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A Systematic Investigation of Interoperability Issues and Solutions Between Architectural BIM models and Building Energy Modeling: Case Studies

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Master's thesis

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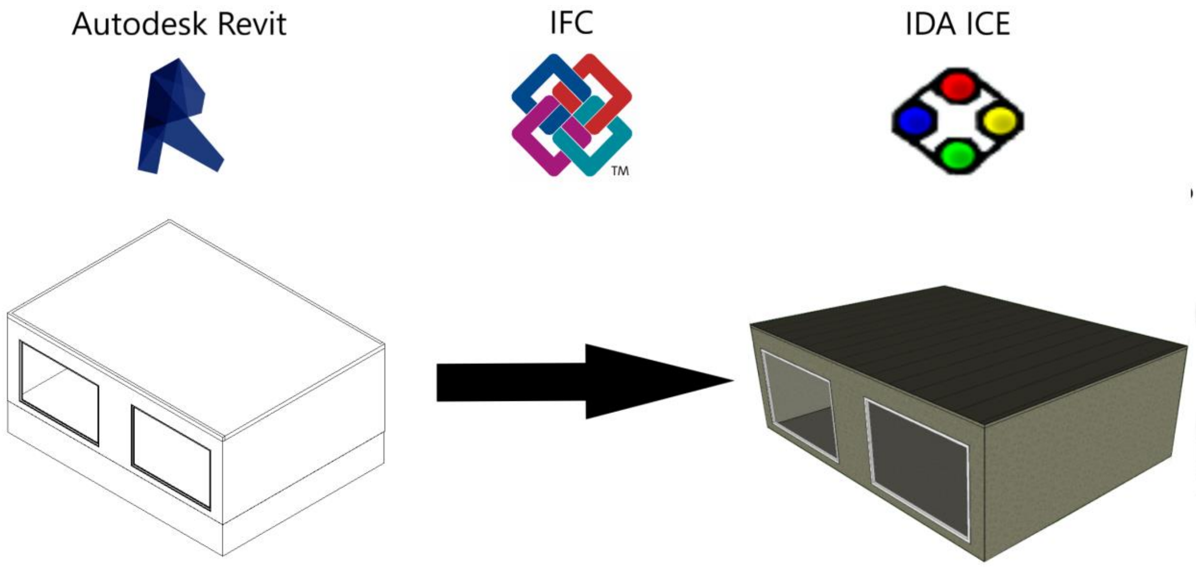

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Acknowledgement

This master thesis serves as an end product of the integrated five-year master program Civil and Environmental Engineering located under the Faculty of Engineering at the Norwegian University of Science and Technology – NTNU. The thesis belongs to the specialization program Building and Material Engineering. The report has been compiled during the spring semester and corresponds to 30 credits.

The thesis involves a case studies on interoperability issues between the BIM-based CAD software Autodesk Revit and the energy modeling software IDA Indoor Climate and Energy (IDA ICE).

The author of the thesis, Kristian Widding, has carried out the work in single effort. The associate professor Mohamed Hassan Hamdy Mohamed has been of great help as an advisor, assisting with valuable knowledge and guidance throughout the semester, and for that, I am grateful.

Trondheim, 11. June 2018

Kristian Widding

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Abstract

In the design of buildings, the attention on energy performance as a measure to lower the energy consumption and to reduce the emissions of greenhouse gases are increasing. In this regard, building energy modeling (BEM) can be utilized for optimizing the building design, increasing the energy performance. At the same time building information modeling (BIM) is well integrated in the AEC-industry working as a repository for all the relevant project information, including the necessary data for performing an energy and thermal performance simulation. However, when extracting the information from BIM to BEM, the data transformation can be incorrect and/or even incomplete due to the lack of interoperability between the software, causing need for manual effort correcting the energy model.

In this master thesis we will investigate interoperability issues and solutions between the BIM-based computer-aided design (CAD) tool Autodesk Revit and the BEM software IDA Indoor Climate and Energy (IDA ICE) through the exchange format Industry Foundation Classes (IFC). Problems in this context means defective or inaccurate energy models caused by problems such as missing thermal zones and constructions elements, incorrect thermal properties assigned for constructions, etc.

The investigation involves case studies with the aim to automate the data transformation process between Autodesk Revit and IDA ICE. In the case studies the interoperability issues are investigated in a systematic order by dividing the structure of the investigation into Issues, Sub-issues, Sub-sub-issues and Cases. Issue describes the general interoperability issues to be investigated, while Sub-issue and Sub-sub-issue describes the different variations within the same interoperability issue to be investigated. Each combination of Issue, Sub-issue and Sub-sub-issue form a unique Case, which is the building model being used to investigate the interoperability issue. In cases where the interoperability issues cause problems the case studies have also explored solution methods to solve the problems. Three different solution methods have been explored, i.e. by manipulating the BIM models in Revit, by direct editing of the energy models in IDA ICE, or with use of the third-party software SimpleBIM to edit the IFC models before being imported into IDA ICE.

The case studies revealed that many of the interoperability issues caused problems of different nature and severity. In some cases, the problems would only lead to minor anomalies affecting the BEM simulation result, while other problems would cause the energy model to be completely defective, unable to be used for simulation. For most of the problems a solution was provided, either through Revit, IDA ICE or SimpleBIM. Some of the solutions were easy to implement, while others required extensive rework. Anyway, the work of the thesis may provide as a guidance in the process of BIM-based BEM on which interoperability issues that one should be extra aware of and how to solve any associated problems. This should contribute to more extensive use of BEM in the early design phase of building projects that ultimately should lead to increase the quality of green buildings, i.e. reducing the energy consumption and CO_2-emissions of the buildings.

Keywords:

1. Building energy modeling (BEM)
2. Building information modeling (BIM)
3. Interoperability issues
4. IDA ICE
5. Autodesk Revit

Content list

List of Figures

List of Tables

Abbreviations

TABLE 1: ABBREVIATIONS AND EXPLANATIONS

Abbreviation	Explanation
AEC	Architectural Engineering Construction
AHU	Air Handling Unit
BEM	Building Energy Modeling
BEPS	Building Energy Performance Simulation
BIM	Building Information Modeling
BPA	Building Performance Analysis
BPS	Building Performance Simulation
CAD	Computer-aided Design
EPD	Environmental Product Declaration
EU	European Union
FM	Facility Management
gbXML	Green Building Extensive Markup Language
GHG	Greenhouse Gases
HVAC	Heating Ventilation Air-conditioning
IAI	International Alliance for Interoperability
IDA ICE	IDA Indoor Climate and Energy
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Data Dictionary
MVD	Model View Definition
MEP	Mechanical Electrical Plumbing
NZE	Net-Zero Energy
SHGC	Solar Heat Gain Coefficient
SSC	Shortwave Shading Coefficient

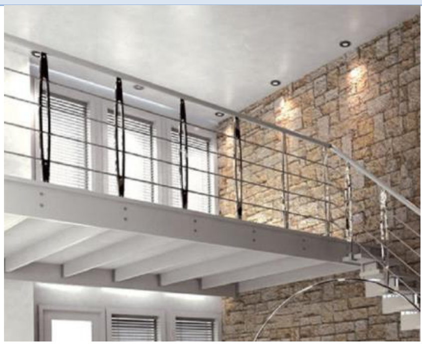
Symbols, Terms and Units

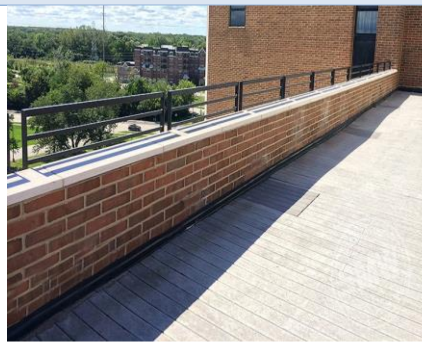
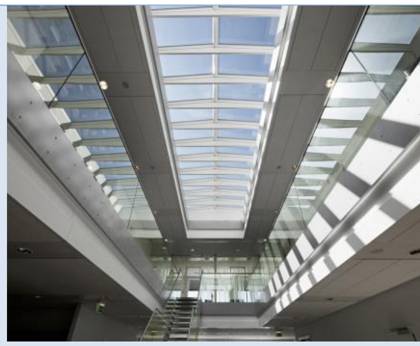
TABLE 2: SYMBOLS: TERMS AND UNITS

Symbol	Term	Unit
A	Area	m^2
C	Heat capacity	J/(kg*K)
d	Thickness	m
R	Thermal heat resistance	$(m^2*K)/W$
Sc	Total shading coefficient	Dimensionless
T	Solar transmittance	Dimensionless
T_{vis}	Visible transmittance	Dimensionless
U-value	Heat transfer coefficient	$W/(m^2*K)$
V	Volume	m^3
ρ	Density	Kg/m^3
λ	Thermal heat conductivity	W/(m*K)
Ψ	Thermal bridge value	W/(m*K)
ψ´´	Normalized thermal bridge factor	$W/(m^2*K)$

Terminology

TABLE 3: TERMINOLOGY: DESCRIPTION AND ILLUSTRATION

Terms	Description	Illustration
Atrium	Defined as an enclosed multi-story space in a building stretching vertically over multiple stories (Gritch and Eason, 2016). Often designed with window surfaces facing the external, either in the top or the sides, for daylight utilization.	 FIGURE 1: ATRIUM
Column	A vertical, rigid and slender construction element either for architectural or structural purposes. Architectural columns are for esthetical reasons, while structural columns are for support. The columns can either be integrated, fully or partially into a wall or be standing openly in a space. Usually made of concrete or steel.	 FIGURE 2: COLUMN
Curtain wall	Curtain wall is defined as a thin, usually aluminum-framed wall, containing in-fills of for example glass or metal panels (Vigener and Brown, 2016). They are non-structural outer walls attached to the structure of the building.	 FIGURE 3: CURTAIN WALL
Mezzanine	An intermediate floor with a ceiling height less than the floor above and below, and which is fully or partially open to the floor below it, constituting one space.	 FIGURE 4: MEZZANINE

Overhang	In building context an overhang is an element that extends or hangs over another part of the building.	 FIGURE 5: OVERHANG
Parapet wall	A low wall or railing around the edge of the roof. May serve as fire protection, safety and/or for esthetical reasons.	 FIGURE 6: PARAPET WALL
Skylight	Skylight is a part of the building´s fenestration system. It is a construction consisting of a frame (made of materials such as aluminum or wood) and glazing as in-fill material, i.e. like a window construction, but rather than a wall hosting the window, the roof is the host.	 FIGURE 7: SKYLIGHT

Chapter 1 Introduction

Background

The climate system and environment as we know it is about to change for the worse, having widespread impact on human and natural systems. Climate changes have been a hot topic for several years emphasizing its causes, effects, and suggestions on solutions to counteract the problem. The major climate changes are increasing concentration of greenhouse gases (GHG) in the atmosphere, greater global average surface temperature, rising sea level and melting of both the arctic ice and the land ice. The effects of these changes are more extreme weather and climate events like for instance lower cold temperature extremes and increasing warm temperature extremes, increase in the number of heavy precipitation events in a number of regions and extreme sea levels (Pachauri et al., 2014).

The response to counteract these climate changes are embodied in agreements and legislations on the international level and aim to reduce overall energy use and release of greenhouse gases. In the European Union (EU), the *Energy Performance of Buildings Directive* and the *Energy Efficiency Directive* are the main legislations concerning these goals in relation to buildings. The European Commission estimates in a report that buildings are responsible for 40% of energy consumption and 36% of CO_2-emissions in the EU alone. In the same report, it is further alleged that the energy consumption could be reduced by about 5-6% and CO_2-emissions by approximately 5% in the whole of EU by improving the energy efficiency of buildings (European Commission, n.d.).

To achieve these goals, optimization of building design and energy systems of buildings are essential. In that regard, whole-building energy modeling (BEM) to analyze and evaluate the building performance, could be a part of the solution.

The process of BEM has typically been known to be cost, time and labor intensive with results not being reproducible and trustworthy. The outcome being lack of BEM in building design, and in those cases that it has been used, it has not contributed significantly (Bazjanac, 2008).

The practice performing BEM has been and still is in many cases to gather geometry information from 2D CAD drawings or 3D models, and manually build the geometry of the energy model accordingly. The thermal view definition of the building, the HVAC-system and plant, lighting, occupant and equipment loads along with the building use schedules has been necessary to gather from the disciplines responsible for the information or to be estimated, assumed and/or simplified by the energy analyst. In either case this has been performed in a manual or semi-manual procedure entering already existing data and with subjective interpretation where needed (Bazjanac, 2008).

It would be most beneficial to implement BEM in the early design phase since this is when there is the most flexibility and the least cost for amendments. However, this is not always the case. Because of BEM´s dependency on other disciplines, the analysis usually starts when the architectural design and design of the HVAC-system have progressed sufficiently to provide enough information to depict the building (Bazjanac, 2008). In many cases this would mean that several important design decisions have already been decided upon, before energy performance measurements is taken into consideration. Another challenge is that building design is an iterative process with the design rapidly changing during the design phase and even throughout parts of the construction phase, eventually evolving into a finale product. This, along with the time and dependency factor of BEM already mentioned, the energy performance evaluation can easily come out of sync with the iterative design process, or to be postponed at a later stage. Without considering the energy efficiency measures in the early design stage, possibilities of reducing energy consumption could be lost. These measures often have a great impact on the building energy performance at a low cost.

The combination of limited project time, implementation of BEM in early design phase and being dependent on other disciplines, while at the same time building design being an iterative process, makes BEM an especially demanding task.

Building information modeling (BIM) as a concept, method or approach to store information, collaborate and communicate in a project environment has the recent years been widely adopted in the AEC-industry. Perhaps the most profound impact of BIM has been the collection of all necessary project data in a 3D-visualization environment, enhancing the collaboration between the disciplines in the building design process.

BIM also has the potential to be utilized in BEM for so-called BIM-based BEM. In BIM-based BEM the 3D model geometry, thermal data on constructions, material properties, etc. stored in a BIM software is exchanged with a BEM software. To be able to exchange the information from BIM to BEM an exchange format is necessary, the most common being the Industry Foundation Classes (IFC) or Green Building Extensible Markup Language (gbXML), but other formats do exist. The exchange processes between BIM and BEM do not always work properly. This can be due to the modeling practice of the participants, interoperability issues or limitations existing in the BIM software, the exchange format or the BEM software.

To aid the BIM-based BEM process, several third-party tools with different scope and capabilities have been developed. These tools are usually limited to a specific BIM and/or BEM software. Their capabilities can be limited to only perform one task, e.g. interpreting and translating the geometry from an architectural view to a thermal view, or they may offer to perform a range of tasks. Either way, their aim is to make the BIM-based BEM process semi- or fully automatic in order to reduce the time and effort spent performing BEM.

Master Thesis Work

Aim

The aim of the master thesis is to reduce the consultation cost in the AEC-industry related to the issue of exchanging data from building information modeling to building energy modeling.

Research Objectives

To reach the aim, several research objectives have outlined.

- Assessment of the interoperability issues effect on energy, thermal and daylighting performance and possible problems caused in BEM by the issues.
- Assessment on how the software Revit and IDA ICE interacts with each other in the BIM to BEM data exchange.
- Assessment of the possibilities and limitations of data exchange between Revit and IDA ICE.
- Assessment of the third-party software SimpleBIM to assist the BIM-based BEM data exchange between Revit and IDA ICE.
- Development of a BIM-based BEM methodology to automate or semi-automate the data exchange between Revit and IDA ICE.

Methodology

To ensure the fulfillment of the research objectives a methodology has been outlined.

- Review of the internal model structure and data exchange capabilities and limitations of Revit and IDA ICE.
- Systematic case studies to investigate if the interoperability issues cause any problems in the data exchange process between Revit and IDA ICE. The case studies also investigate solution methods for the problems that occurred, performed either in Revit, IDA ICE or the third-party software SimpleBIM.

Impact

The fulfillment of the objectives and the aim should contribute to lower the threshold making use of BEM in the AEC-industry throughout building projects, but especially in the early design phase. This should stimulate to better design of high quality green buildings, i.e. buildings with less energy consumption and CO_2-emissions.

The Case Studies

This master thesis investigates interoperability issues between the BIM-based CAD tool Autodesk Revit 2018 and the BEM software IDA ICE version 4.8. The investigation is done through case studies, involving the two software, the exchange format IFC and a third-party software called SimpleBIM. In the case studies, the interoperability issues are investigated through various building models created in Revit, which then are exported as IFC files and imported into IDA ICE. All the building models is based on the BESTEST Case 600 – Base Case Low Mass Building described in the ANSI/ASHRAE Standard 140-2001. The imported IFC models and generated energy models in IDA ICE is explored for relevant findings.

For the interoperability issues where problems occur, different approaches to solve the problem has been tried established. The approaches include manipulating the BIM models in Revit, editing the energy models in IDA ICE or by editing the IFC models in the third-party software SimpleBIM.

The case studies investigate the interoperability issues in a systematic order by dividing the structure of the investigation into Cases, Issues, Sub-issues and Sub-sub-issues. Issue describe the general interoperability issue being investigated. Sub-Issue and Sub-sub-issue describes the variation of options within each interoperability issue, meaning use of different modeling approaches or Revit tools which can be used to model the BIM models containing the interoperability issues. The Cases which constitutes the actual building models are the combination of Issue, Sub-Issue and Sub-sub-issue or only Issue and Sub-issue.

Disposition

The disposition of the thesis is as following. Chapter 2 offers background information on BIM, BEM and the internal model structure and exchange capabilities of Autodesk Revit and IDA ICE. Further on it continues by describing the differences in geometry representation between BIM and BEM, the concept of interoperability and the process of BIM-based BEM. At last it presents energy and thermal concepts and definitions relevant for the case studies and explains how these are managed in IDA ICE. In Chapter 3 the work of the case studies is given. It first presents the interoperability issues possible influences on BEM energy and thermal performance factors and potential technical issues that may occur. It then proceeds by presenting the modeling procedure, the Revit BIM models and the resulting energy models in IDA ICE for all the cases. The chapter also explains the more general part of the Revit modeling, Revit IFC export and the IDA ICE IFC import involved in the case studies. Chapter 4 presents the identified problems and the suggested solutions. Chapter 5 provides a conclusion of the case studies.

Chapter 2 Background (Extended)

This chapter is divided into five main parts; BIM, interoperability, BEM, energy and thermal concepts and definitions and BIM-based BEM third-party methodologies/tools. The first part gives a brief history on collaboration, communication and information sharing in the AEC-industry and BIM´s place in all this. It also explains BIM ´s connection to object-oriented parametric modeling and what separates it from basic 3D modeling. It also includes a review on the internal model structure and exchange possibilities of Autodesk Revit. The second part, interoperability, shortly presents BuildingSMART and relevant interoperability standards and terms. The chapter also explains the differences in geometry representation between BIM and BEM, including architectural and thermal view, space boundaries and thermal zones. The part about BEM first gives a general introduction on building energy modeling before presenting a review on the internal model structure and exchange possibilities of IDA ICE. The next part gives a description on energy and thermal concepts and definitions that are relevant for the work of this thesis. At last the concept of BIM-based BEM methodologies and tools to assist the BIM to BEM data exchange is explained along with a short introduction of the third-party software SimpleBIM.

For the background information that the reader is familiar with, it is recommended to skip these sections and proceed directly to the methodology chapter.

2.1 Building Information Modeling

2.1.1 Collaboration, Communication and Information Sharing in the AEC-Industry

The traditional practice in the AEC-industry to communicate project information has been by sharing of physical paper and 2D computer-aided drawings (CAD). This is still a widely common practice even today. This method is slow and prone to errors compared to BIM, often resulting in costly affairs, delays and friction between the project participants. The industry adapted to overcome these issues by introducing several changes and new measures, one of them being 3D CAD tools (non-BIM-ready). This contributed in reducing the time spent on communicating project information. However, the conflicts regarding design solutions between the disciplines and the critical assessment of building design as an iterative process, would still be cumbersome. The result was to do these assessments in retrospect after completion, meaning cost demanding improvements.

The concept, approach or methodology of building information modeling (BIM) had its introduction already in the mid-1970s, then under the term *building description system*. During the 1980s the term evolved into *building product* *models* and *product information models*. It was not before the year 1986 that the attributes of BIM and the technology to implement it, was described the way we know it today, but then as the term *building model*. During the 1990s the expression *building information modeling* started to appear in both the research community and the industry by vendors coining the term to their products (Eastman et al., 2011).

The figure below shows a simplified summarizing timeline of the collaborative techniques in the AEC-industry and the placement of BIM in that respect.

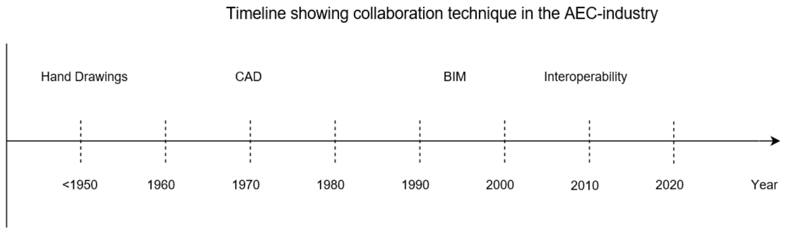


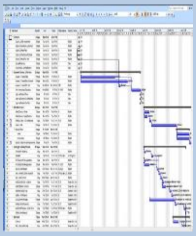
FIGURE 8: TIMELINE ON THE DEVELOPMENT OF COLLABORATIVE TECHNIQUES IN THE AEC-INDUSTRY

There are multiple definitions and understandings of building information modeling in circulation and not one definite definition exists. Some refer to BIM as being process-oriented or product-oriented. In this context BIM is independent of software. Instead it focuses on the process as a methodology to ensure good collaboration and communication in a project environment and being a tool to plan, design, construct and manage buildings and infrastructure. One could also talk about software for design and analysis being qualified as a BIM application, or being a BIM-ready software, meaning they fulfill the necessary conditions being a collaborative BIM tool. In (Eastman et al., 2011) it is suggested that IFC certification be deemed a sufficient, but not necessary condition of such a software.

The introduction of BIM with the possibility to create a virtual 3D model of the building with precise geometry and containing all relevant project information has been very promising for the AEC-industry. It has improved the collaboration between the participants and contributed in a more integrated design and construction process.

The flexibility of BIM has made it applicable in a range of tasks performed in a project environment and even throughout the whole life-cycle of buildings. BIM is differentiated into dimensions depending on the particular data linked to the building information model, ranging from 1D to 7D. The 1D dimension is the starting point or scratch point of the building project and includes data such as building functional program, regulation plans, etc. that should be used for making project strategies, early cost estimation etc. The 2D dimension represent vectors constituting 2D drawings such as floor plan views or elevation views for 2D visualization purposes. The 3D dimension represents the virtual 3D parametric building information model with graphical and non-graphical information. This dimension including both the graphical and non-graphical information would be focus of this thesis. Further on we have the fourth dimension representing time and is for scheduling purposes. The fifth dimension of BIM is cost data and can be utilized for cost estimations and budgeting. The 6D dimension represents the sustainability perspective of the building. This includes environmental and energy related data such as life-cycle assessment information, thermal data on the building envelope, energy systems efficiency, etc. The application of the 6D dimension could for instance be for environmental impact assessment or energy and thermal performance analysis. This dimension is related to the work of this thesis as well. The last dimension, 7D, is for facility management (FM) maintenance and operation purposes, fulfilling the whole life-cycle of the building. Table 4 summarize the data and application of all the BIM dimensions.

TABLE 4: THE BIM DIMENSIONS – DATA AND APPLICATION

Dimensio	1D Scratch Point	2D Vector	3D Parametric Building Information Model	4D Time	5D Cost	6D Sustainability, Environmental, Energy, Thermal	7D Facility Management, Maintenance, Operation
Data	• Existing conditions. • Regulations. • Building functional program.	• 2D drawings. • Floor plan view. • Elevation/ section view.	• Graphical & non-graphical building information.	• Component installation/ construction time. • Building sequences. • Building dependencies.	• Capital cost. • Running cost. • Maintenance cost.	• Environmental product declaration (EPD`s). • Energy systems energy efficiency data. • Life cycle assessment information.	• Component installation date and status. • Maintenance / operation manuals. • Warranty data. • Decommissioning data.
Application	• Project execution strategies. • Building room/ area layout. • Early cost estimations.	• 2D visualization.	• 3D visualization. • 3D Virtual walkthroughs.	• Visualization of project activities and progress. • Time scheduling. • Site planning. • Activity conflict detection.	• Overall project cost estimation. • Budgeting. • Cost plan. • Cost tolerance follow-up.	• Energy and thermal performance analysis. • Environmental impact assessment. • LEED verification.	• Building operation and maintenance purposes.
Illustration							

2.1.2 Computer Aided Modeling versus Building Information Modeling – Traditional Modeling vs. Object-oriented Parametric Modeling

The technology of building information modeling, in the sense of a BIM-based software, has its roots in computer-aided drawing (CAD) and the 3D modeling technologies "constructive solid geometry (CSG)" and the "boundary representation approach (b-rep)".

It is important to differ between BIM design tools and CAD systems because of their differences in properties and how they manage objects. First, CAD tools generate digital files. The first CAD tools produced plot drawings in 2D containing vectors with associated line-types and layer identifications. The development of 3D modeling with the technologies of CSG and b-rep later made it possible to model 3D objects in CAD. As time went by the CAD systems became more intelligent, and the focus shifted from the drawings and 3D models to sharing of information contained within the design, eventually evolving into building information modeling. In this context (Eastman et al., 2011) defined BIM as “a modeling technology and associated set of processes to produce, communicate, and analyze building models”, and presented the following criteria’s necessary to characterize building information modeling:

- The building components should be intelligent objects, i.e. the objects should contain graphic, data attributes and associated rules.
- The objects shall also have data that describes how they behave, e.g. thermal properties, density etc.
- The data must be consistent and non-redundant, i.e. a change in an objects data should be equally represented in all views of the object.
- All views of a model should be represented with coordinate data.

The BIM tools existing now are based on the concept of object-based parametric modeling. Object-based parametric modeling allows for definition and control of 2D and 3D shapes and properties of an object by relating the object to parameters in a hierarchy level and associated rules. The parameter hierarchy can be of the assembly level (group), sub-assembly level (sub-group) or at an individual object level. The parameter values can either be user-defined, fixed or relative to other shapes within the model. The parameters determine the geometrical and non-geometrical properties of the object allowing the object to vary depending on the parameter input. The rules automatically alter the object depending on user control or in the context of change in other objects related to it. Examples of object parameter definitions are for instance *distance* or *angle*, while the rules can be such *as attach to* or *parallel to* (Eastman et al., 2011).

The major difference between non-object-based traditional CAD modeling and object-based parametric modeling is the intelligence of the model. In the former approach any kind of altering of the geometry must be done manually, while in the latter approach form and geometry can change automatically dependent on “high level” user control and change in context.

2.1.3 Autodesk Revit

Autodesk Revit is a series of three software developed by Autodesk, the three being Revit Architecture, Revit Structural and Revit MEP (Mechanical, Electrical and Plumbing). It is a BIM-worthy 3D CAD and object-based parametric modeling software used by disciplines such as architects, structural engineers, MEP engineers, construction professionals, etc. The current version is Autodesk Revit 2018.2. Before 2013 the different Revit disciplines (Architectural, Structural and MEP) were separate programs, but since 2013 they have been integrated into the same software.

The Internal Model Structure of Autodesk Revit

The internal hierarchy structure of Autodesk Revit decides how model elements and information within a model is managed. In respect to the process of BIM-based BEM it is relevant because it is valuable to know how the structure of Revit interacts with the structure of the receiving BEM software.

In Revit the element hierarchy from top to bottom level is “Category”, “Family”, “Type” and “Object Instance”, respectively (Autodesk, 2018). Figure 9 shows the internal model structure of Revit with examples at each level.

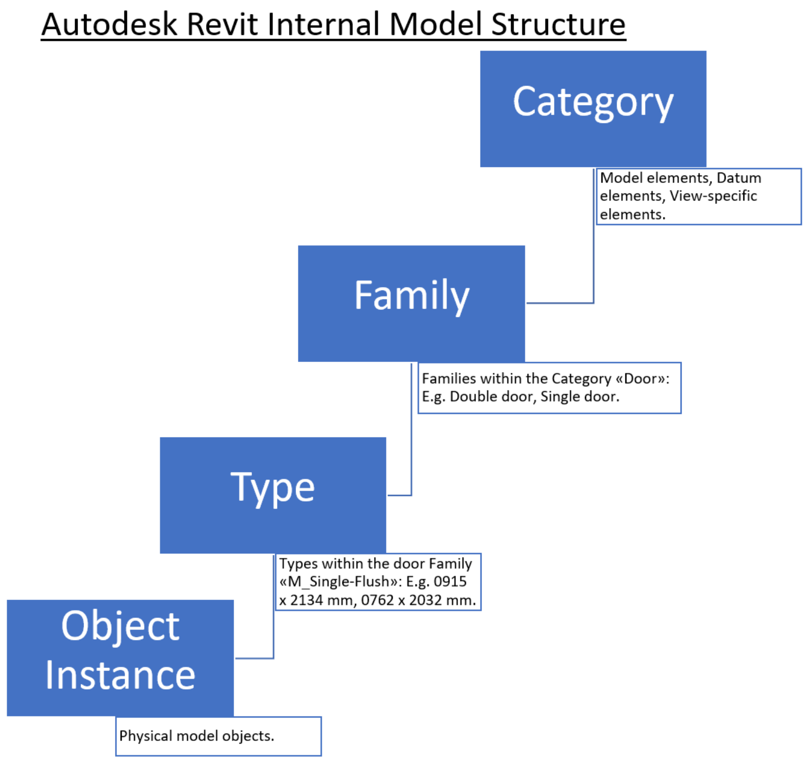


FIGURE 9: AUTODESK REVIT 2018 INTERNAL MODEL STRUCTURE

The top level, “Category”, are built into Revit with a fixed list and consist of three major element groupings – the “Model elements”, “Datum elements” and “View-specific elements”. Figure 10 shows the hierarchy structure of the Revit “Category” element groupings along with examples of instances associated with the groupings.

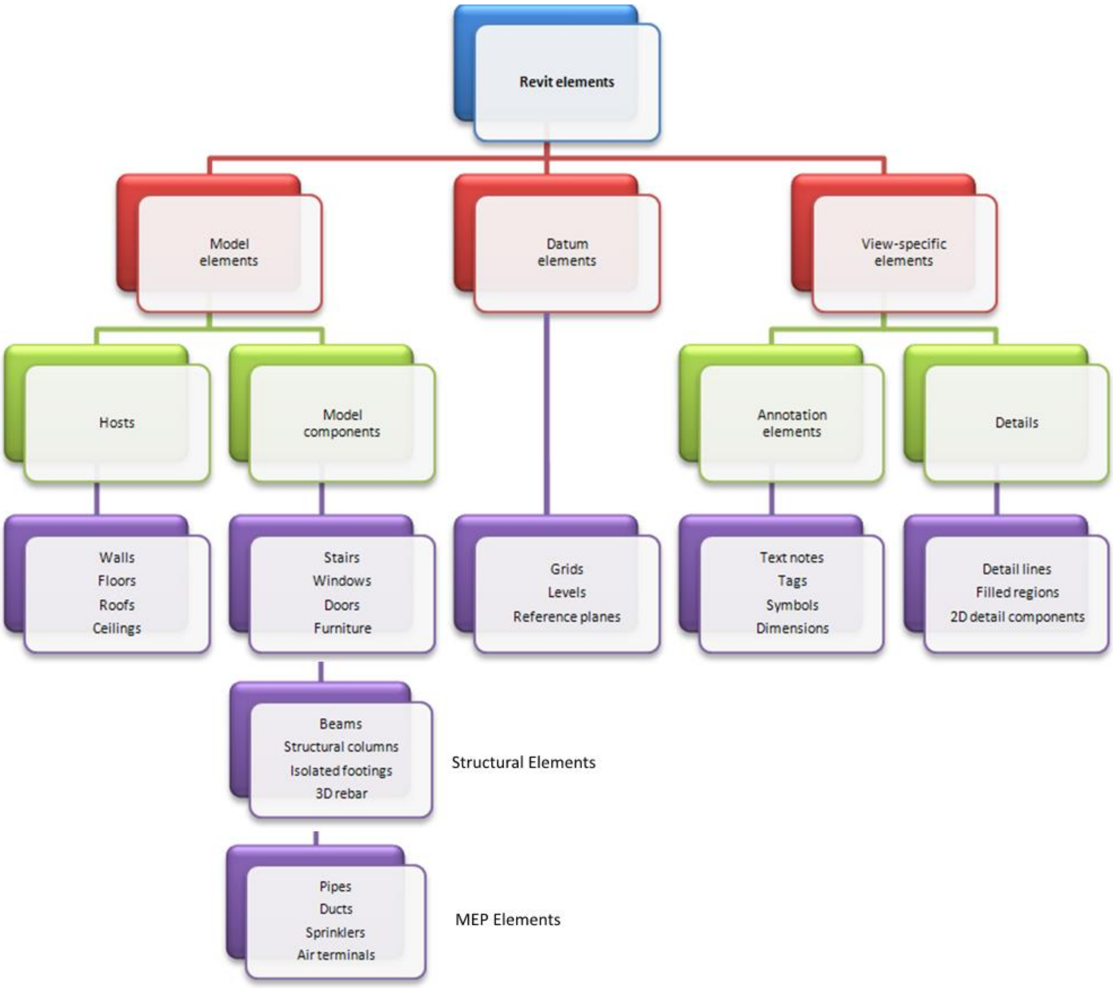


FIGURE 10: AUTODESK REVIT "CATEGORY" STRUCTURE (AUTODESK, 2018)

The groupings contain the geometric definition of an element and the parameters associated to the element, controlling its basic functionality, behavior and features. The "Model elements" are divided into "Host" and "Model components" and represent the 3D geometry of the building model. "Host" elements include elements such as walls (structural and non-structural), floors and ceilings/roofs. "Model components" are all other elements of the building model, for instance windows, doors, beams, sprinklers, ducts etc. "Datum elements" are for example grids, levels, and reference planes, which define the project context. "View-specific elements" are used to describe and document the model and consist of the subcategories "Annotation elements" and "Details". "Annotation elements" are 2D components for documenting and scaling the model. Examples of "Annotation elements" are dimensions, tags or symbols. "Details" on the other hand are 2D items used for detailing the building model in a specific view. Examples of "Details" are detail lines, filled regions etc.

The second level in the hierarchy, "Family", offers more specific characteristics than "Category". Within the "Category" *door* are *Double door* and *Single door* as two examples of "Families".

“Type” is the third level of the hierarchy, representing variations within the different kinds of “Families”. Within the door “Family" *M_Single-Flush* exists several dimensions (e.g. 0915 x 2134 mm) where each specific dimension represents a “Type” or “Type property”.

The fourth and lowest level of the hierarchy is “Object Instances”, being the actual model elements.

Figure 11 is an example illustrating the internal model structure of Autodesk Revit 2018 with the *M_Single-Flush* door. The “Category” of the door is “Model Elements” with the *door creation tool* as the “Model component”, highlighted red to the left in the figure. The “Family”, *M_Single-Flush*, and “Type”, *0915 x 2134mm*, of the door is highlighted in red under “Type Properties” to the right in the figure. The “Object Instance” is seen as the door element itself in the building model, here highlighted blue.

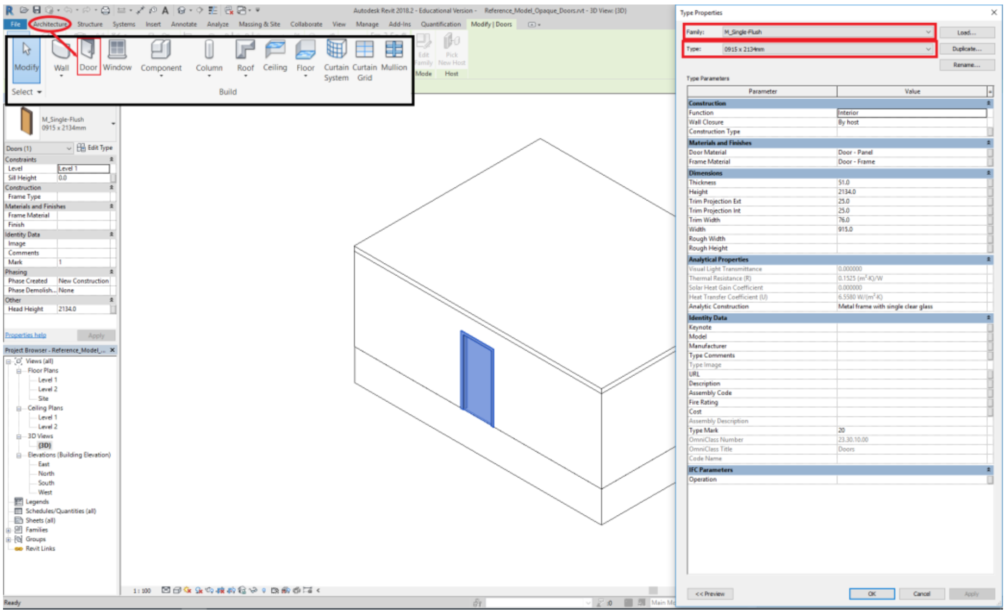


FIGURE 11: A SNAP SHOT SHOWING THE AUTODESK REVIT 2018 INTERNAL MODEL STRUCTURE (MODIFICATIONS IN RED)

The appearance and behavior of an element is determined by both “type properties” and “instance properties”. Within a “Family”, all elements have the same set of “type properties”, while the property values depend on the chosen “Family Type”. “Instance properties” are the same for elements belonging to the same “Family Type”, with values depending on the location of the element (Autodesk, 2018).

To summarize, the hierarchy structure of Revit from top to bottom is “Category”, “Family”, “Type” and “Object Instance”. Objects at the same level of the hierarchy share common characteristics. A modification at a certain level will affect all elements bounded by that level.

Revit Exchange Formats

Revit IFC Export

Revit is fully certified for IFC import and export (Autodesk, 2017a). For import, meaning to open or link an IFC file, it supports the exchange standards IFC2x3, IFC2x2, IFC2x and IFC4 (the latter only with the ability to link). For export it supports the standards IFC4, IFC2x3, IFC2x2. The IFC import/export makes it possible to exchange building models from/to Revit with other IFC-certified software.

Many of the elements found in the internal model structure of Revit corresponds to IFC containers describing building objects including parameters with meaningful values. An example of this is wall objects in Revit which corresponds to the IFC container *ifcWalls*. These objects are automatically being exported from Revit to IFC. Some other Revit "Families" needs to be mapped to IFC containers if they are to be exported. See Appendix A: Table 22, for Revit supported IFC classes for the IFC export mapping file (Autodesk, 2017c).

Other Revit Export Formats

Revit also supports the gbXML export format according to version 0.37 of the gbXML schema for exchange of information with energy and thermal analysis tools.

Other export formats supported by Revit include the CAD formats DWG, DXF, DGN and SAT files, DWF/DWFx files, ADSK exchange file for exchange of building site information, FBX file for 3D view and animation and image file options and more.

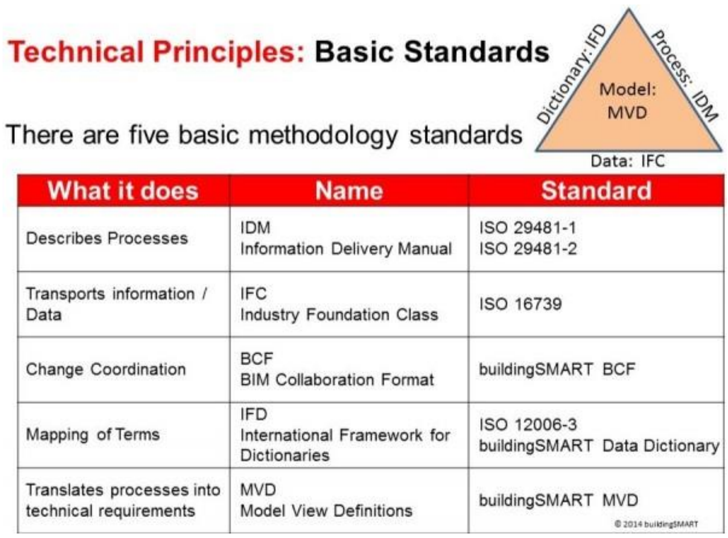
2.2 Interoperability

2.2.1 BuildingSMART

Interoperability is the ability for computers or software to interact with each other despite its system architecture. To improve the interoperability in the AEC-industry, the company Autodesk organized twelve companies in 1995, to prove that interoperability between the many software programs in the building industry would be beneficial for all participants. The seven companies were from design, construction, engineering and software development, all within the building industry. The collaboration concluded that interoperability was feasible and that it had huge commercial potential. It also concluded that it needed international standards open for all, to avoid proprietary barriers between different domains. As a response the International Alliance for Interoperability (IAI) was formed a year later in 1996, with representatives of the building industry from North America, Europe and Asia. A council within IAI was organized with the responsibility to develop international standards. In 2008, IAI changed its name to BuildingSMART (BuildingSMART, n.d.-a).

2.2.2 Interoperability Standards

BuildingSMART has developed five standards with the intention to share and exchange BIM data between all participants involved in the life-cycle of a building, independently on the software application. All five standards are based around the common data schema Industry Foundation Classes (IFC). The five standards are listed in the figure below, followed by a more detailed description on all of them.



What it does	Name	Standard
Describes Processes	IDM Information Delivery Manual	ISO 29481-1 ISO 29481-2
Transports information / Data	IFC Industry Foundation Class	ISO 16739
Change Coordination	BCF BIM Collaboration Format	buildingSMART BCF
Mapping of Terms	IFD International Framework for Dictionaries	ISO 12006-3 buildingSMART Data Dictionary
Translates processes into technical requirements	MVD Model View Definitions	buildingSMART MVD

FIGURE 12: THE FIVE STANDARDS OF BUILDINGSMART (BUILDINGSMART, N.D.-B)

Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC) is an open standard for information sharing in the building industry. IFC is a data schema that can be seen as a large code, which stores information about the building geometry and other relevant building data. Since many participants using unique software applications are involved during the whole life-cycle of a building, the IFC data schema support information sharing across the different tools (BuildingSMART, n.d.-c).

Model View Definition (MVD)

Model View Definition (MVD) is a subset of the IFC schema, which includes implementation guidance for the IFC concepts, classes, relationships, property sets, quantity definitions, etc. used within a subset. The MVDs are used to indicate which data is needed for different domains. All the different parties in an OpenBIM project extract the needed information from the MVD relevant for the work within its own domain (BuildingSMART, n.d.-c).

Information Delivery Manuals (IDM)

Information Delivery Manuals (IDM) is a standard that organize when and which information to be communicated between the participants in the project organization (BuildingSMART, n.d.-c).

BIM Collaboration Format (BCF)

The BIM Collaboration Format (BCF) standard communicates issues, proposals and change requests in the BIM model, without having to exchange the whole BIM model as bulk data. BCF exchange can be done manually with open file XML format (bcfXML) or automated with RESTful webservice (bcfAPI) (BuildingSMART, n.d.-c).

International Framework for Data Dictionary (IFD)

International Framework for Data Dictionary (IFD) standard is a dictionary by BuildingSMART with the purpose to ensure that the participating parties understands the terminology in the OpenBIM models the same (BuildingSMART, n.d.-c).

Green Building Extensible Markup Language (gbXML)

Green Building XML is not a product of BuildingSMART, but like IFC, it's a schema to facilitate the transfer of BIM data to enhance the interoperability between building design and analysis software. The introduction of the gbXML schema came in the year 2000 when the company Green Building Studio submitted for its inclusion in the aecXML(TM). This was an initiative by the company Bentley Systems to provide a framework for using the XML standard for communication and data inter-change in the building industry (de Jong and Van Der Voordt, 2002). In 2009, the gbXML schema became a standalone entity. The schema uses the computer language XML, which makes it possible for computer software to communicate with little or no human interventions.

2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View

The representation of the model geometry in BIM and BEM are distinctive. The representation of building models in BIM tools involves detailed definitions of the geometry, also known as an architectural view. BEM software require less detailed geometry definitions to represent their energy models and is called a thermal view. In the exchange of building geometry from BIM representation to BEM representation, it is necessary to perform actions to interpret, translate, simplify and reduce the geometry.

The building geometry of BEM energy models involves the definition of a system of surfaces. These surfaces include walls, ceilings/roofs, floors/slabs, windows, doors, beams and columns, constituting spatial zones. The name of these surfaces are space boundaries, which define spaces or zones in the energy model, also known as thermal zones. Most BEM tools only considers 1D heat transfer with the direction of heat perpendicular to the space boundary surfaces between the thermal zones and ignore 2D and 3D heat transfer.

As defined by (Bazjanac, 2010), there exists five different types of space boundaries that BEM tools must contain. A brief description of each type and figures to illustrate the different kinds follow below.

1st Level Space Boundary

These space boundaries are surfaces of elements continuously visible within a space, regardless of any intersecting elements or the number of spaces on the other side of the element. 1st level space boundaries may not consider the heat flow through the surfaces and thus are not suitable for use in BEM but are applicable for visualization purposes. Figure 13 illustrates a 1st level space boundary.

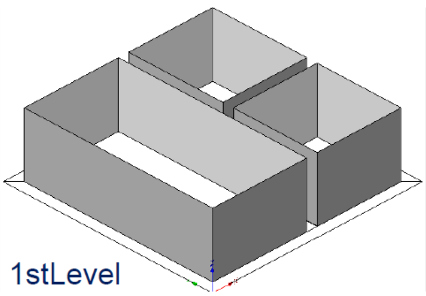


FIGURE 13: 1ST LEVEL SPACE BOUNDARY (WEISE ET AL., 2009)

2nd Level Space Boundary

In BEM each thermal zone has their unique mass and thermal characteristics and control patterns. In these cases, 2nd level space boundaries are imperative to simulate the transmission rate of mass and heat being transported through the surface elements from one zone to another. Figure 14 illustrates how a building model with 1st level space boundaries are translated into an energy model with 2nd level space boundaries. The figure shows two smaller zones having a common wall element bounding them to the larger zone. The bounding wall as a 1st level space boundary is divided in two separate 2nd level space boundaries to correspond to the model´s thermal view.

2nd level space boundaries are further divided into type 2a and 2b. Type 2a is for the case when there is a space on the opposite side of the element providing the space boundary. Type 2b is when there is a cavity on the opposite side of the element providing the space boundary.

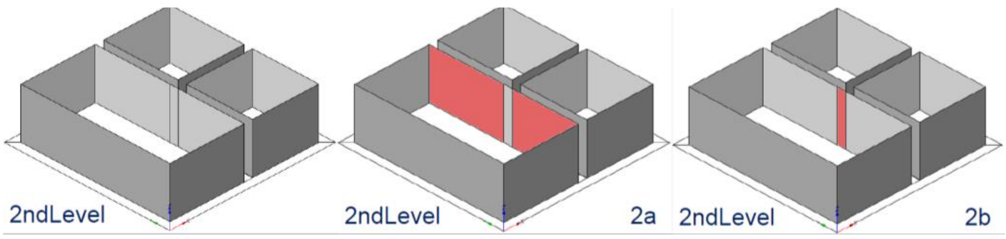


FIGURE 14: 1ST TO 2ND LEVEL SPACE BOUNDARY. LEFT: 1ST LEVEL SPACE BOUNDARY. MIDDLE: 2ND LEVEL SPACE BOUNDARY, TYPE 2A. RIGHT: 2ND LEVEL SPACE BOUNDARY, TYPE 2B (WEISE ET AL., 2009)

3rd and 4th Level Space Boundary

The 3rd level space boundaries are surfaces where there is not occurring any heat transmission because there are no zones on the other side of the surface to receive the perpendicular flow.

The 4th level space boundaries are boundaries that depend on the defined reference line of the walls. They arise when wall elements intersect and merge, and the wall reference line of the wall being intersected is not defined in the plane of the intersection. This will leave a surface area not accounted for.

Figure 15 illustrates both 3rd and 4th level space boundaries.

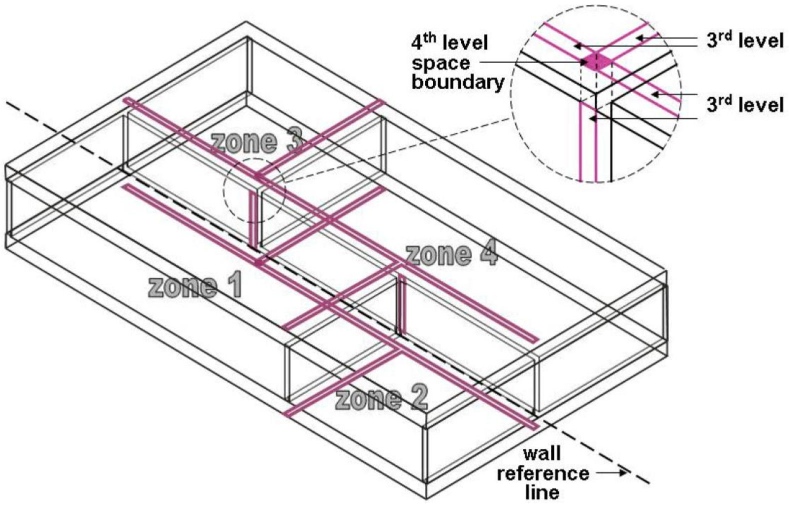


FIGURE 15: 3RD AND 4TH LEVEL SPACE BOUNDARY (BAZJANAC, 2010)

5th Level Space Boundary

Wall elements not intersecting perpendicular to each other result in a part of the intersecting wall to be defined as 5th level space boundary. These space boundaries account for surfaces with transmission of heat not reaching any adjacent zones. Figure 16 is an example of 5th level space boundary.

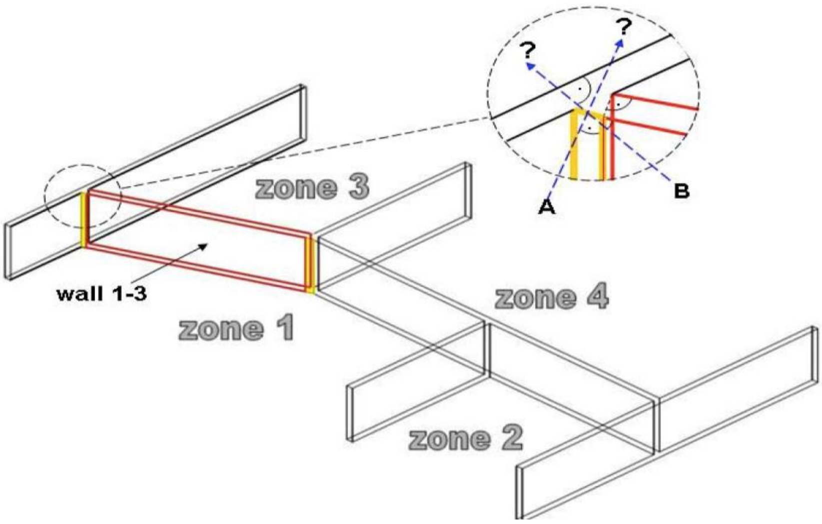


FIGURE 16: 5TH LEVEL SPACE BOUNDARY (BAZJANAC, 2010)

Space boundaries can be defined for internal, external or virtual surfaces. The boundaries come in pairs, one belonging to the outside and one to the inside of an element. External surfaces are an exception to this rule because the outside cannot be defined as a space or zone and therefore external surfaces contain only a single space boundary corresponding to the inside of the element. Internal elements may contain all five levels of space boundary, while external surfaces can only be defined as either 1st or 2nd level space boundary. Virtual surfaces or “air walls” that represent non-physical boundaries of zones are defined as 2nd level space boundary.

Elements that need to be represented with space boundaries include walls, slabs, roofs, columns, windows, doors, and space separators, while elements such as beams, stairs/ramps do not (Weise et al., 2009).

To summarize, 1st level space boundaries is implemented in visualization tools to represent the architectural view of the building geometry and do not consider the heat transmission through surfaces. 2nd level and higher levels of space boundaries are implemented in BEM tools to represent the energy model´s thermal view and do consider the heat transmission through surfaces.

2.3 Building Energy Modeling

2.3.1 General Introduction of Building Energy Modeling

Building energy modeling (BEM) is a physics-based software usually consisting of a simulation engine and a graphical user interface (Maile et al., 2007). It is the process of making use of a computer-based software to build a virtual energy model of a real building and then simulate the behavior of the model in terms of energy flows. The simulation engine contains mathematical and thermodynamically algorithms with fundamental physical principles and engineering models. With dynamic boundary conditions assumed and normally with the help of numerical methods, simulations based on text format input are executed which generates simplified and approximated solutions on a real-world phenomenon (Maile et al., 2007), (Carlucci, 2017).

To perform BEM, essentially six main categories of input parameters are required. These are illustrated in Figure 17. An elaboration on the input categories follow below the figure.

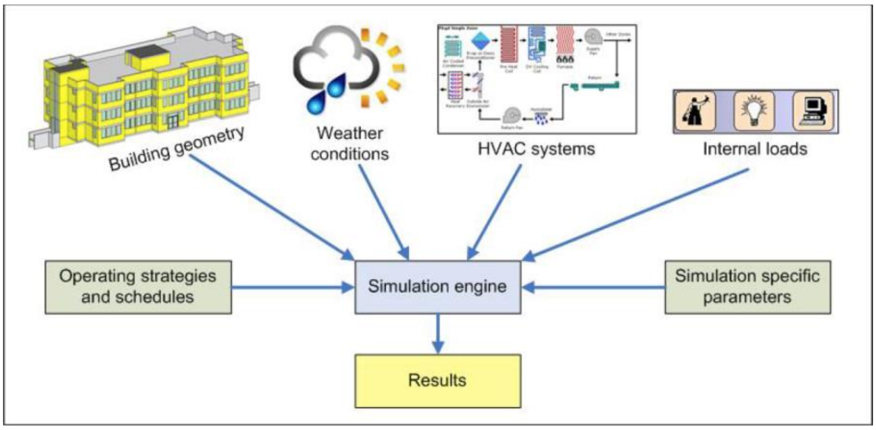


FIGURE 17: BEM INPUT PARAMETERS (MAILE ET AL., 2007)

- The building geometry includes the geometry of external and internal walls, ceilings/roofs, floors/slabs, windows and doors, along with their respective construction materials and thermal properties.
- Local weather conditions, in the form of a climate file, expressing the external load on the building. The climate files represent a statistical reference for the typical climate and weather parameters given at a specific location.
- Internal loads including loads from occupants, lighting and electrical appliances along with their respective schedules of use.
- The HVAC system and plant with operating strategies and schedules.
- Specific simulation parameters such as definition of numeric converge tolerances, period of simulation and simulation time step.

BEM output results can for example be energy use, thermal loads with system responses, thermal comfort indicators, lighting metrics, etc. The results can be utilized for comparison of building design alternatives with the purpose to optimize the building´s design and energy systems, increasing its energy efficiency.

2.3.2 IDA Indoor Climate and Energy (IDA ICE)

IDA Indoor Climate and Energy (IDA ICE) is a building energy modeling software for whole-year detailed and dynamic multi-zone simulation application, developed by EQUA Simulation AB (Equa Simulations, n.d.). The latest version of the software is 4.8 released in the first quarter of 2018. The software enables one to perform analysis on thermal indoor climate and energy consumption of a whole building.

The Internal Model Structure of IDA ICE

During the work of this thesis no documentation on the internal model structure of IDA ICE has yet to be found. Nonetheless, the structure will be given here as understood by the author of this thesis.

The hierarchy structure of IDA ICE seems to be from top to bottom level; “Surface”, “Type”, “Construction” and “Object Instance”. The structure including a description of each level is shown in Figure 18.

IDA ICE Internal Model Structure

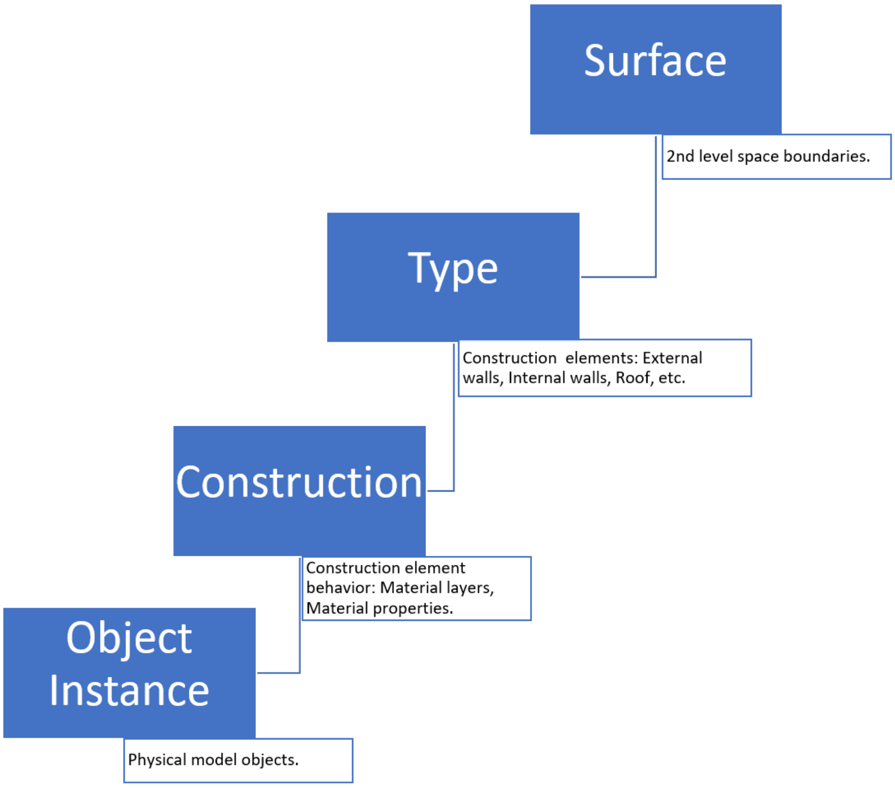


FIGURE 18: IDA ICE INTERNAL MODEL STRUCTURE

The “Surface” level represents the 2nd level space boundaries constituting the energy model. They form the thermal zones of the energy model and manage the heat transmission between the zones. Refer 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View for a more detailed explanation on 2nd level space boundaries.

The next level in the hierarchy structure is “Type”. “Type” describes the construction element of the “Surfaces” and the different kind of types are listed in Table 5.

TABLE 5: IDA ICE “TYPE” CONSTRUCTION ELEMENTS

External wall	Internal wall
Internal floor	Roof
External floor	Basement wall towards ground
Slab towards ground	Glazing
Door construction	Integrated window shading

“Construction” is the third level of the hierarchy structure. In this level the material layers and properties of the “Type construction” elements are defined.

The last level of the hierarchy structure is “Object Instance”. This is the physical element objects of the energy model that are seen in the floor plan view or 3D view of IDA ICE.

Figure 19 illustrates the internal model structure of IDA ICE. The window on the upper right side of the figure shows the different “Type construction” elements. To the lower left side is “Construction” with material layers and properties. On the bottom right side is a 3D view showing the actual physical “Object Instances” constituting the 2nd level space boundary surfaces of the energy model.

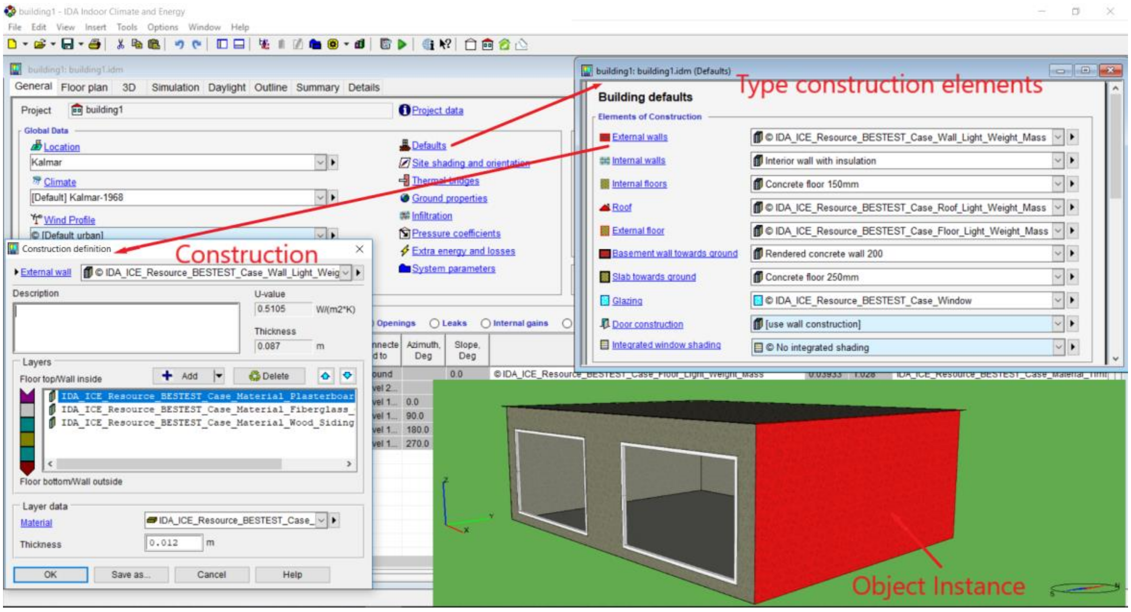


FIGURE 19: A SNAP SHOT SHOWING THE IDA ICE INTERNAL MODEL STRUCTURE (MODIFICATIONS IN RED)

IDA ICE Import

IDA ICE has the ability to import IFC files and version 4.8 of IDA ICE supports the IFC releases IFC2x, IFC2x2 and IFC2x3 (Equa Simulations, 2018).

A small selection of other files that IDA ICE support for import is CAD and vector graphic files such as DXF, DWG and SKP and bitmap files as for instance BMP, JPEG and PNG.

2.4 Energy and Thermal Concepts and Definitions in BEM

In BEM energy and thermal simulation there are many physical phenomena involved that impact the energy balance of the energy model. For those relevant for this thesis the concepts behind these phenomena, how they influence the energy and thermal conditions of the building and how they are managed in IDA ICE will be explained.

Thermal Insulation

Thermal heat conductivity and thermal resistance are two thermal properties important to define a construction thermal insulation. Thermal heat conductivity, λ (W/m*K), is a property measuring a materials ability to conduct or transport heat. Thermal resistance, R (m^2*K)/W, describe the resistance the heat encounter going through a material with a certain thickness, d (m), and a given thermal heat conductivity. Based on these two properties the U-value (W/m^2K), also known as heat transfer coefficient, can be calculated. Below is the formula for thermal resistance and heat transfer coefficient.

$$R = \frac{d}{\lambda}$$

EQUATION 1

$$U = \frac{1}{R}$$

EQUATION 2

The U-value describes the level of difficulty the heat experience going through components, in other words it is a measure on the thermal insulation of building components. The lower the U-value, the better the insulation ability, meaning less heat loss through the component.

In IDA ICE thermal conductivity is one of the three standard material properties. Each construction can consist of several materials, where the total U-value for a construction depends on its composition of materials. For the construction components to have the proper heat loss in BEM, it is important to assign the correct construction to the respective surfaces of the energy model.

Thermal Bridge

A thermal bridge is a part of the building construction that has a lower thermal resistance than the construction in general. The thermal bridges can be defined for each building part separately, Ψ (W/m*K), or as an average for the whole building based on the area of the envelope or the floor area, $\psi^{``}$ (W/K). The latter goes by the name normalized thermal bridge factor. The formula for both definitions are given below. The lower the value, the less heat loss due to thermal bridges.

$$\psi = \sum_k \psi_k * l_k$$

EQUATION 3

$$\psi^{``} = \frac{\psi_k}{A}$$

EQUATION 4

l_k and ψ_k are the length (m) and heat loss (W/(m^2*K) due to the thermal bridge(s) and A is the total area of the envelope/floor.

In IDA ICE the thermal bridges are managed in the “Thermal bridges” option, where the heat loss/gain for every thermal bridge is defined as a value, independently on the geometry of the energy model. Here the heat loss due to thermal bridges is possible to specify as the normalized thermal bridge factor, Ψ`` (W/m^2K), where the m^2 refer to the total floor area of the building. In the case where the floor area of the energy model deviates from the reality and the thermal bridge is specified in this way, the resulting heat loss due to thermal bridges will be incorrect.

Thermal Mass

Thermal mass is a material´s ability to absorb and store heat. It depends on material properties such as heat conductivity, density, ρ (kg/m^3), and specific heat, c (J/kg*K).

Materials such as concrete and brick have a high thermal mass, i.e. a great ability to absorb and store heat, while mineral wool and wood have a low thermal mass.

In buildings thermal mass can be utilized for storing surplus heat and smoothening indoor temperature variations, which can help reduce the energy consumption and increase the thermal comfort.

In IDA ICE heat conductivity, density and specific heat are the three standard material properties. A construction´s material composition decides the thermal mass capacity of the construction. For the construction components to have the proper thermal mass in BEM, it is important to assign the correct construction to the respective surfaces of the energy model.

Solar Heat Gain and Daylighting

The electromagnetic spectra of the sun´s radiation offers solar heat and visible light. This can be utilized in buildings with transparent elements in the building envelope, e.g. windows, skylights and curtain walls. Solar heat is potentially free energy supplied to the building through such elements, meaning possibilities to save energy spent on heating. On the other hand, it can cause undesired problems with overheating, which would then increase energy spent on cooling. The visible light or daylighting can be used as a substitute for artificial lighting, meaning that energy can be saved on the latter. Through a well thought design of the building and proper implementation of operation strategies, a great amount of energy can be gained from solar heat and daylighting.

The amount of solar heat and visible light that pass through transparent elements depends on the transmittance properties of the transparent surfaces. In IDA ICE the glazing properties that accounts for this is the solar heat gain coefficient (SHGC), solar transmittance (T), visible transmittance (T_{vis}), total shading coefficient (Sc) and the shortwave shading coefficient (Ssc).

Shading

Closely related to solar heat gain and daylighting, is shading. Shading can be implemented as a passive measure by strategic design of building components, e.g. overhangs, or with use of active measures, e.g. external blinds. In either case the aim of the measure would be to control the solar heat gain and daylighting going into the building. Shading can also be undesired, often caused by other buildings or nearby terrain.

In IDA ICE shading is possible to implement in a few different ways. Active shading devices can be assigned to each window separately. Passive shading devices or shading caused by nearby buildings or terrain can be modelled as stationary shading objects.

AHU Supply/Return Air Flow

The amount of supply and return air of the air handling unit (AHU) is possible to express in different ways. In IDA ICE the supply and return air for a zone can be specified in either of the units' L/s, m^3/h, $L/(s*m^2)$, $m^3/(h*m^2)$ or air changes per hour (ACH). The two units involving m^2 refer to the floor area of the zone. In the case where the floor area of the energy model deviates from the reality and the air flow rate is specified in $L/(s*m^2)$ or $m^3/(h*m^2)$, the air flow rate will be incorrect.

Infiltration/Exfiltration

Infiltration/exfiltration is air blown into or out from the building through leakage points in the building envelope. It can have several consequences like for instance increased use of heating energy, structural problems (moisture damage), draught and worse thermal comfort conditions.

In IDA ICE the infiltration is accounted for either as wind driven or as a fixed infiltration flow. The wind driven infiltration rely on the air tightness of the building at a given pressure difference. For this method the pressure coefficients of each external face of the building and internal leakage paths (doors and leak areas) between zones must be defined. For the second method the infiltration is independent on the wind and is rather specified in air changes per hour for the whole building as a constant value. Either way, the air tightness for the wind driven flow and the fixed infiltration flow is distributed proportionally to the zones depending either on zone volume, the external surface area of the zone or the zone floor area. In the case where either of these parameters for the energy model deviates from the reality and the infiltration/exfiltration is distributed proportionally to the respective parameter, the infiltration/exfiltration rate will be incorrect.

2.5 BIM-based-BEM and Third-party Software

BIM-based BEM

The utilization of BIM for BEM purposes, or BIM-based BEM have a great potential to reduce time and effort spent on BEM modeling and performance analysis.

Building the energy model geometry from scratch based on 2D drawings or a 3D model and to gather energy and thermal relevant data from several disciplines and then to manually insert them into the BEM software is a cumbersome and error-prone task. In this respect, BIM as a repository containing building geometry, material, technical and HVAC data can be utilized. The introduction of interoperability between design and analysis software in the AEC-industry with exchange formats such as IFC has made it possible to exchange data from one software to another. In this way the energy model geometry can be automatically generated based on the BIM building model geometry and energy and thermal relevant data can be exchanged directly from to BIM to BEM.

However, the exchange process is not always flawless due to lack of interoperability between the software, causing missing or misinterpreted data in the exchange. This ultimately result in erroneous energy models in need of manual validation and remodeling.

As a response to the issues encountered in the process of BIM-based BEM, several third-party tools have been developed to support the process for it to be semi- or even fully automatically. This thesis will make use of the third-party software SimpleBIM to support the data exchange between Revit and IDA ICE.

SimpleBIM

SimpleBIM is a software developed by Datacubist with the aim to support the process of BIM-based BEM. The tool is able to trim (i.e. remove objects not needed in the model), compress, validate, edit and enrich an IFC model. Datacubist also offers templates or ruleset add-ons for SimpleBIM, which enable the mentioned actions to be executed automatically or semi-automatically. Such a template exists for IDA ICE, which help validate the geometry and objects of the BIM IFC model in accordance with the preferences of IDA ICE. Table 6 shows the rules for IFC objects included in the IDA ICE add-on template.

TABLE 6: SIMPLEBIM IDA ICE ADD-ON TEMPLATE RULES

Building stories	Spaces
Walls	Slabs
Windows	Doors
Curtain walls	Shading objects
Objects unnecessary for thermal or energy performance simulation such as columns, beams, furniture, site objects	Building body detection

Chapter 3 Methodology

The case studies are divided into a hierarchy structure to make sure of a systematic approach. The hierarchy structure consists of *Cases, Issues, Sub-issues* and *Sub-sub-issues,* and is summarized in Table 7.

TABLE 7: THE HIERARCHY STRUCTURE OF THE CASE STUDIES

Structure	Abbreviation	Description
Cases	-	Indicates the building models being investigated.
Issues_Task	I	Indicates the general interoperability issues being investigated.
Sub-issues	SI	Describes the variations or different options of each interoperability issue to be investigated.
Sub-sub-issues	SSI	Describes yet another level of variations or different options of each interoperability issue to be investigated.

Issue describes the general interoperability issue to be investigated, e.g. columns, curtain walls, etc. *Sub-Issue* describes the different variations or options to be explored within each *issue*, e.g. structural columns or architectural columns for the *issue* columns. *Sub-sub-issue* describes further variations or options within a *sub-issue*, e.g. structural columns that are integrated into walls or standing openly in the middle of a room. The *cases* are the combination of *issue*, *sub-issue* and *sub-sub-issue* or only *issue* and *sub-issue.* The *cases* are the actual building models being used to investigate the interoperability issues.

3.1 The Interoperability Issues

The interoperability issues or issues the case studies attend to, are the ones listed below in Table 8.

TABLE 8: SUMMARY OF ISSUES TO BE INVESTIGATED

Issue	Issue Description
I_1	Columns.
I_2	Curtain walls.
I_3	Doors.
I_4	Parapet walls.
I_5	The assembly of external walls in multi-story buildings.
I_6	Atriums within a building as a room/space entirely encapsulated within larger rooms/spaces.
I_7	Mezzanines.
I_8	Curved surface wall elements.
I_9	Overhangs.

This chapter means to explain the influence the interoperability issues may have in regard of physical phenomena related to energy, thermal and daylighting performance in BEM. The definition of the physical phenomena and how they are managed in IDA ICE is given in 2.4 Energy and Thermal Concepts and Definitions Important in BEM. The result of this investigation is summarized in Table 21 in the beginning of Chapter 4 Result and Discussion. Further on this chapter outlines possible problems caused by the interoperability issues in regard of these physical factors and how they may affect the energy and thermal performance of the building. The sub-issues and sub-sub-issues of each interoperability issue to be investigated is also listed.

Issue 1 – Columns

Importance in BEM

Summary points: *Impact on thermal mass, space efficiency, thermal insulation/thermal bridge and daylighting distribution in BEM.*

Columns (see definition Table 3: Terminology column) can impact the result of BEM in several ways. Columns make up some mass and hence contribute with some thermal mass to the building, especially if made of solid concrete. Columns that are not integrated into walls will occupy space, reducing the area and volume of the room. On the other hand, if integrated into walls, they will influence the U-value (i.e. thermal insulation) of the walls. They can cause shading, influencing the daylighting distribution of the building, and in cases where the columns are located outside external elements that are transparent they may impact the solar heat gain.

Usually these impacts will be minor since columns do not constitute a significant volume in total.

Possible Problems

Summary points: *No support for IFC column objects in BEM leading to the neglection of columns in the energy model.*

Many BEM software do not support columns as a building element (United States General Services Administration, 2015). If this is the case, the column objects will be excluded in the BIM-based BEM energy model and thus ignoring all its influences on the energy and thermal performance of the building.

In another case study a BIM-based IFC model with wall-integrated columns was imported into the BEM software IES-VE. The outcome was misinterpretation of the building´s thermal view, leaving open gaps in the wall in place of the columns (Erichsen & Horgen, 2014). This shows that not only may this interoperability issue cause deviations in respect of energy and thermal performance, but it may also corrupt the geometry of the energy model.

Investigation Tasks

The investigation of this issue intends to explore if BIM-based columns modelled in Revit is recognized by IDA ICE, and how these objects influence the generated energy model.

The sub-issues of the investigation consist of modeling the BIM-based columns as architectural and structural columns. The sub-sub-issues involves wall-integrated columns, merged and not merged into wall, and columns located in the middle of the room.

Table 9 lists the sub-issues, sub-sub-issues and cases of the respective issue to be investigated.

TABLE 9: INTEROPERABILITY ISSUE COLUMNS: SUB-ISSUES, SUB-SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_1	Columns.	SI_1	Model creation tool: Structural Column.	SSI_1	Wall-integrated columns (merged with walls).	1
				SSI_2	Wall-integrated columns (not merged with walls).	2
				SSI_3	Column in middle of room.	3
		SI_2	Model creation tool: Column Architectural.	SSI_1	Wall-integrated columns (merged with walls).	4
				SSI_2	Wall-integrated columns (not merged with walls).	5
				SSI_3	Column in middle of room.	6

Issue 2 – Curtain Walls

Importance in BEM

Summary points: *Impact on solar heat gain, daylighting distribution, thermal insulation and thermal mass in BEM.*

Curtain walls (see definition Table 3: Terminology curtain wall) consist of panels either being transparent or opaque with mullions/bars separating the panels.

Curtain wall systems are often built in relation to the façade of the building. In such cases a transparent curtain wall can contribute with solar heat and daylight into the building. The significance of this impact will depend on the area and transmittance properties of the transparent elements, but also the orientation of the curtain wall and shading conditions. The material properties of the curtain wall panels will have an impact on the thermal insulation and thermal mass of the building as well.

Possible Problems

Summary points: *Incorrect properties of curtain wall elements in BEM.*

In Revit the curtain wall “Family” is part of the Revit “Category” model element “Walls”. When modeling curtain walls in Revit the default panels are glazed, i.e. transparent. However, importing BIM-based transparent curtain walls into BEM has been known to cause problems (Equa Simulations, 2017), resulting in the transparent BIM-based curtain wall elements to be interpreted as opaque wall elements in BEM. This results in the solar heat gain and daylighting due to the curtain wall to be completely ignored and the thermal insulation and thermal mass to be incorrect.

Investigation Tasks

The investigation intends to explore if it is possible to transfer transparent curtain wall elements from Revit to IDA ICE and map these elements to transparent IDA ICE resources.

The issue includes three sub-issues. In these sub-issues the three different curtain wall "Family Types": "Curtain Wall", "Exterior Glazing" and "Storefront", are investigated.

Table 10 lists the sub-issues and cases of the respective issue to be investigated.

TABLE 10: INTEROPERABILITY ISSUE CURTAIN WALLS: SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_2	Curtain walls.	SI_1	Model creation tool: Wall. →System Family: Curtain Wall. →Type: Curtain Wall.	N/A.	N/A.	7
		SI_2	Model creation tool: Wall. → System Family: Curtain Wall. →Type: Exterior Glazing.	N/A.	N/A.	8
		SI_3	Model creation tool: Wall. → System Family: Curtain Wall. →Type: Storefront.	N/A.	N/A.	9

Issue 3 – Doors

Importance in BEM

Summary points: *Impact on thermal insulation, thermal mass, solar heat gain and daylighting distribution in BEM.*

Doors, external or internal, are hosted by walls but may have material properties that differ from the walls. This means that doors contribute with their own thermal insulation (if external) and thermal mass to the building. External doors that are transparent will influence the solar heat gain and daylighting as well.

Since the total area of doors usually composes a minor part of the total wall surface area, these impacts are expected to be small.

Possible Problems

Summary points: *No support for IFC door objects in BEM, and hence incorrect properties for doors.*

Door objects is claimed to be an IFC object class not supported by IDA ICE (Datacubist, n.d.). This can cause problems with mapping BIM-based IFC door objects to corresponding IDA ICE door resources with the same material properties.

Investigation Tasks

The investigation intends to explore if the BIM-based IFC object class *door* is possible to transfer from Revit to IDA ICE and map it to the corresponding IDA ICE door resource.

The issue only has one sub-issue that basically is to model a door in Revit using the modeling tool "Door".

Table 11 shows the sub-issue and case of the respective issue to be investigated.

TABLE 11: INTEROPERABILITY ISSUE DOORS: SUB-ISSUE AND CASE

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_3	Doors.	SI_1	Model creation tool: Door. → Family: M_Single-Flush	N/A.	N/A.	10

Issue 4 – Parapet Walls

Importance in BEM

Summary points: *Impact on thermal bridges, solar heat gain and daylighting distribution in BEM.*

Buildings usually have a thermal bridge located in the intersection between the roof and external walls. If the building contains a parapet wall (see definition Table 3: Terminology parapet wall), these elements will impact the heat loss due to this thermal bridge.

In the case where a building both contains parapet walls and skylights (see definition Table 3: Terminology skylights) at the same time, the parapet walls may influence the solar heat and daylighting going through the skylights. This will depend on the suns angle on the sky, i.e. if the sun is set low or high on the sky. This imply that the influence will be larger for some areas than others.

Possible Problems

Summary points: *Difficultly including parapet walls due to strict geometry representation in BEM. Misinterpretation of the building´s thermal view leading to overestimation of the room height and hence volume of zones.*

Due to BEM´s strict geometry representation in terms of space boundaries and thermal zones and limitation to 1D heat transfer (refer 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View), BIM-based parapet walls may prove to be difficult to include in the energy model of BEM.

In another case study (Erichsen & Horgen, 2014), a BIM-based BEM model with parapet walls resulted in the energy model´s thermal view to be misinterpreted. The misinterpretation caused the height and hence the volume for the energy model´s thermal zones located underneath the roof construction to be overestimated.

Investigation Tasks

The investigation will explore different ways to model a parapet wall in Revit and see if it is interpreted correctly in IDA ICE. This imply a solution that includes the physical geometry of the parapet wall in the energy model, while at the same time not leading to misinterpretation in the thermal view of the building.

The issue includes three sub-issues. In the first sub-issue the parapet walls are modelled by extending the external walls above the roof construction. In the second sub-issue the parapet walls are modelled as “Wall sweep structures”. In the third sub-issue the parapet walls are modelled as “In-Place wall sweeps”.

Table 12 lists the sub-issues and cases of the respective issue to be investigated.

TABLE 12: INTEROPERABILITY ISSUE PARAPET WALLS: SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_4	Parapet walls.	SI_1	Use of the modeling tool “Wall” to extend the ordinary external walls above the roof.	N/A.	N/A.	11
		SI_2	Use of the modeling tool “Wall” with a “Parapet wall sweep” structure as part of the wall.	N/A.	N/A.	12
		SI_3	Use of the modeling tool “In-Place wall sweep” as a separate parapet wall element apart from the wall below.	N/A.	N/A.	13

Issue 5 – Assembly of External Walls in Multi-story Buildings

Importance in BEM

Summary points: *The correct thermal view, i.e. correct interpretation of space boundaries and thermal zones, in order to make the right assumptions on energy and thermal conditions of the energy model.*

The model geometry representation of BIM and BEM differ as explained in 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View. In a BIM model where the purpose is to visualize the architectural view of the building, it makes no difference if the external walls over multiple stories consist of one element in total or as one element per story. In BEM on the other hand, due to the strict geometry representation in terms of space boundaries and thermal zones, it is imperative to have a wall element for each story to get the correct representation of the building´s thermal view. A correct thermal view is important to make right assumptions on the energy and thermal conditions of the building.

Possible Problems

Summary points: *Misinterpretation of the building´s thermal view, resulting in incorrect assumptions for the energy and thermal conditions of the building.*

External walls as single elements extending over multiple stories is not an issue in the case of the geometry representation of BIM, but do not comply with BEM geometry representation. A possible problem may occur if the BIM-based IFC model is built according to an architectural view rather than a thermal view and the BEM software is not able to translate from one view to the other. This could lead to misinterpretation of the energy model´s space boundaries and space definitions, causing the assumptions on energy and thermal conditions of the building to be incorrect.

Investigation Tasks

The investigation intends to explore if the modeling of external walls in BIM affect how the BEM software interpret the thermal view of the generated energy model.

The issue consists of two sub-issues. In the first sub-issue the external walls of a two-story building will be modelled as a single element. In the second sub-issue a separate wall element is modelled for each story.

Table 13 lists the sub-issues and cases of the respective issue to be investigated.

TABLE 13: INTEROPERABILITY ISSUE THE ASSEMBLY OF EXTERNAL WALLS IN MULTI-STORY BUILDINGS: SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_5	The assembly of external walls in multi-story buildings.	SI_1	Modeling approach: To model the external walls in a two-story building as a single element extending over both stories.	N/A.	N/A.	14
		SI_2	Modeling approach: To model the external walls in a two-story building as single elements for each story.	N/A.	N/A.	15

Issue 6 – Atriums

Importance in BEM

Summary points: *Impact on solar heat gain, daylighting distribution and air/mass flow and ventilation behavior in BEM.*

Atrium spaces (see definition Table 3: Terminology atrium) may be utilized for natural ventilation in buildings. They are usually designed to be tall open areas, containing glazed surfaces facing the external and linked to many of the other spaces of the building. By designing it this way, the atrium may collect heat from the adjoining spaces of the building, but also gain solar heat through the transparent surfaces, both of which will warm the air of the atrium. This will create a stack pressure due to the tall column of warm air in the atrium that will draw air into the space from the adjoining spaces. By eventually leading the warm air out through roof openings of the atrium and supply a ventilation flow of fresh air at a lower level of the space, a natural ventilation system is created for the building (Holford and Hunt, 2000). The transparent surfaces of the atrium facing the external will also contribute with solar heat gain and affect the daylighting distribution of the building.

Possible Problems

Summary points*: Misinterpretation of the building´s thermal view, resulting in incorrect assumptions for the energy and thermal conditions of the building.*

There have been reported in an earlier case study to be an issue exporting a BIM model with an atrium space located in the middle of the building (i.e. as a space entirely encapsulated by larger spaces) to BEM (Erichsen & Horgen, 2014). The issue caused misinterpretation of the building´s thermal view, resulting in missing thermal zones. Ergo, a possible problem with BIM models containing atrium spaces may be the corruption of the energy model´s geometry in BEM.

Investigation Tasks

The investigation will explore if a Revit BIM model with an atrium space extending over several stories that are encapsulated entirely by larger spaces is interpreted correctly in IDA ICE.

The issue consists of two sub-issues and sub-sub-issues. In the first sub-issue the atrium space will be modelled as a separate space with internal walls. In the second sub-issue the modeling tool “Shaft Opening” is being used to model the atrium space. The sub-sub-issues intends to investigate if the structure of the floor and roof construction has any impact on the generated energy model.

Table 14 lists the sub-issues, sub-sub-issues and cases of the respective issue to be investigated.

TABLE 14: INTEROPERABILITY ISSUE ATRIUMS: SUB-ISSUES, SUB-SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_6	Atrium within a building as a space entirely encapsulated by larger spaces.	SI_1	Modeling approach: To model the atrium as a separate space comprised of internal walls.	SSI_1	Roof & floor structure as single elements covering the whole footprint of the building.	16
				SSI_2	Roof & floor structure as separate elements for the smaller and the larger space of the building footprint.	17
		SI_2	Modeling approach: Use of the Revit modeling tool “Shaft Opening” to model the atrium space.	SSI_1	Roof & floor structure as single elements covering the whole footprint of the building.	18
				SSI_2	Roof & floor structure as separate elements for the smaller and the larger space of the building footprint.	19

Issue 7 – Mezzanines

Importance in BEM

Summary points: *Impact on thermal bridges, thermal mass, space efficiency, daylighting distribution and air/mass flow conditions in BEM.*

Mezzanine spaces (as defined in Table 3: Terminology mezzanine) are fully or partially open to the space constituting the floor below the mezzanine. In BEM it is important to interpret these spaces as being open to each other because of its impact on the exchange of air/mass conditions between the thermal zones of the energy model. The floor construction constituting the mezzanine also provide some mass, hence they contribute with thermal mass to the building, especially if the floor construction is made of solid concrete. The mezzanine floor also occupies some spatial area and make up some floor area for the building. In some cases, these types of construction may influence the daylighting distribution of the building.

Possible Problems

Summary points*: Incorrect BEM thermal view resulting in incorrect assumptions for the energy and thermal conditions of the building.*

In a BIM-based CAD tool like Revit it is certainly possible to model the architectural view (refer 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View) of a building containing a mezzanine construction with openings between the mezzanine space and the rest of the building. However, a corresponding thermal view of the building may prove difficult to be interpreted correctly in BEM due to BEM´s strict geometry representation in terms of space boundaries and thermal zones. A possible problem that may occur is that IDA ICE by default create construction elements for the boundaries of any Revit-defined space. This would cause the mezzanine space to be enclosed by walls, when it rather should have had an opening to the floor space below.

Investigation Tasks

The investigation intends to explore several approaches creating a BIM model containing a mezzanine construction in Revit and see how this is interpreted in IDA ICE.

The issue consists of eight cases in total, all in which involves a two-story building with a mezzanine construction. The issue is divided into two sub-issues, the first one containing three sub-sub-issues and the second one containing five sub-sub-issues. The two sub-issues differentiate between the Revit room/space definitions of the building. The sub-sub-issues focus on how the border between Revit-defined rooms/spaces are modelled. This involves the use of either the Revit tool “Room Separator” or to model a construction with an opening between the rooms/spaces.

Table 15 lists the sub-issues, sub-sub-issues and cases of the respective issue to be investigated.

Table 15: Interoperability issue Mezzanines: Sub-issues, sub-sub-issues and cases

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_7	Mezzanines.	SI_1	Two rooms/spaces defined in total.	SSI_1	Use of "Room Separator" lines between rooms/spaces.	20
				SSI_2	A wall with opening created between mezzanine space and rest of the building.	21
				SSI_3	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between mezzanine space and rest of the building.	22
		SI_2	Three rooms/spaces defined in total.	SSI_1	Use of "Room Separator" lines between rooms/spaces.	23
				SSI_2	A wall with opening created between mezzanine space and rest of the building.	24
				SSI_3	A wall with opening created between all three rooms/spaces.	25
				SSI_4	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between mezzanine space and rest of the building.	26
				SSI_5	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between all three rooms/spaces.	27

Issue 8 – Curved Surfaces

Importance in BEM

Summary points: *Impact on solar heat gain, daylighting distribution and space efficiency in BEM.*

The majority of BEM software calculate only 1D heat transfer and allow only for elements to be represented as flat surfaces (refer 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View). This cause curved surface elements generated in BIM to be translated into segments of flat surface elements when transferred to BEM.

The segmentation of curved surface elements into flat surface elements will create a discrepancy in the area/volume between the BIM and the

BEM model, i.e. affecting the space efficiency of the energy model. Curved surface elements containing windows, which are being segmented into flat surface elements, can lead to inaccurate representation of solar heat gain and daylighting distribution in BEM.

Both the effects mentioned above will depend on the detail level of the segmentation.

Possible Problems

Summary points*: Too coarse segmentation can lead to inaccurate solar heat gain, daylighting distribution and space* efficiency. *Too fine segmentation can lead to problems with wall hosting windows and longer simulation run time.*

To get the least deviation on solar heat gain, daylighting distribution and space efficiency, the segmentation of the curved surface elements into flat surface elements should be as fine as possible. However, because window constructions must be contained entirely within a single wall element in BEM, a too fine segmentation could lead to problems with windows not finding a hosting wall to attach. A very fine segmentation will also lead to longer simulation run time because of more space boundaries leading to more heat transfer equations needed to be solved.

The level of detail for the segmentation rely on the built-in algorithm of the BEM software. This level of detail should not be too coarse or too fine.

Investigation Tasks

The investigation seeks to find out how well curved surface elements created in Revit are being translated to segments of flat surface elements in IDA ICE.

The issue consists of two sub-issues. These two involves a building with a plain curved surface wall and another building with a curved surface wall hosting windows.

Table 16 shows the sub-issues and cases for the respective issue.

TABLE 16: INTEROPERABILITY ISSUE CURVED SURFACES: SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_8	Curved surface wall elements.	SI_1	Transformation of curved surface wall element to segments of flat surface wall elements.	N/A.	N/A.	28
		SI_2	Transformation of curved surface wall elements hosting windows to segments of flat surface wall elements.	N/A.	N/A.	29

Issue 9 – Overhangs

Importance in BEM

Summary points: *Impact on thermal bridges, solar heat gain and daylighting distribution in BEM.*

For the overhang´s influence on thermal bridges, refer Issue 4 – Parapet Walls: Importance in BEM. Overhang constructions located above windows or other transparent construction elements will cause shading that may result in less solar heat and daylight to enter the building. The greatness of the impact will depend on the suns angle on the sky, which means that the effect will be greater in some areas than others.

Possible Problems

Summary points: *Difficultly including overhang constructions due to strict geometry representation in BEM. Misinterpretation of the building´s thermal view leading to the area/volume of thermal zones to be overestimated.*

Due to BEM´s strict geometry representation in terms of space boundaries and thermal zones and limitation to 1D heat transfer (refer 2.2.3 Geometry Representation in BIM and BEM – Architectural View and Thermal View), BIM-based overhang constructions may prove to be difficult to include in the energy model of BEM.

In another case study (Erichsen & Horgen, 2013), a BIM-based BEM model with overhang constructions resulted in the energy model´s thermal view to be misinterpreted. The misinterpretation caused the area/volume of the energy model´s thermal zones connected to the overhang to be overestimated.

Investigation Tasks

The investigation will explore if a Revit BIM model containing overhangs is interpreted correctly in BEM.

The issue contains two sub-issues. The first sub-issue concentrates on roof overhangs. The second sub-issue focus on overhangs caused by a recess in the façade.

In Table 17 the sub-issues and cases of the respective issue are shown.

TABLE 17: INTEROPERABILITY ISSUE OVERHANGS: SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_9	Overhangs.	SI_1	Roof overhangs.	N/A.	N/A.	30
		SI_2	Overhangs caused by a recess in the façade.	N/A.	N/A.	31

3.2 The Case Studies

3.2.1 Introduction

The workflow of the case studies was first to create the building models in Autodesk Revit 2018. See chapter 3.2.2 General Modeling in Autodesk Revit for general modeling conventions followed in Revit and chapter 3.2.4 Cases for a detailed elaboration on the Revit modeling of each the model cases.

The next step was to export the Revit-built BIM models as IFC files, refer chapter Autodesk Revit IFC Export for this part. If exceptions were made in the IFC export as described here, this will be mentioned specifically in the relevant cases.

The third and last step was to import the IFC files into IDA ICE version 4.8, map the IFC objects to IDA ICE resources and generate the energy model. See chapter IDA ICE IFC Import and Mapping IFC Data to IDA ICE Resources for this part. If exceptions were made from the procedure described in the above chapters, this will be mentioned specifically in the relevant cases.

In IDA ICE the imported IFC models and the generated energy models was thoroughly analyzed. Any findings on problems that might affect the energy, thermal and/or daylighting simulation results and/or technical issues has been identified and are given in Chapter 4 Result and Discussion: 4.1 Identified Problems.

Figure 20 is a flowchart illustrating the outlined workflow of the case studies.

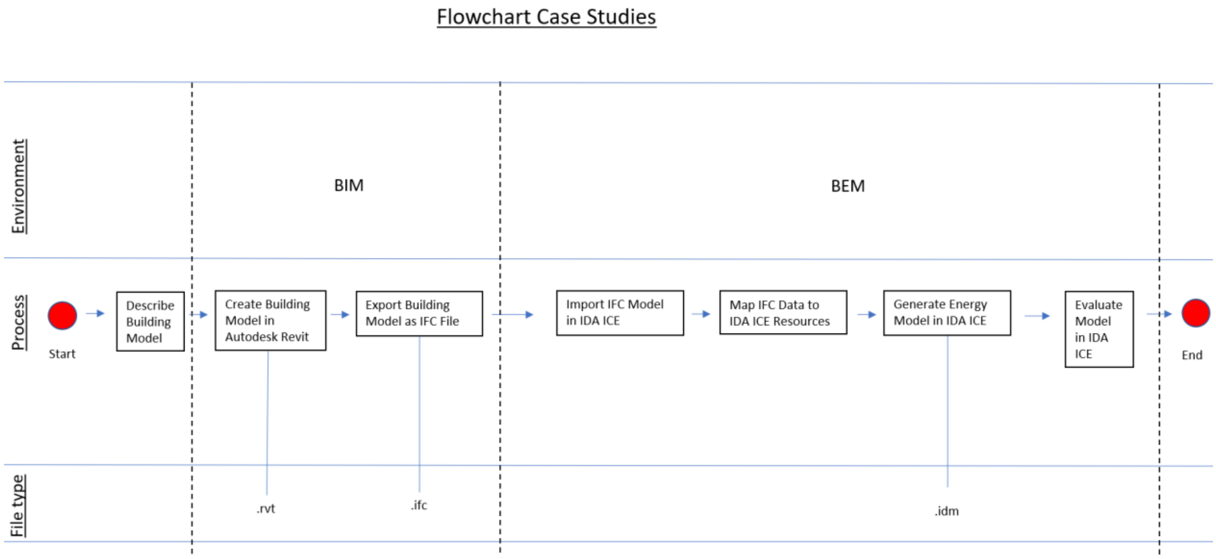


FIGURE 20: FLOWCHART CASE STUDIES

For the cases where problems did arise, a solution or workaround that partially or completely solve the problems of the issue has been tried established. Three different solution methods were explored. An overview of the three different solution methods and the suggested solutions is given in Chapter 4 Result and Discussion: 4.2 Suggested Solutions.

3.2.2 General Modeling Conventions in Autodesk Revit

During the modeling of the case models in Revit, the modeling conventions as advised by the manual/help site of Autodesk and the *BIM Guide for Energy Performance* by the U.S. General Services Administration was followed (Autodesk, 2018), (United States General Services Administration, 2015). Any Revit user should conform to these modeling conventions but are especially important to follow in the case where the model is to be shared with another software through an exchange format. The relevant modeling conventions for modeling the case models on a general basis are given below. Readers already familiar with the interface and tools of Revit may skip this chapter and proceed to the next.

<u>Modeling of Wall, Roof and Floor Constructions</u>

Use of the correct modeling tool when creating building elements, e.g. the “Wall” creation tool to create wall elements. This is important to follow in order for the objects to be included as the intended object types when exported to a given data schema, which in this case studies would be the IFC schema. This is also valid for other building element types such as roofs, slabs/floors, etc.

In Revit the tools for the most common building element types is found in the “Architecture” tab shown with red marking in Figure 21.

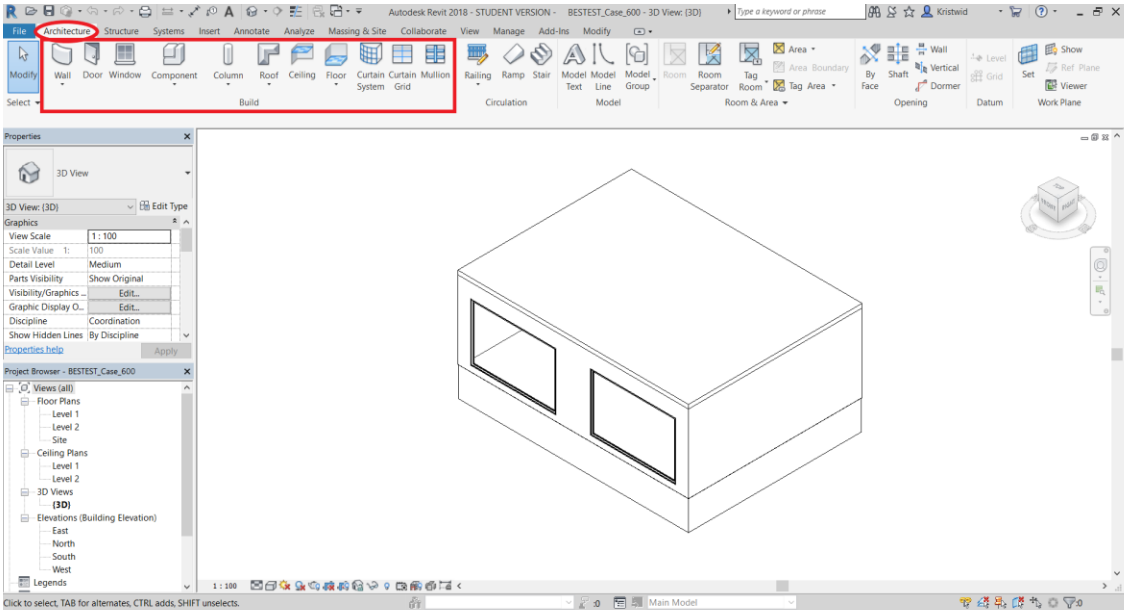


FIGURE 21: A SNAP SHOT SHOWING AUTODESK REVIT 2018 MODELING CREATION TOOLS (MODIFICATIONS IN RED)

Modeling of Window and Door Constructions

The modeling of windows is done by using the “Window” creation tool inserting the window directly into the hosting wall component and no let it extend outside the wall geometry. To first cut an opening in the wall and then place the window construction in the respective opening can cause problems for the BIM authoring tool to interpret the relationship between the wall, window and opening correctly (United States General Services Administration, 2015). The same apply for doors.

In Revit the tools to model window and door constructions are found in the same location as walls, floors and roof construction, refer Figure 21.

Definition of Rooms and Spaces

The definition of rooms/spaces in BIM are important so that the receiving BEM software correctly interprets and translates the spaces of the building model into corresponding thermal zones in the energy model.

Defining rooms and spaces in Revit are done with the “Room” defining and “Space” defining tool, respectively. The “Room” defining tool is located under the “Architecture” tab, marked red in Figure 22. The “Space” defining tool is located under the “Analyze” tab, refer the red marking in Figure 23.

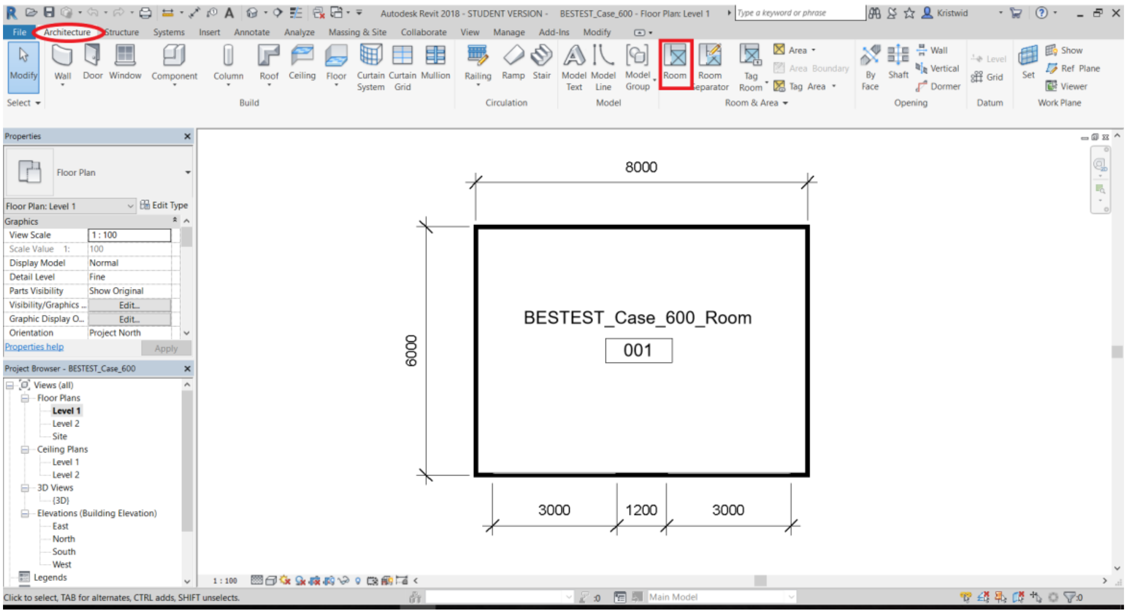


FIGURE 22: A SNAP SHOT SHOWING AUTODESK REVIT "ROOM" DEFINING TOOL (MODIFICATIONS IN RED)

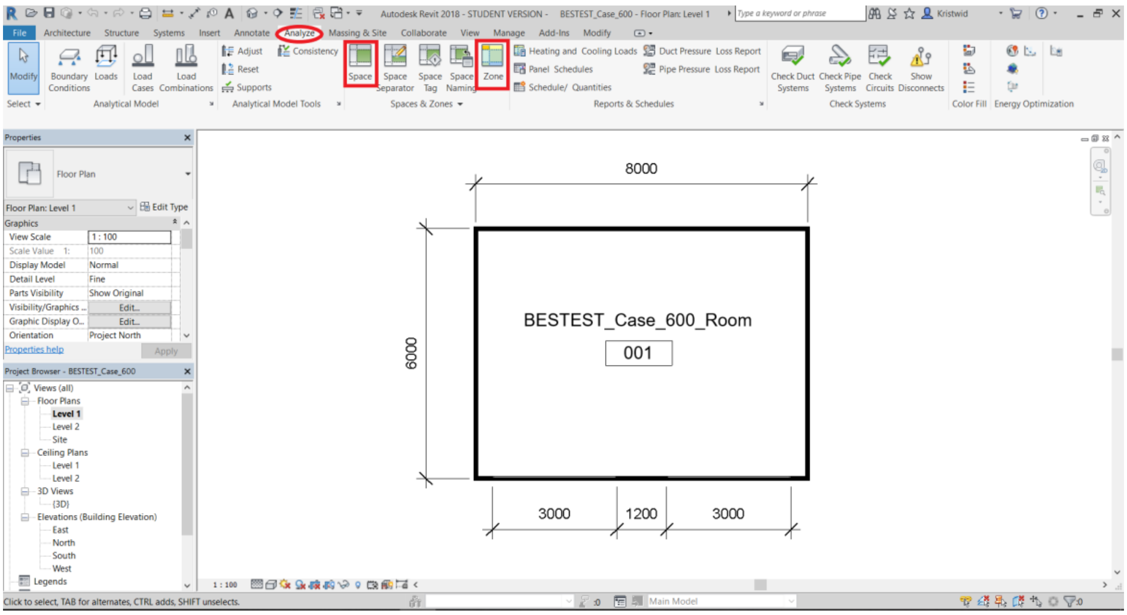


FIGURE 23: A SNAP SHOT SHOWING AUTODESK REVIT "SPACE" DEFINING TOOL (MODIFICATIONS IN RED)

The defined rooms/spaces have by default no height, and thus needs to be defined in order for the definitions to account for the spatial area of the spaces. This is done by defining the property input value for "Upper limit" and "Level" (lower limit) of the room/space definition, refer Figure 24. For the rooms/spaces to be easily recognized in the IFC to IDA ICE resource mapping procedure of IDA ICE, it can be helpful to name both the rooms and the spaces. The room and space property bars with the property input values as it was defined for the BESTEST Case 600 model is shown in Figure 24.

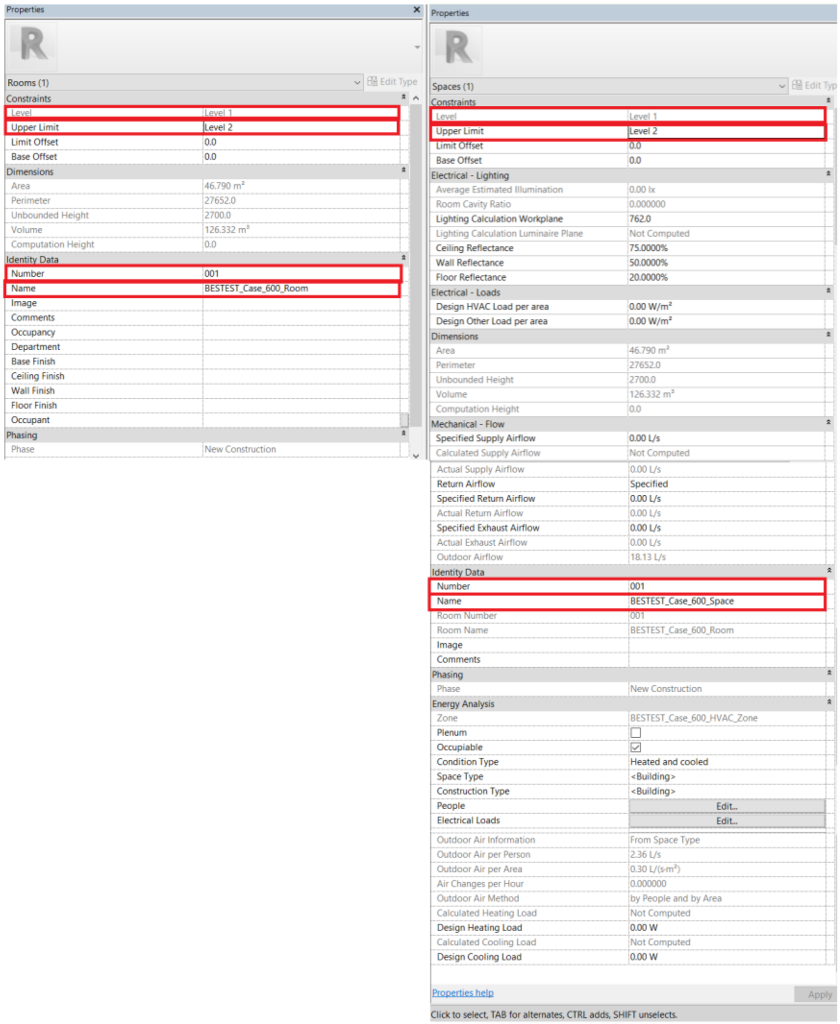


FIGURE 24: A SNAP SHOT SHOWING REVIT PROPERTY BARS – LEFT: ROOM PROPERTIES. RIGHT: SPACE PROPERTIES (MODIFICATIONS IN RED)

Defining Material Layer Sets and Material Properties

The material layer sets of constructions in BIM are important to define so that the receiving BEM software may recognize them as IFC material layer data. The Revit-based IFC material layers will then be available to be mapped to IDA ICE material resources in the mapping procedure of IDA ICE.

The material layer sets (structure) and material properties of the walls, roof and floor construction for the case models were based on the BESTEST Case 600. The case originates from the ANSI/ASHRAE Standard 140-2001 *Standard Method of Test for the Evaluation of Building Energy Analysis*

Computer Programs. Refer Appendix B for the full description of the BESTEST Case 600 – Base Case Low Mass Building.

The information that has been used modeling the constructions of the case models are the material layer sets with thicknesses and the material properties heat conductivity (λ), density (ρ) and heat capacity (C_p).

In Revit the definition of the material layer sets and material properties for constructions are done as outlined in the procedure listed below.

- Select a construction element.
- Select “Edit Type” in the properties bar, refer Figure 25.
- In the “Type Properties” window, select “Edit Structure”, refer Figure 25.
- In the “Edit Assembly” window, define the function, material and thickness of the different layers.
- In the “Edit Assembly” window, enter the “Material Browser” by selecting the symbol marked red in Figure 26.
- In the “Material Browser”, select the red marked symbol in Figure 27 to create new materials.
- The thermal material properties are inserted in the tab called “Thermal”, see Figure 27.

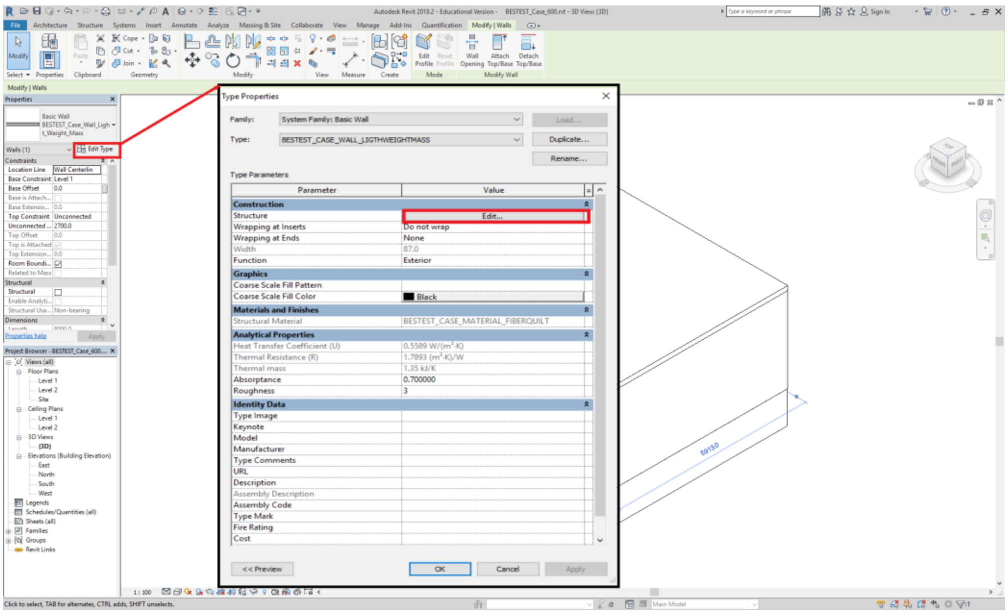


FIGURE 25: A SNAP SHOT SHOWING AUTODESK REVIT – PROPERTY BAR “EDIT TYPE” – TYPE PROPERTIES “EDIT STRUCTURE” (MODIFICATIONS IN RED)

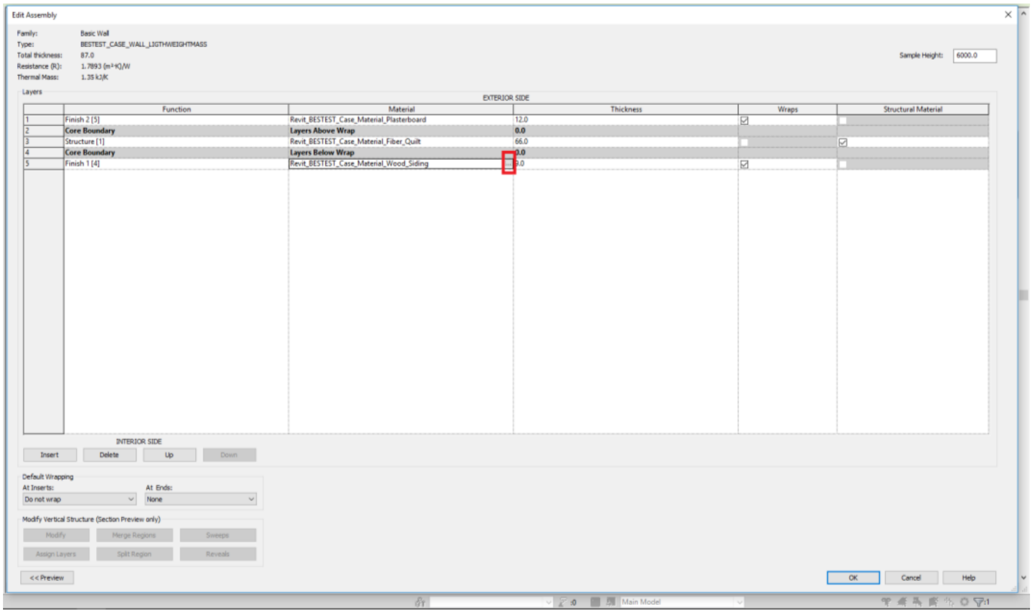


FIGURE 26: A SNAP SHOT SHOWING AUTODESK REVIT – "EDIT ASSEMBLY" – "MATERIAL BROWSER" (MODIFICATIONS IN RED)

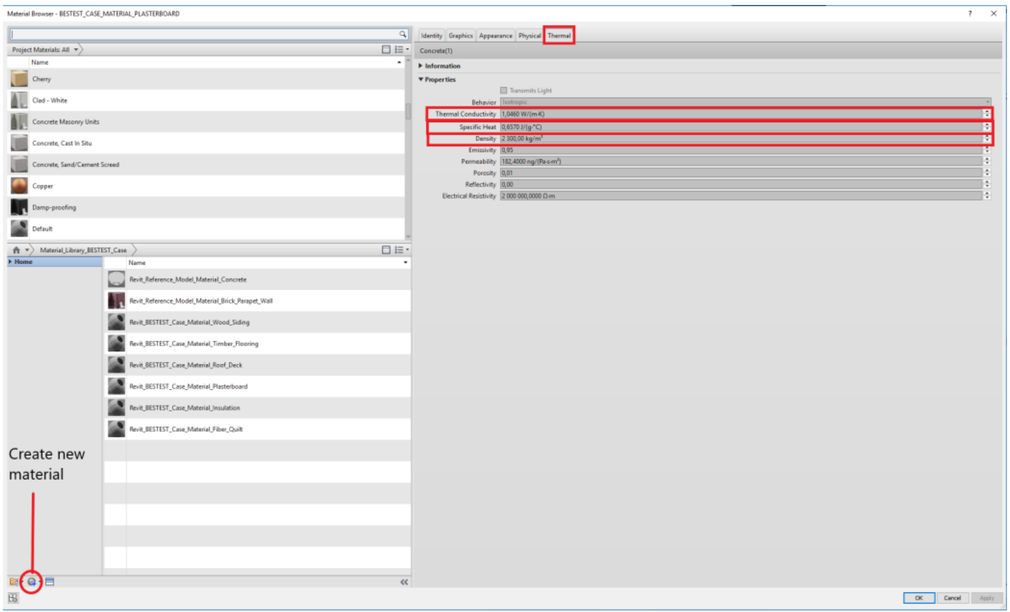


FIGURE 27: A SNAP SHOT SHOWING AUTODESK REVIT – "MATERIAL BROWSER" – NEW MATERIAL & THERMAL PROPERTIES (MODIFICATIONS IN RED)

In the case of the window construction as many as 18 properties were given in the description of the BESTEST Case 600. Revit is only able to include a few of these properties, namely the ones marked in red in Figure 28. The combination of these properties is determined based on the "Analytical Construction" selected from the predefined database within Revit. However, it is possible to define own "Analytic Constructions" for windows, but this is for more advanced users. In the case studies the workaround defining an own analytic window construction has been done. This analytic window construction with its respective properties is seen in Figure 28.

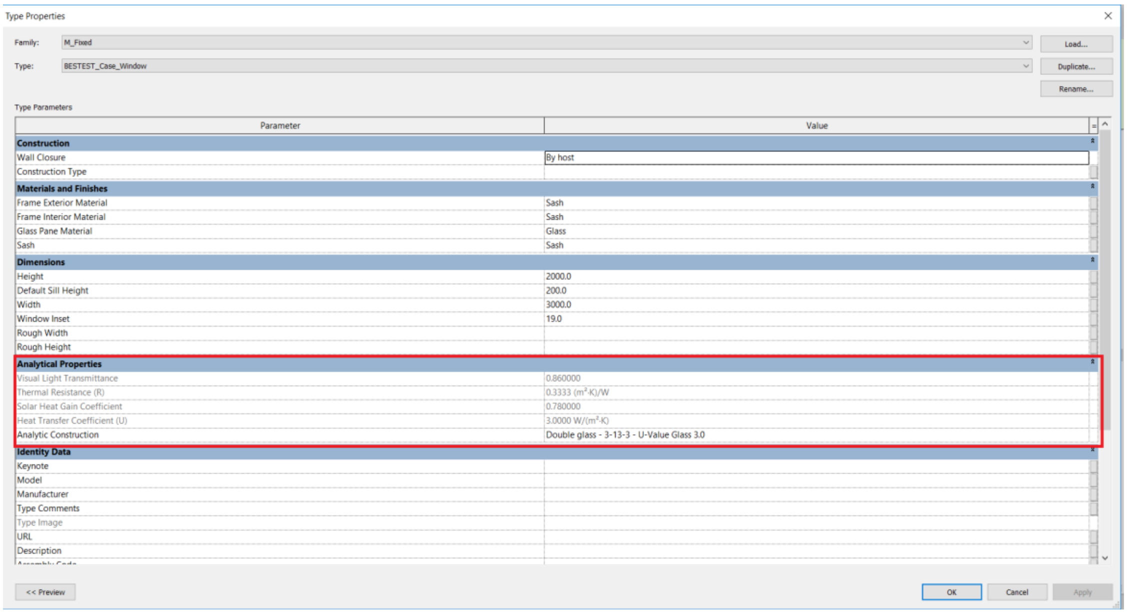


FIGURE 28: A SNAP SHOT SHOWING AUTODESK REVIT – "TYPE PROPERTIES" – "ANALYTICAL PROPERTIES" (MODIFICATIONS IN RED)

Modeling of Mass Objects

Mass objects is used throughout the case study on several occasions and therefore the procedure on how to use it in Revit is included here.

The procedure is listed below along with Figure 29 illustrating the steps.

- Select the tool "In-Place Mass" located under the "Massing & Site" tab.
- Select preferred drawing tool.
- After having finished drawing the sketch, select "Create Form – Solid Form" and click "Finish Mass".

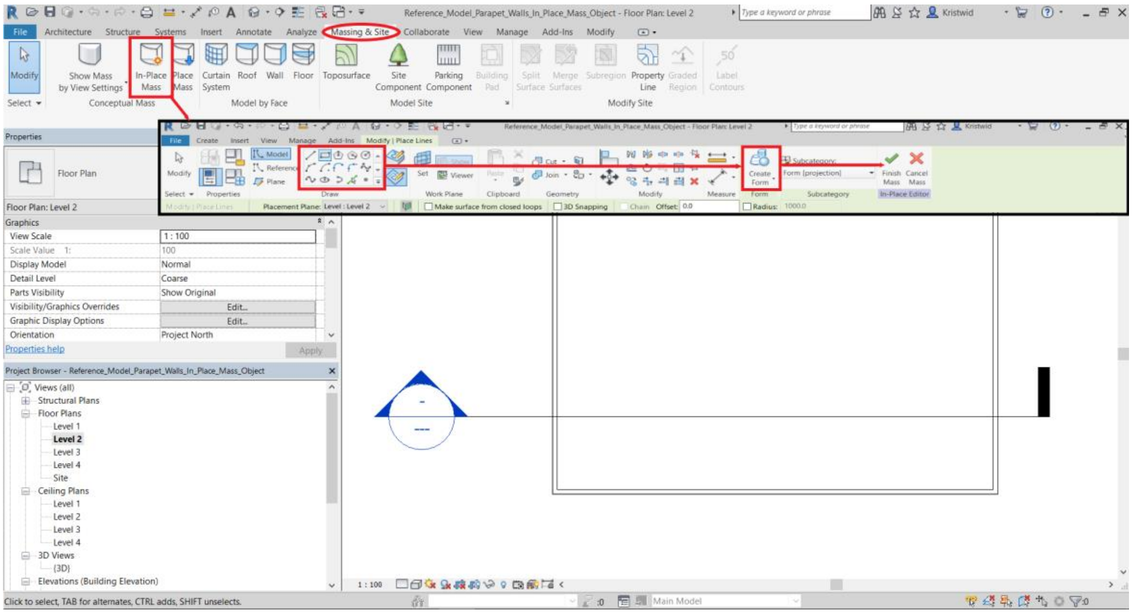


FIGURE 29: AUTODESK REVIT "IN-PLACE MASS" OBJECT

3.2.3 The Information Exchange between Autodesk Revit and IDA ICE

In the data exchange, i.e. IFC export and import between Revit and IDA ICE, there are multiple setup options. This chapter describes the process of the data exchange and explains the different export/import options along with the general setup for the case studies.

Autodesk Revit IFC Export

In Revit the IFC export is located under the "File" tab and then by selecting "Export" and "IFC", refer Figure 30. This opens the window "Export IFC" shown in the upper right side of the figure. By selecting "Modify setup" the window in the lower right side of the figure appear, offering modification options for the IFC file export.

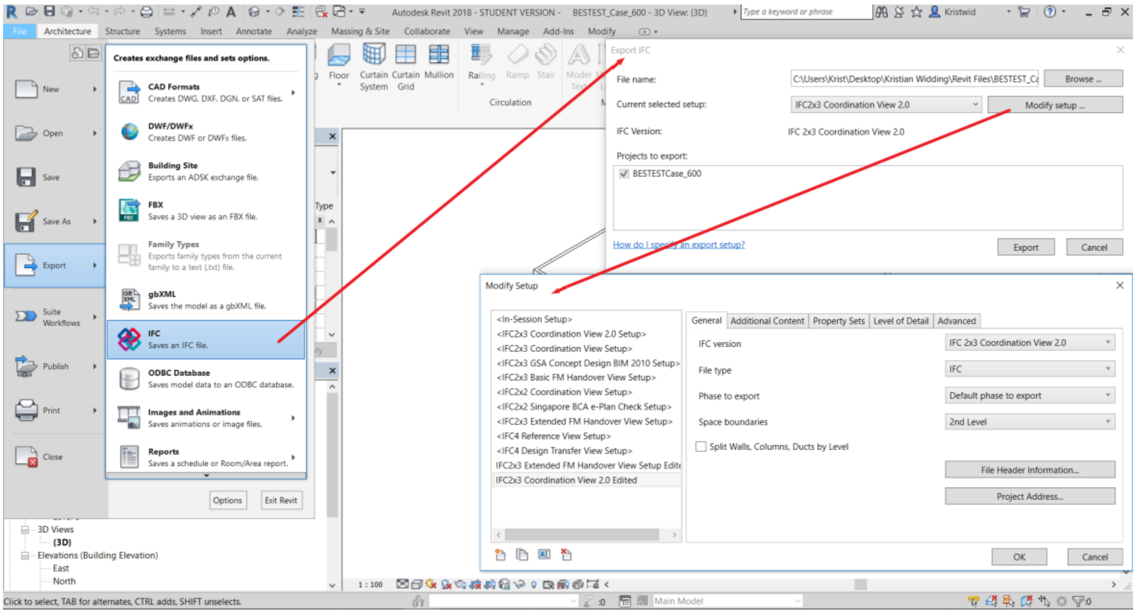


FIGURE 30: A SNAP SHOT SHOWING AUTODESK REVIT IFC EXPORT (MODIFICATIONS IN RED)

Revit offers to export IFC files in several different formats and setups. Table 18 gives a description on the different setup options. The same table also provides information on the selected options and options that will be investigated in the case studies.

TABLE 18: SUMMARY OF AUTODESK REVIT IFC EXPORT SETUP

IFC Modify Setup Tab	Setup Option	Description (Autodesk, 2017b)	Selected Option	Reason of Chose
General	IFC version.	N/A.	IFC 2x3 Coordination View 2.0 (default).	Known certification and support. Latest supported IFC version by IDA ICE.
	File type.	N/A.	IFC (default).	Correct IFC file type for IDA ICE import.
	Space boundaries.	The level of room/space boundaries exported.	2nd level.	Best suitable option for BEM geometry representation because it considers materials of building elements and adjacent spaces behind elements, providing thermal properties.
	Split Walls, Columns, Ducts by Level.	Allows Revit to divide multi-level walls, columns and ducts by each level that is defined as a building story.	Normally unchecked (default), but option is to be investigated in issue 5.	N/A.
	Phase to export.	Phase of document to export.	Default phase to export (default).	N/A.
	The options "File Header Information" and "Project Address".	Information about author, organization or project.	N/A.	Not of importance in BEM.
Additional Content	Export 2D plan view elements.	Option to include 2D elements supported by IFC export such as notes and filled regions.	Unchecked (default).	Not of importance in BEM.
	Export linked files as separate IFCs.	Option to check if there are any Revit links in the project that is desirable to save as a separate IFC file.	Unchecked (default).	N/A.
	Export only elements visible in view.	Option on whether to export the entire model or only elements visible in the current view.	Unchecked (default).	Desired to export entire model.
Property Sets	Export Revit property sets.	Option to decide if Revit-specific property sets based on parameter groups is to be included or exclude.	Unchecked (default).	N/A.
	Export IFC common property sets.	Decides whether to include or exclude the IFC common property sets.	Checked (default).	N/A.
	Export base quantities.	Option to include/exclude base quantities for model elements in the export data. The model geometry is used to generate base quantities, which then reflect the actual physical quantity values, independent of measurement rules or methods.	Unchecked (default).	N/A.

	Export schedules as property sets.	Option to determine if export of schedules as custom property sets is to be included/excluded.	Unchecked (default).	N/A.
	Export only schedules containing IFC, Pset, or Common in the title.	Option to determine if only schedules containing “IFC”, “PSet”, or “Common” in their title is to be exported.	Unchecked (default).	N/A.
	Export user defined property sets.	Option to export user-defined property sets.	Unchecked (default).	N/A.
	Export parameter mapping table.	Option to export custom parameter-mapping table.	Unchecked (default).	N/A.
Level of Detail	Level of detail for some element geometry.	Option controls the level of tessellation, BRep and profile representation accuracy for the Revit elements elbows, floors, pipe fittings, railings, ramps, spaces and stairs.	High.	Desired to have highest accuracy for Revit elements.
Advanced	Export parts as building elements.	Option to determine whether building elements are exported as standard IFC elements or as IfcBuildingElementPart.	Unchecked (default).	N/A.
	Allow use of mixed "Solid Model" representation.	Option to allow for mixing BRep and extrusion geometries for an entity. Results in smaller IFC files, but files not strictly within the IFC MVDs anymore.	Unchecked (default).	Want the IFC file to be fully within the IFC MVD.
	Use active view when creating geometry.	Option to determine if only geometry in active view or all the geometry is to be exported.	Unchecked (default).	Desired to export all the geometry.
	Use family and type name for reference.	Option to use either family and type name or only type name for references.	Unchecked (default).	N/A.
	Use 2D room boundaries for room volume.	Option whether to use the simplified room volume calculation, a calculation based on 2D extrusion of the room boundaries, or to use the Revit calculated room geometry to calculate the room volume.	Unchecked (default).	Desired to use the most accurate method for calculation of room volume.
	Include IFCSITE elevation in the site local placement origin.	Option to decide whether to include the elevation from the Z offset of the IFCSITE local placement.	Unchecked (default).	N/A.
	Store the IFC GUID in an element parameter after export.	Option to determine if the generated IFC GUIDs is to be stored in the project file after export. IFC GUID parameters will be added to elements and their type, along with Project Information for Project, Site and Building GUID.	Unchecked (default).	N/A.
	Export bounding box.	Option to export bounding box representation.	Unchecked (default).	N/A.

IDA ICE IFC Import

To import IFC models in IDA ICE, select “IFC” and then “Import” located in the “Floor plan” tab, refer Figure 31.

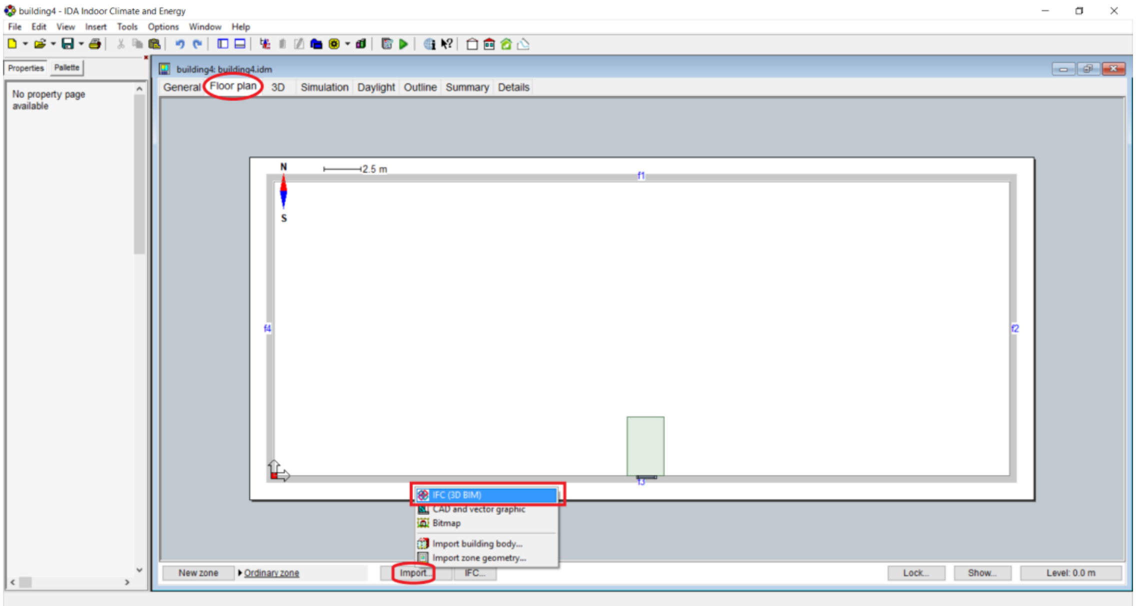


FIGURE 31: A SNAPSHOT SHOWING IDA ICE IFC IMPORT (MODIFICATIONS IN RED)

The window "Preferences" seen in Figure 32 will appear, displaying the IFC import setup options.

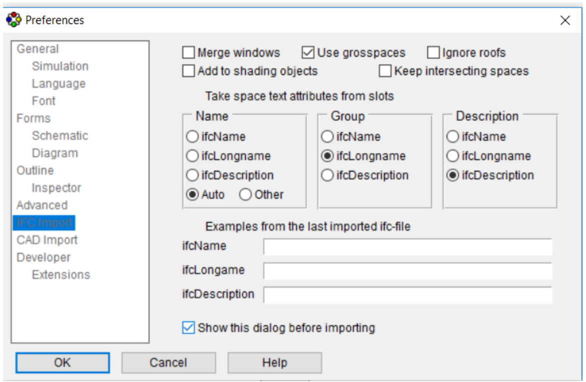


FIGURE 32: A SNAP SHOT SHOWING IDA ICE IFC IMPORT PREFERENCES

Table 19 gives a description of the IDA ICE IFC import options. The table also provides information on the selected options and options that will be investigated in the case studies.

Table 19: IDA ICE IFC import options – Description and selected options

Setup Option	Description	Selected Option	Reason of Chose
Merge windows	Option to determine whether to merge all windows hosted by the same wall into a single window with a total window area equal to the area of all the windows of the respective wall.	Unchecked (default).	Not of interest to merge windows.
Use grossspac es	Option to determine if the shape of the building story is taken from the space which covers every space on the story, or to be calculated from the outline of the walls.	Checked (default).	Desired that spaces define the building story.
Ignore roofs	Option to ignore the shape of the roof construction and replace it with a simple plane roof.	Unchecked (default).	Not of interest to simplify the roof construction.
Add to shading objects	Option on whether to include the whole IFC model as a shading object.	Unchecked (default).	Desired to select single IFC objects as shading objects.
Keep intersectin g spaces	Option on whether to import all spaces or to exclude the larger spaces of any intersecting spaces.	Normally unchecked (default), but option is to be investigated in issue 6.	N/A.
The space text attributes from slots	Every space has an individual and a group name. In IFC files these names can be found in the slots ifcName, ifcLongName or ifcDescription. The individual and group name of spaces can be asserted to different slots, depending on the CAD software.	N/A.	N/A.

A 2D- or 3D view of the IFC model is now to be seen in either the “Floor plan” or “3D” tab of IDA ICE, respectively.

Mapping IFC Data to IDA ICE Resources

The BIM-based IFC objects is possible to map to IDA ICE resources. This function is found under “Mapping” located in the “Floor plan” tab, see Figure 33.

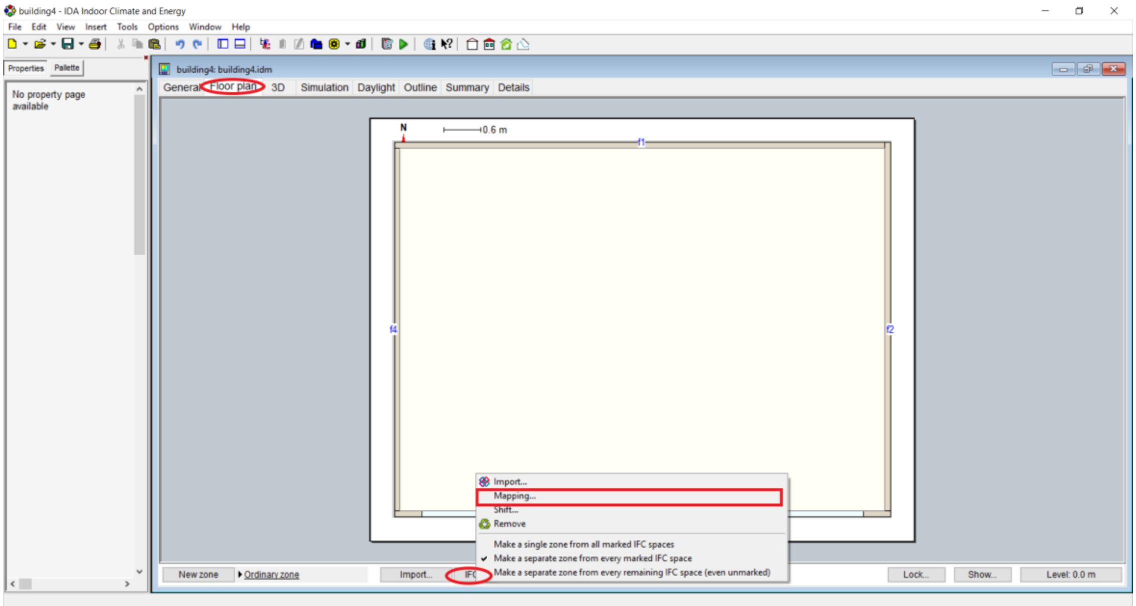


Figure 33: A snap shot showing IDA ICE mapping function (modifications in red)

Here the IFC objects can be mapped to the IDA ICE resource categories “Constructions”, “Materials”, “Windows”, ”Openings“ and “IFC spaces”. Figure 34 is an example where IFC objects have been mapped to IDA ICE resources.

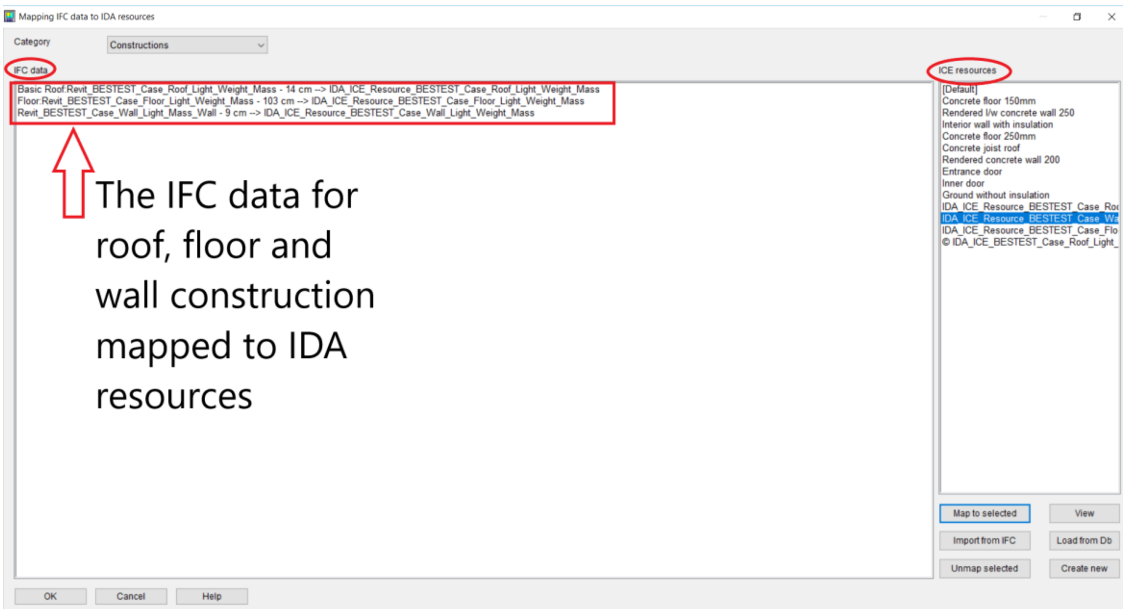


Figure 34: A snap shot showing IDA ICE – Mapping IFC objects to IDA ICE resources (modifications in red)

After completing the mapping procedure, the BIM-based BEM energy model is ready to be generated. This is done by selecting IFC spaces when inside the “Floor plan” tab and select “New Zone”.

It is possible to hide the IFC model from the 3D view by unchecking the IFC model in “Visual filter”, which is opened by right clicking the window when in 3D view.

3.2.4 Cases

In this chapter all cases of the case studies are presented. Each case begins by explained why the case is investigated in a building physics point of view. It then goes on to describe any case specific Revit modeling if relevant, along with a description and illustration of the Revit BIM model. The description of the cases will only include the characteristics of the models that differentiates them from the BESTEST Case 600 model. Unless otherwise mentioned, it can be assumed that the Revit BIM models are similar to this model. At last any case specific IDA ICE import is described, along with an illustration of the resulting energy model.

Case 1

<u>Modeling in Revit</u>

In Revit the modeling tool “Structural Column” was used to model the column elements, refer Figure 35.

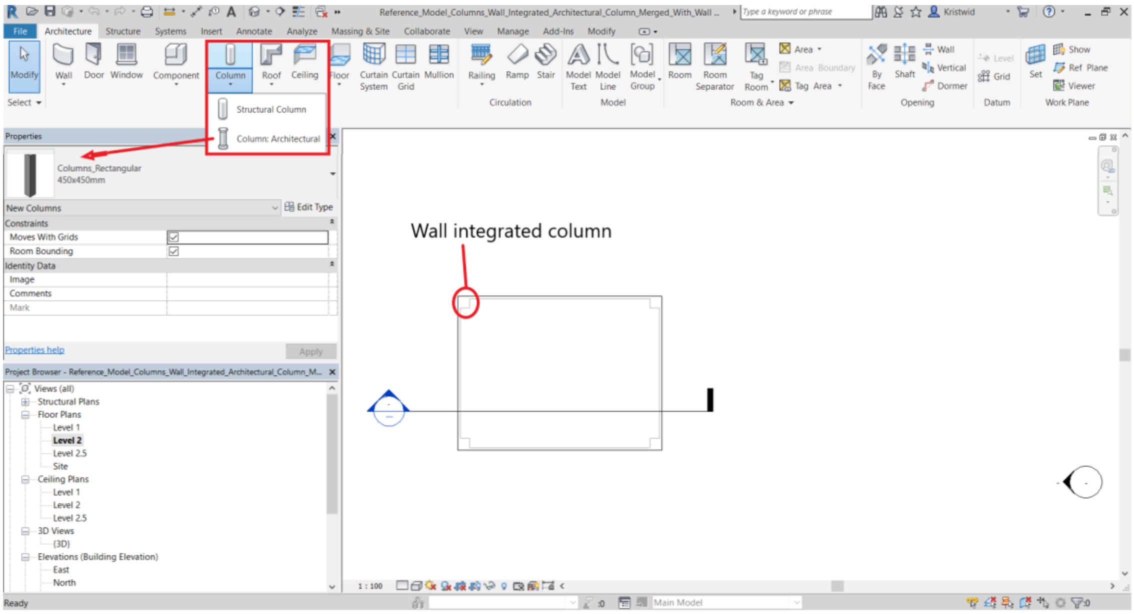


Figure 35: A snap shot showing Autodesk Revit modeling tool “Column” (modifications in red)

The room and space definition were applied after finishing modeling the columns. The room/space definition did not include the area of the columns in Revit, as seen in Figure 36. The order in which the definition of the room/space and the modeling of columns was carried out, made no difference on this matter. It was neither possible to edit the room/space definition so to include the area of the columns.

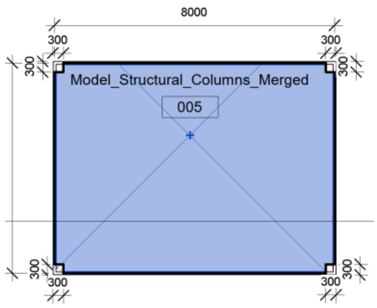


FIGURE 36: THE ROOM/SPACE DEFINITION OF THE BUILDING MODEL WITH STRUCTURAL COLUMNS IN THE CORNERS

Revit BIM Model Description and Illustration

Windows to south removed.

In each corner of the room are structural columns of the family “Concrete Square” and type “300 x 300mm”, merged into walls.

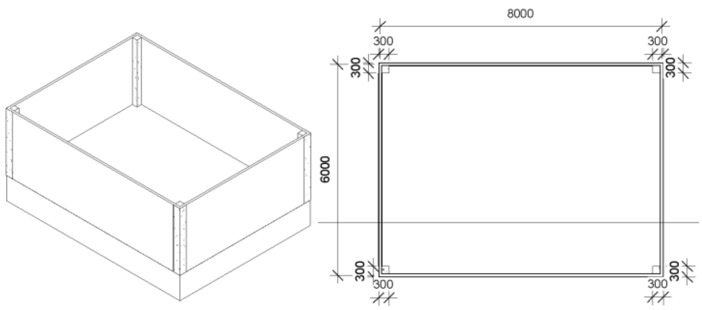


FIGURE 37: REVIT BIM MODEL – STRUCTURAL COLUMN CORNERS (MERGED) – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

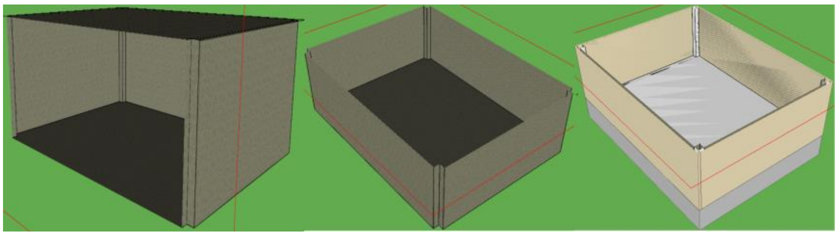


FIGURE 38: IDA ICE ENERGY MODEL – STRUCTURAL COLUMN CORNERS (MERGED) – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 2

Modeling in Revit

Same as case 1.

Revit BIM Model Description and Illustration

Same as case 1, except that each column in corners are not merged into walls.

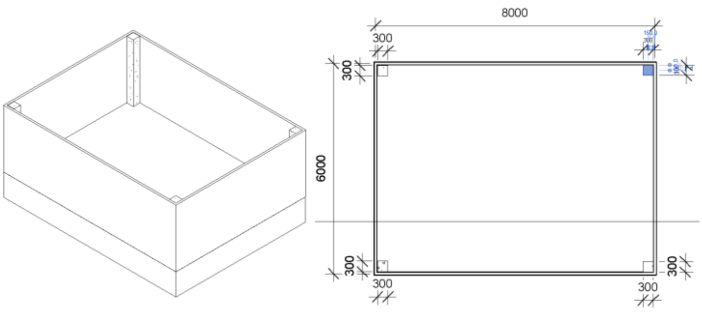


FIGURE 39: REVIT BIM MODEL – STRUCTURAL COLUMN CORNERS (NOT MERGED) – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

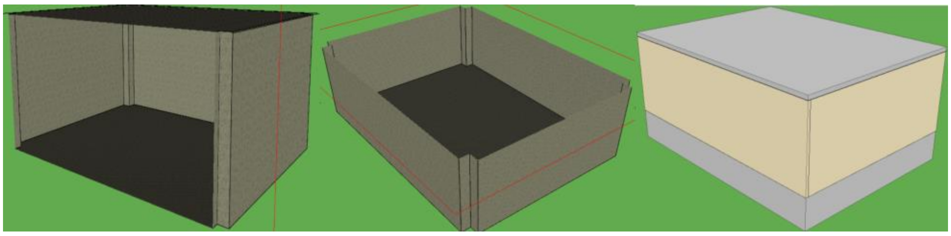


FIGURE 40: IDA ICE ENERGY MODEL – STRUCTURAL COLUMN CORNERS (NOT MERGED) – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 3

Modeling in Revit

Same as case 1.

Revit BIM Model Description and Illustration

Windows to south removed.

A structural column of the family “Concrete Square” and type “300 x 300mm” placed in the middle of the building.

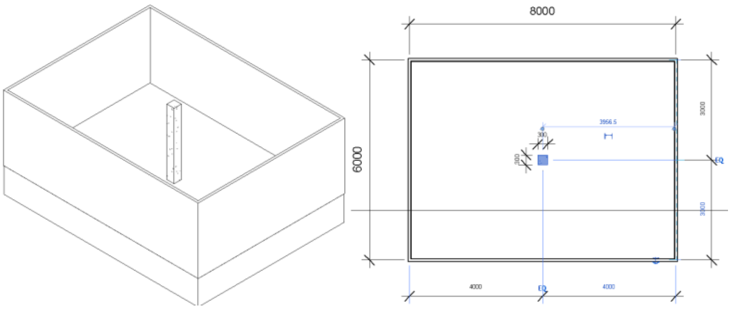


FIGURE 41: REVIT BIM MODEL – STRUCTURAL COLUMN CENTER – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

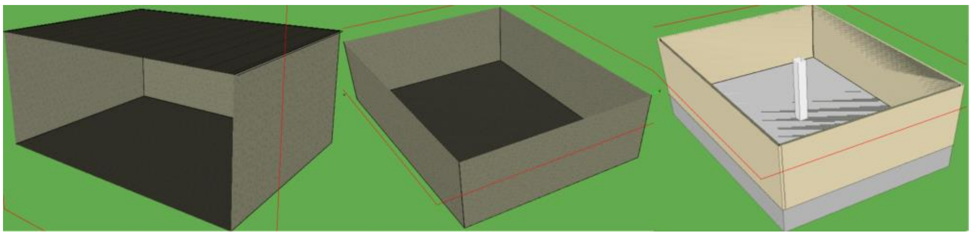


FIGURE 42: IDA ICE ENERGY MODEL – STRUCTURAL COLUMN CENTER – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 4

Modeling in Revit

Same as case 1, but instead of the “Structural Column, the column tool “Architectural: Column” was used, refer Figure 35.

Revit BIM Model Description and Illustration

Windows to south removed.

In each corner of the room are architectural columns of the family “M_Rectangular Column” and type “475 x 610mm”, merged into walls.

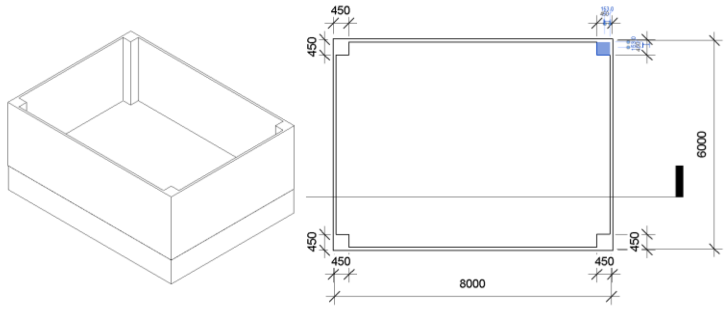


FIGURE 43: REVIT BIM MODEL – ARCHITECTURAL COLUMN CORNERS (MERGED) – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

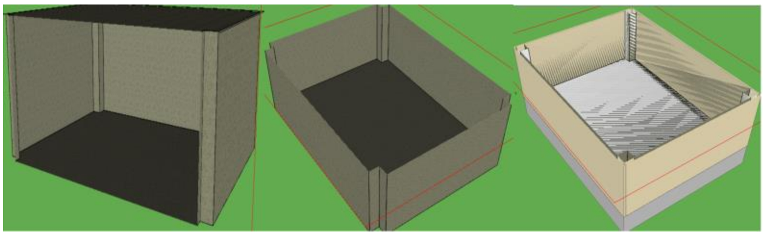


FIGURE 44: IDA ICE ENERGY MODEL – ARCHITECTURAL COLUMN CORNERS (MERGED) – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 5

Modeling in Revit

Same as case 4.

Revit BIM Model Description and Illustration

Same as case 4, except that each column in corners are not merged into walls.

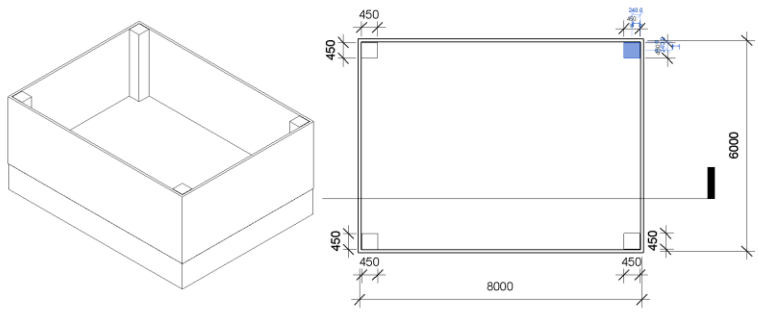


FIGURE 45: REVIT BIM MODEL – ARCHITECTURAL COLUMN CORNERS (NOT MERGED) – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

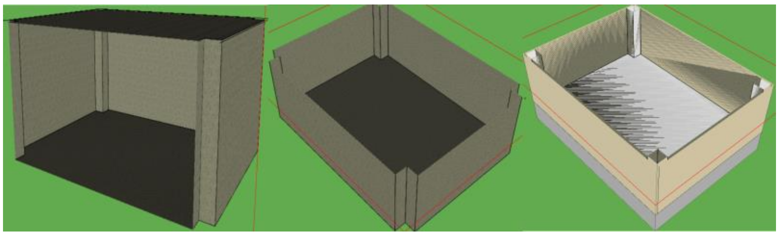


FIGURE 46: IDA ICE ENERGY MODEL – ARCHITECTURAL COLUMN CORNERS (NOT MERGED) – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 6

Modeling in Revit

Same as case 4.

Revit BIM Model Description and Illustration

Windows to south removed.

An architectural column of the family “M_Rectangular Column” and type “475 x 610mm”, placed in the middle of the room.

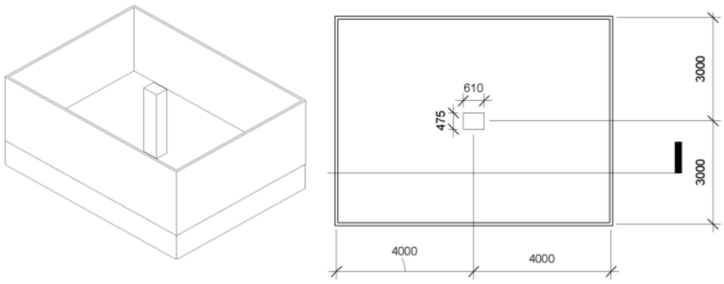


FIGURE 47: REVIT BIM MODEL – ARCHITECTURAL COLUMN CENTER – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

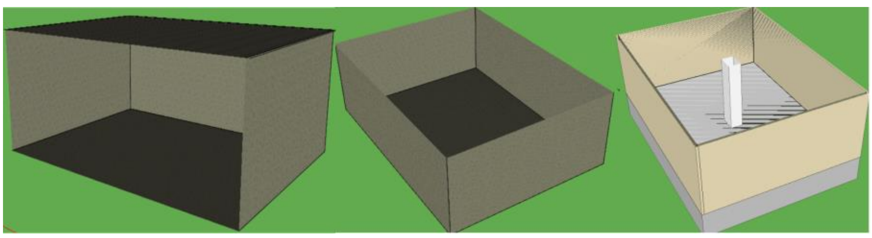


FIGURE 48: IDA ICE ENERGY MODEL – ARCHITECTURAL COLUMN CENTER – LEFT: THERMAL ZONE SECTION VIEW. MIDDLE: THERMAL ZONE SECTION VIEW. RIGHT: IFC MODEL SECTION VIEW

Case 7

Modeling in Revit

The south wall of the building is modeled as a curtain wall. Curtain walls are modeled using the “Wall” creation tool with the wall family “Curtain Wall”, refer Figure 49. There are three different family types of this system family, namely “Curtain Wall”, “Exterior Glazing” and “Storefront”. In this case the type “Curtain Wall” is being used.

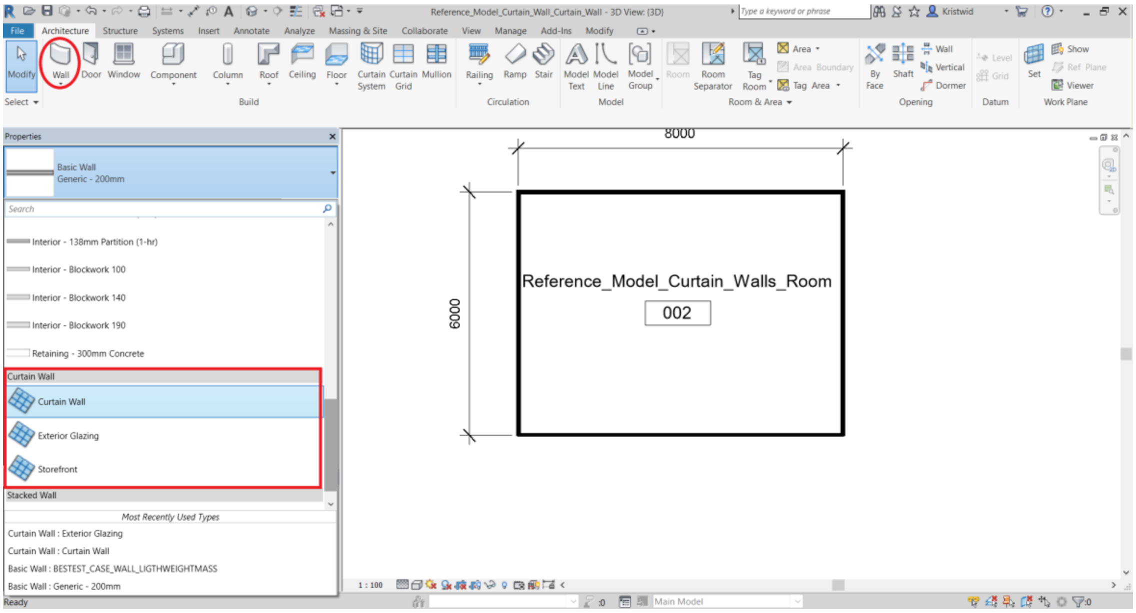


FIGURE 49: A SNAP SHOT SHOWING AUTODESK REVIT CURTAIN WALL MODELING TOOL (MODIFICATIONS IN RED)

The curtain wall appears as a transparent element in the Revit BIM model, see Figure 50.

Revit BIM Model Description and Illustration

Windows to south removed.

The south wall a transparent curtain wall element of the system family “Curtain Wall” and family type “Curtain Wall”. Consists of a single glazed curtain panel, no mullions/bars.

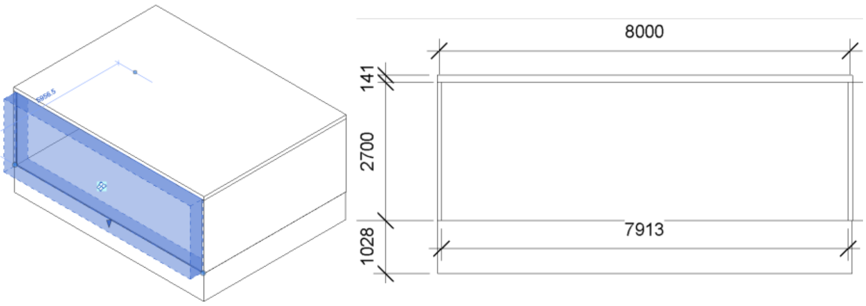


FIGURE 50: REVIT BIM MODEL – CURTAIN WALLS – TYPE: CURTAIN WALL – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

<u>IDA ICE Energy Model</u>

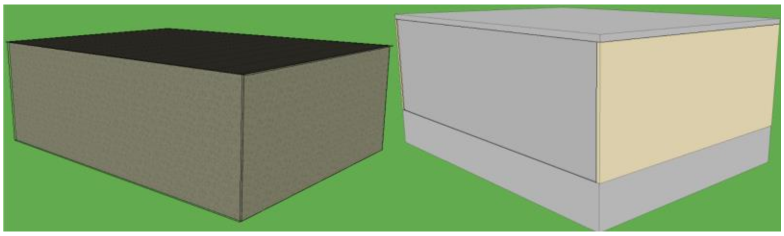


FIGURE 51: IDA ICE ENERGY MODEL – CURTAIN WALLS – TYPE: CURTAIN WALL – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 8

<u>Modeling in Revit</u>

Same as case 7, except that in this case the family type “Exterior Glazing” is used to model the curtain wall element.

<u>Revit BIM Model Description and Illustration</u>

The south wall a transparent curtain wall element of the system family “Curtain Wall” and family type “Exterior Glazing”. Consists of five glazed curtain panels. Grid layout with no mullions/bars defined as seen in Figure 52.

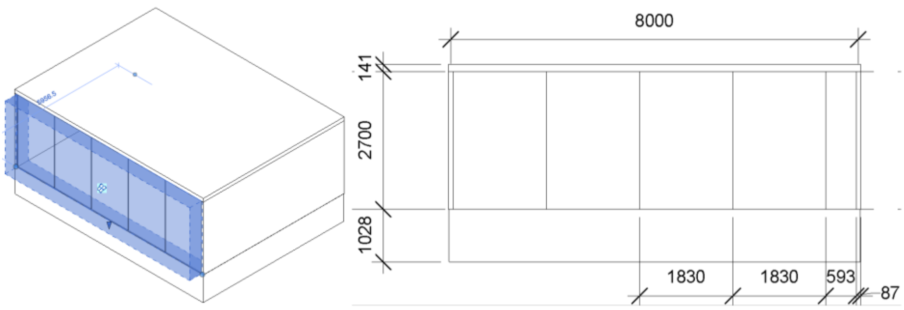


FIGURE 52: REVIT BIM MODEL – CURTAIN WALLS – TYPE: EXTERIOR GLAZING – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

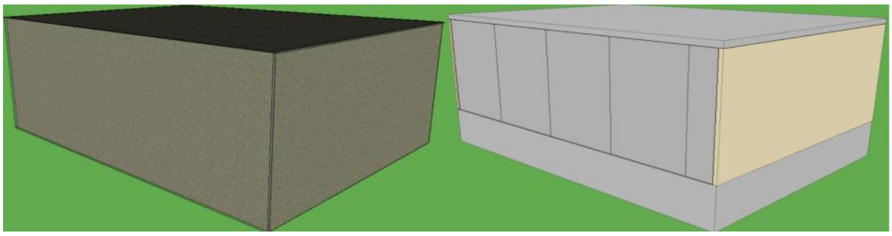


FIGURE 53: IDA ICE ENERGY MODEL – CURTAIN WALLS – TYPE: EXTERIOR GLAZING – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 9

Modeling in Revit

Same as case 7, except that in this case the family type “Storefront” is used to model the curtain wall element.

Revit BIM Model Description and Illustration

The south wall a transparent curtain wall element of the system family “Curtain Wall” and family type “Storefront”. Consists of multiple glazed curtain panels with horizontal and vertical aluminum rectangular mullions/bars with dimension 50 x 150 mm. Grid layout as seen in Figure 54.

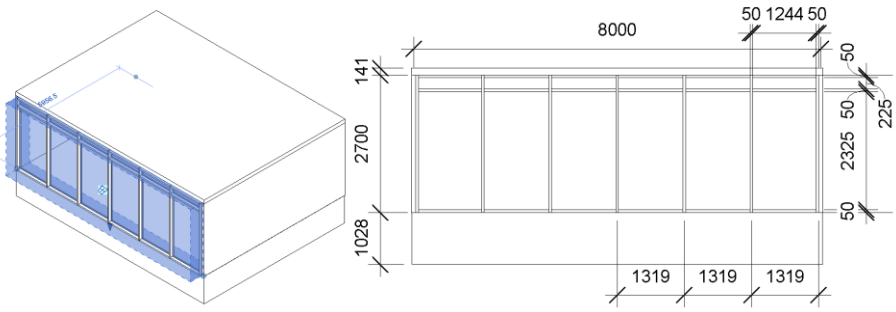


FIGURE 54: REVIT BIM MODEL – CURTAIN WALLS – TYPE: STOREFRONT – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

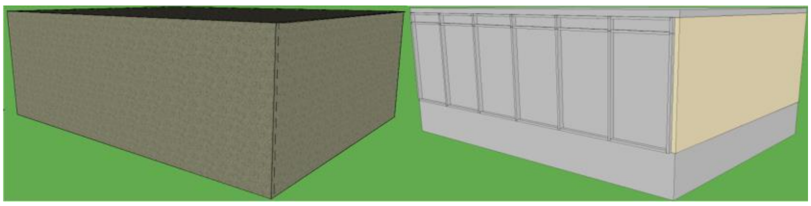


FIGURE 55: IDA ICE ENERGY MODEL – CURTAIN WALLS – TYPE: STOREFRONT – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 10

Modeling in Revit

Modeling the door in Revit follows the procedure described in 3.2.2 General Modeling Conventions in Autodesk Revit: Modeling of Window and Door Constructions.

Revit BIM Model Description and Illustration

Windows to south removed.

A door of the family “M_Single-Flush” and family type “0915 x 2134mm” placed in middle of south wall.

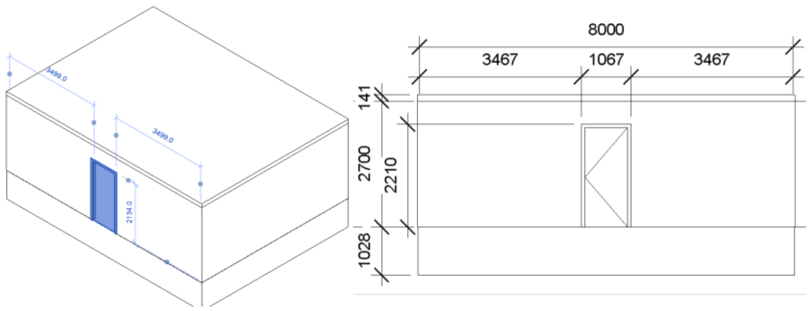


FIGURE 56: REVIT BIM MODEL – DOORS – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

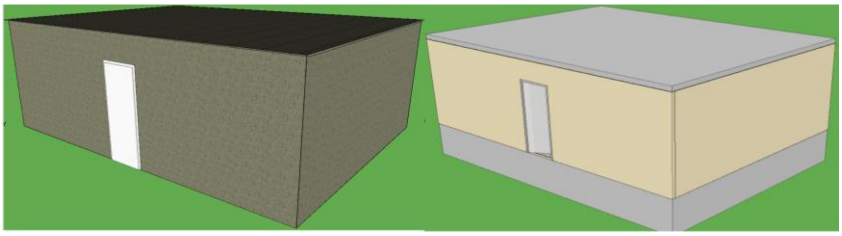


FIGURE 57: IDA ICE ENERGY MODEL – DOORS – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 11

Modeling in Revit

A new (elevation) “Level" was created 1,1 meters above the top of the roof and then the top constraint of the 1st level walls were fixed to this level.

Revit BIM Model Description and Illustration

Windows to south removed.

Parapet walls with a height of 1,1 meters on all sides of the building.

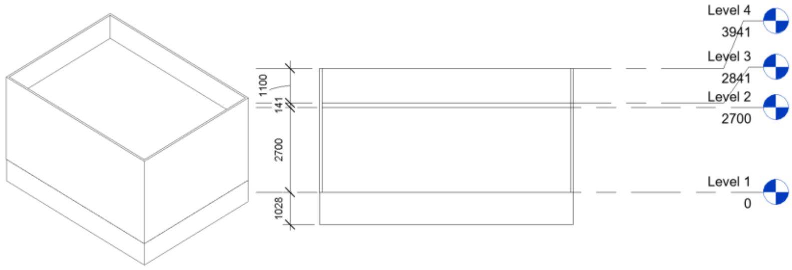


FIGURE 58: REVIT BIM MODEL – PARAPET WALLS – EXTENDED WALL – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

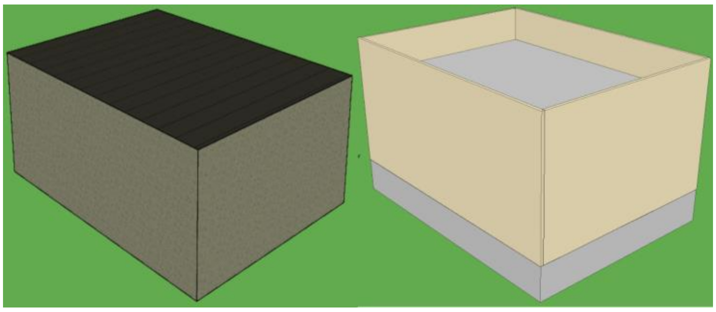


FIGURE 59: IDA ICE ENERGY MODEL – PARAPET WALLS – EXTENDED WALL – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 12

Modeling in Revit

In this case the Revit tool “Model In-Place” with the family category “Walls” and “Solid Sweep” was used to model the parapet walls. See Figure 60 and Figure 61 illustrating the procedure for this.

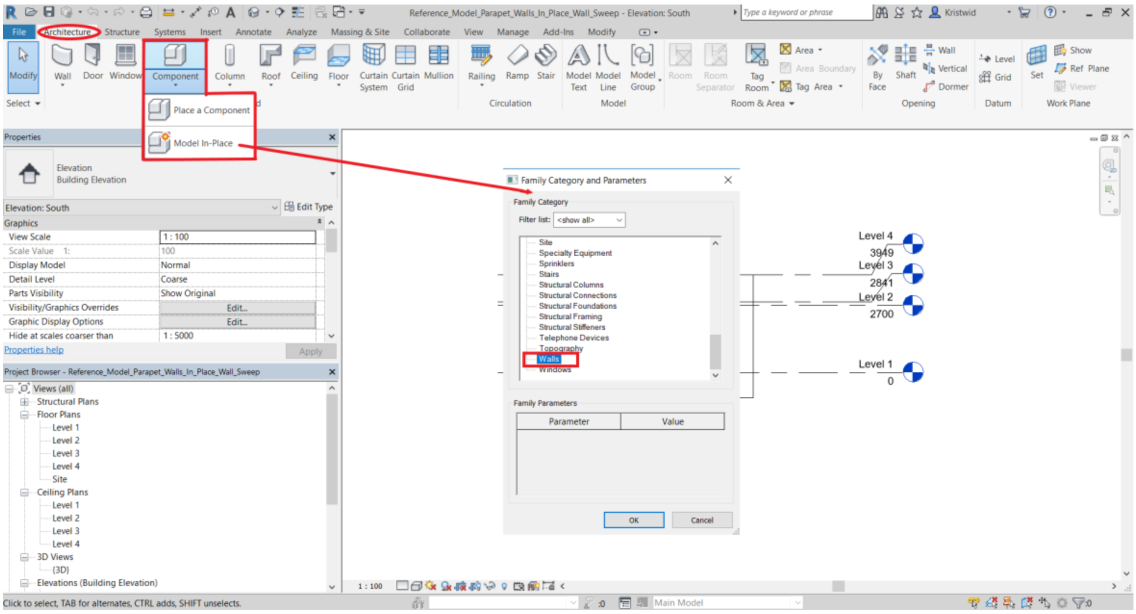


FIGURE 60: A SNAP SHOT SHOWING AUTODESK REVIT "MODEL IN-PLACE" MODELING TOOL (MODIFICATIONS IN RED)

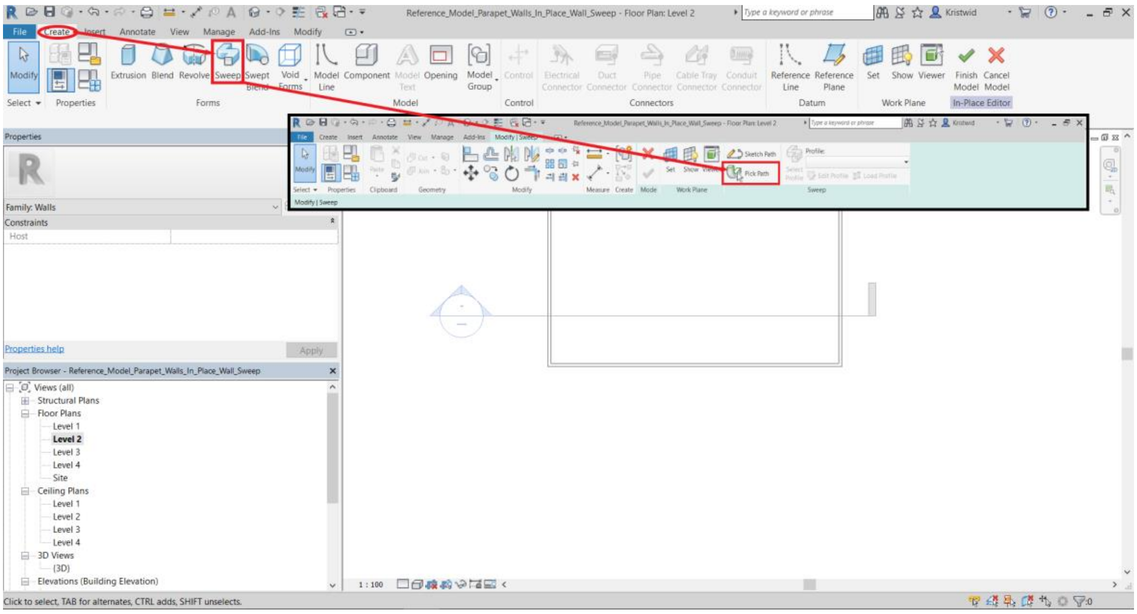


FIGURE 61: A SNAP SHOT SHOWING THE AUTODESK REVIT "SOLID SWEEP" TOOL OF THE "MODEL IN-PLACE" MODELING TOOL (MODIFICATIONS IN RED)

<u>Revit BIM Model Description and Illustration</u>

Same as case 11.

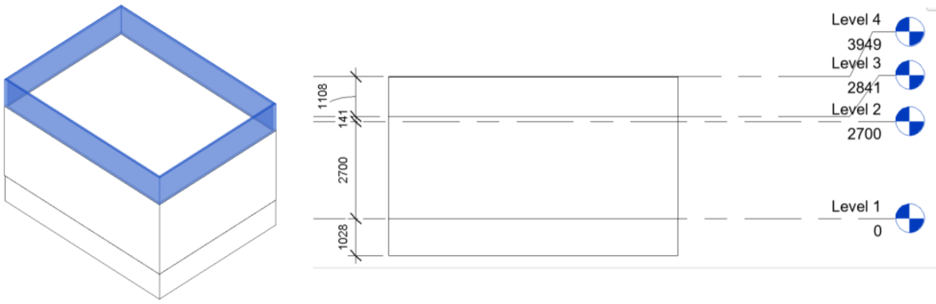


FIGURE 62: REVIT BIM MODEL – PARAPET WALLS – IN-PLACE WALL SWEEP – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

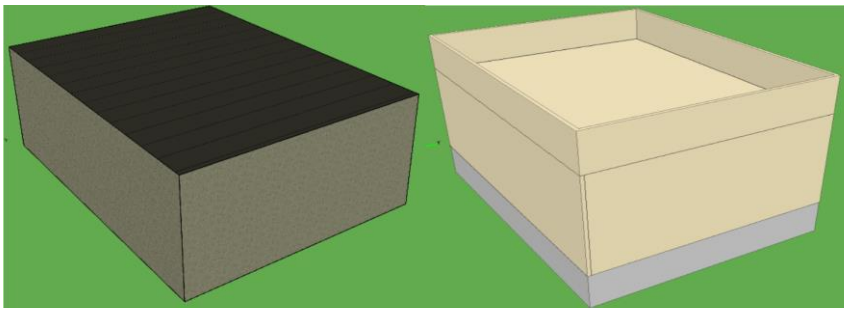


FIGURE 63: IDA ICE ENERGY MODEL – PARAPET WALLS – IN-PLACE WALL SWEEP – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 13

Modeling in Revit

The vertical wall sweep structure is done by entering “Edit Type” located in the property bar of the walls. Then select “Edit Structure” which will open the “Edit Assembly” window. Select the view “Section: Modify type attributes”, and then choose “Sweeps” which will open the window “Wall Sweeps”. Here the parapet wall profile can be loaded by choosing “Load Profile”. The chosen profile will appear in this window and is also shown in the preview of the “Edit Assembly” window. Figure 64 and Figure 65 illustrate the outlined procedure.

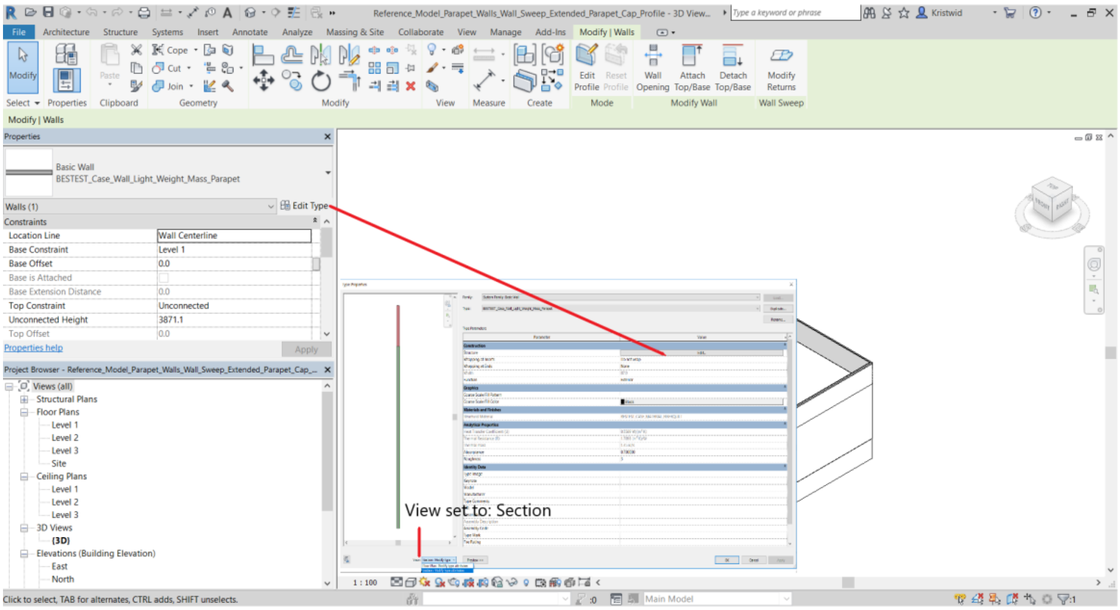


FIGURE 64: A SNAP SHOT SHOWING THE PROCEDURE CREATING VERTICAL WALL SWEEP STRUCTURE IN AUTODESK REVIT – PART 1 (MODIFICATIONS IN RED)

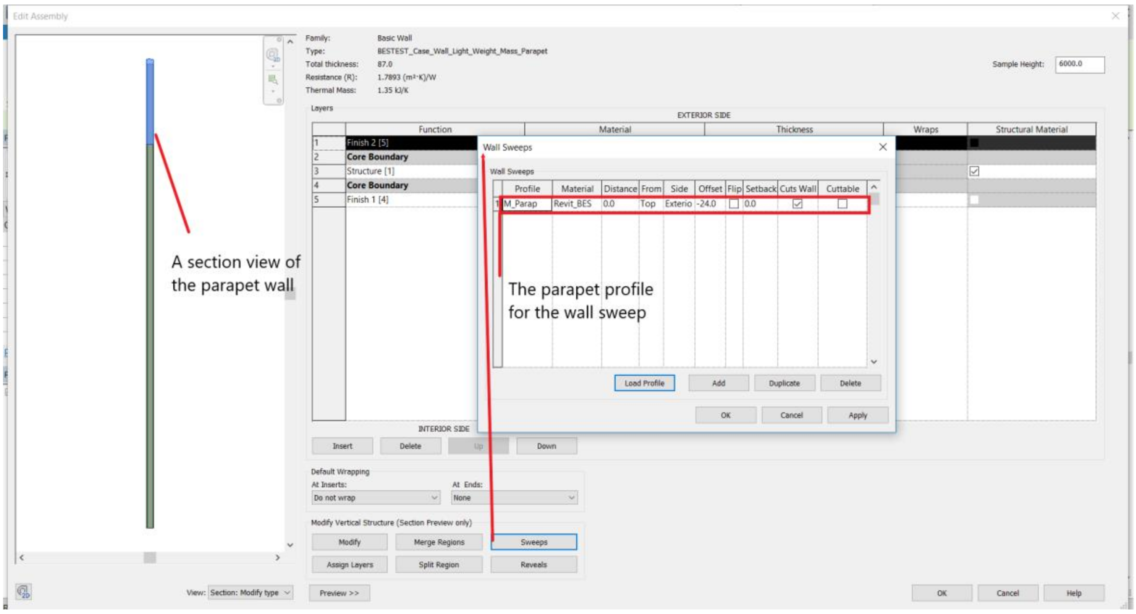


FIGURE 65: A SNAP SHOT SHOWING THE PROCEDURE CREATING VERTICAL WALL SWEEP STRUCTURE IN AUTODESK REVIT – PART 2 (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

Same as case 11.

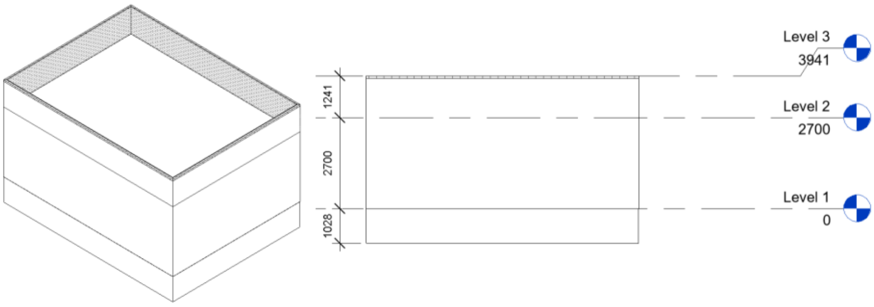


FIGURE 66: REVIT BIM MODEL – PARAPET WALLS – VERTICAL WALL SWEEP STRUCTURE – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

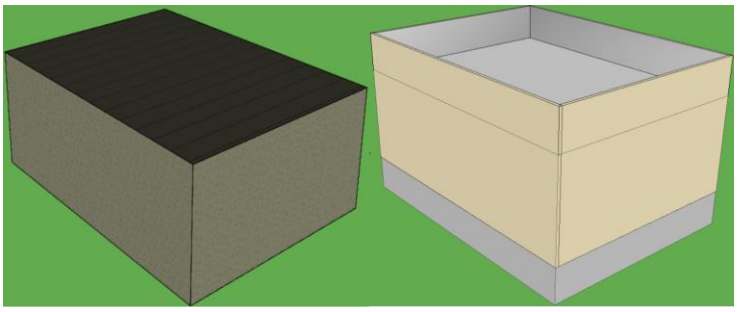


FIGURE 67: IDA ICE ENERGY MODEL – PARAPET WALLS – VERTICAL WALL SWEEP STRUCTURE – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 14

Modeling in Revit

The base and top-level constraint of the wall is set to level 1 (top of ground floor) and level 3 (bottom of roof).

The internal floor construction separating 1st and 2nd level is connected to the inside of the walls.

In addition to the standard Revit IFC export settings as given in Autodesk Revit IFC Export, a modified IFC export with the option named “Split Walls, Columns, Ducts by level” checked, was also tested for this case.

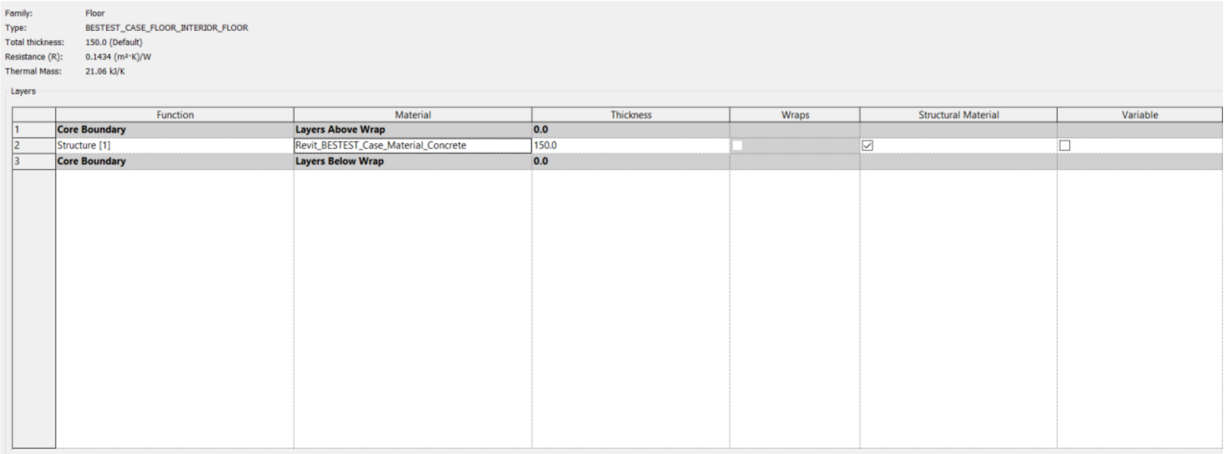
Revit BIM Model Description and Illustration

Rectangular building, two floors, two rooms. The external wall elements modeled as single elements covering both stories.

Height per floor: 2,7 m.

Windows to south removed.

Internal floor construction has a thickness of 0,150 m, structure as seen in Figure 68 and material properties of concrete as seen in Figure 69.



	Function	Material	Thickness	Wraps	Structural Material	Variable
1	**Core Boundary**	**Layers Above Wrap**	**0.0**			
2	Structure [1]	Revit_BESTEST_Case_Material_Concrete	150.0	☐	☑	☐
3	**Core Boundary**	**Layers Below Wrap**	**0.0**			

FIGURE 68: A SNAP SHOT OF AUTODESK REVIT SHOWING THE STRUCTURE OF THE INTERNAL FLOOR CONSTRUCTION

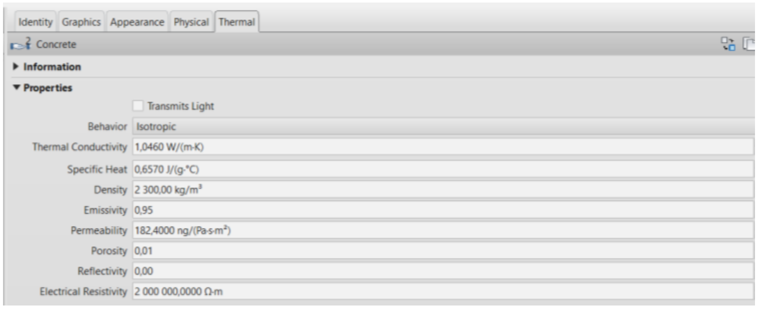


FIGURE 69: A SNAP SHOT OF AUTODESK REVIT SHOWING THE MATERIAL PROPERTIES OF CONCRETE

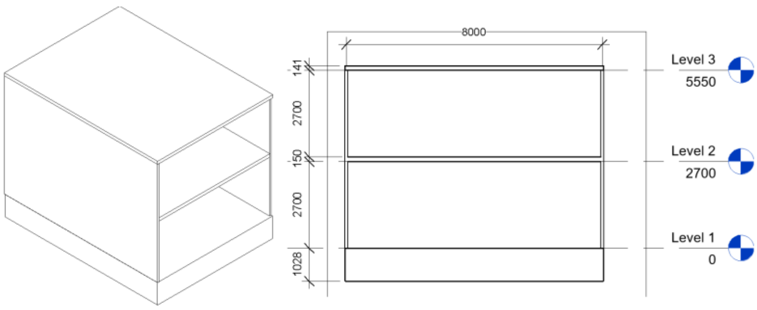


FIGURE 70: REVIT BIM MODEL – A TWO-STORY BUILDING WITH A WALL ELEMENT COVERING BOTH STORIES – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

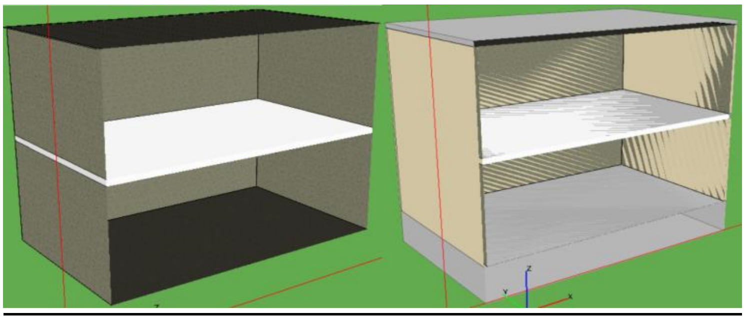


FIGURE 71: IDA ICE ENERGY MODEL – A TWO-STORY BUILDING WITH A WALL ELEMENT COVERING BOTH STORIES – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 15

Modeling in Revit

The base and top-level constraint of the 1st level walls is set to level 1 (top of ground floor) and level 2 (bottom of internal floor), while the base and top-level constraint of the 2nd level walls is set to level 2 and level 3 (bottom of roof).

Revit BIM Model Description and Illustration

Same as case 14, except that the external wall elements are modeled as two elements covering one story each.

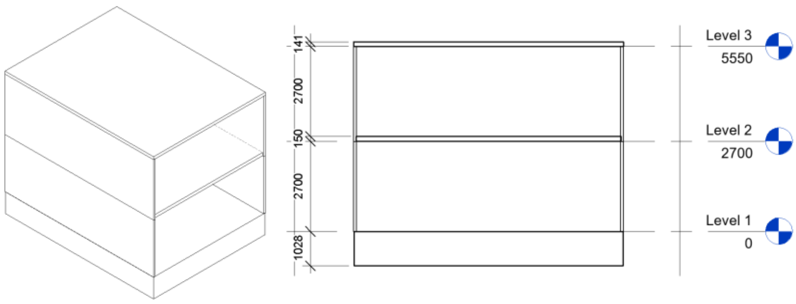


FIGURE 72: REVIT BIM MODEL – A TWO-STORY BUILDING WITH ONE WALL ELEMENT FOR EACH STORY – LEFT: 3D VIEW. RIGHT: ELEVATION VIEW

IDA ICE Energy Model

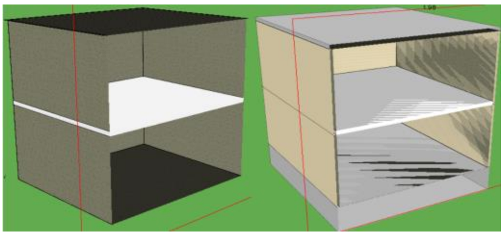


FIGURE 73: IDA ICE ENERGY MODEL – A TWO-STORY BUILDING WITH ONE WALL ELEMENT FOR EACH STORY – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 16

Modeling in Revit

The atrium space is made of internal walls. Internal walls are modeled the same as external walls, refer [Modeling of Wall, Roof and Floor Constructions](#). The atrium space extends from top of slab to bottom of roof construction.

Three rooms/spaces in total were defined for the building, i.e. for the 1st and 2nd level space and the atrium space.

Revit BIM Model Description and Illustration

Rectangular building, two floors. An atrium space in middle of building. Three rooms/spaces in total.

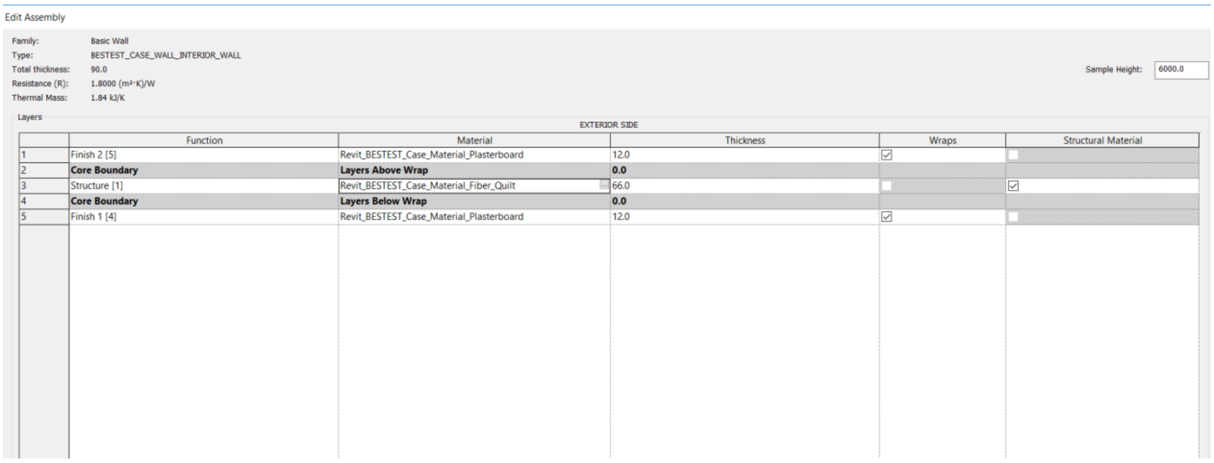
Height per floor: 2,7 m.

Windows to south removed.

The external floor and roof construction as single elements covering the whole building footprint.

Internal floor construction same as case 14.

Internal wall construction has a thickness of 0,090 m and structure as seen in Figure 74.



Edit Assembly

Family: Basic Wall
Type: BESTEST_CASE_WALL_INTERIOR_WALL
Total thickness: 90.0
Resistance (R): 1.8000 (m²·K)/W
Thermal Mass: 1.84 kJ/K

Sample Height: 6000.0

Layers

EXTERIOR SIDE

	Function	Material	Thickness	Wraps	Structural Material
1	Finish 2 [5]	Revit_BESTEST_Case_Material_Plasterboard	12.0	☑	☐
2	**Core Boundary**	**Layers Above Wrap**	**0.0**		
3	Structure [1]	Revit_BESTEST_Case_Material_Fiber_Quilt	66.0	☐	☑
4	**Core Boundary**	**Layers Below Wrap**	**0.0**		
5	Finish 1 [4]	Revit_BESTEST_Case_Material_Plasterboard	12.0	☑	☐

FIGURE 74: A SNAP SHOT OF AUTODESK REVIT SHOWING THE STRUCTURE OF THE INTERNAL WALL CONSTRUCTION

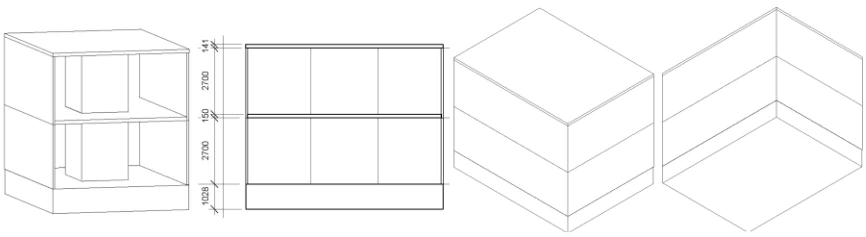


FIGURE 75: REVIT BIM MODEL – ATRIUM SPACE WITH ROOF AND FLOOR COVERING THE WHOLE BUILDING FOOTPRINT – LEFT: 3D VIEW. MIDDLE: ELEVATION VIEW. RIGHT: ROOF AND FLOOR AS ONE ELEMENT

IDA ICE Energy Model

In addition to the standard IDA ICE IFC import as given in IDA ICE IFC Import, the option “Keep intersecting spaces” was also explored for this case.

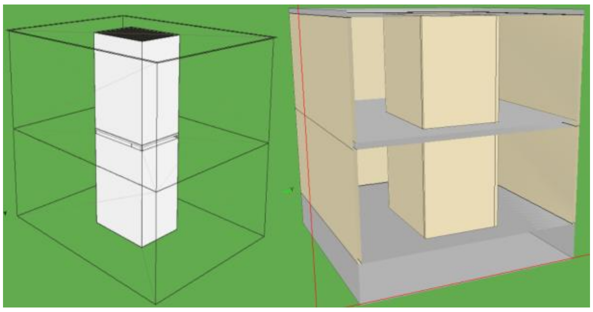


FIGURE 76: IDA ICE ENERGY MODEL – ATRIUM SPACE WITH ROOF AND FLOOR COVERING THE WHOLE BUILDING FOOTPRINT – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 17

Modeling in Revit

Same as case 16.

Revit BIM Model Description and Illustration

Same as case 16, except that the external floor and roof construction is modeled in two parts, i.e. one part for the larger space and the other part for the atrium space.

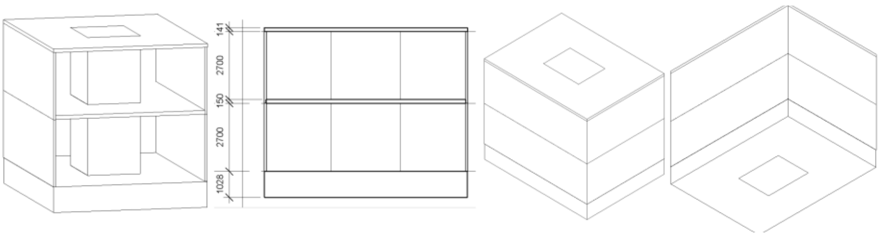


FIGURE 77: REVIT BIM MODEL – ATRIUM SPACE WITH ROOF AND FLOOR AS TWO ELEMENTS – LEFT: 3D VIEW. MIDDLE: ELEVATION VIEW. RIGHT: ROOF AND FLOOR AS TWO ELEMENTS

IDA ICE Energy Model

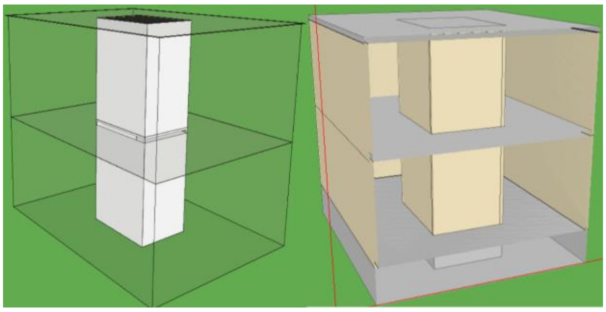


FIGURE 78: IDA ICE ENERGY MODEL – ATRIUM SPACE WITH ROOF AND FLOOR AS TWO ELEMENTS – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 18

Modeling in Revit

In this case the Revit tool "Shaft Opening" is being used to create an opening in the internal floor separating 1st and 2nd level. Figure 79 shows where to locate the respective tool in Revit. The base and top constraint of the shaft opening is set to level 1 (top of floor) and to level 3 (bottom of roof). The shaft opening is meant to constitute the atrium space.

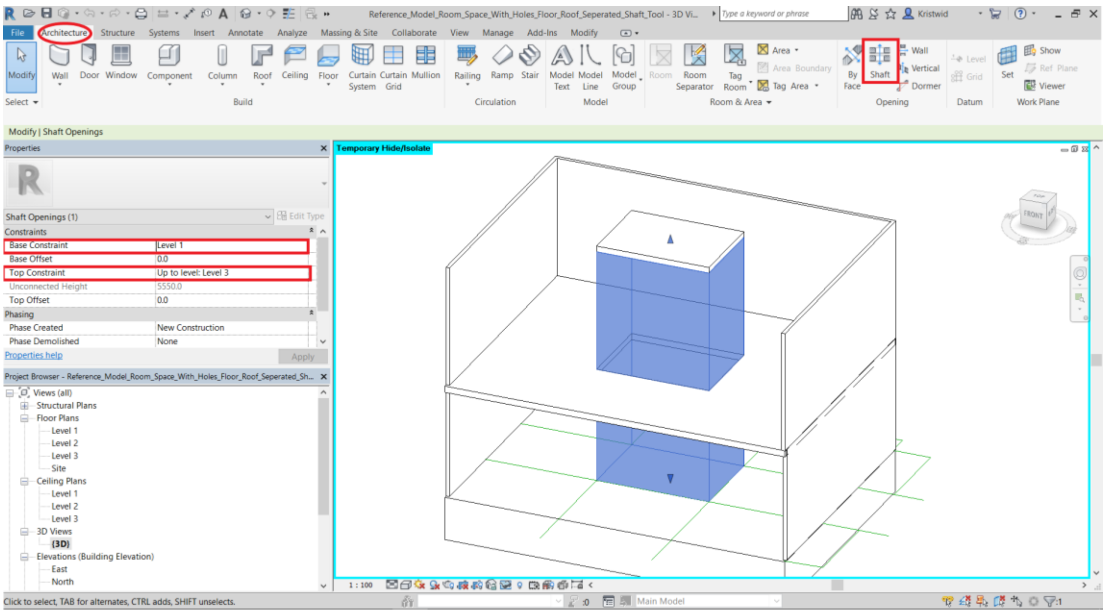


FIGURE 79: A SNAP SHOT SHOWING THE AUTODESK REVIT "SHAFT OPENING" TOOL (MODIFICATIONS IN RED)

It was not possible to define an own room/space for the area of the shaft opening, instead the room/space at 1st and 2nd floor covered the whole area of the floor.

Revit BIM Model Description and Illustration

Same as case 16, except that a shaft opening constitutes the atrium space rather than internal walls.

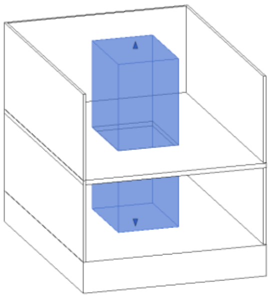


FIGURE 80: REVIT BIM MODEL – ATRIUM SPACE AS SHAFT OPENING AND WITH ROOF AND FLOOR COVERING THE WHOLE BUILDING FOOTPRINT – 3D VIEW

IDA ICE Energy Model

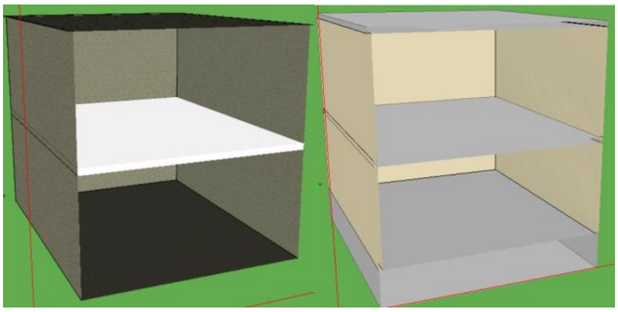


FIGURE 81: IDA ICE ENERGY MODEL – ATRIUM SPACE AS SHAFT OPENING AND WITH ROOF AND FLOOR COVERING THE WHOLE BUILDING FOOTPRINT – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 19

Modeling in Revit

Same as case 18.

Revit BIM Model Description and Illustration

Same as case 17, except that a shaft opening constitutes the atrium space rather than internal walls.

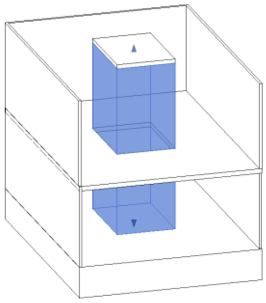


FIGURE 82: REVIT BIM MODEL – ATRIUM SPACE AS SHAFT OPENING WITH ROOF AND FLOOR AS TWO ELEMENTS – 3D VIEW

IDA ICE Energy Model

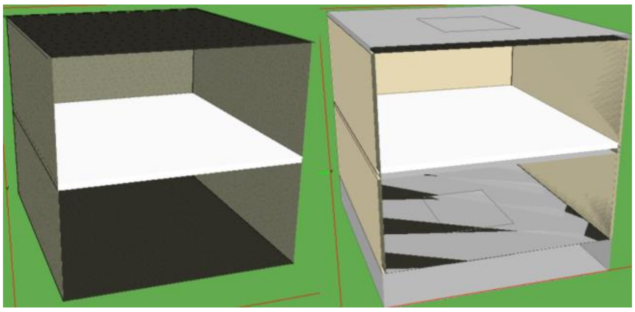


FIGURE 83: IDA ICE ENERGY MODEL – ATRIUM SPACE AS SHAFT OPENING WITH ROOF AND FLOOR AS TWO ELEMENTS – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 20

Modeling in Revit

The mezzanine structure at 2nd floor is modeled as a floor construction covering only half the area of the floor level. To model floor constructions, refer Modeling of Wall, Roof and Floor Constructions.

To be able to define a room/space for the mezzanine space when no wall is defined between the area of the mezzanine and the rest of the building, a room separation line must be made using the Revit tool “Room Separator”. This is illustrated in Figure 84.

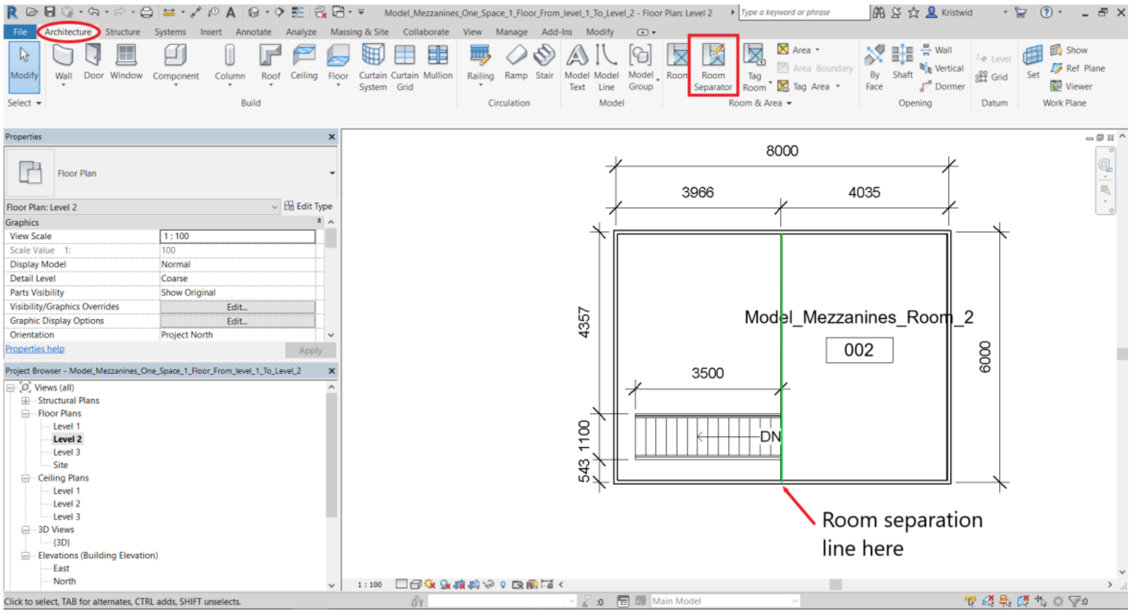


FIGURE 84: A SNAP SHOT SHOWING THE AUTODESK REVIT "ROOM SEPARATOR" TOOL (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

Rectangular building, two floors. The 2nd floor construction cover half of 2nd level and constitutes the mezzanine space. Room separation line separating mezzanine space from rest of building. Two rooms/spaces defined in total.

Height per floor: 2,7 m.

Windows to south removed.

Internal floor construction same as case 14.

Stair construction: System family "Assembled Stair", type "190mm max riser 250mm going".

Railing construction: System family "Railing", type "900mm Pipe".

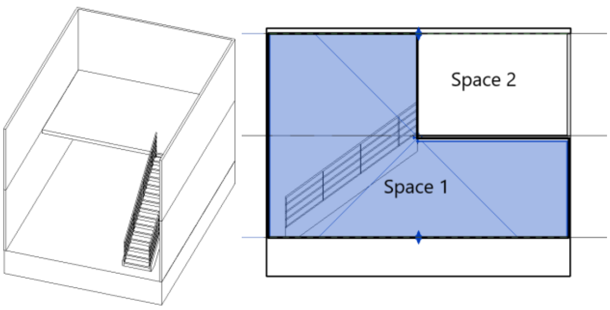


FIGURE 85: REVIT BIM MODEL – MEZZANINE CASE 20 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

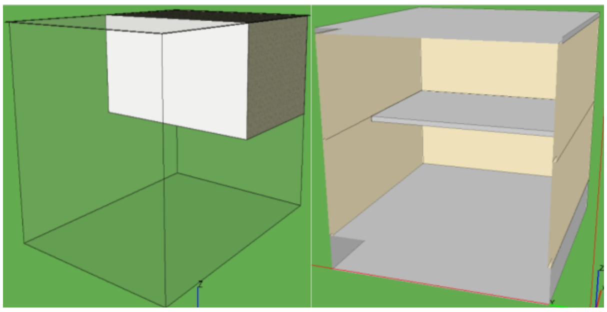


FIGURE 86: IDA ICE ENERGY MODEL – MEZZANINE CASE 20 – LEFT: BUILDING BODY & THERMAL ZONE. RIGHT: IFC MODEL

Case 21

Modeling in Revit

In contrast to case 20, the area of the mezzanine space is separated from the rest of the building by modeling a wall with opening as illustrated in Figure 88. For modeling of walls, refer [Modeling of Wall, Roof and Floor Constructions](). The “Wall Opening” tool in Revit is shown in Figure 87.

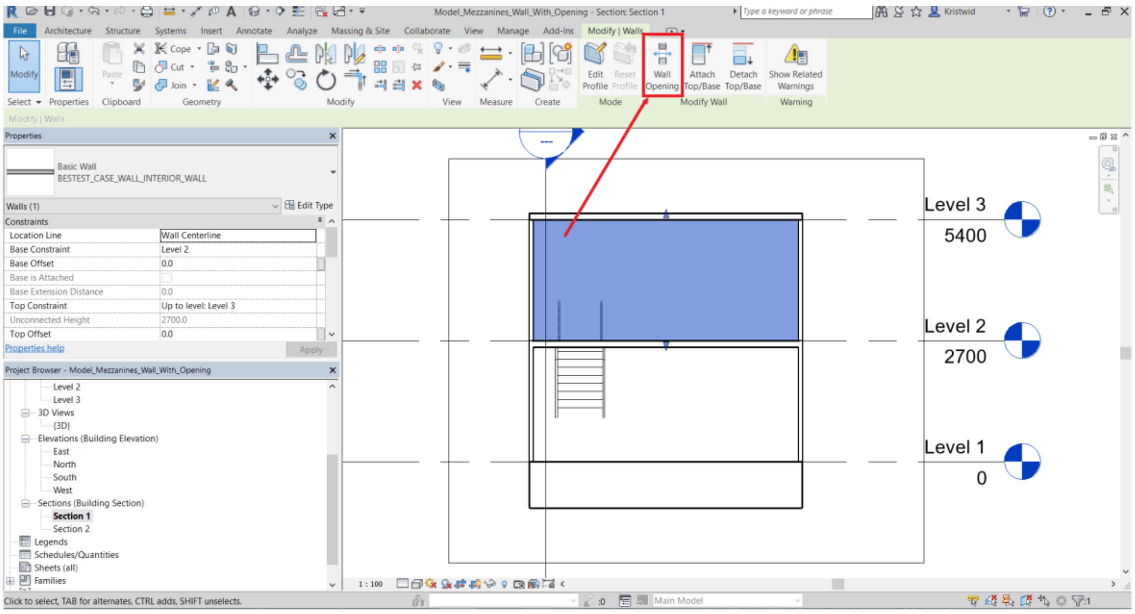


FIGURE 87: A SNAP SHOT SHOWING THE AUTODESK REVIT “WALL OPENING” TOOL (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

Same as case 20, except that a wall with opening now separates the mezzanine space from the rest of the building. Still two rooms/spaces defined in total.

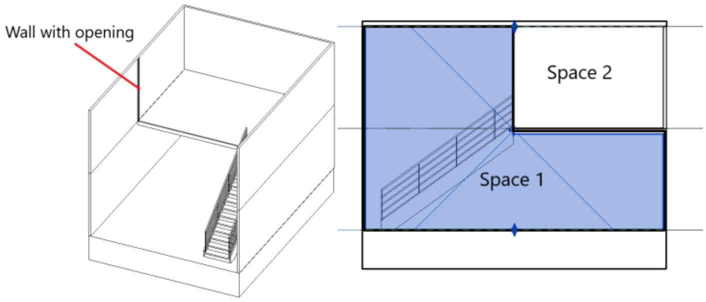


FIGURE 88: REVIT BIM MODEL – MEZZANINE CASE 21 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

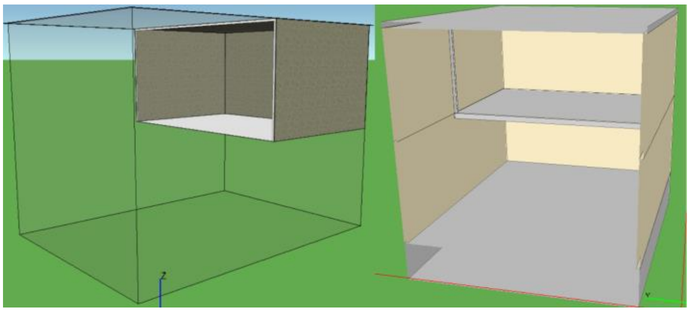


FIGURE 89: IDA ICE ENERGY MODEL – MEZZANINE CASE 21 – LEFT: BUILDING BODY & THERMAL ZONE. RIGHT: IFC MODEL

Case 22

Modeling in Revit

In addition to the modeling procedure described in case 21, this case also deals with the Revit tool “Opening by face” used to create an opening in the floor construction. Figure 87 shows the location of the tool in Revit. In this case the 2nd level floor covers the whole area of the 2nd level. The “Opening by face” tool is used to create an opening for half the area of the 2nd level floor. The other half of the 2nd level floor now constitutes the mezzanine space.

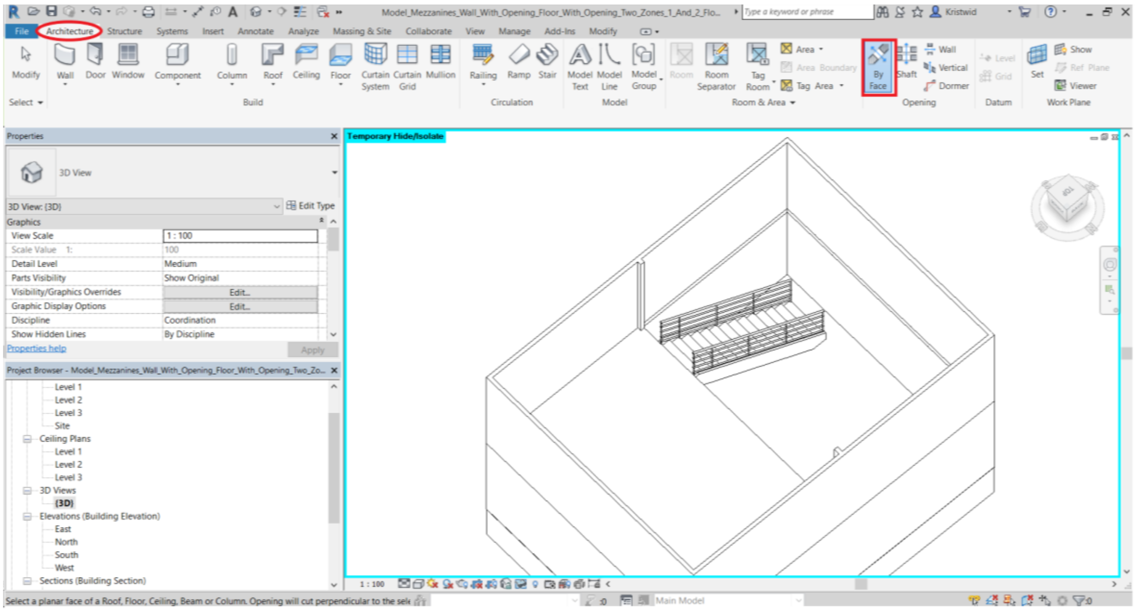


FIGURE 90: A SNAP SHOT SHOWING THE AUTODESK REVIT "OPENING BY FACE" TOOL (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

Same as case 21, except that there is an opening in the 2nd level floor. Still two rooms/spaces defined in total.

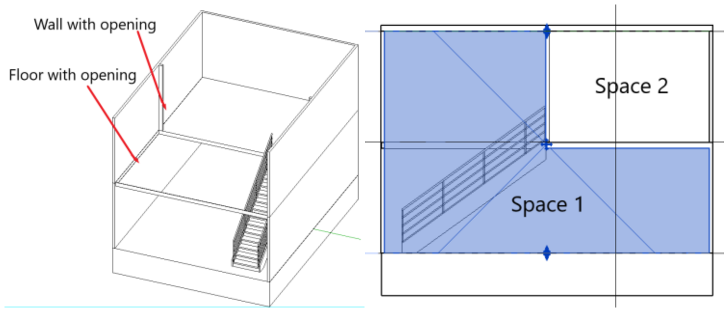


FIGURE 91: REVIT BIM MODEL – MEZZANINE CASE 22 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

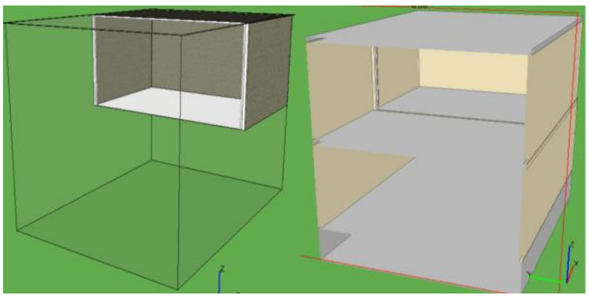


FIGURE 92: IDA ICE ENERGY MODEL – MEZZANINE CASE 22 – LEFT: BUILDING BODY & THERMAL ZONE. RIGHT: IFC MODEL

Case 23

Modeling in Revit

Same as case 20.

Revit BIM Model Description and Illustration

Same as case 20, except that there are three rooms/spaces defined in total.

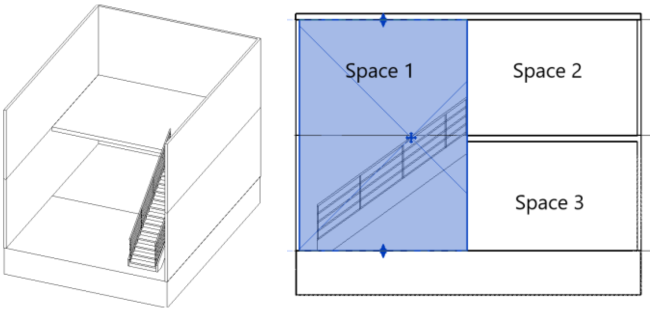


FIGURE 93: REVIT BIM MODEL – MEZZANINE CASE 23 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

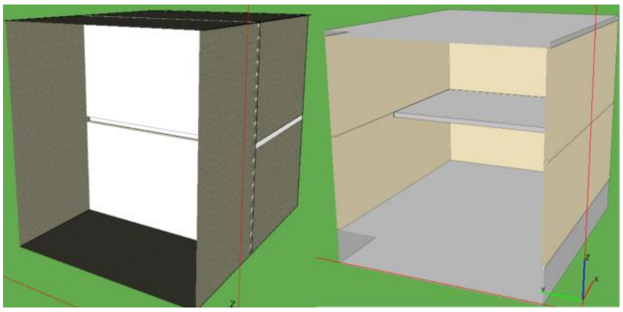


FIGURE 94: IDA ICE ENERGY MODEL – MEZZANINE CASE 24 – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 24

Modeling in Revit

Same as case 21.

Revit BIM Model Description and Illustration

Same as case 21, except that there are three rooms/spaces defined in total.

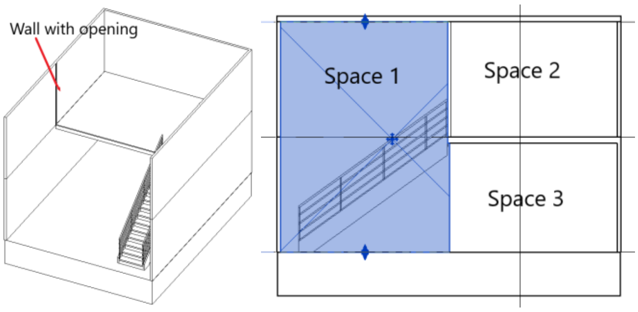


FIGURE 95: REVIT BIM MODEL – MEZZANINE CASE 24 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

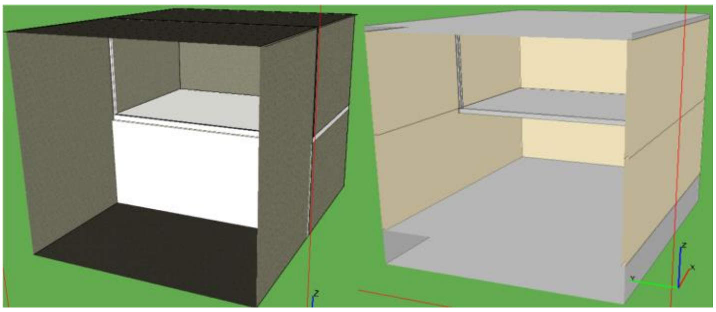


FIGURE 96: IDA ICE ENERGY MODEL – MEZZANINE CASE 24 – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 25

Modeling in Revit

Same as case 21.

Revit BIM Model Description and Illustration

Same as case 24, except that an additional wall with opening is created in 1st floor. Still three rooms/spaces defined in total.

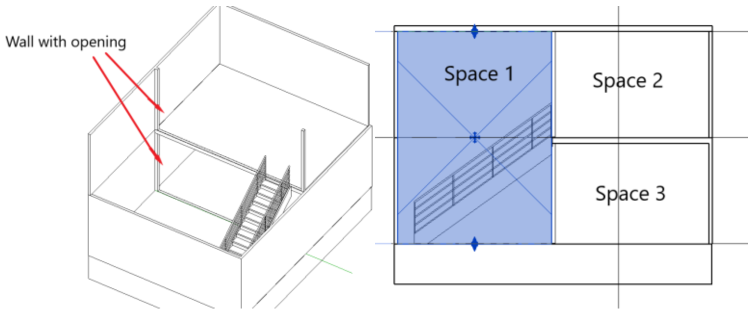


FIGURE 97: REVIT BIM MODEL – MEZZANINE CASE 25 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

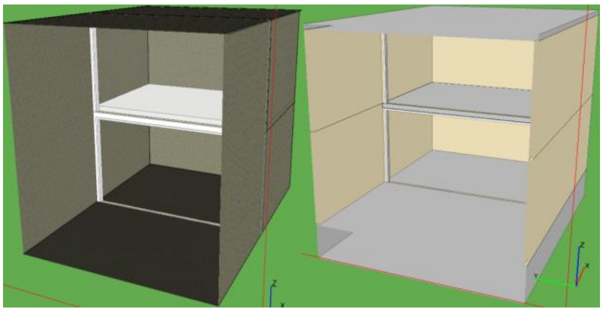


FIGURE 98: IDA ICE ENERGY MODEL – MEZZANINE CASE 25 – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 26

Modeling in Revit

Same as case 21 and 22.

Revit BIM Model Description and Illustration

Same as case 22, except that there are three rooms/spaces defined in total.

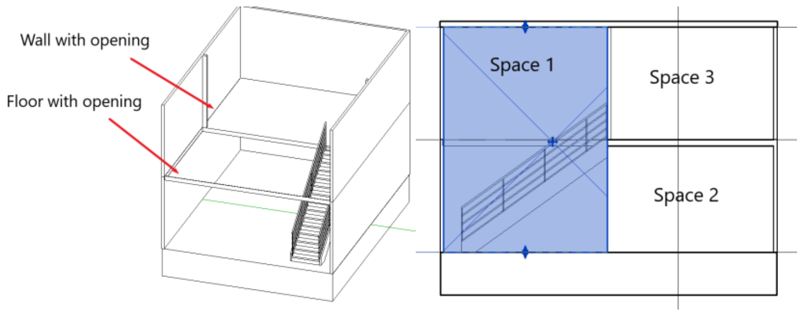


FIGURE 99: REVIT BIM MODEL – MEZZANINE CASE 26 – LEFT: 3D VIEW. RIGHT: SECTION VIEW

IDA ICE Energy Model

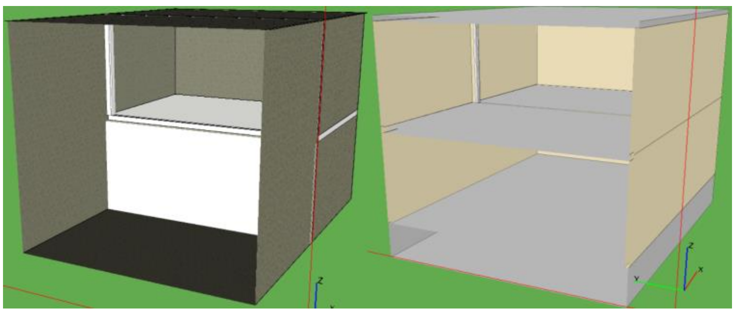


FIGURE 100: IDA ICE ENERGY MODEL – MEZZANINE CASE 26 – LEFT: THERMAL ZONE. RIGHT: IFC MODEL

Case 27

Modeling in Revit

Same as case 21 and 22.

Revit BIM Model Description and Illustration

Same as case 26, except that this model has an additional wall with opening created in 1st floor. Still three rooms/spaces defined in total.

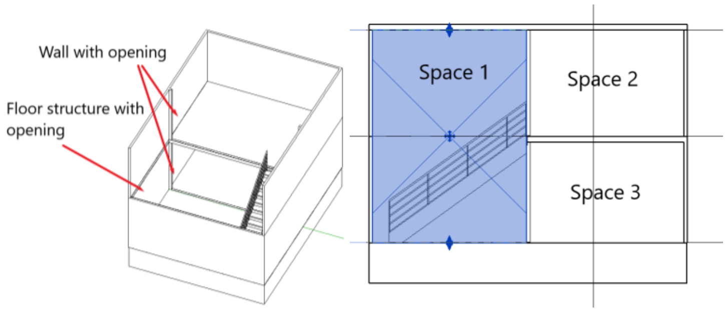


Figure 101: Revit BIM model – Mezzanine case 27 – Left: 3D view. Right: Section view

IDA ICE Energy Model

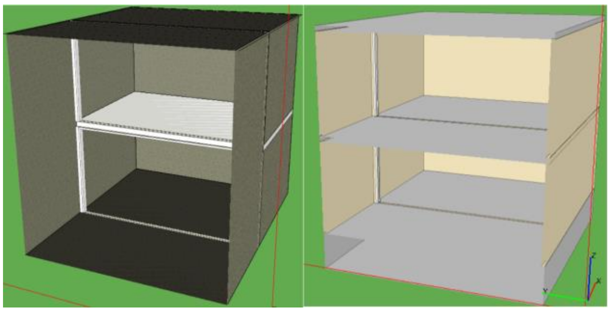


Figure 102: IDA ICE energy model – Mezzanine case 27 – Left: Thermal zone. Right: IFC model

Case 28

Modeling in Revit

The curved surface wall element is made by using the “Wall” tool with the drawing option “Start-End-Radius Arc”.

In case of building models with curved surface wall elements, it is important to uncheck the “Defines slope” option when creating the roof construction. The option is shown in Figure 103. If the option is checked, the user won’t be able to create a flat roof.

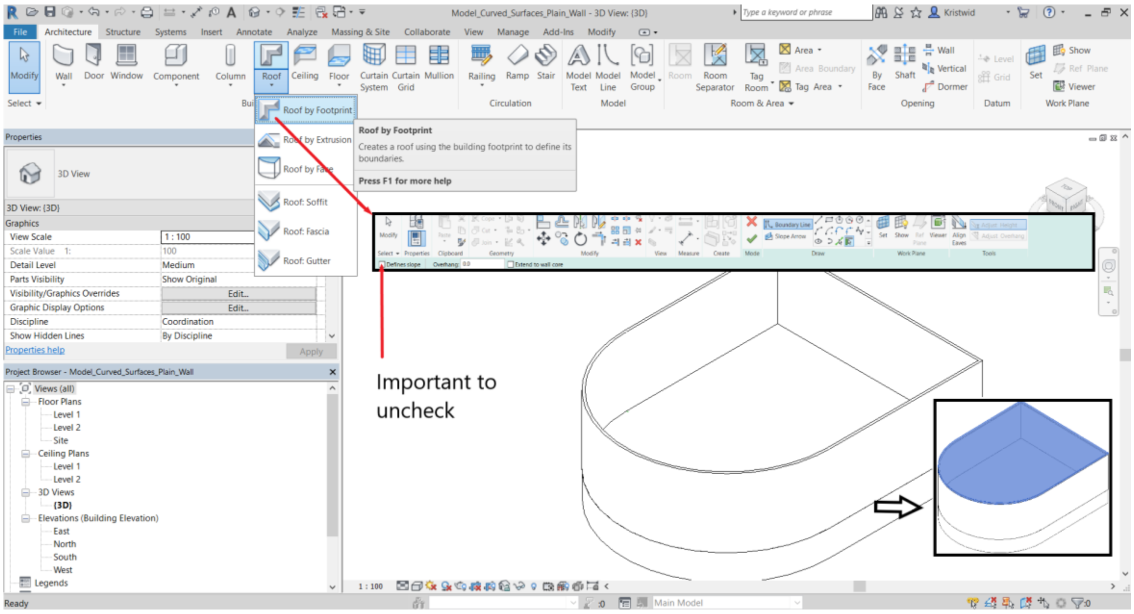


FIGURE 103: A SNAP SHOT SHOWING THE AUTODESK REVIT "ROOF BY FOOTPRINT" TOOL (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

East, west and north walls is straight. Length west and east wall: 6 m, length north wall: 8 m. One floor, one room/space.

Windows to south removed.

South wall is curved with an arc radius of 4 m.

Height: 2,7 m.

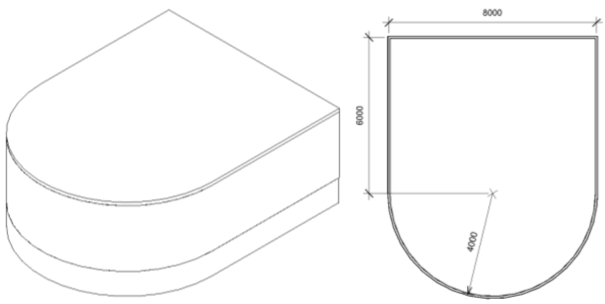


FIGURE 104: REVIT BIM MODEL – PLAIN CURVED SURFACE WALL – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

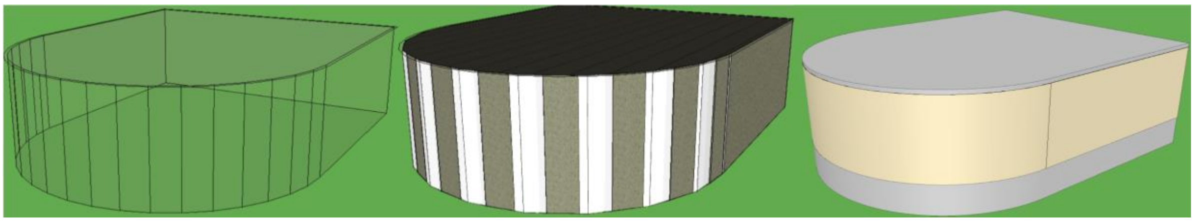


FIGURE 105: IDA ICE ENERGY MODEL – PLAIN CURVED SURFACE WALL – LEFT: BUILDING BODY. MIDDLE: THERMAL ZONE. RIGHT: IFC MODEL

Case 29

Modeling in Revit

Same as case 28 and in addition the modeling of window constructions. To model windows, refer Modeling of Wall, Roof and Floor Constructions.

Revit BIM Model Description and Illustration

Same as case 28, except that the curving wall now hosts seven window constructions of the family “M_Fixed” and type “0,915 X 0,610mm”. Refer Figure 106 for the layout of the windows.

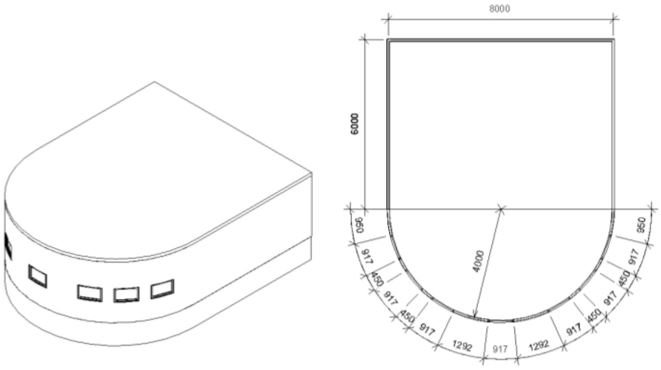


FIGURE 106: REVIT BIM MODEL – CURVED SURFACE WALL WITH WINDOWS – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

IDA ICE Energy Model

N/A. IDA ICE IFC import failed.

Case 30

Modeling in Revit

To model roof overhangs the roof editor must be activated. When in this mode the length of the overhang is to be inserted in the “Overhang” option marked red in Figure 107. In this case the length was set to 0,4 meters.

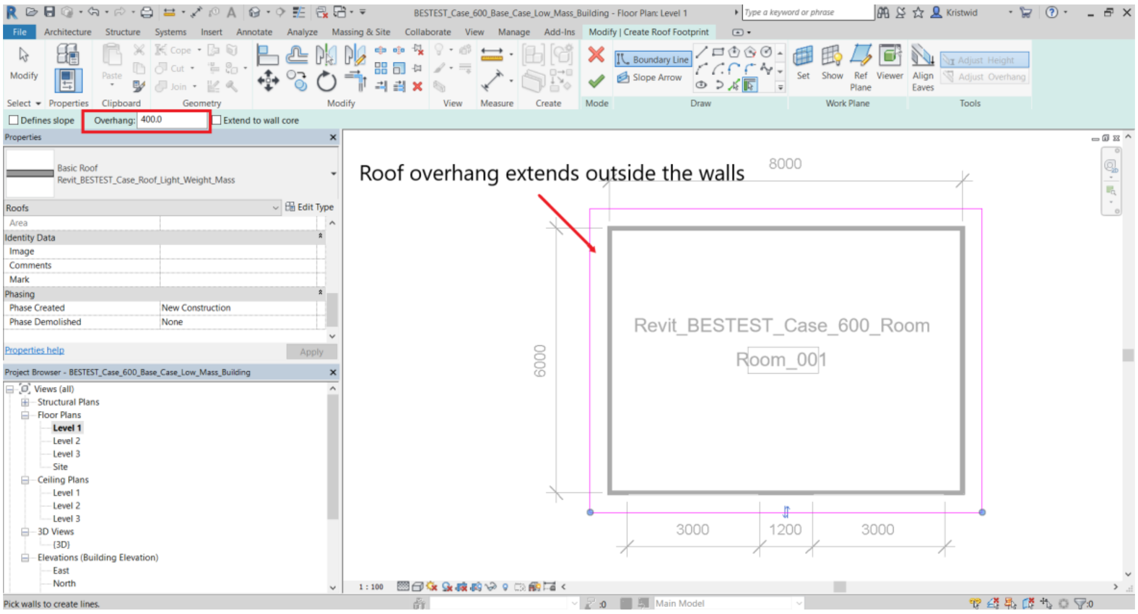


FIGURE 107: A SNAP SHOT SHOWING THE AUTODESK REVIT ROOF "OVERHANG" OPTION (MODIFICATIONS IN RED)

Revit BIM Model Description and Illustration

Rectangular building, one floor, one room/space.

Roof overhang construction extends 0,4 m outside the wall constructions of the building on all sides.

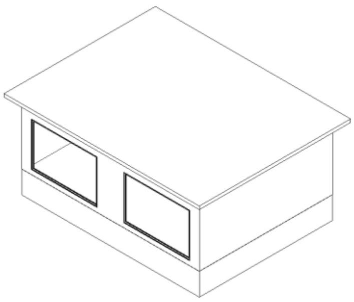


FIGURE 108: REVIT BIM MODEL – ROOF OVERHANG – 3D VIEW

IDA ICE Energy Model

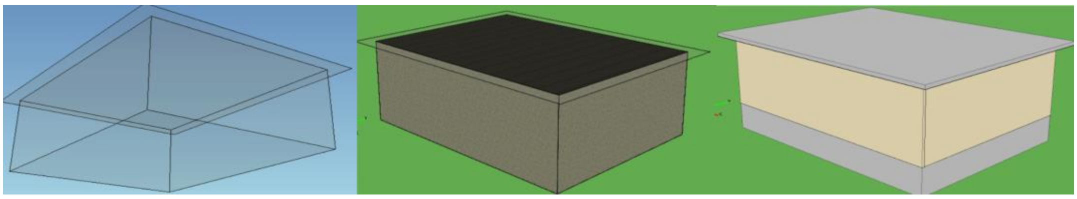


FIGURE 109: IDA ICE ENERGY MODEL – ROOF OVERHANG – LEFT: BUILDING BODY. MIDDLE: THERMAL ZONE. RIGHT: IFC MODEL

Case 31

Modeling in Revit

Nothing of particular interest to report, refer description.

Revit BIM Model Description and Illustration

Rectangular, three-story building. A recess (depth 1 m, width 2 m) in the east facade constituting a balcony. Three rooms/spaces defined in total (no room/space defined for balcony).

Height per floor: 2,7 m.

Internal floor construction same as case 14.

One of the balcony walls hosts a door of the family “M_Single-Flush” and type “0915 x 2134mm”.

Railing construction: System family “Railing”, type “1100mm”.

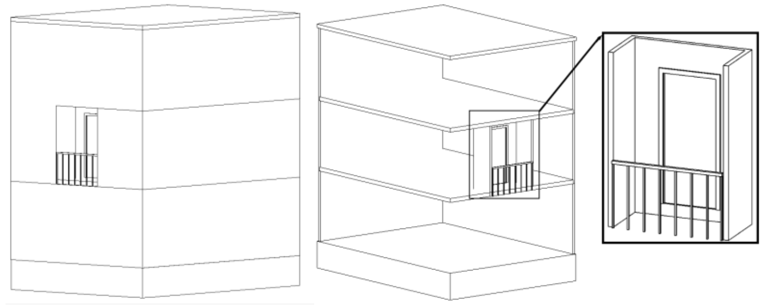


FIGURE 110: REVIT BIM MODEL – BALCONY OVERHANG – LEFT: 3D VIEW. RIGHT: 3D VIEW OF BALCONY DETAIL

IDA ICE Energy Model

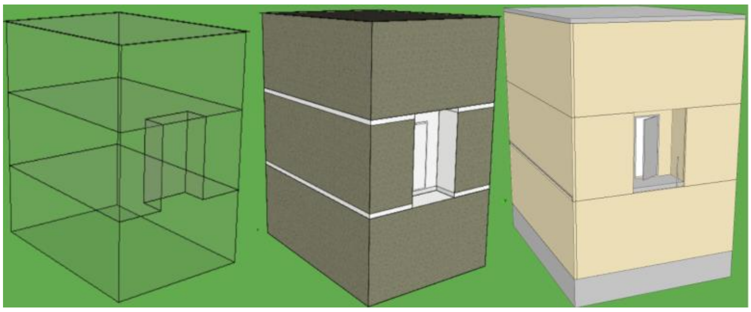


FIGURE 111: IDA ICE ENERGY MODEL – BALCONY OVERHANG – LEFT: BUILDING BODY. MIDDLE: THERMAL ZONE. RIGHT: IFC MODEL

Chapter 4 Result and Discussion

The results and discussion of the case studies are divided in the two main sub-chapters 5.1 Identified Problems and 5.2 Suggested Solutions. The first chapter presents and discuss the findings of the case studies. The results will be presented problem by problem (refer Table 21), and within each problem only the relevant cases will be given in succession of the cases. For cases of the same issue having the same outcome for a given problem, the results will be presented collectively for these cases. The second chapter presents the suggested solutions for each of the occurring problems.

4.1 Identified Problems

Table 20 is a summary of all the investigated issues, sub-issues, sub-sub-issues and cases.

TABLE 20: SUMMARY OF INTEROPERABILITY ISSUES, SUB-ISSUES, SUB-SUB-ISSUES AND CASES

Issue	Issue Description	Sub-Issue	Sub-Issue Description	Sub-sub-issue	Sub-sub-issue Description	Case
I_1	Columns.	SI_1	Model creation tool: Structural Column.	SSI_1	Wall-integrated columns (merged with walls).	1
				SSI_2	Wall-integrated columns (not merged with walls).	2
				SSI_3	Column in middle of room.	3
		SI_2	Model creation tool: Column Architectural.	SSI_1	Wall-integrated columns (merged with walls).	4
				SSI_2	Wall-integrated columns (not merged with walls).	5
				SSI_3	Column in middle of room.	6
I_2	Curtain walls.	SI_1	Model creation tool: Wall. →System Family: Curtain Wall. →Type: Curtain Wall.	N/A.	N/A.	7
		SI_2	Model creation tool: Wall. → System Family: Curtain Wall. →Type: Exterior Glazing.	N/A.	N/A.	8
		SI_3	Model creation tool: Wall. → System Family: Curtain Wall. →Type: Storefront.	N/A.	N/A.	9
I_3	Doors.	SI_1	Model creation tool: Door. → Family: M_Single-Flush	N/A.	N/A.	10
I_4	Parapet walls.	SI_1	Use of the modeling tool “Wall” to extend the ordinary external walls above the roof.	N/A.	N/A.	11
		SI_2	Use of the modeling tool “Wall” with a “Parapet wall sweep” structure as part of the wall.	N/A.	N/A.	12
		SI_3	Use of the modeling tool “In-Place wall sweep” as a separate parapet wall element apart from the wall below.	N/A.	N/A.	13

I_5	The assembly of external walls in multi-story buildings.	SI_1	Modeling approach: To model the external walls in a two-story building as a single element extending over both stories.	N/A.	N/A.	14
		SI_2	Modeling approach: To model the external walls in a two-story building as single elements for each story.	N/A.	N/A.	15
I_6	Atrium within a building as a space entirely encapsulated by larger spaces.	SI_1	Modeling approach: To model the atrium as a separate space comprised of internal walls.	SSI_1	Roof & floor structure as single elements covering the whole footprint of the building.	16
				SSI_2	Roof & floor structure as separate elements for the smaller and the larger space of the building footprint.	17
		SI_2	Modeling approach: Use of the Revit modeling tool “Shaft Opening” to model the atrium space.	SSI_1	Roof & floor structure as single elements covering the whole footprint of the building.	18
				SSI_2	Roof & floor structure as separate elements for the smaller and the larger space of the building footprint.	19
I_7	Mezzanines.	SI_1	Two rooms/spaces defined in total.	SSI_1	Use of “Room Separator” lines between rooms/spaces.	20
				SSI_2	A wall with opening created between mezzanine space and rest of the building.	21
				SSI_3	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between mezzanine space and rest of the building.	22
		SI_2	Three rooms/spaces defined in total.	SSI_1	Use of “Room Separator” lines between rooms/spaces.	23
				SSI_2	A wall with opening created between mezzanine space and rest of the building.	24
				SSI_3	A wall with opening created between all three rooms/spaces.	25
				SSI_4	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between mezzanine space and rest of the building.	26
				SSI_5	• An opening in the floor not constituting the area of the mezzanine. • A wall with opening created between all three rooms/spaces.	27
I_8	Curved surface wall elements.	SI_1	Transformation of curved surface wall element to segments of flat surface wall elements.	N/A.	N/A.	28
		SI_2	Transformation of curved surface wall elements hosting windows to segments of flat surface wall elements.	N/A.	N/A.	29
I_9	Overhangs.	SI_1	Roof overhangs.	N/A.	N/A.	30
		SI_2	Overhangs caused by a recess in the façade.	N/A.	N/A.	31

Table 21 relates the BIM-based BEM interoperability issues (cases) to the possible problems that may occur affecting the energy and thermal performance factors or cause technical issues. The identified problems in this chapter follows the order in which the problems are presented in this table.

TABLE 21: BIM-BASED BEM INTEROPERABILITY ISSUES AND POSSIBLE IMPACT ON ENERGY AND THERMAL PERFORMANCE FACTORS AND TECHNICAL ISSUES (CASE NUMBER IN PARENTHESES)

	Interoperability Issue								
Problem: Physical/ Technical Impact	1	2	3	4	5	6	7	8	9
1. Thermal insulation	✓ (1,2,4,5)	✓ (7,8,9)	✓ (10)						✓ (31)
2. Thermal bridge	✓ (1,2,4,5)	✓ (7,8,9)	✓ (10)	✓ (11,12,13)			✓ (20,21,22,23, 24,25,26,27)		✓ (30,31)
3. Thermal mass	✓ (1,2,3,4,5,6)	✓ (7,8,9)	✓ (10)	✓ (11,12,13)			✓ (20,21,22,23, 24,25,26,27)		✓ (30,31)
4. Volume	✓ (1,2,3,4,5,6)						✓ (20,21,22,23, 24,25,26,27)	✓ (28,29)	
5. Area	✓ (1,2,3,4,5,6)						✓ (20,21,22,23, 24,25,26,27)	✓ (28,29)	
6. Shading	✓ (1,2,3,4,5,6)			✓ (11,12,13)					✓ (30,31)
7. Daylighting distribution	✓ (1,2,3,4,5,6)	✓ (7,8,9)	✓ (10)	✓ (11,12,13)		✓ (16,17,18,19)	✓ (20,21,22,23, 24,25,26,27)	✓ (29)	✓ (30,31)
8. Solar heat gain	✓ (1,2,3,4,5,6)	✓ (7,8,9)	✓ (10)	✓ (11,12,13)		✓ (16,17,18,19)		✓ (29)	✓ (30,31)
9. Air/mass flow conditions						✓ (16,17,18,19)	✓ (20,21,22,23, 24,25,26,27)		
10. Thermal view/building body/thermal zones	✓ (1,2,3,4,5,6)			✓ (11,12,13)	✓ (14,15)	✓ (16,17,18,19)	✓ (20,21,22,23, 24,25,26,27)	✓ (28,29)	✓ (30,31)
11. No IFC object support	✓ (1,2,3,4,5,6)		✓ (10)						
12. Incorrect Interpretation of IFC object properties		✓ (7,8,9)							
13. Simulation run time								✓ (28,29)	
14. IFC import failure								✓ (29)	

Problem 1 & 2 – Thermal Insulation/Thermal Bridge

Case 1-2, 4-5

In the cases with the columns in the corners of the building, either merged or not merged into the walls, the outcome was the neglection of the columns in the energy model. The columns were instead replaced with an inward corner consisting of two wall elements that were incorrectly mapped with the default external wall construction “[Default] Rendered l/w concrete wall 250” of IDA ICE. This result for one of the resulting energy models (example taken from case 1) is illustrated in Figure 112. The result will lead to the thermal insulation/thermal bridges, i.e. the heat transmission loss, for this part of the building envelope to be incorrect.

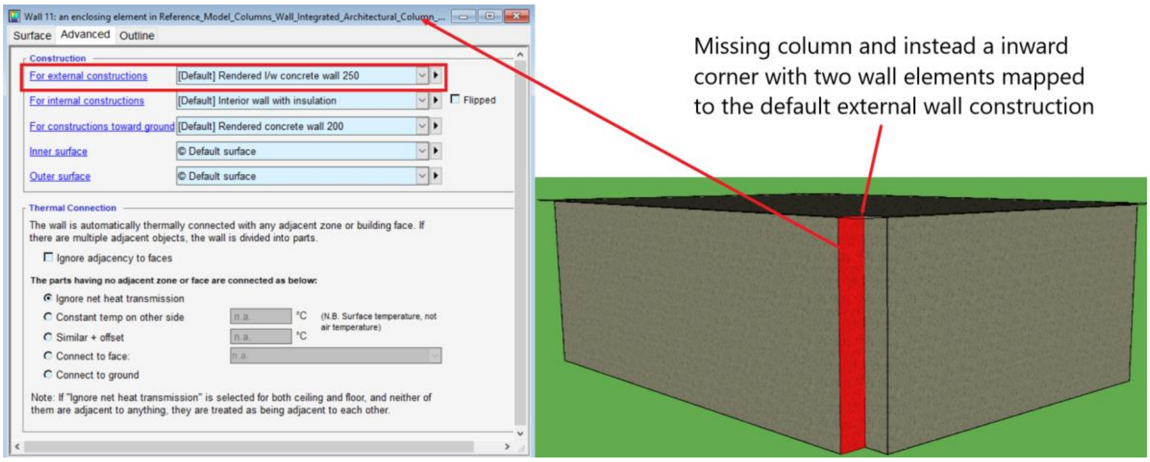


FIGURE 112: IDA ICE ENERGY MODEL – MISSING COLUMN REPLACED WITH WALL ELEMENTS MAPPED WITH THE DEFAULT EXTERNAL WALL CONSTRUCTION (EXAMPLE TAKEN FROM CASE 1)

Case 7-9

As a consequence of Problem 12 for the respective cases, the curtain wall element with glazed curtain wall panels are assigned to an opaque external wall construction element. This element is by default mapped to the external construction “[Default] Rendered l/w concrete wall 250” with material properties (heat conductivity, density and heat capacity) not corresponding at all with the properties of glazed panels, causing the thermal insulation and hence the heat transmission loss for this wall part to be incorrect.

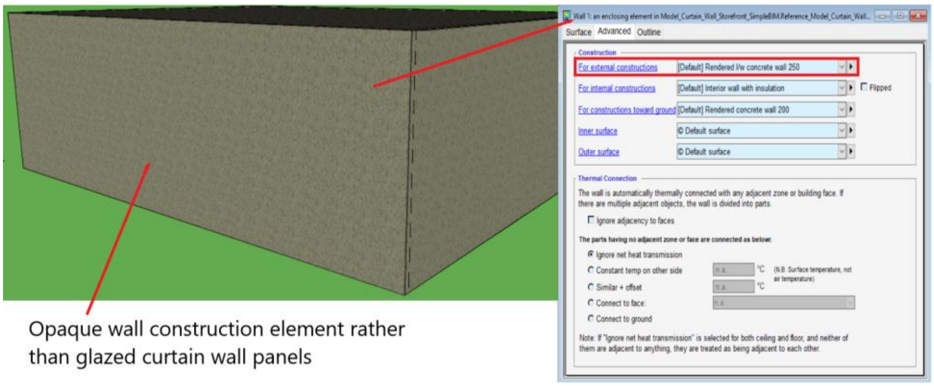


FIGURE 113: IDA ICE ENERGY MODEL – WALL CONSTRUCTION ELEMENT WITH INCORRECT MATERIAL PROPERTIES

Case 10

Due to Problem 11 for the respective case, the door is by default assigned to the construction “[Default] [use wall construction]” with material properties (heat conductivity, density and heat capacity) that do not correspond to the door construction, refer Figure 114. This will lead to the thermal insulation and hence the heat transmission loss through the door to be erroneous.

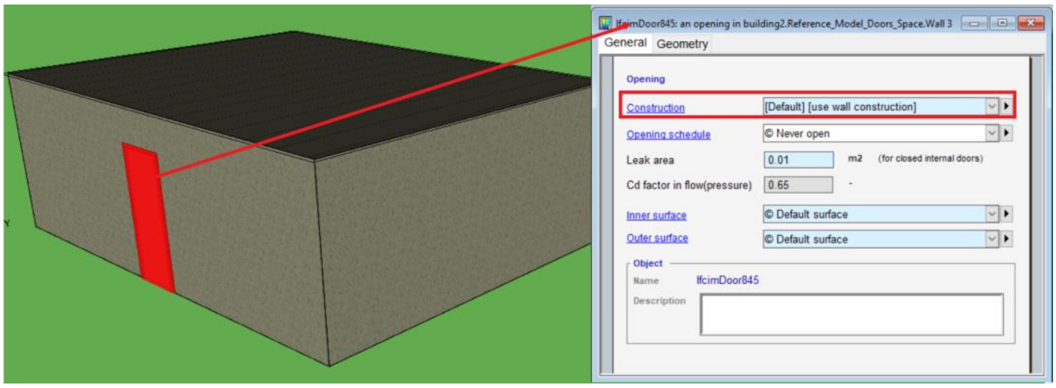


FIGURE 114: IDA ICE ENERGY MODEL – DOOR CONSTRUCTION ELEMENT WITH INCORRECT MATERIAL PROPERTIES

Case 11-13

All three model cases with a parapet wall resulted in a building body and thermal zone that corresponded to the room/space of the building with no regard of the parapet walls, see Figure 115 (example taken from case 11). The outcome implies that the mass of the parapet walls is neglected in the energy model of IDA ICE. However, its influence on the thermal bridge located in the intersection between the external walls and roof construction is taken care of in another way in IDA ICE, refer Suggested Solution Problem 1 & 2 for the respective cases.

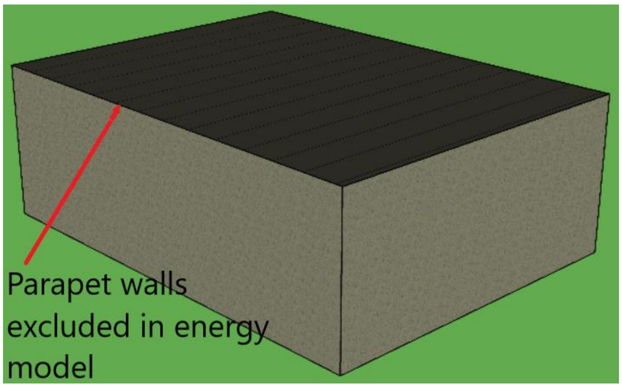


FIGURE 115: IDA ICE ENERGY MODEL – PARAPET WALL CONSTRUCTIONS IGNORED (EXAMPLE TAKEN FROM CASE 11)

Case 20-27

For all model cases involving a mezzanine construction, the mezzanine floor was included in the energy model. However, its influence on the thermal bridge located in the intersection between the internal floor construction (mezzanine floor) and the external walls is taken care of in another way in IDA ICE, refer Suggested Solution Problem 1 & 2 for the respective cases.

However, due to Problem 10 for some of the mezzanine cases, it makes only sense to discuss this problem for case 25 and 27 since their energy models were correct. Refer Problem 10 for case 20-27.

Case 30

The case resulted in a thermal zone corresponding to the room/space of the building with no regard of the overhang construction, see Figure 116. The result implies that the mass of the overhang is neglected in the energy model of IDA ICE. However, its influence on the thermal bridge located in the intersection between the external walls and roof construction is taken care of in another way in IDA ICE, see Suggested Solution Problem 1 & 2 for the respective cases.

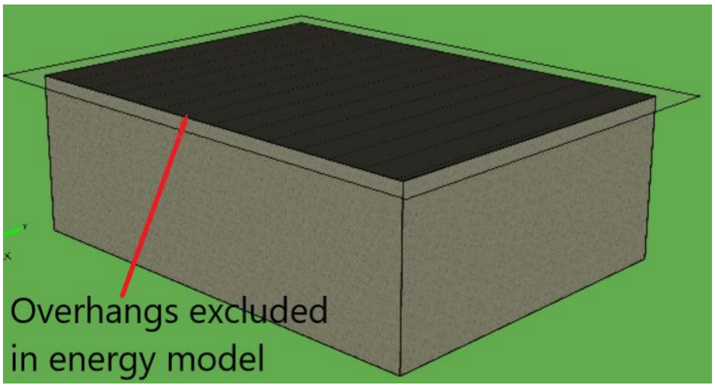


FIGURE 116: IDA ICE ENERGY MODEL – ROOF OVERHANG IGNORED

Case 31

Due to [Problem 12](#) of the respective case, the balcony walls, floor and roof constructions are interpreted as internal elements mapped to their respective internal construction. Figure 117 is an example illustrating the problem showing how one of the balcony walls is mapped to the internal construction “[Default] Interior wall with insulation”. This results in the material properties (heat conductivity, density and heat capacity) and hence the thermal insulation ability of the current elements to be incorrect, ultimately leading to the heat transmission loss of these elements to be erroneous.

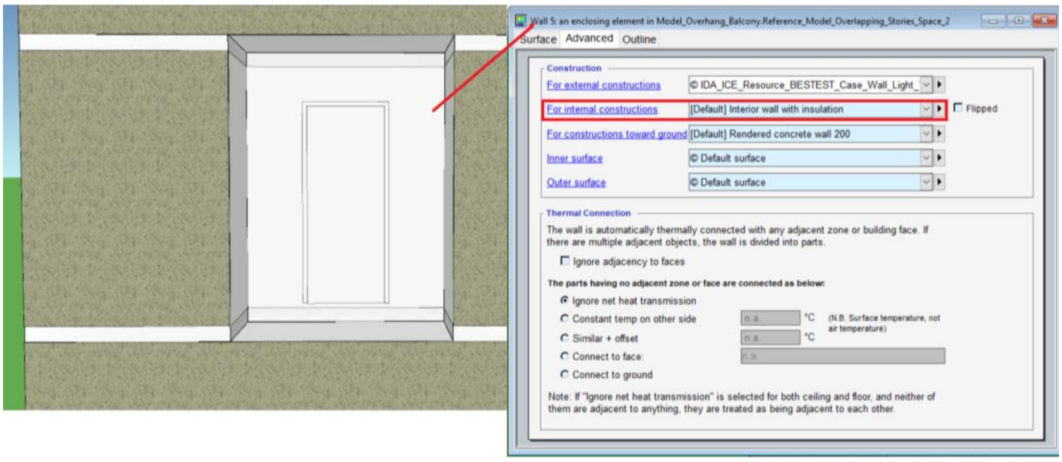


FIGURE 117: IDA ICE ENERGY MODEL – BALCONY WALLS, ROOF AND FLOOR CONSTRUCTION ELEMENTS WITH INCORRECT MATERIAL PROPERTIES

Problem 3 – Thermal Mass

Case 1-6

In all cases involving columns, the columns were neglected in the energy model (refer the respective cases in [Problem 11](#)) and hence their contribution on thermal mass. Figure 118 below shows the energy model for one of the cases (example taken from case 6). The figure shows that the column that was supposed to be in the middle of the energy model´s thermal zone is missing.

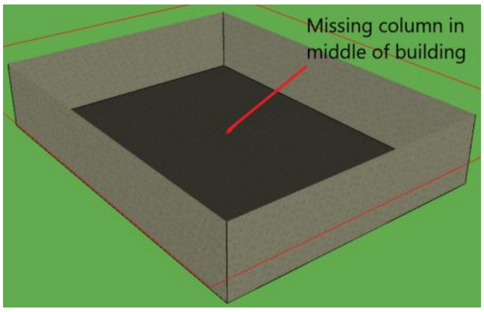


FIGURE 118: IDA ICE ENERGY MODEL – MISSING COLUMN IN MIDDLE OF BUILDING (EXAMPLE TAKEN FROM CASE 6)

Case 7-9

For the same reasons as explain for the respective cases in Problem 1 & 2, the curtain wall elements are assigned incorrect material properties, causing the thermal mass of the elements to be wrong.

Case 10

For the same reasons as explained for case 10 in Problem 1 & 2, the door is assigned wrong material properties, causing the thermal mass of the element to be incorrect.

Case 11-13

Refer findings and discussion of case 11-13 in Problem 1 & 2. The neglection of the parapet walls in the energy model results in ignoring the wall´s contribution on thermal mass to the building.

Case 20-27

The mezzanine floor was assigned the correct construction with associated material properties for all model cases, i.e. the mezzanine´s impact on thermal mass was interpreted correctly.

However, due to Problem 10 for some of the mezzanine cases, it makes only sense to discuss this problem for case 25 and 27 since their energy models were correct. Refer Problem 10 for case 20-27.

Case 30

For the same reasons as explained in case 30 in Problem 1 & 2, the roof overhang´s contribution on thermal mass to the building is ignored in the energy model of IDA ICE.

Case 31

Due to the same reasons as explained for the case in Problem 1 & 2, the thermal mass ability of the balcony walls, roof and floor constructions becomes incorrect.

Problem 4 & 5 – Volume and Area of Room/Space

Case 1-2, 4-5

For the cases with columns located in the corners of the building, the area and volume of the room was correctly interpreted as the building body and thermal zone did not include the area of the columns, but rather created an inward corner in their place. Figure 119 (example taken from case 6) shows that the area and volume between the Revit BIM model and the energy model in IDA ICE is identical.

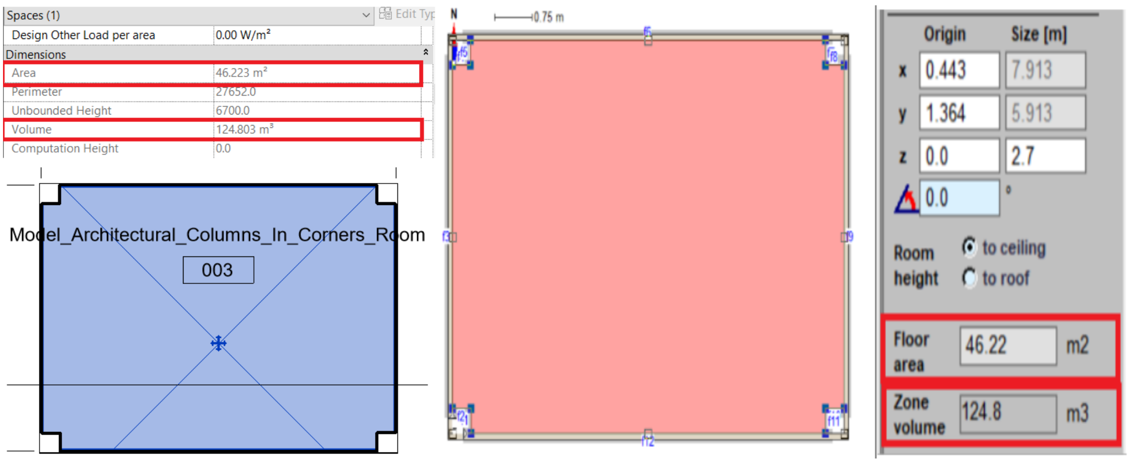


FIGURE 119: COMPARISON OF AREA AND VOLUME BETWEEN THE REVIT BIM MODEL AND THE ENERGY MODEL IN IDA ICE (EXAMPLE TAKEN FROM CASE 6) – LEFT: REVIT MODEL. RIGHT: IDA ICE MODEL

Case 3, 6

For the cases involving a column located in the middle of the building, the energy model´s thermal zone did not include the column, see Figure 120, and hence the column´s influence on area/volume is neglected. A comparison of the area and volume between the Revit BIM model and the energy model in IDA ICE is seen in Figure 121 (example taken from case 6). The deviation in the values corresponds to the area/volume of the column.

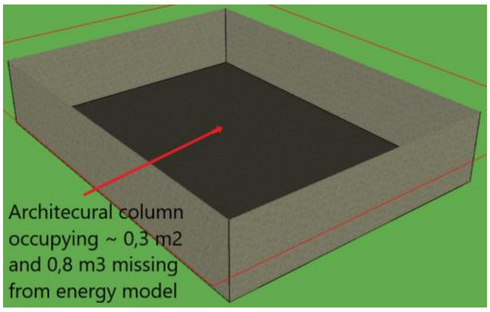


FIGURE 120: IDA ICE ENERGY MODEL – THE BIM-BASED ENERGY MODEL WITH MISSING COLUMN IN THE MIDDLE OF THE BUILDING (EXAMPLE TAKEN FROM CASE 6)

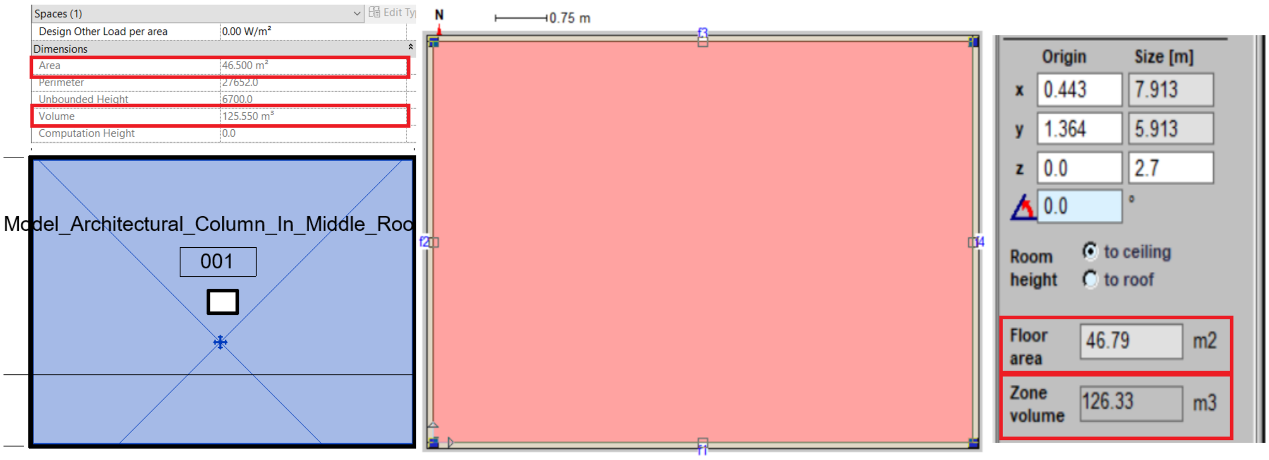


FIGURE 121: COMPARISON OF AREA AND VOLUME BETWEEN THE REVIT BIM MODEL AND THE ENERGY MODEL IN IDA ICE (EXAMPLE TAKEN FROM CASE 6) – LEFT: REVIT MODEL. RIGHT: IDA ICE MODEL

Case 20-27

Due to Problem 10 for some of the mezzanine cases, it makes only sense to discuss this problem for case 25 and 27 since their energy models were correct. Refer Problem 10 for case 20-27.

For these two cases both the total area and volume were identical for the Revit BIM model and the energy model, as shown in Figure 122 (example taken from case 27).

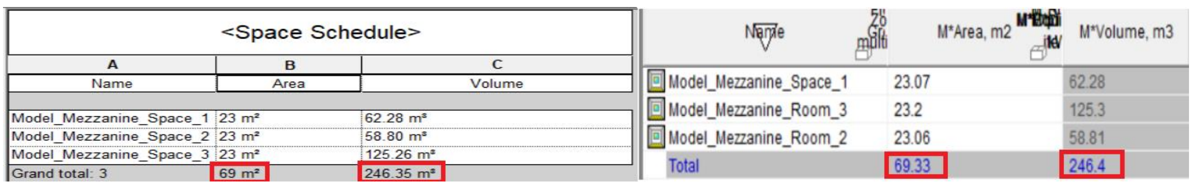


FIGURE 122: COMPARISON OF AREA AND VOLUME BETWEEN THE REVIT BIM MODEL AND THE ENERGY MODEL IN IDA ICE (EXAMPLE TAKEN FROM CASE 27) – LEFT: REVIT MODEL. RIGHT: IDA ICE MODEL

Case 28

A comparison between the Revit BIM model and the energy model in IDA ICE shows that the difference in area and volume is neglectable, refer Figure 123 below.

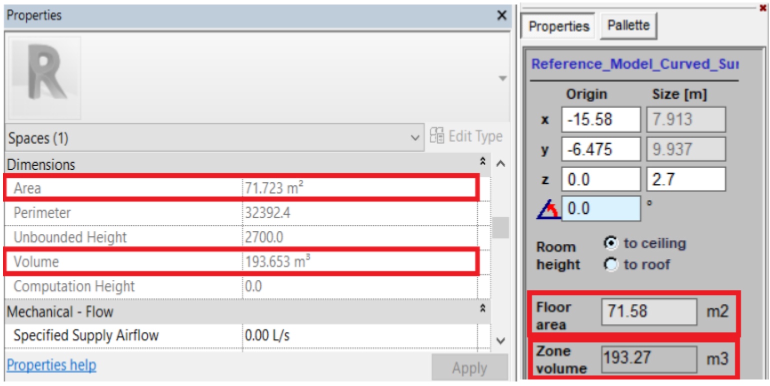


FIGURE 123: COMPARISON OF AREA AND VOLUME BETWEEN THE REVIT BIM MODEL AND THE ENERGY MODEL IN IDA ICE – LEFT: REVIT MODEL. RIGHT: IDA ICE MODEL

Case 29

No energy model available for investigation, refer Problem 14 of the case.

Problem 6 – Shading

Case 1-6

For all cases involving columns it was possible to select the IFC column objects separately in IDA ICE and include them as shading objects. Figure 124 (example taken from case 4 and 6) illustrates the selection of the IFC column objects in IDA ICE.

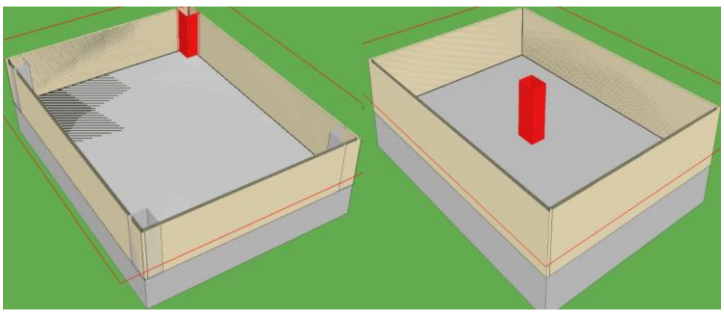


FIGURE 124: IDA ICE IFC MODEL– SELECTION OF IFC COLUMN OBJECTS TO BE INCLUDED AS SHADING OBJECTS

Case 11

The case did not cause any direct problem regarding shading. Nonetheless, it is neither the preferred way to model a parapet wall for inclusion as a shading object in IDA ICE. By including the parapet wall IFC object as a shading object, the whole wall had to be included as well, see Figure 125. The result was expected since the parapet wall was modeled in Revit just as an extension of the wall below. This should not be a problem unless new window constructions are created for the BIM-based energy model in IDA ICE after the import. Then the shading IFC wall object would cover for any daylight and solar heat to enter this new window construction. The point is that by including more IFC objects than necessary to shade in IDA ICE would only make the energy model more complex, meaning more objects that potentially can interfere the BEM simulation result if not handled carefully

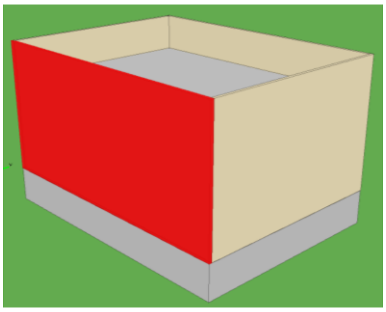


FIGURE 125: IDA ICE IFC MODEL – SELECTION OF THE PARAPET WALL TO BE INCLUDED AS SHADING OBJECT

In respect to this case an additional investigation was performed on the BESTEST Case 600 model. The purpose was to explore how the solar heat gain for a building with windows would be influenced with and without the IFC model included as a shading object. A whole year simulation for the BESTEST Case 600 model with and without the IFC model included as a shading object was performed and compared. The result of the simulations is seen in Figure 126 below. The total energy for "Window and Solar" without the IFC model included was approximately 2500 kWh. The same total was approximately 2950 kWh when the IFC model was included. The result is surprising and emphasize the conclusion of the current case.

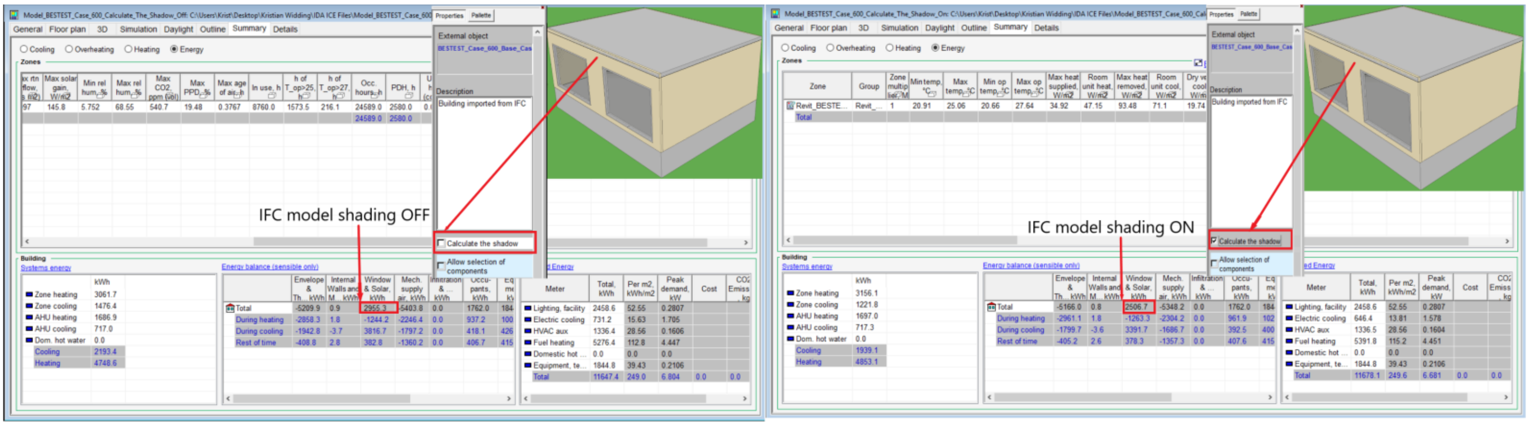


FIGURE 126: IDA ICE – ENERGY RESULT "WINDOW & SOLAR" – LEFT: IFC MODEL EXCLUDED. RIGHT: IFC MODEL INCLUDED

Case 12

For this case the parapet wall IFC object included not only the parapet walls but also the roof construction, see Figure 127. The whole idea of including the parapet walls as shading objects was to simulate its influence on solar heat gain and daylighting distribution due to potential roof skylights. In other words, the case is a problem in regard of shading.

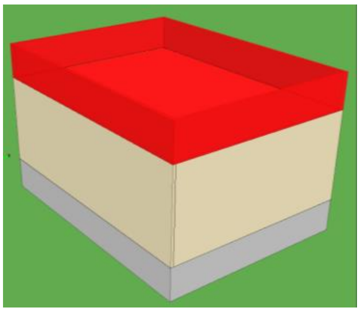


FIGURE 127: IDA ICE IFC MODEL – SELECTION OF THE PARAPET WALL TO BE INCLUDED AS SHADING OBJECT

Case 13

For this case it was possible to select the parapet wall IFC object by itself, see Figure 128. It thus seems to be the best approach modeling parapet walls for the purpose of including it as a shading object in IDA ICE.

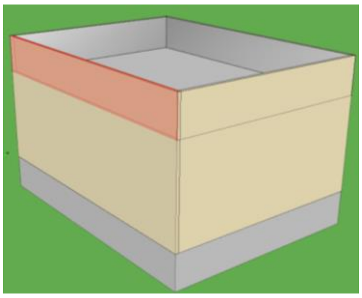


FIGURE 128: IDA ICE IFC MODEL – SELECTION OF THE PARAPET WALL TO BE INCLUDED AS SHADING OBJECT

Case 20-27

Due to Problem 10 for some of the mezzanine cases, it makes only sense to discuss this problem for case 25 and 27 since their energy models were correct. Refer Problem 10 for case 20-27.

For case 25 the IFC mezzanine floor construction was interpreted correctly and there was no problem to include it as a shading object, refer Figure 129.

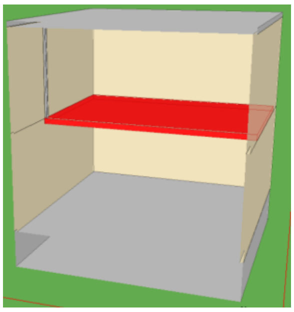


FIGURE 129: IDA ICE IFC MODEL – SELECTION OF THE MEZZANINE FLOOR TO BE INCLUDED AS SHADING OBJECT

In case 27 however, the IFC mezzanine floor construction was interpreted incorrectly as seen in Figure 130. The object covered the whole area of the 2nd floor when it should have been an opening in the floor for the part not constituting the area of the mezzanine. If the shading of this object was to be included, the shading conditions would not depict the actual situation causing the daylighting distribution to be wrong.

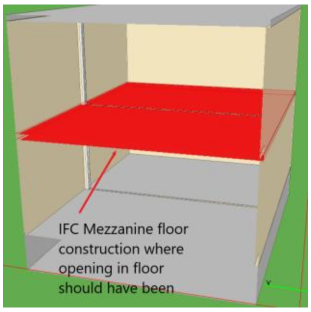


FIGURE 130: IDA ICE IFC MODEL – SELECTION OF THE MEZZANINE FLOOR TO BE INCLUDED AS SHADING OBJECT

Case 29

No energy model available for investigation, refer Problem 14 of the case.

Based on the segmentation level of the curved surface wall in case 28 (refer to case 28, Problem 12) the difference in shading conditions between the perfect curved surface wall and the same wall as segmented flat surfaces is considered to be minor. This is however only a hypothetical comparison since a perfect curved surface wall cannot exist in IDA ICE and because it was not even managed to import the current IFC model into IDA ICE.

Case 30

The roof overhang construction was not possible to include as a shading object on its own, but rather included the whole IFC roof construction, refer Figure 131. The result was expected since the overhang construction was modeled in Revit as a horizontal extension of the roof. In most cases this will be an adequate solution to simulate the shading caused by the overhang. If skylights were to be modeled in IDA ICE after creating the BIM-based energy model, the shading of the IFC roof would completely block any solar heat and daylight through these skylights. In such cases there would be a problem implementing the roof overhang this way, and therefore an alternative solution to model the roof overhang is provided.

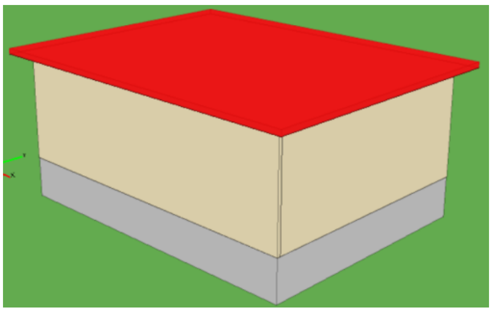


FIGURE 131: IDA ICE IFC MODEL – SELECTION OF THE ROOF OVERHANG TO BE INCLUDED AS SHADING OBJECT

Problem 7 & 8 – Daylighting and Solar Heat Gain

Case 1-6

There was no problem including the columns as shading objects, refer case 1-6 in Problem 6. Because of this, the column´s potential influence on daylighting and solar heat gain may be considered if desired.

Case 7-9

As a consequence of Problem 12 of the respective cases, any potential daylight and solar heat gain due to the transparent curtain wall panels are completely neglected in the energy model of IDA ICE.

Case 10

IFC door objects are interpreted as "Large vertical openings" in IDA ICE, refer Problem 12 for the respective case. These types of objects are opaque constructions with no possibility to be mapped to transparent constructions. In the case of a transparent glass door, the daylighting distribution and solar heat gain due to the door will be completely ignored in the energy model of IDA ICE.

Case 11-13

Refer findings and discussion in Problem 6 of case 11, 12 and 13.

Case 20-27

Refer findings and discussion in Problem 6 of the respective cases.

Case 29

No energy model available for investigation, refer issue described in Problem 14 of the same case. However, a hypothetical discussion on the shading conditions and hence the influence on daylighting and solar heat gain is already given earlier, see case 29 in Problem 6.

Case 30

Refer findings and discussion of case 30 in Problem 6.

Case 31

No problem with daylighting and solar heat gain was found for this case.

Problem 9 – Air/Mass Flow Conditions

Case 16-19

Problem 10 for the respective cases implies that BEM implementation of a BIM-based atrium space (at least when the atrium is located in the middle of the building surrounded by larger spaces) to be utilized for natural ventilation is corrupted as well.

Case 20-27

Due to Problem 10 for some of the mezzanine cases, it makes only sense to discuss this problem for case 23-27 since their energy models had all thermal zones intact. Refer Problem 10 for case 20-27.

When room separation lines are utilized to separate rooms/spaces in Revit, IDA ICE incorrectly creates internal walls instead of openings between the corresponding thermal zones. The resulting energy models in such cases will of course not depict the correct exchange of air/mass between the zones.

Of the relevant cases, the problem occurred for case 23, 24, and 26, while for case 25 and 27 the thermal zone relationship and thus the exchange of air/mass between them was interpreted correctly. The result is illustrated in Figure 132 with case 23 and 25 as examples.

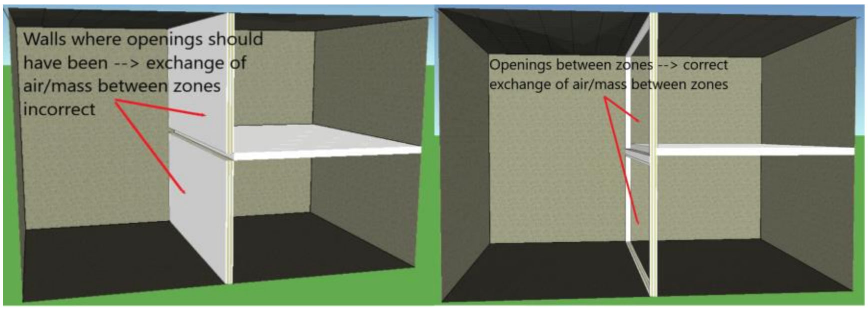


Figure 132: IDA ICE energy model – Incorrect and correct exchange of air/mass between zones. Left: Case 23. Right: Case 25

Problem 10 – Thermal View/Building Body/Thermal Zones

Case 1-2, 4-5

In all the cases where the columns were in the corners of the building, merged or not merged into walls, the thermal view of the building was misinterpreted. This resulted in the generated building body and thermal zone to be incorrect, which is seen in Figure 133 (example taken from case 4). The figure shows that an inward corner shape is generated for the building body in place of the columns. For the thermal zone, two external wall elements constitute the inward corner.

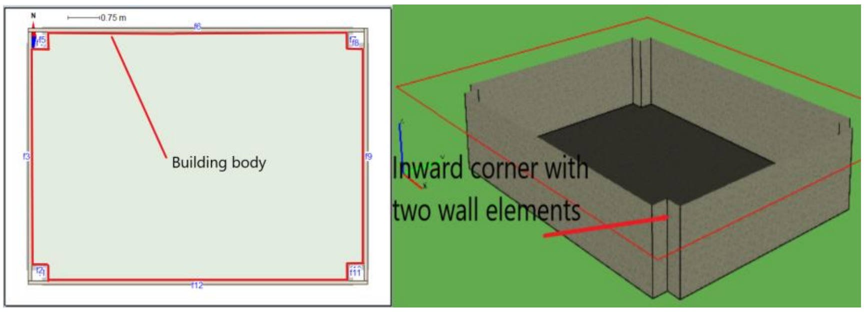


FIGURE 133: IDA ICE ENERGY MODEL – LEFT: FLOOR PLAN VIEW. RIGHT: 3D VIEW

Case 3, 6

The building body and thermal zone of the energy model was interpreted correctly in the cases where the column was located in the middle of the building. Figure 134 illustrates the building body and thermal zone in IDA ICE (example taken from case 6).

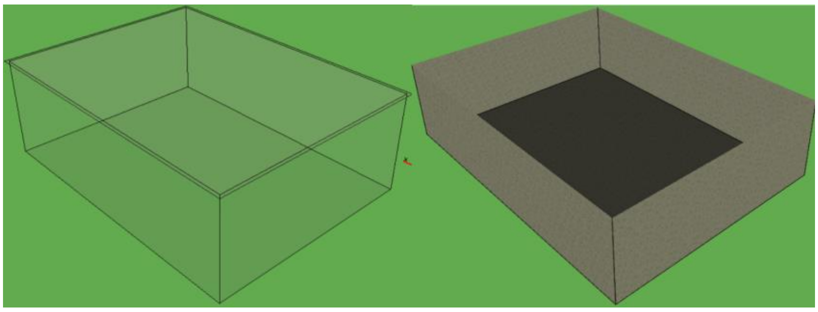


FIGURE 134: IDA ICE ENERGY MODEL – LEFT: BUILDING BODY. RIGHT: THERMAL ZONE

Case 11-13

For none of the model cases involving parapet walls the thermal view was misinterpreted, which had been reported in an earlier case study to be an occurring problem for such cases. The building body and thermal zone had a height corresponding to the room height defined in Revit, i.e. 2,7 meters. Refer Figure 135 below for the resulting energy model in IDA ICE.

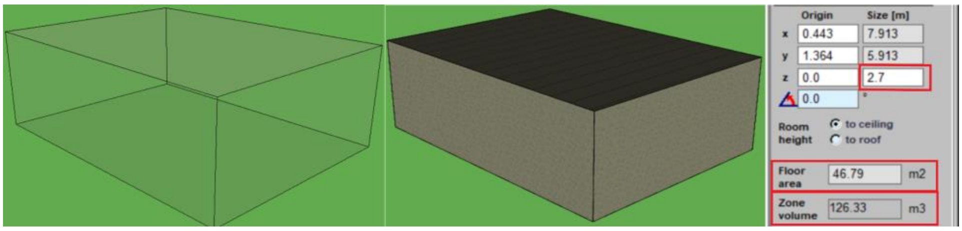


FIGURE 135: IDA ICE ENERGY MODEL – LEFT: BUILDING BODY. RIGHT: THERMAL ZONE

Case 14

The case model did not cause any misinterpretation of the energy model´s thermal view, see Figure 136.

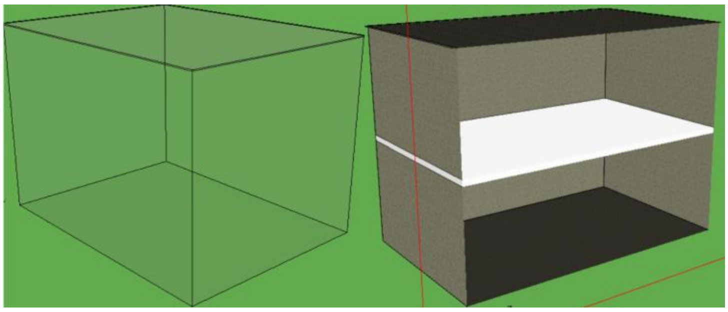


FIGURE 136: IDA ICE ENERGY MODEL – LEFT: BUILDING BODY. RIGHT: THERMAL ZONE

Some warning messages were generated upon the IDA ICE IFC import though, see Figure 137. The warning messages is believed to indicate that some adjustments have been performed on the IFC model by IDA ICE to be suitable for generating the BIM-based energy model.

Warning: Local coord.systems of following IFCOPENINGELEMENTs are related to LCS 122 while must be related to LCS 425: #483, 483, 483
Warning: Local coord.systems of following IFCOPENINGELEMENTs are related to LCS 122 while must be related to LCS 560: #599, 599, 599
Warning: Local coord.systems of following IFCOPENINGELEMENTs are related to LCS 122 while must be related to LCS 616: #655, 655, 655

FIGURE 137: IDA ICE – IFC IMPORT WARNING MESSAGES

Nonetheless, both the building body and the thermal zones were correct.

Case 15

The IDA ICE IFC import did not bring about any warning messages in this case. Apart from that, all results were the same as for case 14 in respect of the thermal view. Therefore, refer case 14 above.

Case 16-17

For the cases where the atrium space was modeled as a separate room/space enclosed by internal walls (independent on whether the floor and roof construction were modeled as a single element or partitioned elements), the thermal view of the energy model was misinterpreted. The outcome upon generating the energy model was a thermal zone created only for the atrium space, while the larger spaces on the 1st and 2nd level were ignored completely. See Figure 138 for the resulting energy model.

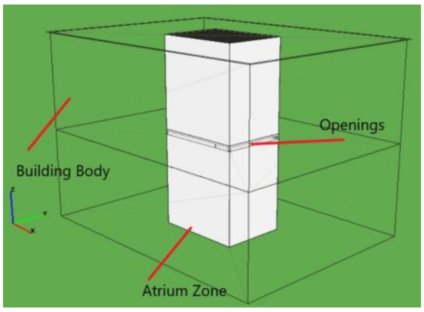


FIGURE 138: IDA ICE ENERGY MODEL – ZONE CREATED FOR ATRIUM SPACE. BUILDING BODY BASED ON THE LARGER SPACES

This relates to one of the warning messages that appeared upon the IDA ICE IFC import, referring to the one reading "For each pair of intersecting spaces the bigger one is removed". All the messages are seen in Figure 139.

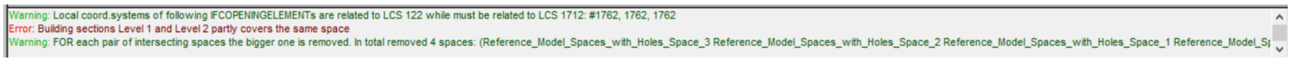

Warning: Local coord.systems of following IFCOPENINGELEMENTs are related to LCS 122 while must be related to LCS 1712: #1762, 1762, 1762
Error: Building sections Level 1 and Level 2 partly covers the same space
Warning: FOR each pair of intersecting spaces the bigger one is removed. In total removed 4 spaces: (Reference_Model_Spaces_with_Holes_Space_3 Reference_Model_Spaces_with_Holes_Space_2 Reference_Model_Spaces_with_Holes_Space_1 Reference_Model_S

FIGURE 139: IDA ICE – IFC IMPORT WARNING AND ERROR MESSAGES

It seems IDA ICE recognize the atrium space (as a space fully enclosed by other spaces) to be intersecting the larger spaces, and thus only keep the smaller (atrium) space. The building body of the energy model was on the other hand based on the outer boundary of the larger spaces, which is correct.

Another minor problem (probably as a consecution of the bigger issue) was the creation of three openings in the atrium zone. These openings were located in the intersection between the atrium walls and the internal floor construction. The openings are shown in Figure 139 as well.

The energy model is not suitable for BEM simulation and would need extensive rework.

Alternative IFC import setup

A modified version of the two cases (but not included as separate cases) were to import the IFC models into IDA ICE with the IFC import option “Keep intersecting spaces” checked. This gave rise to some other results, but nonetheless unacceptable problems related to misinterpretation of the thermal view.

With this option checked, a thermal zone was created for all three spaces. At first glance the energy model can seem to be a clear improvement compared to the previous one. The issue though, was that the atrium zone existed within the two larger zones, without any connection to each other. This is illustrated in Figure 140. To the left of the figure is the energy model with the atrium zone and the two larger zones in what can look like a correct model, but to the right it is seen that the zone at 1st floor has no connection to the atrium zone. The same apply at the 2nd floor.

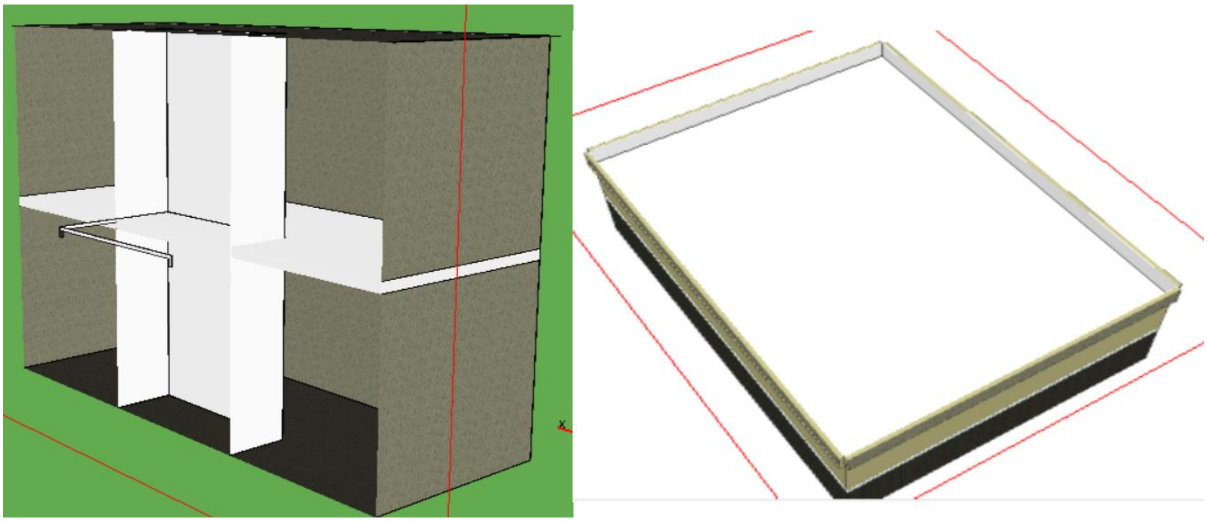


FIGURE 140: IDA ICE ENERGY MODEL – MODIFIED IFC IMPORT SETTINGS

This energy model is neither suitable for BEM simulation and would need extensive rework as well.

Case 18-19

The cases had identical outcomes regarding the energy model´s thermal view, which were misinterpreted. The generated energy model in IDA ICE included only the larger zones of each floor, ignoring the atrium zone. This was an expected outcome since the room/space definition of each floor in Revit included the whole area of the floors, not taking into account the shaft opening. Figure 141 shows the resulting building body and thermal zones for the cases (example taken from case 19).

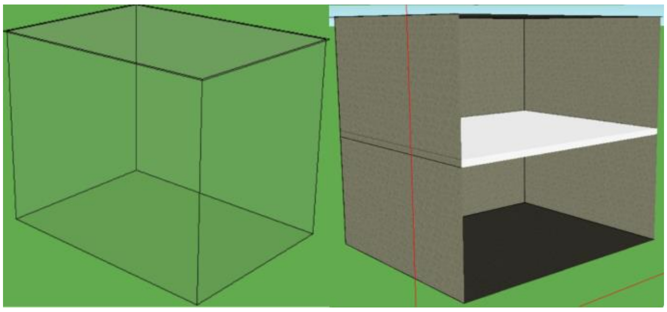


FIGURE 141: IDA ICE ENERGY MODEL – LEFT: BUILDING BODY. RIGHT: ENERGY MODEL

The IFC import of case 18 and 19 generated the warning messages of Figure 142 and Figure 143, respectively. The messages inform that some changes have been made to the IFC slab and IFC room/space at 1st floor, probably to make the IFC model better suited for generating the BIM-based energy model.


Warning: Shapes of the following spaces have been simplified: Reference_Model_Spaces_with_Holes_Space_1, Reference_Model_Spaces_with_Holes_Room_1

FIGURE 142: IDA ICE – IFC IMPORT WARNING MESSAGE CASE 18

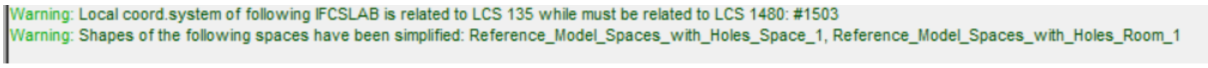

Warning: Local coord.system of following IFCSLAB is related to LCS 135 while must be related to LCS 1480: #1503
Warning: Shapes of the following spaces have been simplified: Reference_Model_Spaces_with_Holes_Space_1, Reference_Model_Spaces_with_Holes_Room_1

FIGURE 143: IDA ICE – IFC IMPORT WARNING MESSAGES CASE 19

This approach modeling the atrium space in Revit can hardly be said to be an interoperability issue causing the lack of the atrium zone in the energy model of IDA ICE. This is because it has more to do with how Revit interpret the space of the shaft opening rather than IDA ICE misinterpreting the spaces of the building. Either way, the result is presented here as to show that it is not a valid way of modeling such a case for it to be understood correctly by IDA ICE.

Case 20-22

For all three model cases involving the mezzanine construction and which only consisted of two rooms/spaces, the energy model´s thermal view was corrupted. The missing thermal zone corresponds to the room/space defined in Revit that consisted of more than one height, see this illustrated for all three cases in Figure 144. IDA ICE is not able to interpret and translate a Revit defined room/space with more than one height and hence the missing thermal zone.

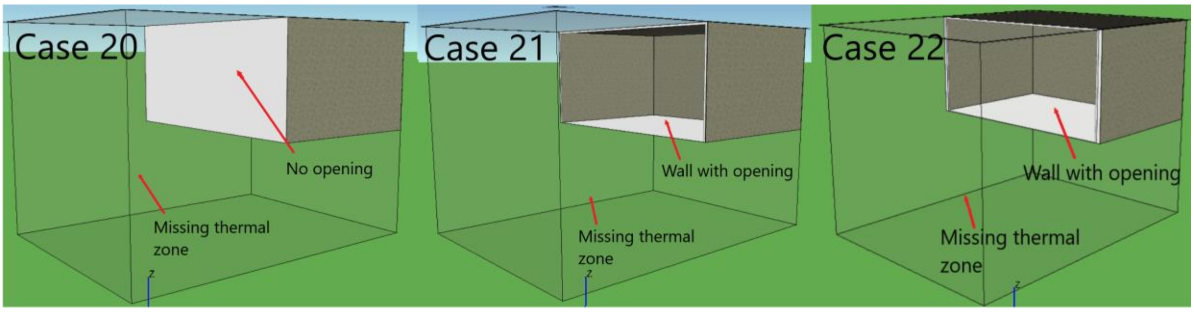


FIGURE 144: IDA ICE ENERGY MODEL – ROOM/SPACE WITH TWO HEIGHTS LEADING TO MISSING THERMAL ZONE – FROM LEFT TO RIGHT: CASE 20, 21 AND 22

Case 23, 24, 26

All the Revit BIM models involving a mezzanine (case 20-27) consisted of a single open spatial area. What sets these cases apart from each other are the arrangement of rooms/spaces and how these are separated with either room separation lines and/or walls with openings.

Where the rooms/spaces were set apart from each other with a room separation line, IDA ICE was not able to interpret the thermal view of the energy model correctly. In these cases, IDA ICE created an internal wall instead of having an opening between the thermal zones. The result is illustrated in Figure 145.

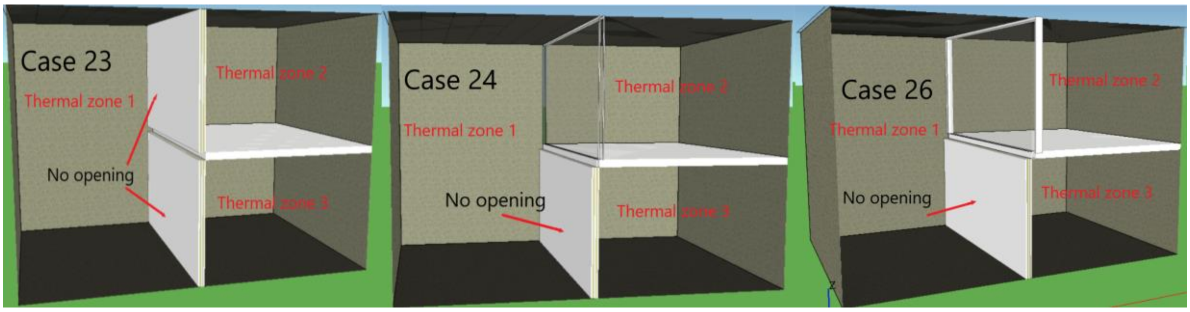


FIGURE 145: IDA ICE ENERGY MODEL – CREATION OF AN INTERNAL WALL WHERE ROOM SEPARATION LINES SEPARATES ROOMS/SPACES – FROM LEFT TO RIGHT: CASE 23, 24 AND 26

Refer case 25 and 27 below for the result of using walls with opening to separate the rooms/spaces of the building model.

Case 25, 27

In the model cases where the rooms/spaces were separated by walls hosting openings and all rooms/spaces were defined with only one height, the thermal view of the energy models were interpreted correctly by IDA ICE. The walls hosting openings correctly creates openings between the thermal zones of the energy model, refer Figure 146 (example taken from case 27). For the issue regarding rooms/spaces with multiple heights, refer Problem 10 for the related cases 20-22 above.

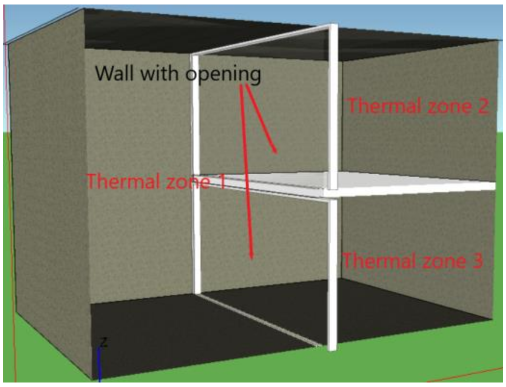


FIGURE 146: IDA ICE ENERGY MODEL – CORRECTLY INTERPRETED THERMAL VIEW

Case 28

Both the building body and thermal zone of the energy model was interpreted correctly by IDA ICE, see Figure 147.

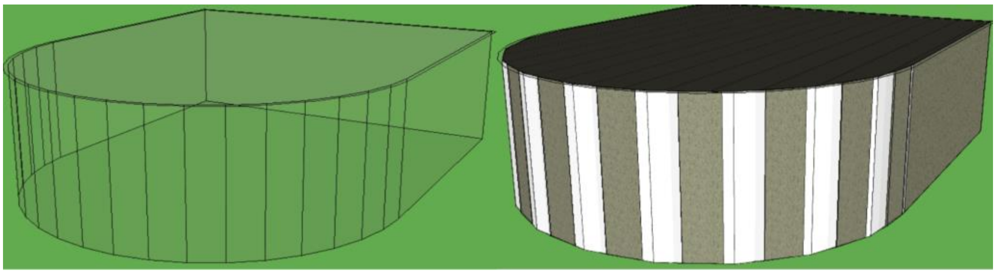


FIGURE 147: IDA ICE ENERGY MODEL – LEFT: BUILDING BODY. RIGHT: THERMAL ZONE

Case 29

No energy model available for investigation, refer Problem 14 of the respective case.

Case 30

The case did not cause any problem with IDA ICE´s thermal view of the building model. Figure 148 illustrates both the building body and the thermal zone created in IDA ICE. The figure shows that the building body for the roof construction extends outside the walls to include the area of the roof overhang. Nevertheless, the thermal zone corresponds to the room/space of the building.

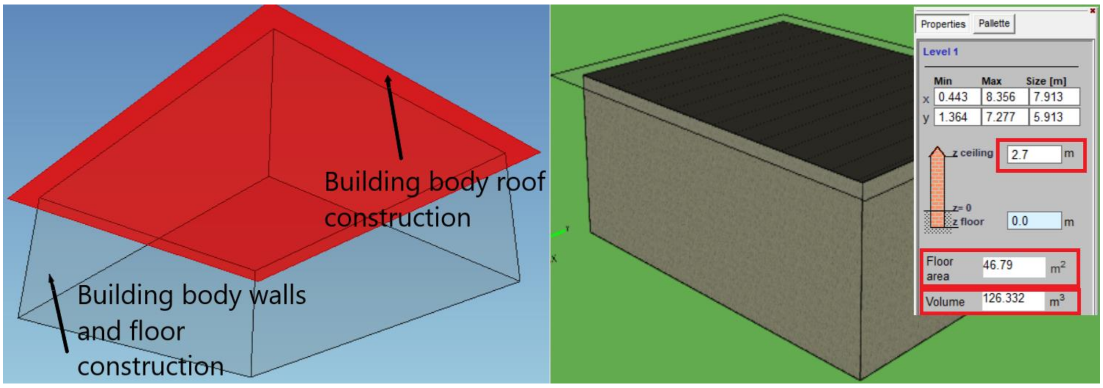


FIGURE 148: IDA ICE ENERGY MODEL – ROOF OVERHANG – LEFT: BUILDING BODY. RIGHT: THERMAL ZONE

Case 31

The recess in the façade constituting the balcony cause the building bodies at level 1 and level 2 to overlap at the balcony walls and roof construction, refer Figure 149. This is the cause of another problem, refer [Problem 12] for the respective case.

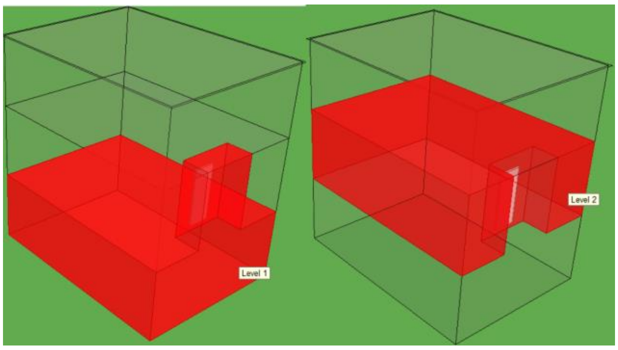


FIGURE 149: IDA ICE ENERGY MODEL – OVERLAPPING BUILDING BODIES – LEFT: BUILDING BODY LEVEL 1. RIGHT: BUILDING BODY LEVEL 2

Problem 11 – No IFC Object Support

Case 1-6

In all model cases involving BIM IFC column objects, the columns were completely ignored in the energy model. Based on these results, it can be concluded that IDA ICE does not support the IFC column object, which is the cause of all the other problems related to columns.

Case 10

The investigation revealed that the IFC door object was not recognized by IDA ICE, and thus not available to be mapped to any IDA ICE door resource. Upon generating the energy model in IDA ICE, the door was by default set as a

“Large vertical opening” with the default construction “[Default] [use wall construction] as seen in Figure 150. In IDA ICE doors are also recognized as a “Large vertical opening”, but the “Construction” input would be a door construction rather than the “[Default] [use wall construction]” which is the case here. In other words, the problem is that it is not possible to automatically map an IDA ICE door construction to the “Large vertical opening”, causing the material properties of the door to be incorrect. Figure 150 shows the energy model with the default properties of the “Large vertical opening” in IDA ICE.

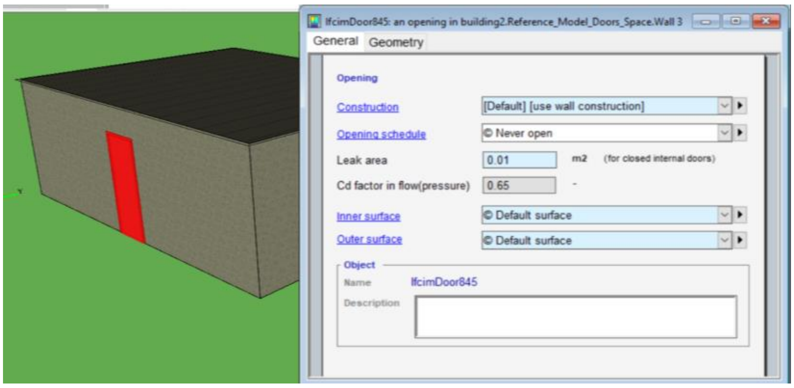


FIGURE 150: IDA ICE ENERGY MODEL – THE DOOR AS A “LARGE VERTICAL OPENING” WITH DEFAULT PROPERTIES

Problem 12 – Incorrect Interpretation of IFC Object Properties

Case 7-9

The transparent BIM-based curtain wall IFC object, regardless of the Revit curtain wall type, was identified by IDA ICE as a construction element, i.e. as an external/internal wall, floor, or roof construction. This means that the curtain wall is understood as an opaque element with no options to be automatically mapped to any transparent IDA ICE resources. Figure 151 shows the mapping function of IDA ICE and the IFC curtain wall object recognized as a construction element.

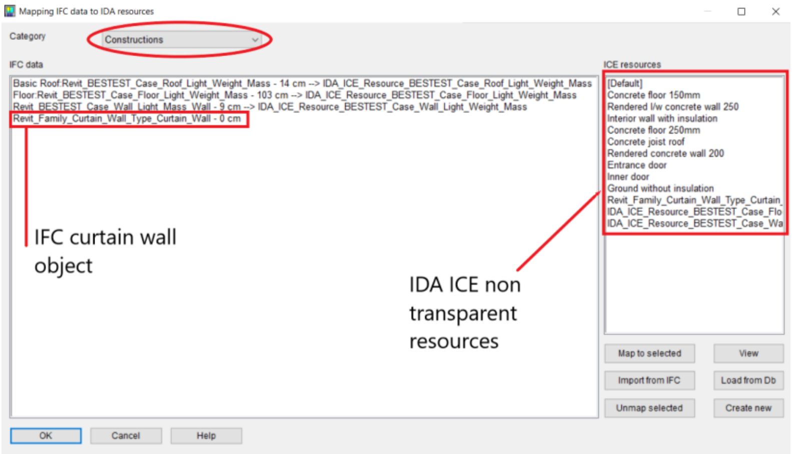


FIGURE 151: IDA ICE – MAPPING FUNCTION – CATEGORY "CONSTRUCTIONS"

In Figure 152 the IFC model and the energy model in IDA ICE containing the curtain wall is seen (example taken from case 7). To the left in the figure, the curtain wall IFC object is represented as the gray opaque element. To the right in the figure is the thermal zone of energy model. Here it is seen that the curtain wall is mapped to an opaque wall construction, since there was no option to map it to a transparent element.

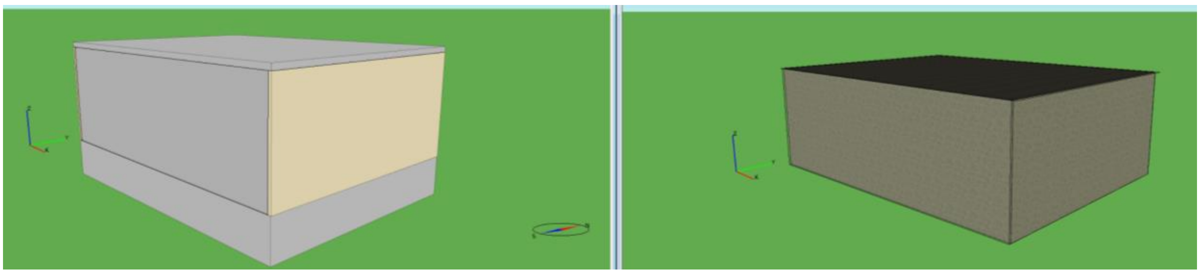


FIGURE 152: IDA ICE – CURTAIN WALLS – LEFT: IFC MODEL. RIGHT: ENERGY MODEL

Case 28

The IFC model was successfully imported into IDA ICE and the curved surface wall was automatically transformed into multiple segments of flat surface wall elements, see Figure 153.

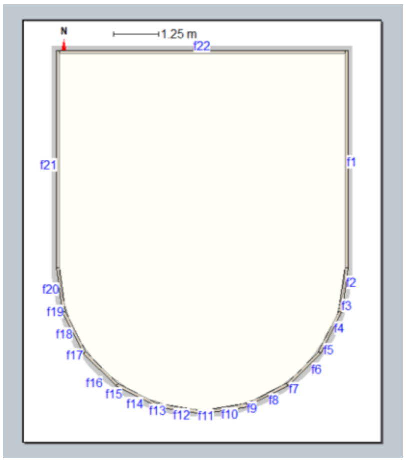


FIGURE 153: IDA ICE – PLAIN CURVED SURFACE WALL – MULTIPLE SEGMENTS OF FLAT SURFACE ELEMENTS – FLOOR PLAN VIEW

The curved surface wall with an initial arc radius of 4 meter was divided into a total of 19 flat surface elements.

The energy model did involve some issues, see Figure 154. Half of the flat surface elements were white-colored, and the other half were brown-colored. The brown-colored elements indicate external wall construction and the white-colored elements indicate internal wall construction. In this case the whole wall should be defined as an external construction, so the white-colored wall elements facing the external are wrong. Each pair of white and brown-colored field were part of the same wall surface element, see Figure 155.

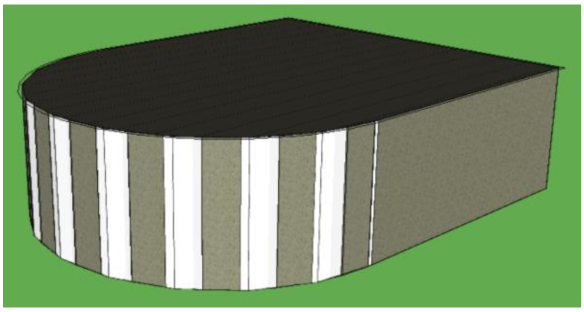


FIGURE 154: IDA ICE – PLAIN CURVED SURFACE WALL – LEFT: IFC MODEL. RIGHT: ENERGY MODEL

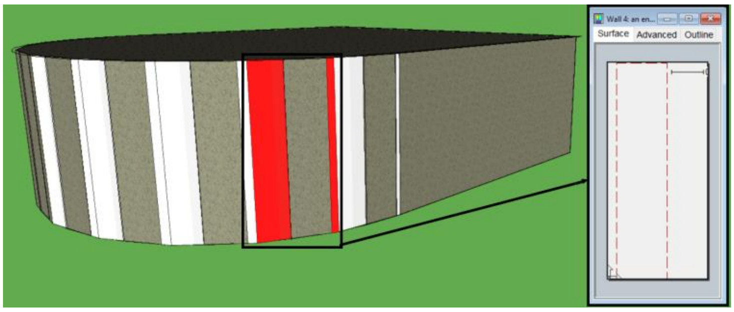


FIGURE 155: IDA ICE – PLAIN CURVED SURFACE WALL – MISINTERPRETATION OF THE FLAT WALL ELEMENTS

The problem causing the issue seems to be the distance between the thermal zone and the building body, which controls the thermal connection of surfaces and hence decides the definition of the type construction element of the surfaces.

Case 31

Due to Problem 10 of the case, the walls, floor and roof construction of the recess is misinterpreted as internal surfaces, see Figure 156. Rather than being mapped to their external constructions as they should, they are mapped to their internal constructions. This will cause the material properties of these elements to be incorrect.

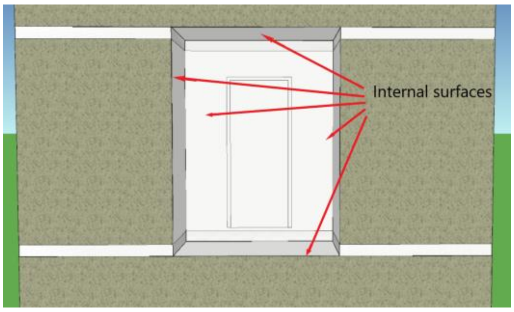


FIGURE 156: IDA ICE ENERGY MODEL – BALCONY WALLS, ROOF AND FLOOR WRONGLY INTERPRETED AS INTERNAL SURFACES

Problem 13 – Simulation Run Time

Case 28

Problem has not been investigated because there is no reference to compare against. However, a reflection on the issue is given below.

The IDA ICE energy model is like a large simultaneous system of equations for all processes of the building. It is claimed by EQUA (developer of IDA ICE) that the correlation between the number of equations and simulation run time is roughly linear to the problem size (Equa Simulations, n.d.). Therefore, it can be expected that the simulation run time will increase by the increased number of flat surface elements that are created, due to more equations that have to be solved.

Case 29

No energy model available for simulation, refer Problem 14 of the respective case. Nonetheless, refer case 28 above for a discussion on the matter.

Problem 14 – IFC Import Failure

Case 29

The IFC model was not successfully imported into IDA ICE. The error message generated when trying to import the IFC model is seen in Figure 157.

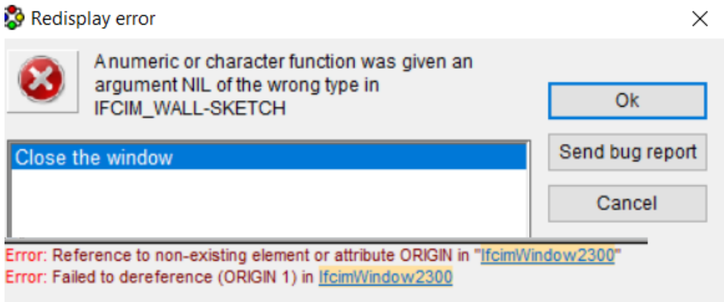


FIGURE 157: IDA ICE – IFC IMPORT ERROR MESSAGE

It seems that IDA ICE, because of the segmentation of the curved surface wall into several flat surface elements, struggle to locate the hosting wall elements for the type construction element window and fail to deference the windows to the segmented wall surfaces.

4.2 Suggested Solutions

Since some cases cause more than one problem, these cases may have more than one suggested solution. In this way the solutions solve different problems and in total will be a complete solution for the case. On the other hand, a problem for a case may be the cause for all the other problems related to the case. By solving the main problem all other problems are also solved.

Three different solution methods have been investigated.

Solution method 1 is done by direct manipulation of the BIM model in Autodesk Revit. By manipulation means workarounds, i.e. modeling techniques not following the modeling conventions or standard approach. A flowchart of solution method 1 is seen in Figure 158.

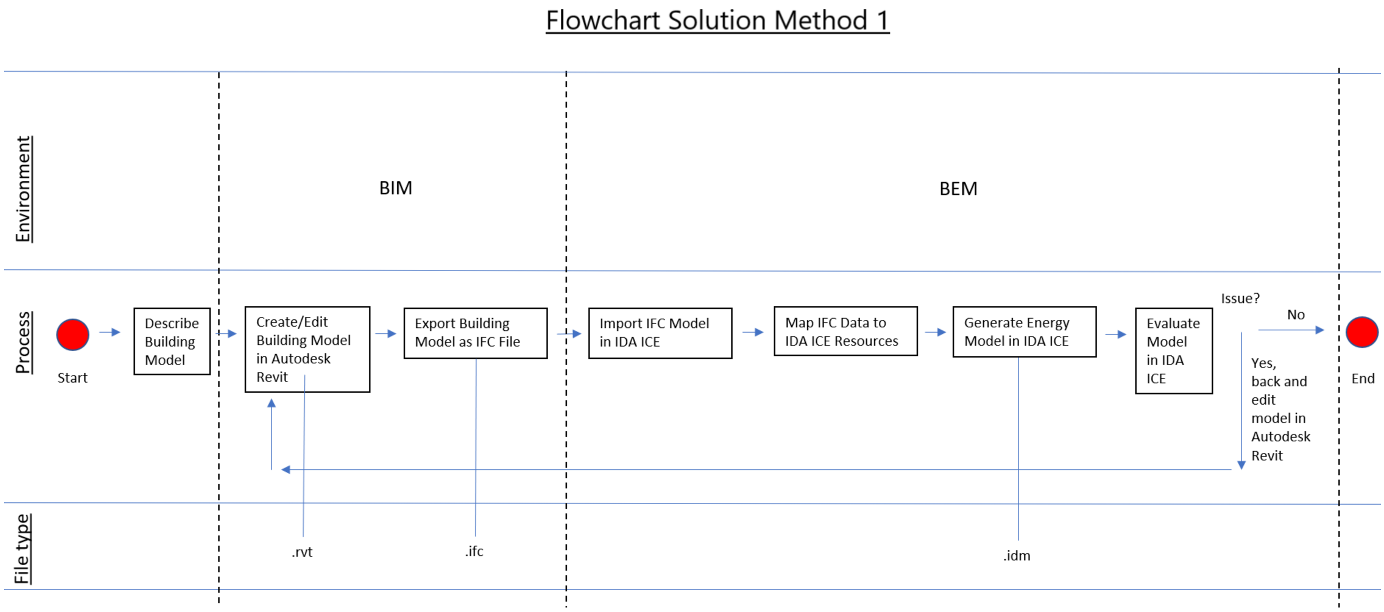


FIGURE 158: FLOWCHART SOLUTION METHOD 1

Solution method 2 involves a fix directly on the BEM energy model performed in IDA ICE. A flowchart of solution method 2 is seen in Figure 159.

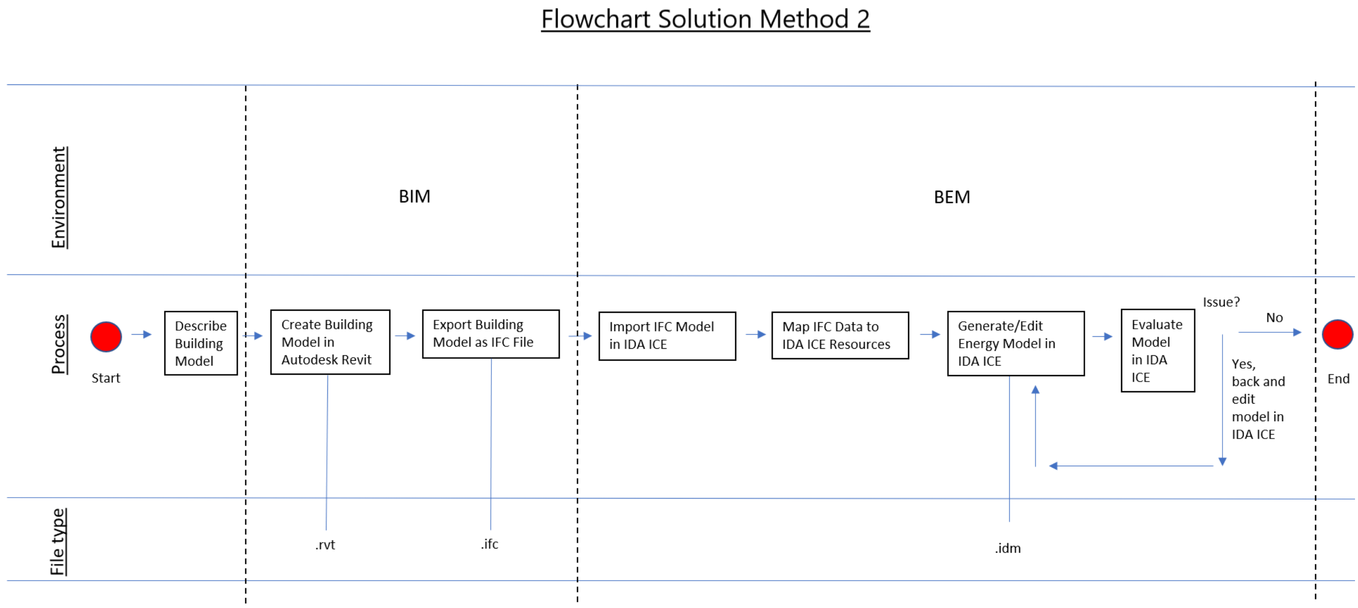


FIGURE 159: FLOWCHART SOLUTION METHOD 2

Solution method 3 involves editing and/or validating the IFC model with the third-party software SimpleBIM. A flowchart of solution method 3 is seen in Figure 160.

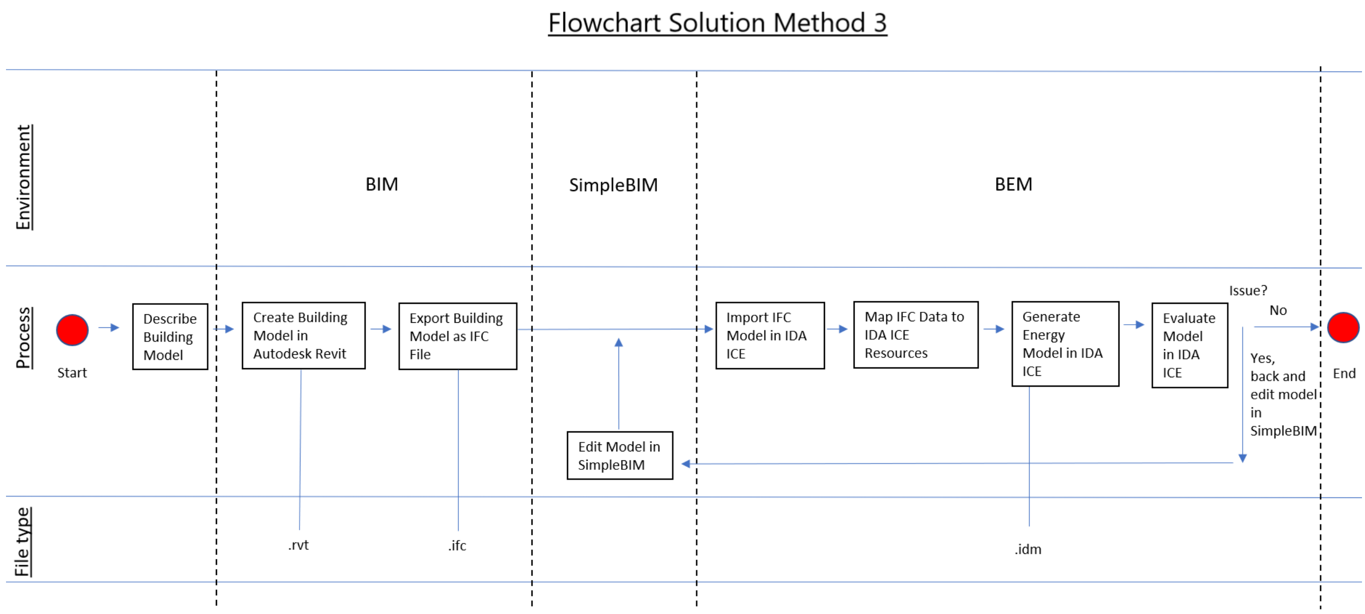


FIGURE 160: FLOWCHART SOLUTION METHOD 3

General Procedure in SimpleBIM

Since solution method 3 makes use of SimpleBIM with the IDA ICE add-on, a general introduction of the software and its interface is presented.

The IDA ICE add-on is selected upon the startup of SimpleBIM, see Figure 161.

Before the imported IFC model appear in the interface of SimpleBIM, the software performs a few actions in advance. The actions included are such as transformation and simplification of the IFC data, search for overlapping spaces, and reloading the edited IFC model.

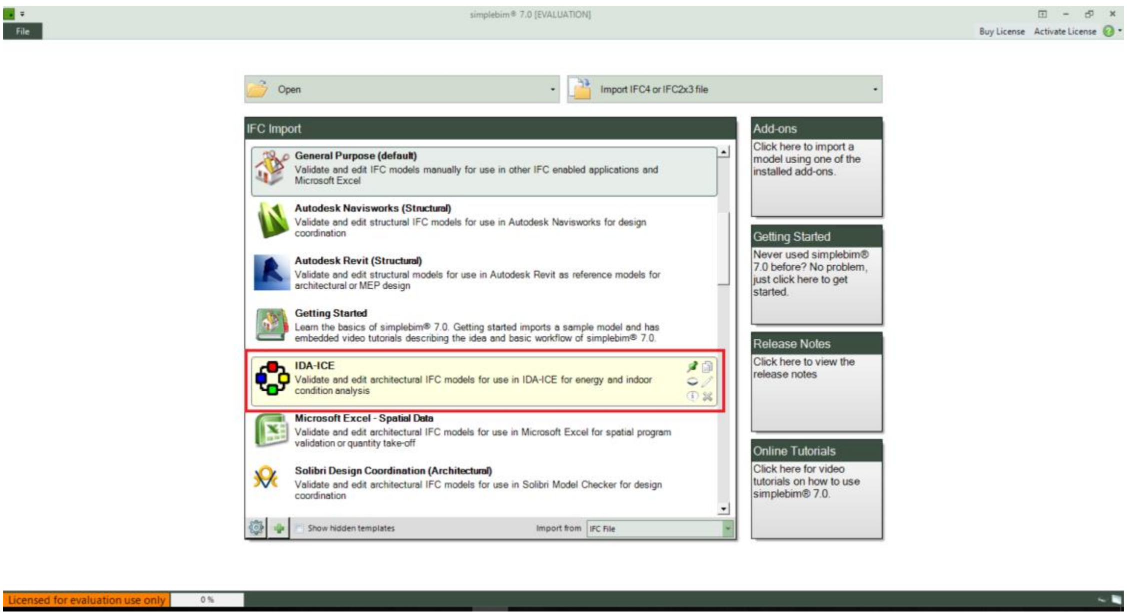


FIGURE 161: A SNAP SHOT SHOWING THE SIMPLEBIM STARTUP MENU – IDA ICE ADD-ON (MODIFICATIONS IN RED)

The interface of SimpleBIM with an imported IFC model is shown in Figure 162.

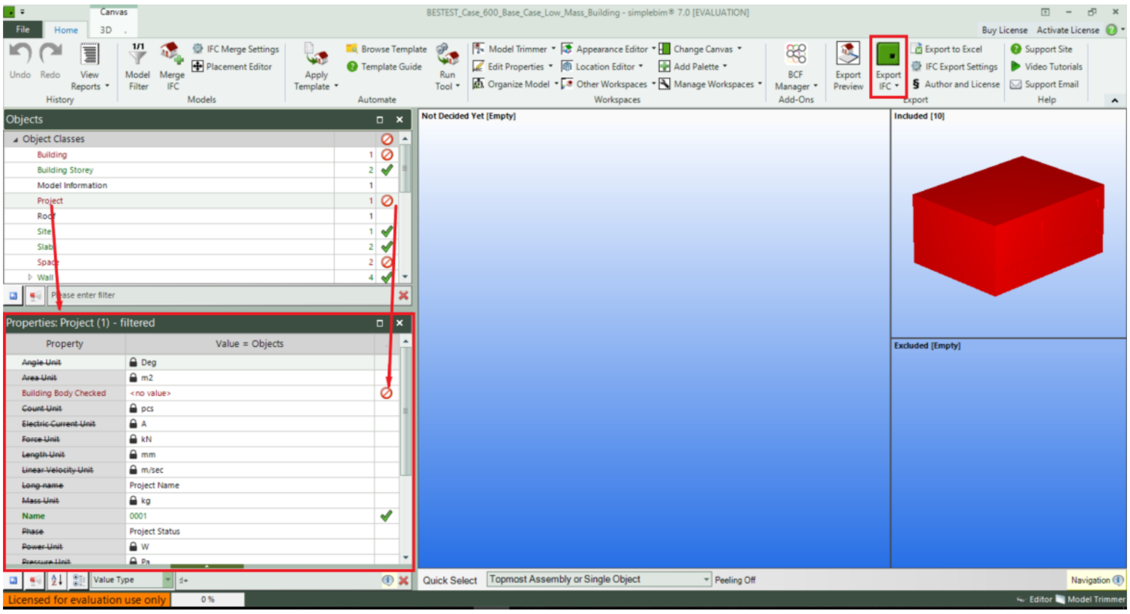


FIGURE 162: A SNAP SHOT SHOWING THE SIMPLEBIM INTERFACE (MODIFICATIONS IN RED)

On the left-hand side of the interface is the object and property bars. The object bar shows the object classes and object groups of the IFC model. The bar displays if the IFC objects did pass/not pass the validation checks according to the preferences given by the IDA ICE add-on. The property bar displays the properties and associated values of the objects.

On the right-hand side of the interface are three windows showing the IFC objects that have been excluded, included and not yet decided upon to include/exclude.

The software has several applications, but two applications have been especially important through the work of this thesis. One of them is the editing of object properties with the purpose to pass the validation check of IFC objects. The second one is trimming the IFC model for unnecessary objects for the purpose of energy and thermal simulation, e.g. objects such as chairs, tables, etc.

After completing the editing and/or trimming, the modified IFC model is ready to be exported as an IFC file again. The IFC export option of SimpleBIM is seen in Figure 162.

Suggested Solution Problem 1 & 2

Case 1-2, 4-5

<u>Solution Method 2</u>

Problem solved following the procedure described in case 11-13 of the same [Suggested Solution Problem](). In this case though, the relevant thermal bridges are the “External wall/internal wall” or “External wall/external wall” depending on the location of the column, refer Figure 163.

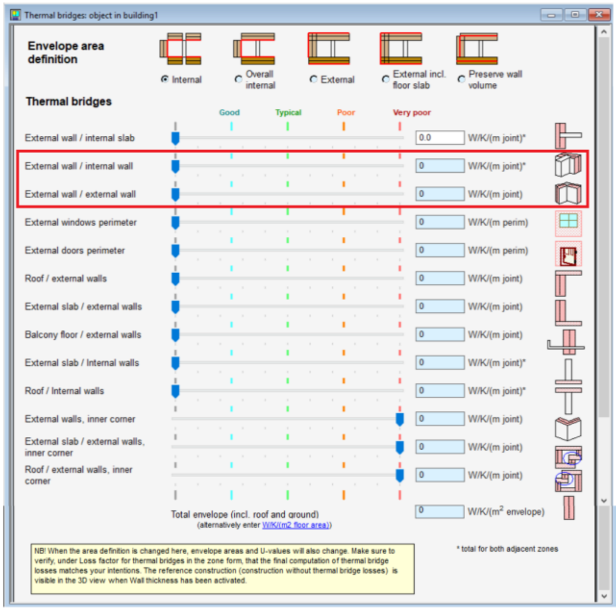


FIGURE 163: A SNAP SHOT SHOWING THE IDA ICE THERMAL BRIDGE OPTION – “EXTERNAL WALL/INTERNAL WALL” AND “EXTERNAL WALL/EXTERNAL WALL” (MODIFICATIONS IN RED)

Case 7-9

Problem solved otherwise, refer case 7-9 in [Suggest Solution Problem 12]().

Case 10

<u>Solution Method 2</u>

The suggested solution solves the problem related to the interoperability issue by manually configuring the “Construction” input of the “Large vertical opening”.

The procedure is outlined in Figure 164. The “Large vertical opening” is selected. In the field “Construction”, select a door construction consisting of materials with thermal properties that corresponds to the properties of the BIM IFC door.

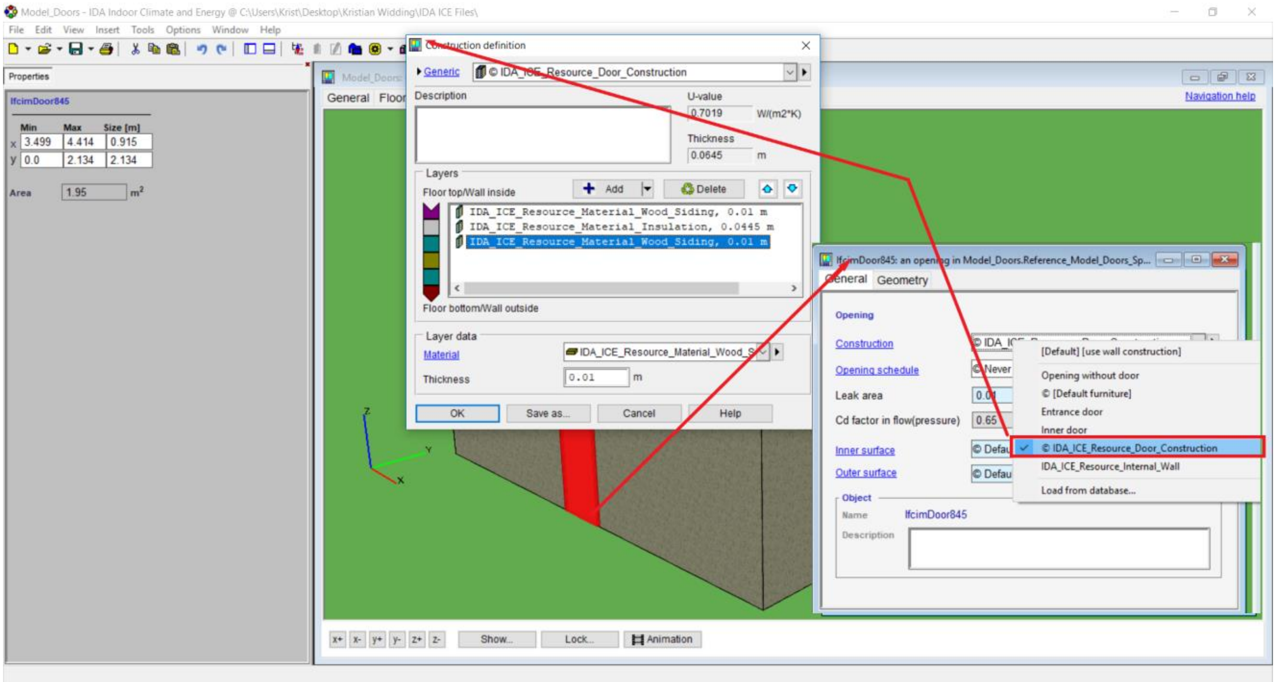


FIGURE 164: A SNAP SHOT OF IDA ICE SHOWING THE SOLUTION CORRECTING THE THERMAL INSULATION OF THE DOOR (MODIFICATIONS IN RED)

Case 11-13

<u>Solution Method 2</u>

The neglected parapet walls from the energy models’ geometry and hence its influence as a thermal bridge is managed otherwise in IDA ICE. The thermal bridge heat loss/gain for different parts of the building can be managed in the option called “Thermal bridges” located under the “General” tab in IDA ICE, refer Figure 165. The relevant thermal bridge in this case is the “External slab/external walls”.

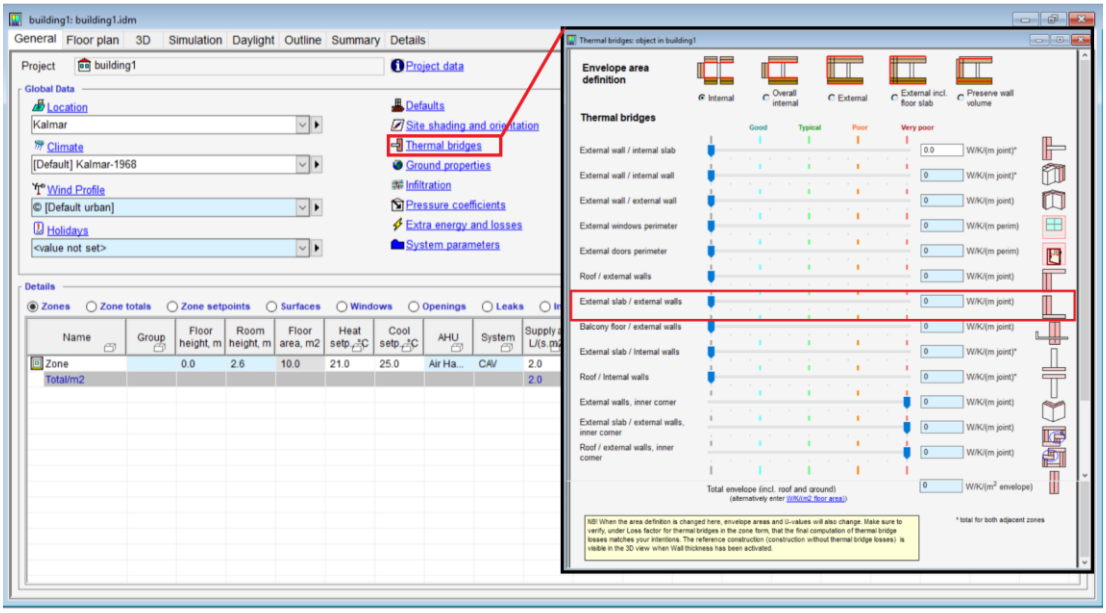


FIGURE 165: A SNAP SHOT SHOWING IDA ICE THERMAL BRIDGE OPTION – "EXTERNAL SLAB/EXTERNAL WALLS" (MODIFICATIONS IN RED)

Case 20-27

The mezzanine floor construction´s influence as a thermal bridge is taken care of following the [Suggested Solution Problem 1 & 2] of case 11-13. In this case though, the relevant thermal bridge is the "External wall/internal slab", see Figure 166 below.

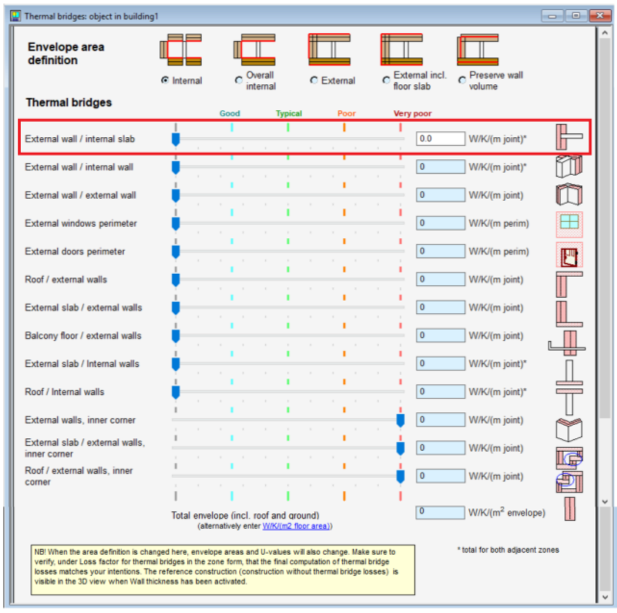


FIGURE 166: A SNAP SHOT SHOWING THE IDA ICE THERMAL BRIDGE OPTION – "EXTERNAL WALL/INTERNAL SLAB" (MODIFICATION IN RED)

Be sure to create the model case of this interoperability issue according to the procedure of case 25 or 27, see the referred cases in Suggested Solution Problem 10.

Case 30

Problem solved, refer procedure described in Suggested Solution Problem 1 & 2 of case 11-13.

Case 31

Problem solved otherwise, refer the Suggested Solution Problem 10 for the respective case.

Suggested Solution Problem 3

Case 1-6

Solution Method 2

The suggested solution solves the problem with the thermal mass of the columns not being accounted for.

When inside a thermal zone in IDA ICE, internal mass can be added to the zone with the object “Wall mass” as located entirely inside the zone. By utilizing this object, the column can be convert to the equivalent mass in wall with the same material properties. The “Wall mass” object is located in the “Palette” bar on the left side of the IDA ICE interface as illustrated in Figure 167. The input for the object is “Area” (m^2) per side of a two-sided wall, “Construction”, “Surface” and “Convective heat transfer coefficient” (W/m^2*K).

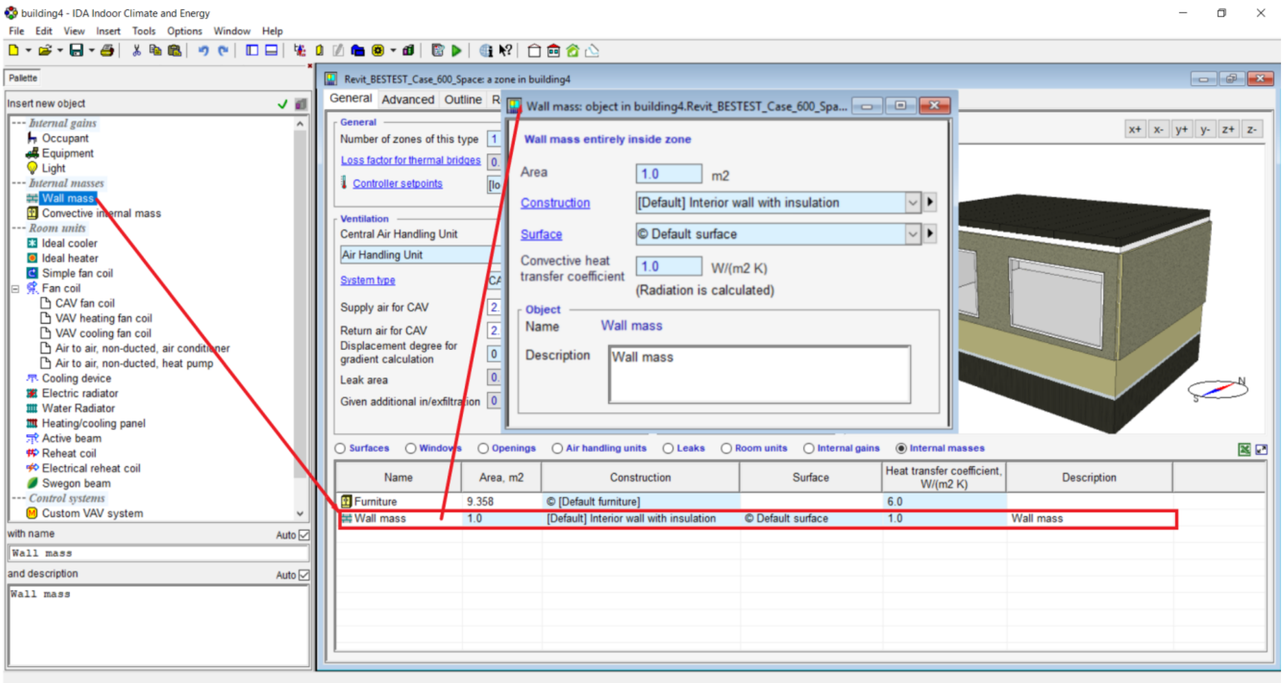


Figure 167: A snap shot of IDA ICE showing the solution to include the thermal mass of columns (modifications in red)

Example: In the case of the architectural concrete column with dimensions 0,475 X 0,610 m and height 2,7 m (the column of case 4, 5 and 6), this equals approximately 0,8 m^3 of concrete mass. With use of the “Wall mass” object a single column of this type could for instance be converted to a 0,150 m wide concrete wall (to be configured in the “Construction” input) with a height of 2,7 m and approximately a length of 2 m (to be configured in the “Area” input).

This might be a cumbersome way of solving the problem, especially for larger more complex cases. Nonetheless, it is the solution that has been found.

Case 7-9

Problem solved otherwise, refer Suggested Solution Problem 12 for the respective cases.

Case 10

Problem solved by following the procedure described in Suggested Solution Problem 1 & 2 for the same case.

Case 11-13

Problem can be solved following the procedure described in Suggested Solution Problem 3 for case 1-6. However, the parapet wall´s thermal mass is difficult to convert to the equivalent of wall mass located entirely inside the zone. The influence is probably minimal and thus can be neglected.

Case 20-27

No problem and hence no solution provided.

Case 30

Problem can be solved following the procedure described in Suggested Solution Problem 3 for case 1-6. However, the overhang´s thermal mass is difficult to convert to the equivalent of wall mass located entirely inside the zone. The influence is probably minimal and thus can be neglected.

Case 31

Problem solved otherwise, refer Suggested Solution Problem 10 for the respective case.

Suggested Solution Problem 4 & 5

Case 2-3, 4-5

No problem found for these cases and hence no solution required.

Case 3,6

No solution found for these cases.

Case 20-27

No problem and hence no solution provided.

Case 28

Neglectable influence on area/volume as explained in Problem 4 & 5 for the respective case and hence no solution provided.

Case 29

N/A. Refer Problem 14 for the respective case.

Suggested Solution Problem 6

Case 1-6

There was no problem to include the columns as shading objects. However, due to other problems related to columns (i.e. regarding the thermal view), the method of using the “In-Place Mass” tool as described in case 13 below can be an alternative way of modeling columns for the purpose of shading. This method also allows the IFC column objects to be selected to shade, while at the same time generating a more predictable thermal view of the energy model. However, it should be noted that all the other problems related to columns is still an issue implementing this method.

Case 11

Case did not cause any direct problem with shading. Nevertheless, it is recommended to model the parapet walls following either the procedure described in case 13 or the alternative suggested solution of case 13 described below.

Case 12

Because of the problem occurring for the case, it is recommended to model the parapet walls following either the procedure described in case 13 or the alternative suggested solution of case 13 described below.

Case 13

Solution Method 1

First of all, to include separate IFC objects as shading objects in the energy model of IDA ICE, one simply has to select the entire IFC model and enable “Allow selection of components”. The IFC objects can then be selected separately and by checking the option “Calculate the shadow”, the objects are included as shading objects. See procedure illustrated in Figure 168.

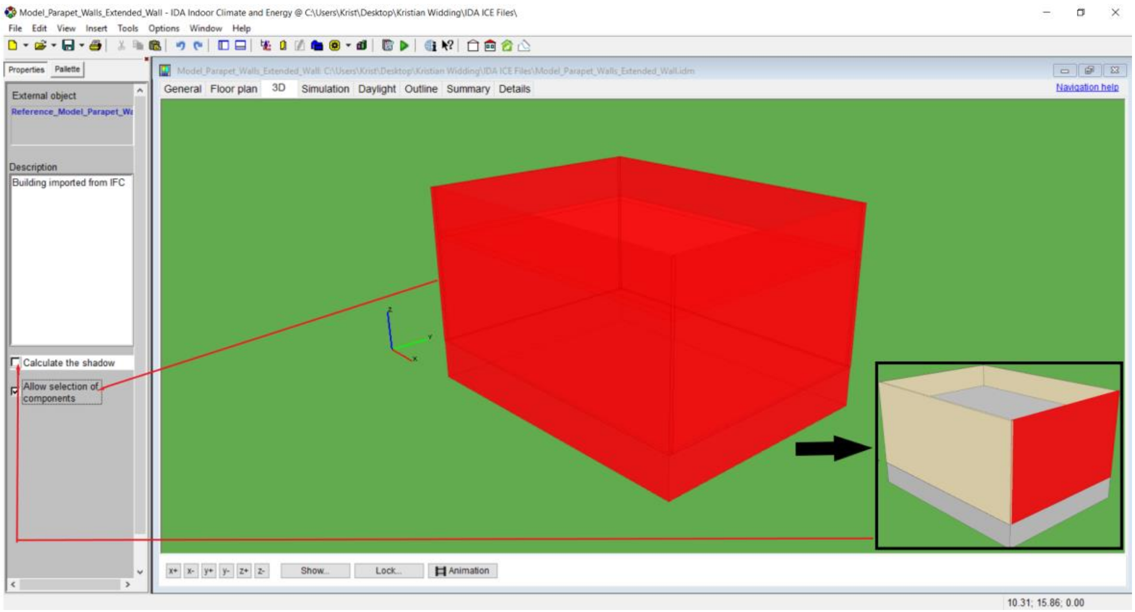


FIGURE 168: A SNAP SHOT OF IDA ICE SHOWING HOW TO INCLUDE IFC OBJECTS AS SHADING OBJECTS (MODIFICATIONS IN RED)

Alternative Suggested Solution Method 1

The suggested solution is an alternative approach to model the parapet walls in Revit for the purpose to include the parapet walls as shading objects in IDA ICE.

The workaround solution makes use of the Revit tool “In-Place Mass” to model the parapet walls as mass objects, refer the procedure described in 3.2.2 General Modeling Conventions in Autodesk Revit: Modeling of Mass Objects. The resulting IFC model in IDA ICE is seen in Figure 169. Compared to the result of case 13 where the parapet wall had to be selected for each wall, it now exists as a single entity available to be selected and included as a shading object.

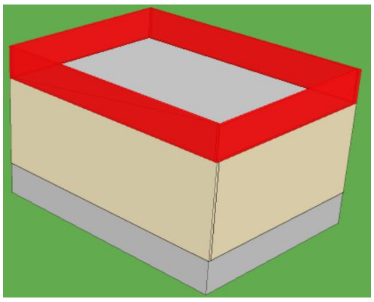


FIGURE 169: IDA ICE IFC MODEL – SELECTION OF IFC PARAPET WALLS TO BE INCLUDED AS SHADING OBJECTS

Case 20-27

No problem to include the mezzanine floor construction as a shading object if the modeling procedure of case 25 is followed. To include IFC objects as shading objects, follow Solution Method 1 of case 13 above.

Case 29

N/A. Refer Problem 14 for the respective case.

Case 30

Case did not cause any direct problem with shading. The procedure described in case 30 is an appropriate method in most cases to model overhangs that should be included as shading objects. Nevertheless, the alternative suggested solution for problem 6 of case 13 can also be applied.

Suggested Solution Problem 7 & 8

Case 1-6

No problem found for these cases, nevertheless refer recommendation in Suggested Solution Problem 6 for the respective cases.

Case 7-9

Problem solved otherwise, refer Suggested Solution Problem 12 for the respective cases.

Case 10

In the case of transparent glass doors, two solutions are provided. The first solution involves a workaround in Revit, while the second solution is done through manual editing of the energy model in IDA ICE.

Solution Method 1

In Revit, instead of modeling transparent glass doors as door objects, these constructions can be modelled as window objects. In this way the objects will be recognized in IDA ICE as transparent window constructions available to be mapped to a window with the desired properties.

If implementing this solution, it is important to be aware that there are some differences between window and door constructions in IDA ICE. For instance, windows do not contain the material properties density and specific heat as the door does and hence the thermal mass of the object will not be considered, but this is assumed to be negligible for glass doors anyway. Window constructions neither have the input options for leak area and pressure in flow (Cd factor) impacting the air leakage of the building. There are other differences between window and door constructions as well, and on the other hand, window constructions contain several other options that doors do not possess. Figure 170 shows the property bars of the “Basic window” and “Door” construction of IDA ICE.

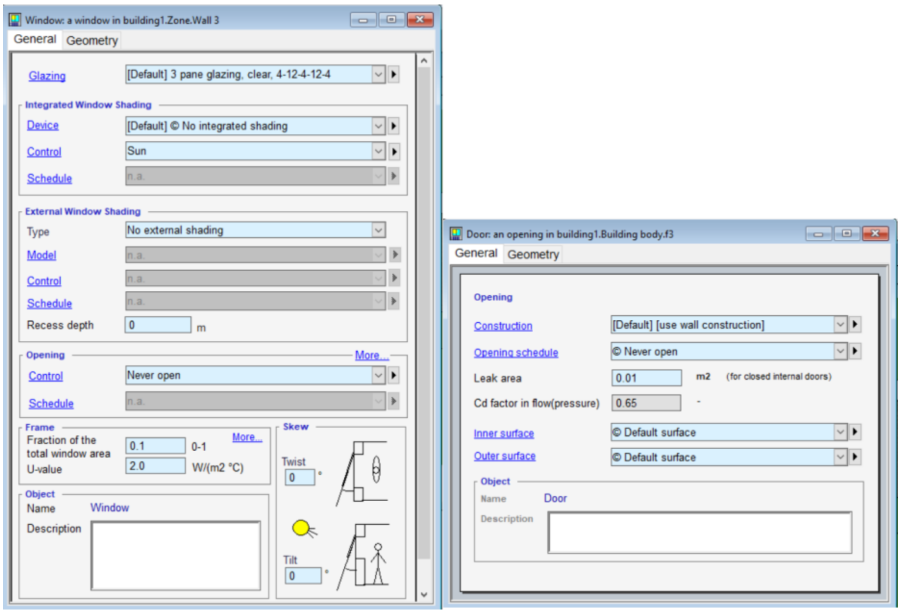


FIGURE 170: A SNAP SHOT OF IDA ICE SHOWING THE PROPERTIES FOR A "BASIC WINDOW" AND "DOOR" CONSTRUCTION

<u>Solution Method 2</u>

If the problem is to be solved directly in IDA ICE, the "Large vertical opening" needs to be deleted and replaced with a window construction. Refer the discussion above on the differences between window and door constructions in IDA ICE.

Case 11

No direct problem, but it is encouraged to follow the recommendation of Suggested Solution Problem 6 for the same case.

Case 12

Follow the recommendation in Suggested Solution Problem 6 for the respective case.

Case 13

Refer Suggested Solution Problem 6 for the respective case.

Case 20-27

Refer Suggested Solution Problem 6 for the respective cases.

Case 29

N/A. Refer Problem 14 for the respective case.

Case 30

N/A. Refer the recommendation of Suggested Solution Problem 6 for the respective case.

Case 31

No problem found and hence no solution required.

Suggested Solution Problem 9

Case 16-19

Refer Suggested Solution Problem 10 for the respective cases.

Case 20-27

Refer Suggested Solution Problem 10 for case 23, 24 and 26 and case 25 and 27.

Suggested Solution Problem 10

Case 1-2, 4-5

Solution Method 1

The suggested solution is a workaround solution performed in Revit to model columns. The solution makes it possible for the BIM model to contain column objects, but also generates a more predictable building body and solves the problem with the wrongly mapped external wall constructions of the thermal zone.

Instead of using the “Column” tool, the tool “In-Place Mass” (refer 3.2.2 General Modeling Conventions in Autodesk Revit: Modeling of Mass Objects) is used to model the columns as mass objects. Figure 171 shows the Revit BIM model for the solution. The figure shows that the room/space definition now includes the whole room (including the area of the columns) and with the columns still visible in the model.

The resulting IFC model and energy model in IDA ICE is seen in Figure 172. The generated building body is now rectangular in shape (without the inward corners). The thermal zone consists of only four wall elements which are mapped to the correct IDA ICE external construction resource.

The columns as IFC mass objects were still possible to select separately and available to include as shading objects.

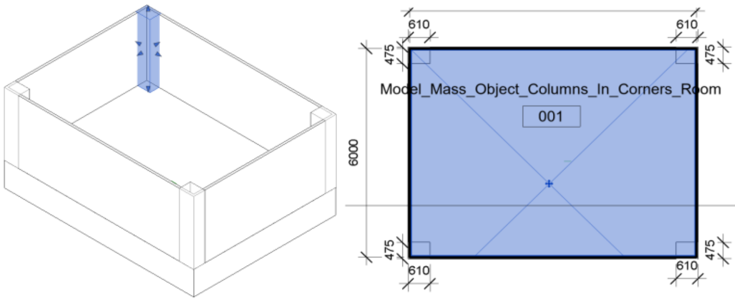


FIGURE 171: REVIT BIM MODEL WITH COLUMNS AS "IN-PLACE MASS" OBJECTS – LEFT: 3D VIEW. RIGHT: FLOOR PLAN VIEW

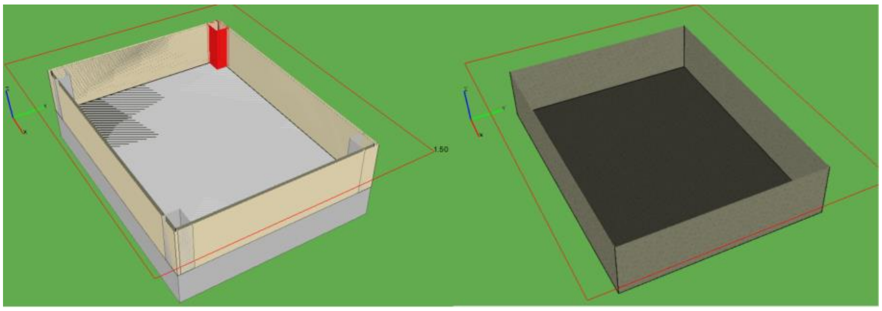


FIGURE 172: IDA ICE ENERGY MODEL WITH COLUMNS AS "IN-PLACE MASS" OBJECTS – LEFT: IFC MODEL. RIGHT: THERMAL ZONE

Case 3,6

Cases did not cause any misinterpretation of the energy model´s thermal view and thus no solution is provided.

Case 11-13

Cases did not cause any misinterpretation of the energy model´s thermal view and thus no solution is provided.

Case 14

Case did not cause any misinterpretation of the energy model´s thermal view and thus no solution is provided.

Case 15

Case did not cause any misinterpretation of the energy model´s thermal view and thus no solution is provided.

Case 16-17

<u>Solution Method 2</u>

The suggested solution involves a manual fix in IDA ICE with case model 16 as the base for the solution. For this model the atrium zone was the only zone to be generated. From there on the solution continuous by deleting the wrongly made “Openings” in the atrium zone and manually model the thermal zones for the two larger spaces of the building.

The procedure is illustrated in Figure 173, Figure 174 and Figure 175 below. In the floor plan view of IDA ICE, the object “Zone” is used to create zones that goes around the atrium zone at both floor levels. Since the larger surrounding zones has to go all the way around the atrium zone and border to itself at the end, an internal wall at each floor that should not exist is generated. To get rid of the internal walls the object “Opening without door” is inserted into the internal walls and is made to cover the whole area of the walls. The resulting energy model is seen in Figure 175.

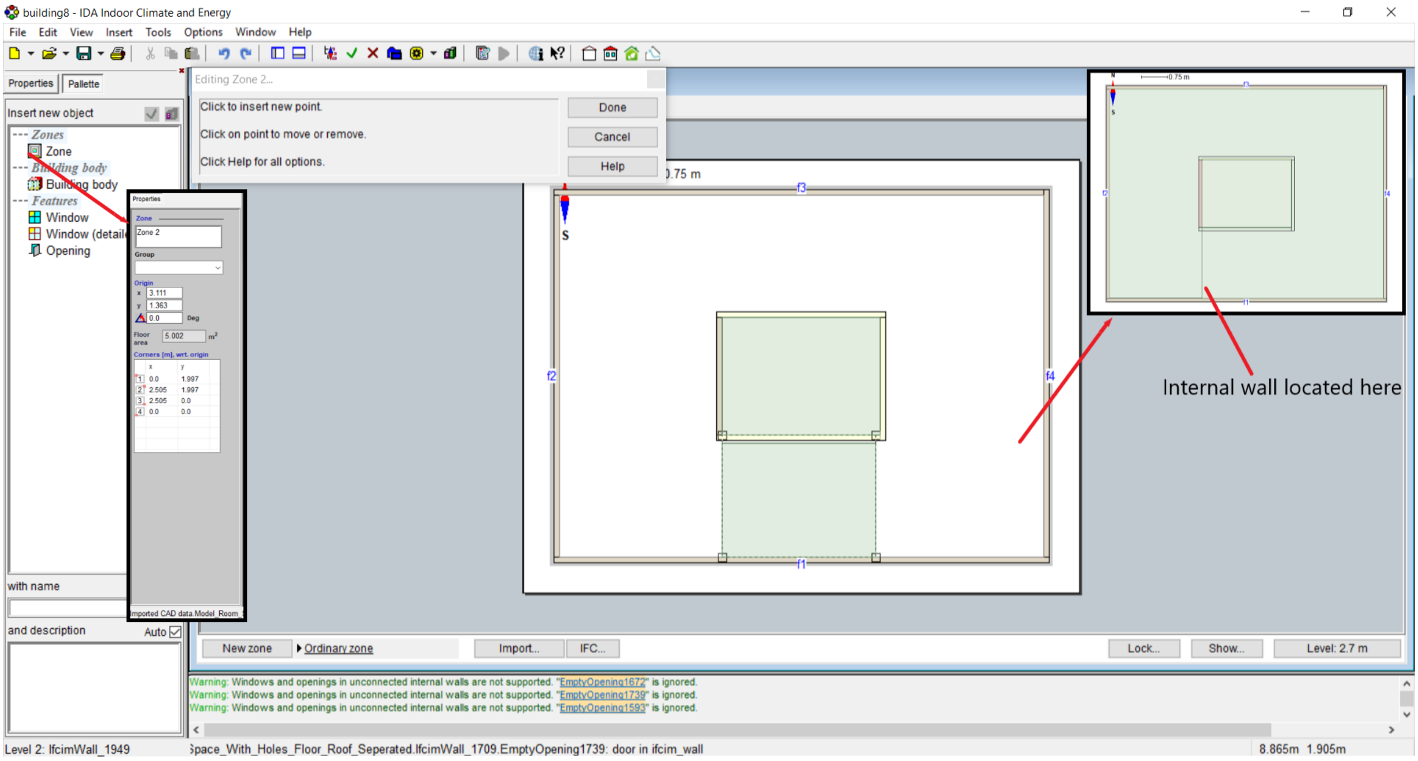


FIGURE 173: A SNAP SHOT OF IDA ICE SHOWING THE “ZONE” CREATION TOOL (MODIFICATIONS IN RED)

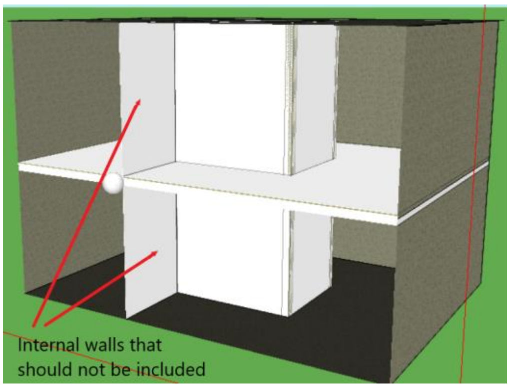


FIGURE 174: IDA ICE ENERGY MODEL – THE CREATION OF THE LARGER SURROUNDING ZONES AND THE BIPRODUCT OF INTERNAL WALLS THAT SHOULD NOT EXIST

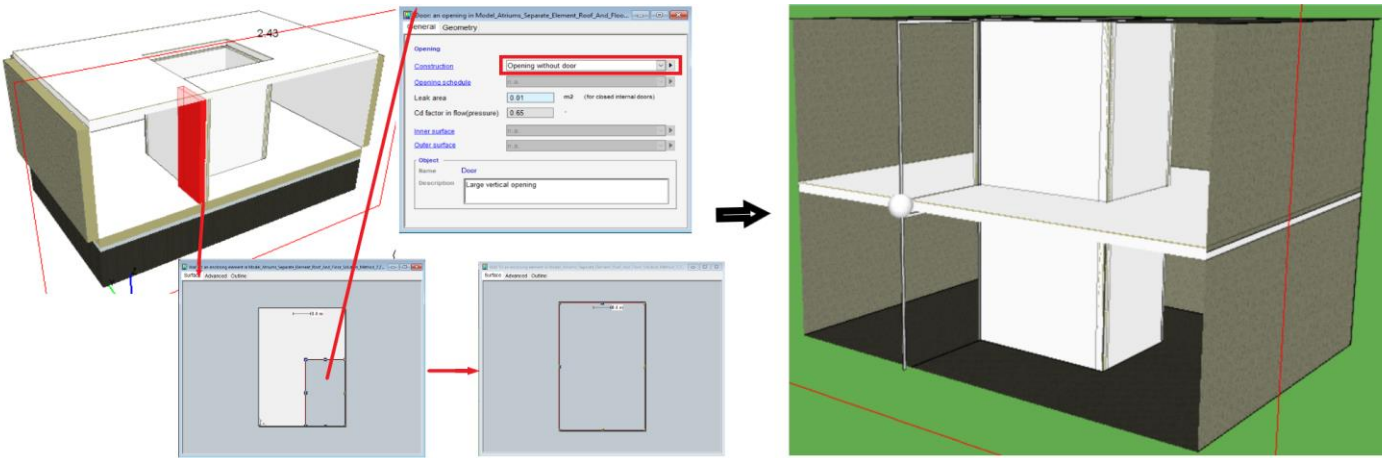


FIGURE 175: IDA ICE – THE PROCEDURE CREATING "OPENING WITHOUT DOOR" IN THE INTERNAL WALLS

The solution method is cumbersome, but no other solution has been found in either Revit, IDA ICE or SimpleBIM.

Case 18-19

Refer Suggested Solution Problem 10 of case 16-17 described above.

Case 20-22

Solution Method 1

The suggested solution for the current problem has been implemented in several of the cases related to this interoperability issue (case 23-27).

Since IDA ICE does not support a room/space defined in Revit with more than one height, such a room/space would have to be divided in two individual spaces, each consisting of only one height. Figure 176 is an example illustrating the solution.

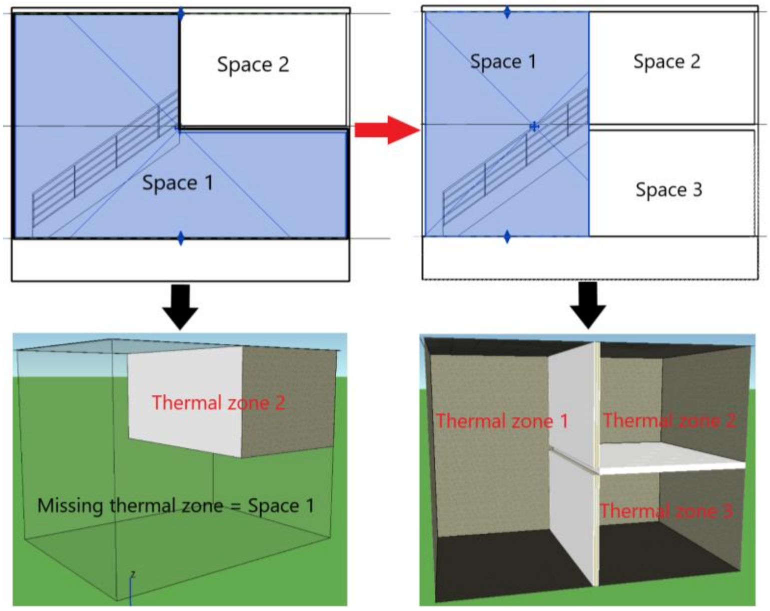


FIGURE 176: REVIT TO IDA ICE – THREE ROOMS/SPACES INSTEAD OF TWO ROOMS/SPACES – LEFT: CASE 20. RIGHT: CASE 23

Case 23, 24, 26

Solution Method 1

The suggested solution for the current problem has been implemented fully or partially in several of the cases related to this interoperability issue (case 21-22 and 24-27).

To have openings defined between thermal zones in a BIM-based energy model in IDA ICE, a wall with opening should be defined in Revit between room/space definitions. Refer the procedure for this described in Case 21. Figure 177 shows case 24 where this has been partially implemented. A wall with opening was created in Revit at the 2nd level and IDA ICE correctly interprets an opening between the thermal zones here. A room separation line was defined in Revit at the 1st level and thus IDA ICE incorrectly creates an internal wall here instead.

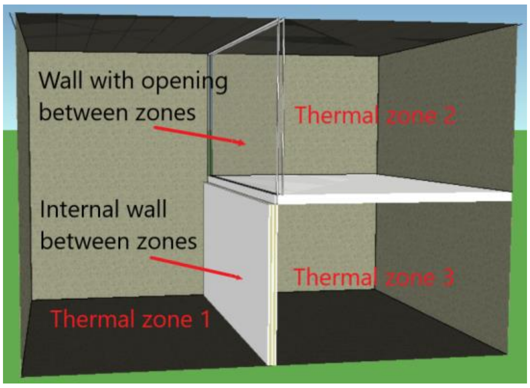


FIGURE 177: IDA ICE ENERGY MODEL – WALL WITH OPENING AND INTERNAL WALL BETWEEN THERMAL ZONES

Case 25, 27

No problem concerning the thermal view for these two cases. When dealing with a building model involving a mezzanine construction, follow Suggested Solution Problem 10 for case 20-22 and 23, 24 and 26. Figure 178 shows case 25 where these solutions has been fully implemented, generating an energy model with a thermal view complying with the Revit BIM model.

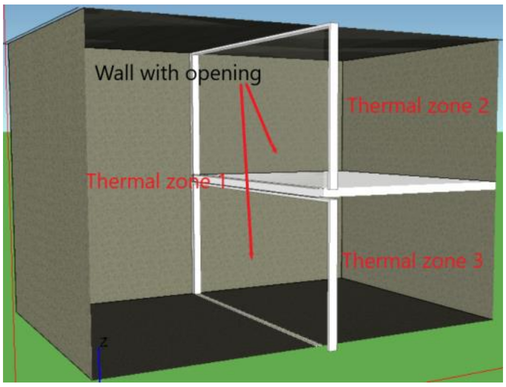


FIGURE 178: IDA ICE BIM-BASED ENERGY MODEL COMPLYING WITH THE REVIT BIM MODEL

Case 28

Case did not cause any misinterpretation of the energy model´s thermal view and thus requires no solution.

Case 29

No energy model, refer Problem 14 of the respective case.

Case 30

Case did not cause any misinterpretation of the energy model´s thermal view and thus no solution is provided.

Case 31

Problem solved otherwise, see Suggested Solution Problem 12 for the respective case.

Suggested Solution Problem 11

Case 1-6

No direct solution was found for the problem, but it led to other secondary problems which has been solved. Refer the suggested solutions for case 1-6 for the relevant secondary problems.

Case 10

No direct solution was found for the problem, but it led to other secondary problems which has been solved. Refer the suggested solutions for case 10 for the relevant secondary problems.

Suggested Solution Problem 12

Case 7-9

Solution Method 3

The solution involves the use of SimpleBIM to solve the problem with the transparent BIM IFC curtain wall elements being recognized as opaque construction elements in IDA ICE.

The procedure is described below and illustrated in Figure 179. The problem causing the error was an incorrect value for the property “Is Transparent” of the IFC object “Plate”, i.e. the curtain wall. The property of the object was edited in SimpleBIM. The original value for this property was set to <no value>, causing the object not to pass the validation check (indicated with a red sign). The value of the property was instead set to <Yes>. The edited IFC model was then exported as an IFC file by SimpleBIM before being imported into IDA ICE.

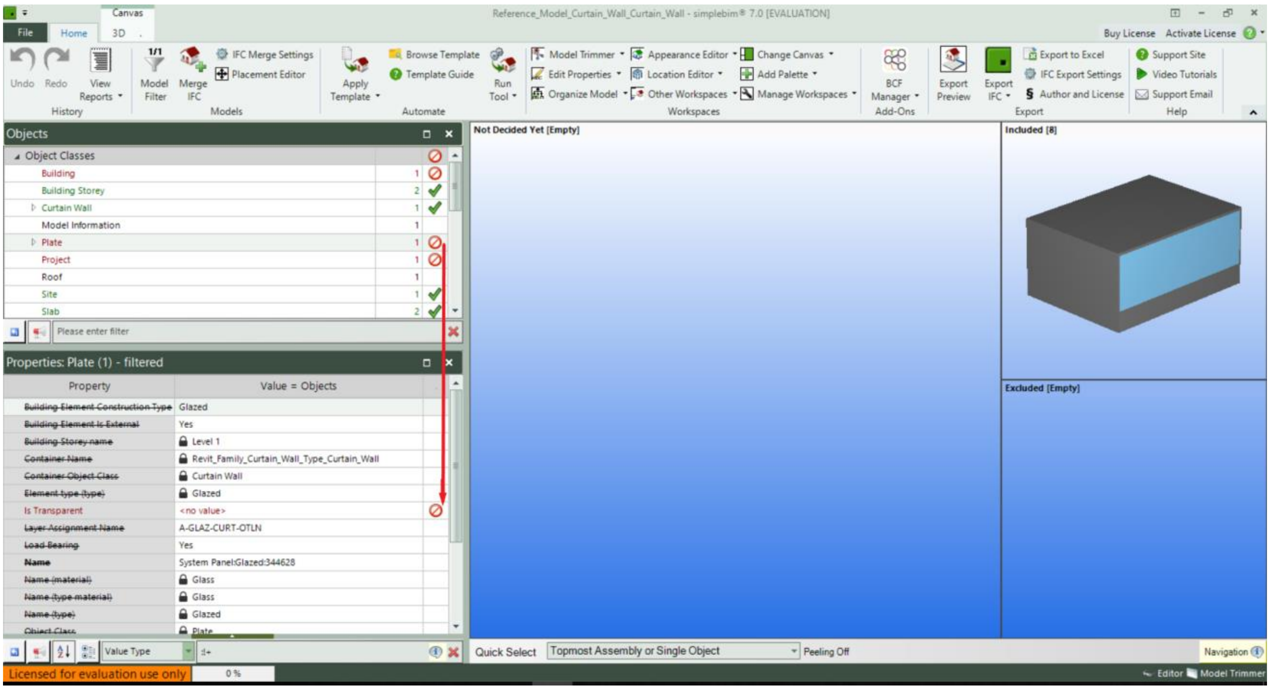


Figure 179: A snap shot of SimpleBIM showing the solution making the curtain walls transparent (modifications in red)

In IDA ICE the curtain wall, regardless of the Revit curtain wall "Type", was now recognized as both an IFC construction called "dummy_wall_style – 0 cm" and an IFC window called "Transparent plate", see Figure 180.

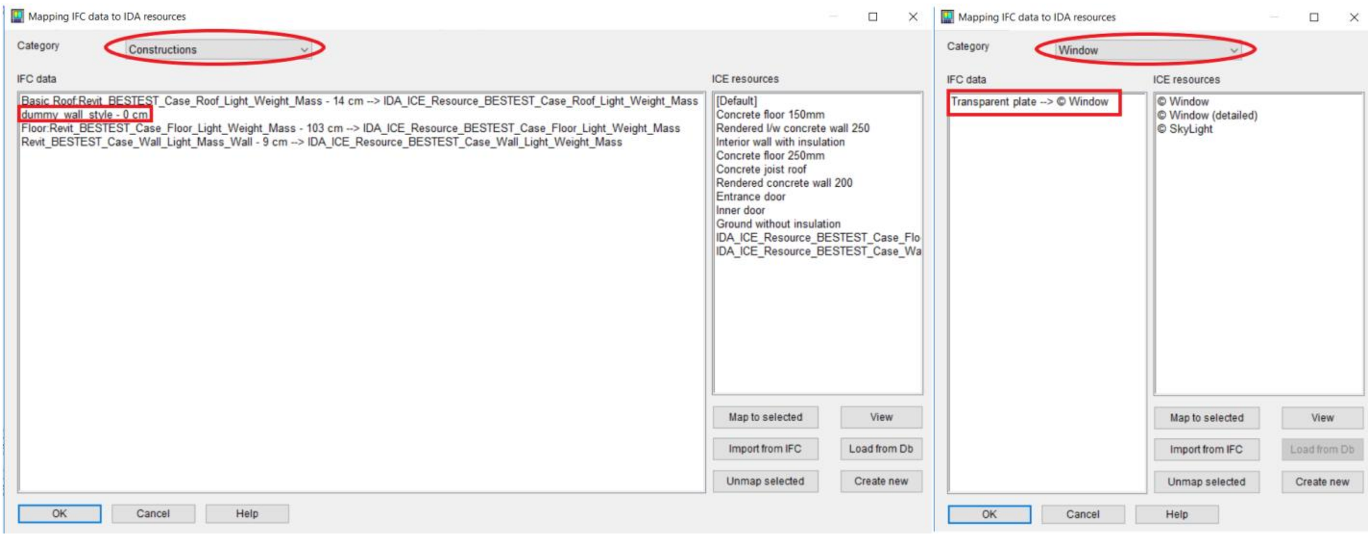


Figure 180: A snap shot showing the IDA ICE mapping function (modifications in red)

By mapping the "Transparent plate" to for example the IDA ICE resource "© Window", the transparent parts of the IFC curtain wall objects now became transparent. Figure 181, Figure 182 and Figure 183 shows the imported IFC model to the left and the energy model to the right for all three cases.

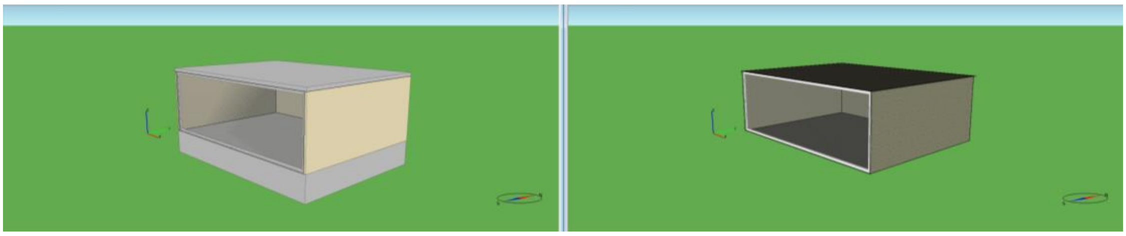


FIGURE 181: IDA ICE – CURTAIN WALL – TYPE: CURTAIN WALL – LEFT: IFC MODEL. RIGHT: ENERGY MODEL

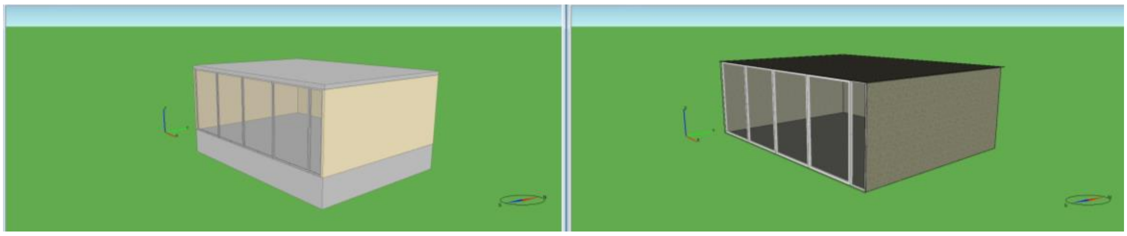


FIGURE 182: IDA ICE – CURTAIN WALL – TYPE: EXTERIOR GLAZING – LEFT: IFC MODEL. RIGHT: ENERGY MODEL

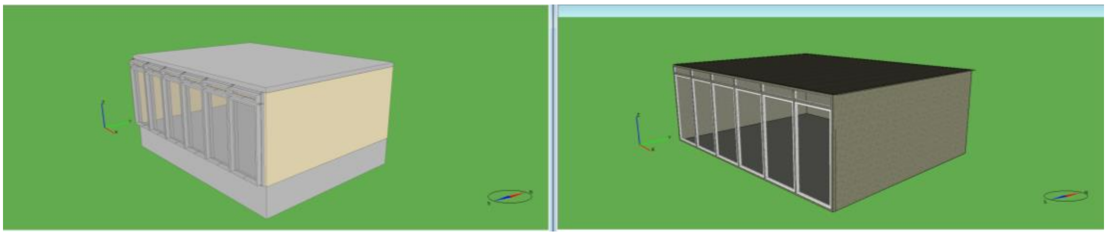


FIGURE 183: IDA ICE – CURTAIN WALL – TYPE: STOREFRONT – LEFT: IFC MODEL. RIGHT: ENERGY MODEL

In the figures above, it is seen that the curtain wall of case 7 consist of a single window, while the curtain wall of case 8 and 9 consist of several windows. These results correspond to the BIM models created in Revit. The reason why the energy model of case 8 and 9 consist of several windows is due to either the grid layout or mullions/bars separating the panes or glasses of the Revit BIM curtain wall structure.

A closer look at the curtain walls of case 8 and 9 reveals a few issues with these constructions in IDA ICE.

The curtain wall of case 8, see Figure 184, consists of 5 window constructions, where the frame of the windows would be equivalent to the vertical grid lines of the BIM curtain wall element (no mullions/bars were defined). Although it is possible to map the panes of the curtain wall to the desired IDA ICE window construction, the input values of “U-value” and “Fraction of the total window area” of the window frame is set to the default values as illustrated in the figure below. This cause the thermal insulation/thermal bridge of the window frames to be incorrect and hence the heat transmission loss through the frames to be wrong. These input values would have to be manually corrected in IDA ICE. The same apply for the frames of the window constructions in case 9.

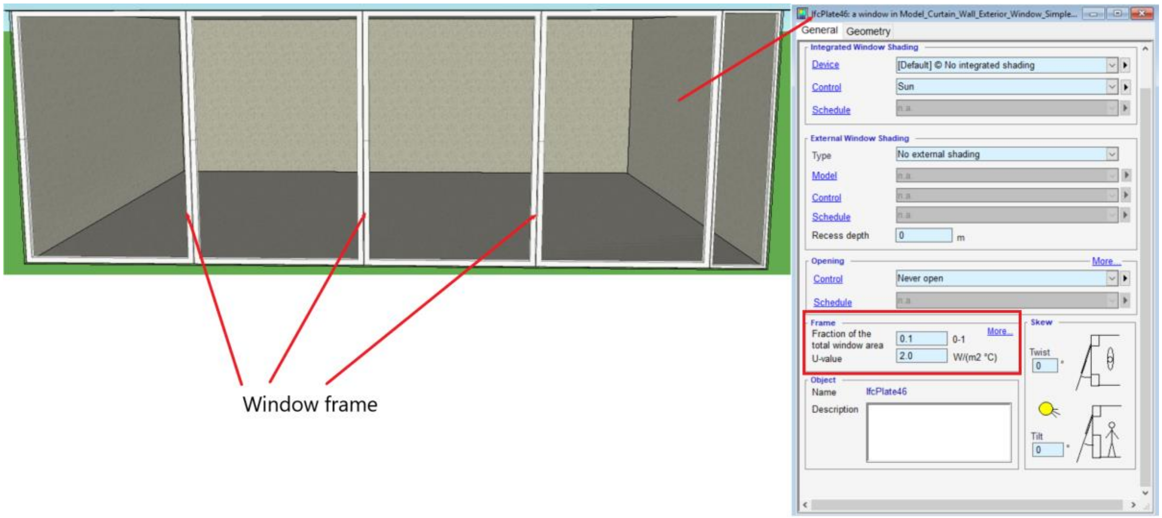


FIGURE 184: IDA ICE ENERGY MODEL – CURTAIN WALL – TYPE: EXTERIOR GLAZING – WINDOW PROPERTIES

Case 9 has an additional problem with small wall elements (mapped to the default external wall construction “[Default] Rendered l/w concrete wall 250”) created in place of the horizontal and vertical aluminum mullions of the curtain wall. These wall elements cause the thermal insulation and thus the heat transmission loss due to the mullions to be incorrect. The solution for solving this problem would be to select the curtain wall and manually edit the window constructions so that they fill the whole area of the wall. Then the properties “U-value” and “Fraction of the total window area” of the window frames could be edited for it to correspond to the properties of the mullions.

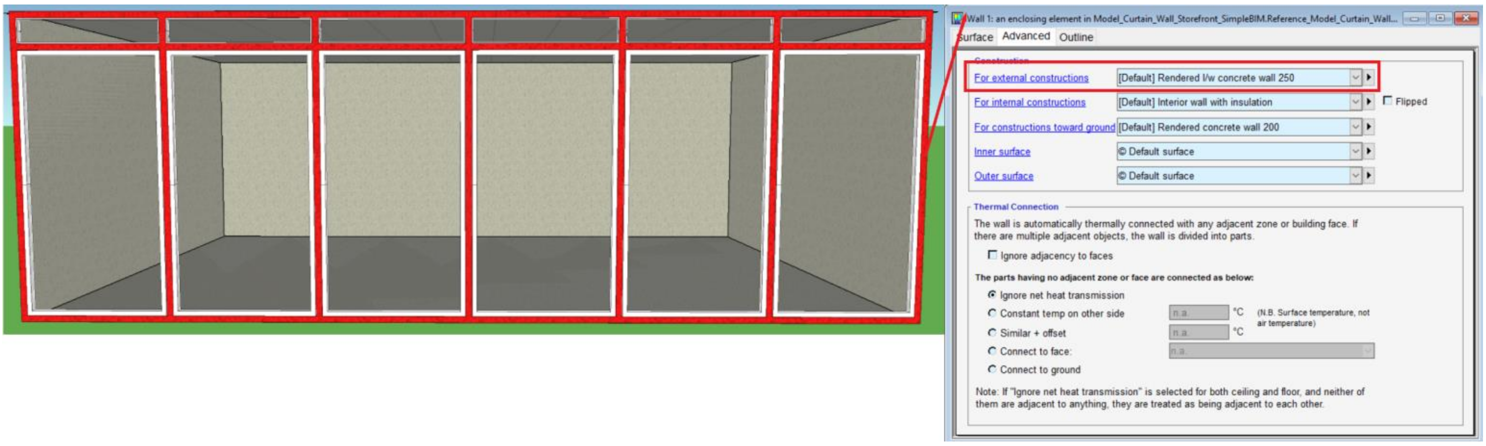


FIGURE 185: IDA ICE – CURTAIN WALL – TYPE: STOREFRONT – SMALL WALL ELEMENT STRIPES CREATED BETWEEN WINDOW CONSTRUCTIONS

Case 28

<u>Solution Method 2</u>

The solution solves the problem by manually editing the property of the flat surface wall elements in IDA ICE.

The wall surface elements having incorrect construction definition were edited as illustrated in Figure 186. The thermal connection of the elements was set to "Connect to face:" instead of the default value "Ignore net heat transmission". The configuration made all the wall elements as external constructions and the resulting energy model is seen in Figure 187.

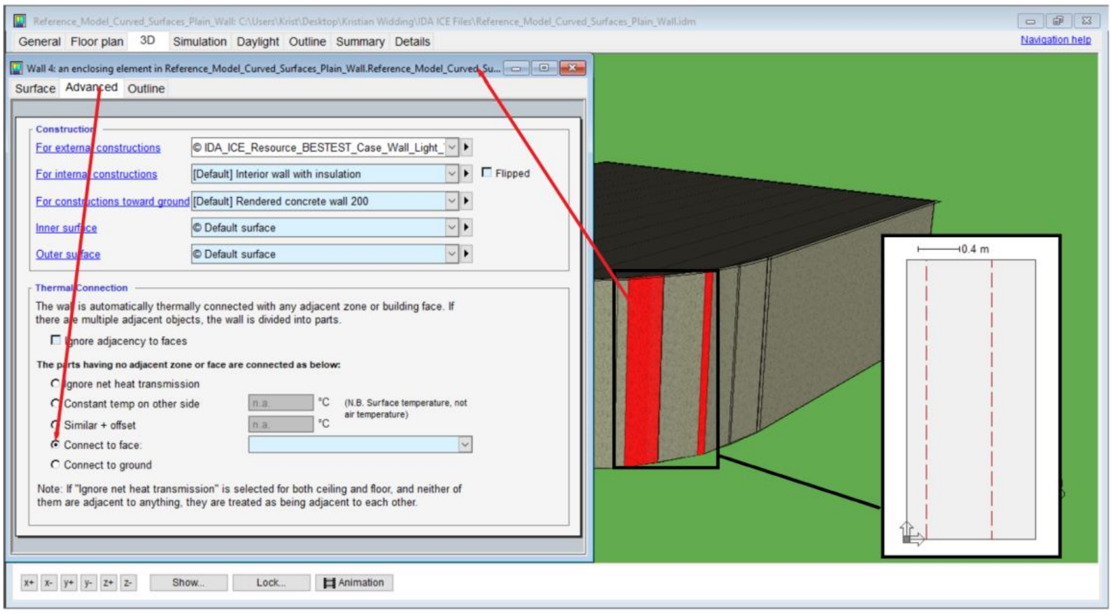


FIGURE 186: A SNAP SHOT OF IDA ICE SHOWING THE SOLUTION FOR CORRECTION THE WALL ELEMENTS WITH WRONG CONSTRUCTION DEFINITION (MODIFICATIONS IN RED)

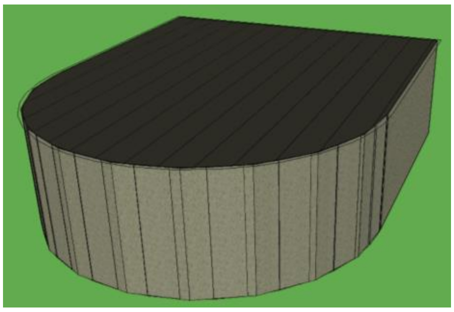


FIGURE 187: IDA ICE ENERGY MODEL – RESULT AFTER EDITING THE PROPERTY OF THE WALL ELEMENTS

Case 31

<u>Solution Method 2</u>

The proposed solution solves the problem by editing the roof of the building body at level 1, so that the building bodies at level 1 and level 2 do not overlap each other.

In the floor plan view of IDA ICE, enter the roof editor of the building body at level 1, see Figure 188. In the roof editor follow the procedure of Figure 189 to remove all unnecessary corners, i.e. keeping only the corners corresponding to the corners of the building. Now the resulting building bodies do not overlap each other anymore, refer Figure 190. The wall, floor and roof surfaces of the balcony are interpreted correctly as external surfaces, see Figure 191.

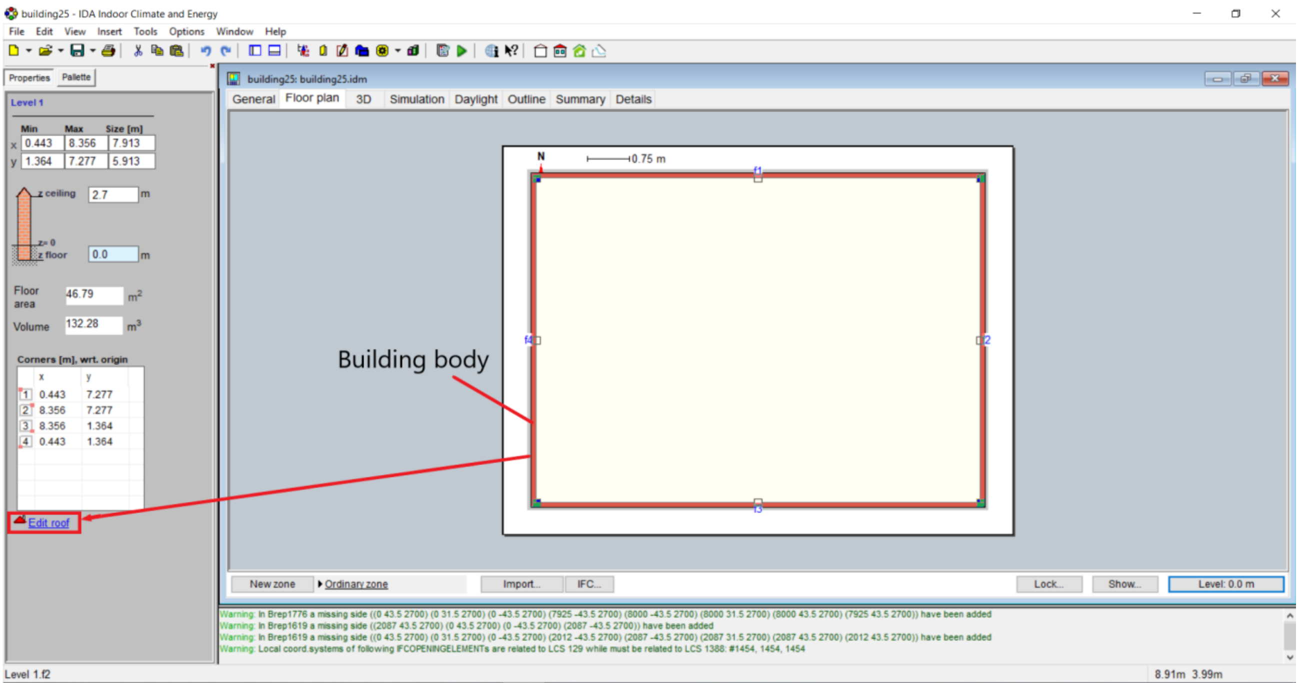


FIGURE 188: A SNAP SHOT OF IDA ICE SHOWING THE "EDIT ROOF" OPTION IN THE FLOOR PLAN VIEW (MODIFICATIONS IN RED)

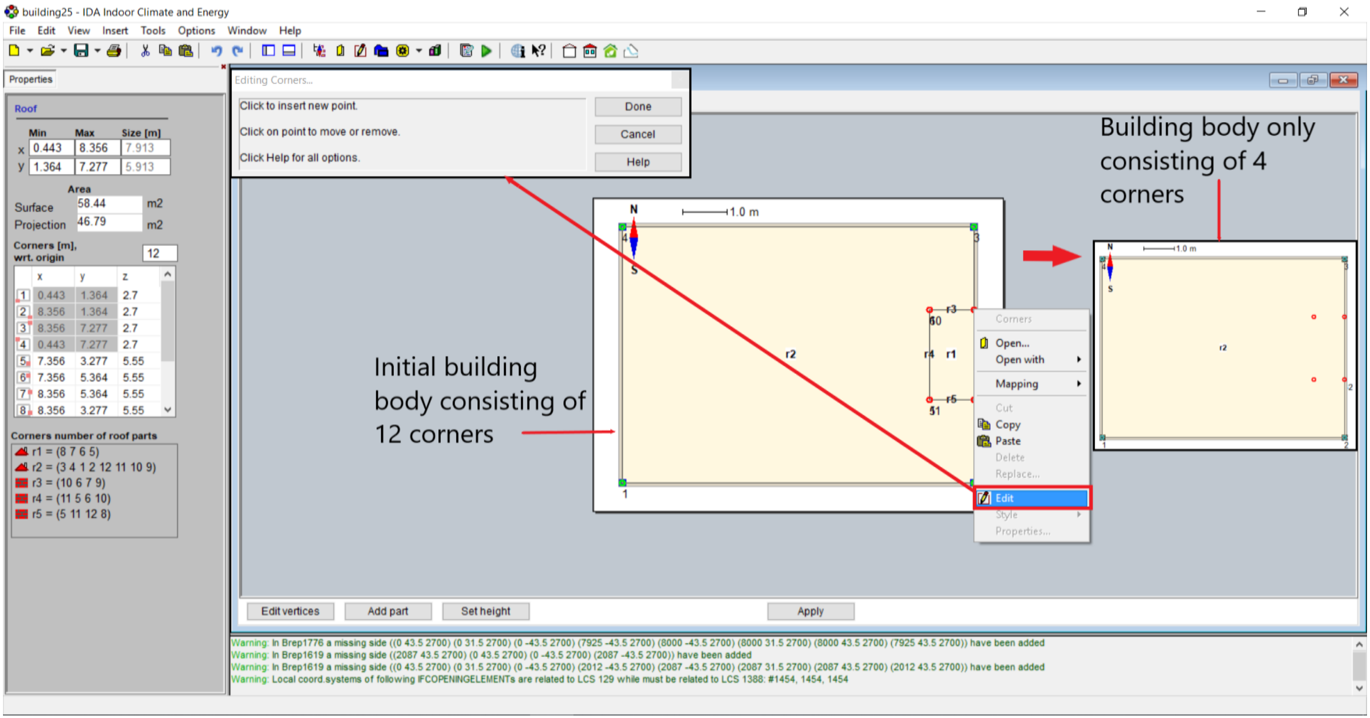


FIGURE 189: A SNAP SHOT OF IDA ICE SHOWING THE ROOF EDITOR (MODIFICATIONS IN RED)

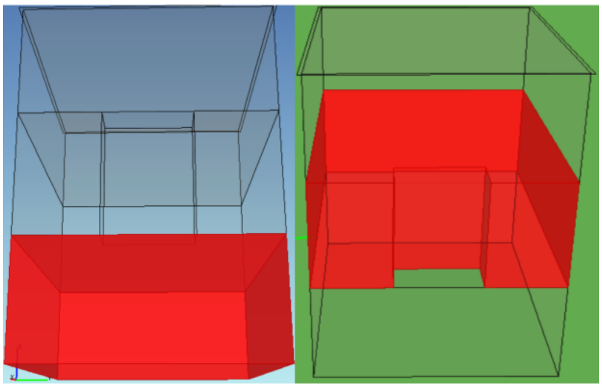


FIGURE 190: IDA ICE ENERGY MODEL – BUILDING BODIES 1ST AND 2ND LEVEL NOT OVERLAPPING EACH OTHER

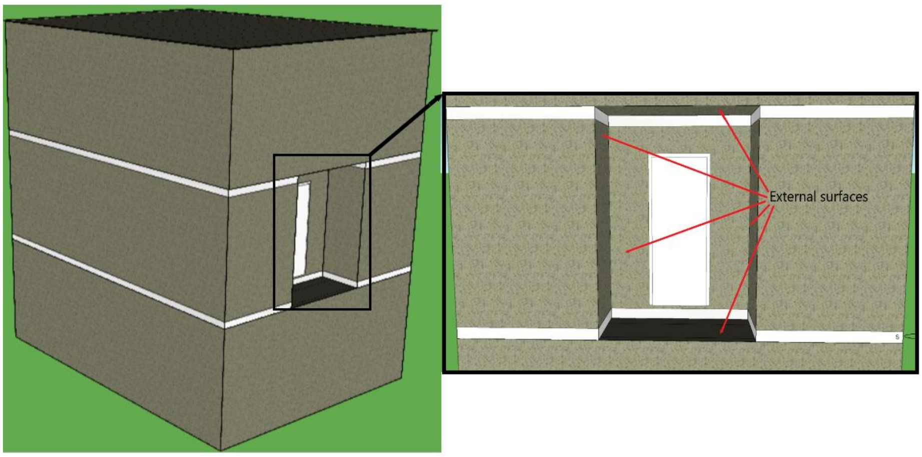


FIGURE 191: IDA ICE ENERGY MODEL – BALCONY WALL, FLOOR AND ROOF SURFACES INTERPRETED AS EXTERNAL ELEMENTS

Suggested Solution Problem 13

Case 28

N/A. Refer discussion in Problem 13 for the respective case.

Case 29

N/A. Refer discussion in Problem 13 of case 28.

Suggested Solution Problem 14

Case 29

No solution was found by any of the solution methods.

A suggested workaround solution could be to create the same BIM model without windows in Revit, import the BIM-based IFC model into IDA ICE and manually attach the window constructions to the flat surface wall elements in IDA ICE.

Chapter 5 Conclusion

The aim of this thesis has been to reduce the consultation cost in the AEC-industry related to BIM-based building energy modeling, with the intended impact to reduce the threshold utilizing BEM in early design phase and consequently stimulate for more effective design of high quality green buildings. This has been achieved through case studies investigating a selection of BIM-based BEM interoperability issues between the BIM design software Autodesk Revit and the BEM analysis software IDA ICE.

The thesis work began by introducing background information in chapter 2 on building information modeling (BIM), interoperability, building energy modeling (BEM), important energy and thermal concepts and definitions and the process of BIM-based BEM. Chapter 3 continued by describing the importance of the interoperability issues in regard of building energy and thermal performance, explaining potential problems that may occur for each issue, defining the cases of the study and explaining the Revit to IDA ICE exchange process. In chapter 4, the identified problems for the cases and suggested solutions to overcome the problems were presented and discussed.

The following are concluding remarks and reflections obtained from the case studies investigating the interoperability issues in the BIM to BEM data exchange between Autodesk Revit 2018 to IDA ICE version 4.8.

- Interoperability issue 1 (Case 1-6) showed that BIM IFC column objects is not supported by IDA ICE as a building element and hence is excluded in the energy model. This has several implications on the energy and thermal performance of the energy model. For all cases the thermal mass of the columns is neglected. This may be solved by implementing the equivalent in wall mass. Columns located near or in walls caused the mapping of constructions for some of the wall surface elements to be incorrect, leading to the thermal insulation of the walls to be wrong. This would have to be solved manually in IDA ICE. For columns located inside the building, the area and volume of the columns were ignored. This may influence the AHU supply/return air flow rate of zones, since these values can be dimensioned depending on the zone floor area. It can also affect the simulation output values as they often are stated in m^2 floor area. In respect to the zone area, this can be solved by manipulating the net floor area value of the zone in IDA ICE. The IFC column objects were possible to include as shading objects and thus their influence on solar heat gain/daylighting may be considered.
- In interoperability issue 2 (Case 7-9) it was revealed that transparent BIM-based IFC curtain wall elements were recognized as opaque wall elements mapped to the default wall construction in IDA ICE. Obviously the material properties of the wall construction do not correspond to the glazed panels of the curtain wall, resulting in the thermal insulation and thermal mass ability for the element to be wrong. The solar heat gain and utilization of daylight is completely ignored as well. A fix for this was executed in SimpleBIM by editing

the property controlling the transparency of the IFC curtain wall object. The solution had some minor issues though, causing the properties of the window frames not to reflect the properties of the curtain wall mullions.

- From interoperability issues 3 (case 10) it can be concluded that the BIM IFC object door is not supported by IDA ICE. The door was not available to be automatically mapped to the desired door construction, but rather was mapped to the same construction as the walls. This results in the thermal insulation and thermal mass ability for the door to be incorrect. In the case of a transparent door, the solar heat gain and utilization of daylight due to the door will also be ignored. To solve the problem the construction of the door would have to be manually edited in IDA ICE.
- In interoperability issue 4 (Case 11-13) it was shown that BIM-based parapet walls were excluded from the energy model. This implies that its mass is not taken into account, i.e. its effect on the roof/external wall thermal bridge and as thermal mass. Nonetheless, its contribution on thermal mass is assumed to be negligible and the heat gain/loss due to thermal bridges is managed in the thermal bridges option, independently on the geometry of the energy model. In regard of shading and hence the influence on solar heat gain and daylighting distribution, none of the cases caused any direct problem, although the approach of case 13 is recommended to follow.
- Interoperability issue 5 (Case 14-15) proved that the assembly of the external walls (as one element per story or one element extending over multiple stories) made no difference, resulting in the energy model´s thermal view to be correct either way. Consequently, it is not necessary to model external walls in accordance with the thermal view of the building model since IDA ICE correctly interprets the thermal view of the model regardless.
- Interoperability issue 6 (Case 16-19) revealed that IDA ICE did not manage to correctly interpret the model cases with an atrium space located inside the building, causing severe problems with the energy model´s thermal view. IDA ICE misinterpreted the atrium space to be intersecting the other spaces of the building, resulting in missing thermal zones. The resulting BEM model was not suitable for simulation and the problem had to be solved by extensive manual remodeling in IDA ICE.
- Interoperability issue 7 (Case 20-27) demonstrated two main issues. The first being IDA ICE not able to import BIM IFC spaces with more than one height defined, with the outcome of missing the corresponding thermal zone in the energy model. The solution to overcome the problem was simply to make sure all spaces was defined with only one height. The second problem was that IDA ICE by default creates internal walls between the border of zones, even though the spaces are open to each other in the BIM model. This will of course not depict the proper exchange of air/mass between the zones in IDA ICE. To solve the problem, a wall with an opening to separate the spaces must be created in Revit.
- Interoperability issue 8 (Case 28-29) showed that the building with the plain curved surface wall was translated into multiple segments of flat surface elements without problems. The difference in area/volume between the Revit

BIM model and the IDA ICE energy model was insignificant. However, the segmented wall elements were interpreted both as external and internal surface elements, resulting in the thermal insulation and thermal mass of the wall elements to be incorrect. The problem was solved in IDA ICE by manually editing the thermal connection of the walls. For the case involving a building with a curved surface wall hosting windows, the IFC import failed. The problem is likely IDA ICE not being able to deference the window constructions to the segmented wall elements. No solution was found for this problem, but one approach to bypass the issue would be to import the curved surface wall without windows and model the windows in IDA ICE afterwards. Based on the observed segmentation level of the wall, the potential solar heat gain and daylighting distribution for such a wall with windows should be sufficiently accurate.

- Interoperability issue 9 (Case 30-31) involved both roof overhang and balcony overhang due to a recess in the façade. The roof overhang was excluded from the energy model, with the same implications on energy/thermal impacts and solutions as discussed for the parapet walls of interoperability issue 4. The balcony overhang caused problems with the generated building bodies overlapping each other. This resulted in the balcony walls, roof and floor constructions to be misinterpreted as internal surfaces mapped to their respective internal constructions, causing the thermal insulation and thermal mass ability of these elements to be incorrectly. The problem was solved in IDA ICE by manually editing the building bodies before generating the energy model.

For any future work on the subject, several suggestions on extended research topics are given below.

- Investigation of more interoperability issues to get a better understanding of the possibilities and limitations regarding the BIM to BEM data exchange between Autodesk Revit and IDA ICE.
- Exploring alternative solutions for the problems of the investigated interoperability issues, which may provide easier and more effective solution methods dealing with the occurring problems.
- A more detailed investigation of the different IFC export and import options of Revit and IDA ICE, along with the IFC schema. This would give a better understanding on their impact on the data exchange and how they might be exploited in that respect.
- A study comparing the simulation results between the BIM-based BEM energy models integrated with the interoperability issues and corresponding energy models created directly in IDA ICE as the reference. This will help quantify the deviation in energy and thermal performance caused by the interoperability issues and may reveal the usability of the BIM-based BEM energy models in a more clearer sense.

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Appendix A: Autodesk Revit 2018 supported IFC classes

Table 22: Autodesk Revit 2018 supported IFC classes (Autodesk, 2017c)

IfcActuatorType	IfcAirTerminalBoxType	IfcAirTerminalType	IfcAirToAirHeatRecoveryType
IfcAlarmType	IfcAnnotation	IfcBeam	IfcBoilerType
IfcBuildingElementPart	IfcBuildingElementProxy	IfcBuildingStorey	IfcCableCarrierFittingType
IfcCableCarrierSegmentType	IfcCableSegmentType	IfcChillerType	IfcCoilType
IfcColumnType	IfcCompressorType	IfcCondenserType	IfcControllerType
IfcCooledBeamType	IfcCoolingTowerType	IfcCovering	IfcCurtainWall
IfcDamperType	IfcDistributionChamberElementType	IfcDistributionControlElement	IfcDistributionElement
IfcDistributionFlowElement	IfcDoorType	IfcDuctFittingType	IfcDuctSegmentType
IfcDuctSilencerType	IfcElectricApplianceType	IfcElectricFlowStorageDeviceType	IfcElectricGeneratorType
IfcElectricHeaterType	IfcElectricMotorType	IfcElectricTimeControlType	IfcElementAssembly
IfcEnergyConversionDevice	IfcEvaporativeCoolerType	IfcEvaporatorType	IfcFanType
IfcFastenerType	IfcFilterType	IfcFireSuppressionTerminalType	IfcFlowController
IfcFlowFitting	IfcFlowInstrumentType	IfcFlowMeterType	IfcFlowMovingDevice
IfcFlowSegment	IfcFlowStorageDevice	IfcFlowTerminal	IfcFlowTreatmentDevice
IfcFooting	IfcFurnishingElement	IfcFurnitureType	IfcGasTerminalType
IfcHeatExchangerType	IfcHumidifierType	IfcJunctionBoxType	IfcLampType
IfcLightFixtureType	IfcMechanicalFastenerType	IfcMemberType	IfcMotorConnectionType
IfcOpeningElement	IfcOutletType	IfcPile	IfcPipeFittingType
IfcPipeSegmentType	IfcPlateType	IfcProtectiveDeviceType	IfcPumpType
IfcRailing	IfcRamp	IfcReinforcingBar	IfcReinforcingMesh
IfcRoof	IfcSanitaryTerminalType	IfcSensorType	IfcSite
IfcSlab	IfcSpace	IfcSpaceHeaterType	IfcStackTerminalType
IfcStair	IfcSwitchingDeviceType	IfcSystemFurnitureElementType	IfcTankType
IfcTransformerType	IfcTransportElementType	IfcTubeBundleType	IfcUnitaryEquipmentType
IfcValveType	IfcWall	IfcWasteTerminalType	IfcWindowType

Appendix B: Description BESTEST Case 600 – Base Case Low Mass Building

Building Model Description

1.2.1 Case 600 – Base Case Low Mass Building

The basic test building (Figure 1) is a rectangular single zone (8 m wide x 6 m long x 2.7 m high) with no interior partitions and 12 m^2 of windows on the south exposure. The building is of lightweight construction with characteristics as described below. For further details refer to Section 5.2.1 of ANSI/ASHRAE Standard 140-2001.

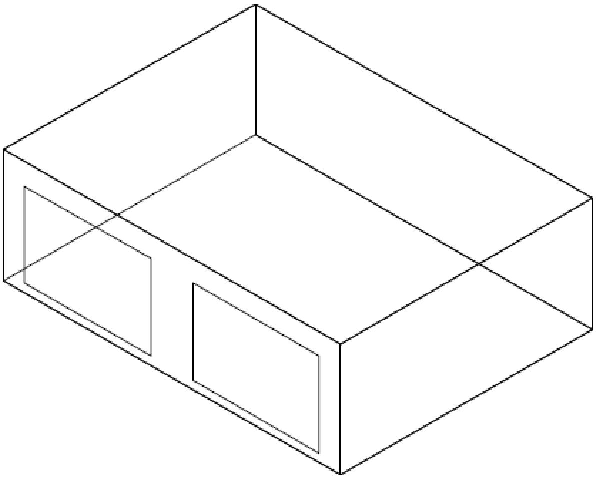

Figure 1 Base Building (Case 600) - Isometric View of Southeast Corner with Windows on South Wall

Wall Construction (light weight mass)

Element	k (W/m-K)	Thickness (m)	U (W/m^2-K)	R (m^2-K/W)	Density (kg/m^3)	Cp (J/kg-K)
Int. Surface Coeff.			8.290	0.121		
Plasterboard	0.160	0.012	13.333	0.075	950	840
Fiberglass Quilt	0.040	0.066	0.606	1.650	12	840
Wood Siding	0.140	0.009	15.556	0.064	530	900
Ext. Surface Coeff.			29.300	0.034		
Overall, air-to-air			0.514	1.944		

Testing with ANSI/ASHRAE Std. 140 3 June 2004

FIGURE 192: BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – DESCRIPTION PART 1 (HENNINGER AND WITTE, 2004)

Roof Construction (light weight mass)

Element	k (W/m-K)	Thickness (m)	U (W/m^2-K)	R (m^2-K/W)	Density (kg/m^3)	Cp (J/kg-K)
Int. Surface Coeff.			8.290	0.121		
Plasterboard	0.160	0.010	16.000	0.063	950	840
Fiberglass Quilt	0.040	0.1118	0.358	2.794	12	840
Roof Deck	0.140	0.019	7.368	0.136	530	900
Ext. Surface Coat			29.300	0.034		
Overall, air-to-air			0.318	3.147		

Floor Construction (light weight mass)

Element	k (W/m-K)	Thickness (m)	U (W/m^2-K)	R (m^2-K/W)	Density (kg/m^3)	Cp (J/kg-K)
Int. Surface Coeff.			8.290	0.121		
Timber Flooring	0.140	0.025	5.600	0.179	650	1200
Insulation	0.040	1.003	0.040	25.075		
Overall, air-to-air			0.039	25.374		

Window Properties

Extinction coefficient	0.0196/mm
Number of panes	2
Pane thickness	3.175 mm
Air-gap thickness	13 mm
Index of refraction	1.526
Normal direct-beam transmittance through one pane	0.86156
Thermal Conductivity of glass	1.06 W/mK
Conductance of each glass pane	333 W/m^2K
Combined radiative and convective coefficient of air gap	6.297 W/ m^2K
Exterior combined surface coefficient	21.00 W/ m^2K
Interior combined surface coefficient	8.29 W/ m^2K
U-value from interior air to ambient air	3.0 W/ m^2K
Hemispherical infrared emittance of ordinary uncoated glass	0.9
Density of glass	2500 kg/m^3
Specific heat of glass	750 J/kgK
Interior shade devices	None
Double-pane shading coefficient at normal incidence	0.907
Double-pane solar heat gain coefficient at normal incidence	0.789

FIGURE 193: BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – DESCRIPTION PART 2 (HENNINGER AND WITTE, 2004)

There is 0.2 m of wall below the window and 0.5 m of wall above the window.

Windows are described in EnergyPlus using the Windows 5 format. Additional glass properties are required for the front side and back side. In consultation with F. Winkelmann of LBNL, it was recommended that the window described above for the ANSI/ASHRAE Standard 140-2001 test be modeled as follows in EnergyPlus:

MATERIAL:WINDOWGLASS,

Glass Type 1,	!A1 [NAME] BESTEST CLEAR 1/8 IN
SpectralAverage,	!A2 [Optical data type {SpectralAverage or Spectral}]
,	!A3 [Name of spectral data set when Optical Data Type = Spectral]. MATERIAL:WINDOWGLASS, BESTEST CLEAR 1/8 IN
0.003175,	!N1 [Thickness {m}] 1/8"
0.86156,	!N2 [Solar transmittance at normal incidence]
0.07846,	!N3 [Solar reflectance at normal incidence: front side, calc from n=1.526, Tsol=.86156]
0.07846,	!N4 [Solar reflectance at normal incidence: back side]
0.91325,	!N5 [Visible transmittance at normal incidence, scaled from Window4 ID=1]
0.08200,	!N6 [Visible reflectance at normal incidence: front side, based on Window4 ID=14]
0.08200,	!N7 [Visible reflectance at normal incidence: back side]
0.0,	!N8 [IR transmittance at normal incidence]
0.84,	!N9 [IR emittance: front side]
0.84,	!N10 [IR emittance: back side]
1.06;	!N11 [Conductivity {W/m-K}]

MATERIAL:WINDOWGAS,

Air Space Resistance,	!A1 [Name] BESTEST AIR GAP 1/2 IN
AIR,	!A2 [Gas type (Air - Argon - Krypton - Xenon - SF6 - Custom)]
0.013;	!N1 [Gap width {m}] 1/2 inch

CONSTRUCTION, BESTEST DOUBLE PANE, ! Material layer names follow:

Glass Type 1,

Air Space Resistance,

Glass Type 1;

FIGURE 194: BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – DESCRIPTION PART 3 (HENNINGER AND WITTE, 2004)

Infiltration: 0.5 air change/hour

Internal Load: 200 W continuous, 60% radiative, 40% convective, 100% sensible

Mechanical System: 100% convective air system, 100% efficient with no duct losses and no capacity limitation, no latent heat extraction, non-proportional-type dual setpoint thermostat with deadband, heating <20°C, cooling >27°C

Soil Temperature: 10C continuous

FIGURE 195: BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – DESCRIPTION PART 4 (HENNINGER AND WITTE, 2004)

Revit BIM Model Description and Illustration

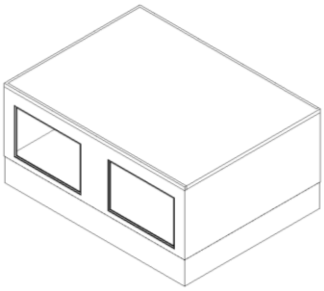

FIGURE 196: REVIT BIM MODEL – BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – 3D VIEW

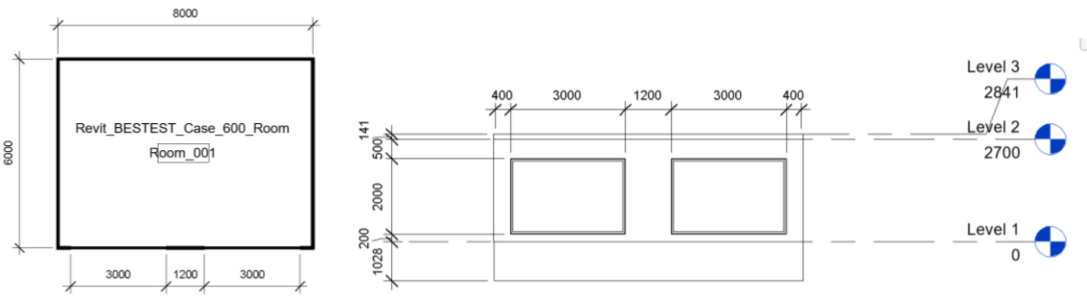

FIGURE 197: REVIT BIM MODEL – BESTEST CASE 600 – BASE CASE LOW MASS BUILDING – LEFT: FLOOR PLAN VIEW. RIGHT: SOUTH ELEVATION VIEW