readings should be also annotated to ensure that the comparison between predicted and measured values is made by referring to the same reporting period.

2.3 Weather data

Weather data are the most common independent variable affecting energy use. The most common weather data affecting energy use are outdoor air temperature and humidity (outdoor air conditions). Solar radiation (or cloud cover), and wind speed and direction can also affect building energy use. Accurate and consistent measurement and observations of weather conditions are critical.

At a minimum, the modeler collects hourly weather data that correspond to the same period as the energy use data to which the model will be calibrated. Data obtained from government weather stations can be considered the most reliable source of data for sites near the station. However, these data are limited to the location where weather stations are placed. Moreover, variations in microclimates can produce significant variation in weather data even over short distances due to change in terrain, altitude, and building density. This may justify the use of on-site instrumentation.

When using government weather stations, the station that most closely represents the microclimatic conditions at the project site should be used, even if there are other stations closer to the project site. Where a nearby weather station is unavailable, a more distant station may be used if its weather pattern is well correlated to the pattern at the facility, even if the total heating or cooling conditions are somewhat different. In this case, short-term weather data from the site should be compared with the weather observations recorded at several weather stations to determine which station most closely corresponds to the site's local weather conditions.

Although some modelers have reported using average or typical year weather data for model calibration, this approach is not recommended, as the comparison utility data are probably related to actual weather from the time in question. Several studies have shown that using an average year weather file in simulation can introduce error into the simulation that is large as some of the differences that are being sought in the analysis.

2.4 Building plans

As-built plans are preferable, but whatever plans can be useful for data collection. When on-site, the accuracy of building geometry and construction materials represented in plans must be confirmed. Building exterior and its surrounding should be documented, considering its architectural and shading features such as trees, type of tree, near buildings, etc. Building's north-south orientation should be also annotated.

2.5 On-Site survey

Visit the site and collect data by making visual observations of in situ building system components. Data that may be collected during a site survey include the following:

- *lighting systems*. Fixture counts, types, nameplate data from lamp and ballasts, 24-hour weekday, weekend, and holiday schedule of lighting use, characteristics of fixtures for estimating radiative and convective heat flows, thermal zone assignments, diversity of operation;
- *plug loads*. Counts of and nameplate data from plug-in devices, 24-hour weekday and weekend schedules, diversity of operation;
- *HVAC systems*. Quantities, capacities, operating characteristics, and part-load performance curves of primary equipment (e.g. chillers and boilers); system zoning; interior zone temperature setpoints and schedules, etc.
- *Building envelope and thermal mass*. Dimensions and thermal resistance of external and interzonal surfaces, the orientation of external surfaces, thermal mass characteristics of the material of construction, dimensions, visible and infrared transmittance of external transparent surfaces (windows, doors, and skylights), spacing of framing materials, and shading from nearby objects.
- *Building occupants*. Population counts; weekday, weekend, and holiday schedules; activity levels; assignment to thermal zones.

2.6 Operators and Occupants interview

Schedules of occupancy and operation should be investigated by data collection forms provided to the occupants. Information should include building use, thermostat settings, occupancy, operational data, windows opening, lighting, and equipment use. Any operating problems/special conditions should be identified and replicated by the calibrated model.

2.7 Spot and short-term measurements

Spot and short terms measurements are measurements that are taken for a moment, usually using handled instruments, or for longer periods with instruments having data logging capabilities that are set up and left in place. Despite spot measurements are less expensive, short-term measurements provide valuable information regarding the schedule of use. The in-situ measurements may include the following:

- *Lighting systems*. Operating schedules, fixture power, lighting levels;
- *Plug loads*. Operating schedules and electric power;

- *HVAC systems*. Space temperature and humidity, carbon dioxide levels, air and water flows, static pressures, and temperatures, etc;
- *Building ventilation and infiltration*. If resources permit, building ventilation and infiltration should be measured because these values often vary from expectations;
- *Energy use and operating schedules*.

2.8 Missing data

Missing data may be estimated or interpolated from measured data using statistically valid engineering techniques. The data used to interpolate or estimate the missing data shall represent the full range of operating conditions experienced during the missing data interval (if the dependent variable data are missing) or similar adjacent intervals (if data for the independent variables are missing). The data set used for interpolation or estimation of missing data should be an order of magnitude greater than the missing data interval (e.g. for monthly data, 12 months; for daily data, 7 to 14 days; for hourly data, 12 hours; etc.). The specific methodology used for interpolating or estimating missing data should be reported. A summary of missing data should be also reported.

3. Model enrichment

When preparing the simulation input data for the model and performing preliminary analysis, special attention should be paid to the issues discussed below. In general, a complete copy of the input data of BEM should be provided indicating which data are known and which are assumed. The source of all data should be reported as well as their best-guess estimates and range of variation for both known and unknown parameters.

3.1 Geometry and architectural features.

Many programs allow visualizing BEMs. This feature may help ensure that building input parameters, especially geometrical ones, are consistent with the actual building. This step is useful especially for BEMs created from BIMs. Indeed, these BEMs may be characterized by missing parts due to interoperability issues in the BIM-to-BEM process. The user should be also aware that over-specifying architectural details may do not have an impact on building energy use.

3.2 Estimating plug loads based on nameplate ratings

Although measurements are preferable, plug loads may be estimated by taking inventory and summing connected loads. When doing so, the nameplate should not be entered into the simulation software. On average, most plug-load devices operate at an average power much lower than that of the nameplate rating. The actual operating power is obtained by multiplying the nameplate power by a use factor (generally 0.3 is used as a common rule of thumb).

3.3 Lighting heat loads

BEMs often require information about the heat gain characteristic of each lighting fixture. In this case, the heat gain multiplier must be identified considering the lighting typology and the extent to which the lighting fixture is in thermal communication with spaces.

3.4 HVAC system zoning

The most important aspect to duplicate in a BEM is the on/off characteristic of a zone. Testing the zoning assumptions in a simulation program usually requires simulating the building with actual hourly weather data and taking hourly recordings of interior zone temperatures to compare against simulated temperatures.

3.5 HVAC system simulation

In many cases, it may not be possible to exactly simulate a building's HVAC system. In such cases, the modeler is cautioned to ensure that the operating conditions of the HVAC system being modeled are being met by the simulation program, even if the schematic diagram may differ from the system being modeled.

3.6 Infiltration rates

Infiltration rates are difficult to be measured and may be treated as an unknown parameter that can be iteratively solved with the automatized tool once the major parameters are determined. This approach, however, is only recommended as a last resort.

3.7 Minimize default values

All default input values should be checked and thoroughly understood since default values have little resemblance to the actual building being simulated. In general, the fewer the number of default values adopted, the more representative the simulation will be (but only if the changes are well reasoned). This also includes inspection of the default performance curves of systems and plants, since such curves significantly impact the simulation results. Any program default values that are altered, however, should be well documented.

4. BEM Calibration

When available, not only monthly energy consumption and/or demand for space heating should be used for comparison, but also hourly energy consumption and spot measurements of key components and systems. Since monthly utility bills present so many fewer data points for calibration, this method is not as reliable as comparing hourly data. Because of this, comparing to monthly utility bills is only acceptable when hourly data are not available and cannot be collected. It is also important that the simulated quantities are summed over the same days that the meter was read for the bills.

5. References

[1] ASHRAE Standards Committee, ASHRAE Guideline 14-2014 Measurement of Energy and Demand Savings, (2014).

[2] EVO, IPMVP - International Performance Measurement and Verification Protocol - Concepts and Options for Determining Energy and Water Savings Volume 1, (2012).