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DIPLOMARBEIT

GENERATION AND APPLICATION OF A BIM-BASED REPOSITORY OF HIGHLY INSULATED BUILDING CONSTRUCTION DETAILS

unter der Leitung von

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KURZFASSUNG

Es besteht in der heutigen Zeit eine große Notwendigkeit der Verbindung von Werkzeugen zur Darstellung und topologischen Modellierung von Bauwerken und Werkzeugen zur Performance-Evaluierung dieser Bauwerke. Diese interoperable Verbindung ist in den letzten Jahren zu einem wichtigen Forschungsgegenstand in der AEC-Community (Architecture, Engineering, andConstruction) geworden und eine Vielzahl von Projekten und Publikationen sind in den letzten Jahren zu der Thematik erschienen. Ein Grund dafür, warum dieses Thematik als sehr wichtig betrachtet wird, liegt daran, dass der Großteil der Design-Entscheidungen, die dazu führen, dass ein Gebäude energieeffizient wird, in sehr frühen Entwurfsphasen getroffen werden müssen. Daher kann eine rasche und sinnhafte Verbindung von Design und Design-Evaluation als wichtige Notwendigkeit der Gebäudegestaltung im 21. Jahrhundert bezeichnet werden.

Diese Master-Arbeit ist in Bemühungen eingebettet, ein Decision-Support-System für Studierende und Stakeholder im Design- und Bauprozess zu erschaffen, welches Information zur richtigen baulichen Ausgestaltung von Baudetails in einfacher, rascher und vor allem zuverlässiger und umfassender Form zu liefern im Stande ist. Die präsentierten Informationen sollen Zeichnungen, semantische Informationen und Performance-Daten der Details beinhalten. Zur einfachen Erweiterung ist das Studium des Transfers zwischen Zeichen- bzw. Modellierwerkzeugen und Performance-evaluierungs-Tools erforderlich. In dieser Arbeit werden die Transfermöglichkeiten zwischen aktuellen Building-Information-Modelling-Werkzeugen (BIM, namentlich Autodesk Revit und Graphisoft ArchiCAD) sowie einem State-of-the-art numerischen Wärmebrücken-Simulations-Werkzeug (AnTherm) untersucht. Wärmebrückensimulationen können dazu beitragen, die negativen Effekte von Wärmebrücken (Kondensat, Schimmel, reduzierte Innenoberflächentemperaturen, Bauteilzerstörung) durch deren Vermeidung zu verhindern. Daher ist eine Verbindung dieser Werkzeuge als wesentlicher Bestandteil einer Unterstützung und Rationalisierung des Planungsprozesses zu betrachten.

Diese Arbeit beinhaltet einen ausführlichen Überblick über das Potential dieser Verbindung, untersucht im Detail die Verbindungsmöglichkeiten zwischen den Werkzeugen und illustriert diese und liefert einen „proofofconcept“ hierzu. Letzteres wird über die Verwendung der beschriebenen Verbindungsmöglichkeiten anhand eines Satzes von Details und die Dokumentation des Prozesses erreicht. Die Arbeit schließt mit einer SWOT-Analyse (Strengths-Weaknesses-Opportunities-Threats) des Ansatzes ab und möchte mittels Guidelines für den Transferprozess und Empfehlungen für zukünftige Weiterentwicklungen dazu beitragen, Building Information Modelling und Building Performance Simulation näher zusammenzubringen.

Stichwörter:

Building Information Modelling, numerische Wärmebrückensimulation, Antherm, Revit, ArchiCad, Design Unterstützung, Nachhaltigkeit.

ABSTRACT

The concept of merging energy performance tools with design software can be considered as a recent trend in the AEC (Architecture, Engineering and Construction) industry and has been constantly explored in a multitude of research projects and publications during the last few years. This is due to the fact that majority of decisions, resulting in sustainable building design solutions, are required to be made in early phases of the building development and planning. In recent times, the consideration of energy requirements within initial design phases is indispensable.

This contribution is embedded in the design concept for a decision support system that is oriented towards sustainable building design. Thereby, a repository of contemporary building construction details should be presented in a form that offers helpful information for both students and professionals. This information includes drafts of the details and performance implications via utilization of state of the art Building Information Modeling (BIM) techniques. This contribution addresses the specific transfer process between widely used drafting and building information modeling tools (Autodesk Revit and Graphisoft ArchiCAD) and a specific building performance evaluation tool, namely the numeric thermal bridge simulation tool - AnTherm. Such evaluations are used to avoid the negative effects of thermal bridges, which are condensation, mold growth, increased heat loss, reduced comfort as a result of lowered indoor surface temperatures, and building construction decay. This link between design tools and performance assessment has the capability to fundamentally support the building design and delivery process.

This thesis includes a comprehensive overview of the potential of a link between these tools, illustrates the development of information transfer between them, and delivers a proof of concept for the overall approach. This is done via application of the transfer process to a set of building construction joints and the presentation of the results for this set. The work concludes with a summary of strengths and weaknesses of the approach, a guideline for smooth conduction of such transfers, and - as an outlook - with recommendations for future development.

Keywords

BIM, numeric thermal bridge simulation, building construction joints, Revit, ArchiCAD, AnTherm, repository, decision support system, sustainability, thermal bridges

CONTENTS

ABBREVATIONS

AEC	Architecture, engineering, construction
BIM	Building Information Modelling
CAD	Computer aided design
DXF	Drawing Exchange Format
gbXML	Green Building XML
IFC	Industry Foundation Class
XML	Extensible Markup Language

NOMENCLATURE

Q	Heat flow rate, [W]
R	Thermal resistance, [m^2KW^{-1}]
U	Thermal transmittance, [$Wm^{-2}K^{-1}$]
L^{2D}	Thermal coupling coefficient, [$Wm^{-1}K^{-1}$]
θ_{min}	Minimum interior surface temperature, [°C]
θ_i , θ_e	Temperatures of inside and outside space, [°C]
c	Specific heat capacity, [$Jkg^{-1}K^{-1}$]
d	Thickness, [m]
m	Mass, [kg]
l	Length, [m]
λ	Thermal conductivity, [$Wm^{-1}K^{-1}$]
μ	μ-factor, [-]
ρ	Density, [kgm^{-3}]
Ψ	Linear heat transmittance value, [$Wm^{-1}K^{-1}$]
f_{Rsi}	Temperature factor, [-]

1 INTRODUCTION

1.1 Overview

With the advancement of computational tools for building design, performance is getting a more prominent role as a driving force in an early stage of the planning process. Building performance analysis is usually performed after the initial design phase, or after the completion of architectural design and construction documents (Gerber et al. 2013). In this praxis, the analysis is performed on a very limited set of design alternatives rather than to support early-stage design decisions, where a broader range of possibilities for more optimal solutions may exist.

The lack of domain knowledge, interoperability of various software tools, limitations of design cognition and complexity represent some of the main obstacles on the way to conceptual energy performance feedback. Consequently, all performance assessments are typically performed when the building is already finalized, with the limited set of explored design alternatives. This lack of continuous building analysis of sustainability in the planning and design process leads to ineffective solutions, which in most cases cannot fulfill a set of criteria for sustainable design (Azhar et al. 2009).

Rising energy prices imposes an importance of minimized heat loss in a building with a desired shape and function. This requirement can be fulfilled only if the building design is thermally optimized, at the beginning of the planning process. All potential problems in building process must be considered on time, in the early phase of building design, so that future issues can be foreseen and avoided (Gerber et al., 2013).

The main objectives of this research is a development of theoretical and methodological framework, serving as a base for implementation of digital parametric design tools and processes into the sustainable architectural design, in order to improve the thermal performance and energy efficiency in an architectural form.

The primary goal of this study is to create software support in the form of construction details repository with the purpose of explaining and presenting potential problems in building structures. More specifically, the practical aim of this research is developing the BIM (Building Information Modeling) component database, which can be used as an educational tool, capable of supporting and facilitating the daily work of designers by giving suggestions for optimized construction details.

The importance of this BIM-based database is in a better understanding of a building process before construction is built in reality, using simulations of potential thermal losses in building design. This BIM repository is meant to be a teaching support that will simplify users' access to energy analysis by means of a user-friendly interface for predicting building problematic in the practice. Work process will be based on examination and description of workflow between widely used BIM modeling tools (Autodesk Revit and Graphisoft ArchiCAD) and building performance evaluation software - AnTherm. Information transfer will be examined and presented with the purpose to define intelligible guidelines for smooth conduction in data transfer and provide theoretical background for further development. Challenges and barriers, which result from the integration of design with BIM platforms and selected building thermal simulation tool, will be also discussed in this thesis.

1.2 Motivation

Computer modeling approach and simulation analysis represent a powerful technology for addressing structural issues in buildings. Nowadays with the development of contemporary buildings, the planner needs to face the number of requirements that must be fulfilled in order to meet sustainable design standards in a limited time frame. The design and construction industry are moving towards Building Information Modeling (BIM) that provides numerous advantages of traditional 3D CAD (Computer-aided design), as well as an additional layer of data and parameters. This data source contains characteristics of a structure consisting of 'intelligent objects' rather than simple lines, arcs, and text (Narowski et al. 2011). The concept lies within the idea to create a model, which is beyond 3D visualization modeling - building with all properties, problematic, environmental impacts, etc. The aim is to extract this data from the model for further analysis in search of a feedback and the most effective building solution. This way of modeling helps architects, engineers, and constructors to visualize a construction object in a simulated environment and to identify potential design, construction or operational issues.

In current practice, many digital building models do not contain sufficient information about sustainable building performance analysis. Parametric building modeling technology, present in BIM practice, offers an integrated database of structured data. The integration of BIM modeling tools with commercially available energy analysis tools simplifies the process of building performance analysis (Bahar et al. 2013).

The repository can be very helpful in the design process since it supports decision making by giving descriptive explanations, templates, building and components examples and procedural methods for determining appropriate installation and systems. This knowledge-based support should provide quantitative answers regarding the impact of the design decisions in early stages of building design. Its importance lies in the ability to provide a user with valuable insights and directions during the design process.

In the planned BIM repository, based on detailed information of the construction's components and thermal performance results, the planner will have: a fast overview of junction design solutions; thermal performance indicators; data about mold formation and condensation risk and possibility to choose an optimized building detail in order to minimize heat loss in building design.

1.3 Background

Simulation became an integrated element of building design process. The increased complexity of building design process has led to the broader use of Building Performance Simulation (BPS) tools between diverse designs teams involved in building design (Attia, 2010). Attia (2010) states that continuingly growing number of BPS tools don't necessary reflect a ground breakthrough within building design community. Most BPS tools are difficult and cumbersome to use and mainly still oriented towards final design stages.

The explanatory power of graphical output is important for a better understanding of simulation results. Users prefer the results presented in a visual format in a concise and straightforward way, rather than those summarized in numerical tabulation.

1.3.1 Overview

There are fundamental differences between an architectural model used to generate construction documents and an energy model. From the architects' perspective, visual character of a building model is important because it represents design intent. From the engineers' perspective, reduction of the variables in a model consequently reduces the analysis time. Therefore, they require only that set of information, which is relevant for energy performance.

In recent times, architects became deeply engaged in the BPS community. For them, the most common barrier in dealing with BPS tools is interpretation of simulation outputs, which often lack variety and visual qualities. Architects need the fundamental understanding of basic building physics that allows them to recognize and implement simulation feedback into building design process (Lin and Gerber, 2013).

A small percent of existing energy evaluation performance tools are used by architects for evaluation of building concepts. A number of studies illustrate that building simulation tools are inadequate, user-hostile and complicated to be used by architects in early stages of building design (Attia et al. 2012). From only 10% of available energy performance tools intended for architects' use, just 1% can be used in the initial design stage. Apart from the limited tool availability, the effective interoperability between tools for design and energy simulation tools is also an issue (Attia, 2010). A significant amount of information is lost during the data transfer between those tools. Figure 1 shows architects' rank of the most important features of a BPS tool.

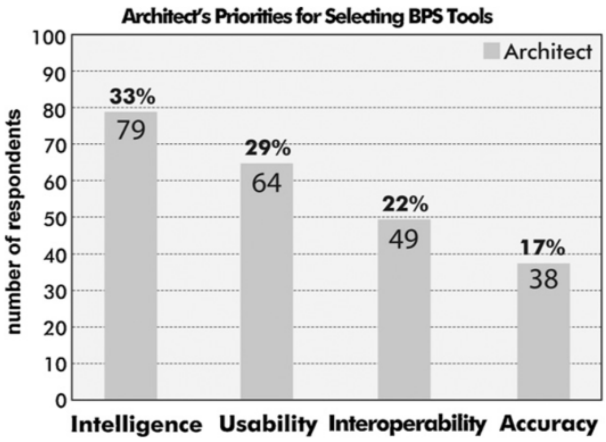


Figure 1 - The most important features of a Building Performance Simulation (BPS) tool named by architects (Attia, 2010)

Most of the building simulation tools still prefer to use simplified, one-dimensional models and complex descriptions of heat flow through a building envelope. Outputs from energy simulation tools are often displayed in value tables which are too detailed and complex in their appearance.

The interface of planned BIM repository should facilitate ready-to-use default templates which are transparent, with simple entry values and easy access to details in software's library. Therefore, this friendly interface should allow users to create and modify their own customizable building components.

Construction junctions play a prominent role in the overall thermal behavior of a building. Therefore, through planning and design are significant for creation of an energy efficient building. In general, these details represent the connection between plane elements of the building envelope, having a relatively high geometrical complexity. For the thermal evaluation of the building construction details, basically, two different options are available:

1. computer programs specified for energy simulation;

2. catalogs which offers a certain amount of drawings of building details with thermal relevant results.

On the one hand, specified building simulation programs require a good knowledge in building physics field, therefore, a limited number of experts are able to use such tools. Nevertheless, these tools offer a good precision and a broad flexibility. On the other hand, the building catalogs do not require the same level of expertise in building physics, and therefore can be used on a larger scale (e.g. by architects and students), but their flexibility is constrained. The differences occur very often between the detail under consideration in the current project and the catalog detail (Wouters et al. 2001).

1.3.2 BIM

The concept of Building Information Modeling (BIM) is an intelligent model-based process that allows multidisciplinary information to be superimposed on one model (Figure 2). It creates high-quality construction document production, construction planning and energy performance predictions (Azhar et al., 2008). The difference between BIM and CAD is in their conceptual differences between entity-based and object-based models. CAD represents entity based building models based on raw graphic entities such as lines and arcs and doesn't provide rich semantic information about the buildings as BIM do. Object-based model in BIM approach comprises parametric objects such as wall, columns, slabs and windows and therefore is considered more powerful and sophisticated than an entity-based model (Kumar, 2008). BIM allows design decision making process to take place during the building concept phase. This is possible because BIM provides an opportunity for sustainability measures and performance analyses to be implemented throughout the design process (Schueter and Thessling, 2008).

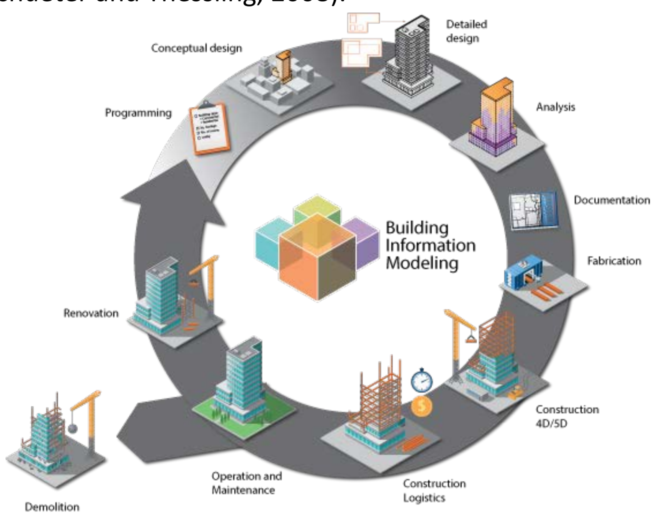


Figure 2 – BIM (http://www.lr.org/en/utilities-building-assurance-schemes/building-information-modelling/)

The knowledge from the design phase can easily be transferred into the operational phase. Building Performance Based Design Method (BPBDM) has an ability to estimate the impact of a design solution because it uses detailed building model to simulate, analyze and predict the behavior of the system (Autodesk, 2008).

The AEC (architecture, engineering, and construction) industry is in constant search for new ways to improve collaboration and interoperability of BIM platforms via new technology and open-standard programs, in order to share information among the various design and simulation tools.

1.3.3 Design decision system support

One of the major reasons that prevents architects from using energy-oriented tools is the fact that besides a limited number of available designer-oriented energy simulation tools, the designers are often unfamiliar with energy simulation tools, which are generally outside of their area of expertise. In practice, experts in energy performance fields apply those tools because they are familiar with specialized nature of energy simulation programs. Also, another drawback of current practice is that building performance validation is usually done after building design process is finished, instead of in earlier phases, when those results can influence the initial building design for a better solution (Aksamija,2013)

Evolutionary energy performance feedback for design (EEPFD)

Evolutionary energy performance feedback for design (EEPFD) is developed to incorporate conceptual energy analysis and design exploration of building details and geometry, for the purpose of providing early stage design performance feedback (Lin and Gerber, 2013). EEPFD is invented to provide designers with energy performance feedback during the conceptual design stage, where overall building form has not yet been finalized.

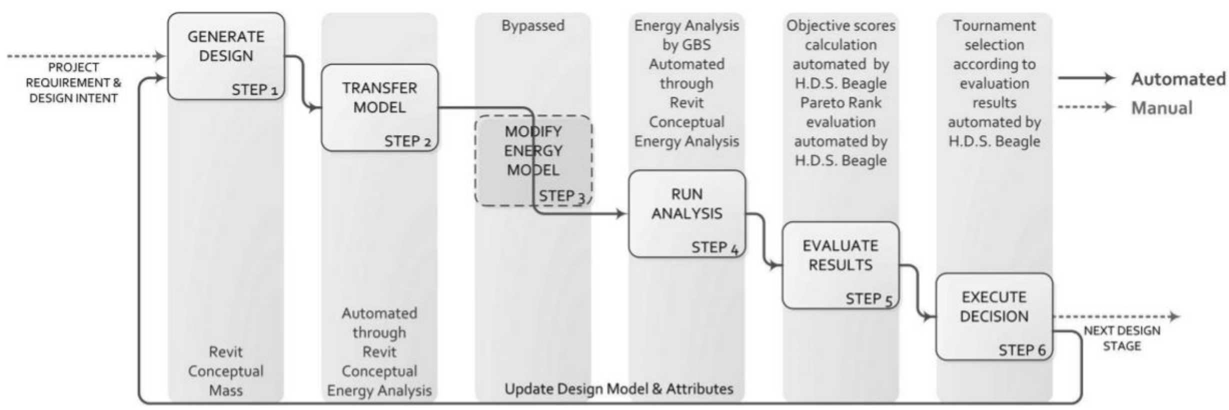


Figure 3 - EEPFD's process (Lin and Gerber, 2013)

The process of applying EEPFD to obtain performance feedback for design decisions are described and classified in six steps (Figure 3). Firstly, the model has been generated by the user through a parametric model. All model information and requirements are provided manually by the user. The process is cycled through steps until the automation loop is interrupted either by the user or by meeting of the system's termination criteria.

1.3.4 Computerized thermal bridge atlases

Computerized thermal bridge atlas represents an extremely powerful tool for so-called global actions, which can be used in relation to all building types (Wouters et al. 2001). The main advantage of this atlas is its user friendliness. It offers a large possibility of modifying the chosen detail by changing layer thickness, type of materials, boundary conditions and etc. Results are represented by colorful pictures showing the isothermal lines, the heat flux lines, and other simulated values, which are generally used for better understanding of thermal processes in building construction.

KOBRA and EUROKOBRA

KOBRA is software developed by Physibel and it offers a fast selection of a building detail from a graphical database with the possibility of modification by changing its dimensions and materials (Wouters and Schietecat, 2001). After the selection of detail, a thermal bridge analysis carried out by reporting relevant information about its thermal behavior, with presented f_{Rsi} (evaluation of condensation risk) and ψ-values (evaluation of extra heat loss). KOBRA program is accompanied by an extensive thermal bridge database EUROKOBRA, which contains relevant building details (Figure 4).

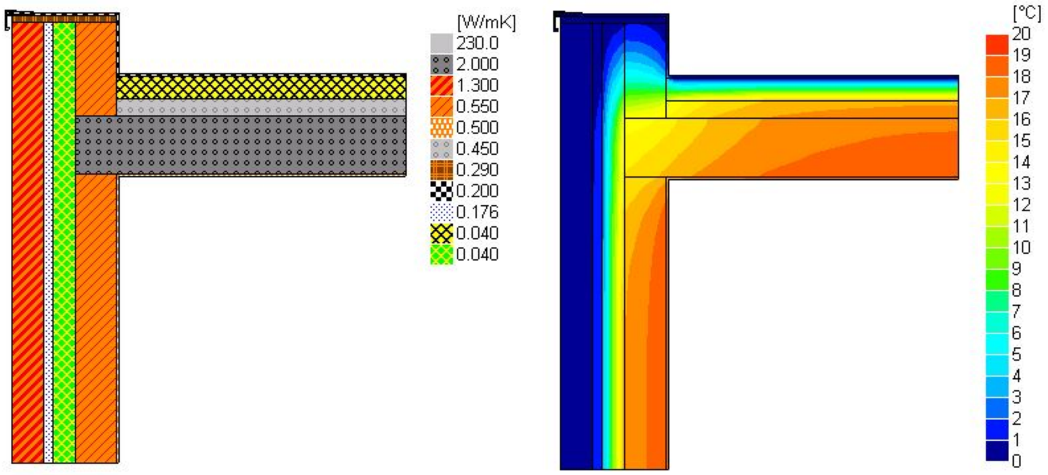
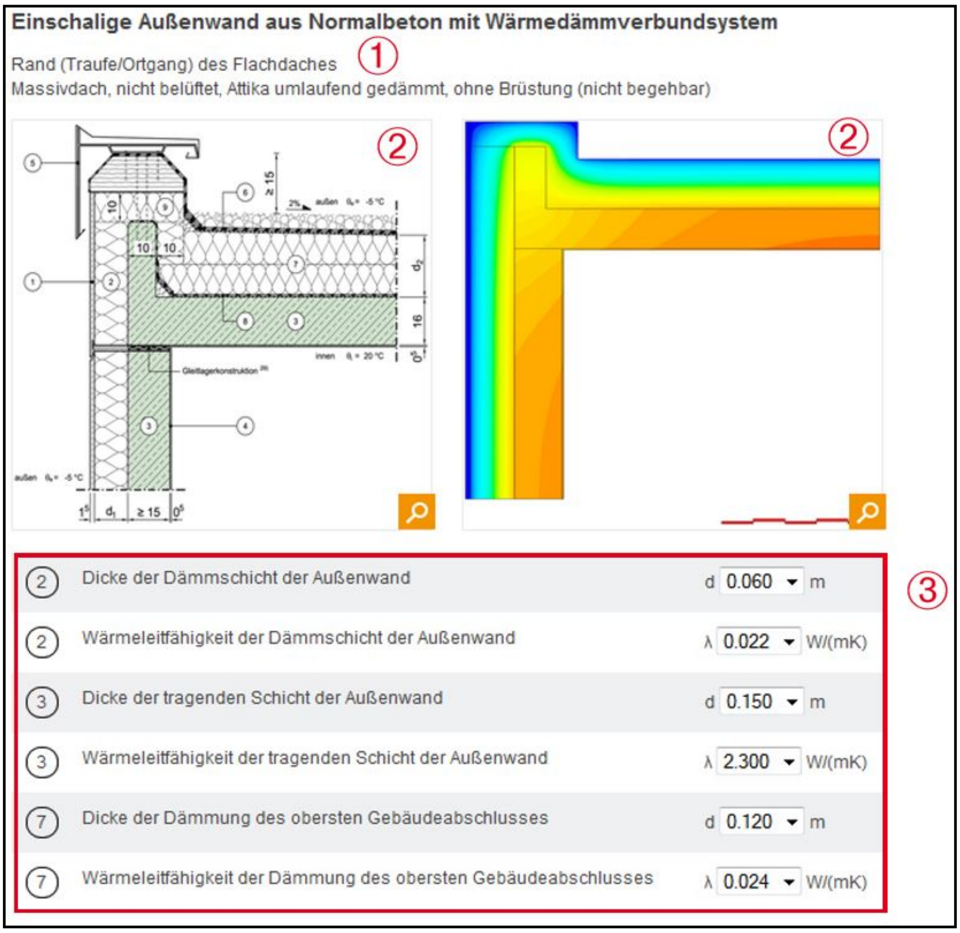


Figure 4 - KOBRA database (Wouters et al, 2001)

Planungsatlas Hochbau

Planungsatlas Hochbau (planning atlas of building construction) has been developed at the Technical University of Dortmund (Department of Building physics and technical building services). This planning atlas represents an interactive platform, which is available at www.planungsatlas-hochbau.de and is free of charge. This atlas covers the various types of building construction details, typically used for residential and non-residential buildings built in massive construction. The interactive platform offers the possibility of selecting different construction details, which can be modified in various ways (Figure 5).



1. Textual description of the building construction detail
2. Graphical representation of the selected detail with the temperature image
3. Configuration table that offers possibility of modification of the selected value

Figure 5 - Plannungsatlas Hochbau (Beton, Planunsatlas für den Hochbau)

Besides the graphical representation of a designed detail with the temperature profile, the results of the thermal simulation are also presented in the table by computing the following values: U-value for the designed detail, the linear thermal transmittance (ψ-value) and minimal surface temperature (θ_{min}). All information about selected detail from atlas is available for download in DWG/DXF as well as .pdf, .png, .doc and .ndw formats.

2 THEORETICAL FRAMEWORK

2.1 Fundamentals of building physics

2.1.1 Thermal bridges

Thermal bridges represent '' weak'' points in building construction, through which heat can escape, making a negative impact on surface and interior temperatures. Thermal bridges occur generally at junctions between building components or where the building structure changes its composition. Those locations are the typical places for moisture and mold appearances in buildings. In general, thermal bridges can occur at paces with a gap between materials and structural surfaces (Figure 6).

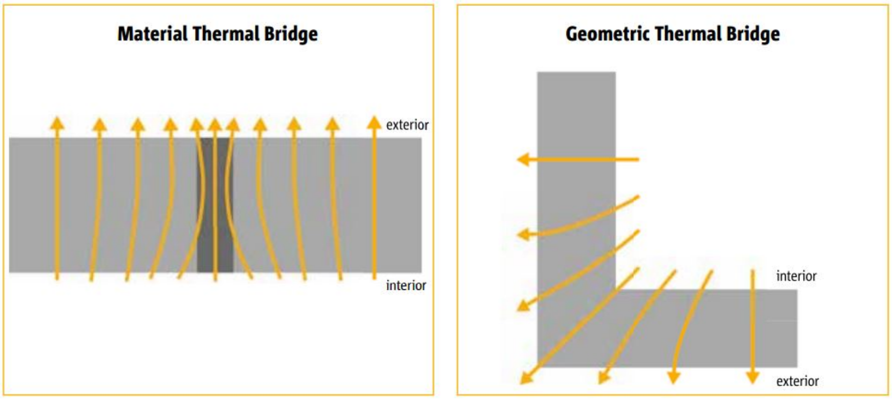


Figure 6 - Thermal bridges (http://m.schoeck.co.uk/en_gb/causes-of-thermal-bridging)

Localized area through which heat flow is increased (thermal bridge) is named ''disturbed area'' and it is distinguished from the ''undisturbed'' adjacent building elements. It is noticeable that isotherms (lines of equal temperature) are running parallel and linear to the surface of the structure in ''undisturbed'' element area. In the ''disturbed area'' of the building component, the isotherms are running as curved lines, approaching the surface in the joint area (Figure 7). This phenomenon is leading to a temperature drop on a surface.

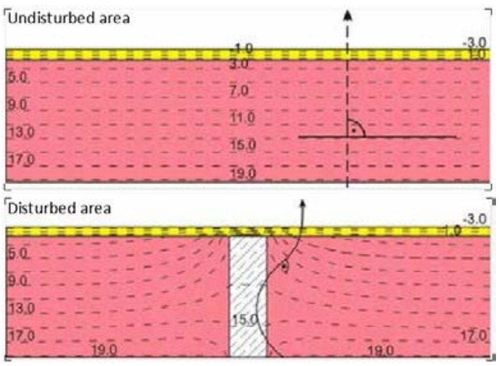


Figure 7 - Isotherms (Beton, Planunsatlas für den Hochbau)

In order to know the building's true thermal performance, overall R-values (resistance) of such assemblies as walls, roofs, floors, and glazing must be calculated. The total R-value (or "overall" R-value) of an insulated assembly may be higher or lower than the R-value of the insulation, depending on the assembly's construction. Thermal bridging represents situation when the overall R-value is lower than the insulation's R-values.

Placing a good conductor in parallel with good insulation is often referred to as "thermal bridging" because it provides a path for heat flow that bypasses the main insulation. Steel studs and metal window frames are common thermal bridges (Schöck Isokorb, 2015).

Classification of thermal bridges:

The general classification of the thermal bridges:

1 – Geometrical (form-related) thermal bridge

2 – Structural (material-related) thermal bridge

3 – Hybrid forms

Geometrical thermal bridges, as the name suggests, are the results of the geometry of thermal envelope. Typical examples include: a corner of an external wall; wall/roof junctions; wall/floor junctions; junctions between windows or doors and walls; junctions between adjacent walls. This type of thermal bridges occurs due to the difference between the internal and external area. They can be 2-dimensional (where 2 planes intersect) or 3-dimensional (where 3 or more planes intersect). If the geometry of building envelope is more complex, then the geometrical thermal bridging is likely to take place.

Structural thermal bridges occur in places where materials with different conductivity are combined (used in combination). In practice, structural connections often lead to heat loss and drop of surface temperatures in the room. Problems such as condensation and mold formation often can be often caused by structural thermal bridges.

Hybrid forms represent a combination of geometrical effects and structural effects of thermal bridges. Typical examples are junctions between walls and base plates above unheated basements, balcony details and details of eaves connections to unheated attics.

Besides this main classification, the thermal bridges can be also distinguished in two groups: linear and punctuate. Linear thermal bridges include the thermal bridges that occur as areas that extend longitudinally along building component junctions. Punctuate thermal bridges are represented by areas which are smaller in comparison to the total building area.

Consequences of thermal bridges

Thermal bridges represent areas of the construction elements, which have a greater permeability comparing to the rest of the thermal elements due to the structural or geometric composition. Higher heat losses occur through thermal bridges and directly influence interior comfort. Thermal bridges are the reason of uncontrollable heat losses of the building.

Low surface temperatures in the region of thermal bridges can lead to surface condensation, if those temperatures are below the dew point of the air. As a result, it most certainly leads to moisture and mold growth.

Recommendation for the minimization of thermal bridges in building construction

In order to avoid the appearance of thermal bridges in building construction, the shape of a building design should be compact. In other words, the appearance of geometrical thermal bridges is more probable in complex building envelopes. Also, the sharp building corners can lead to geometrical thermal bridging. Avoiding the insulation layer penetration is recommended in order to ensure a continuous insulation layer. This would guarantee no weakening of the insulation level and the avoidance of "insulation gaps".

2.1.2 Numerical calculation of thermal bridges

For the identification of thermal bridges in a building two key modeling outputs are defined: linear thermal transmittance (ψ-value) and temperature factor (f_{Rsi}). These key outputs are important to validate the adequacy of particular building details and help with the development of better solutions to improve the thermal performance of the junctions.

When the building structure is being analyzed, it is important to define which features affect the heat flow through the building and should be assigned to U-value, and which affect the heat flow through the thermal bridge and should be assigned to ψ-value. If these two effects are not precisely defined, the heat loss could be calculated twice because some features will be included in both effects.

International building standards EN ISO 10211 set out criteria for carrying out numerical calculations. This standard describes both: two and three – dimensional numerical modeling of building details. Methods for the calculation of the heat flows and surface temperatures, as well as, method for deriving linear thermal transmittance values, are described in next steps.

Linear thermal transmittance (ψ)

Linear thermal transmittance represents heat flow rate in the steady state divided by length and by the temperature difference between the environments on either side of a thermal bridge. It is expressed in $W \cdot m^{-1} \cdot K^{-1}$ (EN ISO 10211). For calculating ψ-value, it is important from the total heat flow (from the external to the internal environment) to subtract heat flow expressed by U-value multiplied by the length of the element.

The ψ-value is given by:

$$\Psi = L^{2D} - \sum(U \times l) \quad , [Wm^{-1}K^{-1}] \qquad (1)$$

where:

L^{2D} the total heat flow through the two-dimensional numerical model, $[Wm^{-1}K^{-1}]$

U the U-value of the plane building element, $[Wm^{-2}K^{-1}]$

l the length (in the two-dimensional model) over which U applies, [m]

Figure 8 illustrates the correct use of the length (l) in building construction. The schemes describe two examples: the junction of an external wall with an internal partition and the junction of an external wall with a partition wall (Ward, 2006).

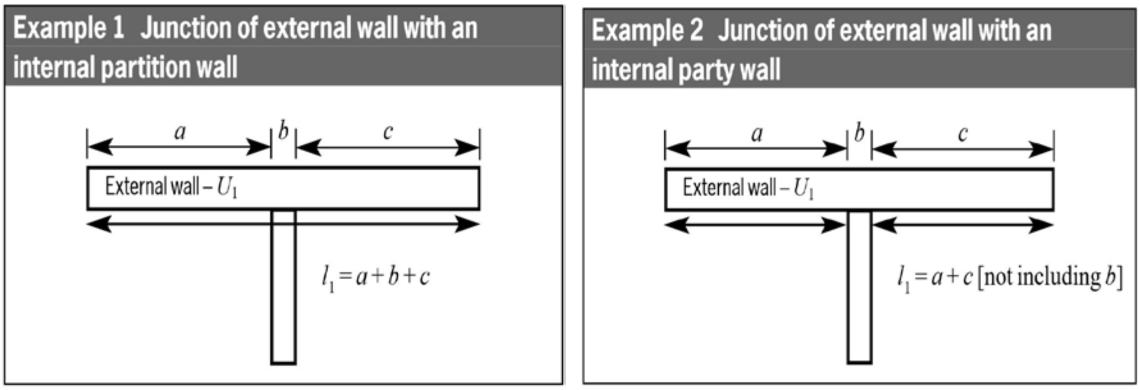


Figure 8 - Calculation of length l (Ward, 2006)

Temperature factor (f_{Rsi})

The temperature factor (f_{Rsi}) represents the risk of surface condensation or mold growth on any building detail.

The f_{Rsi} value is given by:

$$f_{Rsi} = \frac{\theta si - \theta e}{\theta i - \theta e} \quad , [-] \qquad (2)$$

where:

θ_{si} the surface temperature, [°C]

θ_i internal environmental temperature, [°C]

θ_e the temperature of the external environment, [°C]

Temperature factor depends only on the structure and not on the imposed air temperatures. Once it has been calculated for any particular internal and external environmental temperature, it can be used for calculation of surface temperature for any other set of conditions (Ward and Sanders, 2007). Formula is:

$$\theta_{si} = \theta_e + f_{Rsi} (\theta_i - \theta_e) \quad , [°C] \tag{3}$$

where:

f_{Rsi} temperature factor, [-]

θ_{si} the surface temperature, [°C]

θ_i internal environmental temperature, [°C]

θ_e the temperature of the external environment, [°C]

2.2 General conditions for calculations of thermal bridges

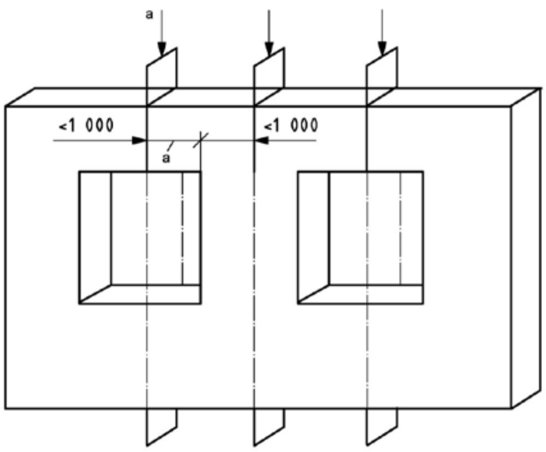
Before the modeling stage, certain rules and guidelines should be precisely defined, in order to provide a feasible model for detail's design and simulation. This modeling process includes BIM platforms, where details are modeled, and energy performance software, where details are simulated. Recently developed plug-ins are aimed to facilitate architects in dealing with energy simulation analysis but, the most of these platforms do not offer detailed and precise outputs, compared to energy performance tools developed exclusively for this purposes. *AnTherm* (Analysis of Thermal behavior of Building Constructions with Heat Bridges) represents the reliable tool for evaluating thermal performance thoroughly and precisely, therefore this software tool has been chosen for energy simulation. The choice of the software was based upon the fact that besides thermal heat bridges calculation expertise its license has been provided by authors of the software. Demonstration license for AnTherm with 1.000.000 equation cells has been used for the purpose of this thesis.

2.2.1 Modeling approach

The set of criteria should be fulfilled in modeling stage in order to satisfy requirements for successful export and energy simulation in BPS tool. For proper simulation of thermal bridges, the main guidelines are set according to EN ISO 10211 standard as requirements for model development. The main approach is that all building model subdivisions, such as construction details, must be made in such way that no differences in calculation outcome between building itself and a separated part should appear. This decomposition must be done in a way by choosing appropriate cut-off planes.

The geometrical model should be created properly. Cut-off planes should be taken at least 1m away from the thermal bridge or 3 times the thickness of the element. In the case that model contains repeating thermal bridges; it would extend up to a plane of symmetry (Figure 9).

The major topic of this thesis includes building construction details. Details are represented as 2D building section drawings, where the cut-off planes are positioned at a distance of at least d_{min} (minimum thickness) from the central element (Figure 10).



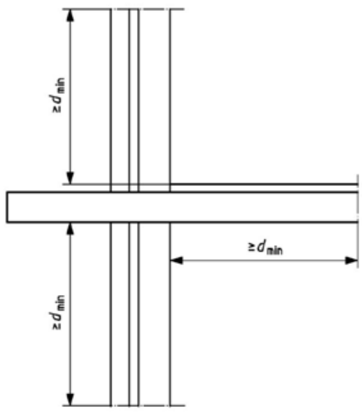


Figure 9 - Symmetry cut-off planes (ISO 10211) *Figure 10 - Symmetry cut-off planes (ISO 10211)*

Similar to some other modeling software packages, AnTherm can deal only with rectangular shapes, parallel to X, Y and Z – axes. This simulation tool is not able to reproduce slope lines, therefore, the sloping parts in the geometry of detail should be approximated with steps of a certain size and number. The size and the number of steps should be defined by considering the angle of the slope β and the thickness d of any thin layer along the slope. Thin layers are those layers which are less than 4mm thick. The research paper of Tim Ward and Chris Sanders "Conventions for calculating linear thermal transmittance and temperature factors" offers an explanation that β is the angle of the slope and y/x = tan (β) as it is shown at Figure 11. If tan (β) > 1, i.e. β > 45°, then x < y, otherwise x > y. The smaller of x or y must be no greater than 2.5 × the thickness, d, of the sloping thin layer. For any sloping part of the geometry that is not a part of a thin layer, the smaller of x or y must be no greater than 10 mm.

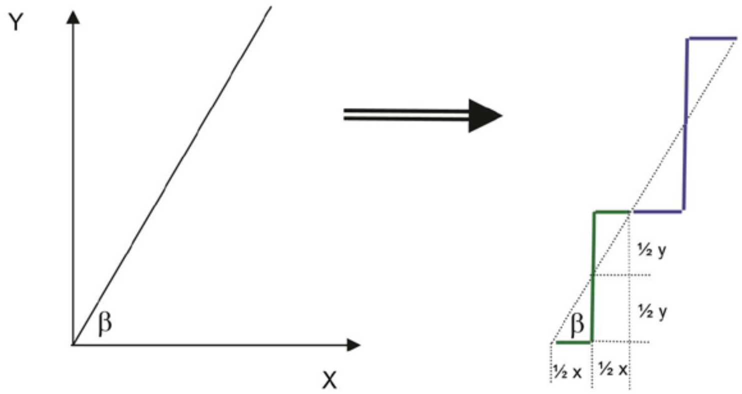


Figure 11 - Stepping of slope for rectangular modeling software (Ward, 2006)

2.2.2 Geometrical boundary conditions

If the heat transfer through the ground level (foundations, floor plates, and basement) is included in the calculation, the values indicated in Table 1 should be taken into account.

Table 1 – Geometrical boundary conditions

Direction	Calculation purpose	
	Surface temperatures	**Heat flow**
Distance to horizontal cut-off plane inside the building	at least 1m	at least 1m
Distance to horizontal cut-off plane outside the building	at least 1m	*
Distance to vertical cut-off plane below ground floor level	at least 3m	*
Distance to vertical cut-off plane below ground floor level if that level is >2m below surface of the soil	at least 1m	*

- *According to DIN 4108 supplementary sheet 2 no soil has to be included in the calculation model. The system boundaries have to be set along the construction element's outside surface.*

  Table according to ISO 10211 and DIN 4108

Air spaces in construction

Airspace should be treated as a material with given thermal resistance. The reason is that radiation and convection heat transfer is approximately proportional to the temperature difference between the bounding surfaces. For the modeling purpose, the airspace is created as a material with an equivalent thermal conductivity.

2.2.3 Software for numerical calculation - AnTherm

AnTherm is an energy-oriented tool for calculating heat flow through building construction elements such as thermal heat bridges and vapor bridges. This software calculates the distribution of temperature, heat streams and vapor diffusion streams in building components and it represents a very reliable tool for evaluating the thermal performance of a building. This software is fully validated according to EN ISO 10211 standard.

AnTherm is modeling software which can represent only rectangular shapes and therefore it is not capable of modeling sloped lines and curve – shaped details. The strategy for modeling sloped lines is described in more detail in the paragraph above (2.2.1 Modeling approach). Each rectangular element is defined with 4 coordinates of X1, X2 and Y1, Y2.

Layers in building construction are represented as layers in Element Browser in AnTherm. Each layer can be defined by adding specific materials from *Materials Database* or by creating a new material by adding specific values (Figure 12). AnTherm offers a material choice of layers with many specified characteristics, such as density (ρ), thermal conductivity (λ), c (specific heat), water vapor diffusion resistance factor (μ). The source of data can be also chosen from Material – Database which offers data from DIN, ES ISO, IBO, ÖNORM standards.

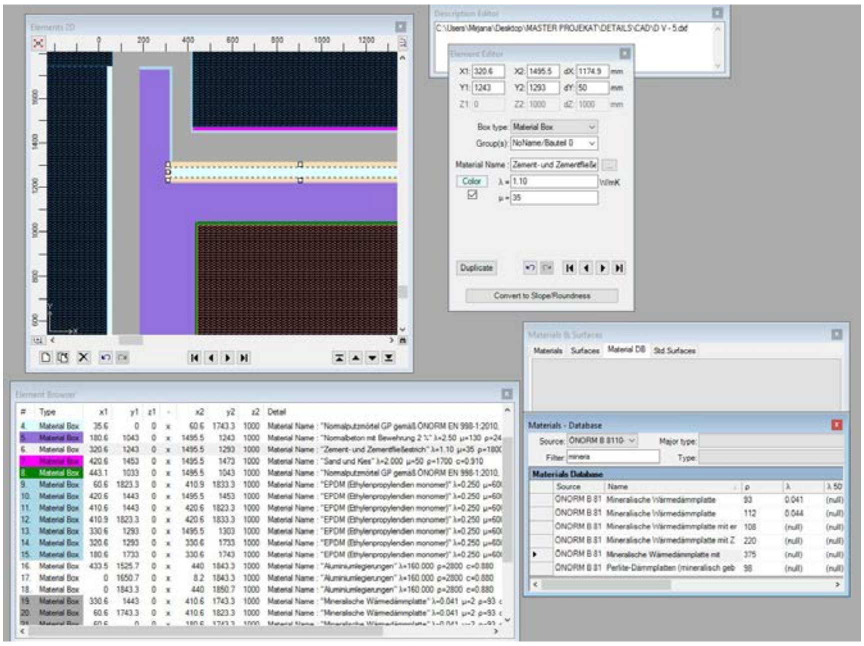


Figure 12 – User interface in AnTherm

Two major parameters should be defined before running the simulation in AnTherm:

1. The **surface thermal resistance** R_s [m^2KW^{-1}] for internal and external spaces should be specified depending on the heat flow direction and surface temperatures.

2. The **boundary conditions (temperatures)** of simulation should be defined before the details are implemented in energy –simulation process.

Surface thermal resistances

Reference values for surface resistance are taken for ISO 6946 standard and these values are shown in Table 2.

Table 2 - Surface thermal resistances

	R_{si} [m^2KW^{-1}]	R_{se} [m^2KW^{-1}]
Heat flow direction		
Heat flow horizontally (+-30°)	0.13	0.04
Heat flow upwardly	0.10	0.04
Heat flow downwardly	0.17	0.04
Surface temperatures		
Heated rooms	0.25	0.04
Unheated rooms	0.17	0.04
Glazing	0.13	0.04

***Rsi** – internal surface resistance; **Rse** – external surface resistance*

Boundary temperatures

The boundary temperatures according to ISO 4108 standard are represented in Table 3.

Table 3 - Boundary temperatures

Location	Purpose of the calculation	
	Surface temperatures	Heat flow
Internal		
General	$\theta_i = 20$ °C	$\theta_i = 20$ °C
Unheated rooms	$\theta_i = 10$ °C	$\theta_i = 10$ °C
Unheated attics	$\theta_u = -5$ °C	$\theta_u = 0$ °C
External		
Outside air	$\theta_e = -10$ °C	$\theta_e = -10$ °C
Soil	$\theta_G = 10$ °C	$\theta_e = 5$ °C

Heat transfer coefficients

For a calculation of linear thermal transmittance (ψ-value), it is necessary to make the calculation of the heat transfer coefficient (U-value) of the undisturbed building components.

U-value represents heat flow through a specific section detail due to a difference between external and internal temperatures of the environment from both sides of a detail, and it is expressed in $Wm^{-2}K^{-1}$.
The U-values are calculated by using DIN EN ISO 6946 standard.

Material characteristic

Thermal conductivities of materials are assigned according to ÖNORM B 8110-7 standard which is set in parameters in "Materials-Database" in AnTherm software.

Temperature factor

In order to avoid the risk of surface condensation or mold growth for specific building detail, evaluation result should meet critical temperature factor f_{Rsi}. The values of critical temperature factor that should be met for avoiding mold growth are presented in Table 4. In this work, the value of $f_{Rsi} \geq 0.71$ has been taken into account.

Table 4 - Temperature factor (Ward,2006)

Type of building	f_{CRsi}
Dwellings, residential buildings, schools	0.75
Swimming pools (including a dwelling with an indoor pool)	0.90

Output results

AnTherm can provide computational results as textual reports as well as graphical evaluation of the simulated building component. Graphical evaluations are used to visualize simulation results as two or three – dimensional picture renderings. Textual reports can be saved as PDF, XLSX, DOCX or image file for further processing.

AnTherm generates a graphical visualization of the following outcomes through a specific building component (Figure 13):

- Temperature profile of detail
- Heat flow in the detail
- Saturation vapor and vapor flux
- Partial pressure

- Pressure difference
- Relative humidity
- Condensation, mold growth, and corrosion risk

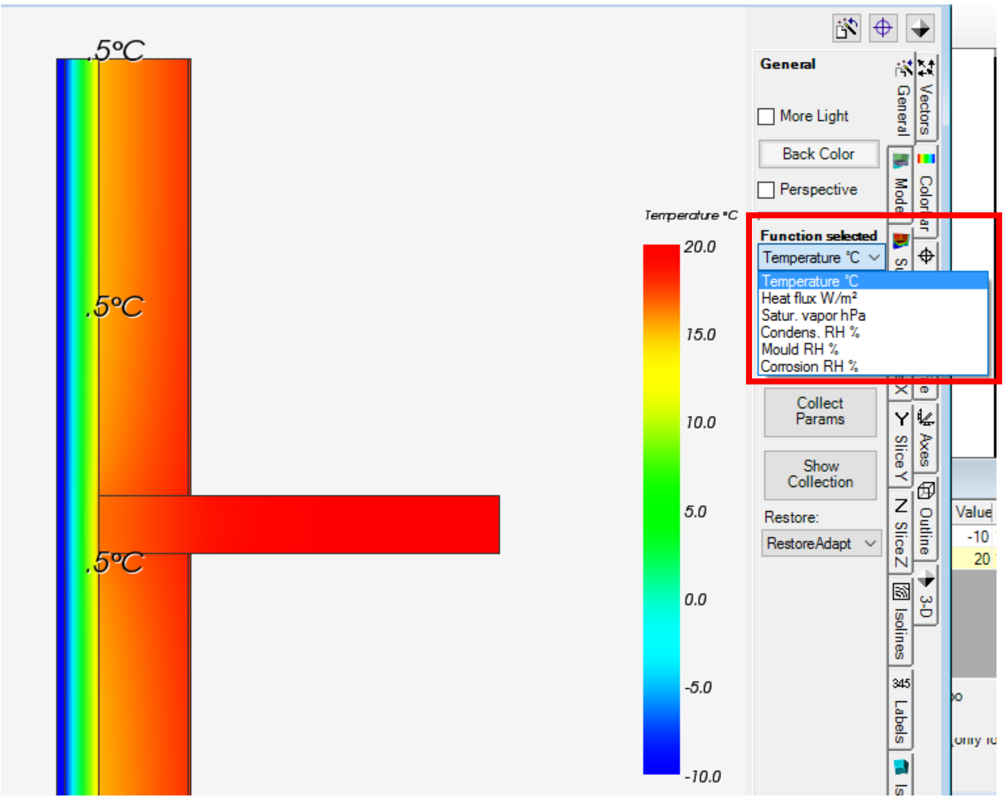


Figure 13 – Visual representation of results in AnTherm

3 METHOD

3.1 General approach

The main focus of this research lies in examination of interfaces as a crucial factor for process integration and efficiency. The goal is to draw a picture of the principles of data exchange between software tools, which involve BIM platforms - Revit and ArchiCAD with energy evaluation tool - AnTherm. Interoperability of the BIM model will be evaluated in terms of efficiency of data exchange and transferability, as well as simplicity of the process.

In a view of challenges of integrating building design with energy oriented performance simulation, they can be classified in two research focus groups. The first focus group considers testing the interoperability between tools in sense of import/export problematic, data model and process standardization. The second focus group involves creating and representing instant/intelligent BIM-based repository of construction details, with a graphical representation of simulation analysis. This thermal-based information can further support design decision making during the early conceptual stages (Figure 14).

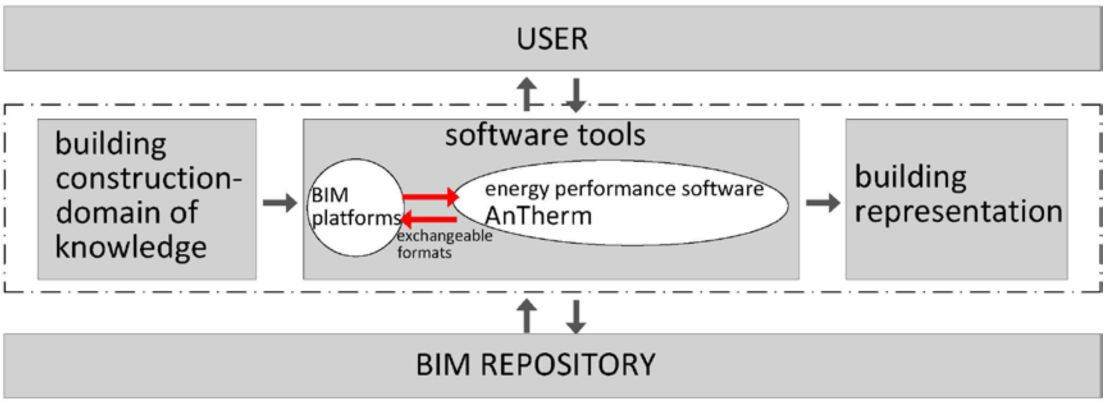


Figure 14 – Method for creating BIM repository

Construction details are modeled in two BIM-based CAD programs, Autodesk Revit 2014 and Graphisoft ArchiCAD 20, and analyzed in energy evaluation tool (AnTherm 8) in order to identify and avoid problematic issues such as thermal bridges and condensation in building construction and renovation. Moreover, the goal of this intelligent knowledge-based repository of building construction details is to rationalize and explain building behavior, as well as offer guidance for the user during the decision-making process. The potential and effectiveness of the BIM process in collaboration with energy performance software are examined and described by outlining the weak points and formulating recommendations for further development. Results are summarized as a sequence of guidelines and recommendations suggesting an optimal workflow for each BIM platform, as well as a creation of a knowledge-based repository of building construction details.

3.2 Research objectives

Generation of BIM component database in Autodesk Revit and Graphisoft ArchiCAD with evaluation in energy performance software (AnTherm) will demonstrate interoperability of those tools and possibilities for further development. The database will be a significant aid for performing complex building performance analysis, in order to ensure an optimized building design.

The major question under consideration is the following:

How effective is BIM platform in collaboration with thermal performance software?

3.3 Software tools used in this work

A building creation process has traditionally been separated into sequential set of activities. In the first stage of design, architects start with general guidelines to create a design, and then model the object in certain software, to verify its compliance with the performance goals. If the proposed design solution does not match with projects' requirements and goals, the architects would have to return to the beginning of the design process. This approach of trials and errors continues until the design, fulfilling desirable requirements and energy performance, is found. Architects' obligation is to expand its scope of responsibility beyond function and aesthetics of proposed design (Attia, 2010; Gerber et al., 2013).

The AEC (architecture, engineering, construction) industry is under the growing pressure in terms of time and cost reductions (time and costs), and keeping up with quality requirements in energy and recourse efficiency field. Software tools are upgrading fast in order to keep up with market requirements. BIM platforms are based on parametric building modeling technology, that use relational database together with a design model to capture and present building information dynamically (Autodesk, 2014). *Autodesk Revit Architecture* and *Graphisoft ArchiCAD* represent widespread BIM platforms used by architects in their practice. These programs are fairly similar in their modeling approach and usability. Architects mainly choose between them over competing software based on personal preferences.

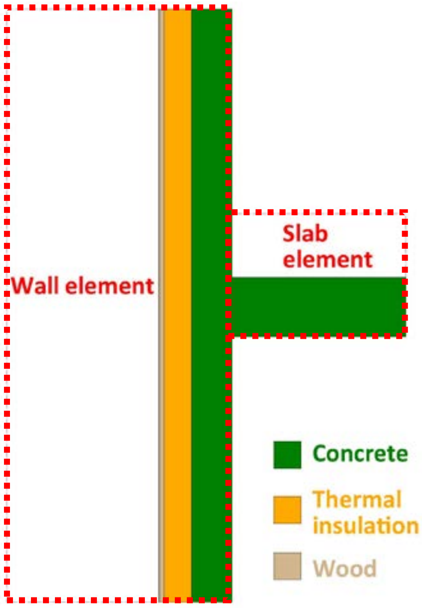
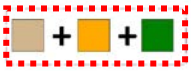
The goal of this thesis is an analysis of BIM potential in collaboration with energy performance tool and outlining the improvements which can be brought into architects' workflow.

Terminology

BIM and BPS tools use different terminology for specifying layers or building elements used in modeling. In order to avoid possible misunderstanding, the terms are classified in the following Table 5.

The term *layer* is used for a single layer of a building element. *Building element* represents composite structure as a whole. Layers combined into composite are referred to as *materials*. The combination of more building elements is referred to as *structures*.

Table 5 - Terminology for building elements and layers

<table>
<tr><th></th><th>Current study</th><th>Revit</th><th>ArchiCAD</th></tr>
<tr><td rowspan="2">
</td><td>
Layers
- in BIM models referring to materials
- in CAD files referring to drawing objects</td><td>Material</td><td>Building material</td></tr>
<tr><td>
Building element
- referring to the physical part of building construction
- may be individual materials /assemblies of materials</td><td>Family</td><td>Construction elements</td></tr>
</table>

Revit uses so-called *families* to describe building elements such as walls, slabs, columns etc. For the same structural elements ArchiCAD software uses the term *construction elements,* or often called - *smart objects*. Geometry in AnTherm entered by rectangular areas is assigned to materials, power sources or spaces. Material Boxes can be specified by applying a specific type of materials in Element Browser.

3.3.1 Revit

Autodesk Revit is software specifically built for BIM, supporting all phases of design and all architectural drawings and schedules that are required for a building project. In this thesis, Revit 14 has been used. This tool is similar to CAD (Computer-Aided Design) programs but is used for creation of not only 2D drawings but also 3D models. All model components are represented as real-world elements such as columns, walls, beams, etc. Once the parametric building model is built, the views (sections and callouts) can be automatically generated from it. All changes in the physical model will automatically update all dependencies. This virtually eliminates the need to re-draw multiple drawings and details when changes occur in the model (Autodesk,2008).

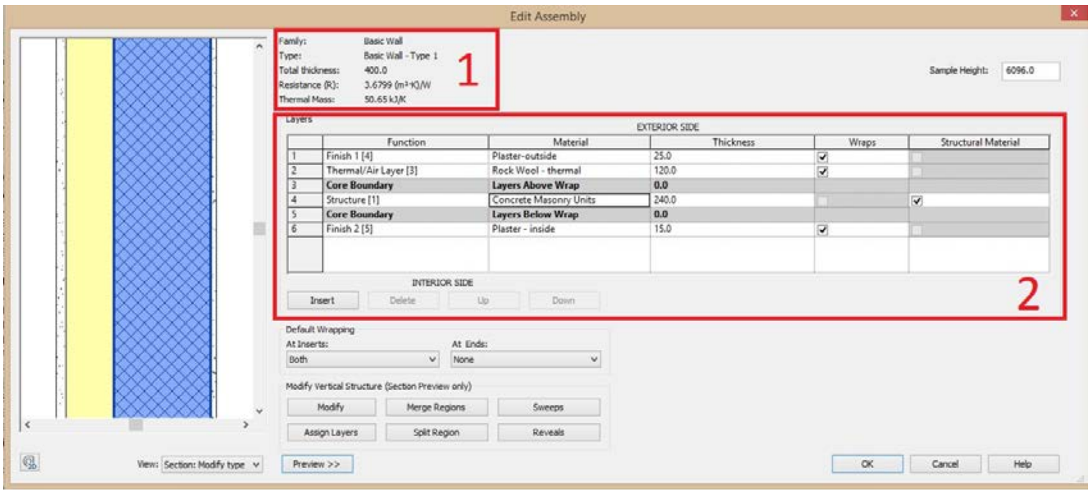
Organization of information in a Revit model

All building elements in Revit are divided into so-called *families*. A *family* represents a group of elements with a common set of properties (family type parameters) and a related graphical representation. When an element is created in a project, that element is firstly assigned by element category, then by family, family type and by instance.

Those categories of objects (Revit families) are divided into two groups:

- System families
- Component families (Loadable and In-place families)

Category of *system families* includes basic building elements such as walls, floors, ceilings, roofs and other elements that would be assembled on a construction site (Figure 15). System families are built inside a project which means that they cannot be loaded from external files or saved in locations external to the project (Autodesk,2014).



1 – General information about selected model component what offers beside of family name and type also information about the thickness of the component as well as resistance (R) and thermal mass.

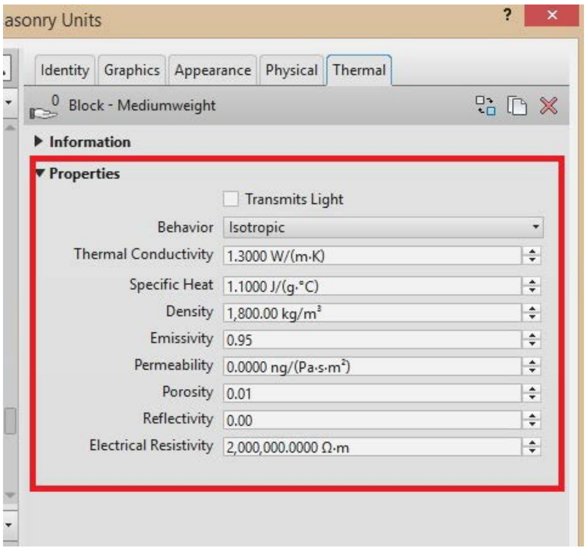
2 – Layers panel with listed all component layers where user can modify material and thickness of selected layer

Figure 15 – System family in Revit

Unlike system families, *component families* are created in external .rfa (Revit family) files and imported or loaded into the project. Component *families* represent those building elements that would usually be purchased, delivered and installed in and around a building (windows, doors, fixtures, casework, furniture and planting).

Materials of construction element layers and their thicknesses can be defined for each layer in the Edit Assembly dialog. Each material in Revit model carries thermal properties information. When preparing a model for energy analysis, the user can define thermal properties for the materials and elements included in the simulation.

Thermal conductivity, specific heat and density properties (thermal properties needed for energy analysis), can be defined on the Thermal tab of the material Browser for selected material (Figure 16).



Thermal properties of material:

1 - Behavior of material: isotropic / orthotropic

2 - Thermal conductivity

3 - Specific heat

4 - Density

5 - Emissivity

6 - Permeability

7 - Porosity

8 - Reflectivity

9 - Electrical resistivity

Figure 16 - Thermal properties of material in Revit

Export possibilities

Revit itself provides a wide spectrum of transfer possibilities to a number of different energy evaluation programs. Exchange of model information between different software is established by using a data exchange facility, generally based on a standardized neutral file format. The possible export format types (Figure 17) would be described in detail in the chapter 3.4.2 about interoperability between tools.

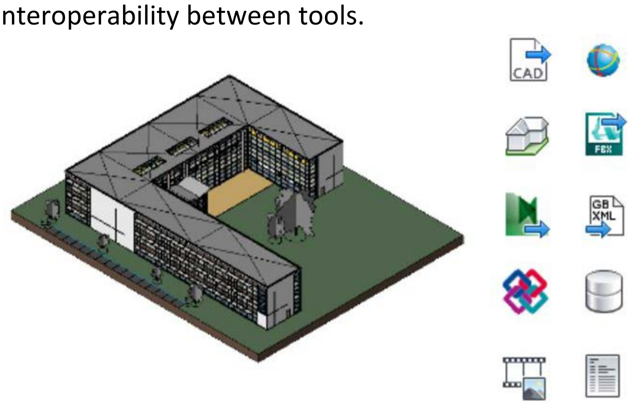


Figure 17 - Export possibilities in Revit (https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2016/ENU/Revit-DocumentPresent/files/GUID-A5E61A08-9635-44D0-93CA-75C15282119B-htm.html)

3.3.2 ArchiCAD

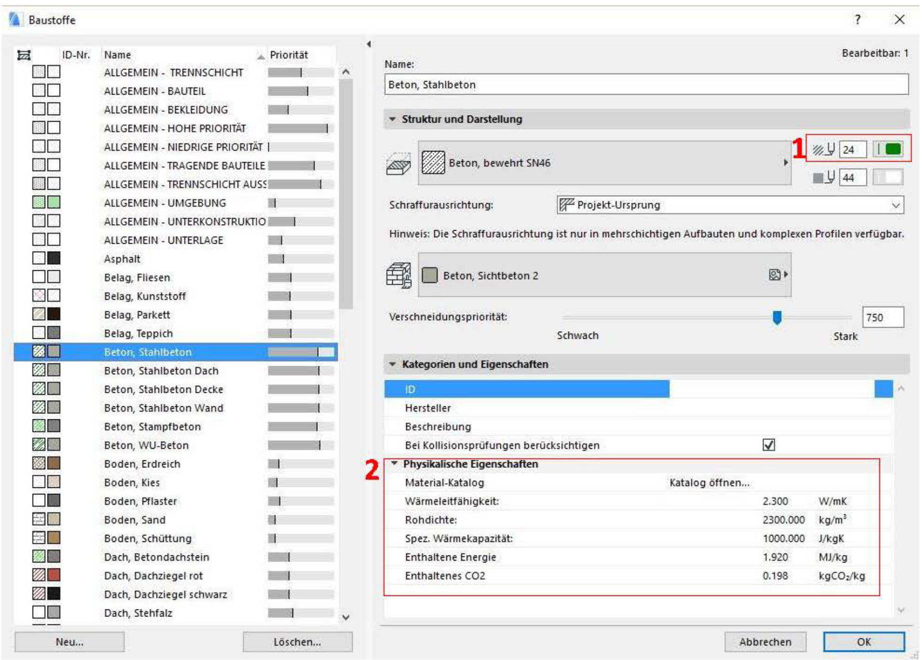
ArchiCAD software has been developed by Hungarian company – Graphisoft. ArchiCAD was a first CAD product available for a personal computer that was able to create both 2D and 3D geometry. Furthermore, this software has been described as the first commercial BIM product for personal computers. The tool uses parametrically defined building objects, and thus supports BIM collaborative work (Graphisoft, ArchiCAD software). In this thesis, the ArchiCAD 20 has been used.

Information organization in an ArchiCAD model

The model in ArchiCAD can be created by using data-enhanced parametric objects, often called "smart objects". This BIM software allows creation of a "virtual building" with virtual structural elements like walls, slabs, roofs, doors, windows and furniture. ArchiCAD application is viewed as one of many satellite applications orbiting a virtual building model rather than being seen as the central repository for the entire model (Graphisoft, Help Center). These modeling elements (objects) are capable of representing the behavior of common building elements.

Defining building material properties

Materials which can be assigned to the model components are located in Material Editor where the user can choose the type of materials from ArchiCAD library or create a new material. All materials in the library carry the thermal properties information (Figure 18).



1 – Color definition

2 – Thermal properties such as Thermal conductivity (λ), Specific heat (c) and Density (ρ)

Figure 18 - Material Editor in ArchiCAD (Concrete material)

Composite structure

The thickness and layer types of building element can be defined in *Multilayer elements Editor*, where the user can choose different materials and their thicknesses (Figure 19).

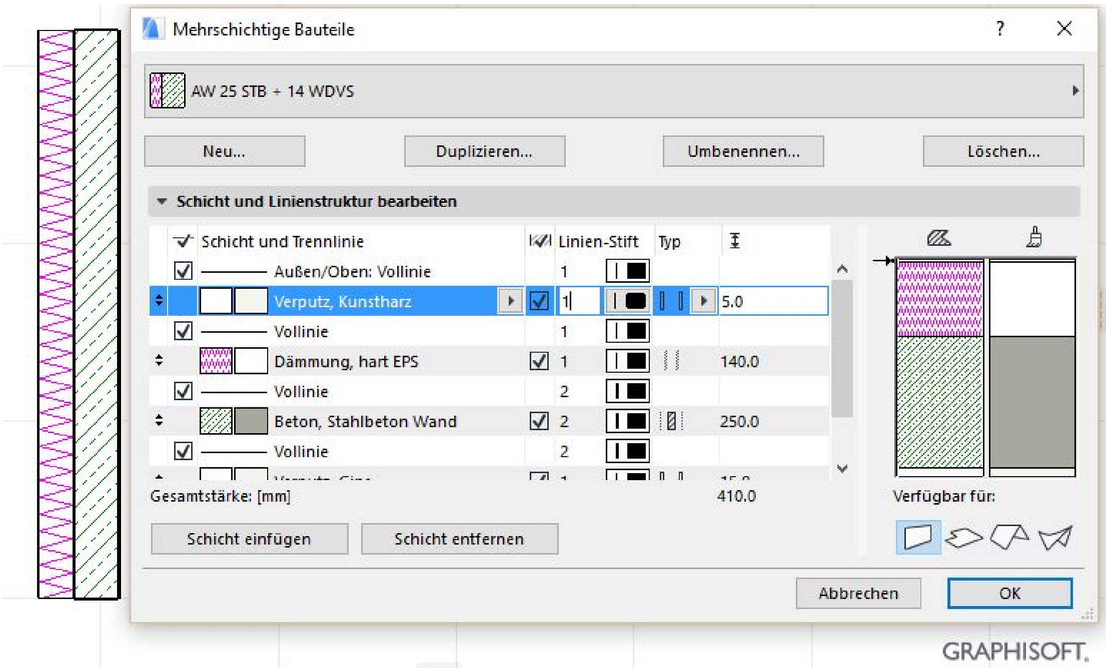


Figure 19 - Defining layers of building elements in ArchiCAD

Data exchange

Graphisoft is one of the founders of the Open BIM concept, which represents a universal approach to the collaborative design, realization, and operation of buildings based on open standards and workflows. Formats that can be imported and exported from ArchiCAD platform are DWG, DXF, IFC and BCF (The BIM Collaboration Format which represents an open file XML format).

3.3.3 AnTherm

AnTherm software represents a reliable tool for heat flow calculation in building construction elements (thermal bridges). This tool provides a thorough and reliable evaluation of thermal performance in accordance with current European standards (EN ISO). AnTherm has been developed by T.Kornicki, *Dienstleistungen in EDV und IT* based in Vienna, Austria. License for AnTherm for purpose of this thesis has been provided by Ms. Kornicki.

AnTherm offers four different types of elements for modeling (AnTherm, Help):

1 - **The Material Box** (Building component) is represented with rectangular "filled" region in space with one homogeneous material. Building materials are defined by name and thermal conductivity [$Wm^{-1}K^{-1}$]. AnTherm has a large database of building materials covered by

actual standards (Figure 20). Users can choose from a wide range of predefined materials, calibrate them or create new.

Coordinate input

Type of the element

Material name

Thermal properties of material:

λ [$Wm^{-1}K^{-1}$] defines the *Thermal Conductivity* of the material

μ [-] defines the *Water vapour diffusion resistance* of the material

ρ [kgm^{-3}] defines the *mass density* of the material

c [$Jkg^{-1}K^{-1}$] defines the *heat capacity* of the material

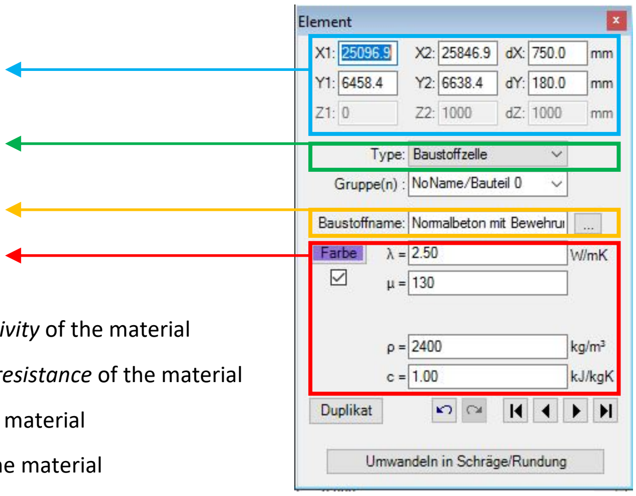


Figure 20 - Element Editor in AnTherm

2 - **The Space Boxes** represent spaces at boundaries of a component and they are showed as air-filled elements which are characterized by surface resistance R_{si} [m^2KW^{-1}]. In this work, all surface resistances are applied according to Table 2 (p.22). It is important for all spaces boxes to be assigned appropriate name. Unique temperature condition must be applied additionally during simulation process for all defined space areas in the model (Table 3 – p.22).

3 - **The Power Source**

4 - **The Empty Boxes** are used to cut areas of the building construction creating adiabatic boundaries.

Modeling approach as well as obtaining results in AnTherm software has been in detail explained in chapter *2.2.3 Software for numerical calculation* in this thesis.

Import possibilities

Files created with other software applications can be imported into the application and the data will be transformed to a valid new project (Figure 21). The model draft can be imported from selectively preprocessed DXF, Waebru, Kobru86 and Heat2/3 files.

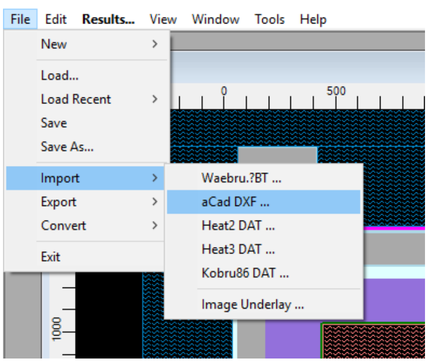


Figure 21 – Import possibilities in AnTherm

3.4 Interoperability between used software tools

Interoperability could be defined as the ability of different software tools and information technology systems to exchange information and to use information that has been exchanged. Software interoperability should ideally be a smooth data exchange between different software tools, eliminating the need for duplicate data generation and minimizing the possibility of human error (Moon et al. 2011).

Interoperable software makes the possibility of streamline transfer of building information to and from modeling software and energy simulation tools. This advantage offers a significant reduction in time, costs and additional efforts in the design process.

Interoperability between BIM-based design and simulation tools can improve the workflow between design documents and analysis applications, where information contained in the models can be used for analysis process as well. Aiming to identify the vital capabilities of BPS tools, Attia (2010) identified Interoperability of Building Modeling (IBM) as one of five vital criteria. IBM would lead to better energy conscious decisions early in the design process as well as to a better collaboration between the design and engineering teams.

3.4.1 Design optimization

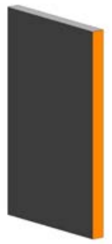
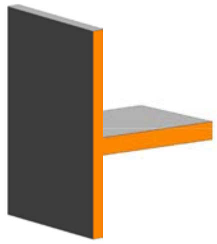
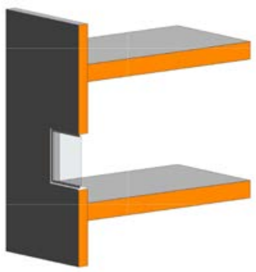
This thesis will explore feasibility and compatibility in software workflow of energy performance tool (AnTherm) with the widespread BIM-platforms, Autodesk Revit and Graphisoft ArchiCAD. Interoperability between those tools will be examined via exchangeable formats, which can be operative in analyzed tools.

Modeling approach strategy

Besides geometry, that is the main aspect of model representation, the information about building material data is necessary for the thermal simulation. Building materials (composites and layers) are specified by architects in BIM model as a part of their professional routine.

The objective of this section is to develop an understanding of import/export capabilities and interoperable file formats. For that purpose, the *phases* for detail creation are established in order to test interoperability between tools. Steps are developed by starting from the simplest model element (box with applied one material) and continuing with increased complexity of the detail model by adding other building construction elements and layers (Table 6).

Table 6 - Model development phases

	Model development phases		**Description**
1		**Simple element**	Wall Wall – represented as one box element with applied concrete material
2		**Several elements**	Wall + Slab Wall element with two applied materials – concrete and rock wool as thermal insulation. Floor element has only concrete material applied .
3		**Several elements with additional objects**	Wall + Slab + Window In this stage of model development an additional object is added - Window (materials: wood for framing and glass)

Model development phases have been carried out in order to outline potential advantages and disadvantages of BIM modeling approach in building design. The import/export possibilities for both tools are first tested on the basic, one component model described as Phase 1.

The correct use of building materials is crucial for creating accurate energy analysis report. Building material combines three types of properties: color (the texture of material), cut-fill (graphical representation of material in 2D drawings) and physical properties (thermal conductivity, density, heat capacity and etc.). For the purpose of this thesis, building materials are applied from existing *Building material database* (Library) in both BIM tools. The idea is to examine the efficiency of extracted data from two BIM platforms.

Layers vs categories

AutoCad as well as ArchiCAD uses layers to manage data. Revit has no layers, instead it uses categories. These two are not equal. Layers are user – defined, meaning that user can create, delete or rename the layer. Categories in Revit are completely built into the software, hence they can't be added, renamed or deleted. In ArchiCAD user is reqired to define the layer, where a newly created element is placed. In Revit, this process is automatically defined. The category in Revit fundamentally defines the nature of an element.

3.4.2 Import and export capabilities

Data exchange process between BIM and energy simulation tools depends on the analysis' objectives and on the type of information/data that is required. BIM model provides relevant information for energy analysis simulation because the defined materials are carrying all necessary thermal properties. The data extracted from a BIM model and enriched with the information on material properties would be preferred for the thermal analysis. "Direct BIM to BEM (Building Energy Model)" technology eliminates the possibility of data loss or distortion that might occur during BIM data conversion or remodeling (Attia, 2010).

Table 7 illustrates data interchange possibilities between BIM platforms and thermal insulation tool (AnTherm).

Table 7 – Interoperability of file formats between BIM and AnTherm

Tool	Application	Input data	Output data	Interoperable File Formats
AUTODESK® REVIT®	BIM platform for modelling	CAD formats* gbXML IFC	CAD formats* gbXML IFC	CAD formats* gbXML IFC
GRAPHISOFT ARCHICAD	BIM platform for modelling	CAD formats* gbXML IFC	CAD formats* gbXML IFC	CAD formats* gbXML IFC
antherm enjoy understanding thermal bridges antherm.eu	Thermal heat/cold bridge simulation software calculates distribution of temperature, heat streams and vapor diffusion streams	XML DXF WAEBRY HEAT 2 HEAT 3 Kobru86	CSV file Image to file 3D scene to file	**DXF**

*CAD formats – DWG, DXF, DGN, ACIS (SAT)

Simple geometry study case is created in each BIM program and then exported with all available options. Each export possibility is analyzed and explained.

There are three commonly used file formats for data exchange that are explored in this chapter – IFC, gbXML and DXF file. The Industry Foundation Class (IFC) and Green Building XML (gbXML) have been developed to facilitate the interoperability of building information between different software platforms. This data exchange formats carry both: semantic and geometric information about building construction model. DXF (Drawing Exchange Format) file brings only geometric information.

IFC file

The most formats describe only the geometrical information of the model. The format which includes both - geometrical and physical representation of the model is IFC file - Industry Foundation Classes developed by International Alliance for Interoperability (IAI). IFC file is an international information exchange standard that allows multidisciplinary cooperation across different software applications. IFC is an object-based file format developed by buildingSMART to facilitate interoperability in the architecture, engineering, and construction (AEC) industry. This file is a neutral and open specification for Building Information Models (BIM) and it can facilitate direct exchange of input and output data with other simulation software (buildingSMART,2014). IFC file is a type of file that only exchanges data between other formats and when it is imported into certain software it gets converted into that software's format (Bahar et al.2013).

Model information can be exported as IFC file from BIM platforms but AnTherm doesn't support this format.

XML file

Extensible Markup Language (XML) is a format that is both - human readable and machine readable which emphasize simplicity, generality, and usability over the Internet. XML file was introduced by World Wide Web Consortium in 1998 as markup language with a definite standard and flexible usability across the Internet. It became widely used for the structure of documents as well as for exchanging information between different systems (gbXML, 2014).

The introduction of BIM modeling is related with the developing of another typology of XML format – the gbXML. Green Building XML (gbXML) schema represents a computer language specifically developed to facilitate the transfer of building properties stored in BIM to analysis software. This format is generally used for data exchange between BIM platforms and energy simulation tools.

The model described as phase 1 in Table 6 has been exported from Revit as a gbXML file. Revit has the gbXML embedded export. All information which has been specified by the user in layer properties is preserved in the gbXML file. The same model has been modeled in AnTherm software and saved as an XML file. The concrete material has been applied to both models. Comparison between gbXML extracted from Revit and XML file extracted from AnTherm on the example of Concrete layer material is showed in Table 8.

Table 8 - XML schema comparisons between Revit and AnTherm

Comparison of XML files on *Concrete* layer material

```
</Material>
<Material id="mat-lay-cons-1-4">
        <Name>Concrete Masonry Units: 240 [mm]</Name>
        <R-value unit="SquareMeterKPerW">0.184615</R-value>
        <Thickness unit="Meters">0.240000</Thickness>
        <Conductivity unit="WPerMeterK">1.300000</Conductivity>
        <Density unit="KgPerCubicM">1800.000000</Density>
        <SpecificHeat unit="JPerKgK">840.000000</SpecificHeat>
</Material>
```

```
<ObservedMaterial>
  <Name>Leichtbeton geschl.(1800)+poröser Zuschlag</Name>
  <Lambda>1.3</Lambda>
  <Mue>70</Mue>  not in the Revit material database!!!
  <Rho>1800</Rho>
  <Ce>1.1</Ce>
  <Appearance>
    <ElementColorForSerialization>-65536</ElementColorForSerialization>
  </Appearance>
</ObservedMaterial>
<ObservedMaterial>
```

Geometrical representation / Thermal properties

The structures of the XML files from both tools are not consistent. However, there is a set of thermal properties which can be found in both schemas. Thermal conductivity (λ), density (ρ) and specific heat (c) are included as material thermal properties in both XML files. Water vapor diffusion resistance factor (μ-mue value) is not included in gbXML format extracted from Revit. Comparing the geometric textual description in both schemas, it can be noted that Revit reports the thickness of every single material layer in mm. AnTherm reports the specific 3D Cartesian coordinates of the observed element.

ArchiCAD platform doesn't offer built-in option for gbXML export, therefore only gbXML file, exported from Revit tool, has been analyzed and compared with XML file extracted from simulation software. In conclusion, XML file format cannot be used for transferring information between BIM platform (Revit) and AnTherm.

DXF file

DXF (Drawing Exchange Format) is a CAD file format, developed by Autodesk in 1982 as a solution for data exchange issues between AutoCAD software and other programs. It consists of regular text files that can be edited with Notepad or other simple ASCII editor.

Before the model has been exported from BIM platforms as DXF file, it should be adjusted to meet specific criteria in order to be successfully imported into AnTherm software.

Exchange requirements for DXF file:

The requirements that should be fulfilled for DXF import in AnTherm (AnTherm,Help):

- The model should be drawn in polylines (other graphical elements such as hatches, lines, dots, blocks, etc. can be skipped in the process of reading the file)
- Only closed polylines which segments are parallel to the axes can be processed (every sloped segment will be dropped in process of reading the file). Those polylines should not intersect each other because this can lead to not reliable results.
- All assigned layers for detail segments (layers, line types, and colors of polylines) will be interpreted specifically by the application. It is very beneficial to use layer numbers, line types and line colors in drawings design in order to create meaningful and helpful groupings.
- Drawing units should be in mm
- DXF file coordinates should be saved by specifying the smallest number of digits

3.4.3 DWG/DXF Export setup

Export methods, file naming conventions, data export options, and layering standards should be considered before exporting a BIM model. Via Translator settings dialog box user can define how elements in BIM platforms will be interpreted when exported as DXF/DWG files. Because of the difference between BIM modeling platforms and CAD tools, it is essential to use conversion rules for correct conversion of elements and parameters. These rules are stored in a so-called Translator file available in Revit as well as in ArchiCAD tool.

Revit

In the Export Layers dialog box, categories, and subcategories of Autodesk Revit host elements are mapped to a layer name and color number for use in a DWG or DXF file. Mapping is defined by using settings specified in special text files in the Revit\Data directory. By analysing the example of Wall category, which is showed in Figure 22, we can notice that subcategories are classified by a function that they have in a host element (in our case Wall family element). Sub-categories are recognized as finish, membrane or structure layer but without material definition. That means that export translator recognizes function of material in building element but not the specific type of material (Figure 23). The same material applied to two different positions in building element will be recognized as two different subcategories. The software supplies files for the AIA, BS1192, ISO 13567, and CP 83 standards. The user can select from these or create custom standards.

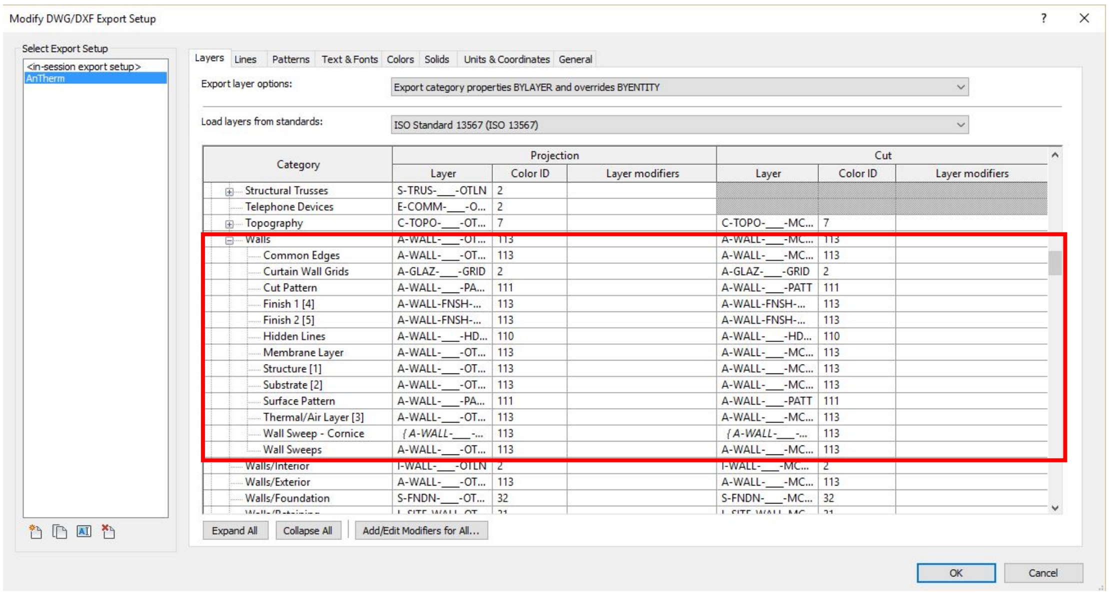


Figure 22 - Export Setup dialog box in Revit – example: Wall family

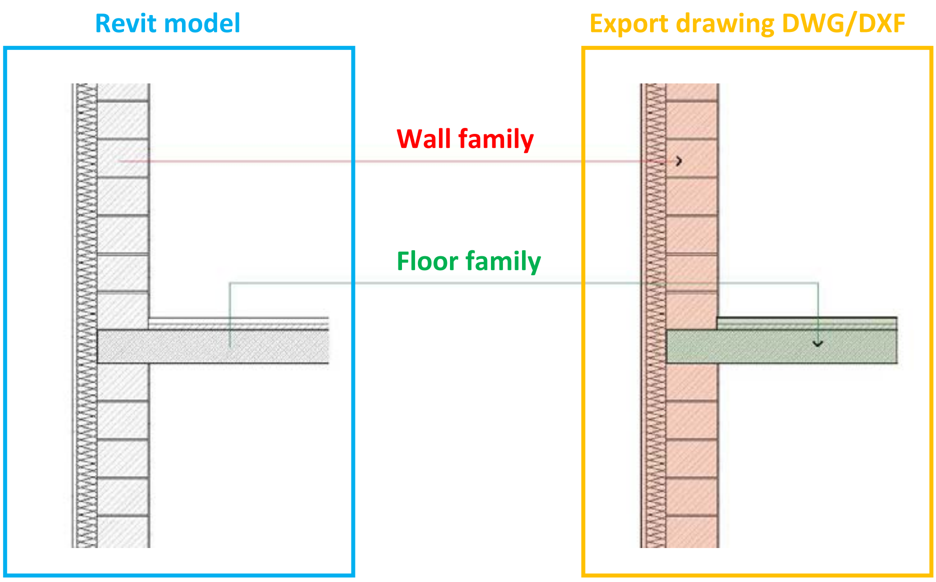


Figure 23 - Revit export translation principle

ArchiCAD

The default Pen-Based Layer Names table in ArchiCAD is taken as a template for color translation setting (Table 9). Names of layers (materials) are taken from Material Database (ÖNORM B 8110-7:20) in AnTherm software:

Table 9 – Color translation method between ArchiCAD and AnTherm

	Color ID - RGB	Pen Number ArchiCAD	Layer name ArchiCAD	Layer name AnTherm
	255.0.0	21	Mauerwerk gedämmt	Mauerziegel gelocht (Lochanteil ≤ 25 %) + Normalmauermörtel
	196.0.0	22	Mauerwerk ungedämmt	Leichtbetone mit Blähton oder Ziegelsplitt als Leichtgesteinskörnung
	0.255.0	23	unbewehrter Beton	Normalbeton ohne Bewehrung
	0.128.0	24	bewehrter Beton	Normalbeton mit Bewehrung 2 %
	161.205.161	25	Stein	Kalkstein
	0.0.255	26	Stahl	Stahl
	210.180.140	27	Holz	Holz
	184.86.0	28	Holzwerkstoffe	Sperrholz und Furnierschichtholz
	255.0.255	29	Dämmstoff hart	Dämmstoff aus gebundenem EPS-(RECYCLING) Granulat Typ BEPS-T 1000a
	255.170.0	30	Dämmstoff weich	Mineralische Wärmedämmplatte
	255.170.205	31	Kunststoff	Unterlage (Gummi, Kunststoff)
	0.0.0	32	Dichtstoff	EPDM (Ethylenpropylendien monomer)
	0.255.255	33	Glas	Glas
	255.100.0	34	Gipskartonplatten, Gips	Gipskartonplatte
	170.100.70	35	Erdmaterial	9.3 Erdstoffe (kiesig, locker) 2000
	205.173.0	36	Rollierung, Schüttung	Blähton-Trockenschüttung
	127.127.127	37	Sand, Kies	Sand und Kies
	24.153.231	38	Putz	Normalputzmörtel GP gemäß ÖNORM EN 998-1:2010, Abschnitt 3.7

In ArchiCAD Translator Export Setup, it is set that particular colors are translated into particular layers in DWG/DXF file. Colours and names of layers are defined according to Table 9. The translator is set to create layers according to *Layer or Declared Pen Number*. This option offers the possibility for the creation of custom layers according to any entries in the Pen-Based Layer Names table. All remaining elements will be created based on the existing ArchiCAD layers. Pen-based Layer Names allow the creation of the exact DWG/DXF layer by the specification of the ArchiCAD pen number (Figure 24). This strategy ensures that the model information stored in BIM model elements is exported to the proper CAD layer.

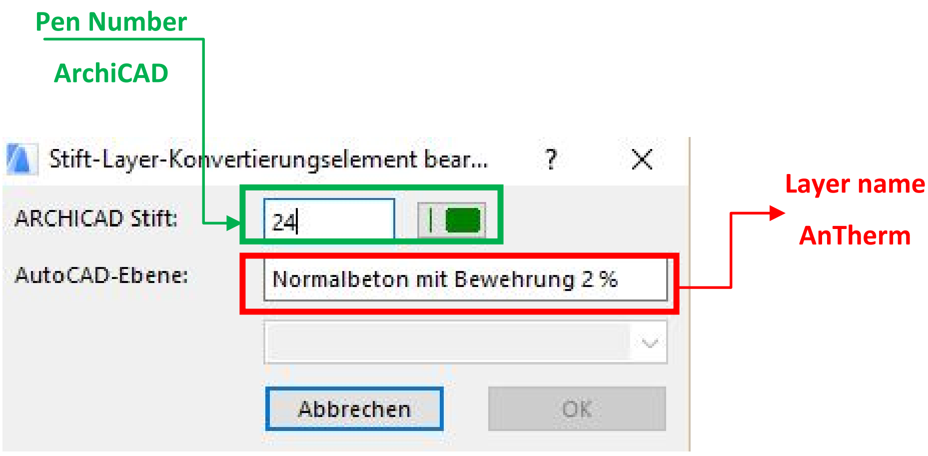


Figure 24 - Pen-based Layer Names conversion in ArchiCAD

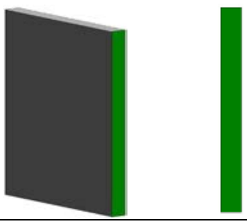
3.4.4 DXF file comparison

The quality of extracted DXF files from Revit and ArchiCAD have been examined and compared. The steps are set according to modeling approach strategy explained in Table 6. The examination process starts with the most simplified object element, defined as phase 1, and continues with more complex building models. The translator settings for both BIM platforms are set according to the principles explained in the previous chapter. The results will be compared and solutions for achieving the operable DXF file (for AnTherm import) from BIM tools will be offered.

Phase 1: Simple surface - Basic wall

One component model is created as building element (the same in both BIM platforms), instantly generated as a 3D model. The section has been taken in order to get 2D information for DXF export. The applied material is *Concrete* with defined color RGB 0.128.0 (Table 9 - p. 43). Comparative analysis of extracted DXF file from Revit and ArciCAD is showed in Table 10.

Table 10 - Phase 1 DXF comparison

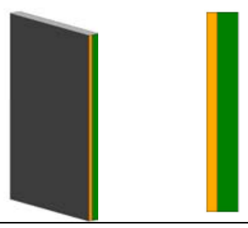
	Revit	ArchiCAD
3D 2D 	 - lines and hatch are on the same layer (in this case: wall)	 - lines and hatch are on the defined layer -color carries a name of the material (defined in Export Setup)

Legend: **Concrete**

Organization of elements in Revit is logical and very consistent. Categories such as walls, beams, columns etc. are precisely defined as realistic building elements. However, this precise definition of category types in DXF file is translated in that way that all drawing elements such as lines and hatches are on the same layer. For example, the wall element modeled in Revit with the concrete material is translated to 2D drawing with lines and hatch placed on the same wall layer. On the other hand, DXF file extracted from ArciCAD software carries information about material name applied to a building element. Coloured hatch is placed on the layer with the previously defined material name in Export Setup, while lines are placed to another layer (defined in layer setup in ArchiCAD).

On the first phase development model (Table 11) additional material (thermal layer) is assigned to the wall element. In DXF file exported from Revit, the color/material definition is not present. Thermal and construction material are placed on the same layer – wall.

Table 11 - Phase 1(with additional thermal insulation layer) DXF comparison

	Revit	ArchiCAD
3D 2D 	 - no different color and material definition of various layers in one building element/object - lines and hatches are on the same layer (in this case: wall)	 - lines and hatches are on the defined layer -colors carry the names of the materials (defined in Export Setup)

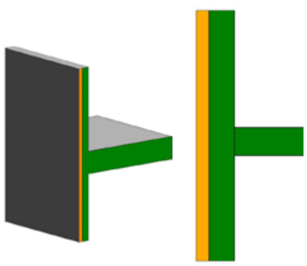
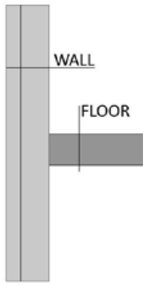
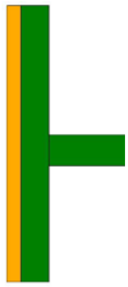
Legend: **Concrete, Thermal insulation**

DXF file exported from ArchiCAD shows more complexity because it carries specifically defined names of material types, which is important for further thermal analysis. Defined colors are caring the defined names of materials (in this case concrete and thermal insulation layer).

Phase 2 - Joint: Connection between wall and slab element

In this phase, the junction between two building elements is tested (Table 12). The wall and slab are created in both BIM platforms. Concrete material is assigned to the slab. The same concrete material is assigned to the wall accompanied with the thermal insulation layer. DXF file from Revit recognizes used building construction elements in the model - wall and floor, but without materials.

Table 12 - Phase 2 DXF comparison

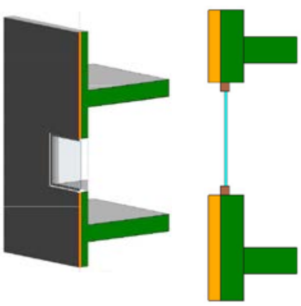
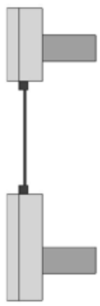
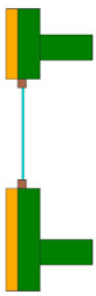
3D 2D	Revit	ArchiCAD
	 - no different color and material definition of various layers in one building element/object - lines and hatches are on two layers (wall and floor)	 - lines and hatches are on the defined layer -colors carry the names of the materials (defined in Export Setup)

Legend: **Concrete, Thermal insulation**

Phase 3 - Opening: Window

The phase 3 examined how exported file carries information when an opening (window) is added (Table 13). The window object is inserted into the wall element.

Table 13 - Phase 3 DXF comparison

3D 2D	Revit	ArchiCAD
	 - no different color and material definition of various layers in one building element/object - lines and hatches are on the three layers (wall, floor, and window)	 - lines and hatches are on the defined layers -colors carry the names of the materials (defined in Export Setup)

Legend: **Concrete, Thermal insulation, Glass, Wood**

Revit DXF file recognizes building construction elements as separated layers, in this example: wall, floor, and window. However, although those elements have the same material (concrete in wall and floor element), this file grouped all drawing elements such as lines and hatches in one layer - according to the element type. The window contains of a wooden frame and glass as main materials, but in DXF file all these different hatches and lines are placed on the one - window layer. The same model has been created in ArchiCAD and DXF file extracted from this model carries material names defined in Table. Color ID carries information about the material name, hence green is concrete; orange is thermal insulation, while window component consists of brown and blue (wooden frame and glass).

Remarks

Revit translates different layers, which are part of the same building element, into the same layer in AutoCAD according to the building element type. ArchiCAD offers better control over exported building elements and layers into DXF file. Colour definition of each layer that is part of a building element, offers the possibility of translating layer's geometrical information with the corresponding material name.

Despite thorough preparation in DXF Export Setup, the direct import of DXF file that was extracted from both BIM platforms into AnTherm software is not possible (Figure 25).

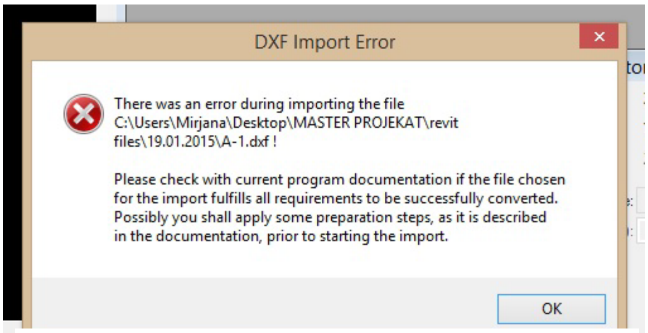


Figure 25 – DXF import error in AnTherm

The reason lies in the complexity of DXF file extracted from BIM platforms. Such DXF file is not able to recognize which lines should be connected and transferred to polylines because the section is taken from the parametric 3D model and cut from building elements (Figure 26). The DXF file exported from Revit and ArchiCAD contains a lot of drawing elements that are not readable in AnTherm software.

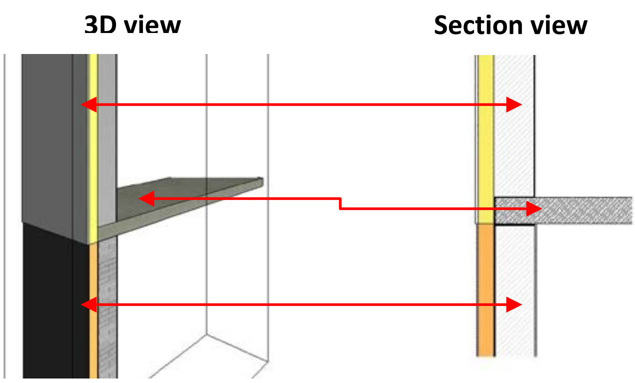


Figure 26 - Principle of modeling in BIM tools

3.4.5 Solutions for design workflow

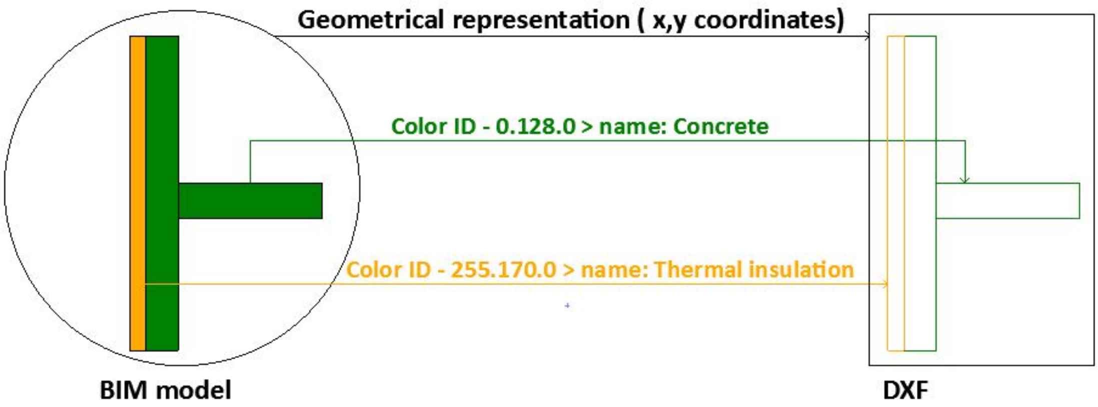


Figure 27 - Schematic representation of data exchange between tools via DXF file

Figure 27 illustrates the process of data exchange between tools via DXF file. This specifically prepared import file in AnTherm should contain closed polylines with material name definition. Colour ID carries the material name information. The name of layer material should correspond to the name of material from Material Database in AnTherm. This connectivity should provide the automatic recognition of material type where the thermal properties of material–should be instantly added to it. The idea is to make an intelligent system where the manual adaptation of the model should be minimized and, if possible, avoided.

As it is previously mentioned, one of the main requirements for DXF import in AnTherm software is that model should be drawn in polylines. Only closed polylines can be successfully readable in AnTherm. Revit tool cannot create polylines while ArchiCAD offers this possibility.

Revit

In order to provide a functional file that can be successfully imported and operated in AnTherm tool the intermediate step has been added. The required intermediate step is carried out in AutoCAD software. AutoCAD is since 1982 present on the market and today it represents one of the most integrated software in day-to-day activities of the design process. This program has been developed and marketed by Autodesk. AutoCAD software has been used to additionally prepare exported DXF file from Revit in order to satisfy DXF import requirements for energy simulation program. This tool has been chosen because it allows full compatibility with Revit platform. Proposed method ensures successful operation between Revit and AnTherm tool because DXF file adapted in AutoCAD is perfectly readable in AnTherm. This manual adaptation of DXF file, in one more program in between, is interrupting the linear workflow between Revit and AnTherm, hence the main idea of BIM modeling - the automatic flow of data is not fully satisfied.

ArchiCAD

During the model creation process in ArchiCAD, building materials are assigned to the structure of construction elements. Each material has been defined with specific color ID, in order to match with DXF Export setup preferences. Polylines have been created additionally, in ArciCAD software on 2D section, where original BIM 3D model has been used as a reference, with specific color definition according to layer materials. Creation of polylines can be done fast and considerably easy inside ArchiCAD. After additional correction, the construction detail, now represented as 2D-polyline drawing, has been exported as DXF file. No intermediate steps in extra software are required in this process. DXF file exported from ArchiCAD is fully readable in AnTherm software.

Workflow suggestions

In order to obtain functional DXF file that can be read in AnTherm software, the next steps should be followed for both BIM platforms (Figure 28).

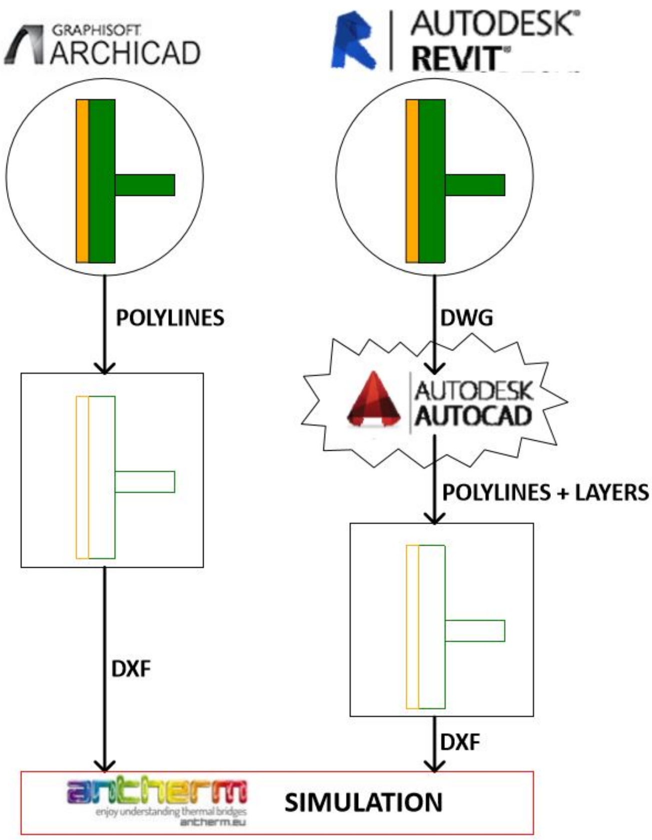


Figure 28 – Suggestion of workflow between BIM platforms and AnTherm

4 PERFORMANCE STUDY

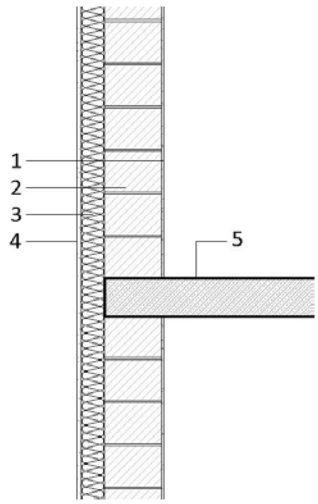
The potential and effectiveness of the BIM process in collaboration with energy performance software are examined on a Case Study model. Interoperability between BIM platforms (Revit and ArchiCAD) and energy tool is tested and export/import problematic is addressed.

4.1 Case Study – BIM in the detail creation practice

The external wall detail has been chosen as a Case Study example (Table 14).

Table 14 - Material properties of basic wall detail

External wall – Case Study



BIM model

Layers

	Name	d [mm]	λ [$Wm^{-1}K^{-1}$]	μ [-]	ρ [kgm^{-3}]	c [$Jkg^{-1}K^{-1}$]
1	Plaster	10	0.49	20	1300	1
2	Concrete brick	300	1		1200	1.13
3	Mineral wool	120	0.041	2	93	1
4	Plaster	25	1.05	35	1800	1
5	Concrete	200	2.3	130	2300	1

Table 15 describes which materials are assigned from AnTherm material database library (ÖNORM B 8110-7). This classification is important in order to define naming of the layers during the DXF translation of BIM model.

Table 15 – Matching material names with AnTherm material database

Name of material	AnTherm - ÖNORM B 8110-7
Plaster	Normalputzmörtel GP gemäß ÖNORM EN 998-1:2010, Abschnitt 3.7
Concrete brick	Betonhohlsteine
Mineral wool	Mineralische Wärmedämmplatte
Plaster	Normalputzmörtel GP gemäß ÖNORM EN 998-1:2010, Abschnitt 3.7
Concrete	Normalbeton mit Bewehrung 2 %

4.1.1 Case Study - Revit

Setting up the model in Revit

In the first step - whole initial geometry with all parameters, layers and materials is defined (provided) manually by the user. In this phase, all materials are selected from the existing material database in Revit. After the parametric model has been created in 3D, the section has been defined. The callout of the section is selected as reference data for drawing export (Figure 29).

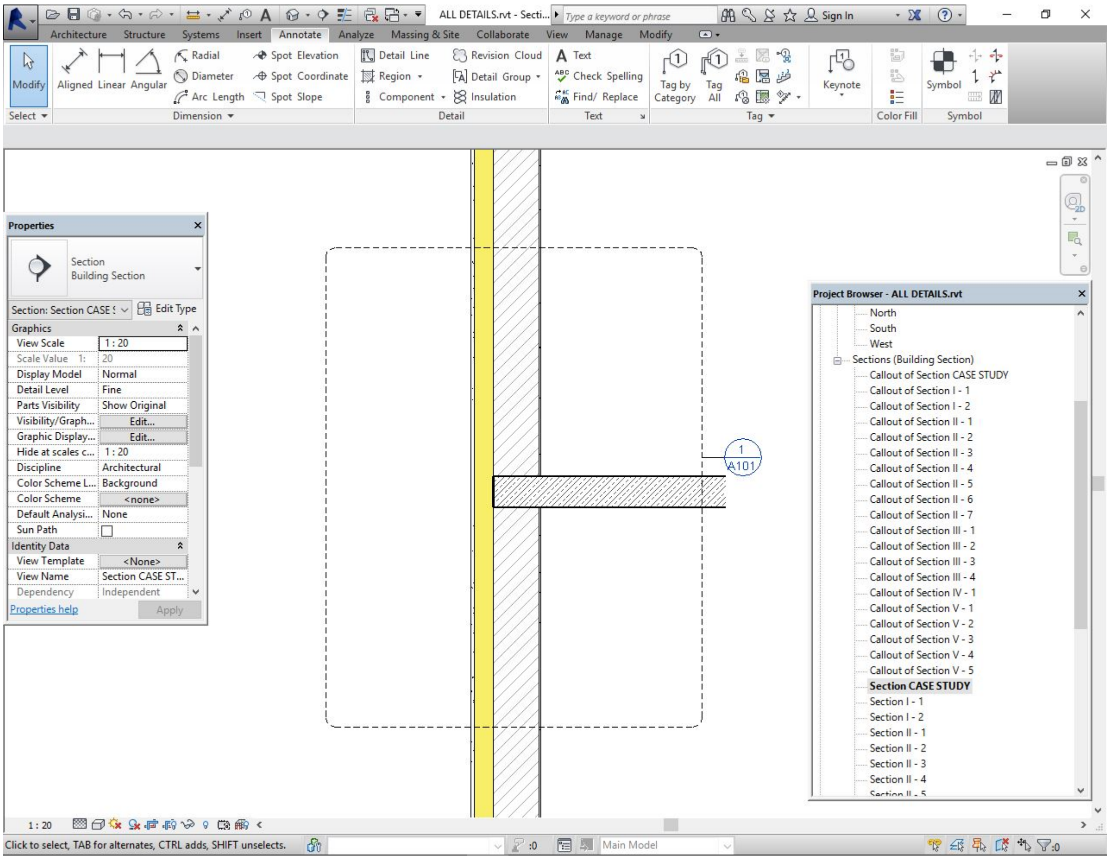


Figure 29 - Modeling in Revit

Exporting from Revit software

When preparing to export a Revit model, export methods should be considered as well as file naming conventions, data export options, and layering standards. Currently selected view in the program is exported as DWG or DXF (in our case Callout of selected detail). Export setup dialog box offers a modification of exporting data such as all layer definitions, lines, pattern, colors, units etc. In our case the layer names in Revit model are changed in order to correspond to the layer names described in Table 15; units are set to millimeter; export data as polylines has been selected (Figure 30).

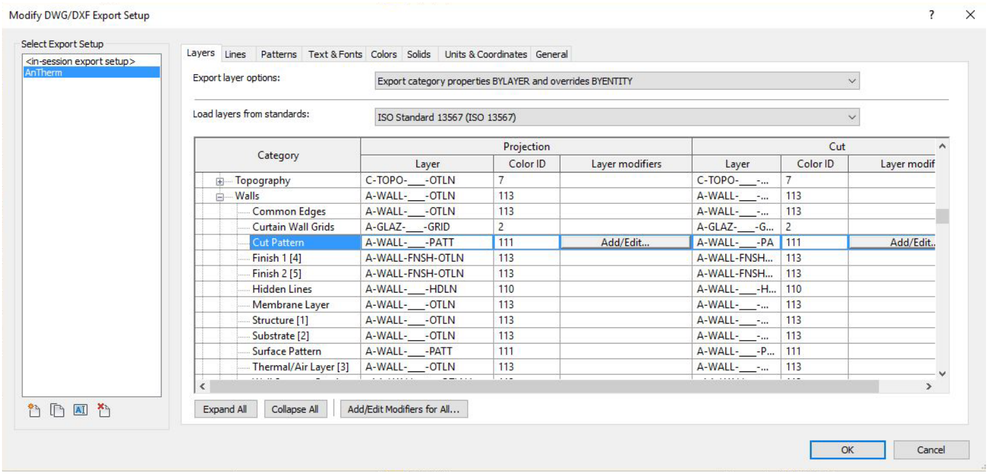


Figure 30 - Export setup - Revit

Adjusting the model in AutoCAD

DXF file directly exported from Revit platform contains lines and hatches which cannot be read in simulation software. In Export setup there is no possibility to adjust an exported file in the way that will answer to AnTherm import requirements, therefore the manual adaptation in AutoCAD is necessary. Revit doesn't work with layers and everything created in this tool is a part of building construction elements offered by the platform. Figure 31 shows adaptation steps of DXF file in AutoCAD through deleting lines and converting hatches into polylines.

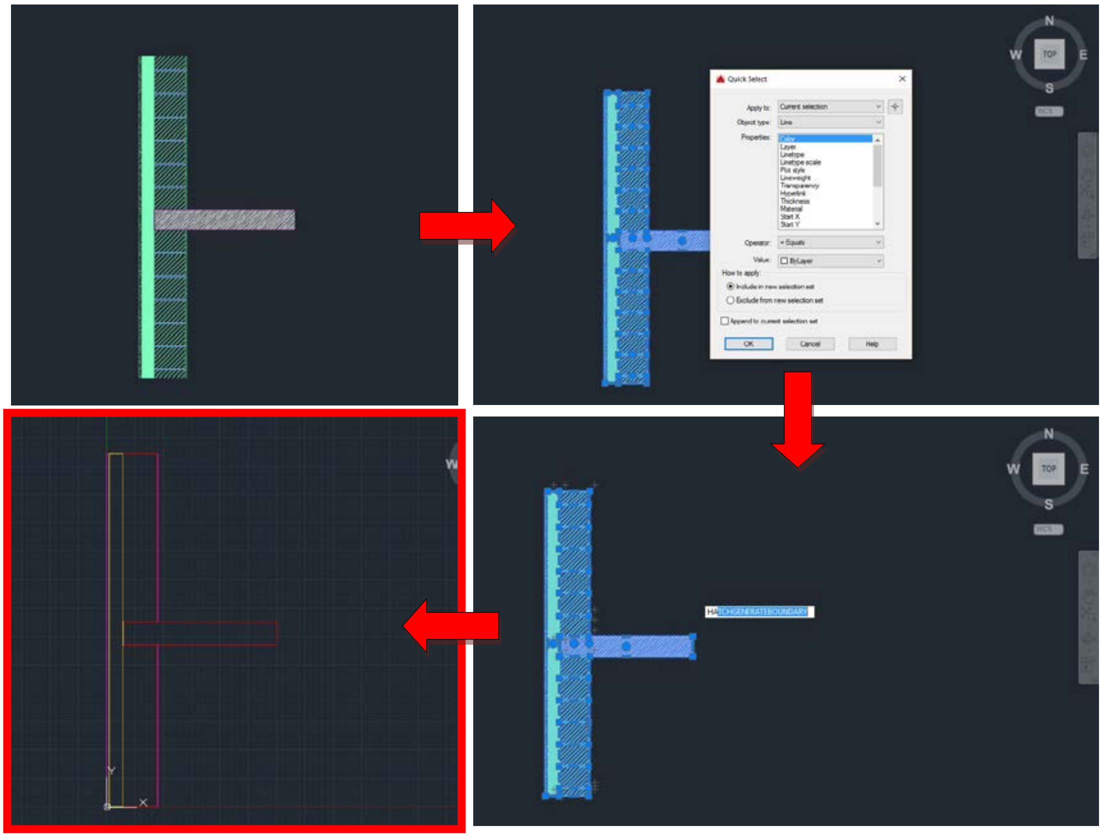


Figure 31 - Adjusting DXF file in AutoCAD

In order to simplify and accelerate the process of adaptation of DXF file in AutoCAD, it is recommended to have a template file with predefined layers according to material names. After manual adaption of the drawing, the prepared DXF file is ready to be imported into AnTherm and simulated.

4.1.2 Case Study - ArchiCAD

During the first modeling step the building materials are defined by choosing specific pen number what defines the specific color (in this thesis according to the Table 9). Detail component has been created by using building objects: wall and slab. The thicknesses and materials of layers have been defined and building section has been set in order to obtain 2D drawing. Polylines are drawn over the section with colors (with specific pen number) that correspond to the building layers, while using the original BIM model as a reference (Figure 32).

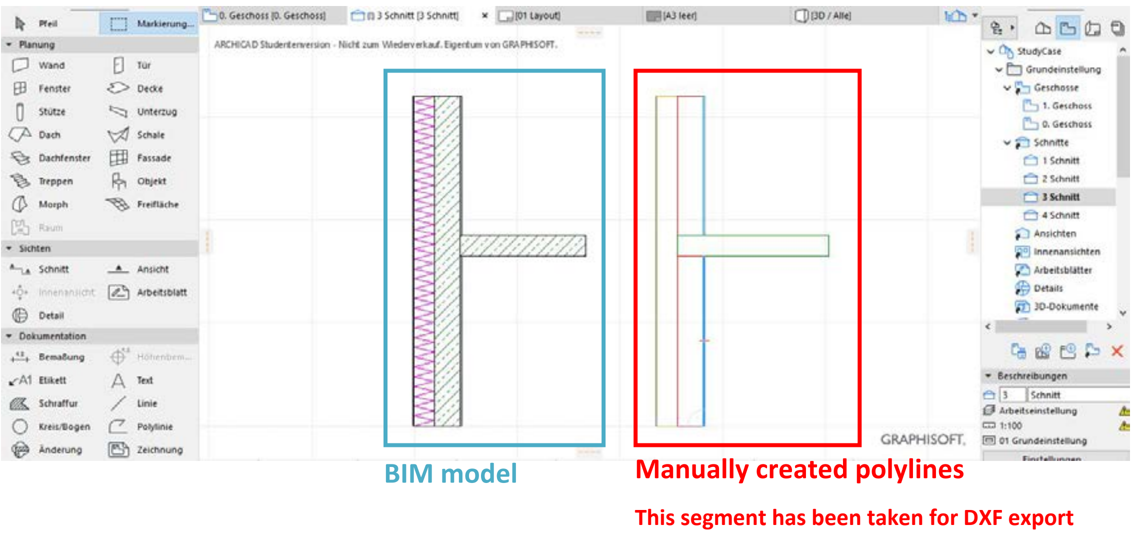


Figure 32 - ArchiCAD model preparation

Previously prepared mode for DWG/DXF export is set in ArchiCAD Translator Export Setup. In this mode, DXF will be created according to the set of rules that are explained in Chapter 3.4.3 of this work. Defined pen number of each polyline in ArchiCad is translated to the corresponding CAD layer (Figure 33). Besides geometrical export this option enables also naming export of created detail element.

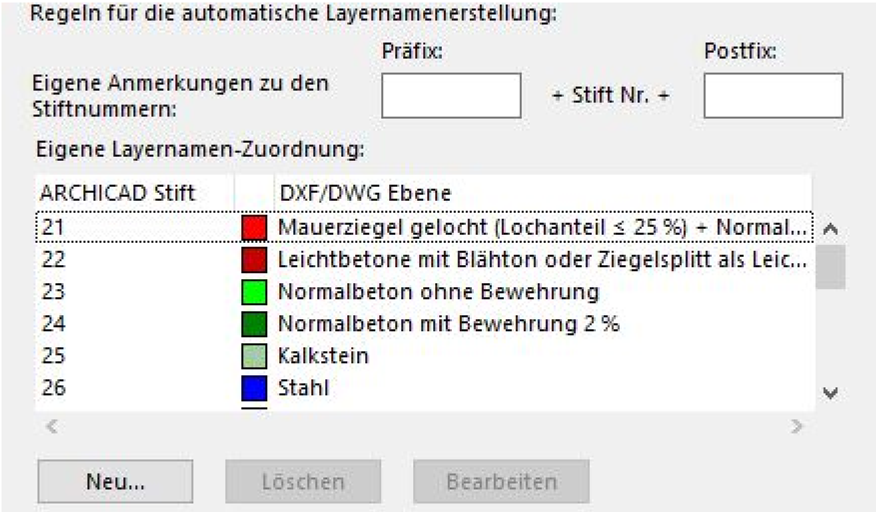


Figure 33 - ArchiCAD Translator Export Setup

Simulation of Study Case in AnTherm

As the first step in energy simulation software, the DXF file has been imported. Closed polylines are translated into Material Boxes in AnTherm. Each Material Box carries the specific name according to the material that it represents (Figure 34).

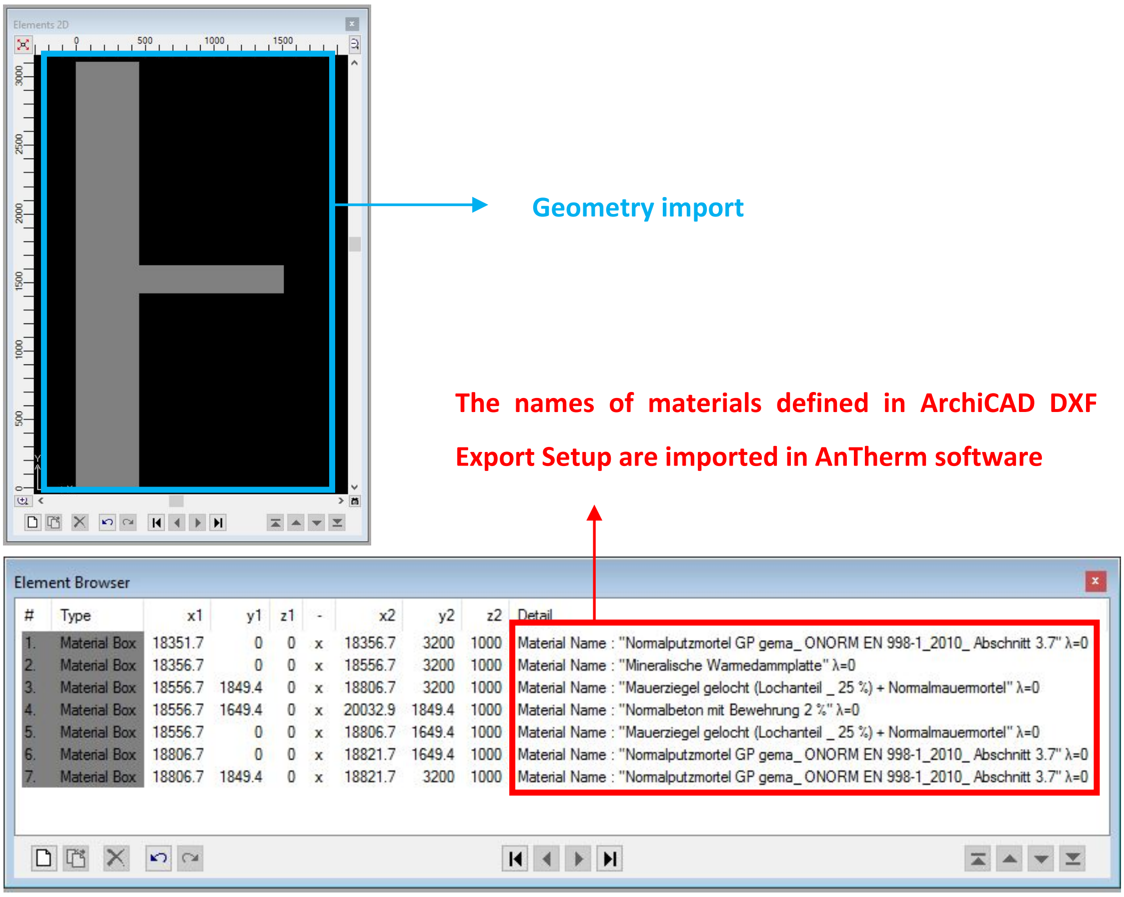


Figure 34 - DXF import in AnTherm

Post processing of imported data

Imported DXF file provides only geometry data and material names, therefore the data of the imported model must be post-processed, prior to further thermal calculation in the AnTherm software. DXF file carries only material names without thermal properties, hence the manual assignment of materials must be done. The materials are assigned from materials database in AnTherm (source: ÖNORM B 8110-7).

The space boxes (internal and external) that are connected to the model must be created manually. Boundary conditions must be assigned to the created space boxes. Surface resistances, as well as boundary temperatures, are assigned according to standard model preparation described in chapters 2.2.3 and 2.2.4. After the boundary conditions are defined with exterior temperature θ_e = -10°C and interior temperature θ_i = 20°C, the first step of analysis can be done. After all fulfilled criteria the model has been simulated.

Presentation of Results

Graphical representation of simulated detail includes *Temperature profile* image as well as *Heat flux* and *Pressure difference* images. This visual representation clearly points out processes that occur in building construction detail. AnTherm provides a series of different outputs for the thermal evaluation. Important values that are taken into account in this thesis are thermal coupling coefficient (L^{2D}), the linear thermal transmittance (ψ), low interior surface (θ_{min}) and temperature factor (f_{Rsi}). Results of these outputs are listed below in Table 16.

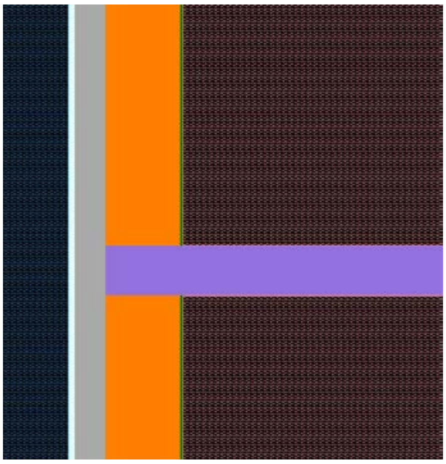
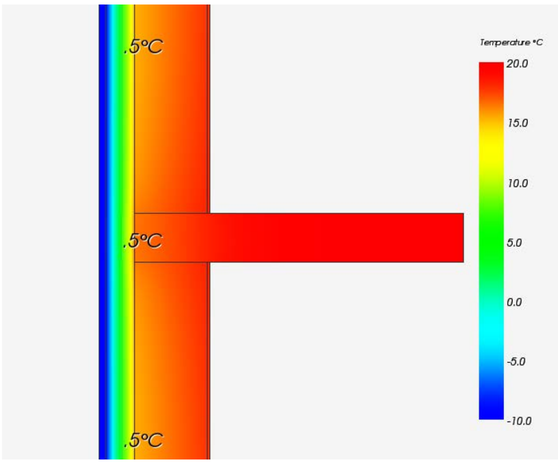
Analysis of workflow

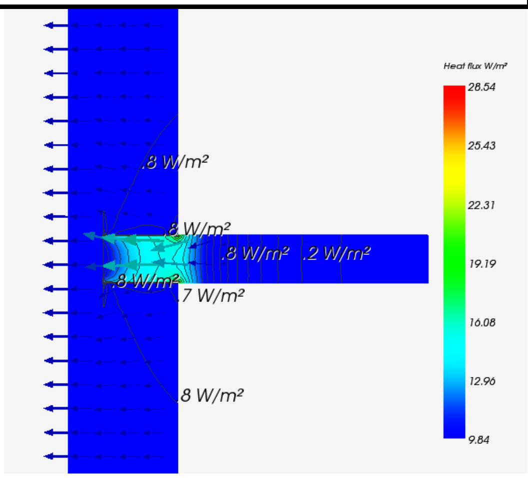
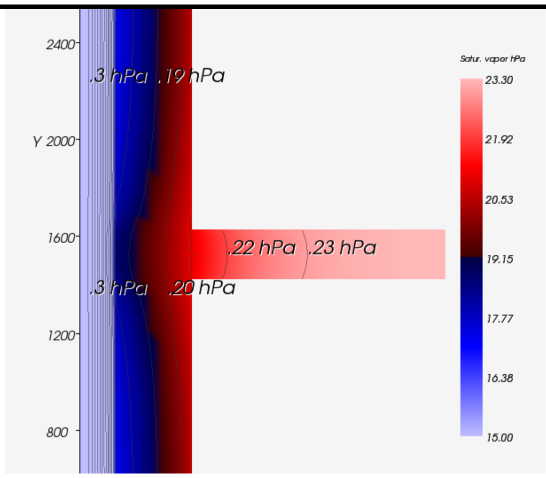
For the current Case Model Study, the DXF file has shown sufficiently high efficiency in successfully extracting and storing building geometry data. Besides geometry information, the names of layers - materials are also imported into energy simulation tool. Despite the fact that the names of imported material boxes from DXF file and material database (ÖNORM B 8110-7) in AnTherm are identical, the software cannot recognize them. Thermal properties are not automatically assigned to the material, therefore, the manual adaptation of model is necessary.

Following the principle of extracting and translating building geometry information via DXF file described in Chapter 3.4.3, we can conclude that exported DXF files from both BIM tools (Revit - AutoCAD and ArchiCAD) have shown the same level of quality during import into AnTherm. More effort has been done in the process of extracting data from Revit platform because one additional softer had to be included.

Table 16 - Results of Case Study

Study Case – Basic wall

Simulation model	**Temperature profile**
	

Heat flux	**Pressure difference**
	

Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
0.909912	0.006812	17.90	0.93

4.2 Modification of the layers

The case study model, which was described in previous chapter, has been modified in order to analyze thermal performance of different materials and material combinations. Four different scenarios that were simulated are presented in Table 17.

Table 17 - Modification scenarios

Scenario 1	External wall without thermal insulation
Scenario 2	External wall with facade bricks
Scenario 3	External wall with concrete construction
Scenario 4	External wall with ventilation layer

In the first place, the BIM model was modified according to the described scenarios. In this process, the same materials and boundary conditions were assigned to the model as in the Case study example. In Revit software, all modifications were done by changing layer thicknesses and type of materials in element editor in element family. The manually adaptation was done in AutoCAD software in order to extract functional DXF file. In ArchiCAD tool, the process of obtaining defined scenarios was less time consuming because all the modifications were done by changing geometry and colors of polylines in the section drawing. After updating the 2D drawings in ArchiCAD, DXF file was exported and simulated in AnTherm. The same boundary conditions and surface thermal resistance are applied to all four modifications (Figure 35).

Boundary conditions

R_{se} (heat flow) = 0.04m^{2}KW^{-1}; R_{se} (temperature) = 0.04m^{2}KW^{-1} & θ_e= -10 °C

R_{si} (heat flow) = 0.13m^{2}KW^{-1}; R_{si} (temperature) = 0.25m^{2}KW^{-1} & θ_i= 20 °C

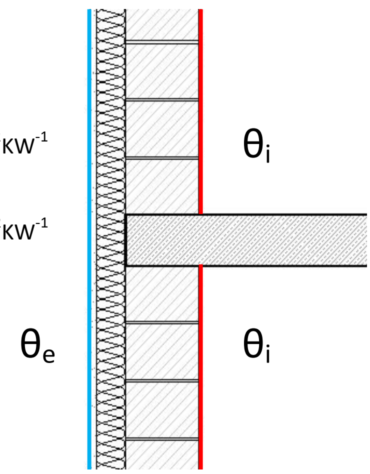


Figure 35 - Boundary conditions of wall-slab junction detail

Scenario 1

In the first modification, the thermal layer is omitted. Facade layer (plaster) is applied directly on the concrete bricks. This modification is done in Revit software by deleting thermal insulation layer in Wall family and updating the DXF file in AutoCAD software. In

ArchiCAD section view the same process has been done, where after updating Wall building element by turning off thermal insulation layer, the polylines have been drawn over the original BIM model.

As the results on page 58 show, overall thermal performance of this scenario doesn't meet minimal performance requirements. Without thermal insulation the heat loss through a building component is significantly higher. The risk of mold formation and condensation is bigger because temperature factor (f_{Rsi}) doesn't meet defined criteria (f_{Rsi} < 0.71 - Mold growth assessment criterion not fulfilled; f_{Rsi} < 0.69 – Condensation assessment criterion not fulfilled).

Scenario 2

In the second modification, the facade layer is changed in the way that the brick facade is used instead of the plaster material. This modification has been done by changing the finishing material and thickness of the layer in Wall family (Revit) and Wall element (ArchiCAD). The principle of extracting DXF file from both platforms follows the same steps as described earlier in this study.

By increasing the thickness of the finishing layer from 25mm to 120mm and replacing it with the material with lower thermal conductivity (λ), the detail showed better overall thermal performance than the one described in Scenario 1.

Scenario 3

Scenario 3 offers modification in wall construction where instead of the concrete bricks, as in the first two scenarios, a concrete wall is implemented. In this modification, the outside wall has two layers: facade brick with a thickness of 120mm and concrete wall – 200mm. With the lowest temperature factor (f_{Rsi} = 0.60) this scenario has the highest risk for condensation and mold formation.

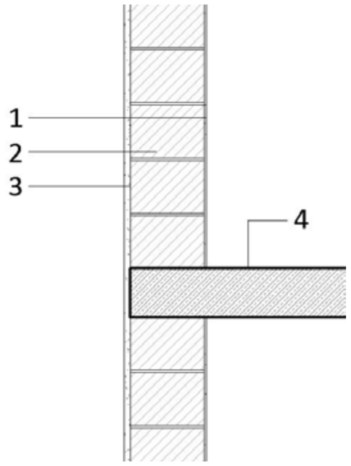
Scenario 4

The last modification, named Scenario 4, shows the best results because the air layer was added into the wall element construction. Since the air layer has the lowest thermal conductivity (λ = 0.025 $Wm^{-1}K^{-1}$), it increases the overall thermal performance of this scenario.

All scenarios have been modified in the similar way in BIM platforms. The results of each scenario are presented in the following tables.

Table 18 - Scenario 1

Scenario 1 - External wall without thermal insulation



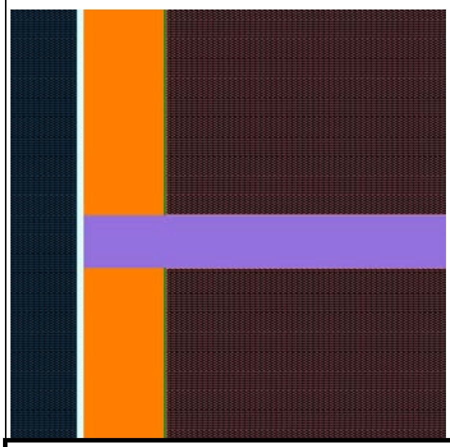
BIM model

Layers

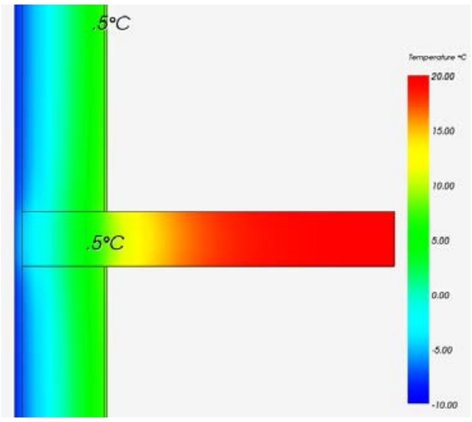
	Name	d [mm]	λ [$Wm^{-1}K^{-1}$]	μ [-]	ρ [kgm^{-3}]	c [$Jkg^{-1}K^{-1}$]
1	Plaster	10	0.49	20	1300	1
2	Concrete Brick	300	1		1200	1.13
3	Plaster	25	1.05	35	1800	1
4	Concrete	200	2.3	130	2300	1

Scenario 1 - Results

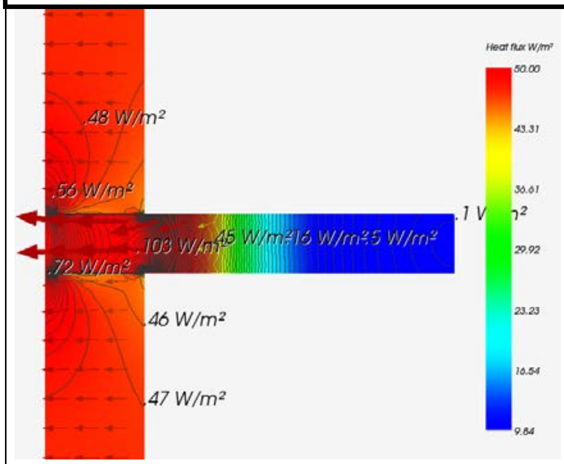
Simulation model



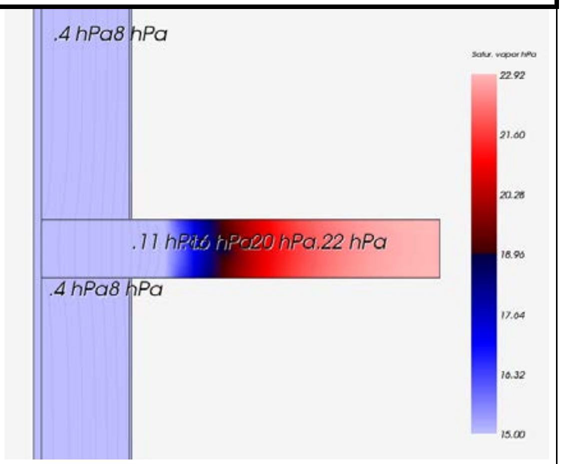
Temperature profile



Heat flux



Pressure difference

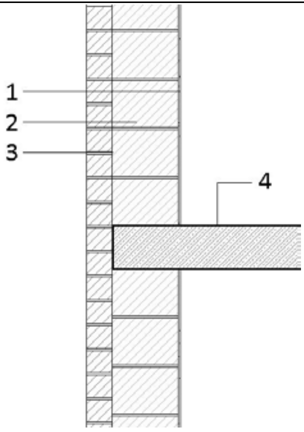


Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	$θ_{min}$ [°C]	f_{Rsi} [-]
6.387741	0.344391	8.17	0.61

Table 19 - Scenario 2

Scenario 2 - External wall with façade bricks

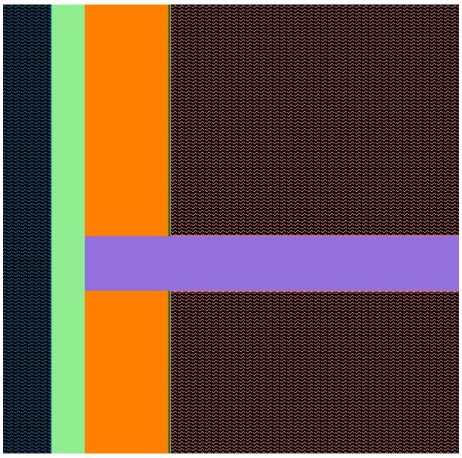


Layers

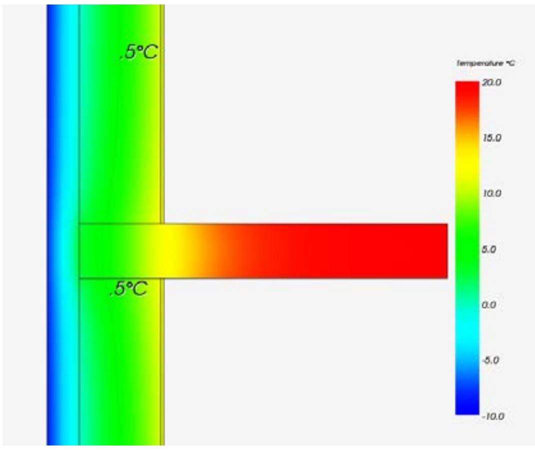
	Name	d [mm]	λ [Wm^{-1}K^{-1}]	μ [-]	ρ [kgm^{-3}]	c [Jkg^{-1}K^{-1}]
1	1	Plaster	10	0.49	20	1300
2	2	Concrete bricks	300	1		1200
3	3	Façade bricks	120	0.52	10	1200
4	4	Concrete	200	2.3	130	2300

Scenario 2 - Results

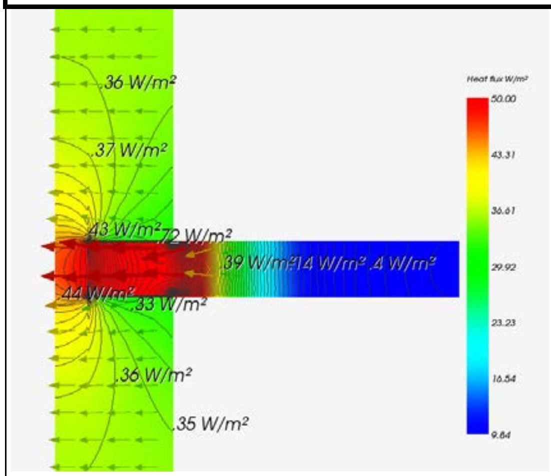
Simulation model



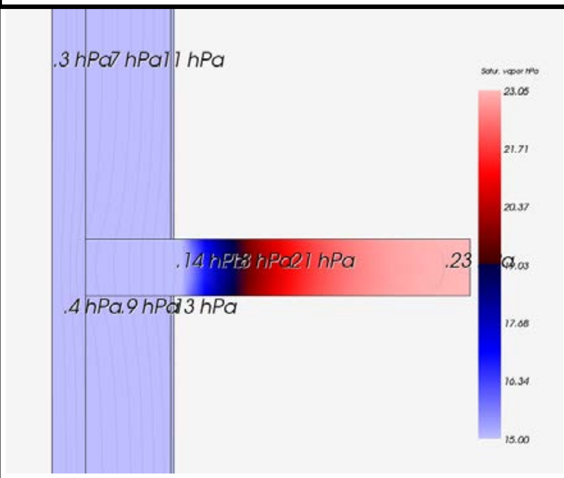
Temperature profile



Heat flux



Pressure difference

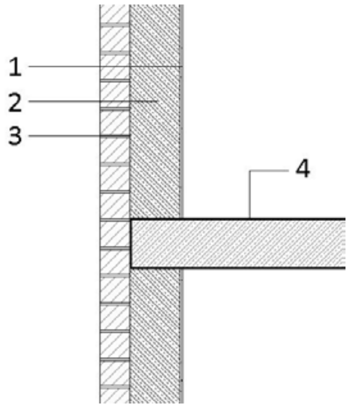


Output results

L^{2D} [Wm^{-1}K^{-1}]	ψ – value [Wm^{-1}K^{-1}]	θ_{min} [°C]	f_{Rsi} [-]
4.468609	0.159549	11.09	0.70

Table 20 - Scenario 3

Scenario 3 - External wall with façade bricks and concrete construction

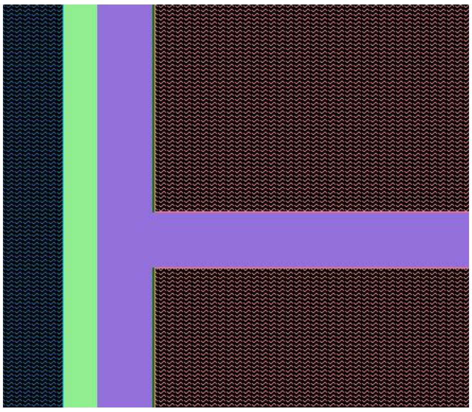


Layers

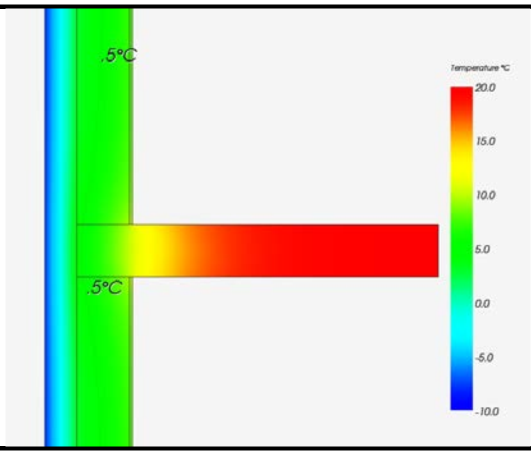
	Name	d [mm]	λ $[Wm^{-1}K^{-1}]$	μ [-]	ρ $[kgm^{-3}]$	c $[Jkg^{-1}K^{-1}]$
1	Plaster	10	0.49	20	1300	1
2	Concrete	200	2.3	130	2300	1
3	Façade bricks	120	0.52	10	1200	1
4	Concrete	200	2.3	130	2300	1

Scenario 3 - Results

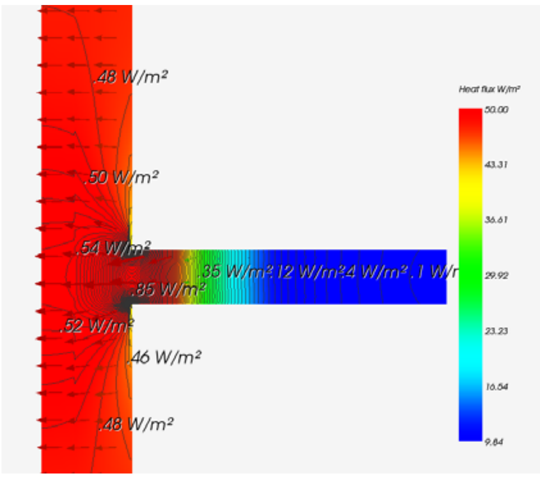
Simulation model



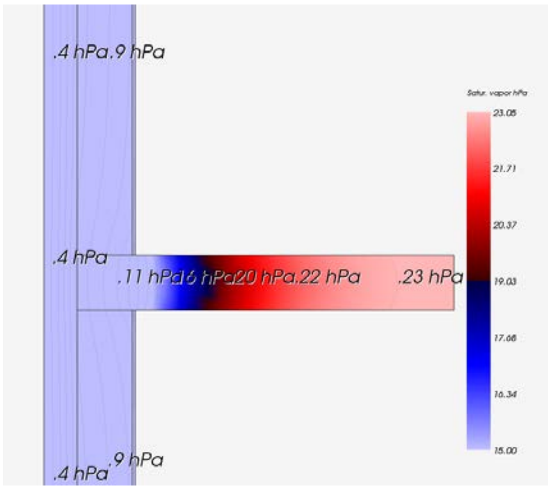
Temperature profile



Heat flux



Pressure difference

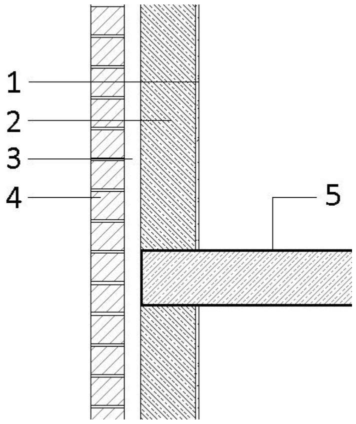


Output results

L^{2D} $[Wm^{-1}K^{-1}]$	ψ – value $[Wm^{-1}K^{-1}]$	$θ_{min}$ [°C]	f_{Rsi} [-]
6.190683	0.074957	8.07	0.60

Table 21 - Scenario 4

Scenario 4 - External wall with façade bricks and concrete construction with ventilation

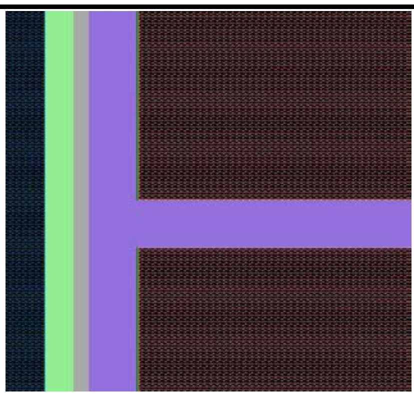


Layers

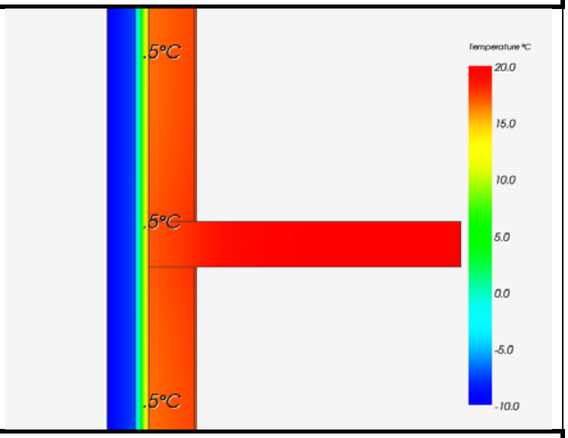
	Name	d [mm]	λ [$Wm^{-1}K^{-1}$]	μ [-]	ρ [kgm^{-3}]	c [$Jkg^{-1}K^{-1}$]
1	Plaster	10	0.49	20	1300	1
2	Concrete	200	2.3	130	2300	1
3	Air	60	0.025	0	1	1.008
4	Façade bricks	120	0.52	10	1200	1
5	Concrete	200	2.3	130	2300	1

Scenario 4 - Results

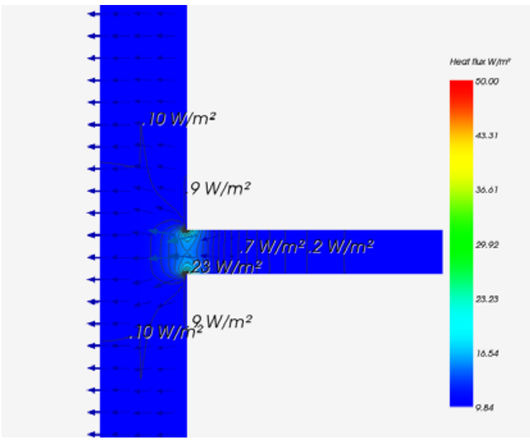
Simulation model



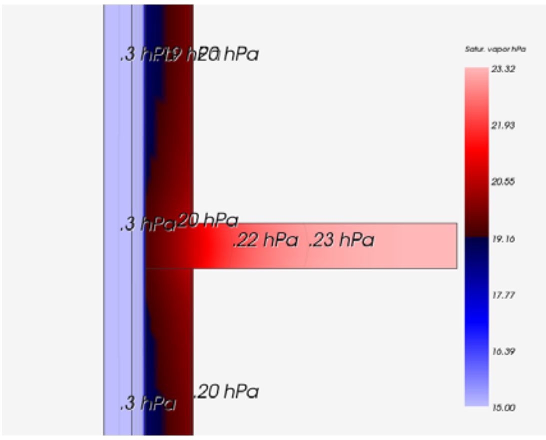
Temperature profile



Heat flux



Pressure difference



Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
1.070815	0.002236	17.54	0.92

5 RESULTS

This chapter contains the details of the most common building junctions which are to be used as validation examples in presenting thermal performance. All building details are set in an identical way described in study case modeling approach (chapter 4.1). Details were grouped into five main groups according to book *Standard Detail Sammlung* by Peter Beinhauer (2003), which has been used as the main reference for building construction details repository. The standardized building details were chosen particularly in those parts where thermal bridges are most common (Figure 36).

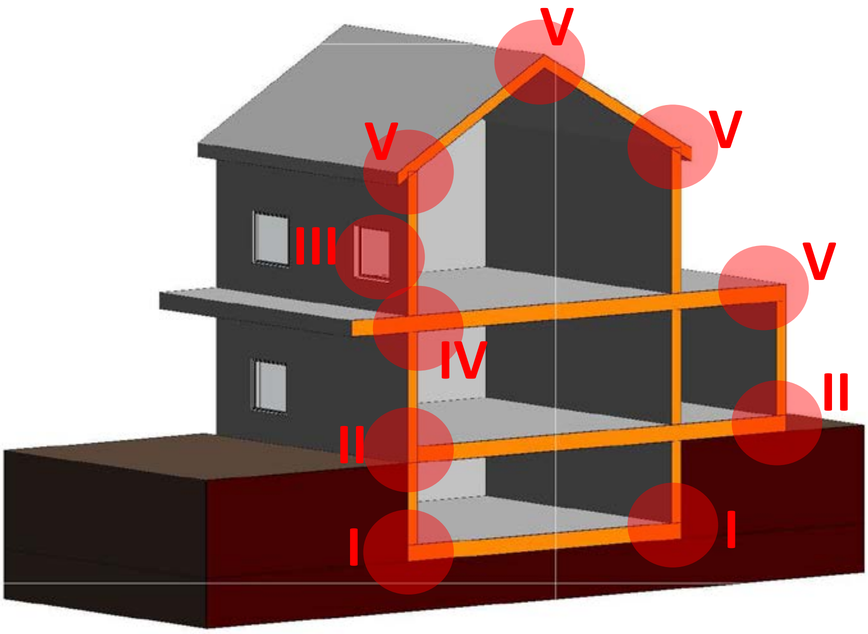


Figure 36 - Classification of details - Schema

Details have been classified into five main groups (Table 22), and in the following chapters the typical examples (main representative) from each group will be presented and explained. All other details, which are modeled and simulated, are gathered and presented in Appendix of this thesis.

Table 22 - Classification of construction details

	Area	Detail
I	**Foundation**	Strip foundation with rigid insulation
II	**External wall**	External wall with concrete blocks
III	**Windows**	Window in Exterior wall (facade bricks)
IV	**Balconies**	Balcony with parapet
V	**Roofs**	Ventilated pitched roof

Building construction details have been modeled and simulated and the obtained results of the simulation with a graphical representation of each representative detail are presented. The following examples give the information required to create two-dimensional models of classified details.

5.1.1 I – Foundation

Thermal properties of the soil

EN ISO 13370

The thermal properties of the soil depend on various factors such as density, the degree of water saturation, particle size, type of minerals which are present in particles, frozen or unfrozen state, etc. Therefore, thermal properties of different places and at different depths at the same location can differ significantly one from another. For the heat transfer calculations, the soil is simplified and treated as homogeneous – isotropic material.

Table 23 - Density and thermal conductivity of different types of soil - EN ISO 13370

	ρ [kgm^{-3}]	**λ** [$Wm^{-1}K^{-1}$]
Silt	1400 - 1800	1.0 – 2.0
Clay	1200 - 1600	0.9 – 1.4
Peat	400 - 1100	0.2 – 0.5
Dry sand	1700 - 2000	1.1 – 2.2
Wet sand	1700 - 2100	1.5 – 2.7
Rock	2000 - 3000	2.5 – 4.5

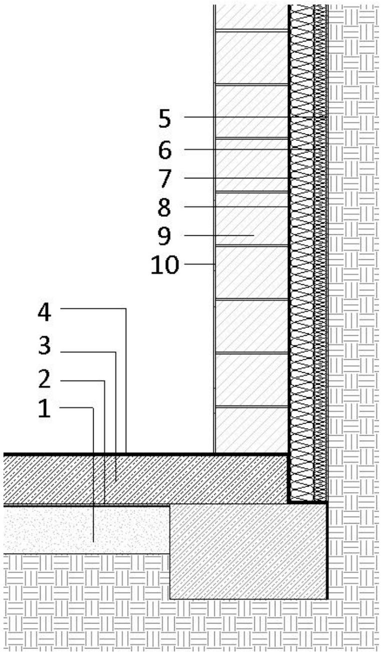
Parameters which have been taken for thermal performance calculations are: density ρ=2000 kgm^{-3}; heat capacity is c=1000 $Jkg^{-1}K^{-1}$ and thermal conductivity is defined as λ=2 $Wm^{-1}K^{-1}$.

Detail

The first foundation example includes strip foundation detail where the basement is under the ground level. Construction of this detail consists of a concrete plate as main floor element and concrete blocks used for the wall construction. Section of the detail with all material properties is presented in Table 24.

Table 24 – Material properties of foundation detail

Detail I – 1 – Strip foundation with rigid insulation



Layers						
	Name	**d** [mm]	**λ** [$Wm^{-1}K^{-1}$]	**μ** [-]	**ρ** [kgm^{-3}]	**c** [$Jkg^{-1}K^{-1}$]
1	Gravel	200	2	50	1700	0.91
2	PE foil	-	0.25	6000	1500	1
3	Concrete	200	2.5	130	2400	1
4	Waterproofing	10	0.25	6000	1500	1
5	Filter	10	0.049	-	12	-
6	Semi-rigid insulation	50	0.047	5.5	99	1.25
7	Rigid insulation	100	0.041	2	93	1
8	Waterproofing	-	0.25	6000	1500	1
9	Concrete blocks	300	1.2	-	1400	1.11
10	Plaster	10	0.49	20	1300	1

The soil has been modeled as Material element in AnTherm with defined thermal conductivity λ = 2 $Wm^{-1}K^{-1}$. The interior of basement space is treated as heated area, and according to that thermal state, the internal surface resistance (R_{si}) and boundary conditions are applied (Figure 37). -Obtained results are presented in Table 25.

Boundary conditions

R_{si} (heat flow) = 0.13m^2KW^{-1}; R_{si} (temperature) = 0.25m^2KW^{-1} & θ_i= 20 °C

R_{si} (heat flow) = 0.17m^2KW^{-1}; R_{si} (temperature) = 0.25m^2KW^{-1} & θ_i= 20 °C

R_{se} (heat flow) = 0.04m^2KW^{-1}; R_{se} (temperature) = 0.04m^2KW^{-1} & θ_e= -10 °C

Soil: ρ = 2000 kgm^{-3}, - λ = 2 $Wm^{-1}K^{-1}$, c = 1000 $Jkg^{-1}K^{-1}$

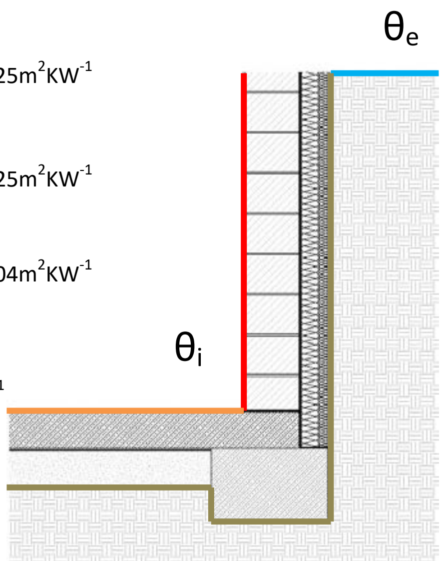
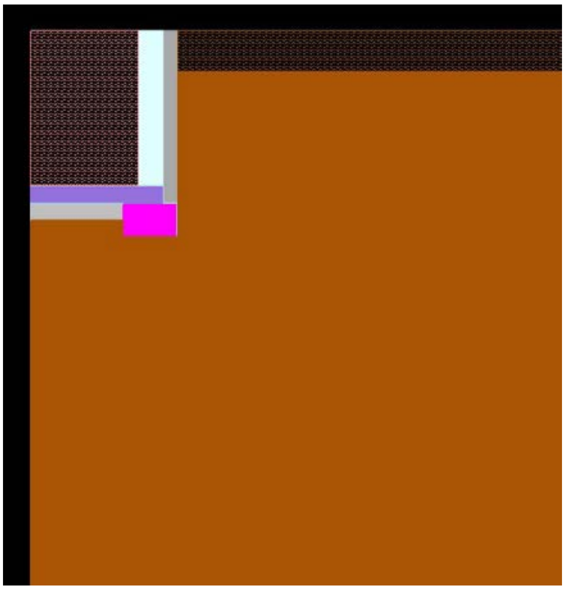
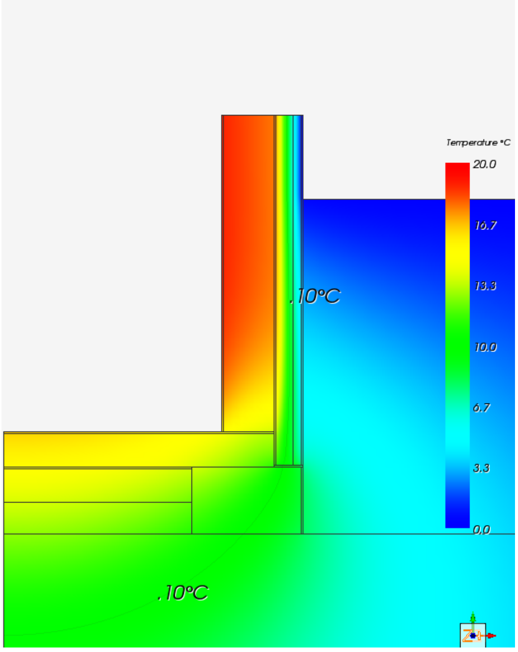
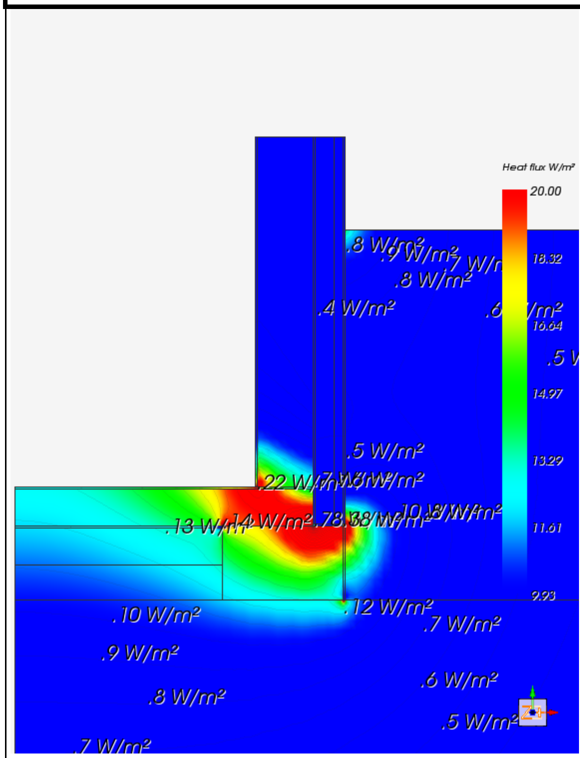
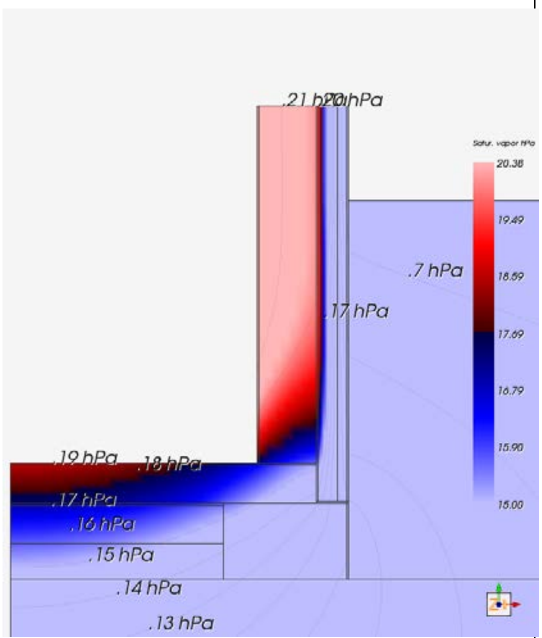


Figure 37 - Boundary conditions of foundation detail

Table 25 - Results of foundation detail

<table>
<tr><th colspan="2">Results Detail I - 1</th></tr>
<tr><th>Simulation model</th><th>Temperature profile</th></tr>
<tr><td></td><td>
</td></tr>
<tr><th>Heat flux</th><th>Pressure difference</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

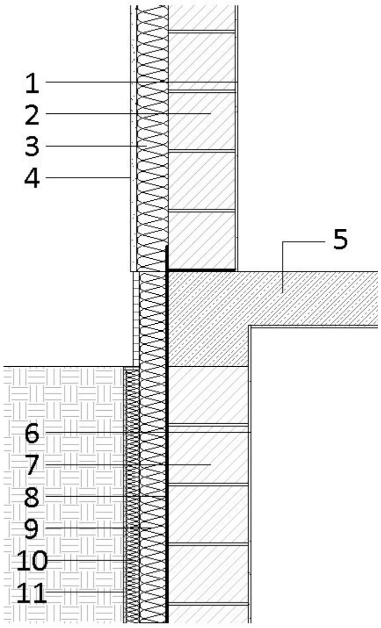
Output results			
L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
1.068957	0.283873	15.19	0.80

5.1.2 II - External wall

The second simulation case represents a cross-section of a brick masonry wall and concrete slab (Table 26). Part of the wall belongs to the underground area as a part of basement space. For the thermal properties of the soil, the parameters which have been used are: density ρ=2000 kgm^{-3}; heat capacity c=1000 Jkg^{-1}K^{-1} and thermal conductivity λ=2 Wm^{-1}K^{-1}. The boundary conditions are applied according to the Figure 38. Results are classified and listed in Table 27.

Table 26 - Material properties of external wall

Detail II – 1 – External wall with concrete blocks, thermal insulation, and plaster finishing



Layers						
	Name	d [mm]	λ [Wm^{-1}K^{-1}]	μ [-]	ρ [kgm^{-3}]	c [Jkg^{-1}K^{-1}]
1	Plaster	10	0.49	20	1300	1
2	Bricks	250	0.44	15	1200	1
3	T.I.	120	0.041	2	93	1
4	Plaster	25	1.05	35	1800	1
5	Concrete	200	2.5	130	2400	1
6	Plaster	10	0.49	20	1300	1
7	Concrete blocks	300	1.2	-	1400	1.11
8	Waterproofing	-	0.25	6000	1500	1
9	Rigid insulation	100	0.041	2	93	1
10	Semi-rigid insulation	50	0.047	5.5	99	1.25
11	Filter	10	0.049	-	12	-

Boundary conditions

R_{si} (heat flow) = 0.13m^{2}KW^{-1}; R_{si} (temperature) = 0.25m^{2}KW^{-1} & θ_i= 20 °C

R_{se} (heat flow) = 0.04m^{2}KW^{-1}; R_{se} (temperature) = 0.04m^{2}KW^{-1} & θ_e= -10 °C

Soil: ρ = 2000 kgm^{-3}, - λ = 2 Wm^{-1}K^{-1}, c = 1000 Jkg^{-1}K^{-1}

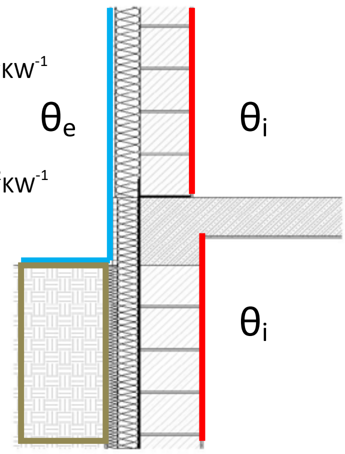
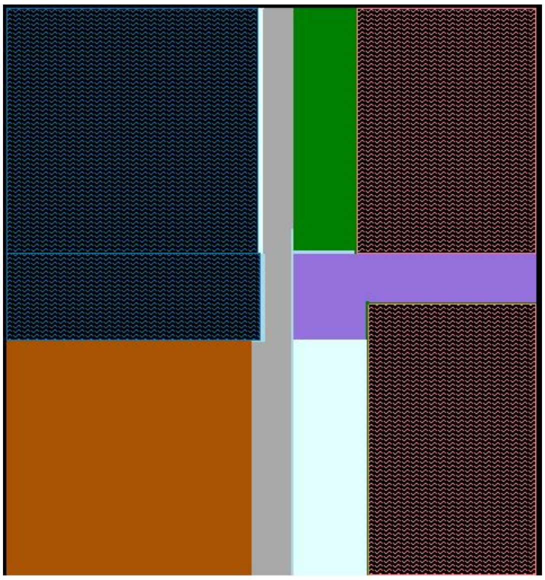
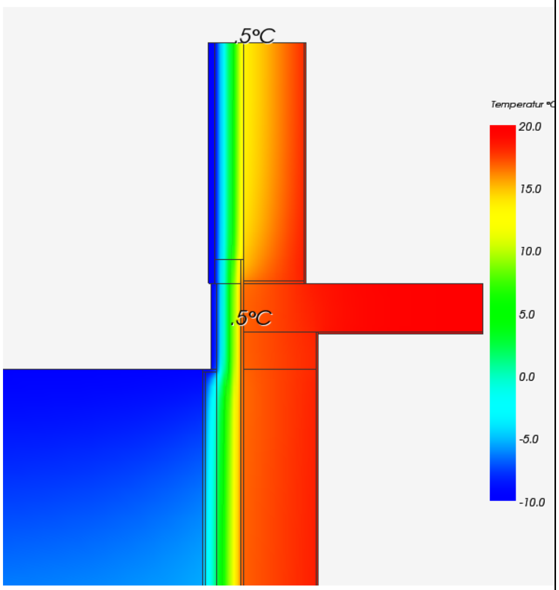
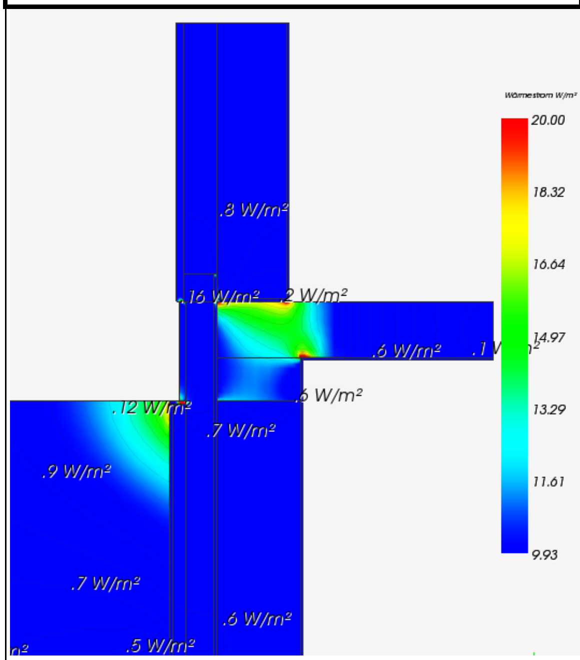
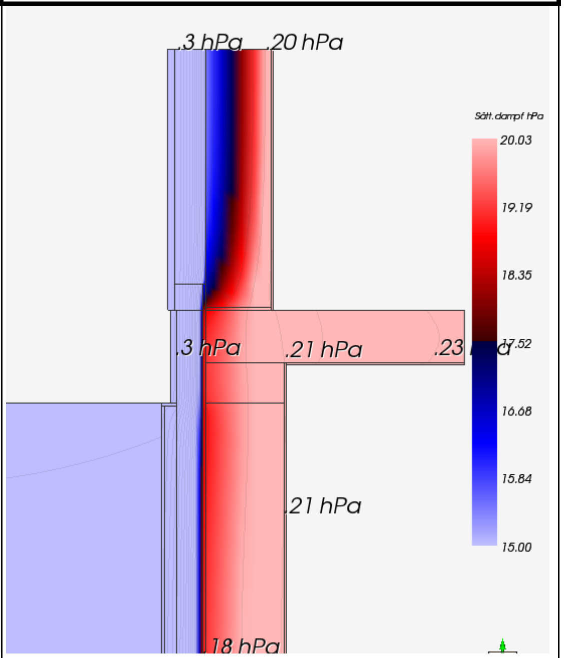


Figure 38 - Boundary conditions of external wall

Table 27 - Results of external wall detail

Results Detail II - 1

Simulation model	**Temperature profile**
	

Heat flux	**Pressure difference**
	

Output results

L^{2D} $[Wm^{-1}K^{-1}]$	**ψ – value** $[Wm^{-1}K^{-1}]$	θ_{min} [°C]	f_{Rsi} [-]
0.596075	0.087610	18.06	0.94

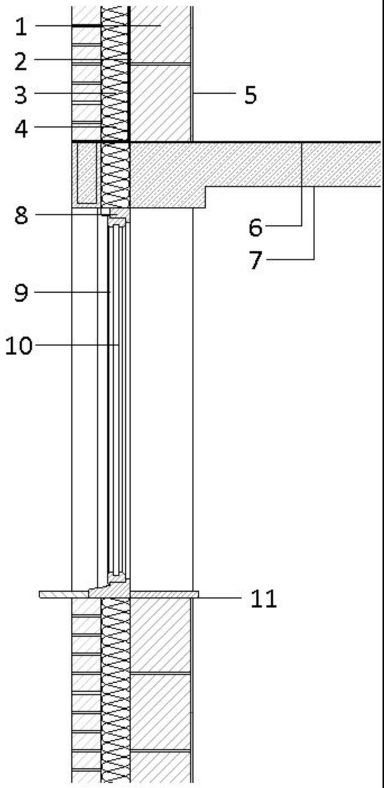
5.1.3 III - Windows

Junctions around windows and doors in the walls represent one of the most typical examples of thermal bridges. Windows should be sealed that moisture is kept out of the construction joint in order to avoid thermal bridge appearance. This applies on both: rain on the outside as well as the humidity inside. The correct connection of the window frames is important to ensure the requirements for the airtightness of the building envelope.

Simulation of window detail in this thesis assumes masonry wall with a thickness of 240mm with a multiple-glazed window with argon filling (Table 28).

Table 28 - Material properties of window detail

Detail III – 1 – Window



Layers

	Name	d [mm]	λ $[Wm^{-1}K^{-1}]$	μ [-]	ρ $[kgm^{-3}]$	c $[Jkg^{-1}K^{-1}]$
1	Concrete blocks	250	1.2	-	1400	1.11
2	Waterproofing	-	0.25	6000	1500	1
3	Thermal insulation	120	0.044	3	112	1
4	Façade brick	120	0.48	10	1100	1
5	Plaster	10	0.49	20	1300	1
6	Concrete	180	2.5	130	2400	1
7	Plaster	10	0.49	20	1300	1
8	PVC	80	0.170	-	1390	0.9
9	Glass	10	1	-	2500	0.750
10	Argon	10	0.0017	-	2	0.519
11	Wood	20	0.110	-	425	1.6

Openings such as windows and doors represent parametric objects with real-world behaviour and attributes in BIM tools. In BIM model the elements and objects are in consistent relationship between each other as the model is manipulated. For example, in a parametric window object, if the dimension is changed, the walls automatically follow the revised window line. Parametric model also provides tabular views of objects (door schedule, window schedule, etc.) and the interaction between those and a model. If an object is edited graphically, the list will be updated automatically; if the same object is edited in a list, the all graphic views will be automatically updated.

Free parametric BIM objects can be downloaded in many design software formats. For the purpose of this detail creation the window has been loaded from the existing Revit and ArchiCAD library and then modified according to the selected detail described in Table 28. In the parametric model the window object has been automatically implemented into the wall element.

Original parametric model has been used as a base for polyline creation for AnTherm DXF import. The level of detail dictates the time that is need for manual adaptation of the model. Window BIM object contains a high level of detail which requires more time investment for DXF preparation.

In modeling process all non-rectangular parts in Window detail are created by an arrangement of steps along the length of slope. In import process AnTherm disassembles steps into separated material boxes. Boxes with the same name can be simultaneously defined with the same material which accelerates the process.

After the materials are applied and Space boxes are defined the simulation process has been run. Values for surface thermal resistances as well as boundary temperatures are defined according to the Figure 39.

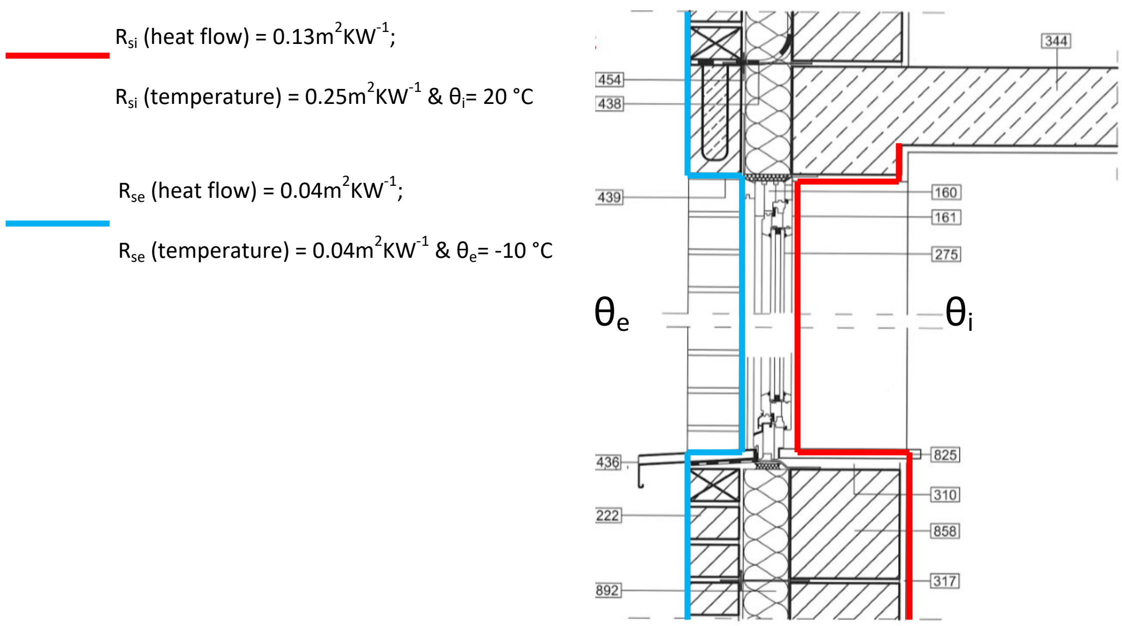
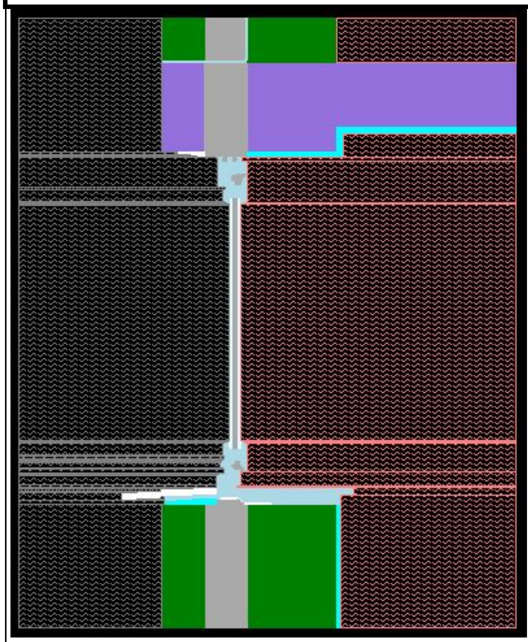
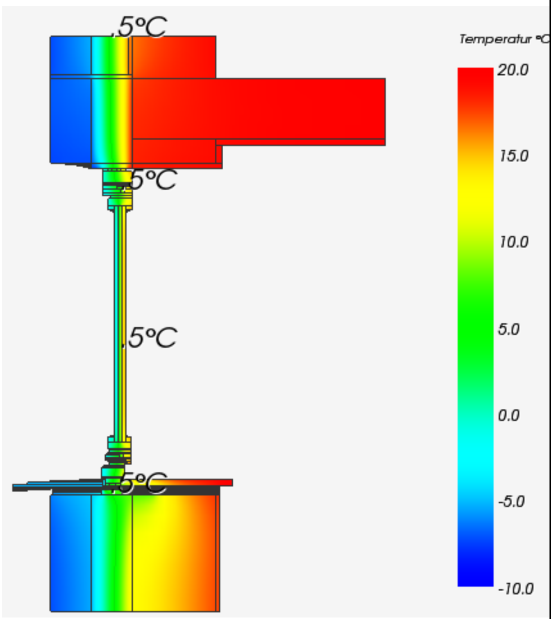


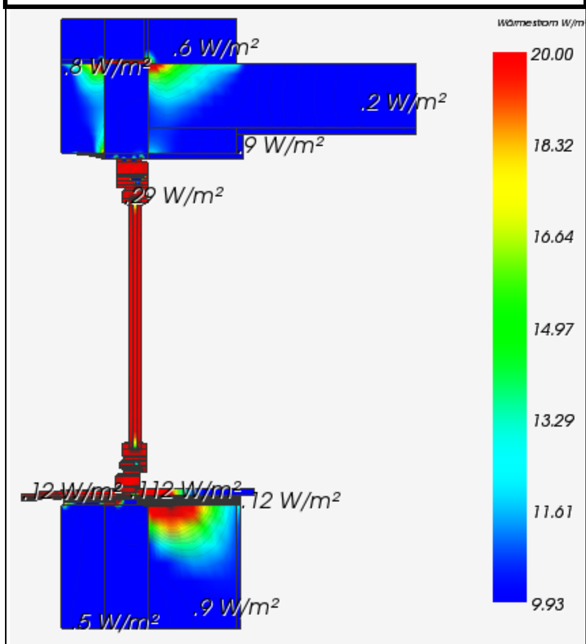
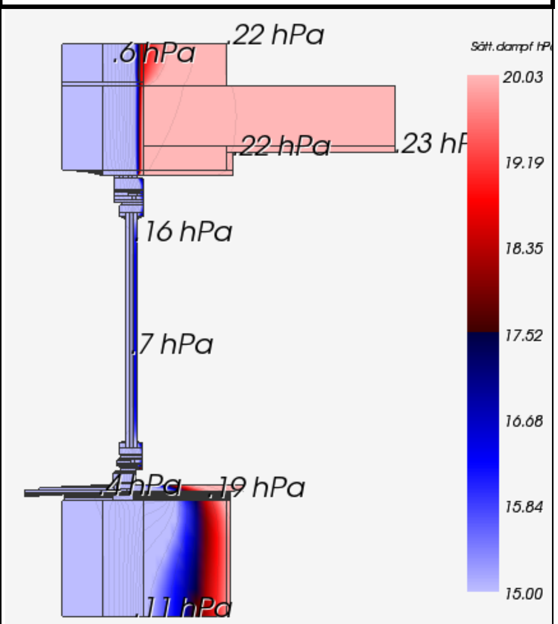
Figure 39 - Boundary conditions of window detail

The obtained results are presented in the following Table 29.

Table 29 - Results of window detail

Results Detail III - 1

Simulation model	**Temperature profile**
	

Heat flux	**Pressure difference**
	

Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
1.255593	0.82339	9.88	0.66

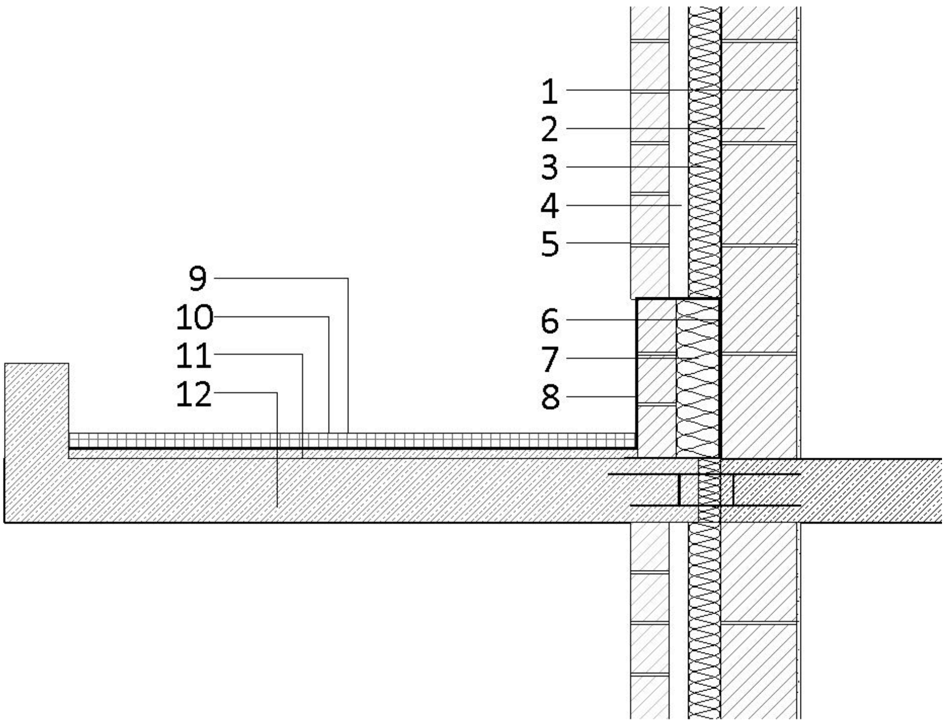
5.1.4 IV – Balconies

In many buildings, exposed slab edges and balconies represent one of the elements that are most prone to thermal bridging. Thermal bridging at balconies slabs results in heat bypassing the wall insulation, reducing in thermal comfort near the external wall which has an effect on energy consumption of a whole building (Schöck Isokorb, 2015).

This simulation case assumes the balcony detail described in Table 30.

Table 30 - Material properties of balcony detail

Detail IV – 1 – Balcony



Layers

	Name	d [mm]	λ [$Wm^{-1}K^{-1}$]	μ [-]	ρ [kgm^{-3}]	c [$Jkg^{-1}K^{-1}$]
1	Plaster	10	0.49	20	1300	1
2	Bricks	240	0.38	10	900	1
3	Thermal insulation	100	0.041	2	93	1
4	Air	60	0.025	-	1	1.008
5	Facade bricks	120	0.38	10	900	1
6	Waterproofing	-	0.25	6000	1500	1
7	Thermal insulation	140	0.041	2	93	1
8	Waterproofing	-	0.25	6000	1500	1
9	Tiles	40	1.3	-	2300	0.840
10	Waterproofing	10	0.25	6000	1500	1
11	Screed	30	0.22	-	1000	0
12	Concrete	200	2.5	130	2400	1

Balcony can be modeled in BIM tools as an extension of a structural floor or as an additional floor element. There is also a possibility of loading a balcony as a parametric object from BIM library. In this example balcony has been created as an additional floor element with relevant architectural finishes. Railings in this case have not been modeled since the main focus for thermal analysis is on a junction between floor and wall area.

Boundary conditions for this study case are applied according to Figure 40.

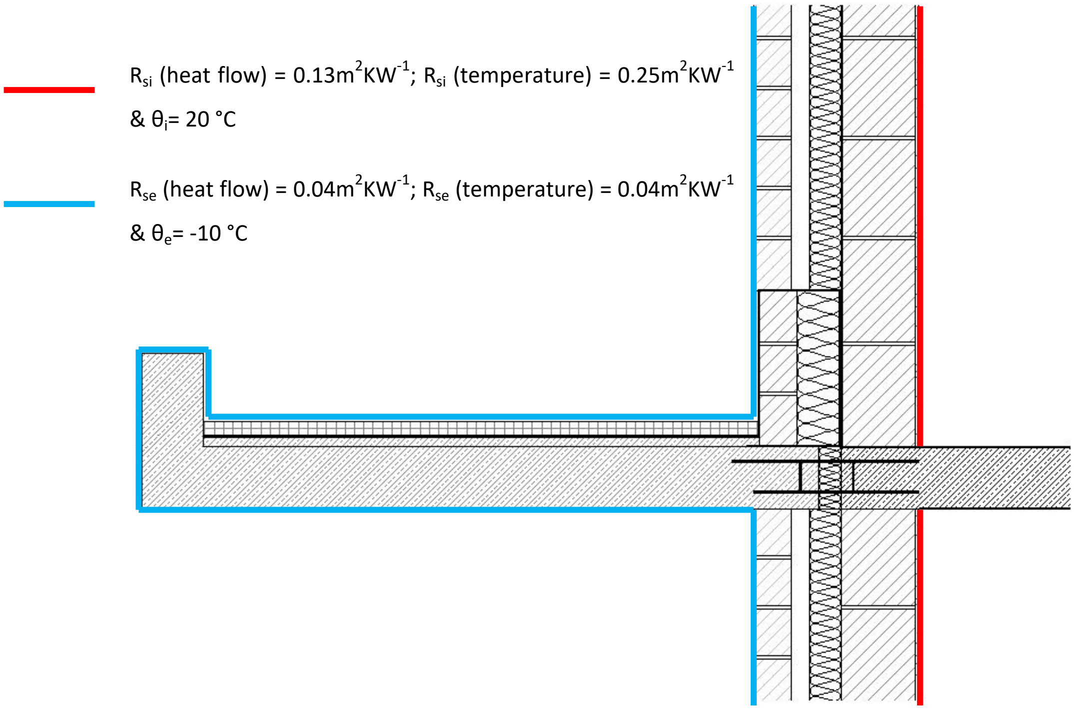


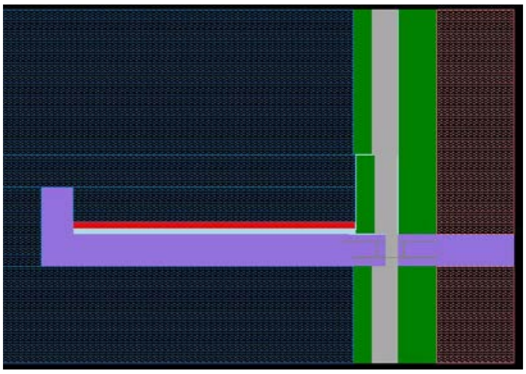
Figure 40 - Boundary conditions of balcony detail

As an outcome of energy simulation, following results have been obtained (Table 31).

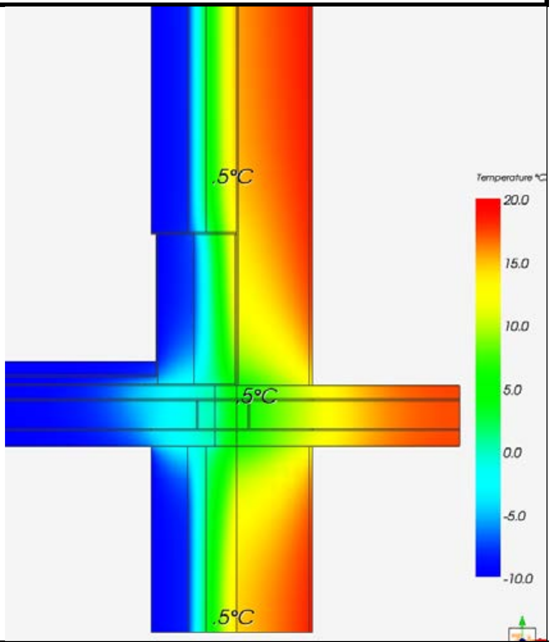
Table 31- Results of balcony detail

Results Detail IV - 1

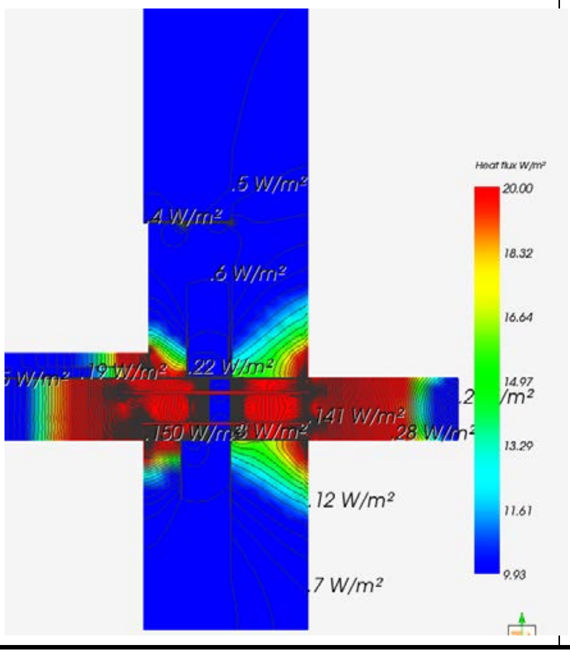
Simulation model



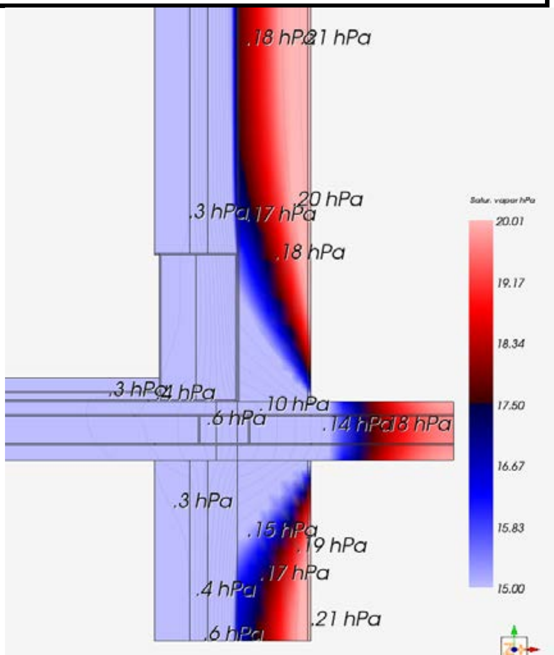
Temperature profile



Heat flux



Pressure difference



Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	$θ_{min}$ [°C]	f_{Rsi} [-]
1.266311	0.893656	11.51	0.72

5.1.5 V – Roofs

If a roof is insulated at a ceiling level, it is usual to ventilate the roof space, in which case the temperature of the ventilated roof space is similar to the temperature of the external air (θ_e). In general, the ventilation factor is not usually known and for such examples of roof spaces the temperature of the space should be taken to be 1 °C (Ward,2006). If the eaves are ventilated, which is usually the case, the air space considered for ventilation is treated in the same way as external air space. The boundary temperatures are defined according to the standards set in Table 3. In the situation where the ventilated eaves are analyzed, the boundary condition of θ_e = -10°C is applied because the ventilated area is treated as external air. Thermal resistances are defined according to the suggestions listed in Table 2 where the values for upwardly heat flow direction have been taken (Figure 41).

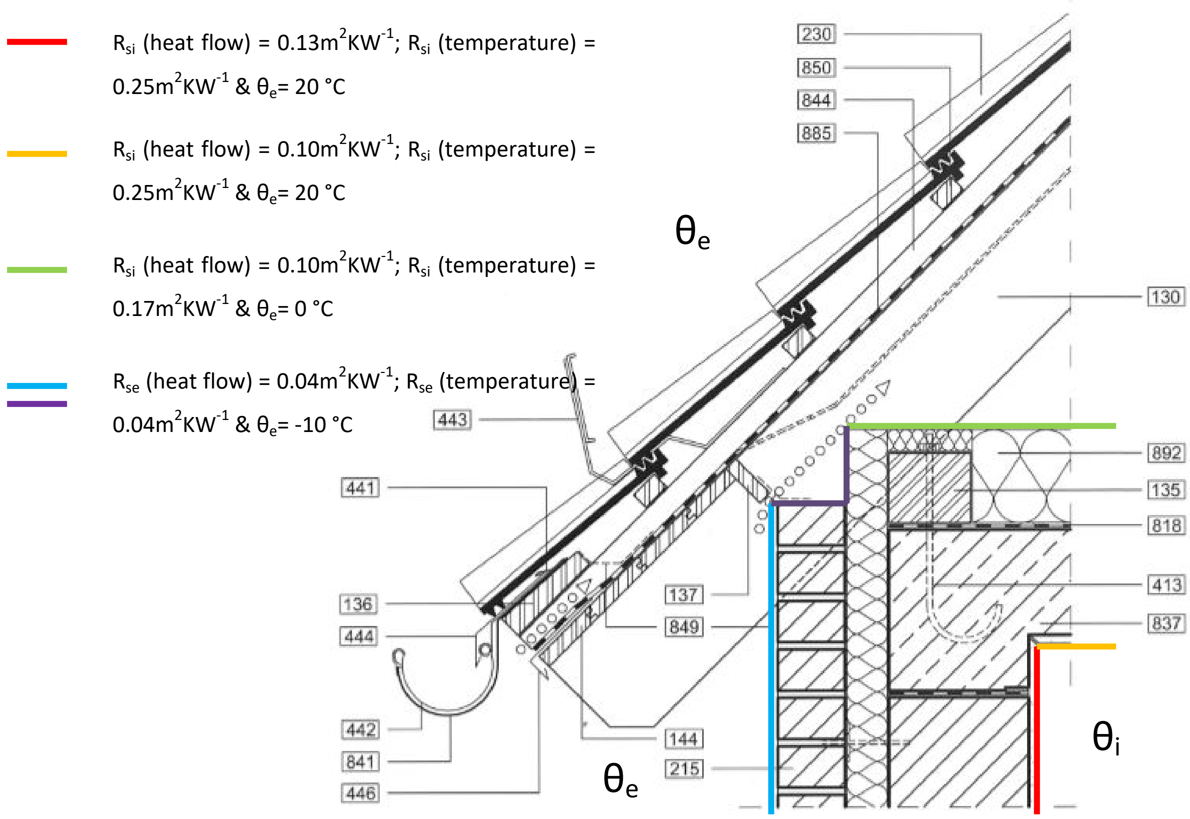
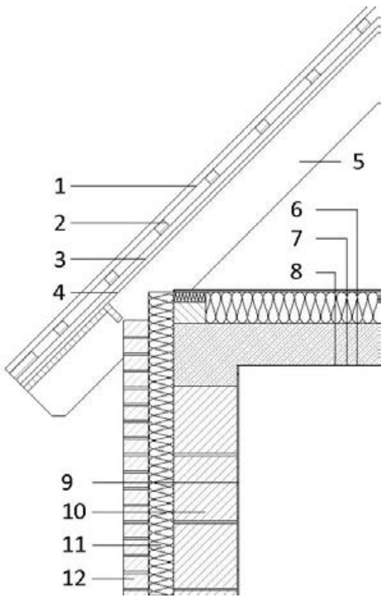


Figure 41 - Boundary conditions of pitched roof detail

Roofs are one of the most complex architectural elements to model. These building elements can be created in BIM models from footprint outlines, as extrusions or from mass instances. In Revit software, roofs (similar to walls and slabs) represent system components that means that they are defined within the Revit project file, not as separate Revit family components (.rfa files). User can specify slope by editing the slope angle value in roof element. The roof detail has been modeled according to Table 32.

Table 32 - Material properties of roof detail

Detail V – 1 – Ventilated pitched roof



Layers

	Name	d [mm]	λ $[Wm^{-1}K^{-1}]$	μ [-]	ρ $[kgm^{-3}]$	c $[Jkg^{-1}K^{-1}]$
1	Roof tiles	200	1	40	2000	0.8
2	Laths	2x200	0.11	-	425	1.6
3	Waterproofing	10	0.25	6000	1500	1
4	Plywood	20	0.140	-	575	1.6
5	Wood	240	0.11	-	425	1.6
6	Thermal insulation	150	0.044	3	112	1
7	Waterproofing	-	0.25	6000	1500	1
8	Concrete	200	2.5	130	2400	1
9	Plaster	10	0.49	20	1300	1
10	Concrete blocks	250	0.59	10	1400	1
11	Thermal insulation	80	0.044	3	112	1
12	Facade brick	120	0.18	15	600	1

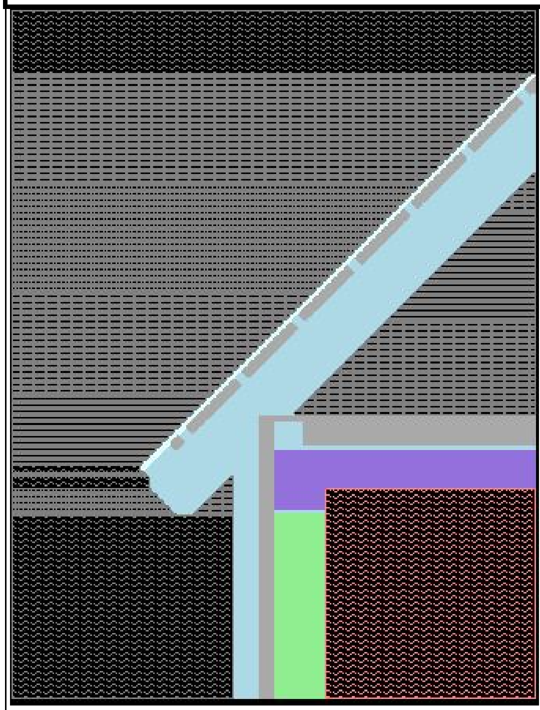
As it is previously mentioned, AnTherm software can work only with the rectangular geometry, therefore the certain modeling steps need to be done before the drawing is imported and analyzed in this tool. Sloping part of the roof geometry is modeled by an arrangement of steps along the length of the slope determined according to steps (Figure 11) described in the chapter 2.2.1 *Modeling approach*. During the import process AnTherm detaches the stepped polyline into small separated model boxes. Each of these boxes must be classified according to its type. Material from the Material database in AnTherm can be easily assigned to all Material boxes with the same name. This simultaneous process cannot be applied to the Space boxes that are included into model. Process of defining the Space boxes with corresponding surface thermal resistances (R_{si} and R_{se}) was done step by step for each single box. This method was time consuming.

After boundary conditions are defined with interior (θ_i) and exterior temperatures (θ_e) (Figure 41), the simulation was run. Results can be seen in the following Table 33.

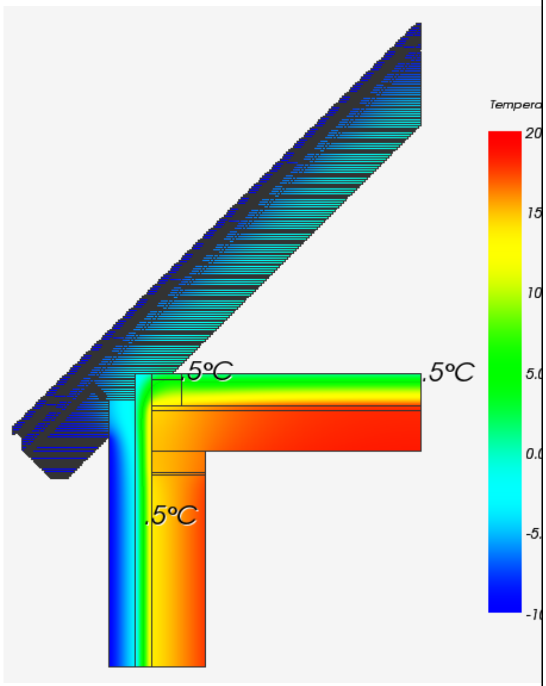
Table 33 - Results of roof detail

Results Detail V - 1

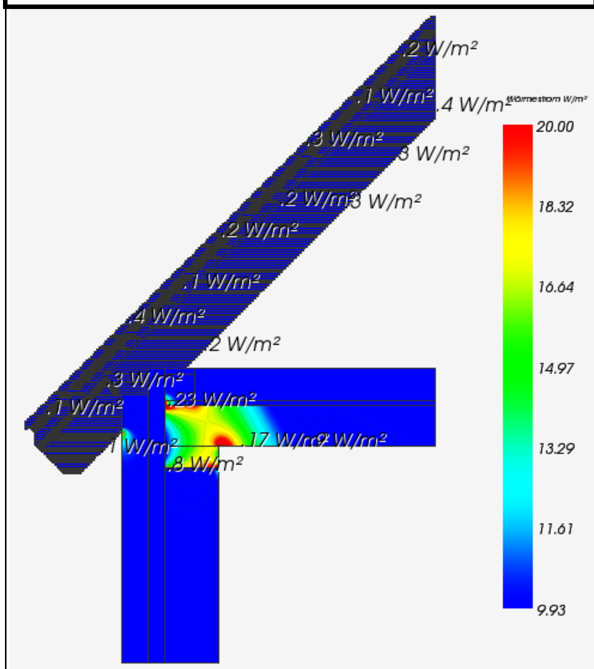
Simulation model



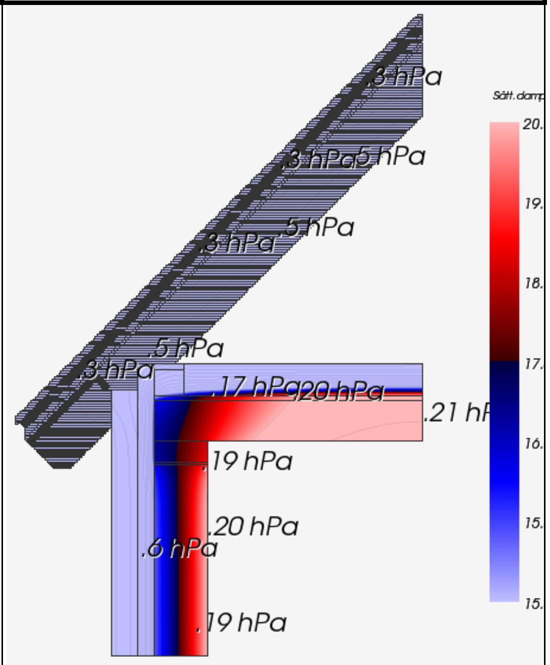
Temperature profile



Heat flux



Pressure difference



Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
0.419177	0.174099	16.36	0.88

6 DISCUSSION

The main purpose of this thesis was the creation of an intelligent-based repository of building construction details in order to offer guidance for the user during the decision-making process. The potential and effectiveness of the BIM process in collaboration with energy performance software was examined and described by outlining the weak points and formulating recommendations for further development. Results are summarized as a sequence of guidelines and recommendations suggesting an optimal workflow for each BIM platform, as well as a creation of a knowledge-based repository of building construction details.

Therefore, efforts of this thesis can be summarized into two main groups:

- Workflow: Examination of BIM modeling approach
- Repository: Creating repository with standardized building construction details

Workflow

The efficiency of data transfer should reduce redundancy and duplicated data generation. Successful information export is strongly related to the quality of a building model as well as to a predefined export setup in order to answer to the requirements for data import in energy evaluation software. It is important to note that there are still limitations related to the transferrable building data between BIM and energy simulation software, which represents one of the main obstacles in successful software collaboration.

Streamline data transfer in the case of interaction of BIM platforms with AnTherm software is not feasible. The reason lies within the fact that complex model information that is extracted from BIM parametric model is not readable in energy simulation tool which requires simplified geometry data input. Therefore, the additional adaptation of BIM model is necessary in order to provide successful import in energy evaluation tool.

AnTherm is a powerful thermal bridges simulation tool, which requires an explicit input data for generating a precise outcome. Results show that only specially prepared DXF file with closed polylines can be read in AnTherm in order to run energy simulation analysis. Circumstance related to the import possibilities in AnTherm software restricts the easy exchange of data and affects the workflow. BIM platforms provide a wide spectrum of transfer possibilities to a number of different energy evaluation programs that include data exchange by the means of IFC and gbXML files. AnTherm software, itself, doesn't support those formats reducing in that way other possibilities for an automated workflow, which stands for the main idea of BIM approach.

DXF file is the only file format that can be read by both BIM and AnTherm tool. Yet, information that is carried by a DXF file is rudimentary and primarily consists of geometrical information represented by a drawing. Thermal properties data, required for energy evaluation analysis, cannot be included in DXF file. Therefore, the manual adaptation of imported file is necessary in order to enable energy simulation.

The examined cases showed that direct import of DXF file extracted from both BIM platforms is not possible. The reason lies in complexity of DXF file that carries a big number of geometrical information which is not readable in AnTherm. Successful DXF import in AnTherm tool requires a simplified file with closed polylines, which should be manually prepared either in BIM platform or in additional software.

In the examined case of DXF import from Revit, the additional software has been introduced. AutoCAD tool has been used for creation of DXF file extracted from Revit platform, as Revit alone was not able to export operable DXF file. In the case of DXF import from ArchiCAD, the direct workflow with AnTherm has been established because ArchiCAD is capable of using polylines for model creation. In both BIM platforms the original parametric model has been used as a reference where polylines have been drawn additionally over the model.

Repository

The important contribution of this thesis is the collection and thermal analysis of the typical construction junctions of a building. It is essential to have precise information about the thermal properties of building components in every planning phase in order to achieve sustainability standards. Expected heat losses through geometrical or material-conditioned thermal weaknesses in construction details can already be revealed, analyzed and specifically minimized during the planning stage.

Examined details can be easily consulted in this thesis with a graphical representation of each detail, modeled in Revit and ArchiCAD, and accompanied by the temperature profile, heat flux, and pressure difference. All outputs are classified in tables with general information about linear thermal transmittance (ψ-value), thermal coupling coefficient (L^{2D}) and temperature factor (f_{Rsi}). All details are accompanied with a table that offers information concerning the materials, their thicknesses, and all related thermal properties. In this context, the current study represents a useful handbook that, besides software guide about modeling and simulating building details, offers a useful self-learning tool with typical thermal bridges in building construction.

7 CONCLUSION AND RECOMMENDATIONS

In the course of examination of the workflow between two BIM based platforms and an energy simulation program, one can clearly observe that the whole process requires an additional adjustment and further improvement. Manual adaptation of the model is time consuming with routine repetitive steps performed either in BIM modeling tool or in the simulation tool. Furthermore, the process of manual adaptation can lead to a loss of model accuracy and the quality of the data.

It is desirable to establish effective workflow between BIM modeling tools and energy simulation software. BIM authoring tools offer the possibility of useful data exchange with energy simulation tool via complex IFC and gbXML files, which besides geometrical information carry also thermal characteristics of materials. In contrast, DXF file carries simplified information, in comparison with other file formats developed specifically for data exchange with energy simulations tools. AnTherm software is not capable of reading those. Manual adaptation of exported building model in energy simulation tool is necessary in order to apply missing material properties. The users are required to specify these inputs for a successful simulation run.

In overall, model import in DXF format to AnTherm is a manual process with no direct, linear workflow with the original model created in BIM platforms. More efforts should be done by energy software developers in order to create the possibility of wide data exchange with other modeling programs, establishing in that way an open platform for collaboration with modeling tools. Moreover, future improvements should be focused on more effective input data in energy evaluation tool in order to establish faster evaluation process. Besides defined geometry, the automated transfer of building materials and their thermal properties along with an imported model is desirable. If the correct building material name is defined in export translator in BIM platforms and it corresponds to the name from AnTherm material database, the automated process of recognizing and applying materials in AnTherm import would be beneficial. Furthermore, additional efforts should be done in creating the possibility for polyline export of 3D parametric model from both BIM platforms Revit and ArchiCAD. The possibilities of the DXF file customization in data export translator should be expanded, especially in Revit platform.

The successful BIM collaboration of BIM modeling tools and AnTherm simulation software requires improvements of both platforms. Successful information sharing between different models is essential to achieve crucial demand for better interoperability between various software applications across the AEC industry.

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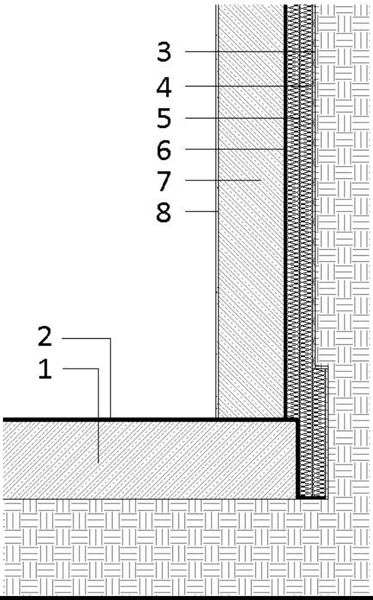
APPENDIX

A. Details

Detail I – 2 – Foundation plate with concrete cellar wall

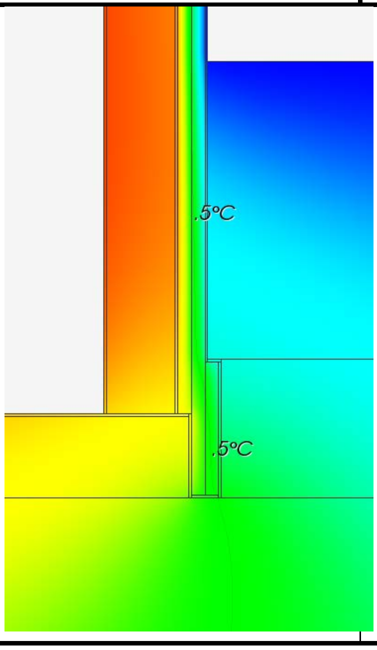


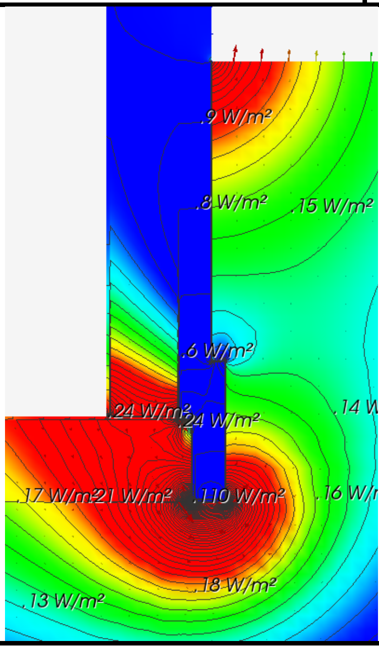
Layers

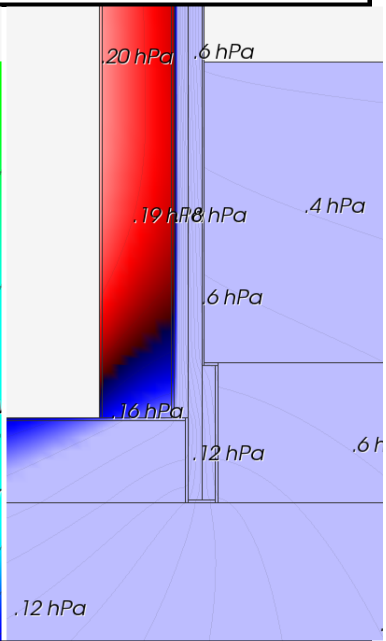
	Name	d [mm]	λ [Wm^{-1}K^{-1}]	µ [-]	ρ [kgm^{-3}]	c [Jkg^{-1}K^{-1}]
1	Concrete	300	2.5	130	2400	1
2	Waterproofing	10	0.25	6000	1500	1
3	Filter	10	0.049	-	12	-
4	Semi-rigid insulation	50	0.047	5.5	99	1.25
5	Rigid insulation	50	0.041	2	93	1
6	Waterproofing	-	0.25	6000	1500	1
7	Concrete	250	1.2	-	1400	1.11
8	Plaster	10	0.49	20	1300	1

Results Detail I - 2

Temperature profile	Heat flux	Pressure difference



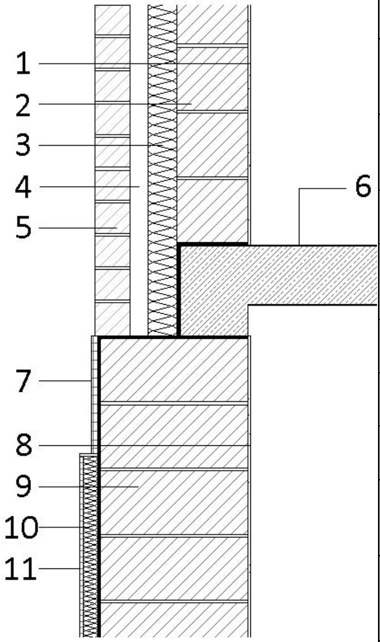




Output results

L^{2D} [Wm^{-1}K^{-1}]	ψ – value [Wm^{-1}K^{-1}]	θ_{min} [°C]	f_{Rsi} [-]
0.867338	-0.296712	14.57	0.82

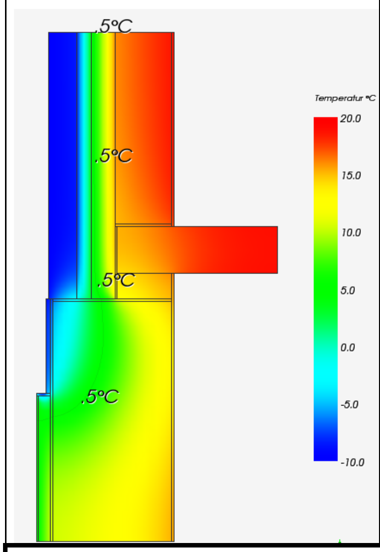
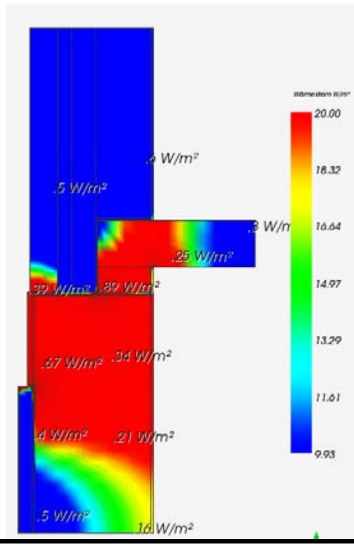
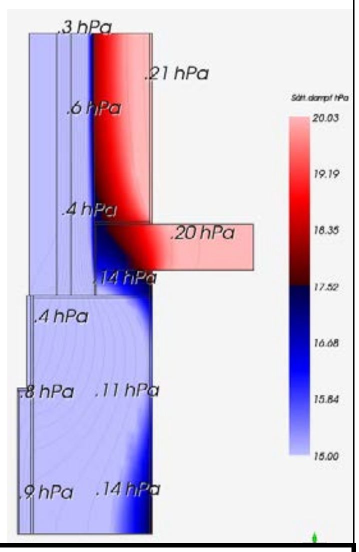
Detail II – 7 – External wall with ventilated layer and facade bricks



Layers

	Name	d [mm]	λ $[Wm^{-1}K^{-1}]$	μ [-]	ρ $[kgm^{-3}]$	c $[Jkg^{-1}K^{-1}]$
1	Plaster	10	0.49	20	1300	1
2	Concrete brick	240	1		1200	1.13
3	Mineral wool	100	0.041	2	93	1
4	Air	60	0.025		1	1.008
5	Facade brick	120	1		1200	1.13
6	Concrete	200	2.5	130	2400	1
7	Plaster	20	0.49	20	1300	1
8	Plaster	10	0.49	20	1300	1
9	Concrete brick	500	1		1200	1.13
10	Semi-rigid insulation	50	0.047	5.5	99	1.25
11	Waterproofing	-	0.25	6000	1500	1

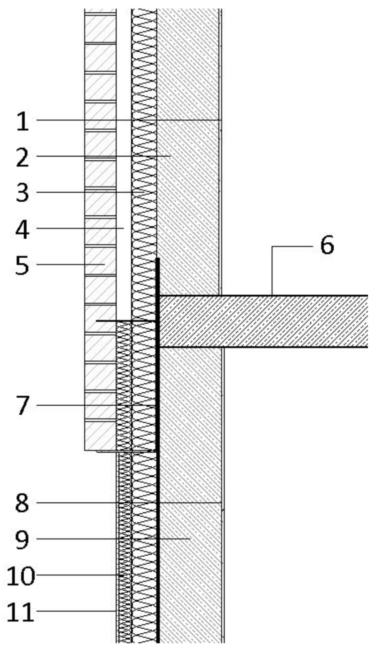
Results Detail II - 7

Temperature profile	Heat flux	Pressure difference
		

Output results

L^{2D} $[Wm^{-1}K^{-1}]$	ψ – value $[Wm^{-1}K^{-1}]$	$θ_{min}$ [°C]	f_{Rsi} [-]
1.115991	0.337971	13.80	0.79

Detail II – 8 – External wall

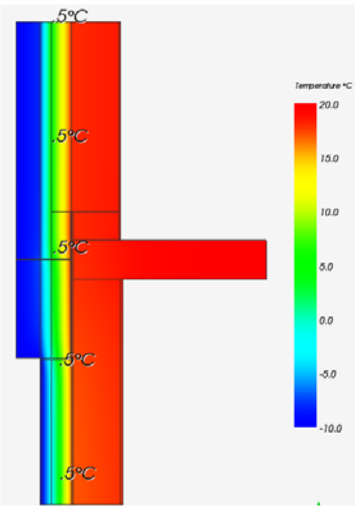


Layers

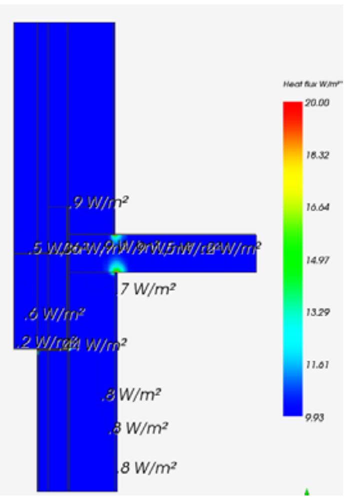
	Name	**d** [mm]	**λ** [Wm^{-1}K^{-1}]	**μ** [-]	**ρ** [kgm^{-3}]	**c** [Jkg^{-1}K^{-1}]
1	Plaster	10	0.49	20	1300	1
2	Concrete	200	2.5	130	2400	1
3	Mineral wool	100	0.041	2	93	1
4	Air	60	0.025		1	1.008
5	Facade brick	120	1		1200	1.13
6	Concrete	200	2.5	130	2400	1
7	Waterpro ofing	-	0.25	6000	1500	1
8	Plaster	10	0.49	20	1300	1
9	Concrete	200	2.5	130	2400	1
10	Semi-rigid insulation	50	0.047	5.5	99	1.25
11	Waterpro ofing	-	0.25	6000	1500	1

Results Detail II - 8

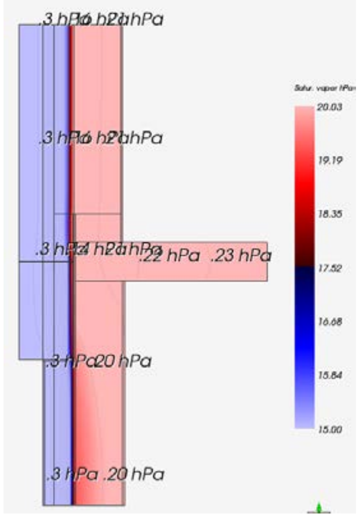
Temperature profile



Heat flux



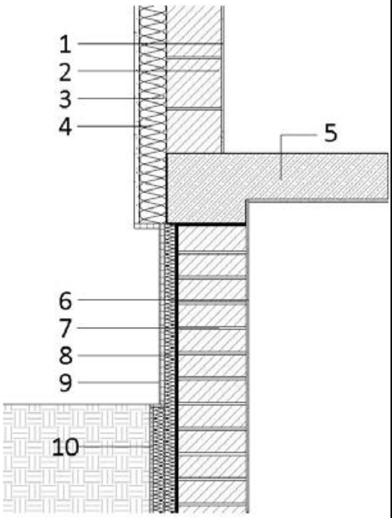
Pressure difference



Output results

L^{2D} [Wm^{-1}K^{-1}]	**ψ – value** [Wm^{-1}K^{-1}]	**θ$_{min}$** [°C]	**f$_{Rsi}$** [-]
0.579828	-0.009332	18.0	0.93

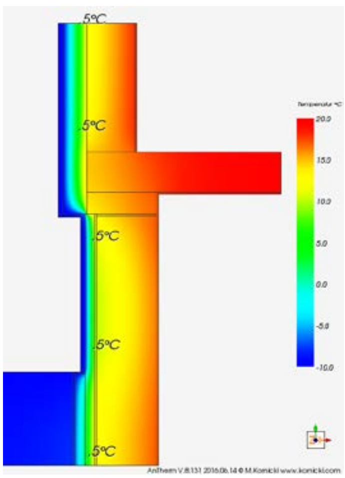
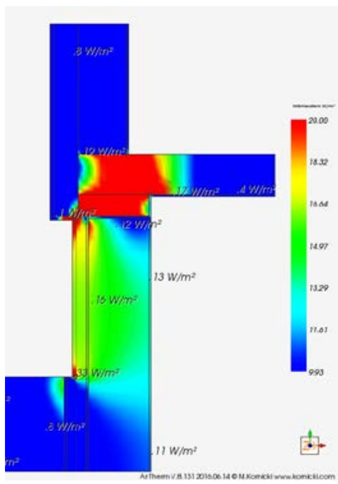
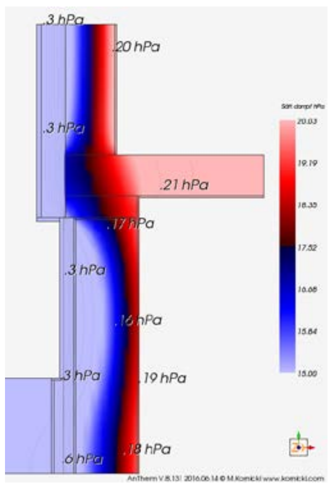
Detail II – 9 – External wall



Layers

	Name	d [mm]	λ [Wm^{-1}K^{-1}]	μ [-]	ρ [kgm^{-3}]	c [Jkg^{-1}K^{-1}]
1	Plaster	10	0.49	20	1300	1
2	Bricks	240	0.34	10	1050	1
3	T.I.	120	0.041	2	93	1
4	Plaster	25	1.05	35	1800	1
5	Concrete	200	2.5	130	2400	1
6	Plaster	10	0.49	20	1300	1
7	Bricks	300	0.69	10	1050	1
8	Waterproofing	-	0.25	6000	1500	1
9	Plaster	20	0.49	20	1300	1
10	Semi-rigid insulation	50	0.047	5.5	99	1.25

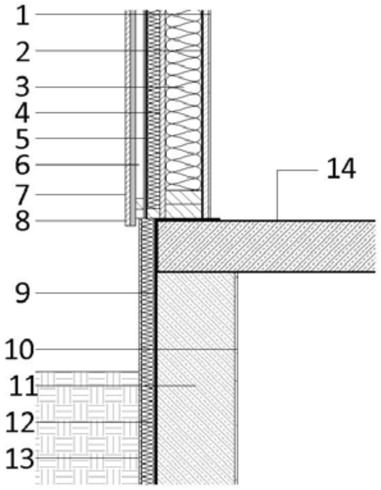
Results Detail II - 9

Temperature profile	**Heat flux**	**Pressure difference**
		

Output results

L^{2D} [Wm^{-1}K^{-1}]	**ψ – value** [Wm^{-1}K^{-1}]	**θ$_{min}$** [°C]	**f$_{Rsi}$** [-]
0.953294	0.276407	16.62	0.89

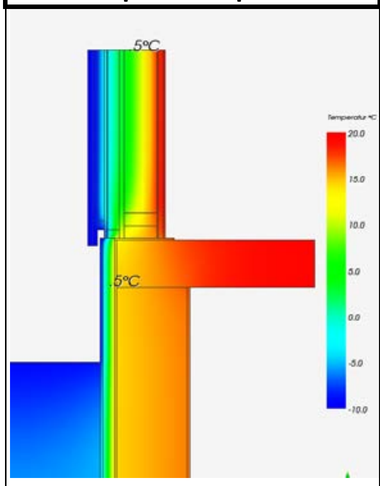
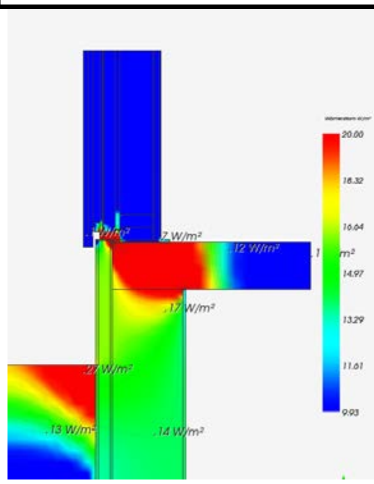
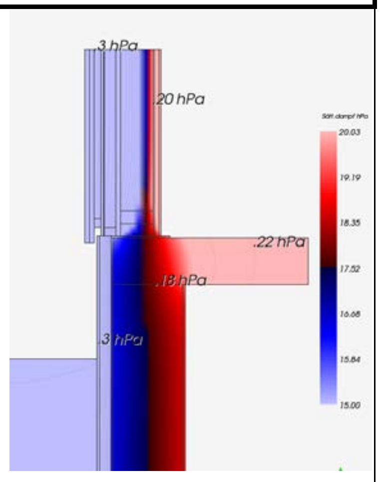
Detail II – 10 – External wall



Layers

	Name	d [mm]	λ [$Wm^{-1}K^{-1}$]	μ [-]	ρ [kgm^{-3}]	c [$Jkg^{-1}K^{-1}$]
1	Gypsum wall	10	0.190	10	600	1
2	Plywood	20	0.130	50	650	1.7
3	Rock wool	140	0.041	2	93	1
4	Ivory	20	0.24	250	1000	1.6
5	Thermal insulation	50	0.041	2	93	1
6	Plywood	10	0.130	50	650	1.7
7	Air	30	0.025	-	1	1.008
8	Wood - finish	40	0.11	-	425	1.6
9	Concrete	20	2.5	130	2400	1
10	Plaster	10	0.49	5.5	1300	1
11	Concrete	300	2.5	130	2400	1
12	Semi-rigid insulation	50	0.041	2	93	1
13	Filter	10	0.049	-	12	0
14	Concrete	200	2.5	130	2400	1

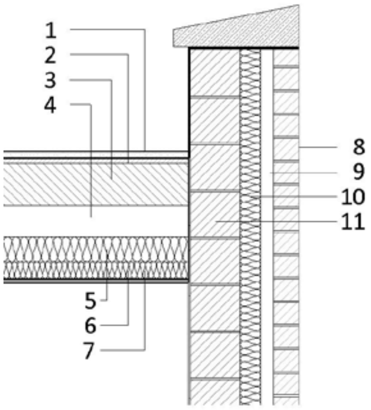
Results Detail II - 10

Temperature profile	Heat flux	Pressure difference
		

Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	$θ_{min}$ [°C]	f_{Rsi} [-]
0.727616	0.465133	16.52	0.88

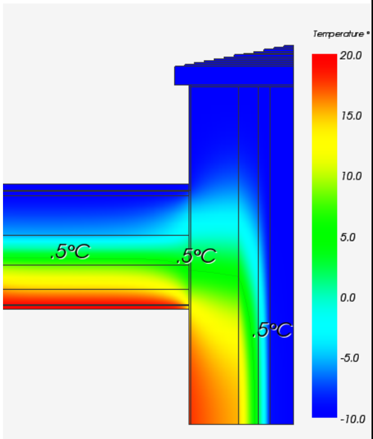
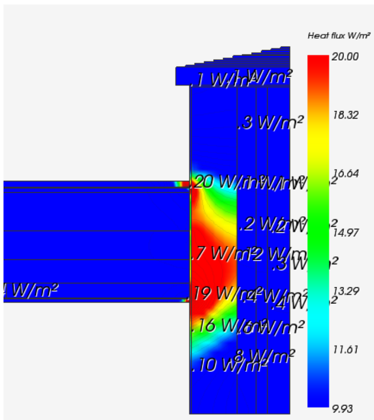
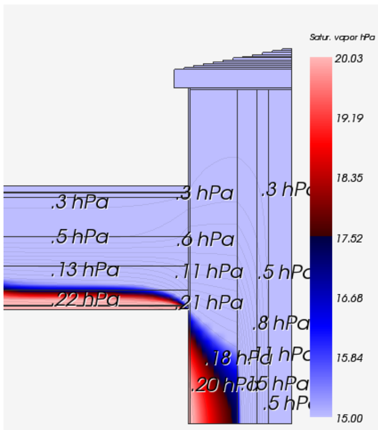
Detail V – 2 – Flat roof – wooden construction



Layers

	Name	d [mm]	λ [Wm⁻¹K⁻¹]	μ [-]	ρ [kgm⁻³]	c [Jkg⁻¹K⁻¹]
1	Gravel	30	2.000	50	1700	0.910
2	Waterproofing	-	0.25	6000	1500	1
3	Wood	200	0.110		425	1.6
4	Air	150	0.025		1	1.008
5	Mineral wool	120	0.041	2	93	1
6	Mineral wool	80	0.041	2	93	1
7	Plywood	15	0.160	220	675	1.6
8	Facade brick	120	1		1200	1.13
9	Air	60	0.025		1	1.008
10	Mineral wool	100	0.041	2	93	1
11	Concrete brick	240	1		1200	1.13

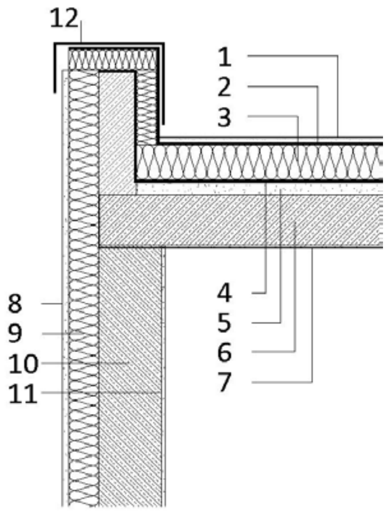
Results Detail V - 2

Temperature profile	Heat flux	Pressure difference
		

Output results

L^{2D} [Wm⁻¹K⁻¹]	ψ – value [Wm⁻¹K⁻¹]	θ_{min} [°C]	f_{Rsi} [-]
0.402041	0.194561	13.48	0.78

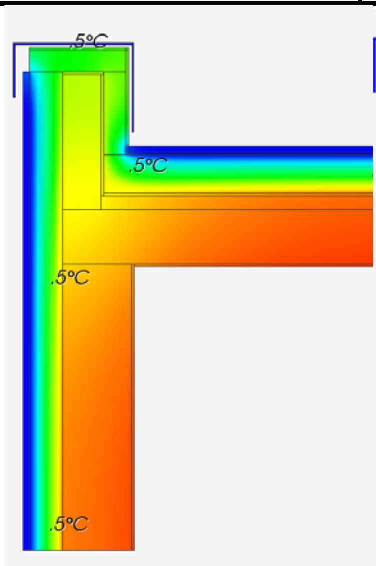
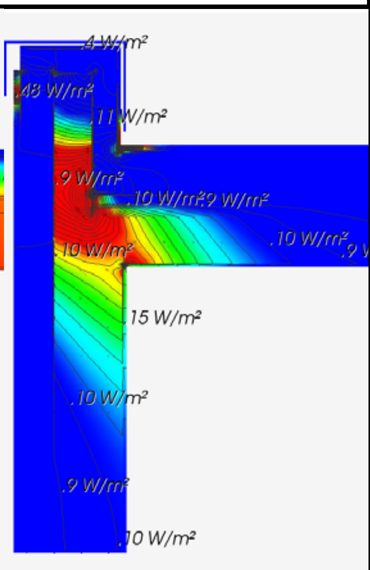
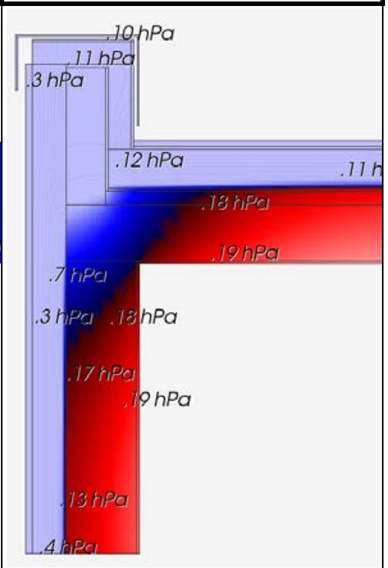
Detail V – 3 – Flat roof



Layers

	Name	d [mm]	λ [Wm⁻¹K⁻¹]	μ [-]	ρ [kgm⁻³]	c [Jkg⁻¹K⁻¹]
1	Gravel	30	2	50	1700	0.91
2	Waterproofing	-	0.25	6000	1500	1
3	Thermal insulation	150	0.041	2	93	1
4	PE foil	-	0.25	6000	1500	1
5	Screed	50	1.10	35	1800	1.08
6	Concrete	200	2.5	130	2400	1
7	Plaster	10	0.49	20	1300	1
8	Plaster	25	1.05	35	1800	1
9	Thermal insulation	120	0.041	2	93	1
10	Concrete	250	2.5	130	2400	1
11	Plaster	10	0.49	20	1300	1
12	Aluminum	6	160	-	2800	0.880

Results Detail V - 3

Temperature profile	Heat flux	Pressure difference
		

Output results

L^{2D} [$Wm^{-1}K^{-1}$]	ψ – value [$Wm^{-1}K^{-1}$]	θ_{min} [°C]	f_{Rsi} [-]
0.829259	0.230424	15.82	0.86