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HEATING SYSTEMS IN AN OFFICE
Building simulation

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DESCRIPTION

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Abstract

Heating is one of essential parts of building's HVAC systems. Nowadays, there are a lot of different solutions for heating a building. The wide variety of heating options can create difficulties in selecting the one. This is the reason why deeper analysis and comparison of heating systems should be made.

The main aim of this Bachelor thesis is to answer a question – can energy be saved in an energy – efficient office building? For answering this question, the different type of hydronic heating solutions (radiators, underfloor and ceiling heating, heating panels and fan coils) will be compared.

In this study case, a two floor office building located in Finland will be investigated. The total heated area of this building is 1806,4 m^2 with the volume of 6322,0 m^3. The building will be modelled by using IDA ICE simulation tool. In the first simulation part, the different heating systems will be compared. Later, after choosing the most suitable heating solution for an office in the terms of energy consumption, the energy savings will be defined by changing parameters of air tightness, building orientation, glazing type of windows and solar shading solutions.

As the results of this work, the heating systems for an office building will be analyzed and the most suitable solution will be found. In addition to this, the ways of energy saving in an office will be discovered and the influence of the building construction, engineering solutions and its location on the energy consumption will be established.

Subject headings, (keywords)

Heating systems, building simulation, energy consumption, energy saving

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CONTENTS

1 INTRODUCTION

Energy consumption in the world is increasing nowadays. People tend to live more and more comfortably, which affects the consumed amount of energy. Especially, the good thermal conditions are needed where people spend a huge part of the time – at work. Therefore, the sustainability and energy efficiency of the systems should be widely considered and the solutions should be found to save energy.

One of the most essential parts in the building's HVAC (Heating, Ventilation and Air Conditioning) system is heating. Without sufficient and satisfactory thermal conditions in a building, it is hard to imagine a comfortable living or working place. This is a reason why a lot of attention should be paid to the heating system.

There are a lot of different ways and solutions of heating a building. The dissatisfaction of inefficient and expensive heating is caused by the lack of knowledge of all available solutions. The wide variety of heating options creates difficulties of choosing the one. While selecting a heating solution not only the amount of energy consumption, but also the operating and life cycle costs should be taken into account.

It is impossible to evaluate all the aspects which influence the operation of heating system, its energy consumption, thermal conditions with the designed values or all possible problems before the building is constructed and settled to use it. However, in this technology age the special computer programmes are created in order to answer all the questions. What is more, the energy saving ways and the best properties and solutions in the building can be found.

In this thesis, the different type of heating solutions (radiator heating, underfloor heating, ceiling heating, heating panels and fan coils) will be investigated and compared. All these heating solutions are based on the hydronic system.

In this work an office is chosen as an investigated building for several reasons. The most important of them is that in the offices the newest, innovative and more expensive systems can be installed compared to residential buildings. There you can think about the efficiency, not only about the costs. The productivity and atmosphere in the working places is also affected by the HVAC systems, especially heating, because the thermal conditions are one of the most important factors.

In this Bachelor thesis the suitable heating systems for an office building will be analyzed and the best solution will be found. In addition to this, the ways of energy saving in an office will be discovered and the influence of the building materials, its construction, engineering solutions and its location on the energy consumption will be established.

2 AIMS AND METHODS

2.1 Aims

The main aim of this Bachelor thesis is to answer a question – can energy be saved in an office building? At first, to get an answer to this research question, it will be figured out which heating system is the most suitable for the office building. In order to get acquainted with different types of heating solutions, the radiator heating, underfloor heating, ceiling heating, heating panels and fan coils will be investigated.

The most important key in the comparison process will be the amount of energy consumption. Moreover, to compare different types of heating systems and answer which is the best, is quite difficult task, because the compared heating solutions have the different ways of transferring a heat. That is why the simulation programme will be used.

The other very important idea of answering my question is to investigate how the parameters of building and its engineering solutions affect the energy consumption. After the selection of the best heating system, one more simulation will be made to analyze how the changes of engineering solutions in the building can reduce its energy consumption.

2.2 Methods

In this study case, a two floor office building located in Finland will be investigated. The total heated area of this building is 1806,4 m^2 with the volume of 6322,0 m^3. All design values, calculations and data for simulation will be according to so called standard use from National Building Code of Finland.

First of all, in order to get acquainted with different types of heating system a literature sources will be studied. Then the main concepts of the systems, their main features, operation and equipment will be presented. A comparison of suitable heating systems for an office will be done and three solutions of heating an office will be selected.

All these three heating systems will be compared again with a simulation programme IDA ICE and the most efficient heating system in terms of energy consumption result will be determined and simulated again. The design of the building and all heat losses calculations will be done by simulation tool.

For this study part, the simulation programme IDA ICE will be used. This computer tool is a multifunctional simulation tool for the investigation of the processes of a building, such as the heat losses through building envelope as well as through thermal bridges, the total heating energy demand or a thermal indoor climate in different rooms. What is more, IDA ICE also can compare simulation results with the real measured data in different locations.

Another method is a simulation of an office with the most suitable heating system for this building. During this last simulation the factors of energy consumption of a building will be observed and the solutions for an energy saving in an office will be determined. In this simulation part the air tightness, glazing type of windows, solar shading and orientation of the building will be changed by using IDA ICE software tool. What is more, the differences of energy consumption of this office will be compared whether it is located in Finland and in Lithuania.

The last method is the analysis of results. The data obtained during these simulations will be studied and aspects of energy saving in an office will be established. Finally, the research question will be answered and the solutions with suggestions will be presented.

3 BACKGROUND

To start with, in this chapter the main aspects of heating system will be described. First of all, in order to understand the heating process, the ways of heating transfer should be known. Later, the basic parts of heating system and its working principles will be described. After this, the main things about heating energy consumption and its calculation will be represented. Finally, the simulation programme which will be used in this thesis will be introduced briefly.

3.1 Heat transfer

The heat transfer is a physical process of exchanging the thermal energy between the systems because of the temperature differences. There are three different ways of transferring the heat, such as conduction, convection and radiation. The interaction between these processes characterizes the mean of heat transfer. The heat is transmitted to building premises by the heat transfer and that is how heating in a building is maintained.

Heat conduction represents an interaction of thermal energy between the heating medium, which can be water or air, and the surfaces. It is heat flow inside any material without movement of it. This type of heat transfer mainly occurs in solid bodies and it is influenced by the properties of the material.

Heat convection takes places between the flowing fluid and a surface or vice versa. In the building heating systems the flowing fluid is water or air. This way of heat transfer is divided in two types as natural or forced convection. The natural convection is caused by the air temperature or density differences. The forced convection takes place over the pressure difference of the air.

Heat radiation means the transfer of thermal energy between surfaces in a case of electromagnetic waves. It can reflect, absorb and penetrate heat. The radiation always occurs when the temperature of the body is higher than 0 Kelvin.

Figure 1 shows an example of heat transferring ways in a room premise, which warms the indoor space. The heat conduction transfers heat into the room through floor because of hot heating fluid in the pipes. One part of solar energy penetrates through the window indoors and other part is absorbed into the window. The person also releases heat because he is warmer than the indoor air and the heat radiation occurs. What is more, electronic devises release heat in terms of natural convection and fans inside computer are the cause of forced convection.

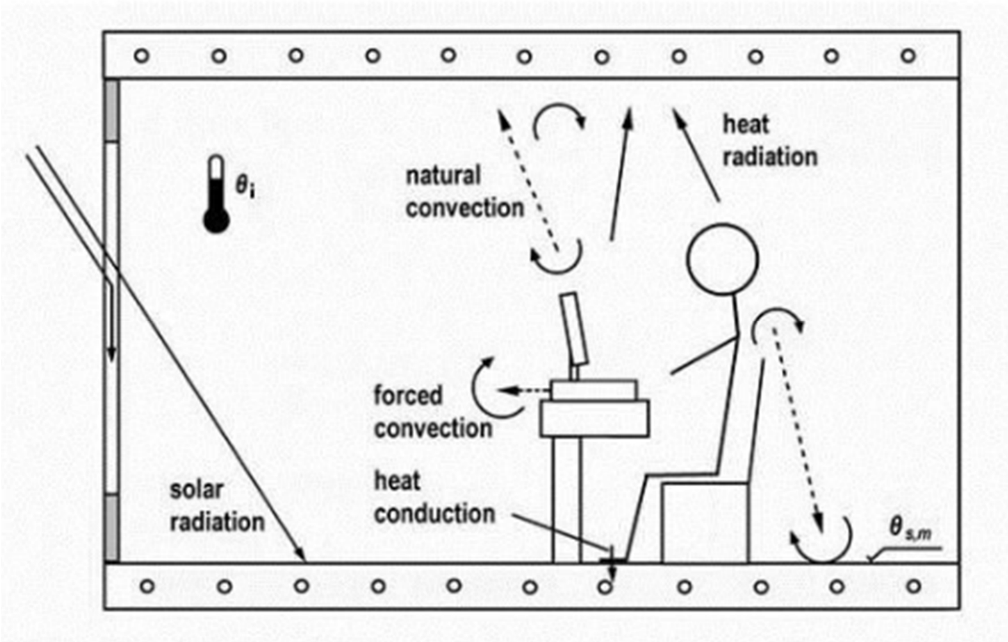

FIGURE. 1. Thermal balance in a room premises /1/

3.2 Heating system

The main idea of a hydronic heating system is to create healthy and satisfactory indoor conditions in all building. With a help of heating system the comfortable indoor thermal conditions can be kept in economical way despite the different outdoor air conditions during the heating season. Usually, in a hydronic heating system, the heat is produced not only for space heating, but also the heat demand for hot domestic water and ventilation is taken into account as well.

Hydronic or water based heating system is the most popular heating system in buildings. It is also more efficient heating way compared to the air heating, because water is 4,2 times better heat transfer medium than air. In this type of heating system, the heating fluid, usually hot water or water mixed with another component is circulated through all building heating network. There are two ways of heating systems' network installation. It can be installed inside the room premises and connected to the heat emitters (radiators, convectors, coils, etc) or can be located inside the building elements as for example floor heating. Due to this copper, steel or plastic is selected as the material of the pipes, in which heating fluid is running.

For hydronic heating system the heat can be produced with different heat sources such as a boiler by burning different type of fuels, district heating substation or a heat pump. A hydronic heating system is a closed system. At first water is heated in the heat source flowing to the different zones of a building. As it reaches the heat emitter it heats the room space and goes back to the heat source through the return water pipes and is warmed up again. This process of water circulation in the heating network runs continuously with a help of a pump.

All water based heating systems are characterized and can be divided into such five main parts: heat source, heat emitter device, system network and equipment, control devices and safety and expansion devices. These devices allow to control and maintain the steady desired indoor air temperature.

3.3 Heating energy consumption

All the following equations needed for calculations of heating energy consumption are taken from D5 of National Building Code of Finland /2/.

The net energy need for space heating $Q_{\text{heating, spaces, net}}$ is calculated according to this equation /2/:

$$Q_{\text{heating, spaces, net}} = Q_{\text{space}} - Q_{\text{int.heat}} \quad (1)$$

where:

$Q_{\text{heating, spaces, net}}$ - net heating energy need for heating spaces in a building, kWh

Q_{space} - heating energy need for heating spaces in buildings, kWh

$Q_{\text{int.heat}}$ - heat loads recovered for heating, kWh

The heating energy need for heating spaces Q_{space} is calculated according to this equation /2/:

$$Q_{space} = Q_{conduct}+Q_{air\ leakage}+Q_{supply\ air}+Q_{make\text{-}up\ air} \qquad (2)$$

where:

$Q_{conduct}$ - conduction heat loss through the building shell, kWh

$Q_{air\ leakage}$ - air leakage heat loss, kWh

$Q_{supply\ air}$ - heating of supply air in a space, kWh

$Q_{make\text{-}up\ air}$ - heating of make-up air in a space, kWh

Conduction heat loss through the building shell $Q_{conduct}$ is calculated according to this equation /2/:

$$Q_{conduct} = Q_{exterior\ wall} + Q_{ceiling} + Q_{floor} + Q_{window} + Q_{door} + Q_{thermal\ bridges} \qquad (3)$$

where:

$Q_{exterior\ wall}$ - heat losses of conduction through external walls, kWh

$Q_{ceiling}$ - heat losses of conduction through ceiling, kWh

Q_{floor} - heat losses of conduction through floor, kWh

Q_{window}- heat losses of conduction through windows, kWh

Q_{door} - heat losses of conduction through external doors, kWh

$Q_{thermal\ bridges}$ - heat losses of conduction through thermal bridges, kWh

The heat losses of building components Q_i are calculated according to this equation /2/:

$$Q_i = \Sigma U_i A_i\ (T_{ind} - T_{outd})\ \Delta t/1000 \qquad (4)$$

where:

Q - heat loss of a building element, kWh

U_i - thermal transmittance coefficient, W/m^2K

A_i - area of building element, m^2

T_{ind} - indoor air temperature, ˚C

T_{outd} - dimensioning outdoor temperature,˚C

Δt - time period, h

Heating energy need for building according to National Building Code of Finland D5 is calculated based on energy required for heating spaces, heating domestic hot water and heating supply air in ventilation system /2/:

$$Q_{heating} = \frac{Q_{heating\ spaces} + Q_{vent} + Q_{DHW} - Q_{solar}}{\eta_{prod}} \qquad (5)$$

where:

$Q_{heating}$ - energy consumption of heating system, kWh/a

$Q_{heating\ spaces}$ - energy consumption of heating spaces, kWh/a

$Q_{heating\ vent}$ - energy consumption of ventilation system, kWh/a

$Q_{heating\ DHW}$ - energy consumption of heating domestic hot water, kWh/a

Q_{solar} - domestic hot water produced with solar collectors, kWh/a

η_{prod} -efficiency of heating energy production, -

η_{prod} is the efficiency of each part of the system which takes into account losses in every part of the system like losses in production of heat (in the heat source) and losses of heat storage in water tank.

Energy consumption of heating spaces $Q_{heating\ spaces}$ is calculated according to this equation /2/:

$$Q_{heating\ spaces} = \frac{Q_{heating\ spaces\ net}}{\eta_{heating\ spaces}} - Q_{distribution\ out} \qquad (6)$$

$Q_{heating\ spaces\ net}$ - net energy needed for space heating, kWh/a

$Q_{distribution\ out}$ - heat loss into a non-heated room in heat distribution, kWh/a

$\eta_{heating\ spaces}$ - heating system efficiency in heating spaces, -

The heating system efficiency $\eta_{heating\ spaces}$ takes into account all losses in space heating system, such as losses in the heat distribution network, heat emitter devices and control system.

Energy consumption of domestic hot water system $Q_{heating\ DHW}$ is calculated according to this equation /2/:

$$Q_{heating\ DHW} = \frac{Q_{heating\ DHW\ net}}{\eta_{DHW}} + Q_{DHW\ storage} + Q_{DHW\ circulation} \qquad (7)$$

where:

$Q_{heating\ DHW}$ - energy consumption of heating domestic hot water, kWh/a

$Q_{HDW\ net}$ - net energy needed for domestic hot water, kWh/a

$Q_{DHW\ storage}$ - heat losses from storage, kWh/a

$Q_{DHW\ circulation}$ - losses from domestic hot water circulation, kWh/a

η_{HDW} - efficiency of domestic hot water transfer, -

Energy for producing hot domestic water $Q_{heating\ HDW}$ does not depend on the weather conditions.

Energy consumption of ventilation system $Q_{heating\ vent}$ is calculated according to this equation /2/:

$$Q_{heating\ vent} = \rho_i \cdot c_{pi} \cdot t_d \cdot t_v \cdot q_v \cdot (T_{sp} - T_{rec}) \cdot \Delta t/1000 \qquad (8)$$

where:

$Q_{heating\ vent}$ - heating energy need for ventilation system, kWh/a

ρ_i - density of air, 1.2 kg/m^3

c_{pi} - air specific heat capacity, 1 kJ/(kgK)

t_d - ventilation system`s mean daily running time ratio, h/24

t_v - ventilation system`s weekly running time ratio, days/7

$q_{v,supply}$ - supply air flow, m^3/s

T_{sp} - supply air temperature, ˚C

T_{recov} - temperature of air after the heat recovery, ˚C

Δt - time period length, h

The net purchased energy of the building $E_{purchased}$ is calculated according to this equation from National Building Code of Finland, D3 /3/:

$$E_{purchased} = \frac{Q_{heating} + W_{heating} + W_{ventilation} + W_{appliances} + W_{lightning} - W_{u.s.g.energy}}{A_{net}} \quad (9)$$

where:

$E_{purchased}$ - net purchased energy, kWh/a

$Q_{heating}$ - energy consumption of heating system, kWh/a

$W_{heating}$ – electricity consumption of heating devices, kWh/a

$W_{ventilation}$ – electricity consumption of ventilation devices, kWh/a

$W_{appliances}$ – electricity consumption of consumer appliances, kWh/a

$W_{lightning}$ – electricity consumption of heating, kWh/a

$W_{u.s.g.energy}$ – amount of used self generated electricity, kWh/a

A_{net} - net heated area, m^2

According to the National building code of Finland, D3, in the total energy consumption calculations the outdoor weather data, indoor climate conditions and the standardized use of the building such as time of occupancy, number of occupants and internal heat gains should always be included /3/.

3.4 Design values

The office building investigated in this thesis is located in Helsinki, Finland. This area belongs to the weather zone I and has outdoor air temperature t_{out} = - 26˚C and annual mean outdoor temperature $t_{mean\ out,\ a}$ = +5,3˚C.

The reference values of thermal transmittance coefficient U of the designed building components are taken from National Building Code of Finland D3 /3/. The reference values are presented in table 1 for thermal loss calculations through the building envelopes.

TABLE 1. Reference values of thermal transmittance coefficients of building components /3/

Building component	Thermal transmittance coefficient U
Wall	0,17 W/(m^{2}K)
Upper floor	0,09 W/(m^{2}K)
Base floor (against the ground)	0,16 W/(m^{2}K)
Window, door	1,0 W/(m^{2}K)

The energy consumption is calculated with the set values of the indoor temperature and the volume flow which is stated in National Building Code of Finland D3 /3/. These values correspond to the standard use of the building, the values for an office building is shown in table 2.

TABLE 2. The designing values of the indoor temperature and the air volume flow for an office /3/

Type of the building	Air flow, dm^3/(s m^2)	Heating limit, °C	Cooling limit, °C
Office building	2	21	25

The operational time of the ventilation system in an office building is presented below, in table 3. The heating system operates continuously. The internal thermal loads, which are gained due to the lightning, electric devices and people in the office, can be found in table 3 as well. The following values are taken from the newest version of National Building Code of Finland, D3 /4/.

TABLE 3. Standard use of office building and internal heat gains per heated net area /4/

Type of the building	Period of use			Degree of use	Lightning W/m^2	Devices W/m^2	People W/m^2	Density of persons m^2/person
	hours	h/24h	d/7d					
Office building	7:00 – 18:00	11	5	0.65	12	12	5	17

According to National Building Code of Finland, the ventilation system should start to operate one hour before the period of use and finish one hour later. In this case, the ventilation system operates from 6.00 – 19.00 h in an office building.

In calculations of the heating energy needed for domestic hot water, the specific consumptions and its corresponding net demand of heating energy is used from table 4. These values are stated in National Building Code of Finland, when the temperature for domestic cold water is 5 °C and for domestic hot water is 55 °C /3/.

TABLE 4. Specific consumption of domestic hot water and the net heating energy needed per heated net area /3/

Type of the building	Specific consumption of DHW $dm^3/(m^2\ a)$	Heating energy $kWh/(m^2\ a)$
Office building	103	6

All the designing values for this case study building which was presented above are taken from National Building Code of Finland, Part D3 /3, 4/.

3.5 Energy efficiency

For designing the heating systems, the total energy consumption of the building and the E - value must be calculated. The E - value is the ratio of the net purchased energy consumption of the building per year calculated with the coefficients of the energy forms per net area heated. For E – value calculations the building type standard consumption is used /3/.

The total purchased energy consumption of the building per its net heated area, E-value, is calculated according to this equation /3/:

$$E - value = \frac{\sum E_{purchased} \cdot \eta}{A_{net}} \qquad (10)$$

where:

E-value - total energy consumption of the building, kWh/m^2

$\sum E_{purchased}$ - the sum of purchased energy of the building, kWh

η - energy form coefficient,

A_{net} - net heated area, m^2

According to National Building Code of Finland, part D3, the E - value for office type building must not exceed 170 kWh/(m^2 a) per year /4/. The coefficients of energy form for total energy consumption are given in table 5.

TABLE 5. Coefficients of energy form /4/

Energy form	Energy form coefficient
Electricity	1.7
District heating	0.7
District cooling	0.4
Fossil fuels	1.0
Renewable fuels used in the building	0.5

The building is called the energy efficient, when the amount of supplied energy to it is maintained as low as possible. The main idea of designing an energy efficient building is to use the engineering solutions which reduce the amount of energy needed for building systems operation. The amount of energy which is used to maintain the building operation depends on many variables, but the type and purpose of the building, climate and design of HVAC systems are included as the main aspects /5, p.18/.

The ways of energy saving and reducing should be studied at the stage of building designing. In the designing process of energy efficient building the following aspects need to be taken into account /5/:

- Building:
  - External structures (wall construction, insulation, air tightness),
  - Size, shape and orientation,
  - Planning.
- Windows:
  - Shading design,
  - Glazing.
- Lightning:
  - Usage of low energy lights,

- Usage of daylight.

- HVAC system design:
  - Start the space heating only when indoor air temperature is below 20 °C,
  - Start the comfort cooling only when indoor air temperature is above 25 °C,
  - Efficient design of boiler and chiller,
  - Heat recovery for ventilation system.

According to the “HVAC in Sustainable Office Buildings” /5/, a lot of engineering solutions should be considered in designing the office building. However, only the first two from the list will be analyzed in my project. The different types of air tightness, glazing type of windows, solar shading and orientation of the building will be investigated by using a simulation programme. This will help to find the ways of reducing the required amount of energy for an office building. Evidently, it will make the building more energy efficient and sustainable.

3.6 Building simulation

Nowadays the building simulation programmes are becoming more and more valuable in engineering field. The simulation tools allow investigating the building performance during its life cycle. The simulation programmes are also useful because they can estimate the operation of the systems and processes before the building is constructed. Moreover, it can also let us to find the best engineering and construction solutions for the building services.

In this work the IDA ICE simulation programme will be used in order to make better comparison of heating systems and accurate calculations of energy consumption of the case study office building. This software tool allows equipping the investigated building with different types of heating system. It will show the exact energy consumptions and building performances with different type of heating solutions. Furthermore, it will help to find the energy saving ways in the building and compare the energy consumption for heating of the building in different locations – Finland and Lithuania.

4 COMPARISON OF HEATING SYSTEMS

In the following chapter, the five different heating systems as the radiator heating, underfloor heating, ceiling heating, heating panels and the fan coils will be introduced. The analysis of these heating solutions will be made in the terms of their' operation, application, installation and controlling. The positive and negative aspects of indoor climate conditions and affects to the interior with different heating systems will be presented as well.

4.1 Heating with radiators

Radiators are the most traditional and commonly used heat emitter devices in buildings nowadays. In general, radiators are determined as the simple heat exchangers which transfer heat to the building premises through the circulated water inside of them. The thermal energy is transmitted to the room spaces mainly by the convection process due to the pipes inside the radiators which usually are covered by fins in order to increase the surface area which can transfer more heat.

Radiators can be made in a wide variety of depths, sizes, lengths and even colours. The following types of radiators are the most commonly used /6, ch. 32/:

- Column radiators are manufactured from metal sections/columns which are welded together

FIGURE 2. Example of column radiator /7/

- Panel radiators consist of manufactured flat metal panels

FIGURE 3. Example of panel radiator /8/

- Finned tube radiators are made of steel or copper pipes. For steel pipes can also be used stainless steel or acid-proof steel.

FIGURE 4. Example of finned tube radiator /9/

Radiators can provide the temperature control only during the heating season. At first, the capacity of radiators is selected according to the heat loads of the space – the heat released from radiator should balance the heat losses in the room. The indoor air temperature can also be controlled with a help of thermostat valves, which are installed near the radiators. The indoor air temperature is controlled by regulating the water flow through radiator. The hydronic balancing of heating system can also be made with pre-setting values which are set in the thermostats of the radiators /10 /.

As it was mentioned before, radiators transmit heat to the premises due to the natural convection with the help of high temperature water circulating in it. The space heating occurs because of temperature difference between the radiator surface and the indoor air. As a result of natural convection process, the warm air goes to the upper part of the room and the colder air stays in the lower part. Then the warm air gets cooler, it comes down to the floor, the circulation of air begins and the vertical temperature difference in the room becomes smaller.

According to newest regulations, for new buildings the required hot water temperature in secondary radiator heating system loop is designed as 45 ˚C in the inlet and 30 ˚C in the outlet of radiator. The temperature can vary and also reach 60˚C in the inlet of radiator, it depends on the size and heating capacity of the terminal device. The heating capacity of the radiator depends on the heat load of the heated space. The total heating capacity is the sum of capacity of all installed radiators in the building and does not have specific limitations in the heating power /11/.

Radiators are typically installed in the areas where the biggest heat losses are found, such as under the windows, along cold walls or at the doorways and paths /6/. This way of integration of the radiators compensates the thermal losses and temperature discrepancy and thus improves the thermal conditions in the room. By installing the radiators not only the rooms' temperature asymmetry should be considered but also its visual appearance. Radiators do not allow using the internal room space completely. What is more, the length of radiator should be approximately the same as the window which is above radiator, also the height and type of radiators in the room should be identical as well.

Looking from the indoor climate aspect, it is quite difficult to prevent radiators from collecting the dust. To clean dusts which are accumulated inside the radiators is difficult task. In addition to this, the health problems for occupants can appear. What is more, the operation of radiators can cause the convective air flows that may transfer the dust from the floor to the walls /11/.

4.2 Underfloor heating

A few years ago the underfloor heating system was quite unusual type of heating in buildings, although its use started in ancient times. However nowadays it becomes more and more familiar and commonly used solution for space heating. In hydronic underfloor heating system the hot water is circulated in pipes which are installed in the floor construction. The heating pipes which form the heating loops are laid down evenly through all space area according to the calculations of heat loads and requirements of the system. Then, the all heated space is warmed up and the distribution of heat is even in the all premise.

The separate calculations in terms of heat demand and loss of the room, the type of floor construction is needed to make for every building space. According to these calculations the way of installing the pipes, their diameters and a distance between them, also the number of heating loops is selected.

The hydronic underfloor heating is based on the low temperature hot water system. In addition to this, the required inlet water temperature to the room is lower than radiator heating and reaches 30 - 35 ˚C. The installed pipes in the floor construction can also be used for underfloor cooling in summer time. The floor temperature with underfloor heating system is limited; it cannot exceed 29 ˚C in the occupied zone and 35 ˚C in the perimeter area near walls. /1./

In every heated space a separate loop should be laid. Although, according to the size of the area, it can be that more than one loop needs to be installed. The loops are connected to the manifold system, through which the hot water reaches the heated space. Usually, one manifold is used for heating 6 - 8 rooms. Its place in the building should also be considered in order to avoid long distances of pipe laying.

Every separate space has its own thermostat controller, which regulates the comfortable indoor air temperature. When the air temperature reaches the desired or designed limit, the sensor sends a signal to the manifold and it stops the water flow to the given room. The heat accumulated in the floor is gradually released to the indoor environment. When the indoor air temperature drops till the lowest set limit, the water flow is released to the room again. These heating cycles take place continuously according to the heating demand and designed values.

Usually the pipes are laid in the concrete and covered with insulation material. This type of installation is called a ”wet” system. The insulated material is required to reduce the thermal losses through ground. The concrete floor is the best solution for underfloor heating because its thermal conductivity is higher than that of the other types of floors. It also transfers heat uniformly. Nevertheless, all kind of floor construction can be used with underfloor heating system, just more technical solutions are required e.g. the aluminium plates under the parqueted floor.

The main pipe materials for underfloor heating can be copper, steel or plastic. Thus, today the light plastic is commonly used such as polyethylene, polybutylene and polypropylene pipes. The use of light plastic in underfloor heating is good for its flexibility, easier installation and lower cost /11/. The heating pipes can be installed according to three different methods as single, double or helical laying, which are shown in figure 5 below.

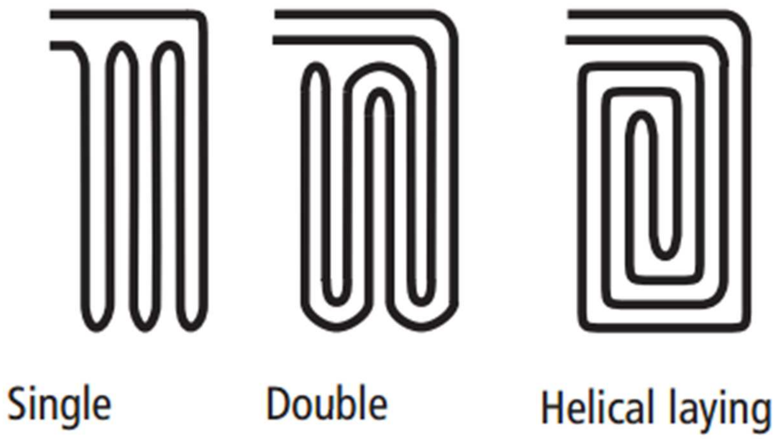

FIGURE 5. Different ways of pipes layout /12/

The heating loops also can be laid in different ways, but usually pipes are first installed near the external walls, where the heat losses are the biggest. Furthermore, the second small heating loop can be laid near the external wall, in which the window is placed. These types of loops installation can be seen in figure 6.

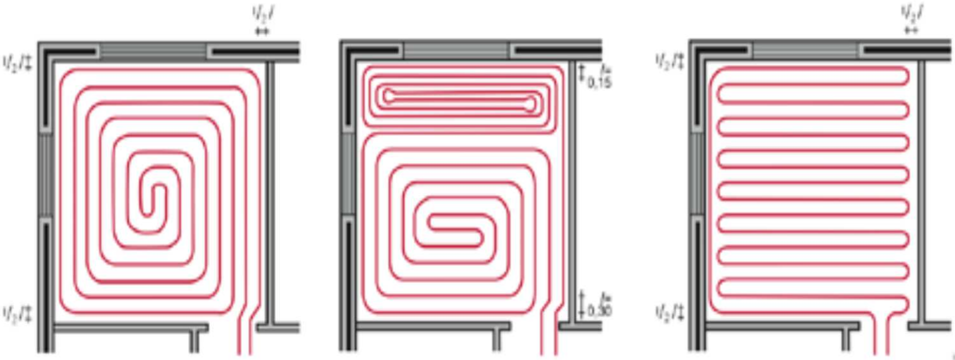

FIGURE 6. Different laying of loops near external walls /11/

The pipes installed in the floor construction do not take extra place in the room space and for this reason it does not make problems with interior design. Another advantage of underfloor heating that it is easy to keep the room premises clean – there are no additional devices which can collect dust that is why this heating solution is satisfactory even for allergic and sensitive people.

4.3 Ceiling heating

The hydronic ceiling heating system is almost the same heating solution as underfloor heating (Chapter 4.2). The main and the biggest difference is the pipes' installation place. As in underfloor heating the pipes are laid in the floor construction, in ceiling heating the pipes are mounted onto the ceiling slabs. The pipes of ceiling heating are embedded in the same configuration as in the floor heating (see figure 5 and 6). The installation of the pipes in the concrete of the ceiling surface is defined as the ”wet” system. The ”dry” ceiling heating system will be analyzed in the following Chapter 4.4. All the possible installation ways of all ceiling heating solutions are presented in figure 7.

Ceiling heating can cause comfort problems due to high mean radiant temperature at humans head level. In addition to this, the surface temperature of the ceiling and its heating output should be limited. However, the maximum allowed surface temperatures for ceiling heating are higher compared to underfloor heating solution, in case there is no direct contact between the surface and human body. Nevertheless, in this case the height in which the ceiling heating is installed should be considered /11/.

Even the ceiling heating is usable solution for the space heating, the underfloor heating remains more effective solution in terms of the direct thermal energy transfer to humans because of their feet contact with the floor. Whereas, this engineering solution is the best for cooling mode, which is typically applied in offices, hospitals and commercial buildings. /11./

4.4 Heating panels

Panel heating is such kind of heating solution when the indoor air temperature is controlled by the warm surfaces, called panels, which can be mounted on the floor, walls or ceilings. In hydronic panel heating the hot water is circulated through the pipes, which are installed into the panels. The panels are called radiant, when at least 50% of heat is transferred by the thermal radiation /5, ch. 15/. This type of heating solution is also can be counted as floor or ceiling heating and can look almost the same, but the different way of pipes installation, which are embedded in the fabricated panels, makes this heating solution distinguish between others. Compared to the “wet” underfloor or ceiling heating systems, panel heating is called as a “dry” heating solution.

Hydronic radiant panels’ heat distribution network is usually made from two or four pipe system. The heating panels transfer the thermal energy through active temperature control surfaces to heating spaces by thermal radiation and natural convection /6, ch. 6/.

While designing the panel heating system it is necessary to determine the area and type of the panels, supply water temperature and water flow rate, amount of panels and their placing. These decisions are made mainly by the heat demands and loads of the heating space.

The hydronic heating panels have a wide variety of solutions for heating the space, which depends on the installation place, materials of the pipes and construction of the panels. The available solutions will be shortly introduced in the following paragraphs.

There are three types of hydronic metal ceiling panels /6/:

1. Light aluminium panels with attached pipe network,

2. Aluminium face sheet panels combined with the copper pipes,
3. Excluded aluminium face sheet panels with the copper pipes.

The installation of metal ceiling panels creates the suspended ceiling. This type of panel solution requires the acoustic insulation. The ceiling panels can be designed as the heating emitters to the exact space which requires the concentrated heat flux or can be installed over the all space area.

The all possible applications of ceiling heating are showed in figure 7 below. The first one is a “wet” ceiling heating solution, when pipes are embedded inside the concrete ceiling slab. The second one is the heating panels made from gypsum with embedded pipes inside, which are plastered to the ceiling. The last way of applying the ceiling heating is using the metal heating panels, which form the suspended ceiling.

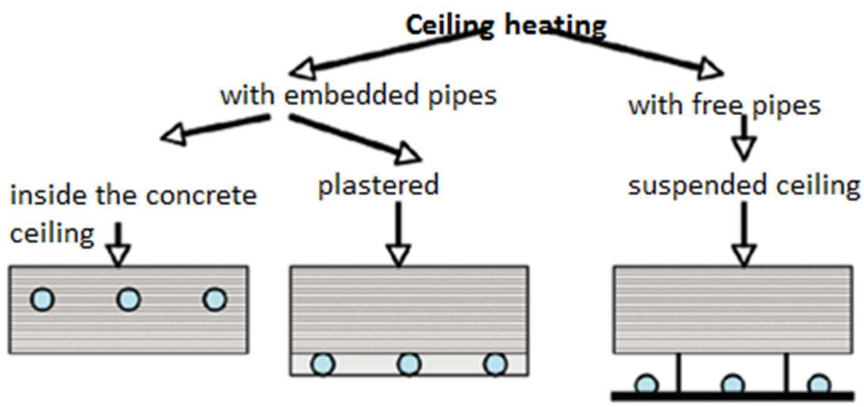

FIGURE 7. Types of ceiling heating systems /11/

Other material used for panel heating is gypsum. This type of panel heating is usually applied for wall construction, but also is suitable for ceilings and floors. The pipes are fabricated into the gypsum sheets which are plastered to the buildings’ envelope construction. For wall heating, the panels are installed onto the external walls of the building. The example of this heating system’ installation is presented in figure 8.

FIGURE 8. Example of heating panels installation to the walls /11/

Wall heating panels are the least used heating panel solution compared with all possible applications. Nevertheless, it can be the best way of heating the space when other solutions cannot be utilized and panels cannot be applied to the floor or ceiling. With wall heating panels, the interior and location of furniture should be considered in order to have the maximum heat transfer to the space /11/.

There are two different solutions for the floor heating panels. The first one is when the manufactured gypsum panels with the pipe network inside are mounted in or below the subfloor. In the second case, the pipes are attached to the subfloor using the metal panels, usually aluminium sheets. The metal covering is required for better the better heat transfer to the space. In these both solutions, the last floor layer is laid on the subfloor layer /6, ch. 6/.

The way of controlling the “wet” and “dry” surface heating systems are the same, as it was discussed in Chapter 4.2. The dimensioning, spacing and laying of the heat pipes are also done by the identical way.

4.5 Fan coils

Fan coil is the terminal device which combines both heating and ventilation processes. The main elements of fan coil are a finned - tube heating coil and a fan. The fan section is responsible of circulating the air continuously within the room spaces through the coil, which is supplied with hot water. The other important elements in the fan coil are motor, damper, filter and automatic control devices. With a help of fan, no ventilation – air ductwork is needed for this system. The fan coils can also be used for cooling processes, where the main fluid is chilled water. /13, ch. 13.5./ The example of the fan coil device is showed in figure 9.

FIGURE 9. Example of a fan coil /14/

Fan coils can provide the room temperature control during heating and cooling seasons by supplying the desired air temperature. Fan coils operate at medium water temperature, the supply water temperature for heating purpose is in a range of 60 – 45 ˚C with the available temperature drop of 5 -10 ˚C. The heating power for this terminal device is unlimited and is related to the size of the coil and the fan. /11./

When there is a change in the air temperature of the heated room, the room thermostat sets the signal to the automatic control valve. The valve opens or closes in order to regulate the hot water flow to the fan coil to provide the required amount of heat to the room by the circulating air. The set point can be selected to the desired limit. The heating capacity of this terminal device can be controlled by regulating the hot water flow through coil, air bypass or fan speed /13, ch. 13.5/.

The fan coil system is the convective heating system which is based on the controlling of air temperature by blowing heated air to the space. For this reason, using fan coils for space heating can cause few problems such as the bigger risk of draft and temperature bedding. The higher air velocity in the room also can be the purpose of an undesirable dust circulation in the room.

This type of heating system requires more maintenance and service work compared to others. As it at the same time offers ventilation to the space, with the time, the fan in this device releases more noise, which can become undesirable. Every fan coil also should have the condense line inside that requires periodical cleaning. Due to this fact, it is difficult to control the bacterial growth, which has a good environment to grow. The filters are also needed to change quite often because of their small size and poor effectiveness. /13, ch. 13.5./

Fan coils are typically mounted on the floor and ceiling or can be applied in the recess of the room. It is also possible to locate them on the walls, but in this case the integration level is lower. /6, ch. 31.1./

4.6 Summary of the heating systems

Every heating system has its own benefits and negative aspects. Obviously, there is no question of comparing the different heating systems only by the theoretical background – system characteristic, designing water temperatures and other requirements. There are too many variables in selecting the heating system. As it was discussed previously, even the same heating system has the different solutions of installation way and place, the type of heating device or pipes. The main differences between analyzed heating systems are presented in table 6.

TABLE 6. Comparison of heating systems in terms of different aspects

Characteristic	Radiators	Underfloor heating	Ceiling heating	Heating panels	Fan coils
Type	Hydronic system	Hydronic system	Hydronic system	Hydronic system	Hydronic system
Working temperatures	45 (60) – 30˚C	35 – 30 ˚C	40 – 35 ˚C	40 – 35 ˚C	60 – 50 ˚C
Control	Air temperature	Air and operative temperature	Air and operative temperature	Air and operative temperature	Air temperature
Main controlling device	Thermostatic valve	Thermostatic sensor	Thermostatic sensor	Thermostatic sensor	Control valve
Main heat transfer way	Natural convection	Radiation, natural convection	Radiation, natural convection	Radiation, natural convection	Forced convection
Heating capacity	No limitations	165W/m^2	90W/m^2	Depends on installation place	No limitations
Typically installation place	Under windows	In the floor construction	In the ceiling construction	Floors, walls, ceilings	Floor or ceiling
Comfort	Collection of dust, higher vertical temperature difference	Uniform thermal environment	Uniform thermal environment	Uniform thermal environment	Draft risk, dust movement, air stratification affect
Application of cooling	No	Yes	Yes	Yes	Yes
Interior	Terminal devices occupy the room space	Free use of internal place	Free use of internal place	Free use of internal place (for wall panels, the place of furniture should be considered)	Terminal devices occupy the room space

Another very important aspect in comparing the different heating systems is the variaton of air temperature in the heated space. In figure 10 is showed the temperature variations in underfloor heating, ceiling heating and heating with radiators and fan coils. The measurements of the temperature were done at the 0.1m (ankle level), 1.6m (neck level of standing person) and 2.7 m height of the room. These points were selected due to the humans’ body sensibility. All these heating systems are compared with the ideal heating systems prototype.

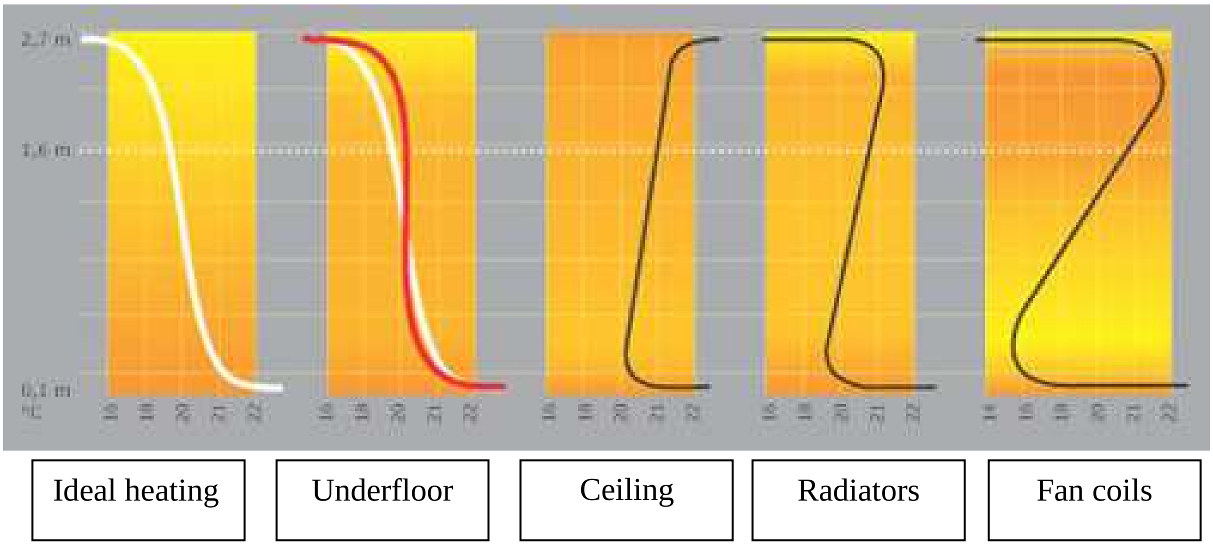

FIGURE 10. Air temperature variation in a space with different types of heating systems /15/

As we can see from figure 10, the underfloor heating system is the nearest heating solution to an ideal heating. This means that occupants feel the best thermal comfort in the room with integrated underfloor heating system. Ceiling heating takes the second place, while heating with radiators and fan coils create the much bigger vertical temperature difference in the heating space, which means the lower thermal comfort. The temperature asymmetry is lower in heating with radiators system than fan coils. The heating panels have the same temperature variation performance as underfloor or ceiling heating and depend on their installation place.

All these reasons show why the building simulation tool will be used. The computer programme will help to find the answer, which heating system is the most suitable and effective for an office building in the terms of energy consumption.

For the first office simulation part, the radiator heating, underfloor heating and ceiling panels are selected. The choice was made by predicating on different installation place, supply and return water temperatures also by the performance of temperature variation in the heating space. The fan coils were rejected because to compare the heating systems with the combination of heating and ventilation system is quite beside the purpose.

5 BUILDING SIMULATIONS

5.1 Simulations of the heating systems

In the first office simulation part, the radiator heating, underfloor heating and ceiling panels as the main solutions for space heating will be compared. The best heating system for an office will be found in the terms of lowest energy consumption and E – values. For this case study, a two floor building with the net heated area 1806.4 m^2 will be investigated. The office plans and the explications of the rooms can be found in Appendices. The building is located in Helsinki, weather zone I. The climate data is taken as Helsinki – Vantaa 2012 reference weather data. An office building is connected to the district heating system. The main entrance of the building is orientated to the North West. The building is showed in figure 11.

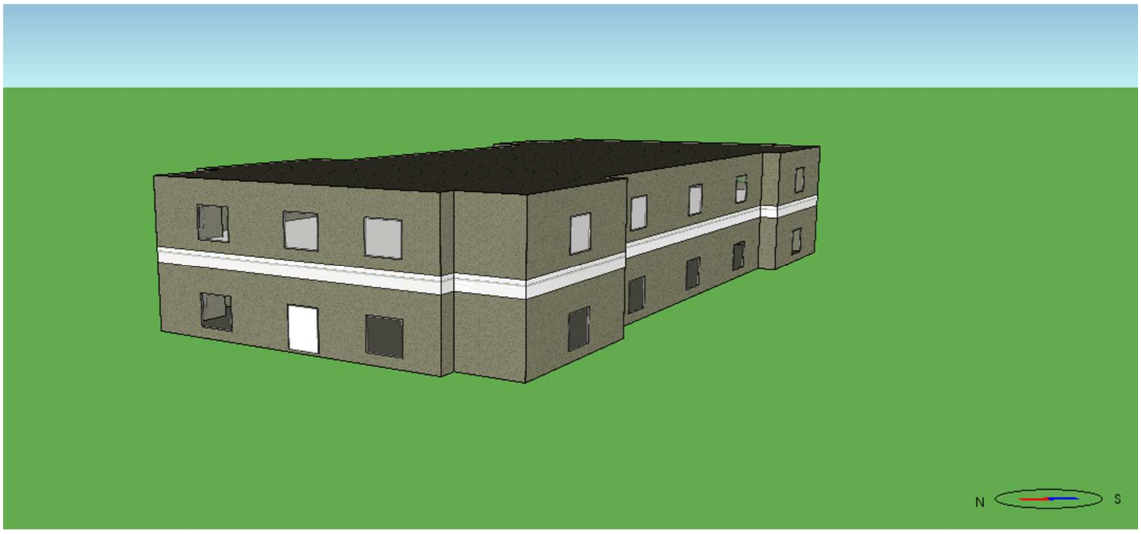

FIGURE 11. Building facade and orientation

For the first simulation all the design values, needed for energy consumption calculations, are taken from the National Building Code of Finland, D3 /3, 4/. All these values are regulated for an office type of a building. The detailed values are presented in the chapter 3.4. The initial data needed for the first simulation part is showed in the following tables and figures.

The selected layers, thickness and U – values of different building envelopes are given in table 7.

TABLE 7. Constructions of building envelope

Envelope	Layers	Thickness, m	U – value, $W/(m^2K)$
External wall	Plaster of lime mortar	0,01	0,17
	Concrete	0,1	
	Mineral wool	0,252	
	Concrete	0,1	
	Plaster of lime mortar	0,01	
	∑	0,472	
Roof	Bitumen	0,01	0,09
	Mineral wool	0,486	
	Concrete	0,15	
	Plaster of lime mortar	0,01	
	∑	0,656	
External floor	Linoleum	0,005	0,16
	Aerated concrete	0,02	
	Concrete	0,1	
	Polystyrene	0,235	
	∑	0,360	
Internal wall	Gypsum board	0,013	2,11
	Air gap	0,07	
	Gypsum board	0,13	
	∑	0,096	
Internal floor	Linoleum	0,2	0,29
	Aerated concrete	0,08	
	Insulation	0,05	
	Concrete	0,47	
	∑	0,8	

The extra conductance coefficients needed for calculation of heat looses through thermal bridges are taken from National Building Code of Finland, D5 /2/. The main material for all external building envelopes' frames is a concrete. Values of thermal bridges for different study case building envelopes and constructions are showed in figure 12.

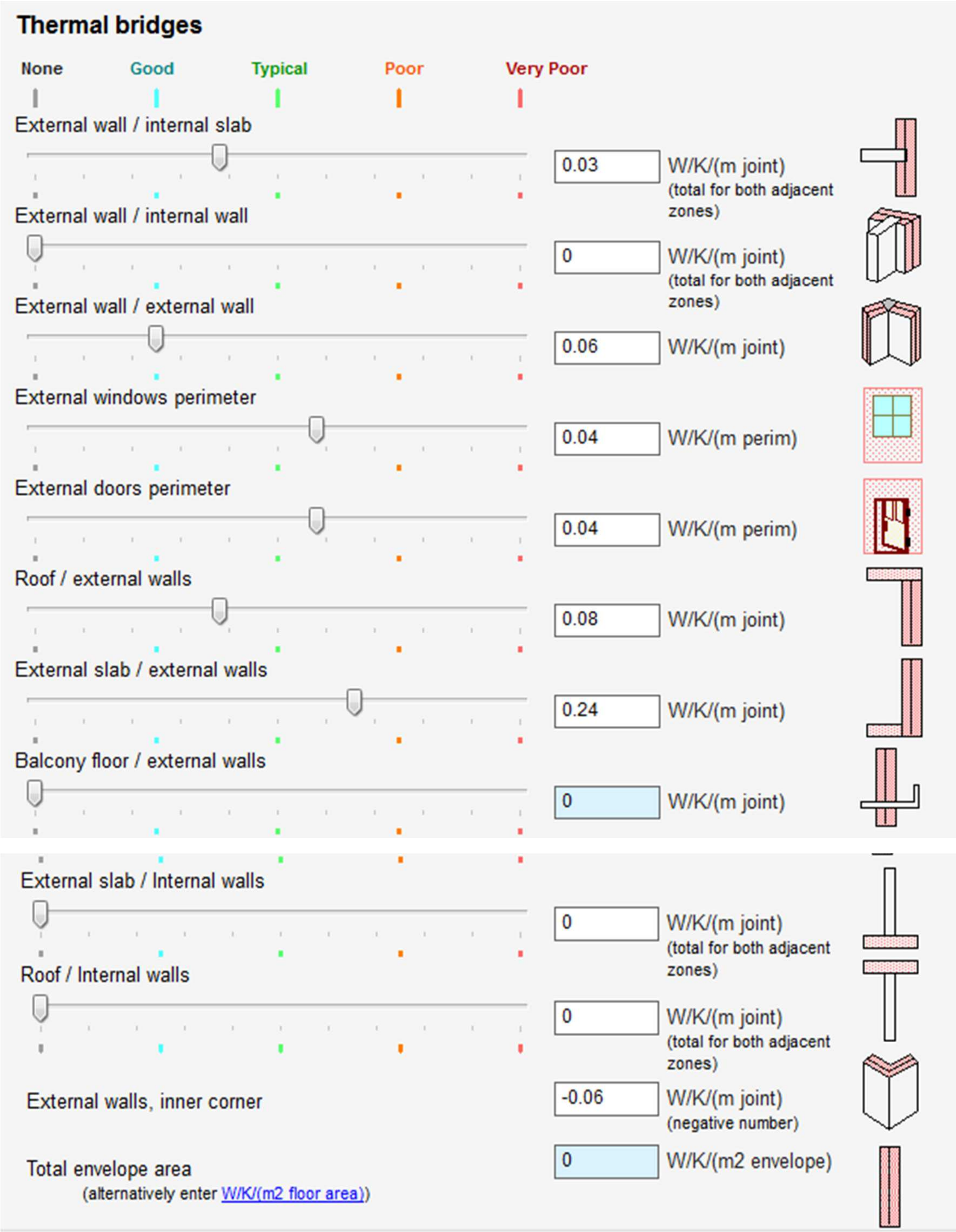

FIGURE 12. Extra conductance coefficients of thermal bridges for different building envelopes and constructions

Extra energy and losses in this case includes the thermal energy needed for domestic hot water and distribution losses of domestic hot water circuit. The values taken for the calculation and simulation processes are given in figure 13.

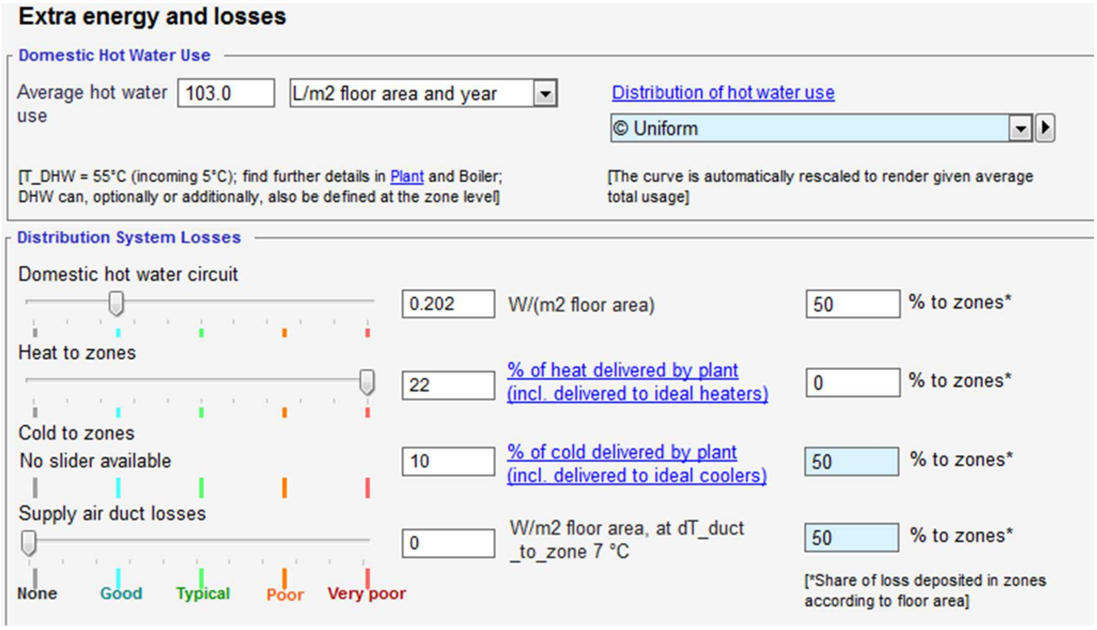

FIGURE 13. Extra energy and losses of an office building

In this case study, the plate heat exchanger is selected as the heat recovery unit with a heat recovery efficiency η = 0,6. The exhaust air temperature is limited and cannot exceed 0 ˚C in order to avoid the frost formation on the extract air side during winter time. The specific fan power (SFP) is equal to 2 kW/(m^3/s) and is divided into 1,2 kW/(m^3/s) for a supply air fan and 0,8 kW/(m^3/s) for an exhaust air fan. For an office' ventilation system, the central air handling unit with constant air volume system (CAV) is selected.

All the values which were mentioned in this chapter will be used for the whole first office building simulation process. The calculated heat demand for this office building is showed in table 8.

TABLE 8. Heat losses of the study case building

Zone of the building	Heat losses, W
1^{st} floor	19446
2^{nd} floor	25007
∑	44453

By knowing the heat demand for an office building, the designing and simulation of different heating systems can be made. The total heat demand of a building is 44,5 kW.

The heating systems will be designed separately for the 1st and the 2nd floors according to their own heat demand.

5.1.1 Heating with radiators

At first, the study case building will be simulated with installed radiator heating system. The initial data for designing the radiator heating system is given in table 9.

TABLE 9. Initial data for designing the heating system with radiators

	1st floor	2nd floor
Maximum heating power	20,0 kW	25,0 kW
Supply water temperature	50 ˚C	
Return water temperature	30 ˚C	

The annual efficiency of distribution system of radiators is $\eta_{space} = 0,9$ /4/.

The main needed information for comparing different heating systems is the amount of delivered and used energy for heating purposes. The distribution losses of heating systems will also be considered. The simulation results with radiator heating system are presented below.

TABLE 10. Delivered energy overview with radiator heating system

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	40296	22,3	68503	37,9
	Equipment, facility	40296	22,3	68503	37,9
	HVAC aux	31183	17,3	53020	29,4
	Cooling	3772	2,1	6413	3,6
	Heating	100911	55,9	70637	39,1
	Domestic hot water	14449	8,0	10114	5,6
	Total	230912	127,8	277190	153,4

TABLE 11. Used energy with radiator heating system

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
1	9991.0	0.0	8686.0	0.0	1190.0
2	9172.0	0.0	8066.0	0.0	1075.0
3	8411.0	0.0	7067.0	0.0	1190.0
4	4058.0	-0.0	3118.0	38.5	1152.0
5	903.1	-0.0	435.7	751.9	1190.0
6	330.3	-0.0	48.0	1460.0	1152.0
7	4.4	0.0	0.7	3694.0	1190.0
8	26.6	6.7	15.6	3319.0	1190.0
9	1082.0	0.0	521.1	160.0	1152.0
10	3917.0	0.0	2310.0	0.0	1190.0
11	7308.0	0.0	5433.0	0.0	1152.0
12	9393.0	0.0	7586.0	0.0	1190.0
Total	54596.4	6.7	43287.0	9423.4	14013.0

Annual distribution losses for radiator heating system is 12010,8 kWh/a.

5.1.2 Underfloor heating

The initial data for the 1st and the 2nd floors of an office is the same. The design power is 22 W/m^2 for the 1st floor and 28 W/m^2 for the 2nd. The supply water temperature is 40 ˚C with the temperature drop of 5 ˚C. The annual efficiency of distribution system of underfloor heating of ground based laying (1st floor) is η_{space} = 0,8 and η_{space} = 0,85 for slab against warm spaces (2nd floor) /4/. The heating pipes are laid in the depth of 0,04 m under the floor surface. For this simulation, the "wet" underfloor heating solution is selected, where pipes are installed in the concrete floor slab. In this case, the heat transfer coefficient 30 W/m^{2}K. The installation way of underfloor heating system is showed in figure 14.

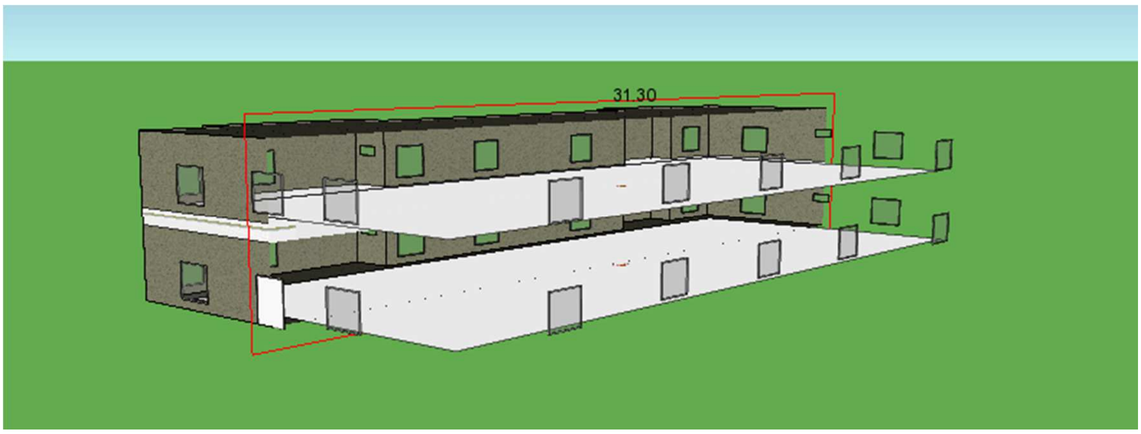

FIGURE 14. Underfloor heating laying in an office

The simulation results with underfloor heating system are presented below.

TABLE 12. Delivered energy overview with underfloor heating system

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	40320	22,3	68544	38,0
	Equipment, facility	40320	22,3	68544	38,0
	HVAC aux	31235	17,3	53100	29,4
	Cooling	3777	2,1	6421	3,6
	Heating	107418	59,5	75193	41,6
	Domestic hot water	14449	8,0	10114	5,6
	Total	237519	131,5	281916	156,1

TABLE 13. Used energy with underfloor heating system

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
1	11794.0	0.0	8390.0	0.0	1190.0
2	10487.0	0.0	7757.0	0.0	1075.0
3	9609.0	0.0	6794.0	0.0	1190.0
4	4141.0	0.0	2947.0	38.9	1152.0
5	740.8	0.0	459.0	752.7	1190.0
6	310.0	0.0	53.8	1458.0	1152.0
7	0.0	0.0	0.7	3694.0	1190.0
8	0.0	17.0	16.2	3321.0	1190.0
9	1128.0	0.0	541.2	159.7	1152.0
10	4842.0	0.0	2212.0	0.0	1190.0
11	8941.0	0.0	5227.0	0.0	1152.0
12	10502.0	0.0	7304.0	0.0	1190.0
Total	62494.8	17.0	41701.9	9424.3	14013.0

Annual distribution losses for underfloor heating system is 13747,3 kWh/a.

5.1.3 Ceiling panels

For the last simulation in this part, the metal ceiling heating panels are selected. The panels are designed separately for each floor according to its heat demand. As it was mentioned before, the 1st floor needs 19,5 kW for heating the spaces and the 2nd – 25,0 kW as well. The designing power value for 1st floor is taken with a reserve and reaches 20 kW. The simulation programme will not take more power than it is needed for heating. The annual efficiency of distribution system of ceiling heating of system against warm spaces (1st floor) is η_{space} = 0,9 and η_{space} = 0,85 for system installed against ceiling (2nd floor) /4/. The supply water temperature is set to 40 ˚C. The installation way of ceiling heating panels is showed in figure 15.

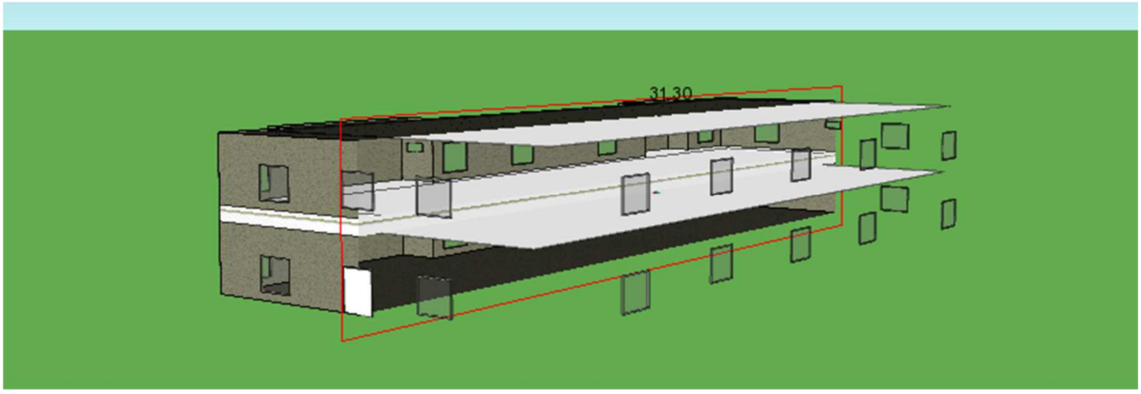

FIGURE 15. Ceiling heating panels in an office

The simulation results with ceiling panel heating system are presented in the tables below.

TABLE 14. Delivered energy overview with ceiling heating panels

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	40316	22,3	68537	37,9
	Equipment, facility	40316	22,3	68537	37,9
	HVAC aux	31289	17,3	53191	29,4
	Cooling	3778	2,1	6423	3,6
	Heating	1004400	57,8	73080	40,5
	Domestic hot water	14449	8,0	10114	5,6
	Total	234548	129,8	279882	154,9

TABLE 15. Used energy with ceiling panel heating system

kWh (sensible and latent)

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
1	10415.0	0.0	8805.0	0.0	1190.0
2	9389.0	0.0	8107.0	0.0	1075.0
3	8693.0	0.0	7131.0	0.0	1190.0
4	3768.0	0.0	3144.0	38.6	1152.0
5	686.3	0.0	520.0	753.9	1190.0
6	150.0	0.0	67.0	1461.0	1152.0
7	0.0	0.0	0.7	3699.0	1190.0
8	0.0	10.5	16.4	3323.0	1190.0
9	1142.0	0.0	655.7	159.8	1152.0
10	4686.0	0.0	2487.0	0.0	1190.0
11	8416.0	0.0	5534.0	0.0	1152.0
12	9795.0	0.0	7662.0	0.0	1190.0
Total	57140.3	10.5	44129.8	9435.3	14013.0

Annual distribution losses for ceiling panel heating system is 12574,2 kWh/a.

5.1.4 Results

The energy performance results of an office with the radiator heating, underfloor heating and ceiling heating panels will be compared. The simulation results as a delivered energy, E – value, used energy for heating and distribution losses in the heating network for every case are presented below.

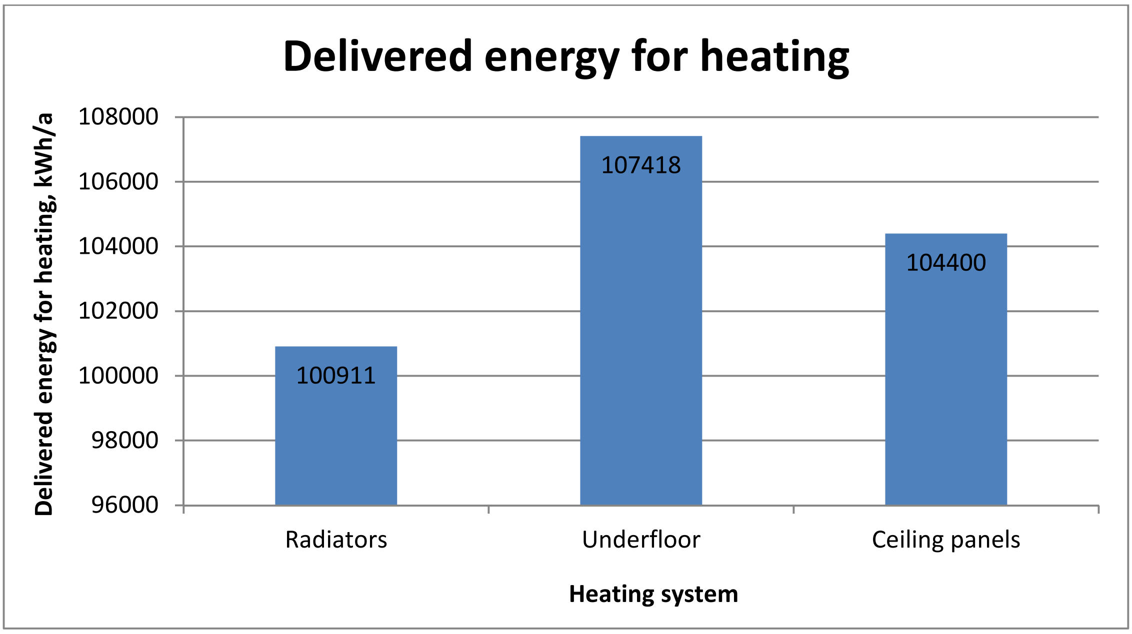

FIGURE 16. Annual delivered energy for heating of different systems

The annual delivered energy for heating is given in figure 16. As we can see from the graph, the radiator heating requires the lowest amount of energy needed for heating purpose from all heating solutions. The ceiling panel heating takes the 2nd place while underfloor heating shows the worst results. This means that underfloor heating needs the biggest amount of the delivered energy for heating.

The total delivered energy of an office with different heating systems is showed in figure 17.

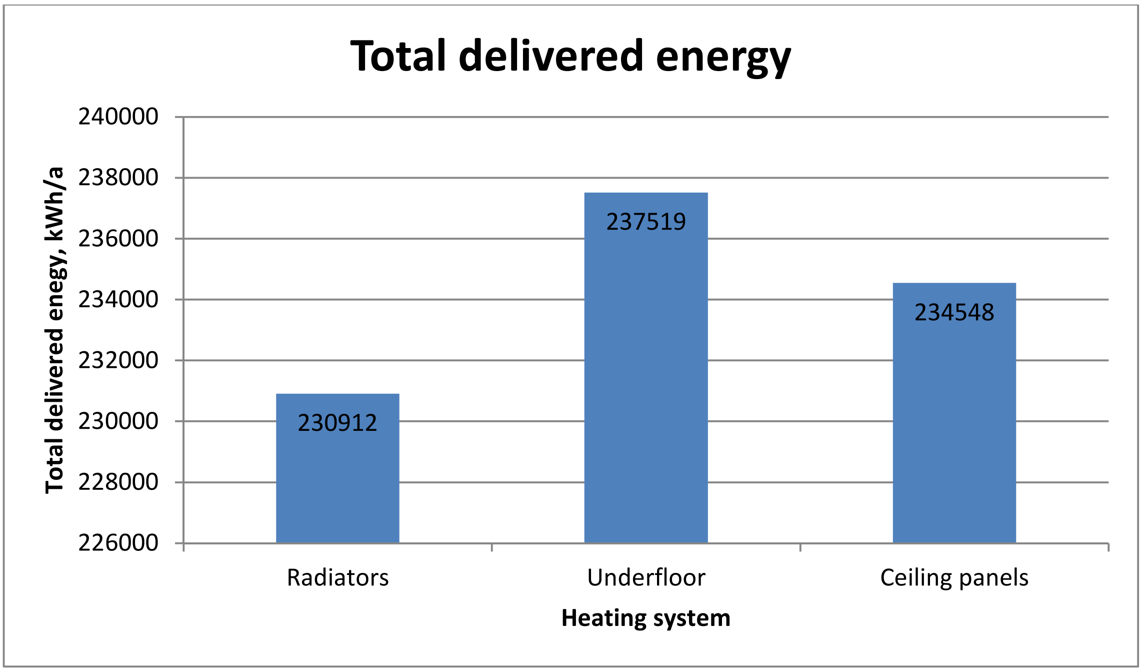

FIGURE 17. Total delivered energy with different heating systems

The graph shows the same tendency as it was discussed before with delivered energy for heating purposes, because the total delivered energy with different heating systems differs almost only due to different heating solutions. Once again, the radiators need the lowest amount of energy per year. The ceiling panels require more than 3600 kWh and underfloor - more than 6600 kWh each year compared to radiator heating solution.

In the following figure 18, the E – values for every heating system case are given. The E – value shows the relationship between the total delivered energy per total heated area. For this study case, an office building, the E – value cannot exceed 170 kW/m^2 /4/.

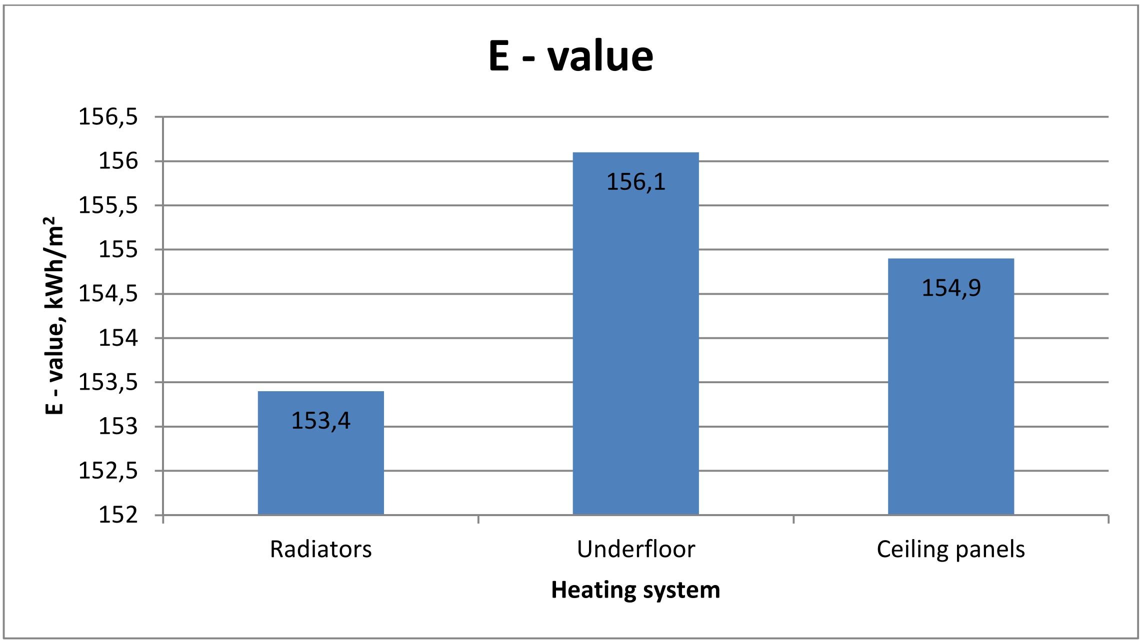

FIGURE 18. E – value with different heating systems

The E – value graph shows that in all different cases, the energy consumption per heated area does not overpass the maximum limited value. This office building is quite energy efficient, because ≈ 155 kWh/m^2 is much smaller than 170 kWh/m^2 limited in National Building Code of Finland, D3 /4/. The differences between all 3 study cases are rather small, though the building with radiator heating shows the best result when E – value is 153,4 kWh/m^2.

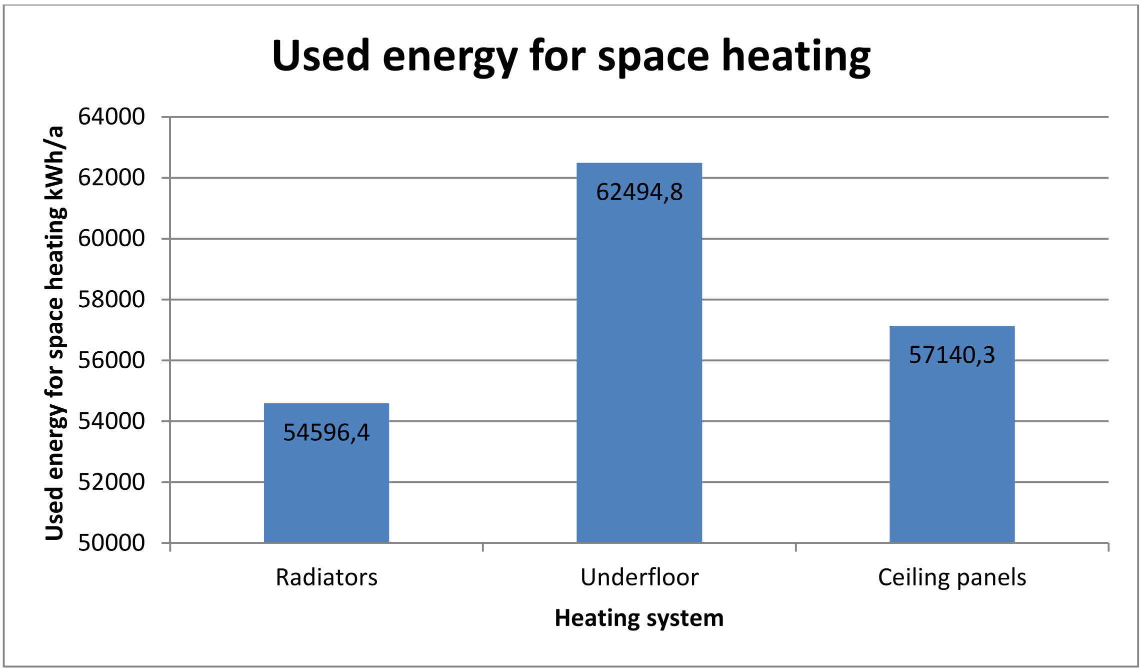

FIGURE 19. Annual used energy for space heating of different heating systems

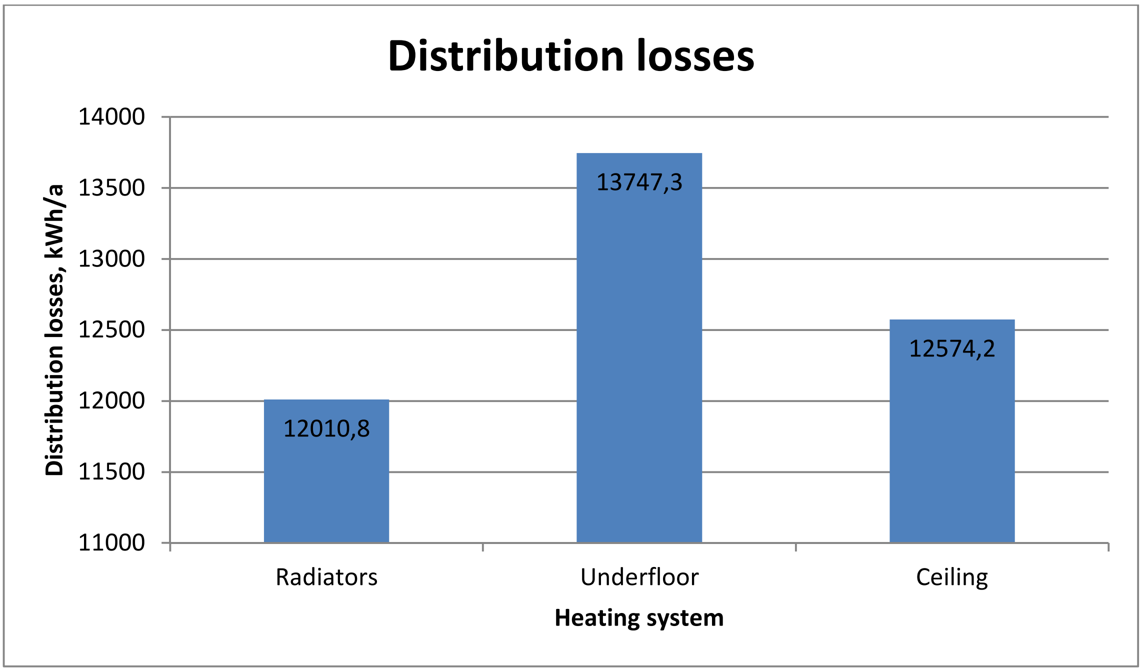

FIGURE 20.Distribution losses of different heating systems

In figure 19 and 20 presents the annual used energy for space heating and distribution losses of different heating systems. In both cases the radiator heating is leading with the lowest results. The radiator heating solution has the lowest distribution losses in the system because of the highest efficiency of distribution for space heating η_{space}.

Other important aspects in comparing the heating solutions are the created indoor climate and thermal conditions in an office. In all three study cases, the percentage of total occupant hours with thermal dissatisfaction (PPD) is the same and reaches 6%. According to Standard EN 15251 “Indoor environmental parameters of assessment of energy performance of buildings”, an office building with all 3 different heating solutions corresponds to the best I Category of a building thermal comfort. /17./ The value of CO_2 concentration in an office building is 436,5 ppm and states constant in all three cases and does not exceed the limited value of 750 ppm for the best building class S1. /18./ Nevertheless that the CO_2 concentration as well as a relative humidity, which varies from 30,3 to 30,7 %, is controlled by the ventilation system and the heating solutions do not take part in this, the results show that indoor climate conditions in this office building is satisfactory and meet the requirements.

The comparison results of indoor air and operative temperatures with different heating systems are given in the charts below.

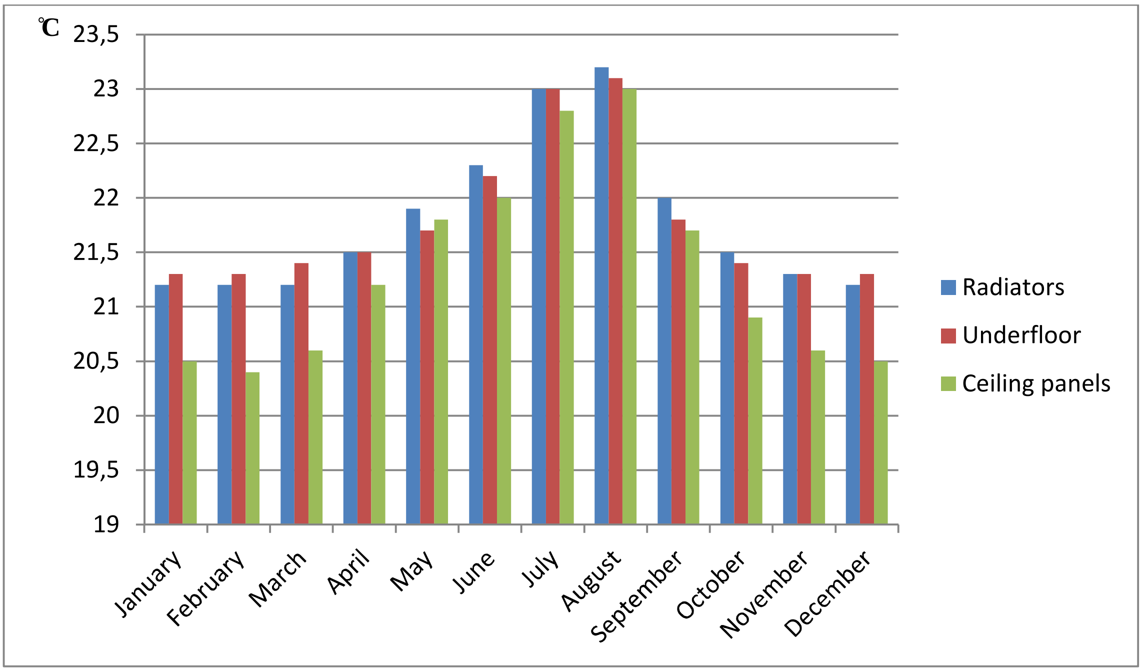

FIGURE 21. Indoor air temperatures in an office with different heating systems

As we can see from figure 21, with the same designed heat power the different indoor air temperatures were reached for different heating solutions. The radiators and the underfloor heating show relative similar results, while ceiling panels are lagging. This characteristic claims that for maintaining the required indoor air temperature, the different designing heat power should be selected for different heating systems. In this case, the indoor air with ceiling panel heating solution does not reach the 21 ˚C during the heating season. This means that the designing heat power should be increased, because the system with the maximum power input does not reach the needed values. Comparing the radiators with underfloor heating, we can see that with the same heating power, the higher indoor air temperatures are reached with underfloor heating solution. This indicates that the lower heating power can be designed for maintaining the required indoor air temperature.

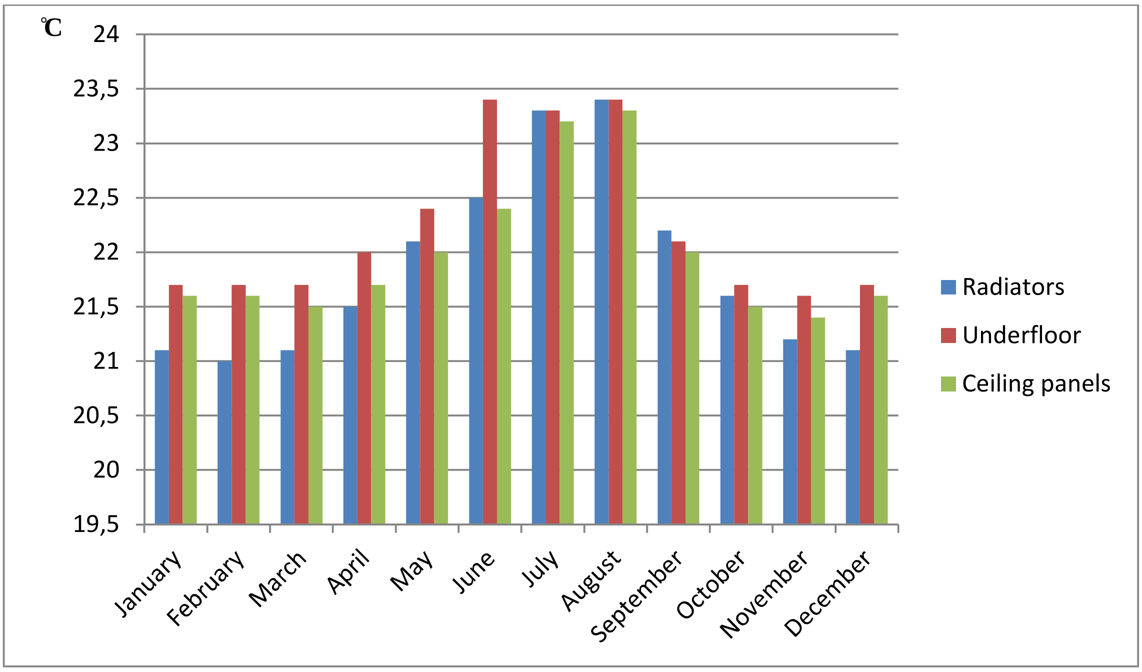

FIGURE 22. Operative temperatures in an office with different heating systems

Figure 22 illustrates the changes of operative temperature in an office with different heating systems. The results show that the indoor air and operative temperatures are almost the same, maintained by a convective radiator heating system – the occupants feel the same temperature as the heat emitter device, radiator, releases to the room. The radiant heating solutions as underfloor or ceiling panel heating, reach the higher operative temperatures with the same designing heat power. The occupants with radiant heating systems feel higher temperature than is released from the heating panels. This means that the lower temperatures are needed to feel the desired thermal comfort.

To sum it up, in spite of the fact that radiator heating system has the highest supply water temperature compare to other heating systems, the simulation shows that this is the best heating solution for this case study building. Taken into consider the all energy consumption aspects, the radiator heating system is the leader compare to underfloor and ceiling heating solutions. Even the simulation results show the small differences between underfloor and ceiling panel heating, although the ceiling panels is a better heating solution for this office building than underfloor. The lowest amount of energy consumption and heat losses in distribution network indicate that heating with radiators is the most suitable solution for this building in the terms of energy efficiency. This is the reason why radiator heating system in an office building is selected for the second simulation part.

5.2 Simulations of energy saving

In this chapter the more detailed analysis of a study case building with the radiator heating system will be made. The second simulation will help to find the answer if the energy consumption of an office can be reduced. In this part, the parameters of building air tightness, glazing type of windows, solar shading and orientation of the building will be changed by trying to find the best solutions for this building. Finally, the differences of energy consumption of this office will be compared whether it is located in Finland and in Lithuania.

5.2.1 Air tightness

One of the cheapest ways to reduce the building energy consumption is by making the building more air thigh. The simulation with 4 different leakage air values (q_{50}) will be made in order to investigate how the leakage air through building envelopes change the energy consumption.

TABLE 16. Energy performance with different air leakage values

q_{50},m^3/h, m^2	Q_{leak}, kW	Delivered energy, kWh
1	1,83	210068
2	3,65	215702
3	5,72	221238
4	7,31	226939

In table 16 is showed the simulation results of heat losses and total delivered energy with different q_{50} values. We can see from the results that with lower q_{50} value, the lower heat losses due to leakage air through building envelopes are gotten. This means that with lower q_{50} value, the less energy for heating is needed. In figure 23 below is presented the visual data of the heat losses due to air leakage and an annual delivered energy dependence on the air leakage coefficients. The graph shows that by reducing the air leakage in the building and making it more air tight, the better performance of energy consumption is achieved.

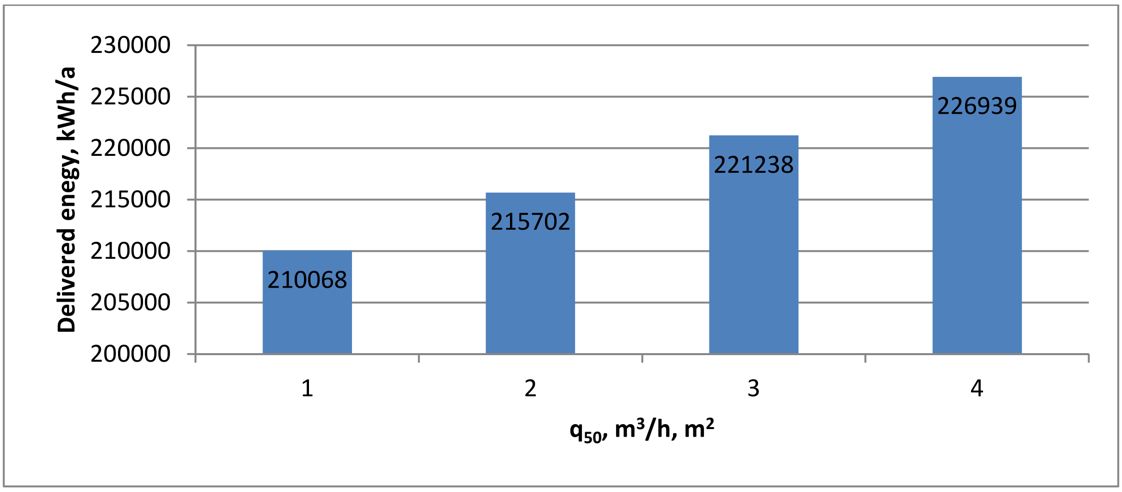

FIGURE 23. Delivered energy for different q_{50} values

5.2.2 Glazing type of the windows

The type of windows' glazing also affects the energy demand of the building. The different glazing types of windows will be compared with different solar energy transmittance coefficients (g – value) by trying to keep the same thermal transmittance coefficient (U – value) of the windows. The best type of windows will be found in the terms of lowest energy consumption. The simulation results are given in table 17.

TABLE 17. Energy performance with different glazing types of the windows

Glazing type	g - value	Solar transmittance	U – value, $W/(m^2K)$	Delivered energy, kWh
Pilkington Optitherm S3 (4-15Ar-4-12Ar-S(3)4)	0,55	0,47	1,0	210098
Saint Gobain T4-12m. PLANNITHERM ULTRA +ar	0,56	0,46	1,0	209937
Saint Gobain D4-15m. PLANNITHERM ONE+ar	0,49	0,44	1,0	210889
Saint Gobain T4-12m. PLANNITHERM ONE+ar	0,46	0,38	0,95	210563

Figure 24 illustrates the simulation results with different types of window glazing. As we can see from the graph, the best glazing type solution is the Saint Gobain T4-12m. PLANNITHERM ULTRA + ar with the g – value of 0,56. The higher g – value requires the less energy demand, which means the lower energy consumption as well. The glazing type with higher g – value transmits the bigger amount of solar radiation to the room and with higher solar gains of the building, the heat demand for heating purposes are reduced.

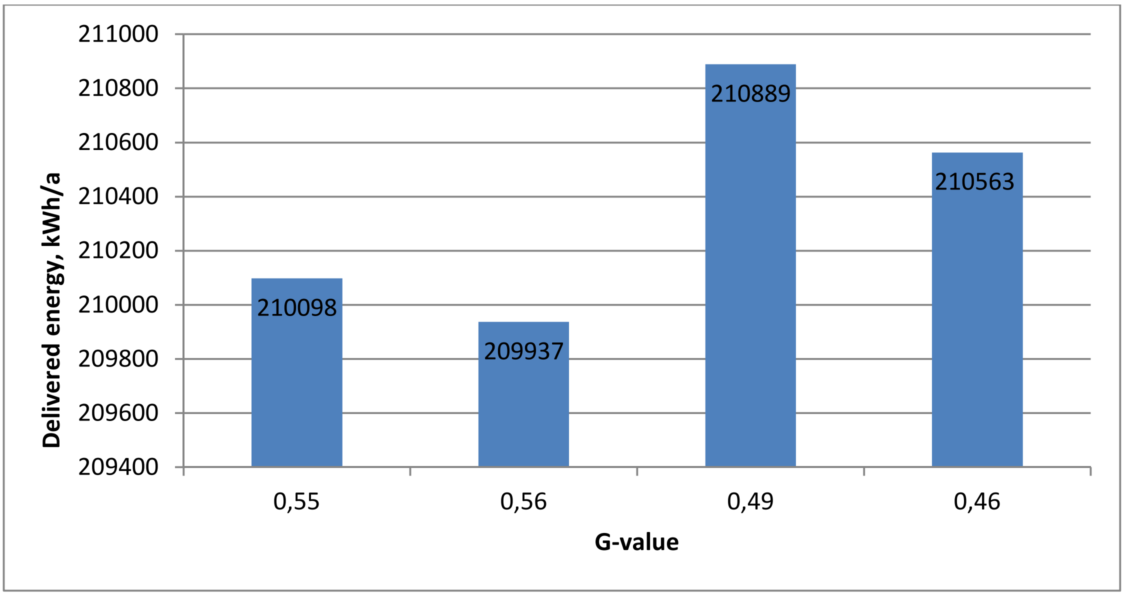

FIGURE 24. Delivered energy for different types of g - values of windows

Windows with higher g – value mean not only the lower heat power during the heating season but also a higher cooling power in summer due to the better solar transmittance to a building. In this case, for better evaluation of energy savings, the cooling demand of an office could also be taken into consideration.

5.2.3 Orientation of the building

Orientation of the building, especially its windows; is an important factor in energy consumption calculations because the solar radiation is the reason of external solar gains to a building. These heat gains reduce the required thermal energy in building during the heating season and can cause the overheating in summer time. In this work, the energy demand both for heating and cooling systems will be considered.

There are two different types of windows in this office - 31 windows with the dimensions of 2,0×1,7 m, 2 windows of 1,2×1 m and 4 smaller windows of 1,2×0,5 m. The total area of all windows is 110,2 m^2. The area of external door is 3,78 m^2.

The building orientation to all possible sides will be investigated in order to find the best direction of an office. The building orientation is set according to its main entrance. All simulation results with different types of directions are given in table 18 and figures below.

TABLE 18. Energy consumption with different building orientation sides

Orientation of a building	Direction of windows	Delivered energy, kWh	Energy for heating, kWh	Energy for cooling, kWh
East	5 windows to East 14 windows to South 8 windows to West 10 windows to North	213056	83081	3782
South East	5 windows to South East 14 windows to South West 8 windows to North West 10 windows to North East	212868	82868	3796
South	5 windows to South 14 windows to West 8 windows to North 10 windows to East	213206	83202	3803
South West	5 windows to South West 14 windows to North West 8 windows to North East 10 windows to South East	213343	83353	3789
West	5 windows to West 14 windows to North 8 windows to East 10 windows to South	213576	83592	3774
North West	5 windows to North West 14 windows to North East 8 windows to South East 10 windows to South West	213315	83344	3788
North	5 windows to North 14 windows to East 8 windows to South 10 windows to West	213361	83337	3802
North East	5 windows to North East 14 windows to South East 8 windows to South West 10 windows to North West	213155	83173	3785

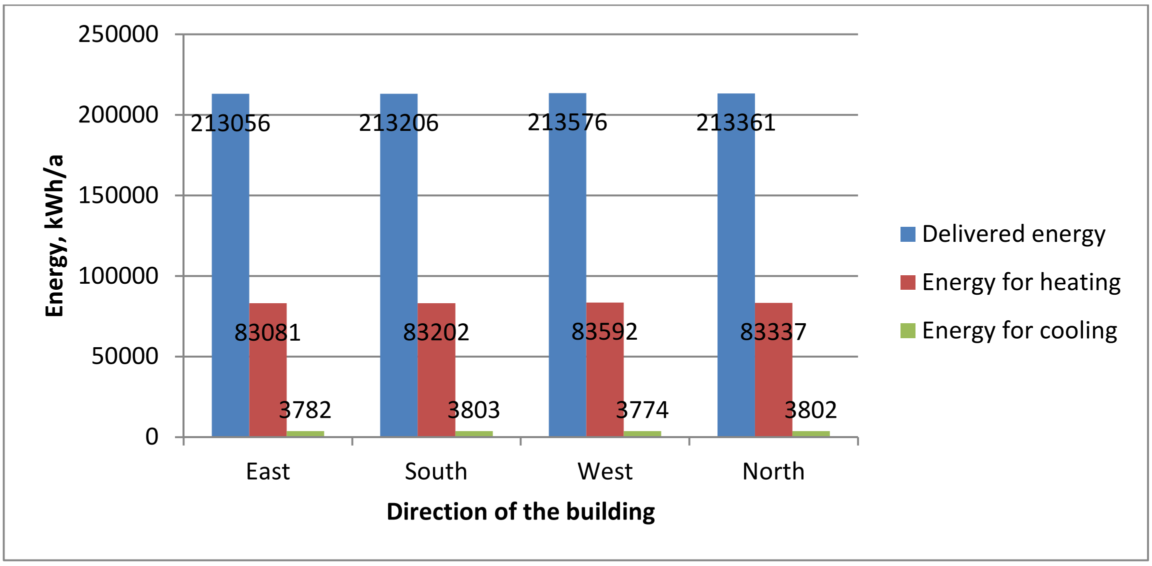

FIGURE 25. Energy consumption with different direction sides of a building

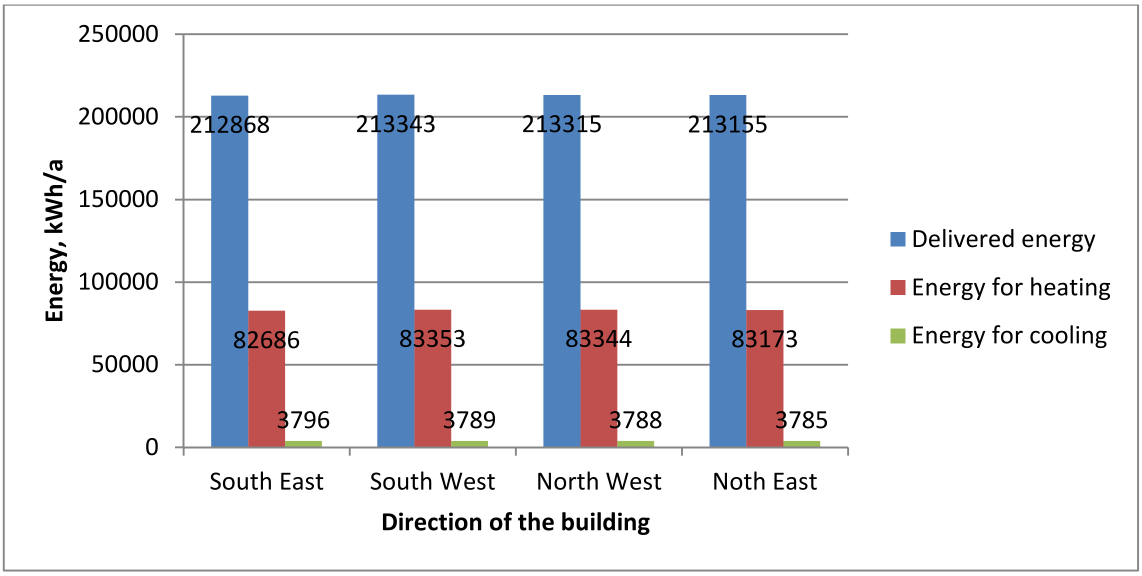

FIGURE 26. Energy consumption with different direction sides of a building

The simulations show quite similar results with different direction sides of an office building. Although, the simulation result of South East direction makes it conspicuous because of the lowest values of delivered energy and energy needed for heating. In this case, the amount of needed energy for cooling purpose is in the middle compared to other directions, but orientation (to West side) with lowest amount of energy for cooling requires the highest amount of delivered energy. This is the reason why it can be concluded that the best energy performance of this office building is when it is situated to the South East side with the energy consumption of 212868 kWh.

5.2.4 Solar shading

Simulation results show that the operative temperature in this office building does not exceed 27℃ during all year. This means that where is no need to install the external shadings in this building which can help to avoid the overheating process during the summer time. The installation of external shadings without the consideration also can increase the heat demand of building during the heating season because the external shadings prevent the transmittance of solar radiation through windows.

In this case, the energy consumption with integrated window shading will be analyzed. The selected internal blinds can be easily controlled by the occupants. These internal blinds can be lifted up or dropped down according to solar radiation and light. This solar shading solution is cheaper and much easier removable compare to external solar shadings.

In this study case, one floor is modelled as one zone. In the real building, there are several zones in the floor, so these results of simulation are not comparable to real building. The more detailed model of an office building is needed to get more trustful simulation results.

The results of purchased energy with installed internal blinds are showed in table 19 and figure 27.

TABLE 19. Comparison of solar shading types

Type of solar shading	Energy for heating, kWh/a	Energy for cooling, kWh/a	Delivered energy, kWh/a
No	82868	3796	213206
With internal blinds	80732	4006	210954

Figure 27 illustrates the simulation results and shows that installed internal blinds reduce the required energy for heating, as well as the total delivered energy per year. Despite the fact that an office building with integrated internal blinds needs the bigger amount of energy for cooling, the total energy of a building is still being saved. The energy savings for heating (2136 kWh/a) purposes overweigh the higher energy demand for cooling (210 kWh/a) more than 10 times. The E – value of this office building with integrated internal blinds is 145,8 kWh/m^2.

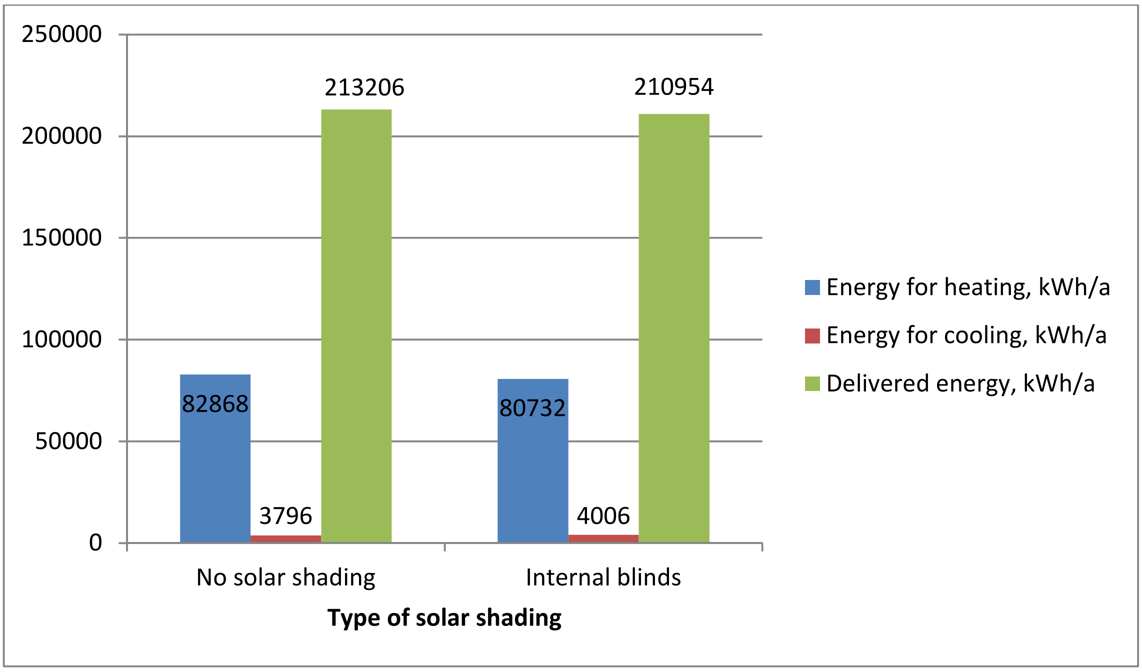

FIGURE 27. Comparison of solar shading types

5.2.5 Location of the building

In this part, the energy consumption of an office building will be compared in the different locations. The final version of simulated office in Helsinki will be paralleled with the same building which is located in Vilnius, Lithuania. Only the location and weather data will be changed, all other parameters of the building and engineering solutions will stay unaltered.

TABLE 20. Data of Helsinki and Vilnius weather zones

City	Latitude, °	Longitude, °	Elevation, m	Designing outdoor temperature, C	Annual mean outdoor temperature, ℃
Helsinki	60.1 N	24.56 E	4	-26	+5,3
Vilnius	54.63 N	25.28 E	156	-23	+8,5

The simulation results of an office building with location in Helsinki and in Vilnius are presented in figure 28.

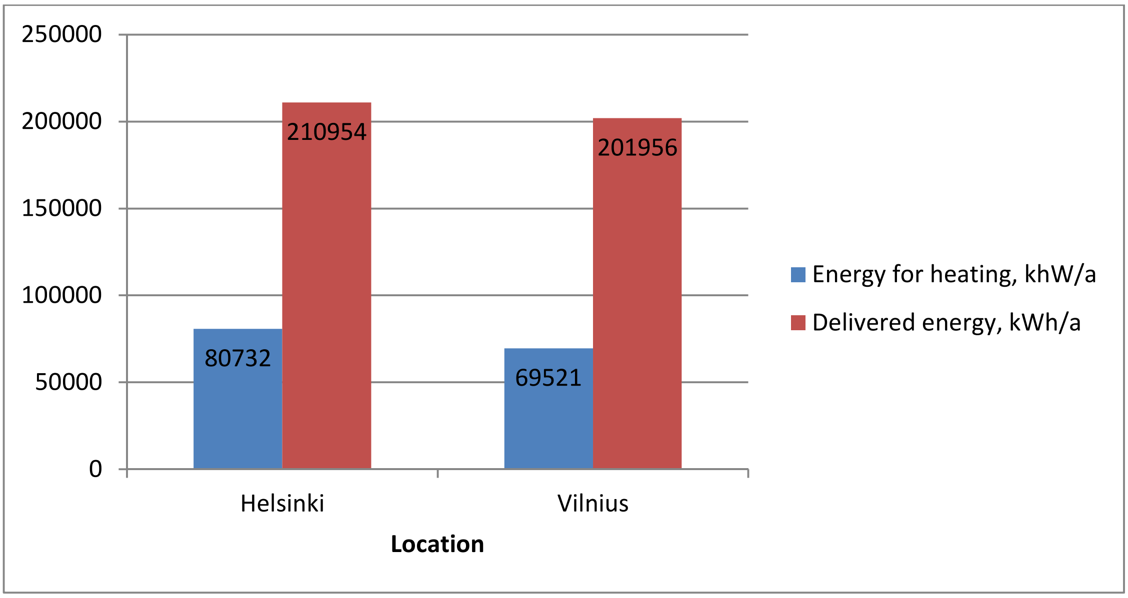

FIGURE 28. Comparison of different locations of an office

As figure 31 illustrates, the heat demand of an office building located in Vilnius is lower compared to its location in Helsinki. This can be explained by the higher designing outdoor temperature in Vilnius during heating season than in Helsinki. The warmer climate and the lower temperature difference between the outdoor and indoor air needs the less energy for heating per year. The Lithuanian Technical Regulation of Building Constructions (STR) /19/, the same as National Building Code of Finland, does not regulate the reference values for thermal transmittance coefficients (U – value) of building envelopes. This means that the higher U – values of materials or thinner building envelopes can be selected for this building in Lithuania.

6 DISCUSSION

The main idea of this Bachelor thesis was to find an answer if the energy can be saved in an office building. This work mainly concentrated on heating systems. The study case building is located in Helsinki, Finland with the total heated area of 1806,4 m^2.

Firstly of all, the comparison of heating systems was made in order to figure out which one from the radiator heating, underfloor heating, ceiling heating, heating panels and fan coils is the most suitable for an office building. The results of technical literature review and the first simulation part show that the best heating solution in terms of energy consumption for this case study building is radiator heating. Nevertheless, the radiator heating system does not show the best results in the created thermal comfort and temperature variation in the space. This states that at present there is no heating solution, which gives the best values in all categories. The heating solutions which maintain better indoor climate require more energy and vice versa.

In the second simulation of this work, the different factors and parameters of an office building were changed. With the help of simulation software IDA ICE, the different properties of air tightness, glazing types of windows, orientation of building and solar shading solutions were investigated. The main aim of these changes was to understand how the simple engineering solutions can affect the energy consumption of a building.

The parameters of construction elements and materials, shape and area of an office had not been changed during the simulation process. By analyzing the simulation results it was determined that:

- The air tight building has less heat losses due to leakage air and this reduces the thermal energy demand. In designing process, the lowest allowable air tightness value should be selected.
- Windows with the same U – value but higher g – value and solar transmittance coefficient reduces the needed total energy of a building because a better transmittance of solar radiation to the building premises increases the external heat gains, which decrease the heat losses.

- The simulation with an office building showed the best energy performance results with its orientation to the South East side. Orientation of the building, especially its windows, is an important factor of energy demand due to the solar gains to the building. The variation of amount of delivered energy to the building between different orientation sides was more than 700 kWh per year.
- Even the simplest type of internal shading decreases the needed thermal energy demand for building.

The simulations of an office situated in different locations defined that higher amount of thermal energy is needed for the building in a colder climate zone. The better insulation materials and lower thermal transmittance coefficients of building constructions are required in Helsinki than in Vilnius. Nevertheless, in order to save energy by reducing the heat losses due to conduction through the building construction elements, the materials with the best U – values should always be selected.

Comparing the primary version of this office building with the same office after the 2nd simulation part of changing the parameters of a building, it is obvious that by taking into consideration the parameters, which were mentioned above, the energy can be saved. The results show that after all possible simulations, the delivered energy for heating purposes decreases from 100911 kWh/a to 80732 kWh/a. Due to the changes of air tightness, g – value, orientation of building and shadings more than 20000 kWh of energy can be saved per year.

7 CONCLUSIONS

Nowadays, in energy saving times, people started to take care about the environment and sustainability all around them. The considered designing of HVAC systems in buildings is one of essential part of reaching it. The many variables should be taken into account for finding the best solutions in buildings in order to create the required conditions and satisfactory climate indoors.

In this technology ages the computer simulation programmes are used to find the most suitable engineering solutions for buildings. These programmes allow investigating the building with different solutions and stated conditions, which let to analyze all possible designing ways. What is more, the computer simulation tools let designers to predict the energy performance of the building.

In this Bachelor's thesis, the simulation programme IDA ICE was one of the main tools in finding the answer to my research question. With the help of IDA ICE, it was established that the radiator heating system is the most suitable for the study case office building. It showed that more engineering solutions for underfloor and ceiling panel heating should be made to increase their system efficiency and reduce the distribution losses. Moreover, the programme let to find the energy saving ways. The considered designing of orientation of building, glazing type of windows, air tightness and solar shading solutions can reduce the energy consumption in buildings. Finally, answering to my research question, the considered solutions in building designing process can save the energy even in the energy – efficient buildings. This study case showed that more than 20000 kWh of energy can be saved each year.

In my point of view, the simulation programmes will be more and more used in the designing process of buildings' HVAC system. Computer tools make calculations easier, faster and more precise, also let the engineers to predict the energy performance after the installation of systems. This helps to design the most suitable and energy efficient systems, which save buildings' energy and fit to the high requirements.

For further studies, all the heating systems could be analyzed more. The design of different heating systems could also be done. What is more, for finding the energy savings, few areas as solar shadings or glazing types of windows should be focused on for more detailed investigation. This could be reached by creating more accurate model of an office building, which would be comparable with the real case.

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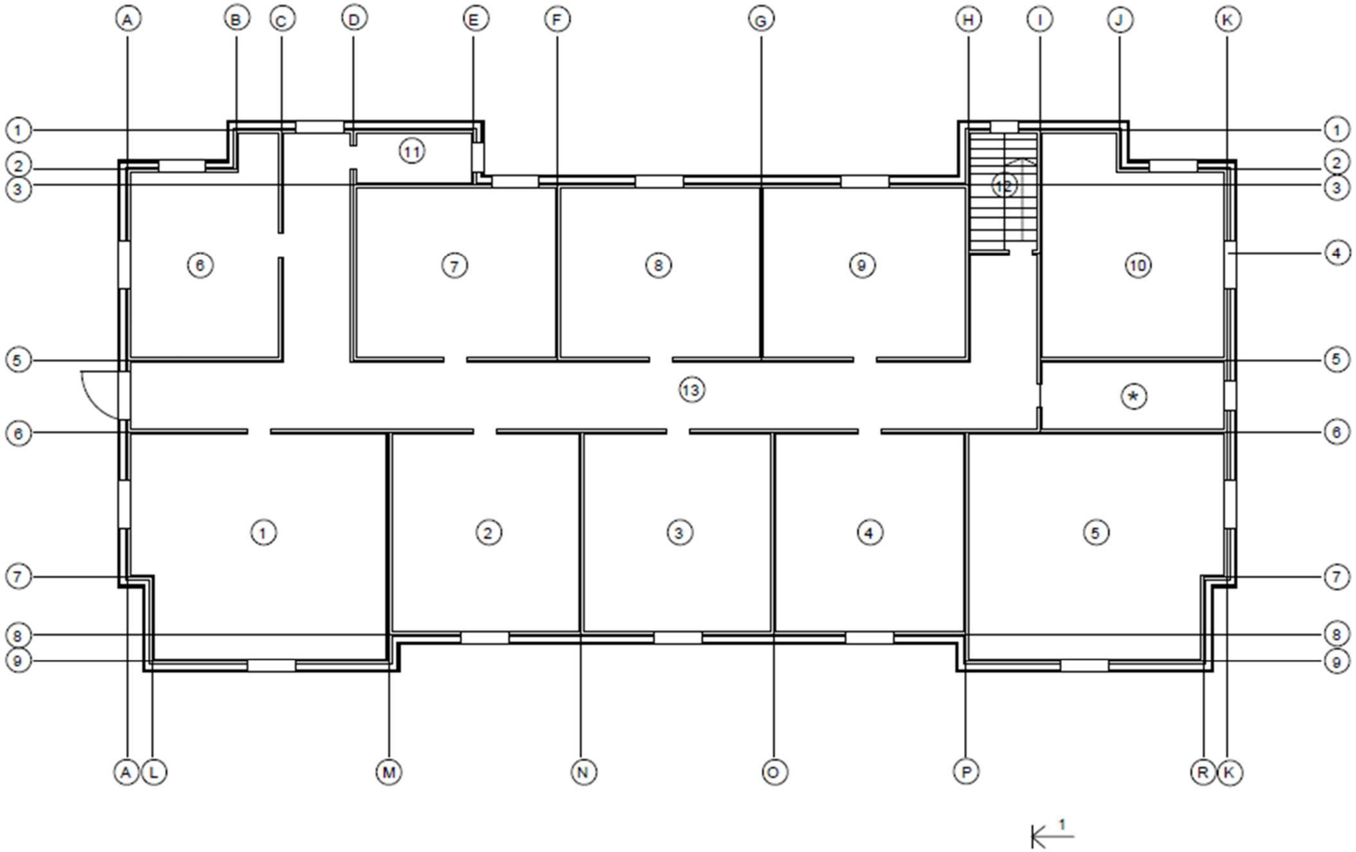
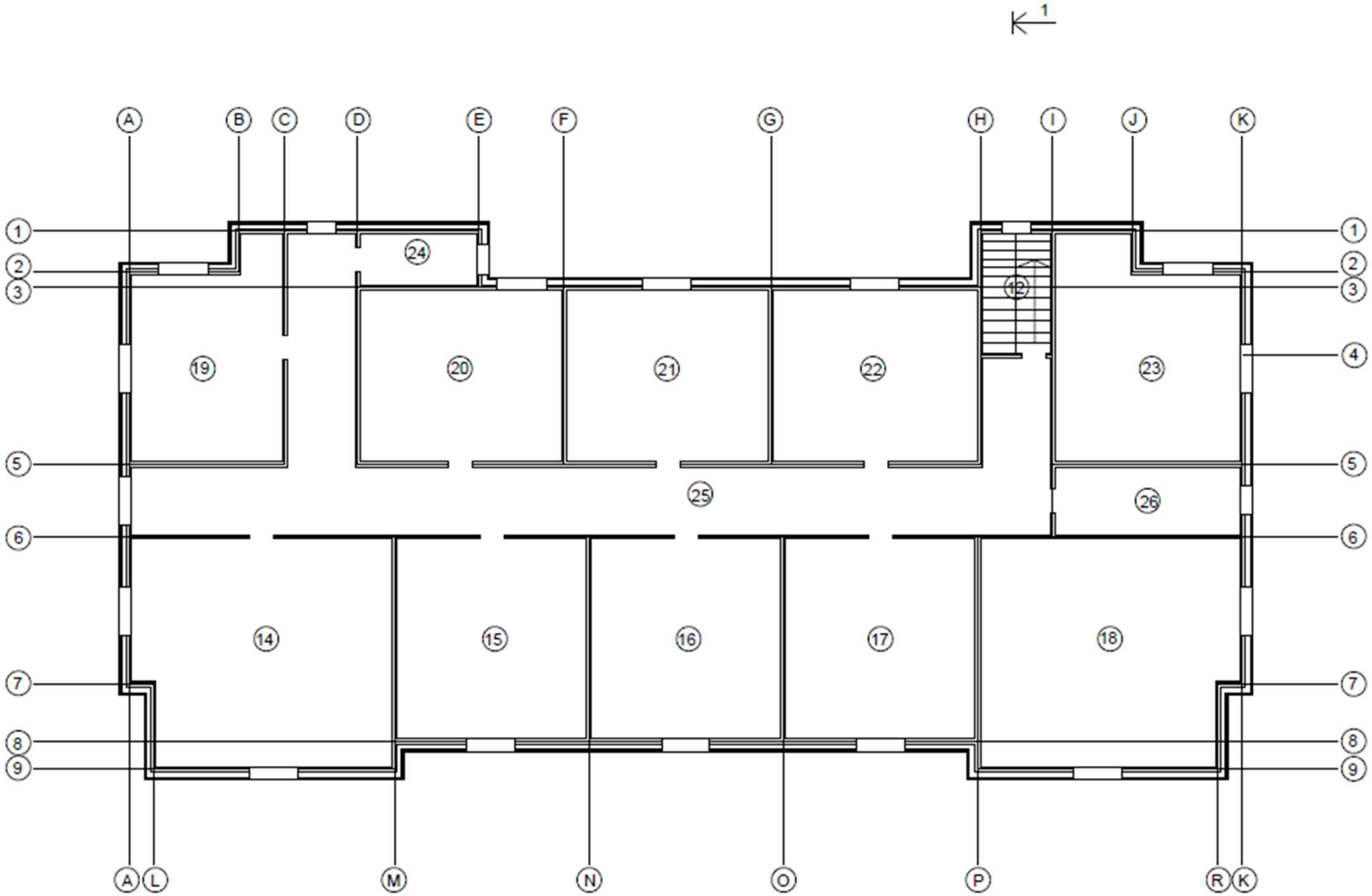
Plan of first floor



Explication of the rooms		
Room No	Type	Area, m²
1	Office room	149,6800
2	Office room	64,1200
3	Office room	64,1200
4	Office room	64,1200
5	Meeting room	149,6300
6	Copying room	75,8800
7	Office room	58,6900
8	Office room	58,6900
9	Office room	59,3900
10	Break room	64,4900
11	WC	10,6600
12	Straicase	13,7100
13	Corridor	145,6300
*	Technical room	21,8300
	Total:	903,2000

Plan of second floor



Explication of the rooms		
Room No	Type	Area, m²
14	Meeting room	149,6800
15	Office room	64,1200
16	Office room	64,1200
17	Office room	64,1200
18	Meeting room	149,6300
19	Storage	75,8800
20	Office room	58,6900
21	Office room	58,6900
22	Office room	59,3900
23	Break room	64,4900
24	WC	10,6600
12	Straicase	13,7100
25	Corridor	145,6300
26	WC	21,8300
	Total:	903,2000