BIM4EEB

BIM based fast toolkit for
Efficient rEnovation in Buildings

D2.2 List of Designers' Needs and Requirements for BIM-Based Renovation Processes

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D2.2 List of Designers’ Needs and Requirements for BIM-Based Renovation Processes

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EXECUTIVE SUMMARY

This deliverable presents on one hand a general view of the designer requirements and on the other hand, the concept of performance based decision making with a specific use case of the BIM-assisted scenario simulator.

The deliverable D2.1 renovation process, which was previously presented from the general point of view, is updated here from the designers point of view related to the new activities and roles found. The idea in energy performance work is that the model and energy calculation gradually refines from simple monthly calculation with basic information into a dynamic simulation with an accurate building information model (BIM) and detailed information about technical building systems. The requirements for the data to enable performance based decision making are concluded. In addition to the contents of the required data, they also include requirement for the data management system and data quality.

Building Energy simulation (BES) tools are used for conducting energy analysis of the buildings' performance under different retrofitting plans. In addition to energy, BES can also calculate other important performance indicators (e.g. CO_2 emissions, LCC, LCA, occupant's satisfaction and indoor environment quality).

On a general level, the input data to BES are the weather, building envelope, geometry and orientationHVAC system and the occupant's behaviour. The heating and cooling set-points and the air ventilation rates are the most influential parameters on the building's energy consumption. Besides, in cold weathers, main effects on the heating load come from the building envelope parameters of the window U-value, window g-value and wall conductivity. In hot weathers, the cooling load is mainly affected by the solar-heat gains, the internal heat gains from the occupant's behaviour, and the heaviness of the structures. In addition to its influence on the output results of BES, occupant's behaviour related to peoples existence and use of appliances and lighting is one major factor that can cause discrepancies between simulation prediction and the real energy use.

The accurate acquisition of As-is data for buildings that are subjected to retrofitting represents a practical challenge for BIM-based energy simulations. This is because old buildings normally lack complete and updated documentation of both geometrical and non-geometrical data that are required by energy simulation. Appropriate equipment and methods are needed to monitor, collect and manage the as-is data of buildings. Examples are laser scanning and photogrammetry and building's energy-related performance tests.

In addition to its completeness and updated information, the BIM data should also be interoperable with BES in an easy and automatic manner without a need for the repetition of the exhaustive input data. While this is the ambition of the automatic BIM-BES interoperability, it is found that this is not always possible with the existing tools and there is a need for different levels of manual interventions.

The BIM Assisted Scenario Simulator tool was presented and the workflow of its use was defined. The most important finding related to the renovation process was the importance of the **need for the performance based building design** in the early design phases, where the most important decisions are made according to costs and performance. The exhaustive data definitions (in Annex 1) related to the commercial energy simulation tool IDA Indoor Climate and Energy by a Swedish company Equa (IDA-ICE) open a landscape of huge set of details to be defined. This huge set (+ 1000 parameters) can be narrowed according to the findings in chapter 3, which lists the most important input variables related to the impact on the indoor climate and energy. This narrowed list (< 100 parameters) has to be understood as a living document at the moment of writing, because the **fast mapping** tool development in WP5 might ease the parameter collection of a renovated building to a new level, where currently hard to find parameters has to be defaulted, but in the future they are easy to collect. The second finding derived from tool definition was the **need for the enhanced collaborative design work.** The indoor climate and energy design is a multi-domain challenge and it should always be considered as a team work. All tools around the future building renovation design should comply and support this approach. The performance based building design process assumes that design selections are validated against the **Owners Project Requirements (OPR’s)** in each design stage before moving to a following design stage. The design team will handle the detailed technical selections affecting to the OPR’s using the tool. The management of the consistency of the detailed technical parameters against the OPR’s has traditionally been handled manually between design domains resulting to the design errors or time consuming updates, whenever the technical detail has changed. The BIM Assisted Scenario Simulator will tackle the complexity of the energy and indoor climate design by

(1) speeding up the decision making
(2) enhancing the collaboration between the design domains
(3) enabling the cross domain transparency of the technical details in the design team
(4) resulting better indoor climate and energy selections in the renovation.

PUBLISHING SUMMARY

Key elements in the renovation process are the performance based building design in the early phases, where the most important decisions are made according to costs and performance, and enhanced collaborative design work. All tools should comply and support this approach. The performance based building design process assumes that design selections are validated against the Owners Project Requirements (OPR’s) in each design stage before moving to a following design stage. The BIM Assisted Scenario Simulator will tackle the complexity of the energy and indoor climate design by speeding up the decision making, enhancing the collaboration between the design domains and enabling the cross domain transparency of the technical details in the design team, that results in better indoor climate and energy selections in the renovation.

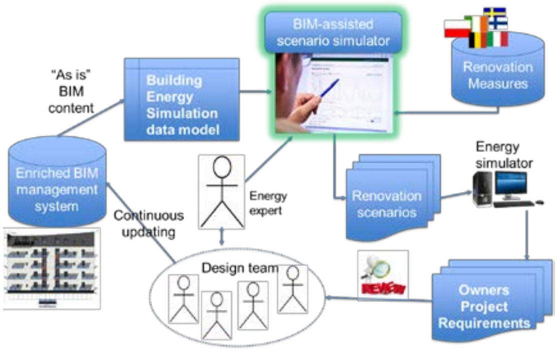

Figure 1 BIM assisted scenario simulator

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TERMS AND DEFINITIONS

Table 1: Terms and definition of the principal stakeholders involved in a renovation process. The most important ones for this deliverable are marked with the green colour.

Term	Definition	Source
Client	The party commissioning the design and construction of a project. The client may be an individual or a company. In the latter case, an individual should act as a single point of responsibility for decision and communication even if numerous bodies, or individuals, within the client organisation will contribute to decisions.	[RIBA, 2013] Project Roles Table
Owner	A person, a group of people, a company or a public administration who owns a built asset	Authors
End-user	A person that lives/ works in a built asset (synonym: occupant). A person that uses a built asset.	Authors
Client Adviser	A consultant providing strategic or specialist advice particularly during the early project stages.	[RIBA, 2013] Project Roles Table
Technical adviser	A consultant employed by the client to provide specific advice	[RIBA, 2013] Project Roles Table
Project Leader	The party responsible for managing all aspects of the project and ensuring that the project is delivered in accordance with the Project Programme.	[RIBA, 2013] Project Roles Table
Lead designer	The party responsible for managing all aspects of the design, including the co-ordination of the design and the integration of specialist subcontractors' design, where applicable, into the coordinated design.	[RIBA, 2013] Project Roles Table
Architectural designer	The party responsible for carrying out the architectural design	Authors
Structural designer	The party responsible for carrying out the structural design	Authors
Building services designer	The party Responsible for carrying out the building services design	Authors
Site surveyor	In the first-line management who monitors and regulates employees in their performance of assigned or delegated tasks. Supervisors are usually authorized to recommend and/or effect hiring, disciplining, promoting, punishing, rewarding, and other associated activities regarding the employees in their departments.	Authors
Cost consultant/ quantity surveyor	The party responsible for producing Cost Information as the design progresses. This information will vary depending on the project, but may include the overall Project Budget, estimates of the construction cost and life cycle cost analysis.	Authors, adapting [RIBA, 2013] Project

		Roles Table
Health and safety adviser	Responsible for health and safety aspects as defined by legislation and in line with other project objectives and health and safety best practice	[RIBA, 2013] Project Roles Table
Acoustic consultant	Provides specialist acoustic advice on particular projects in relation to sound quality in spaces or noise transfer between rooms or from the external environment.	Authors
Facilities management (FM) adviser	Reviews the design proposals and comments on facilities management and in-use maintenance matters.	Authors
Information manager	Manages the flow of information between parties – note that this is not a design role.	Authors
Access consultant	Provides specialist advice in relation to disabled and other access issues.	Authors
Cladding specialist	Undertakes specialist design and/or reviews of aspects of the external cladding of a building, particularly where bespoke solutions are proposed.	Authors
Interior designer	Provides particular design services in relation to the interior design of a project.	Authors
Lighting designer	Provides specialist lighting advice internally or in relation to the floodlighting and external lighting of a project.	Authors
Construction leader	The party responsible for constructing the project and for providing construction advice in the early stages.	[RIBA, 2013] Project Roles Table
Contract administrator	The party responsible for the administration of the Building Contract, including issuing of additional instructions and the various certificates if required in the national framework.	[RIBA, 2013] Project Roles Table
Operational leader	Responsible for the facilities management (FM) aspects of the building.	Authors
Party wall surveyor	Provides specialist advice in relation to adjacent properties and issues such as right of light.	Authors
Security adviser	Considers security issues in relation to the design of a building.	Authors
Master planner	Provides specialist advice for larger sites in relation to planning, roads, social issues and other high-level strategies.	Authors
Planning consultant	Provides specialist advice in relation to planning applications.	Authors
Sustainability adviser	Provides strategic advice in relation to green issues.	Authors
Contractor	Independent entity that agrees to furnish certain number or quantity of goods, material, equipment, personnel, and/or services that meet or exceed stated requirements or specifications, at a mutually agreed upon price and within a specified timeframe to another independent entity called contractee, principal, or project owner.	Authors
Sub-contractor	A person or company that does part of a job that another person or company is responsible for	Authors
Supplier	A party that supplies goods or services. A supplier may be distinguished	Authors

	from a contractor or subcontractor, who commonly adds specialized input to deliverables.	
Maintenance planner	Person who creates maintenance schedules, maintain parts inventory and work closely with maintenance staff, contractors and outside vendors.	Authors
Fire safety designer	Provides special set of practices intended to reduce the destruction caused by fire.	Authors
Landscape architect	Responsible for carrying out the landscape design.	Authors
Local authority	An organization that is officially responsible for all the public services and facilities in a particular area.	Authors
Tenderer	A person or company that estimates the cost of a proposed project or someone who presents a payment to another.	Authors

Table 2: Terms and definition of the stages in the life cycle of built assets. The most important ones for this deliverable are marked with the green colour.

Term	**Definition**	**Source**
Initiative	Stage where the need for a construction or urban project emerges and is established	[EN 16310, 2013]
Initiation	Stage where the context of the facility or product to be developed is identified and the requirements are defined	[EN 16310, 2013]
Concept design	Sub-stage where plans for the asset(s) are developed that offer options and solutions on a planning scale, to determine the general form and schematic layout of the asset(s) to be built within the allocated area	[EN 16310, 2013]
Preliminary design	sub-stage where a design of the asset is developed that offers a broad insight covering planning aspects, functional organisation, spatial structure and general appearance, enabling the client to make informed strategic choices between functional concepts and options envisaged	[EN 16310, 2013]
Developed design	sub-stage where the design of the asset is further developed, providing detailed representations of the layout, the structure, associated technologies and the appearance of the asset and where suitable methods of construction, the use of materials and typical technical details as necessary for a good understanding of the asset to be built are examined	[EN 16310, 2013]
Detailed design	sub-stage where the project is fully described, so that equipment manufacturing and asset construction and installation of equipment can take place	[EN 16310, 2013]
Procurement	stage where fabrication / construction / installation sites are provided/agreed with equipment and materials and fabrication / construction / installation contracts are awarded	[EN 16310, 2013]
Construction contracting	sub-stage where contracts for supply of construction services, installations and materials are awarded	[EN 16310, 2013]
Pre-construction	sub-stage where the actual construction of the asset is prepared and scheduled and project specific prefab parts and components may be produced	[EN 16310, 2013]
Construction	sub-stage where the asset is built in compliance with the contract documents and applicable regulatory requirements	[EN 16310, 2013]

Commissioning	sub-stage where is it verified that installed equipment is ready for use	[EN 16310, 2013]
Handover	sub-stage where final checks of compliance with the contract documents are performed. At this point the project is handed over to the client and where the starting points and conditions for maintenance and operations are established	[EN 16310, 2013]
Regulatory approval	sub-stage where is established and confirmed by the authorities that the built asset complies with the regulatory requirements and that the asset is released for use	[EN 16310, 2013]
Operation	sub-stage where the facility is being run and exploited and where the expected performance is monitored and managed	[EN 16310, 2013]
Maintenance	sub-stage where the asset is maintained according to predetermined objectives	[EN 16310, 2013]
Revamping	sub-stage where the built asset is updated for continued use	[EN 16310, 2013]
Dismantling	sub-stage where the built asset is taken down, removed and (partly) recycled after it's functional and/or economic life span	[EN 16310, 2013]
As-is	The stage of the information capture of the building to be renovated on a specific point (=the latest) in time. The 'As-is' is understood as a latest content of the information model. The content of the building information evolves during the design phases.	Authors

1 Introduction

The task and the deliverable describing the work have a dual target. On one hand there is the topic "List of Designers' Needs and Requirements for BIM-Based Renovation Processes" which refers to the needs of the designers in a wide scope. On the other hand, there is the task description, which specified a focused use case for BIM-assisted scenario simulator to support energy-related decision-making in the refurbishment process, when the enriched BIM models are available.

> ***"****The task will list requirements needed to ease a* ***performance-based decision-making*** *during renovation activities. In particular, a specific use case is a* ***BIM-assisted scenario simulator*** *to support* ***energy-related decision-making in the refurbishment process, when the enriched BIM models are available****. The task goes into details of the* ***energy assessment input specification for enriched BIM*** *in the design phase of different refurbishment types and feeds the WP3 ontology development and WP4 platform development as a specific use case. The output will describe designers' needs and requirements for BIM-based renovation processes (D2.2)."*

The deliverable presents a general view of the designer requirements in chapter 2. This will be utilised especially in the work packages three and four, which create the ontologies and data model (WP3) and finally the BIM management system (WP4).

The concept of performance based decision making is presented in the chapter 3 and the specific use case of the BIM-assisted scenario simulator in chapter 4. The requirements for the data to enable performance based decision making are presented in the chapter 5. They will serve the task 6.6, which will implement the specified simulator tool.

2 List of Designers’ Needs and Requirements for BIM-Based Renovation Processes

The general frame for the renovation process has been described in the deliverable “D2.1 Definition of relevant activities and involved stakeholders in actual and efficient renovation processes” and shown in detailed tables of actions. Deliverable “D3.1 A BIM-based framework for building renovation using the linked data approach and ontologies” has described the use cases for energy efficiency assessment in different phases of the construction project. To define the designers needs in the process, these two approaches are merged in the task 2.2. There is also on-going work related to the requirements in the tasks 2.4 (digital logbook exploitation) and task 3.3 (BIM representation on different levels of detail corresponding to renovation process modelling). While this task (2.2) defines the requirement for a specific use case in energy performance simulation, task 2.4 presents a wider view on how the information is stored into digital logbooks. Task 3.3 approach is from the BIM side and it presents what is possible from the BIM perspective.

BIM4EEB focuses on the energy efficient renovation of the residential stock in order to decrease the energy consumption and achieve the European energy savings target for 2020 and 2030. The energy efficiency is in the focus of this task 2.2, but finally that is the indicator how all the design is evaluated. By definition the energy efficiency is the energy divided by the provided service. The building cannot be energy efficient, if it is not well designed, comfortable, healthy and support productivity of the occupants. How the different quality indicators are valued is defined in the Owners Project Requirements (OPR) that follow every decision in the construction process. The concept of **performance based design** is needed, if the quality of the design and the owners satisfaction to the renovation project results wanted to be guaranteed. The need and reasoning behind the performance based building design is, that building owner communicates his/her requirements for the renovation at higher level than the actual detailed design selections are made in the design team. Also individual detailed design selections, which only professional persons understand, are complex - or even contractionary - related to each other, when compiled back to the OPR’s. Well defined performance based design process assumes that the owner’s capability to comment or approve on the possible design alternatives is only the metrics presented in the level of owner’s requirements - no deeper than that (Figure 2).

Every design phase contains decision point, where the design team has to check that the owner’s requirements are fulfilled before proceeding to the next phase. This leads to a need for simulation and calculation tools, where the detailed and interlinked design selections can be compiled back to the level of owner’s requirements (check point arrows between the phases in the Figure 2). In addition, this leads to a need for more collaborative teamwork of the designers, because of the complex relations between the technical details and the owner’s requirements. The performance based design requires that architects learn to understand and interpret the impact of the technical details of the domain designers and the domain designers learn to communicate the technical details to the architect. Of course, there should exist computer tools and BIM Management systems that ease this communication. BIM4EEB will propose BIM tools to ease this communication. The performance based design will not work without good and easy-to-use tools, which give the possibility to guide the design selections in the design process.

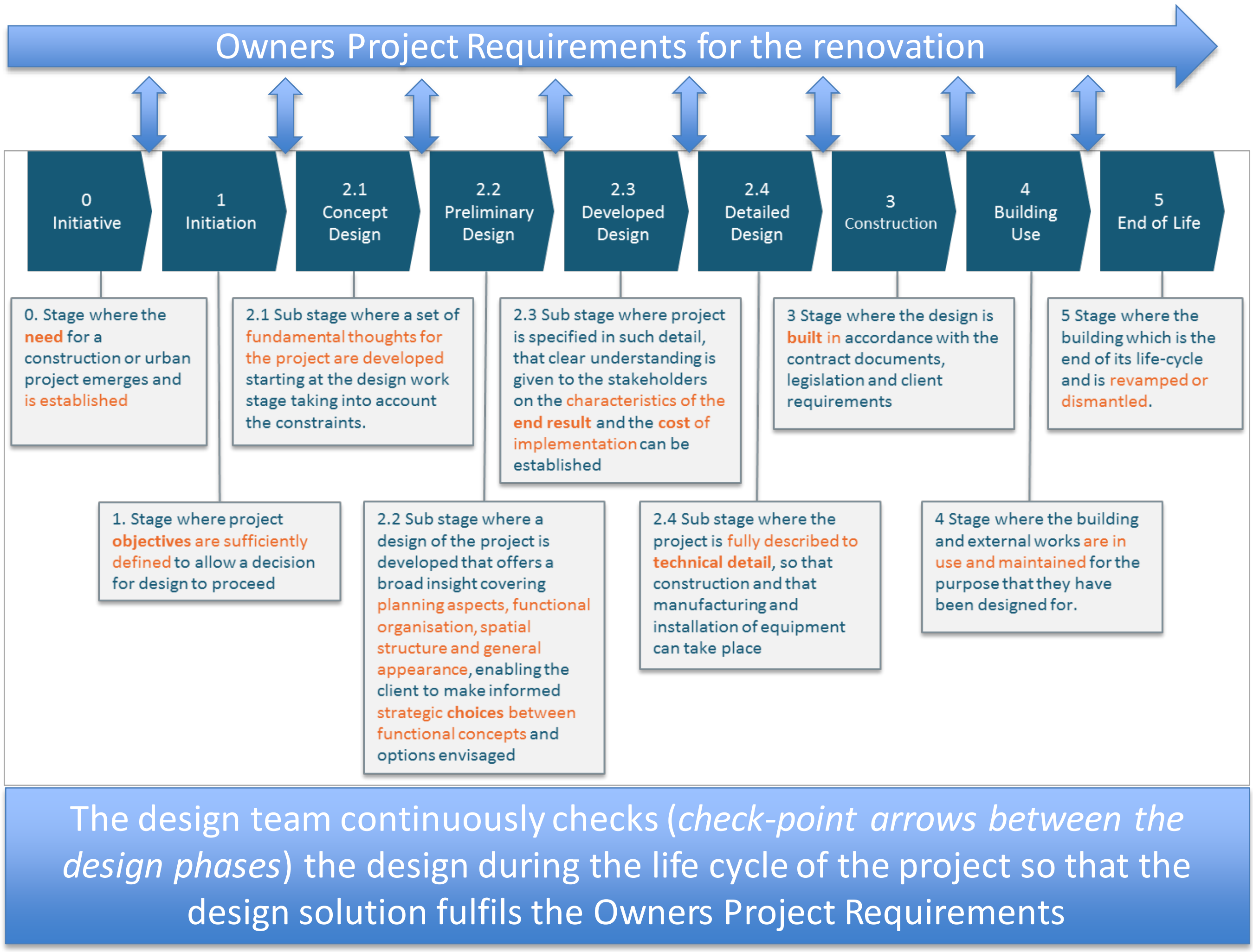


Figure 2 The performance based design and the management of the owners requirements in the renovation design process

Before starting creating BIM model for renovation, designers of each disciplines must perform a series of activities aimed to determining the state/quality of existing building it's element and installed devices.

In order to perform above, it's necessary to obtain knowledge from archival documentation of a building and it's necessary to check it completeness during local vision.

Designers will need to analyse all documents related to the building from beginning of its existing.

Table 3 Use cases and relevant requirement vs renovation process

Use cases and relevant requirement adapted from D3.1	Additions to the tables in D2.1
Use Case 0 Initiative: Preliminary decision for the renovation (go / no go desicion)	

• Owners financial feasibility requirements • Monitored historical energy performance data. • Building condition surveys and assessments and energy audit reports from facility management. • Common knowledge of the typical renovation measures available for the building to be renovated (e.g. national renovation cost and savings database).	D2.1 Table 4 additions • energy expert finds the typical renovation measures
Use Case 1 Initiation: Renovation project initiation	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" available • Targets from the "3.7 Indoor air quality" available • Monitored historical energy performance data is available	D2.1 Table 5 additions • Fast mapping team provides initial geometry information to the architect. • Energy expert helps to set the strategic environmental and financial targets of the owner (OPR). • Energy expert helps to set the occupant's behavior and comfort related targets • Energy expert helps set the Indoor air quality related targets • Energy experts helps set the first estimate targets for heating, electricity and cooling energy needs Function no 46 "owner monitors the results of building renovation simulation" is moved to later phase.
Use Case 2.1 Concept Design: Quick calculation to find the design alternatives at conceptual level	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" available • Targets from the "3.7 Indoor air quality" available • OPR's compiled to more specific numerical energy efficency indicators (probably kWh/m²,a) available • Design alternatives of the architect related to the energy efficiency available • List of available HVAC, structural and electrical renovation measures at the conceptual level to be applied available (the conceptual renovation measure database).	D2.1 Table 6 additions • The architect provides design alternatives related to energy efficiency • Each designer (HVAC, lighting, structural, electrical etc.) provides list of alternative measures at concept level • Model coordinator starts compiling the BIM • Energy expert makes a quick calculation to find feasible design alternatives at conceptual level • Project manager communicates renovation alternatives with the building owner

Use Case 2.2 Preliminary Design: Preliminary energy simulations of the design alternatives	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" available • Targets from the "3.7 Indoor air quality" available • OPR's compiled to more specific numerical energy efficency indicators (probably kWh/m²,a) available • Fast mapping data (geometry, materials, structures, product installations) of the building to be renovated available • The general technical energy efficiency data of the products related to the renovation concepts available • The preliminary architectural design(s) related to the concepts available	D2.1 Table 7 additions • Fast mapping expert provides the collected data (to the BIM management system) • Model coordinator ensures that the latest information is included in the BIM • The design team prepares a set of available design alternatives • Energy expert simulates the selected alternatives to find (pareto-) optimal alternatives for the owner review • The renovation alternative approved by the owner is selected.
Use Case 2.3 Developed Design: More detailed energy simulation of the design alternatives	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" by space types and their purpose of use • Targets from the "3.7 Indoor air quality" by space types and their purpose of use • OPR's compiled to more specific numerical energy efficency indicators (probably kWh/m²,a). • Domain specific BIM's (architecture, HVAC, structures, electricity) related to the renovation alternative approved by the owner available. The BIM contains the space layout according to their purpose of use. • The general technical energy efficiency data of the products related to the renovation concepts.	D2.1 Table 8 additions • The design team finds real product candidates for the technical building systems • Model coordinator ensures that the latest information is included in the BIM • The energy expert refines the simulation
Use Case 2.4 Detailed Design: More detailed simulation of the design alternatives	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" by space types and their purpose of use available	D2.1 Table 9 additions • The design team prepares control system descriptions for the technical building systems • The design team prepares the O&M strategy for/with the owner • Model coordinator ensures that the latest information is included in the BIM

• Targets from the "3.7 Indoor air quality" by space types and their purpose of use available • OPR's compiled to more specific numerical energy efficency indicators (probably kWh/m²,a). • The developed design available. • The benchmark database of the realised operation and maintenance costs and savings related to the product candidates to be used in the renovation (lifetime database of the existing products) available. • The operation and maintenance strategy of the owner.	• The energy expert updates the simulation • The energy expert creates an O&M digital twin model
Use Case 3 Construction: Implementation of the planned renovation measures	
• The strategic environmental and financial targets of the owner (OPR). • Targets from the "3.5. Occupant's behavior and comfort" by space types and their purpose of use • Targets from the "3.7 Indoor air quality" by space types and their purpose of use • OPR's compiled to more specific numerical energy efficency indicators (probably kWh/m²,a). • The detailed design and blueprints available • The digital twin of the detailed design available • The performance test plans available • The operation and maintenance plan available	D2.1 Table 10 additions • The model coordinotor ensures that "As designed" data model is updated to "As built" model • Energy expert and design team prepare a performance test plan
Use Case 4 Building Use: Operation and maintenance of the renovated building	
• The strategic environmental and financial targets of the owner (OPR). • The 'As built' operation and maintenance plan available • The 'As built' -version of the digital twin available • The handover documentation of the installed products available • The user guides available	D2.1 Table 11 additions • The owner orders an energy audit regularly to ensure that the digital twin is "As built and as operated and as maintained'" and technical building systems work as designed also after changes in building use.
Use Case 5 End of Life: Demolision and recycling of the renovated building	
• The owners environmental strategy concerning the recycling available	D2.1 Table 12 additions

• The 'As built and as operated and as maintained' -version of the digital twin	

The structure in D2.1 is defined following the EN 16310 [EN 16310, 2013]. The details at each stage of the overall renovation process are presented in the following tables that are updated here according the additions above. The tables are not republished in total. Some parts have been excluded and marked with three dots.

Table 4: Workflow in a renovation process in case of private works - Initiative, Table 4 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT
1	Inhabitant/ End-user	needs	a renovation intervention	If the inhabitant/ end-user is the owner
New	Energy Expert	finds	typical renovation measures	
5	Client/Owner	appoints	an adviser to provide a cost-benefits appraisal and a preliminary business case	If the owner is able to esteem cost-benefits
9	Client/Owner	evaluates	preliminary business case	

Table 5: Workflow in a renovation process in case of private works - Initiation, Table 5 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT
10	Client/Owner	decides	to undertake a renovation process	
11	Client/Owner	appoints	a project leader to manage the renovation project	
12	Project leader	identifies	clients/owner needs and user requirements	
New	Fast mapping team	provides	initial geometry information to the architect.	
New	Energy Expert	helps	to set the strategic environmental and financial targets of the owner (OPR).	
New	Energy Expert	helps	to set the occupant's behavior and comfort related targets	
New	Energy Expert	helps	to set the Indoor air quality related targets	
New	Energy Expert	helps	to set the first estimate targets for heating, electricity and cooling energy needs	
16	Site surveyor	carries out	measured surveys and condition surveys of existing structures or buildings on site (site survey), measuring each room and building component in order to return a geometrical representation of the building to be renovated	if the project leader is a site surveyor
17	Site surveyor	documents	the present condition of the property, highlighting areas of failure or concern	
21	Site surveyor	combines	the scanning data with installation schemes and existing drawings	if laser scanning has been undertaken for the site survey

23	Project leader	examines	how the project can meet stated requirements and aspirations	
34	Project leader	assembles	project team	
35	Lead designer	identifies	needs for specialist consultants	
39	Information manager	defines	information exchange objectives	
46 Modified	Owner	monitors	the results of building renovation ~~simulation~~ energy calculation [The calculations in initiation phase are probably simple monthly calculations - not real simulations.]	
47	Owner	monitors	building energy performance (near real time)	

Design related activities are further specified in the next phase. The design is splitted into sub-phases: concept design, preliminary design, developed design and detailed design.

The idea in energy performance work is that the model and energy calculation/simulation gradually refines. In the concept design there is maybe a plan that an exhaust air heat pump could be installed. In the preliminary design, the heat pump could get an approximate power, price and other most important variables. In the developed design an example product name and model should be found and finally the detailed design would get to control logic and usage pattern of the heat pump. Similarly, the BIM model of the building would gradually refine from simplified geometry model into accurate system model. In the future, the final model should be a digital twin that really emulates the reality. While going towards this future, the result can be called a facility management model or as-built model.

Table 6: Workflow in a renovation process in case of private works - Concept design, Table 6 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT
54	Lead designer	examines	the principal elements of the brief, if already defined by the client, or the objectives and requirements the project has to satisfy	
55 Modified	Architectural designer	produces	concept sketches or possibly concept BIM model and undertake preliminary investigations.	
New	Architectural designer	provides	design alternatives related to energy efficiency	
66	Project leader	considers	options for construction strategy	
67	Lead designer	checks	design from specialist consultants for compliance with the general design	
New	Each designer	provides	list of alternative measures at concept level	
70	Information manager	manages	information exchange level 1 (brief and feasibility)	
New	Modelling coordinator	starts	compiling the BIM	
71	Information manager	produces	end of stage report for client approval	
72	Information manager	considers	changes required to the brief	
New	Energy	makes	a quick calculation to find feasible design alternatives	

	expert		at conceptual level	
New	Project leader	communicates	renovation alternatives with the building owner	

Table 7: Workflow in a renovation process in case of private works - Preliminary design, Table 7 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT
73	Project leader	develops	the concept design and chosen options as approved by the client and previewed with the authorities	
New	Fast mapping expert	provides	the collected data (to the BIM management system)	
77	Architectural designer	produces	technical reports to explain design options	
78	Architectural designer	produces	architectural plans and documentation describing the project to a level of detail as required for Planning or Building permit applications (based on the approved design)	It can be postponed to developed or detailed design
New	The design team	prepares	a set of available design alternatives	
79	Architectural designer	collates	additional technical documentation from technical specialist consultants; such as acoustic, thermal, fire safety, environmental and other appraisals as required by applicable legislation	
91	Lead designer	integrates	as necessary into overall design documentation (including technical sub-disciplines of construction such as structural, mechanical, electrical, HVAC, geotechnical, fire security, acoustics, lighting, etc.)	
93	Information manager	manages	information exchange level 2	
New	Model coordinator	ensures	that the latest information is included in the BIM	
New	Energy expert	simulates	simulates the selected alternatives to find (pareto-) optimal alternatives for the owner review	
New	Owners	selects	the optimal solution from the simulated alternatives	

Table 8: Workflow in a renovation process in case of private works - Developed design, Table 8 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT
95	Project leader	develops	the approved preliminary design up to an appropriate level, providing the basic information required for issue of contract plans and specifications	
New	The design team	finds	real product candidates for the technical building systems	
New	Model coordinator	ensures	that the latest information is included in the BIM	
New	Energy expert	updates	the simulation	

Table 9: Workflow in a renovation process in case of private works - Detailed design, Table 9 in D2.1

N.	WHO	MAKES	WHAT	SHORTCUT

119	Architectural designer	provides	calculations and specifications intended for construction and enabling contractors to build the works	
New	Design team	prepares	control system descriptions for the technical building systems	
New	Design team	prepares	the O&M strategy for/with the owner	
New	Model coordinator	ensures	that the latest information is included in the BIM	
New	Energy expert	updates	the simulation	
New	Energy expert	creates	an O&M digital twin model	
124	Architectural designer	collates	additional technical documentation from technical specialist consultants; such as acoustic, thermal, fire safety, environmental and other appraisals as required by applicable legislation.	
134	Project leader	analyses	tender returns, make recommendations to client and enable him to pass construction contracts with each respective trade.	

The next phase is the **construction** and **commissioning** phase.

Table 10: Workflow in a renovation process in case of private works - Construction, Table 10 in D2.1

N.	WHO	MAKES	WHAT	WHEN
140	Contract administrator	reviews	contracts and agreed project objectives	Pre-construction
141	Inhabitant/ End-user	uploads	information requested from contractors for the renovation process, if necessary	Pre-construction
143	Project leader	monitors	construction progress and compliance with plans	Commissioning
144	Project leader	inspects	contractors' activity and execution of the works	Commissioning
147	Project leader	undertakes	final clarification of design details prior to implementation	Commissioning
153	Project leader	oversees	preparation of as-built documentation	Commissioning
155	Inhabitant/ End-user	updates	information about comfort conditions during renovation process	Commissioning
156	Inhabitant/ End-user	feels	comfort/ discomfort during the renovation process	Commissioning
158	Project leader	oversees	issue of as-built documentation and final accounts	Handover
160	Structural, Electrical, HVAC, water and waste designer	produces	architectural plans and documentation describing the project to a level of detail as required for Planning or Building permit applications (based on the approved design)	Commissioning

New	Model coordinator	ensures	that "As designed" data model is updated to "As built" model	Commissioning
New	Energy expert and the design team	prepare	a performance test plan	Commissioning

Following the construction phase, the building use stage (operation & maintenance) is started.

Table 11: Workflow in a renovation process in case of private works - Use, Table 11 in D2.1

N.	WHO	MAKES	WHAT	WHEN
165	Project leader	reviews	project performance and additional project information as required	Operation
166	Facilities management (FM) adviser	provides	advice to program planned maintenance and periodical performance testing	Operation
167	Sustainability adviser	monitors	sustainability performance	Operation
170	Inhabitant/ Owner	uploads	ad hoc information related to operational processes that may be useful for the renovation process	Operation
174	Project leader	prepares	documentation to obtain permits for possible changes of use, renovation or redesign	Maintenance
175	Project leader	sets out	procurement documentation and tender procedures for facility management, maintenance, and possibly renovation	Maintenance
New	Owner	orders	an energy audit regularly to ensure that the digital twin is "As built and as operated and as maintained"' and technical building systems work as designed also after changes in building use.	

Eventually, the decommissioning workflow is analysed for private buildings. The building owner in private projects has a key role as the responsible to trigger the dismantling process while it also monitors the financial parameters associated with this activity.

The above detailed steps of the renovation process highlight the specificities of a private project. Considering that the scope of the BIM4EEB project is to address both types of buildings, the aforementioned usage flows are analysed also for public works in D2.1. However, energy related activities don't differ much in the public and private works and there is no need to separate these two in this deliverable. Same new roles could be added also to public works.

3 Perfomance Based Decision Making during Renovation Activities

3.1 State-of-the-Art in Performance Based Decision Making

There could be various scenarios of retrofitting of buildings that may include different parts of the building's envelope and its HVAC system, including also different levels of integration of onsite renewable energy technologies. In order to explore best combinations of retrofitting actions, the energy performance of each retrofitting scenario has to be evaluated. For this purpose, Building Energy Simulation (BES) tools are used in analysing each retrofitting scenario by comparing different design solutions in terms of targets of energy, cost, thermal comfort and satisfying criteria set by regulations and building codes.

BIM tools are commonly used to describe the properties of the buildings' components. When combined with BIM tools, BES tools can get the full description of the required data to perform the energy simulations, therefore avoiding any repetition of feeding again the input data to the BES tool. However, retrieving data from existing buildings can pose challenges about the accuracy, completeness and update of the BIM data.

3.1.1 Building Energy Simulation (BES)

"Building Performance simulation is the replication of aspects of building performance using a computer-based mathematical model created on the basis of fundamental physical principles and sound engineering practice" [De Wilde, 2018]

Building Energy simulation (BES), allows making energy analysis of the buildings' performance under different operating conditions in a faster way with lower cost compared to making real measurements.

With BES, one can calculate different key performance indicators (KPIs) and compare between different cases of design and operation of buildings. Despite that the main purpose of the BES is to find energy performance, other main targets can be to calculate the CO_2 emissions, cost (investment cost, operating cost and Life-Cycle Cost LCC), occupant's satisfaction and indoor environment quality in each room. BES can express the performance of the building spaces showing the levels of temperature, humidity, natural lighting, illumination, heating and cooling loads etc.

BES handles building's spaces as thermal zones, where the energy required to keep a zone at predefined set- conditions of temperature, humidity, and/or CO_2, are calculated at each time-step.

BES can also be used for sizing of the components of the Heating, Ventilating and Air-Conditioning (HVAC) system, e.g. fans, blowers, chillers, boilers, air handling units, heat exchangers, thermal storage tanks, heat pumps, electric heaters, room heating/cooling units and components of the renewable energy systems (e.g. PV and solar-thermal panels). In addition, the control system can be simulated and tuned during the simulation before implementing it in the real system.

BES can be used for the design of new buildings and retrofitting. Basically, there is no difference in how the tool can handle the simulation in these two cases. However, it is the accuracy of the input data that matters, as for new buildings, more accurate data is available while for retrofitting the uncertainty in the accuracy of the input data is very high. Normally BES is used in the early design phase of buildings to assess the performance and contribute in the selection of the components of the construction and the energy systems. However, BES is also used during the buildings' operation phase for the purposes of control and performance forecast.

Detailed BES tools can be dynamic whole-building simulation tools, which target to capture the behaviour of the building under different variable external and internal conditions. The external conditions are those connected to the location of the building and the weather conditions, while the internal conditions are those associated with the type and use of the building and the HVAC system.

3.1.2 List of tools, features and usage

There is an increasing number of energy simulation software tools. The Building Energy Software Tools (BEST-D) Directory https://www.buildingenergysoftwaretools.com/ by the United States Department of Energy, which is currently hosted by IBPSA-USA gives a list of a total number of 198 BES tools showing information about the capabilities, use with different building types, operating platform, pricing and updates.

In general, BES software can be classified into three categories [Østergård et al., 2016]

1. Software with integrated simulation engine (e.g. EnergyPlus, ESP-r, IES-VE, IDA ICE)
2. Software that uses an external simulation engine (e.g. Designbuilder, eQuest, RIUSKA, Sefaira)
3. Plugins for other software enabling certain performance analysis (e.g. DIVA for Rhino, Honeybee, Autodesk Green Building Studio)

However, such classification cannot exactly apply to all tools, e.g. ESP-r can also be used as a modeller to EnergyPlus and there are also other applications using the IDA simulation environment. In the above, simulation engine refers to the repeatedly used solution approach that dynamically solves the encountered heat transfer equations, while the modeller application is the interface. Most modeller applications have a graphical user interface (GUI), which creates an input file to the simulation engine.

Table 12 presents a review of some simulation tools and general features including the type of the user, the design stage at which the tool is used, its interoperability and complexity, and the objective of the calculations.

Basic information about most common simulation engines and modeller applications are given in Table 13 [Østergård et al., 2016], [Judkoff, 2008].

Table 12 Comparison of softwares adapted from [Østergård et al., 2016]

	Software	Users			Design stage				Interoperability	Core complexity	Objectives					
		Architects	Engineers		Conceptual	Preliminary	Detailed	Management			Energy	Thermal	Daylight	Air Quality	LCA	LCC
BES (own engine)	Be10 (ISO 13790 monthly)[1]	A	E			x			SA	Low	x	(x)				
	Bsim		E			x	x		SA	High	x	x	x	x		
	DOE2 (Freeware)		E				x		SA	Medium	x					
	EnergyPlus (E+) (Freeware)		E				x		SA	High	x	x		x		
	EPC (ISO 13790 hourly)	A	E		x	x			SA	Medium	x					
	ESP-r (Freeware)		E				x		SA	High	x	x		x		
	IDA-ICE (Commercial)		E			x	x		FE	High	x	x	x	x		
	iDbuild		E		x	x			SA	Medium	x	x	x	x		
	IESVE	A	E			x	x	x	FE	High	x	x	x	x	x	x

	Software	Users			Design stage				Interoperability	Core complexity	Objectives					
BES (external engine)	Radiance	A	E			x	x		SA	High			x			
	VELUX Daylight Visualizer	A	E		x	x	x		FE	High			x			
	A+E3D	A			x	x			IN	Be10	x	(x)	(x)			
	Daysim	A	E		x	x	x		RT	Radiance			x			
	DesignBuilder	A	E			x	x		FE	E+, Radiance, jE+	x	x	x	x		x
	eQuest		E			x	x		SA	DOE2	x					
	N++		E		x	x	x		S	E+, jE+, GenOpt	x	x		x		
	OpenStudio		E			x	x	x	FE	E+, Radiance	x	x	x	x		x
	Riuska		E			x	x		FE	DOE2, own engine	x	x		x		
	Sefaira	A			x	x			RT	E+, Radiance	x	x	x			
Plug-in	DIVA for Rhino	A	E		x	x	x		RT	Radiance			x			
	Green Building Studio	A	E		x	x			FE	DOE2	x					
	HoneyBee (GH)	A	E		x	x	x		FE	OpenStudio, E+, Radiance	x	x	x			x
	jEPlus (+JESS)		E			x	x		RT	E+, DesignBuilder, N++	x	x	x	x		x
	Parametric Analysis Tool		E			x	x		FE	OpenStudio	x	x	x	x		x
	Solon	A	E			x	x		FE	Green Building Studio	x					
Glue[2]	Dynamo	A	E		x	x			-	-						
	Grasshopper (GH)	A	E		x	x			-	-						

[1]Be10 is mandatory to use for code compliance in Denmark
[2]Glue refers to software that enables linking between Building Simulation (BES) software and geometrical modelling through graphical programming (also referred to as algorithmic modelling)

x indicates fulfilment of the requirement

(x) indicate that software include the specific feature without satisfying the requirement

SA - Standalone	IN- Integrated	LCC - Life Cycle Costs	UA - Uncertainty Analysis
FE - File exchange	RT- Run-time	LCA - Life Cycle Analysis	SA - Sensitivity Analysis
S-Separated			OAT - One-at-a-time

Table 13 Overview of simulation engines and modeler applications adapted from [Østergård et al., 2016] and [Judkoff, 2008]

Simulation engine	Developer	First Release	Technology	Modeling Language	License	Current Version in June 2019	Modeler applications and GUI
ApacheSim	Integrated Environmental Solutions Ltd., UK				Commercial	6	VE 2018

Carrier HAP	United Technologies, US				Commercial	5.11	Carrier HAP
DOE-2	James J. Hirsch & Associates, US	1978			Freeware	2.2	eQuest, RIUSKA, EnergyPro, GBS
Energy+	Lawrence Berkeley National Laboratory, US	2001			Freeware	9.1.0	DesignBuilder, OpenStudio, many others
ESP-r	University of Strathclyde, UK	1974			Freeware	13.3.3	ESP-r
IDA	EQUA Simulation AB, SE	1998	DAE	NMF, Modelica	Commercial	4.8	ICE, ESBO
SPARK	Lawrence Berkeley National Laboratory, US	1986	DAE		Freeware	2.01	VisualSPARK
TAS	Environmental Design Solutions Limited, UK				Commercial	9.4.3	TAS 3D Modeler
TRNSYS	University of Wisconsin-Madison, US	1975		FORTRAN, C/C++	Commercial	18	Simulation Studio, TRNBuild

3.1.3 Input data and output data to building simulation tool

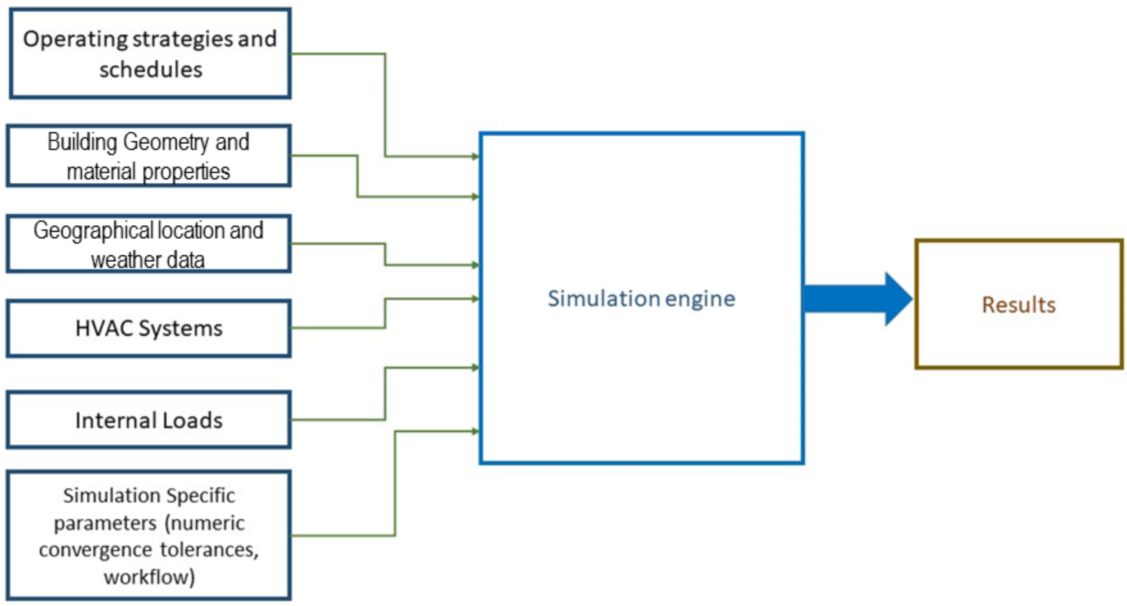


Figure 3 General input data of thermal simulation engines adapted from [Bahar et al., 2013]

The required level of details of the input and output data from a building energy performance simulation tool depends on the application and the need for the required details. In addition, the need for detailed input data depends on the different assumptions and methods used in the solution of the involved physical models in the simulation.

A typical building simulation model will require the following input data (Fig. 3):

- Geographical location and Site information: building location and orientation (also shading in relation to surrounding buildings, and the ground properties)
- Weather data: ambient air temperature, relative humidity, direct and diffuse solar radiation, wind speed and direction
- Building geometry: dimensions of the building and all of its components, rooms, external and internal walls, doors, windows, glazing, roof, ceiling, floor, internal & external shadings
- Composition, material of construction, thickness, thermal and physical properties of the building elements by spaces
- Thermal bridges, openings and air infiltration in the building envelope
- Profiles (level and time schedule) of internal loads from occupants, appliances, devices, equipment, and lighting by spaces
- Components of the heating, ventilation and air-conditioning (HVAC) system including energy generation, storage, distribution and delivery, and their specifications: efficiencies, flow rates, and temperature levels by spaces
- Control specifications and operation strategy of the HVAC system and room units: temperature, humidity and fluid flow settings, lighting, window opening and shadings

In addition to calculating the hourly and total energy load profiles (for heating, cooling, ventilation, electricity and lighting), other output data are: temperatures (zone as well as surfaces temperatures), zone CO2-concentration, comfort indicators (e.g. Fanger's Predicted Mean Vote PMV and Predicted Percentage Dissatisfied PPD), and relative humidity.

BES is mostly used in the design phase of buildings, but it can also be used in the operation phase. This later is mostly connected with the control of the building's operation in the next time steps by predicting the building's performance in conjugation with the weather and energy network forecasts and the internal loads and use.

The International Building Performance Simulation Association (IBPSA) http://www.ibpsa.org/ is dedicated to improving the built environment through information exchange and distribution and events organization between building performance simulation researchers, developers and practitioners on international level.

3.1.4 Impact of the input data on the results of BES

The effect of the input data to BES on the energy demand results can be evaluated by setting uncertainty ranges around selected parameters in the input data and calculate the effect of these parameters on the produced results. Tian et al. 2018 listed the sources of uncertainty in building energy simulation input data as follows: weather, building envelope, HVAC system and the occupant's behaviour. The paper extends the building envelope parameters to the following sources: thermal properties (thermal conductivity, density, specific heat capacity, window U-value and Solar-Heat Gain Coefficient SHGC of the windows), surface properties (absorption, emissivity and reflectance), and other sources (internal and external convective heat transfer coefficients, air tightness, infiltration and components thicknesses).

To find the effect of the input data on the energy simulation results, Ioannou et al. 2015 simulated a reference building (TU Delft Concept House) with three different heating systems. The results show that if behavioural parameters are not included in the analysis, the most important parameters that affect the heating consumption results are the window U-value, window g-value and wall conductivity. When the uncertainty of the building-related parameters increases, the impact of the wall conductivity considerably increases. This is because it is easy to find the the U-value and g-value for windows, but the higher uncertainty will come from the U-values of the walls. An important finding was that when behavioural parameters related to thermostat use and variations in the ventilation flow rate are added to the analysis, the effecet of the building parameters is reduced.

Tian et al. 2015 investigated several statistical methods in order to identify key parameters influencing the heating and cooling loads in buildings and to create reliable meta-models that can quantify the heating and cooling loads as a function of the key parameters. The results of the analysis from campus buildings indicate that the heating load was mainly influenced by the building envelope components (most important is the wall U-value) and the internal heat gains. On the other hand, the cooling load was found to be affected by the internal heat gains, where the number of hours of using the internal lighting was the dominant parameter.

Egan et al. 2018 used the Differential Sensitivity Analysis (DSA) computational method to identify the most influential input parameters for a given set of Irish residential dwellings archetypes. The aim was to find how the simulated building energy consumption will change as the input data is varied. The most influential input parameters were then identified in order to form a guideline on minimum set of accurately-defined input data. Five base-case archetype buildings were modelled representing a major portion of the Irish dwellings. All building models predicted the annual energy use to within 10% of the actual measured data and the seasonal energy demand profiles were well-matched. Performing sensitivity analysis on the parametric data identified the most influential input parameters. Table 14 shows the input parameters that were investigated and their data range.

Table 14 Input parameter range of values and increments adapted from [Egan et al., 2018]

Parameter	Unit	Acronym	Minimum	Maximum	Increment
External wall U-value	$W\ m^{-2}\ K^{-1}$	U_wall	0.1	1.1	0.25
Roof U-value	$W\ m^{-2}\ K^{-1}$	U_roof	0.1	0.9	0.2
Ground floor U-value	$W\ m^{-2}\ K^{-1}$	U_floor	0.1	1.1	0.25
Internal partition U-value	$W\ m^{-2}\ K^{-1}$	U_part	1	3	0.5
External door U-value	$W\ m^{-2}\ K^{-1}$	U_door	0.5	3	0.5
External wall internal thermal mass	$kJ\ m^{-2}\ K^{-1}$	Thm_mass_wall	75	175	25
Roof internal thermal mass	$kJ\ m^{-2}\ K^{-1}$	Thm_mass_roof	125	225	25
Ground floor internal thermal mass	$kJ\ m^{-2}\ K^{-1}$	Thm_mass_floor	100	200	25
External wall emissivity		Wall_emiss	0.15	0.95	0.2
External wall solar absorptance		Wall_abs	0.15	0.95	0.2
Roof emissivity		Roof_emiss	0.15	0.95	0.2
Roof solar absorptance		Roof_abs	0.15	0.95	0.2
Window-to-Wall Ratio	%	WWR	10	70	20
Glazed portion U-value	$W\ m^{-2}\ K^{-1}$	U_g	0.6	4.6	1
Frame U-value	$W\ m^{-2}\ K^{-1}$	U_frame	0.5	4.5	1
Solar heat gain coefficient		SHGC	0.1	0.9	0.2
Light transmittance value		V_t	0.19	0.99	0.2
Heating system seasonal COP/efficiency		COP_sys	0.5	2.5	0.5

Auxiliary energy consumption	kWh m^{-2} $year^{-1}$	E_aux	1	5	1
Heating set-point temperature	$^{\circ}C$	HSPT	18	23	1
Heating set-back temperature	$^{\circ}C$	HSBT	10	14	1
DHW usage	L m^{-2} day^{-1}	DHW_use	0.5	3.5	1
Occupancy density	m^{2} $person^{-1}$	Occ_gains	0	0.1	0.025
Lighting density	W m^{-2}	L_dens	1	9	2
Equipment density	W m^{-2}	Equip_dens	1	21	5
Air changes per hour	ach	ACH	0.5	1.5	0.2
Orientation	$^{\circ}$	Orientation	0	180	45

The results indicate that hourly air-change-rate (ACH) was the most influential parameter in all the studied cases. In addition, the heating-set-point-temperature (HSPT) has a very high influence on the dwelling's energy consumption, particularly for the archetypes that had larger volumes and external surface areas. In all the cases, the U-value of the glazing (U_g) showed to be more effective than any U-value parameter of the opaque building elements. The window's SHGC also indicated to be a highly influential parameter. The daily domestic-hot-water (DHW) consumption levels also strongly affected the energy requirements. To rank these results, a thorough analysis of the results was conducted using the relative influence that each input parameter has on the output, which was quantified by a non-dimensional Influence Coefficient (IC). The paper used a cut-off point of IC = 0.04 to include the parameters in the minimum set of accurately-defined input data. The ranked input parameters are indicated in Table 15 according to their impact on the output results of the energy consumption for each building archetype.

Table 15 Minimum set of input data adapted from [Egan et al., 2018]

Rank	Detached	Semi-detached	Bungalow	Mid-floor apartment	Top-floor apartment
1	HSPT	HSPT	HSPT	ACH	ACH
2	ACH	ACH	ACH	U_g	DHW_use
3	U_g	U_g	DHW_use	DHW_use	U_g
4	U_wall	DHW_use	U_wall	SHGC	SHGC
5	SHGC	U_wall	WWR	Orientation	U_roof
6	DHW_use	SHGC	U_g	COP_sys	HSPT
7	COP_sys	Orientation	COP_sys	HSPT	Orientation
8	WWR	COP_sys	Orientation	WWR	COP_sys
9	–	WWR	SHGC	Equip_density	U_wall
10	–	–	U_roof	U_wall	WWR
11	–	–	–	–	Equip_density
12	–	–	–	–	Roof_abs
13	–	–	–	–	Roof_emiss

Rodríguez et al. 2013 investigated an intermediate flat located in Malaga- south of Spain in a sensitivity analysis case study. Two methods were used in the sensitivity analysis: using original 130 inputs (combination of microparameters and macroparameters) and analysis using 16 macroparameters. Each selected macroparameters has to have a physical meaning and can characterize the thermal performance of the building. The macroparameters for this case study are shown in Table 16.

Table 16 Macroparameters in the case study [Adapted from Rodríguez et al., 2013].

Macroparameter	Notes
Weather	
Occupancy	
Global transfer coefficient (W/m^2 K)	Calculated taking into account the surface of every envelope element of the building, including windows
Calorific capacitance (kJ/m K)	Construction thermal inertia
Solar heat gain coefficient (SHGC)	Solar energy transmittance of a window or door as a whole
Global percentage of radiant gains	Ratio of radiant internal gains to total internal gains
Global infiltration (ach)	Weighted value taking into account the volume of every zone
Global heating set-point temperature (C)	Weighted value considering the volume of every zone
Global cooling set-point temperature (C)	Weighted value considering the volume of every zone
Ground reflectivity	
Boundary conditions	Related to the surface temperature of the surface in contact with the building corridor
Heating capacity (W)	Sum of all the heating equipment capacities
Cooling capacity (W)	Sum of all the cooling equipment capacities
Flow (m^3/s)	Sum of all HVAC systems flows
Heating COP	COP at rated conditions
Cooling COP	COP at rated conditions

The results of the sensitivity analysis using the original 130 inputs indicate that the most influential parameters are the occupancy profile and the weather data. The dominance of these two parameters was the same conclusion made using the 16 macroparameters. Further investigation of the latter macroparameters method was done by fixing the two dominant parameters and studying the effect of the other parameters, which found that the cooling set-point temperature is the most influential, followed by the ground reflectivity. The effect of any parameter can differ according to the prevailing weather. In a warmer weather with a higher occupancy profile, the larger influence of the input data uncertainty is due to the cooling device COP and the Solar-Heat Gain Coefficient (SHGC) of windows. In a colder weather with low occupancy profile, the heating set-point temperature is very important.

It can be concluded from the above that the effect of the input data depends on the prevailing weather conditions and the archetypes of the buildings. The heating and cooling set-points and the air ventilation rates are the most influential parameters on the building's energy consumption. Besides, in cold weathers, main effects on the heating load come from the solar gains through the glazing, building envelope parameters of the window U-value, window g-value, wall conductivity and the heaviness of the building's structure. In hot weathers, the cooling load is mainly affected by the internal heat gains from the occupant's behaviour.

3.1.5 The Performance Gap in Buildings Energy Simulation

Despite the advancement in energy simulation tools nowadays, a significant discrepancy can be found between predicted and actual energy performance of buildings, which is referred to as the performance gap [De Boeck et al., 2015].

de Wilde, 2014 indicates that a direct comparison of predicted .vs. measured annual energy use is difficult. This is due to uncertainties in the data available in the design stage, which propagate in the energy simulations, and also because of the lack of accurate measurements data. The study indicates the effect of the external conditions (e.g. outdoor temperature) on the performance gap as well as the temporal resolution of the energy measurements. The paper refers to ensuring that state-of-the-art models are used and that at the same time the data used as input for the simulations are up-to-date. Once updated input data are used and the tool is calibrated against the measurements, the simulated energy results can be of higher quality. However, it is important to remember that energy efficiency is only one performance aspect of buildings. Further work will then be needed to deal with the gaps in the other aspects of the building's performance like thermal comfort, indoor air quality, etc.

According to Khoury et al. 2017, there are several factors that can cause the energy performance gap in retrofitted buildings. These factors can be encountered at different stages during the building retrofit process. These are identified as follows: inaccurate values used as default numbers coming from codes and standards; quality of input data used in the simulation (e.g. weather data, estimated geometries, shading factors, etc.); model limitations; factors related to the quality of the execution, operation and monitoring by the energy operator and the occupant's behaviour data.

Apart from modelling errors or faulty construction, De Boeck et al. 2015 indicate that the performance gap is due to several parameters. These parameters include the influence of the occupant's behaviour, day lighting control strategies and uncertainty in the available data about the material properties, design parameters and climatic data. The paper concludes that assumptions on climate and occupant behaviour can have a big impact on the energy performance of a building.

Occupant's behaviour is one major factor that can cause discrepancies between simulation prediction and real energy use. Therefore, accurate information and modelling with regard to the occupant presence and behaviour is very important for reliable energy simulation [Ahn et al., 2017]. Over the past several decades, occupant's presence in building has been considered as fixed profiles in energy simulation. Recently, stochastic models have been used to account for the dynamic occupant behaviour, which is based on empirical and probabilistic transition rules, e.g. Markov Chain. A significant difference is observed in energy predictions between three models used in energy simulations. Ahn et al. 2017 show that occupant presence in studied rooms and buildings follows a "random walk" pattern. This latter is a mathematical formalization of a path that consists of a succession of random steps, which cannot be predicted stochastically.

Zhang, et al. 2018 investigated the role of occupant's behaviour in building energy performance in the literature. Relevant articles were reviewed with in-depth focus on specific research topics in this field. As a result, they estimated that the energy-saving potential of occupant behaviour in building energy performance can range between 10% to 25% for residential buildings, and 5% to 30% for commercial buildings.

In addition to all the uncertainties in the asset rating, it is also important to remember that the measured energy consumptions in the operational rating also have uncertainties. The measurements themselves can be uncertain and the measured entity may not be the same that is included in the asset rating, e.g. the asset rating is simulated for a building only, but measured energy might include outdoor lighting that is not included in the simulation. In an existing building analysis, it might be very difficult to find out which part of the energy used on a site is included in which measurement. Also, if the operational rating is calculated using adjustments, they bring uncertainty to the end result, e.g. weather correction based on heating and cooling degree days is only an estimate how much energy the building would have used on other weather. When these adjustments get complicated, there are more and more assumptions that the energy expert must make.

3.2 Use of BIM with BES

According to [ISO/IEC JTC1 2382-01, 2003], Information Technology Vocabulary Fundamental Terms, interoperability is defined as "The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units".

The gained advantage of interoperability is its ability to transfer data between different software without a need for replicating the data, and therefore more than one software can use the same data for various purposes.

In this section, we introduce basic interoperability of BIM platforms and the interoperability of BIM with most common BES tools, which is on general application level and not necessarily dedicated for energy retrofitting.

3.2.1 BIM-platforms overview

Designers' Needs and Requirements are strictly connected with every day design environment. For proper analysis of BIM interoperability is crucial to properly define BIM-oriented platform. Object oriented design methodology, which is one of main principles of BIM technology, required precise software formula. BIM-Based Renovation Processes should investigate most popular advanced BIM-based software. There are several solutions on the market but only few are widely used. Major full BIM-based design platforms are: Revit, ArchiCAD, Tekla Structure, MicroStation, AllPlan. Design processes are often assisted by models review software like Navisworks, Solibri Model Checker or SimpleBIM. BIM-based platforms propagate multidisciplinary design and offer file exchange with other analysis software's like BES platforms. Every day design practice, which is strong time-dependable, generates needs of multidisciplinary design decisions on a single platform. Interoperability on BIM-Based platform propagates through file exchanges modules and may differ in each case. Table 17 presents the file formats that are currently supported by the aforementioned tools.

Table 17 Major file exchanged formats of the BIM-platforms

Tool	Input formats	Output formats
Revit	.gbXML, .dwg, .dxf, .dgn, .sat, .skp, .3dm, .rcp. ifc, .dwf, ifcXML, .ifcZip	.dwg, .dxf, .dgn, .sat, .dwf, .dwfx, . adsk, .fbx, .nwc, .gbXML, .IFC,
ArchiCAD	.dwg, .dxf, .dgn, .ifc, ifcXML, IfcZip, .bcf, .c4d, .3dm, .3ds, .kml, .dwf,. skp, .xyz	.dwg, .dxf, .dgn, .ifc, ifcXML, .IfcZip, .bcf, .nwc,.smc,.c4d, .3dm, .3ds, .atl, .kml, .gbxml, .dwf, .obj, .skp
Tekla Structure	.dwg, .dxf, .bcf, .btl, .abs, .stp, .step, .ifc, .dgn, .skp	.dwg, .dxf, .bcf, .btl, .abs, .stp, .step, .ifc, .dgn, .pdms, .skp,

Tool	Input formats	Output formats
MicroStation	.dwg, .dxf, .fbx, .skp, .step, .sat	.dwg, .dxf, .fbx, .skp, .step, .sat, .ifc
AllPlan	.dxf, .dwg, .dwt, .dxb, .dgn, .ifc, .ifcXML, .cd4, .skp, .3dm, .stl, .wrl, .plt, .hp, .hpg, .hpl, .prn	.dxf, .dwg, .dgn, .ifc,.ifcXML, .c4d, .skp, .cpixml, .3dm, .wrl, .dae, .kmz, .stl, .u3d, .svg, .3ds

3.2.2 Interoperability through BIM Platform

Most data transfer for energy-related analysis in the architecture, engineering and construction (AEC) industry is executed using the two well-known schemes, the Industry Foundation Classes (IFC) and the Green Building XML schema (gbXML).

The Industry Foundation Classes (IFC) data model is used to describe building and construction industry data developed by buildingSMART (formerly the International Alliance for Interoperability, IAI). IFC is a platform-neutral open-file format specification, which eases information exchange among IFC-software applications. IFC facilitates data interoperability in the AEC industry.

The Green Building XML schema (gbXML) http://www.gbxml.org/ was developed to facilitate the transfer of building information in CAD-based building information models and enable interoperability between disparate building design and engineering analysis software tools. The aim is to assist architects and engineers to design more energy efficient buildings. gbXML is a type of XML (eXtensible Markup Language) file, which is a type of text-friendly computer language that allows software programs to communicate information with little to no human interaction. XML provides a non-proprietary, persistent, verifiable, easy to understand file format that may be used to create customized markup language and data schemes with semantic content [Sanhudo et al., 2018].

gbXML is the product source language for building's energy analytical models focused solely on the building's thermal and energy-related characteristics. On the other hand, IFC presents a broader area of application in the AEC industry and is primarily the product language of a building's 3D geometry and metadata including its geometry, construction characteristics, fixtures, furniture, etc. Therefore, it does not exclusively focus on energy modelling.

BIM models can be directly imported to different building simulation tools using the IFC and gbXML data schemes. Thus, avoiding the double work of feeding the input data or the need for remodelling the building in each tool. This leads to significant reduction in modelling resources and efforts. The quality of data transfer between different application tools depends on the development of these two data formats, but also on the way of implementation by the users [Sanhudo et al., 2018].

3.2.3 Interoperability of BES with BIM

Bahar et al. 2013 reviewed 14 selected BES tools that are most applicable to the BIM application. These tools can be used at different stages of the life-cycle of a building and are able to exchange data with other tools using IFC and gbXML files. These BES tools are: DPV (Design Performance Viewer), Design Builder, Ecotect, eQUES, EnergyPlus, EcoDesigner, ESP-r, Green Building Studio, Lesosai, IDA ICE, IES VE, TRACE700, TRNSYS and Riuska. Table 18 indicates the application and interoperability of the reviewed

BES tools with BIM.

Table 18 Interoperability of building energy simulation tools adapted from [Bahar et al., 2013]

Tool	Application	Input data	Output data	BIM based geometry import
DPV (Design Performance Viewer)	Environmental design, thermal design and analysis, heating and cooling loads, energy cost, Exergy/CO2, life cycle assessment, scheduling.	CAD-BIM revit	-	The building model is directly built in the CAD-BIM environment.
DesignBuilder	Environmental design, 3D Model (3D Design), thermal design and analysis, heating and cooling loads, natural and artificial lighting, Internal air, mean radiant and operative temperatures, humidity, CO2 emissions, solar shading, heat transmission, solar shading, scheduling.	gbXML, .dxf, .pdf, .bmp, .jpg	CAD: AutoCAD, Microstation, SketchUp using 3-D dxf, .epw, .csv, .tmy, .tmy2	Provides interoperability with BIM models through its .gbXML import capability.
Ecotect	Environmental design, 3D Model (3D Design), thermal design and analysis, heating and cooling loads, Validation; Solar control, overshadowing, prevailing, winds & air Flow, natural and artificial lighting, life cycle assessment, life cycle costing, scheduling, geometric and statistical acoustic analysis.	.dwg, .ifc,gbXML, .obj, 3DS, .xml, ASCII, etc.	Metafiles, Bitmaps or animations. RADIANCE, POV Ray, VRML, AutoCAD dxf, EnergyPlus, ESP-r, ASCII Mod files, XML, etc.	Imports CAD-BIM models from most CAD software
eQUEST	Energy performance, simulation, energy use analysis, conceptual design performance analysis, 3D Model (3D Design), thermal design and analysis, heating and cooling loads, Solar control, overshadowing, Lighting system, life cycle assessment, life cycle costing, Scheduling.	gbXML, .dwg, dxf	dxf, gbXML, .xls	Support gbXML format

Tool	Application	Input data	Output data	BIM based geometry import
EnergyPlus	Energy Simulation, thermal design and analysis, Heating and cooling loads, Validation; Solar control, Overshadowing, Natural and artificial lighting, Life cycle assessment, Life cycle costing, Scheduling.	ifc, gbXML, text	ASCII	.ifc compatible. (BIM Application)
EcoDesigner	Energy balance evaluation, CO2, overshadowing, heating, cooling, lighting, water use, Life cycle costing, Scheduling, prime energy usage (gas, energy, electricity etc.)	gbXML	gbXML, .pdf	Provides another dimension in the BIM environment for the architect in shaping his design
ESP-r	Environmental Design, 3D Design, thermal design and analysis, heating and cooling loads, Solar control, lighting, natural ventilation, combined heat and electrical power generation and photovoltaic facades, acoustic analysis, life cycle and environmental impacts assessments.	XML	XML, csv, VRML	no
Green Building Studio	Environmental Design, thermal analysis, annual energy consumption (electric and gas), Carbon emissions, day lighting, water usage and cost, Life cycle costing, natural ventilation.	gbXML-enabled BIM or 3D-CAD	gbXML, VRML	Supports gbXML format and has easy interoperability with BIM Application
Lesosai	thermal design and analysis, Heating and cooling loads, Solar control, CO2, natural and artificial lighting, life cycle assessment, life cycle costing, Scheduling.	gbXML, .nbdm, .skp	.xls, .xml, .pdf, .bld, .txt files	Supports gbXML format and has easy interoperability with BIM Application
IDA ICE	Environmental design, 3D Model (3D Design), thermal design and analysis, heating and cooling, Solar and shading, surface transmissions, air leakage, cold bridges and furniture, lighting, Air	.ifc, .dxf, .dwf, .3ds, .cgm, .cmx, .dgn	.html, .doc, .xls, .jpeg, .jpg, .png, .tiff, .bmp	.ifc compatible. (BIM Application)

Tool	Application	Input data	Output data	BIM based geometry import
	CO_2 and moisture levels, Energy costing.			
IES VE	Thermal design and analysis, heating and cooling loads, CO_2, Validation; Solar, Shading, Lighting, Airflow, Life cycle costing, Scheduling, fire evacuation.	gbXML, .dxf, .dwg	.ve	Supports gbXML format and has easy interoperability with BIM Application
TRACE 700	Environmental design, 3D Model (3D Design), thermal design and analysis, heating and cooling, life cycle costing, plants system.	gbXML	.pdf, .rtf, .txt, .doc, .xls	Supports gbXML format and has easy interoperability with BIM Application
TRNSYS	Environmental design, 3D Model (3D Design), thermal design and analysis, heating and cooling loads, Solar control, overshadowing, prevailing winds & air Flow, electrical, photovoltaic, hydrogen systems, Life cycle costing.	.skp, ASCII, .xml	ASCII (Simulation Studio Tool : HTML, C++)	no
Riuska	Environmental design, 3D Model, thermal design and analysis, heating and cooling loads, validation; Solar control, overshadowing, lighting, life cycle assessment, life cycle costing, scheduling.	.ifc	.ifc	.ifc compatible. (BIM Application)

In addition, there are several BIM tools that have integrated add-ons or support by external tool, which are able to perform building energy performance. Examples are the three CAD software programs: Revit, Archicad/Ecodesigner, and Sketch-Up. Energy performance simulation can be performed in these tools by the built-in thermal tool or alternatively by another BIM-interoperable BES tool. [Bahar et al. 2013]

Revit (Architecture and MEP) by Autodesk is basically built for BIM. Green Building Studio and Ecotect are integrated with Revit, known as Project Vasari. Revit links with DPV (Design Performance Viewer), Design Builder, EnergyPlus, eQUEST, ESP-r, Lesosai, TRNSYS, IDA ICE, IES VE, TRACE700 and Riuska.

ArchiCAD supplied by Graphisoft/Abvent is an architectural BIM/CAD tool. EcoDesigner is built into ArchiCAD as an interface. The ArchiCAD BIM program also links with Design Builder, Ecotect, EnergyPlus, Green Building Studio, Lesosai, TRNSYS, IDA ICE, IES VE, TRACE700, and Riuska. Within ArchiCAD, it is possible to create zones and then export the simplified energy model to Ecotect using Green Building Studio’s gbXML format, where the energy analysis is handled.
Google SketchUp does not offer direct support for BIM. SketchUp integrates with certain plugins like IES VE-Ware, Lesosai and TRNSYS. SketchUp has links to ESP-r. It also integrates OpenStudio, which is a free plugin for the SketchUp 3D drawing program that supports whole building energy modelling using EnergyPlus. With the OpenStudio plug-in, it is possible to create and edit building geometry in the input files of the EnergyPlus and allow launching the simulations and visualization of the results without leaving SketchUp. With this plugin, SketchUp is able to both import and export gbXML files. Fig 4 shows a sketch of data exchange connection between these three tools and the BES tools.

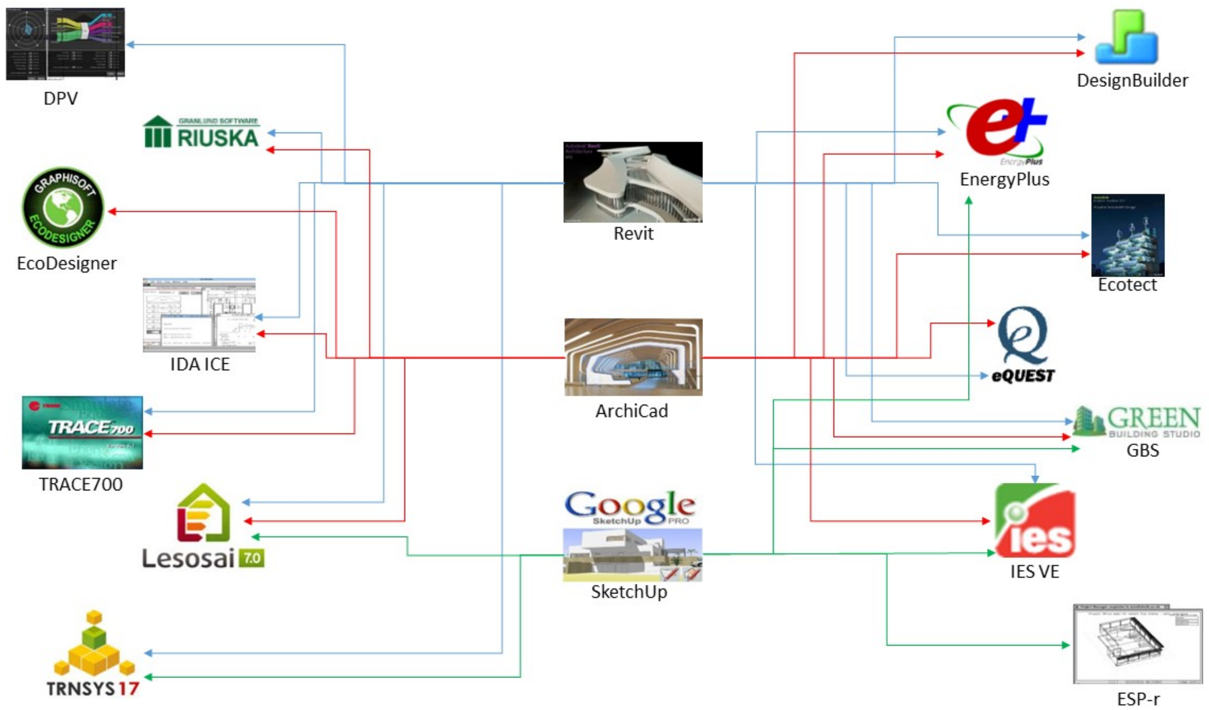


Figure 4 Summary of data exchange adapted from [Bahar et al., 2013]

3.3 BIM for retrofitting

Using BIM for retrofitting includes additional challenges for finding updated information of the as-is data and the data acquisition for the geometry and the energy-related calculations.

3.3.1 As-is BIM for retrofitting

BIM contains both geometrical and non-geometrical description of the building data. Accurate acquisition of as-is data is one of the most challenging tasks for BIM-based energy modelling retrofitting.
Existing buildings that are subjected to retrofitting normally lack complete data and documentation. Moreover, even for the available original data of the building, it is expected that the composition and performance of the building elements have changed or degraded with time. These represent practical challenges for BIM when used to express existing buildings complete data. Therefore, appropriate equipment and methods should be incorporated to monitor, collect and manage the as-is data of buildings. In the next subsections, the data acquisition and data management of the building data is presented. [Sanhudo et al., 2018]

3.3.2 Data acquisition

Data acquisition for BIM include data related to both the geometry and that needed for the execution of energy simulation, which are normally conducted by non-destructive methods.

Geometrical data
The development of technology in the recent years has facilitated the acquisition of more accurate 3D as-is building data. The detailed description of the data can enable the generation of more accurate BIM models that can be used in buildings retrofitting.

Sanhudo et al. 2018 collected basic information about as-is survey technologies (Table 19). Examples are laser scanning, photogrammetry, 3D camera ranging, topographic methods and videogrammetry. These techniques require the use of expensive and fragile equipment, which have to be operated by skilled personnel and require time for conducting them. The other methods are RGB-D, time-of-flight, phase measurement and optical triangulation, which also need similar requirements but may produce lower accuracy data. From the above-mentioned methods, two are found to be most popular: laser scanning and photogrammetry.

Table 19 Methods for geometric data acquisition adapted from [Sanhudo et al., 2018]

Method	Automation of spatial data retrieval	Fieldwork	Spatial data accuracy	Spacial data resolution	Equipment cost	Equipment portability	Data retrieval speed	Range distance	Data treatment	Operation time
Traditional Methods[a]	No	Simple but time consuming	Low accuracy (2.46 cm)		Low (few hundreds)	Portable, lightweight	Long		Simple but time consuming, requires at least 2 persons	Operates day and night
Photogrammetry	Manual or Semi-automated	Complex and time consuming	Accurate (> 1 mm depending on	Low	Low (few hundreds)	Portable, lightweight	Non real time retrieval	Medium	Simple but time consuming	Sensitive to light
Videogrammetry	Semi-automated		Accurate	High	Low (few hundreds)	Portable, lightweight	Real time retrieval	Medium	Complex	Sensitive to light
3D Camera Ranging	Automated		Medium accuracy	Low	Medium	Portable	Real time retrieval	Short range	Complex	Operates day and
Laser Scanning	Automated	Simple and quick	Highly accurate (can achieve 0.6 mm)	High	High (thousands)	Non-portable	Non real time retrieval	Long range (depending on required precision may achieve 700 m)	Complex	Operates day and night
Topographic Methods	No	Complex and time consuming	Highly accurate		High (thousands)	Non-portable	Non real time retrieval	Long range	Complex and time consuming	Operates day and night

[a] Use of equipment such as flexometers, measuring tape, poles, squares, plumb lines, etc.

Energy-related data

Energy performance of a building depends on the characteristics of the building envelope, the integrated energy system and the actual use of the building. Accurate data describing these characteristics can be collected from performing tests and measurements on the building components. Table 20 indicates multiple exhaustive surveying tests for the collection of BIM data of building components thermal properties required for energy performance retrofitting.

In recent years, there has been a focus by BIM users to apply thermography as a method for collection of visual data for both the geometry and energy-related analysis. An example is the use of infrared thermography since thermal cameras can capture wide range of surface temperatures data. These data can be used to identify heat losses due to thermal bridges and air leakage infiltration/exfiltration through the building envelope. A main disadvantage of thermography is the need for thousands of thermal images to execute a proper analysis. In addition, this will require extensive manual effort to assign the accumliated data to the building component models, which can affect the accuracy of the produced models. Additionally, it is indicated that there is work that combine geometric information coming from laser scanning with thermography, which can allow introducing thermal data into the spatial information of the building components. Examples are given where thermography data was added to visual information of 3D model and also for others where an automated method is used for directly updating the thermal data in the gbXML files of the as-is BIM models [Sanhudo et al., 2018].

Table 20 Energy performance tests and output adapted from [Sanhudo et al., 2018]

Test	Output
Heat Flux Measurement	• Envelope thermal resistance (R-values); • Envelope thermal transmittance (U-values).
Blower Door	• Air tightness.
Thermography	• Leak identification; • Thermal bridge detection.
Smoke Testing	• Leak identification.
Air Handler Flow Measurements	• Leak identification.
Delta-Q Test	• Leak identification.
True Flow Plates Test	• Leak identification.
Thermal Anemometry Using Hotwire	• Fluid velocity;
Anemometers	• Leak identification.
Tracer Gas Measurement	• Air change rates; • Leak identification.
Indoor Comfort (Thermometers, humidemeters, anemometer, ...)	• Interior temperature; • Interior relative humidity; • Air velocity.
Cavity Temperature Measurement	• Cavity temperature.
Carbon Dioxide Sensor	• Carbon Dioxide (CO_2) content.
Pyranometer Tests	• Vertical radiation; • Window glazing solar transmittance.
Weather Station Measurement	• External temperature; • External relative humidity; • Wind speed; • Wind direction; • Barometric pressure; • Rainfall.
Partial Deconstruction	• Building element component identification.
Construction Observation	• Anomaly identification.

3.3.3 Advanced BIM for retrofitting

In this section, we present a new process proposed by [Scherer et al., 2018] in a recent publication for the creation of a BIM model of an existing building undergoing a retrofitting process, which the authors have named "**BIMification**". As was indicated in the previous sections, creating a BIM model of an existing building is unlike that for a newly designed building. In the latter, BIM is created from scratch with the help of e.g. BIM/CAD, while in existing buildings, it has to be generated from the actual "as-is" state with practically no or very limited documentations of incomplete 2D drawings or only some data.

In this section, we follow the "**BIMification**" process proposed by [Scherer et al., 2018] for the creation of BIM of an existing building subjected to retrofitting and use their terminology.

Suggested process
BIM documentation does not normally exist neither is the update of the building information and performance. Therefore, it is believed that *BIMification* is a prerequisite for a BIM-based energy support process for retrofitting.

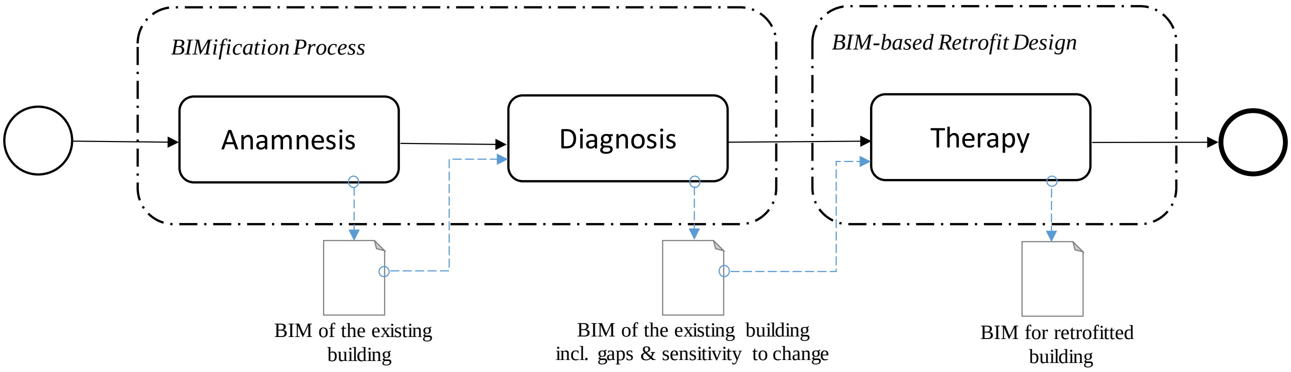


Figure 5 Proposed 3-stage method adapted from [Scherer, et al., 2018]

The suggested BIMification approach is composed of three main stages (Anamnesis, Diagnosis and Therapy) as shown in Fig. 5. The first two stages (Anamnesis and Diagnosis) can be categorized as *BIMification Process*, third one (Therapy) as *BIM-based retrofitting design*.

In the first two stages, **Anamnesis**, is dedicated to the survey and collection of facts about the building, while **Diagnosis**, is dedicated to the analysis and interpretation of the collected data to obtain the necessary understanding of the building and its performance.

The Anamnesis stage can be detailed in two groups as shown in Fig.6: (1) ***basic BIMification*** (composed of three tasks: Geometrical BIMification, Topological BIMification and Neighbourhood BIMification), and (2) ***advanced BIMification*** (composed of two tasks: Element BIMification and Behaviour BIMification).

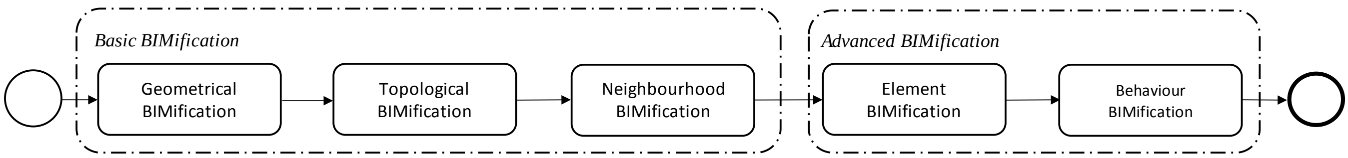


Figure 6 Structure of the Anamnesis stage adapted from [Scherer, et al., 2018]

Basic BIMification three tasks are:
- **Geometrical BIMification**, is the pure geometric model which is extracted from observations of the existing building and is described by objects according to the geometrical criteria.
- **Topological BIMification**, is the first simple topological model representing the adjacency of spaces and zones and their usage.
- **Neighbourhood BIMification**, is the relevant neighbourhood geometry model, which includes some infrastructure information.

In the above, survey of the building and neighbourhood can provide data that can be integrated with thermal and permeability observation data. Different methods and devices for the achievement of this were developed in recent years, especially related to surface and volume reconstruction from photogrammetric images and laser-scan point clouds as was explained in the previous sections.

Currently, there exist already commercial softwares, which can provide such basic BIMification services but could still be limited to specific data models. One of the early ones in this domain is TrueCADD (www.truecadd.com), which offers point cloud 3D modelling from 3D laser scanning, surface recognition from the point cloud data, and creating Revit geometry from that data, thereby covering quite well geometrical, topological and environmental modelling.

The **Advanced BIMification** tasks are **Element BIMification** and **Behaviour BIMification**:
Element BIMification, is the structuring of the geometrical model in correctly assembled building elements expressed in IFC and modelling the building as built, where former construction knowledge templates can be integrated. It leads to a full topological model on element level complementing the topological space model from the topological BIMification task.

Semantic enrichment of the identified building elements based on a BIM ontology is necessary in order to establish a reliable building information model that can be used in the further steps.

Element BIMification includes (Fig. 7):

- **Proxy Mapping** of the objects to appropriate instances of IFC building element subclasses (such as IfcWall, IfcSlab, IfcRoof, IfcWindow etc.) via annotation using class level (TBox) ontology queries and rules.
- **Mapping** the generated modelling instances to a reduced ontology representation, e.g. with the help of IfcOWL tool.
- **Checking** the resultant ontology model by applying rule-based checking rules for corrections.
- **Applying appropriate knowledge templates** in order to fill in any missing technical information.

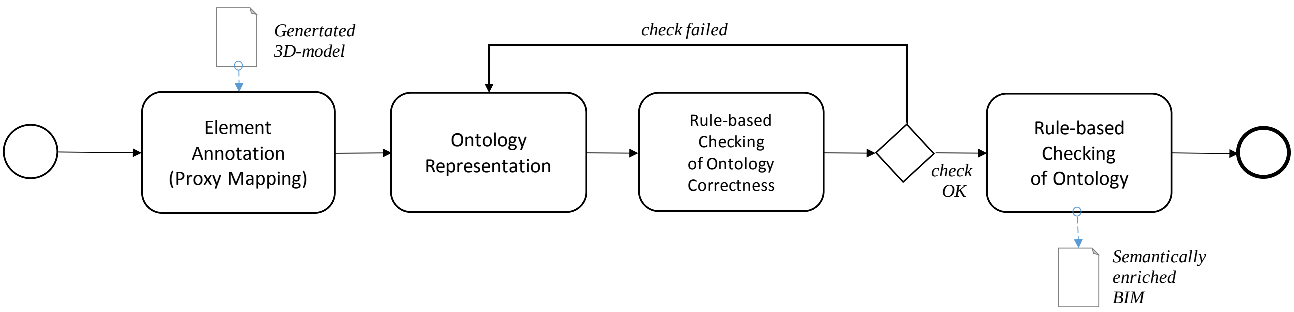


Figure 7 Subtasks of the element BIMification adapted from [Scherer, et al., 2018]

Behaviour BIMification, is the semantic enrichment of the building elements with additional technical information about the behaviour of the elements (heat and moisture transfer properties, structural strength etc.), which leads to IFC elements enriched with performance information.

Acquiring additional behavioural information about the building elements is normally not a simple job that may need different types of expertise and tools, especially when only minimal interventions and non-destructive material identification methods are applied. Therefore, the authors suggest limiting this to an energy model with low level of details, which can be well appropriate for a single-zone. The thermal model performance can be compared with measured data, and thus the model can be adjusted to the actual behaviour using a sensitivity-analysis. The investigated behavioural parameters can include:

- Thermal properties of the construction materials (e.g. heat capacity and thermal conductivity)
- Thermal properties of windows (e.g. U-value and the solar heat gain coefficient)
- Properties of massive constructions of walls, slabs, roofs, floors, etc. (e.g. insulation thickness, density and porosity)
- Usage-profile and time-schedule of the appliances, equipment, lighting, etc., and their associated heat emissions.

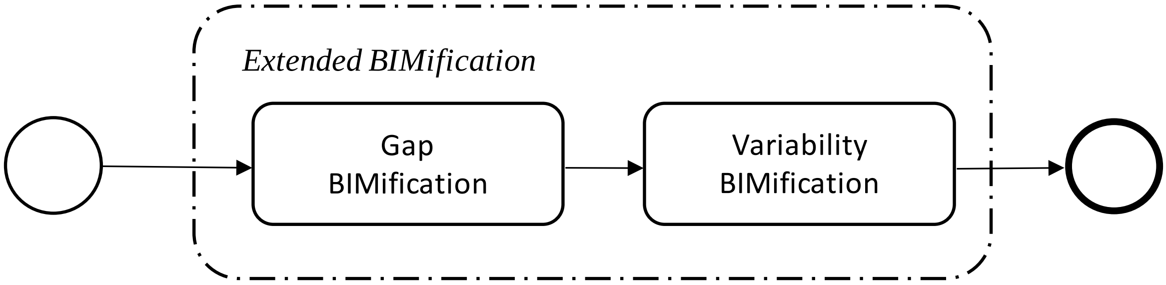


Figure 8 Structuring of the diagnosis stage adapted from [Scherer, et al., 2018]

Diagnosis stage

Diagnosis stage is an **extended BIMification** and is composed of two tasks (Fig. 8):

- **Gap BIMification**, aims to diagnose main problems in the building construction or HVAC system that should first draw the designer's attention. Examples of the problems that have to be examined are moisture problems, material deterioration, leaks in the HVAC system, window frame conditions and structural weakness.

- **Variability BIMification**, aims to find the sensitivity of the building elements and HVAC system components to assumed variations in the operating conditions and element properties in order to identify early renovation procedures for the energy performance improvement. This is done by combining the created BIM model of the building under renovation, the data obtained in the anamnesis step and the guidance got from the gap analysis in addition to the selection of different types of new building materials, technical system components and added energy technologies. Iterative methods can be used to test different possible combinations. This can be conducted by sensitivity analysis, including using energy simulation tools but can also extend to include life cycle LCA/LCC calculations as well as assessment of the indoor air comfort.

The **Therapy stage** is performed after the Diagnosis stage. The Therapy stage includes the actual retrofitting design using the rich and fully developed BIM model supported by identified renovation procedures and energy simulation tool to predict the improved energy performance, in addition to other life-cycle targets.

Application of knowledge templates can make the Diagnosis and the Therapy processes faster and more efficient. This is done by filling-in missing information retrieved from knowledge module that contains stored information on best practice examples for fast detailing of the existing building and the planned retrofitting actions.

3.3.4 Interoperability problems

Despite the presented knowledge about the combination of the BIM models with building’s energy simulation tools, several interoperability problems have been identified that can limit the application. In this subsection, the main problems identified by Sanhudo et al. 2018 are indicated:

- Location and weather data
  Simulations tools are reported to be incapable of acquiring the weather data despite that they are stored in the BIM tools.

- Geometry
  Several geometrical data transferring problems were reported that were mostly related to improper transferring of spaces and thermal zones boundaries, which produced duplicate, overlapping and/or missing objects. Examples of these problems are the inaccurate definition of walls centrelines, incorrect calculations of space volumes due to existence of false floors/suspended ceilings and undefined space boundaries due to complicated geometries.

- Material properties
  Data schemes may contain very detailed information regarding material properties. However, it is very possible that such data cannot be properly accessed by the BIM or simulations tools because the tools lack the means to import/export these properties. Example are cases where the solar and infrared absorptivity parameters stored in data schemes are missing in some BIM tools, despite being required by energy analysis software. In another case, manual interventions were required to introduce the material properties because the IFC and gbXML schemes were not able to export the data of thermal conductivity, density and specific heat capacity.

- Building technical systems
  Most simulation tools display limited interoperability regarding HVAC system components data. This problem is increasingly important due to the importance of such components and the lack of solutions in the IFC format (IFC4) according to [Gourlis et al., 2017].

- Building operation
  In many cases, the software tool may fail to acquire the operation data (such as building usage, devices operating schedules, internal load profiles, etc.) from the data schemes. Accordingly, it may be reset to its default setting values or ask for manual inputs.

4 BIM Assisted Scenario Simulator (and applying it to retrofitting)

The BIM Assisted Scenario Simulator will be a tool, which supports the **concept of performance based building design** in the early design phases, where the most important decisions are made related to the costs and performance. This tool development assumes that the design team has higher level performance targets available for the building to be renovated. These targets are called Owners Project Requirements (OPR's), which include for example project and design goals, measurable performance criteria, cost targets, etc. The performance based building design process assumes that design selections are validated against the OPR's in each design stage before moving to a following design stage. In addition of the OPR's, this development assumes that the planning is always made according to the local laws and building requlations.

The OPR's related to the energy and indoor climate will be simulated with the tool to be developed. The design team will handle the detailed technical selections affecting to the OPR's using the BIM Assisted Scenario Simulator. The management of the consistency of the detailed technical parameters (*see the simple example in the next paragraph below*) against the OPR's has traditionally been handled mainly manually between design domains resulting to the possible design errors or time consuming updates, whenever the technical detail has changed. Furthermore, the many of the technical details are most likely inter-linked to each other or can even be contradictionary, which makes the building energy design a challenging task. The BIM Assisted Scenario Simulator will tackle the complexity of the energy and indoor climate design by

(1) speeding up the decision making
(2) enhancing the collaboration between the design domains
(3) enabling the cross domain transparency of the technical details in the design team
(4) resulting better indoor climate and energy selections in the renovation.

A simple example of the higher level OPR-target is a **specific heating energy consumption target** (kWh/m²,a), which is affected by the detailed technical parameters like:

- Floor area of the building
- U-values of the walls, windows, ground floor and roof
- materials of the structures (dynamics and heat gain utilisation)
- indoor setpoint during winter (also a part of OPR's)
- visual environment (also can be a part of OPR's), indoor space colouring and the lighting system (=heat load)
- CO_2-levels in the space (also can be a part of OPR's)
- ventilation heat recovery
- number of occupants and their user profiles
- g-value of the window glazing (solar gain)
- solar shadings
- reflectance of the neighbouring buildings
- orientation of the roofs (renewable heating energy production)
- air tightness of the envelope (infiltration)
- hot water system (tap technology, shower heads, heat recovery technology, possible solar system)
- location and insulation of the heat distribution system components
- boiler efficiency by load levels

More detailed description of the data model derived from the content of the Chapter 3 and Chapter 4.1 related to the technical parameters is presented in the Appendix II.

4.1 Use case(s) of the BIM assisted energy scenario simulator

This chapter will contain a typical usage story and the derived use cases for the BIM assisted energy scenario simulator. In addition, the tool development and the workflow descriptions act as a practical requirement analysis framework for the detailed data definition (in chapter 5) of the BIM Management system and help to understand which kind of information should be available in the different renovation design phases. The main questions are:

- Who are the users of the tool and which phases of the design the tool will be used?
- What are the questions that the design team will solve, when using this tool?
- What kind of simulation time performance is expected? 5 min per case?

The intended scenario simulator tool will be used several times during the design process as the design evolves. The intended usage is **collaborative** (=during the design team meetings) and as automated as possible to minimise the need of labour. In addition, the results should be available in an hour, so that decision making can be done in one design meeting. This will ease and speed up the decision-making. The user of the tool will be a professional role called "*Energy expert*", who can be a separate consultant or any member of the design team with energy expertise designer e.g. architect or building services engineer. The general overview of the scenario simulator tool is presented in the Figure 9.

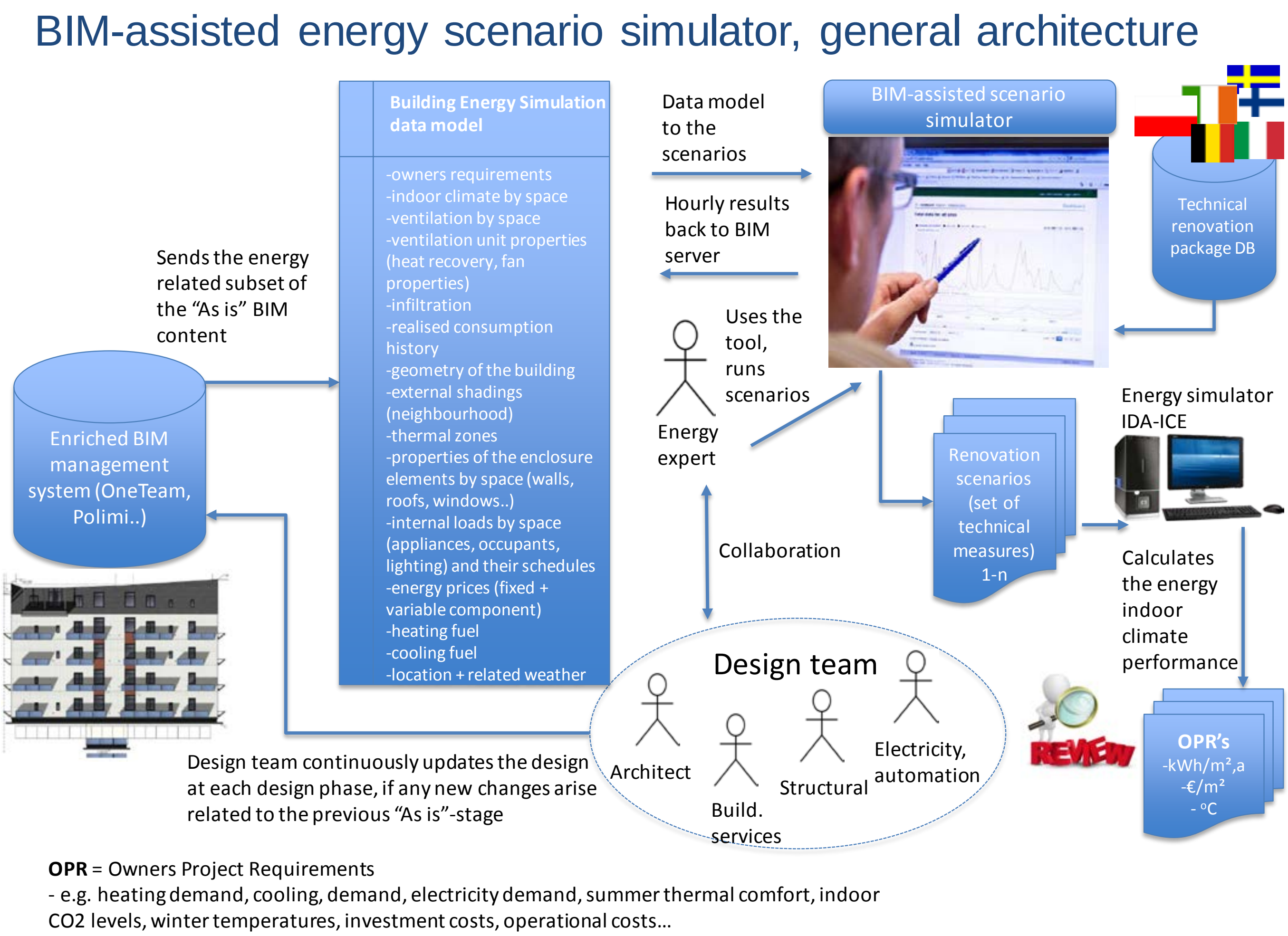


Figure 9 The general overview of the BIM-assisted energy scenario simulator

The targeted design phases are: (1) *Concept design* and (2) *Preliminary Design*, where the sophisticated building simulation will create the best value giving an opportunity to balance the value of good indoor climate conditions and the energy consumption. These phases bind the largest share of the foreseen construction costs of the renovation project.

> ***The assumption behind the collaborative design work is that the latest information is available in the BIM Management server. Each of the design domains have access to the latest design model of the building. The BIM Management system will be capable of compiling the energy related subset of the latest building data to the energy simulation purposes.***

The main functionalities of the tool are:

- To build a representative **"As-is"** energy and indoor climate model of the building using Building Energy Simulation data model, which is a subset of the content in the enriched BIM
- To apply the **renovation scenarios**, which is set (1-n) of technical packages containing localized (by country) renovation measures and their technical details
- To present the **impact** of each renovation scenario in terms of **Owners Project Requirements** (OPR) related to the energy and indoor climate to support the decision making of the design team

The tool will be connected to the BIM Management system to be able to request the **"As-is"-stage** of the building to be renovated (the energy and indoor climate related subset of the building BIM data). This energy related data set is called a "Building energy simulation data model", which contains the relevant and cleaned building parameters from the energy and indoor climate point of view. This cleaning process called "Bimification" has been discussed more detailed in the chapter 3.3.3.

There will be one main language version in English and BIM4EEB-partners will each translate their national vocabulary. The tool itself will not contain a building energy solver, but it will use the commercial tool IDA-ICE as a backend system to solve the thermodynamics. The IDA-ICE tool solves the energy demand of the building services according to the indoor climate (temperatures, CO2-levels, Fanger indices, relative humidity, air age). The simulations can be done at the space by space level, which enables the summer thermal comfort calculations. IDA-ICE has some modelling capabilities for the daylighting, but the model is approximate compared to the domain specific lighting simulation tools. In addition, the acoustics and detailed CFD air flow simulation inside the space is missing in IDA-ICE, so draft and noise modelling should be done with other tools.

4.1.1 The usage story of the energy scenario simulator

This chapter gives an overview of the expected workflow in the phase of concept design, when the design team uses the scenario simulator tool. The usage story presents the collaboration of the design team, some examples of detailed renovation measures and the final review in the context of a Finnish apartment building renovation planning session. This story will create the basis for the use case definition. The story assumes that the fast mapping has produced the BIM-model of the existing building to be renovated.

The story begins:

The *design team* (architect, building services, structural, electrical) is expected to propose a set of renovation measures for the owner in the concept phase for an apartment building in Finland. The owner has indicated as the Owners Project Requirements (OPR) that the direct **payback time** of the investments should be **less than 30 years** and the budgeted **maximum amount of investment is 300 €/floor m²**. In addition, the **energy efficiency** of the renovated building should be **30% better** after the renovation and the indoor environment is according to the Finnish Indoor climate guideline class S2.

The building properties (*this is a fictitious one, the WP8 pilot buildings should be used as early as possible*) is as followed:

- Apartment building 2000 floor-m², built on 1972, located in Helsinki, Southern Finland (Figure 10)
- 50 residents in 28 apartments, 8 floors
- Heating system: Connected to the district heating, radiator network
- Mechanical exhaust ventilation, no heat recovery
- Outdated envelope: prefabricated concrete elements original from 1972, wooden windows (2-glazing), roof is ok, no leaks, but the end of the technical life time is approaching in 2 years
- Indoor climate: unbalanced (20-25 °C) indoor temperature in apartments during winter
- Historical heating consumption is 182 kWh/m² per a,
- Historical electricity consumption (apartments + facility) is 45 kWh/m² per a.

Figure 10 The Finnish apartment building to be renovated in the IDA-ICE building energy simulator (left) and in Google Maps (right). The building is a typical sub urban building from the 1970's.

The design team asks the *energy expert* to check the renovation opportunities using the *"BIM-assisted energy scenario simulator-tool"*. The team checks the BIM Management server and notices that the latest version of the **"fast mapped"** building model delivered by the fast mapping consultant RISE is in the BIM management system. The *Architect* confirmed that digital geometry is valid and it has already been checked against the existing building manual documentation and drawings. The surroundings and the neighbourhood are not modelled yet, so the shading of the neighbouring buildings have to be checked in the next design phase, the preliminary design.

The current version in the BIM-server is a **simplified box**-like model with all outer envelope elements, so it doesn't contain the detailed inner space lay-out yet. The *design team* agrees that this is sufficient in the phase of concept design. The energy model is fetched from the server and the tool asks few questions like the country to automatically use the localized database of technical renovation packages.

The *energy expert* calibrates the model by running a few simulations, so that the **"As-is"** consumption is close to the historical consumption to get the representative baseline for the scenarios. The main parameters in the calibration process are the infiltration and the ventilation details of the building. Also some adjustments might be needed in the user profiles e.g. hot water demand and electricity. This takes a few minutes. During the calibration, the *design team* familiarises themselves by reading the building condition survey documentation, where the expected renovation items are listed by the third party consultant.

The *design team* begins to apply the renovation scenarios using the approach "*energy efficiency and indoor climate first*", so that the **low heating and cooling demand** and the maximised **occupant comfort** defined in OPR's come first in the priority order and after that the possible energy production solutions.

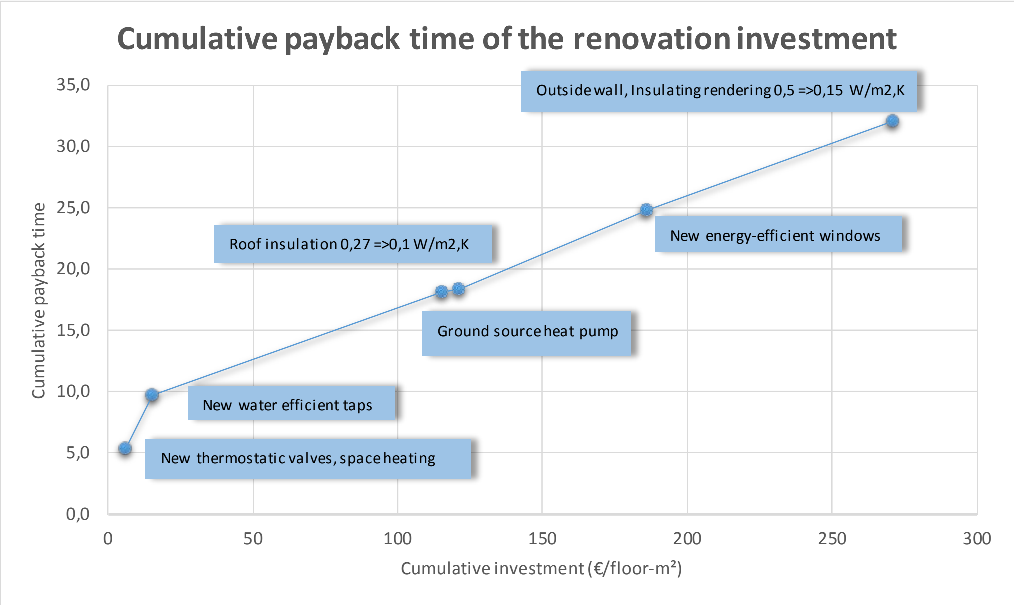
- The *architect* suggests a prefabricated concrete envelope to over clad the old facade. The *energy expert* applies the envelope package from the Finnish default database containing the upper floor insulation, outside wall and windows to be renovated. The *structural designer* suggests that the outer layer of the old prefabricated element walls and the old insulation should be removed to guarantee the risk-free load bearing structure. The envelope package contained an energy efficient insulation rendering for walls (U-value 0,15 W/m2,K), which was selected. The *architect* suggests highly efficient cold climate triple-glazing (U=0,75 W/m2,K) to minimise the draft problems during winter. This glazing type was also included in the envelope package. The glazing package contained also optimised g-value 0.38 for the solar protection to guarantee the pleasant thermal comfort during summer.
- The *building service engineer* suggests to tackle first the unbalanced winter indoor temperature issue with new thermostatic valves for indoor temperature control. Also, new water efficient taps for showers are suggested and finally the replacement of the old district heating to the ecological ground source heat pump. These measures are applied to the model.

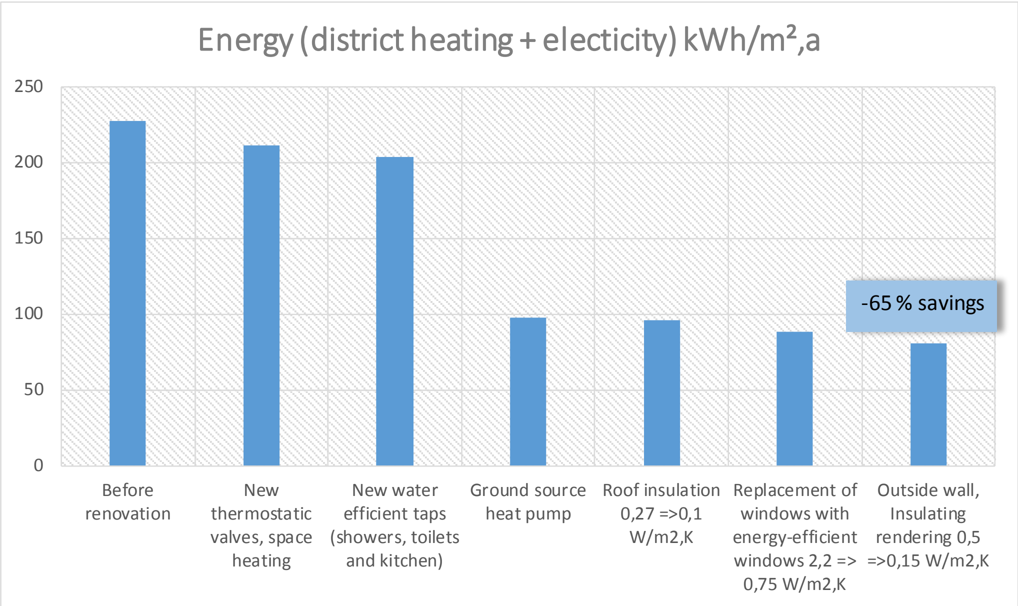
The *energy expert* suggests a little coffee break for the time that the tool simulates the cases and compiles the results. After the 20 min break, the simulations are ready and the design team begins to review the results.

The *design team* starts the review. The tool sorts the renovation measures of the scenario in the order of "most profitable first". The *design team* reviews the simulation results and notices that the maximum amount of investment (**300 €/floor-m²**) has not been exceeded and the energy efficiency is much better than requested - **up to 65%** and as a bonus the **CO2-emissions have decreased 80%**.

Unfortunately, the overall payback time of the selected packages is **32 a**, so little over the 30 a threshold set by the owner. The indoor climate conditions during winter were balanced and ok, but the summer thermal comfort will need more attention. The examples of the possible illustrations of the owners project requirements (OPRs) are presented in Figure 11.

The design team decides to suggest the first five measures and prepares to present also the 6th one to the owner as a basis for the discussion, because the renovation of the worn outside walls would bring new value and better aesthetics for the occupants and for the urban environment.





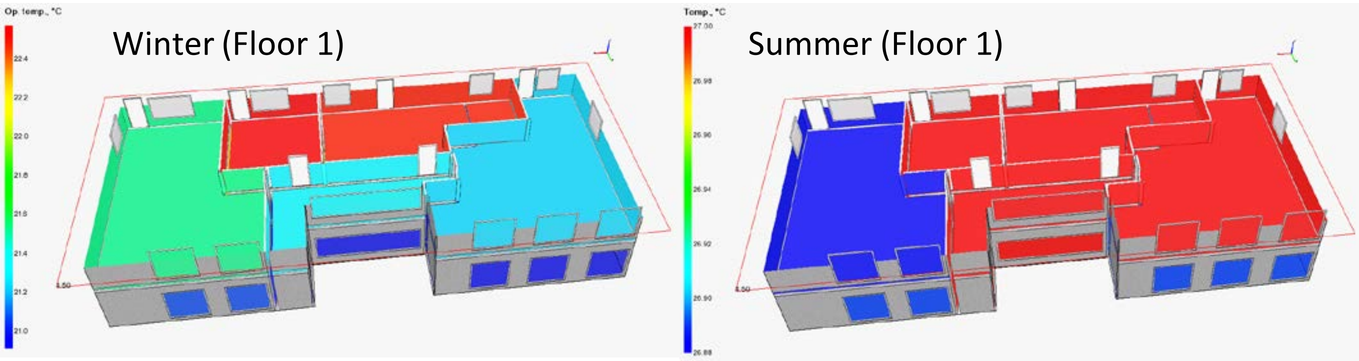


Figure 11 The examples of illustrations of the Owner Project Requirements in the scenario simulator tool.

4.1.2 UC1: Create the "As-is" energy and indoor climate simulation model

ID:	UC1: Create the "As-is" energy and indoor climate simulation model
Title:	Initiation of the "As-is" baseline building energy model for the renovation scenario purposes
Description:	The actor builds the first version of the energy simulation model and compares the result to the historical consumption data. The target is to find a "As-is"-parameters for the energy simulation to make the energy scenarios. The "As-is"-parameters create a representative digital energy model of the building to be renovated. The calibrated energy model forms a solid bases for the future renovation scenarios.
Primary Actor:	Energy expert, design team
Preconditions:	1. Owners Project Requirements (OPR's) available 2. Fast mapping of the renovated building done 3. Fast mapped building data compiled to the energy model in the BIM Management server 4. Historical energy consumptions of the building available, historical indoor climate conditions 5. BIM Management server connection available
Postconditions:	1. "As-is" calibrated building ready for the energy scenarios 2. The simulated "As-is" energy consumption inline with the historical consumption 3. "Building energy simulation data" updated to the BIM Management server
Main Success Scenario:	1. Open the BIM Assisted energy scenario simulator -tool 2. Confirm country and location of the case building 3. The energy expert gets the "Building energy simulation data" for the renovated building from the BIM Management server 4. Cross-check the building geometry in collaboration with the architect (main parameters: total volume, total floor area, orientation, dimensions of the building, areas of the envelope components) 5. Run the first energy simulation and compare the results of the historical consumptions to the simulated ones 6. Fine tune energy related input parameters (indoor temperature, ventilation, infiltration, U-values, number of occupants), if needed to set the simulated consumption inline with the historical energy consumption 7. Update the "As-is" modifications back to the BIM Management server in the form of "Building energy simulation data" 8. Close the BIM Assisted energy scenario simulator -tool
Extensions:	Item 4: In case of the need for the building geometry editing, let architect update the fast mapped building model in the BIM Management server and start from item 3 again
Frequency of Use:	1-3 times during the design process
Status:	Draft
Priority:	Normal

4.1.3 UC2: Apply scenario to the building to be renovated

ID:	UC2: Apply scenario to the building to be renovated
Title:	Creating a set of renovation scenarios composed of the technical measures that fulfill the targetted OPR's (i.e. energy efficiency, costs, payback time and indoor climate)
Description:	The design team applies the renovation scenario(s), which is a set (1-n) of technical packages containing localized (by country) renovation measures and their technical details and costs. The energy expert as a user builds the scenario(s) in collaboration with the design team. The collaborative design workflow consists of finding the renovation measures that enable the targetted energy efficiency level with the help of the BIM assisted energy scenario simulator. The target is to find a set of available design alternatives for the owner review that are inline with the energy related OPR's.
Primary Actor:	Energy expert, design team
Preconditions:	1. Owners Project Requirements (OPR's) available 2. "As-is"-building handled, calibrated and available 3. Techical renovation package database contains suitable set of measures related to the building in concern 4. BIM Management server connection available 5. Building condition survey documentation available 6. Optional: Building energy audit documentation available
Postconditions:	1. The renovation scenarios defined and simulated
Main Success Scenario:	1. The energy expert opens the BIM Assisted energy scenario simulator -tool and selects the suitable "As-is"-building for the basis of the scenarios 2. Collaborate with the design team (architect, building services, structure, electricity) • Check the Building condition survey documentation • Check the Owners Project Requirements (OPR's) • Pick a suitable set of techical renovation measures from the national database that satisfy the renovation need defined in the building condition survey 3. Combine the renovation measure to form a scenario 4. Run the energy simulations 5. Save the scenarios 6. Close the BIM Assisted energy scenario simulator -tool
Extensions:	Item 3: Continue to item 2, if more scenarios are needed
Frequency of Use:	2-5 times during the design process
Status:	Draft
Priority:	Normal

4.1.4 UC3: Review Owners Project Requirements

ID:	UC3: Review Owners Project Requirements
Title:	The renovation scenario review by the design team
Description:	The design team reviews the scenario results in terms of the Owners Project Requirements (OPR) related to the financial targets, energy targets and indoor climate targets and makes the decisions needed. The target is to find a set of available design alternatives for the owner review that are inline with the energy related OPR.
Primary Actor:	Energy expert, design team
Preconditions:	1. Owners Project Requirements (OPR's) available 2. Scenarios simulated 3. BIM Management server connection available
Postconditions:	1. Set of available design alternatives to be proposed for the owner that are inline with the energy related OPR.
Main Success Scenario:	1. The energy expert opens the BIM Assisted energy scenario simulator -tool and selects the suitable “As-is”-building with simulated scenarios 2. Select the building from the list and open the review view 3. Collaborate with the design team (architect, building services, structure, electricity) • Check the Owners Project Requirements (OPR's) • Compare the scenario simulation results to the OPR's • Choose and conclude the suitable number (1-3) of renovation alternatives, delete the unnecessary ones 4. Close the BIM Assisted energy scenario simulator -tool
Extensions:	Item 3: Go to UC2, if the design team notices that a scenario is missing or OPR's are not fulfilled
Frequency of Use:	2-5 times during the design process
Status:	Draft
Priority:	Normal

4.1.5 UC4: Update the "As-is" stage from the BIM management system

ID:	UC4: Update the "As-is" stage from the BIM management system
Title:	Updating of the previous "As-is" calibrated building energy model with newer one
Description:	In case of any changes to the original/previous "As-is"-model, the user can fetch the updated version of the "As-is"-stage from the BIM management system to be re-simulated and to be reviewed against the previous scenarios. The target is to check the energy scenarios, when better and newer knowledge of the building has arisen during the design process.
Primary Actor:	Energy expert, design team
Preconditions:	1. Owners Project Requirements (OPR's) available 2. Newer "Building energy simulation data" -model in the BIM Management server available 3. BIM Management server connection available
Postconditions:	1. The updated "As-is" calibrated building ready for the energy scenarios 2. The simulated "As-is" energy consumption inline with the historical consumption 3. The "Building energy simulation data" (Appendix II) data updated to the BIM Management server
Main Success Scenario:	1. The energy expert opens the BIM Assisted energy scenario simulator -tool and selects the existing "As-is"-building with simulated scenarios 2. The energy expert gets the updated version "Building energy simulation data" for the renovated building from the BIM Management server 3. Run the energy simulation and compare the results to the previous version of the "As-is"-building 4. Calibrate the energy related input parameters (indoor temperature, ventilation, infiltration, U-values, number of occupants), if needed to set the simulated consumption inline with the previous version and historical consumption 5. Update the new version of the "As-is" modifications back to the BIM Management server in the form of "Building energy simulation data" 6. Close the BIM Assisted energy scenario simulator -tool
Extensions:	Item 5: Continue to UC2 and UC3 to check that the OPR's are still fulfilled
Frequency of Use:	1-2 times during the design process
Status:	Draft
Priority:	Normal

5 Requirements for Enriched BIM Management system

The usage story and the related use cases of the Energy Scenario Simulator tool in Chapter 4 have been used as a tool for the higher-level requirement setting of the BIM Management system to be developed. The generalised findings of the definition work are summarised in the Table 21. The most important findings are in general: (1) the time saving, (2) better collaboration of the design team enabling the better quality design and (3) the better indoor climate and energy selections.

Table 21. The needs of the design team for the BIM Management system derived from the Energy Scenario simulator use cases and usage story

Designers need	Requirement	Example	Targeted function
Minimise the manual data mapping	Support for the iterative design and construction process, no waterfall approach	-"As-is" stage of the building to be renovated changes during the process. The amount of information varies between the design stages and new knowledge will arise during the design	Better collaboration between design domains, up-to-date BIM models always available
The content of the Building Energy Simulation data needs to be compiled from various levels of details and quality	Ability to create an export of the Building Energy Simulation data, which is an energy related simplified subset of the building derived from the Enriched BIM management system	-Outside walls in the concept phase modeled as facades per orientation. The detailed design contains the prefabricated elements made by the structural designer	Automated BIM object compiling with various levels of details. Designer has access to the latest up-to date data.
Possibility to mark building objects, if they are renovated or not	Support for the "tagging" of the individual BIM-objects in "As-is"-BIM and in design models	-Renovation measures will be applied to all BIM-objects in the scenario tool. In real world case some instance of walls or windows can't be renovated, so it should be tagged as "Do not apply the renovation measure"	Automated applying of renovation scenarios in scenario simulator tool
Easy reviewing of the results and impact of the design solutions	Support for the linking of the individual BIM-objects to technical details behind the OPR's in design models	-Indoor temperature simulation results linked to the zone, floor	Ease the compiling of the OPR's by BIM object Transparency of the technical details related to the OPR's
Data quality of the fast mapped BIM (inventory) has to be good to speed up the designers work	Support for the automated "fast mapped inventory BIM" checks in the BIM Management server	-no missing or overlapping building components like walls -no duplicates	The modeling work of the architect can be decreased considerably
Seamless multi domain design work of the design team	Automated engineering domain model updates itself from the architectural model and vice versa, support of the various levels of technical details	-The indoor environment design can utilize modelling tools like (1) space air flow modelling in CFD, (2) space lighting level simulators, (3) energy simulations, (4) carbon footprint and LCA simulations, (5) thermal comfort simulations, (6) indoor air quality simulations (6) acoustics simulations etc. -space reservations of the building installations	Time saving, fewer design errors, no manual data mapping
Easy linking of the external information to the design model	Support for the BIM object linking to the external data sources	-Heat pump product data from the manufacturers catalog in the internet -Historical energy consumption in the utility registers	Enriched BIM
The different levels and resolutions of the design data need to be handled easily	Ability to tag objects and variables by priority or other data quality level information	-mandatory / not mandatory -defaulted / product data -design phase	Enriched BIM

The enriched BIM that should be available from the BIM management system to enable the energy performance assessment should contain the information in the chapter 3.1.4 Impact of the input data on the results of BES.

An example of a detailed list of variables used in an IDA-ICE model is presented in Appendix I. The detailed list of variables and parameters vary a lot depending on a building type and technical building systems that exist in the building. A model of smart and over-engineered office building will need much more information than simple one-family-house with natural building systems. More detailed description of the data model derived from the content of the Chapter 3 and Chapter 4.1 related to the technical parameters of the Buiding Energy Simulation data model is presented in the Appendix II.

While not all the information is available in the early phases of the project, there is a possibility to use national databases of typical structures. In this project these could be linked directly to the building management system or two could be utilised as part of the scenario tool. Such databases could be e.g. national energy performance certificate registers, EPB standard annexes, EU building stock observatory or European projects such as iBroad and Tabula. In addition, default values in the building energy simulation software could be used as national databases.

As important as the amount of information, is also the quality and governance of the information. There must be a clear data management plan to make sure that data quality parameters such as data accessibility, data consistency, data currency, data granularity, data precision, data accuracy, data comprehensiveness, data definition, data relevancy and data timeliness, are always managed properly. On the other hand the governance and ownership of the data is required to make sure that each piece of information has an owner that can give the consent to use the data in different situations.

Tools developed in work package 3 will help in maintaining the data quality and governance. When the data is handled as part of an appropriate data model instead of single data points, both functions are much easier to implement. The concept of linked data will also help keeping the data up-to-date. Not all the data needs to be stored in a centralised database, but it can also reside in the original database and linked from there to the BIM management system.

6 Conclusions

The full automation of the process proposed for BIM-based energy retrofitting can be briefed in the following steps [Sanhudoa et al., 2018]:

- Data acquisition, which is composed of *Geometrical data* and *Energy-related data*. In the former, two methods are shown to be most favourable: laser scanning and photogrammetry, which have clear advantages and also potential for development in the technology. The Energy data is supported by different energy performance tests, e.g. co-heating tests, Thermography, blower door test, etc.), as was outlined by Table 19.
- Creation of building modelling, when sufficient data is complete, where the aim is to implement automatic BIM modelling based on the data acquired in the previous step.
- Interoperability check for the quality of the IFC model imported from the BIM, which may need to return to the previous step for more accurate data if such data is missing.
- Building energy analysis, which starts by checking the completeness of the data imported from the interoperability step for performing the energy simulation. After that, it is to execute the simulations for different retrofitting design options. The simulation results are then subjected to analysis, which may need to re-do the simulations using modified designs when the original ones are not found satisfactory. The process ends by selecting the best solutions with the respect to the set targets of e.g. energy, CO_2 emissions, comfort and cost.

The aim of the above-mentioned framework is a fast, accurate and knowledgeable decision-making process to identify best solutions to apply in energy retrofitting based on the entire process of data acquisition, transfer, processing and analysis.

Getting the energy performance assessed as early as possible has a great effect on its impact. Early knowledge will help in making right decisions to comply with the owners project requirements that could be e.g. low investment cost or maximised indoor environment quality and support for occupant productivity. Late decisions and changes are difficult in the construction process. Since most of the costs are committed in the beginning, late changes will mean high additional costs for the project. Therefore late energy performance assessments often get only a noticing role. They may find problems in the design, but chances are already too expensive and cannot be done. Figure 12 illustrates the situation.

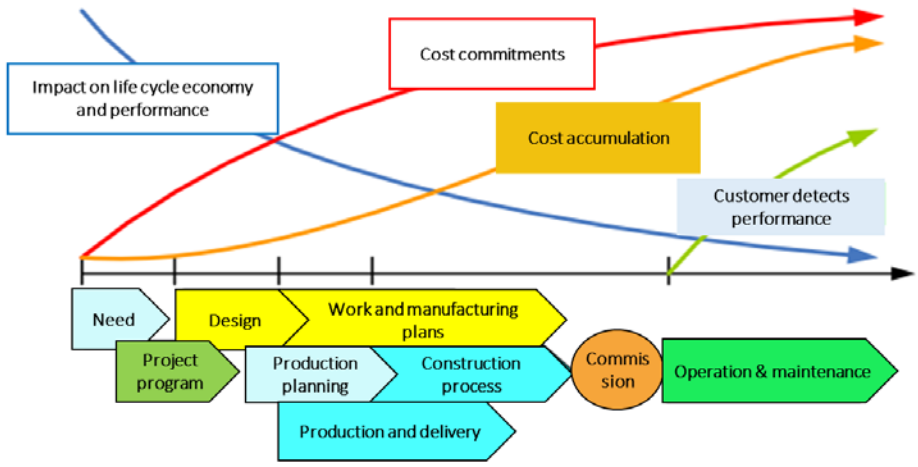


Figure 12 Committed costs and possibilities to affect on energy performance. Adapted from [Pietiläinen et al. 2007]

Despite the progress achieved in building energy simulation tools, much of the potential in their interoperability with BIM tools remains largely to be explored and developed. Several interoperability constraints can be faced in the integration of energy simulation tools within a BIM workflow as was identified in this report. More work is needed for overcoming the existing limitations of data interoperability and automatic as-is modelling.

Recently, Scherer et al. 2018 proposed a new approach (BIMification method) for the creation and use of rich-BIM in retrofitting of buildings, which is still in early stages of implementation. The benefit of the methodology is in putting all steps together in a consistent overall process, providing for an interoperable BIM for energy retrofitting of buildings. According to the authors , there are no results of the implementation of the full process but several methods partially supporting the realization of the BIMification method have been developed, e.g. within the ISES project (Intelligent Services for Energy-Efficient Design and Life Cycle Simulation) and eeEmbedded project (Collaborative Holistic Design Laboratory and Methodology for Energy-Efficient Embedded Buildings http://eeembedded.eu/). This refers to the semi-automated identification of the building façade, various BIM querying and filtering methods and use of knowledge templates to compensate the lack of actual data.

By enabling well-structured BIM creation, it is believed that BIM can highly facilitate energy-based decision making for retrofitting of buildings, which is expected to bring significant benefits for the building system identification and efficient energy retrofitting process.

The BIM Assisted Scenario Simulator tool was presented and the workflow of it's use was defined. The most important finding related to the renovation process was the importance of the **need for the performance based building design** in the early design phases, where the most important decisions are made related to the costs and performance. The tool to be developed creates an excellent approch to define the requirements of the BIM Management server to be developed. The exhaustive data definitions related to the commercial energy simulation tool IDA-ICE (in Appendix 1) open a landscape of huge set of details to be defined. This huge set (+ 1000 parameters) can be narrowed according to the findings in chapter 3, which lists the most important input variables related to the impact on the indoor climate and energy. This narrowed list (< 100 parameters in Appendix II) will create the basis of the interoperability data model between the BIM Management server and the BIM Assisted Scenario Simulator. Other parameters can be defaulted according to the tool defaults. This narrowed parameter list has to be understood as a living document at the moment of writing, because the **fast mapping** tool development in WP5 might ease the parameter collection of a renovated building to a new level, where nowadays hard to find parameters has to be defaulted, but in the future they are easy to collect.

The second finding of the BIM Assisted Scenario Simulator tool definition was the **need for the enhanced collaborative design work.** The indoor climate and energy design is a multi-domain challenge and it should always be considered as a team work and all tools around the future building renovation design should comply and support this approach. The performance based building design process assumes that design selections are validated against the **Owners Project Requirements (OPR's)** in each design stage before moving to a following design stage. The design team will handle the detailed technical selections affecting to the OPR's using the tool. The management of the consistency of the detailed technical parameters against the OPR's has traditionally been handled manually between design domains resulting to the design errors or time consuming updates, whenever the technical detail has changed. The BIM Assisted Scenario Simulator will tackle the complexity of the energy and indoor climate design by

(1) speeding up the decision making
(2) enhancing the collaboration between the design domains
(3) enabling the cross domain transparency of the technical details in the design team
(4) resulting better indoor climate and energy selections in the renovation.

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8 Appendix I

A sample list of parameters that are required from the BIM management system to perform an energy performance simulation. Some of the higher hierarchy level rows have been excluded. The complete list is available from the authors.

Table A1 Legend for the table A2

H	Hierarchy level in the variable list
I.ve	Initiative phase
I.on	Initiation phase
CoD	Concept design phase
PrD	Preliminary design phase
DvD	Developed design phase
DtD	Detailed design phase
Con	Construction
Use	Building use
EoL	End of Life
NR	Not required. The parameter is internal information in IDA-ICE and there is no need to share outside the program.
I	Informal. Internal information in energy performance simulation, but it sharing it gives information that may be beneficial to others.
L1	Level 1. Required information in the phase. First estimate that might not be based on measurements or drawings.
L2	Level 2. Required information in the phase. Values based on existing drawings or measurements. Simplifications allowed.
L3	Level 3. Required information in the phase. Verified values based on existing drawings or measurements. Only minor simplifications.
L4	Level 4. Required information in the phase. Accurate digital twin that can be trusted in all the design tasks in the process.

Table A2 A sample list of parameters for energy performance simulation

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Ce-Building building1	0		L1	L1	L1	L2	L3	L3	L3	L4	L3
Location = Kalmar	2	Location for calculating the sun position etc.	L1	L1	L1	L2	L3	L3	L3	L4	L3
Wind Profile = © [Default urban]	2		L1	L1	L1	L2	L3	L3	L3	L4	L3
Climate = [Default] Kalmar-1968	2	Name of the weather file for simulation	L1	L1	L1	L2	L3	L3	L3	L4	L3
Site object	2	Site position and orientation of the building	NR	NR	NR	L1	L2	L3	L3	L4	L3
Site size[1:4]	4		NR	NR	NR	L1	L2	L3	L3	L4	L3
Site size[1] = -100.0 m	6		NR	NR	NR	L1	L2	L3	L3	L4	L3
Orientation = 0.0 Deg	4		NR	NR	NR	L1	L2	L3	L3	L4	L3
XY-ORIGIN[1:2]	4		NR	NR	NR	L1	L2	L3	L3	L4	L3
XY-ORIGIN[1] = 0.0 m	6		NR	NR	NR	L1	L2	L3	L3	L4	L3
X-DIRECTION = 0.0 Deg	4		NR	NR	NR	L1	L2	L3	L3	L4	L3
ARCDATA	4		NR	NR	NR	L1	L2	L3	L3	L4	L3
Simulation data	2	IDA internal parameters. Good to know when reading the results.	NR	I	I	I	I	I	I	I	NR
Model Type = Energy	4		NR	I	I	I	I	I	I	I	NR
HMAX = 1.5	4		NR	I	I	I	I	I	I	I	NR
STARTUP-PHASE	4		NR	I	I	I	I	I	I	I	NR
CALCULATION-PHASE	4		NR	I	I	I	I	I	I	I	NR
Spec. simulations	2	IDA internal parameters. Good to know when reading the results.	NR	I	I	I	I	I	I	I	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Resource Energy wizard	4	This is energy use case	NR	I	I	I	I	I	I	I	NR
System parameters	2	IDA internal parameters. Good to know when reading the results.	NR	I	I	I	I	I	I	I	NR
Minimum massflow for water circuits = 1.0E-8 kg/s	4		NR	I	I	I	I	I	I	I	NR
Minimum volume flow for air circuits = 0.01 L/s	4		NR	I	I	I	I	I	I	I	NR
cp for water and coolant circuits = 4187 J/(kg K)	4		NR	I	I	I	I	I	I	I	NR
Reference air density at 20 Deg-C = 1.1978 kg/m3	4		NR	I	I	I	I	I	I	I	NR
P-band for proportional temperature controllers = 2.0 Deg-C	4		NR	I	I	I	I	I	I	I	NR
Temperature offset for cooling panel control = 2.0 Deg-C	4		NR	I	I	I	I	I	I	I	NR
Pressure threshold for air flow control = 5.0 Pa	4		NR	I	I	I	I	I	I	I	NR
DP0_AIR_NATURAL = 1.0 Pa	4		NR	I	I	I	I	I	I	I	NR
Pressure threshold for water flow control = 200 Pa	4		NR	I	I	I	I	I	I	I	NR
EXTERNAL_LEAK_N = 0.6	4		NR	I	I	I	I	I	I	I	NR
Solar radiation level at which integrated shadings are drawn = 100 W/m2	5		NR	I	I	I	I	I	I	I	NR
INTERNAL_SHADING_CONTROL_ANGLE = 90 Deg	4		NR	I	I	I	I	I	I	I	NR
External s-w absorptance of window frames = 0.5	4		NR	I	I	I	I	I	I	I	NR
CO2_AMBIENT = 400.0 ppm (vol)	5		NR	I	I	I	I	I	I	I	NR
REF_CELL_SIZE = 0.03 m	4		NR	I	I	I	I	I	I	I	NR
NUMERICAL_AIR_MASS = 10 kg	4		NR	I	I	I	I	I	I	I	NR
CHIL_COP = 2 dimless	4		NR	I	I	I	I	I	I	I	NR
TCOIL = 15 Deg-C	4		NR	I	I	I	I	I	I	I	NR
SLIDE_LEN = 15 min	4		NR	I	I	I	I	I	I	I	NR
Envelope area definition = Internal	4		NR	I	I	I	I	I	I	I	NR
Zone area for per-area results = Net area	4		NR	I	I	I	I	I	I	I	NR
DAYLIGHT_AT = At first occupant	4		NR	I	I	I	I	I	I	I	NR
DAYLIGHT_HEIGHT = -1.0 m	4		NR	I	I	I	I	I	I	I	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
TAU_HEAT_MONITOR = 24 hours	4		NR	I	I	I	I	I	I	I	NR
Model of diffuse radiation = Perez	4		NR	I	I	I	I	I	I	I	NR
PMV_LO = -1	4		NR	I	I	I	I	I	I	I	NR
PMV_HI = 1	5		NR	I	I	I	I	I	I	I	NR
BUILDING_SELF_SHADING = True	5		NR	I	I	I	I	I	I	I	NR
CUT_SHADES_AT_FACE = True	4		NR	I	I	I	I	I	I	I	NR
CONNECT_ADJACENT = True	4		NR	I	I	I	I	I	I	I	NR
SHADING_CALCULATION_GRID = 15 Deg	4		NR	I	I	I	I	I	I	I	NR
EL-METER	4		NR	I	I	I	I	I	I	I	NR
HEATING_COP = 1 dimless	6		NR	I	I	I	I	I	I	I	NR
COOLING_COP = 3 dimless	6		NR	I	I	I	I	I	I	I	NR
DOMWAT_COP = 1 dimless	6		NR	I	I	I	I	I	I	I	NR
FUEL-METER	4		NR	I	I	I	I	I	I	I	NR
DISTRICT-METER	4		NR	I	I	I	I	I	I	I	NR
SCHEDULE_SMOOTHING_FANOUT = 5	4		NR	I	I	I	I	I	I	I	NR
SCHEDULE_SAMPLE_WIDTH = 0.2 h	4		NR	I	I	I	I	I	I	I	NR
CD_LO = 0.65 dimless	4		NR	I	I	I	I	I	I	I	NR
ADJACENCY-DIST-HOR = 0.5 m	4		NR	I	I	I	I	I	I	I	NR
ADJACENCY-DIST-VERT = 0.8 m	4		NR	I	I	I	I	I	I	I	NR
TEMP_H_LOW = 25 Deg-C	4		NR	I	I	I	I	I	I	I	NR
TEMP_H_HIGH = 27 Deg-C	4		NR	I	I	I	I	I	I	I	NR
TEMP_TOLERANCE_ULH = 1 Deg-C	4		NR	I	I	I	I	I	I	I	NR
OCCUPANCY_THRESHOLD = 0.01 dimless	4		NR	I	I	I	I	I	I	I	NR
LIGHT-SENSOR-SIDE = Outside	4		NR	I	I	I	I	I	I	I	NR
Jäähdytysraja = 26 Deg-C	4		NR	I	I	I	I	I	I	I	NR
LOCAL-FI-SHOW-ALL = NIL	4		NR	I	I	I	I	I	I	I	NR
Rakennuksen käyttötarkoitusluokka = <value not set>	4		NR	I	I	I	I	I	I	I	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Thermal bridges	2	Values for thermal bridges in the building	NR	NR	NR	NR	L1	L2	L2	L4	NR
Total envelope (incl. roof and ground) = 0 W/(m2 K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External wall / internal slab = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External wall / internal wall = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External wall / external wall = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External windows perimeter = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External doors perimeter = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Roof / external walls = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External slab / external walls = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Balcony floor / external walls = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External slab / Internal walls = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Roof / Internal walls = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External walls, inner corner = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Roof / external walls, inner corner = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
External slab / external walls, inner corner = 0 W/(m K)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Infiltration	2	Method and numeric values for the infiltration	NR	NR	NR	NR	L1	L2	L2	L4	NR
METHOD = Wind driven flow	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Alternative units = ACH (building)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
Infiltration units for zones = L/(s.m2 ext. surf.)	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
LEAKAGE = 0.5	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
P = 50 Pa	5		NR	NR	NR	NR	L1	L2	L2	L4	NR
Extra energy and losses	2	Losses in technical building systems	NR	NR	NR	NR	L1	L2	L2	L4	NR
Hot water use = 0.0	4	Domestic hot water	NR	NR	NR	NR	L1	L2	L2	L4	NR
Unit for hot water use = L/per occupant and day	5		NR	NR	NR	NR	L1	L2	L2	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
NOCC = 1	4		NR	NR	NR	NR	L1	L2	L2	L4	NR
HOT-WATER-SCHEDULE = © Uniform	4	Profile for DHW use	NR	NR	NR	NR	L1	L2	L2	L4	NR
TSUP = 5 Deg-C	4	Supply temperature of domestic water	NR	NR	NR	NR	L1	L2	L2	L4	NR
Domestic hot water circuit = 0.0 W/m2	4	Losses in DHW system	NR	NR	NR	NR	L1	L2	L2	L4	NR
HOT-CIRCUIT-TO-ZONES = 50 %	4	Losses in DHW system	NR	NR	NR	NR	L1	L2	L2	L4	NR
Heat to zones = 0.0	4	Losses in heating system	NR	NR	NR	NR	L1	L2	L2	L4	NR
HEAT-UNIT = % of heat delivered by plant (incl. delivered to ideal heaters)	5	Losses in heating system	NR	NR	NR	NR	L1	L2	L2	L4	NR
HEAT-TO-ZONES = 50 %	4	Losses in heating system	NR	NR	NR	NR	L1	L2	L2	L4	NR
Cold to zones = 0.0	4	Losses in cooling system	NR	NR	NR	NR	L1	L2	L2	L4	NR
COLD-UNIT = W/m2 floor area	5	Losses in cooling system	NR	NR	NR	NR	L1	L2	L2	L4	NR
COLD-TO-ZONES = 50 %	4	Losses in cooling system	NR	NR	NR	NR	L1	L2	L2	L4	NR
Supply air duct losses = 0.0 W/m2	4	Losses in ventilation system	NR	NR	NR	NR	L1	L2	L2	L4	NR
AIRDUCT-TO-ZONES = 50 %	4	Losses in ventilation system	NR	NR	NR	NR	L1	L2	L2	L4	NR
BOIL-IDLE = 0 W	4	Losses in heating system	NR	NR	NR	NR	L1	L2	L2	L4	NR
CHIL-IDLE = 0 W	4	Losses in cooling system	NR	NR	NR	NR	L1	L2	L2	L4	NR
Building body	2	Building geometrics	NR	NR	L1	L2	L3	L3	L4	L4	L3
Building body	4		NR	NR	L1	L2	L3	L3	L4	L4	L3
PROTECTED_SHAPE = False	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:2]	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 0.0 m	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
z ceiling = 6.0 m	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
z floor = -1.0 m	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
Surface = © Default surface	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face f1	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
PCOEF[1] = 0.0 dimless	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 90.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face GROUND-FACE	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 0.0 m	12		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face f2	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1] = 0.0 dimless	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 50.0 m	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 90.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face GROUND-FACE	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 50.0 m	12		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face f3	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
PCOEF[1] = 0.0 dimless	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 50.0 m	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 90.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face GROUND-FACE	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 50.0 m	12		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face f4	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 0.0 m	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 90.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face GROUND-FACE	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 0.0 m	12		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face Crawl space	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
PCOEF[1] = 0.0 dimless	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 0 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 180.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Face GROUND-FACE	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1, 1] = 0.0 m	12		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Roof-Face Roof	6		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1:8]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
PCOEF[1] = 0.0 dimless	10		NR	NR	L1	L2	L3	L3	L4	L4	L3
Ground reflectance = 0.2	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
NCORN = 4 items	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Slope = 0.0 Deg	8		NR	NR	L1	L2	L3	L3	L4	L4	L3
Zones	2	Simulation zones. Typically spaces in the IFC, but seldom all of them need to be simulated and some can also be merged in the model preparation.	NR	NR	L1	L1	L2	L3	L4	L4	NR
Ce-Zone Zone	4	Example of zone information. Only one zone in this model	NR	NR	L1	L1	L2	L3	L4	L4	NR
Ida resources	6		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Setpoint_Collection [local for zone]	8	Control system setpoints	NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_VENT_AIR = 0.3 L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_VENT_AIR = 7 L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
THERMOSTAT_MIN = 21 Deg-C	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
THERMOSTAT_MAX = 25 Deg-C	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_VENT_SUP = NIL L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_VENT_SUP = NIL L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
DESIGN_MIN = 19	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
DESIGN_MAX = 30	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_HUMIDITY = 20 %	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_HUMIDITY = 80 %	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_CO2 = 700 ppm (vol)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_CO2 = 1100 ppm (vol)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_LIGHT = 100 lx	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_LIGHT = 10000 lx	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MIN_DP = -20 Pa	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
MAX_DP = -10 Pa	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
THERMOSTAT_MIN_SCHEDULE = <value not set>	10	Thermostat profiles for intermittent heating	NR	NR	L1	L1	L2	L3	L4	L4	NR
THERMOSTAT_MAX_SCHEDULE = <value not set>	10	Thermostat profiles for intermittent heating	NR	NR	L1	L1	L2	L3	L4	L4	NR
Model type = Default	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
GROUP =	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
Multiplicity = 1	7		NR	NR	L1	L1	L2	L3	L4	L4	NR
In use = <when occupied>	7		NR	NR	L1	L1	L2	L3	L4	L4	NR
Loss factor for thermal bridges	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
EXTRA-LOSS = 0 W/K	8		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Geometry	6	Zone geometry	NR	NR	L1	L1	L2	L3	L4	L4	NR
Origin[1:2]	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Origin[1] = 24.0 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Origin[2] = 0.0 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
NCORN = 4 items	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Corners[1:4, 1:2]	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Corners[1, 1] = 0.0 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONTOURS = NIL	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Ceiling height = 2.6 m	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
HEIGHT-TO-ROOF = False	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Orientation = 0.0 Deg	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Floor height from ground = 0.0 m	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
ZONE-VOLUME = 26.0 m3	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
EXTSURF-AREA = 7.34265 m2	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Facade area facing ~A = 6.5 m2	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
CENTRAL-AHU	6	Air-handling in the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Select central AHU = Air Handling Unit	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
System type = CAV	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
BALANCED = False	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Return air for CAV = 2.0 L/(s m2)	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Supply air for CAV = 2.0 L/(s m2)	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Return terminal height = 2.6 m	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Connected as = Central AHU	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
AIR	6	Air change parameters	NR	NR	L1	L1	L2	L3	L4	L4	NR
Stratification = 0	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Air velocity at occupants = 0.1 m/s	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Given additional in/exfiltration = 0	8		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Infiltration area (at 4 Pa) 1 m above floor = 3.07E-4 m2	9		NR	NR	L1	L1	L2	L3	L4	L4	NR
Controller = <controlled by setpoints>	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
Controller setpoints = [local for zone]	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
DHW	6	Domestic hot water in the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Hot water use = 0.0	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Unit for hot water use = L/per occupant and day	9		NR	NR	L1	L1	L2	L3	L4	L4	NR
NOCC = 1	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
HOT-WATER-SCHEDULE = © Uniform	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Calculate daylight = False	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
Calculate cfd = False	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
A901	6		NR	NR	L1	L1	L2	L3	L4	L4	NR
Conditioning = Conditioned	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
DCV required (6.4.3.9) =	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Min outdoor air = 2.0 L/(s m2)	9		NR	NR	L1	L1	L2	L3	L4	L4	NR
System type = [Default] System 7 - VAV with Reheat	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Residential? = [Default] Non-residential	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Belong to floor/group = AUTO	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Keep envelope =	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Air handling units	7	Air handling units used in the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
CENTRAL-AHU	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Select central AHU = Air Handling Unit	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
System type = CAV	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
BALANCED = False	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Return air for CAV = 2.0 L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Supply air for CAV = 2.0 L/(s m2)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Return terminal height = 2.6 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Connected as = Central AHU	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Surfaces	6	Surfaces of the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Floor	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Ceiling	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Wall 1	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Wall 2	8	Example wall in the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Wall 3	8	Example wall in the zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Geometry	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Corners[1:4, 1:3]	12		NR	NR	L1	L1	L2	L3	L4	L4	NR
Corners[1, 1] = 2.5 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONTOURS = NIL	12		NR	NR	L1	L1	L2	L3	L4	L4	NR
Slope = 90.0 Deg	12		NR	NR	L1	L1	L2	L3	L4	L4	NR
IF_NOT_CONNECTED = Ignore net heat transmission	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
IGNORE_ADJACENT_FACE = False	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONSTRUCTION_INTERNAL = [Default] Interior wall with insulation	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONSTRUCTION_INTERNAL_FLIPPED = False	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONSTRUCTION_EXTERNAL = [Default] Rendered l/w concrete wall 250	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CONSTRUCTION_GROUND = [Default] Rendered concrete wall 200	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Inner surface = © Default surface	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Outer surface = © Default surface	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Features	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Ce-Window Window	12	Example window in the wall	NR	NR	L1	L1	L2	L3	L4	L4	NR
X = 0.6 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Y = 0.8 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
DX = 1.25 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
DY = 1.2 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Z = 0.0 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Glazing = [Default] 3 pane glazing, clear, 4-12-4-12-4	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Integrated shading = [Default] © No integrated shading	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Control of integrated shading = Sun	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
External shading type = No external shading	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Recess depth = 0 m	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Opening control = Never open	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
OPENING-HEIGHT = 100 %	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
OPENING-WIDTH = 100 %	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
CD_LO = 0.65 dimless	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Wall-Part Frame	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Frame area fraction = 0.1 dimless	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
Frame U-value = 2.0 W/(m2 K)	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
Construction = <value not set>	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
Inner surface = © Default surface	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
Outer surface = © Default surface	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
TWIST = 0 Deg	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
TILT = 0 Deg	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Lining inner surface = © Default surface	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Lining outer surface = © Default surface	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
A901	14		NR	NR	L1	L1	L2	L3	L4	L4	NR
Framing = Nonmetal framing	16		NR	NR	L1	L1	L2	L3	L4	L4	NR
Enclosing-Element Wall 4	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Internal gains	6	Internal heat gains in a zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Light Light	8	Lights	NR	NR	L1	L1	L2	L3	L4	L4	NR
X = 1.077 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Y = 1.486 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
DX = 0.5384 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
DY = 0.743 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Control = Schedule	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Rated input = 50.0 W	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Luminous efficiency = 12	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Convective fraction = 0.3	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
LUMEN_PER_WATT_VISIBLE_RAD = NIL	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Number of = 1	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Schedule = © Always on	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Z = 0.0 m	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy meter = [Default] Lighting, facility	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Occupant Occupant	8	Occupants	NR	NR	L1	L1	L2	L3	L4	L4	NR
Activity level = 1.0 Met	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CLOTHING-VAR = False	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Clothing = 0.85 clo	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CLOTHING-TOL = 0.25 clo	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Number of = 1	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Schedule = © Always present	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Position[1:3]	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Position[1] = 1.35 m	12		NR	NR	L1	L1	L2	L3	L4	L4	NR
Equipment Equipment	8	Apliances	NR	NR	L1	L1	L2	L3	L4	L4	NR
Emitted sensible power = 150.0 W	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Longwave Radiation Fraction = 0.0	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Humidity = 0.0 kg/s	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
LIQ_EMISSION = 0.0 kg/s	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
CO2 emission = 0.0 mg/s	10		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Number of = 1	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
UTIL_FACTOR = 1 dimless	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Schedule = © Always on	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Position[1:3]	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Position[1] = 0.0 m	12		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy carrier = Electricity	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy meter = [Default] Equipment, tenant	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Internal masses	6	Internal masses in a zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Mass Furniture	8		NR	NR	L1	L1	L2	L3	L4	L4	NR
Area = 2.0 m2	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Envelope = © [Default furniture]	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Heat transfer coefficient = 6.0 W/(m2 K)	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Room units	6	Heating and cooling devices in zone	NR	NR	L1	L1	L2	L3	L4	L4	NR
Hc-Unit Ideal cooler	8	Ideal cooler system in this model.	NR	NR	L1	L1	L2	L3	L4	L4	NR
Max power = 2000 W	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Coil temperature = 15 Deg-C	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Sensor = Air temperature	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy carrier = [Default] Electricity	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy meter = [Default] Electric cooling	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Controller = PI	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Chiller COP = 3	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
EMISS = 1	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Hc-Unit Ideal heater	8	Ideal heater system in this model.	NR	NR	L1	L1	L2	L3	L4	L4	NR
Max power = 1000 W	10		NR	NR	L1	L1	L2	L3	L4	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Sensor = Air temperature	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy carrier = [Default] Fuel	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Energy meter = [Default] Fuel heating	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Controller = PI	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
Boiler efficiency = 0.9	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
EMISS = 1	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
LW_RAD_FRACTION = 0.4	10		NR	NR	L1	L1	L2	L3	L4	L4	NR
HVAC components	2	HVAC components in the model. These are referred in the zones.	NR	NR	NR	L1	L2	L3	L4	L4	L3
Ah-Macro Air Handling Unit	4	Air handling unit	NR	NR	NR	L1	L2	L3	L4	L4	L3
IDA Resources	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Schedule data AirSupSchedule	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
Schedule rule default	11		NR	NR	NR	L1	L2	L3	L4	L4	L3
Constant = 16.0	15		NR	NR	NR	L1	L2	L3	L4	L4	L3
Parameters	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Interfaces	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Air_Sup (sf.FANOUT) <— LIB.AIRPLUG.INLET	10		NR	NR	NR	L1	L2	L3	L4	L4	L3
Boundary objects	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Source-Constant SupConst	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
X = 16.0	10		NR	NR	NR	L1	L2	L3	L4	L4	L3
Source-Constant AIR-SUPPLY-STRATEGY	9		NR	NR	NR	L1	L2	L3	L4	L4	L3
X = Constant	10		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference AirExhaustRef	9		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference AirSupplyRef	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference AirExhaustRef	6		NR	NR	NR	L1	L2	L3	L4	L4	L3

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Reference AirSupplyRef	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Prim-Macro Plant	4	"Plant", heating and cooling energy generation system e.g. boiler or district cooling heat exchanger.	NR	NR	NR	L1	L2	L3	L4	L4	L3
Interfaces	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
AHU_sup_cold (chil.OUTLET1) <— LIB.WATPLUG.INLET	10		NR	NR	NR	L1	L2	L3	L4	L4	L3
Boundary objects	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef1	8		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Reference TAmbRef1	6		NR	NR	NR	L1	L2	L3	L4	L4	L3
Boundaries	2		NR	NR	L1	L2	L3	L4	L4	L4	NR
Source-File Climate file	4	The weather file in the model	NR	NR	L1	L2	L3	L4	L4	L4	NR
Source-Object Ground	4		NR	NR	L1	L2	L2	L3	L4	L4	NR
MODEL = ISO-13370	6		NR	NR	L1	L2	L2	L3	L4	L4	NR
Ground layer outside basement's walls = © [Default ground with insulation]	6		NR	NR	L1	L2	L2	L3	L4	L4	NR
Ground layer under basement's slab = © [Default ground with insulation]	6		NR	NR	L1	L2	L2	L3	L4	L4	NR
Temperature below the ground layer = 10 Deg-C	6		NR	NR	L1	L2	L2	L3	L4	L4	NR
Energy meters	2	Energy meter objects contain primary energy factors and CO_2 emissions of the energy fraction	L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Lighting, facility	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Rate plan = <value not set>	6		L1	L2	L2	L3	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Primary energy factor = NIL dimless	6		L1	L2	L2	L3	L3	L3	L3	L4	NR
CO2 emission per kWh = NIL g/kWh	6	Facility and tenant share of the energy are separated in the reporting	L1	L2	L2	L3	L3	L3	L3	L4	NR
Role = Facility	6		L1	L2	L2	L3	L3	L3	L3	L4	NR
Color = #S(RGB RED 240 GREEN 240 BLUE 0)	6		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Lighting, tenant	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Equipment, facility	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Equipment, tenant	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Electric cooling	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Fuel cooling	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter District cooling	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter HVAC aux	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Electric heating	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Fuel heating	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter District heating	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Heating, tenant	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Domestic hot water	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter PV production	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter Wind turbine production	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Energy-Meter CHP electricity	4		L1	L2	L2	L3	L3	L3	L3	L4	NR
Walls, slabs, roof	2	Wall, slab and roof objects	NR	NR	L1	L2	L3	L3	L3	L4	NR
Enclosing-Element Wall 1	4		NR	NR	L1	L2	L3	L3	L3	L4	NR
Enclosing-Element Wall 2	4		NR	NR	L1	L2	L3	L3	L3	L4	NR
Enclosing-Element Wall 3	4	One wall object opened as an example	NR	NR	L1	L2	L3	L3	L3	L4	NR
Geometry	6		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Corners[1:4, 1:3]	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Corners[1, 1] = 2.5 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
CONTOURS = NIL	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Slope = 90.0 Deg	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
IF_NOT_CONNECTED = Ignore net heat transmission	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
IGNORE_ADJACENT_FACE = False	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CONSTRUCTION_INTERNAL = [Default] Interior wall with insulation	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CONSTRUCTION_INTERNAL_FLIPPED = False	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CONSTRUCTION_EXTERNAL = [Default] Rendered l/w concrete wall 250	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CONSTRUCTION_GROUND = [Default] Rendered concrete wall 200	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Inner surface = © Default surface	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Outer surface = © Default surface	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Features	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Ce-Window Window	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
X = 0.6 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Y = 0.8 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
DX = 1.25 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
DY = 1.2 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Z = 0.0 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Glazing = [Default] 3 pane glazing, clear, 4-12-4-12-4	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Integrated shading = [Default] © No integrated shading	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Control of integrated shading = Sun	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
External shading type = No external shading	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Recess depth = 0 m	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Opening control = Never open	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
OPENING-HEIGHT = 100 %	10		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
OPENING-WIDTH = 100 %	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
CD_LO = 0.65 dimless	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Wall-Part Frame	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Frame area fraction = 0.1 dimless	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
Frame U-value = 2.0 W/(m2 K)	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
Construction = <value not set>	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
Inner surface = © Default surface	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
Outer surface = © Default surface	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
TWIST = 0 Deg	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
TILT = 0 Deg	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Lining inner surface = © Default surface	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Lining outer surface = © Default surface	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
A901	10		NR	NR	L1	L2	L3	L3	L3	L4	NR
Framing = Nonmetal framing	12		NR	NR	L1	L2	L3	L3	L3	L4	NR
Enclosing-Element Wall 4	4		NR	NR	L1	L2	L3	L3	L3	L4	NR
Windows	2	Window objects	NR	NR	L1	L2	L3	L3	L3	L4	NR
Ce-Window Window	4	One window object opened	NR	NR	L1	L2	L3	L3	L3	L4	NR
X = 0.6 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Y = 0.8 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
DX = 1.25 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
DY = 1.2 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Z = 0.0 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Glazing = [Default] 3 pane glazing, clear, 4-12-4-12-4	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Integrated shading = [Default] © No integrated shading	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Control of integrated shading = Sun	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
External shading type = No external shading	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Recess depth = 0 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Opening control = Never open	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
OPENING-HEIGHT = 100 %	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
OPENING-WIDTH = 100 %	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CD_LO = 0.65 dimless	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Wall-Part Frame	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Frame area fraction = 0.1 dimless	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Frame U-value = 2.0 W/(m2 K)	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Construction = <value not set>	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Inner surface = © Default surface	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Outer surface = © Default surface	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
TWIST = 0 Deg	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
TILT = 0 Deg	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Lining inner surface = © Default surface	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Lining outer surface = © Default surface	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
A901	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Framing = Nonmetal framing	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Internal gains	2	Internal gain objects	NR	NR	L1	L2	L3	L3	L3	L4	NR
Light Light	4	Light object	NR	NR	L1	L2	L3	L3	L3	L4	NR
X = 1.077 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Y = 1.486 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
DX = 0.5384 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
DY = 0.743 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Control = Schedule	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Rated input = 50.0 W	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Luminous efficiency = 12	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Convective fraction = 0.3	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
LUMEN_PER_WATT_VISIBLE_RAD = NIL	6		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Number of = 1	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Schedule = © Always on	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Z = 0.0 m	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy meter = [Default] Lighting, facility	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Occupant Occupant	4	Occupant object	NR	NR	L1	L2	L3	L3	L3	L4	NR
Activity level = 1.0 Met	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CLOTHING-VAR = False	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Clothing = 0.85 clo	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CLOTHING-TOL = 0.25 clo	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Number of = 1	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Schedule = © Always present	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Position[1:3]	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Position[1] = 1.35 m	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Equipment Equipment	4	Equipment object	NR	NR	L1	L2	L3	L3	L3	L4	NR
Emitted sensible power = 150.0 W	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Longwave Radiation Fraction = 0.0	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Humidity = 0.0 kg/s	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
LIQ_EMISSION = 0.0 kg/s	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
CO2 emission = 0.0 mg/s	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Number of = 1	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
UTIL_FACTOR = 1 dimless	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Schedule = © Always on	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Position[1:3]	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Position[1] = 0.0 m	8		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy carrier = Electricity	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy meter = [Default] Equipment, tenant	6		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Room units	2	Heating and cooling unit objects	NR	NR	L1	L2	L3	L3	L3	L4	NR
Hc-Unit Ideal cooler	4	Types of coolers and related parameters were ideal in this simulation, but could be e.g. cooling panel.	NR	NR	L1	L2	L3	L3	L3	L4	NR
Max power = 2000 W	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Coil temperature = 15 Deg-C	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Sensor = Air temperature	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy carrier = [Default] Electricity	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy meter = [Default] Electric cooling	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Controller = PI	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Chiller COP = 3	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
EMISS = 1	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Hc-Unit Ideal heater	4	Types of heaters and related parameters were ideal in this simulation, but could be e.g. water radiators or electric floor heating	NR	NR	L1	L2	L3	L3	L3	L4	NR
Max power = 1000 W	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Sensor = Air temperature	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy carrier = [Default] Fuel	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Energy meter = [Default] Fuel heating	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Controller = PI	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
Boiler efficiency = 0.9	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
EMISS = 1	6		NR	NR	L1	L2	L3	L3	L3	L4	NR
LW_RAD_FRACTION = 0.4	6		NR	NR	L1	L2	L3	L3	L3	L4	NR

Parameter and example value	H	Comment	I.ve	I.on	CoD	PrD	DvD	DtD	Con	Use	EoL
Wall constructions	2	Wall contruction objects	NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef © [Default furniture]	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef © [Default ground with insulation]	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Concrete floor 150mm	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Rendered l/w concrete wall 250	4	One wall object opened as an example	NR	NR	NR	L1	L2	L3	L3	L3	NR
layer-1	6		NR	NR	NR	L1	L2	L3	L3	L3	NR
Material = Render	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
Thickness = 0.01 m	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
layer-2	6		NR	NR	NR	L1	L2	L3	L3	L3	NR
Material = L/W concrete	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
Thickness = 0.25 m	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
layer-3	6		NR	NR	NR	L1	L2	L3	L3	L3	NR
Material = Render	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
Thickness = 0.01 m	8		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Interior wall with insulation	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Concrete floor 250mm	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Concrete joist roof	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Rendered concrete wall 200	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Entrance door	4		NR	NR	NR	L1	L2	L3	L3	L3	NR
Walldef Inner door	4		NR	NR	NR	L1	L2	L3	L3	L3	NR

9 Appendix II

The schematic UML-chart of the **Building Energy Simulation (BES)** objects and their relations in the data model is presented in the Figure A1.

The table A3 presents the synthesis of the most important parameters with their data types restructured into a data model format to simulate the building in the energy scenario simulator and to communicate the results of the energy performance and of the indoor climate. The exhaustive data definition related to the commercial energy simulation tool (in the previous Appendix 1) has been narrowed to the most important parameters.

The Building Energy Simulation data model creates the basis of the interoperability data model between the WP4 BIM Management server and the BIM Assisted Scenario Simulator. In addition, the data model contains the ways to handle the historical data related to the energy and indoor climate and the ways to store the renovation scenarios and their results in the form of Owners Project Requirements.

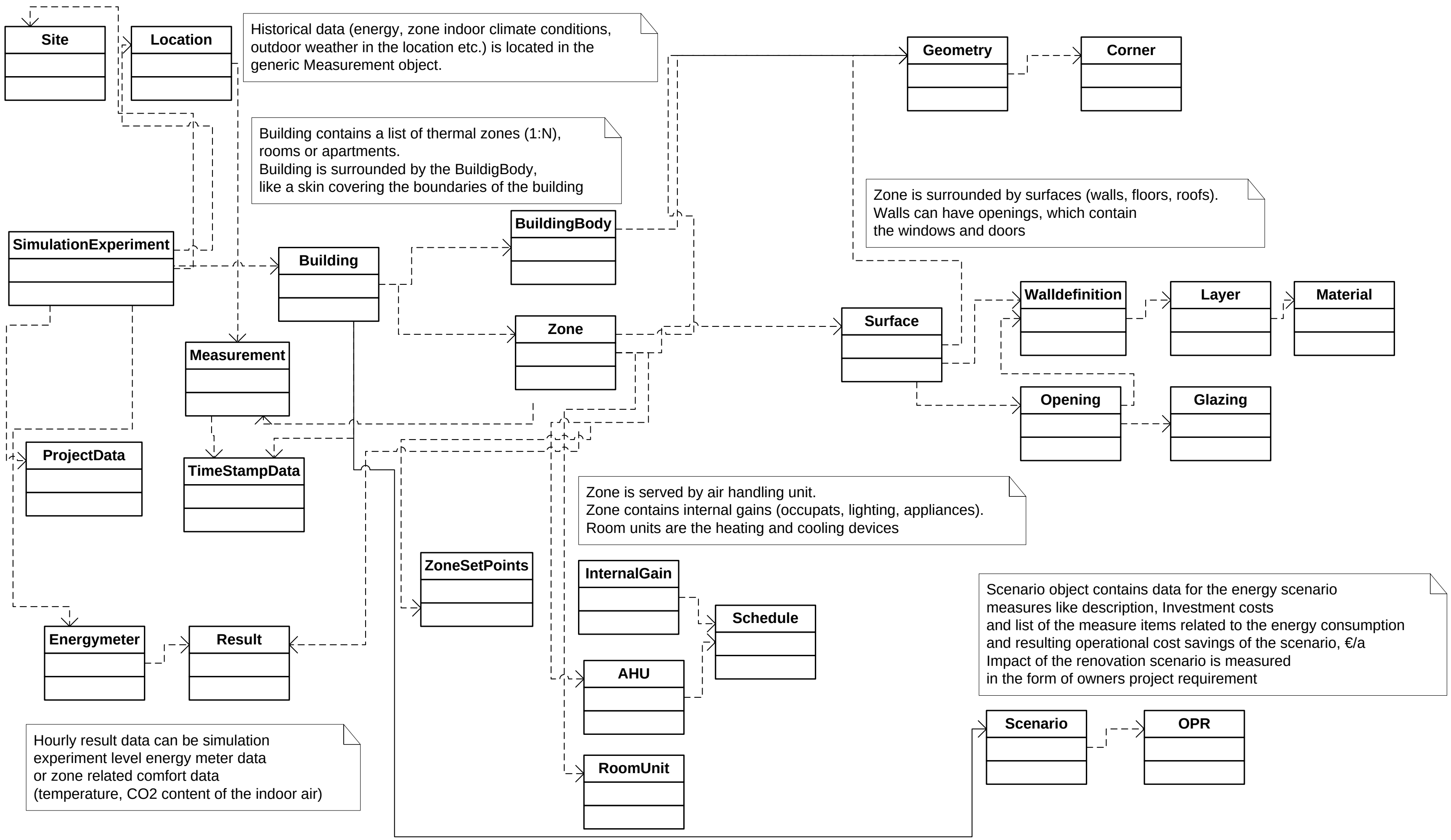

Figure A1. A simplified UML-chart of the Building Energy simulation objects and their relations to each other

Table A3 BIM4EEB Building Energy Simulation data model definition for the renovation scenario simulator

Object	Attribute	Data type	Description
SimulationExperiment			*Simulation case object in form of general project data*
	projectdata (1:1)	**ProjectData**	*General data of the simulation project*
	Location (1:1)	**Location**	*Location for calculating the sun position etc.*
	Building (1:1)	**Building**	*The building data to be simulated*
	Site (1:1)	**Site**	*Site data*
	DeliveredEnergy (1:N)	**Energymeter**	*Metered delivered energy of the building by end use and by carrier*
	PrimaryEnergy	**Result**	*Hourly primary energy of the building (sum of all end uses)*
	CO2Emissions	**Result**	*Hourly CO2 emissions of the building (sum of all end uses)*
	RenewableElectricity	**Result**	*Metered renewable electricity production of the building*
	RenewableHeating	**Result**	*Metered renewable heating production of the building*
	RenewableCooling	**Result**	*Metered renewable cooling production of the building*
ProjectData			*Project Data object*
	Customer	String	*Customer of the simulation project*
	Run by	String	*The name of the energy expert running the simulation project*
	Description	String	*Description of the simulation project*
BuildingBody			*BuildingBody object*
	Name	String	*Name of the building body*
	bodyGeometry (1:1)	**Geometry**	*Geometry of the building body*

	bodyHeight	Double	*Height of the building body from the site ground surface level in meters (site origo is located in Z=0 m)*
Building			*Building object*
	Name	String	*Name of the building*
	bldgBody (1:1)	**BuildingBody**	*Geometrical presentation of the building surface (creates a boundary between bldg and environment)*
	bldgThermalZones (1:N)	**Zone**	*Thermal zones composing the building*
	SpaceHeatingEfficiency	Double	*Overall efficiency of the space heating system, dimless*
	DHWHeatingEfficiency	Double	*Overall efficiency of the domestic hot water heating system, dimless*
	CoolingCOP	Double	*Overall efficiency of the cooling system, dimless*
	HotWaterDemand	Double	*Domestic hot water demand of the building l/floor-m2,a*
	HotWaterCirculation	Boolean	*True = has hot water circulation system, False=does not have*
	EnergyCarrierForSpaceHeating	enumeration	*Gas, Oil, District, Electricity*
	EnergyCarrierForSpaceHeating	enumeration	*Gas, Oil, District, Electricity*
	EnergyCarrierForCooling	enumeration	*Gas, Oil, District, Electricity*
	PrimaryEnergyFactorGas	Double	*Primary energy factor of the energy carrier, dimless*
	PrimaryEnergyFactorOil	Double	*Primary energy factor of the energy carrier, dimless*
	PrimaryEnergyFactorDistrict	Double	*Primary energy factor of the energy carrier, dimless*
	PrimaryEnergyFactorElectricity	Double	*Primary energy factor of the energy carrier, dimless*
	CO2FactorGas	Double	*CO2 emission factor of the energy carrier, kg/kWh*
	CO2FactorOil	Double	*CO2 emission factor of the energy carrier, kg/kWh*
	CO2EnergyFactorDistrict	Double	*CO2 emission factor of the energy carrier, kg/kWh*
	CO2EnergyFactorElectricity	Double	*CO2 emission factor of the energy carrier, kg/kWh*

	TSupplyDHW	Double	*Temperature of the cold domestic water (cold water from the city systems)*
	TsetpointDHW	Double	*Supply temperature of the domestic hot water (hot water to showers and taps)*
	SpecificHotWaterCircuitLoss	Double	*Domestic hot water circuit loss, in W/floor-m2*
	InfiltrationAirChange	Double	*Infiltration air change of the building, 1/h*
	historicalData (0:N)	**Measurement**	*The measurement history of the building (mainly energy/operational costs of energy) gas, electricity, etc.*
	scenarios (0:N)	**Scenario**	*The list of scenarios made for the building*
Site			*Site position and orientation of the building*
	x	Double	*x coordinate for the Site origo, m*
	y	Double	*y coordinate for the Site origo, m*
	DX	Double	*Width of the site in m (rectangular supported), m*
	DY	Double	*Height of the site in m (rectangular supported), m*
	X_direction	Double	*Offset from the south degrees (default =0), gives a possibility to turn the site to various orientations, deg*
Location			*Location object*
	Country	String	*Country*
	City	String	*City*
	Latitude	Double	*Latitude degrees (positive northern hemisphere)*
	Longitude	Double	*Longitude degrees (negative east from Greenvich)*
	Elevation	Double	*Elevation from the sea level, meters*
	Time zone	Integer	*Time zone hours from Greenvich (negative to east from Greenvich)*
	Tdrybulb (8760)	Double	*Dry-bulb temperature, Deg-C, for each hour of the year*
	RH (8760)	Double	*Rel humidity of air, %, for each hour of the year*
	WindDir (8760)	Double	*Direction of wind, Deg, for each hour of the year*

	WindSpeed (8760)	Double	*Speed of meteorological wind, m/s, for each hour of the year*
	DirectNormalSolarRadiation (8760)	Double	*Direct normal rad, W/m2, for each hour of the year*
	DiffuseSolarRadiation (8760)	Double	*Diffuse rad on hor surf, W/m2, for each hour of the year*
	TwinterDesignDay	Double	*Outside air design day Dry-bulb temperature, Deg-C for sizing the heating system*
	TmaxSummerDesignDay	Double	*Maximum (daytime) dry bulb for summer design day, Deg-C for sizing the cooling system*
	TminSummerDesignDay	Double	*Minimum (nighttime) dry bulb for summer design day, Deg-C for sizing the cooling system*
	TmaxWetBulbSummerDesignDay	Double	*Maximum (daytime) wet bulb for summer design day, Deg-C for sizing the cooling system*
	historicalWeatherData (0:N)	**Measurement**	*The measurement history of the location (mainly outdoor conditions) temperature, humidity, solar radiation*
Zone			*Zone object*
	Name	String	*Name of the Zone (Zone1, bedroom, etc..)*
	zoneGeometry (1:1)	**Geometry**	*Geometry of the zone = floor geometry*
	zoneControllerSetPoints (1:1)	**ZoneSetPoints**	*Setpoints of the heating, cooling ventilation*
	zoneSurfaces (1:N)	**Surface**	*Surfaces delimiting the zone boundaries (walls etc..)*
	zoneInternaGains	**InternalGain**	*Internal gains in the zone (occupants, appliances, lighting)*
	zoneRoomUnits	**RoomUnit**	*Heating and cooling devices*
	zoneSelectedCentralAHU (1:1)	AHU	*Air handling unit serving the zone*
	zoneAirHandlingSystemType	enumeration	*(CAV,VAV CO2 control)*
	zoneReturnAirFlow	Double	*Return air flow of the zone in L/(s m2)*
	zoneSupplyAirFlow	Double	*Supply air flow of the zone in L/(s m2)*
	CeilingHeight	Double	*Height from the floor surface to the ceiling surface*

	FloorHeight	Double	*Height of the floor surface from the site ground level in meters (site origo is located in Z=0 m)*
	zoneTemp	**Result**	*Hourly temp of the zone, in oC*
	zoneCO2	**Result**	*Hourly CO2-content of the zone, in ppm*
	zoneRH	**Result**	*Hourly relative humidity of the zone, in %*
	FloorHeight	Double	*Height of the floor surface from the site ground level in meters (site origo is located in Z=0 m)*
	historicalData (0:N)	**Measurement**	*The measurement history of the zone (mainly indoor climate) temperature, humidity*
Surface			*Surface object presenting the walls, roof and floors*
	surfaceName	String	*Name of the surface (Wall1, Roof1 etc..)*
	surfaceType	enumeration	*OutsideAir, GrawlSpace, ToGround,Internal*
	surfaceGeometry (1:1)	**Geometry**	*Geometry of the surface*
	surfaceSlope	Double	*Slope (in degrees) of the surface 0 deg =floor, 180 deg = ceiling/roof, 90 deg = vertical wall*
	surfaceConstruction	**Walldefinition**	*Structure definition*
	surfaceArea	Double	*Area of the surface excluding the openings and windows in m2*
	surfaceWindow (0:N)	**Opening**	*Windows in the surface (supported only in the object facing outside)*
	surfaceDoor (0:N)	**Opening**	*Doors in the surface*
Walldefinition			*Data type to descripe the opaque envelope elements*
	walldefinitionName	String	*Name of the opaque envelope element*
	NumberOfLayers	Double	*Number of layers composing the structure*
	wallDefLayer (1:N)	**Layer**	*Set of layers in the wall, slab, roof and doors*
Layer			*Layer object*
	layerName	String	*Name of the layer*
	layerMaterial (1:1)	**Material**	*Layer material*
	layerThickness	Double	*Thickness of the layer*

Material			*Material object*
	materialName	String	*Name of the material*
	materialThermalConductivity	Double	*Thermal conductivity in W/(m K)*
	materialDensity	Double	*Density in kg/m3*
	materialSpecificHeat	Double	*Specific heat in J/(kg K)*
Geometry			*Geometry object*
	originX	Double	*Left down corner location in the site coordinate system X in meters related to the site origo*
	originY	Double	*Left down corner location in the site coordinate system Y in meters related to the site origo*
	NumberOfCorners	Long integer	*Number of polygon coordinates creating the shape of the zone (floor)*
	Corners (3:N)	**Corner**	*List of polygon coordinate pairs (creating the start and end points of the facet) (3:N) (X,Y) in meters in relation to the object origo in the left down corner of the object, looked from inside, zone and floor has the same origo. Clockwise direction by definition*
	Orientation	Double	*Orientation of the object related to the site (site positive Y-axis = 180 degrees, negative Y-axis 0 degrees) clockwise direction*
Corner			*Corner object creating the facet of a polygon*
	startX	Double	*Starting point of the facet*
	startY	Double	*Starting point of the facet*
	endX	Double	*End point of the facet*
	endY	Double	*End point of the facet*
ZoneSetPoints			*Set point object*
	HeatingSetPoint	Double	*Heating set point in oC*
	CoolingSetPoint	Double	*Cooling set point in oC*
	CO2SetPoint	Double	*Maximum CO2-lev of the zone when CO2-controlled ventilation, in ppm*

	NightSetBackTemperature	Double	*Set back temperature for heating between 10 PM and 6 AM*
AHU			*Air handling unit object*
	Name	String	*Name of the air handling unit*
	SupplyFanSFP	Double	*Specific power consumtion in kW/(m3/s)*
	ReturnFanSFP	Double	*Specific power consumtion in kW/(m3/s)*
	SupplyAir setpoint	Double	*Supply air setpoint in oC (the air that is delivered to the zones)*
	HeatRecoveryEfficiency	Double	*Exhaust air heat recovery efficiency (0-1)*
	SupplyAirIsHeated	Boolean	*True=is heated to setpoint value, False = floating*
	SupplyAirIsCooled	Boolean	*True=is cooled to setpoint value, False = floating*
	ahuSchedule	**Schedule**	*Schedule of the air handling unit*
Schedule			*Schedule object to handle weekly usage using three type days*
	Name	String	*Name of the schedule*
	weekdays (24)	Double	*Proportional (0-1) value for each hour of the weekday (Mon-Fri)*
	saturdays (24)	Double	*Proportional (0-1) value for each hour of the Saturday*
	sundays (24)	Double	*Proportional (0-1) value for each hour of the Sundays*
Opening			*Opening object for doors and windows locating in the surfaces*
	openingName	String	*Name of the opening (Door1, Window1 etc..)*
	x	Double	*x coordinate of the window left lower corner looked from inside of the space, in meters*
	y	Double	*y coordinate of the window left lower corner looked from inside of the space, in meters*
	DX	Double	*Width of the opening in m (rectangular supported)*
	DY	Double	*Height of the opening in m (rectangular supported)*
	Glazing (0:1)	**Glazing**	*Glazing part of the opening (outside windows)*

	OpaguePart (0:1)	**Walldefinition**	*Opague part of the opening (doors in general)*
	IntegratedShadingType	enumeration	*NoShading, BlindBetweenThePanes, InternalCurtain*
	OpeningControl	enumeration	*NeverOpen, TemparatureControlled*
	FrameAreaFraction	Double	*Share of the frame area (0-1) dimless*
	FrameUvalue	Double	*Frame U-value in W/m2,K*
Glazing			*Glazing object*
	g_value	Double	*Solar heat gain coefficient (0-1) dimless*
	Tau	Double	*Solar transmittance (t) (0-1)dimless*
	VisibleTransmittance	Double	*Visible transmittance (0-1) dimless*
	U_value	Double	*U-value in W/(m2 K)*
	InternalEmissivity	Double	*Internal emissivity (0-1) dimless*
	ExternalEmissivity	Double	*External emissivity (0-1) dimless*
InternalGain			*Internal gain object (occupants, appliances, lighting)*
	EmittedSensiblePower	Double	*Nominal sensible power of the gain in W*
	gainSchedule	**Schedule**	*Schedule of the gain*
	GainType	enumeration	*Electricity, Heating, DHWHeating, Occupant*
RoomUnit			*Room units for heating and cooling*
	maxPower	Double	*Nominal power of the room unit, in W*
	sensorType	enumeration	*Air temperature, Operative temperature*
Energymeter			*Result object to carry the hourly results of the simulated energy data (Delivered energy, CO2, primary energy)*
	EnergyCarrier	enumeration	*Gas, Oil, District, Electricity*
	EnergyUse	enumeration	*Space heating, Space cooling, DHW, Household electricity, Facility electricity, Lighting, HVAC*
	MeteredEnergy	**Result**	*Metered energy data item for each hour of the year*
Result			*Result object to carry the hourly results of the simulated items*

	Name	String	*Name of the result data (Temperature, relative humidity, heating power, cooling power, CO2-emission….)*
	unit	Double	*SI-Unit of the result data item*
	data (8760)	Double	*Result data item for each hour of the year*
Measurement			*Result object to carry the hourly results of the simulated items*
	Name	String	*Name of the result data (Temperature, relative humidity, heating power, cooling power, CO2-emission….)*
	unit	Double	*Unit of the result data item*
	DataItem(1:N)	**TimeStampData**	*Result data item for each hour of the year*
	DataSource	String	*Description of the source*
	Reliability	enumeration	*0=Uncalibrated, 1=Calibrated, xx=something else….*
TimeStampData			*Result object to carry the hourly results of the simulated items*
	Time	Date	*Time stamp of the value dd.mm.yyyy hh:mm.ss*
	Value	Double	*The value of the related time stamp*
Scenario			*Scenario object, which contains data for the energy scenario measures*
	Name	String	*Name of the renovation scenario*
	Description	String	*Short description*
	Investment	Double	*Investment cost of the scenario, €*
	measure(1:N)	**RenovationMeasure**	*List of the measure items related to the energy consumption*
	energySavings	Double	*Operational energy cost savings of the scenario, €/a*
	oprs(1:N)	**OPR**	*Impact of the renovation scenario in the form of owners project requirement*
RenovationMeasure			*Result object to carry the hourly results of the simulated items*
	Name	String	*Name of the technical measure affecting the energy and indoor climate*

	Description	String	*Short description*
	ObjID	String	*Object (in the BES data model) of which value is to be changed*
	ValueName	String	*The attribute of the object to be changed (layer thickness, AHU heat recovery, g-value, U value etc...)*
	Value	Double	*The new value*
OPR			*Object containing the Owners Project Requirements in the numerical form*
	Name	String	*Name of the requirement (specific proimary energy consumption, carbon foorprint...)*
	Description	String	*Short description*
	Unit	String	*Unit of the OPR data item (kWh/floor-m²,a, oC, etc...)*
	Value	Double	*Value of the OPR*