The assessment of apartment and school building measures to improve building performance in Finland

Master Thesis

International Master of Science in Construction and Real Estate Management

Joint Study Program of Metropolia UAS and HTW Berlin

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Author

Hatef Hajian

Conceptual Formulation

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Date: 17.04.2018

Master Thesis for Mr. Hatef Hajian

Student Number: 1707884

Thesis Title

How to increase the energy efficiency in renovation by integrating implemented passive house technologies

Abstract

The building sector has got a great portion of carbon dioxide gas emission around the world. Considering the rule that avoids the demolishing old buildings in most of countries, the importance of renovation comes into account. Although renovation gives a new face to interior space of buildings and renew them, it improves the energy efficiency of the buildings as well. Energy is expensive and to have sustainable cities, using high-tech techniques in renovation is a must to reach more energy efficient buildings. The aim of this paper is study how to develop the energy consumption measuring methods as well as implement passive house techniques in renovation, to find more energy efficient renovation methods.

Introduction

By considering the impacts of climate change and all environmental issues which are happening around us, the importance of caring about our planet efficiently gets more and clear influence in decision makers around the world. It becomes a global concern and periodically countries around the world get to gather to set restricted rules to stop more damages to the environment. Most of the developing countries should follow sustainable development goals and strategies which are set by the United Nation organization in Conference Paris 2015 and Conference Bonn 2017. Among the sustainable development criteria, housing has got a significant role in terms of its environmental impacts. In the residential building sector, constructing new housings is very less and most of the considerations are towards to renovate old buildings to emit less carbon dioxide gas and more energy efficient.

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Thesis Hypothesis

To make renovation more energy efficient, utilizing the high-tech techniques and implementing BIM into account are in demand. In short term, maybe the cost of executing updated methods seems a bit high but, less energy consumption and will decrease in long-term undoubtedly. To use energy in its efficient way, energy consumption monitoring is important, also by modelling the energy saving patterns with computers and software, it is easier to anticipate the impacts of energy efficient methods. By implementing techniques which are used in passive housing like sealing the building thoroughly, using the energy produced by building habitats, utilizing green energies like wind and solar energies and finally by increasing social awareness of using passive house technique benefits in renovation and encouraging people by considering some bonus, more energy efficient buildings are achievable.

Another aspect is energy measurement. Obviously as the energy measurement gets more accurate, finding solutions for avoiding energy waste will be more feasible. By finding ways to measure the energy consumption more accurate and how to utilize these measurements via software leading to have more energy efficient renovations is desired.

Methodology

To implement passive house techniques, knowing the concept and methods of building passive house and utilizing the passive house technology should be done by literature review and studying academic journals. To have a clear picture of the methods of energy consumption measurement, studying academic journals related to the matter is in demand. After getting to know the passive house concept and techniques as well as energy consumption methods in building sector, implementing the proposed techniques to increase energy efficiency renovation in terms of case study may provide the desirable results of the article.

Research Questions

1. How to integrate passive house techniques and BIM to implement energy efficient renovation?
2. How to categorize implementing passive house techniques in renovation with respect to geographical and climate characteristics of the respective area.
3. How to measure the energy consumption more accurate and how to implement it with software?
4. How to decrease the essential cost of implementing high tech techniques in renovation to make buildings more affordable?
5. How to set a plan to increase the social awareness of benefits of utilizing energy efficient techniques despite their high essential cost?

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Expected Results

Monitoring and controlling energy to minimize the energy consumption needs accuracy and since BIM in a precise process and to achieve high energy efficiency, high tech, and updated techniques should utilize. To make more clear renovation techniques and methods, more accurate data and measurements are desired. Finding accurate ways to measure energy consumption to monitor whether the proposed renovations methods work out efficiently for respective cases before and after renovation, is achievable by improving energy measurement. Therefore, finding the answers of mentioned research questions seems feasible.

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12 DEZ. 2018
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REQUEST TO CHANGE THE TITLE OF THE FINAL THESIS

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I wish to request for the following change to the title of my thesis.

Previous title:

How to increase the energy efficiency in the renovation by integrating implemented passive house technologies in cold climate countries

New title to be confirmed:

The assessment of apartment and school building measures to improve building performance in Finland

Please note that changing the title of the final thesis does not constitute a rejection of the topic as defined by § 21, no. 2 of HTW's Examination Framework Regulations!

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Conceptual Formulation

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Abstract

There are several tasks which are performed by buildings. These are usually referred to as building functions. The building performance is a characteristic of a structure that demonstrates how well the construction performs its functions. The efficiency of the construction method could also be affected (Kirimtat *et al.*, 2019). The building's efficiency relies on the building's reaction to external loads or shocks. The building performance measures can be described as energy consumption, CO2 emission, perceived indoor air quality, renovation cost, cost of improving indoor air quality, living quality, and ownership. Taking the above measures into account, the building performance is greatly influenced by measures such as energy consumption, CO2 emissions, and perceived indoor air quality. Thus, building performance can enhance significantly by boosting the three specified measures.

Introduction

Building performance relates to functionality efficiency and its environmental and user influence. The building performance is mostly influenced by essential elements like the engineering and architectural design, building material selection, site environment, energy consumption, and sustainability (Bardage, 2017). On the other hand, building performance initiatives aim at enhancing the energy performance of current structures through an extensive strategy to energy, comfort, and productivity improvement.

Due to the severe climate condition in countries like Finland, the outer layer of the external wall should be maintained well to avoid damages and to fall apart. Therefore, renovating the external wall seems the most common stage in the renovation process. Since then, the thickness of the insulation layer of both case studies will get enhanced based on the Structural Energy Efficiency in Renovation (Ojanen, Nykänen and Hemmilä, 2017), and the results will be studied in three measures called as energy consumption, CO2 emission, and perceived indoor air quality.

Thesis Hypothesis

The measures which the building performance could be evaluated are energy consumption, CO2 emission, perceived indoor air quality, renovation cost, cost of improving indoor air quality, living quality, and ownership. The most important measures which the building performance is significantly getting influenced are energy consumption, CO2 emissions, and perceived indoor air quality. Therefore, by improving the three specific measures, building performance can considerably improve.

Studying the impact of improving the external wall insulation layer on the beholding performance measures such as the energy consumption, CO2 emission, and perceived indoor air quality, is providing a comprehensive assessment to the building performance.

Methodology

To reach a certain level of knowledge regarding building performance, several related scientific articles and related books should have been studied. To perform the energy simulation in order to obtain precise results, the software called IDA ICE should have been learned as well. In the process of case study selection, the aim is to cover the most common building types the residential building and school in Finland. The commonly used step of the renovation process, which is replacing the insulation layer of the external wall with greater thickness is taking into consideration as the renovation work.

Researched Questions

1. What is the comprehensive meaning of the term "building performance"?
2. What are the measures, including the building performance? And what are the most important measures?
3. How improving the thickness of external wall insulation layer in buildings could affect the building performance?
4. How replacing the insulation layer of the external wall might affect the building performance measures individually?

Expected Results

Relative reduction of the energy consumption regarding improving the thickness of the external wall insulation layer and enhancing the U-Value of the eternal wall. Facing uncertainty regarding the effects of using better insulation layer of the external wall in measures such as CO2 emission and the perceived indoor air quality.

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Bardage, S. L. (2017) *Performance of buildings*, *Performance of Bio-based Building Materials*. Elsevier Ltd. doi: 10.1016/B978-0-08-100982-6.00006-9.

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12th of June 2018

Signature of the 1st Supervisor

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Abstract

There are several tasks which are performed by buildings. These are usually referred to as building functions. The building performance is a characteristic of a structure that demonstrates how well the construction performs its functions. The efficiency of the construction method could also be affected. The building's efficiency relies on the building's reaction to external loads or shocks.

The building performance measures can be described as energy consumption, CO2 emission, perceived indoor air quality, renovation cost, cost of improving indoor air quality, living quality, and ownership. Taking the above measures into account, the building performance is greatly influenced by measures such as energy consumption, CO2 emissions, and perceived indoor air quality. Thus, building performance can enhance significantly by boosting the three specified measures.

The case studied which are discussed in this thesis are a residential building and a school located in Helsinki. The difference between the three indicated measures such as energy consumption, CO2 emission, and perceived indoor air quality is argued before and after renovation. The renovation process is limited only in changing the external wall composition of both case studies, which is one of the essential steps in the renovation. Both cases studies are modeled in IDA ICE software, and discussions are based on the outcome results of the respective software.

Both building element characteristics of case studies are extracted from the typical original design values of buildings book in Finland 2018 called as Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja. The legal requirements and standards which have to be satisfied after the renovation process are based on the national building code of Finland.

By improving the external wall insulation layer thickness from 75 mm to 170 mm in the apartment and 90 mm to 190 mm in the school, the energy consumption decreases by 10.96% in the apartment and 13.34% in the school. Moreover, due to the improvement of the external wall insulation layer, the external wall U-Value has been reduced for 61.71% and 63.49% respectively in the apartment and the school. However, there is no significant changes in the CO2 emission and perceived indoor air quality measures since the airflow influences the mentioned measures which is not studied in this research.

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1 Literature Review

1.1 Energy Performane

Building performance relates to functionality efficiency and its environmental and user influence. The building performance is mostly influenced by essential elements like the engineering and architectural design, building material selection, site environment, energy consumption, and sustainability (Bardage, 2017). On the other hand, building performance initiatives aim at enhancing the energy performance of current structures through an extensive strategy to energy, comfort, and productivity improvement.

The measures which the building performance could be evaluated are energy consumption, CO2 emission, perceived indoor air quality, renovation cost, cost of improving indoor air quality, living quality, and ownership. The most important measures which the building performance is significantly getting influenced are energy consumption, CO2 emissions, and perceived indoor air quality. Therefore, by improving the three specific measures, building performance can considerably improve.

Depending on the assessment condition of a building which is going to be renovated, the depth of renovation may get determined. It may be done solely by improving the insulation layer of external walls, performing deep renovation including the external wall insulation layer improvement, enhancing the roof and floor insulation layers, utilizing triple glazing and insulated doors, using shading devices in upper floors, improving the central heat system, developing more efficient ventilation system, etc.

Due to the severe climate condition in countries like Finland, the outer layer of the external wall should be maintained well to avoid damages and to fall apart. Therefore, renovating the external wall seems the most common stage in the renovation process. Since then, the thickness of the insulation layer of both case studies will get enhanced based on the Structural Energy Efficiency in Renovation (Ojanen, Nykänen and Hemmilä, 2017), and the results will be studied in three measures called as energy consumption, CO2 emission, and perceived indoor air quality.

The simulation process takes place in IDA ICE software. The IFC file of both cases studies have been imported to the IDA ICE. To avoid repetitive work, the procedure of importing and adjusting parameters in IDA ICE software have been explained for the apartment case study (Section 5.1.3), and it is not repeated in the school case study section.

1.2 Energy Consumption

The construction is one of the leading energy consumers. As stated in the United Nations Environment Programme (UNEP, 2012), the amount of 30 percent to 40 percent of global energy consumption is accredited for the construction industry, and by taking into account the construction and demolition, it can reach up to 50 percent. Regarding the International Energy Agency (IEA, 2018), the amount of energy supplied to the construction industry in 2010 was proximate to 23,7 PWh, and in 2040, it could touch 38.4 PWh.

Allouhi *et al.*, (2015) also explain that the construction industry is regarded as the most significant single participant in global energy consumption and a decent perspective of the energy consumption definition and framework in buildings are therefore vital for forming appropriate long-term initiatives on energy. Energy consumption is one of the significant issues in the construction sector, whereas climate change describes a current energy consumption and development paradigm. Also, energy is among the most severe geopolitical and economic concerns. Energy saved is cheaper than every new production, excluding reliance on energy inputs. Buildings are accountable for the EU's most significant contributor to energy consumption.

Furthermore, there is a tight connection between energy and economic development, and hence a proper understanding and constant monitoring of energy consumption are necessary, which can only be accomplished by quantifying and categorizing it by sector and the end user also the most significant hurdles of twenty-first-century energy advancements are undoubtedly guaranteeing energy supply and reducing the impact on the environment so then assessing previous data and predicting the future energy consumption patterns are essential steps for supply concerns methods and formulating future energy production (Allouhi *et al.*, 2015).

(De Silva and Sandanayake, 2012) points out the five most critical factors affecting building energy consumption under the name of climate, building-related physical features, occupant-related attributes, building system-related elements, and socio-economic and legal features.

1.3 Perceived Indoor Air Quality

The indoor air quality is predominant human attention. During a lifetime, more than half of the needed body's intake is breathed in indoor spaces. Based on the recent study by Sarigiannis, Gotti, and Karakitsios (2018), around 90 percent of European citizens spend indoors, in their residences, working environments, schools and public areas in modern society. About two-thirds of the mentioned time estimated to be spent at home (Sarigiannis, Gotti, and Karakitsios, 2018). Among the health threats in households, mold growth, Indoor Air Quality (IAQ), convenience at home, moisture, noise, climate indoors, hygiene appliances absence, Volatile Organic Compounds (VOC), and sewage equipment are the important ones.

The quality of the construction due to the construction material used and equipment, the size or the design of a particular residence, are either actively or passively linked to many health issues (Sarigiannis, Gotti and Karakitsios, 2018). According to (de Oliveira Fernandes *et al.*, 2008) priorities for poor IAQ diseases were found to be allergic and asthmatic diseases, lung cancer, chronic obstructive pulmonary disease, respiratory infections in the air, cardiovascular mortality and morbidity, odor and irritation symptoms. Although the quality of the indoor environments has undeniably improved throughout the last 20 years, many harmful health effects still exist with regard to these areas. The fact that the health effects of the indoor environment have been recognized rapidly over the past few years has made this clear.

Debates in the past year concentrated on indoor environmental quality components (mainly particulate matter, bioaerosols, and chemical products) and comfort indicators (temperature, airflow, and moisture). Despite scientific advancement in understanding the difference between the indoor environment and health, however, such attempts are still categorical, studies often address a small number of potential health pressures as well as related health problems, along with exposure to VOCs, breathing problems and illness (Sarigiannis, Gotti and Karakitsios, 2018)

The science community has recently started to consider the link between the built environment and public health as a complicated relationship among building employees with a variety of physical, chemical, biological and socio-economic factors (Sarigiannis, Gotti and Karakitsios, 2018). According to the 40 experts from 18 countries hosted by international consultation in the World Health Organization in Geneva (WHO, 2012), in order to help to improved health, and finally to contribute to the development of the global "healthy housing" guidelines that help to avoid a broad array of illnesses and unintended injuries, this new embedded view should lead the development of ' primary preventive ' measures relating to building housing, refurbishment, use and support.

1.4 Indoor Pollutants

Carbon Dioxide (CO2), which comes from human and animal breathing, is by far the most popular indoor pollutant (Ramalho et al., 2015). It is a colorless gas that also comes through both the combustion of automobiles from the outside to the inside. The indoor air quality is a measure of personal comfort. A higher proportion indicates the defect of adequate fresh air indoor air. Modern construction embedded device has a CO2 sensor system that allows indoor density to be controlled. The air conditioning system generally is performed automatically by the sensor data, so that the CO2 absorption can be moved with fresh air.

Asbestos is commonly utilized in construction materials with thermal strength in developing counties (Sakhi *et al.*, 2019). The asbestos is widely used in roofs, ceilings, walls, building insulating parts, friction products, heat resistance fabric, etc. Moreover, the purification of construction materials can produce asbestos.
Lead is another significant indoor air pollutant. In developing countries, it is generally utilized in construction materials like wall paints, water pipes, etc. Therefore, it can be migrated to the human being body from paint, drinking water, food, contaminated soil, and dust (Tham, 2016).
The other indoor air pollutant is carbon monoxide (CO). It is an odorless substance which could find in gas and liquid phases. Inside a building, it could exist in unvented kerosene heaters, wood stoves, fireplaces, gas stoves, or faulty chimneys are

available (Susan A. Rice and Associate, 2004). In general, the combustion of automobiles, smoking, etc. also migrate it from outside to inside.

Radon is a tasteless, colorless, odorless, and natural radioactive inert gas (Pampuri, Caputo and Valsangiacomo, 2018). Its presence is hard to detect. It mostly exists in materials such as granite, sand, cement, slag, brick, soil, and gypsum in particular (Pampuri, Caputo and Valsangiacomo, 2018). The rocks also include Radon which moves upward. Therefore, it might expose to the building and enter internal spaces. (Pampuri, Caputo and Valsangiacomo, 2018) explains that the natural stone material, artificial brick, brick and ceramics, concrete and gypsum also release radon natural stone (Marble, granite).

Benzene is a colorless volatile gas (Aung *et al.*, 2019). It gains a unique aroma that is mildly water soluble. It is usually used as an organic solvent. Toluene and xylene are also benzene congeners, which are found in paint, coating, glue, butty, thinner, adhesives, etc. (Aung *et al.*, 2019).

Ammonia exists in the gas phase. It is colorless with a volatile and powerful irritating aroma and high solubility (Tham, 2016). Ammonia is mostly used in constructing concrete walls. It is often added to the concrete as an anti-freezer element in cold climate counties and in construction works which are held during the winter season. In the utilization phase, due to internal temperature fluctuation and humidity changes, Ammonia might be released from the wall. It may lead to increase the Ammonia concentration in internal ambient (Santamouris, 2007).

(Liu, Miao and Li, 2019) notes the formaldehyde as another essential indoor air pollutant. Formaldehyde is the primary source of adhesive. The wide range of glues is made of formaldehyde, which is often used in wood panels (Liu, Miao and Li, 2019). Formaldehyde pollution, therefore, comes from inside decoration panels. Formaldehyde is also present in the laminated floor, fiberboard of medium density, plywood, blackboard particles, and other panels (Liu, Miao and Li, 2019).

The primary source of volatile organic compounds (VOC) is the building materials and furniture (Harb, Locoge and Thevenet, 2018). A significant number of VOCs are also released into indoor air in wood-based panels. The maximum range of volatile organic compounds (VOC) has also been emitted from the vinyl and Poly Vinyl Chloride (PVC) floors. Approximately 200 types of VOCs are found, for instance, aliphatic, aromatic and halogenated hydrocarbon, etc. (Harb, Locoge and Thevenet, 2018).

(Aung *et al.*, 2019) states that indoor pollution is a common problem with biological pollutants. Mold, pollen, mites, dust, bacteria, etc. are included. Various sources for such pollutants are available in dwellings. It also explains that plants cause pollen, while viruses and bacteria are passed down to humans and animals. Mold, mildew pollution could be caused by the air conditioning unit. The increased growth of biological pollutants can be caused by improper ventilation, poor airtightness, higher relative humidity, and faulty jointing.
Pesticide products are frequently used as a disinfected insecticide (Thomas *et al.*, 2019). It is used to regulate various pollutants such as microbes and fungi. It comes in spray form, liquid, powder, and so on. The product is toxic.

(Santamouris, 2007) points out that the increase in indoor mixtures of CO, VOC, and Particulate Matter (PM) contributes significantly to indoor smoking. The particular matter (PM) is the total amount of all liquid and solid particulates, many of which are dangerous suspended in the air. Accordingly, the indoor densities of smoke, ethylbenzene, toluene, and xylene (BTEX), which are far more critical than the participation from nearby traffic sources, are dominated by the existence of Secondhand Smoke (SHS). In addition to SHS, various other indoor sources contribute to an increased risk of cancer. The median levels of pollutants that are detected both indoor and traffic sources in European residences (CO, NO2, PM10, and PM2,5) is shown in figure 1 whereas the average BTEX density in residential buildings in Europe is illustrated in figure 2.

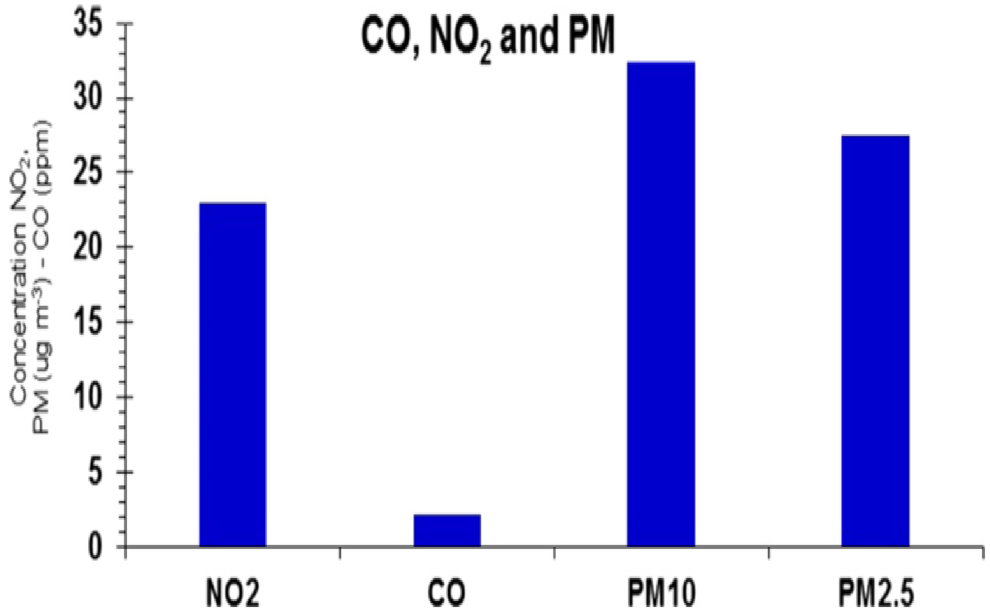


Fig. 1: The average concentration of CO, NO2, particulate matter (PM)10, and PM2.5 in residential dwellings in Europe.[1]

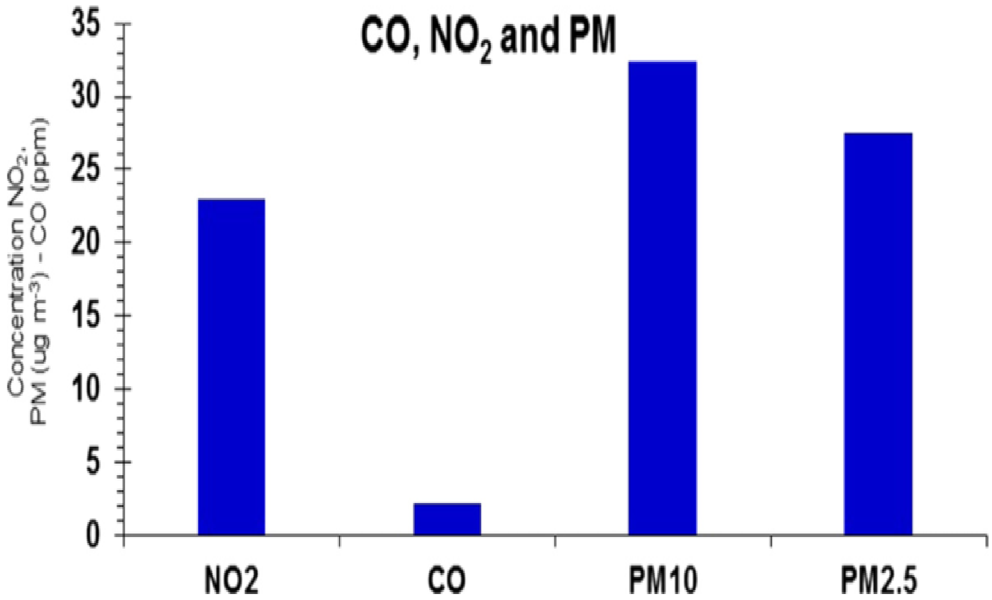


Fig. 2: Median density in residential residences in Europe of CO, NO2, particulate (PM)10 and PM2.5.[2]

[1] Reference: (Sarigiannis, Gotti and Karakitsios, 2018)
[2] Reference: (Sarigiannis, Gotti and Karakitsios, 2018)

1.5 Global Health Influence and Performance

European countries are shifting their demand from traditional to energy-efficient buildings. They start paying more attention to the environment and comfort indoors, as they affect public health and performance. The collaborative council developed a list of surveys that provided an optimum preference for indoor environmental conditions. In highly energy-efficient residences, Europeans do not accept weak indoor environmental conditions. Several articles noticed the effects on human health and work performance of poor indoor environmental conditions.

(Tham, 2016) argue in such a way that there are four significant criteria indoor environments such as thermal comfort, indoor air quality, acoustic and building lighting system. Thermal comfort is connected directly to the performance of the workers. Change in a few degrees of air temperature could influence the typing, ability to concentrate on people, learning quality, and signal identification (Thomas *et al.*, 2019).

One of the most significant factors for human health is indoor air. Moreover, it has already demonstrated that there is a close relationship between indoor air quality and public health. (Sarigiannis, Gotti and Karakitsios, 2018) notes that the indoor air pollutant sources are complex to detect. Prevalent indoor air contaminants include carbon dioxide, carbon monoxide, total volatile organic compound, ammonia. The increase in CO2 concentration may result in headache, dizziness, respirability, sweating, difficulty with vision, coma, vomiting, hearing problems, etc. (Wenden, 1981).

The effect on different concentration levels of carbon monoxide (CO) is different. First, higher levels of headaches, dizziness, and confusion. Secondly, chest pain and heart disease are at a low concentration. Last but not least, the average concentration can reduce vision and brain functions. CO also causes the human body to absorb oxygen (Harb, Locoge and Thevenet, 2018).

The Volatile Organic Compounds (VOC) are hazardous to the human body. It causes specific issues such as eye, nose, and throat irritation, liver and kidney damage, etc. (Liu, Miao and Li, 2019). Cancer in the human body is supposed to be found due to VOCs. Formaldehyde may cause nose, mouth, throat, skin, and alimentary canal cancer (Aung *et al.*, 2019). Low dosage contact can result in chronic respiratory diseases, syndrome of pregnancy, etc. Headache, dizziness, and vomiting may result from moderate toxicity (Aung *et al.*, 2019).

(Harb, Locoge and Thevenet, 2018) states that alkaline vapors are ammonia. It corrosively weakens human organs. For the building of associated disease, molds are responsible. Some molds produce organic volatility and smell. Exposure to such molds for a long time has a public health impact (Sakhi *et al.*, 2019). Building materials, books, foods, and towels are also damaged. Between 52 to 58 percent of dwellings have these kinds of problems in Finland, and sadly, children are the most affected target groups (Liu, Miao and Li, 2019).

Flaked lighting, blinking, contrast, poor position, etc. can include poor lighting (Kelly and Fussell, 2019). Because of the weak lighting system, employees feel slow and fatigued. The precision of the work, production, quality, and quantity are also reduced. Theoretically, different lights can enhance the performance of the work. After a change of the lighting system, 6 percent of the efficiency of postal workers increased, even so, the reading performance of buildings with daylight and a bigger window is improved from 16 to 26 percent (Kelly and Fussell, 2019). Weak illumination can lead to eye strain, impaired vision, and headache.

(Ryu and Song, 2019) states that In the open office, noise is by far the most significant problem. Higher acoustics can increase stress, frustration, disease, and employee turnover in the open office. It also causes physical problems like headache and heart disease. (Ryu and Song, 2019) also found that the concentration, memory, and accuracy improved as conventional noise is reduced. Moreover, a noisy environment has a significant impact on the human psychological condition.

1.6 Reason for Investigation

Building performance is an integrative criterion, including specific measures like energy consumption, CO2 emission, and indoor air quality. The primary reason for this research is the assessment, in order to form its explicit importance, of the particular interventions under the term building performance.

Both apartment building and the school are the typical ordinary buildings in Finland concerning the year of construction and material composition and characteristics of the building elements among existing residential and educational buildings. Another reason for the research is to cover more areas of the same Finnish buildings.

The energy consumption, CO_2 emission, and indoor air quality are the most concerned measures among another measure such as renovation cost, indoor environment quality cost, living quality, and ownership which are included under the building performance. However, from an economic point of view, indeed, the cost of renovation and improving the indoor environment are one of the primary measures which have to be concerned. Analyzing the effect of the most three common measures is another reason for this study to be more comprehensive.

All in all, this study attempts to address the most prevalent steps that are incorporated in the construction of most of Finland's present housing and education structures to widen the vital region of studies.

1.7 Research Objectives

The objectives in any renovation process could be taken into account as sustainability, legal requirements, economic, trend, keep or increase value, social aspects, technical goals, religion, etc. Indeed the economic objectives are the most concerned objectives for the owners or client. Therefore the economic concerns are taken more under discussion and assessment concerning other objectives.

In this research, the economic, sustainability, and legal requirement objective will be studied for the two case studies. The energy consumption measure discusses the economic objective as well as the legal requirement objective, whereas the perceived indoor air quality includes the sustainability objective.

The amount of specific U-Value of the external wall which has to be fulfilled after renovation or the determined amount of energy in terms of KWh/m^2 in case of deep renovation including improving ventilation and heating system based on the national building code of Finland is considered as legal requirements while assessing the energy consumption measure. Furthermore, the amount of running (operational) CO_2 emission after renovation will be investigated under the CO_2 emission measure.

2 Methodology

2.1 EQUA Simulation AB and IDA ICE

EQUA Simulation AB is a Swedish corporation devoted solely to the growth of state-of-the-art building and tunnel simulation tools. It was founded in 1995, though it launched in the middle of 1980s. The firm was headquartered in Stockholm (Sweden). It delivers its products and services to leading clients internationally (EQUA Simulation AB, 2019).

(EQUA Simulation Technology Group, 2014) explains that the IDA Indoor Climate and Energy (IDA ICE) is an energy simulation software and is one of the EQUA Simulation AB software among IDA ESBO (IDA Early Stage Building Optimization), IDA Tunnel and IDA RTV (IDA Road Tunnel Ventilation). The IDA Indoor Climate and Energy (IDA ICE) application is an energy simulation software that is designed and created by the EQUA simulation AB technology group which has been utilized to analyze the models in this research (EQUA Simulation AB, 2019).

IDA ICE is a new class of simulation tool which brings building performance to a different scale. The building, its systems, and its controllers are precisely designed to ensure maximum feasible energy consumption and convenience for occupants and is a precise and dynamic multi-zone simulation application, which is creative and trustworthy year-round, for indoor thermal testing and energy consumption for the entire building (EQUA Simulation Technology Group, 2014).

The IDA ICE interface makes it easy to construct and visualize simple and advanced situations and still offers full versatility for experienced users. The model in each stage can get improved with 3D graphical and tabular feedback. The IDA ICE accepts all 2D and 3D prevalent CAD (Computer-Aided Design) files and supports IFC (Industry Foundation Classes) models, e.g., ArchiCAD, Revit, AutoCAD, and MagiCAD Architecture (EQUA Simulation AB, 2019).

The detailed building information which is required for the simulation process such as location, climate, building elements material, site shading and orientation, thermal bridges, ground properties, infiltration, pressure coefficient, extra energy and losses, system parameters, etc., will be imported. Then the software will simulate the building based on input data and provides the analyzed information like energy calculation and results, simulation summary, time series diagrams, system energy reports, etc.

Buildings separate the interior from the exterior environment. The difference between the comfortable condition of the indoor environment and the outdoor environment directly impacts the amount of energy consumed by the dwelling. Moreover, the climate has a significant effect on building energy consumption in countries with severe climate condition such as Finland.

The potential of building elements to minimize thermal exchange between indoor and outdoor ambiance emerges into the second major factor influencing the building energy consumption. The energy consumption decreases by mitigating the heat transfer coefficient of the building elements. The building's heat loss is calculated mainly through evaluation of thermal conduction, thermal convection, thermal ventilation, etc.

The number of inhabitants, customs, lifestyle, religion, and all aspects that frame human attributes and morals all directly affect the building energy consumption. These variables vary by region and therefore need to be taken into account when considering energy consumption.

The highest percentage of energy being used in a house or building is utilized in indoor air heating or cooling. Cooking also needs a considerable amount of energy and is a cost which can not be avoided. Furthermore, homes have several energy-intensive electrical appliances. Additionally, buildings have several energy-intensive electrical appliances. Lighting an essential part of any indoor environment is often less energy consumption than other electrical appliances.

The amount of energy consumption in buildings is also influenced by the economy, society, and legal requirements in any country. The socio-economic pattern of energy consumption in society shapes the nation's vogue and affects the amount of energy consumption directly. Another critical factor in reducing energy consumption is the legal requirements set by governments to mitigate energy consumption.

The renovation process is only concentrated on the improving U-value of external walls in both case studies. The energy consumption will be compared before and after renovation in the building and the school. The renovation process takes place by improving the insulation layer of the external wall composition.

2.2 Case Study (Apartment)

2.2.1 Location, Typology, and Characteristics

The apartment which is going to be studied is located in Piispantie 5, 00370, Helsinki, Pitäjänmäki, Finland. In the area of almost 53 m^2, there are two bedrooms and a kitchen as it is shown in figure 3. The building was constructed in 1964.

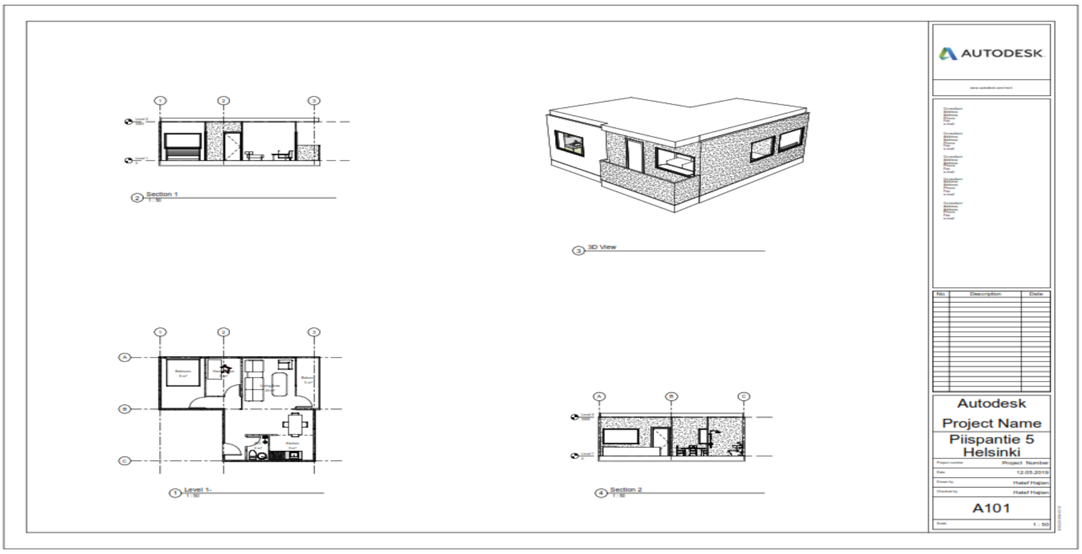


Fig. 3: The 3D, plan, and section views of the apartment.[3]

The apartment is placed on the first floor of a block of apartments, located in the North West side of Helsinki. It has got three floors, concrete structure, no elevator, and no laundry rooms as it is illustrated in figure 4.

Fig. 4: Apartment[4]

[3] Referenece: own figure.
[4] Referenece: own figure.

According to table 1, the total number of residential buildings which have been constructed in the 1960s is about 42,000. Although, the number of dwellings which received the building permit in the next decade is slightly more, since the number of newly built apartments is close in two neighboring decades, is it reasonable enough to consider the building as a case study and analyzing the building performance.

Type of building		Construction material							
		Total	%	Stone	%	Wood	%	Other,unknown	%
Buildings total	1960	832 460	100,0	55 008	6,6	777 452	93,4	..	..
	1970	837 948	100,0	83 125	9,9	754 823	90,1	..	..
	1980	934 845	100,0	120 608	12,9	814 237	87,1	..	..
	1990	1 162 410	100,0	168 818	14,5	956 626	82,3	36 966	3,2
	2000	1 299 624	100,0	194 725	15,0	1 040 189	80,0	64 710	5,0
	2010	1 446 096	100,0	229 311	15,9	1 163 138	80,4	53 647	3,7
Residential buildings	1960	725 932	100,0	25 586	3,5	700 346	96,5	..	..
	1970	768 204	100,0	58 287	7,6	709 917	92,4	..	..
	1980	842 662	100,0	89 490	10,6	753 172	89,4	..	..
	1990	1 004 809	100,0	121 291	12,1	870 314	86,6	13 204	1,3
	2000	1 120 714	100,0	138 357	12,3	935 928	83,5	46 429	4,1
	2010	1 234 602	100,0	159 441	12,9	1 039 706	84,2	35 455	3,7
Other buildings	1960	106 528	100,0	29 422	27,6	77 106	72,4	..	..
	1970	69 744	100,0	24 838	35,6	44 906	64,4	..	..
	1980	92 183	100,0	31 118	33,8	61 065	66,2	..	..
	1990	150 249	100,0	47 394	31,5	82 661	55,0	20 194	13,4
	2000	178 910	100,0	56 368	31,5	104 261	58,3	18 281	10,2
	2010	211 494	100,0	69 870	33,0	123 432	58,4	18 182	8,6

Tab. 1: Number of buildings by construction material 1960-2010.[5]

The building typology is categorized according to section 4.3.6 of the Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja which means “typical original design values for existing old buildings” in English. The building is a three-story concrete block of apartments (‘Tyypillisiä olemassa olevien vanhojen

[5] Official Statistics of Finland (OSF): Buildings and free-time residences [e-publication]. ISSN=1798-6796. 2010, Appendix table 4. Number of buildings by construction material 1960-2010 . Helsinki: Statistics Finland [referred: 13.5.2019]. Access method: http://www.stat.fi/til/rakke/2010/rakke_2010_2011-05-26_tau_004_en.html

rakennusten alkuperäi- siä suunnitteluarvoja’, 2018). The element characteristics are thus shown in Table 2.

Building Element	**Characteristics**
Foundation	Reinforced concrete
External Wall	Concrete (Thk. 70 mm) + Thermal insulation (Thk. 75 mm) + Concrete (Thk. 50 mm)
Internal Wall	Concrete (Thk. 70 mm)
Floor	Concrete slab (Thk. 100 mm) + Thermal insulation (Thk. 50 mm)
Roof	Leca crushed stone + load bearing plate (Thk. 190 mm)

Tab. 2: The apartment building elements specifications.[6]

Since the Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja does not specify the type of doors and windows, the windows and doors are assumed the most frequently used ones as two-pane glazing and rendered respectively.

The external wall of the building has been built with sandwich panels. A sandwich panel is a construction component composed of slender layers of robust material, kept in a specific form to the form that bread slices shape a filling sandwich (Shaban and Mazaheri, 2019). They explain that the selection of materials is influenced by weight, strength, durability, and costs. Sandwich panels are more robust than a single strong product and withstand pressures with a lower overall weight. The unit resistance largely relies on the intensity and density of the adhesive bond between the components.

These units can be intended for building walls, floors, or roofs of buildings. The outermost layers of a sandwich panel are often built of a beach for the construction. The layers are attached to a core of sandwich panel, which insulates and tightens the board, with adhesive and strain. Cores consist of a broad range of components. The core often involves an expands such as polystyrene or polyurethane foam material (Shaban and Mazaheri, 2019).

[6] Reference: Energiatodistusopas 2018 Vanhojen rakennusten tyypillisiä suunnitteluarvoja.

The external wall composition has extracted from the Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja and the structural energy efficiency in the construction report. The thickness of the thermal insulation layer is considered as 75 mm (Ojanen, Nykänen and Hemmilä, 2017).

Since the apartment is located on the first floor, there are outdoor air and indoor air on both sides of the floor slab. Therefore, the thermal insolation layer is considered on the floor. However, in intermediate floors due to avoiding the heat caused by solar radiation, especially in summer condition to get trapped in the floor, there is no thermal insulation layer considered on the floor.

Moreover, there is no temperature difference between intermediate floors, so there is no need to insulate them from each other. This may not affect energy consumption but have a significant influence on the internal temperature. It is, therefore, as it is shown in figure 2, the upper floor glazings are fully provided by shading devices.

2.2.2 Renovation Objective and Approach

The renovation process aims to lessen the energy consumption by reducing the heat transfer coefficient (U-value) of structural members through replacing more heat transfer resistant doors and windows as well as adding better insulation layers onto the exterior walls and roof.

The 3D model of the apartment was initially prepared by Autodesk Revit 2018 in order to access drawings, accurate dimensions and, also the IFC file to feed into the energy simulation software called IDA Indoor Climate and Energy (IDA ICE) as it is shown in figure 5.

Among the several objectives of the renovation process, the energy consumption of the apartment is going to be measured before, and after the rehabilitation. The simple method of calculation is to compute the U-value of the structural elements before and after the rehabilitation process and reckon the amount of saved energy by subtracting before and after renovation energy losses of the apartment. Because many certain factors are affecting building energy consumption such as indoor and outdoor temperature, climate, daylight, shading, thermal bridges, etc. those are considered by the energy simulation software IDA ICE, to achieve more precise results. Therefore, the model is analyzed in the mentioned software.

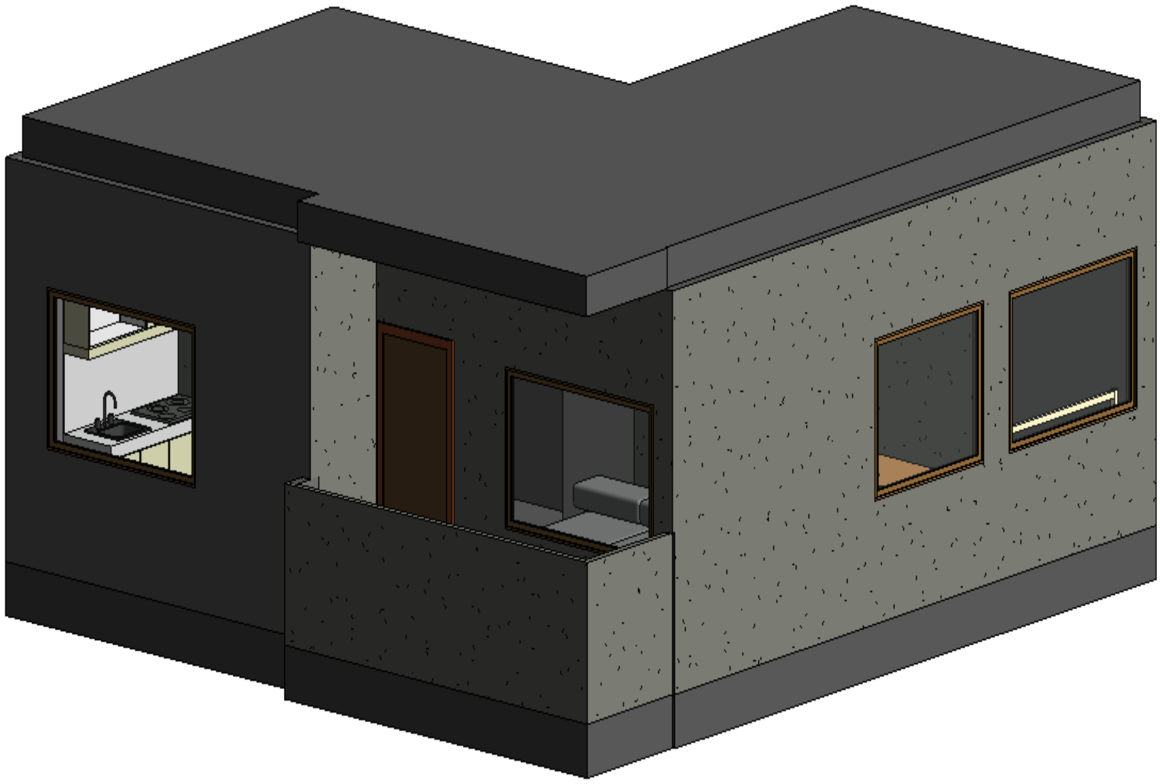


Fig. 5: The rendered 3D model of the apartment.[7]

According to the decree of the Ministry of the Environment on Improving the Energy Performance of Buildings Undergoing Renovation or Alteration in Finland (Kimmo Tiilikainen, 2016), an economically feasible solution is a cost-effective alternative based on examination. For economic feasibility, for residential buildings, the examination period shall be thirty years, and for other buildings twenty years if the ordinary building or system life cycle or part shall be as good as that. It also mentioned that a renovation is significant if the total cost of the renovations for the structure envelops or technical building systems based on the costs of reconstruction is greater than 25 percent of the building's value, excluding the value of the land on which the building is located. A renewal of the building is essential.

The decree of the Ministry of the Environment on Improving the Energy Performance of Buildings Undergoing Renovation or Alteration in Finland (Kiuru and Kauppinen,

[7] Reference: own figure.

2013) points out that The following conditions have to be complied with when an increase in building energy efficiency is scheduled and implemented through the construction component:

1. External walls: The initial U-value into 0.5 but not greater than 0.17 W/(m2 K). When the desired usage building has altered, 0.60 W/(m2 K) or better is the original U-value into 0.5.
2. Roofs: The primary U-value into 0.5, but does not exceed 0.09 W/(m2 K). However, if the expected use of the building is switched, 0.40 W/(m2 K) or better is the original U-value into 0.5.
3. Floors: As far as feasible, energy efficiency is enhanced.
4. The U-value must be 1.0 W/(m2 K) or higher for the new windows and internal gates. The thermal resistance should be enhanced as far as feasible when repairing old windows and outside doors.

Considering deep renovation including improving the U-value of building elements, ventilation system renewal, central heating system improvement, etc., the total energy efficiency of the apartment building has to be reached to130 kWh/m2 K (primary energy).

For two reasons, the renovation of the outside walls is vital. First, because of the severe weather conditions in Finland they have included the greatest area between building elements and second, they must be well maintained to protect the building against the weather to prevent damage from external walls and the façades. Therefore, only the outside walls of both the residential construction and the school are taken into consideration in this research.

Practically, despite trying to avoid any space between layers of the external wall, while renovating it, there will be still gaps between layers. The gaps will affect the final U-value of the external wall. To avoid this in practice, the thickness of the insulation layer will keep slightly higher than the one, in theory, to compensate for the lack of final U-value amount in the external wall.

2.3 Case Study (School)

2.3.1 Location, Typology, and Characteristics

The school which is going to be studied is a typical school building, and it is located in Helsinki, Finland. It has four stories, and there are twelve rooms, including classrooms, laboratories, faculty rooms, restrooms, etc. on each floor. The 3D view of the school is shown in figure 6.

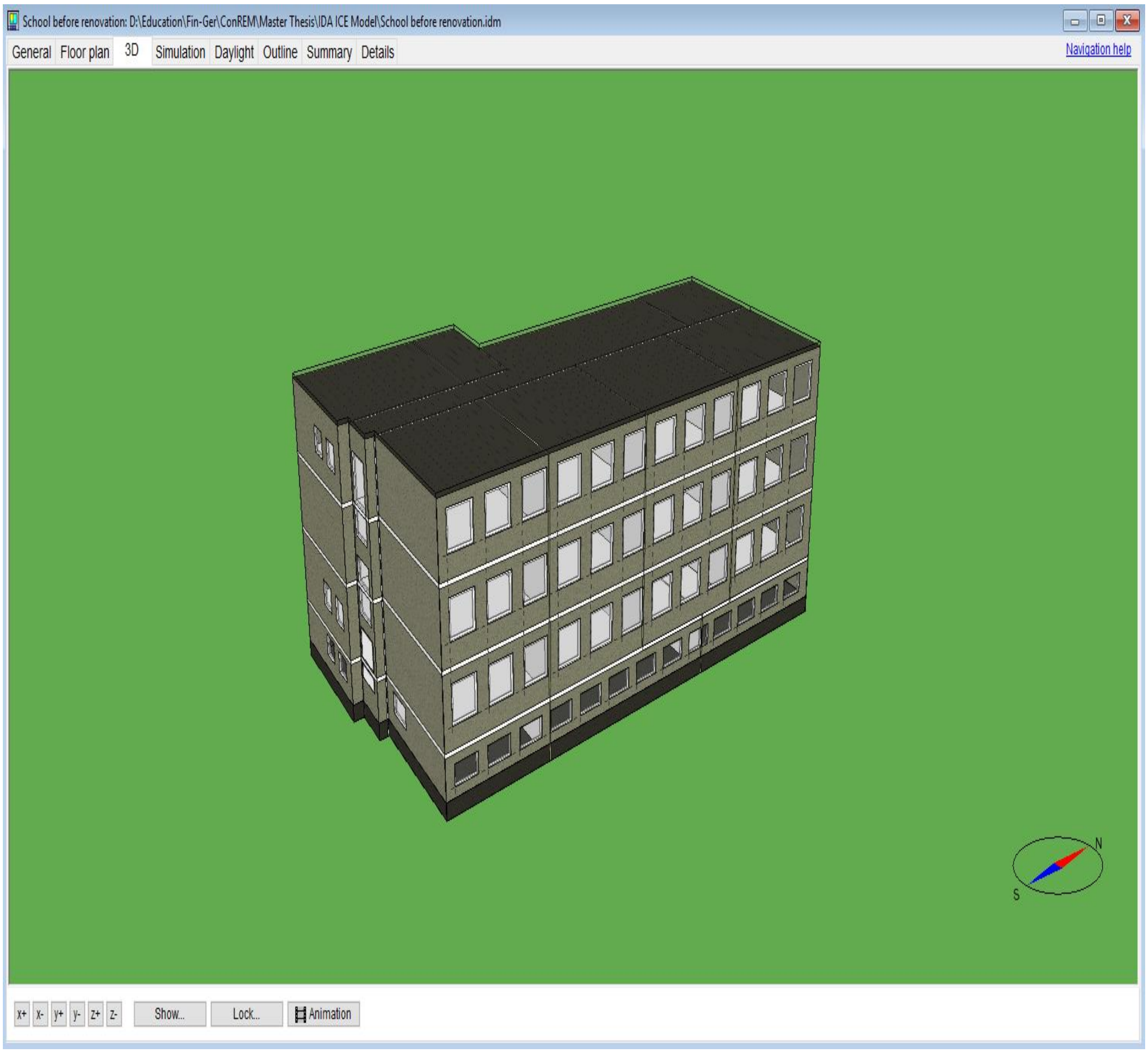


Fig. 6: The 3D view of the school.

The school was built in 1963. Its floor area is 2021 m², and the volume of the model on four floors is 6,273.7 m². The ratio of windows area to the area of the whole envelope is 11.8 %.

According to Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja, which means "typical original design values for existing old buildings" in English, the building element specifications are explained in table 3.

Building Element	Characteristics
Foundation	Steel Concrete Slab
External Wall	Painted concrete (Thk. 50-70 mm) + Thermal insulation (mineral wool) (Thk. 90 mm) + Concrete (Thk. 70-150 mm) + Screed Coating
Internal Wall	Concrete (Thk. 70 mm)
Ground Floor	Moisture-insulated reinforced concrete slab (Thk. 50 mm) + Thermal insulation + Plastic insulation plate below the gravel
Roof	Crackle + Triple blanket + Concrete (Thk. 50 mm) + Load bearing plate (Thk. 190 mm)

Tab. 3: The school building elements specifications.[8]

2.3.2 Renovation Objectives and Approach

The goal of the renovation process is to decline the amount of U-value of the external walls of the school. However, in the deep renovation process, the windows, doors, floors, roofs, central heating system, and, the ventilation system may get renovated. However, since the external wall renovation is the most common economic and effective way to decrease the energy consumption and leads to fewer energy bills amount, the objective of this study has been set for renovating external walls only.

The decree of the Ministry of the Environment on Improving the Energy Performance of Buildings Undergoing Renovation or Alteration in Finland (Kiuru and Kauppinen, 2013) points out that The following conditions have to be complied with when an increase in building energy efficiency is scheduled and implemented through the construction component:

1. External walls: The initial U-value into 0.5 but not greater than 0.17 W/(m2 K). When the desired usage building has altered, 0.60 W/(m2 K) or better is the original U-value into 0.5.
2. Roofs: The primary U-value into 0.5, but does not exceed 0.09 W/(m2 K). However, if the expected use of the building is switched, 0.40 W/(m2 K) or better is the original U-value into 0.5.
3. Floors: As far as feasible, energy efficiency is enhanced.

[8] Reference: Energiatodistusopas 2018 Vanhojen rakennusten tyypillisiä suunnitteluarvoja.

4. The U-value must be 1.0 W/(m2 K) or higher for the new windows and internal gates. The thermal resistance should be enhanced as far as feasible when repairing old windows and outside doors.

Considering deep renovation including improving the U-value of building elements, ventilation system renewal, central heating system improvement, etc., the total energy efficiency of the school have to fulfill 150 kWh/m²K (primary energy).

2.4 Interveiw (Research Method)

(Saunders, Lewis and Thornhill, 1970) points out that the research is described as the systematic implementation of the family used to provide reliable data on issues while the educational research is a systematic implementation of the family of techniques used to provide reliable data about issues of education.

According to (Saunders, Lewis and Thornhill, 1970), qualitative research relies on the creation by the rich description of meaning and comprehension. It can be a beneficial strategy for studying instructional issues that need to develop and understand complex social environments and the significance that individuals bring to their experiences in these environments (Saunders, Lewis and Thornhill, 1970). It also explores that quantitative research generally aims to explain, predict, and study relationships and to describe present circumstances or to examine potential effects or influences on identified results.

The research design could be qualitative, quantitative, or a mixed methods design. The qualitative research differs from qualitative research in several ways as they are mentioned in table 4.

Qualitative Research	Quantitative Research
Comprise and consider the human outlook	Population characteristics comparison or correlation
Less statement to population groups	Generalization to populations
Rich descriptions	Numerical summaries
Depth	Breadth
Small sample	Large sample
Designated methods of trusting the results	The recommended validity and reliability process

Tab. 4: The difference between qualitative and quantitative research.[9]

(Saunders, Lewis and Thornhill, 1970) comments that the interviews may be categorized as follows:

- Structured interviews
- Semi-structured interviews
- Unstructured or in-depth interviews

Structured interviews use a predetermined, ' standardized ' or identical set of issues and are referred to as interview questionnaires, whereas in semi-structured interviews the researchers will find a list of subjects and issues to cover, although these can differ from one interview to the other. While providing a specific organizational framework about the research subject, some questions may get skipped in particular interviews (Saunders, Lewis and Thornhill, 1970). It also explains that unstructured interviews are casual and they are used to explore general areas which the researcher is interested.

2.5 IDA ICE Software General Settings

At the start of the simulation process, the building geometry should be used to enter the software by either AutoCAD (DWG) file or IFC file. The IFC model file for the Autodesk Revit 2018 has supplied to the IDA ICE in this study. In the case of DWG files, the body of the building should get matched with the geometry of the floor plan.

Defining default construction is one of the main steps in the simulation process. The EQUA simulation technology group has provided additional data based on the region’s constructional regulations as an additional plugin into the IDA ICE. Since the building

[9] Reference: Saunders

is located in Helsinki Finland, the Finnish regulation file is installed as well. The additional file contains the database of construction material used in Finland.

For model attribution in the building interface element, the default building material should be specified. The process of attribution begins by determining individual building element types, as shown in figure 7.

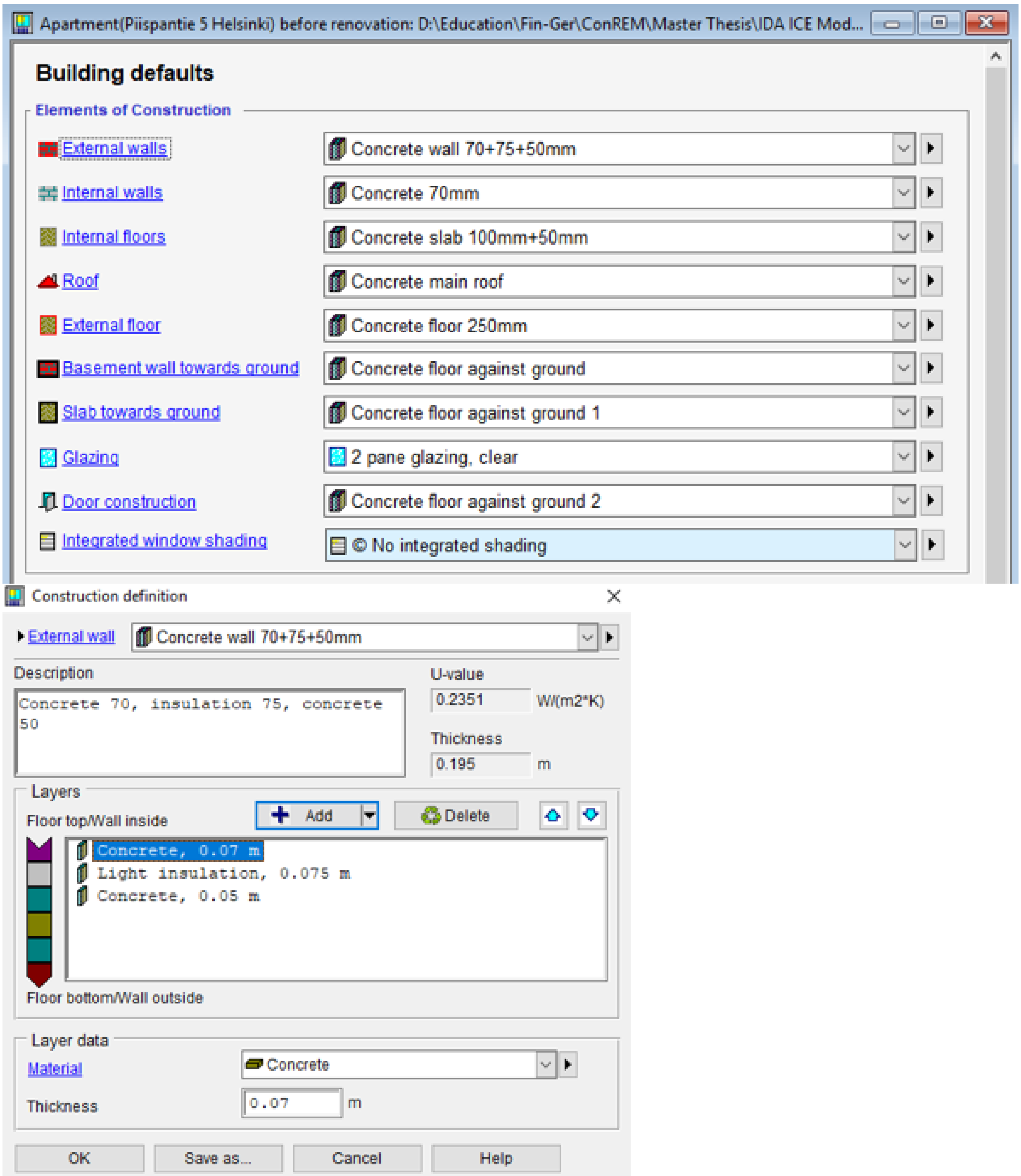


Fig. 7: The external wall building material attribution and construction definition before the renovation process.

As illustrated in figure 7, the external wall material construction is defined and based on the layer by layer material definition, the U-value and thickness will be automatically calculated. The layers can be added, deleted, or rearranged during the construction material determination process.

The floor plan must be split into a separate zone to obtain reliable energy simulation outcomes. Zone templates contain several default settings which automatically get attributed to a new zone. The zones either get specified in the IFC file or are will be set in IDA ICE software. The minimum and maximum desired temperature along with other parameters like mechanical supply and return airflow, relative humidity, level of CO2, daylight at workspace and envelope pressure difference are stated in control setpoints window as demonstrated in figure 8.

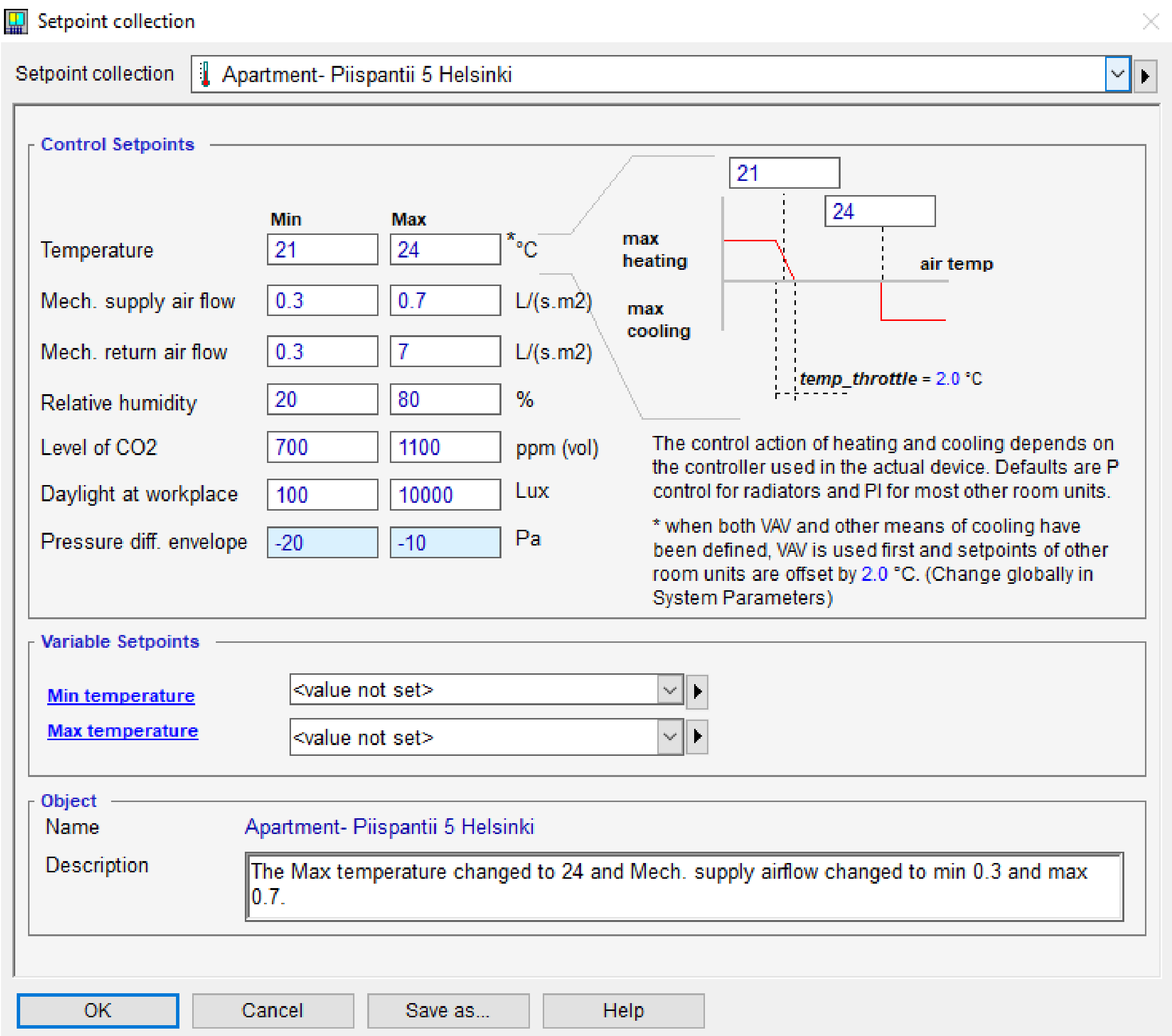


Fig. 8: Setpoint Collection window in IDA ICE software.

The mechanical supply and return airflow is the amount of air which enters and leave the envelope usually driven by a mechanical source. The relative humidity is defined as the amount of water vapor in the air, and it depends on the air temperature. As high as the temperature rises, the amount of water vapor, which can be stored in the air increases. Filling up the air with the maximum amount of vapor in a specific temperature raises the relative humidity to 100%, and the dew point will be reached. The water vapor above 100% relative humidity will not stay inside the air and will condensate into water droplets.

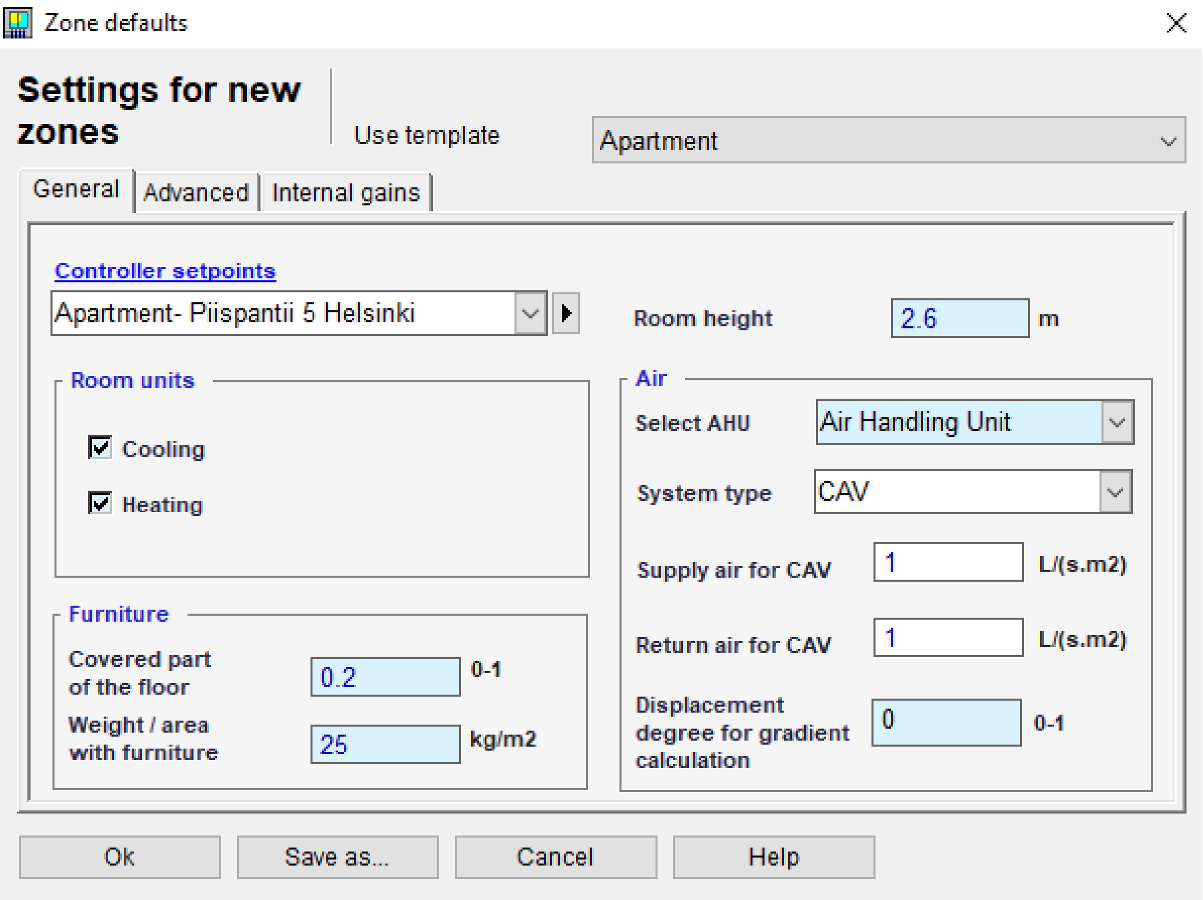


Fig. 9: Zone specification window.

The covered furniture area of the floor, the weight of the furniture and the height of the zone are the factors which should be specified in the zone specification window. The air handling unit has got only one option. The Variable Air Volume (VAV) which varies the airflow at steady air temperature and the Constant Air Volume (CAV) which provides constant airflow at various temperatures are is determined in the zone specification window. Since the system type has opted as the constant air volume (CAV), then the amount is defined as 1 L/(s.m²) by default.

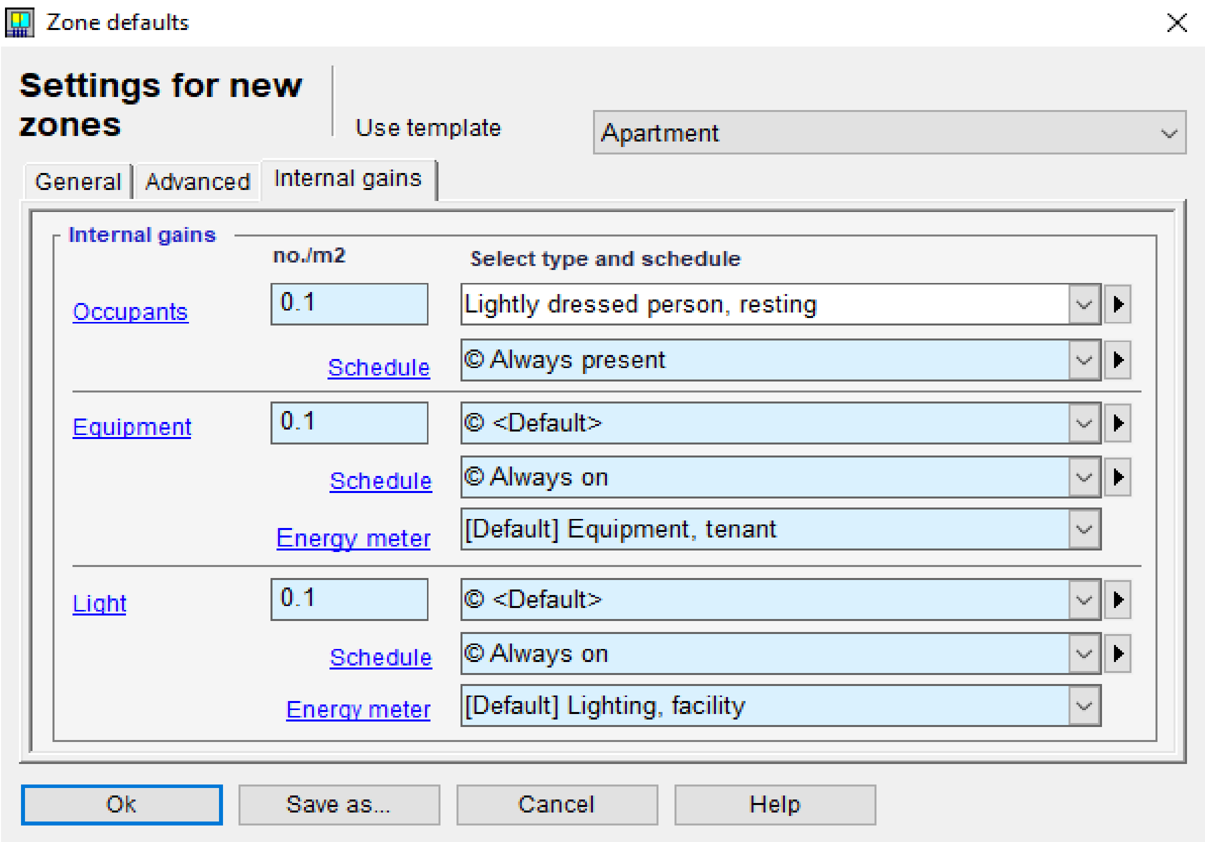


Fig. 10: Internal gains window.

There are two window types called standard window and detailed window and one opening type in the IDA ICE software. The glazing properties can be set in the glazing property window, as illustrated in figure 11. The integrated window shading includes the devices and how to control and schedule them. The characteristics of external window shading, which is defined as an element which provides shading to the building such as site fence, drop arm awning, or a balcony will be determined as well.

Regarding the glazings and windows, the following terms and their definition should be considered:

Shading Coefficient: (Kirimtat et al., 2019) states that the shading coefficient is an indicator of the heat insulation of glass windows or panels. This is especially important when assessing how well the glass protects the interior of a building from immediate sunlight. Several variables, including the color, density, and reflection of the glass, affect the measurement of the coefficient.

Solar Heat Gain Coefficient (SHGC): The SHGC is a portion of solar incident radiation that is entered via a window, which is transported straight and inhaled and then discharged inside (Košir et al., 2018). SHGC expresses itself as a range from 0 to 1. The less solar heat it transmits, the reduced the solar heat gain coefficient in a window.

Solat transmittance: solar transmission means radiation transmission to an interior across a window; the τ_e transmission factor radiation achieves values, from 0 to 1 (Kirimtat et al., 2019).

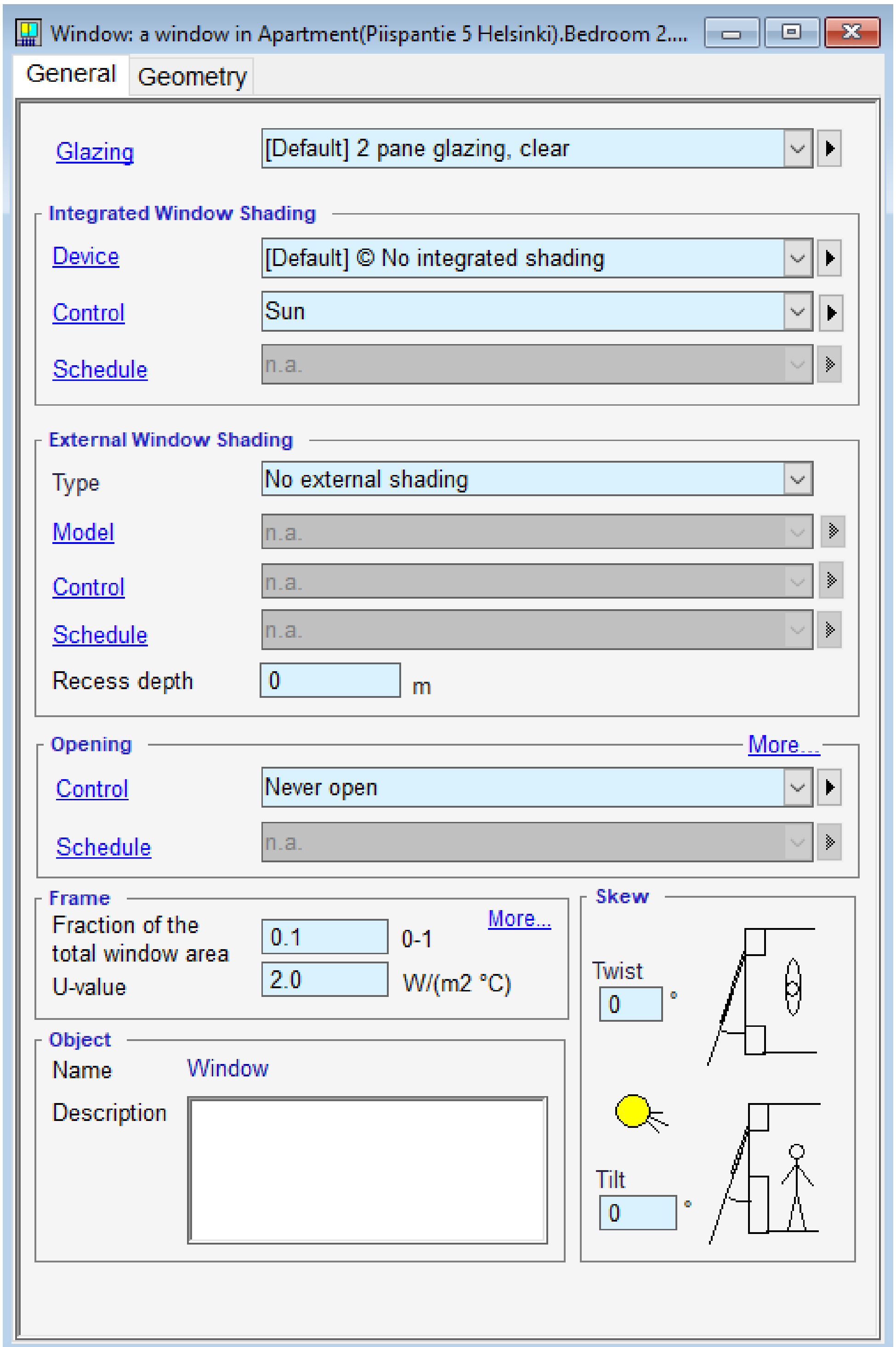


Fig. 11: Glazing property window.

Visible Transmittance: Visible Transmission (VT) is an optical feature indicating how much visible light is transferred (Košir et al., 2018). The VT ranges from 0 to 1 in theory. The larger the VT, the higher the brightness. To maximize daylight, a large VT is desired.

Emissivity: (Petrichenko, Ürge-Vorsatz and Cabeza, 2019) explains that emissivity is a measure of the infrared power capacity of an object. The energy emitted shows the object's temperature. The emissivity can be between 0 (glossy mirror) and 1.0 (blackbody).

The ventilation opening can also get controlled and scheduled in the opening section. The fraction of the total window area and the U-value are specified in the frame part. It is also possible to change the twist and the tilt of the window and allows the inclusion of non-vertical windows to vertical facade surfaces.

The software can determine the construction type and the opening schedule of an opening. The certain amount of leak is always associated with the openings. If an opening defined to be open in the model, by direction airflow of the modeling can be calculated, and radiation will also be considered.

IDA ICE provides the possibility to adjust side shading and orientation factors such and surrounding buildings, wall, trees, and so on. The orientation and location of the building body could reset according to geographical factors.

Since the apartment locates on the first floor of the building, as it is shown in figure 12, the only shading element around the apartment are trees opposite to the balcony.

Fig. 12: The shading element(trees) opposite to the balcony.

The location and climate data are the main parts of the global data for the simulation model. The location would be uploaded from the database of the software. The additional local installation file based on each country (in this case, Finland) and climate data helps to achieve a precise location, and climate condition leads to gain more accurate simulation results. The summer and winter design days data are demonstrated in the middle of figure 13.

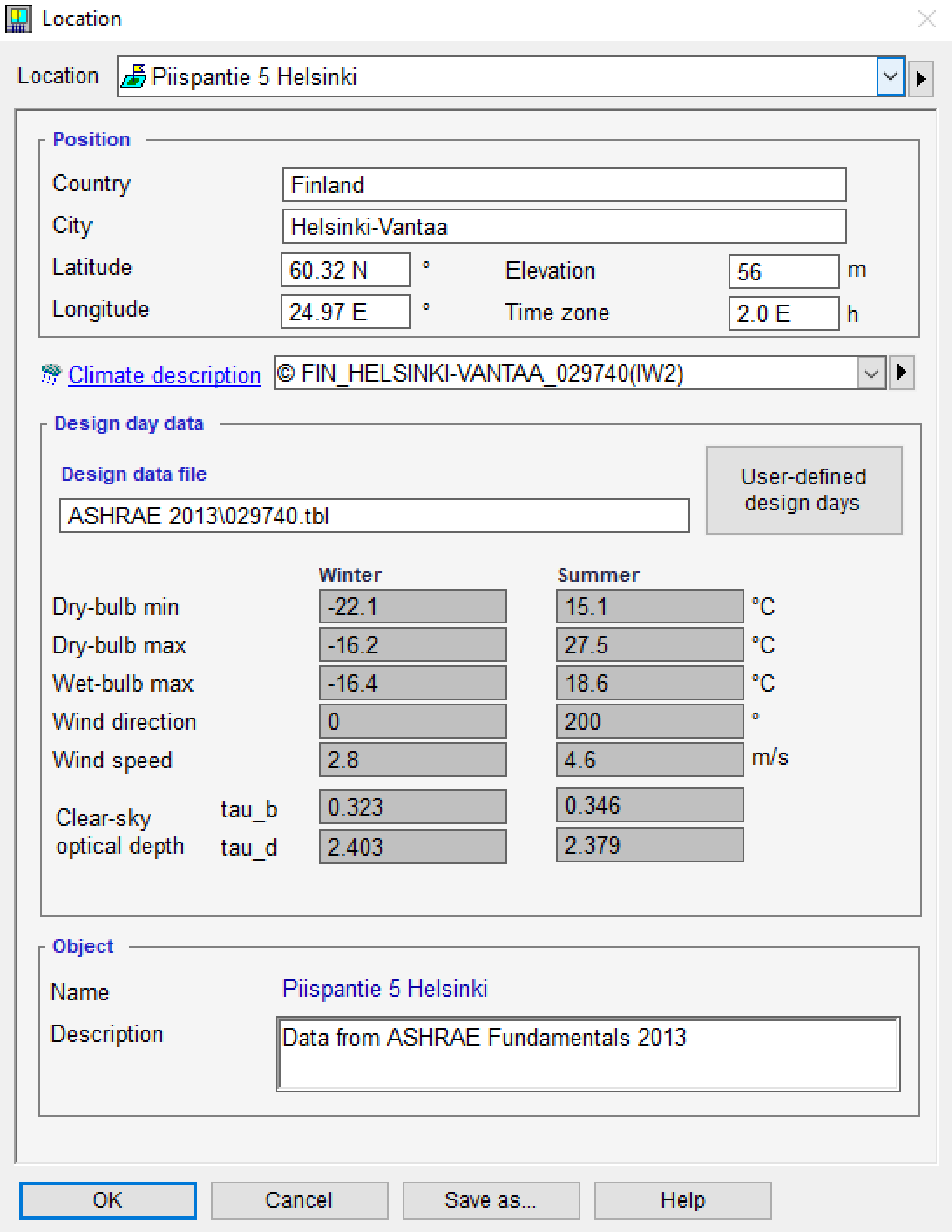


Fig. 13: Location and climate characteristics window.

During the simulation, the temperature will vary within the minimum and maximum dry-bulb temperature in a sinus curve. The Dry Bulb temperature generally applies to the air temperature in the environment. Additionally, the absolute humidity remains constant, whereas the relative humidity varies. The absolute humidity is defined as the quantity of water vapor in an air unit. The wind direction and wind speed are used to calculate accurate pressure coefficients, which is defined as the pressure that occurs on the different surfaces of the building envelope.

For custom or advanced simulation level, the user could specify the synthetic summer or winter, but for heating and cooling load in low production, the program will automatically utilize the appropriate set. The monthly climate diagram and report of the building location are shown in figure 14 and 15.

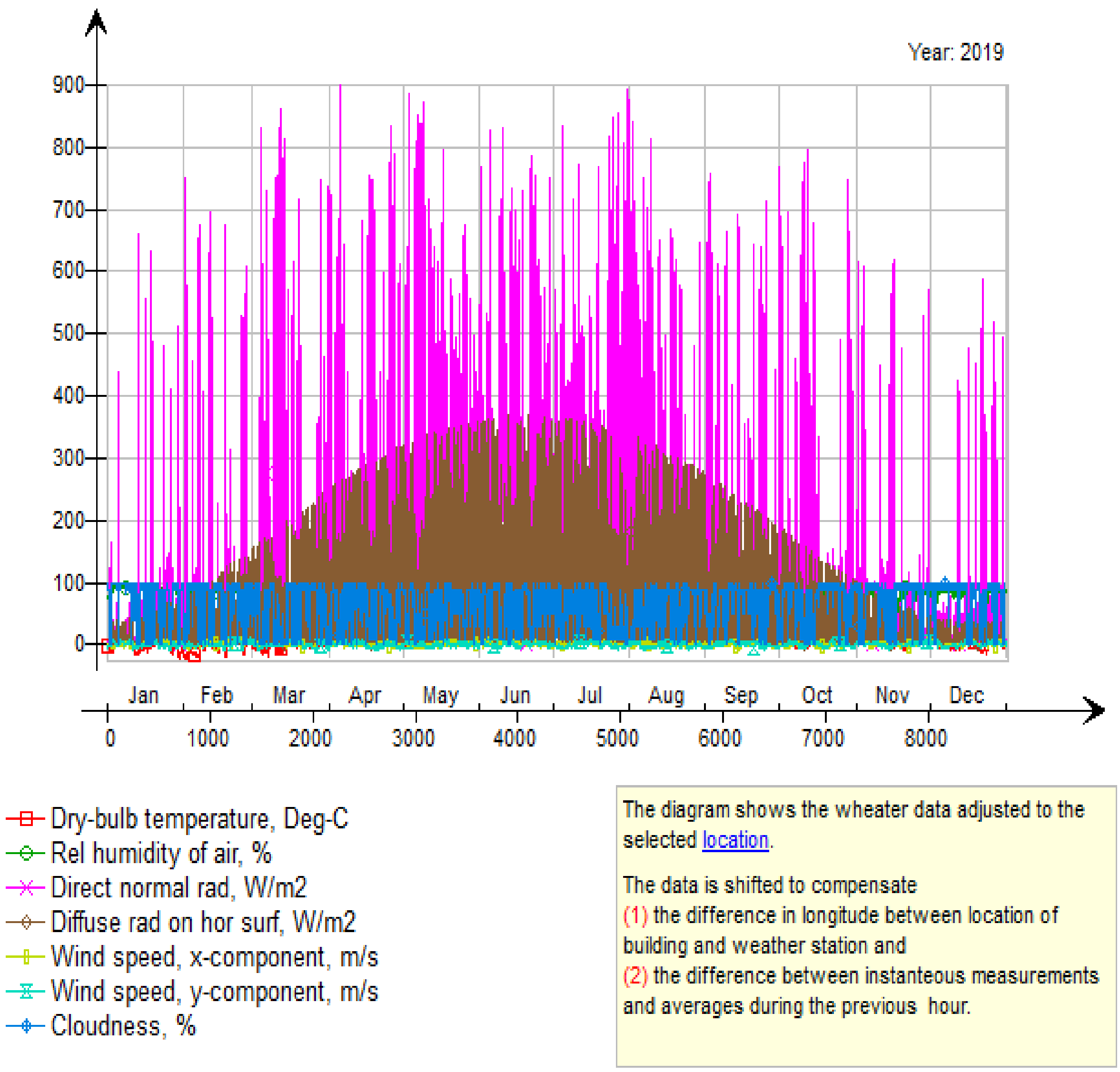


Fig. 14: The monthly climate diagram of the building location.

Climate file

IDA Indoor Climate and Energy 4.801 License: ICE40X:ICE40XL:19MAY/G5L7Z (trial license)

Object: Climate file

Description:

Date: 2019-01-01 - 2019-12-31

Saved: 16/03/2019 23:13:34

	Variables						
	Dry-bulb temperature, Deg-C	Rel humidity of air, %	Direct normal rad, W/m2	Diffuse rad on hor surf, W/m2	Wind speed, x-component, m/s	Wind speed, y-component, m/s	Cloudness, %
January	-3.1	89.4	37.3	9.4	1.5	0.3	73.1
February	-4.5	83.7	71.7	24.6	1.5	0.8	70.9
March	-1.4	82.1	127.0	51.6	0.4	-0.1	56.1
April	4.4	69.0	160.6	86.7	0.6	0.4	58.5
May	10.2	61.1	218.2	113.5	0.6	0.3	57.6
June	14.4	64.3	212.6	128.2	1.5	0.9	60.2
July	17.3	69.3	226.2	118.2	1.0	0.1	52.5
August	16.0	73.4	158.6	99.1	0.8	-0.8	61.2
September	11.7	78.3	129.1	64.4	-0.1	0.2	66.6
October	5.6	86.6	93.2	32.4	-0.2	0.3	70.8
November	2.7	82.6	43.8	13.6	1.2	0.9	76.3
December	-2.1	86.9	31.0	6.0	1.2	0.7	77.8
mean	6.0	77.2	126.1	62.5	0.8	0.3	65.1
mean*8760.0 h	52495.1	676412.5	1104803.0	547362.0	7224.2	2826.7	570000.0
min	-4.5	61.1	31.0	6.0	-0.2	-0.8	52.5
max	17.3	89.4	226.2	128.2	1.5	0.9	77.8

Fig. 15: The monthly climate report of the building location.

The Air Handling Unit (AHU) is defined as a device adopted in the heating, ventilation, and air conditioning system to control and distribute air. There are several prespecified air handling units included in the software. However, the program will automatically comprise in the model as a default.

The standard air handling unit contains a heat exchanger, a heating coil, and a cooling coil, an exhaust fan and, a supply air stream fan, as illustrated in figure 16. In a standard air handling unit, there are three ways to specify the temperature of supply air named as constant, schedule, and graph. In the constant method, the permanent temperature of the supply air is determined as 16℃. Nevertheless, there will be a temperature increase due to the fan in the supply air stream. In the schedule method, the temperature timetable is determined. In graph method, the supply air temperature is a function of the climate data, which is determined in the climate file.

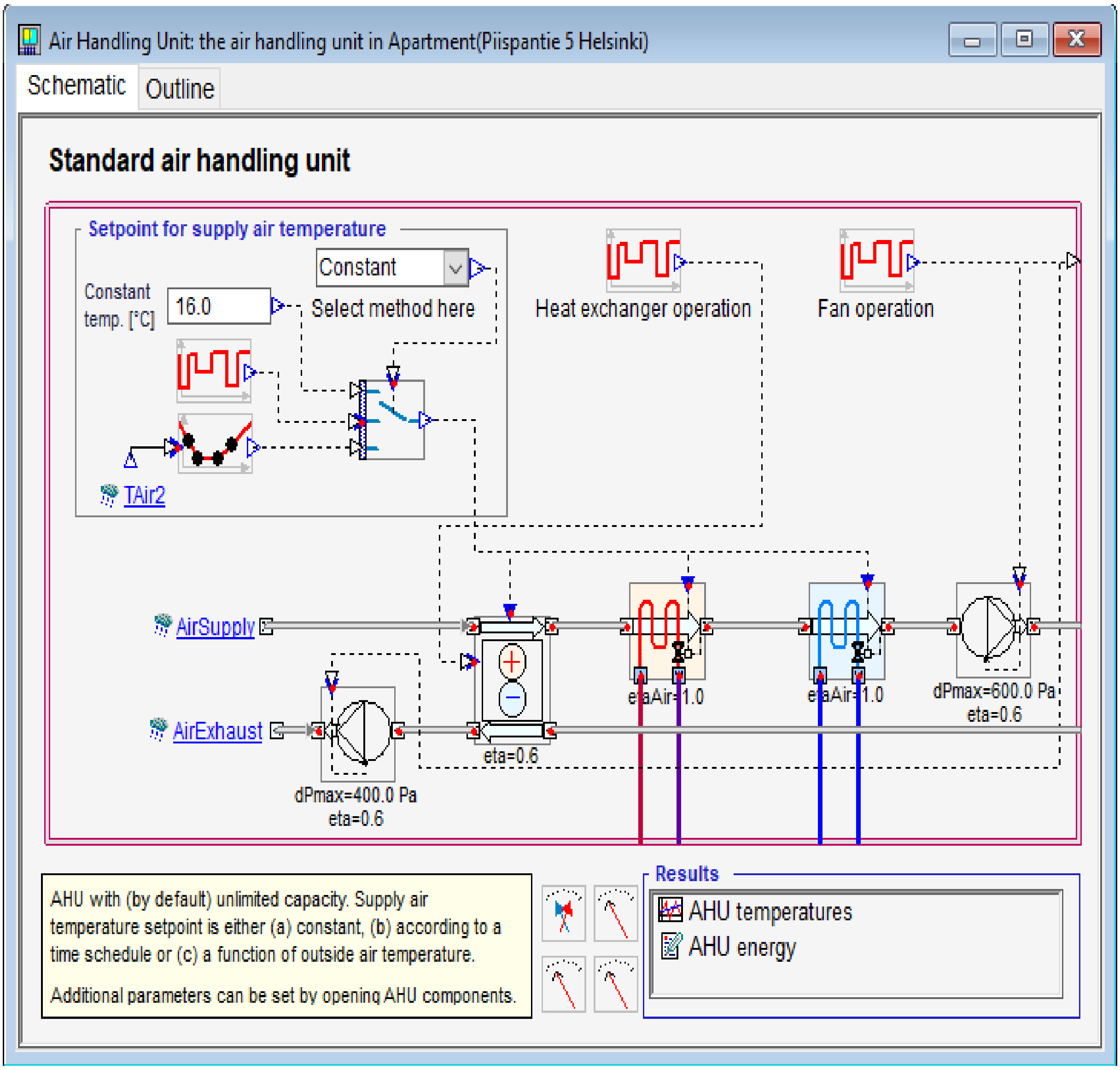


Fig. 16: The standard Air Handling Unit (AHU).

If there are several zones with different ventilation strategies, there is a possibility to specify the number of air handling units. Moreover, the air supply to the zones can be controlled.

In addition to temperature control, the cooling coil can also be utilized for humidity control such that it removes the moisture of the air if the surface temperature of the coil is below the due point temperature of the air which passes over the coil.

Infiltration is defined as the uncontrollable or unintended entry of external air into a building. Infiltration or the air leakage commonly occurs via cracks in the envelope and through openings. There are two methods to calculation infiltration in the software which named as wind-driven flow and fixed infiltration. In the wind-driven flow method, the infiltration calculation is based on the wind pressure, whereas, in the fixed infiltration rate method, the air filtration rate and its unit are fed to the software.

The template of the distributed infiltration air is defined in the zone distribution part as it is shown in figure 17. As a default, the infiltration is distributed proportionally to the external surface area. The pressure acting on the building envelope can be specified in the pressure coefficient window. The pressure coefficients are employed to measure the wind pressure based on velocity and wind direction on different exterior surfaces of the envelope. The pressure coefficients depend on the building shape and surrounding air dynamic conditions.

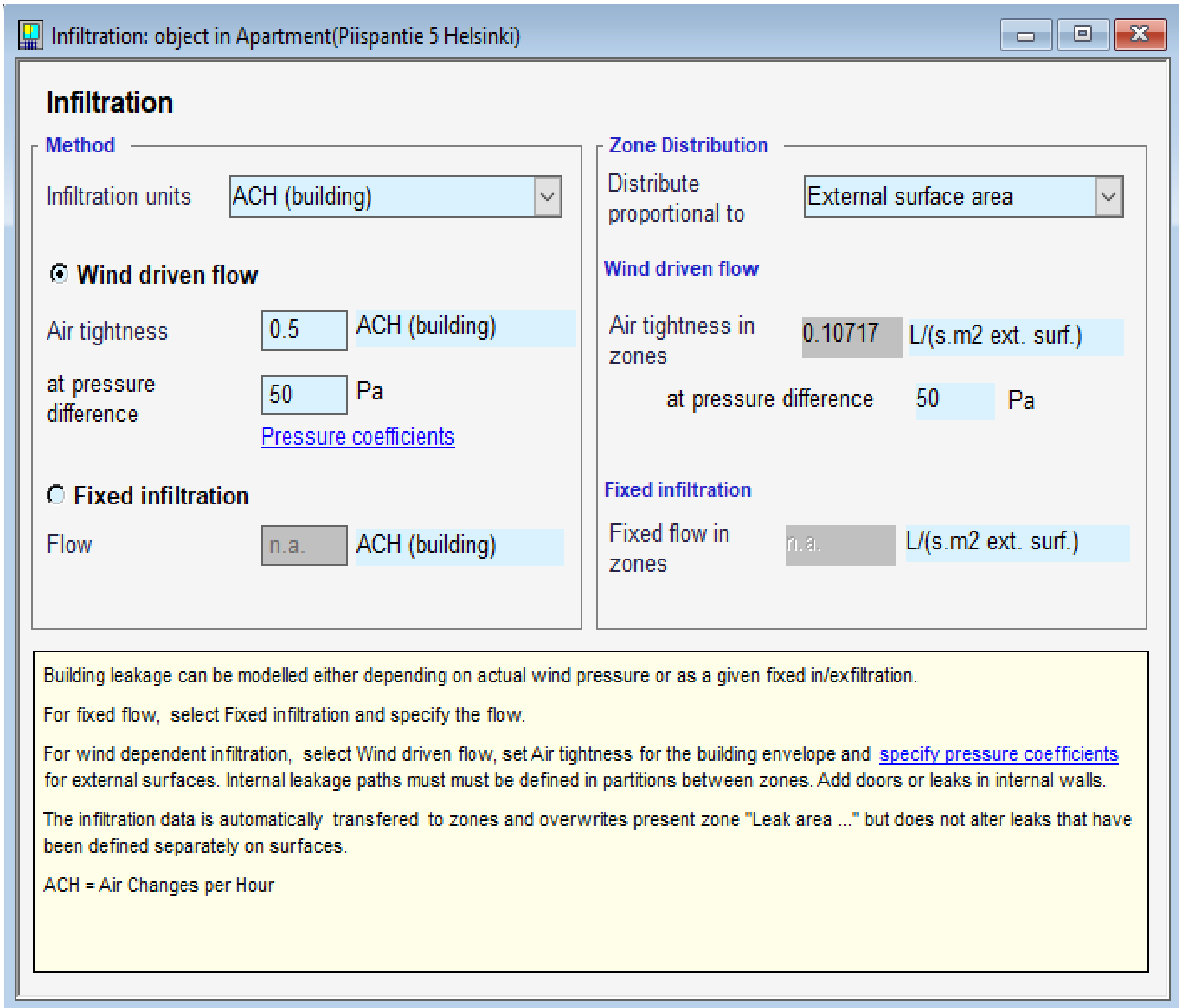


Fig. 17: Infiltration

The thermal bridge is defined as a weak link in the outer shell (roof, facade, or floor) of the building envelope. It is also named as the cold bridge or heat bridge. It occurred in places where the thermal insulation gets discontinued, or the floor slabs do not smoothly meet up. The thermal bridge causes heat loss and condensation where the warm indoor air meets the cold surfaces leads to producing odor nuisance and mold.

The different types of thermal bridges are presented in figure 18. The heat loss associated with thermal bridges is generally found in W/K (meter joint). The only exception is the external wall where it is defined as W/K (m² envelope). Data related to the thermal bridges can be defined in different ways either by moving the slider through good, typical, poor, and very poor conditions or by directly feeding the data.

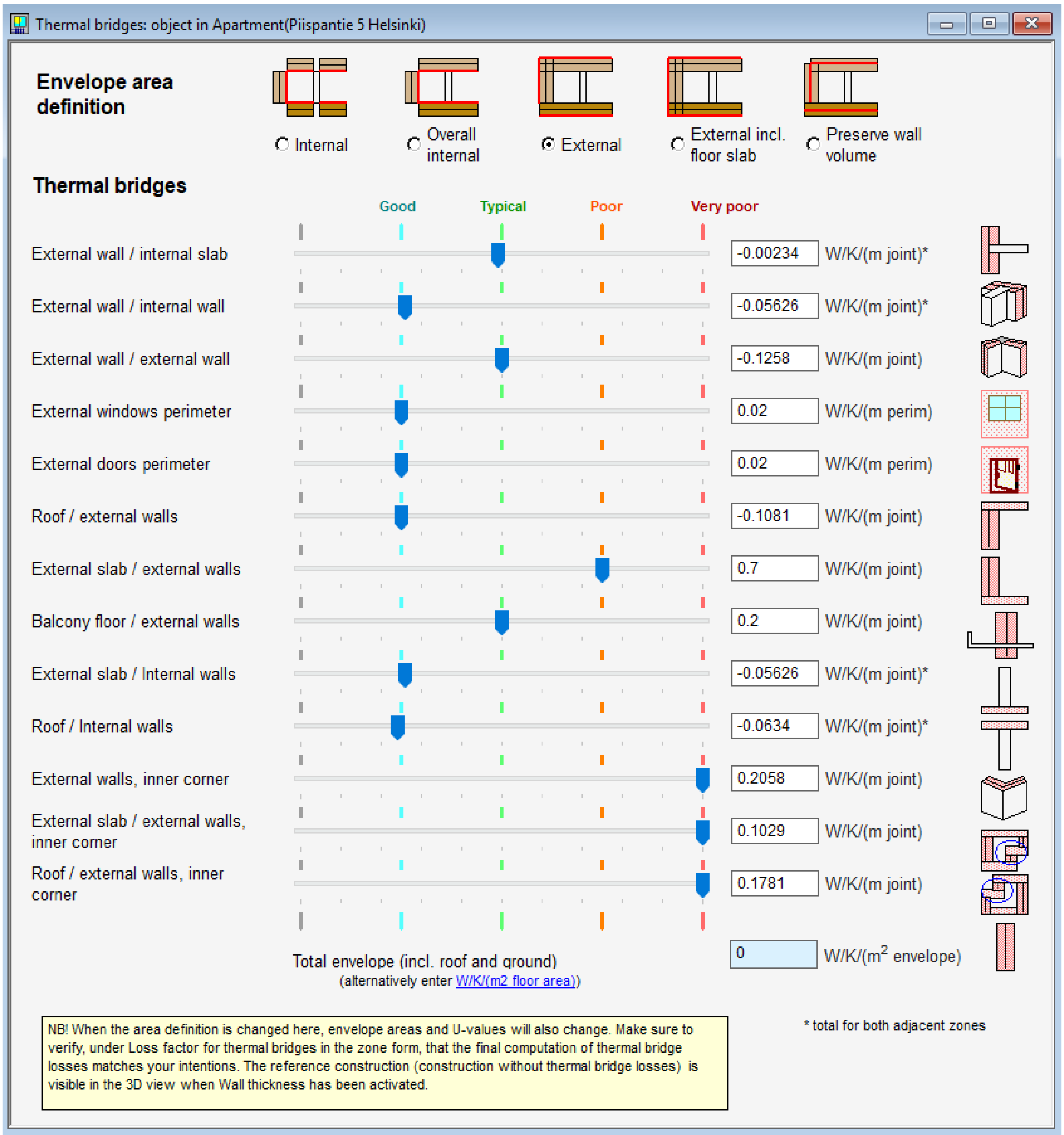


Fig. 18: The thermal bridge window.

Once all the thermal bridge data have been defined, the IDA ICE calculated the thermal bridge loss factor for every zone. The loss factor is a function of the geometry which has been defined for each zone is shown in figure 19.

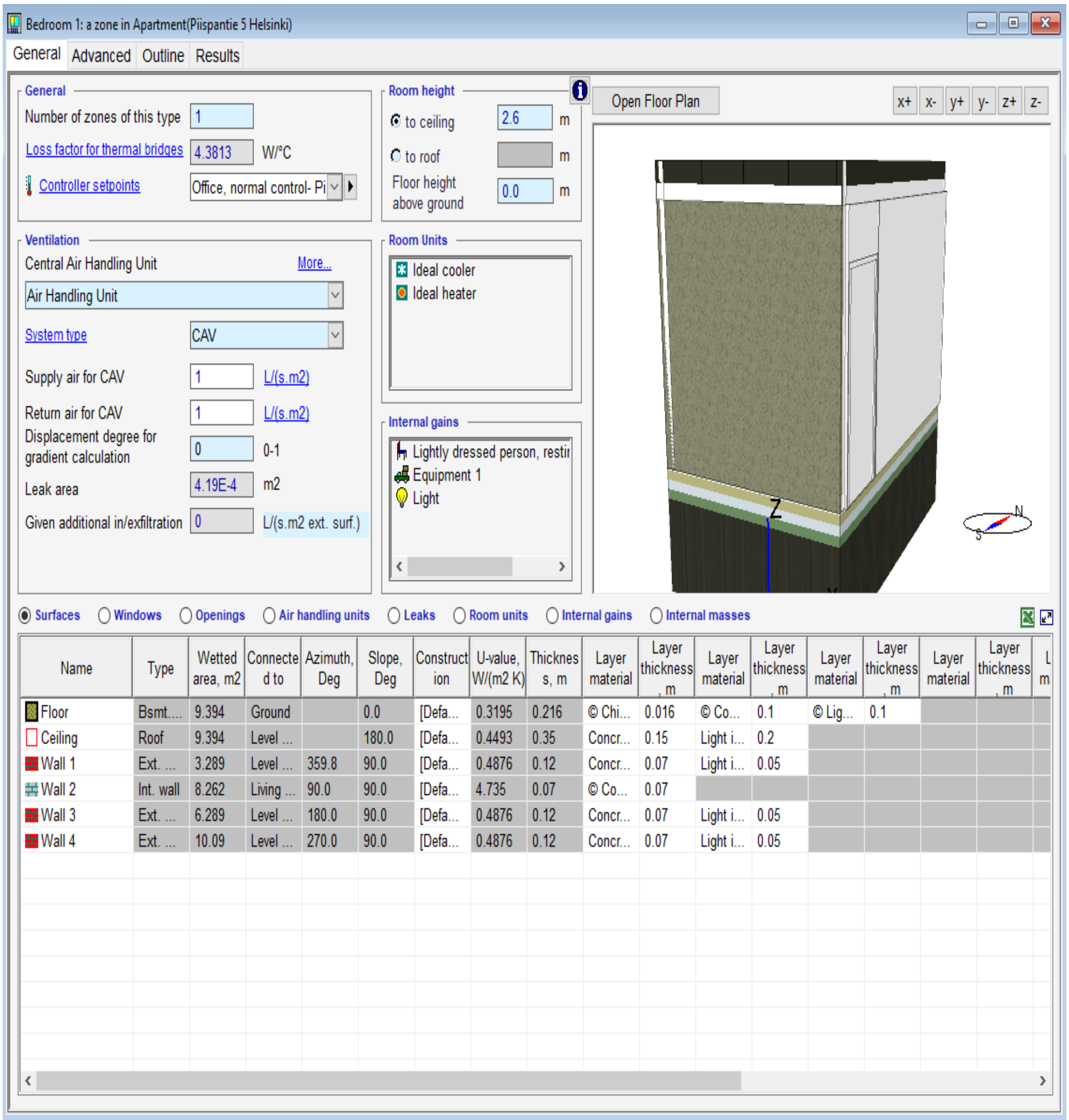


Fig. 19: The thermal bridge loss factor in every zone.

Two different materials and soil layers can be specified in the ground properties tab, as illustrated in figure 20. The ground layers under the basement slab and the ground layers outside basement walls. The ground layers in both parts can get determined by opening the definition of material and soil properties. IDA ICE always includes the insulation layer as a default definition in the construction definition window, as shown in figure 20.

The ground temperature is related to the climate condition where the ground is located. The ground temperature profile can be calculated in two ways: the ISO-13370 and the calculation method, which has been implemented in the IDA ICE version 3.0. If the annual climate file has not been selected, the ground temperature, which will be used for the calculation, must be specified by the user.

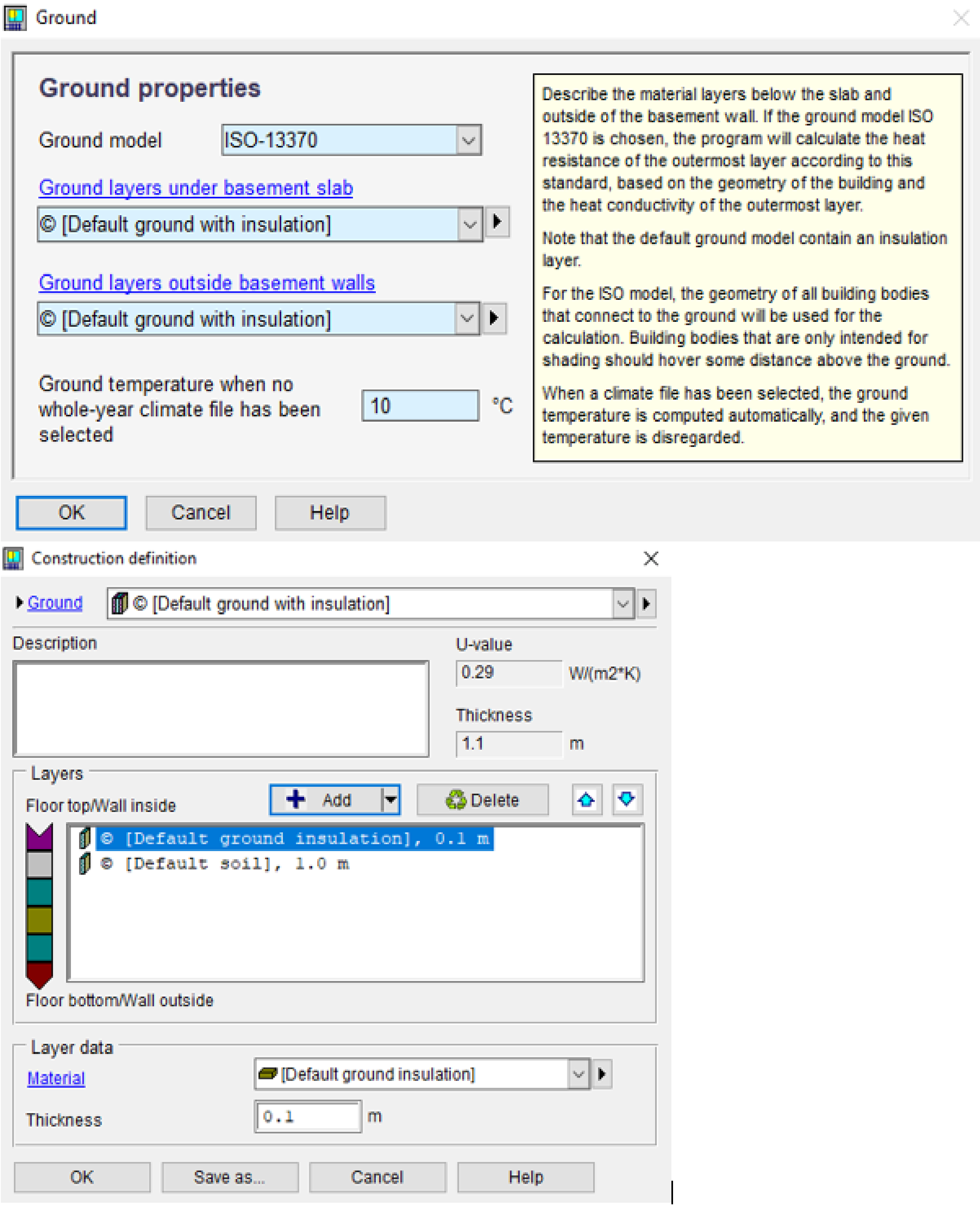


Fig. 20: Ground properties and construction definition.

The energy associated with domestic hot water usage is specified as default by litre per occupant and day, as shown in figure 21. There are also other units which can be used. In this case study, the number of 4 occupants is assumed, and every occupant consumes 60 litres of hot water per day.

The distribution system losses can be specified in the extra energy and losses window. The distribution system losses are associated with the domestic hot water circuit, heating, cooling, and ventilation. Heating and cooling distribution losses can be determined into different units either as a percentage of the heat delivered by the plant or W/(m^2 floor area).

The distribution system losses can be defined by either moving the slider between none, good, typical, poor, and very poor indicators or by feeding them directly into the software. The percentage of the distribution losses associated with zones should be determined as internal gains. The losses are shared between zones according to the floor area of the zones.

The plant losses are defined either for the chiller idle consumption or boiler idle consumption. The energy usage of an elevator or external lighting system of the building can be determined in the additional energy use part of figure 21.

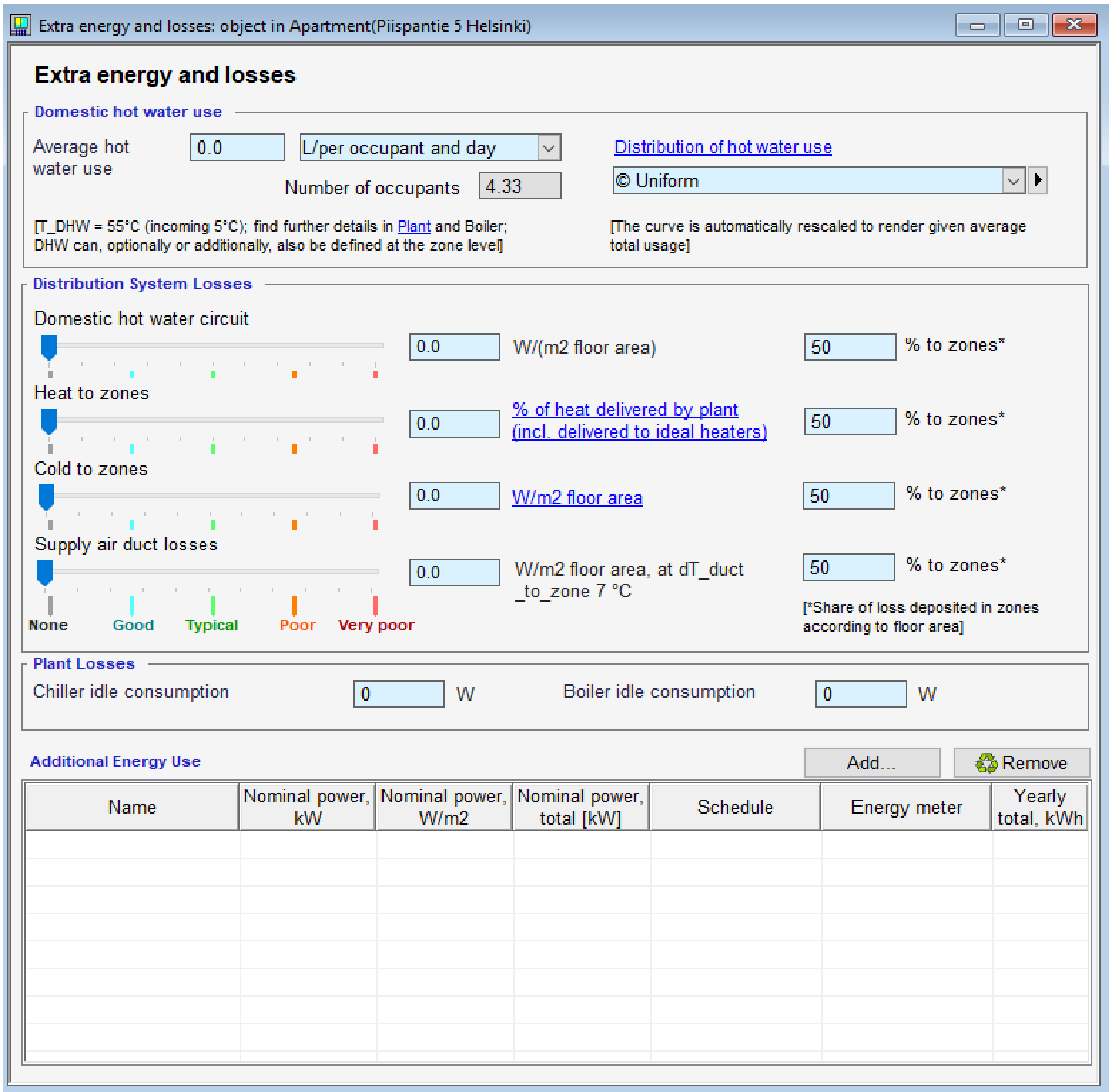


Fig. 21: Distribution system losses.

In the IDA ICE software, the simulation is carried out based on the heating load, cooling load, energy, overheating as well as custom simulation. It is also possible to simulate the model which has been built at an advanced level as it is shown in figure 22.

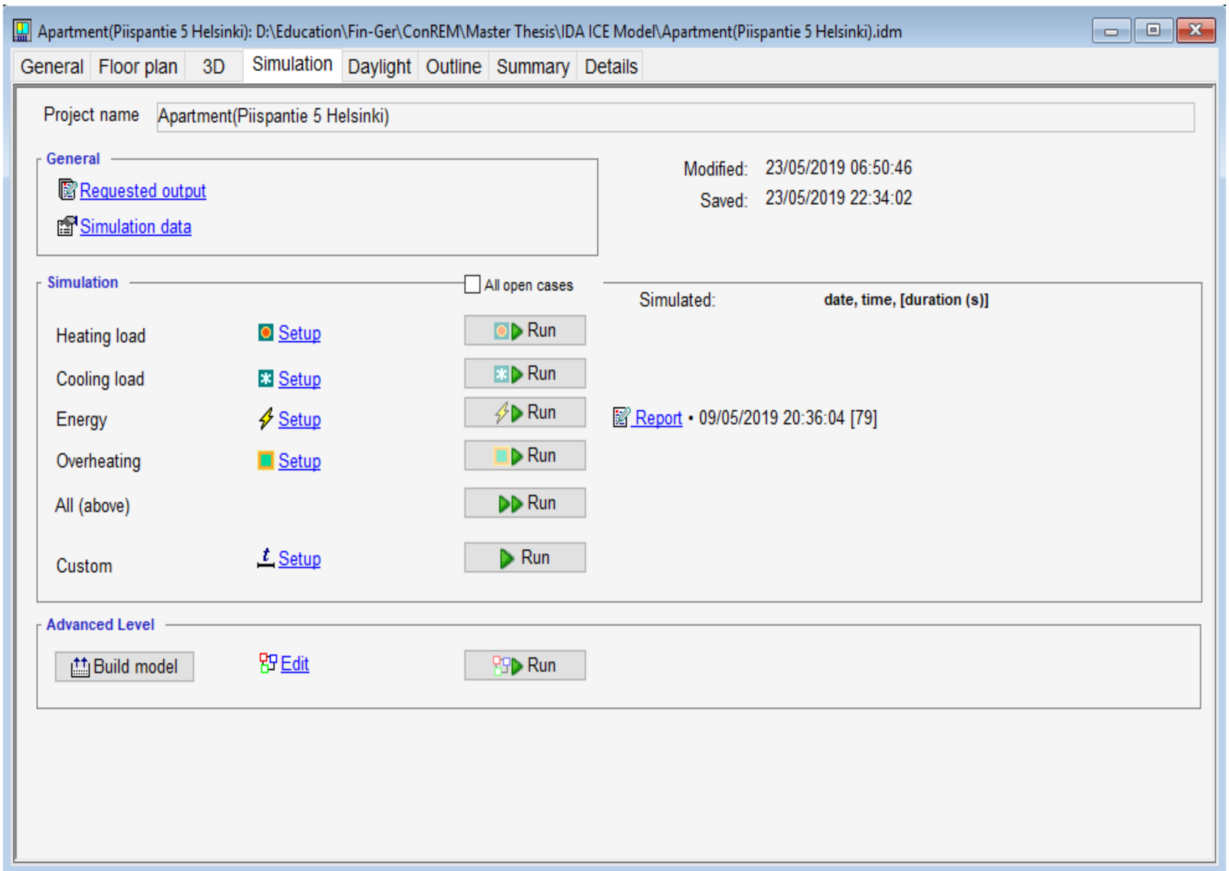


Fig. 22: Simulation window.

Several simulation parameters have to be specified for heating load calculation as it is illustrated in figure 23. The maximum heat supply or room unit heat can be determined as the variables for the simulation process. The fan status, whether they are off or they run according to the schedule, is specified in ventilation mode. The proportion of internal heat gains, which is considered during the load calculation, should be determined as well and as a default, the internal heat gain is wholly emitted.

The definition of weather data is defined either by using synthetic weather or a specific period from the climate file. The synthetic weather option is used in this study, and the simulation period has set for 15th of February 2019, and the fixed ambient temperature is specified as -26 ℃. The exact date of simulation should be determined by the user due to the sun position and solar radiation.

After specifying all the input data, the simulation run is initiating, and the table of simulation results appears as is displayed in figure 24. The heat supplied column shows the overall heating load in each zone, and the room unit heat column points out the heat that has been provided by the room units.

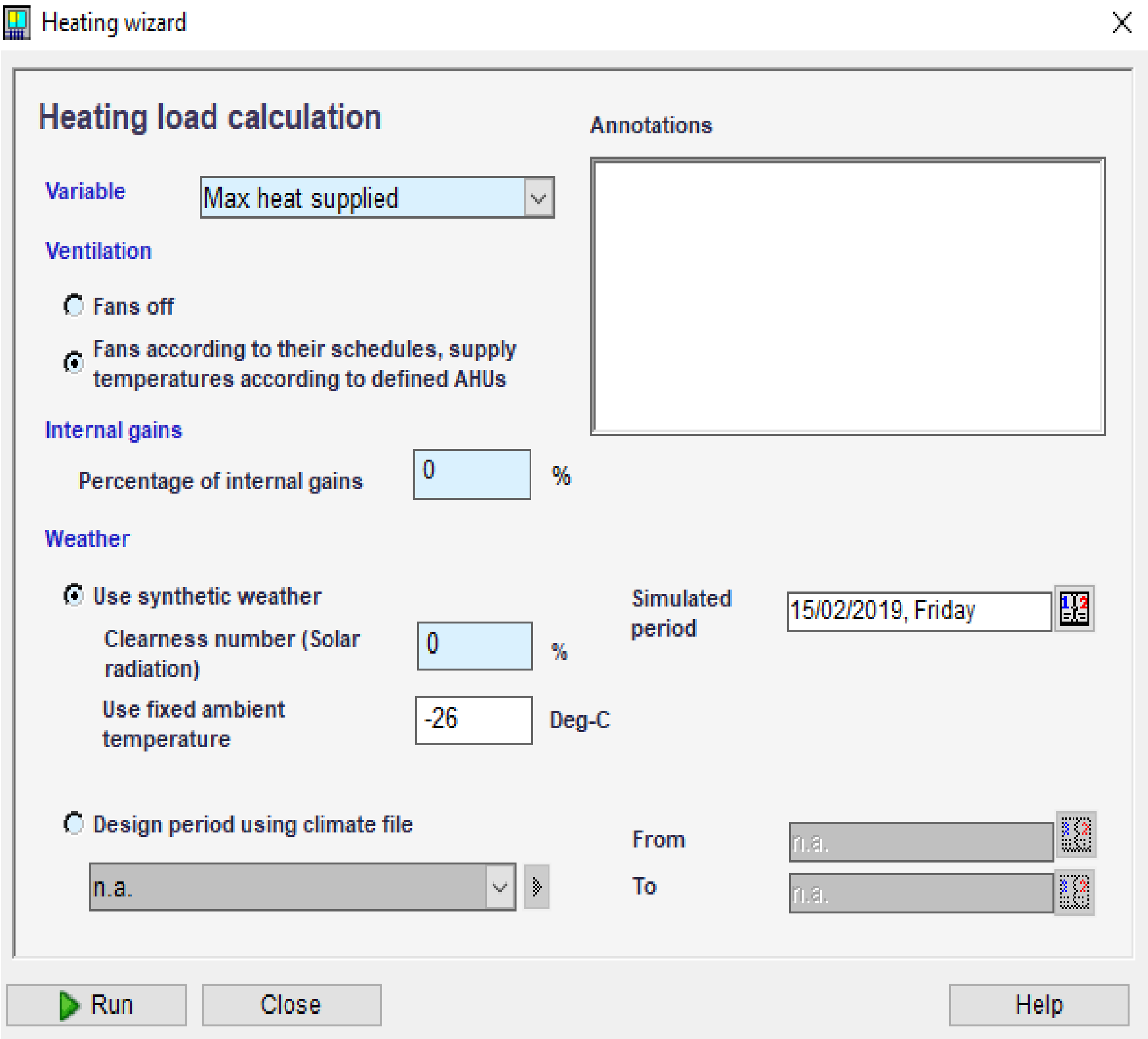
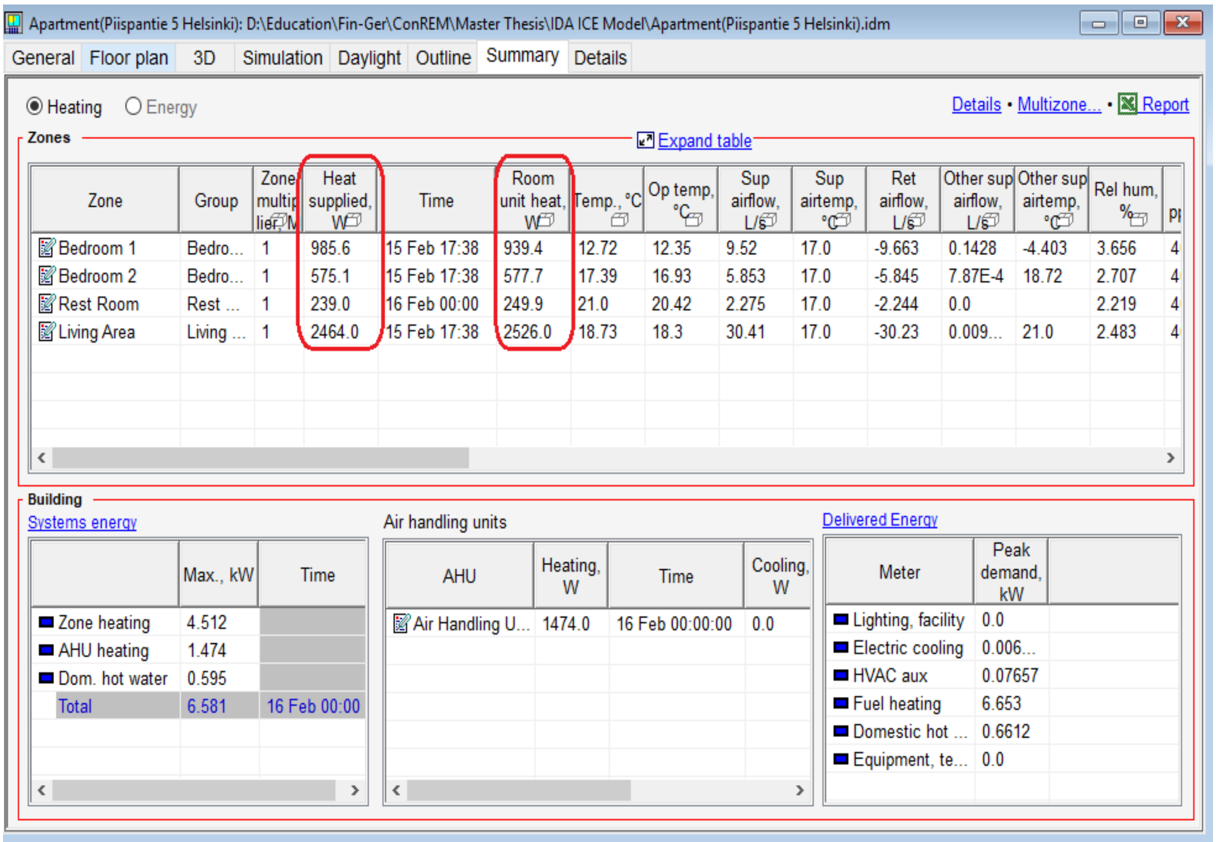


Fig. 23: Heating load calculation.



Apartment(Piispantie 5 Helsinki): D:\Education\Fin-Ger\ConREM\Master Thesis\IDA ICE Model\Apartment(Piispantie 5 Helsinki).idm

General | Floor plan | 3D | Simulation | Daylight | Outline | Summary | Details

Heating / Energy — Details • Multizone... • Report

Zones — Expand table

Zone	Group	Zone multiplier	Heat supplied, W	Time	Room unit heat, W	Temp., °C	Op temp, °C	Sup airflow, L/s	Sup airtemp, °C	Ret airflow, L/s	Other sup airflow, L/s	Other sup airtemp, °C	Rel hum, %	pl
Bedroom 1	Bedro...	1	985.6	15 Feb 17:38	939.4	12.72	12.35	9.52	17.0	-9.663	0.1428	-4.403	3.656	4
Bedroom 2	Bedro...	1	575.1	15 Feb 17:38	577.7	17.39	16.93	5.853	17.0	-5.845	7.87E-4	18.72	2.707	4
Rest Room	Rest ...	1	239.0	16 Feb 00:00	249.9	21.0	20.42	2.275	17.0	-2.244	0.0		2.219	4
Living Area	Living ...	1	2464.0	15 Feb 17:38	2526.0	18.73	18.3	30.41	17.0	-30.23	0.009...	21.0	2.483	4

Building

Systems energy

	Max., kW	Time
Zone heating	4.512	
AHU heating	1.474	
Dom. hot water	0.595	
Total	6.581	16 Feb 00:00

Air handling units

AHU	Heating, W	Time	Cooling, W
Air Handling U...	1474.0	16 Feb 00:00:00	0.0

Delivered Energy

Meter	Peak demand, kW
Lighting, facility	0.0
Electric cooling	0.006...
HVAC aux	0.07657
Fuel heating	6.653
Domestic hot ...	0.6612
Equipment, te...	0.0

Fig. 24: Table of heating load simulation results.

The heating load simulation results in the 3D model are displayed in figure 24. The heating load visualization of the performance predictions is shown in figure 25.

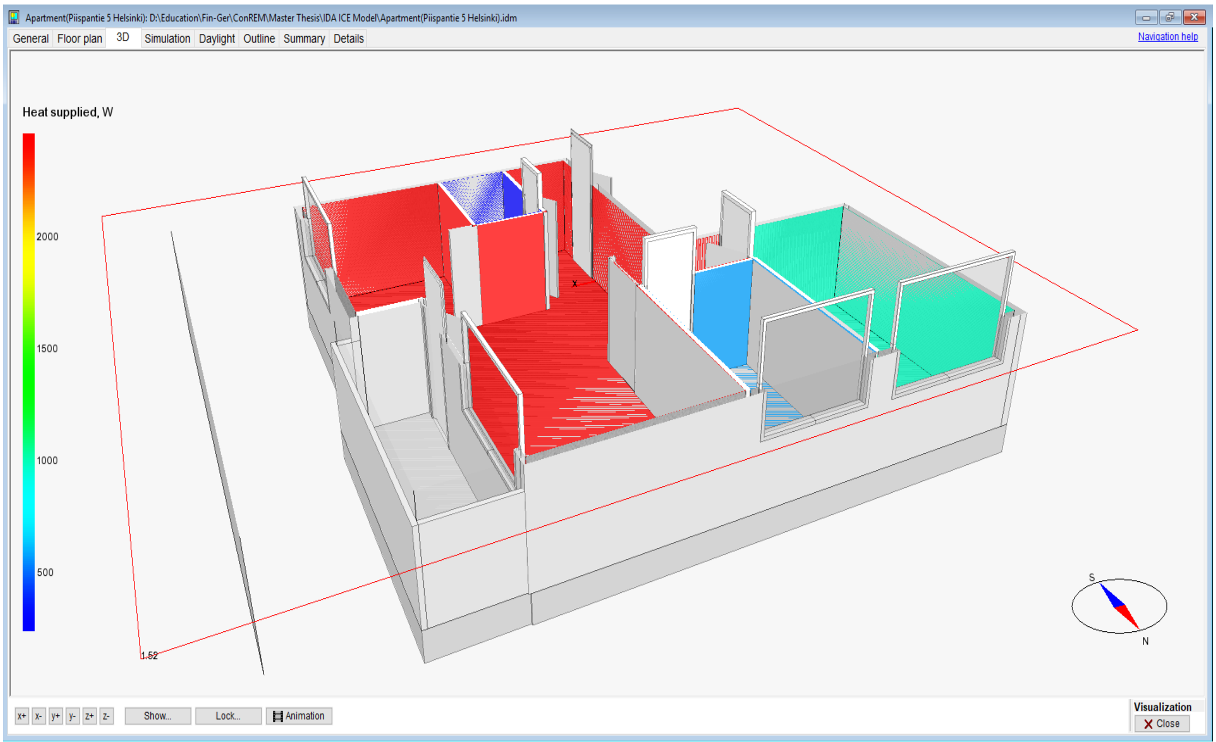


Fig. 25: The heating load visualization of the performance predictions.

To carry out the cooling calculation, several simulation parameters have to be specified, as is illustrated in figure 23. As a default by the software, all internal heat gains are included in the calculation. The climate file is used for prediction of the cooling loads. The simulation period is specified between the 15th to 20th of July 2019.

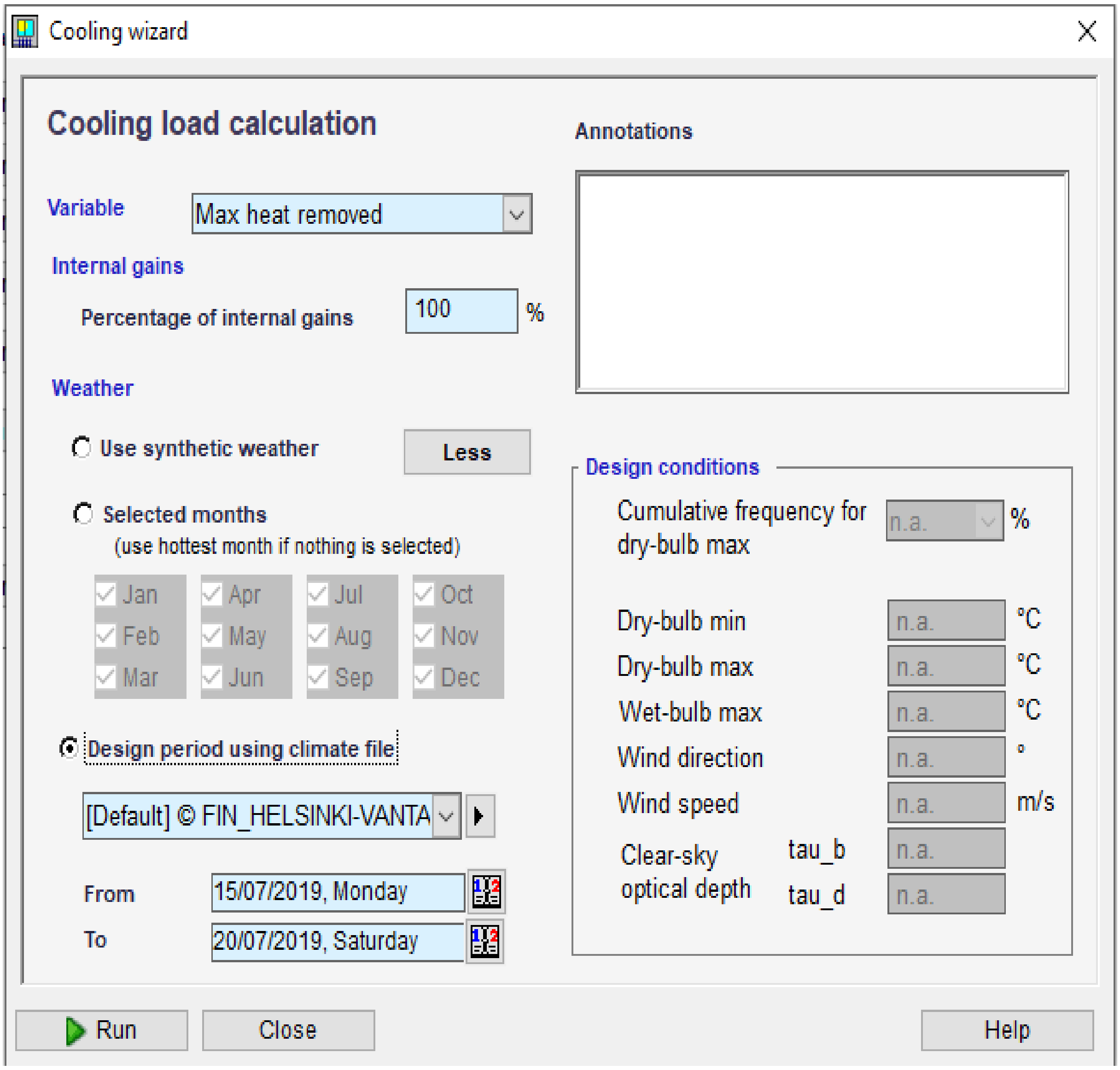


Fig. 26: Cooling load calculation.

After initiating the simulation run, the tabular overview of the cooling load performance predictions appears as it is shown in figure 26. The heat removed column represents the heat that has been removed from the zones by the air handling units and the room units. The room unit cool column indicates the heat that has been removed by only room units, as illustrated in figure 27.

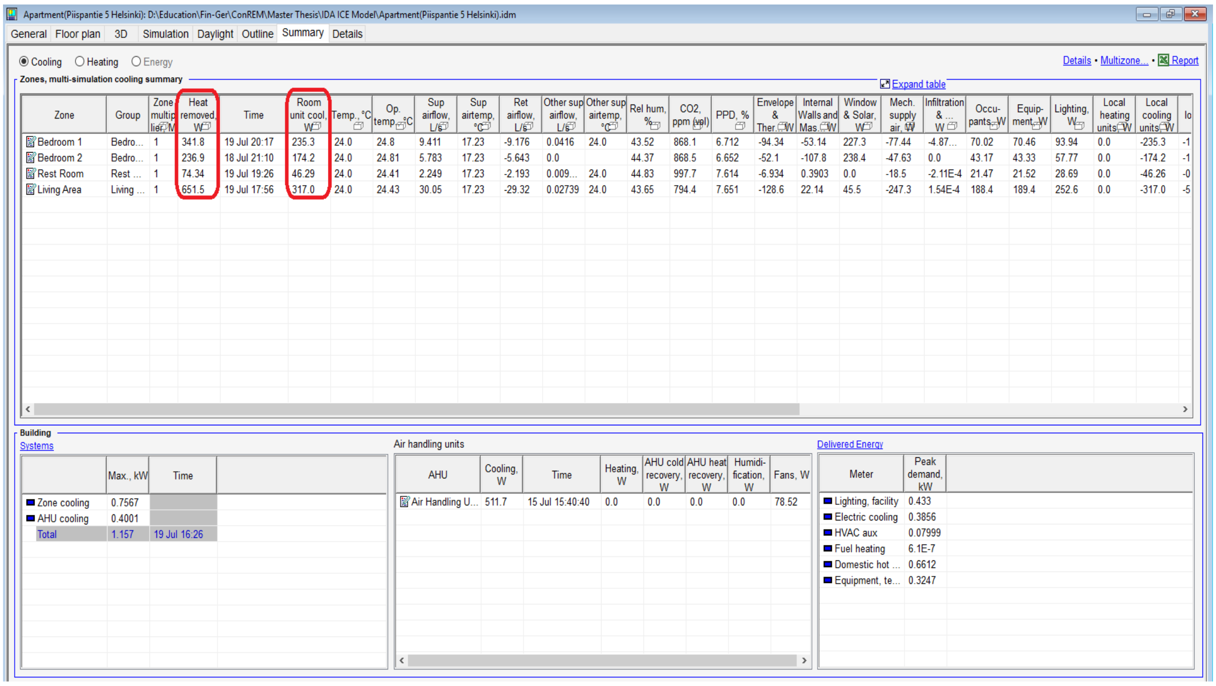


Fig. 27: Table of cooling load simulation results.

Figure 28 shows the cooling load visualization of the performance predictions.

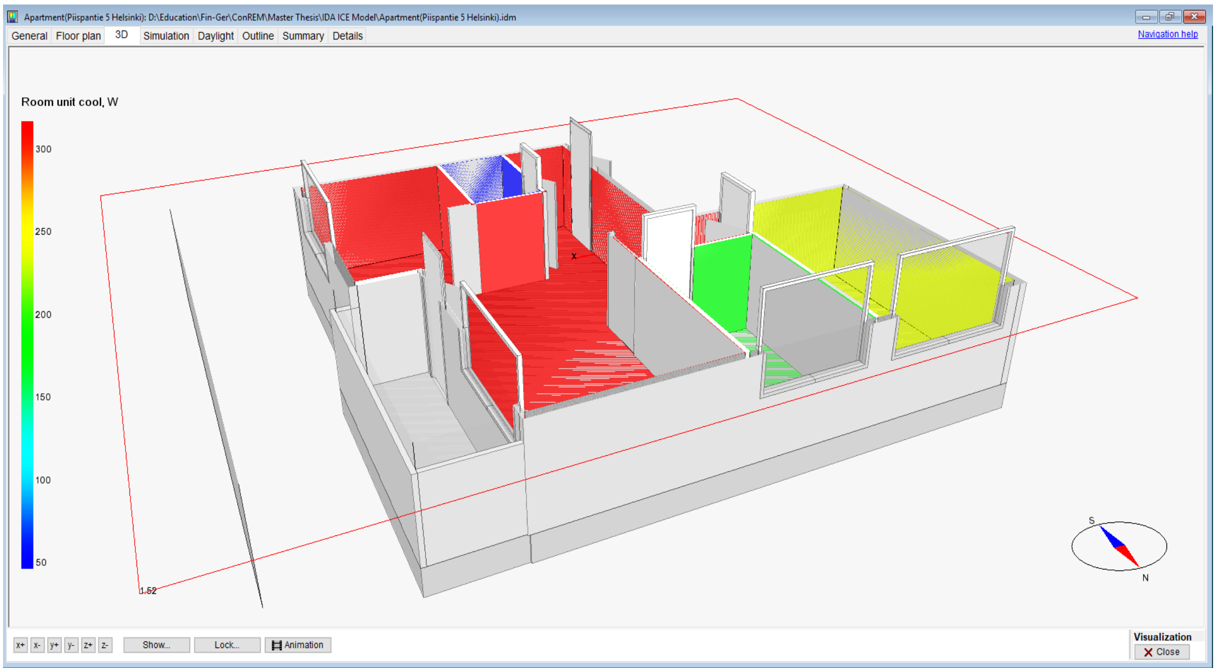


Fig. 28: The cooling load visualization of the performance predictions.

In the IDA ICE software, the energy calculation is always carried out for the entire year. The percentage of the internal loads such as equipments, occupants, and lights during the simulation study is specified, and by default, they are considered as 60 percent, as shown in figure 29. In the energy simulation, the climate set is used rather than synthetic climate data.

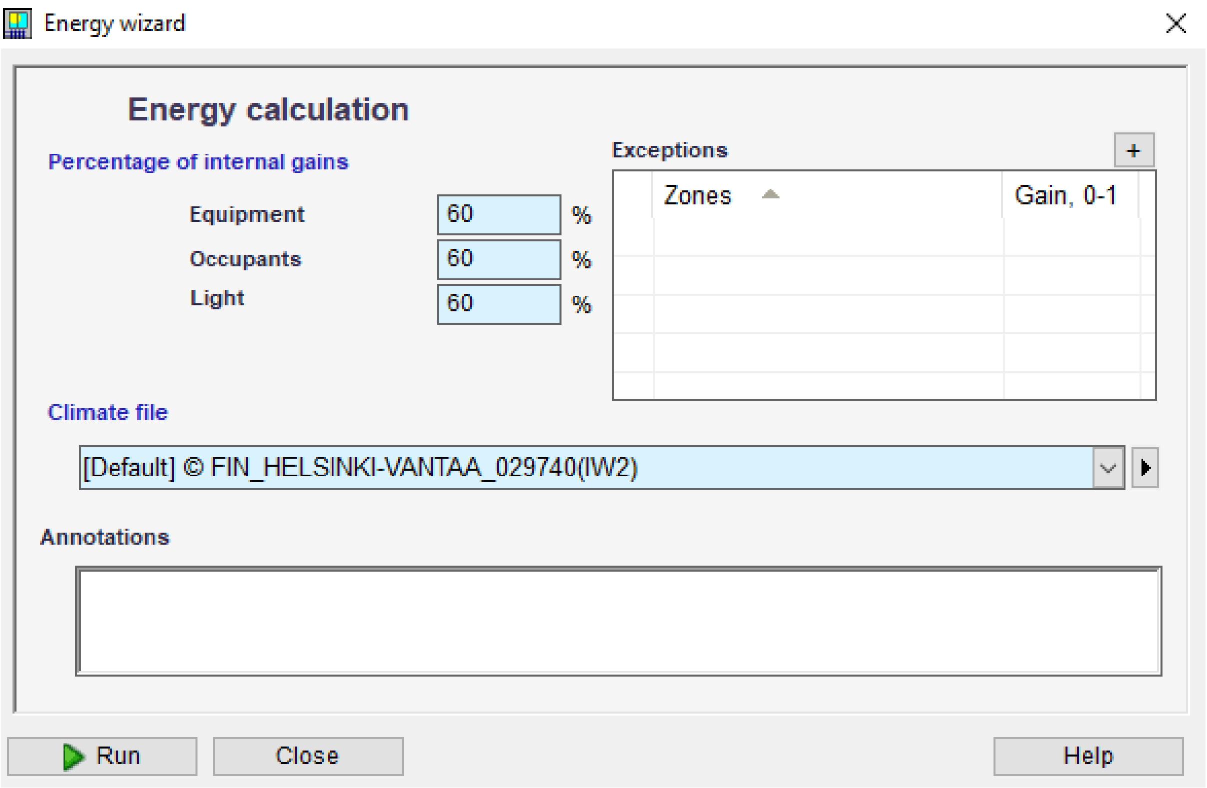


Fig. 29: Energy calculation.

The tabulation results of the energy simulation and energy visualization of the performance predictions are shown in figures 30 and 31, respectively.

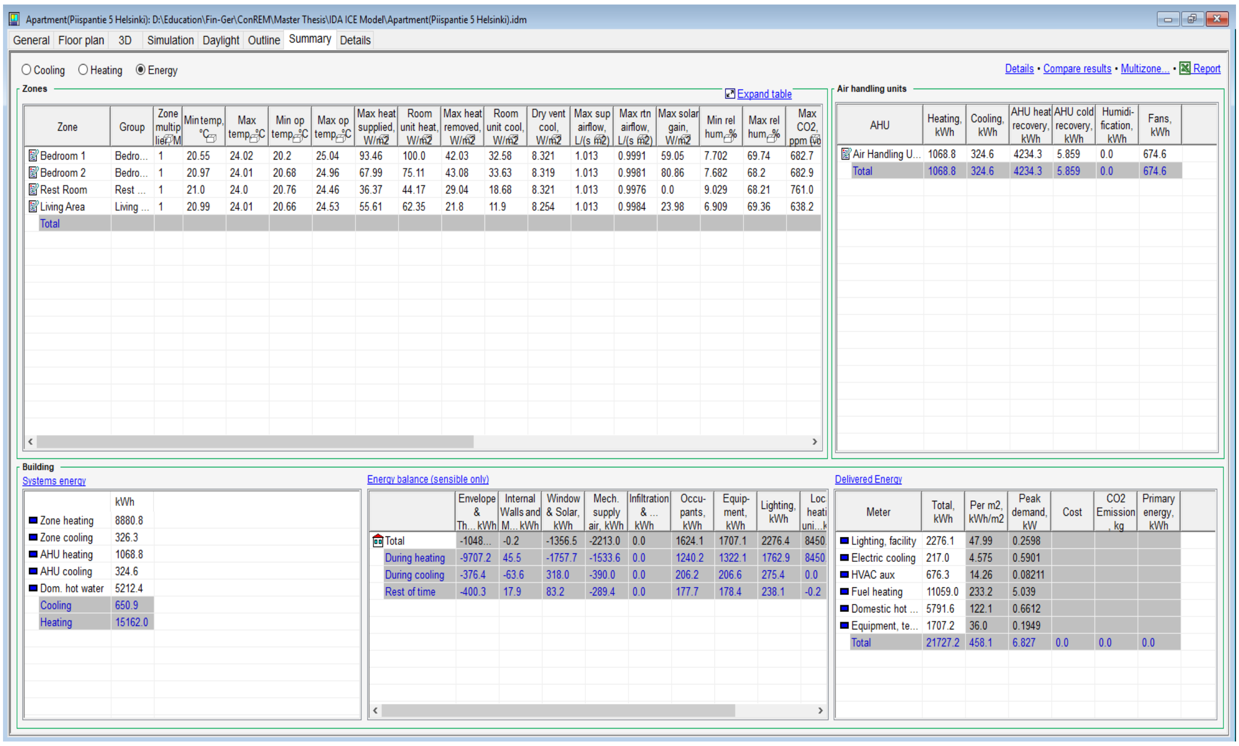


Fig. 30: Table of energy simulation results.

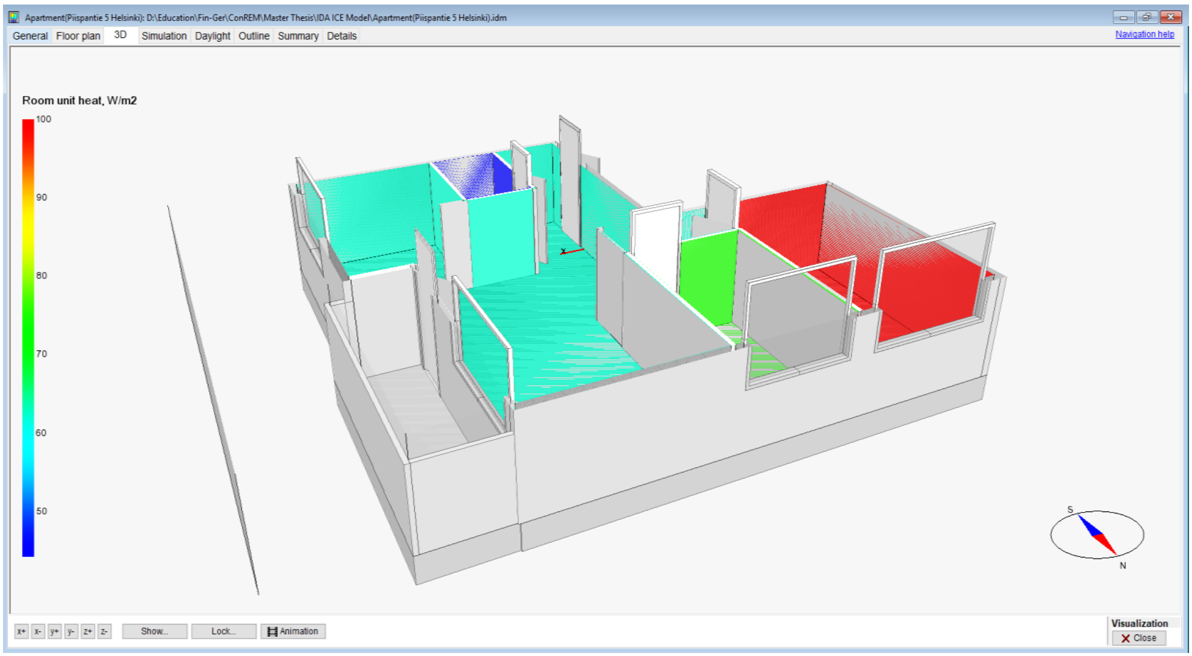


Fig. 31: The energy visualization of the performance predictions.

An overview table with key variable after the simulation has finished is provided as the summary of the simulation as it is presented in figure 32. The table shows the actual maximum values of the variables and not those values that occur in maximum or minimum load.

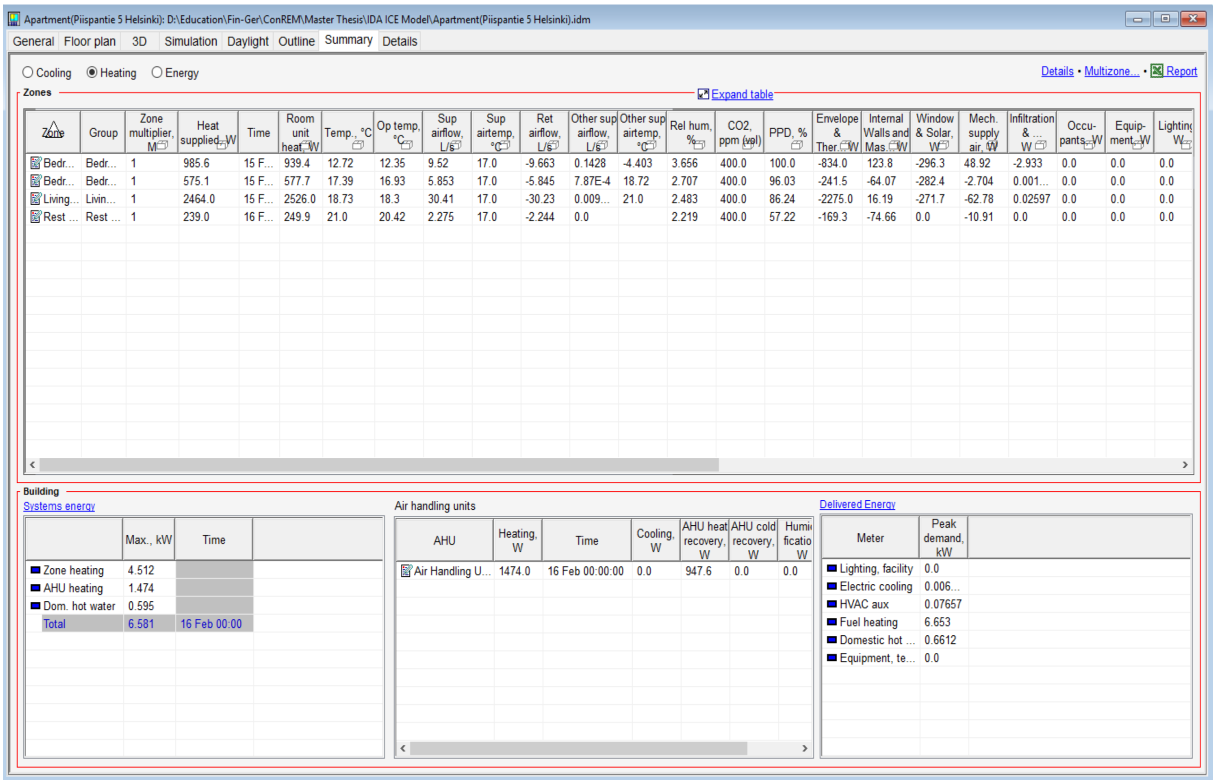


Fig. 32: The heating load summary table.

The list and meaning of the heading variables are defined in table 5:

Heading	Unit	Explanation
Zone	--	An enclosed area name with specific characteristics and illustrated in the floor plan
Group	--	The group name (assigned by the user or by the tool that created the model).
Zone Multiplier	M	The number of rooms with these conditions. The "Total" row shows (where applicable) the sums over all zones counting with zone multipliers
Heat supplied	W	Maximal value of the total supplied heating power (both sensible and latent) delivered to the zone from mechanical and natural ventilation (including leaks and infiltration) and from local units (both convective and radiative). Note that this is the actual heat supplied and not that which would be required to maintain a certain temperature. Make sure that the setpoint temperature has been fulfilled.
Time		The time for the given peak.
Room unit heat	W	Maximal value of the heating power delivered to the zone by room units (both convective and radiative). The time for this maximum may be different from the total peak. The peak time is given as a tooltip.
Temp.	℃	Mean air temperature in the zone at the time of maximal heat supply.
Op temp	℃	The operative temperature at the position of the first occupant at the time of maximal heat supply. Empty if no occupants in a zone
Sup air-flow	L/s	Mechanical air supply flow rate at the time of maximal heat supply.
Sup air-temp	℃	The temperature of air supplied by mechanical ventilation (mean value in case of multiple supply ducts) at the time of maximal heat supply. Empty if there was no air supply at that time.
Ret air-flow	L/s	Mechanical air return flow rate at the time of maximal heat supply.
Other sup air-flow	L/s	Air supply flow rate from openings, open windows and doors, leaks, chimneys, and infiltration at the time of maximal heat supply.
Other sup air-temp	℃	Air supply flow rate from openings, open windows and doors, leaks, chimneys, and infiltration at the time of maximal heat supply.
Rel hum	%	Relative humidity of the air in the zone at the time of maximal heat supply.
CO2	ppm (vol)	The concentration of CO2 in the zone at the time of maximal heat supply.
PPD	%	Percentage of people dissatisfied at the time of maximal heat supply. Calculated for all occupants present at that time. Empty if no occupancy at that time
Envelope and Thermal bridges	W	Heat gained through external walls, floors, roofs and through thermal bridges at the time of maximal heat supply in Watt.
Internal wall and Masses	W	Heat gained through internal walls, floors, ceilings and internal masses at the time of maximal heat supply in Watt.
Windows and solar	W	Net heat gain through external windows, i.e., through long and short wave radiation as well as via transmission trough pane and frame. Advected heat through

		open windows is included in Infiltration and openings. Note that transmission only is presented in a separate table at the time of maximal heat supply in Watt.
Mech supply air	W	Sensible heat supplied by mechanical ventilation at the time of maximal heat supply in Watt.
Infiltration and openings	W	Sensible heat supplied via air from leaks and openings. For systems with only mechanical exhaust ventilation, all supply air will be accounted for here at the time of maximal heat supply in Watt.
Occupants	W	Sensible heat from people in the zone, i.e., excluding heat from perspiration, at the time of maximal heat supply in Watt.
Equipment	W	Heat from equipment in the zone, e.g., computers, etc. at the time of maximal heat supply in Watt.
Lighting	W	Heat from artificial lighting at the time of maximal heat supply in Watt.
Local heating units	W	The heat from controlled heating units, e.g., radiators, fan coils etc at the time of maximal heat supply in Watt.
Local cooling units	W	Sensible heat from controlled cooling units, e.g., chilled beams, fan coils, etc at the time of maximal heat supply in Watt.
Net losses	W	The heat from pipes, ducts, etc., the leakage from which has been defined in Extra energy and losses at the time of maximal heat supply in Watt.
Envelope and Thermal bridges	W/m²	Heat gained through external walls, floors, roofs and through thermal bridges at the time of maximal heat supply in Watt per meter square.
Internal Walls and Masses	W/m²	Heat gained through internal walls, floors, ceilings and internal masses at the time of maximal heat supply in Watt per meter square.
Windows and Solar	W/m²	Net heat gain through external windows, i.e., through long and short wave radiation as well as via transmission trough pane and frame. Advected heat through open windows is included in Infiltration and openings. Note that transmission only is presented in a separate table at the time of maximal heat supply in Watt per meter square.
Mech. Supply air	W/m²	Sensible heat supplied by mechanical ventilation at the time of maximal heat supply in Watt per meter square.
Infiltration and Openings	W/m²	Sensible heat supplied via air from leaks and openings. For systems with only mechanical exhaust ventilation, all supply air will be accounted for here at the time of maximal heat supply in Watt per meter square.
Occupants	W/m²	Sensible heat from people in the zone, i.e., excluding heat from perspiration, at the time of maximal heat supply in Watt per meter square.
Equipment	W/m²	Heat from equipment in the zone, e.g., computers, etc. at the time of maximal heat supply in Watt per meter square.
Lighting	W/m²	Heat from artificial lighting at the time of maximal heat supply in Watt per meter square.
Local heating units	W/m²	The heat from controlled heating units, e.g., radiators, fan coils etc at the time of maximal heat supply in Watt per meter square.

Local cooling units	W/m²	Sensible heat from controlled cooling units, e.g., chilled beams, fan coils etc. at the time of maximal heat supply in Watt per meter square.
Net losses	W/m²	The heat from pipes, ducts, etc., the leakage from which has been defined in Extra energy and losses at the time of maximal heat supply in Watt per meter square.

Tab. 5: The explanation of heading variables in figure 32.[10]

The time series diagrams which are automatically generated by IDA ICE are provided in the Details tab. As an example, the main temperature in bedroom one is shown in figure 33. The time series diagram presents both mean air temperature and operative temperature. The operative temperature is calculated based on the mean temperature and the mean radiant temperature. The mean radiant temperature is defined as the air temperature under indoor condition (Walikewitz *et al.*, 2015). The mean radiant temperature is derived from the surface temperatures and the calculation based on the area weighting.

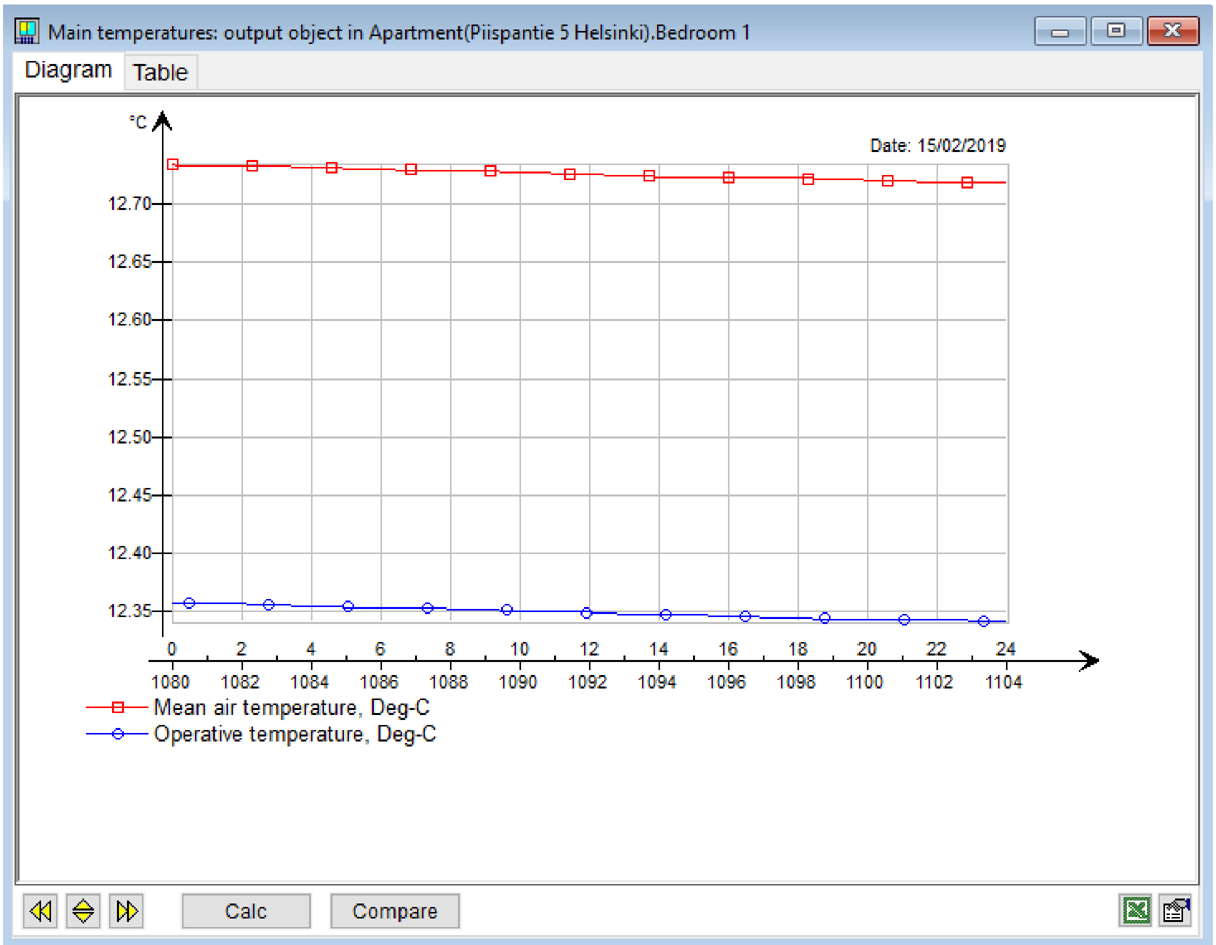


Fig. 33: The diagram of main temperature in bedroom one.

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[10] Reference: Tables for heating simulation, IDA ICE.

IDA ICE presents not only the information as a function of time but also as a function of absolute values, positive values, negative values, duration, and carpet plot. For instance, the duration curves are presented in figure 34.

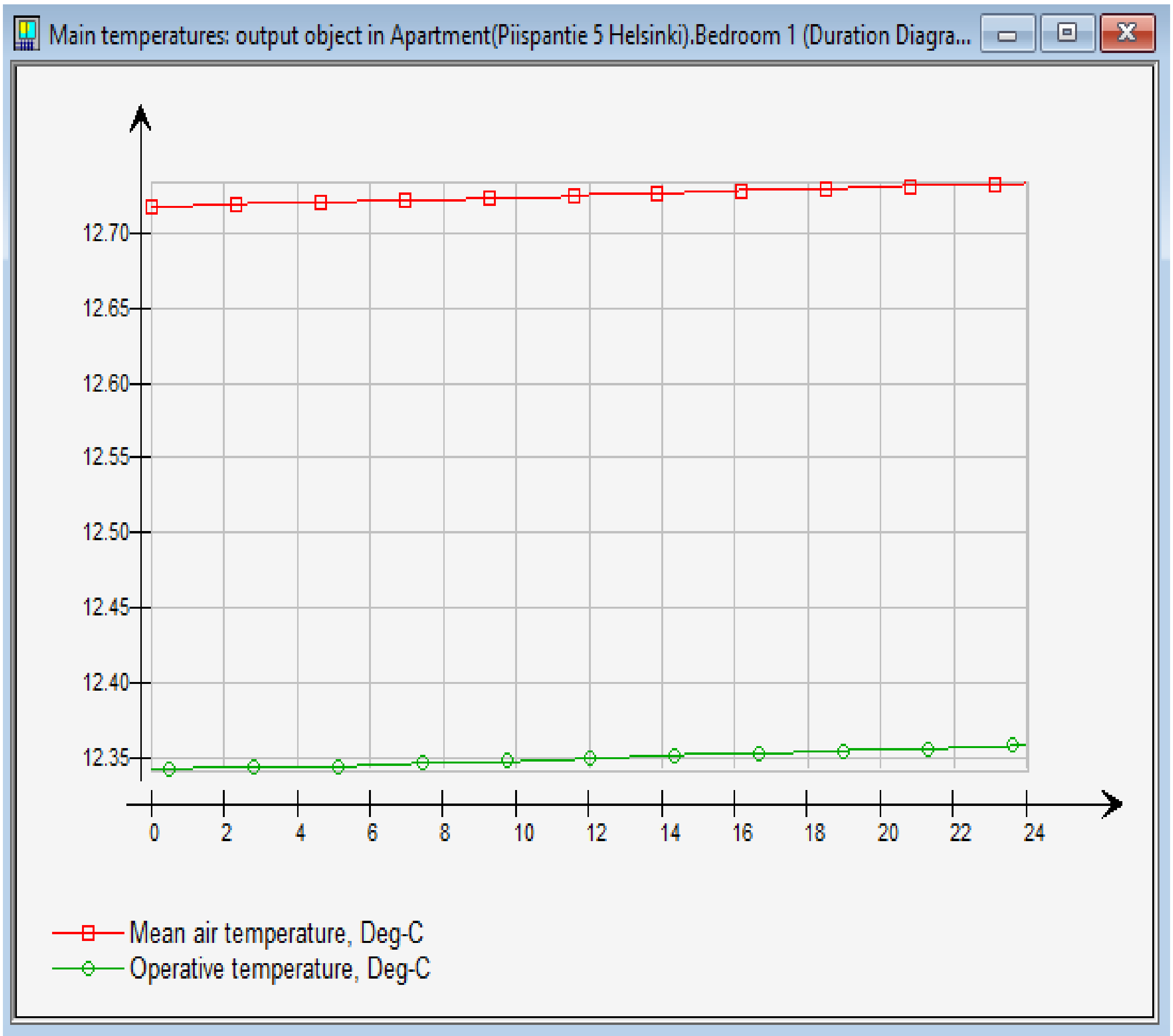
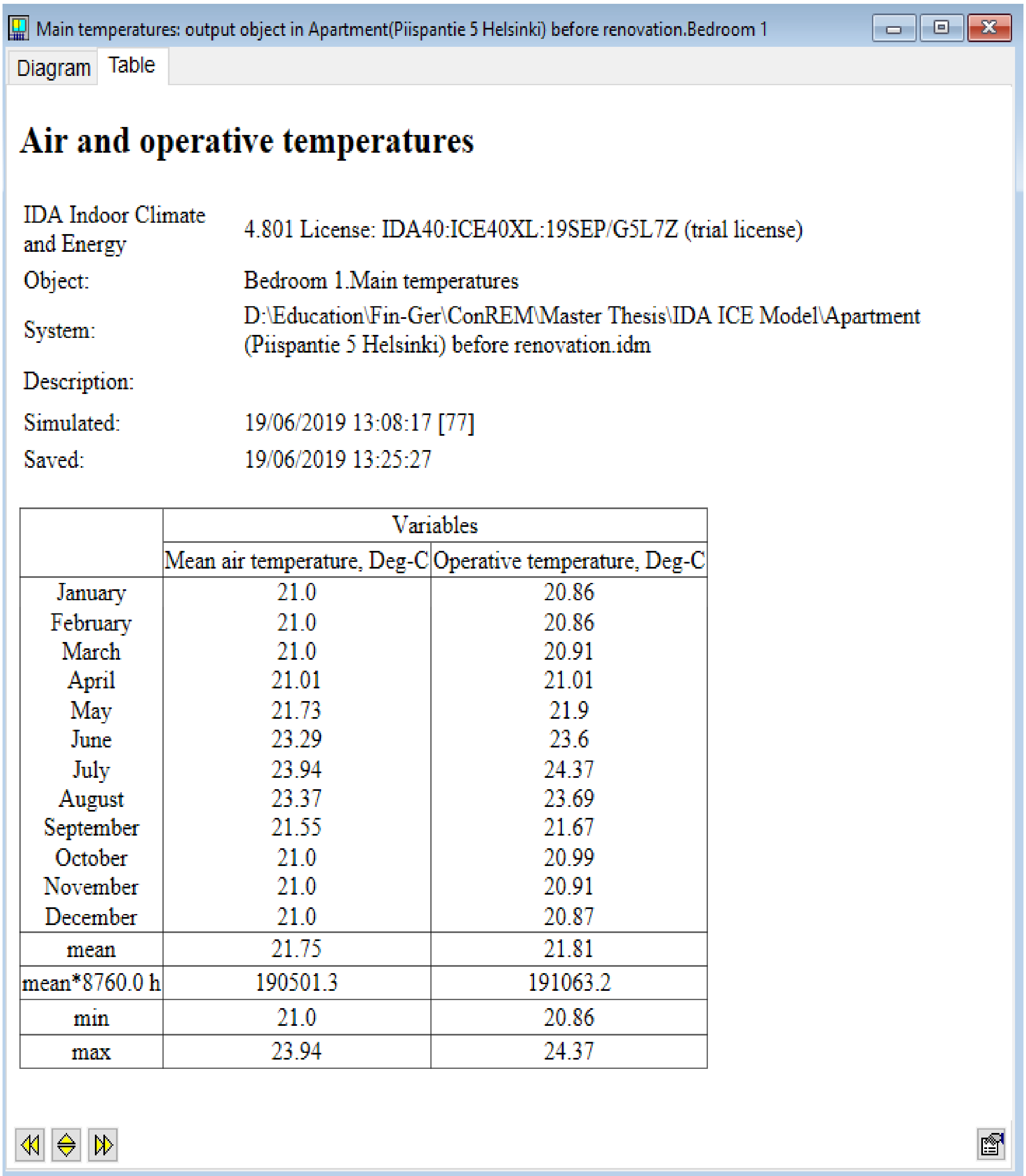


Fig. 34: The duration diagram.

The duration curve displays how many hours the room is below a specific temperature. The data associated with the details tab can also get represented in tabular format. The tabular view of the main temperature in bedroom one is displayed in figure 35. The mean air temperature and the operative temperature is listed hourly during the day 15th of February 2019.

The presented data in diagram or tabular format can be navigated between different display periods such as hour, date, week, month, year, last day of simulation and, entire simulation period.



Main temperatures: output object in Apartment(Piispantie 5 Helsinki) before renovation.Bedroom 1

Diagram Table

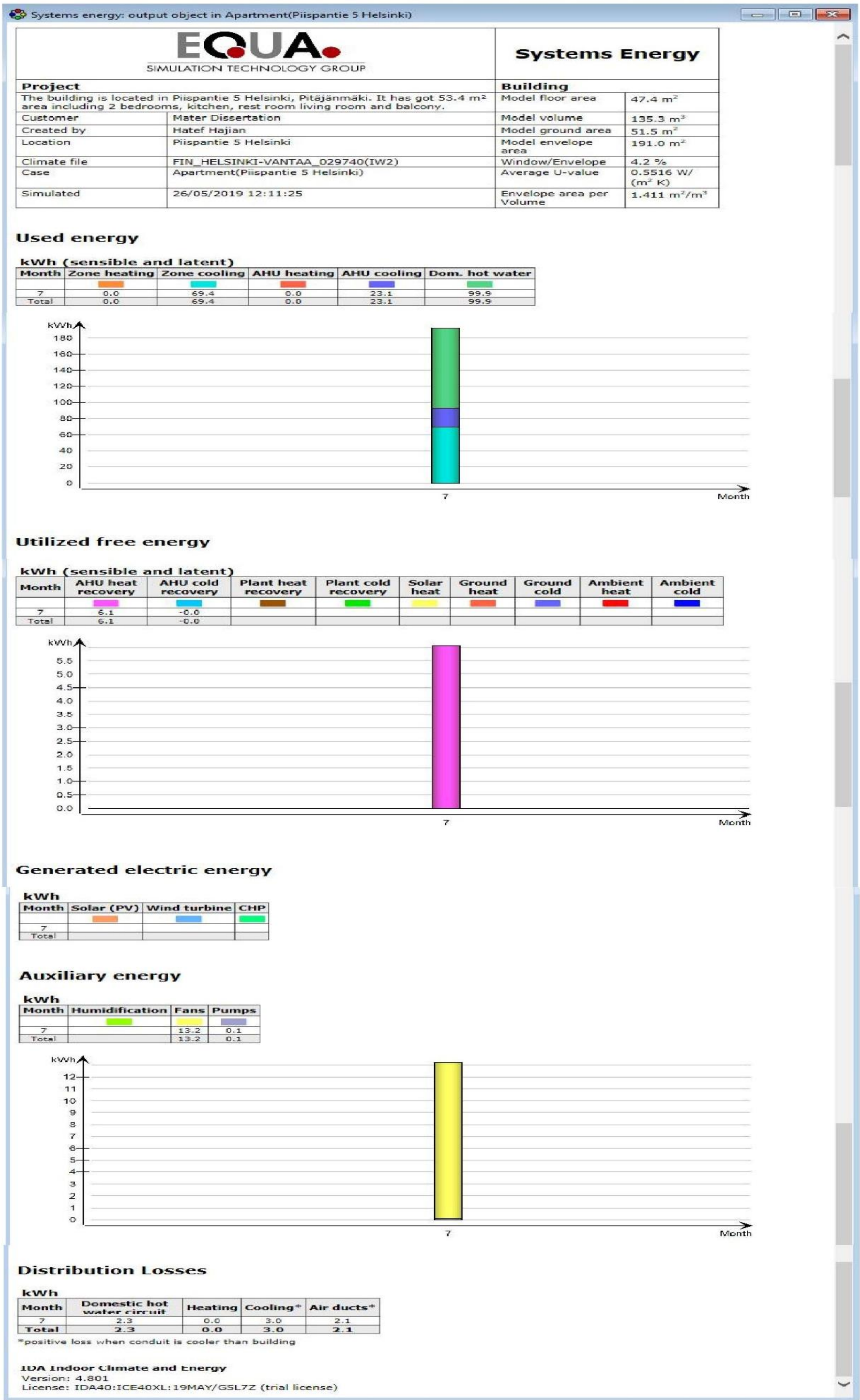
Air and operative temperatures

IDA Indoor Climate and Energy	4.801 License: IDA40:ICE40XL:19SEP/G5L7Z (trial license)
Object:	Bedroom 1.Main temperatures
System:	D:\Education\Fin-Ger\ConREM\Master Thesis\IDA ICE Model\Apartment (Piispantie 5 Helsinki) before renovation.idm
Description:	
Simulated:	19/06/2019 13:08:17 [77]
Saved:	19/06/2019 13:25:27

	Variables	
	Mean air temperature, Deg-C	Operative temperature, Deg-C
January	21.0	20.86
February	21.0	20.86
March	21.0	20.91
April	21.01	21.01
May	21.73	21.9
June	23.29	23.6
July	23.94	24.37
August	23.37	23.69
September	21.55	21.67
October	21.0	20.99
November	21.0	20.91
December	21.0	20.87
mean	21.75	21.81
mean*8760.0 h	190501.3	191063.2
min	21.0	20.86
max	23.94	24.37

Fig. 35: The table of main temperature in bedroom one.

The energy reports are accessed in IDA ICE details tab. For instance, the systems energy report is shown in figure 36.



Systems energy: output object in Apartment(Piispantie 5 Helsinki)

EQUA SIMULATION TECHNOLOGY GROUP

Systems Energy

Project		Building	
The building is located in Piispantie 5 Helsinki, Pitäjänmäki. It has got 53.4 m² area including 2 bedrooms, kitchen, rest room living room and balcony.		Model floor area	47.4 m²
Customer	Mater Dissertation	Model volume	135.3 m³
Created by	Hatef Hajian	Model ground area	51.5 m²
Location	Piispantie 5 Helsinki	Model envelope area	191.0 m²
Climate file	FIN_HELSINKI-VANTAA_029740(IW2)	Window/Envelope	4.2 %
Case	Apartment(Piispantie 5 Helsinki)	Average U-value	0.5516 W/(m² K)
Simulated	26/05/2019 12:11:25	Envelope area per Volume	1.411 m²/m³

Used energy

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
7	0.0	69.4	0.0	23.1	99.9
Total	0.0	69.4	0.0	23.1	99.9

Utilized free energy

kWh (sensible and latent)

Month	AHU heat recovery	AHU cold recovery	Plant heat recovery	Plant cold recovery	Solar heat	Ground heat	Ground cold	Ambient heat	Ambient cold
7	6.1	-0.0							
Total	6.1	-0.0							

Generated electric energy

kWh

Month	Solar (PV)	Wind turbine	CHP
7			
Total			

Auxiliary energy

kWh

Month	Humidification	Fans	Pumps
7		13.2	0.1
Total		13.2	0.1

Distribution Losses

kWh

Month	Domestic hot water circuit	Heating	Cooling*	Air ducts*
7	2.3	0.0	3.0	2.1
Total	2.3	0.0	3.0	2.1

*positive loss when conduit is cooler than building

IDA Indoor Climate and Energy
Version: 4.801
License: IDA40:ICE40XL:19MAY/G5L7Z (trial license)

Fig. 36: The systems energy report.

3 Results

3.1 Apartment

3.1.1 Energy Consumption before and after Renovatio

The energy consumption will be studied by improving the thickness of the thermal insulation layer of the external walls because of the following reasons:

- Renovating external walls is one of the primary steps in the renovation process.
- The external walls are covering a large area of the residential buildings, which are the barrier between the outdoor and indoor environment.
- The necessity for repairing the outer layer of the external wall (facade) frequently in countries with a severe climate condition like Finland.

The thermal insulation layer before the renovation process is considered as 75 mm, which is extracted from Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja and the structural energy efficiency in the construction report. The energy consumption of the apartment before the renovation in IDA ICE software is shown as a part of the delivered energy report in figure 37. It is noted as the Fuel heating and mentioned the amount of 6,842 kWh.

The process of the renovation of the insulation layer of the external wall may perform in two methods. Either by removing the old mineral wool and substituting the new mineral wool insulation layer with the desired thickness or by removing the old mineral wool and replacing it with the Expanded Polystyrene (EPS). The EPS material offers several advantages as compared to the mineral wool isolation such as more comfortable to fit, less weight, quicker to alter, simpler to attach to the next composite external wall layers.

To replace the new insulation layer, either the mineral wool or EPS, the outer layer of the external wall should get demolished. After changing the insulation layer, the same outer layer of the external wall may get replaced, or the outer layer of the external wall might be built by appending a mesh into the insulation layer and spraying cement which is resistant against severe climate condition. In this study, the first method is considered.

Delivered Energy: output object in Apartment(Piispantie 5 Helsinki) before renovation

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
The building is located in Piispantie 5 Helsinki, Pitäjänmäki. It has got 53.4 m² area including 2 bedrooms, kitchen, rest room living room and balcony.		Model floor area	47.4 m^2
Customer	Mater Dissertation	Model volume	135.3 m^3
Created by	Hatef Hajian	Model ground area	53.4 m^2
Location	Piispantie 5 Helsinki	Model envelope area	195.8 m^2
Climate file	FIN_HELSINKI-VANTAA_029740(IW2)	Window/Envelope	4.1 %
Case	Apartment(Piispantie 5 Helsinki) before renovation	Average U-value	0.3691 W/(m^2 K)
Simulated	18/06/2019 16:32:52	Envelope area per Volume	1.447 m^2/m^3

Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	31 %

Delivered Energy Overview

	Purchased energy		**Peak demand**
	kWh	**kWh/m^2**	**kW**
Lighting, facility	2276	48.0	0.26
Electric cooling	233	4.9	0.6
HVAC aux	676	14.3	0.08
Total, Facility electric	3185	67.2	
Fuel heating	6842	144.3	3.64
Domestic hot water	5792	122.1	0.66
Total, Facility fuel*	12634	266.4	
Total	15819	333.6	
Equipment, tenant	1707	36.0	0.19
Total, Tenant electric	1707	36.0	
Grand total	17526	369.5	

*heating value

Fig. 37: The delivered energy report of the apartment before renovation.

According to (Ojanen, Nykänen and Hemmilä, 2017), the thickness of the insulation layer in the external wall in considered as 170 mm in the renovation process. The amount of energy consumption is studied after the renovation by changing the thickness of the insulation layer in the external wall from 75 mm to 170 mm. The external wall composition after the renovation is illustrated in figure 38.

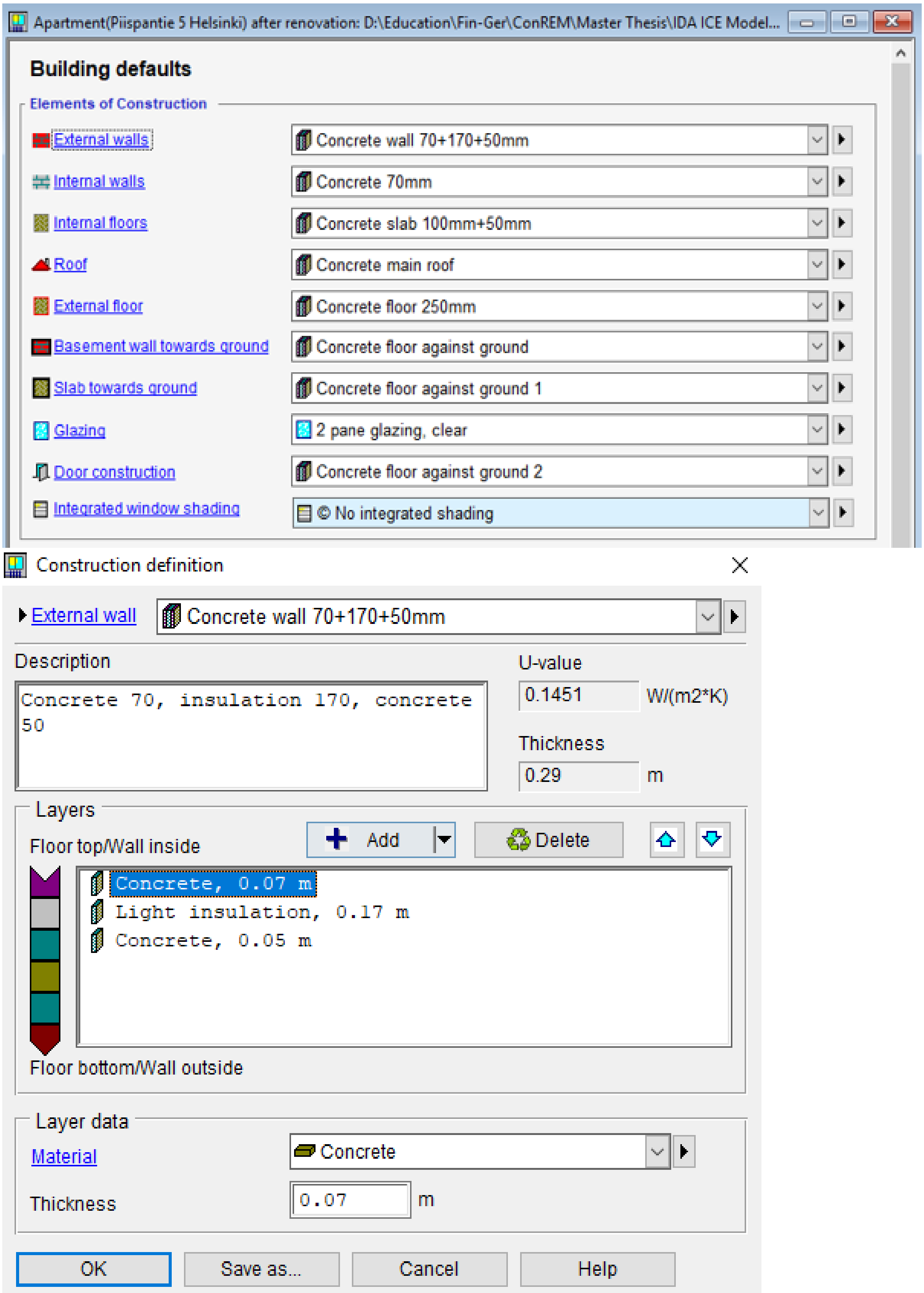


Fig. 38: The external wall building material attribution and construction definition after the renovation process.

The fuel heating amount of 6,092 kWh is shown in figure 39, which is driven after enhancing the insulation thickness of the external wall from 75 mm to 170 mm.

Delivered Energy: output object in Apartment(Piispantie 5 Helsinki) after renovation

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
The building is located in Piispantie 5 Helsinki, Pitäjänmäki. It has got 53.4 m² area including 2 bedrooms, kitchen, rest room living room and balcony.		Model floor area	47.4 m^2
Customer	Mater Dissertation	Model volume	135.3 m^3
Created by	Hatef Hajian	Model ground area	55.9 m^2
Location	Piispantie 5 Helsinki	Model envelope area	201.7 m^2
Climate file	FIN_HELSINKI-VANTAA_029740(IW2)	Window/Envelope	3.9 %
Case	Apartment(Piispantie 5 Helsinki) after renovation	Average U-value	0.3272 W/(m^2 K)
Simulated	18/06/2019 18:03:25	Envelope area per Volume	1.491 m^2/m^3

Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	30 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	2276	48.0	0.26
Electric cooling	237	5.0	0.6
HVAC aux	676	14.3	0.08
Total, Facility electric	3189	67.2	
Fuel heating	6092	128.5	3.46
Domestic hot water	5792	122.1	0.66
Total, Facility fuel*	11884	250.6	
Total	15073	317.8	
Equipment, tenant	1707	36.0	0.19
Total, Tenant electric	1707	36.0	
Grand total	16780	353.8	

*heating value

Fig. 39: The delivered energy report of the apartment after renovation.

3.1.2 Renovation Goals Achievements

According to the Ministry of the Environment degree on improving the energy performance of buildings undergoing renovation or alternation (Kimmo Tiilikainen, 2017), in case of any renovation on external walls, the U-value after the renovation should be decreased to half of the external wall U-value before renovation. However, this amount should not be higher than 0,17 W/m²K.

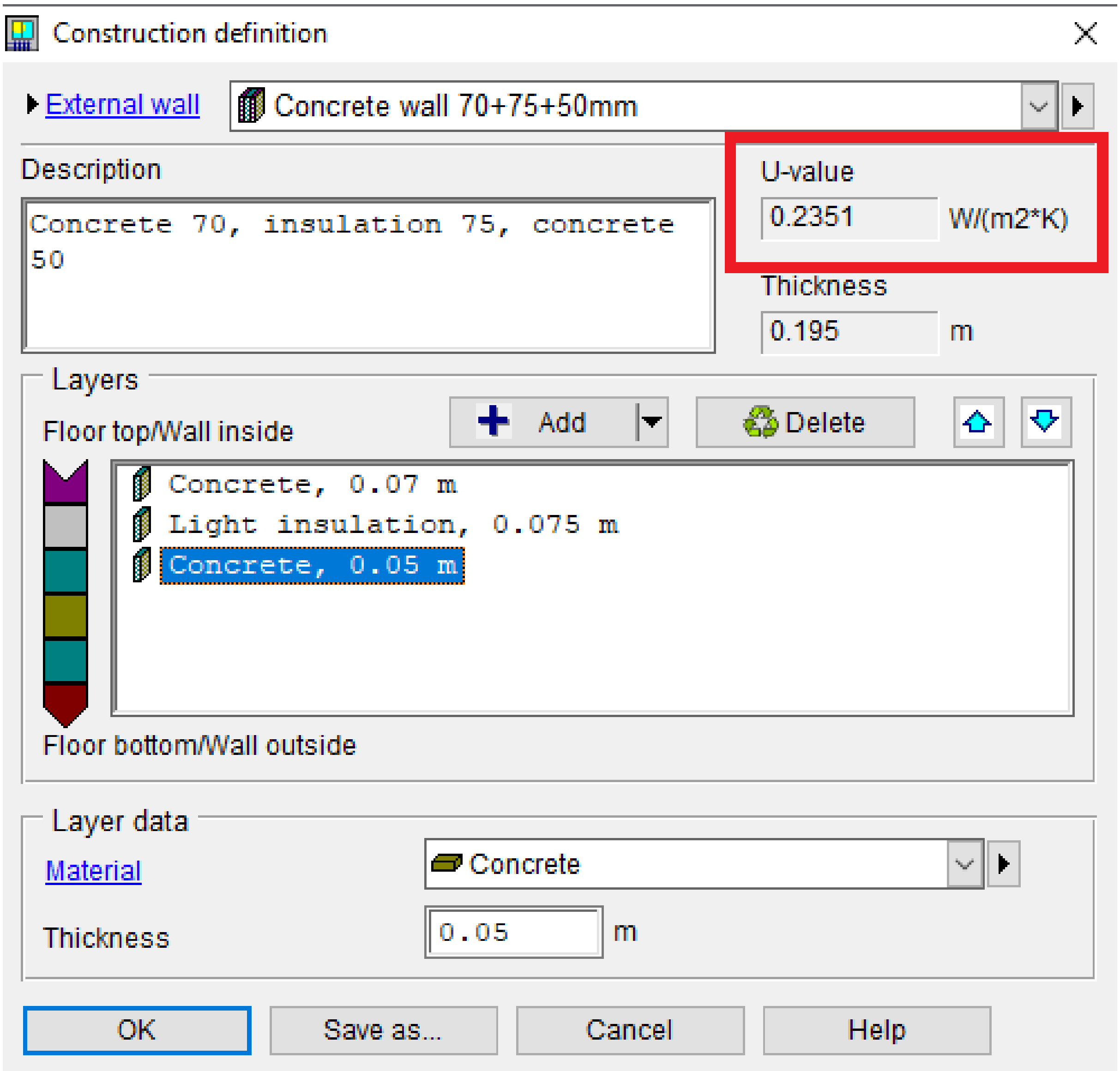


Fig. 40: The external wall U-Value of the apartment before renovation.

The external wall U-value before and after the renovation process is expressed as 0,2351 and 0,1451 W/m²K, respectively, as are shown in above figure 40 and 41. It is evident as the amount of external wall U-value after renovation is not met as the half of the external wall U-value before renovation however the amount of 0,1451 W/m²K does not exceed 0,17 W/m²K.

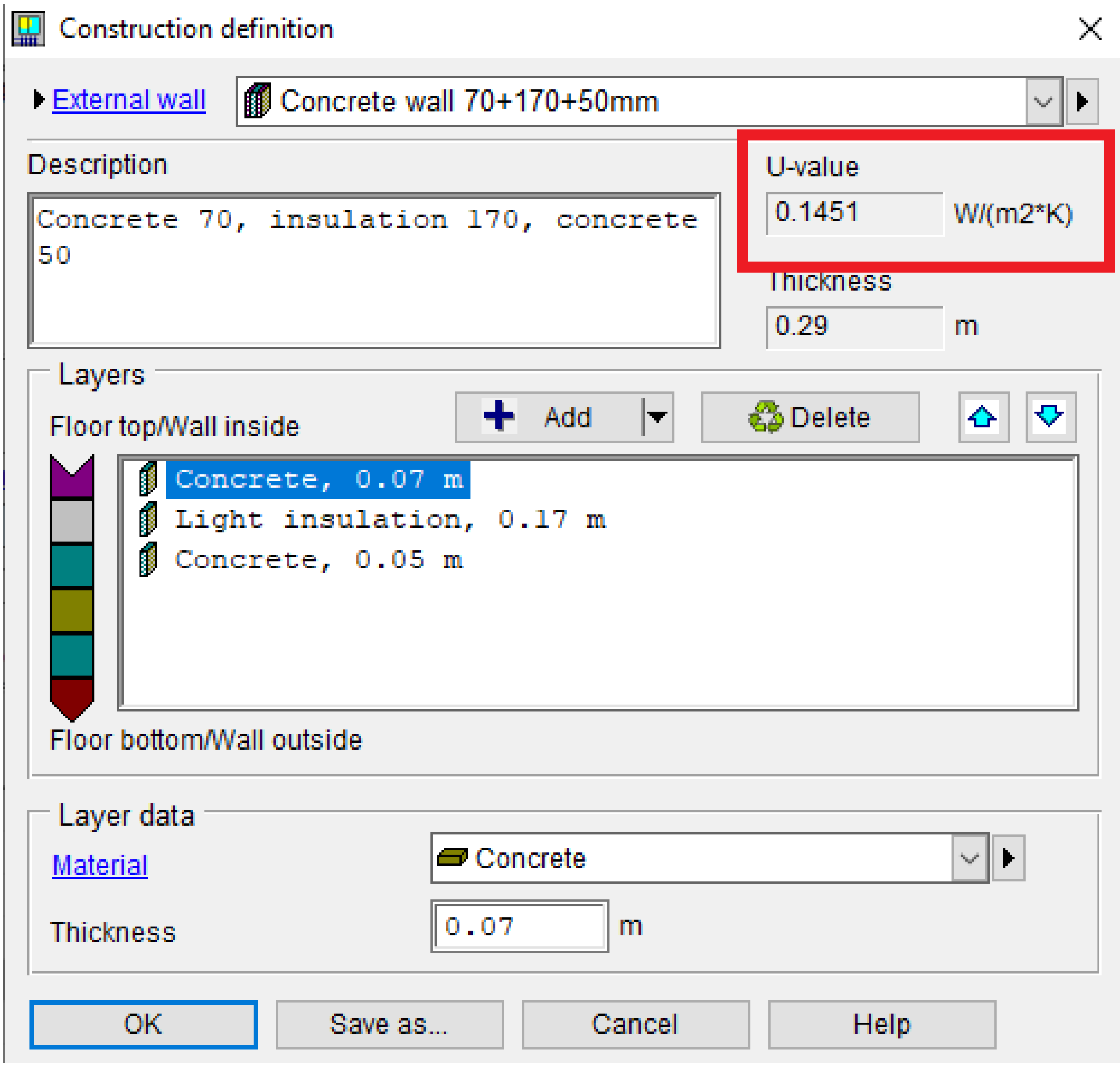


Fig. 41: The external wall U-Value of the apartment after renovation.

3.1.3 CO2 Emission before and after Renovation

The amount of maximum heat supplied, room unit heat, and maximum CO2 per each zone are expressed in tables 6 and 7 before and after renovation, respectively. As it is shown in both tables, the amount of CO2 does not change before and after renovation. The reason is that the maximum CO2 in tables is referred to as the amount of CO2 inside every zone. The amount of CO2 inside every zone changes when the amount of airflow in the respective zones fluctuates. Since there is no relation between the changing the insulation layer of the external wall and the amount of airflow inside each zone, there is no improvement in the maximum amount of CO2.

Before Renovation			
Zone	Max heat supplied, W/m2	Room unit heat, W/m2	Max CO2, ppm (vol)
Bedroom 1	66,54	73,65	682,7
Bedroom 2	50,08	57,21	682,9
Rest Room	8,722	16,53	761
Living Area	29,41	36,15	638,2
Total	154,752	183,54	

Tab. 6: The max heat supplied, room unit heat, and Max CO2 for each zone before renovation in the apartment.

After Renovation			
Zone	Max heat supplied, W/m2	Room unit heat, W/m2	Max CO2, ppm (vol)
Bedroom 1	61,75	68,88	682,7
Bedroom 2	48,5	55,63	682,9
Rest Room	3,994	11,8	760,9
Living Area	25,46	32,21	638,2
Total	139,704	168,52	

Tab. 7: The max heat supplied, room unit heat, and Max CO2 for each zone after renovation in the apartment.

However, the maximum heat supplied for all zones before the renovation is 154,752 W/m², and after renovation, it has decreased to 139,704 W/m², which means 9,72% r reduction. If the primary energy company which supplies the hot air into the district emits an amount of CO2 gr/Kwh into the environment, then the reduction in maximum heat supply leads to a reduction of CO2 emission in a primary energy company.

Calculating the amount of CO2 emission is possible in IDA ICE. However, it required to input the amount of CO2 emission in g/kWh from the energy meters of the apartment which unfortunately collecting data from energy meters was impossible due to the location of the apartment in Finland while the thesis is getting prepared in Germany. The table which is provided to input the amount of CO2 emission in IDA ICE is shown in figure 42.

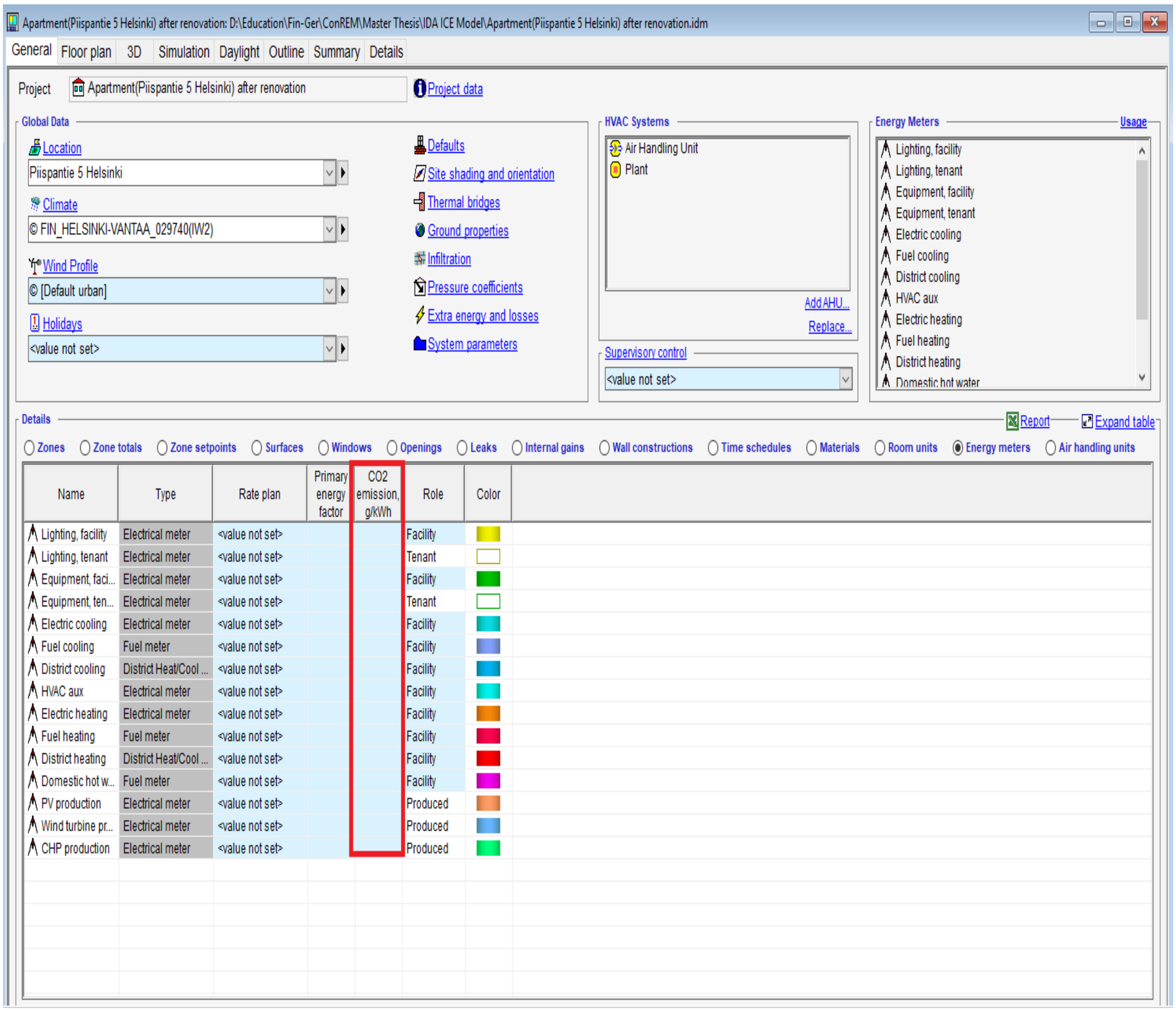


Fig. 42: The provided table in IDA ICE to input the amount of CO_2 emission from energy meters.

3.1.4 IAQ before and after Renovation

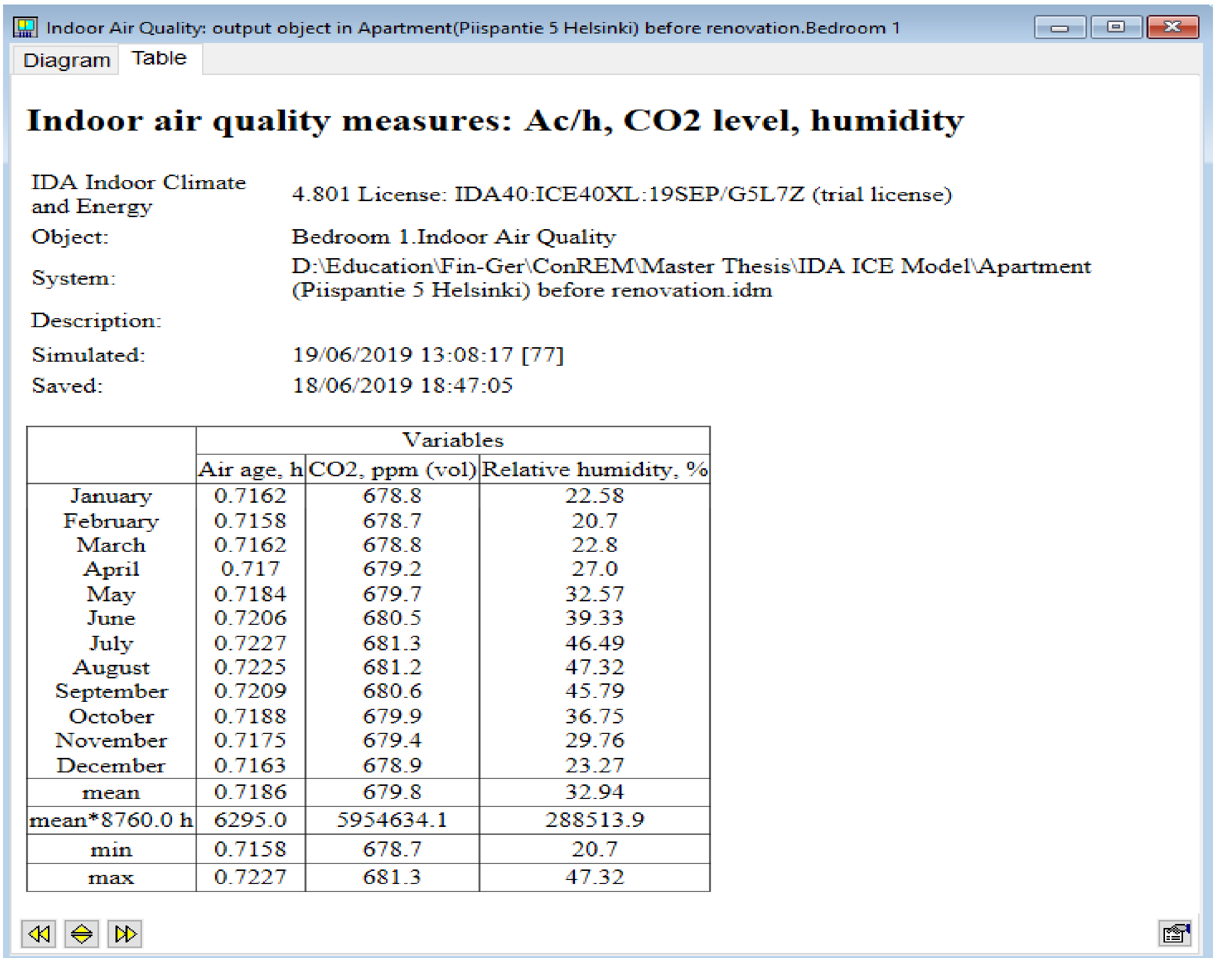
The indoor air quality is measured based on three variables called Air Age, CO_2, and Relative Humidity in IDA ICE software. The air age is defined as when air is born, and it enters to the same room. If it enters the other room, it is already old. The air age is a better indicator when compared to Air Change per Hour (ACH) because the air change per hour treats all air equally, and it does not consider the old and new air. (Hou *et al.*, 2017) points out that the Air Change per Hour or air change rate is a measure of the air volume that is added or removed in space (usually in a room or home), divided by the volume of space. If air is either uniform or perfectly mixed within space, changes in the air per hour are an indication of the time that the air is replaced in a given space

(Hou et al., 2017). The higher the air change rate is, the less importance has the wall insulation layers thickness.

In a well-combined ventilation case, the proper air volume altered will be 63.2% in 1 hour and 1 ACH (Sarigiannis, Gotti and Karakitsios, 2018). One ACH means that the air in the room is changed one time per hour. However, the ventilation rates are 0.5 ACH in the residential buildings and 2 ACH in schools (Tiilikainen and Outinen, 2016).

The CO2 is expressed as the concentration of CO2 in the zone at the time of maximal heat supply. Moreover, the relative humidity is defined as the relative humidity of the air in the zone at the time of maximal heat supply.

All measures which are included in indoor air quality are based on the airflow. Meaning that if the air flow does not change, there will be no changes in the mentioned measures. Therefore, as it is shown in figure 43, there is no improvement in the measures while improving the insulation layer of the external wall.



Indoor Air Quality: output object in Apartment(Piispantie 5 Helsinki) before renovation.Bedroom 1

Diagram Table

Indoor air quality measures: Ac/h, CO2 level, humidity

IDA Indoor Climate and Energy	4.801 License: IDA40:ICE40XL:19SEP/G5L7Z (trial license)
Object:	Bedroom 1.Indoor Air Quality
System:	D:\Education\Fin-Ger\ConREM\Master Thesis\IDA ICE Model\Apartment (Piispantie 5 Helsinki) before renovation.idm
Description:	
Simulated:	19/06/2019 13:08:17 [77]
Saved:	18/06/2019 18:47:05

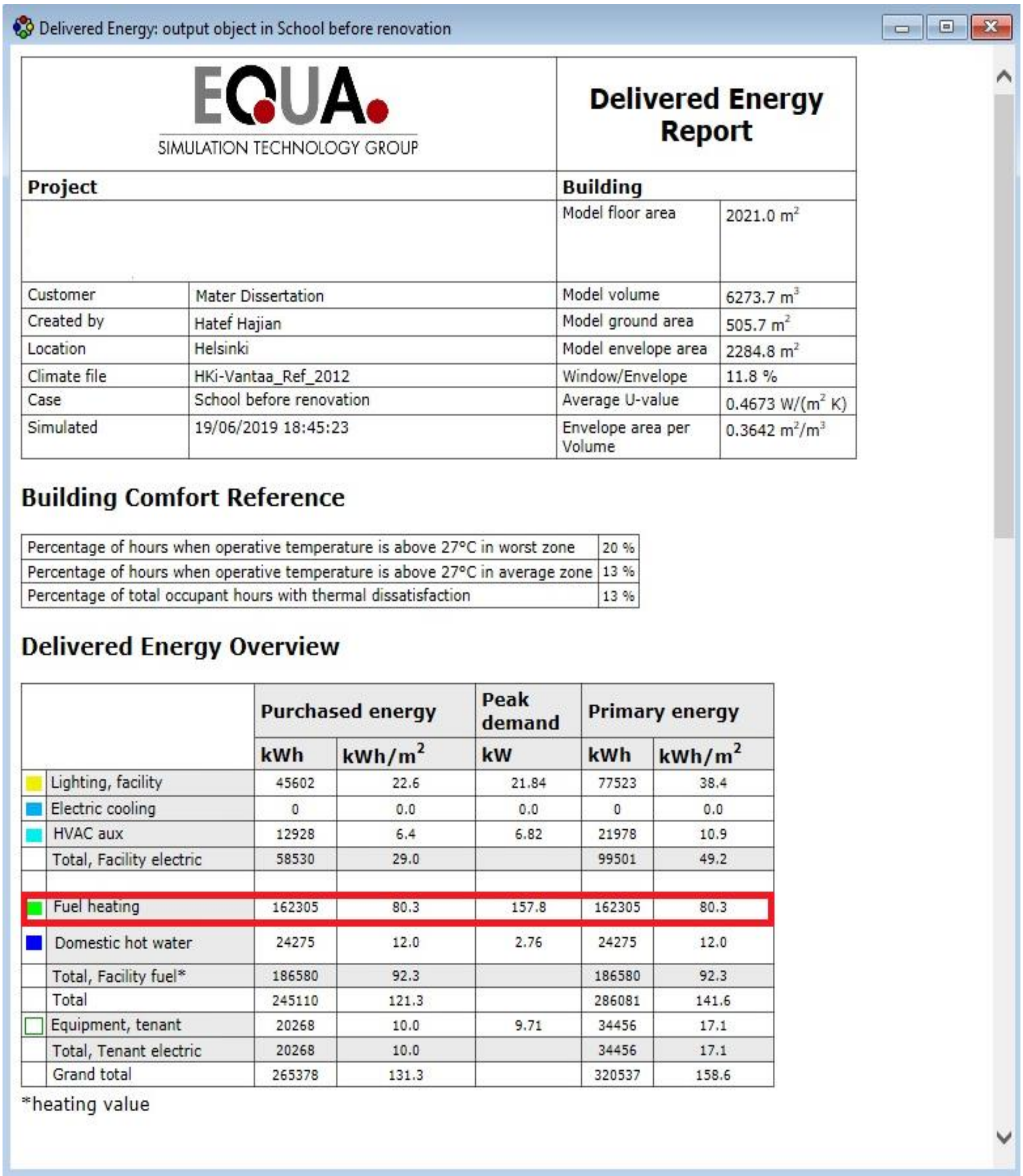
	Variables		
	Air age, h	CO2, ppm (vol)	Relative humidity, %
January	0.7162	678.8	22.58
February	0.7158	678.7	20.7
March	0.7162	678.8	22.8
April	0.717	679.2	27.0
May	0.7184	679.7	32.57
June	0.7206	680.5	39.33
July	0.7227	681.3	46.49
August	0.7225	681.2	47.32
September	0.7209	680.6	45.79
October	0.7188	679.9	36.75
November	0.7175	679.4	29.76
December	0.7163	678.9	23.27
mean	0.7186	679.8	32.94
mean*8760.0 h	6295.0	5954634.1	288513.9
min	0.7158	678.7	20.7
max	0.7227	681.3	47.32

Fig. 43: The Indoor Air Quality measures before renovation in bedroom 1.

3.2 School

3.2.1 Energy Consumption before and after Renovation

To avoid repetitive information, since the renovation approach of both case studies is the same, all IDA ICE settings which have been considered in the IDA ICE Software General Settings (Section 5.1.3) are kept in the school case study IDA ICE settings.



Delivered Energy: output object in School before renovation

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		Building	
		Model floor area	2021.0 m²
Customer	Mater Dissertation	Model volume	6273.7 m³
Created by	Hatef Hajian	Model ground area	505.7 m²
Location	Helsinki	Model envelope area	2284.8 m²
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	11.8 %
Case	School before renovation	Average U-value	0.4673 W/(m² K)
Simulated	19/06/2019 18:45:23	Envelope area per Volume	0.3642 m²/m³

Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	20 %
Percentage of hours when operative temperature is above 27°C in average zone	13 %
Percentage of total occupant hours with thermal dissatisfaction	13 %

Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	kWh/m²	kW	kWh	kWh/m²
Lighting, facility	45602	22.6	21.84	77523	38.4
Electric cooling	0	0.0	0.0	0	0.0
HVAC aux	12928	6.4	6.82	21978	10.9
Total, Facility electric	58530	29.0		99501	49.2
Fuel heating	162305	80.3	157.8	162305	80.3
Domestic hot water	24275	12.0	2.76	24275	12.0
Total, Facility fuel*	186580	92.3		186580	92.3
Total	245110	121.3		286081	141.6
Equipment, tenant	20268	10.0	9.71	34456	17.1
Total, Tenant electric	20268	10.0		34456	17.1
Grand total	265378	131.3		320537	158.6

*heating value

Fig. 44: The delivered energy report of the school before the renovation.

The thermal insulation layer is 90 mm, obtained from Tyypillisiä olemassa olevien vanhojen rakennusten alkuperäisiä suunnitteluarvoja and the thermal energy efficiency in the construction document before the renovation phase. As a portion of the energy report provided in figure 44, the energy consumption in the apartment is presented before the renovation of IDA ICE software. The quantity of heating is observed as the fuel heating as 162,395 kWh.

The thickness of the insulation layer in the external wall in the renovation phase is regarded at 190 mm (Ojanen, Nykänen and Hemmilä 2017). After the renovations, the quantity of energy consumed is researched by altering the layer thickness from 90 mm to 190 mm in the exterior wall. Figure 45 shows the fuel heating of 140,654 kWh after the enhancement of the insulation layer thickness of the external wall.

Delivered Energy: output object in School after renovation

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		Building	
		Model floor area	2021.0 m²
Customer	Mater Dissertation	Model volume	6273.7 m³
Created by	Hatef Hajian	Model ground area	505.7 m²
Location	Helsinki	Model envelope area	2284.8 m²
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	11.8 %
Case	School after renovation	Average U-value	0.3709 W/(m² K)
Simulated	19/06/2019 19:48:18	Envelope area per Volume	0.3642 m²/m³

Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	22 %
Percentage of hours when operative temperature is above 27°C in average zone	17 %
Percentage of total occupant hours with thermal dissatisfaction	14 %

Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	kWh/m²	kW	kWh	kWh/m²
Lighting, facility	45598	22.6	21.84	77517	38.4
Electric cooling	0	0.0	0.0	0	0.0
HVAC aux	12926	6.4	6.82	21974	10.9
Total, Facility electric	58524	29.0		99491	49.2
Fuel heating	140654	69.6	149.4	140654	69.6
Domestic hot water	24275	12.0	2.76	24275	12.0
Total, Facility fuel*	164929	81.6		164929	81.6
Total	223453	110.6		264420	130.8
Equipment, tenant	20265	10.0	9.71	34450	17.1
Total, Tenant electric	20265	10.0		34450	17.1
Grand total	243718	120.6		298870	147.9

*heating value

Fig. 45: The delivered energy report of the school after renovation.

3.2.2 Renovation Goals Achievements

In the case of any renovations on external walls, U-value, regarding renovation, should be reduced to half the external wall U-value, according to the Ministry of the Environment, which aims at improving the energy performance of buildings undergoing renovation (Kimmo Tiilikainen, 2017). This value should nevertheless not exceed 0,17 W / m2K.

As shown in figures 46 and 47, the exterior wall U-value, before and after the renovation process, is expressed as 0,2068 and 0,1313 W / m2K. The value of the external wall U-value does not exceed0,17 W / m2 K as half of the external Wall U-value before renovation.

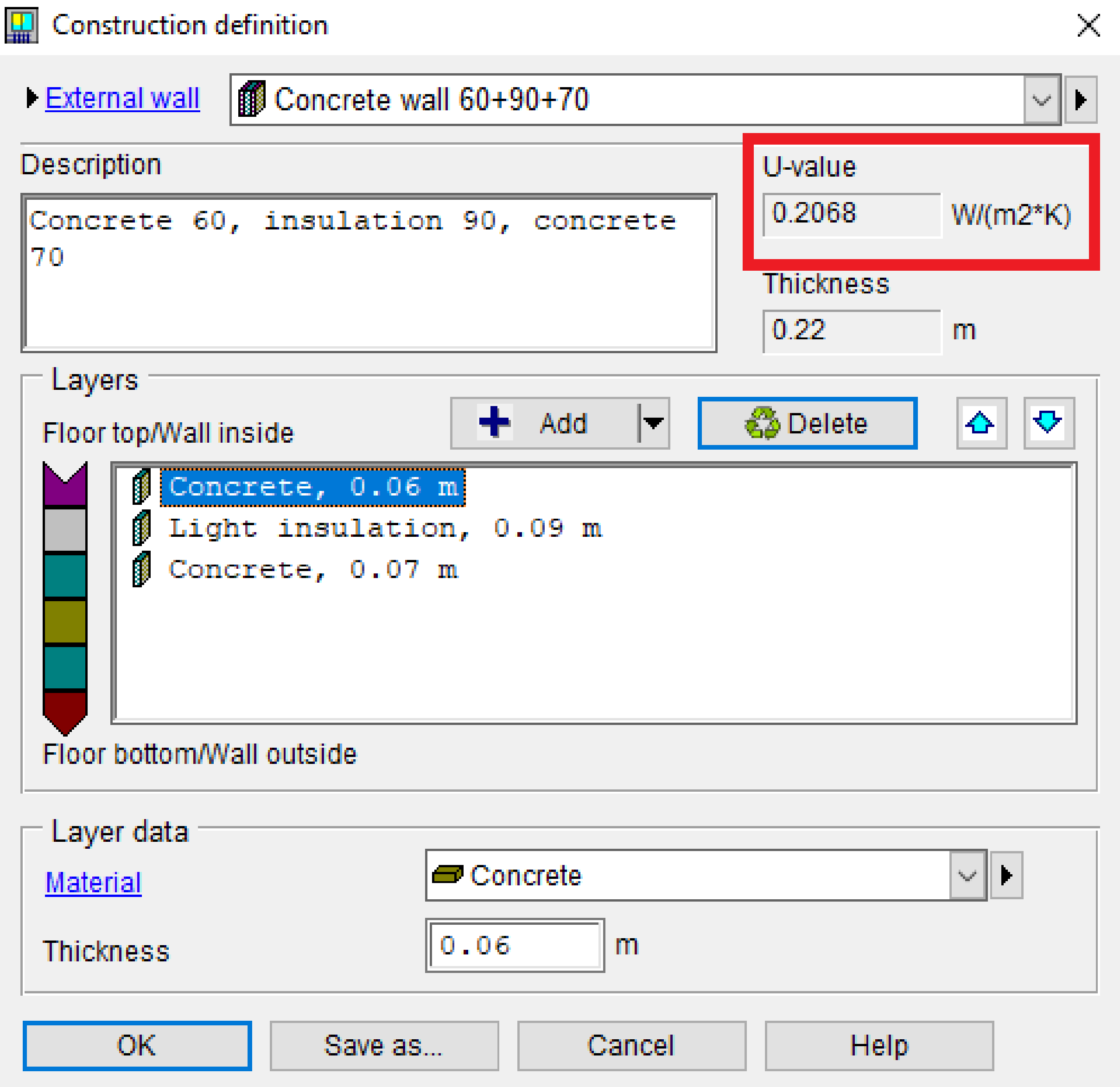


Fig. 46: The external wall U-Value of the school before renovation.

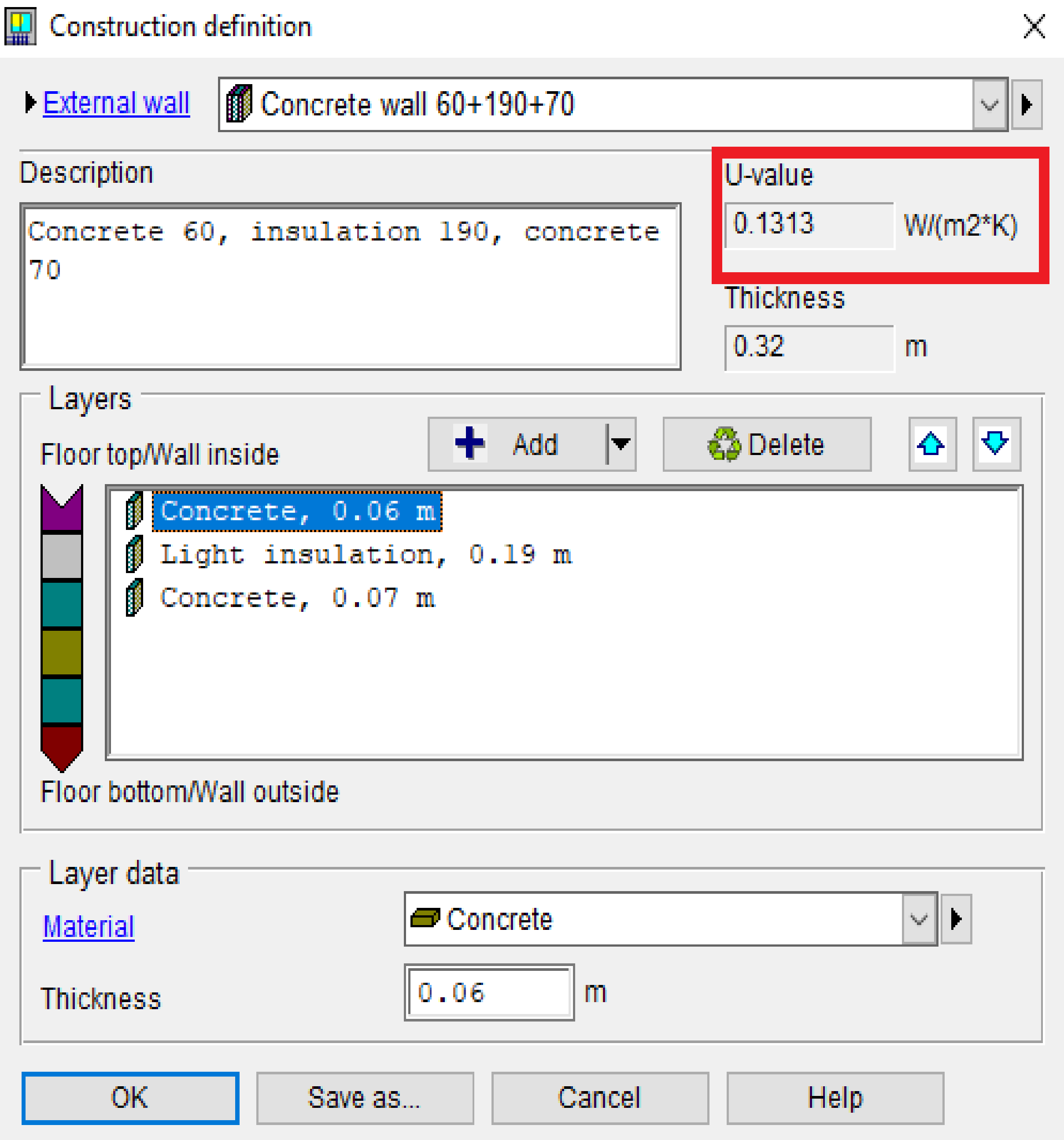


Fig. 47: The external wall U-Value of the school after renovation.

3.2.3 CO2 Emission before and after Renovation

As it is briefly discussed in the previous part, the amount of maximum CO2 in zones does not differ before and after the renovation process due to considering the unchanged amount of airflow in respective zones.

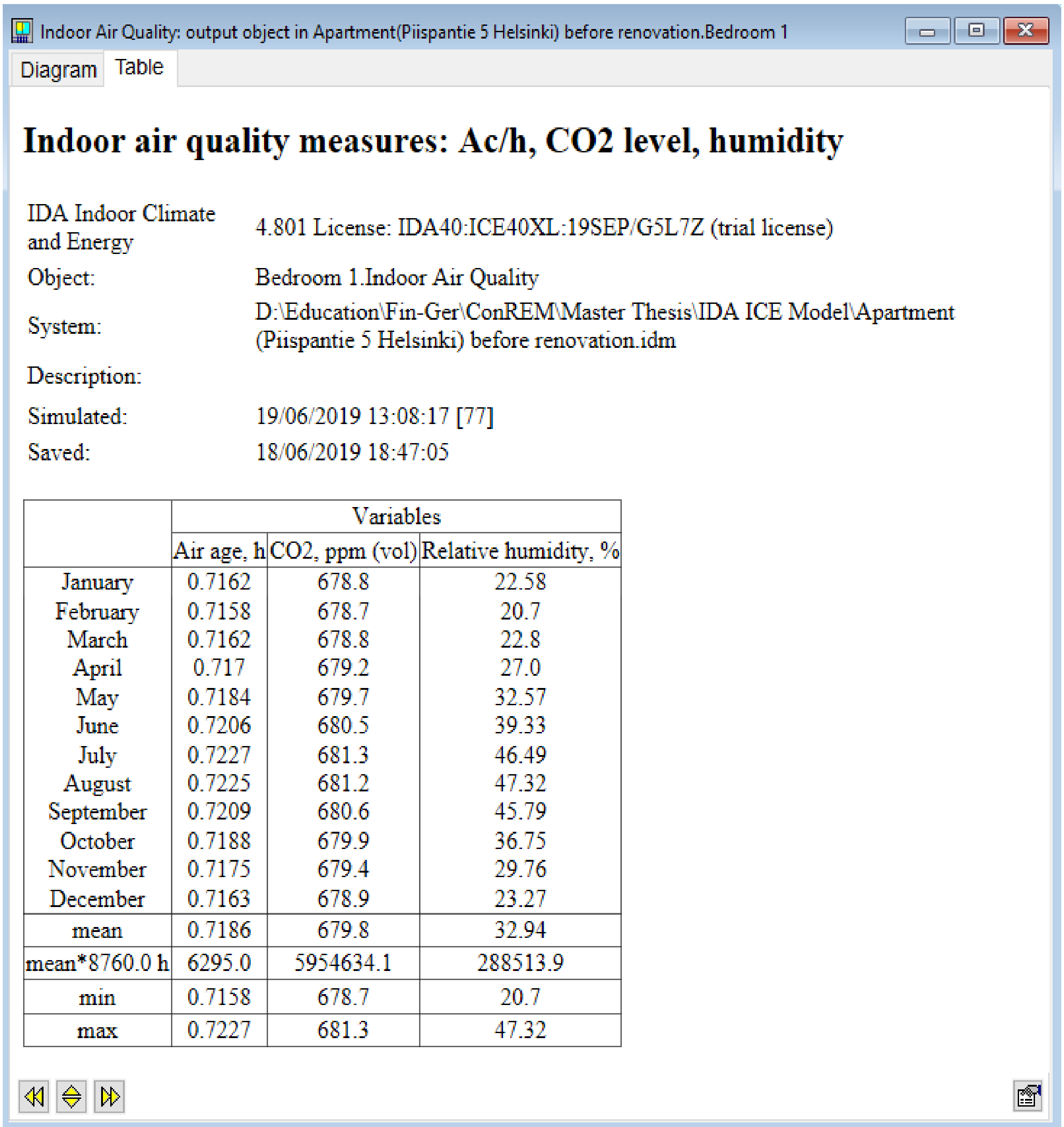
3.2.4 IAQ before and after Renovation

The indoor air quality is measured based on three variables called Air Age, CO_2, and Relative Humidity in IDA ICE software. The air age is defined as when air is born, and it enters to the same room. If it enters the other room, it is already old. The air age is a better indicator when compared to Air Change per Hour (ACH) because the air change per hour treats all air equally, and it does not consider the old and new air. (Hou *et al.*, 2017) points out that the Air Change per Hour or air change rate is a measure of the air volume that is added or removed in space (usually in a room or home), divided by the volume of space. If air is either uniform or perfectly mixed within space, changes in the air per hour are an indication of the time that the air is replaced in a given space (Hou et al., 2017). The higher the air change rate is, the less importance has the wall insulation layers thickness.

In a well-combined ventilation case, the proper air volume altered will be 63.2% in 1 hour and 1 ACH (Sarigiannis, Gotti and Karakitsios, 2018). One ACH means that the air in the room is changed one time per hour. However, the ventilation rates are 0.5 ACH in the residential buildings and 2 ACH in schools (Tiilikainen and Outinen, 2016).

The CO_2 is expressed as the concentration of CO_2 in the zone at the time of maximal heat supply. Moreover, the relative humidity is defined as the relative humidity of the air in the zone at the time of maximal heat supply.

All measures which are included in indoor air quality are based on the airflow. Meaning that if the air flow does not change, there will be no changes in the mentioned measures. Therefore, as it is shown in figure 48 and 49, there is no improvement in the measures while improving the insulation layer of the external wall.



Indoor Air Quality: output object in Apartment(Piispantie 5 Helsinki) before renovation.Bedroom 1

Diagram Table

Indoor air quality measures: Ac/h, CO2 level, humidity

IDA Indoor Climate and Energy	4.801 License: IDA40:ICE40XL:19SEP/G5L7Z (trial license)
Object:	Bedroom 1.Indoor Air Quality
System:	D:\Education\Fin-Ger\ConREM\Master Thesis\IDA ICE Model\Apartment (Piispantie 5 Helsinki) before renovation.idm
Description:	
Simulated:	19/06/2019 13:08:17 [77]
Saved:	18/06/2019 18:47:05

	Variables		
	Air age, h	CO2, ppm (vol)	Relative humidity, %
January	0.7162	678.8	22.58
February	0.7158	678.7	20.7
March	0.7162	678.8	22.8
April	0.717	679.2	27.0
May	0.7184	679.7	32.57
June	0.7206	680.5	39.33
July	0.7227	681.3	46.49
August	0.7225	681.2	47.32
September	0.7209	680.6	45.79
October	0.7188	679.9	36.75
November	0.7175	679.4	29.76
December	0.7163	678.9	23.27
mean	0.7186	679.8	32.94
mean*8760.0 h	6295.0	5954634.1	288513.9
min	0.7158	678.7	20.7
max	0.7227	681.3	47.32

Fig. 48: The Indoor Air Quality measures before renovation in bedroom 1.

Indoor Air Quality: output object in Apartment(Piispantie 5 Helsinki) after renovation.Bedroom 1

Diagram Table

Indoor air quality measures: Ac/h, CO2 level, humidity

IDA Indoor Climate and Energy	4.801 License: IDA40:ICE40XL:19SEP/G5L7Z (trial license)
Object:	Bedroom 1.Indoor Air Quality
System:	D:\Education\Fin-Ger\ConREM\Master Thesis\IDA ICE Model\Apartment (Piispantie 5 Helsinki) after renovation.idm
Description:	
Simulated:	19/06/2019 06:26:58 [76]
Saved:	18/06/2019 18:19:39

	Variables		
	Air age, h	CO2, ppm (vol)	Relative humidity, %
January	0.7162	678.8	22.58
February	0.7158	678.7	20.7
March	0.7162	678.8	22.8
April	0.717	679.2	26.99
May	0.7184	679.7	32.35
June	0.7206	680.5	39.02
July	0.7227	681.3	46.43
August	0.7226	681.2	46.97
September	0.721	680.6	45.34
October	0.7188	679.9	36.72
November	0.7175	679.4	29.76
December	0.7163	678.9	23.27
mean	0.7186	679.8	32.82
mean*8760.0 h	6295.1	5954628.1	287470.7
min	0.7158	678.7	20.7
max	0.7227	681.3	46.97

Fig. 49: The Indoor Air Quality measures after renovation in bedroom 1.

3.3 Interview

This dissertation is designed as a qualitative study. An interview has been conducted regarding the indoor air quality in dwellings and schools with Dr. Pekka Tuomaala who is a principal scientist and an expert in indoor air quality research area works at VTT (Valtion Teknillinen Tutkimuskeskus) or Technical Research Center of Finland.

The interview questions may be classified as four separate parts. Questions one to five may be categorized as standard data. They are more focused on primary and general information. Question six is concentrated on indoor air quality in new buildings. Questions seven to thirteen are concerned about indoor air quality in existing buildings, and question fourteen and fifteen are more looked into the available opportunities in the future.

The interview questions summary is as follow:[11]

1. What does the term “perceived indoor air quality” mean to you? Does it differ from apartment to school? How?
   According to my knowledge, the term ”perceived indoor air quality” is NOT adequately defined. To me, it means how occupants experience indoor air, and there are some sub-classifications (such as stuffiness, freshness, odorless, moisture, etc.) utilized in different questionnaires. There is no doubt that indoor air quality differs from housing to schools. Because in residential buildings and schools, the design of structures, construction methods, utilization type, ventilation techniques, occupant types, needs, etc., vary, the requirements of indoor air quality also vary.

2. How would you rank the perceived indoor air quality among the building performance measures(Energy consumption, CO2 emission, Renovation cost, Indoor air improvement cost, and living quality), and why?
   I would like to rank the perceived indoor air quality as the topmost essential measures because of the more number of hours usually people stay indoors and the harmful influences on humans due to lack of proper indoor air quality which results in eye, skin, respiratory, etc. symptoms.

[11] The summary has been approved by the interviewee at 15.06.2019.

3. What are the existing Finnish perceived indoor air quality standards and regulations in the apartment and school renovation process?
   There seem to be only some limit values for different parameters (CO_2, PM, etc.). In the future, I would like to have some systematic way to summarise a well-argued total value for indoor air quality.

4. How is social awareness among Fins regarding the perceived indoor air quality in apartments and schools?
   In general, people are quite worried about indoor air quality issues. It turns to be more severe in cold climate countries like Finland. However, in many cases, the solid fact is missing, and therefore, people are most often talking about FEELINGS and not about facts.

5. What is the current perceived indoor air quality condition in Finnish apartments and schools?
   I think situations vary a lot. Moreover, since the facts and systematic classification methodology is still missing, we are not able to give any exact data related to this topic.
6. What are the leading indicators (factors) which influence the perceived indoor air quality in Finnish apartments and schools?
   Most often, we are talking about CO_2, PM, and VOCs.

7. What are the criteria for perceived indoor air quality in Finnish apartments and schools which are not renovated?
   General classification criteria are missing. Therefore, we are just trying to fulfill those limit values given in regulations and recommendations.

8. What are the most common methods to improve the perceived indoor air quality during the renovation process in Finnish apartments and schools?
   The practical and conventional methods of improving indoor air quality are balancing ventilation systems and trying to avoid different moisture failures.

9. What are the minimum requirements to enhance the perceived indoor air quality in Finnish apartments and schools?

The minimum requirements to keep the building in acceptable indoor air quality condition is balancing ventilation systems and trying to avoid different moisture failures.

10. What are the common challenges in the perceived indoor air quality improvement process in Finnish apartment and school renovation and the ways to cope up with them?

    The main challenge is to increase public awareness about the importance of indoor air quality and moreover providing solutions to avoid poor indoor air quality. Providing economical, practical approaches to boost indoor air quality could be considered as another challenge. The target values in standards also need to be improved and more supported.

11. How do the occupants benefit from providing adequate perceived indoor air quality in apartments and schools?

    In dwellings, the general well-being of occupants could be improved. Surely, adequate indoor air quality defeats occupants against harmful health effects and symptoms. The proper indoor air quality not only increase the quality of healthiness of students but also help them to better learning.

12. How does the market reflect the applied charges spent for improving the perceived indoor air quality in the private construction sector?

    There seems to be lack of knowledge related to impacts of better indoor air quality, and therefore, the investment cost is typically minimized.

13. Does the Finnish government consider subsidies for improving the perceived indoor air quality during the renovation?

    Not according to my knowledge.

14. What will be the threats and opportunities towards the perceived indoor air quality improvements in the future?

    Missing indoor air quality classification is a threat because no significant improvement will happen. The informative and well-argued indoor air quality classification methodology would open new business models when overall optimization can supplant partial optimization.

15. What are the research demands regarding the perceived indoor air quality shortly?
New indoor air quality classification is in high demand. Based on holistic air quality monitoring and occupant perception data, the methodology is needed.

4 Discussion of Results

Table 8 shows a summary of the impact based on altering the thickness of the insulation layer of the external wall on energy consumption and U-value of the wall. As it is expressed in the mentioned table, the insulation layer thickness of the external wall has increased from 75 mm to 170 mm regarding (Ojanen, Nykänen and Hemmilä, 2017). Therefore, the amount of energy consumption (kWh and kWh/m²) after the renovation has decreased by 10,96% concerning its value before renovation. Consequently, the amount of U-value has been dropped off by 61,71% after the renovation of the external wall. However, the decline in the amount of U-value after renovation does not fulfill the building code limitations if Finland which states that the amount of U-value after the external wall renovation should achieve the half of its amount before renovation.

Status	External Wall Layers (from internal towards external)	Insulation Layer Thickness (mm)	Energy Consumption (kWh)	Energy Consumption (kWh/m²)	U-value (W/m²K)
Before Renovation	Concrete 70 mm Insulation 75 mm Concrete 50 mm	75	6,842	144.3	0.2351
After Renovation	Concrete 70 mm Insulation 170 mm Conceret 50 mm	170	6,092	128.5	0.1451
Decreased Percentage after Renovation			10.96%	10.96%	61.71%

Tab. 8: The summary of altering the external wall insulation layer impact of energy consumption and U-value of the apartment.

Table 9 summarizes the effect on energy consumption and U-value of the external wall, depending on modifications in the thickness of the insulation layer of the. The thickness of the insulation material of the external wall has risen from 90 to 190 mm (Ojanen, Nykänen and Hemmilä 2017), as shown in table 9.

The quantity of energy consumption (kWh and kWh/m²) after renovation, therefore, dropped by 13.34% in terms of its value before renovation. As a result, after the renovation of the external wall, the U-value decreased by 63.49%. However, following renovation, the decrease in U-values does not comply with when the building code limit of Finland says that after renovation, the quantity of U-value should reach half its pre-renovation value.

Status	External Wall Layers (from internal towards external)	Insulation Layer Thickness (mm)	Energy Consumption (kWh)	Energy Consumption (kWh/m²)	U-value (W/m²K)
Before Renovation	Concrete 60 mm Insulation 90 mm Concrete 70 mm	90	162,305	80.3	0.2068
After Renovation	Concrete 60 mm Insulation 190 mm Conceret 70 mm	190	140,654	69.6	0.1313
Decreased Percentage after Renovation			13.34%	13.34%	63.49%

Tab. 9: The summary of altering the external wall insulation layer impact of energy consumption and U-value of the school.

It is concluded that the improvement in the thickness of the insulation layer of the external wall does not affect the amount of maximum CO2 in all zones. The reason is that the amount of maximum CO2 in each zone depends on the amount of airflow which enters and leaves the zone. Since in this study, the ventilation characteristics remain constant; as a result, there will be no improvement in the amount of maximum CO2 emission.

There is a considerable reduction in the amount of heat supplied to each zone. If the provided domestic hot water company in the district emits an amount of CO2 to the environment for producing energy to heat the domestic water, since the apartment needs less heat supplied after the renovation, therefore the amount of supplied heat will decrease as well, and consequently less CO2 will be emitted to the environment.

Furthermore, calculating the amount of CO2 emission by the building is feasible in IDA ICE. Moreover, it is achieved by entering the amount of CO2 emission of the energy meters such as lighting facility, electric cooling, fuel cooling, electric heating, district heating, domestic hot water, etc. which due to the long distance between Germany and Finland, it was impossible for the author to provide reliable data.

According to (BSI, 2011), the average CO2e impact of the concrete is approximately 100 kg CO2e per tonne. The amount of 127.8 tonnes of concrete is used for the construction of the apartment, while 2,083.2 tonnes is utilized for building the school. Therefore according to table 10, the approximate amount of CO2e which has emitted to the atmosphere to provide adequate concrete to build the apartment and the school are 12,780 kg and 208,302 kg respectively.

Building	**Approximate Concrete Weight (tonne)**	**Approximate CO2e (kg)**
Apartment	127.8	12,780
School	2,083.2	208,320

Tab. 10: The utilized amount of concrete weight tonne) and CO2e emitted (kg).

The following points may be labeled with regard to the gathered responses from the interview:

- The term perceived indoor air quality is not adequately defined to the interviewee. It describes how occupants experience indoor air.

- The indoor air quality surely is placed in topmost building performance measures due to the significant amount of time that occupants stay indoor and the harmful impact on humans based on lack of indoor air quality.
- According to the interviewee, there are specific values for indoor air quality evaluation for different parameters such as CO2 and PM.
- People in society are worried about indoor air quality issues. However, in many cases, solid facts are missing considering concerns about feeling are more than facts.
- The interviewee explains that the systematic classification methodology regarding perceived indoor air quality is missing in Finland.
- The leading indicators which influence the perceived indoor air quality are CO2, PM, and VOCs.
- Considering the lack of general classification criteria, experts try to fulfill the limited values in regulations and recommendations.
- Balancing ventilation systems and trying to avoid moisture levels are the most common methods to improve perceived indoor air quality during the renovation process.
- Considering unknown renovation starting points, and not adequately defined target values, the common challenges in perceived indoor air quality improvement are not clearly characterized.
- The dwelling occupants benefit from the improved indoor air quality by providing general well-being and avoiding harmful health effects and symptoms, whereas pupils benefit it in increasing the learning level.
- In the private construction sector, due to a lack of knowledge of better indoor air quality, the investment costs are typically minimized.
- According to the interviewee knowledge, there is no considerable subsidiary strategy of the Finnish government to improve the perceived indoor air quality.
- The missing indoor air quality classification is a threat towards the perceived indoor air quality, and consequently, no significant improvement will occur. The informative and well-argued indoor air quality classification methodology would open new business models when overall optimization can supplant partial optimization.

- The new indoor air quality classification is in high demand, and based on holistic air quality monitoring and occupant preception data, the methodology is needed.

Regarding IDA ICE indoor quality measures, since all measures are influenced by the air flow and in this study, no changing on the ventilation system and consequently the airflow is studied. Therefore there are no changes in three indoor air quality measures before and after the renovation either in the apartment and the school.

Moreover, in a well-combined ventilation case, the proper air volume altered will be 63.2% in 1 hour and 1 ACH (Sarigiannis, Gotti and Karakitsios, 2018). One ACH means that the air in the room is changed one time per hour. However, the ventilation rates are 0.5 ACH in the residential buildings and 2 ACH in schools (Tiilikainen and Outinen, 2016). The higher the air change rate is, the less importance has the wall insulation layers thickness.

5 Conclusion

This study examines the outcomes of the assessment of the energy consumption, emissions of CO2, and perceived indoor air quality impacts of the external wall insulation layer on building performance. The U-value of the external wall has also been researched in addition to energy consumption.

Table 11 summarises the decreased percentage of the energy consumption (kWh and kWh/m²) and U-value per (W/m²K) while improving the insulation layer thickness from 75 mm to 170 mm. It shows, by just altering the insulation layer thickness, 10.96% of the energy consumption before renovation could be saved while 61.71% reduction in U-Value of the external wall is achieved.

Status	Insulation Layer Thickness (mm)	Energy Consumption (kWh)	Energy Consumption (kWh/m²)	U-Value (W/m²K)
Before Renovation	75	6,842	144.3	0.2351
After Renovation	170	6,092	128.5	0.1451
Decreased Percentage after Renovation		10.96%	10.96%	61.71%

Tab. 11: Enhancing insulation layer thickness of the external wall of the apartment.

There is a slight improvement in the amount of saved energy consumption (kWh and kWh/m²) and U-Value in the school case study due to the size of the buildings as they are shown in table 12. Since the insulation layer thickness changes from 90 mm to 190 mm, 13.34% of the energy consumption has been consumed less, and the U-Value of the external wall has been improved for 63.49%.

Status	Insulation Layer Thickness (mm)	Energy Consumption (kWh)	Energy Consumption (kWh/m²)	U-Value (W/m²K)
Before Renovation	90	162,305	80.3	0.2068
After Renovation	190	140,654	69.6	0.1313
Decreased Percentage after Renovation		13.34%	13.34%	63.49%

Tab. 12: Enhancing insulation layer thickness of the external wall of the school.

Regarding the CO_2 emission, it is found that improvements in the thickness of the external wall isolation layer do not influence the maximum amount of CO_2 in all zones. The reason is that the maximum amount of CO_2 in each zone relies on the airflow in and out of the zone. Since the characteristics of ventilation remain permanent in this research, the maximum CO_2 emissions are no enhancement.

However, the quantity of heat provided to each zone is significantly reduced. If a supplier of domestic hot water in the district emits CO_2 for the energy production to heat domestic water because the apartment or the school require less heat supplied after the renovation, the quantity of heat supplied will also reduce, which will emit less CO_2 into the atmosphere.

Additionally, IDA ICE can calculate the quantity of CO_2 emissions through the building. Moreover, it is possible to calculate the CO_2 emitting quantity by the energy meters such as lighting facility, electric cooling, fuel cooling, electric heating, district heating, domestic hot water, etc. which due to the long distance between Germany and Finland, it was impossible for the author to provide reliable data.

According to (BSI, 2011), the average CO_2e impact of the concrete is approximately 100 kg CO_2e per tonne. The amount of 127.8 tonnes of concrete is used for the construction of the apartment, while 2,083.2 tonnes is utilized for building the school. Therefore, the approximate amount of CO_2e which has emitted to the atmosphere to provide adequate concrete to build the apartment and the school are 12,780 kg and 208,302 kg, respectively.

The findings from the interview, which has been conducted in the perceived indoor air quality are as follows:

- The indoor air quality surely is placed in topmost building performance measures due to the significant amount of time that occupants stay indoor and the harmful impact on humans based on lack of indoor air quality.
- There are specific values for indoor air quality evaluation for different parameters such as CO_2 and PM.
- The systematic classification methodology regarding perceived indoor air quality is missing in Finland.
- The leading indicators which influence the perceived indoor air quality are CO_2, PM, and VOCs.

- Balancing ventilation systems and trying to avoid moisture levels are the most common methods to improve perceived indoor air quality during the renovation process.
- In the private construction sector, due to a lack of knowledge of better indoor air quality, the investment costs are typically minimized.
- There is no considerable subsidiary strategy of the Finnish government to improve the perceived indoor air quality.
- The missing indoor air quality classification is a threat towards the perceived indoor air quality, and consequently, no significant improvement will occur. The informative and well-argued indoor air quality classification methodology would open new business models when overall optimization can supplant partial optimization.
- The new indoor air quality classification is in high demand, and based on holistic air quality monitoring and occupant preception data, the methodology is needed.

As all measures are influenced by air flow, no changes to the ventilation system are researched in IDA ICE and the airflow accordingly. The internal performance controls are affected by airflow. The three indoor air quality measures called Air Age, CO2, and Relative Humidity do not, therefore, change either in the apartment or school before and after renovation.

In a well-combined ventilation case, the proper air volume altered will be 63.2% in 1 hour and 1 ACH (Sarigiannis, Gotti and Karakitsios, 2018). One ACH means that the air in the room is changed one time per hour. However, the ventilation rates are 0.5 ACH in the residential buildings and 2 ACH in schools (Tiilikainen and Outinen, 2016). The higher the air change rate is, the less importance has the wall insulation layers thickness.

Regarding the perceived indoor air quality, lack of systematic classification methodology and indoor air quality classification may lead to work more in these areas in the future, which is definitely in demand and will be highly appreciated.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 21.06.2019

Location, Date

Signature of the student

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