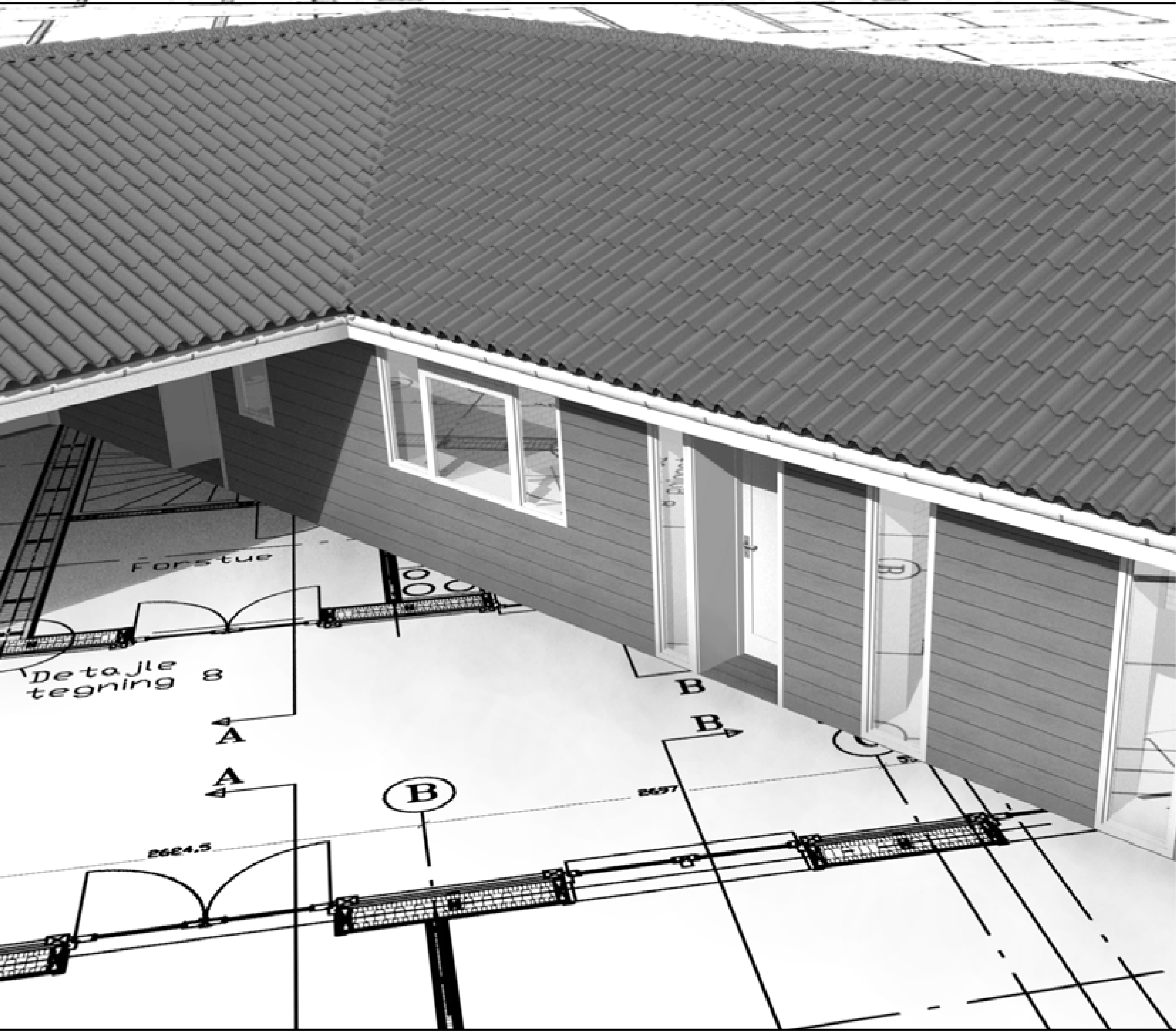
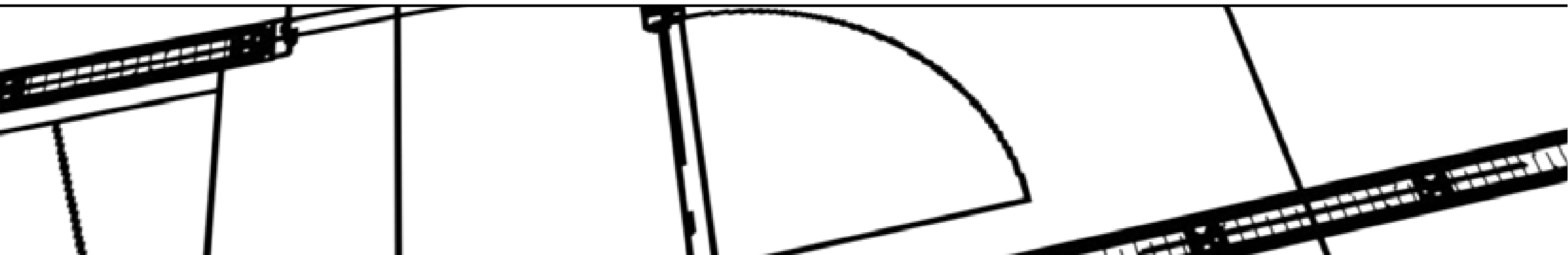
Master Thesis, September 2010



Rune Andersen

Building Information Modelling used in planning of energy retrofitting of buildings

-By developing an integrated design proces method and a IFC-import capacity for WinDesign



Title sheet

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Preface

The current thesis is the final part of the Master of Science program in Civil Engineering (MSc). It is performed at the Technical University of Denmark (DTU) at the Department of Civil Engineering, Building Services (BYG-DTU).

The project period started the 9th of April 2010 and ended with submission the 30th of September 2010. The study attainment and performance of the project correspond to 30-ECTS points.

The thesis has a cross-disciplinary structure where Building Energy and Building Information Modelling (BIM) are combined. It is based on the European research project *Interreg IV*, ”*Integration between Sustainable Construction Processes*”, which includes the aim of developing new methods and tools supporting integrated design and the utility of BIM in retrofitting projects.

A compact disc (CD) is enclosed and contains all the files which have been developed in relation to the thesis. Whenever the thesis refers to a file which are attached on the CD, its name and folder are described.

The author of this thesis would like to thank all who have participated with help and guidance.

Thanks to my supervisors from the Department of Civil Engineering, Building Services (BYG-DTU), Svend Svendsen, Jan Karlshøj, and Lies Vanhoutteghem.

A special thanks is expressed to Maja Asaa, Thomas Hejnfelt, and Daniel Reinert from Grontmij | Carl Bro. They have commented on the project findings on monthly meetings and contributed with knowledge from their own experiences assuring the relevance of the project to the building industry.

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Rune Andersen Date

Abstract

The current report is performed as a Master Thesis at the Technical University of Denmark. It examines the potential of Building Information Modelling (BIM) and integrated design when planning energy retrofitting of buildings. The hypothesis, *"when planning a retrofitting project, optimization of energy performance and indoor environment can be improved by using BIM and integrated design in the early design phases"*, is demonstrated by solving the three main parts:

I. Design process method

A design process method was developed in order to structure and utilize BIM in the early design phases of energy retrofitting projects. Information Delivery Manuals (IDM) was found to be an optimal method for this matter, and the specific IDM developed for the current design process method was referred to as Information Delivery Manual on Energy Retrofitting (IDMoER). It was developed for three specific applications; ArchiCAD, WinDesign, and Visualizer. Required information for the design process method was stated and input data for the applications were indentified.

II. Data transfer

Data transfer between ArchiCAD, WinDesign, and Visualizer are within IDMoER performed as a digital process. Until now, WinDesign has not had the capacity to import IFC-files. Such capacity has been developed, which allows WinDesign to act within the BIM-process. It was found that the validity of the IFC-capacity for WinDesign is within an acceptable level, and this allows it to be used in the early design phases. However, further improvements are needed for using the tool in practice.

III. Case studies

The usability of IDMoER and the IFC-capacity of WinDesign was tested in two case studies; a single family type house and a simple office building. Due to limitations of WinDesign, It was found that IDMoER was most applicable for small buildings. Within the two case studies, it was shown that the energy consumption could be reduced by 45% and 53%, respectively, while still having an optimal indoor environment.

In general, the findings of the currents thesis suggest that IDMoER is a useful method for integrating BIM in the early design phases of an energy retrofitting process, and along with WinDesign and Visualizer it ensures an optimal basis for decision on a further design development. However, even though the possibilities are many, there are still many things to consider and improve in relation to implementing BIM strategies in the AEC industry.

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I. Design process method

II. Data tranfer

III. Case studies

List of abbreviations

Abbreviation	Meaning	Description
AEC	Architecture, Engineering, and Construction	Used when referring to the whole industry which are surrounding building construction projects.
BIM	Building Information Modelling/Model	Method of generating and administrating building data.
CAD	Computer Aided Design	The use of computer technology for the design of objects.
CD	Compact Disc	Unit for storing of data
CS	Cooling Season	Describes in days the length of the cooling season
DDSS	Design Decision Support Systems	Tools to support the decision-making within the design process of a building construction project.
DF	Daylight Factor	Factor which is used to express the level of daylight in a reference point in a building.
DRY	Danish Reference Year	Reference year based on data for direct normal solar, diffuse, and global radiance on horizontal surface, outdoor temperature, and other weather data.
DTU	Technical University of Denmark	Technical University which educates Bachelors and Masters in engineering.
EEDDSS	Environmental Design Decision Support Systems	Tools with special focus on energy and environmental aspects to support the decision-making within the design process of a building construction project.
ESCO	Energy Service Company	Public-private business strategy related to energy retrofitting of buildings.
HVAC	Heating, Ventilation, and Air Conditioning	Used to define a certain part of the building construction process considering Heating, Ventilation and Air Conditioning.
HS	Heating Season	Describes in days the length of the heating season
IDM	Information Delivery Manual	Method that aims to describe and identify the processes undertaken within building construction projects and the information required for their execution in relation to the usability of BIM.
IDMoER	Information Delivery Manual on Energy Retrofitting	Design process method using IDM on energy retrofitting projects. ArchiCAD is used to create a Building Information Model (BIM) and WinDesign and Visualizer are used as tools to analyze issues related to energy and indoor environment.

IESVE	Integrated Environment Solutions Virtual Environment	Portfolio of simulation tools for analysis and development of design solutions.
IFC	Industry Foundation Classes	Open file format developed for the purpose of sharing information in the Building sector.
ISO	International Standards Organization	An international organisation which develops standardification. Composed of representatives from various nations.
kWh	Kilo Watt Hour	Unit of energy
SBi	Statens Byggeforsknings-institut	Building Research Institute. Part of the University of Aalborg and financed by the state.
SSC	Solar Shading Coefficient	Affectivity of a solar shading. It is given as the ration between the total solar energy transmittance of the window combined with the shading device and the total solar transmittance of the window alone.
STEP	STandard for the Exchange of Product model data	ISO standard for the computer-interpretable representation and exchange of product manufacturing information
VBA	Visual Basic for Applications	Event-driven programming language developed by Microsoft. Used in the Microsoft application Visual Basic.

Symbols and Notations

Symbol	Description	Unit
A_{floor}	Floor area	[m^2]
$A_{w,i}$	Window area	[m^2]
$A_{sol,i,HS/CS}$	Effective collecting area of the window with a given orientation and tilt angle for the heating/cooling season	[m^2]
E	Level of light	[LUX]
E_{ref}	Total energy performance of windows	[kWh/m^2]
E_{Vent}	Energy consumption for ventilation system	[kWh/m^2]
$E_{windows}$	Energy consumption for the windows	[kWh/m^2]
$f_{H,m}$	Fraction of the month that is a part of the heating season	[-]
$F_{sh,ob,i,HS/CS}$	Shading reduction factor due to external obstacles for the window during the heating/cooling season	[-]
g	Solar heat gain coefficient	[-]
$G_{HS/CS}$	Number of degree-hours during the heating/cooling season calculated for a reference indoor temperature of 20°C/26°C	[°C]
$I_{sol,i,HS/CS}$	Total incident solar radiation per m^2 of the window area, with a given orientation and tilt angle, over the heating/cooling season	[kWh/m^2]
l	Lenght	[m]
L_{HS}	Actual length of the heating season	[Days]
n	Design value for the number of the persons in the room	[-]
q_b	Ventilation rate for emissions from building	[$l/s, m^2$]
q_{inf}	Infiltration rate for normal buildings	[$l/s, m^2$]
q_p	Ventilation rate for occupancy per person	[l/s, pers.]
q_{tot}	Total ventilation rate of the room	[l/s]
q_v	Ventilation rate	[$l/s, m^2$]
$Q_{C,nd}$	Monthly energy need for cooling	[MJ]
$Q_{H,nd}$	Monthly energy need for heating	[MJ]
$Q_{H/C,ht}$	Heat transfer by transmission and ventilation, heating/cooling season	[kWh]
$Q_{H/C,gn}$	Total heat gains including solar gains and internal gains, heating/cooling season	[kWh]
$Q_{V,pre\text{-}heat}$	Energy need for pre-heating of ventilation air	[MJ]
$Q_{V,pre\text{-}cool}$	Energy need for pre-cooling of ventilation air	[MJ]
SEL	The specific energy consumption	[W/(L/S)]
T_d	Hours per week where the ventilation system is active	[hours]
U	Heat transfer coefficient	[W/m^2K]
UA	Product of u-value and the area which belongs to it	[W/K]
$\eta_{HS,gn}$	Utilization factor for solar gains, heating season	[-]
$\eta_{CS,ls}$	Utilization factor for heat loss, cooling season	[-]
Ψ	linear heat loss coefficients	[W/m^2K]

1. Introduction

The overall structure of the current thesis is illustrated below.

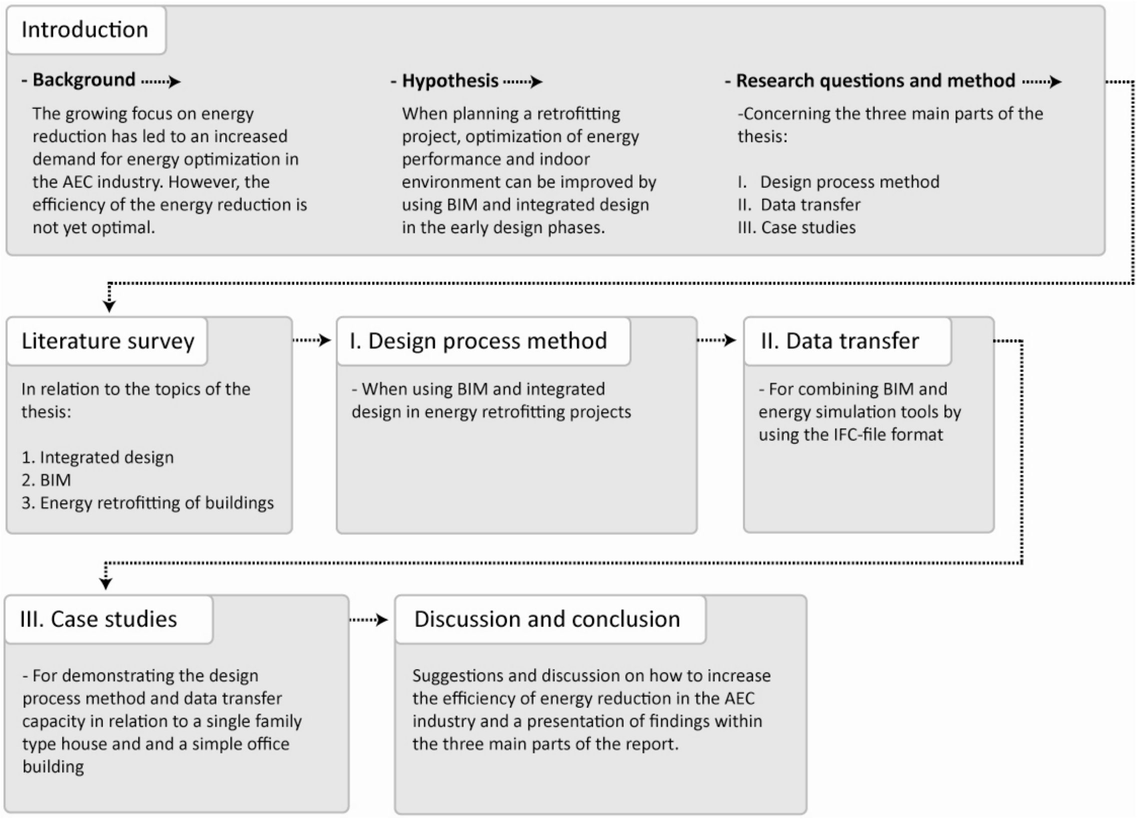


Figure 1 An illustration presenting the structure of the current thesis. AEC: Architectural, Engineering, and Construction. BIM: Building Information Modelling. IFC: Industry Foundation Classes.

1.1. Background

The existing building stock in the European Union is responsible for around 40% of the total energy consumption in the region [10, 61]. In a long term perspective, the Danish government[1] has a vision of being 100% independent of fossil fuels. Therefore, great attention needs to be pointed at not only new buildings, but also the energy consumption of the existing building stock [63].

Only large retrofitting projects are currently subjected to the Danish building regulations from 2008 [21]. However, it is expected that modifications of the building law regarding smaller retrofitting projects will take effect the 1st of January 2011 [35]. In addition, within 2011 the state of Denmark is with reference to the Danish Energy Agency imposed to reduce its energy consumption with 10% compared to 2006. The completion of the energy reduction shall be performed with public transparency and encourage a conscious energy behaviour [17].

[1] At the time of writing, the Danish government consist of two right-wing parties (*Venstre* and *Det Konservative Folkeparti)*

The new vision and tightened energy demands for buildings have led to an increased demand for energy optimization of the Architecture, Engineering, and Construction (AEC) industry. However, recent investigations have documented that the efficiency of the AEC industry still develops slowly and is low compared to other sectors [16]. New methods to support the processes within the AEC industry are therefore needed, and two suggestions can be the use of integrated design and BIM.

Integrated design is a method which, due to the new sustainability tendencies in the AEC industry, has evolved in the recent years. This method utilizes the strength of multidisciplinary design consultancies to optimize the building design and reduce its energy consumption [66]. Previous experiences of using the integrated design method in building construction projects show a relative potential reduction of the energy consumption by 60 to 70 percent compared to a traditional building project [46].

Building Information Modelling (BIM) is a method that focuses on generating and administrating building data [65]. In the year of 2003, the Danish government launched a new political plan of action called *Staten som bygherre – Vækst og effektivisering i byggeriet*[2] [19]. The goal was to increase the focus on how to optimize the AEC industry. The political initiative resulted in a project called *"The Digital Construction"* with the purpose of improving the interdisciplinary use of digital information within the industry. The use of BIM created the foundation of the project, and it is the main method for handling and generating digital data. As a result of this project, the Danish government demanded that all governmental clients should make use of digital applications in their building projects, starting from the beginning of 2007. It was further demanded that the file format, Industry Foundation Classes (IFC), should be used to communicate between the different applications [20].

The economical potential of using digital data in the AEC industry is significant. The report *"Digital forvaltning af bygninger fra vugge til grav"* from 2009, argues that digitalization can generate an economical potential of 17 billion DKK / year in Denmark [11]. In accordance, another research study from the National Institute of Building Sciences in the United States argues that digitalization in the AEC industry may result in savings in the range of 15.8 billion USD / year in USA [44].

1.2. Hypothesis

As stated in part 1.1, there is a large potential for energy savings present in the existing building stock, and it may be reduced by utilizing the methods of BIM and integrated design including energy simulation tools. This leads to the following hypothesis:

When planning a retrofitting project, optimization of energy performance and indoor environment can be improved by using BIM and integrated design in the early design phases.

A building construction process usually involves a wide variety of areas within the AEC industry, but as delimited in the hypothesis, the thesis focuses on to issues related to energy and indoor environment. To demonstrate the hypothesis, the thesis presents the following three main parts:

[2] Translated to English: *The state as client – Growth and efficiency improvement in the building industry*

I. Development of a ***design process method*** by using BIM and integrated design in energy retrofitting projects
II. Development of ***data transfer*** potentials by IFC
III. Testing of the design process method and IFC-data transfer in two ***case studies***

Before these parts are presented, a literature survey investigates essential issues regarding BIM, integrated design, and energy retrofitting of buildings.

1.3. Research method

1.3.1. Research questions

The following research questions are raised in relation to the three main parts of the thesis:

I. Development of a ***design process method*** by using BIM and integrated design in energy retrofitting projects:

1. Which informations are required to perform the design optimization?
2. Which activities should be performed in the design process and how can they be structured in order to utilize the potential of BIM and integrated design?

II. Development of ***data transfer*** potentials by IFC:

1. How is a BIM-model developed that can support the design process method by exporting IFC-files?
2. How is the IFC-data used to support the analysis of energy consumption and the indoor environment within the design process method?

III. Testing of the design process method and the IFC data transfer in two ***case studies***:

1. How does the design process method perform in relation to energy retrofitting of a single family type house?
2. How does the design process method perform in relation to energy retrofitting of a simple office building?

1.3.2. Research sources

- Materials

The research material includes a variety of literature which is differentiated in the following groups:

- Standards for evaluation of energy calculations and indoor environment
- Project-based articles
- Evidence-based articles
- Building laws
- Academic dissertations and Guidelines
- Manuals

Literature which may have a conflict of interests in relation to economical or other benefits has been excluded from the study.

- Project consultants

Scientists from the Technical University of Denmark (DTU) and the consultant company Grontmij|Carl Bro[3] are included as research sources. To assure triangulation and to increase relevance and usability of the project to the building industry, both groups have continuously evaluated and verified the project.

Scientists from the Technical University of Denmark (DTU):

- Svend Svendsen, Professor, DTU, Department of civil engineering
- Jan Karlshøj, Associated professor, DTU, Department of civil engineering
- Lies Vanhoutteghem, PhD-student, DTU, Department of civil engineering

Grontmij|Carl Bro:

- Daniel Reinert, Grontmij | Carl Bro, Energy specialist, Master of Engineering
- Thomas Hejnfelt, Grontmij | Carl Bro, BIM-specialist, Master of Engineering
- Maja Asaa, Grontmij | Carl Bro, Team manager, Designer mDD

1.3.3. Methods for the main parts; I.-III.

I. Development of a *design process method* by using BIM and integrated design in energy retrofitting projects

The design process method is developed for a multidisciplinary design consultancy, and therefore several consultants should ideally be involved in the process. However, in the current thesis the design process method is limited to focus on optimization of the energy consumption and indoor environment. Evaluations on stability, cost, and architecture will be presented as well, because these areas are considered to be essential in order to verify the energy retrofitting measures.

The design process method is developed in relation to a number of specific applications. These are WinDesign, Visualizer, and ArchiCAD. Thus, the method may only be utilized when using these applications and it is limited by their level of performance.

Furthermore, the design process method is only developed for the early design phases (pre-design phase and concept design phase).

II. Development of *data transfer* potentials with IFC

WinDesign is further developed so that it may import and utilize information stored in IFC-files. ArchiCAD acts as the BIM-application from where the IFC-files will be exported.

Only the information stated within the design process method should be transferred from ArchiCAD to WinDesign.

[3] See www.grontmij-carlbro.com for more information about the company

III. Testing of design process method and IFC-data transfer in two *case studies*

Two case studies are performed to validate and explore the potentials of the developed design process method and the IFC-data transfer. The aim is to present design solutions for energy retrofitting projects, which fulfill the newest and future requirements for energy consumption and indoor environment.

The buildings used for the two case studies are different and represent a single family type house and a simple office building. The single family type house is represented by a building developed by InterByg A/S[4] and the simple office building is represented by building number 118 at the Technical University of Denmark (DTU).

The case studies will aim at following the progression of the design process method and only focus on issues related to energy and indoor environment.

[4] For more information, see www.interbyg.dk

2. Literature survey

2.1. Introduction

The literature survey is divided into four parts. The first three parts present Integrated Design, BIM, and energy retrofitting of buildings. Finally, a fourth part discusses how these three topics may interact together.

2.2. Integrated design

The growing focus on sustainability is one of the areas that make integrated design highly relevant. Integrated design is a method for design optimization by utilizing the strength of multidisciplinary design consultancies [66].

The method has its origin in development of new buildings, and the descriptions in this part are based hereupon. A survey of how integrated design may be used in retrofitting of existing buildings is presented in part 2.5.

2.2.1. Background

To gain an understanding of integrated design, it is important to have basic knowledge of the traditional building construction process. The process is commonly divided into three phases; design, construction, and operation phase. The design phase is typically divided into three sub-phases; pre design, concept design, and design development. Through these sub-phases the consultants (architects and engineers) develop the complete building design and prepare it for construction (Figure 2) [26]. Intentions of the design sub-phases and the role of the consultants in Denmark are accounted in the guideline *Description of services – Building and Planning* [14].

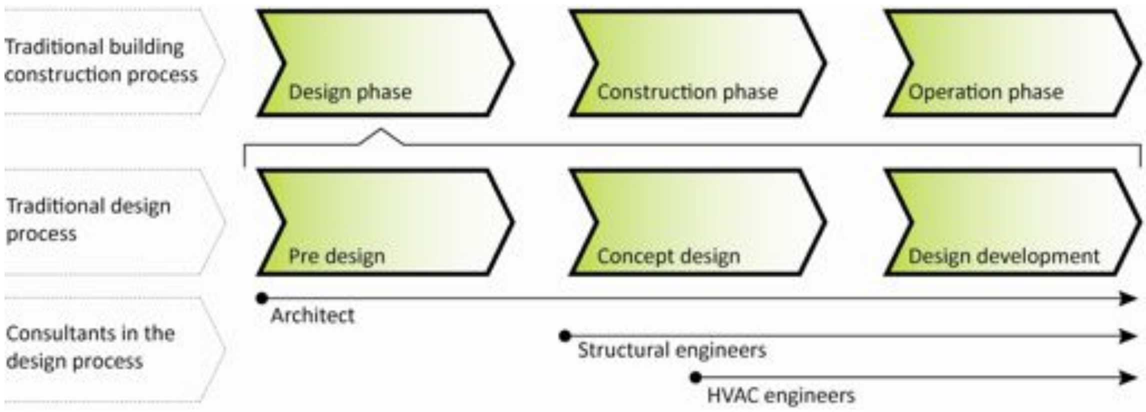


Figure 2 Overview of the traditional building construction process and the traditional design process, where the consultants get involved in different phases of the process. The figure illustrates a simplified outline of the reality. Inspired by [43]. HVAC: Heating, Ventilation, and Air Conditioning.

Simplified, the traditional design process is executed as a linear process where the consultants work interdisciplinary in a decision-making process. From the requirements set by the client, the architect starts shaping ideas which creates the basic plan of the building project [66]. When the architect has finished the conceptual design, the structural and heating, ventilation and air conditioning (HVAC) engineers get involved in the project and are bounded to the overall framework made by the architect.

The late involvement of engineers in the traditional design process implies that important design decisions are made without their supervision. This may have a negative impact on the energy consumption and indoor environment of the final building project. HVAC engineers are hereby often forced to optimize the energy consumption and indoor environment by use of advanced technical equipment that are costly, and only results in a marginal decrease of the energy performance [26, 41].

An increased attention must be on the traditional design phase if the an energy optimization should be optimal [30]. Tools used for such optimization will often be computer applications, which can simulate and analyze how the building will perform under different design alternatives. Handling of such applications requires an understanding of the thermal building physics and energy standards. This understanding is not a typical skill for the architect, but often a key competence of the HVAC engineer. In such cases, it would be an advantage to use the knowledge possessed by the HVAC engineer in the early design phases. This leads to the fundamental idea of integrated design [66] (Figure 3).

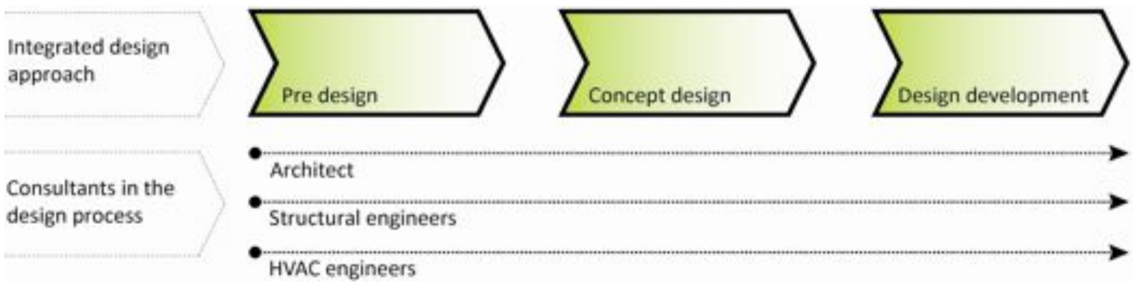


Figure 3 Illustration of the integrated design approach, where all the consultants are involved in the process from the beginning. The figure illustrates a simplified outline of the reality [43].

It is well-proven that changes and improvements are relatively easy to make in the early design phases, but become increasingly difficult as the building construction project develops [46] (Figure 4).

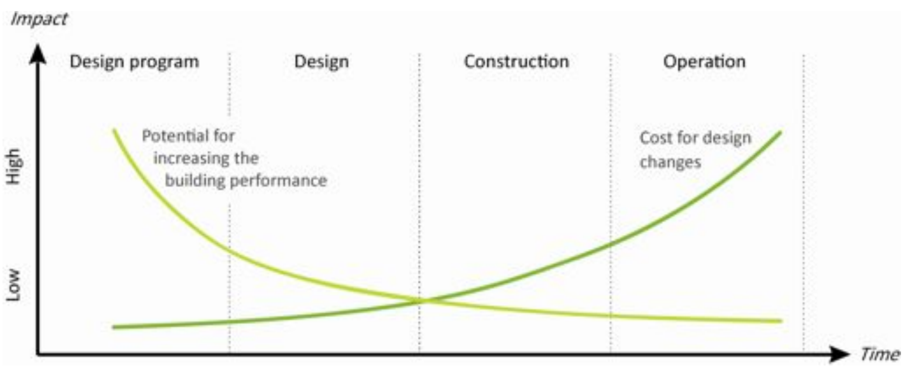


Figure 4 The range of possibilities to change the building design drops significantly while costs and disruption increase as the project progresses [24].

2.2.2. Integrated design process

Integrated design is characterized as a process represented throughout the whole design phase [26]. The linear decision-making process used in the traditional design process is redefined when using an integrated design approach, since the consultants work simultaneously and develop the building design together. The multi-disciplinary workflow is often complied by using iterative loops in the decision-making process. Each loop assures the participation of all consultants and contributes to continuous re-optimization of the building design. The iterative process can, however, be difficult to control and have a tendency to divert from the focus of the original design goal [26]. An extensive research and testing of integrated design has been carried out by the International Energy Agency in their Task 23 "*Optimization of Solar Energy Use in Large Buildings"* (further referred to as *Task 23*). In Task 23, it is proposed that the integrated design process is created by a combination of the linear and iterative process to avoid diverting from the original design goal (Figure 5) [26]. The recurrent linear processes between the iterative loops consist of evaluation rounds to assure that the overall process is in line with the design goals.

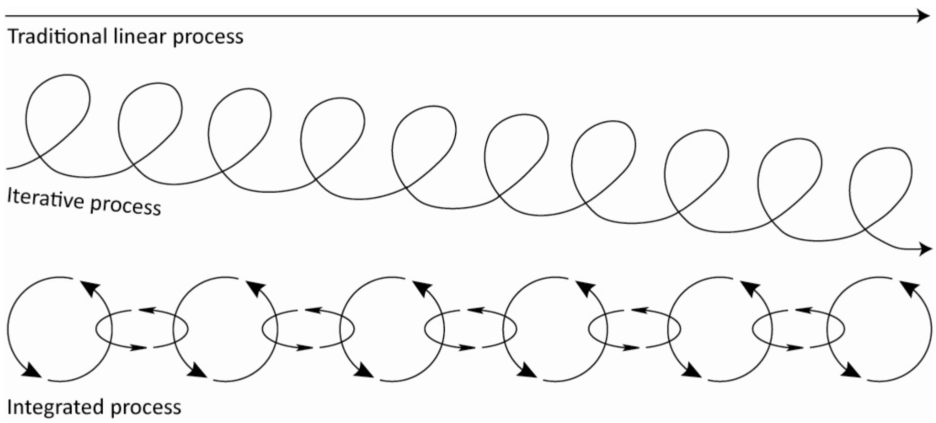


Figure 5 Conceptual representation of the traditional (linear), iterative, and integrated processes [26].

2.2.2.1. Overall process structure

The very beginning of the building construction project is the crucial time for the integrated design process. Carefully prepared design goals for the further design process can contribute significantly to the performance of the project. It is therefore important that discussions between the client and the consultants are performed in the very beginning of the design process, so that uncertainties and conflicting objectives among the consultants will be identified and solved initially [41, 46]. The integrated design process will, as the traditional, be divided in three sub-phases; pre-design, concept design, and design development (Figure 6).

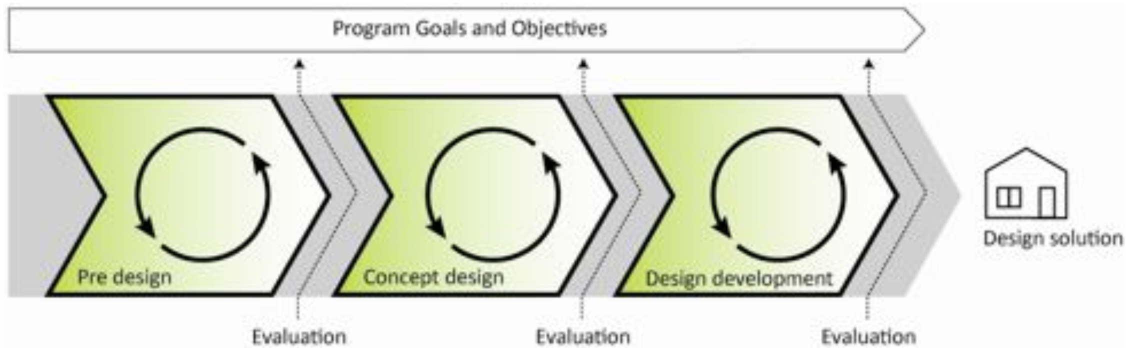


Figure 6 Illustration of the integrated design process. Iterations are performed in each sub-phase and linked together by evaluations that refer to the program goals and objectives [26].

Iterations are performed in each sub-phase, and each iteration results in different design alternatives which are discussed in an evaluation round. By the evaluation round, one of the design alternatives is selected for further development based on the design goals established. Thus, the evaluation creates a milestone on the linear backbone of the design process and forms a transition between two design sub-phases. These milestones ensure a constant design progression towards the final goal [26].

In *Task 23,* a number of characteristics may describe the integrated design process [26]:

- Inter-disciplinary work from the beginning of the design process between all consultants
- Test of various design alternatives by use of simulation tools
- Development of well-formulated performance targets and design strategies
- A more active role of the client
- The architect as teamwork leader instead of sole form designer

2.2.3. Tools to support integrated design

A core issue in integrated design is tools to support the decision-making within the design process [42]. Tools developed for this purpose can be described as Design Decision Support Systems (DDSS). These tools can address numerous aspects such as cost estimations, structural analyses, energy and environmental issues, etc. As the current thesis focuses on the aspect of energy and thermal indoor environment, only tools supporting these aspects are discussed. These tools are referred to as Energy and Environmental Design Decision Support Systems (EEDDSS). EEDDSS are intended to support the decision-making throughout the whole design process and may be grouped in four categories [7].

- **Design guidelines**: Give general design advice
- **Traditional physical calculation method (steady state)**: Focus on limited aspects of the building physics.
- **Correlation based methods**: Consider all physical aspects, which influence the building performance and take restrictions in design specifications and performance assessments into account.
- **Building simulations**: Create a virtual building model where users can specify detailed parameters that influence the building performance. This results in performance predictions as close to the reality as possible.

A wide range of EEDDSS are developed and available on the market (Table 1).

Table 1 Examples of EEDDSS available on the market. The examples are primarily from the three last categories stated above.

Application	Description	Owners
B-Sim	Advanced tool with own modeling interface. Capable of simulating thermal indoor environment, energy consumption, level of daylight, moisture transport, natural ventilation, etc.	Danish Building Research Institute (SBI)
Be06	Tool developed primarily to document that energy performance complies with the requirements in the Danish Building Code. However, it is also usable for energy optimization in the design phase.	Danish Building Research Institute (SBI)
Ecotect	Tool with own modeling interface. Developed for environmental analyses in the conceptual design phase. Includes abilities to analyze issues related to solar, thermal, lighting, and shading energy, etc.	Autodesk
Heat 2/3	Tool for detailed analyses of transient and steady-state heat transfer in building constructions.	Blocon
iDbuild	Tool for parameter variations of performance-decisive parameters. The application evaluates energy performance and indoor environment on room level.	Technical University of Denmark (DTU)
RIUSKA	Tool for dynamic simulation of comfort and energy consumption in building services design and facility management.	Granlund
IESVE	Portfolio of simulation tools for analysis and development of design solutions. It has its own modeling interface, and can perform simulations on various levels, mostly concerning issues about energy, service, and environment.	Integrated Environmental Solutions
WinDesign	Tool primarily developed to optimize the choice of window solutions in new buildings or renovation projects. It allows evaluations of energy performance and thermal comfort in an Excel-based simulation engine.	Technical University of Denmark (DTU)
Visualizer	A simple application to perform daylight analysis. It is capable of importing building geometries from other applications and has a render function to visualize different daylight scenarios.	Velux and Luxion

All EEDDSS applications have different approaches to support the integrated design process. They may only be useful for a specific consultant such as the architect or HVAC-engineer and vary in their level of analytic detail. Some are developed for a specific sub-phase in the design process and others are intended for the whole design process. This thesis will mainly focus on the EEDDSS application WinDesign, which is further developed and used for energy calculations and evaluation of the indoor environment in the two case studies. However, WinDesign does not allow analyses of daylight conditions. Thus, Visualizer is used for such analyses. WinDesign and Visualizer are discussed further in the following parts.

2.2.4. WinDesign

WinDesign is an EEDDSS tool developed at the Technical University of Denmark (DTU). The application is based on Microsoft Office Excel 2007 and Microsoft Visual Basic. It is an open source application adjustable for further development. The calculation method is developed in accordance with EN ISO 13790 and complies with the European Directive on the energy performance of buildings (EPBD) [57].

Several reasons underlie the choice of using WinDesign as EEDDSS in the present thesis.

- The open Microsoft Excel and Visual Basic based programming ease the possibilities of adjustment and processing of data
- It is based on the International standard EN ISO 13790 and complies with both Danish and Swedish building regulations
- Calculations are performed on hourly basis from few input data
- It is developed to analyze new buildings as well as retrofitting of existing buildings
- It is developed at DTU and are free available for all interested consultants
- It is used in teaching at the DTU and may as well be used in the AEC industry

2.2.4.1. Main objectives and limitations of WinDesign

The main objective of WinDesign is to support the consultants in relation to energy consumption and thermal indoor environment. Furthermore, it is developed to be used in the early design phases and operates from simple data input. Simulations can be performed on the building as a whole or for each of the rooms in the building. However, WinDesign is only developed to analyze one storey buildings with up to 12 rooms, and with a maximum of 10 windows in each room.

The simple data input required by WinDesign limits the complexity of its analysis. The following issues are not evaluated in WinDesign:

- Domestic hot water
- Electric equipment
- Efficiency of heat supply systems
- Electrical consumption for ventilation, circulation pumps, etc.

2.2.4.2. Structure of WinDesign

The structure of WinDesign is divided into four steps, each to be used for a different kind of analyses. The steps build upon each other and together they represent a full analysis of how a specific building design performs according to energy, thermal comfort, and cost [55].

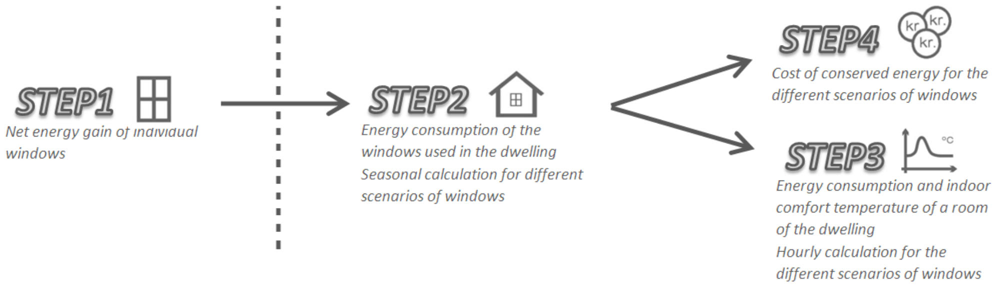


Figure 7 Structure and progression flow of WinDesign. Information stated in step 1 may, if wanted, be utilized in step 2. Information stated in step 2 is mandatory and forms the basis of step 3 and 4.

The idea is that the different steps gradually increase in level of detail supporting the design decisions throughout the design process. The four steps are generally characterized as [29, 55]:

- STEP 1: The Net Energy Gain is calculated for a number of window products based on a reference building and their properties.
- STEP 2: The building is defined and energy consumption may be evaluated with different scenarios of windows, U-values, internal gains, etc.
- STEP 3: The thermal comfort and energy consumption are evaluated for the individual rooms based on hourly calculations.
- STEP 4: An economical evaluation, based on the criterion of *Cost of Conserved Energy*, is performed to compare cost and savings for the different design scenarios.

However, only step 2 and step 3 are used further in this thesis as these are sufficient to perform analysis on energy consumption an indoor environment. Thus, only these steps are described further.

2.2.4.3. Calculation methods for STEP 2 and STEP 3

In this part, the main theory used for calculations in step 2 and 3 are described.

STEP 2 – *Energy consumption of windows and building (seasonal calculation)*

The energy consumption for the windows and building are calculated based on the seasonal method described in EN ISO 13790, 2008 [29]. The length of cooling and heating season is also calculated. The actual length of the heating and cooling season, L_{HS} and L_{CS}, is calculated for each month according to equation (1.1):

(1.1)
$$L_{HS} = \sum_{m=1}^{m=12} f_{H,m} \text{ and } L_{CS} = \sum_{m=1}^{m=12} f_{C,m}$$

Where

$f_{H,m}$ = the fraction of the month that is a part of the heating season. Calculated from equation (1.2), and is determined for each month during the year

$f_{C,m}$ = the fraction of the month that is a part of the cooling season. Calculated from equation (1.3) and is determined for each month during the year

(1.2) $$f_{H,m} = Q_{H,nd}/(Q_{H,nd} + Q_{C,nd} + Q_{V,pre-heat} + Q_{V,pre-cool})$$

(1.3) $$f_{C,m} = Q_{C,nd}/(Q_{H,nd} + Q_{C,nd})$$

where

$Q_{H,nd}$ is the monthly energy need for heating [MJ]

$Q_{C,nd}$ is the monthly energy need for cooling [MJ]

$Q_{V,pre-heat}$ is the energy need for pre-heating of ventilation air [MJ]

$Q_{V,pre-cool}$ is the energy need for pre-cooling of ventilation air [MJ]

Five different window scenarios may be defined for comparison. The energy consumption for the windows is described by equation (1.4) and (1.5) [29].

Heating season:

(1.4) $$E_{windows,HS} = \frac{\sum_i (U_{w,i} \cdot A_{w,i} \cdot G_{HS} - \eta_{HS,gn} \cdot F_{sh,ob,i,HS} \cdot A_{sol,i,HS} \cdot I_{sol,i,HS})}{A_{floor}} \ [kWh/m^2]$$

Cooling season:

(1.5) $$E_{windows,CS} = \frac{\sum_i (F_{sh,ob,i,CS} \cdot A_{sol,i,CS} \cdot I_{sol,i,CS} - \eta_{CS,ls} \cdot U_{w,i} \cdot A_{w,i} \cdot G_{CS})}{A_{floor}} \ [kWh/m^2]$$

Where

$U_{w,i}$ = the thermal window transmittance [W/m^{2}K]

$A_{w,i}$ = the window area [m^2]

$G_{HS/CS}$ = the number of degree-hours during the heating/cooling season calculated for a reference indoor temperature of 20°C/26°C

$F_{sh,ob,i,HS/CS}$ = the shading reduction factor due to external obstacles for the window during the heating/cooling season [-]

$A_{sol,i,HS/CS}$ = the effective collecting area of the window with a given orientation and tilt angle for the heating/cooling season [m^2]

$I_{sol,i,HS/CS}$ = the total incident solar radiation per m^2 of the window area, with a given orientation and tilt angle, over the heating/cooling season [kWh/m^2]

$\eta_{HS,gn}$ = the utilization factor for solar gains, heating season [-]

$\eta_{CS,ls}$ = the utilization factor for heat loss, cooling season [-]

A_{floor} = the heated floor area [m^2]

The energy consumption for heating and cooling in the building is described in equation (1.6) and (1.7) [29].

(1.6) $$\text{Energy consumption for heating: } Q_{H,nd} = \frac{Q_{H,ht} - \eta_{HS,gn} Q_{H,gn}}{A_{floor}} \quad [kWh/m^2]$$

(1.7) $$\text{Energy consumption for cooling: } Q_{C,nd} = \frac{Q_{C,gn} - \eta_{CS,ls} Q_{C,ht}}{A_{floor}} \quad [kWh/m^2]$$

Where

$Q_{H/C,ht}$ = the heat transfer by transmission and ventilation, heating/cooling season [kWh]

$Q_{H/C,gn}$ = the total heat gains including solar gains and internal gains, heating/cooling season [kWh]

Step 3 – *Energy consumption and indoor comfort (hourly calculations)*

The energy demand for heating and cooling and the thermal indoor environment are calculated. Calculations are carried out on an hourly basis in accordance with the *simple hourly method* described in EN ISO 13790, 2008 [25]. The calculations are as default based on hourly weather data from the Danish Reference Year. Weather data from a specific location or time period may be implemented in IWEC-format[5] [55]. Such weather data will further be referred to as *specific weather data*.

2.2.4.4. Representation of geometry

WinDesign does not have a graphical engine and all geometrical representations are defined by numerical values typed in by the user. All geometrical representations shall, in accordance with EN ISO 13790, 2008 [25], be expressed in internal dimensions (Figure 8). All further considerations regarding geometry issues will have to comply with this matter.

[5] File-format containing hourly weather data [55]

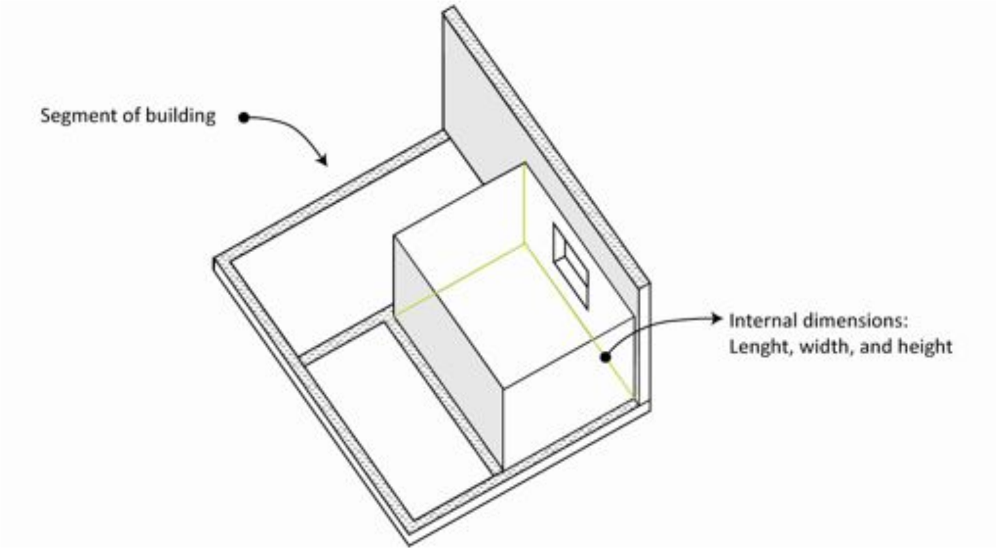


Figure 8 Illustration of some internal dimensions (length, width, and height) in a segment of a building. Note: The illustration is not created or exported by WinDesign, but do just illustrate the concept.

2.2.5. Visualizer

Visualizer is an application developed by VELUX[6] and Luxion[7]. The application can be downloaded for free at www.velux.dk. It is a simple tool for analysis of daylight in buildings. The application allows importation of building geometries from other applications in DWG-, DXF-, SKP-, and OBJ format and is thus able to interact with several BIM-applications[8]. The current thesis will use the DWG-format for interaction between the BIM-application and Visualizer.

Visualizer allows several simulation outputs, such as photorealistic renderings and luminance, illuminance, and daylight factor maps.

The theory for the daylight calculations has not been available and will therefore not be described further. However, the application has been validated against CIE 171:2006 - Test Cases to Assess the Accuracy of Lightning Computer Program[31]. The validation was passed and conclusions are described in Annex A.

2.2.5.1. Import of BIM-model into Visualizer

When importing a BIM-model into Visualizer a number of precautions have to be noticed.

The BIM-model will have to be exported in DWG-, DXF-, SKP-, or OBJ format. Visualizer will import all identical layers, which are visible in the BIM-model, as one block. Material properties will have to be assigned in Visualizer after the importation. However, these properties can only be assigned to each block. For example, if all walls are within the same layer in the BIM-model, these will be imported as one block and can only be assigned with one material property. In case that different material properties are needed for each wall, these would have to be within separate layers in the BIM-model.

[6] More information on www.velux.dk
[7] More information in www.luxion.com
[8] Descriptions of BIM-applications and BIM-models are found in part 2.3

2.3. Building Information Modelling/Model

Building Information Modelling (BIM) is a method of generating and administrating building data. Usually, the method has its origin in a 3D model called the Building Information Model which is also referred to as BIM. To distinguish between the two meanings of the abbreviation, this thesis will use the term “BIM-process” when referring to Building Information Modelling and “BIM-model” when referring to Building Information Model [65].

The following part describes the phenomenon of BIM. Other relevant issues such as data sharing and an Information Delivery Manual (IDM) are also described.

2.3.1. Background

The idea of optimizing the data-exchange in the AEC industry by use of computer applications has existed for several years. The *General AEC Reference Model* was developed in 1988 as a high level data model to link various modeling concepts within and outside the AEC industry [28, 64]. However, as mentioned above, recent investigations have documented that the efficiency of the AEC industry still develops slowly and is low compared to other sectors [16].

The AEC industry is characterized by its fragmented structure and processes containing large amounts of information. A building construction project often consists of impermanent constellations and various influences by different companies. Thus, it is difficult to share, utilize, and maintain the flow of information generated throughout the building construction process. Furthermore, it makes it difficult to implement standards on how to use and handle data, which is highly developed in other sectors. This issue is perceived as one of the main challenges in order to make the AEC industry more effective [18].

As mentioned above, in 2003 the Danish government launched a new political plan of action to increase focus on how to optimize the growth of the AEC industry[9] [19]. The political initiative resulted in the project *“The Digital Construction”* which purpose was to improve the sharing of digital information in the AEC industry by using the method of BIM. This is consistent with many other countries, where the development and implementation of BIM in the AEC industry is also highly prioritized. Finland initiated already in 1985 the project RATAS which focuses on utilizing the potential of BIM in the AEC industry [2].

As a result of *“The Digital Construction”*, the Danish government demanded that all governmental clients should make use of digital applications in their building projects from the beginning of 2007 [20]. The demands are shortly described below [58]:

- Use of digital tendering
- Use of building information model
- Use of digital project web
- Use of digital hand-over

[9] Translated in English: *The state as a client – Growth and efficiency improvement in the AEC industry*

2.3.2. Concept of BIM

As described in the introduction, the abbreviation BIM has a bifurcate meaning. To ease the understanding, the following part is divided into two; BIM-model and BIM-process.

2.3.2.1. BIM-model

The BIM-model represents the foundation for the BIM-process. It functions as a database for the project, and may contain information about the building geometry, spatial relations, building location, properties, quantities of the building components, etc. It is most commonly represented as a 3D model built from a number of adjustable objects, which can range from furniture to construction elements (Figure 9) [65]. It is these objects that carry the information of the building project and form the BIM-model based on their relations to each other. For example, a window is placed in a specific wall which in turn is connected to a specific floor.

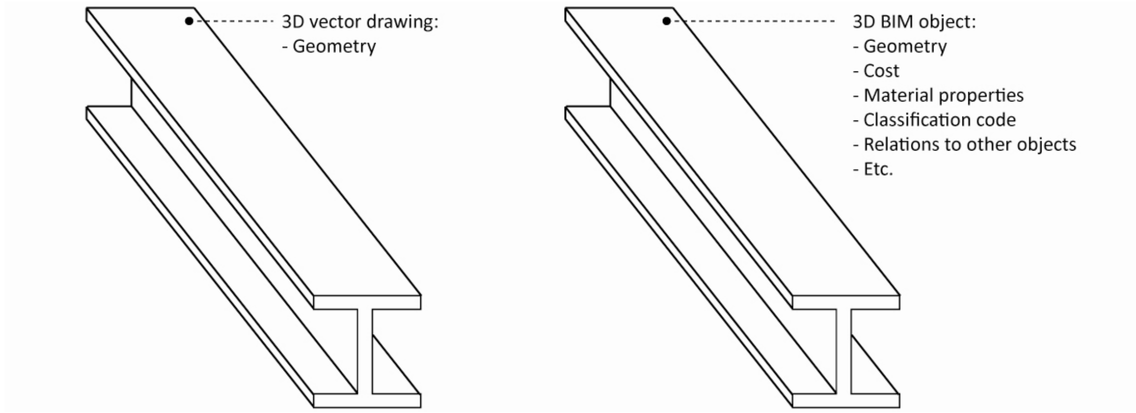


Figure 9 Representation of the difference between a traditional 3D vector drawing and an intelligent 3D BIM object

The BIM-model is created with a BIM-application which is capable of working with objects (Table 2). Some applications have their focus on creating the 3D BIM-models of the architectural building geometry. Others concentrate on creating the building parts for the BIM-model, such as ventilation systems, piping, or structural elements. An important capacity of the BIM-models is their ability to store information about rooms. Such information may consist of volume, internal heat gains, application, etc. Further it may contain information of its boundaries as for instance wall, floor, and ceiling areas. Such information is valuable when performing analyzes of energy and indoor environment and will be utilized further in the current thesis. From the 3D BIM-model it is possible to extract views, such as elevations, sections, and other information contained in the BIM-model.

Table 2 Examples of BIM-applications which are capable of working with objects

Application	Company	Description
ArchiCAD Bentley Architecture Revit Architecture VectorWorks	Graphisoft Bentley Autodesk Nemetschek	Architectural BIM-model software with object orientated structure.
AutoCAD MEP MagiCAD	Autodesk Progman Oy	BIM-model software intended for HVAC engineers when developing service systems.

There are many direct advantages of using a BIM-model, for instance cost estimation, quantity evaluations, 3D building representation, re-use of data, etc. Many other possibilities are also present when the information from a BIM-model is connected with other BIM-related applications and used throughout the building construction process; see part 2.3.2.2 [8]. However, BIM may also lead to disadvantages. At present time the method increases rapidly within the AEC industry and consultancies may be forces by the authorities to use it. This challenges the existing routines, methods, and processes used in the industry and may cause frustrations among the consultants.

2.3.2.2. BIM-process

The communication between the BIM-model and other applications usable in a building construction project is the main concept of the BIM-process [44]. As previously mentioned, the BIM-model contains valuable information, which can be extracted and used in applications for energy simulations, acoustic conditions, facility management, etc. These interactions between the BIM-model and other applications can be used throughout the whole lifecycle of the building, from cradle to grave, and all parties in the project can participate (Figure 10) [44]. The digital interoperability makes the building construction process transparent for all the participants. This makes it possible to give a continuous feedback on results in relation to energy, construction, maintenance, etc., or to explore the relative effect of different design alternatives [8].

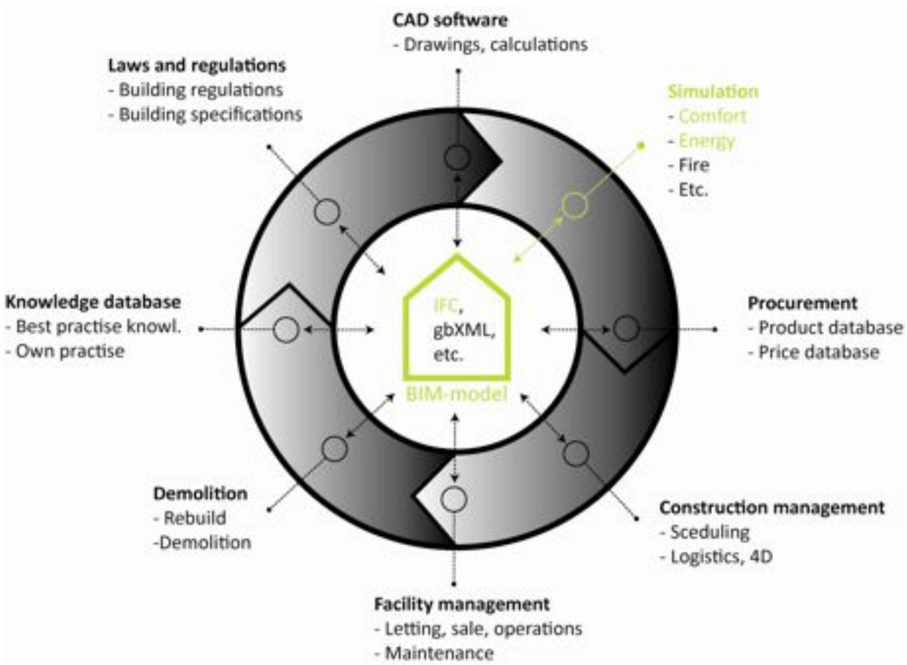


Figure 10 Conceptual illustration of the BIM-process. The BIM-model is centralized in the middle and communicates with additional applications (illustrated by the small circles) during the life-cycle of the building. The communication may be performed with open file formats as IFC, gbXML, and CIS/2. The green high-lights illustrate the focus area of this thesis. Inspired by [44].

The BIM-process depends on the ability of sharing information between applications, organisations, IT systems, and databases. Open file standards that consider the benefits of all applications in the process and not one software vendor may be the solution for achieving an optimal BIM-process [54]. This issue is compiled by the Industry Foundation Classes (IFC). IFC is an open object orientated file format. It can contain information from the BIM-model and can be accessed by other applications for further analyzes in most aspects of the building construction process. Other file standards similar to IFC, such as gbXML and CIS/2, have also been developed. They are, however, only intended to support the information-sharing regarding energy simulations and structural design. In Denmark, the use of the IFC-format is compulsory when using BIM for state-aided building projects. Other countries, such as the US, Norway, and Finland, have similar requirements [32]. The IFC-format will therefore act as the standard for information-sharing used further in the present thesis and is discussed in part 2.3.3.

Another issue to consider is the relation between information gathered in the BIM-model and the level of information that is needed in the building construction process. These matters are described by an Information Delivery Manual (IDM), which provides an approach on how to manage the information required in a BIM-process, see part 2.3.4 [3].

2.3.3. Data sharing with IFC

As mentioned above, IFC is a file format developed to share information within the building construction process. It is developed by *buildingSMART*[10], which is a non-profit organisation working with optimization of communication, productivity, quality, etc. in the AEC industry [32]. IFC specifications have been released in several formats. The format used in this thesis will be IFC 2x3.

IFC is developed in close relation to the *STandard for the Exchange of Product model data* (STEP). STEP has been initiated by the *International Standards Organization*[11] and focuses on defining general standards for exchange of product information.

The content of IFC 2x3 may vary in size and can handle both small and large information loads. It may also contain information from many professions, such as the architect, HVAC engineer, structural engineer, etc. The content of IFC represents building components such as walls, ceilings, beams, doors, etc. More abstract phenomena, such as activities, spaces, quantities, construction cost, relation of components, etc., are also represented by the content of IFC. This information is stored in individual *entities* and *attributes*, which may contain various properties such as name, type, values, etc. [5].

Many BIM-applications are capable of exporting IFC-files, but they often have different IFC-export settings and algorithms. Depending on the use of a certain BIM-application, the same BIM-model may result in different IFC-files [43]. However, a new version IFC (IFC 2x4) has currently been released. In this new version of IFC the flexibility is decreased and the data structure is concretised, which intentionally shall increase the uniformity of IFC-files exported from different applications [4].

The current thesis will focus on the BIM-application ArchiCAD. It has the capability of exporting IFC-files and other formats as DWG, DXF, and OBJ. Further it is capable of

[10] See www.buildingsmart.com for more information on *buildingSMART*
[11] See www.iso.org for more information on International Standards Organization

2.3.3.1. Structure of the IFC-format

The architecture of IFC 2x3 is separated into four main layers (Figure 11). A core layer in the middle, an interoperability layer and a domain layer in the top, and a resource layer in the bottom. Each layer is comprised by several categories. It is within each of these categories that the individual entities are defined. Entities located in a given layer can only refer to entities in the same layer or a lower layer in the architecture [43].

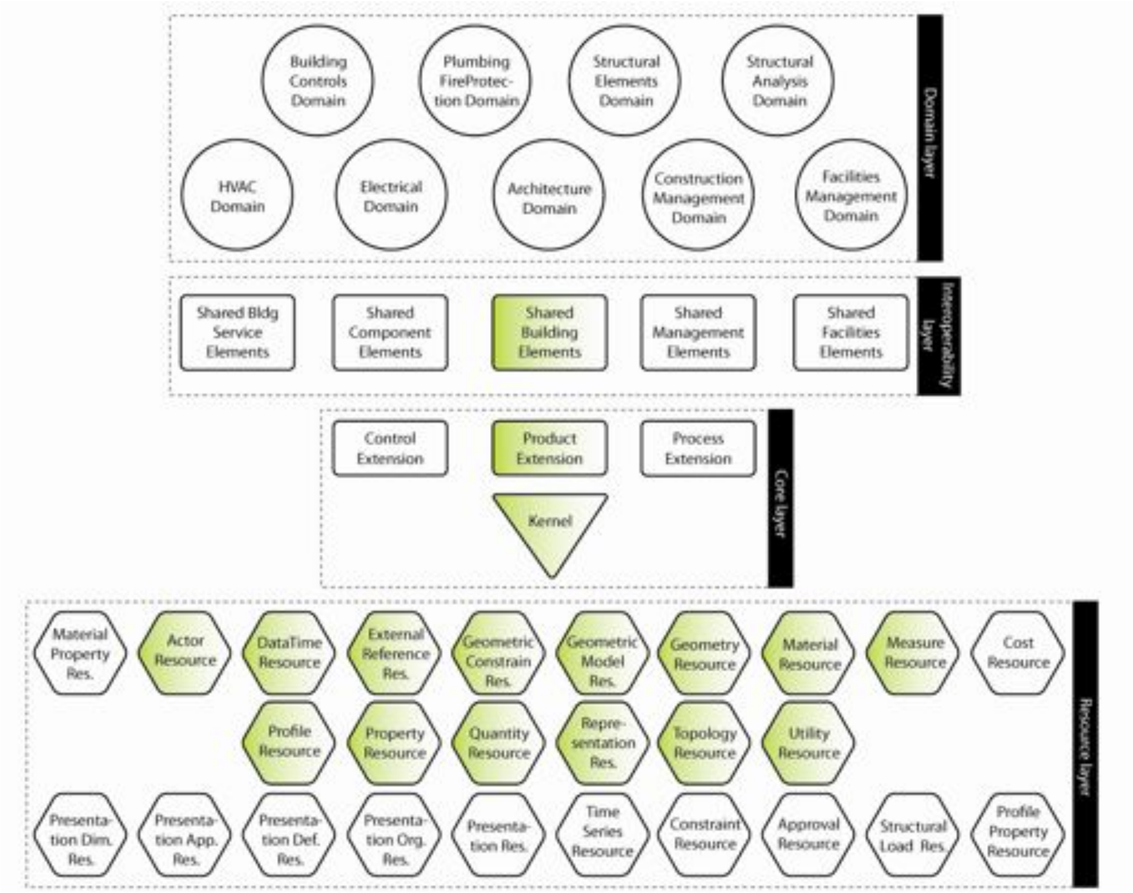


Figure 11 Architecture of IFC 2x3. The green categories are certified by ISO/PAS 16739[12]. Inspired by [5] Dim.: Dimension. Res.:Resource. App.: Appearance. Def.: Definition. Org.: Organization.

The entities which are used in this thesis are further examined and documented in part 4.

2.3.3.2. IFC exploration

IFC-files are organized in a hierarchical structure containing all entities and attributes. This hierarchical structure can be accessed by an IFC-explore[13] or IFC-viewer[14], Annex B.

[12] International Standard Organisation (ISO). See www.iso.org for more information
[13] A free IFC explore is available at http://groups.yahoo.com/group/ifcsvr-users/
[14] An IFC-viewer may be downloaded from www.dds-cad.net

2.3.3.3. Interaction with IFC

If other applications should benefit from the information stored in the IFC file, they would have to allow interaction with it. One way to interact with an IFC-file is by using an IFC toolbox. Several of such toolboxes exist, for instance the IFCsvr ActiveX component[15]. This toolbox is developed by SECOM Co., ltd[16] and is free to use. It is furthermore possible to implement the IFCsvr ActiveX component into Visual Basic. As WinDesign is an application based on Visual Basic, this toolbox will be used further and will be referred to as IFCsvr. By using scripts in Visual Basic information stored in entities or attributes in the IFC-file can then be accessed by using IFCsvr in WinDesign (Figure 12).

```
Public Function GetAllSlabNames ()

        objIFCsvr = New IFCsvr.R300
        objDesign = objIFCsvr.OpenDesign(”FileName.ifc”)

        Worksheets("SheetName").Activate
        Set r1 = ActiveSheet.Range("A1")

        Dim objIfcSlab As IFCsvr.Entity
        Dim newSlab As Single
        Dim SlabName As String

        newSlab = 0

        For Each objIfcSlab In objDesign.FindObjects(”IfcSlab”)

                SlabName = objIfcSlab.Attributes(”Name”).Value

                r1.Offset(1 + newSlab, 1).Value = SlabName

                newSlab = newSlab + 1

        Next objIfcSlaB
End Function
```

Figure 12 Example of a call in Visual Basic where all names of slabs present in the IFC-file are returned and printed in a worksheet in Excel. The script is performed in the programming language Visual Basic for Applications (VBA).

2.3.4. Information Delivery Manual (IDM)

The concept of IDM is developed by buildingSMART. The IDM aims to describe and identify the processes undertaken within building construction projects, and the information required for their execution in relation to the usability of BIM. The technical architecture of IDM is composed of three components described as process map, exchange requirements, and functional parts (Figure 13) [33].

[15] The IFCsvr ActiveX component, instructions, and samples are free to download at http://groups.yahoo.com/group/ifcsvr-users/
[16] See www.secom.co.jp/english/

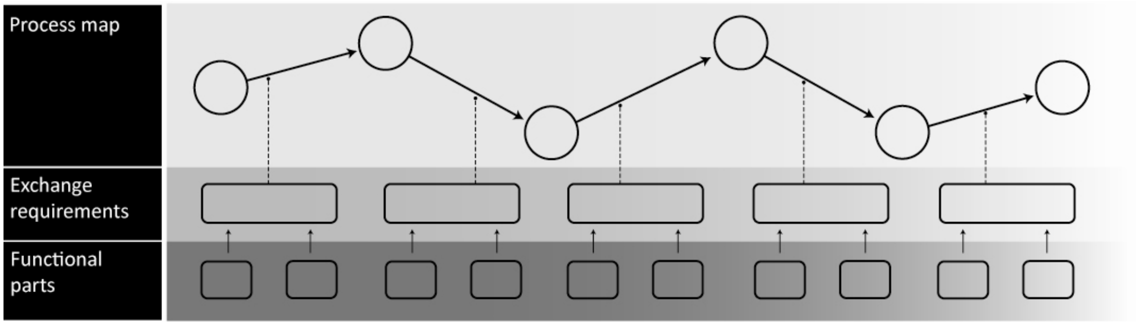


Figure 13 The technical architecture of IDM. Composed of a process map, exchange requirements and functional parts. Inspired by [33].

2.3.4.1. Process maps

The process map displays the flow of activities within the boundary of a specific phase or topic related to a building construction project. The main purpose of the process map is to provide an understanding of how these activities work, the consultants involved, and the information exchanged [33].

The IDM process maps are drawn based on a set of core elements according to the Business Process Modelling Notation (BPMN)[17] (Figure 14). An example of a process map is shown in Annex C.

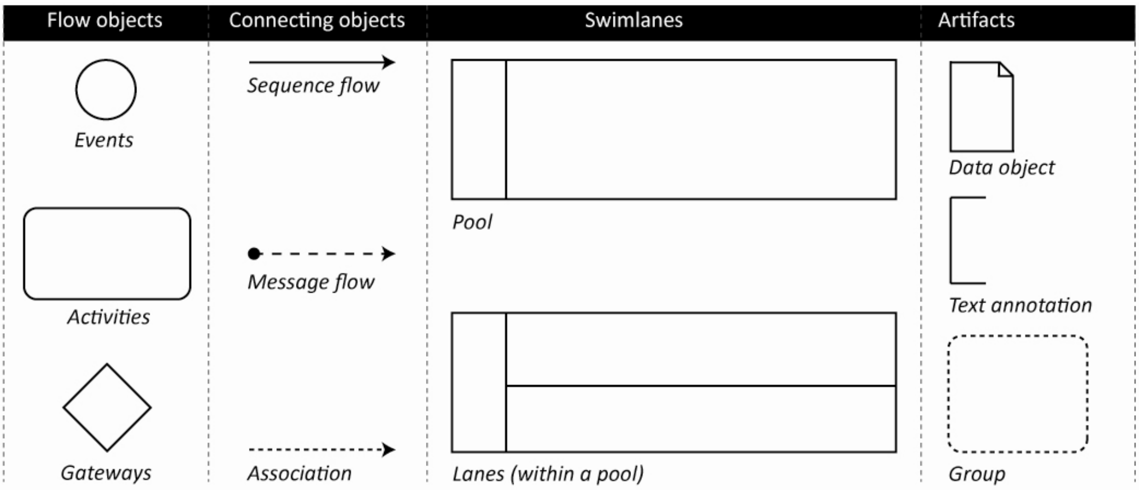


Figure 14 Set of core elements within the BPMN. These are the elements which together form the process map. Inspired by [51]. BPMN: Business Process Modelling Notation.

The understanding of the core elements is described below.

Flow objects:

- *Events* - Point out where something notable happens. There are three types of events: *Start, Intermediate, and End*
- *Activities* - Describe the work tasks in the process
- *Gateways* - Point out where processes may diverge (depending on decisions)

[17] See www.bpmn.org for more information

Connecting objects:

- *Sequence flow* - Used to show the order (the sequence) in which activities in a process will be performed
- *Message flow* - Used to show the flow of messages between participants or activities in the process
- *Association* - Used to associate flow objects with data, text, and other artifacts

Swimlanes:

- *Pool* - Representation of the participants which are involved in the process
- *Lanes* - Sub-partition within the pool. Used to organize and categorize activities

Artifacts:

- *Data objects* - Define the information exchanged between activities
- *Text annotation* - Provide additional text information to the process map
- *Group* - May be used to ease the understanding of a process map

2.3.4.2. Exchange requirements

The exchange requirements define the information which is needed to support a particular activity, event, or gateway within the process map. One activity provides a set of data (the exchange requirement), which is used for another activity (Figure 15).

2.3.4.3. Functional parts

The Functional parts define the information used to support the exchange requirements. They each provide a detailed technical specification of the exchanged information. For example, to exchange a building model, it is necessary to model the walls, windows, slabs, etc. The action of modeling each of these elements is described within their Functional part (Figure 15).

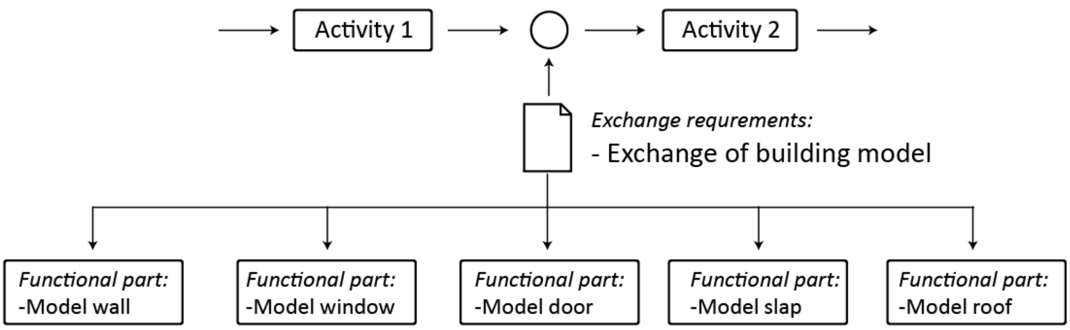


Figure 15 Example of exchange requirements between two activities, and the relation between exchange requirements and functional parts. Inspired by [33].

A number of Functional parts are defined by BuildingSmart, but are found insufficient for the current thesis. However, in part 4.2.4, it is defined how BIM-models are developed which are sufficient for the current thesis.

2.4. Energy retrofitting of buildings

Traditional retrofitting projects have the intention to prevent existing buildings from falling into decay, upgrade their functionality and refresh their architectural expression. These intentions are also concerned in energy retrofitting projects, which though also has the intention to decrease the energy consumption. Issues related to energy retrofitting projects with relevance for the current thesis are described in the following parts.

2.4.1. The construction process for retrofitting of buildings

Similar to the traditional construction process for new buildings, the construction process for retrofitting of buildings may be divided in three phases; design phase, construction phase, and operation phase [40]. However, due to the focus of the present thesis, only the design phase is described further.

The design phase for retrofitting of buildings may also, as for the design phase when constructing new buildings, be divided into three sub-phases; pre-design, concept design, and design development [6]. However, the retrofitting building project is influenced by other design boundaries as it relies on the conditions of an existing building (Figure 16).

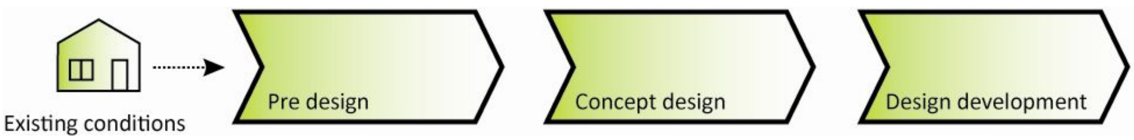


Figure 16 Illustration of the design phase in retrofitting of buildings and their connection to the existing conditions

General intentions of the three design sub-phases and the role of the consultants are described in Table 3.

Table 3 General intentions of the design sub-phases for retrofitting of buildings

Design sub-phases:	General intentions:
Pre-design:	Based on the existing conditions, the pre-design phase has to process the first ideas and requests from the client in preparation for decisions regarding the projects realization. An estimation of the financial framework may be performed.
Concept design:	The concept design phase results in a suggestion for the project solution based on the pre-design development. The cost of the project solution is stated. The result of the concept design forms the basis of an approval in principle from the authorities.
Design development:	The design development phase forms the basis for a final approval of the authorities. The project is developed in a detail which permits a final clarification of conditions, tendering, contracting, and the construction.

2.4.2. Barriers for energy retrofitting of buildings

Completions of energy retrofitting projects are faced with barriers and challenges. A research study from the Danish Building Research Institute, points out four main barriers of interest when dealing with energy retrofitting of buildings:

1. Scientific work and evolution
2. Demonstration and testing
3. Campaigns telling the necessity of energy savings
4. Initiative from the building owners

The research study concluded that the three first barriers did not cause any problems. It is well known among scientist, constructors, and designers how to perform an energy retrofitting project in practice, and most people are aware of the necessity of energy savings. However, the barrier concerning the initiative from the client was found problematic [45]. Many reasons may contribute to the lack of initiative among the building owners. For instance, uncertainty of financial issues and lack of a broad view of the entire retrofitting process. Another reason may be that many building owners have to invest in professional consultants just to clarify if any energy savings would be present at all [34].

2.4.3. Current business strategies, concepts, and tools for energy retrofitting of buildings

The following part describes some current approaches in relation to the process-optimization of energy retrofitting of buildings. Common to all the approaches is their intention to overcome the barriers expressed above.

- **Energy Service Companies (ESCO)**

Energy Service Companies (ESCO) is a public-private business strategy related to energy retrofitting of buildings. It is developed in the US and England in the 1980s and has recently been adapted in the Danish AEC industry. The concept of the ESCO strategy is simple; a private consulting company (the ESCO company) performs an energy retrofitting, which is financed by the energy savings obtained in relation to the new retrofitting measures. The strategy is based on an energy-guarantee issued by the ESCO company, ensuring that the promised energy savings are obtained (Figure 17). Thus, the economical risk relies on the ESCO company and not on the building owner.

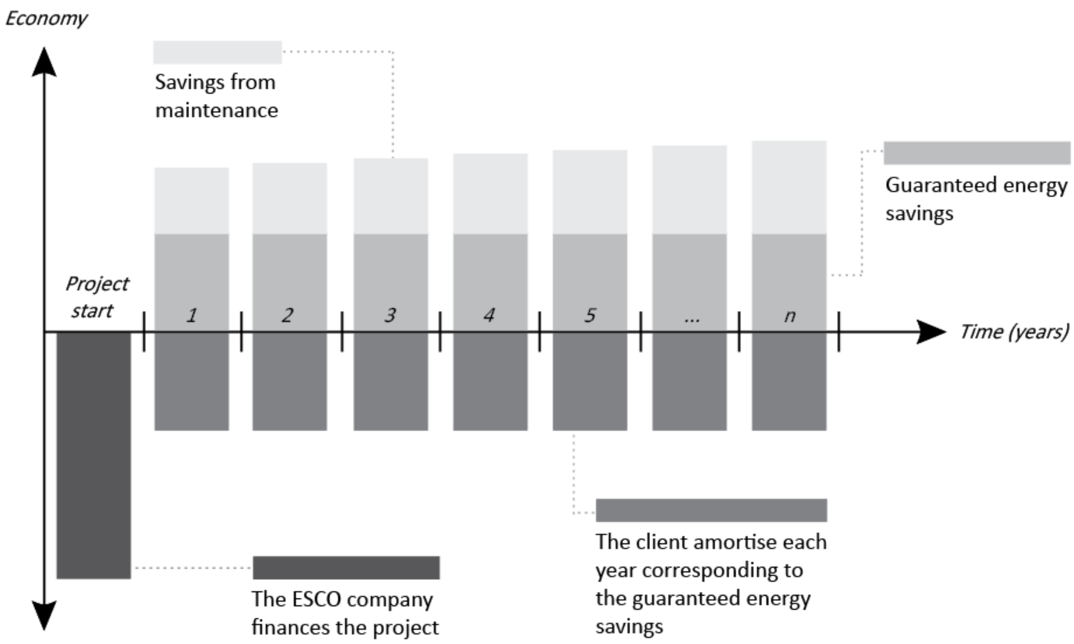


Figure 17 Illustration of the economical aspects in the ESCO strategy. Inspired by [32].

The approach is rewarding for both client and ESCO company, and it contributes further to the reduction of energy consumption in the existing building stock. The client benefits from the strategy since the retrofitting project is performed without any extra investment cost. The ESCO company benefits from the strategy because it may entail an increased interest among the clients to perform energy retrofitting projects [33].

- **Energikocept.dk and Renovering2010.dk**

Both *Energikoncept.dk* and *Renovering2010.dk* are digital web-based tools that may help building owners and consultants to estimate potential energy savings in relation to retrofitting projects in the early design phases. Both tools are developed to work from few input data. Energikoncept.dk is developed by *Grundejernes Investeringsfond* and *Realdania*[18]. It has a simplified calculation engine compared to Be06 and is not suitable for any detailed analysis. However, the tool can give an overview of potential retrofitting measures and their effect on the energy consumption, architecture, indoor climate, and operation of a building [27]. Renovering2010.dk is developed by *Videncenter for Energibesparelser i bygninger*[19] and is based on Be06 calculations. However, the tool is not usable as documentation for authority approval in a retrofitting project. The calculation engine can work out the potential energy savings when re-insulation of the building envelope, renewal of the heating source or installation of solar heating systems or heat pumps [62].

[18] More information about *Grundejernes Investeringsfond* and *Realdania*, see www.gi.dk and www.realdania.dk, respectively

[19] More information about *Videncenter for Energibesparelser i bygninger*, see www.byggeriogenergi.dk.

2.4.4. Requirements

The building requirements related to energy retrofitting are investigated from a Danish perspective. New regulations concerning energy consumption in buildings are under development and will, if adopted, increase the energy requirements even further [49]. These regulations may affect the AEC industry in the near future and are therefore also described. Furthermore, the current thesis considers the indoor environment as an important issue in relation to energy retrofitting of buildings.

2.4.4.1. Energy

The Danish building regulations describe an energy frame, which consists of the total energy consumption from heating, cooling, ventilation, domestic hot water, and lighting[20] (Table 4). The requirements in the energy frame have to be obeyed when constructing a new building. In case of projects with substantial retrofitting or change of employment[21], either the energy frame or alternative requirements have to be obeyed [21]. However, the current thesis will only reflect on the requirements stated in the energy frame.

The energy frame is divided into different classes; mandatory, low energy class 2, low energy class 1, and low energy class 0. The requirements in each class vary according to the type of building that is evaluated. The requirements stated by the mandatory class have to be fulfilled as a minimum. Low energy class 2, 1, and 0 are optional, but are expected to become mandatory in the future (Table 4) [49].

Table 4 Schematic representation of requirements stated in the energy frame [21, 22]

Energy frame requirement	Building type		
	Dwellings, student accommodation, hotels etc.	Offices, schools, institutions etc.	
Mandatory	70+ 2200/A kWh/m^2 pr. year	95+ 2200/A kWh/m^2 pr. Year	Law
Low energy class 2	52.5+ 1650/A kWh/m^2 pr. Year	71.3+ 1650/A kWh/m^2 pr. year	Law taking effect 01.01. 2011
Low energy class 1	30+ 1000/A kWh/m^2 pr. year	41+ 1000/A kWh/m^2 pr. Year	Expected law in 2015
Low energy class 0	17.5+550/A kwh/ m^2 pr. year	25+ 550/A kWh/m^2 pr. year	Expected law in 2020

Building owners committed to the state are assigned to a number of additional demands in relation to the energy consumption.

1. All state owned institutions are required to save 10% of their total energy consumption for electricity and heating by 2011
2. Demands for data transparency of the energy consumption are tightened up

[20] Energy consumption for lighting is only considered as a part of the energy frame in office- and institution building [21].
[21] Substantial retrofitting: The retrofitting should influence more than 25% of the envelope or constitute more than 25% of the latest taxable value of the property [21].

2.4.4.2. Future energy requirements and initiatives

The Danish government has launched an energy strategy dealing with the future reduction of energy consumption in new and existing buildings. It contains a list of different initiatives, which may result in a future change of the existing building law (Table 5) [49].

Table 5 Schematic presentation of potential future requirements, which may have an influence on energy retrofitting of buildings. ESCO: Energy Service Companies

Initiatives	Description
Requirements for components when retrofitting of buildings	By change of the building law, it should be possible to make demands on single replacements of building components.
Promote the usage of ESCO	Carry out a number of efforts that can contribute to an increased use of ESCO´s in municipalities, regions, the state, and the private sector to decrease the energy consumption in existing buildings.
Provisions about building extensions	The current energy requirements for building extensions could be tightened.

2.4.4.3. Indoor environment

No requirements for the indoor environment in relation to retrofitting of buildings are stated in the Danish Building Regulations 2008 [21]. However, research has proven that the indoor environment has a significant influence on human comfort, health and productivity [47]. Consequently, the indoor environment is considered as an important issue in the current thesis in order to develop an optimal energy retrofitting solution. Thus, the following part will describe important parameters for evaluation of the indoor environment.

The indoor environment depends on several factors. Overall, five main perspectives are described by the World Health Organization; thermal, atmospheric, visual, acoustic, and mechanic environment [60]. In relation to the capabilities of WinDesign and Visualizer, only the thermal, atmospheric, and visual environments are described in this part and used further in the thesis.

- Thermal environment

The thermal indoor environment depends on temperature fluctuations, which can be perceived by the human skin. It is dependent on five factors; operative temperature, clothing, activity, air velocity, and air humidity [24].

To simplify the influence by these five factors, average criteria's for the thermal indoor environment are defined by type of building or space, and a specific temperature range (Table 6).

Table 6 Criteria's of temperature ranges for hourly calculation of cooling and heating [24]

Type of building or space	Category	Temperature range for heating (°C)	Temperature range for cooling (°C)
Residential buildings (living room, bed room)	I II III	21-25 20-25 18-25	23.5-25.5 23-26 22-27
Office and space with similar activity (Single office open plan office conference room, etc.)	I II III	21-23 20-24 19-25	23.5-25.5 23-26 22-27

In Denmark, it is recommended that temperatures above 26°C only appear for a maximum of 100 hours/year. Temperatures above 27°C are recommended only to appear for 25 hours/year [12].

- Visual environment

The level of daylight in the building is important in order to gain an optimal visual comfort. The daylight factor (DF) is used to evaluate the level of daylight for a reference point in a room. It is defined by equation (1.8) [21]. Normally, DF is used to assess the most critical conditions which appear on days where the sky is overcast.

(1.8) $$DF = \frac{E_{Inside}}{E_{Outside}} * 100\%, where\ E\ is\ the\ light\ level\ defined\ in\ LUX$$

In Denmark the building regulations state that the acceptable level of daylight for a workplace is 2%. It is furthermore recommended that the window area in a room should be at least 10% of the floor area [21].

Other standards have a more detailed classification of the daylight factor (Table 7).

Table 7 Categorization of different daylight factors (DF) [23, 37]

Reference	Categorization	DF
[23]	Category I	5%
	Category II	3%
	Category III	1%
[37]	Unacceptable	<1%
	Acceptable	1-2%
	Preferred	2-3%
	Ideal for paperwork but to illuminated for computer work	>5%

- Atmospheric environment

The atmospheric environment concerns the parameters that affect our respiratory passages. Common parameters to pollute the atmospheric environment are CO_2, moisture, mould, tobacco smoke, etc. To avoid these pollutants, either the source should be eliminated or the polluted air should be removed by ventilation.

For non-residential buildings, the ventilation rate may be calculated from equation (1.9) [24].

$$q_{tot} = n \cdot q_p + A_{floor} \cdot q_b \quad (1.9)$$

where

q_{tot} = Total ventilation rate of the room [l/s]

n = Design value for the number of the persons in the room

q_p = ventilation rate for occupancy per person [l/s, pers.]

A_{floor} = room floor area [m^2]

q_b = Ventilation rate for emissions from building [l/s, m^2]

Examples of recommended ventilation rates for both residential and non-residential buildings are shown in Annex D.

All buildings will have an air change due to infiltration. For normal buildings an infiltration rate, q_{inf}, is:

$$q_{inf} = 0.13 \frac{l}{s} \, perheated\ floor\ area\ (m^2) \quad (1.10)$$

The ventilation rate due to venting may for normal buildings be set to 2.25 h^{-1} (air change per hour) [52].

2.4.5. Energy retrofitting measures

As explained above, an energy retrofitting project is somehow similar to a traditional retrofitting building project. However, the basis for decision on which retrofitting measures to chose may deviate from the traditional approach, due to the increased focus on optimizing the energy consumption and indoor environment.

The retrofitting measures are divided in two main categories; building envelope and building installations, which both contain a number of sub-categories (Figure 18) [60].

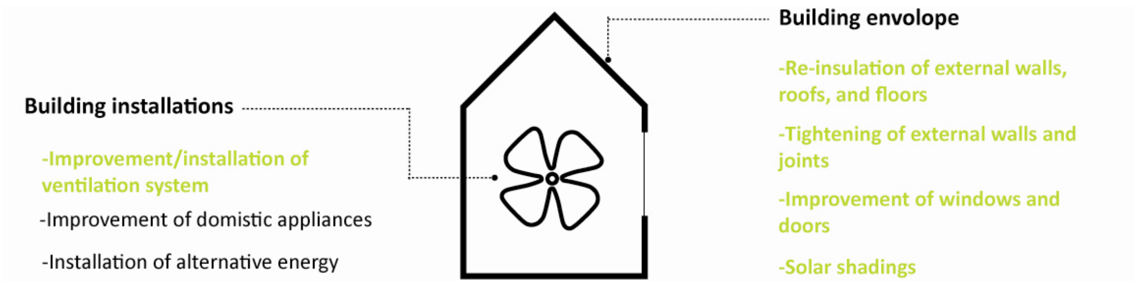


Figure 18 Overview of potential retrofitting measures which may decrease the energy consumption and optimize the indoor environment of existing buildings. The retrofitting measures highlighted with green are those which effect can be analysed by WinDesign and Visualizer.

Some relevant issues according to how retrofitting measures may affect the energy consumption and indoor environment are shortly described in the following.

- Envelope

Re-insulation of the building envelope can have a great impact on the energy consumption. However, this impact will decrease significantly according to the insulation condition of the existing walls. Re-insulation of an existing wall can be performed in three different ways; internal, external, or cavity wall insulation. Advantages and disadvantages are present for all three solutions, see Annex E [60].

- Windows

Former guidelines state that low energy buildings must have small windows facing north and large windows facing south. However, studies with new low energy windows have shown that this contention is not necessarily true. Larger windows facing north may improve the lighting conditions, and smaller windows may decrease the risk of overheating and energy used for cooling [39]. Likewise, this issue is examined in a research study performed at DTU. From investigations of 25 rooms it was concluded that the distribution of windows was ideal with 20% facing south. These conclusions are based on evaluations of heating demands, overheating, and daylight [53].

- Shadings

Overheating is a major problem in the existing building stock. It is estimated that the energy consumption used for cooling is 3-5 times bigger than for heating. A simple way to decrease the solar energy, which often causes the overheating, is by using shadings. In general, solar shadings are divided in two types; internal and external [60].

External solar shading has the best shading efficiency as the solar radiation is blocked before entering the window glazing. Internal shadings are less effective but are easier to adjust and are not exposed for the outdoor climate. The shadings may be movable or fixed. Movable shadings can, manually or automatically, adjust their position depending on sun position and appearance. However, many of such shadings (screens or venetian blinds) will block some of the view through the window. A solution to this disadvantage could be to use fixed horizontal shadings above the window. They will block the sun when it has a high altitude and let it penetrate when it is low. Accordingly, most of the sun will be blocked during summer where the risk of overheating is high. Besides their effect on reducing the risk of overheating, the use of shadings can also have an insulating effect when used during night time [60]. The effect of different shadings on solar gains and their insulation potential is shown in Annex E.

2.4.6. Evaluation of existing conditions

The condition of the existing building forms the baseline of the energy retrofitting project; where is the building located, how is it orientated, which materials are used in the construction, etc. All these existing matters may influence the performance evaluation of an energy retrofitting project and should therefore be obtained [9].

2.4.6.1. Inspection methods

Several inspection methods may be used in order to obtain the necessary information concerning the existing building. The current thesis will distinguish between two inspection fields; *Geometry* and *Properties*. *Geometry* will contain inspection methods related to the building geometry. *Properties* will contain inspection methods, which may state necessary properties of materials, building components, and the total building (Table 8).

Table 8 List of different inspection methods for evaluation of existing conditions regarding properties of materials, building components, and the total building.

Inspection method	Description
Original drawings	Original 2D drawings are available for most buildings and may state the materials of the construction and descriptions of components.
Home condition report	A home condition report is composed by a building expert and contains information about the structural condition of the building.
Energy label[22]	An energy label is composed by an official energy consultant and describes the condition of the building in relation to energy.
The former energy consumption	From previous energy bills it is possible to collect information of the existing performance conditions.
Thermal camera	A thermal camera can measure heat difference on a building components or joints. It creates a visual description of the location and amount of heat transfer in building components.
Blower door[23]	A blower door test can measure the air tightness of a specific building.

2.4.6.2. Standard properties

Obtaining exact information from an existing building may be difficult and time consuming. Standard properties represent an average value of previous measures for similar building components or types. Examples of some standard values are present in Annex F.

[22] More information on www.energitjenesten.dk
[23] More information on www.blowerdoor.dk

2.5. Interaction between integrated design, BIM, and retrofitting of buildings

2.5.1. Introduction

In the previous parts, integrated design, BIM, and energy retrofitting of buildings are described individually. However, their relation needs a further elaboration. This part will therefore describe existing experiences and research projects focused on this matter.

2.5.2. Integrated design and BIM

The researchers of a Dutch pilot project found BIM to be an important factor for a successful integrated design project and showed that the method resulted in better collaboration and communication between the consultants in the design process. It was however argued that an essential difficulty was the time needed to create the BIM-models. The models may vary in complexity depending on which and how a specific BIM application is used, and the time spend to create the models is often reflected in its complexity. Thus, the researchers of the pilot project suggested that when BIM applications are used in integrated design, it is important that their complexity aligns with the degree of complexity needed at the present phase of the project [48].

Another project dealing with this issue is a previous master thesis from DTU; *Integrated Data and Process Control During BIM Design* [43]. The thesis demonstrated how integrated design could be improved by using BIM and IFC data transfer and a methodology of integrated BIM design were developed. In relation this methodology an IFC interface for the Danish calculation tool Be06 was also developed. Findings and conclusions stated are has been utilized further in the current thesis when developing the data transfer potential; main part II. The key conclusions from the thesis are as stated below:

- Further attention needs to be directed on how information stored in the BIM-model become valid for other in the BIM-process
- The IFC capability was indentified for five EEDDSS tools and it was found that 70% of the required information could be derived from the IFC-file.
- Guidelines of how to use BIM in the design process and further demonstration projects are needed to gain a better BIM-process.
- Information for spaces and space boundaries could preferably have been utilized better when developing the IFC interface.

2.5.3. Integrated design and BIM in energy retrofitting projects

Recently, the tendency of using BIM in the AEC industry for retrofitting projects has increased. Central findings from different research and practical projects are described below.

The research project *"Digital opmåling og registrering[24]"* describes several benefits from using BIM in retrofitting projects. The benefits of using BIM relevant to the current thesis are described below.

[24] Reseach project performed by the Landowners' Investment Association (GI)

- Stores geometrical representations and other information about the building, which are beneficial in future retrofitting projects
- Creates overviews of small and large building portfolios
- Counting of building elements, areas, prices, etc
- Control of collision between existing building parts and new retrofitting measures

The BIM-model increases the visual understanding of the project and creates a better dialog between consultants, building owner, and tenants [59]. This finding is also one of the main conclusions from a retrofitting project performed on a Danish hospital where BIM was used as a central tool [15].

One of the main challenges when using BIM in retrofitting projects is the digitalization of the existing geometry. How are the geometries of different building elements obtained and which level of complexity is needed. These questions are answered in the publication *"Digitalt landkort[25]"* [38]. The publication presents a table listing digital measurement tools for geometrical analysis, which could be used to obtain the existing conditions of a building on different level of complexity (Annex G).

On the face of it, integrated design seams most suitable for new buildings, as many design parameters are fixed by the existing conditions in a retrofitting project. However, integrated design is still beneficial in retrofitting projects. For instance a building owner wants to invest in a new mechanical cooling system. Instead of investing in a new cooling system which is dimensioned to the existing cooling demand, it might be beneficial to reduce the cooling demand of the house and invest in a smaller and less costly system. This cost saving might be larger than the investment cost of a new solar shading system which can reduce the cooling demand [50].

[25] Translated to English: A digital map

3. Development of a design process method for using BIM and integrated design in energy retrofitting projects

3.1. Introduction

As stated in the literature survey, BIM-models may contain lots of information, which may vary in detail. The BIM-model should only be developed to an information level which corresponds to what is required in the building construction process. This part of the thesis indentifies which information that is required in the design process of an energy retrofitting project, to perform analyses in WinDesign and Visualizer. The information is gathered in a design process method based on IDM and it is named Information Delivery Manual on Energy Retrofitting (IDMoER). It structures information flows and activities and relate it to the BIM-model. According to the focus of the thesis, only the pre-design and concept design phases are described.

3.2. Analysis of input data required for WinDesign

As mentioned in part 2.2.4, the structure of WinDesign is divided into 4 steps. WinDesign does not have a geometrical engine, hence, all geometrical values should be defined numerical. Simulations can be performed on the entire building level and for each of the rooms in the building, and input data will therefore refer to both the entire building and each room. As the thesis is delimited to step 2 and 3, only these steps are described further.

The user interfaces for input data in WinDesign (step 2 and 3) are shown in Annex H.

Table 9 Specification of input data for step 2 in WinDesign (Building information).

Input data for Step 2 in WinDesign (Building information)	
Dimensions (internal)	Heated floor area (m^2)
	Floor to ceiling height (m)
Constructions	Wall area (m^2)
	Roof area (m^2)
	Floor area (m^2)
	U-value wall (W/m^2K)
	U-value roof (W/m^2K)
	U-value floor (W/m^2K)
	Length walls/roof (m)
	Length walls/floor (m)
	Length walls/window (m)
	Ψ value walls/roof (W/mK)
	Ψ value walls/floor (W/mK)
	Ψ value walls/window (W/mK)
Internal gains	Internal gains (W/m^2)
Infiltration	Infiltration (h-1)
Ventilation	Ventilation rate (h-1)
	Efficiency of heat recovery unit (-)
Setpoint temperatures	Heating (°C) and Cooling (°C)

Table 10 Specification of input data for step 2 in WinDesign (Room information).

Input data for Step 2 in WinDesign (Room information)	
Window	Area (m^2)
	U-value (W/m^2K)
	g-value (-)
	Orientation (°)
	Tilt angle (°)
	Shadings from surroundings (°)
	Shadings from overhang (°)
	Shadings from side fins (°)
	Number of equal windows in same room (-)

Table 11 Specification of input data for step 3 in WinDesign. Only input data for one room is shown. However, with similar input data, it is possible to define up to 12 rooms in WinDesign.

Input data for Step 3 in WinDesign		
General room data	Heating and cooling	Heating/cooling setpoint (°C)
	Venting	Venting rate (h-1)
		Setpoint (°C)
	Indoor thermal comfort evaluation	Temperature (°C)
Individual room data	Room 1	Floor area (m^2)
		UA - value (W/K)
Weather data	IWEC weather file	

3.3. Analysis of required input data for Visualizer

In Visualizer the building is defined in 6 steps, and it mainly requires information regarding the building geometry. Much of this information can be defined by the model import function as described in part 2.2.5 (Table 12).

Table 12 required input data for Visualizer. DIM.: Dimension

Steps in Visualizer to define the building geometry	Description	Steps which are supported by the import function
Step 1: Floor/Walls	Dim. and location of floor and walls	X
Step 2: Roof/Ceiling	Dim. and location of roof and ceiling	X
Step 3: Windows/Doors	Dim. and location of windows and doors	X
Step 4: Surfaces	Texture, color, specularity, roughness	
Step 5: Furniture	Selection of pre defined furniture's	
Step 6: Location	Longitude, latitude, and north orientation	

3.4. The Design process method

As stated in the literature survey, IDM is a method that describes and identifies the processes undertaken within building construction projects and the relation to BIM applications. The method of IDM is used and elaborated in the following part to describe activities, intensions, and information flow in the pre-design and concept design phases for energy retrofitting of buildings. ArchiCAD is used as BIM-application, and WinDesign and Visualizer are used regarding analysis of energy consumption and indoor environment. As mentioned above, in the current thesis, the design process method will be referred to as IDMoER (Figure 19).

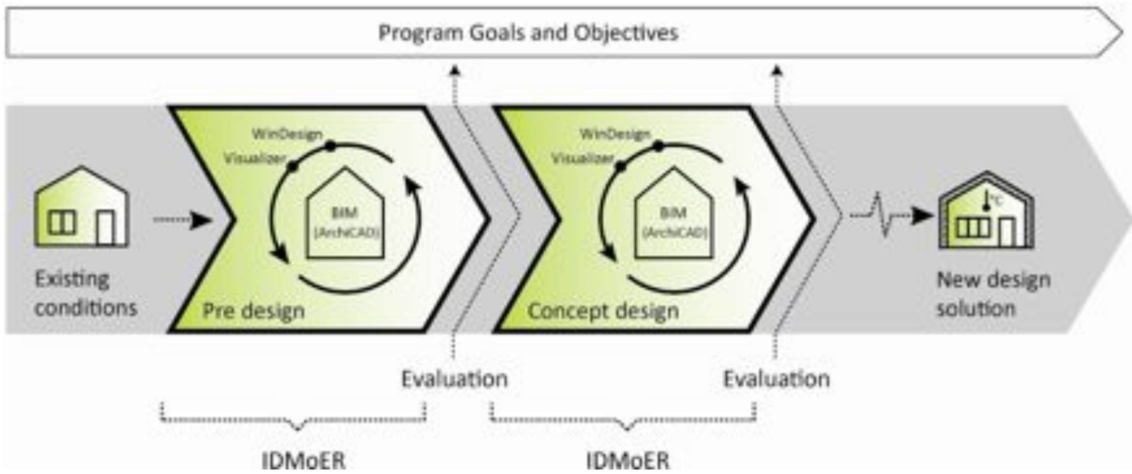


Figure 19 Illustration of the integration of ArchiCAD, WinDesign, and Visualizer in the pre-design phase and concept design phase for an energy retrofitting project. IDMoER is used to structure and describe the process flow and activities in the BIM-process within each phase. The last bended arrow indicates that the design process continues.

The technical architecture of IDM is composed by a process map, exchange requirements, and functional parts, see part 2.3.4. The same composition is used for the development of IDMoER. However, this part only focuses on the process map and exchange requirements.

3.4.1. IDMoER for the pre-design phase

The main intention of the pre-design phase is to develop and demonstrate potential design solutions. As described in the literature survey, an important issue in the pre-design phase is to motivate the client to take initiative. The IDMoER for the pre-design phase has this issue as its main focus. The design solutions must be performed fast with reliable and comprehensible results to engage the client. ArchiCAD is used as BIM-application to administrate and illustrate the design solution. Descriptions of how to develop the BIM-model in ArchiCAD is presented in part 4.2.4.2. WinDesign (step 2) and Visualizer are used to perform analyses of the energy consumption and indoor environment. To optimize the process speed, the client is imposed to gather the information of the existing conditions, which are required by the consultancy to perform the design solutions.

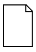
3.4.1.1. Process map description

- General idea:

The process map illustrates a chronological progression in the pre-design phase starting with a request from the client and ending with a potential design solution (Figure 20). Different consultants are involved and will perform different activities during the design process. When a design solution is finished a loop in the process will allow the development of a new design solution.

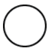
- Pools/Swim lanes: 

The pool represents the consultants which are involved in the design process. Each consultant is divided within individual swim lanes. The consultants represented are a cost consultant, an architectural consultant, a structural consultant, a BIM- consultant, and an energy consultant. The consultants represent a multidisciplinary consultancy. The client is also represented in a swim lane. However, even though the consultants are divided in different swim lanes, they are not stopped from working as a team.

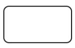
- Data objects: 

The data objects define specific information which is used or produced by the consultancy. An energy retrofitting project relies on the existing conditions. This information should therefore be provided by a data object. Another fundamental issue for the energy retrofitting project is to gain an insight of the project boundaries set by the client. These will be defined by the client's requests for the level of energy reduction, cost and retrofitting measures. In addition, weather data is needed to perform a trustworthy evaluation of the energy consumption by WinDesign. To perform evaluations of the project cost, also economic data is needed.

This leads to a set of data objects consisting of *existing conditions, client's requests concerning energy, client's request concerning retrofitting measures, client's request concerning cost, weather data, and economical data.*

- Events: 

The energy retrofitting process is started by a request from the client, which is illustrated as the *start event*. As the consultancy has finished a design solution they may develop a new alternative solution, which is illustrated as a loop. When sufficient design solutions are performed, the client will decide whether to choose one of the design solutions and continue with the concept design phase or decline. His choice will mark the end of the design process as the *end event*.

- Activities: 

The activities describe the work performed by the consultancy between the start and end events.

The documentation of the existing conditions provided by the client has to be determined for the further ongoing evaluations. Due to the intention of the pre-design phase, it is important that the description of the existing conditions is performed on a simple level. The existing condition is used for different purposes in the further ongoing evaluations, wherefore the description is divided by construction type, building type, building outline, installations, energy consumption, and indoor environment. Default values are used to perform a simple determination of the construction and building type. These entail uncertainties in the energy evaluation, but ensure a simple, cost-effective and fast process. The building outline represents the geometry of the existing building which is important in order to gain an overview of the composition and distribution of the building. The geometry is used to create a BIM-model by ArchiCAD, which then represents the existing building; *BIM-model (level 1.0)*. The accuracy of the geometry should be kept simple.

Based on the existing conditions and requests from the client, different design solutions are analyzed in WinDesign and Visualizer. The cost of the design solutions is further estimated. Results are evaluated, and the geometry of the BIM-model is adjusted hereupon; *BIM-model (level 1.1)*.

Subsequently, an architectural evaluation ensures that the suggested design solution is realizable according to room distributions, building functions, and stability. In case the design solution may not live up to the architectural requirements, the analysis in WinDesign and Visualizer will be performed once again.

If no problems occur in the architectural evaluation, the retrofitting measures can be elaborated and the BIM-model is updated; *BIM-model (level 1.2)*. Together with the results from WinDesign and Visualizer, the *BIM-model (level 1.2)* presents a design solution for the pre-design phase.

- Gateways: 

The *Gateways* represent activities, which may change the flow of the design process. The architectural evaluation described above and the decisions of the client are considered as *Gateways*.

3.4.1.2. Process map illustration

The process map description above, is illustrated by the BPMN method (Figure 20). The figure is enclosed in a bigger scale in Annex I.

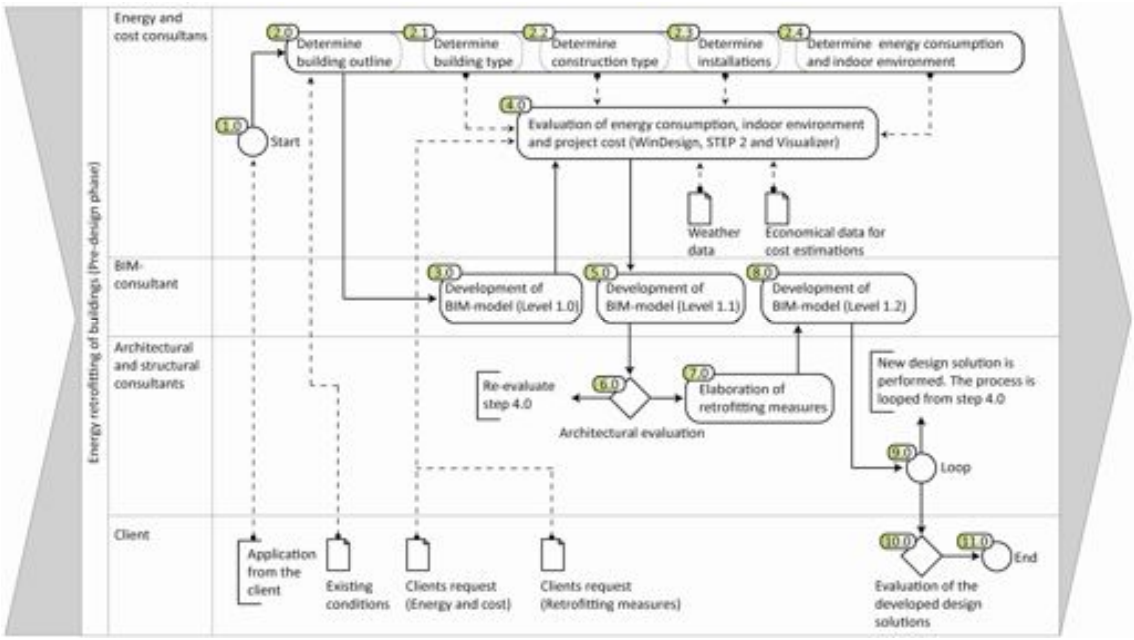


Figure 20 Process map illustrating the complexity of the pre-design phase. The figure is divided into four swim lanes representing the consultants who are involved in the process. The solid arrows indicate the process flow and the dotted arrows indicate the information input from data objects. Numbers indicate different activities, events, and gateways, and they represent the progression of the process. The figure is found in a bigger scale in Annex I.

3.4.1.3. Exchange requirements

All elements (events, activities, and gateways) and information flows illustrated in Figure 20 are individually described below. The ID numbers assigned in the process map illustration refer to the description in Table 13.

Table 13 Description of exchange requirements for the pre-design process map

ID	Description	Information input	Information output
1.0	*Event: Start.* The design process is started by an application from the client	-	-
2.0	*Activity: Determine building outline*. The building outline represents the internal and external geometry of the building. Dimensions are found from digital photos and original 2D drawings.	- Digital photos of the building - Original 2D drawings	- Geometrical representations of external walls, floor, roof, and windows (m^2) - Distribution of internal walls
2.1	*Activity: Determine building type.* The type of building is evaluated and standard values are stated.	- Digital photos of the building - Original 2D drawings - Energy label	- Internal gains (W/m^2) - Infiltration (h^{-1}) - Natural ventilation(h^{-1})
2.2	*Activity: Determine construction type.* The construction types are evaluated.	- Digital photos of the building - Original 2D drawings - Energy label - Home condition report	- U values of walls, floors, roof, and windows (W/m^2K) - Ψ values for joints (W/mK) - g values for windows
2.3	*Activity: Determine installations.*	- Digital photos of the building - Original 2D drawings - Home condition report	- Ventilation rate (h-1) - Efficiency of heat recovery unit (-) - Efficiency of domestic hot water system
2.4	*Activity: Determine energy consumption and indoor environment.* Previous energy consumptions and experiences with the indoor climate are determined and used for comparison with new design solutions.	- Previous energy bills - Home condition report - Previous experiences with the indoor environment	- Previous energy consumption (kWh/m^2) - Conditions of the indoor environment
3.0	*Activity: Development of BIM-model (Level 1.0).* A BIM-model is created based on the outline of the existing building.	- Internal and external geometry of the building as stated in 2.0.	WinDesign: - Heated floor area (m^2) - Floor to ceiling height (m) - Areas for external walls, roof, floor, windows, and doors (m^2) - Orientation of windows and doors (°) - Line Length between constructions (m) Visualizer: -Geometrical representation

4.0	*Activity: Evaluation of energy consumption, indoor environment, and project cost.* They are evaluated for different design solutions by use of step 2 in WinDesign and Visualizer.	- Information inputs are obtained from output generated in: 2.1, 2.2, 2.3, and 3.0. These information are supplemented by: - Clients request (energy) - Clients request (retrofitting measures) - Weather data file (Danish Reference Year (DRY) - Economical data for cost estimation	- Adjusted building geometries and properties of materials. - Energy consumption of a potential design solution (kWh/m^2) - Length of cooling and heating season (days) - Visual environment (DF) - Estimation of project cost (Dkk)
5.0	*Activity: Development of BIM-model (Level 1.1).* The BIM-model (level 1.0) is adjusted according to the design solution found in 4.0	- Adjusted building geometries from 4.0	- Representation of design solution stated in 4.0
6.0	*Gateway: Architectural evaluation*. The architectural evaluation shall ensure that the design solution is realizable: - No collisions are present between existing conditions and retrofitting measures made in the design scenario. - No static failures will occur in relation to the retrofitting measures.	- The BIM-model (Level 1.1) from 5.0	- Acceptance or rejecting of design solution.
7.0	*Activity: Elaboration of retrofitting measures*. The retrofitting measures are elaborated and specific materials and expressions are stated.	- The BIM-model (Level 1.1) from 5.0	- Specific materials and architectural solutions used for the retrofitting measures.
8.0	*Activity: Development of BIM-model (Level 1.2)*. The BIM-model (level 1.1) is adjusted according materials and architectural solutions found in 7.0	- Materials and architectural solutions from 7.0	- Representation of the final design solution for the pre-design phase
9.0	*Activity: Loop*. A new design solution may be performed starting in 4.0	-	-

10.0	*Gateway: Evaluation of the developed design solutions.* The client decide whether to continue the design process in the concept design phase or to decline the design solution.	Results from the activities: 4.0 and 8.0.	- Acceptance or rejecting of design solution.
11.0	*Event: End.* The pre-design phase is ended.	-	-

3.4.2. IDMoER for the concept design phase

The main intention of the concept design phase is to elaborate the design solution found in the pre-design phase. Focus is mostly on further analyses of the energy consumption and indoor environment as the architectural boundaries are set from the pre-design phase. However, architectural and structural evaluations are still present to ensure a proper design solution. WinDesign (STEP 3) is used to perform more accurate analyses of the energy consumption and thermal indoor environment. Visualizer is further used to analyze the visual environment.

3.4.2.1. Process map description

- General idea:

The process map illustrates a chronological progression in the concept design phase (Figure 21). It is started by the client's acceptance of a further design development of one selected design solution from the pre-design phase. When the concept design process ends, the selected design solution will be further detailed and prepared for the design development phase.

- Pools: 

The consultants are the same as for the pre-design phase. However, the cost consultant will have a separate swim lane as the cost estimation is no longer a part of the design optimization.

- Text annotation: 

Not all information are stored in the BIM-model, WinDesign, and Visualizer. To consider these information in the process map, a text annotation ensures that all the gathered experience from the pre-design phase are passed on to the concept design phase.

- Data objects: 

New data object are necessary to complete the concept design phase. In case that the client has elaborated requests to the retrofitting measures, these will have to be implemented in the design solution.

The information from the pre-design phase stored in the BIM-model, WinDesign, and Visualizer function as data inputs in the current concept design phase and is re-modified to contain updated and more detailed information.

Specific weather data should be implemented in the WinDesign model to optimize the accuracy of the calculations.

To ease the future cost estimations, the BIM-model is further developed to contain information on material costs.

This leads to a set of data objects consisting of *elaboration of the clients request concerning retrofitting measures, economical data for cost estimation, material properties, BIM-model (Level 1.2), Specified weather data, Visualizer, and WinDesign (step 2).*

Events:

Start and end events are present, corresponding to the process map developed for the pre-design phase. However, no loop in the design process is present as the fundamental design solution already is stated in the pre-design phase.

Activities:

In case that the client has elaborated requests for the retrofitting measures, these will be evaluated, and implemented in the BIM-model (Level 2.0), which then contains the updated information of the design solution. Cost information on materials are also implemented and used for cost estimations.

Based on the elaborated information from the BIM-model (Level 2.0) and the specific weather data, the energy consumption and indoor environment are calculated in WinDesign (STEP 3) and Visualizer. The elaborated design solution found by the analyses in WinDesign and Visualizer is implemented in the BIM-model (Level 2.1).

An architectural evaluation of the elaborated design solution is performed. It should re-ensure that no errors are present according to room distribution, functions, and statics. The architectural expression of the retrofitting measures are further evaluated and implemented in the BIM-model (Level 2.2).

The project cost is estimated in accordance with the elaborated design solution to ensure that it is realizable within the budget set by the client.

3.4.2.2. Process map illustration

The process map description above in part 3.4.2.1, is illustrated by the BPMN method (Figure 21). The figure is found in a bigger scale in Annex I.

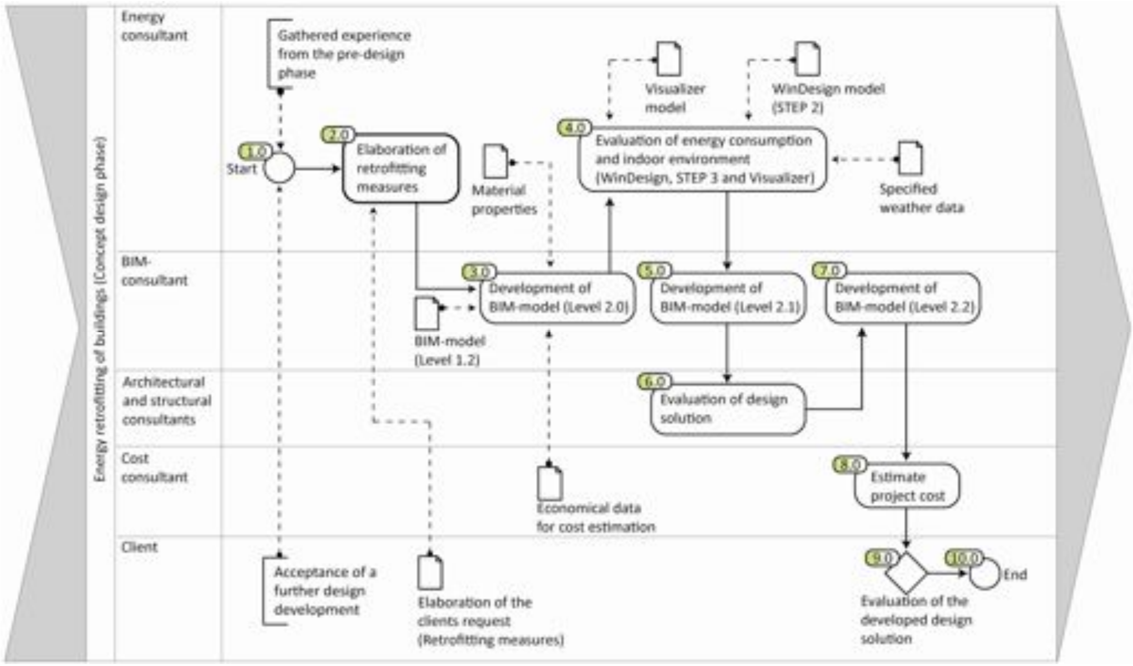


Figure 21 Process map illustrating the complexity of the concept design phase. The figure is divided into five pools representing the consultants who are involved in the process. The solid arrows indicate the sequence flow and the dotted arrows indicate the information input from data objects. Numbers indicates different events, activities and gateways and represents the progression of the process.

3.4.2.3. Exchange requirements

All elements (events, activities, and gateways) and information flows illustrated in Figure 21 are individually described below. The ID numbers assigned in the process map illustration will refer to the description in Table 14.

Table 14 Description of exchange requirements for the concept design process map

ID	Description	Information input	Information output
1.0	*Event: Start.* The design process is started by the client's acceptance of a further design development of one selected design solution from the pre-design phase	-	-

2.0	*Activity: Elaboration of retrofitting measures*. In case that the client has elaborated requests for the retrofitting measures, these are evaluated.	- Selected design solution from the pre-design phase. - An elaboration of the clients requests for the retrofitting measures.	- Elaborated design solution
3.0	*Activity: Development of BIM-model (Level 2.0).* The BIM-model (Level1.2) is elaborated according to the elaborated retrofitting measures. Material cost and material properties are also assigned.	- Elaborated design solution from 2.0 - Material properties (U-values and g-values) - Material cost	WinDesign: - Heated floor area (m^2) - Floor to ceiling height (m) - Areas for external walls, roof, floor, windows, and doors (m^2) - Line Length between constructions (m) - Cost of materials - U-values of material - g-values for windows and doors Visualizer: -Geometrical representation
4.0	*Activity: Evaluation of energy consumption and thermal indoor environment.* WinDesign (STEP 3) and Visualizer are used for analysis.	- Information inputs are obtained from output in 3.0 These information are supplemented by: - Specific weather data file (IWEC-format)	- Adjusted building geometries - Energy consumption of the design solution (kWh/m^2) - Thermal indoor environment (°C) - Visual environment (DF)
5.0	*Activity: Development of BIM-model (Level 2.1).* The BIM-model is adjusted according to the design solution found in 4.0	- Design elaborations found in 4.0	- Representation of the design solution illustrated by the BIM-model (Level 2.1)
6.0	*Activity: Architectural evaluation*. Re-ensure that no errors are present according to room distribution, functions, and statics. Specify expression of retrofitting measures.	- The BIM-model (Level 2.1) from 5.0	- Specific materials and architectural solutions used for the retrofitting measures. -Composition of building components
7.0	*Activity: Development of BIM-model (Level 2.2).* The BIM-model is adjusted according to 6.0	- Materials and architectural solutions from 6.0	- Final design solution for the concept design phase

8.0	*Activity: Estimate project cost*. The total project cost is estimated to ensure that the retrofitting measures fits within the economical request stated by the client.	- Output data for 7.0	- Estimation of project cost (Dkk)
9.0	*Gateway: Evaluation of the developed design solution.* The client decides whether to continue the design process in the design development phase or to decline the design solution	Results from the activities: 4.0, 7.0, and 8.0.	- Acceptance or rejecting of design solution.
10.0	*Event: End.* The concept design phase is ended.	-	-

4. Development of data transfer potentials with IFC

4.1. Introduction

In the IDMoER described in part 3, WinDesign and Visualizer is used as analyzing tools which have to benefit from the information stored in the BIM-model created by ArchiCAD. The following part will be about how this information may be transferred between the three applications. However, as described in the literature survey, Visualizer already has a data-import function. Thus, its interaction with the BIM-model is not analyzed further in this part. WinDesign does not allow such interaction. Therefore, in the following part an IFC-import capacity for WinDesign is developed. From the information output described within the exchange requirements in part 3.4.1.3 and 3.4.2.3 it is stated which data the BIM-model shall transfer to WinDesign. The data transfer capacity developed in the following part, will comply with these data only.

4.2. Development of IFC-import capacity for WinDesign

The current part describes the development of an IFC-import capacity for WinDesign which makes it usable in the IDMoER´s. It is developed by use of IFCsvr described in part 2.3.3.3. In Visual Basic and Excel the IFCsvr is used to locate and gather information stored in the IFC-file exported by ArchiCAD. It is developed only to work for IFC-files in the format 2x3 created by ArchiCAD. The development is based on findings within the thesis "*Integrated Data and Process Control During BIM Design*" [43] described in part 2.5.2.

To gain an overview of the following part, a strategy for the IFC-data process from the BIM-model to WinDesign is described. Further, the elements within the strategy are described in greater detail.

4.2.1. Strategy for the IFC-data process

The strategy is started by that the exportation of an IFC-file from the BIM-model. By use of IFCsvr a VBA script then locate the input data for WinDesign and store it in Excel sheets (the IFC-collector). Finally, a VBA script locates the stored data in the IFC-collector and import them to the correct positions in WinDesign.

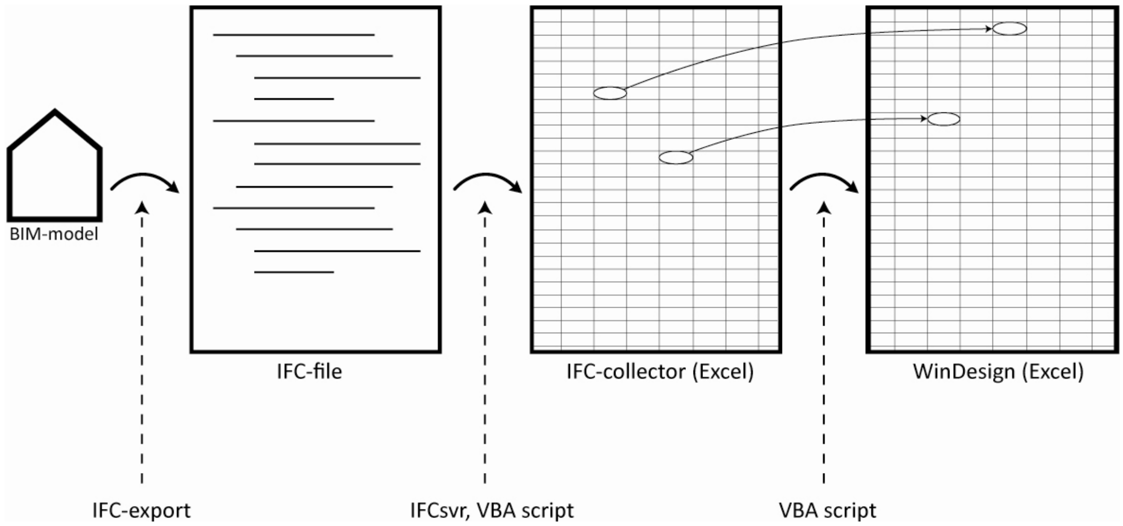


Figure 22 Illustration of the IFC-import strategy from the BIM-model to WinDesign through the IFC-collector

BIM-models may be developed in many different ways, which results in different IFC-files. Further, many settings in the BIM-application may influence the IFC-file which are exported. In order to develop a BIM-model, which can export IFC-files containing the stated input data for WinDesign, it is important to understand the IFC-files' possibilities to store the input data for WinDesign. This issue will be analyzed in part 4.2.2, where IFC entities that satisfy the input data for WinDesign are located. Based on this analysis, an instruction for developing a BIM-model, which is capable of exporting a suitable IFC file, is presented in part 4.2.4.

4.2.2. Input data for WinDesign and IFC possibilities

In IDMoER the input data for WinDesign was stated. These and entities which may contain the data are presented below (Table 15).

Table 15 Presentation of input data for WinDesign (step 2 and 3) and entities, which may contain the data. Some of the required input data is not shown, because they can be derived from other input data in the table

Input data for WinDesign (Step 2 and 3)	IFC - entities
Total wall area	IfcPolyline
Total roof area	IfcPolyline
Room floor area	IfcPolyline
U-value wall	IfcPropertySingleValue
U-value roof	IfcPropertySingleValue
U-value floor	IfcPropertySingleValue
Line length walls/roof	IfcQuantityLength
Line length walls/floor	IfcQuantityLength
Line length walls/window	IfcWindow
Window area/Door area	IfcWindow/IfcDoor
U-value Window/door	IfcPropertySingleValue
g-value Window/door	IfcPropertySingleValue
Orientation Window/door	IfcPropertySingleValue

4.2.3. Relation between IFC entities

In order to locate and use the data stored in the entities shown in Table 15, their relation to the building has to be identified; where are the walls located, which windows are placed in a specific wall, etc. Such relations are also defined by entities (Figure 23).

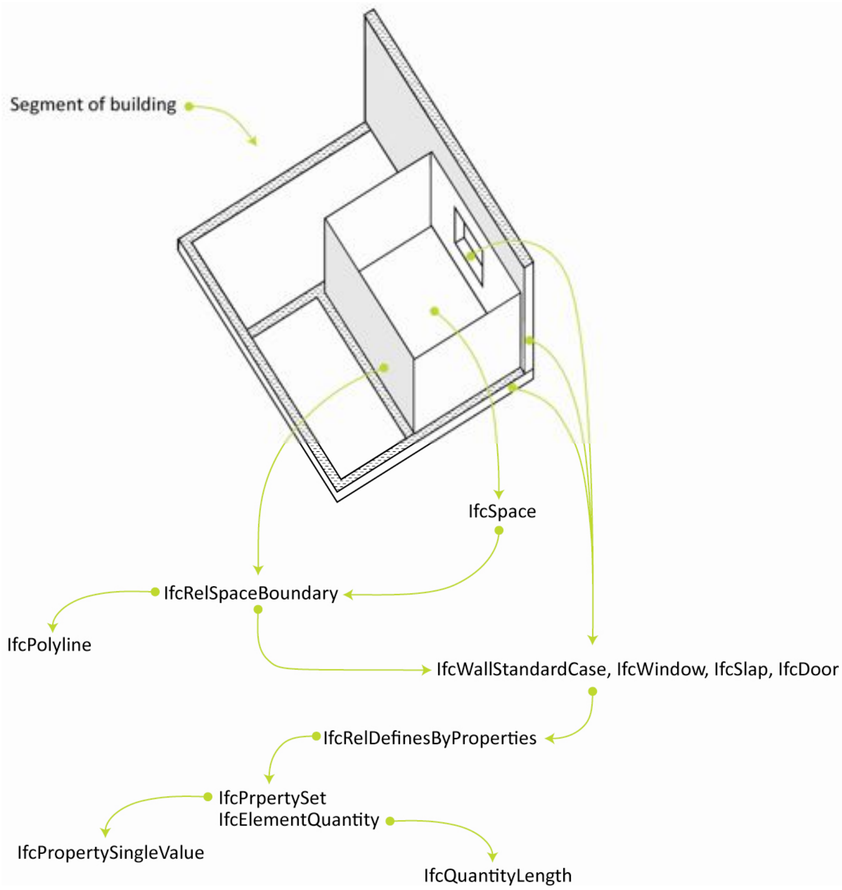


Figure 23 Presentation of entities used to collect the required input data for WinDesign and their relation to each other.

The entity *IfcSpace* represents a room in the building. *IfcSpace* is connected to a set of boundaries (*IfcRelSpaceBoundary*) and all building elements (*IfcWallStandardCase*, *IfcWindow*, etc.) within its contact. An example of how to locate the u-value of a specific wall (wall 1) connected to a specific room (room 1) is demonstrated below:

Locate the *IfcSpace* representing room 1 -> locate the *IfcWallStandardCase* representing wall 1 -> locate the *IfcRelDefinesByProperties* which is connected to the located *IfcWallStandardCase* and also has an *IfcPropertySet* connected -> locate the *IfcPropertySingleValue* connected to the *IfcPropertySet* -> locate the u-value.

4.2.4. Development of BIM-model and adjustments IFC-export settings

This thesis uses ArchiCAD to develop the BIM-model. Thus, the following part is based on this application. In general the BIM-model is developed in normal manners by creating floors, walls, roofs, doors, windows, etc. However, relevant issues in relation to the interaction between BIM-model and WinDesign are described. The description is divided in two parts.

1. General IFC-settings in ArchiCAD
2. BIM-model development in ArchiCAD

4.2.4.1. General IFC-settings in ArchiCAD

Several IFC-settings may be defined in ArchiCAD. Three setting dialogs are placed under *File* -> *File Special* -> *IFC 2x3*.

- *IFC-manager*
- *Options*
- *Merge to IFC-model*

In the *IFC-manager* it is possible to view and adjust the IFC-structure of the model. The IFC-manager also provides possibilities to ad properties to the different objects in the BIM-model (walls, windows, etc). In the *Options dialog* general settings regarding the IFC-export can be set. The *Merge to IFC-model* will export the BIM-model to an IFC-file.

The IFC-manager and Options dialogs are shown in Annex J.

4.2.4.2. BIM-model development in ArchiCAD

In part 5, two case studies will be performed of a single family type house and a simple office building. Therefore, the BIM-model development and IFC-settings for such building types are described in the following. In relation to the IDMoER developed in part 3, the descriptions will be divided in *pre-design* and c*oncept design*. In IDMoER the BIM-model is developed in different levels within the pre-design and concept design phase. However, only geometry adjustments make the difference between level 1.0 and 1.1/1.2, and 2.0 and 2.1/2.2. Thus, the following description is based only on level 1.0 for the pre-design phase and 2.0 for the concept phase.

- Pre-design (Single family type house*)*

Walls (Figure 24)

Place external and internal walls and specify in the IFC-manager:

-> IFC-manager->locate external walls in the containment structure-> Pset_WallCommon->IsExternal-> True.

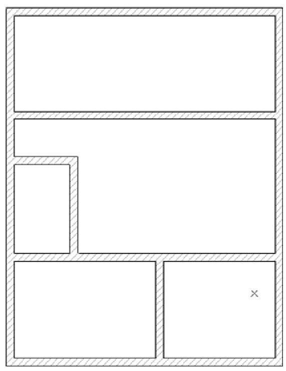


Figure 24 Illustration of BIM-model development (Walls)

Zones (**Figure 25**)

Place all internal zones and specify in the IFC-manager:

-> IFC-manager->locate the internal spaces in the containment structure -> Attributes (IfcSpace):

->LongName -> type in a unique name for the space

-> InteriorOrExteriorSpace -> Internal

Note: The IFC-manager refers to zones as spaces. Adjusting the zone name will NOT change the LongName.

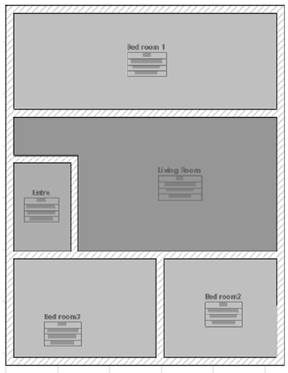


Figure 25 Illustration of BIM-model development (Zones)

Doors and windows (Figure 26)

Place all doors and windows and specify in the IFC-manager:

-> IFC-manager->locate the external doors in the containment structure -> Create New Property:

Name of P.Set: Pset_DoorCommon
Name of Property: Orientation
Type of Property: IfcSolidAngleMeasure

The procedure is also done for all external windows and orientations are filled in.

Note: Doors and windows shall be placed with a lower placement-level of minimum 1 mm.

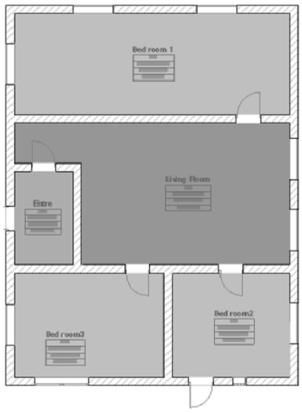


Figure 26 Illustration of BIM-model development (Doors and windows)

Floor and roof (Figure 27)

Place all floors and roofs and specify in the IFC-manager:

External floors:

-> IFC-manager->locate the external floors in the containment structure -> Pset_SlabCommon->IsExternal-> True.

-> IFC-manager->locate the external floors in the containment structure -> Attributes(IfcSlab) -> Description -> Type in: Foundation

Roof:

-> IFC-manager->locate the external roofs in the containment structure -> Attributes(IfcSlab) -> PredefinedType -> Roof

Note: If the insulation is placed in the ceiling, this needs to be defined as the external roof. For all other roofs which are created in the BIM-model the PredefinedType should be NOTDEFINED.

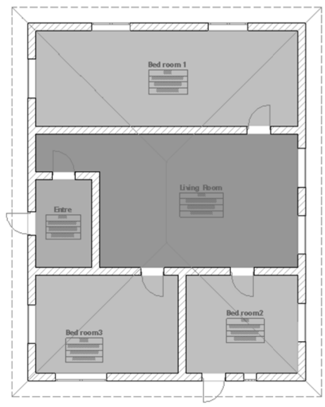


Figure 27 Illustation of BIM-model development (Floor and roof)

Before the BIM-model is exported as IFC-file, some general IFC-settings needs to be set in the *Options dialog*. The correct IFC-settings are shown in Annex J.

- Concept design (Single family type house)

- U-values and g-values (Figure 28)

Properties for building components are adjusted and new are assigned in the IFC-manager.

U-values are assigned to all external componets:

-> IFC-manager->locate the external component in the containment structure -> Pset_(Component)Common -> ThermalTransmittance

g-values are assigned to all external windows and doors:

-> IFC-manager->locate the external windows and doors in the containment structure -> Create New Property:

Name of P.Set: Pset_(Door/Window)Common
Name of Property: SolarEnergyTransmittance
Type of Property: IfcThermalTransmittance

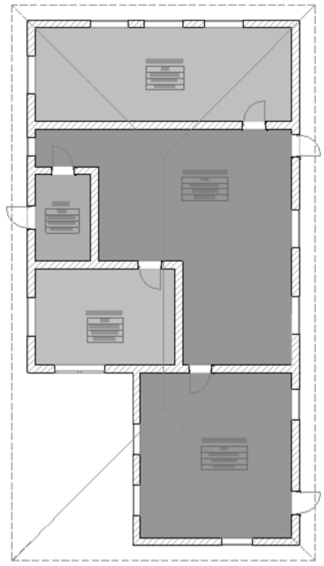


Figure 28 Illustration of BIM-model development (U-values and g-values)

The u-values and g-values are typed in for all the components.

The general IFC-export settings described for the pre-design phase are also used for the concept design phase (Annex J).

- Pre-design/Concept design (Simple office building)

A BIM-model representing a simple office building is in general developed from the same progression described for the single family house above. However, a number of precautions have to be obeyed.

WinDesign may only analyze up till 12 rooms on the same storey. In case that the office building consists of more than 12 rooms and more than one storey, only a section of the building should be imported from the BIM-model. The *IFC-collector* described in the following part is developed to gather information for each room, which are defined by a zone (space) in the BIM-model. Thus, only zones (spaces) in a section consisting of 12 rooms or less on the same floor should be defined in the BIM-model.

4.2.5. Development of the IFC-collector

The *IFC-collector* collects and prepares all the input-data from the IFC-file for WinDesign. This is performed in two steps. Firstly, the raw IFC-data is collected and stored in the Excel sheet *"IFC-Information"*. Secondly, the stored IFC-data is prepared in another Excel-sheet *"IFC-input for WinDesign"* for importation to WinDesign, see Annex K.

4.2.5.1. Collecting the raw IFC data

The collection of the raw IFC data is performed by a VBA script developed in Visual Basic by using the IFCsvr ActiveX component. The following part will describe the main structure of the script and how it works. The entire script is shown Annex L, where its structure can be obtained in detail. An overview of how the script collects the raw IFC data is presented in (Figure 29).

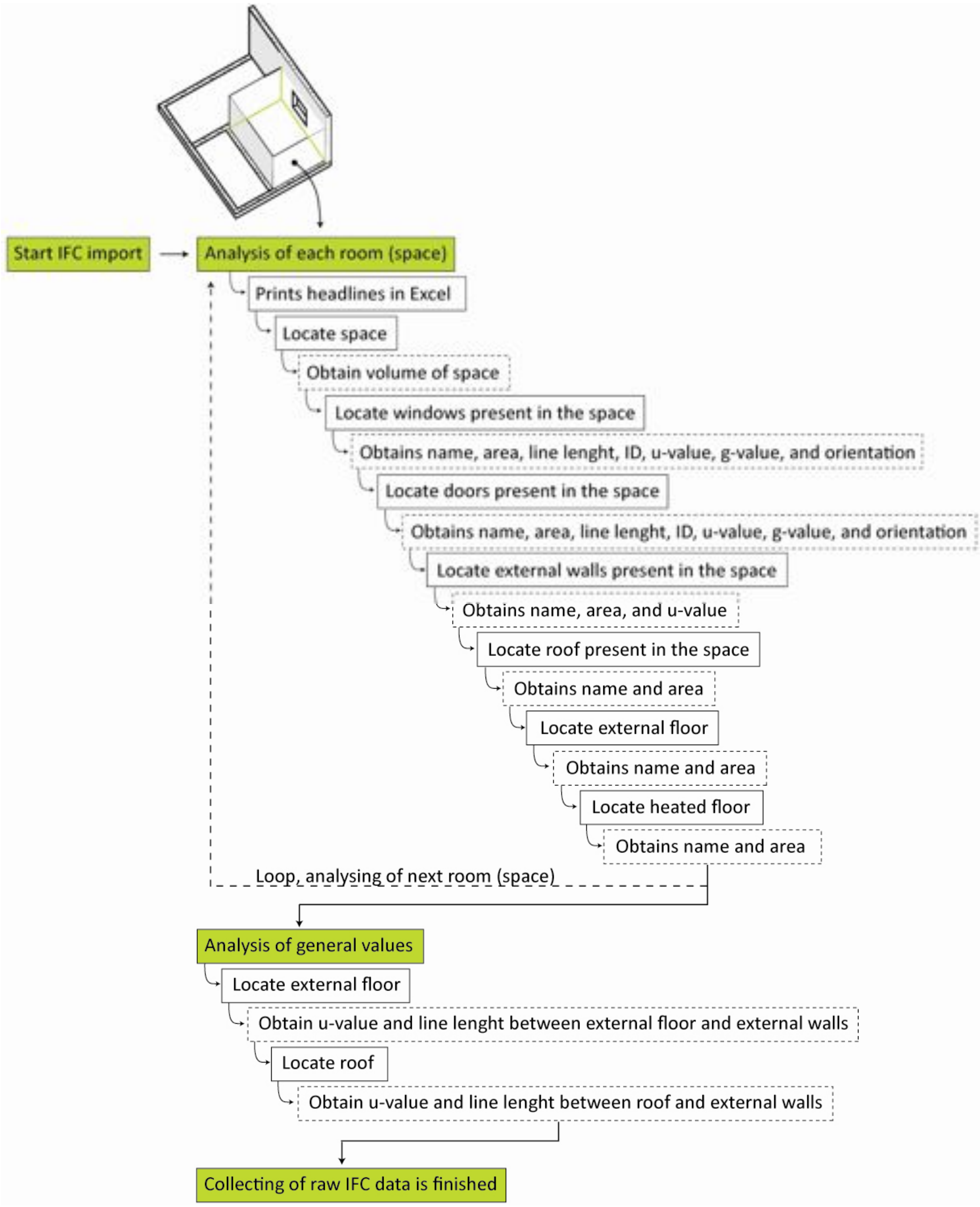


Figure 29 Illustration of how the IFC-import capacity for WinDesign collects the raw IFC data. Each time a value is obtained it will be printed to the excel sheet "IFC-Information".

A description of the main structure of the script is presented below:

- Start import of IFC-data:

The script is started by defining a number of general settings. The IFCsvr ActiveX component is activated for use in the following script. The script examines if the IFC-file is in the format of 2x3 and if the IFC-file is created by ArchiCAD. When these statements are confirmed, the script will begin to locate the input data for WinDesign.

- Analysis of each room:

Most of the input data required for WinDesign refers to the specific rooms in the building. Thus, the IFC-data is analyzed for each room present in the BIM-model.

All headlines representing the input data are printed horizontally to the Excel sheet *"IFC-Information"*. The raw IFC-data will be stored under each headline. This action is done for each zone (space) defined in the BIM-model. Values for each headline are allowed to expand vertically under the headlines. In case, for instance, that three windows are present in one room, three different areas are collected and stored in three individual cells under the headline *WinDoor Area*. This concept is used to collect and store all values, which refer to a specific room.

Each room is analyzed as described in the following:

The volume is found, and this value is present in the entity *IfcQuantityArea*, and it is collected directly from there.

Windows and doors related to the room are analyzed. From the entity *IfcWindow* and *IfcDoor* the height and width of the window and doors are found. From these values the area and line lengths are calculated. Each window and door is assigned with an ID equal to 1. The ID works as an activation sign so that WinDesign knows that a window or door is present.

Properties for the windows and doors are found. The u-value, g-value, and orientation are all found in the *IfcPropertySingleValue*. These values are stored in the BIM-model as described in part 4.2.4.2.

External walls related to the room are analyzed. As WinDesign operates with internal dimensions, the areas are found from boundaries of the room, which are related to an external wall. From the entity *IfcPolyline* related to such boundaries, the area can be found. The *IfcPolyline* is defined by coordinates. From these coordinates the internal area of the external wall is found from equation (1.11).

$$(1.11) \quad Area = \frac{1}{2}\left(X_1 \cdot Y_2 - X_2 \cdot Y_1 + X_2 \cdot Y_3 - X_3 \cdot Y_2 + \cdots + X_{n-1} \cdot Y_n - X_n \cdot Y_{n-1} + X_n \cdot Y_1 - X_1 \cdot Y_n\right)$$

As for the windows and doors, the u-value for the walls is found from the entity *IfcPropertySingleValue*. This value is stored in the BIM-model as described in part 4.2.4.2.

Roofs, external floors, and heated floors related to the room are analyzed. The same procedure, as for the external walls, is performed to find areas of the roof, external floor, and heated floor.

- Analysis general values:

The u-value of the external floor is assumed to be the same for all rooms. This u-value is found from the entity *IfcPropertySingleValue*. The u-value of the roof is also assumed to be the same for all rooms and is also found from the entity *IfcPropertySingleValue*. These values are stored in the BIM-model as described in part 4.2.4.2.

The line length between the external walls and the external floor is found from the perimeter of the external floor stored in the entity *IfcQuantityLength*. The line length between the external walls and the roof is also found from the entity *IfcQuantityLength*.

4.2.5.2. Prepare IFC-information for WinDesign

When the raw IFC-data is collected, it needs to be prepared for import in WinDesign. The preparation is performed in a new Excel sheet *"IFC-input for WinDesign"*, Annex K. The current part will describe issues related to these preparations. The preparation is divided into two, according to the input data for step 2 and 3 in WinDesign.

- Preparation of input data for step 2 in WinDesign

The input data for step 2 in WinDesign is divided within the categories; *Building Information* and *Room information*. Thus, the following description is divided by these categories.

- Building information

- Total external floor area, $A_{ExtFloor,Total}(m^2)$:

The total internal area of the external floor is found by adding the external floor areas from each room, equation (1.12):

(1.12) $$A_{ExtFloor,Total} = \sum_{n=1} A_{ExtFloor,Room(n)}$$

n_{max} = number of rooms present in the building

- Total heated floor area, $A_{HeatFloor,Total}(m^2)$:

The total heated floor area is found by adding the heated floor areas from each room, equation (1.13):

(1.13) $$A_{HeatFloor,Total} = \sum_{n=1} A_{HeatFloor,Room(n)}$$

n_{max} = number of rooms present in the building

- Total window and door area, $A_{WinDoor,Total}(m^2)$:

The total window and door area is found by adding their areas from each room, equation (1.14). Windows and doors are expressed together as *"WinDoor".*

(1.14) $$A_{WinDoor,Total} = \sum_{n=1} A_{WinDoor,Room(n)} \;,\quad A_{WinDoor,Room(n)} = \sum_{m=1} A_{WinDoor(m),Room(n)}$$

n_{max} = number of rooms present in the building
m_{max} = number of windows and doors present for the respective room

- Total internal area of external wall, $A_{ExtWall,Total}(m^2)$:

The total internal area of the external walls is found by extracting the window and door areas for the walls and then add all the new wall areas, equation (1.15):

(1.15) $$A_{ExtWall,Total} = \sum_{n=1} A_{ExtWall,Room(n)} - A_{WinDoor,Total} \quad , \quad A_{ExtWall,Room(n)} = \sum_{m=1} A_{ExtWall(m),Room(n)}$$

n_{max} = number of rooms present in the building
m_{max} = number of external walls present for the respective room

- Total roof area, $A_{Roof,Total}(m^2)$:

The total roof area is found by adding the roof areas from each room, equation (1.16):

(1.16) $$A_{Roof,Total} = \sum_{n=1} A_{Roof,Room(\,n)}$$

n_{max} = number of rooms present in the building

- Building volume, $V_{Total}(m^3)$:

The total building volume is found by adding the volumes from each room, equation (1.17):

(1.17) $$V_{Total} = \sum_{n=1} V_{Room(n)}$$

n_{max} = number of rooms present in the building

- Floor to ceiling height, $h_{Floor\ to\ ceiling}\ (m)$:

The floor to ceiling height is found from the equation (1.18):

(1.18) $$\mathrm{h}_{\mathrm{Floor\ to\ ceiling}} = \frac{V_{Total}}{A_{HeatFloor,Total}}$$

- External wall u-value, $U_{ExtWall,Weightd}(W/m^2K)$:

The total u-value of the external wall is weighted according to the area of each wall. It is found from equation (1.19):

(1.19) $$U_{Ext.Wall,Weigted,Total} = \sum_{m=1} U_{Ext.Wall(m),Weigted} \quad , \quad U_{Ext.Wall(m),Weigted} = \frac{A_{ExtWall(m)}}{A_{Extwall,Total}} \cdot U_{ExtWall(m)}$$

m_{max} = number of external walls present in the building

- Roof u-value, $U_{Roof}(W/m^2K)$:

It is assumed that the u-value for all the roofs is constant. The total u-value for the roof is therefore not weighted according to the area, and it may be obtained directly from the raw IFC data without any preparation.

- External floor u-value, $U_{ExtFloor}(W/m^2K)$:

It is assumed that the u-value for all the external floors is constant. The total u-value of the external floor is therefore not weighted according to the area, and it may be obtained directly from the raw IFC data without any preparation.

- Line length between external walls and external floor, $L_{ExtWalls/ExtFloor,Total}(m)$:

The line length between the external walls and the external floor is stated as the perimeter of the external floor, and it may be obtained directly from the raw IFC data without any preparation.

- Line length between the external walls and the roof, $L_{ExtWalls/Roof,Total}(m)$:

The line length between the external walls and the roof is stated as the perimeter of the roof, and it may be obtained directly from the raw IFC data without any preparation.

- Line length between external walls and windows and doors, $L_{ExtWalls/Windoor,Total}(m)$:

The line length between the external walls and windows and doors is stated as the sum of all window perimeters, equation (1.20):

(1.20)
$$L_{ExtWalls/Windoor,Total} = \sum_{n=1} L_{ExtWalls/Windoor(n)}$$

n_{max} = number of windows and doors present in all rooms

- UA-value total, UA_{Total} (W/K):

The total UA-value is found from equation (1.21). Linear heat loss coefficients (Ψ) are stated in WinDesign and are not imported from the IFC-file.

(1.21)
$$UA_{Total} = A_{ExtFloor,Total} \cdot U_{ExtFloor} + A_{ExtWall,Total} \cdot U_{ExtWall,Weigted} + A_{Roof,Total} \cdot U_{Roof} + L_{ExtWalls/ExtFloor,Total} \cdot \Psi_{ExtWalls/ExtFloor} + L_{ExtWalls/Roof,Total} \cdot \Psi_{ExtWalls/Roof} + L_{ExtWalls/Windoor,Total} \cdot \Psi_{ExtWalls/Windoor}$$

- Room information

WinDesign needs the information for the windows and doors sorted by the rooms they are placed in. The following values are found directly from the raw IFC-data and are stored for each room in the Excel sheet *"IFC-input for WinDesign"*.

- Windoor area, $A_{Windoor}$ (m^2):

- Windoor u-value, $U_{Windoor}$ (W/m^2K):

- Windoor g-value, $g_{Windoor}$ $(-)$:

- Windoor orientation, $Orientation_{Windoor}$ (°):

- Windoor activation, $Activation_{Windoor}$ $(-)$:

If a window is located by the IFC-collector, the value "1" is stored for the respective window. This value is used by WinDesign to activate the window.

- Preparation of input data required for step 3 in WinDesign

The input data for step 3 in WinDesign is needed per room.

- Floor area, $A_{HeatFloor,Room(n)}(m^2)$:

n_{max} = number of rooms present in the building

The heated floor area for each room is found directly from the raw IFC-data and is stored for each room.

- Line length between external walls and the external floor per room, $L_{ExtWalls/ExtFloor,Room}$:

The line length between external walls and the external floor per room is found by weighting the total line length between external walls and the external floor, according to the external wall area of the respective room, equation (1.22).

$$L_{ExtWalls/ExtFloor,Room(n)} = \frac{\sum_{m=1} A_{ExtWall(m),Room(n)}}{A_{ExtWall,Total}} \cdot L_{ExtWalls/ExtFloor,Total} \quad (1.22)$$

n = number of rooms
m_{max} = number of external walls present for the respective room

The line length between external walls per room ($L_{ExtWalls/Roof,Room}$) is found from the same procedure as described in equation (1.22).

- UA-value, UA_{Room} (W/K):

The total UA-value is found from equation (1.23). Linear thermal coefficients are stated as default values and are not found from the IFC-file.

$$UA_{Room(n)} = A_{ExtFloor,Room(n)} \cdot U_{ExtFloor} + A_{Ext,Wall,Room(n)} \cdot U_{Ext,Wall,Room(n)} + A_{Roof,Room(\,n)} \cdot U_{Roof} + L_{ExtWalls/ExtFloor,Room(n)} \cdot \Psi_{ExtWalls/ExtFloor} + L_{ExtWalls/Roof,Room(n)} \cdot \Psi_{ExtWalls/Roof} + L_{ExtWalls/Windows,Room(n)} \cdot \Psi_{ExtWalls/Windows} \quad (1.23)$$

n_{max} = number of rooms
m_{max} = number of external walls present for the respective room

4.2.6. Implementation of IFC-collector in WinDesign

After the IFC-collector has prepared the input data, the VBA script in Visual Basic will locate the data and import it into the correct cells in WinDesign. The VBA script is shown in Annex F.

To activate the VBA script, three buttons are created in both step 2 and 3 in WinDesign. The *"Import-IFC"* button will open a browser window where to locate the IFC-file. The *"Run-IFC"* button will activate the VBA script and import the prepared information for either step 2 or step 3. The "Reset" button will reset all values in the IFC-collector.

The IFC-information is only implemented into SCENARIO 1 in both step 2 and 3 in WinDesign. In these two steps the guideline[26] is also adjusted with information regarding the IFC-import. WinDesign with implemented IFC-capacity is attached on the enclosed CD (*WinDesign -> WinDesign_IFC*).

4.2.7. Validation of IFC-import capacity for WinDesign

A simple test BIM-model has been developed and is used to validate the IFC-import capacity for WinDesign. The test BIM-model is developed according to the description stated in part 4.2.4. The validation is performed by comparing hand-calculated results and the results from the IFC-import capacity in WinDesign.

4.2.7.1. Description of test BIM-model

The test BIM-model represents a simple building with three rooms. Further information is shown in Figure 30. The BIM-model is also available on the enclosed CD (*BIM-model -> Test BIM_model*).

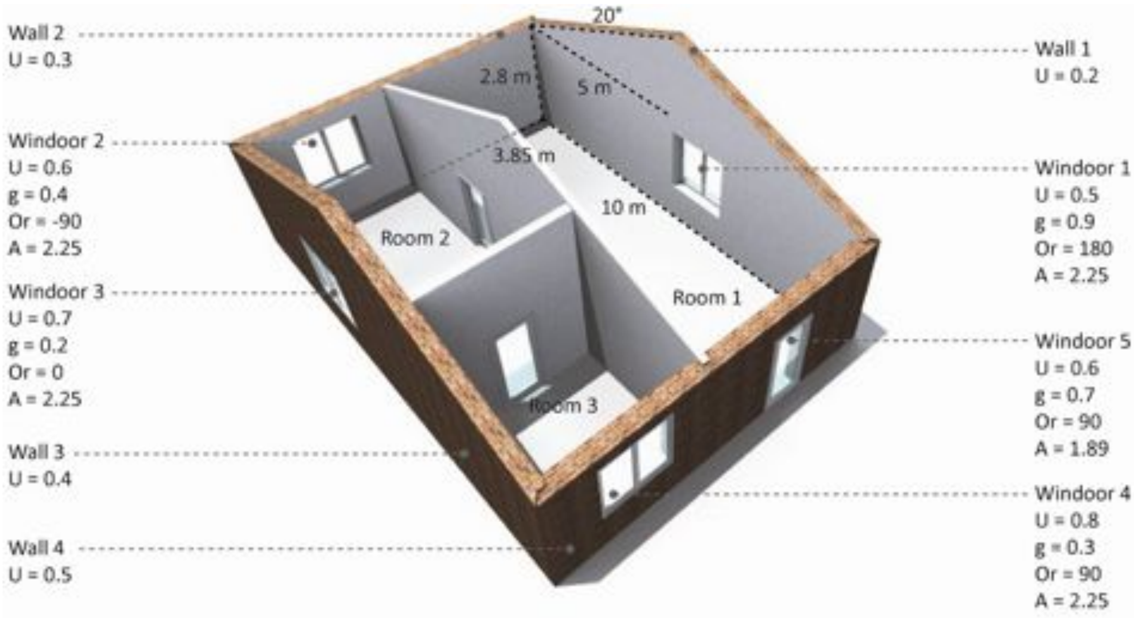


Figure 30 Illustration of the test BIM-model. Windoor: a contraction of windows and doors. Or: orientation. A: Area. U-value for the roof is 0.1 and U-value for the foundation is 0.2.

From information stated in Figure 30, hand-calculated results are stated and shown in Table 16. Results gathered from importing the IFC-file for the test BIM-model, is also shown in Table 16. However, Table 16 will only show results related to Room. Results from Room 2 and Room 3 are found in the WinDesign file attached in the enclosed CD (*WinDesign -> WinDesign_IFC_TestBIM*).

[26] The guideline in WinDesign is a help function that describes how the application works

Table 16 Validation of test BIM-model (Room 1).

WinDesign (STEP 2)	Hand-calculated	IFC-import from test BIM-model
Heated floor area [m^2]	3.85 · 10 = **38.50**	**38.50**
Floor to ceiling height [m]	Volume / heated floor area => (10 · 3.85 · 2.8 + 5 · (4.62-2.8) · 3.85) / 38.5 = **3.71**	**3.72**
Wall area [m^2]	Wall 1: Wall area – windoor area => 10 · 2.8 + 5 · (4.62 – 2.8) – (1.5 · 1.5) = **34.85** Wall 2: Wall area => 3.85 · 2.8 = **10.78** Wall 4: Wall area – windoor area => 3.85 · 2.8 – (2.1 · 0.9) = **8.89** Wall area total = **54.52**	Wall 1 area = **34.95** Wall 2 area = **10.78** Wall 4 area = **8.89** Wall area total = **54.61**
Roof area [m^2]	5.3 · 3.85 · 2 = **40.97**	**40.97**
Wall u-value [w/m^2K]	Wall 1 = **0.2**, Wall 2 = **0.3**, Wall 4 = **0.5**	Wall 1 = **0.2**, Wall 2 = **0.3**, Wall 4 = **0.5**
Roof u-value [w/m^2K]	**0.1**	**0.1**
Floor u-value [w/m^2K]	**0.2**	**0.2**
Length of wall/roof connection [m]	**18.3**	**29.94**
Length of wall/floor connection [m]	**17.7**	**19.73**
Length of wall/windoor connection [m]	1.5 · 4 + 2.1 · 2 + 0.9 · 2 = **12**	**12**
linear heat loss coefficients[a)] [W/mK]	Wall/roof = **0.2**, Wall/floor = **0.1**, Wall/Windoor = **0.4**	Wall/roof = **0.2**, Wall/floor = **0.1**, Wall/Windoor = **0.4**
Windoor area [m^2]	1.5 · 1.5 = **2.25**, 2.1 · 0.9 = **1.89**	Window 1 = **2.25**, Door 1 = **1.89**
Windoor u-value [w/m^2K]	Window 1 = **0.5** , Door 1 = **0.6**	Window 1 = **0.5** , Door 1 = **0.6**
Windoor g-value [-]	Window 1 = **0.9** , Door 1 = **0.7**	Window 1 = **0.9** , Door 1 = **0.7**
Windoor orientation [°]	Window 1 = **180** , Door 1 = **90**	Window 1 = **180** , Door 1 = **90**
WinDesign (STEP 3)	**Hand-calculated**	**IFC-import from test BIM-model**
Floor area [m^2]	**38.50**	**38.50**
UA-value [m^2]	**36.67**[b)]	**39.02**

[a)] Linear heat loss coefficients are stated in WinDesign and are therefore not transferred within the IFC-file. However, they are presents in the table as they are used in the UA-calculations.
[b)] The calculation is performed below.

Calculation of UA – value:

$$38.5\cdot0.2 + 34.85\cdot0.2 + 10.78\cdot0.2 + 8.89\cdot0.5 + 40.97\cdot0.1 + 18.3\cdot0.2 + 17.7\cdot0.1 + 12\cdot0.4 = 36.67$$

Table 16 shows that most of the values are imported correct. The incorrect values are the connection length between construction parts, which is due to the simplification, described in part 4.2.5.2. The simplification results in correct values for the connection lengths if the walls are squared. In this case, the two gable walls are not squared, and a deviation therefore occurs. The incorrect connection length does also cause the deviation in the UA-value, and the total deviation of the UA-value is calculated to be 6%. Due to the rounding's in the calculations, small deviations are also present for the wall area.

4.2.8. Limitations of IFC-import capacity for WinDesign

The IFC import capacity is developed in accordance with the complexity and structure of WinDesign. Thus, the limitations of the IFC-import capacity will follow the limitations of WinDesign.

- As mentioned above, WinDesign is primarily developed to simulate buildings with one storey. Due to this limitation, the IFC-collector may only import information from one storey separately. BIM-models representing buildings with more than one storey have to be developed as described in part4.2.4.

- WinDesign is developed to handle buildings with flat roofs. In case the building has a sloping roof, the height from floor to the ceiling, $\mathrm{h}_{\text{Floor to ceiling}}$ is estimated by equation (1.24).

$$\mathrm{h}_{\text{Floor to ceiling}} = \frac{V_{Total}}{A_{Floor,Total}} \quad (1.24)$$

- The line length between the external walls and the external floor for each room is estimated from equation (1.25).

$$L_{ExtWalls/ExtFloor,Room(n)} = \frac{\sum_{m=1} A_{ExtWall(m),Room(n)}}{A_{ExtWall,Total}} \cdot L_{ExtWalls/ExtFloor,Total} \quad (1.25)$$

n_{max} = number of rooms
m_{max} = number of external walls present for the respective rooms

This assumption has been made to avoid sophisticated geometrical analysis of the IFC-model. It is correct if the building has a flat roof. In case the building has a sloped roof, there will be a deviation on the line length, see part 4.2.7. This is because the area of the gable wall is not proportional with its length. The same issue is relevant for the line length between the external walls and roof for each room.

- As mentioned in the literature survey, WinDesign is developed to handle simple geometries without any curves. Thus, the IFC-import capacity is only workable for such geometries.

- It is assumed that the external floor and the roof have a constant u-value. The BIM-model should therefore only contain one u-value for the entire external floor and one u-value for the entire roof.

- In WinDesign it is possible to specify the tilt angle of each window. This angle-value is not possible to import through the IFC-import capacity, but it will be assigned as a default value of 90°. This is due to an IFC-export failure in ArchiCAD related to sky lights. When placing a sky light in the BIM-model, ArchiCAD will automatically assign four linings to the roof hole. When exporting the IFC-file from ArchiCAD, each of these linings will represent a space boundary in connection to the sky light. As illustrated in Figure 23, the IFC-collector locates the sky light (*IfcWindow*) through the *IfcSpaceBoundary*. Therefore, the IFC-collector will locate 4 sky lights for each time one is placed in the ArchiCAD BIM-model, which is an error.

- The IFC import capacity of WinDesign is limited only to handle IFC-files exported from ArchiCAD in the format 2x3. This is to secure that the IFC-file has a structure that the IFC-collector can read.

- The speed of the IFC-importation is limited by the calculation engine in WinDesign. Each time an orientation for a window or door is defined, WinDesign will calculate its performance.

5. Testing of design process method and IFC-data transfer in case studies

5.1. Introduction

This part presents the usability of IDMoER and the IFC-import capacity for WinDesign. The two case studies represent two different building types; a single family type house and a simple office building. The aim of these case studies is not to develop a final optimal design solution, but to present the potentials when using IDMoER and the IFC-import capacity for WinDesign. The IDMoER is developed for a multidisciplinary consultancy having expertise within many aspects influencing the design process, such as energy, constructions, cost, etc. As delimited in the introduction, the current thesis only focuses on issues related to energy and indoor environment. Thus, only these issues are evaluated and analyzed in the two cases.

The following issues are used as evaluation parameters for the analysis of each case study.

- Energy consumption
- Thermal environment
- Visual environment
- Atmospheric environment

5.2. Case study 1 – Single family type house

In this case study, a single family type house from Interbyg A/S[27]acts as the reference building for the design optimization. All information concerning the reference building is provided by Interbyg A/S. The reference building does not represent a realistic retrofitting project, as it is build recently. However, it is chosen for this case study because of the following:

- It has a simple geometry which is easy to create in a BIM-model
- All information is available from Interbyg A/S
- The building is an example of a typical single family type house which is constructed within the recent years. A type house manufacture, such as Interbyg A/S, may find it relevant to see how BIM-models may be used to optimize the energy consumption and indoor environment in their existing type house catalogue.

The structure of this case study will follow the progression described in IDMoER and will be divided within the pre-design phase and concept design phase.

5.2.1. Pre-design

5.2.1.1. Existing conditions of the reference building

Existing conditions for the reference building are presented in the following part. Drawings are shown in Annex M.

[27] Type house manufacture. More information on www.interbyg.dk

Figure 31 Existing single family type house from Interbyg A/S.

- General geometry and orientation

The building has a heated floor area of 137.7 m2. The floor to ceiling height is 2.38 m. Facades are orientated towards NE, NV, SE, and SV (Annex M). A garage is connected to the building, but it is not a heated part. Thus, shadings for the side, caused by the garage, will have to be considered (Figure 32). The shading conditions illustrated in Figure 32 is obtained from Interbyg A/S. They are based on shading point 1, representing the corner of the shed connected to the main building. Because the garage has a solid roof, the shading conditions should correctly had been based on shading point 2. However, the shading conditions stated by Interbyg A/S are used further in this case study. Further details about the shading conditions are present in Annex N.

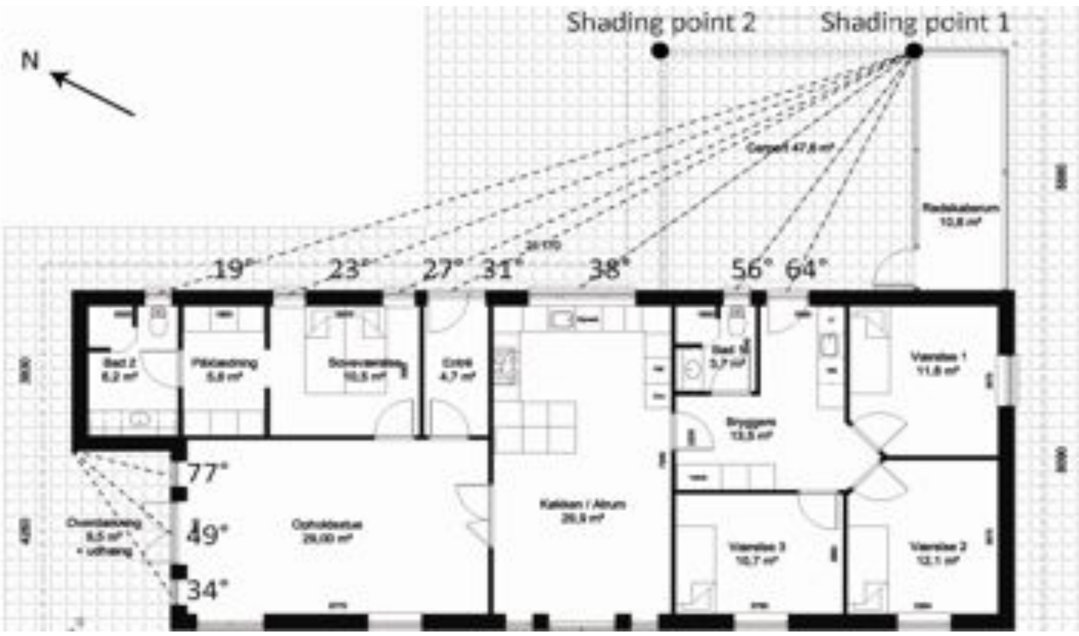


Figure 32 Shading conditions from the garage (without scaling). The shading conditions illustrated, are based on shading point 1.

- Building characteristics

The building envelope consists of a classic composite wall, a sloped roof with brick tiles, and concrete foundation. No insulation has been added to the roof construction, but it has been added to the ceiling, which then is counted as the insulating part of the roof construction (Annex M). No ventilation or cooling systems are installed in the building.

Other building characteristics are described in Table 17, and a detailed description of windows and doors is enclosed in Annex N.

Table 17 Main constructions, u-values, and other characteristics for the reference building

Construction type	Composition	Depth [mm]	U-value [W/m^{2}K]
Wall	Bricks	108.00	0.20
	Insulation	150.00	
	Light concrete	100.00	
Roof (ceiling)	Insulation	400.00	0.09
	Gypsum cladding	26.00	
Foundation	Concrete	120.00	0.12
	Insulation	275.00	
Internal heat gains [W/m^2]			5 .00
Ventilation rate (natural) [h^{-1}]			2.25$^{a)}$
linear heat loss coefficients (Wall/Roof) [W/mK]			0.20
linear heat loss coefficients (Wall/Floor) [W/mK]			0.16
linear heat loss coefficients (Wall/Window) [W/mK]			0.03
Heat capacity [j/Km^2]			360000

a) Value defined in relation to [52]

The infiltration rate is found to:

$$0.13\frac{l}{s}\,perheated\ floor\ area\ (m^2) = \frac{0.13\ \frac{l}{m^2 s}\cdot 3.6\frac{m^3/h}{l/s}}{2.38\ m} = 0.19\ h^{-1}$$

- Energy frame

The energy frame is calculated corresponding to the heated floor area of 137.7 m^2 and used to evaluate new design solutions.

- Energy frame (Mandatory): 70+ 2200/A kWh/m^2 per year = 85.96 kWh/m^2 per year

- Energy frame (Low energy class 2): 52.5+ 1650/A kWh/m^2 pr. year = 64.48 kWh/m^2 per year

- Energy frame (Low energy class 1): 30+ 1000/A kWh/m^2 pr. year = 37.26 kWh/m^2 per year

- Energy frame (Low energy class 0): 17.5+550/A kWh/ m^2 pr. year = 21.49 kWh/m^2 per year

5.2.1.2. Development of BIM-model (Level 1.0)

Based on the existing conditions, the BIM-model (Level 1.0) is created as described in part 4.2.4 (Figure 33 and Figure 34). The BIM-model (Level 1.0) is attached in the enclosed CD (*BIM-models -> Case1_BIM_model_1.0*).

Figure 33 Rendering of the south-west and north-west facing facades from the BIM-model (Level 1.0). At this point, the BIM-model contains information of the building outline and the orientation of windows.

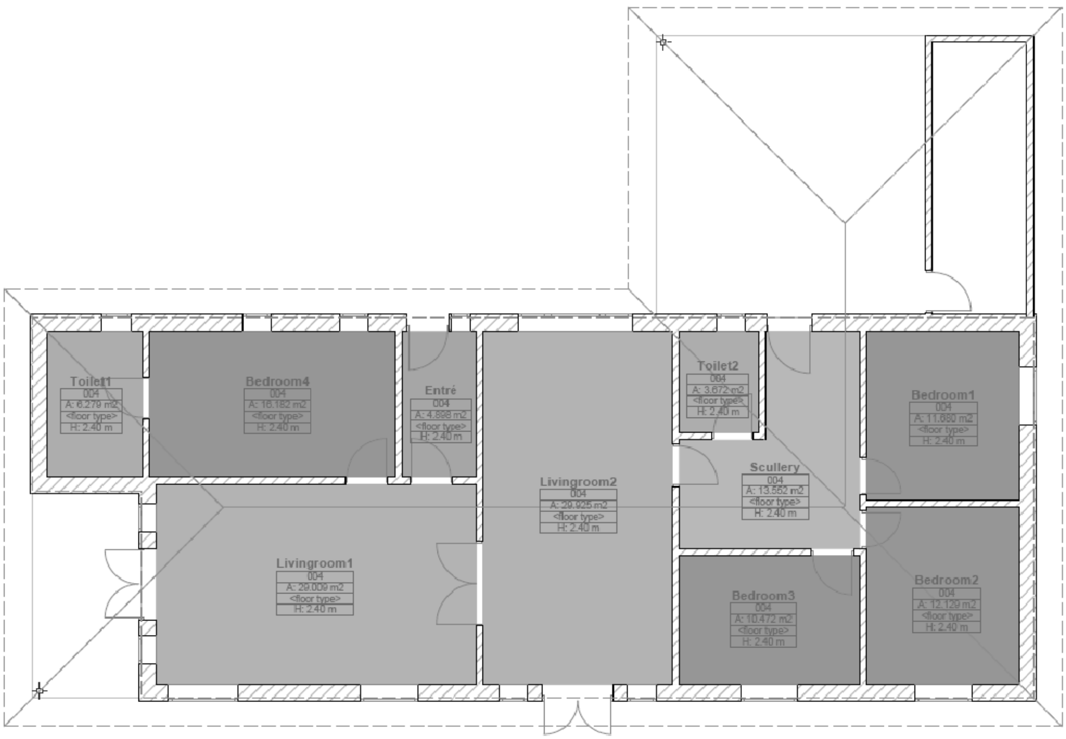


Figure 34 Floor plan of the reference building created from the BIM-model (Level 1.0), (not in scale)

5.2.1.3. Analysis of reference building

Information about the energy consumption and indoor environment of the reference building has not been available for this case study. Thus, to compare with other design solutions, the energy consumption and indoor environment of the reference building are analysed further.

- Energy consumption

The IFC-file exported from the BIM-model (Level 1.0) is imported in WinDesign. U-values, g-values, shading conditions, ventilation rates, and temperature set points are further adjusted. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case1_RefBuilding*).

From these conditions, the energy consumption for heating is calculated in WinDesign (step 2) and found to:

$$Yearly\ energy\ consumption\ for\ heating =\ 65\ kWh/m^2$$

However, the energy frame for dwellings consists of the total energy consumption from heating, ventilation, and domestic hot water. The reference house has no mechanical ventilation. Thus, the energy consumption for ventilation is zero. The energy consumption for domestic hot water is stated as a default value of 13 kWh/m^2 per year [1]. The total energy consumption for heating and domestic hot water may now be found to:

$$Total\ energy\ consumption = 65 + 13 = 78 \frac{kWh}{m^2} per\ year$$

With this energy consumption, the reference building is categorized within the mandatory energy frame of 85.96 kWh/m^2 per year.

- Daylight conditions

The daylight conditions are evaluated by Visualizer. The BIM-model (Level 1.0) is imported and the following material properties are assigned as default values:

- Wall and ceiling surfaces: White paint (Reflectance = 0.90, Roughness = 0.00, Specularity = 0.00)
- Floor surfaces: Wood (Reflectance = 0.35, Roughness = 0.05, Specularity = 0.00)
- Windows and doors: Window glass (Transmittance = 0.78)

Other settings applied for the evaluation are:

- Location: Copenhagen
- Orientation: 324°
- Sky conditions: Overcast
- Date and time: 21th of march, 12:00

Based on these default values, the daylight conditions are found as illustrate in Figure 35.

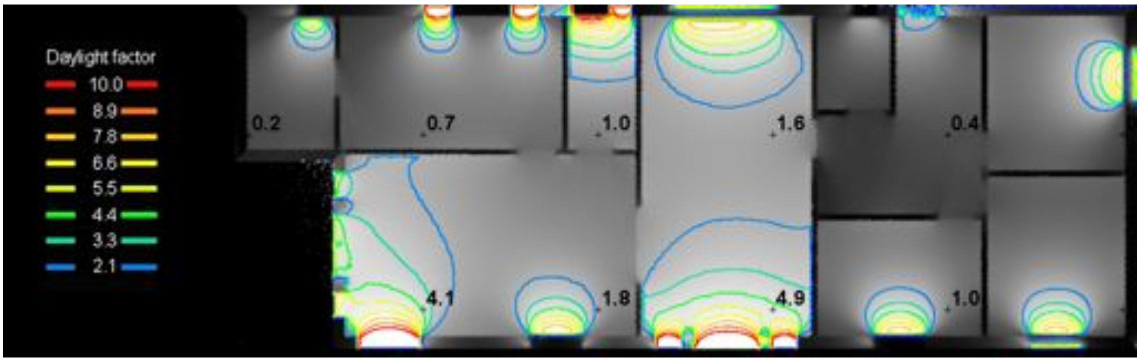


Figure 35 Results of daylight analysis (DF) by Visualizer on the reference building. The garage and shed are not present in the figure, as they are not a part of the main building. However, their shading effect is included in the calculations.

Ideally, the daylight factor should be evaluated as an average value, but as shown in Figure 35, the simulation in Visualizer only results in few specific daylight factor (DF) points. However, it still presents DF-curves, which indicate the daylight conditions in all rooms. It is shown that the daylight conditions are relatively good compared to the standards presented in Table 7. Though, the rooms (toilet 2 and the scullery) which has windows facing the garage, has limited daylight conditions.

5.2.1.4. Optimization of energy consumption and indoor environment

By using WinDesign (step 2) and Visualizer, several improvements of the building are analyzed to assess their effects on energy consumption and indoor environment. However, as WinDesign (step 2) does not allow analysis of the thermal environment, only the visual environment is analyzed in relation to the indoor environment in this phase of the design process.

The improvements are analyzed as individual optimization scenarios within five different categories. To gain an overview of the improvements, the optimization scenarios are presented in tables and the progression of the optimization scenarios are as follow:

- **Building envelope, individually (walls, roof, and windows):** The optimization scenarios (1 – 4 and 7-9) will analyze improvements of the walls, roof, and windows, separately.

- **Building envelope, combined:** Two analyses (5-6) are performed, where improvements of walls and roof are combined.

- **Solar shadings, individually:** Six optimization scenarios (10 - 15) will individually analyze the result from using different solar shadings.

- **Building envelope and solar shadings, combined:** Nine optimization scenarios (16 - 24) will analyze the result from combining the individual improvements.

- **Mechanical ventilation:** One potential optimization scenario from 1-24 are chosen, and it is analyzed how a mechanical ventilation system may affect their energy consumption and indoor environment. The optimization scenarios are named x.1 – x.5, where “x” represents the number of the chosen optimization scenario from 1-24.

The following part presents the design scenarios and their effect on the energy consumption and indoor environment. WinDesign calculates the cooling consumption and cooling season as default in step 2. The result for the cooling consumption is not relevant as no cooling system is installed in the reference building. However, they can be used to evaluate potential risk of overheating and are therefore also presented.

- Building envelope, individually and combined

Table 18 Optimization scenarios with individual and combined improvements of the building envelope (walls and roof). HS: Heating season, CS: Cooling season. The WinDesign file is attached on the enclosed CD (WinDesign -> WinDesign_IFC_Case1_Opt1).

Optimizing scenarios	Ref	1	2	3	4	5
Walls[a)]	*U = 0.62*	-	-	Extra insulation 0.1 m => U = 0.13	Extra insulation 0.2 m => U = 0.1	Extra insulation 0.1 m => U = 0.13
Roof[a)]	*U = 0.42*	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.2 m => U = 0.06	-	-	Extra insulation 0.1 m => U = 0.07
Results						
Heating [kWh/m^2 year]	*65*	60	60	58	57	57
HS [Days]	*238*	233	232	230	230	229
Cooling[kWh/m^2 year]	*14*	15	15	16	16	16
CS [Days]	*131*	136	137	138	139	139

[a)] U-values are calculated in accordance with DS-418 [13], see Annex O. The infiltration rate is reduced with 25% in optimization scenarios where extra external insulation is added.

Table 19 Optimization scenarios with individual and combined improvement of the building envelope (walls, roof, and windows). HS: Heating season, CS: Cooling season. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case1_Opt2*).

Optimizing scenarios	Ref	6	7	8	9
Walls[a)]	*U = 0.62*	Extra insulation 0.2 m => U = 0.1	-	-	-
Roof[a)]	*U = 0.42*	Extra insulation 0.2 m => U = 0.06	-	-	-
Windows[b)]	*U = 0.86 g = 0.58*	-	U=0.7 g=0.52	U=0.6 g=0.52	U=0.5 g=0.52
Results					
Heating [kWh/m^2 year]	*65*	54	64	62	60
HS [Days]	*238*	226	240	238	236
Cooling[kWh/m^2 year]	*14*	16	12	12	13
CS [Days]	*131*	143	127	128	130

[a)] U-values are calculated in accordance with DS-418 [13], see Annex O. The infiltration rate is reduced with 25% in optimization scenarios where extra external insulation is added.
[b)] All doors are defined as windows.

The results presented in Table 18 show a minimal reduction of the energy consumption for all five optimization scenarios. When comparing the improvements of walls and roof, it is found that the improvements of the walls have the biggest effect. This is properly due to its bigger surface area and that the existing u-value is lower than for the roof.

In Table 19 the effect of improvements of the windows is shown. It is found that these improvements have a relatively small effect, which most likely is due to the relatively good condition of the existing windows. However, the energy consumption drops with 5 kWh/m2 per year when improving the u-value from 0.86 W/m^{2}K, in the reference building, to 0.5 W/m^{2}K in optimization scenario 9.

- Solar shadings, individually

Solar shadings of different kind and shading affectivity are analyzed in Table 20. They are characterized by three factors; the Solar Shading Coefficient (SSC), fixed, or movable. The SSC value represents the efficiency of the solar shading. It is given as the ratio between the total solar energy transmittance of the window combined with the shading device and the total solar transmittance of the window alone.

Table 20 Optimization scenarios analyzing different solar shadings. SSC: Solar Shading Coefficient. The WinDesign file is attached on the enclosed CD and (*WinDesign -> WinDesign_IFC_Case1_Opt3*).

Optimizing scenarios	Ref	10	11	12	13	14	15
Shadings[a)]	-	Fixed, SSC = 0.2	Fixed, SSC = 0.4	Fixed, SSC = 0.6	Movable, SSC = 0.2	Movable, SSC = 0.4	Movable, SSC = 0.6
Results							
Heating [kWh/m^2 year]	*65*	77	73	70	72	70	63
Heating season [Days]	*238*	270	260	251	257	251	241
Cooling[kWh/m^2 year]	*14*	5	7	9	8	9	11
Cooling season [Days]	*131*	84	100	114	106	113	124

[a)] Shadings are only placed on windows facing south-west.

The influence of the solar heat gain is clearly shown in Table 20. When the SSC value is 0.2, most of the direct solar radiation is blocked by the solar shading. This will, as shown for optimization scenario 10, result in an increased heating demand, as most of the solar heat gain is kept out of the building. The fictive cooling demand and cooling season for the reference building are both low and may indicate that cooling is a minor problem in the building.

From Table 18, Table 19, and Table 20, it is stated that none of the optimization scenarios reduces the energy consumption significantly.

- Building envelope and solar shadings, combined

In order to achieve a more significant reduction of the energy consumption, the individual improvements described above is now analyzed when combined (Table 21).

Table 21 Optimization scenarios where individual improvements are combined. SSC: Solar Shading Coefficient. Sc: Scenario. HS: Heating season. CS: Cooling season. The WinDesign file is attached in the enclosed CD (*WinDesign -> WinDesign_IFC_Case1_Opt4 and WinDesign_IFC_Case1_Opt5*).

Optimizing sc.	Ref	16	17	18	19	20
Walls a)	*U = 0.62*	Extra insulation 0.1 m => U = 0.13	Extra insulation 0.1 m => U= 0.13	Extra insulation 0.1 m => U = 0.13	Extra insulation 0.2 m => U = 0.1	Extra insulation 0.2 m => U = 0.1
Roof a)	*U = 0.42*	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.2 m => U = 0.06	Extra insulation 0.2 m => U = 0.06
Windows b)	*U = 0.86* *g = 0.58*	U=0.7 g=0.52	U=0.6 g=0.52	U=0.5 g=0.52	U=0.7 g=0.52	U=0.6 g=0.52
Shadings c)	-	Fixed, SSC = 0.2	Fixed, SSC = 0.4	Fixed, SSC = 0.6	Movable, SSC = 0.2	Movable, SSC = 0.4
Results d)						
Heating [kWh/m^2 year]	*65*	60	59	55	57	54
HS [Days]	*238*	262	249	240	246	240
Cooling[kWh/m^2 year]	*14*	5	7	9	8	9
CS [Days]	*131*	91	110	121	114	122

Optimizing sc.	Ref	21	22	23	24
Walls a)	U = 0.62	Extra insulation 0.1 m => U = 0.13	Extra insulation 0.1 m => U= 0.13	Extra insulation 0.1 m => U = 0.13	Extra insulation 0.2 m => U = 0.1
Roof a)	U = 0.42	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.1 m => U = 0.07	Extra insulation 0.2 m => U = 0.06
Windows b)	U = 0.86 g = 0.58	U=0.7 g=0.52	U=0.6 g=0.52	U=0.5 g=0.52	U=0.5 g=0.52
Shadings c)	-	Fixed, SSC = 0.2	Fixed, SSC = 0.4	Fixed, SSC = 0.6	Movable,SSC= 0.2
Results					
Heating [kWh/m^2 year]	65	51	50	50	49
HS [Days]	238	233	231	228	226
Cooling[kWh/m^2 year]	14	11	12	13	14
CS [Days]	131	131	133	136	139

a) U-values are calculated in accordance with DS-418 [13], see Annex O. The infiltration rate is reduced by 25% in optimization scenarios where extra external insulation is added.
b) All doors are defined as windows
c) Shadings are only placed on windows facing south-west.

The combination of different improvements described by the optimization scenarios in Table 21, shows potential of reduction of the energy consumption for heating to 49 kWh/m2 per year. Compared to the reference building, which used 65 kWh/m2 per year, this is a reduction of 25%.

From the 24 optimization scenarios performed, five are chosen and their daylight conditions are further analyzed. The chosen optimization scenarios are number 6, 9, 20, 21, and 24 (without solar shading). Scenario 6 is chosen as it only requires a modification of the external walls and roof. Scenario 9 is chosen as it only would require a replacement of the existing windows. Scenario 20, 21, and 24 are chosen as they represent the scenarios causing the lowest energy consumption.

The daylight potential is analyzed for each of the five selected optimization scenarios where the g-value is changed. The solar shadings are assumed not to have any effect on the daylight conditions, because the daylight factor is calculated from an overcast sky condition, where the solar shadings are not in use.

The g-value is changed from 0.58 to 0.52 in optimization scenario 9, 20, 21, and 24. These properties are adjusted in Visualizer by reducing the transparency of the window glazing. The analysis is performed with the same settings and geometries as described for the reference building. Only the transmittance of the window glazing has been adjusted.

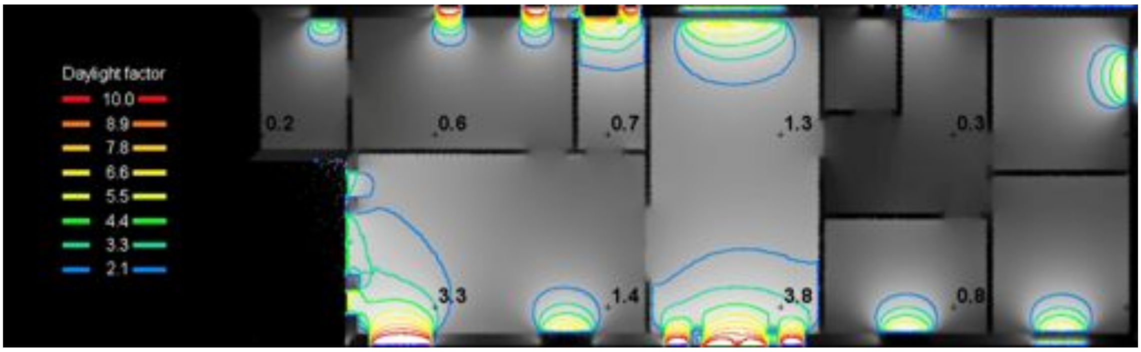


Figure 36 Illustration of daylight conditions (measured in DF) for window transparency of 0.70, corresponding to g = 0.52. General settings in Visualizer correspond to what is described in part 5.2.1.3.

From Figure 36 it is shown that the daylight factor decreases when reducing the transmittance of the windows. However, it is still within an acceptable level, as most of the building has a daylight factor bigger than 1%. As the optimization scenario 24 has the lowest energy consumption, this is consequently chosen for further analyses.

- Mechanical ventilation

In order to reduce the energy consumption even further, the effect of a mechanical ventilation system is analyzed in five optimization scenarios (24.1-24.5) where different adjustments of the system is performed (Table 22).

Table 22 Optimization scenarios concerning the installation of a mechanical ventilation system. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case1_Opt6*).

Optimizing scenarios	Ref.	24.1	24.2	24.3	24.4	24.5
Mechanical ventilation[a)]	-	Vent. rate = $0.5h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $0.6h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $0.7h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $0.8h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $0.9h^{-1}$.Heat recovery, eff. = 0.85
Results						
Heating [kWh/m^2 year]	65	22	23	23	23	25
Heating season [Days]	238	180	182	184	186	188
Cooling[kWh/m^2 year]	14	15	14	12	11	10
Cooling season [Days]	131	142	135	128	123	117

[a)] The mechanical ventilation system also includes cooling. Vent: Ventilation, eff: Efficiency

The mechanical ventilation system shows a significant reduction of both the heating- and cooling consumption. The lowest energy consumption is found for the optimization scenario 24.4. With a ventilation rate of 0.8h-1 and a heat recovery unit, the heating consumption is found to 23 kWh/m2 per year and the cooling consumption is found to 11 kWh/m2 per year.

The electrical energy consumption for the ventilation system is not included in the calculations performed by WinDesign. It is calculated from equation (1.26):

$$E_{vent} = \frac{T_d}{168} \cdot q_v \cdot SEL \cdot 365 \cdot 0.024 \cdot 2.5 \qquad (1.26)$$

Where

T_d = hours per week where the ventilation system is active [hours]

q_v = ventilation rate [L/s per m^2]

SEL = the specific energy consumption = 0.6 [W/(L/S)]

To assess the most critical conditions, the ventilation system is assumed to be active in all hours during the week, resulting in $T_d = 168$

The ventilation rate was for optimization scenario 24.4 stated to 0.8 h^{-1}. In order to get the value in L/s per m^2 the following conversion is performed:

$$0.8\ h^{-1} = \frac{q_v\ \frac{l}{m^2 s} \cdot 3.6 \frac{m^3/h}{l/s}}{2.38\ m} => q_v = 0.52\ \frac{l}{m^2 s}$$

With these values, the energy consumption for the ventilation system is calculated to:

$$E_{vent} = \frac{168}{168} \cdot 0.52 \cdot 0.6 \cdot 365 \cdot 0.024 \cdot 2.5 = 6.83 \frac{kWh}{m^2} per\ year$$

When adding the energy consumption for domestic hot water, the ventilation system, and the heating and cooling consumption for optimization scenario 24.4, the total energy consumption is found to:

$$Total\ energy\ consumption = 23 + 11 + 13 + 6.83 = 53.8 \frac{kWh}{m^2} per\ year$$

The total energy consumption for the reference building was found to 78 kWh/m^2 per year. Thus, with the optimization scenario 24.4 the total energy consumption is reduced by around 31%.

5.2.1.5. Development of BIM-model (Level 1.1 and 1.2)

The adjustments performed in optimization scenario 24.4 are implemented in the BIM-model (Level 1.1) (Figure 37 and Figure 38). The BIM-model (Level 1.1) is enclosed on the CD (BIM-models -> Case1_BIM_model_1.1_1.2). In the IDMoER related to the pre-design phase, an architectural evaluation should ideally verify the design solution represented by the BIM-model (Level 1.1). If complications, such as coalitions between new retrofitting measures and existing constructions, is found these should be adjusted and implemented in the BIM-model (Level 1.2). In this case study, it is assumed that no complications are present. To illustrate an example of how the design solution could change the architectural expression of the reference building, a wooden surface has been added upon the new external wall insulation (Figure 37).

Figure 37 Rendering of the south-west and north-west facing facades from the BIM-model (Level 1.2)

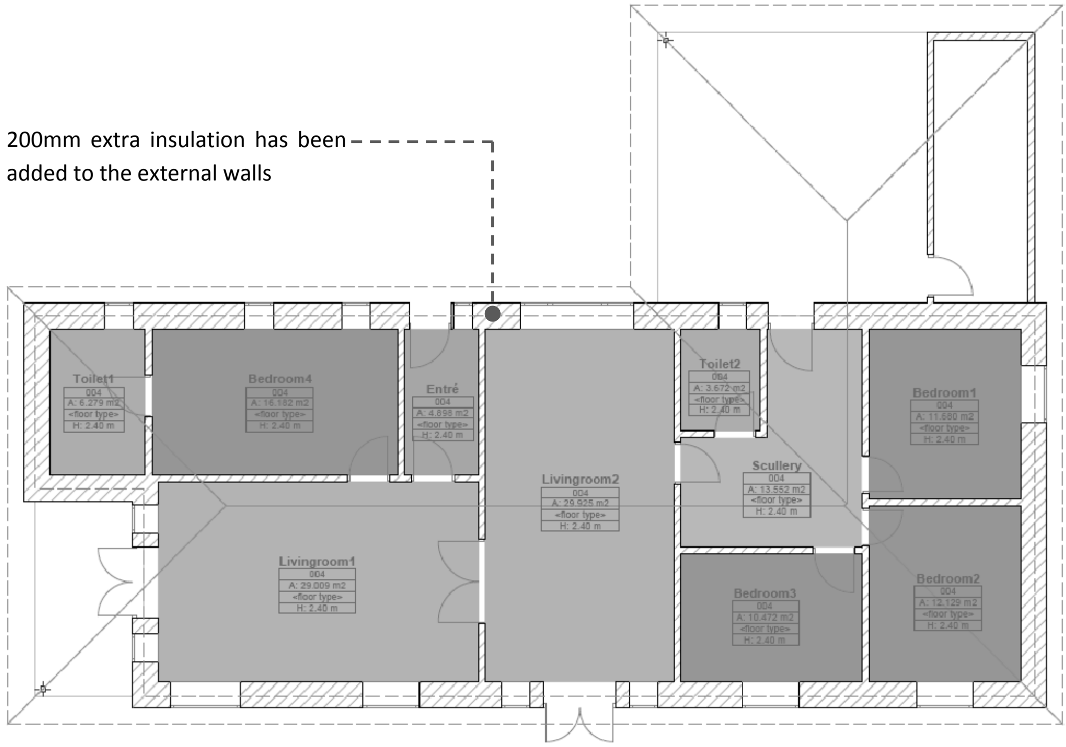


Figure 38 Floor plan of the design solution, where 200mm insulation has been added to the external walls. The floor plan is extracted from the BIM-model (Level 1.2)

This design optimization represents one potential solution for the pre-design phase. Ideally other design solutions should be performed in the pre-design phase. For instance, it would be interesting to see what effect a transparent roof on the garage would have on the indoor environment and energy consumption. Such retrofitting measure would change the shading conditions and allow more daylight to penetrate through the north-east facing windows. Also, it would be interesting to analyze the area distribution of windows in further details.

However, this case study is delimited to present the design solution 24.4 described above.

5.2.2. Concept design

The design solution chosen in the pre-design phase (optimization scenario 24.4) is further analyzed by WinDesign (step 3).

5.2.2.1. Development of BIM-model (Level 2.0)

If the client has any adjustments to the design solution 24.4, these are evaluated and implemented in the BIM-model (Level 2.0). The BIM-model (Level 2.0) is also adjusted to contain u- and g-values for external walls, roof, floor, windows, and doors represented by the design solution 24.4. The BIM-model (Level 2.0) is enclosed on the CD (*BIM-models -> Case1_BIM_model_2.0*).

5.2.2.2. Optimization of energy consumption and indoor environment

The BIM-model (Level 2.0) is exported in IFC-format and imported in WinDesign (step 3). Five new optimization scenarios, concerning the cooling system, are performed based on the design solution 24.4 (Table 23).

Table 23 Optimization scenarios based on the design solution 24.4. Only the cooling system is adjusted. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case1_Opt7*)

Opt. scenarios	Ref.	24.4.1	24.4.2	24.4.3	24.4.4	24.4.5
Cooling	-	Activated, setpoint 24°C	Activated, setpoint 25°C	Activated, setpoint 26°C	Activated, setpoint 27°C	No cooling
Results						
Heating [kWh/m^2 year]	65	21.4	21.4	21.4	14.3	14.3
Cooling [kWh/m^2 year]	14	5.5	2.9	1.5	0.6	0
Hours with overheating (above 26°C) per year	-	0	0	0	152	192

From Table 23, it is found that the optimization scenario 24.4.5 results in the lowest energy consumption of 14.3 kWh/m2 year. However, this optimization scenario results in 192 hours with overheating per year, which is nearly twice as much as the recommended 100 hours, see part 2.4.4.3. The optimization scenarios 24.4.1, 24.4.2, and 24.4.3 are all analyzed with cooling setpoints below or equal to 26°C. Thus, all of them has zero hours with overheating per year. The optimization scenario 24.4.3 has the lowest energy consumption (22.9 kWh/m2 year), while still having zero hours with overheating. This optimization scenario is therefore chosen as the design solution for the concept design phase.

When adding the energy consumption for domestic hot water, the ventilation system, and the heating and cooling consumption for optimization scenario 24.4.3, the total energy consumption is found to:

$$Total\ energy\ consumtion = 22.90 + 13.00\ + 6.83\ = 42.73\ \frac{kWh}{m^2} per\ year$$

With the new improvements of the cooling system and calculations from WinDesign (step 3) this energy consumption for the building is nearly classified as low energy 1. In order to reduce the energy consumption to a level which could classify the building as low energy 1 or 0, a reduction of the energy consumption for domestic hot water could be performed.

The total energy consumption for the reference building was found to be 78 kWh/m^2 per year. Thus, with the optimization scenario 24.4.3 the total energy consumption is reduced by approximately 45%.

The optimization scenario 24.4.3 has a ventilation rate of 0.8h^{-1} = 0.52 $\frac{l}{s}\ perheated\ floor\ area\ (m^2)$, which classifies the atmospheric environment as category I, see Annex D.

5.2.2.3. Development of BIM-model (Level 2.1 and 2.2)

The building envelope has not been changed from what was stated in the pre-design phase. Thus, no further changes have been made in the BIM-model (Level 2.1). However, the detailed level of walls and ceiling has been modified Figure 41. The final design solution is represented in the BIM-model (Level 2.2) (Figure 39, Figure 40, and Figure 41). The BIM-model (Level 2.2) is enclosed on the CD (*BIM-models -> Case1_BIM_model_2.2*).

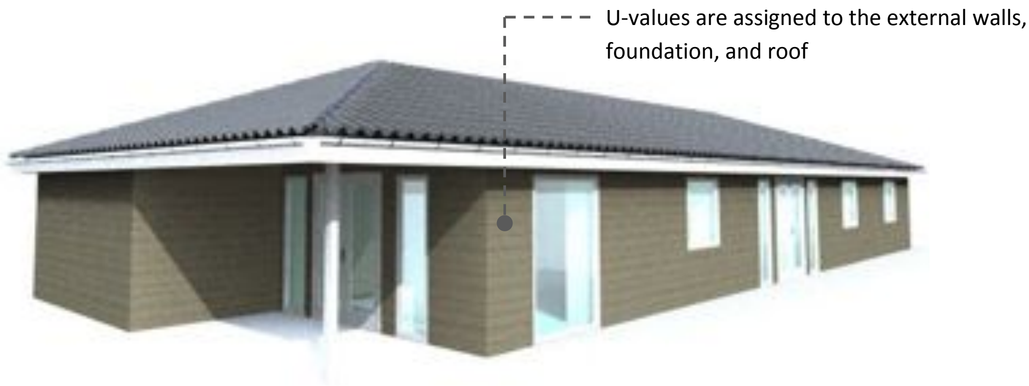


Figure 39 Rendering of the south-west and north-west facing facades from the BIM-model (Level 2.2)

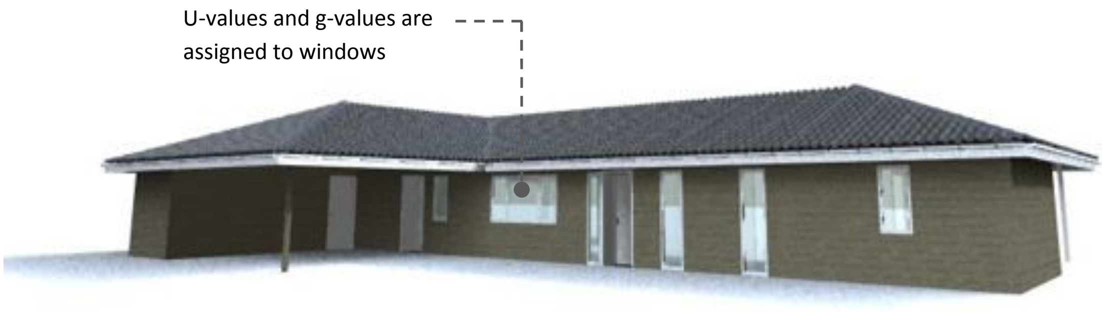


Figure 40 Rendering of the north-east and north-west facing facades from the BIM-model (Level 2.2)

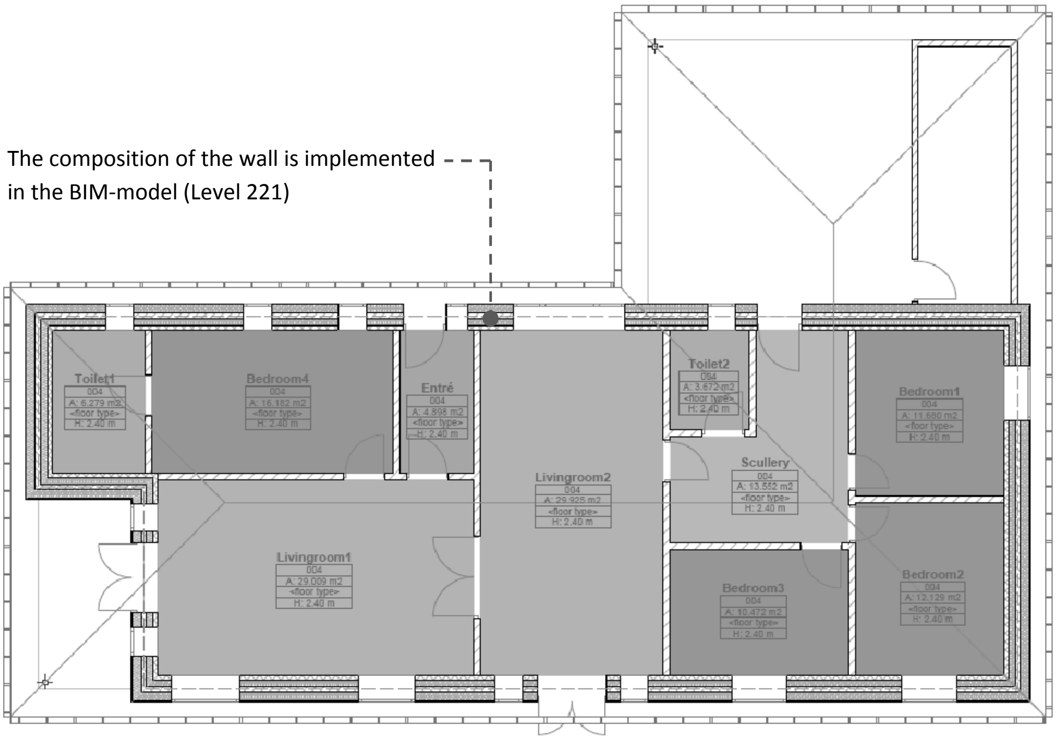


Figure 41 Floor plan from the BIM-model (Level 2.2), (not in scale)

5.3. Case study 2 – Simple office building

This case study is based on a simple office building. The office building is placed at the Technical University of Denmark. It will act as the reference building for the following design optimization in this case study.

All information concerning the reference building is provided by the master thesis *Method for integrated design of retrofitting of existing buildings to low energy level* [36]. The reference building is chosen for this case study for the following reasons:

- Most information is available and already obtained
- It has a simple geometry
- Within near future an energy retrofitting project may be initiated
- It represents a building with more than 12 rooms and it has three floors
- It is of interest for Campus Service[28] to see how BIM-models may be utilized

The structure of this case study will follow the progression of IDMoER, and will be divided in pre-design phase and concept design phase.

5.3.1. Pre-design

5.3.1.1. Existing conditions of reference building

Existing conditions for the reference building are present in the following part. Drawings are shown in Annex P.

Figure 42 Reference building at the Technical University of Denmark (DTU)

- General geometry and orientation

The building has a rectangular floor plan, with a length of 102 m and width of 14.1 m. The length of the building is divided in 34 modules with a distance of 3 m. The width is divided in 3 modules with a distance of 7.3 and 6.8 meter. The building consists of 3 storey's and a non-heated basement. Each storey has a room height of 3.67 meter. The building has a heated floor area of 1300 m2. The two main facades are orientated towards north and south (Figure 43).

[28] Service unit which facilitates the campus area of the Technical University of Denmark

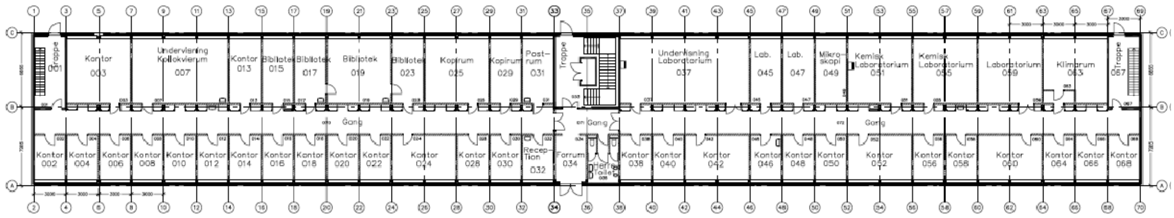


Figure 43 Floor plan of the reference building (not in scale). North: 

The room distribution of the building is divided in two parts by a corridor, and the rooms are either facing north or south. The depth of the rooms facing north is 6.62 m, and 4.82 m for the rooms facing south. The majority of the rooms in the building are offices, but also classrooms, libraries, etc., are present.

- Building characteristics

The structural system of the building consists of columns, beams, and floor slaps. The main facades facing north and south are non-bearing and may be removed without any structural affects. They are characterized by a combination of window strips and bricks. The window strips are composed by wooden frame construction and windows. The gable walls facing east and west act as a part of the structural system and are without windows. An old ventilation system is present in the building, but it is out of function.

Table 24 U-values and other characteristics for the reference building. For further details see Annex Q.

Building component[a)]	U-value [W/m^{2}K]	g-value [-]
North and south facade	0.62	-
Gable walls	0.61	-
Roof	0.42	-
Windows	2.00	0.72
Wooden frame construction	1.15	-
Internal heat gains [W/m^2]	20.00	
Ventilation rate (natural) [h^{-1}]	2.25[b)]	
linear heat loss coefficients (Wall/Roof) [W/mK]	1.26	
linear heat loss coefficients (Wall/Floor) [W/mK]	0.41	
linear heat loss coefficients (Wall/Window) [W/mK]	0.35	
Heat capacity [j/Km^2]	370000	

[a)]Further details, see Annex Q

[b)] Values defined in relation to [52]

The infiltration rate is found to:

$$q_{inf} = 0.13\frac{l}{s}\ perheated\ floor\ area\ (m^2) = \frac{0.13\ \frac{l}{m^2 s} \cdot 3.6 \frac{m^3/h}{l/s}}{3.67\ m} = 0.13\ h^{-1}$$

- Energy frame

The energy frame is calculated corresponding to the heated floor area of 1300 m^2 and used to evaluate potential design solutions.

- Energy frame (Mandatory): 95 + 2200/A kWh/m^2 per year = 96.68 kWh/m^2 per year

- Energy frame (Low energy class 2): 71.3 + 1650/A kWh/m^2 pr. year = 72.57 kWh/m^2 per year

- Energy frame (Low energy class 1): 41 + 1000/A kWh/m^2 pr. year = 41.76 kWh/m^2 per year

- Energy frame (Low energy class 0): 25 + 550/A kWh/ m^2 pr. year = 25.42 kWh/m^2 per year

5.3.1.2. Development of BIM-model (Level 1.0)

The reference building contains more than 12 rooms and has three floors. As WinDesign only analyzes a maximum of 12 rooms in one storey, a section of the reference building including 12 rooms, is chosen to be analyzed (Figure 44). This section will then represent the whole building. A section on the second floor has been chosen, as it is assumed to have the biggest heat loss due to its connection to the roof and therefore represent the most critical conditions for heating demands.

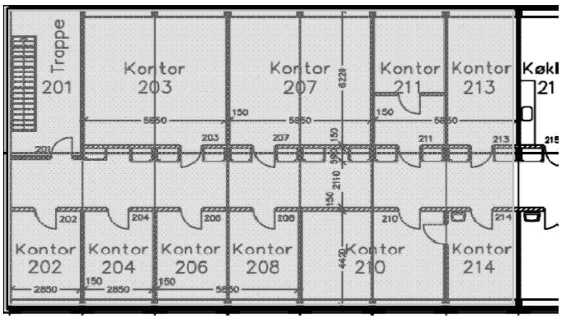


Figure 44 Section (the grey area) of the third floor, which is analyzed in WinDesign. This section will represent the whole building.

The IFC-file exported from the BIM-model should only contain information about the section described above. However, the IFC-collector is developed only to gather information from the BIM-model, which is in relation to a zone (space). Thus, only the zones (spaces) in this section should be defined in the BIM-model as described in part 4.2.4 (Figure 45). The BIM-model (Level 1.0) is attached on the enclosed CD (*BIM-models -> Case2_BIM_model_1.0*).

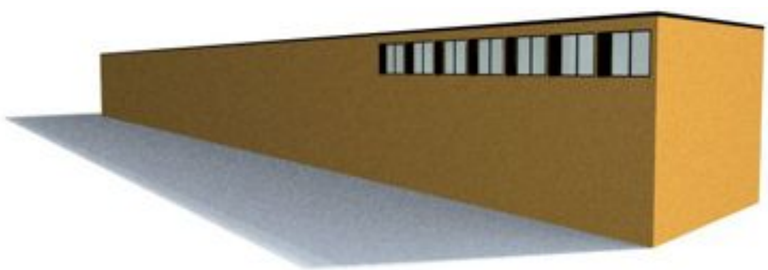


Figure 45 Illustration of the BIM-model (Level 1.0). Only the section which has to be analyzed in WinDesign is modelled with windows and zones (spaces)

5.3.1.3. Analysis of reference building

Information about the energy consumption and indoor environment of the reference building has not been available for this case study. Thus, to compare with other design solutions, the energy consumption and indoor environment of the reference building are analysed further.

- Energy consumption

The IFC-file exported from the BIM-model (Level 1.0) is imported in WinDesign. U-values, g-values, ventilation rates, and temperature set points are further adjusted as described in Table 24. From these conditions, the energy consumption for heating is calculated in WinDesign (step 2) and found to:

$$Yearly\ energy\ consumption\ for\ heating = \ 110\ kWh/m^2$$

The WinDesign file is attached in the enclosed CD (*WinDesign->WinDesign_IFC_Case2_RefBuilding*).

However, the energy frame for offices consists of the total energy consumption for heating, cooling, ventilation, domestic hot water, and lighting. The reference building has neither a cooling system installed nor a working mechanical ventilation. Thus, the energy consumption for ventilation and cooling is 0. The energy consumption for domestic hot water is stated as a default value of 13 kWh/m^2 per year [1]. The energy consumption for lightning is stated to 26 kWh/m^2 per year [36].

The total energy consumption for heating, domestic hot water, and lighting may now be found to:

$$Total\ energy\ consumtion = 110 + 13\ + 26\ = 149\ \frac{kWh}{m^2} per\ year$$

From the total energy consumption stated above it is found that the reference building exceeds the requirements for the energy frame (96.68 kWh/m^2 per year).

- **Daylight conditions**

The daylight conditions are evaluated by Visualizer. The BIM-model (Level 1.0) is imported and the following material properties are assigned as default values:

- Wall and ceiling surfaces: White paint (Refl. = 0.90, Roughness = 0.00, Specularity = 0.00)
- Floor surfaces: Linoleum (Reflectance = 0.59, Roughness = 0.05, Specularity = 0.30)
- Windows and doors: Window glass (Transmittance = 0.72)

Other settings applied for the evaluation are:

- Location: Copenhagen
- Orientation: 340°
- Sky conditions: Overcast
- Date and time: 21th of march, 12:00

Based on these default values, the daylight conditions are found as illustrate in Figure 46.

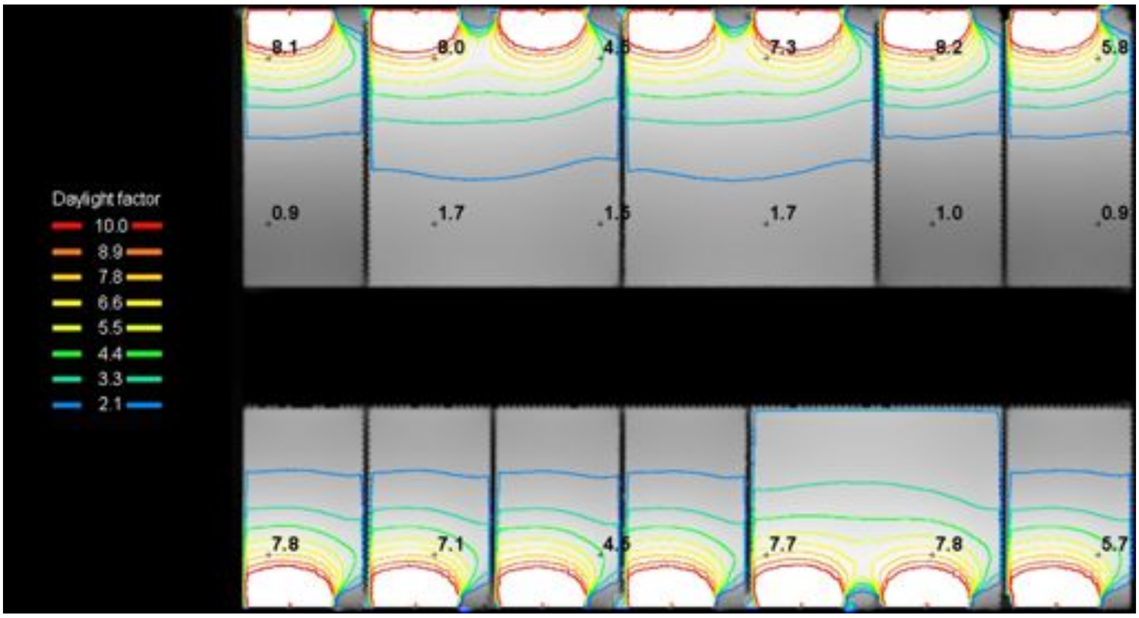


Figure 46 Results of daylight analysis (DF) in Visualizer. Only the section of 12 rooms are analysed.

Ideally, the daylight factor should be evaluated as an average value. As shown in Figure 46, the simulation in Visualizer only results in few specific daylight factor (DF) points. However, it still presents DF-curves, which indicate the daylight conditions of all rooms. It is shown that the daylight conditions are good compared to the standards presented in Table 7. Though, as no windows are connected to the corridor between the north and south facing rooms, the daylight conditions are pure.

5.3.1.4. Optimization of energy consumption and indoor environment

Using WinDesign (step 2) and Visualizer, several improvements of the building are analyzed to se potential effects on energy consumption and indoor environment. However, as WinDesign (step 2) does not allow analyses of the thermal environment, only the visual environment is analyzed in this phase of the design process.

The improvements are analyzed as individual optimization scenarios within three different categories. To gain an optimal overview of the improvements, the optimization scenarios are presented in tables. The progression of the optimization scenarios are as follow:

- **Building envelope (walls, roof, and windows):** Five optimization scenarios (1-5) will analyze improvements of the walls, roof, and window.
- **Solar shadings:** One of the optimization scenarios (1-5) is chosen and the effect of different solar shadings is analyzed in five new optimization scenarios (x.1 – x.5), where "x" is the number (1-5) depending on the first optimization scenario chosen.

- **Mechanical ventilation:** One of the optimization scenarios (x.1 – x.5) is chosen and the effect of different mechanical ventilation systems are analyzed in five new optimization scenarios (x.x.1 – x.x.5).

The following parts will present the design scenarios and their effect on the energy consumption. As mentioned in case study 1, WinDesign calculates the cooling consumption and cooling season as default in step 2. The result for the cooling consumption is not relevant as no cooling system is installed. However, they can be used to evaluate the potential risk of overheating, and are therefore also presented.

- Building envelope

Table 25 Optimization scenarios concerning the building envelope (walls, roof, and windows). The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case2_Opt1*).

Optimizing scenarios	Ref	1	2	3	4	5
Walls[a)]	U = 0.2	Extra insulation 0.2 m => U = 0.15	Extra insulation 0.2 m => U = 0.15	Extra insulation 0.2 m => U = 0.15	Extra insulation 0.2 m => U = 0.15	Extra insulation 0.2 m => U = 0.15
Roof[a)]	U = 0.42	Extra insulation 0.2 m => U = 0.14	Extra insulation 0.2 m => U = 0.14	Extra insulation 0.2 m => U = 0.14	Extra insulation 0.2 m => U = 0.14	Extra insulation 0.2 m => U = 0.14
Windows[b)]	U = 2.00 g = 0.72 A = 4.72	U = 0.5 g = 0.52 A = 4.72	U = 0.6 g = 0.52 A = 4.72	U = 0.7 g = 0.52 A = 4.72	U = 0.5 g = 0.52 A = 4.5	U = 0.5 g = 0.52 A = 4.5
Results						
Heating [kWh/m^2 year]	110	23	25	26	18	19
Heating season [Days]	231	147	151	154	135	138
Cooling[kWh/m^2 year]	57	77	76	75	78	77
Cooling season [Days]	185	278	274	271	294	289

[a)] U-values are calculated in accordance with DS-418 [13], see Annex R. Due to the improvements of walls and roof, the infiltration rate is reduced by 25% in optimization scenarios where extra external insulation is added. The linear heat loss coefficients are also reduced corresponding to: Wall/roof = 0.4 [W/mK] and Wall/window = 0.03 [W/mK].
[b)] All doors are defined as windows.

In general, the improvements result in a significant reduction of the heating demand. However, all of the optimization scenarios may result in overheating, as the cooling consumption and cooling season are significantly high. It is found that the optimization scenario 4 has the lowest energy consumption for heating, and it will therefore be analyzed further. In this optimization scenario the window area and g-value are reduced compared to the reference building. Thus, a daylight analysis is performed in Visualizer (Figure 47). The reduced g-value is adjusted in Visualizer by reducing the transparency of the window glazing. It is not possible to modify the building geometry when the BIM-model is imported to Visualizer. Thus, it has not been possible to adjust the window area.

However, the reduced window area is taken into account by reducing the transparency of the windows by 5%.

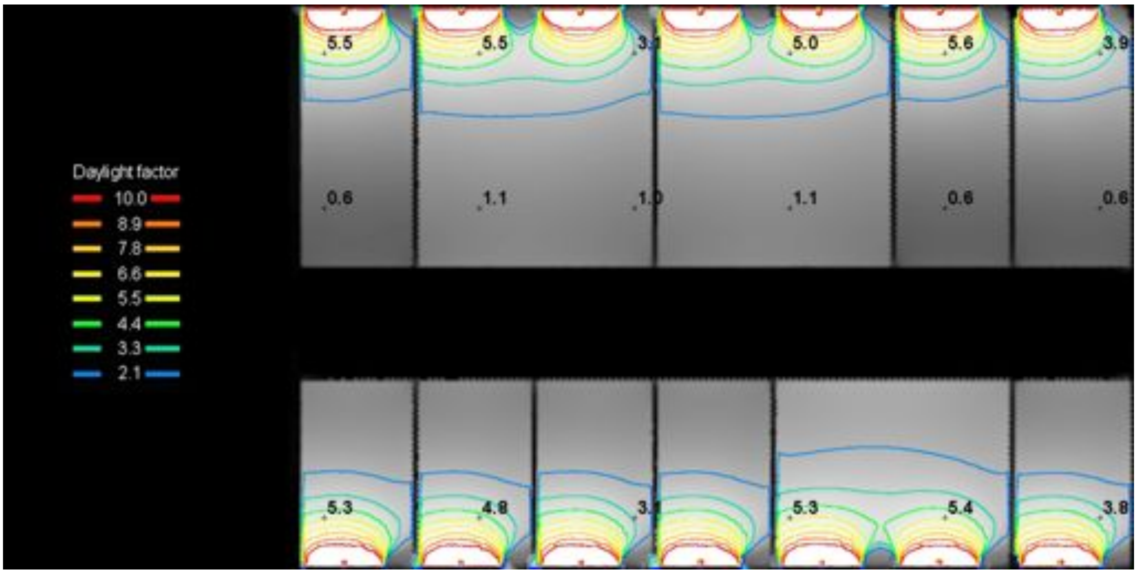


Figure 47 Daylight conditions of the optimization scenario 4. General settings in Visualizer are the same as described in part 5.3.1.3.

From Figure 47 it is found that the daylight conditions for the optimization scenario 4 are still acceptable. Nearly half of the building has a daylight factor (DF) above 2%, which is recommend for a work place.

- Solar shadings

Table 26 Optimization scenarios concerning solar shadings. SSC: Solar Shading Coefficient. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case2_Opt2*).

Optimizing scenarios	Ref.	4.1	4.2	4.3	4.4	4.5
Shadings [a)]	SSC = 1	SSC = 0.2	SSC = 0.4	SSC = 0.6	SSC = 0.8	SSC = 0.9
Results[d)]						
Heating [kWh/m^2 year]	110	24	22	21	19	19
Heating season [Days]	231	166	157	149	142	139
Cooling[kWh/m^2 year]	57	50	57	64	71	75
Cooling season [Days]	185	249	262	273	284	288

From the results shown in Table 26 it is stated that the heating consumption increases when the SSC-value decreases. However, the effect is not significant. It can also be stated that the risk of overheating decreases when the SSC-value decreases. The optimization scenario 4.1 is chosen for further analyzes. It has the highest heating consumption, but it has the lowest risk for overheating due to the low cooling consumption. The solar shadings are assumed not to have any effect on the daylight conditions, as the daylight factor is calculated from overcast sky conditions, where the solar shadings are not in use.

- Mechanical ventilation

In order to reduce the energy consumption and risk of overheating even further, the effect of a mechanical ventilation system is analyzed in five optimization scenarios (24.1-24.5) where different adjustments of the system are performed.

Analyses of potential effects from installing a mechanical ventilation system are performed (Table 27).

Table 27 Optimization scenarios concerning mechanical ventilation. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case2_Opt3*).

Optimizing scenarios	Ref.	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5
Mechanical ventilation[a)]	Non	Vent. rate = $0.6h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $1.0h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $1.4h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $1.8h^{-1}$.Heat recovery, eff. = 0.85	Vent. rate = $2.0h^{-1}$.Heat recovery, eff. = 0.85
Results[b)]						
Heating [kWh/m^2 year]	110	0	0	3	6	8
Heating season [Days]	231	0	0	60	96	109
Cooling[kWh/m^2 year]	57	38	27	19	15	13
Cooling season [Days]	185	225	168	131	100	88

[a)] The mechanical ventilation system also includes cooling. Vent. = Ventilation, eff. = Efficiency

The mechanical ventilation system shows are significant reduction of both the heating- and cooling consumption. The heat recovery unit secures that much of the internal heat gains are reused, which results in very low heating demands. The cooling demand is still high for most of the optimization scenarios. However, it decreases significantly when the ventilation rate is increased. The lowest energy consumption is found for the optimization scenario 4.1.5. With a ventilation rate of $2.0h^{-1}$ and a heat recovery unit, the heating consumption is found to be 8 kWh/m^2 year, and the cooling consumption is found to be 13 kWh/m^2 year.

The electrical energy consumption for the ventilation system is not included in the calculations performed by WinDesign. It is calculated from equation (1.27):

$$E_{vent} = \frac{T_d}{168} \cdot q_v \cdot SEL \cdot 365 \cdot 0.024 \cdot 2.5 \qquad (1.27)$$

Where

T_d = hours per week where the ventilation system is active [hours]

q_v = ventilation rate [L/s per m^2]

SEL = the specific energy consumption = 0.6 [W/(L/S)]

To get the most critical conditions, the ventilation system is assumed to be active in all hours during the week, resulting in $T_d = 168$

The ventilation rate was for optimization scenario 4.1.5 stated to 2.0 h^{-1}. In order to get the value in L/s per m^2 the following conversion is performed:

$$2.0\ h^{-1} = \frac{q_v\ \frac{l}{m^2 s} \cdot 3.6 \frac{m^3/h}{l/s}}{3.67\ m} => q_v = 2.03\ \frac{l}{m^2 s}$$

With these values the energy consumption for the ventilation system is calculated to:

$$E_{vent} = \frac{168}{168}\ \cdot\ 2.03 \cdot 0.6\ \cdot 365\ \cdot 0.024\ \cdot 2.5 = 26.7\ \frac{kWh}{m^2} per\ year$$

When adding the energy consumption for domestic hot water, the ventilation system, lighting and the heating and cooling consumption for optimization scenario 4.1.5, the total energy consumption is found to:

$$Total\ energy\ consumption = 8 + 13 + 13\ + 26\ + 26.7\ \ = 86.7\ \frac{kWh}{m^2} per\ year$$

The total energy consumption for the reference building was found to 149 kWh/m2 year. Thus, with the optimization scenario 4.1.5, the total energy consumption is reduced by approximately 41%.

5.3.1.5. Development of BIM-model (Level 1.1 and 1.2)

The adjustments performed in the optimization scenario 4.1.5 are implemented in the BIM-model (Level 1.1) (Figure 48). The BIM-model (Level 1.1) may be found in the on the enclosed CD (*BIM-models -> Case2_BIM_model_1.1_1.2*). In the IDMoER related to the pre-design phase, an architectural evaluation should ideally verify the design solution represented by the BIM-model (Level 1.1). If complications were found, these should be adjusted and implemented in the BIM-model (Level 1.2). In this case study, it is assumed that no complications are present. To illustrate an example of how the design solution could change the architectural expression of the building, it is assumed that the extra external insulation is covered with plaster painted in the same colour as originally.

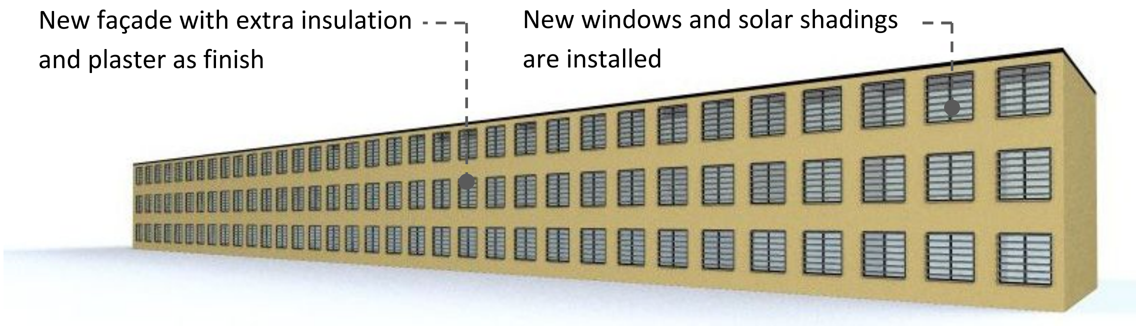


Figure 48 Rendering from the BIM-model (Level 1.2) of the facades facing south and east.

Figure 49 Floor plan from the BIM-model (Level 1.2). The dark grey area represents the section which have been analysed in WinDesign.

This design optimization represents one potential solution for the pre-design phase. Ideally, other design solutions should be performed in the pre-design phase. The client may then decide if one of the design solutions has a potential for further development in the concept design phase. However, in this case study, only one design solution is performed, and will be further analyzed in the concept design phase.

5.3.2. Concept design

The design solution chosen in the pre-design phase (optimization scenario 4.1.5) is further analyzed by WinDesign (step 3).

5.3.2.1. Development of BIM-model (Level 2.0)

If the client has any adjustments to the design solution 4.1.5, these are evaluated and implemented in the BIM-model (Level 2.0). The BIM-model (Level 2.0) is also adjusted to contain u- and g-values for external walls, roof, floor, windows, and doors represented by design solution 4.1.5. The BIM-model (Level 2.0) is enclosed on the CD (BIM-models -> Case2_BIM_model_2.0).

5.3.2.2. Optimization of energy consumption and indoor environment

The BIM-model (Level 2.0) is exported in IFC-format and imported in WinDesign (step 3). Five new optimization scenarios are performed based on the design solution from the pre-design phase (Table 28). Only the cooling system is analyzed.

Table 28 Optimization scenarios based on the design solution 4.1.5. Only the cooling system is adjusted. The WinDesign file is attached on the enclosed CD (*WinDesign -> WinDesign_IFC_Case2_Opt4*).

Opt. scenarios	Ref	4.1.5.1	4.1.5.2	4.1.5.3	4.1.5.4	4.1.5.5
Cooling	-	Activated, setpoint 24°C	Activated, setpoint 25°C	Activated, setpoint 26°C	Activated, setpoint 27°C	No cooling
Results						
Heating [kWh/m^2 year]	65	3.6	3.6	3.6	0.6	0.6
Cooling [kWh/m^2 year]	14	5.3	2.5	1.1	0.2	0
Hours with overheating (above 26°C) per year	-	0	0	0	124	135

From Table 28 it is found that the optimization scenario 4.1.5.5 results in the lowest energy consumption of 0.6 kWh/m^2 year. However, this optimization scenario results in 135 hours of overheating per year. The optimization scenarios 4.1.5.1, 4.1.5.2, and 4.1.5.3 are all adjusted with cooling setpoints below or equal to 26°C. Thus, all of them have zero hours with overheating per year. The optimization scenario 4.1.5.3 has the lowest energy consumption (4.7 kWh/m2 year), while still having zero hours with overheating. This optimization scenario is therefore chosen as the design solution for the concept design phase.

When adding the energy consumption for domestic hot water, the ventilation system, lighting, and the heating and cooling consumption for optimization scenario 4.1.5.3, the total energy consumption is found to:

$$Total\ energy\ consumtion = 4.7 + 13\ + 26 + 26.7\ = 70.4\ \frac{kWh}{m^2} per\ year$$

With this energy consumption the building would be classified as low energy 2 and will result in a reduction of 53% compared to the reference building. From the calculation above it appears that a big part of the energy consumption is due to the domestic hot water production and lighting. In order to reduce the energy consumption to a level which could classify the building as low energy 1 or 0, a reduction of these conditions should be performed.

The optimization scenario 4.1.5.3 has a ventilation rate at 2.0h^{-1} = 1.32 $\frac{l}{s}\ perheated\ floor\ area\ (m^2)$. This will cause the atmospheric environment to be classified as category I, see Annex D.

5.3.2.3. Development of BIM-model (Level 2.1 and 2.2)

The building envelope has not been changed from what was stated in the pre-design phase. Thus, no further changes have been adjusted in the BIM-model (Level 2.1). However, the detailed level of walls and ceiling has been modified. The final design solution is represented in the BIM-model

(Level 2.2) (Figure 50 and Figure 51). The BIM-model (Level 2.2) is enclosed on the CD (*BIM-models -> Case1_BIM_model_2.2*).

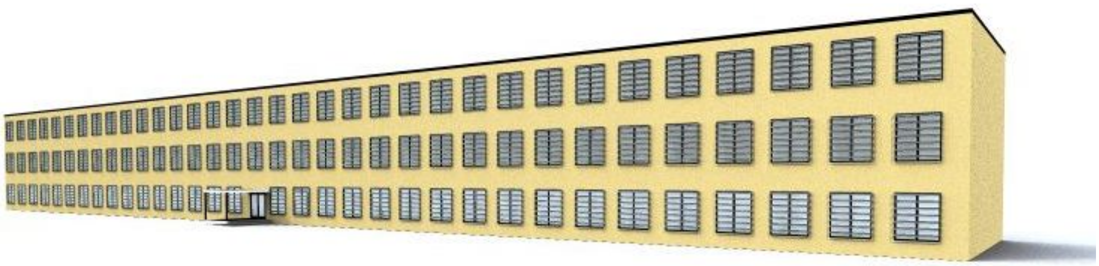


Figure 50 Rendering of the south and east facing facades from the BIM-model (Level 2.2)

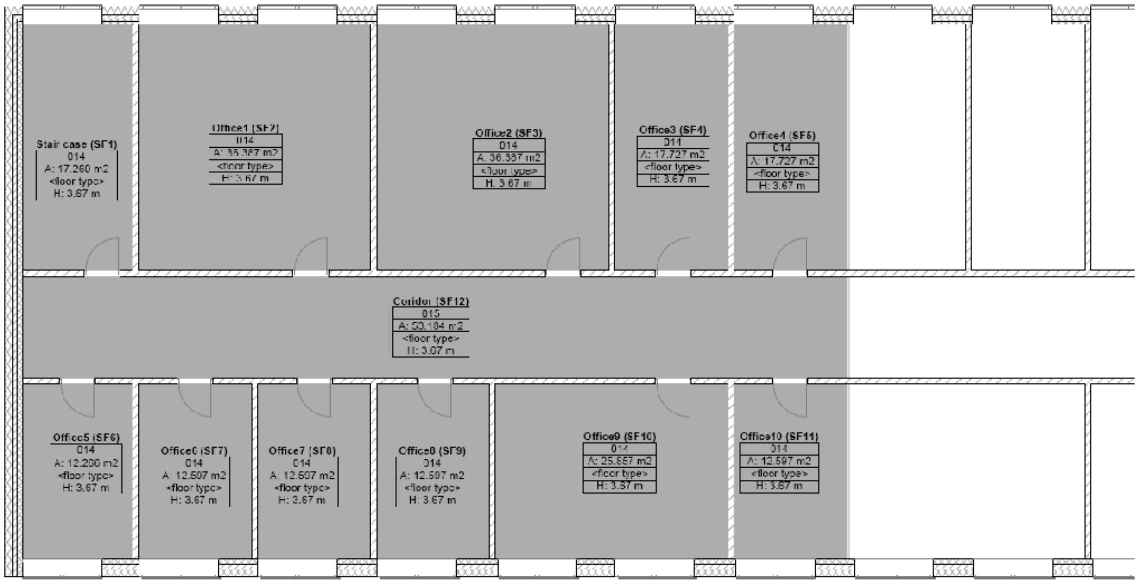


Figure 51 Floor plan from the BIM-model (Level 2.2), (not in scale)

6. Discussion

The current thesis has examined the potential of BIM and integrated design when planning energy retrofitting of buildings. A design process method, the IDMoER, has been developed to structure and utilize BIM for the design process. ArchiCAD is used as BIM application and WinDesign and Visualizer are used as analyzing tools (EEDDSS) within the IDMoER. WinDesign has been further developed to gain import capacity for IFC-files. Finally, the use of IDMoER and the upgraded version of WinDesign have been demonstrated in two case studies.

In part I-III, it is demonstrated how BIM and integrated design may be used to optimize energy performance and indoor environment when planning a retrofitting project. However, as discussed below, even though the possibilities are many, there are still things to consider and improve in relation to implementing BIM strategies in the AEC industry.

6.1. Digitalization of the building construction process

As described in the literature survey, there is a clear vision in the AEC industry towards implementing digital supported processes. The technology is well developed, and many applications are available on the market to support the digital processes. However, according to the literature survey, it seems that the digital vision is present mainly within the *BIM sphere* of organizations, software vendors, and BIM consultants. In this sphere, strategies, methods, and BIM applications are highly developed and understood, but the majority of people working within the AEC industry are outside of the BIM sphere. The applicability of the BIM-process is therefore highly dependent on people who have the qualifications, and it may course frustrations for those who do not. These considerations are also a main conclusion in the master thesis by Treldal, who recommend that guidelines and further attention need to be directed on how information stored in the BIM-model becomes valid for the other participants in the BIM-process [56].

IDM is an attempt to solve the issues stated above by concretizing and conveying the usability of BIM within the AEC industry. The intention is that IDM shall act as a general method focusing on the building development without any affiliations to specific applications in the BIM-process. Within the BIM sphere, they have come to agreement that the data transfer language must be an open data file format, which meets all demands from applications, including simulation tools, in the BIM-process. However, the structure and content of these open data files may vary according to the applications which they are exported from, and therefore, it may require different techniques to locate specific information in an open data file. This matter may cause uncertainties and errors in the data transfer process. Also, it decreases the potential of a broad interaction between all the applications that are present in the BIM-process, and it may influence the feasibility of IDM.

The design process method developed in the current thesis is based on the IDM method. Because of the matter above, the IDMoER is developed to function with specific applications only. These requirements decrease the general broad use of IDMoER, as all the consultants involved in the process are allowed only to use the specific applications, and furthermore, are obliged to use them in a specific way. It is, however, a method to secure that the consultants involved and applications used interact in uniformity.

For implementing digitalization in the building industry, a more flexible BIM-process is desirable, but it requires a higher level of standardization in relation to data transfer issues. The open data files must have a more uniform structure independent of the BIM-application they are created from. The newest version of IFC (2x4) attempt to live up to this vision and may in the future help to optimize the BIM-process. It has a decreased flexibility and the data structure is concretised, which can increase the uniformity of IFC-files.

A general concern when using BIM-models and digital data transfers in building construction projects are the lack of transparency. It can be difficult to validate the automatically generated data that are stored in applications present in the BIM-process. For instance, in case that someone forgets to define an external wall as “external” in the BIM-model, information of that specific wall can cause errors, which are difficult to locate, when it is used in other applications during the process.

6.2. Usability of BIM, WinDesign, and Visualizer for planning of energy retrofitting projects – a good match?

As mentioned in the literature survey, a great potential for energy reduction is present in the early design phases. IDMoER is therefore developed to function in this part of the building construction process, and it is developed as a design process method, which only focuses on energy and indoor environment. In reality, however, many other aspects influence the design solution as well, such as stability, cost, facility management, etc. For ideal usability of IDMoER, they should also be implemented.

The current thesis shows how information stored in a BIM-model may be transferred by IFC-files and utilized in WinDesign. Until now, WinDesign has not had the capacity to import IFC-files. Such capacity is now developed, and it allows WinDesign to act within the BIM-process. Many other analyzing tools do already support importation of IFC-files, so what are the benefits of such an improvement of WinDesign?

First of all, WinDesign is developed at the Technical University of Denmark (DTU), and there is ongoing research on developing the application to fit within the modern AEC industry. This makes the upgrade relevant for the future work. In addition, WinDesign is used for teaching with satisfaction within several courses concerning energy optimization and indoor environment, and here, its simple structure is an advantage.

Furthermore, WinDesign is developed on an open source platform, which makes it possible to assess how the calculations are performed. It results in a transparency that may be beneficial when analyzing the results. Other similar analyzing tools have closed calculation engines, which can make it rather difficult to assess and assure that the results are generated correctly.

Until now, no attention has been paid to how input data for WinDesign can be supported by information stored in IFC-files, and it may be concluded that there are advantages, but also some drawbacks when developing such a capacity. Most of the input data required for WinDesign are structured on room level, and it is easy obtained from the IFC-files, because it may be located in relation to the rooms defined in the BIM-model (spaces and space boundaries). This structure is also recommend by Treldal [56]. However, not all the input data required by WinDesign are related to rooms. Some are related to the entire building and they require another way of handling the IFC-data. If all input data were instead related to room level, it would decrease the complexity of the IFC capacity in WinDesign. Furthermore, the BIM-model may represent many building geometries of different kinds and may contain a lot of information, which are not supported by WinDesign. Thus, the BIM-model must be created within a set of boundaries to secure that information stored in the IFC file complies with the limitations of WinDesign.

In the current thesis, the IFC capacity for WinDesign is developed as an import function. Design alternatives found by the analyses in WinDesign then need to be manually adjusted in the BIM-model. To increase the interaction between the BIM-model and WinDesign, it will be beneficial if the IFC capacity for WinDesign is further developed with an export function. In that way, the interaction between the BIM application and WinDesign will be fully digitalized. This vision is, however, limited because WinDesign does not have a geometrical engine and therefore cannot communicate the adjusted building geometry to the IFC-file. Nonetheless, WinDesign would still be able to export properties for the building elements, ventilation rates, set point temperatures, etc. IFCsvr, which is used in the current thesis to develop the IFC capacity in WinDesign, does allow such adjustments of the IFC-file. Thus, the vision of developing export properties for WinDesign is a realistic vision, although it has geometrical limitations.

In the current thesis, Visualizer has been used along with WinDesign as an analyzing tool for design optimization within IDMoER. This simulation tool was already equipped with an import function to communicate with BIM-models, and when the geometry of the BIM-model is imported in Visualizer, it is possible to analyze the daylight conditions in a fast and intuitive manner. However, after it is imported in Visualizer, the geometry is not adjustable. Its usability in the design optimization process is therefore limited only to analyze adjustments of material properties, such as the transparency of the window glazing.

When discussing the usability of BIM and its simulation tools, here WinDesign and Visualizer, in the early design phases, it is important to see its potential in perspective of the entire building lifetime. The time and effort which are put into creating the BIM-model in the early design phases are usable also for the further building construction process and in the operation phase. The information is stored in the BIM-model.

The constellation of BIM, WinDesign, and Visualizer is useful for analyses and design optimizations of small, solitary and simple energy retrofitting projects. For being useful when analyzing larger building stocks, the analyzing tools require more sophisticated upgrades, which allow analyses on bigger scale.

6.3. Energy reduction in the existing building stock – from theory to practice

The main objective of using the combination of BIM, WinDesign, and Visualizer in IDMoER is to ease and optimize the design process for energy retrofitting projects and thereby decrease the energy consumption cost-effectively in the existing building stock. The web-based tools *Energikoncept.dk* and *Renovering2010.dk* are also developed with this purpose. However, some fundamental differences are present. IDMoER is developed as a uniform process. Information and effort put into the IDMoER are stored in the BIM-model and may be used further in the energy retrofitting process. When using *Energikoncept.dk* and *Renovering2010.dk*, time is spent and effort is made to type in information of the existing building in the web-based user interface. Results are then generated suggesting potential energy retrofitting possibilities and their effect on the energy consumption. However, the information is not stored and may not be used in a further design process, and the programs may only evaluate potential changes in the energy consumption and present the results as values. The interaction between BIM, WinDesign, and Visualizer secures that both energy and indoor environmental aspects are evaluated simultaneously. Furthermore, the results can be presented in both values and visualizations which then may form the basis of a more reliable analysis.

The present thesis has tested the usability and potential of using BIM, WinDesign, and Vizualizer in two case studies and a validation test. In the validation test it was found that a small error is present in the IFC-import capacity due to the simplified method of calculating the length between construction parts. This error can be eliminated by a further elaboration of the IFC-import capacity. However, because of its size of influenze and the magnitude of uncertainties which anyhow are present this early in the design phase, it is not considered as a crucial error.

The case studies tested the usability of IDMoER on a single family type house and a simple office building. In general, the usability of IDMoER was found acceptable and without any major weaknesses. It was shown that the use of IDMoER could visualize the physical design solutions and its effect on energy consumption and indoor environment. Furthermore, it was documented that potential design solutions for a single family type house and a simple office building could reduce the energy consumption with 45 and 53 percent while still having an optimal indoor environment. However, the speed of the IFC-import process could ideally be optimized. The IFC-file exported from the BIM-model representing the single family type house, had an importation time at 90 seconds for step 2, and 12 seconds for step 3. The speed of the IFC-import process is not influenced by the IFC-import capacity, but is due to the calculation engine of WinDesign. An optimization of the process speed therefore requires an optimization of the calculation engine in WinDesign.

WinDesign is originally developed to perform analyses on smaller buildings, which is reflected in the second case study on a simple office building. To respect the analytic boundaries of WinDesign, it was necessary to develop the BIM-model from a set of specific requirements so that analyses could be performed on smaller sections of the building independently. However, such requirements are not optimal, as they may lead to an increased amount of uncertainties.

The time spent and effort made to design the BIM-models were found to be within an acceptable level, because the time spent to create the models is returned by the digital data transfer process. However, it is important to be aware of the BIM-model's level of complexity when it is created based on the existing conditions. The existing information of a building can be obtained from various techniques, but many of them are too complex to be beneficial in the early design phases. The BIM-models used in IDMoER is very simple and do only contain the necessary information to support WinDesign and Visualizer. In order to optimize the speed of the BIM-model development, old models may be re-used. If a consultancy has a data base with several BIM-models, it might be possible to find a stored model, which by simple adjustments may be re-used in a new energy retrofitting project.

The current thesis has demonstrated that BIM can be utilized when planning energy retrofitting projects – but does it improve the effectiveness of the design phase and the size of energy reduction compared to the traditional process? The discussion above mentions advantages as well as disadvantages when using BIM in the energy retrofitting process. Many challenges are present. However, it seems that most of them are due to lack of familiarity and experience with the BIM-process and may become less, as new generations of consultants are coming into the AEC industry and maybe also, when a bigger unity of data handling in the development of BIM and its simulation tools are reached. In order to answer the question stated above, the IDMoER needs to be further upgraded, as suggested in this discussion, and tested in practice for comparison with a traditional design process.

7. Conclusion

The hypothesis, *when planning a retrofitting project, optimization of energy performance and indoor environment can be improved by using BIM and integrated design in the early design phases*, has been demonstrated by answering the research questions within the three main parts:

I. Design process method

A design process method was developed in order to structure and utilize BIM in the early design phases of energy retrofitting projects. IDM was found to be an optimal method for this matter and the specific IDM developed for the current design process method was referred to as IDMoER. It was developed for three specific applications; ArchiCAD, WinDesign, and Visualizer. Required information for the design process method was stated, and input data for the applications were indentified.

II. Data transfer

Data transfer between ArchiCAD, WinDesign, and Visualizer is within IDMoER performed as a digital process. Until now, WinDesign has not had the capacity to import IFC-files. Such capacity has been developed, which allows WinDesign to act within the BIM-process. It was found that the validity of the IFC-capacity for WinDesign is within an acceptable level, and this allows it to be used in the early design phases. However, further improvements are still needed.

III. Case studies

The usability of IDMoER and the IFC-capacity of WinDesign were tested in two case studies; a single family type house and a simple office building. Conclusions reached in these two case studies are listed below.

- WinDesign is originally developed for small buildings. Thus, IDMoER was found to be most optimal in the case study represented by a single family house.
- IDMoER was found less optimal for larger buildings due to the limitations of WinDesign. However, the case study represented by a simple office building, found a method for using IDMoER for a large building.
- It was shown that the use of IDMoER could visualize the physical design solutions and its effect on energy consumption and indoor environment. Furthermore, it was documented that potential design solutions for a single family type house and a simple office building could reduce the energy consumption with 45 and 53 percent while still having an optimal indoor environment.

In general, the findings of the currents thesis suggest that IDMoER is a useful method for integrating BIM in the early design phases of an energy retrofitting process, and along with WinDesign and Visualizer it ensures a useful basis for decisions concerning the further design development. However, even though the possibilities are many, there are still many things to consider and improve in relation to implementing BIM strategies in the AEC industry.

8. Future work

The research performed in the current thesis throws light on several issues, which could be analyzed and developed further.

- IDMoER:

IDMoER is currently only developed to perform design optimizations regarding energy and indoor environmental issues. Ideally, IDMoER should also involve other issues as cost and stability which influence the development of a potential design solution.

It would be interesting to test IDMoER with a more practical approach, where it could be compared with a traditional energy retrofitting process to assess the benefits and difficulties of using this digital approach.

- IFC capacity for WinDesign:

The IFC capacity for WinDesign is not yet fully developed. It would be beneficial to investigate the possibilities of an export function, which would allow a better interaction between the IFC file and WinDesign.

The IFC capacity does currently not support importation of sky lights due to an error accruing when exporting the IFC-file from ArchiCAD. This error should be investigated and the IFC capacity should be further developed to import sky lights.

The simplified method to obtain line lengths between construction parts could also be further optimized, so its accuracy would be precise, independently of the building geometry.

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10. Annex list

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Annex A – Conclusions of CIE 171:2006 - Test Cases to Assess the Accuracy of Lightning Computer Program, for Visualizer

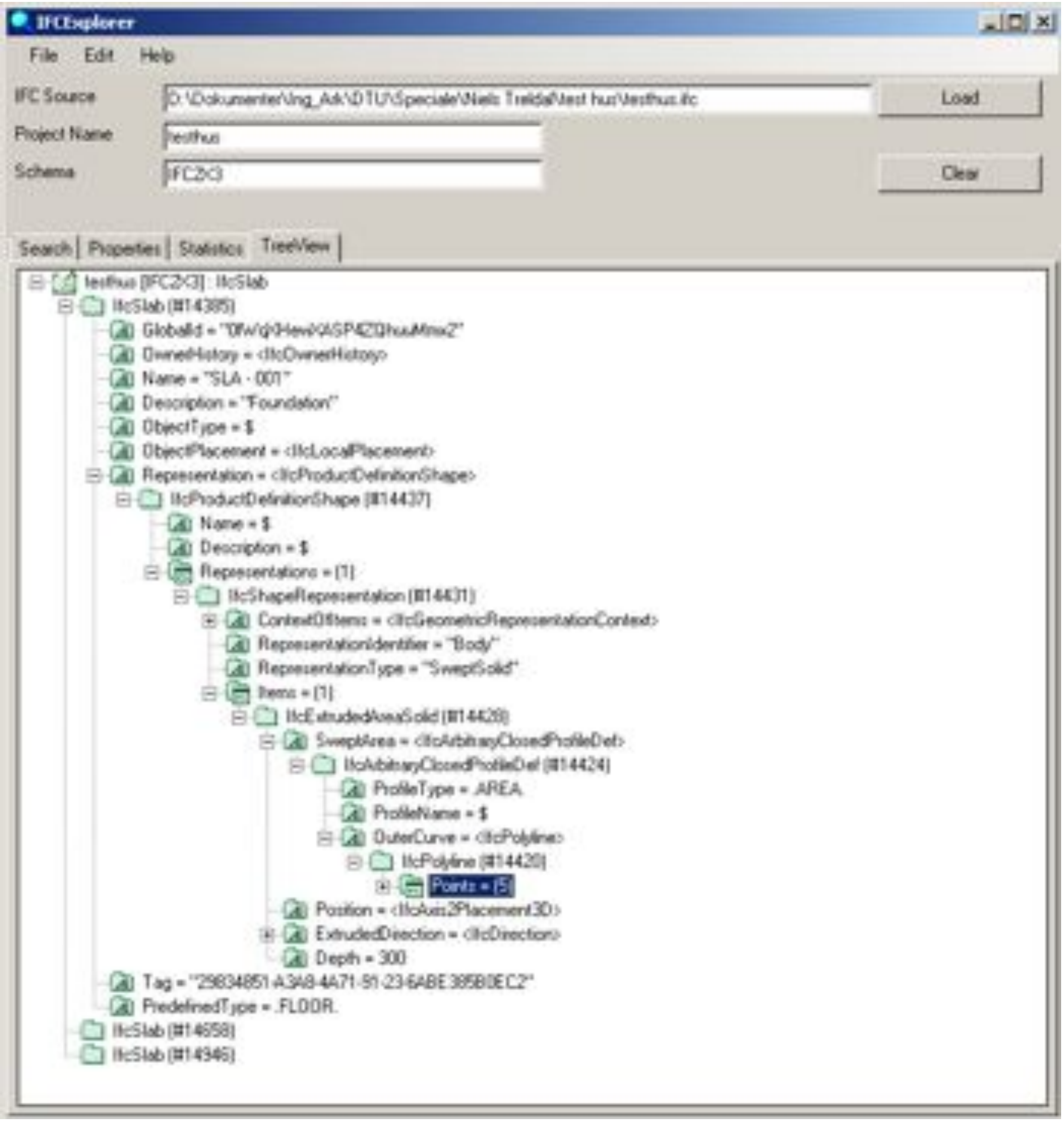
VELUX Daylight Visualizer 2 passed the CIE 171:2006 test cases dedicated to natural lighting. For the custom setting, VELUX Daylight Visualizer 2 simulates the following aspects of natural light transport with a maximal error lower than 5.13 %, and an average error lower than 1.29 %:

- Luminous flux conservation
- Directional transmittance of clear glass
- Light reflection over diffuse surfaces
- Diffuse reflection with internal obstructions
- Sky component for a roof unglazed opening for CIE sky types 1-15
- Sky component under a roof glazed opening for CIE sky types 1-15
- Sky component and external reflected component for a façade unglazed opening for CIE sky types 1-15
- Sky component and external reflected component for a façade glazed opening for CIE sky types 1-15
- Sky component and external reflected component for an unglazed façade opening with a continuous horizontal mask for CIE sky types 1-15
- Sky component and external reflected component for an unglazed façade opening with a continuous vertical mask for CIE sky types 1-15

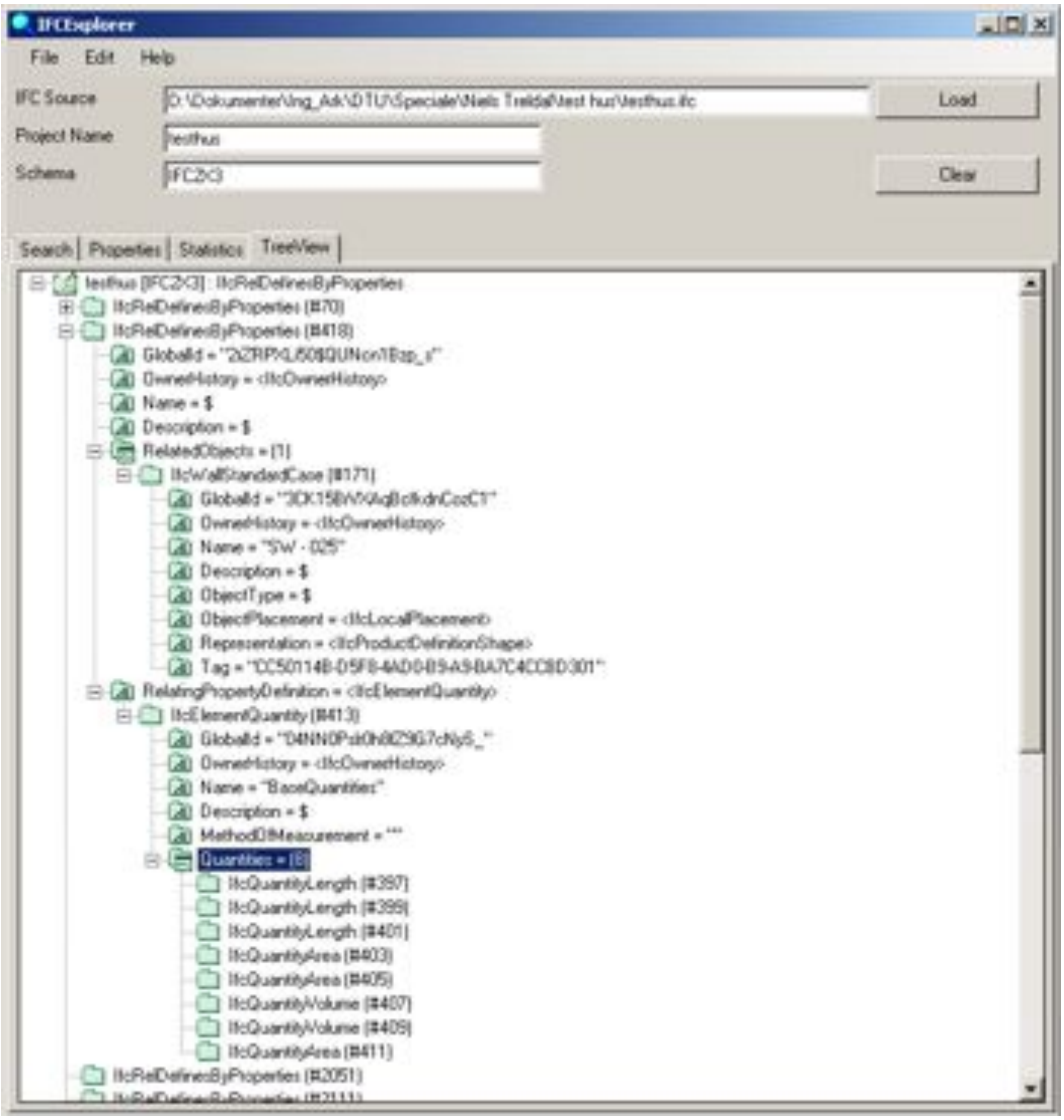
Annex B – IFC Explore and IFC viewer

IFC Explore:

Two examples are shown illustrating the hierarchy structure of an entity and the attributes connected to it.

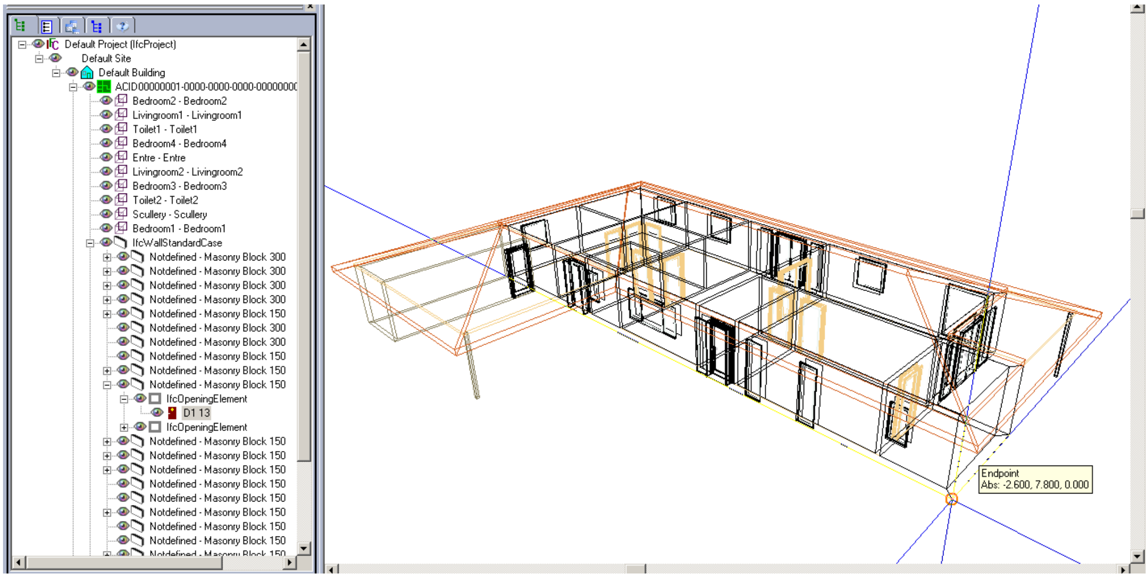


Screenshot from the IFC explore user interface. Hierarchy structure of an entity (IfcSlab)



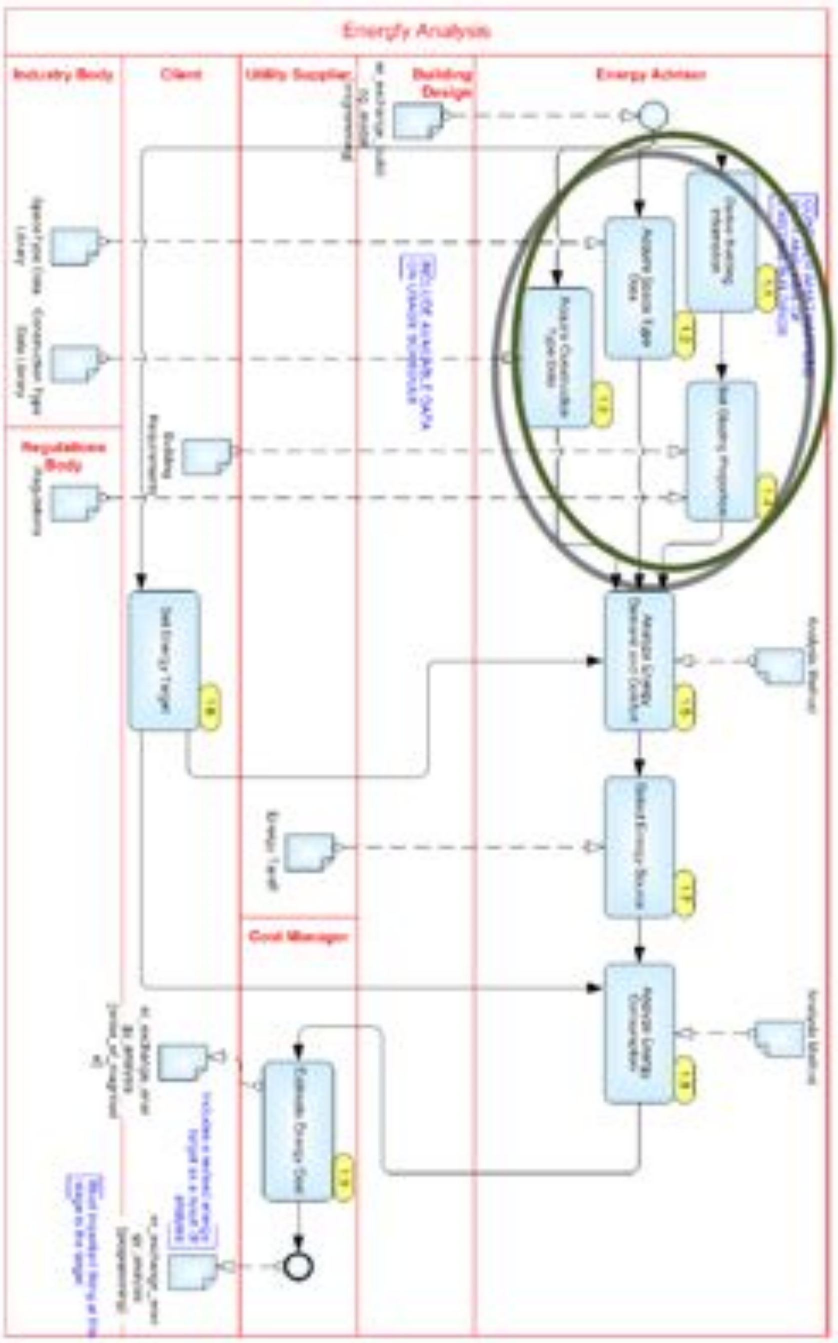
Screenshot from the IFC explore user interface. Hierarchy structure of an entity (IfcRelDefinesByProperties)

IFC viewer:



Screenshot from IFC viewer user interface.

Annex C – Example of process map for IDM



Example of process map for IDM

Annex D – Recommended ventilation rates for residential and non-residential buildings

Recommended ventilation rates for the residences.

Category	Air change rate [1)]		Living room and bedrooms, mainly outdoor air flow		Exhaust air flow, l/s		
	l/s,m² (1)	ach	l/s, pers[2)] (2)	l/s/m² (3)	Kitchen (4a)	Bathrooms (4b)	Toilets (4)
I	0,49	0,7	10	1,4	28	20	14
II	0,42	0,6	7	1,0	20	15	10
III	0,35	0,5	4	0,6	14	10	7

[1)] The air change rates expressed in l/sm² and ach correspond to each other when the ceiling height is 2,5 m

[2)]The number of occupants in a residence can be estimated from the number of bedrooms. The assumptions made at national level have to be used when existing, they may vary for energy and for IAQ calculations.

Recommended ventilation rates for non-residential buildings

Type of building or space	**Cate-gory**	**Floor area m²/per-son**	q_p	q_B	q_{tot}	q_B	q_{tot}	q_B	q_{tot}	**Add when smoking**
			l/s, m² for occupancy	**l/s,m² for very low-polluted building**		**l/s,m² for low-polluted building**		**l/s,m² for non-low polluted building**		**l/s,m²**
Single office	I	10	1,0	0,5	1,5	1,0	2,0	2,0	3,0	0,7
	II	**10**	**0,7**	**0,3**	**1,0**	**0,7**	**1,4**	**1,4**	**2,1**	**0,5**
	III	10	0,4	0,2	0,6	0,4	0,8	0,8	1,2	0,3
Land-scaped office	I	15	0,7	0,5	1,2	1,0	1,7	2,0	2,7	0,7
	II	**15**	**0,5**	**0,3**	**0,8**	**0,7**	**1,2**	**1,4**	**1,9**	**0,5**
	III	15	0,3	0,2	0,5	0,4	0,7	0,8	1,1	0,3

Annex E – Energy and environmental effects of retrofitting measures

Approximate energy savings for re-insulation[1]

Ydervægge af tegl eller beton 1) 2)		
Før	*Efter*	*Besparelse* 3)
0 mm	45 mm	140 kWh
45 mm	95 mm	30 kWh
95 mm	195 mm	20 kWh

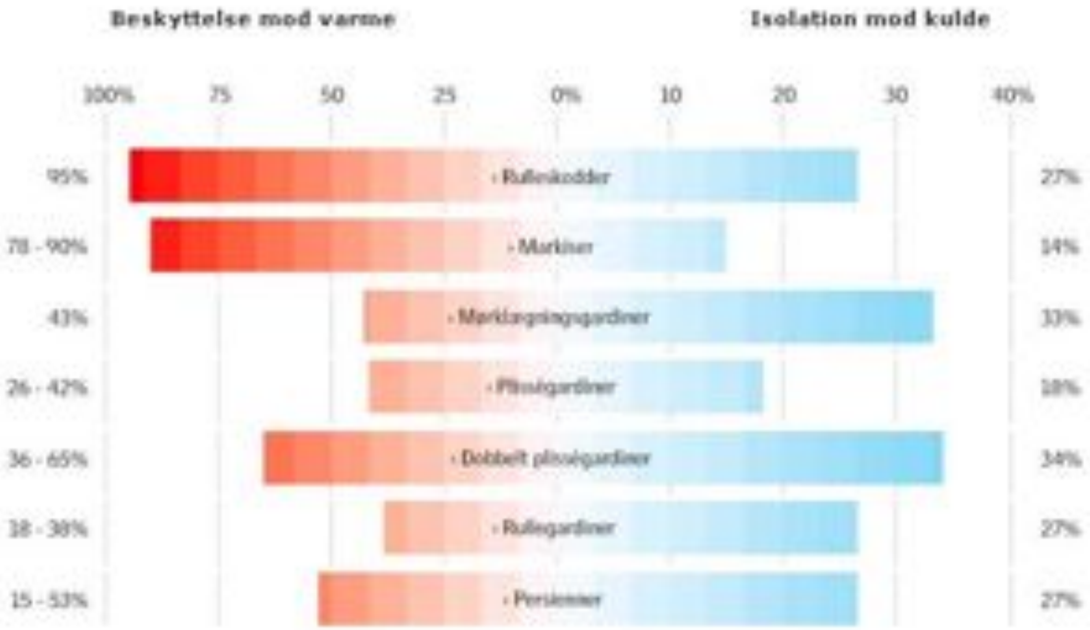
Noter:

1. Besparelsespotentiale er beregnet udfra oplysninger på Rockwools og Isovers hjemmesider. 1 l olie = ca. 10 kWh.
2. Tilsvarende besparelser opnås for tagkonstruktioner. For hulmur vil besparelserne være ca. 25% mindre med samme isoleringstykkelse.
3. Pr. m^2 ydervæg pr. år.

Advantages and disadvantages for external- and internal re-insulation[2]

	UDVENDIG EFTERISOLERING	INDVENDIG EFTERISOLERING
FORDELE	▪ effektivt - den varmeteknisk set bedste løsning ▪ minimerer kuldebroer, øger tæthed ▪ mulighed for høje isoleringstykkelser ▪ begrænset risiko for fugtskader ▪ den termiske masse bevares indvendigt (temperaturstabiliserende) ▪ kan give et arkitektonisk løft på et kedeligt hus	▪ relativt let at gennemføre - begrænsede følgearbejder *) ▪ relativt billigt - ofte kort tilbagebetalingstid ▪ kan gennemføres successivt ▪ kan bringe et meget højt varmetab ned på et acceptabelt niveau
ULEMPER	▪ omfattende indgreb ▪ relativt dyrt - lang tilbagebetalingstid målt i forhold til energibesparelse ▪ ofte mange nødvendige følgearbejder, fx vinduesudskiftning og evt. tagrenovering ▪ ændrer facadeudtrykket	▪ risiko for uheldig fugtophobning i konstruktionen - kræver omhyggelig udførelse ▪ flere og større kuldebroer ▪ tager plads fra boligens brugbare areal ▪ den termiske masse reduceres ▪ mindre effektivt - kan normalt ikke bringe et "acceptabelt" varmetab ned til et lavt niveau
		*) *Hvis rørføringer og radiatorer også skal flyttes eller ændes, vil følgearbejderne blive mere omfattende og dermed dyrere.*

[1] Found at www.dsbo.dk
[2] Found at www.dsbo.dk



Affect of different shadings on solar gains and insulation potential[3]

[3] Found at www.velux.dk

Annex F - General properties for existing buildings

Average U-values of different building components for 6 different time periods.

Area weighted U-values for external walls					
Period of erection	*Farmhouse*	*Single-family house*	*Terrace house*	*Block of flats*	*Trade and service*
1850-1930	0.85	0.86	1.02	1.10	1.04
1931-1950	0.88	0.85	1.00	1.16	1.17
1951-1960	0.86	0.84	0.99	1.00	1.08
1961-1972	0.74	0.65	0.65	0.93	0.69
1973-1978	0.51	0.50	0.54	0.52	0.50
1979-1998	0.46	0.37	0.34	0.36	0.39
Area weighted U-values for external roof					
Period of erection	*Farmhouse*	*Single-family house*	*Terrace house*	*Block of flats*	*Trade and service*
1850-1930	0.34	0.39	0.42	0.45	0.40
1931-1950	0.42	0.39	0.57	0.54	0.29
1951-1960	0.32	0.32	0.25	0.37	0.33
1961-1972	0.36	0.26	0.31	0.44	0.37
1973-1978	0.26	0.26	0.30	0.30	0.29
1979-1998	0.26	0.20	0.20	0.18	0.25
Area weighted U-values for external floor					
Period of erection	*Farmhouse*	*Single-family house*	*Terrace house*	*Block of flats*	*Trade and service*
1850-1930	0.41	0.37	0.42	0.45	0.56
1931-1950	0.34	0.38	0.57	0.48	0.49
1951-1960	0.37	0.36	0.25	0.51	0.51
1961-1972	0.35	0.30	0.31	0.39	0.42
1973-1978	0.27	0.28	0.30	0.27	0.55
1979-1998	0.33	0.24	0.20	0.24	0.55
Area weighted U-values for external windows					
Period of erection	*Farmhouse*	*Single-family house*	*Terrace house*	*Block of flats*	*Trade and service*
1850-1930	2.59	2.56	2.58	2.72	2.60
1931-1950	2.61	2.50	2.46	2.68	2.62
1951-1960	2.52	2.50	2.49	2.69	2.51
1961-1972	2.70	2.52	2.47	2.48	2.62
1973-1978	2.47	2.48	2.46	2.58	2.46
1979-1998	2.43	2.40	2.50	2.41	2.54

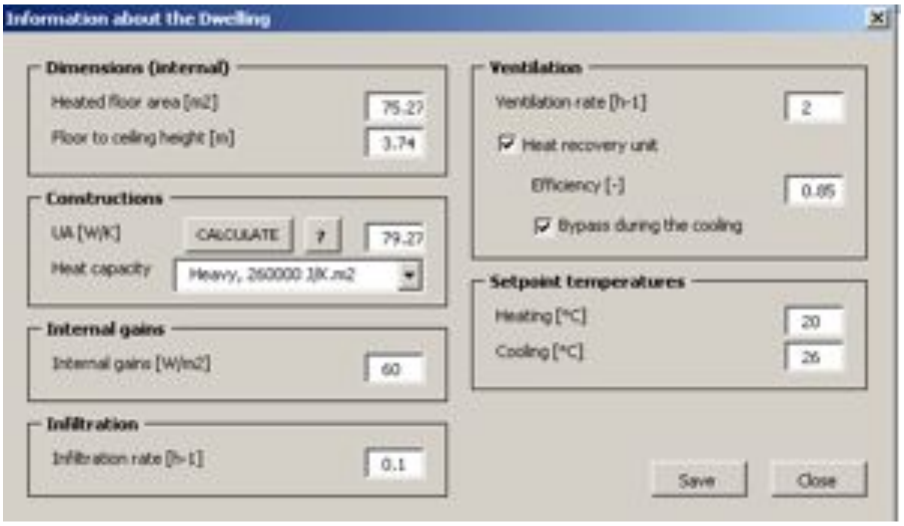
Annex G – List of measurement tools for geometrical analysis

List of digital measurement tools for geometrical analysis of buildings, anno 2009

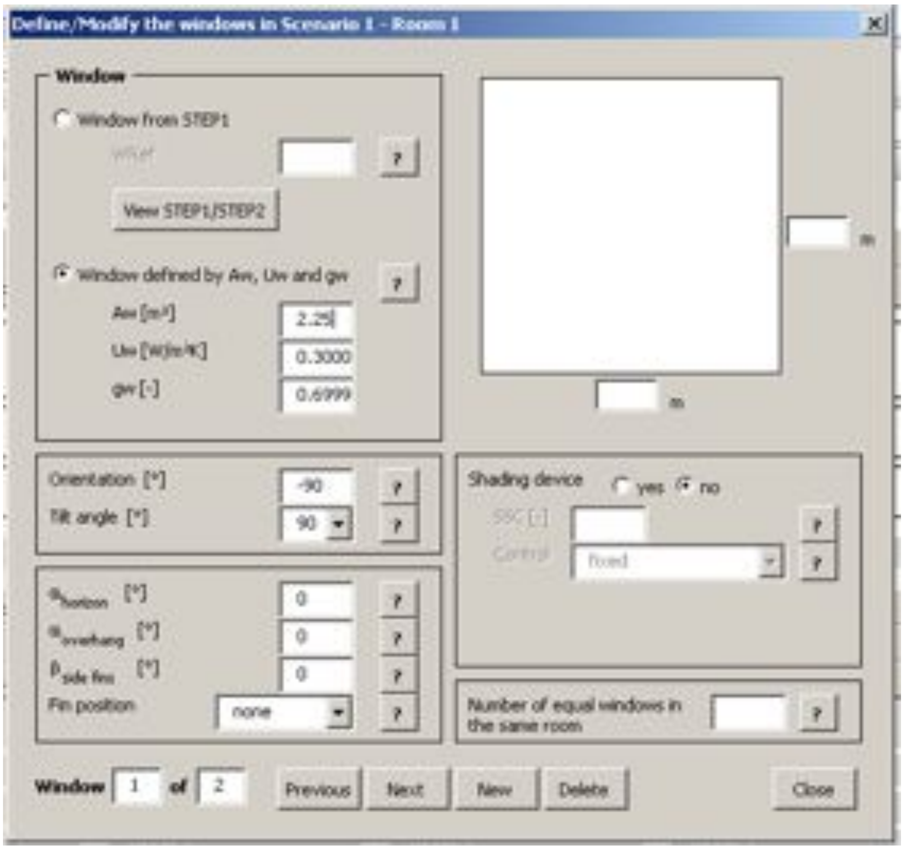
Metode/Værktøj	Kendetegn	Egner sig til	Udbydere (ikke udtømmende)	Opmåling: bearbejdning (tommelfingerregler der skal illustrere forskellene mellem metoderne)
Totalstation	Nemt og hurtigt at sætte op og anvende. Høj præcision i målinger.	Opmåling generelt i 2D og 3D	De fleste landmålere har en totalstation, men det er ikke alle, der kan levere resultatet fornuftigt i en 3D CAD model.	1:2
Totalstation m. indbygget kamera	Som ovenfor men målingerne styres vha. digitale fotos og der skabes god sammenhæng mellem foto registrering og opmåling.	Opmåling generelt i 2D og 3D	Landmålergården	1:2
Specialiserede løsninger baseret på totalstation	Lavet til et formål og derfor optimeret til hastighed og den rette præcision.	Altaner, køkkenbordplader, indbygningsskabe	Altan.dk, Spekva, nytskab.dk	1:0,25
Laser Skanner	Høj detaljeringsgrad, meget efterbearbejdning. Mange punkter at arbejde med gør det langsomt at modellere.	Restaurering, registrering til kopiering fx hos stukatør	Landmålergården, Vektor (Tvilum)	1:4
Fotogrammetri	Utrolig hurtigt at skyde basis billederne. Lav investering i værktøj.	Facadeopmåling, registrering af bygningsdetaljer	3Dphoto, Frilandsmuseet (Nationalmuseet), Landinspektørfirmaet Jeppesen & Bjerre, Lifa, Nellemann & Bjørnkjær	1:10 (til produktion) 1:4 (facademodel)
Fotogrammetri, skanning	Nyt	Restaurering. Bygningselementer med mange detaljer. Svært fremkommelige steder.	3Dphoto	1:10
Traditionel Opmåling	Stadig den mest udbredte metode. Håndholdte laser afstandsmålere bliver mere og mere tilgængelige.	2D plantegninger m. højdekoter	Landmålere, arkitekter der i mindre opgaver selv måler op.	1:1
Ortofoto kombineret med fx skråfotos		3D Bymodeller, byplanlægning.	COWI, Scan kort, Blom info	Ikke undersøgt
GPS	Ikke særlig anvendt i renovering	Landopmåling	Ikke undersøgt	Ikke undersøgt

Annex H - User interfaces for input data in WinDesign

STEP 2:

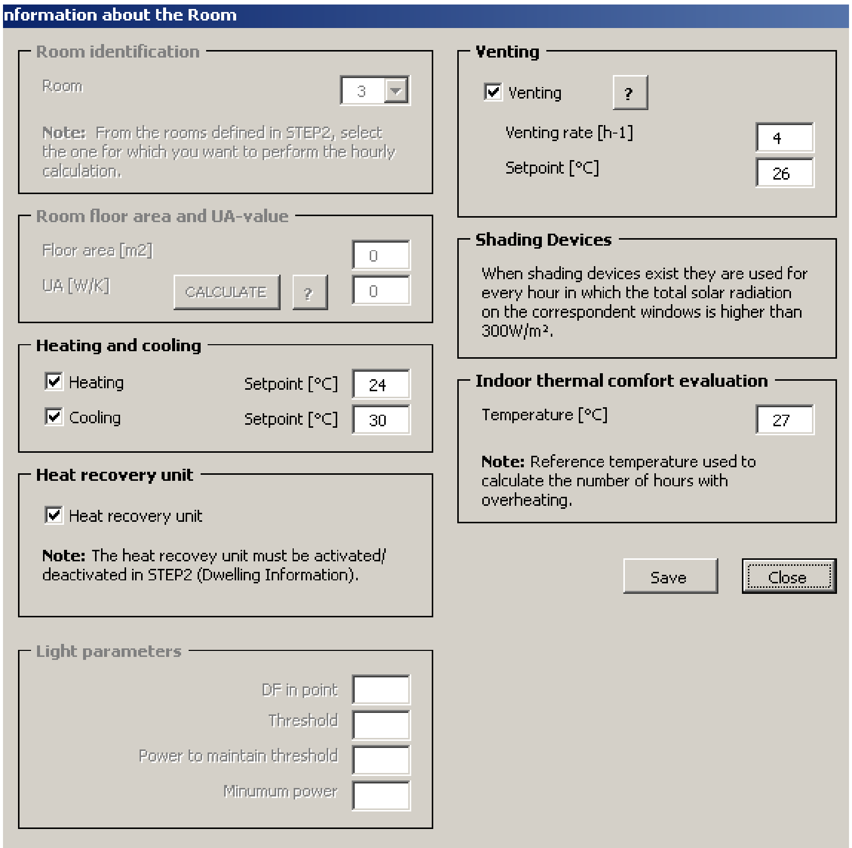


Interface where to define the general values concerning the building

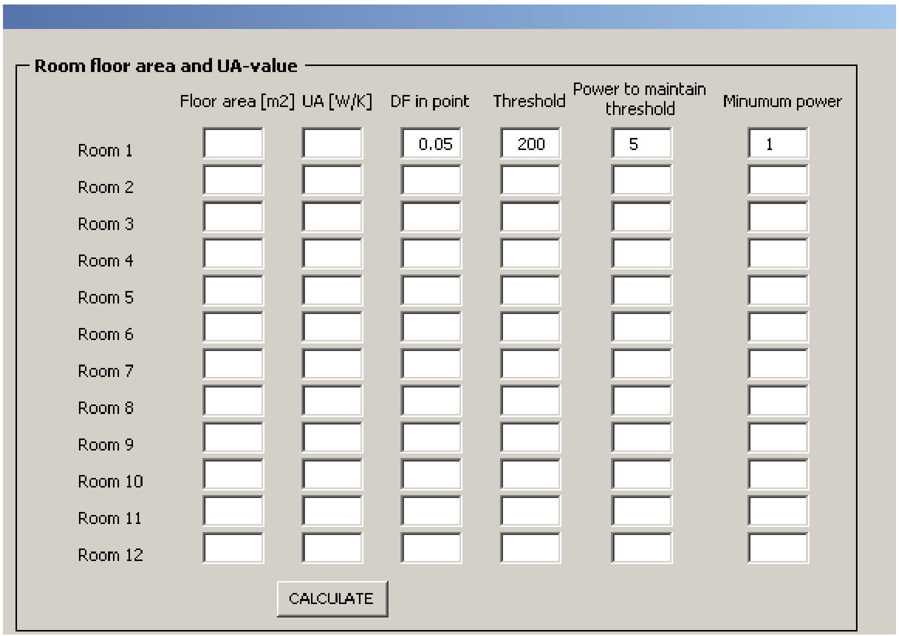


Interface where to define values for windows in specific room

STEP 3:



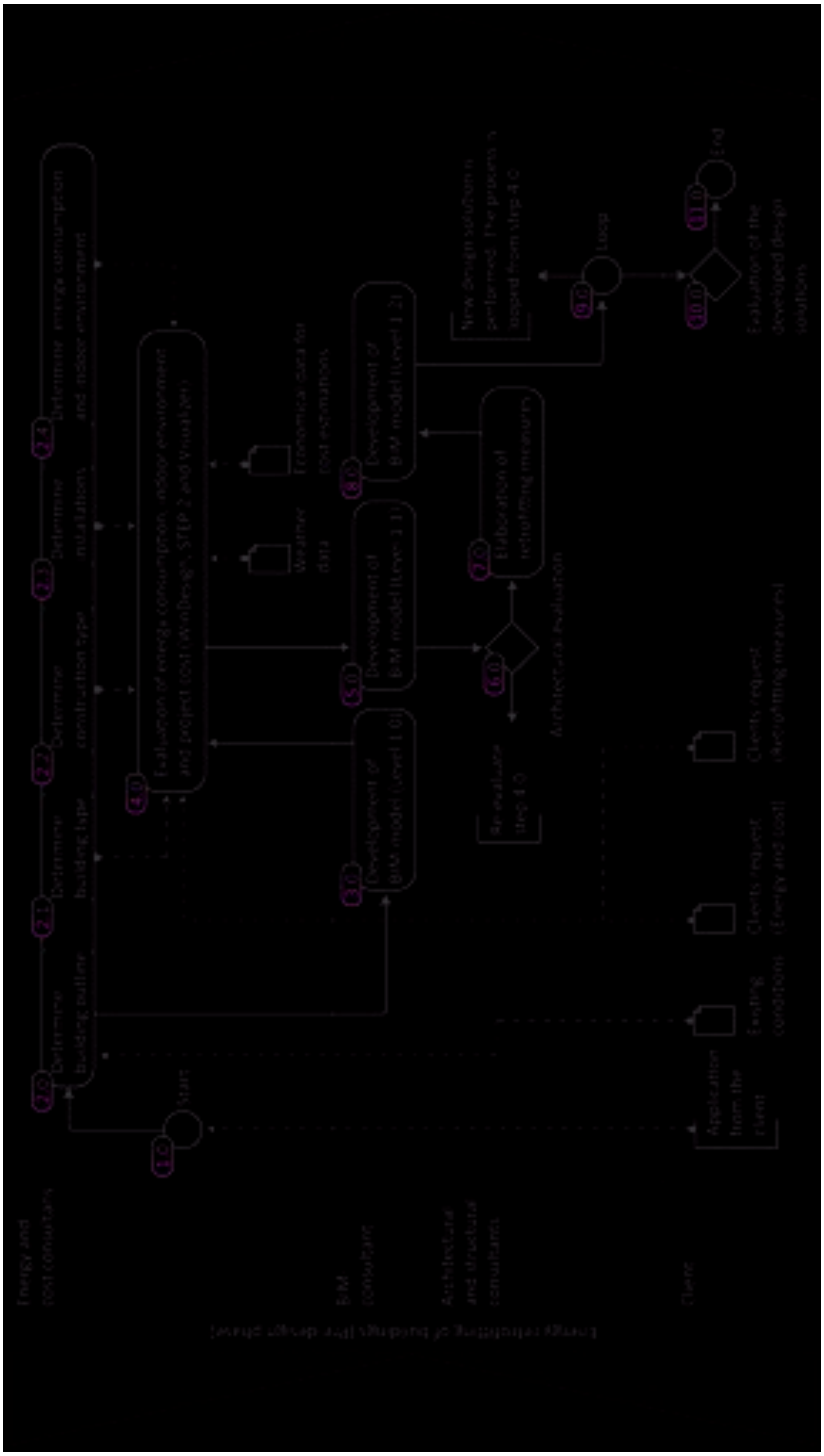
Left side of the interface where to define general values for the rooms



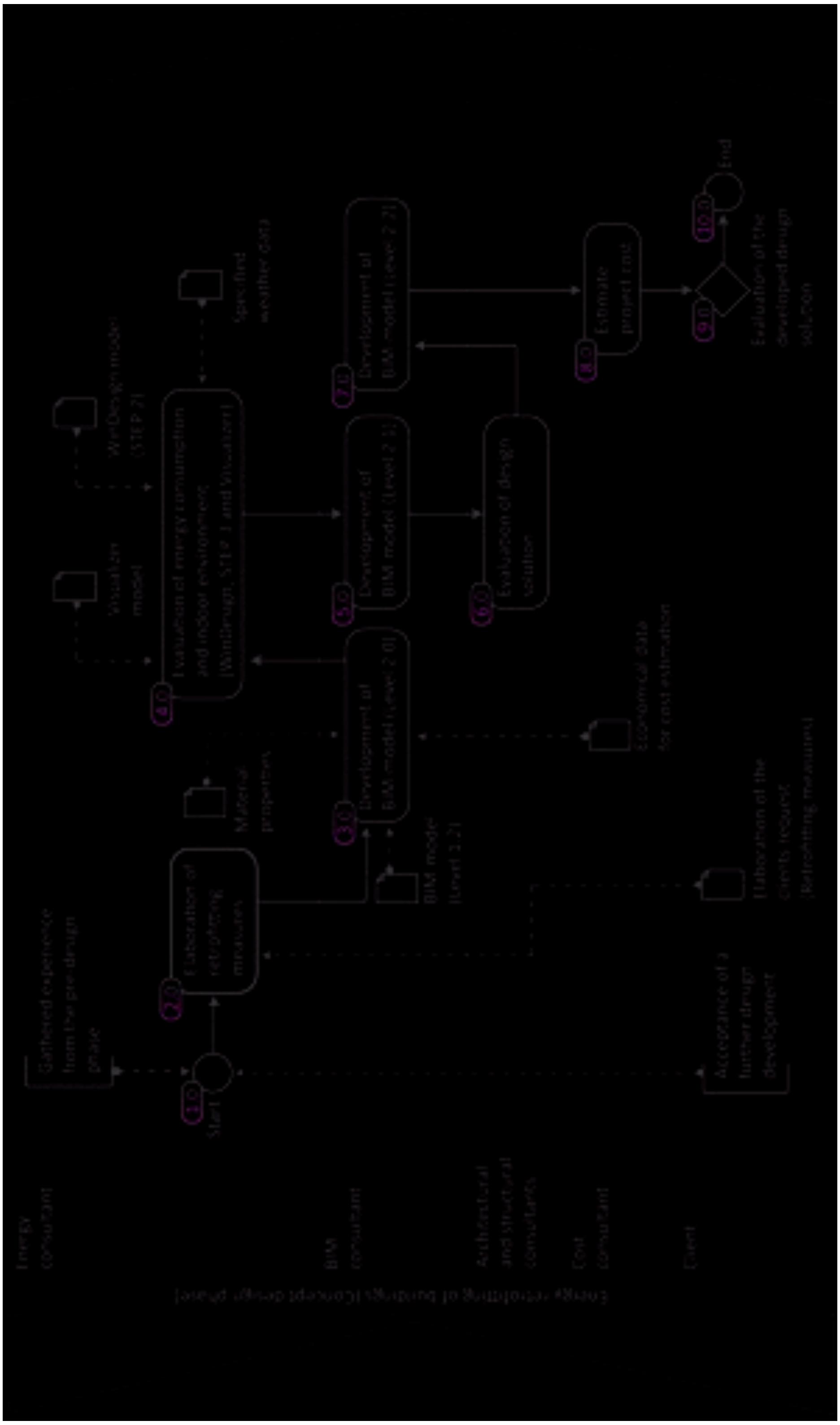
Right side of the interface where to define values for the rooms

Annex I – IDMoER in large scale

Pre-design

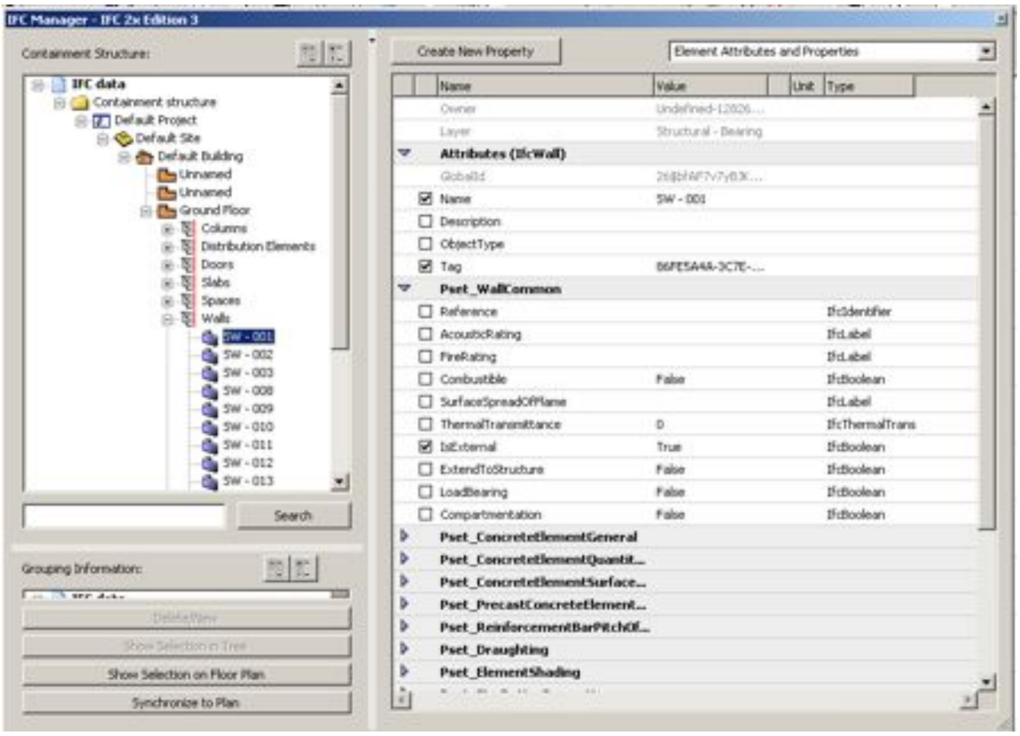


Concept design



Annex J – IFC setting dialogs in ArchiCAD

IFC-Manager:



IFC-manager dialog. The wall "SW – 001" is marked

IFC options:

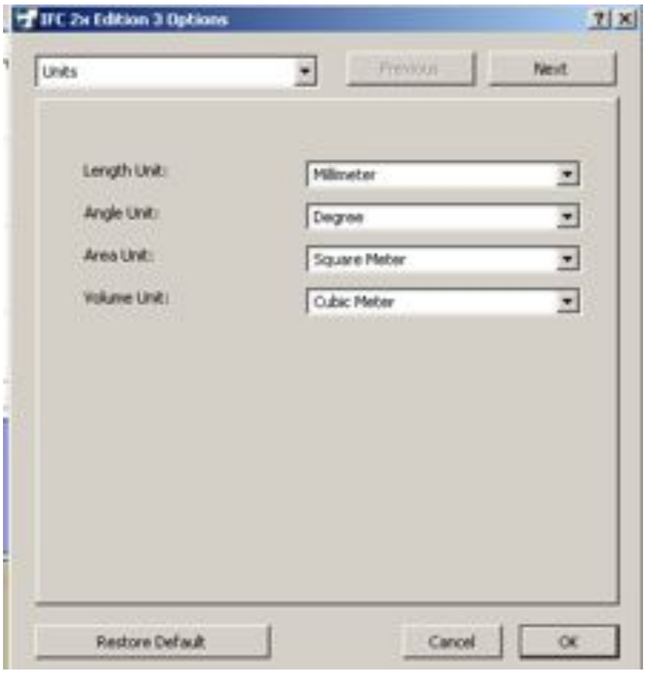


Illustration of the correct IFC-export settings

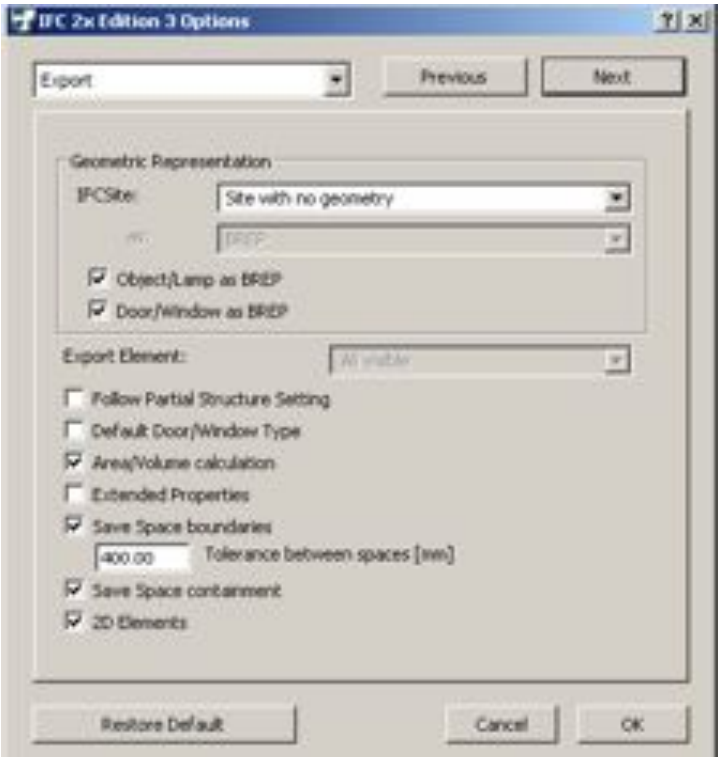
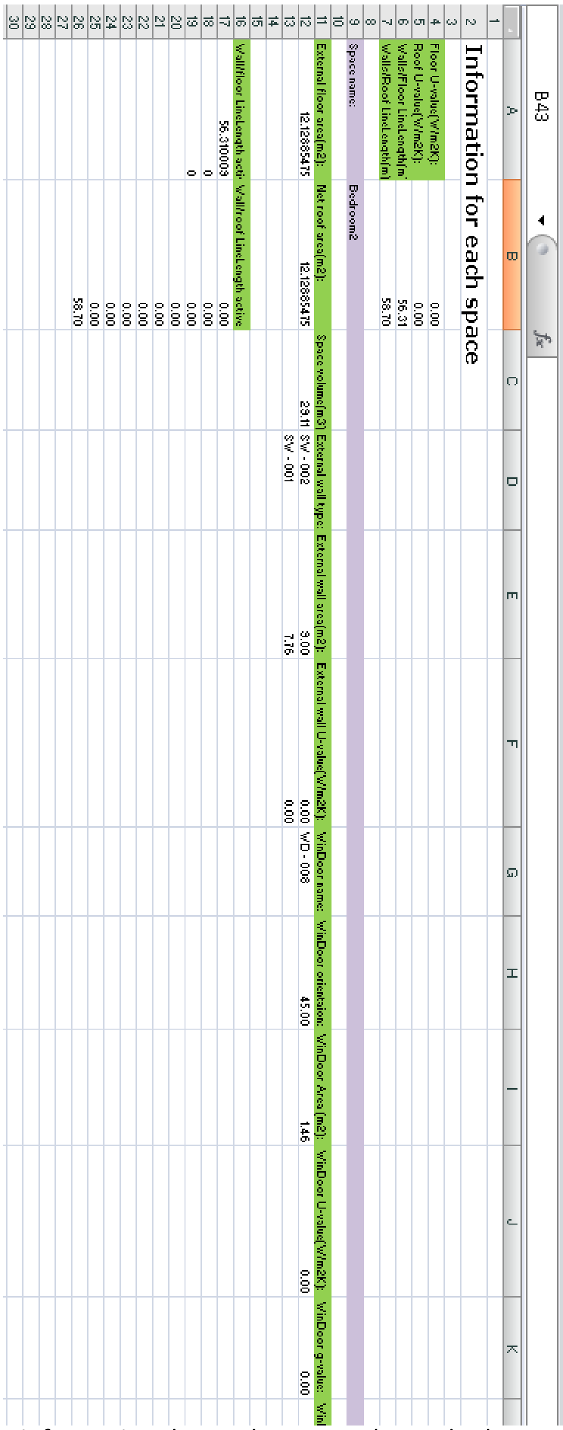


Illustration of the correct IFC-export settings

Illustration of the correct IFC-export settings

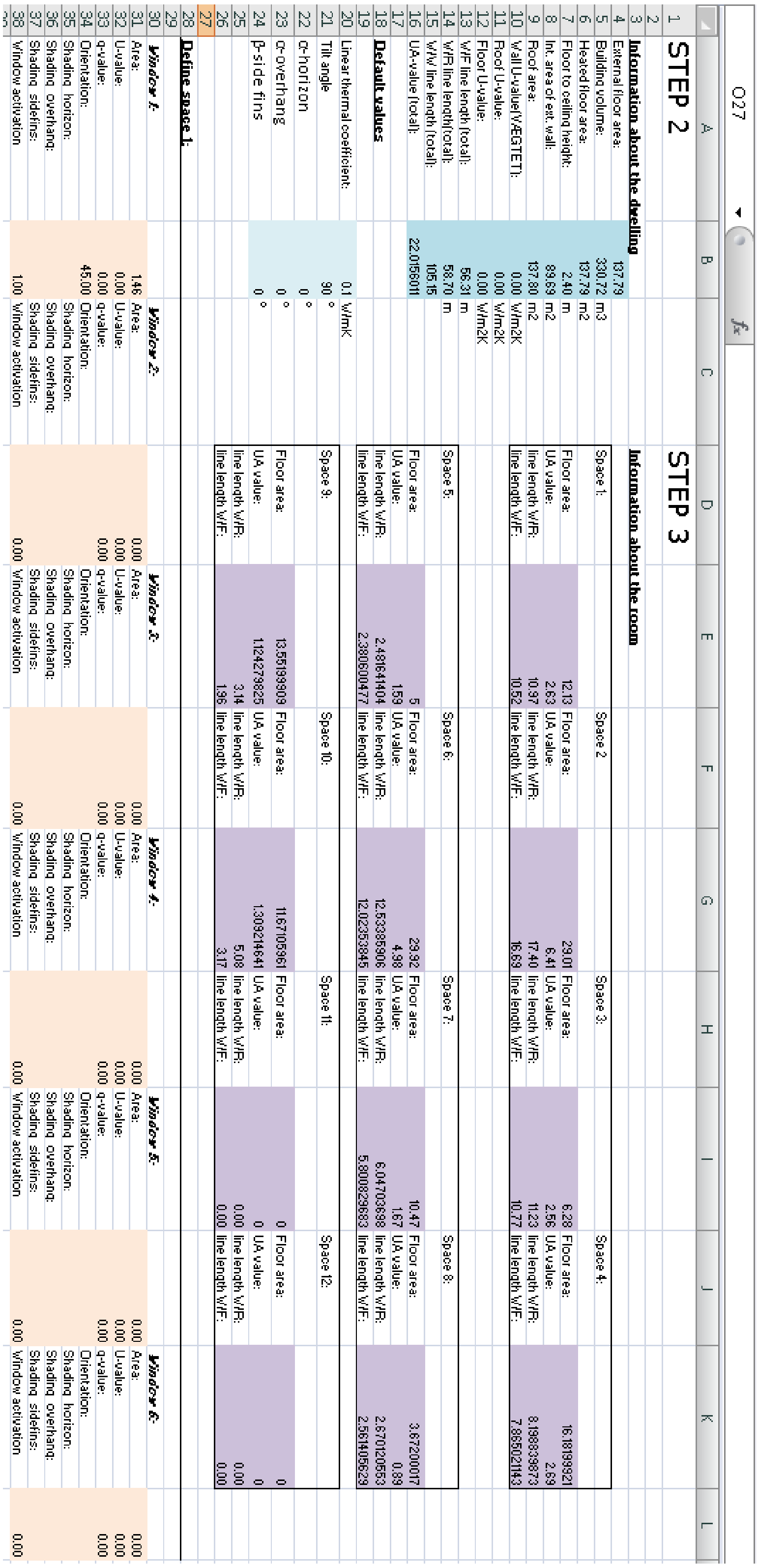
Annex K – Excel sheets in the IFC collector

Excel sheet: *IFC-information*



Screenshot from excel showing the *IFC-information* sheet. The screenshot only shows the raw IFC data for one room. Information for other rooms are collected similarly further right in the sheet.

Excel sheet: *IFC input for WinDesign*



O27

	A	B	C	D	E	F	G	H	I	J	K	L
1	STEP 2			STEP 3								
2												
3	Information about the dwelling			Information about the room								
4	External floor area:	137.79										
5	Building volume:	330.72	m3	Space 1:		Space 2		Space 3:		Space 4:		
6	Heated floor area:	137.79	m2									
7	Floor to ceiling height:	2.40	m	Floor area:	12.13	Floor area:	29.01	Floor area:	6.28	Floor area:	16.18199921	
8	Int. area of ext. wall:	89.69	m2	UA value:	2.63	UA value:	6.41	UA value:	2.56	UA value:	2.69	
9	Roof area:	137.80	m2	line length W/R:	10.97	line length W/R:	17.40	line length W/R:	11.23	line length W/R:	8.198839873	
10	Wall U-value(VÆGTET):	0.00	W/m2K	line length W/F:	10.52	line length W/F:	16.69	line length W/F:	10.77	line length W/F:	7.865021143	
11	Roof U-value:	0.00	W/m2K									
12	Floor U-value:	0.00	W/m2K									
13	W/F line length (total):	56.31	m									
14	W/R line length(total):	58.70	m	Space 5:		Space 6:		Space 7:		Space 8:		
15	W/W line length (total):	105.15										
16	UA-value (total):	22.0156011		Floor area:	5	Floor area:	29.92	Floor area:	10.47	Floor area:	3.67200017	
17				UA value:	1.59	UA value:	4.98	UA value:	1.67	UA value:	0.89	
18	Default values			line length W/R:	2.481641404	line length W/R:	12.53385906	line length W/R:	6.04703698	line length W/R:	2.670120553	
19				line length W/F:	2.380600477	line length W/F:	12.02353845	line length W/F:	5.800829683	line length W/F:	2.561405629	
20	Linear thermal coefficient:	0.1	W/mK									
21	Tilt angle	90	°	Space 9:		Space 10:		Space 11:		Space 12:		
22	α-horizon	0	°									
23	α-overhang	0	°	Floor area:	13.55199909	Floor area:	11.67105961	Floor area:	0	Floor area:	0	
24	β-side fins	0	°	UA value:	1.124279825	UA value:	1.309214641	UA value:	0	UA value:	0	
25				line length W/R:	3.14	line length W/R:	5.08	line length W/R:	0.00	line length W/R:	0.00	
26				line length W/F:	1.96	line length W/F:	3.17	line length W/F:	0.00	line length W/F:	0.00	
27												
28	Define space 1:											
29												
30	Window 1:		Window 2:		Window 3:		Window 4:		Window 5:		Window 6:	
31	Area:	1.46	Area:	0.00	Area:	0.00	Area:	0.00	Area:	0.00	Area:	0.00
32	U-value:	0.00	U-value:	0.00	U-value:	0.00	U-value:	0.00	U-value:	0.00	U-value:	0.00
33	q-value:	0.00	q-value:	0.00	q-value:	0.00	q-value:	0.00	q-value:	0.00	q-value:	0.00
34	Orientation:	45.00	Orientation:		Orientation:		Orientation:		Orientation:		Orientation:	
35	Shading horizon:		Shading horizon:		Shading horizon:		Shading horizon:		Shading horizon:		Shading horizon:	
36	Shading overhang:		Shading overhang:		Shading overhang:		Shading overhang:		Shading overhang:		Shading overhang:	
37	Shading sidefins:		Shading sidefins:		Shading sidefins:		Shading sidefins:		Shading sidefins:		Shading sidefins:	
38	Window activation	1.00	Window activation	0.00	Window activation	0.00	Window activation	0.00	Window activation	0.00	Window activation	0.00

Screenshot from excel showing the *IFC input for WinDesign* sheet. All data from the IFC-information sheet are prepared in this sheet.

Annex L - Script for the IFC capacity for WinDesign

As indicated, the start of the script is based on a script created by Niels Treldal in his Master thesis, Integrated Data and Process Control During BIM Design, 2008.

```
' ==================================================================================
' Following script is created by Rune Andersen, s042556, Technical University of Denmark

' It is based on a script created by Niels Treldal, s021820, Technical University of
Denmark
' ==================================================================================

'----------------------------------------------------------------------------------
' Starts the import of IFC data
'----------------------------------------------------------------------------------

Option Explicit
Public objIFCsvr As IFCsvr.R300
Public objDesign As IFCsvr.Design

Public Function StartImport()
  Dim filename As String
  Dim strSchemaName As String
  Dim ArchiCAD_OK As Boolean
  Dim objIfcApplication As IFCsvr.Entity

   ' Get IFC file

  filename = ActiveSheet.Range("E6").Value

  Set objIFCsvr = New IFCsvr.R300
  If objIFCsvr Is Nothing Then
    MsgBox "IFCsvr is not installed."
    Exit Function
  End If

  Set objDesign = objIFCsvr.OpenDesign(filename)
  If objDesign Is Nothing Then
    MsgBox "IFC file not found."
    Set objDesign = Nothing
    Set objIFCsvr = Nothing
    Exit Function
  End If

   ' Check that the IFC file schema is 2x3 which this script is created for

  strSchemaName = UCase(objDesign.SchemaName)
  ActiveSheet.Range("E7").Value = strSchemaName

  If Not strSchemaName Like "IFC2X3" Then
    MsgBox "IFC Schema not match. The IFC Schema needs to be 2x3 for the script to work!
    ", vbCritical
    Set objDesign = Nothing
    Set objIFCsvr = Nothing
    Exit Function
  End If

   ' Check if file is created using ArchiCAD

  ArchiCAD_OK = False
  For Each objIfcApplication In objDesign.FindObjects("IfcApplication")
    If objIfcApplication.Attributes("ApplicationIdentifier").Value = "ArchiCAD" Then
      ArchiCAD_OK = True
    End If
  Next objIfcApplication

  If Not ArchiCAD_OK Then
    MsgBox "IFC not created using ArchiCAD. This script needs the IFC file to be created
     in ArchiCAD", vbCritical
    Set objDesign = Nothing
    Set objIFCsvr = Nothing
    Exit Function
  End If

   ' Start import of values by calling the function:
```

```
  DataForWinDesign

  'The import has finished

  Worksheets("STEP2").Activate
  Set objDesign = Nothing
  Set objIFCsvr = Nothing

  MsgBox "The IFC-import is complete. IFC-data is implemented in SCENARIO 1 (STEP2)"

  ' MsgBox "End"

End Function

' ===================================================================================
'Following script is created by Rune Andersen, s042556, Technical University of Denmark
' ===================================================================================

'-----------------------------------------------------------------------------------
' Defines the Sub´s used in the following script
'-----------------------------------------------------------------------------------

Private Sub DataForWinDesign()

  Dim objIfcQuantityArea, objIfcQuantityVolume, objIfcWindow, objIfcDoor As IFCsvr.
  Entity
  Dim objIfcWallStandardCase, objIfcPolyline As IFCsvr.Entity
  Dim objIfcRelDefinesByProperties, objIfcRelatedOpeningElement,
  objIfcRelatingOpeningElement, objIfcRelFillsElement As IFCsvr.Entity
  Dim objIfcPropertySingleValue, objIfcSlab, objIfcRelSpaceBoundary,
  objIfcRelatedBuildingElement, objIfcRelatingBuildingElement As IFCsvr.Entity
  Dim objIfcSpace, objIfcRelVoidsElement, objIfcQuantityLength As IFCsvr.Entity

  Dim objAtt As Object
  Dim varAtt As Variant
  Dim r1, r2, r3 As Excel.Range
  Dim strPropertySetName As String
  Dim SpaceName As String
  Dim newSpaceB As Integer
  Dim WindowWidth As Single
  Dim WindowHeight As Single
  Dim newSpace As Integer
  Dim newSlab As Integer
  Dim uValueFloor As Single
  Dim uValueRoof As Single
  Dim uValueWindow As Single
  Dim uValueDoor As Single
  Dim uValueExternalWall As Single
  Dim gValueWindow As Single
  Dim gValueDoor As Single
  Dim OrientationWindow As Integer
  Dim OrientationDoor As Integer
  Dim netSpaceVolume As Single
  Dim WindowArea As Single
  Dim WindowLineLength As Single
  Dim WindowName As String
  Dim DoorArea As Single
  Dim DoorLineLength As Single
  Dim DoorHeight As Single
  Dim DoorWidth As Single
  Dim DoorName As String
  Dim ExternalWallName As String
  Dim ExternalRoofName As String
  Dim ExternalFloorName As String
  Dim TempExternalWallName As String
  Dim OpenID As String
  Dim TempOpenID As String
  Dim TempWindowName As String
  Dim tempCoors As Variant
```

```
Dim noCoors As Integer
Dim i As Integer
Dim externalWallArea As Single
Dim RoofArea As Single
Dim coorsRoof(100, 3) As Single
Dim externalFloorArea As Single
Dim coorsFloor(100, 3) As Single
Dim coorsWall(100, 3) As Single
Dim WallFloorLineLength As Single
Dim WallRoofLineLength As Single
Dim WindowID As Single
Dim DoorID As Single
Dim newcell As Single
Dim newcell2 As Single
Dim TiltAngle As Single
Dim ShadingHorizon As Single
Dim ShadingOverhang As Single
Dim ShadingSidefins As Single
Dim HeatedFloorName As String
Dim HeatedFloorArea As Single
Dim WallFloorLineLength2 As Single
Dim WallRoofLineLength2 As Single
Dim TiltAngleWindow As Single

Worksheets("IFC-information").Activate
Range("A2").Value = "Information for each space"
Set r1 = ActiveSheet.Range("A5")

newSpace = 0
newSlab = 0
newSpaceB = 0

'---------------------------------------------------------------------------------
' Analysis of each room (space)
'---------------------------------------------------------------------------------

For Each objIfcSpace In objDesign.FindObjects("IfcSpace")

  ' Prints general titles for all spaces

  r1.Offset(-1, 0).Value = "Floor U-value(W/m2K):"

  r1.Offset(0, 0).Value = "Roof U-value(W/m2K):"

  r1.Offset(1, 0).Value = "Walls/Floor LineLength(m):"

  r1.Offset(2, 0).Value = "Walls/Roof LineLength(m):"

  ' Prints general titles for each space

  r1.Offset(4, newSpace * 15 + 0).Value = "Space name:"

  r1.Offset(6, newSpace * 15 + 0).Value = "External floor area(m2):"

  r1.Offset(6, newSpace * 15 + 1).Value = "Net roof area(m2):"

  r1.Offset(6, newSpace * 15 + 2).Value = "Space volume(m3):"

  r1.Offset(6, newSpace * 15 + 3).Value = "External wall type:"

  r1.Offset(6, newSpace * 15 + 4).Value = "External wall area(m2):"

  r1.Offset(6, newSpace * 15 + 5).Value = "External wall U-value(W/m2K):"

  r1.Offset(6, newSpace * 15 + 6).Value = "WinDoor name:"

  r1.Offset(6, newSpace * 15 + 7).Value = "WinDoor orientaion:"

  r1.Offset(6, newSpace * 15 + 8).Value = "WinDoor Area (m2):"
```

```
r1.Offset(6, newSpace * 15 + 9).Value = "WinDoor U-value(W/m2K):"

r1.Offset(6, newSpace * 15 + 10).Value = "WinDoor g-value:"

r1.Offset(6, newSpace * 15 + 11).Value = "WinDoor ID"

r1.Offset(6, newSpace * 15 + 12).Value = "Heated floor area"

r1.Offset(6, newSpace * 15 + 13).Value = "WinDoor/Wall LineLength"

r1.Offset(11, newSpace * 15).Value = "Wall/floor LineLength active"

r1.Offset(11, newSpace * 15 + 1).Value = "Wall/roof LineLength active"

' Find space name

SpaceName = objIfcSpace.Attributes("LongName").Value

' Reset values

newSpaceB = 0

' Finds the net volume of each space

For Each objIfcRelDefinesByProperties In objIfcSpace.GetUsedIn(
"IfcRelDefinesByProperties", "RelatedObjects")
  With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
    If .Value.Type = "IfcElementQuantity" Then
      If .Value.Attributes("Name").Value = "BaseQuantities" Then
        For Each objIfcQuantityVolume In .Value.Attributes("Quantities").Value
          If objIfcQuantityVolume.Attributes("Name").Value = "NetVolume" Then

            netSpaceVolume = objIfcQuantityVolume.Attributes("VolumeValue").Value

          End If
        Next objIfcQuantityVolume
      End If
    End If
  End With

Next objIfcRelDefinesByProperties

' Insert information found for space in Excel

r1.Offset(4, newSpace * 15 + 1).Value = SpaceName

r1.Offset(7, newSpace * 15 + 2).Value = netSpaceVolume

' Finds windows which relates to the current space and there area, LineLength, and
name:

For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

  If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

    Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

    If objIfcSpace.Attributes("LongName").Value = SpaceName Then

      Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
      "RelatedBuildingElement").Value

      If objIfcRelatedBuildingElement.Type = "IfcWindow" Then

        WindowHeight = objIfcRelatedBuildingElement.Attributes("OverallHeight").
        Value

        WindowHeight = WindowHeight / 1000

        WindowWidth = objIfcRelatedBuildingElement.Attributes("OverallWidth").Value
```

```
WindowWidth = WindowWidth / 1000

WindowArea = WindowHeight * WindowWidth

WindowLineLength = WindowHeight * 2 + WindowWidth * 2

WindowName = objIfcRelatedBuildingElement.Attributes("Name").Value

WindowID = 1

' Finds properties for the window which relates to the current space:

' Finds the U-value for the window:

For Each objIfcWindow In objDesign.FindObjects("IfcWindow")
  For Each objIfcRelDefinesByProperties In objIfcWindow.GetUsedIn(
  "IfcRelDefinesByProperties", "RelatedObjects")
    If objIfcWindow.Attributes("Name").Value = WindowName Then
      With objIfcRelDefinesByProperties.Attributes(
      "RelatingPropertyDefinition")
        If .Value.Type = "IfcPropertySet" Then
          If .Value.Attributes("Name").Value = "Pset_WindowCommon" Then
            For Each objIfcPropertySingleValue In .Value.Attributes(
            "HasProperties").Value
              If objIfcPropertySingleValue.Attributes("Name").Value =
              "ThermalTransmittance" Then

                uValueWindow = objIfcPropertySingleValue.Attributes(
                "NominalValue").Value

              End If
            Next objIfcPropertySingleValue
          End If
        End If
      End With
    End If
  Next objIfcRelDefinesByProperties
Next objIfcWindow

' Finds the g-value for the window:

For Each objIfcWindow In objDesign.FindObjects("IfcWindow")
  For Each objIfcRelDefinesByProperties In objIfcWindow.GetUsedIn(
  "IfcRelDefinesByProperties", "RelatedObjects")
    If objIfcWindow.Attributes("Name").Value = WindowName Then
      With objIfcRelDefinesByProperties.Attributes(
      "RelatingPropertyDefinition")
        If .Value.Type = "IfcPropertySet" Then
          If .Value.Attributes("Name").Value = "Pset_WindowCommon" Then
            For Each objIfcPropertySingleValue In .Value.Attributes(
            "HasProperties").Value
              If objIfcPropertySingleValue.Attributes("Name").Value =
              "SolarEnergyTransmittance" Then

                gValueWindow = objIfcPropertySingleValue.Attributes(
                "NominalValue").Value

              End If
            Next objIfcPropertySingleValue
          End If
        End If
      End With
    End If
  Next objIfcRelDefinesByProperties
Next objIfcWindow

' Finds the orientation for the window:

For Each objIfcWindow In objDesign.FindObjects("IfcWindow")
```

```
          For Each objIfcRelDefinesByProperties In objIfcWindow.GetUsedIn(
          "IfcRelDefinesByProperties", "RelatedObjects")
            If objIfcWindow.Attributes("Name").Value = WindowName Then
              With objIfcRelDefinesByProperties.Attributes(
              "RelatingPropertyDefinition")
                If .Value.Type = "IfcPropertySet" Then
                  If .Value.Attributes("Name").Value = "Pset_WindowCommon" Then
                    For Each objIfcPropertySingleValue In .Value.Attributes(
                    "HasProperties").Value
                      If objIfcPropertySingleValue.Attributes("Name").Value =
                      "Orientation" Then

                        OrientationWindow = objIfcPropertySingleValue.Attributes(
                        "NominalValue").Value

                      End If
                    Next objIfcPropertySingleValue
                  End If
                End If
              End With
            End If
          Next objIfcRelDefinesByProperties
        Next objIfcWindow

        ' Insert information found for window in Excel

        r1.Offset(7 + newSpaceB, newSpace * 15 + 8).Value = WindowArea

        r1.Offset(7 + newSpaceB, newSpace * 15 + 6).Value = WindowName

        r1.Offset(7 + newSpaceB, newSpace * 15 + 9).Value = uValueWindow

        r1.Offset(7 + newSpaceB, newSpace * 15 + 10).Value = gValueWindow

        r1.Offset(7 + newSpaceB, newSpace * 15 + 11).Value = WindowID

        r1.Offset(7 + newSpaceB, newSpace * 15 + 7).Value = OrientationWindow

        r1.Offset(7 + newSpaceB, newSpace * 15 + 13).Value = WindowLineLength

        r1.Offset(7 + newSpaceB, newSpace * 15 + 14).Value = TiltAngleWindow

        ' Prepare for analisis of the next spaceboundary

        newSpaceB = newSpaceB + 1

      End If
    End If
  End If
Next objIfcRelSpaceBoundary

' Finds doors which relates to the current space and there area and name:

For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

  If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

    If objIfcRelSpaceBoundary.Attributes("InternalOrExternalBoundary").Value =
    "EXTERNAL" Then

      Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

      If objIfcSpace.Attributes("LongName").Value = SpaceName Then

        Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
        "RelatedBuildingElement").Value

        If objIfcRelatedBuildingElement.Type = "IfcDoor" Then

          DoorHeight = objIfcRelatedBuildingElement.Attributes("OverallHeight").
```

```
Value

              DoorHeight = DoorHeight / 1000

              DoorWidth = objIfcRelatedBuildingElement.Attributes("OverallWidth").Value

              DoorWidth = DoorWidth / 1000

              DoorArea = DoorHeight * DoorWidth

              DoorLineLength = DoorHeight * 2 + DoorWidth * 2

              DoorName = objIfcRelatedBuildingElement.Attributes("Name").Value

              DoorID = 1

              ' Finds properties for the Door which relates to the current Space:

              ' Finds the U-value for the door

              For Each objIfcDoor In objDesign.FindObjects("IfcDoor")
                For Each objIfcRelDefinesByProperties In objIfcDoor.GetUsedIn(
                "IfcRelDefinesByProperties", "RelatedObjects")
                  If objIfcDoor.Attributes("Name").Value = DoorName Then
                    With objIfcRelDefinesByProperties.Attributes(
                    "RelatingPropertyDefinition")
                      If .Value.Type = "IfcPropertySet" Then
                        If .Value.Attributes("Name").Value = "Pset_DoorCommon" Then
                          For Each objIfcPropertySingleValue In .Value.Attributes(
                          "HasProperties").Value
                            If objIfcPropertySingleValue.Attributes("Name").Value =
                            "ThermalTransmittance" Then

                              uValueDoor = objIfcPropertySingleValue.Attributes(
                              "NominalValue").Value

                            End If
                          Next objIfcPropertySingleValue
                        End If
                      End If
                    End With
                  End If
                Next objIfcRelDefinesByProperties
              Next objIfcDoor

              ' Finds the g-value for the Door (Should be 0 if there is no glass in the
              door)

              For Each objIfcDoor In objDesign.FindObjects("IfcDoor")
                For Each objIfcRelDefinesByProperties In objIfcDoor.GetUsedIn(
                "IfcRelDefinesByProperties", "RelatedObjects")
                  If objIfcDoor.Attributes("Name").Value = DoorName Then
                    With objIfcRelDefinesByProperties.Attributes(
                    "RelatingPropertyDefinition")
                      If .Value.Type = "IfcPropertySet" Then
                        If .Value.Attributes("Name").Value = "Pset_DoorCommon" Then
                          For Each objIfcPropertySingleValue In .Value.Attributes(
                          "HasProperties").Value
                            If objIfcPropertySingleValue.Attributes("Name").Value =
                            "SolarEnergyTransmittance" Then

                              gValueDoor = objIfcPropertySingleValue.Attributes(
                              "NominalValue").Value

                            End If
                          Next objIfcPropertySingleValue
                        End If
                      End If
                    End With
                  End If
```

```
          Next objIfcRelDefinesByProperties
        Next objIfcDoor

        'Finds the orientation for the Door:

        For Each objIfcDoor In objDesign.FindObjects("IfcDoor")
          For Each objIfcRelDefinesByProperties In objIfcDoor.GetUsedIn(
          "IfcRelDefinesByProperties", "RelatedObjects")
            If objIfcDoor.Attributes("Name").Value = DoorName Then
              With objIfcRelDefinesByProperties.Attributes(
              "RelatingPropertyDefinition")
                If .Value.Type = "IfcPropertySet" Then
                  If .Value.Attributes("Name").Value = "Pset_DoorCommon" Then
                    For Each objIfcPropertySingleValue In .Value.Attributes(
                    "HasProperties").Value
                      If objIfcPropertySingleValue.Attributes("Name").Value =
                      "Orientation" Then

                        OrientationDoor = objIfcPropertySingleValue.Attributes(
                        "NominalValue").Value

                      End If
                    Next objIfcPropertySingleValue
                  End If
                End If
              End With
            End If
          Next objIfcRelDefinesByProperties
        Next objIfcDoor

        ' Insert information found for window in Excel

        r1.Offset(7 + newSpaceB, newSpace * 15 + 8).Value = DoorArea

        r1.Offset(7 + newSpaceB, newSpace * 15 + 6).Value = DoorName

        r1.Offset(7 + newSpaceB, newSpace * 15 + 9).Value = uValueDoor

        r1.Offset(7 + newSpaceB, newSpace * 15 + 10).Value = gValueDoor

        r1.Offset(7 + newSpaceB, newSpace * 15 + 11).Value = DoorID

        r1.Offset(7 + newSpaceB, newSpace * 15 + 7).Value = OrientationDoor

        r1.Offset(7 + newSpaceB, newSpace * 15 + 13).Value = DoorLineLength

        ' Prepare for analisis of the next Spaceboundary

        newSpaceB = newSpaceB + 1

      End If
    End If
  End If
End If
Next objIfcRelSpaceBoundary

' Finds External wall which relates to the current Space.

newSpaceB = 0

For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

  If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

    Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

    If objIfcSpace.Attributes("LongName").Value = SpaceName Then

      Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
      "RelatedBuildingElement").Value
```

```
If objIfcRelatedBuildingElement.Type = "IfcWallStandardCase" Then

  If objIfcRelSpaceBoundary.Attributes("InternalOrExternalBoundary").Value =
  "EXTERNAL" Then

    ExternalWallName = objIfcRelatedBuildingElement.Attributes("Name").Value

    ' Finds the net area of the external wall

    Set objIfcPolyline = objIfcRelSpaceBoundary.Attributes(
    "ConnectionGeometry"). _
    Value.Attributes("SurfaceOnRelatingElement").Value.Attributes(
    "OuterBoundary"). _
    Value.Attributes("Segments").Value.Item(1).Attributes("ParentCurve").Value

    ' Finds the points which defines the external wall

    externalWallArea = 0
    i = 0
    For Each objAtt In objIfcPolyline.Attributes("Points").Value
      tempCoors = objAtt.Attributes(1).Value
      coorsWall(i, 0) = tempCoors(0) / 1000
      coorsWall(i, 1) = tempCoors(1) / 1000
      coorsWall(i, 2) = 0
      i = i + 1

    Next objAtt

    noCoors = i

    ' The area of the external wall is found. The method used is stated: http:
    //www.wikihow.com/Calculate-the-Area-of-a-Polygon

    For i = 0 To noCoors - 2
      externalWallArea = externalWallArea + coorsWall(i, 0) * coorsWall(i + 1
      , 1) - coorsWall(i + 1, 0) * coorsWall(i, 1)
    Next
    externalWallArea = Abs(externalWallArea / 2)

    ' Finds U-value for the external wall which relates to the current space

    For Each objIfcWallStandardCase In objDesign.FindObjects(
    "IfcWallStandardCase")
      For Each objIfcRelDefinesByProperties In objIfcWallStandardCase.
      GetUsedIn("IfcRelDefinesByProperties", "RelatedObjects")
        If objIfcWallStandardCase.Attributes("Name").Value = ExternalWallName
        Then
          With objIfcRelDefinesByProperties.Attributes(
          "RelatingPropertyDefinition")
            If .Value.Type = "IfcPropertySet" Then
              If .Value.Attributes("Name").Value = "Pset_WallCommon" Then
                For Each objIfcPropertySingleValue In .Value.Attributes(
                "HasProperties").Value
                  If objIfcPropertySingleValue.Attributes("Name").Value =
                  "ThermalTransmittance" Then

                    uValueExternalWall = objIfcPropertySingleValue.Attributes(
                    "NominalValue").Value

                  End If
                Next objIfcPropertySingleValue
              End If
            End If
          End With
        End If
      Next objIfcRelDefinesByProperties
    Next objIfcWallStandardCase

    ' Insert information found for external wall in Excel
```

```
            r1.Offset(7 + newSpaceB, newSpace * 15 + 3).Value = ExternalWallName

            r1.Offset(7 + newSpaceB, newSpace * 15 + 5).Value = uValueExternalWall

            r1.Offset(7 + newSpaceB, newSpace * 15 + 4).Value = externalWallArea

            ' Prepare for analisis of the next space boundary

            newSpaceB = newSpaceB + 1

          End If
        End If
      End If
    End If
  Next objIfcRelSpaceBoundary

  ' Finds roof which relates to the current space

  newSpaceB = 0

  For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

    If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

      Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

      If objIfcSpace.Attributes("LongName").Value = SpaceName Then

        Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
        "RelatedBuildingElement").Value

        If objIfcRelatedBuildingElement.Type = "IfcSlab" Then

          If objIfcRelatedBuildingElement.Attributes("PredefinedType").Value = "ROOF"
          Then

            If objIfcRelSpaceBoundary.Attributes("InternalOrExternalBoundary").Value =
             "EXTERNAL" Then

              ExternalRoofName = objIfcRelatedBuildingElement.Attributes("Name").Value

              ' Finds the net area of the external roof

              Set objIfcPolyline = objIfcRelSpaceBoundary.Attributes(
              "ConnectionGeometry"). _
              Value.Attributes("SurfaceOnRelatingElement").Value.Attributes(
              "OuterBoundary"). _
              Value.Attributes("Segments").Value.Item(1).Attributes("ParentCurve").
              Value

              ' Finds the points which defines the external roof

              RoofArea = 0
              WallRoofLineLength = 0

              i = 0
              For Each objAtt In objIfcPolyline.Attributes("Points").Value
                tempCoors = objAtt.Attributes(1).Value
                coorsRoof(i, 0) = tempCoors(0) / 1000
                coorsRoof(i, 1) = tempCoors(1) / 1000
                coorsRoof(i, 2) = 0
                i = i + 1

              Next objAtt

              noCoors = i

              ' Finds the net area of the external roof. The method stated: "http:
              //www.wikihow.com/Calculate-the-Area-of-a-Polygon" is used for the
```

```
calculation
                For i = 0 To noCoors - 2
                  RoofArea = RoofArea + coorsRoof(i, 0) * coorsRoof(i + 1, 1) -
                  coorsRoof(i + 1, 0) * coorsRoof(i, 1)

                Next
                RoofArea = Abs(RoofArea / 2)

                ' Insert information found for roof in Excel

                r1.Offset(7 + newSpaceB, newSpace * 15 + 1).Value = RoofArea

                ' Prepare for analisis of the next space boundary

                newSpaceB = newSpaceB + 1

              End If
            End If
          End If
        End If
      End If
    Next objIfcRelSpaceBoundary

    ' Finds external floor which relates to the foundation and the current space

    newSpaceB = 0

    For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

      If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

        Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

        If objIfcSpace.Attributes("LongName").Value = SpaceName Then

          Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
          "RelatedBuildingElement").Value

          If objIfcRelatedBuildingElement.Type = "IfcSlab" Then

            If objIfcRelatedBuildingElement.Attributes("PredefinedType").Value = "FLOOR"
             Then

              If objIfcRelSpaceBoundary.Attributes("InternalOrExternalBoundary").Value =
               "EXTERNAL" Then

                ExternalFloorName = objIfcRelatedBuildingElement.Attributes("Name").
                Value

                ' Finds the net area of the external floor

                Set objIfcPolyline = objIfcRelSpaceBoundary.Attributes(
                "ConnectionGeometry"). _
                Value.Attributes("SurfaceOnRelatingElement").Value.Attributes(
                "OuterBoundary"). _
                Value.Attributes("Segments").Value.Item(1).Attributes("ParentCurve").
                Value

                ' Finds the points which defines the external floor

                externalFloorArea = 0
                i = 0
                For Each objAtt In objIfcPolyline.Attributes("Points").Value
                  tempCoors = objAtt.Attributes(1).Value
                  coorsFloor(i, 0) = tempCoors(0) / 1000
                  coorsFloor(i, 1) = tempCoors(1) / 1000
                  coorsFloor(i, 2) = 0
                  i = i + 1
```

```
            Next objAtt

            noCoors = i

            'The area of the external floor is found. The method stated: "http://www
            .wikihow.com/Calculate-the-Area-of-a-Polygon" is used for the
            calculation

            For i = 0 To noCoors - 2
              externalFloorArea = externalFloorArea + coorsFloor(i, 0) * coorsFloor(
              i + 1, 1) - coorsFloor(i + 1, 0) * coorsFloor(i, 1)
            Next
            externalFloorArea = Abs(externalFloorArea / 2)

            'Insert information found for roof in Excel

            r1.Offset(7 + newSpaceB, newSpace * 15 + 0).Value = externalFloorArea

            ' Prepare for analisis of the next Spaceboundary

            newSpaceB = newSpaceB + 1

          End If
        End If
      End If
    End If
  End If
Next objIfcRelSpaceBoundary

' Finds heated floor which relates to the current space

newSpaceB = 0

For Each objIfcRelSpaceBoundary In objDesign.FindObjects("IfcRelSpaceBoundary")

  If Not objIfcRelSpaceBoundary.Attributes("RelatedBuildingElement").IsNull Then

    Set objIfcSpace = objIfcRelSpaceBoundary.Attributes("RelatingSpace").Value

    If objIfcSpace.Attributes("LongName").Value = SpaceName Then

      Set objIfcRelatedBuildingElement = objIfcRelSpaceBoundary.Attributes(
      "RelatedBuildingElement").Value

      If objIfcRelatedBuildingElement.Type = "IfcSlab" Then

        If objIfcRelatedBuildingElement.Attributes("PredefinedType").Value = "FLOOR"
         Then

          HeatedFloorName = objIfcRelatedBuildingElement.Attributes("Name").Value

          ' Finds the net area of the heated floor

          Set objIfcPolyline = objIfcRelSpaceBoundary.Attributes(
          "ConnectionGeometry"). _
          Value.Attributes("SurfaceOnRelatingElement").Value.Attributes(
          "OuterBoundary"). _
          Value.Attributes("Segments").Value.Item(1).Attributes("ParentCurve").Value

          ' Finds the points which defines the heated floor

          HeatedFloorArea = 0
          i = 0
          For Each objAtt In objIfcPolyline.Attributes("Points").Value
            tempCoors = objAtt.Attributes(1).Value
            coorsFloor(i, 0) = tempCoors(0) / 1000
            coorsFloor(i, 1) = tempCoors(1) / 1000
            coorsFloor(i, 2) = 0
            i = i + 1
```

```
            Next objAtt

            noCoors = i

            'The area of the heated floor is found. The method stated: "http://www.
            wikihow.com/Calculate-the-Area-of-a-Polygon" is used for the calculation

            For i = 0 To noCoors - 2
              HeatedFloorArea = HeatedFloorArea + coorsFloor(i, 0) * coorsFloor(i + 1
              , 1) - coorsFloor(i + 1, 0) * coorsFloor(i, 1)
            Next
            HeatedFloorArea = Abs(HeatedFloorArea / 2)

            'Insert information found for roof in Excel

            r1.Offset(7 + newSpaceB, newSpace * 15 + 12).Value = HeatedFloorArea

            ' Prepare for analisis of the next Spaceboundary

            newSpaceB = newSpaceB + 1

          End If
        End If
      End If
    End If
  Next objIfcRelSpaceBoundary

  'Finds out if the space is in contact with the external floor and the LineLength
  between external walls and floor

  newSlab = 0

  For Each objIfcSlab In objDesign.FindObjects("IfcSlab")

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")

      WallFloorLineLength2 = 0

      If objIfcSlab.Attributes("PredefinedType").Value = "FLOOR" Then
        If objIfcSlab.Attributes("Description").Value = "Foundation" Then
          With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
            If .Value.Type = "IfcElementQuantity" Then
              If .Value.Attributes("Name").Value = "BaseQuantities" Then
                For Each objIfcQuantityLength In .Value.Attributes("Quantities").Value
                  If objIfcQuantityLength.Attributes("Name").Value = "Perimeter" Then

                    WallFloorLineLength2 = objIfcQuantityLength.Attributes(
                    "LengthValue").Value

                    WallFloorLineLength2 = WallFloorLineLength2 / 1000

                  End If
                Next objIfcQuantityLength
              End If
            End If
          End With
        End If
      End If
    Next objIfcRelDefinesByProperties

    'Finds out if the space is in contact with the roof and the LineLength between
    external walls and roof

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")

      WallRoofLineLength2 = 0

      If objIfcSlab.Attributes("PredefinedType").Value = "ROOF" Then
```

```
          With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
            If .Value.Type = "IfcElementQuantity" Then
              If .Value.Attributes("Name").Value = "BaseQuantities" Then
                For Each objIfcQuantityLength In .Value.Attributes("Quantities").Value
                  If objIfcQuantityLength.Attributes("Name").Value = "Perimeter" Then

                    WallRoofLineLength2 = objIfcQuantityLength.Attributes("LengthValue"
                    ).Value

                    WallRoofLineLength2 = WallRoofLineLength2 / 1000

                  End If
                Next objIfcQuantityLength
              End If
            End If
          End With
        End If
      Next objIfcRelDefinesByProperties

      'Insert information found for slaps in Excel

      r1.Offset(newSlab + 12, newSpace * 15).Value = WallFloorLineLength2

      r1.Offset(newSlab + 12, newSpace * 15 + 1).Value = WallRoofLineLength2

      'Prepare for analisis of the next slap

      newSlab = newSlab + 1

    Next objIfcSlab

    'Prepare for analisis of the next space

    newSpace = newSpace + 1

  Next objIfcSpace

  '-------------------------------------------------------------------------------
  ' Analysis of general values
  '-------------------------------------------------------------------------------

  newSlab = 0

  For Each objIfcSlab In objDesign.FindObjects("IfcSlab")

    uValueFloor = 0
    uValueRoof = 0

    'Finds the U-value of the floor

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")
      If objIfcSlab.Attributes("PredefinedType").Value = "FLOOR" Then
        With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
          If .Value.Type = "IfcPropertySet" Then
            If .Value.Attributes("Name").Value = "Pset_SlabCommon" Then
              For Each objIfcPropertySingleValue In .Value.Attributes("HasProperties").
              Value
                If objIfcPropertySingleValue.Attributes("Name").Value =
                "ThermalTransmittance" Then

                  uValueFloor = objIfcPropertySingleValue.Attributes("NominalValue").
                  Value

                End If
              Next objIfcPropertySingleValue
            End If
          End If
        End With
      End If
```

```
    Next objIfcRelDefinesByProperties

    'Finds the U-value of the roof

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")
      If objIfcSlab.Attributes("PredefinedType").Value = "ROOF" Then
        With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
          If .Value.Type = "IfcPropertySet" Then
            If .Value.Attributes("Name").Value = "Pset_SlabCommon" Then
              For Each objIfcPropertySingleValue In .Value.Attributes("HasProperties").
              Value
                If objIfcPropertySingleValue.Attributes("Name").Value =
                "ThermalTransmittance" Then

                  uValueRoof = objIfcPropertySingleValue.Attributes("NominalValue").
                  Value

                End If
              Next objIfcPropertySingleValue
            End If
          End If
        End With
      End If
    Next objIfcRelDefinesByProperties

    ' Insert information found for slaps in Excel

    r1.Offset(newSlab + 50, 0).Value = uValueFloor

    r1.Offset(newSlab + 50, 1).Value = uValueRoof

    'Prepare for analisis of the next slap

    newSlab = newSlab + 1

  Next objIfcSlab

  'Finds the LineLength between external walls and floor

  newSlab = 0

  For Each objIfcSlab In objDesign.FindObjects("IfcSlab")

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")

      WallFloorLineLength = 0

      If objIfcSlab.Attributes("PredefinedType").Value = "FLOOR" Then
        If objIfcSlab.Attributes("Description").Value = "Foundation" Then
          With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
            If .Value.Type = "IfcElementQuantity" Then
              If .Value.Attributes("Name").Value = "BaseQuantities" Then
                For Each objIfcQuantityLength In .Value.Attributes("Quantities").Value
                  If objIfcQuantityLength.Attributes("Name").Value = "Perimeter" Then

                    WallFloorLineLength = objIfcQuantityLength.Attributes("LengthValue"
                    ).Value

                    WallFloorLineLength = WallFloorLineLength / 1000

                  End If
                Next objIfcQuantityLength
              End If
            End If
          End With
        End If
      End If
    Next objIfcRelDefinesByProperties
```

```
    'Finds the LineLength between external walls and roof

    For Each objIfcRelDefinesByProperties In objIfcSlab.GetUsedIn(
    "IfcRelDefinesByProperties", "RelatedObjects")

      WallRoofLineLength = 0

      If objIfcSlab.Attributes("PredefinedType").Value = "ROOF" Then
        With objIfcRelDefinesByProperties.Attributes("RelatingPropertyDefinition")
          If .Value.Type = "IfcElementQuantity" Then
            If .Value.Attributes("Name").Value = "BaseQuantities" Then
              For Each objIfcQuantityLength In .Value.Attributes("Quantities").Value
                If objIfcQuantityLength.Attributes("Name").Value = "Perimeter" Then

                  WallRoofLineLength = objIfcQuantityLength.Attributes("LengthValue").
                  Value

                  WallRoofLineLength = WallRoofLineLength / 1000

                End If
              Next objIfcQuantityLength
            End If
          End If
        End With
      End If
    Next objIfcRelDefinesByProperties

    'Insert information found for slaps in Excel

    r1.Offset(newSlab + 50, 2).Value = WallFloorLineLength
    r1.Offset(newSlab + 50, 3).Value = WallRoofLineLength

    'Prepare for analisis of the next slap

    newSlab = newSlab + 1

  Next objIfcSlab

  InsertIFCdataSTEP2.InsertIFCdataSTEP2

End Sub
```

```
' ================================================================================
'Following script is created by Rune Andersen, s042556, Technical University of Denmark
' ================================================================================

'-------------------------------------------------------------------------------

' Inserts information in WinDesign (STEP 2)

'-------------------------------------------------------------------------------

'-------------------------------------------------------------------------------
'Copying values for house information
'-------------------------------------------------------------------------------


Public Function InsertIFCdataSTEP2()

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(4, 2).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(3, 2).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(7, 2).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(4, 2).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(10, 2).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(5, 7).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(8, 2).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(5, 8).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(11, 2).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(6, 7).Select
```

```
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(9, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(6, 8).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(12, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(7, 7).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(6, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(7, 8).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(20, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(9, 7).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(10, 7).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(11, 7).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(14, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(9, 8).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False
```

```
'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(13, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(10, 8).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(15, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(11, 8).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(16, 2).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(5, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'-----------------------------------------------------------------------------------
'Copying values for default window values
'-----------------------------------------------------------------------------------

Worksheets("STEP2 - Scenario 1").Activate
Set r3 = ActiveSheet.Range("J11")

newcell = 0

TiltAngle = 90
ShadingHorizon = 0
ShadingOverhang = 0
ShadingSidefins = 0

Do

  r3.Offset(0 + newcell, 0).Value = TiltAngle
  r3.Offset(0 + newcell, 1).Value = ShadingHorizon
  r3.Offset(0 + newcell, 2).Value = ShadingOverhang
  r3.Offset(0 + newcell, 3).Value = ShadingSidefins

  newcell = newcell + 1

Loop Until newcell = 130

'-----------------------------------------------------------------------------------
'Copying values for room 1, window 1-6
'-----------------------------------------------------------------------------------

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window area)
  Sheets("IFC-input for WinDesign").Select
  Cells(31, 2 + newcell2).Select
```

```
        Selection.Copy

        newcell2 = newcell2 + 2

        'Paste onto "STEP2 - Scenario 1" sheet (window area)
        Sheets("STEP2 - Scenario 1").Select
        Cells(11 + newcell, 23).Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False

        newcell = newcell + 1

    Loop Until newcell = 6

    newcell = 0
    newcell2 = 0

    Do

        'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
        Sheets("IFC-input for WinDesign").Select
        Cells(32, 2 + newcell2).Select
        Selection.Copy

        newcell2 = newcell2 + 2

        'Paste onto "STEP2 - Scenario 1" sheet (u-value)
        Sheets("STEP2 - Scenario 1").Select
        Cells(11 + newcell, 24).Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False

        newcell = newcell + 1

    Loop Until newcell = 6

    newcell = 0
    newcell2 = 0

    Do

        'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
        Sheets("IFC-input for WinDesign").Select
        Cells(33, 2 + newcell2).Select
        Selection.Copy

        newcell2 = newcell2 + 2

        'Paste onto "STEP2 - Scenario 1" sheet (g-value)
        Sheets("STEP2 - Scenario 1").Select
        Cells(11 + newcell, 25).Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False

        newcell = newcell + 1

    Loop Until newcell = 6

    newcell = 0
    newcell2 = 0

    Do

        'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
        Sheets("IFC-input for WinDesign").Select
        Cells(34, 2 + newcell2).Select
        Selection.Copy

        newcell2 = newcell2 + 2
```

```
    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(11 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(38, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(11 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '--------------------------------------------------------------------------------
  'Copying values for room 2, window 1-6
  '--------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(43, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(21 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(44, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2
```

```
    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(21 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(45, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(21 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(46, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(21 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(50, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(21 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
```

```
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '--------------------------------------------------------------------------------
  'Copying values for room 3, window 1-6
  '--------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(55, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(31 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(56, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(31 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(57, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(31 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
```

```
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(58, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(31 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(62, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(31 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '---------------------------------------------------------------------------------
  'Copying values for room 4, window 1-6
  '---------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(67, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(41 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
```

```
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(68, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(41 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(69, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(41 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(70, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(41 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1
```

```
Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
  Sheets("IFC-input for WinDesign").Select
  Cells(74, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (window activation)
  Sheets("STEP2 - Scenario 1").Select
  Cells(41 + newcell, 18).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

'---------------------------------------------------------------------------------
'Copying values for room 5, window 1-6
'---------------------------------------------------------------------------------

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window area)
  Sheets("IFC-input for WinDesign").Select
  Cells(79, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (window area)
  Sheets("STEP2 - Scenario 1").Select
  Cells(51 + newcell, 23).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(80, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (u-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(51 + newcell, 24).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1
```

```
Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(81, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (g-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(51 + newcell, 25).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
  Sheets("IFC-input for WinDesign").Select
  Cells(82, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (orientation)
  Sheets("STEP2 - Scenario 1").Select
  Cells(51 + newcell, 9).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
  Sheets("IFC-input for WinDesign").Select
  Cells(86, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (window activation)
  Sheets("STEP2 - Scenario 1").Select
  Cells(51 + newcell, 18).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

'-----------------------------------------------------------------------------------
'Copying values for room 6, window 1-6
```

```
'---------------------------------------------------------------------------------

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window area)
  Sheets("IFC-input for WinDesign").Select
  Cells(91, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (window area)
  Sheets("STEP2 - Scenario 1").Select
  Cells(61 + newcell, 23).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(92, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (u-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(61 + newcell, 24).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(93, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (g-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(61 + newcell, 25).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0
```

```
Do

   'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
   Sheets("IFC-input for WinDesign").Select
   Cells(94, 2 + newcell2).Select
   Selection.Copy

   newcell2 = newcell2 + 2

   'Paste onto "STEP2 - Scenario 1" sheet (orientation)
   Sheets("STEP2 - Scenario 1").Select
   Cells(61 + newcell, 9).Select
   Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
   False, Transpose:=False

   newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

   'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
   Sheets("IFC-input for WinDesign").Select
   Cells(98, 2 + newcell2).Select
   Selection.Copy

   newcell2 = newcell2 + 2

   'Paste onto "STEP2 - Scenario 1" sheet (window activation)
   Sheets("STEP2 - Scenario 1").Select
   Cells(61 + newcell, 18).Select
   Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
   False, Transpose:=False

   newcell = newcell + 1

Loop Until newcell = 6

'---------------------------------------------------------------------------------
'Copying values for room 7, window 1-6
'---------------------------------------------------------------------------------

newcell = 0
newcell2 = 0

Do

   'Select values to copy from "IFC-input for WinDesign" sheet (window area)
   Sheets("IFC-input for WinDesign").Select
   Cells(103, 2 + newcell2).Select
   Selection.Copy

   newcell2 = newcell2 + 2

   'Paste onto "STEP2 - Scenario 1" sheet (window area)
   Sheets("STEP2 - Scenario 1").Select
   Cells(71 + newcell, 23).Select
   Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
   False, Transpose:=False

   newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0
```

```
Do

  'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(104, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (u-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(71 + newcell, 24).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
  Sheets("IFC-input for WinDesign").Select
  Cells(105, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (g-value)
  Sheets("STEP2 - Scenario 1").Select
  Cells(71 + newcell, 25).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
  Sheets("IFC-input for WinDesign").Select
  Cells(106, 2 + newcell2).Select
  Selection.Copy

  newcell2 = newcell2 + 2

  'Paste onto "STEP2 - Scenario 1" sheet (orientation)
  Sheets("STEP2 - Scenario 1").Select
  Cells(71 + newcell, 9).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  newcell = newcell + 1

Loop Until newcell = 6

newcell = 0
newcell2 = 0

Do

  'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
```

```
    Sheets("IFC-input for WinDesign").Select
    Cells(110, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(71 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '--------------------------------------------------------------------------------
  'Copying values for room 8, window 1-6
  '--------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(115, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(81 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(116, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(81 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
```

```
    Sheets("IFC-input for WinDesign").Select
    Cells(117, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(81 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(118, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(81 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(122, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(81 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '-------------------------------------------------------------------------------
  'Copying values for room 9, window 1-6
  '-------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
```

```
    Sheets("IFC-input for WinDesign").Select
    Cells(127, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(91 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(128, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(91 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(129, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(91 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(130, 2 + newcell2).Select
    Selection.Copy
```

```
    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(91 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(134, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(91 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '-----------------------------------------------------------------------------------
  'Copying values for room 10, window 1-6
  '-----------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(139, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(101 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(140, 2 + newcell2).Select
    Selection.Copy
```

```
    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(101 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(141, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(101 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(142, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(101 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(146, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
```

```
    Cells(101 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '--------------------------------------------------------------------------------
  'Copying values for room 11, window 1-6
  '--------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(151, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
    Cells(111 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(152, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(111 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(153, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
```

```
    Cells(111 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(154, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(111 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(158, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(111 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  '---------------------------------------------------------------------------------
  'Copying values for room 12, window 1-6
  '---------------------------------------------------------------------------------

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window area)
    Sheets("IFC-input for WinDesign").Select
    Cells(163, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window area)
    Sheets("STEP2 - Scenario 1").Select
```

```
    Cells(121 + newcell, 23).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (u-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(164, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (u-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(121 + newcell, 24).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (g-value)
    Sheets("IFC-input for WinDesign").Select
    Cells(165, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (g-value)
    Sheets("STEP2 - Scenario 1").Select
    Cells(121 + newcell, 25).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (orientation)
    Sheets("IFC-input for WinDesign").Select
    Cells(166, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (orientation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(121 + newcell, 9).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False
```

```
    newcell = newcell + 1

  Loop Until newcell = 6

  newcell = 0
  newcell2 = 0

  Do

    'Select values to copy from "IFC-input for WinDesign" sheet (window activation)
    Sheets("IFC-input for WinDesign").Select
    Cells(170, 2 + newcell2).Select
    Selection.Copy

    newcell2 = newcell2 + 2

    'Paste onto "STEP2 - Scenario 1" sheet (window activation)
    Sheets("STEP2 - Scenario 1").Select
    Cells(121 + newcell, 18).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=False

    newcell = newcell + 1

  Loop Until newcell = 6

End Function
```

```
' ==================================================================================
'Following script is created by Rune Andersen, s042556, Technical University of Denmark
' ==================================================================================

'--------------------------------------------------------------------------------

' Inserts information in WinDesign (STEP 3)

'--------------------------------------------------------------------------------

'--------------------------------------------------------------------------------
'Copying values for each room (Floor area and UA value)
'--------------------------------------------------------------------------------


Public Function InsertIFCdataSTEP3()

  'Room 1:

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(7, 5).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(43, 3).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(8, 5).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(43, 2).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Room 2:

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(7, 7).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(44, 3).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(8, 7).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(44, 2).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Room 3:

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
```

```
Cells(7, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(45, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(8, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(45, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 4:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(7, 11).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(46, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(8, 11).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(46, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 5:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(16, 5).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(47, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(17, 5).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(47, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 6:
```

```
'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(16, 7).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(48, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(17, 7).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(48, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 7:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(16, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(49, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(17, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(49, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 8:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(16, 11).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(50, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(17, 11).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(50, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False
```

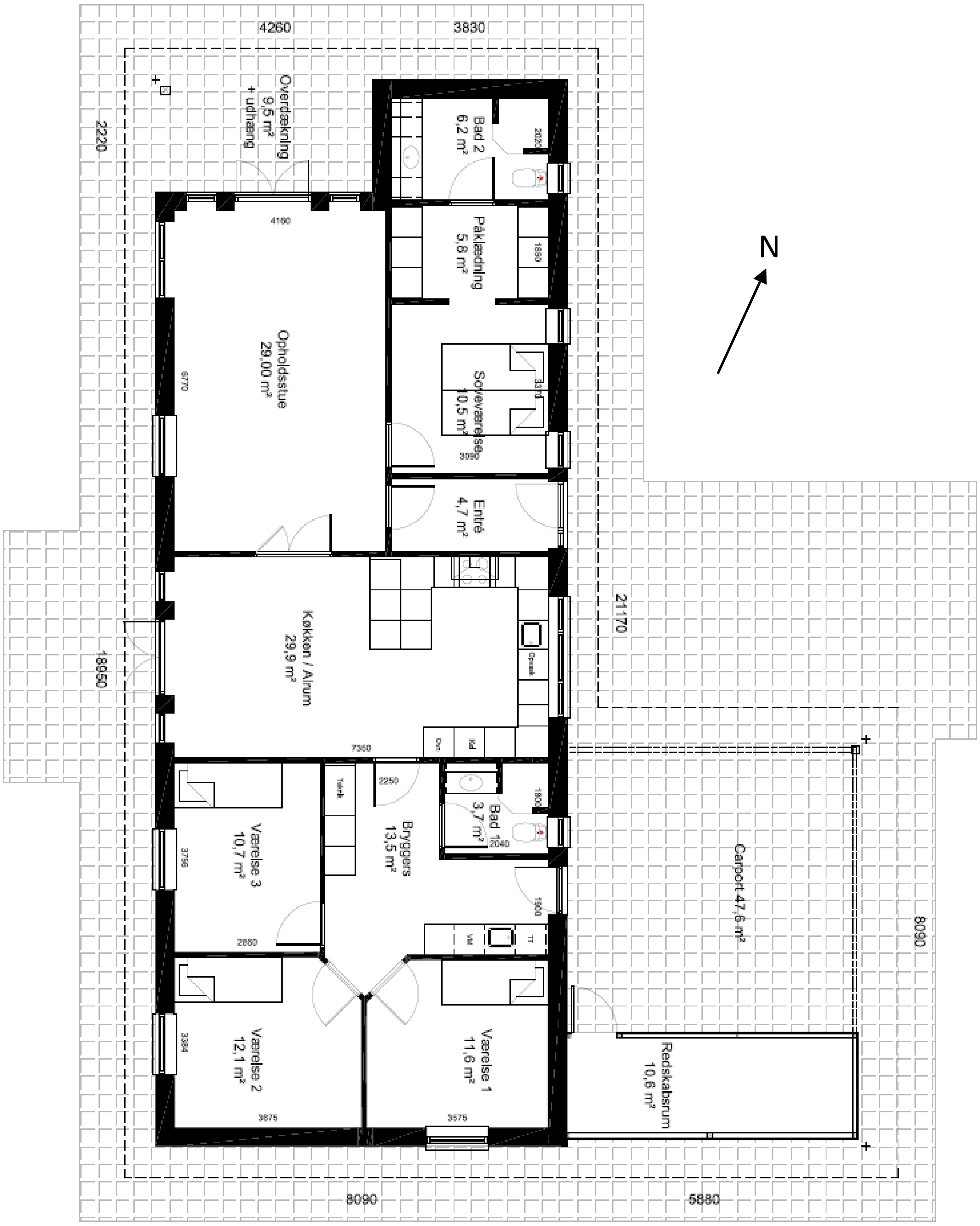
```
'Room 9:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(23, 5).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(51, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(24, 5).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(51, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 10:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(23, 7).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(52, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(24, 7).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(52, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Room 11:

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(23, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(53, 3).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Select values to copy from "IFC-input for WinDesign" sheet
Sheets("IFC-input for WinDesign").Select
Cells(24, 9).Select
Selection.Copy

'Paste onto "HouseInformationScen1" sheet
Sheets("HouseInformationScen1").Select
Cells(53, 2).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
```

```
  False, Transpose:=False

  'Room 12:

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(23, 11).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(54, 3).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

  'Select values to copy from "IFC-input for WinDesign" sheet
  Sheets("IFC-input for WinDesign").Select
  Cells(24, 11).Select
  Selection.Copy

  'Paste onto "HouseInformationScen1" sheet
  Sheets("HouseInformationScen1").Select
  Cells(54, 2).Select
  Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
  False, Transpose:=False

End Function
```

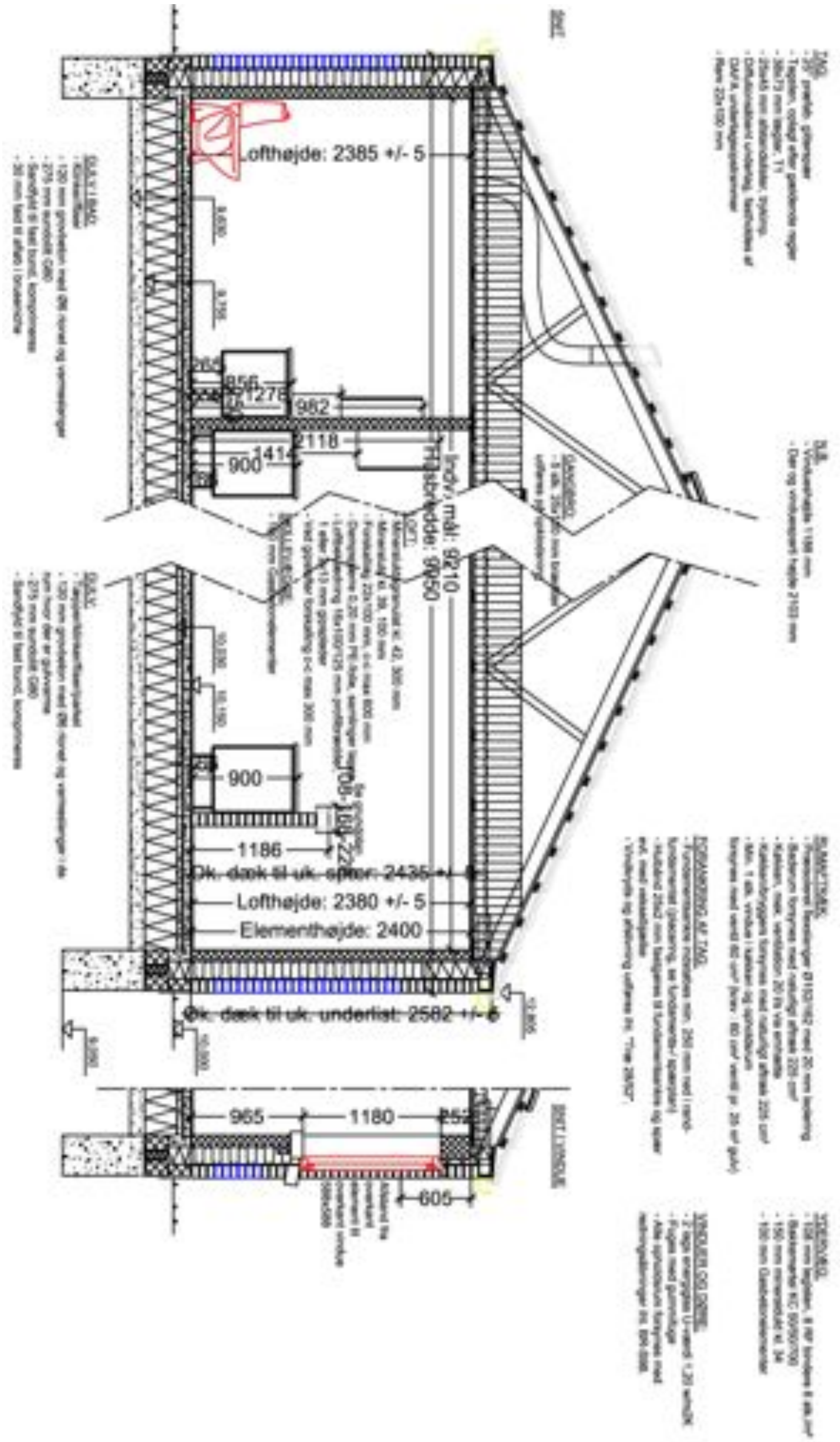
```vb
' ======================================================================================
' Following script is created by Rune Andersen, s042556, Technical University of Denmark
' ======================================================================================


Public Sub ResetContent()

  'Resets the imported IFC-data

  Worksheets("IFC-information").Activate
  Range("A8:FW400").Activate
  Selection.ClearContents
  Selection.ClearComments
  Range("A1").Activate

  'Resets the data which are typed into STEP 2

'Houseinformation:

  Worksheets("HouseInformationScen1").Activate
  Range("B3:B5").Activate
  Selection.ClearContents

  Worksheets("HouseInformationScen1").Activate
  Range("G5:H7").Activate
  Selection.ClearContents

  Worksheets("HouseInformationScen1").Activate
  Range("G9:H11").Activate
  Selection.ClearContents

  Worksheets("HouseInformationScen1").Activate
  Range("G9:H11").Activate
  Selection.ClearContents

'Windowinformation:

  Worksheets("STEP2 - Scenario 1").Activate
  Range("I11:R110").Activate
  Selection.ClearContents
  Selection.ClearComments

  Worksheets("STEP2 - Scenario 1").Activate
  Range("W11:Y110").Activate
  Selection.ClearContents
  Selection.ClearComments

  'IFC file information:

  Worksheets("STEP2").Activate
  Range("E7:E7").Activate
  Selection.ClearContents
  Selection.ClearComments

  Range("A1:A1").Activate

End Sub
```

```
' ==================================================================================
' Following script is created by Rune Andersen, s042556, Technical University of Denmark
' ==================================================================================


Public Sub ResetContent()

  'Resets the imported IFC-data

  Worksheets("IFC-information").Activate
  Range("A8:FW400").Activate
  Selection.ClearContents
  Selection.ClearComments
  Range("A1").Activate

  'Resets the data which are typed into STEP 2

  'Houseinformation (Roominformation):

  Worksheets("HouseInformationScen1").Activate
  Range("B43:C54").Activate
  Selection.ClearContents

  'IFC file information:

  Worksheets("STEP3").Activate
  Range("K6:K6").Activate
  Selection.ClearContents
  Selection.ClearComments

  Range("A1:A1").Activate

End Sub
```

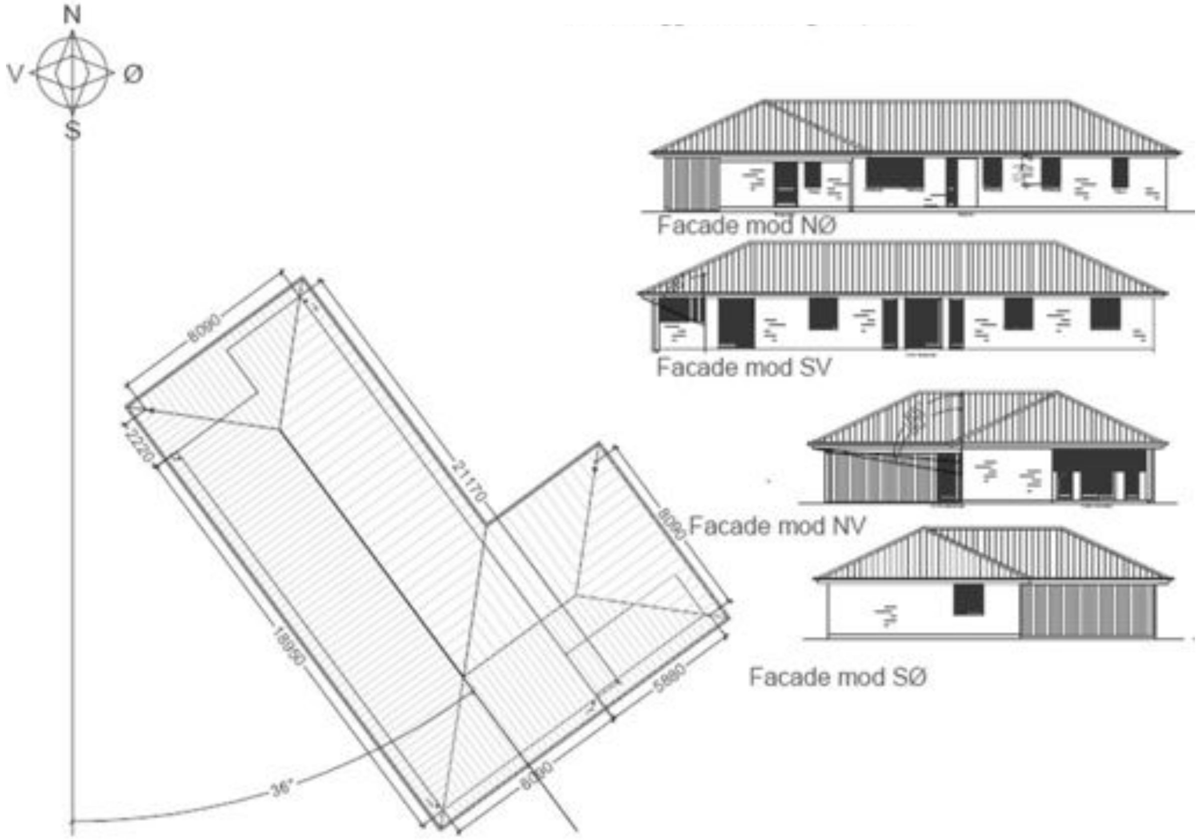
Annex M – Case 1, Reference building, Drawings



Floor plan of the reference building (not in scale)



Section of reference building (not in scale)



Orientation and facades of the reference building (without scaling)

Annex N – Case 1, Reference building, Details of windows , doors, and shading

Overview of windows and doors

Windows and external doors							
Door s	*Room*	*Amount*	*Orientation(°)*	*Slope (°)*	*Area (m^2)*	*U-value (W/m^2K)*	*g-value(-)*
Solid door	Entre	1	NE (-135)	90	2.8 (1.33*2.12)	0.96	0.63
Glazed door	scullery	1	NE (-135)	90	2.0 (0.97*2.12)	1.16	0.63
Glazed door	Living room 1	1	NV (135)	90	3.2 (1.51*2.12)	0.9	0.58
Glazed door	Living room 2	1	SV (45)	90	3.2 (1.51*2.12)	0.9	0.58
Windows	*Room*	*Amount*	*Orientation(°)*	*Slope (°)*	*Area (m^2)*	*U-value (W/m^2K)*	*g-value(-)*
-	Kitchen	1	NE (-135)	90	2.9 (1.19*2.41)	0.83	0.58
-	Toilet 1	1	NE (-135)	90	0.7 (0.61*1.21)	0.96	0.5
-	Bed room 1	1	SE (-45)	90	1.5 (1.21*1.21)	0.83	0.58
-	Bed room 2	1	SV (45)	90	1.5 (1.21*1.21)	0.83	0.58
-	Bed room 3	1	SV (45)	90	1.5 (1.21*1.21)	0.83	0.58
-	Living room 1	1	SV (45)	90	1.5 (1.21*1.21)	0.83	0.58
-	Living room 2	2	SV (45)	90	1.3 (0.61*2.12)	0.82	0.58
-	Living room 1	1	NV (135)	90	1.3 (0.61*2.12)	0.82	0.58
-	Living room 1	1	NV (135)	90	1.3 (0.61*2.12)	0.82	0.58
-	Living room 1	1	SV (45)	90	3.2 (1.48*2.12)	0.75	0.58
-	Toilet 2	1	NE (-135)	90	0.7 (0.61*1.21)	0.96	0.50
-	Bed room 4	1	NE (-135)	90	0.9 (0.71*1.21)	0.92	0.58
	Bed room 4	1	NE (-135)	90	0.9 (0.71*1.21)	0.92	0.58

Overview of shadings for windows and doors

Shadings						
Door s	*Room*	*Orientation*	*Horizon(°)*	*Overhang(°)*	*Left(°)*	*Right(°)*
Solid door	Entre	NE	15	30	0	31
Glazed door	scullery	NE	15	80	0	64
Glazed door	Living room 1	NV	15	30	0	49
Glazed door	Living room 2	SV	15	30	0	0
Windows	*Room*	*Orientation*	*Horizon(°)*	*Overhang(°)*	*Left(°)*	*Right(°)*
-	Living room 2	NE	15	85	0	38
-	Toilet 1	NE	15	44	0	56
-	Bed room 1	SE	15	44	0	0
-	Bed room 2	SV	15	44	0	0
-	Bed room 3	SV	15	44	0	0
-	Living room 1	SV	15	44	0	0
-	Living room 2	SV	15	30	0	0
-	Living room 1	NV	15	30	0	34
-	Living room 1	NV	15	30	0	77
-	Living room 1	SV	15	30	0	0
-	Toilet 2	NE	15	44	0	19
-	Bed room 4	NE	15	44	0	23
-	Bed room 4	NE	15	44	0	27

Annex O – Case 1, Pre-design, Calculation of u-values

U-values stated for the reference building

Reference building			
External Walls			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Light concrete	0.10	0.19	0.53
Insulation	0.15	0.04	4.05
Tiles	0.11	0.75	0.14
Thermal resistance (Inside)			0.13
Thermal resistance (Outside)			0.04
Sum of thermal resistances			4.89
U-value [W/m²K]			**0.20**
Roof/Ceiling			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Gypsum plates	0.01	0.56	0.02
Insulation	0.10	0.05	2.00
Insulation	0.30	0.04	8.11
Thermal resistance (Inside)			0.10
Thermal resistance (Outside)			0.30
Sum of thermal resistances			10.53
U-value [W/m²K]			**0.09**

U-values calculated with 100mm extra insulation

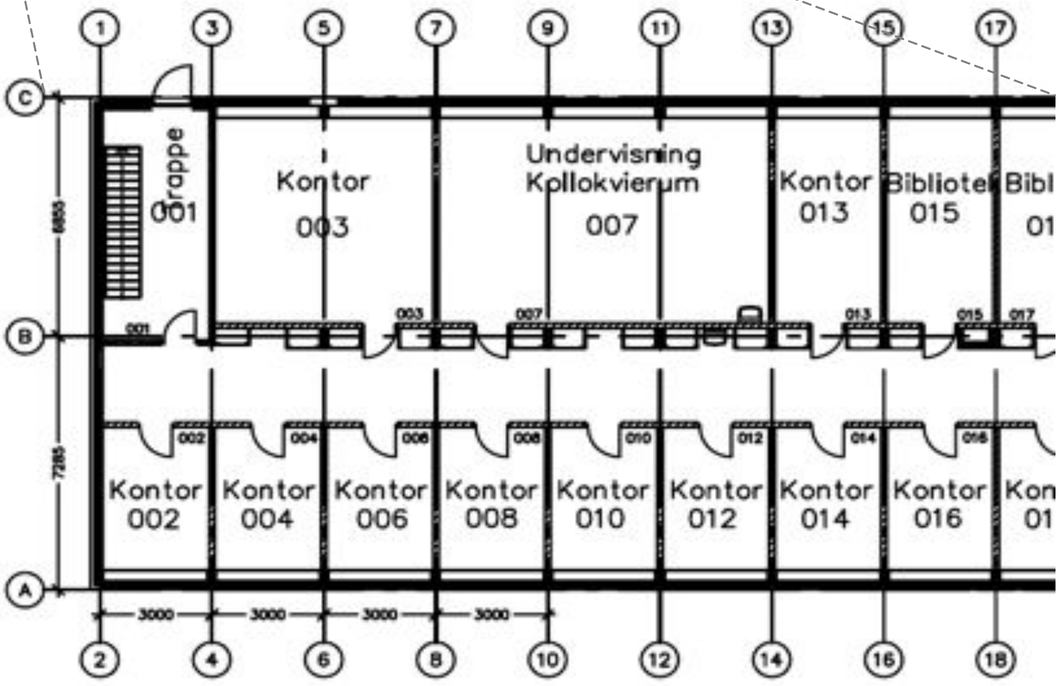
Plus 100 mm insulation (Walls and roof)			
External Walls			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Light concrete	0.10	0.19	0.53
Insulation	0.15	0.04	4.05
Tiles	0.11	0.75	0.14
Extra insulation	0.10	0.04	2.70
Thermal resistance (Inside)			0.13
Thermal resistance (Outside)			0.04
Sum of thermal resistances			7.60
U-value [W/m²K]			**0.13**
Roof/Ceiling			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Gypsum plates	0.03	0.18	0.14
Insulation	0.10	0.05	2.22
Insulation	0.30	0.04	8.11
Extra insulation	0.10	0.04	2.70
Thermal resistance (Inside)			0.10
Thermal resistance (Outside)			0.30
Sum of thermal resistances			13.58
U-value [W/m²K]			**0.07**

U-values calculated with 200mm extra insulation

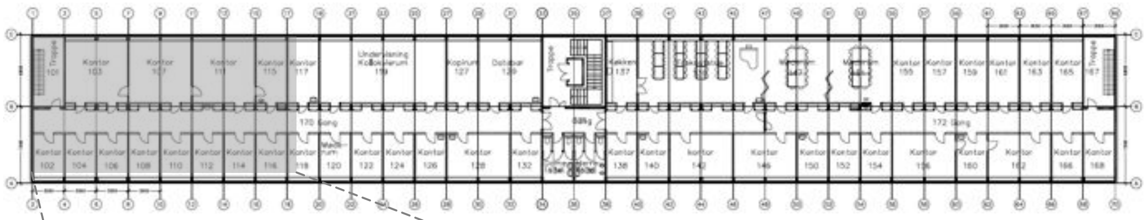
Plus 200 mm insulation (Walls and roof)			
External Walls			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Light concrete	0.10	0.19	0.53
Insulation	0.15	0.04	4.05
Tiles	0.11	0.75	0.14
Extra insulation	0.20	0.04	5.41
Thermal resistance (Inside)			0.13
Thermal resistance (Outside)			0.04
Sum of thermal resistances			10.29977525
U-value [W/m²K]			**0.10**
Roof/Ceiling			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Gypsum plates	0.03	0.18	0.14
Insulation	0.10	0.05	2.22
Insulation	0.30	0.04	8.11
Extra insulation	0.20	0.04	5.41
Thermal resistance (Inside)			0.1
Thermal resistance (Outside)			0.3
Sum of thermal resistances			16.28018018
U-value [W/m²K]			**0.06**

Annex P – Case 2, Reference building, Drawings

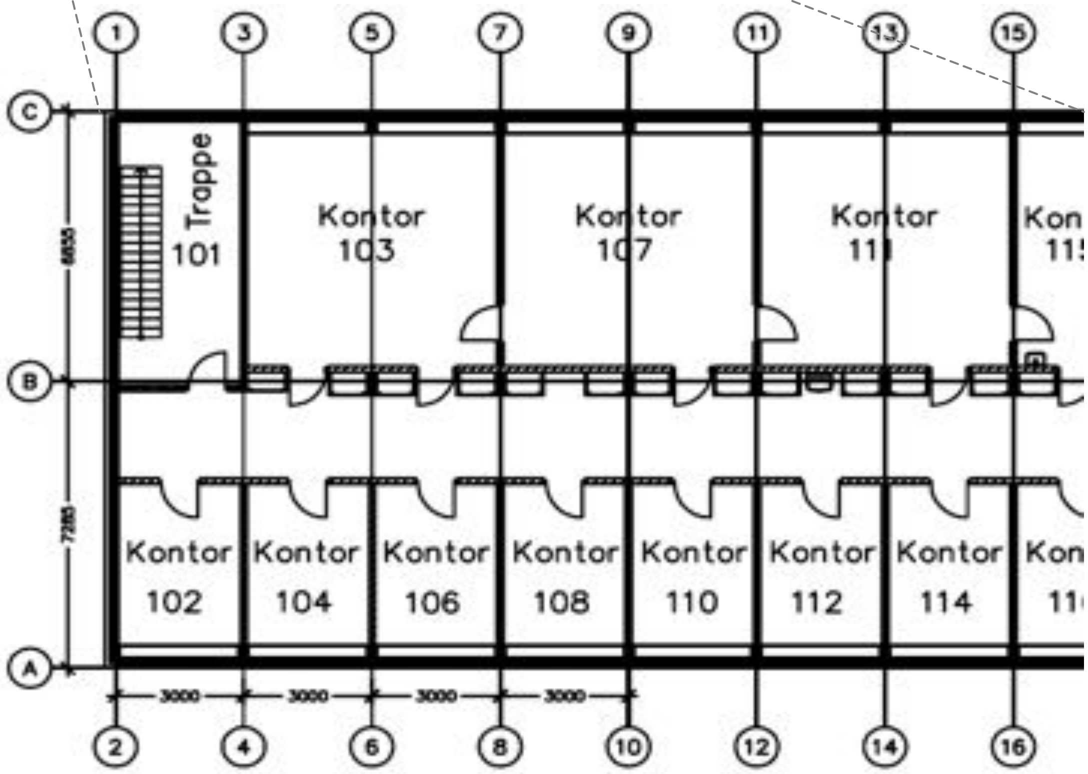
Ground floor. (not in scale). N:



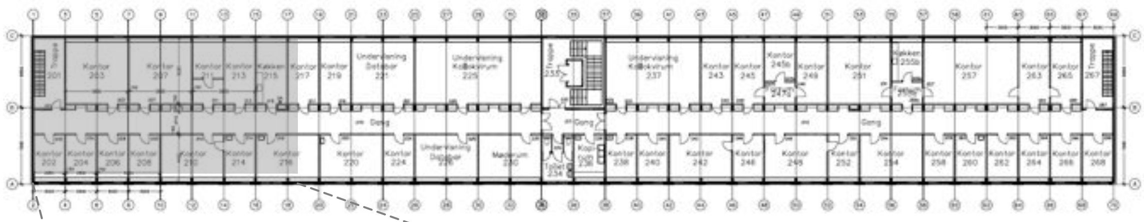
Section of the ground floor, marked with grey in above (not in scale)



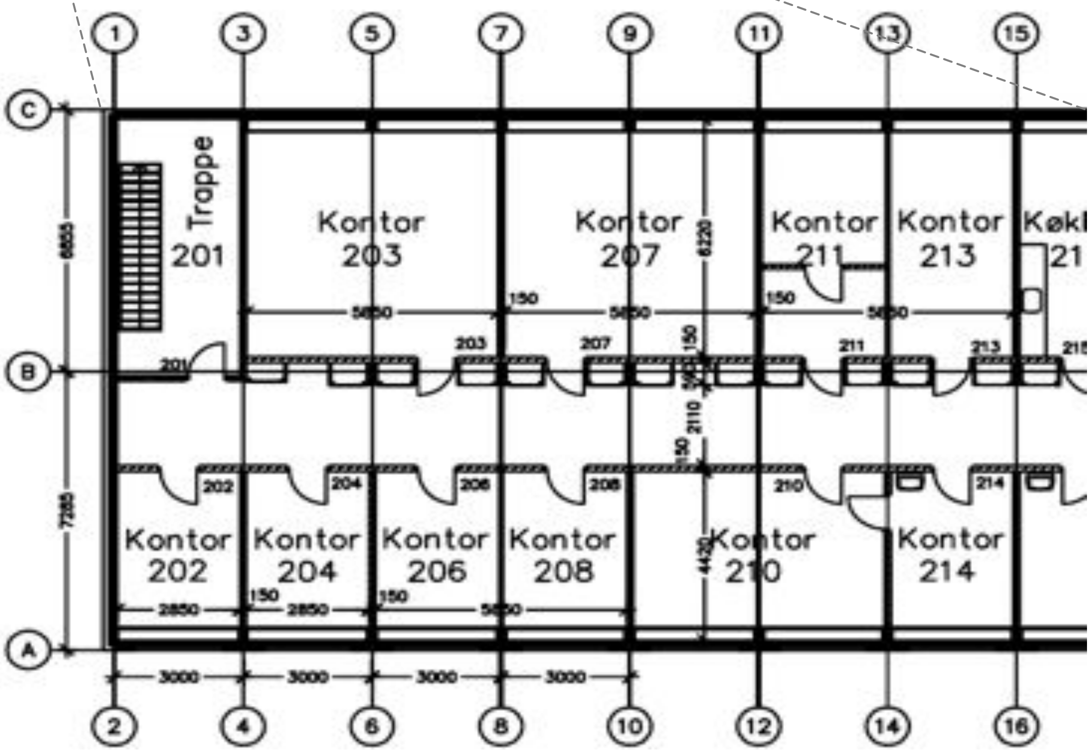
First floor (not in scale). N:



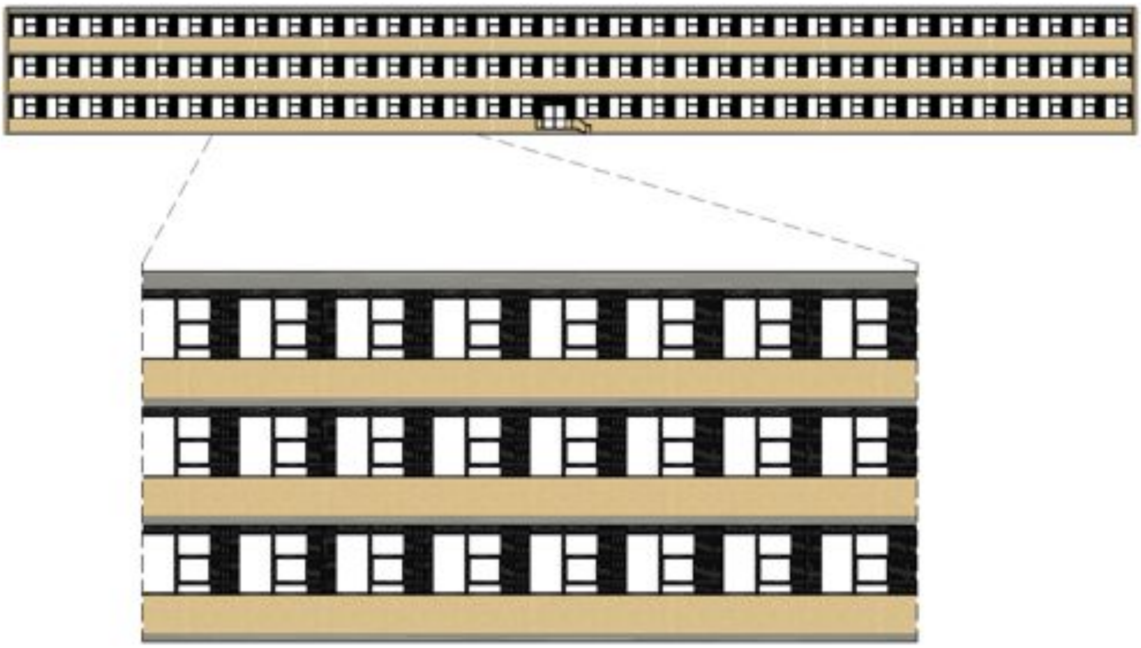
Section of the first floor, marked with grey in the figure above (not in scale)



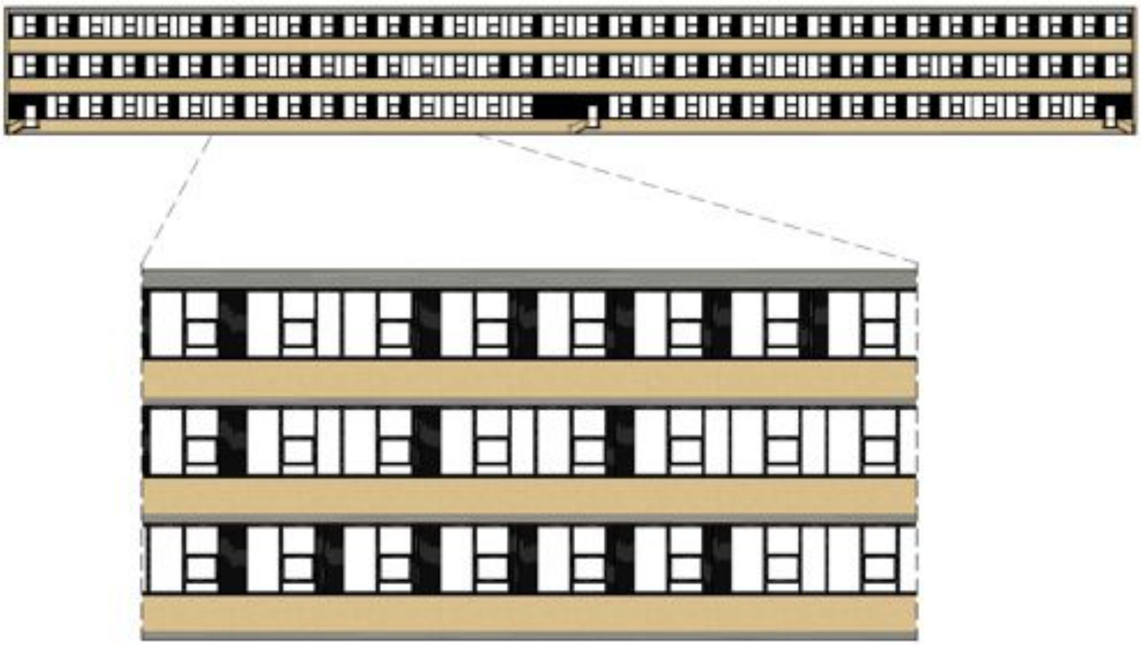
Second floor (not in scale)



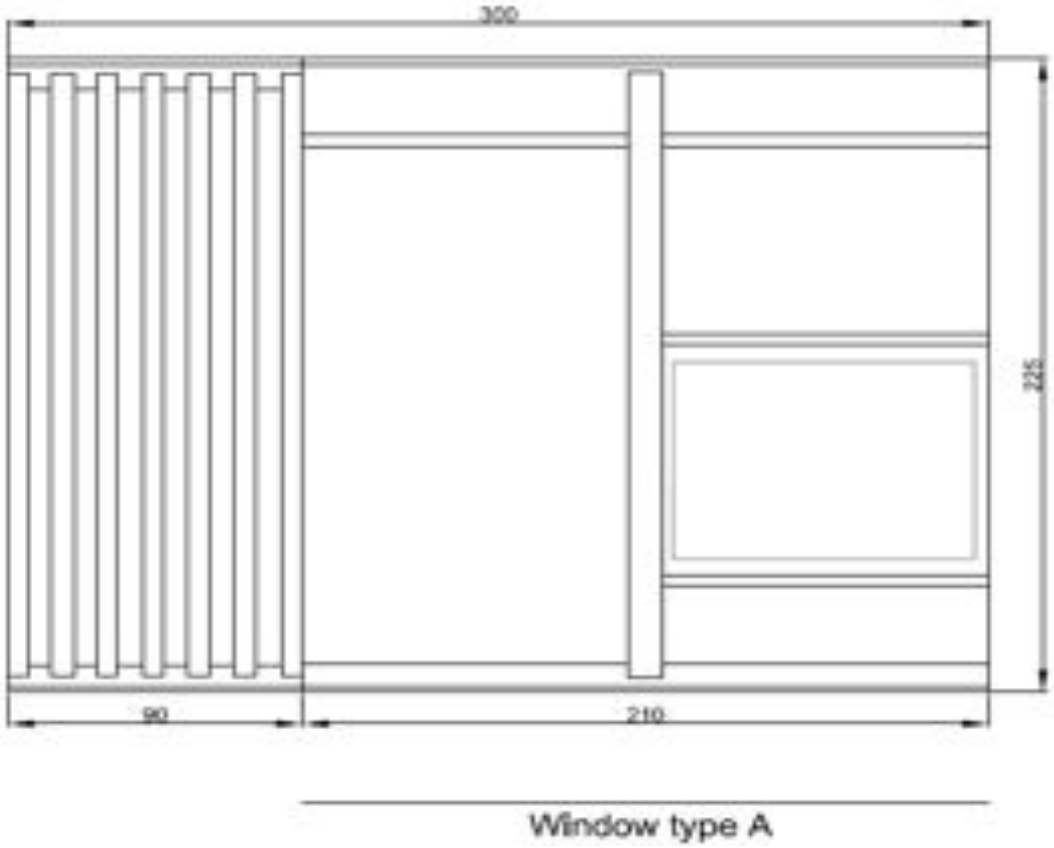
Section of the second floor, marked with grey in the figure above (not in scale)



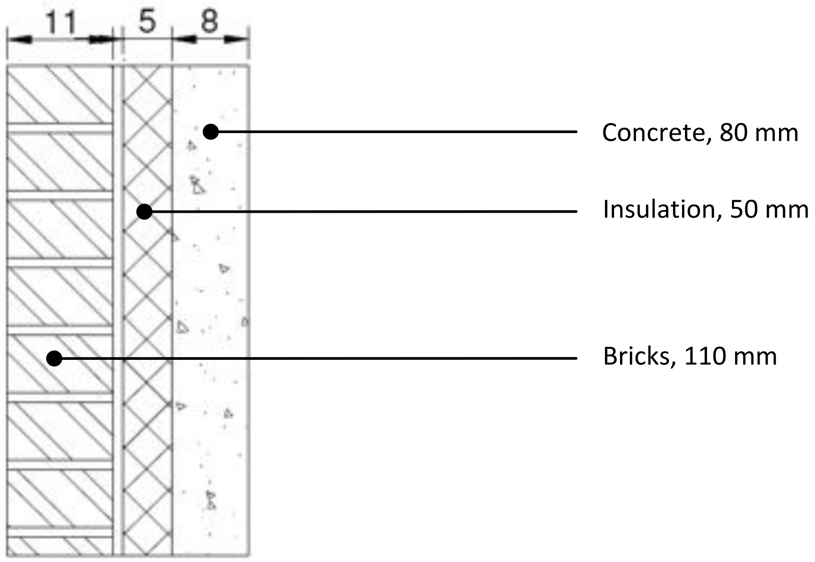
South facing elevation (not in scale)



North facing elevation (not in scale)



Window (not in scale)



Composition of the external wall facing north and south

Annex Q – Case 2, Reference building, General characteristic

Table 1 Composition and u-value of external walls

Wall type	Main composition	Depth [mm]	U-value [W/m^{2}K]
North and south facade	Brick	110	0.62
	Insulation	50	
	Concrete element	80	
Gable walls	Brick	110	0.61
	Insulation	50	
	Concrete	150	

Table 2 Main composition and u-value of the roof

Building component	Main composition	Depth [mm]	U-value [W/m^{2}K]
Roof	Plywood	25	0.42
	Insulation	100	
	Concrete	120	

Table 3 U-values for the windows

	Height [m]	Width [m]	Area [m^2]	U-value [W/m^{2}K]	g-value [-]
Window	2.25	2.1	4.73	2.00	0.72

Table 4 U-value for wooden frame construction

Building component	Main composition	Depth [mm]	U-value [W/m^{2}K]
Wooden frame construction	Plywood	20	1.15
	Insulation	50	
	Plywood	10	

Table 5 Linear heat loss coefficients

Connections	linear heat loss coefficients [W/mK]
Wall and roof	1.26
Wall and Floor	0.41
Wall and Windows	0.35

Table 6 Internal heat gains

Room type	Orientation [°]	Lighting gain [W/m^2]	Equipment gain [w/m^2]	People gain [W/m^2]
Single office	South	9	12	12
Single office	North	13	9	8
Classroom	North	5	3	32

Annex R – Case 2, Pre-design, Calculation of u-values

U-values stated for the reference building

Reference building			
External Walls			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Wall, total			1.44
Thermal resistance (Inside)			0.13
Thermal resistance (Outside)			0.04
Sum of thermal resistances			1.61
U-value [W/m²K]			**0.62**
Roof/Ceiling			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Roof, total			1.98
Thermal resistance (Inside)			0.10
Thermal resistance (Outside)			0.30
Sum of thermal resistances			2.38
U-value [W/m²K]			**0.42**

U-values calculated with 200mm extra insulation

Plus 200 mm insulation (Walls and roof)			
External Walls			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Wall, total			1.44
Extra insulation	0.20	0.04	5.00
Thermal resistance (Inside)			0.13
Thermal resistance (Outside)			0.04
Sum of thermal resistances			6.61
U-value [W/m²K]			**0.15**
Roof/Ceiling			
Materials	Width (W) [m]	Thermal conductivity (λ) [W/mK]	Thermal resistance (R) [m²K/W]
Roof, total			1.98
Extra insulation	0.20	0.04	5.00
Thermal resistance (Inside)			0.10
Thermal resistance (Outside)			0.30
Sum of thermal resistances			7.38
U-value [W/m²K]			**0.14**