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Simplified space-heating distribution using radiators in Norwegian passive houses: Investigations using detailed dynamic simulations

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Master's Thesis
Submission date: July 2015
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Simplified space-heating distribution using radiators in Norwegian passive houses: Investigations using detailed dynamic simulations

Forenklet anlegg for oppvarming ved bruk av radiatorer i Norsk passivhus: Analyse ved detaljert dynamisk simulering

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PREFACE

This report represents my Master Thesis, conducted the last semester in the MSc Energy And Indoor Environment Programme. The thesis was written at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology, in Trondheim, Norway, the spring 2015.

ABSTRACT

Many of the building concepts for current and future energy-efficient buildings are based on highly-insulated building envelopes, such as passive houses, zero emission buildings or nearly-zero energy buildings (nZEB). As the building is highly-insulated, it is possible to simplify the space-heating distribution subsystem and reduce the number of heat emitters to a few elements. One solution is to use a hydronic distribution equipped with few low-temperature radiators, for instance, one in each floor as well as one in the bathroom. This solution reduces thermal losses from the pipes and the investment, but theoretically provides for less thermal comfort than a standard loop.

This thesis examines the relation between energy efficiency and thermal comfort in a passive house, using different water heating systems, ie. when each room there is one heater, and when one heater warms one floor. The analysis was based on the project of existing passive house, located in Trondheim, Norway.

To build and examine the model, the IDA ICE application was used. This program was chosen because of the innovativeness, the ability to create multi-zone models, as well as to perform simulation parameters of indoor climate throughout the building and analyze energy demand.

Simulations were performed for three different temperature cases: constant value of 21°C, 21°C during a day - 19°C at night and the last one - 21°C during a day - 19°C at night with one week of 16 °C (Christmas break). Also considered the effect on the distribution of room temperatures, and thus the thermal comfort of occupants, leaving the door open or closed in the building.

The results showed that the best solution due to thermal comfort and energy efficiency aspect is to simplify the heating distribution system with mandatory leaving the door open and establish a constant temperature equal to 21ºC in the analyzed object.

NOMENCLATURE

$\dot{Q}$	The amount of internal heat generated within the body [W]
$\dot{Q}_d$	Heat loss due to diffusion of water vapor through the skin [W]
$\dot{Q}_w$	Heat loss due to evaporation of sweat from the skin surface [W]
$\dot{Q}_{ou}$	Latent heat loss during breathing [W]
$\dot{Q}_{oj}$	Sensible heat loss during breathing [W]
$\dot{Q}_p$	The amount of heat transmitted by clothing [W]
$\dot{Q}_R$	Heat loss by radiation from the outer surface of the clothes [W]
$\dot{Q}_K$	Heat loss through convection from the outer surface of the clothes [W]
t_s	The average temperature of the skin surface [^oC]
A_{DU}	The body surface area [m^2]
Λ_{Cl}	The total thermal resistance of clothing [clo]
t_w	The air temperature [^oC]
t_{mr}	The mean radiant temperature [^oC]
p_w	The partial pressure of water vapor in the room [Pa]
ν	The relative air velocity [m/s]
PMV	Predicted Mean Vote Index
M	Metabolic rate
L	Thermal load
U	Overall heat transfer coefficient [W/ (m^2·K)]
R	Unit of thermal resistance [m^2·K/W]
Q A	Heat transfer per unit area [W/m^2]
ΔT	Temperature difference across an insulator [K]
L	Material's thickness [m]
qV	Air flow rate through a space [m^3/h]
V	Volume of the space [m^3]
MET	Energy cost of physical activities [-]
CLO	Insulation of clothes [-]
Cp	Specific heat capacity [J/(Kg·K)]
Q_{loss}	The heat loss to the environment from the guide wire heating element [W]
l	The length of the section [mm]
t_{av}	The average temperature of the heating medium in the concerned section [K]

t_e	The standard ambient temperature [K]
R	The sum of the resistance of heat transfer between the outside and the heating medium [mK/W]
R_a	The resistance to heat transfer on the inside of the pipe
R_S	The thermal resistance in the wall of the pipe
R_λ	The conduction resistance of insulation
R_e	The resistance to heat transfer on the outside of the cable to the ambient air
d_{in}	The inner diameter, m
h_a	The heat transfer coefficient on the inside conduit [W / m2K]
λ	The thermal conductivity of the material
d_{ex}	The exterior diameter [m]
d_{in}	The diameter of inner material [m]
h_e	The heat transfer coefficient on the outside wire
h_f	The heat transfer coefficient on the road radiation
h_k	The coefficient of heat transfer by convection
ε	The emissivity of the outer surface of the tube
σ	The Boltzmann constant value = 5,67x10-8, [W/m^2K^4]
τ_e	The temperature of the surface of wire
t_e	The ambient temperature [K]
τe	The conductor surface temperature [K]
d_{ex}^{ins}	The outer diameter of insulation [m]

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1. INTRODUCTION

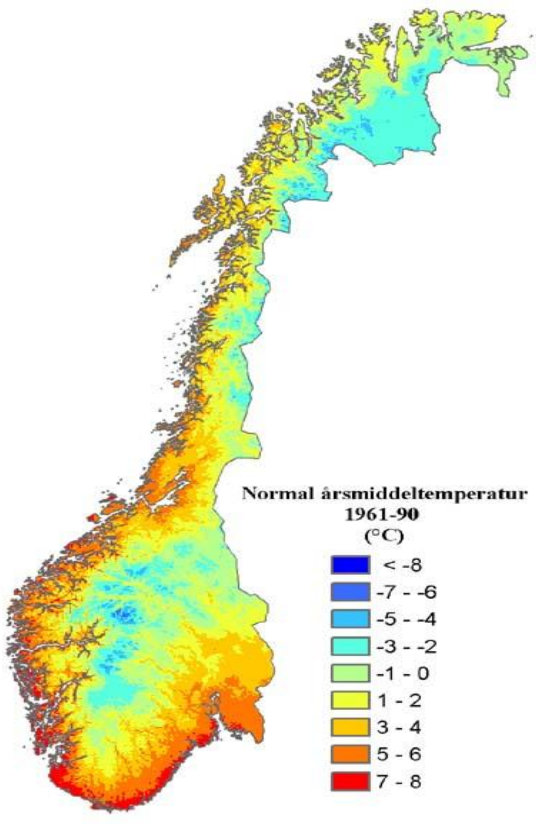
1.1 NORWAY - NATURAL CONDITIONS

Norway's climate shows great diversity. From its most southern point, Lindesnes, to its northern, North Cape, there is a span of 13 degrees of latitude, or the same as from Lindesnes to the Mediterranean Sea. Furthermore there are great dissimilarity in received solar energy during the year. The largest differences we find in Northern Norway, having sun during the night in the summer months and no sunshine at all during winter.

<u>The seasons in Norway:</u>

Winter (December - February)

When it comes to the normal temperature distribution in winter, two main features are evident:
Firstly, the mean temperature in the winter months are above freezing all along the coast from Lista (Vest-Agder) to the Lofoten area (Nordland).
Secondly, the lower inland areas, both in the southern and northern part of Norway, have very low mean temperatures in winter (e.g. the Finnmark Plateau is the coldest area - with mean monthly temperatures -15 °C).



Map 1. Normal annual temperature in Norway [1]

Spring (March - May)

The increasing solar energy during springtime eventually melts the snow cover, and the land areas are being warmed up faster than the sea.

Summer (June -August)

In summer the warmest areas are the southern part of Østlandet and the coastal areas of Sørlandet. The highest monthly mean temperature ever recorded is 22,7 °C for July 1901 in Oslo. The highest recorded maximum temperature is 35,6 °C, measured on June 20th 1970 at Nesbyen (Buskerud).

Autumn (September - November)

During autumn the land areas lose more heat than the sea, and eventually the coastal areas have the highest temperatures. In September the outer part of the Oslofjord has the highest mean temperatures. [1]

1.2 PASSIVE HOUSES

“A Passive House is a building, for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air.” [3]
This is a purely functional definition which doesn't contain any numerical values and is valid for all climates. This definition shows that the Passive House is a fundamental concept and not a random standard.

When building a house investor is looking for savings. It not so long ago when the most important was as cheap realization of investments as possible. This was often at the expense of the quality of project execution and increase the energy consumption of the building. Meanwhile, rising energy prices meant that much greater role began to play future costs of operating the building. As shown by the experience from Norway, solution to minimize these costs proved to be a passive building.

The Passive House is the world leading standard in energy-efficient construction: A Passive House requires as little as 10 percent of the energy used by typical Central European buildings – meaning an energy savings of up to 90 percent. Owners of Passive Houses are barely concerned with increasing energy prices.

- Passive Houses require less than 15 kWh/(m²) per year for heating or cooling
- The heating/cooling load is limited to a maximum of 10 W/m^2
- Conventional Primary energy use may not exceed 120 kWh/(m²) per area unit - but the future is renewable energy supply (PER) with no more than 60 kWh/(m²). This is easy to accomplish with passive houses.[2]
- Passive Houses must be airtight with air change rates being limited to $n50 = 0.6{\cdot}h^{-1}$.
- In warmer climates and/or during summer months, excessive temperatures may not occur more than 10 % of the time.

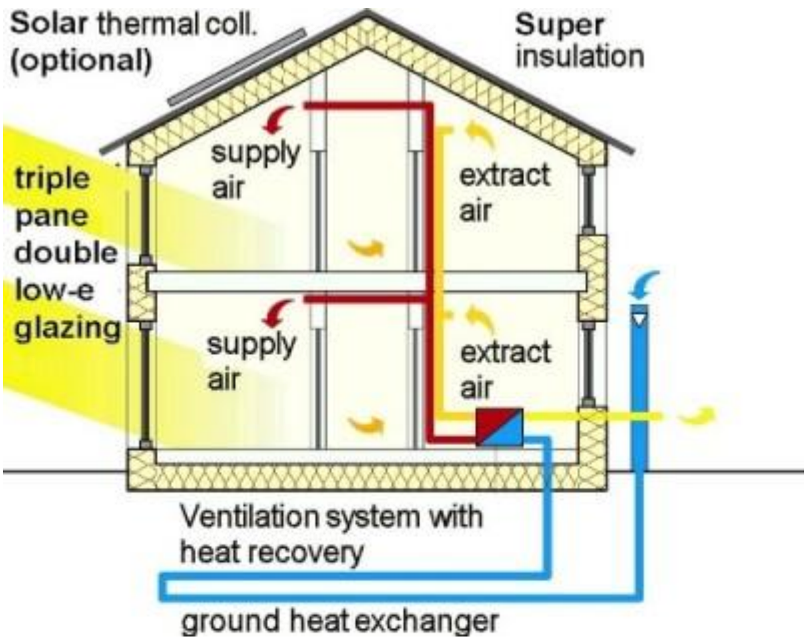


Figure 1. Passive house [2]

The Passive House (Figure 1.) is a sustainable construction concept that provides for affordable, high-quality buildings as well as comfortable, healthy living conditions. And its principles are quite easy to understand:

- As newer buildings are increasingly airtight, ventilation through joints and cracks alone is not sufficient to provide for fresh indoor air. Opening the windows as recommended won't do the job either. Fresh air is not merely a matter of comfort but a necessity for healthy living - Indoor Air Quality (IAQ) is the basic performance goal. Ventilation systems are therefore the key technology for all future residential buildings and retrofits.

- Even though ventilation systems do require an extra investment to begin with they will end up saving considerable amounts of energy costs, provided that they are highly efficient systems. Passive House quality ventilation systems will reduce the operating costs of any building.
- This “supply air heating” concept only works in appropriately insulated buildings – that is in Passive Houses. In expert terms: The transmission and infiltration heating load must be less than 10 W/m² to make sure that the required heat can be provided by the supply air [2].

1.3 NORWEGIAN STANDARDS FOR PASSIVE HOUSES

With the two standards NS 3700 and NS 3701 Standards Norway is the first member of the European Committee for Standardization (CEN) to have a national standard with criteria for Passive Houses covering all building categories defined in the national building code.

NS 3701 was published in September 2012. The standard is a practical utility in the planning, construction of non - residential buildings with very low energy demand.

1.4 THERMAL COMFORT

There are a number of issues related to both the definition of comfort, the methods of its use, as well as its evaluation.

Thermal comfort is a condition in which a person does not feel either cool or warm and is satisfied with thermal environment conditions. In terms of thermal comfort the heat balance of the body is balanced, and heat transfer is accomplished via:

- Radiation,
- convection
- Sweating undetectable
- Evaporation from the respiratory tract.

The heat transfer between the occupants' body and the environment is influenced by physical activity, type of clothing (in particular insulation), and the parameters describing the state of the air in the immediate vicinity of man, ie. air temperature, air velocity, relative humidity of the air as well as the average temperature of radiation.

Body temperature at rest is approximately 36,6°C, and the weighted average skin surface temperature is in the range 32-34°C.

Figure 2 shows the six basic factors which affect thermal comfort.

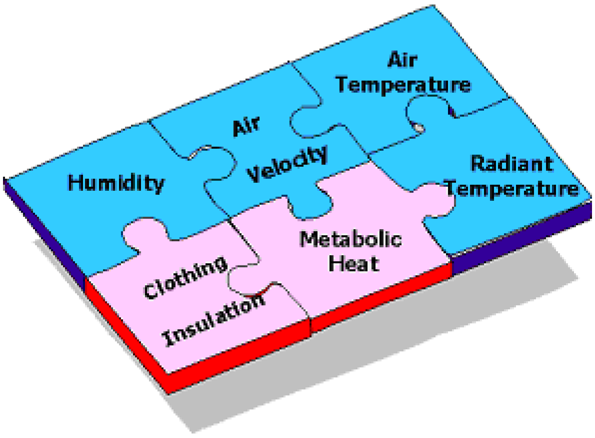


Figure 2. The six basic factors affecting thermal comfort [4]

Environmental factors

- Air temperature - This is the temperature of the air surrounding the body. It is usually given in degrees Celsius (°C).
- Radiant temperature - Thermal radiation is the heat that radiates from a warm object. Radiant heat may be present if there are heat sources in an environment.
- Air velocity - This describes the speed of air moving across the employee and may help cool them if the air is cooler than the environment.

Air velocity is an important factor in thermal comfort for example:

- moving air in warm or humid conditions can increase heat loss through convection without any change in air temperature
- physical activity also increases air movement, so air velocity may be corrected to account for a person's level of physical activity
- small air movements in cool or cold environments may be perceived as a draught as people are particularly sensitive to these movements of air

- Humidity - Relative humidity is the ratio between the actual amount of water vapour in the air and the maximum amount of water vapour that the air can hold at that air temperature.

Personal factors

- Clothing insulation

Thermal comfort is very much dependent on the insulating effect of clothing on the wearer. Wearing too much clothing may be a primary cause of heat stress even if the environment is not considered warm or hot. If clothing does not provide enough insulation, the wearer may be at risk from cold injuries such as frostbite or hypothermia in cold conditions.

- Work rate/metabolic heat

The more physical work we do, the more heat we produce. The more heat we produce, the more heat needs to be lost so we don’t overheat. The impact of metabolic rate on thermal comfort is critical.

A person’s physical characteristics should always be borne in mind when considering their thermal comfort, as factors such as their size and weight, age, fitness level and sex can all have an impact on how they feel, even if other factors such as air temperature, humidity and air velocity are all constant.

Long term effects of mild thermal environment while constant intensity of metabolic processes results in the human body in a state of equilibrium which can be described by the equation of energy balance:

$$\dot{Q} - \dot{Q}_d - \dot{Q}_w - \dot{Q}_{ou} - \dot{Q}_{oj} = \dot{Q}_p = \dot{Q}_R + \dot{Q}_K$$

where:

$\dot{Q}$ – the amount of internal heat generated within the body; W,

$\dot{Q}_d$ – heat loss due to diffusion of water vapor through the skin; W,

$\dot{Q}_w$ – heat loss due to evaporation of sweat from the skin surface; W,

$\dot{Q}_{ou}$ – latent heat loss during breathing; W,

$\dot{Q}_{oj}$ – Sensible heat loss during breathing; W,

$\dot{Q}_p -$ the amount of heat transmitted by clothing; W,

$\dot{Q}_R -$ heat loss by radiation from the outer surface of the clothes; W,

$\dot{Q}_K -$ heat loss through convection from the outer surface of the clothes; W.[8]

As a result of experimental studies Fanger [8] provide empirical relationships binding the skin temperature and heat loss in the evaporation of sweat, recognized as equivalent to subjectively assessed the conditions of thermal comfort, energy expenditure as a function of the body. In general, functional dependencies of this kind take the form of:

$$t_s = f\left(\frac{\dot{Q}}{A_{DU}}\right)$$

$$\dot{Q}_W = A_{DU} \cdot f\left(\frac{\dot{Q}}{A_{DU}}\right)$$

where:

t_s - the average temperature of the skin surface, ^oC

$\dot{Q}_W$ - the amount of heat consumed for the evaporation of sweat, W

$\dot{Q}$ - the amount of internal heat of the body, W

A_{DU} - the body surface area, m^2

Taking into account the above conditions in the energy balance equation allows so called Equation of thermal comfort, which in the general case takes the form:

$$f\left(\frac{\dot{Q}}{A_{DU}}, \Lambda_{cl}, t_w, t_{mr}, p_w, \nu\right) = 0$$

where:

Λ_{Cl} - the total thermal resistance of clothing, clo

t_w - the air temperature, ^oC

t_{mr} - the mean radiant temperature, ^oC

p_w - the partial pressure of water vapor in the room, Pa

ν - the relative air velocity, m/s

Based on the above equation developed form of thermal comfort Fanger [8] developed a series of charts allowing for selection of parameters describing the state of the human environment according to the state of thermal comfort.

To determine the thermal sensation all over the body uses the following indicators: PMV and PPD.

1.5 THERMAL COMFORT EVALUATION MODELS

Predicted Mean Vote Index (PMV) - The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale where:

+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Table 1. 7-point ASHRAE scale of thermal sensation [5]

The PMV index is expressed by P.O. Fanger as:

$$PMV = (0.303\ e^{-0.036M} + 0.028)\ L$$

where:

PMV - Predicted Mean Vote Index

M - metabolic rate

L - thermal load - defined as the difference between the internal heat production and the heat loss to the actual environment

Predicted Percentage Dissatisfied - PPD - index is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment. [6]

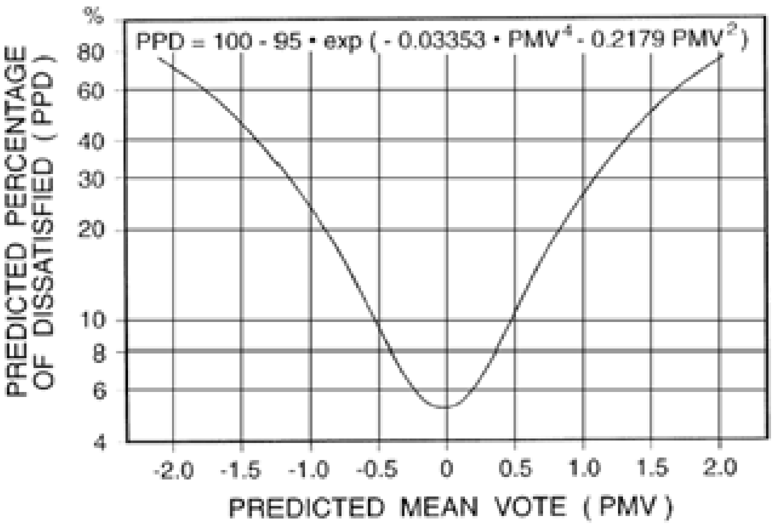


Figure 3. Expected percentage of dissatisfied PPD as a function of PMV predicted mean [7]

1.6 HYDRONIC HEATING SYSTEM

Widely used hydronic space heating systems in European buildings are radiator and floor heating or their combinations. These systems have shown performance complying with the highest indoor climate category thermal comfort specification [9] according to EN 15251:2007 [10].

Hydronic heating systems use water to move heat from where it is produced to where it is needed. The water within the system is neither the source of the heat nor its destination; only its "conveyor belt". Heat is absorbed by the water at a heat source, conveyed by the water through the distribution piping, and finally released into a heated space by a heat emitter.

There are many types of hydronic heating system. Some of them depend on temperature of medium inside:

- Steam or hot water
- Chilled water

Generally hydronic systems are classified in five ways:

- Flow generation (forced flow or gravity flow)
- Temperature (low, medium, and high)
- Pressurization (low, medium, and high)
- Piping arrangement
- Pumping arrangement

As that this work is focused on a comparison of the two ways heat distribution, also drawn up a classification system due to the piping arrangement:

- Single or one-pipe
- Two pipe
- Three pipe
- Four pipe
- Series loop

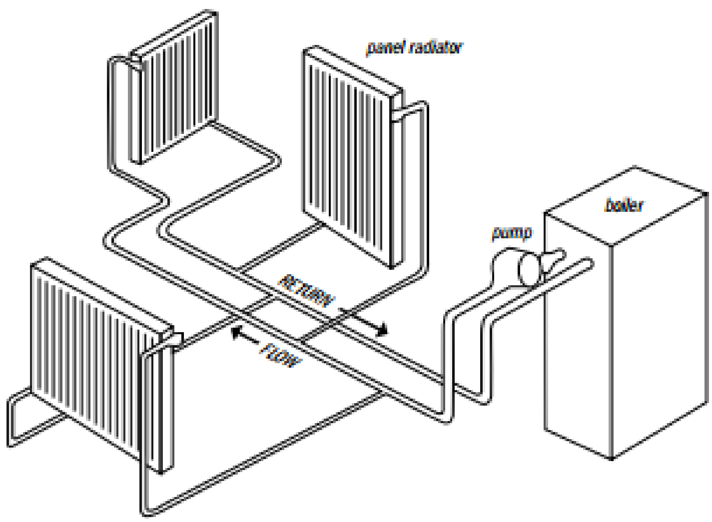


Figure 4. Scheme of hydronic heating system [11]

Figure 4 shows panel radiators which are connected to a heat source by pipes. This system is called "two-pipe" system and was used in the model of building in this thesis.

In this kind of system, the total pipe length from the pump to and from each radiator is shorter for the radiators closer to the pump and longer for the more distant radiators. For this reason the differential pressure can be significantly higher at the closest radiator than at the most distant radiator. This must be taken into consideration when designing the system. The advantage of the direct return system is that pipe routing is more straightforward compared to the reverse return system.

1.7 ENERGY EFFICIENCY

Since the objective of this thesis is to investigate the relationship between energy efficiency and thermal comfort, it should be explained, what exactly is the energy efficiency.

"Efficient energy use, sometimes simply called energy efficiency, is the goal to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature" [11]. This master's thesis focuses on verifying how the change of the heating system - from the traditional water system to a system with one heater warming the entire floor - affects on energy efficiency.

It was also examined how has changed energy efficiency in the case of insulated and non-insulated distribution lines.

There are many motivations to improve energy efficiency. Reducing energy use reduces energy costs and may result in a financial cost saving to consumers if the energy savings offset any additional costs of implementing an energy efficient technology. Reducing energy use is also seen as a solution to the problem of reducing carbon dioxide emissions. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases.[12]

1.8 PURPOSE

The aim of this master's thesis is to find and propose the best way to dimension and improve heating system to achieve thermal comfort and energy efficiency in examinated passive house in Trondheim, Norway.

1.9 THE FOLLOWING TASKS ARE TO BE CONSIDERED

a) Literature review of the existing research in relation with the Master thesis - due to the lack or little access to documentation about the thermal comfort and power demand for heating purposes in passive and nearly-zero emission buildings, this issue was discussed in short way.

b) Design of the standard and simplified distribution loops using usual dimensioning methods.

c) Simulation of the building using a so-called *perfect or ideal heating* and comparison with another already existing simulation in SIMIEN. It will serves as a validation of the building model. In addition, the perfect heating is the reference case without losses from the space-heating system.

d) Simulation of both distribution loops in combination with the building.

e) Analysis and discussion of results.

2. MODEL OVERVIEW

2.1 METHODOLOGY

Presented thesis is based on simulation studies carried out in the ICE IDA program. IDA Indoor Climate and Energy (IDA ICE) is a whole year detailed and dynamic multi-zone simulation application for the study of indoor climate of individual zones as well as energy consumption of an entire building.

2.2 MODEL

The analyzed building is representative of terraced houses. It was introduced to the program based on the construction project of actual building located in Trondheim, Norway.

Figure 5. Front of the building

Figure 5 represents frontal part of the terraced houses, in thesis examined only one part of the whole building.

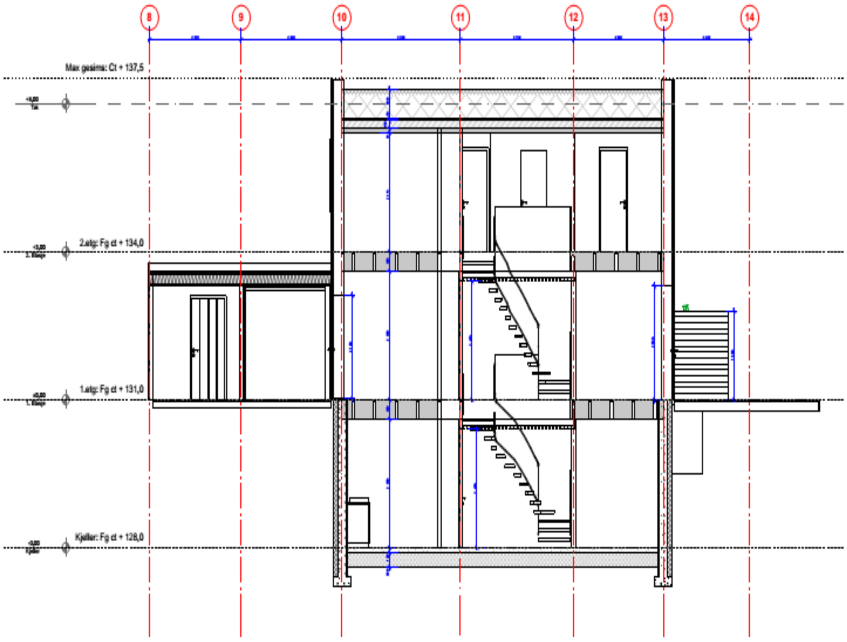


Figure 6. The profile of the building

As is seen in Figure 6 building consists of two floors above the ground: ground floor and first floor, and one underground - the basement.

Below are the fragments of the project, based on which the model was created in IDA ICE aplication (Figures 7-9).

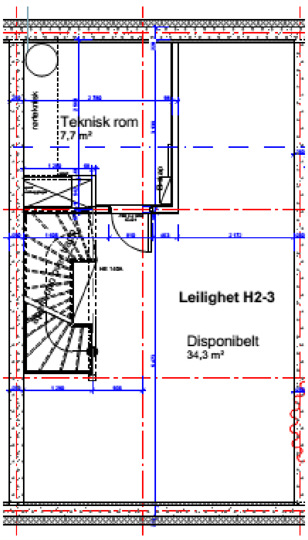


Figure 7. Sketch of the basement

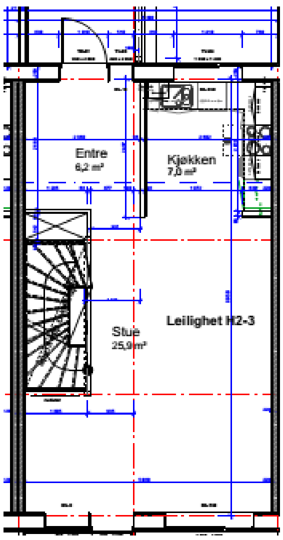


Figure 8. Sketch of the ground floor

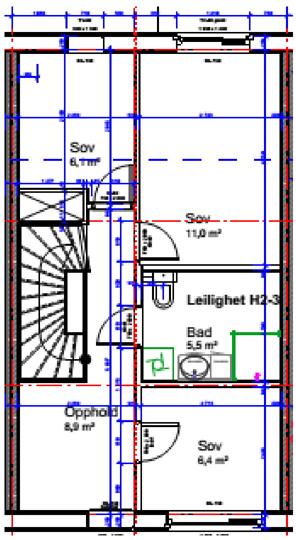


Figure 9. Sketch of the first floor

Main technical data for tested building are shown in Table 2.

Input data Report

Building

Model floor area	136.2 m^2
Model volume	408.7 m^3
Model ground area	45.8 m^2
Model envelope area	185.3 m^2
Window/Envelope	9.2 %
Average U-value	0.2054 $W/(K \cdot m^2)$
Envelope area per Volume	0.4533 m^2/m^3

Table 2. Basic data of the building

The building model build in IDA ICE was shown in the figures 10 - 12.

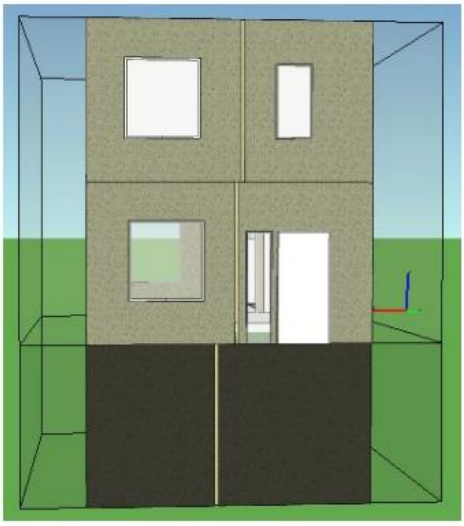


Figure 10. View of the the model from the south

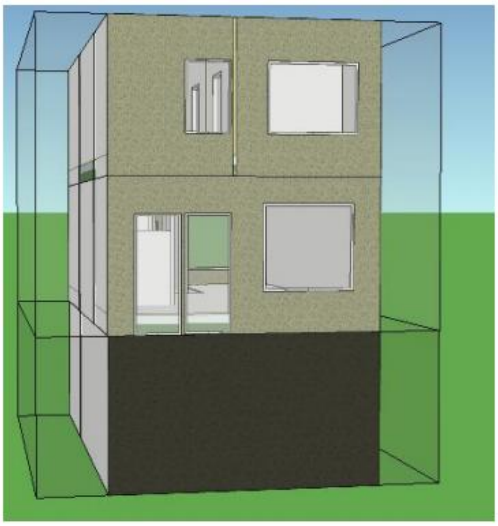
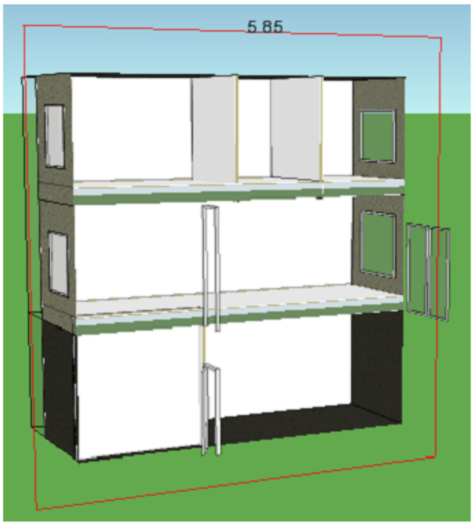


Figure 11. View of the the model from the north

The examined model consists of eleven zones, but two of them, located in the basement are unheated, for this reason they will not be taken into account in accurate analysis. Zones are presented below on the profile of the building:



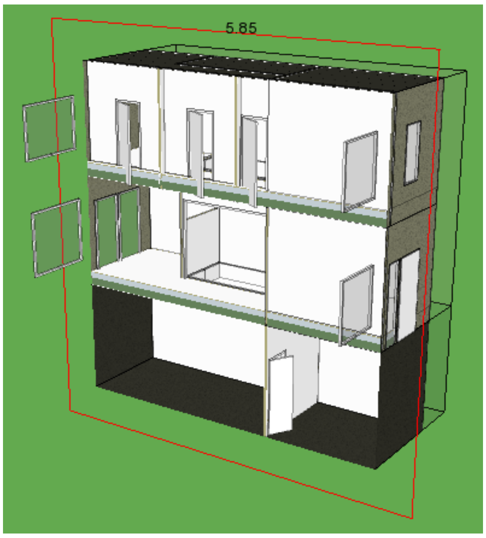
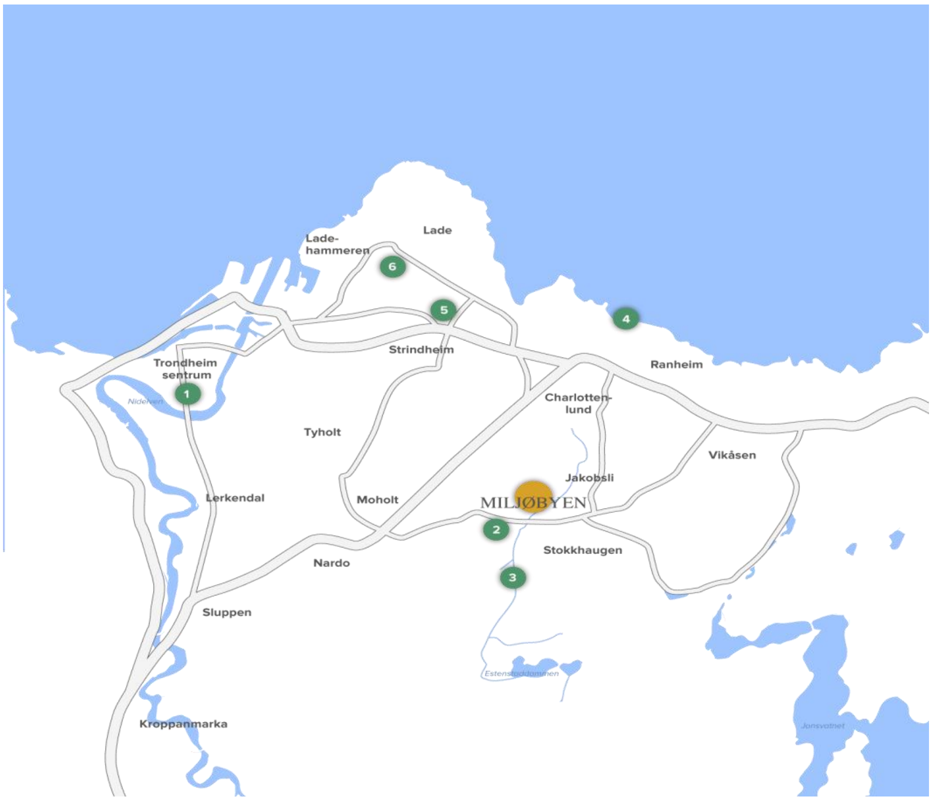


Figure 12, 13. Section through the building showing the spaces

2.3 LOCATION

The building on the basis of which the model was formed, is located in Trondheim, Norway.



Map 2. Location of building in Trondheim

The house is located in the heart of Miljøbyen Granasen all of which consists of passive buildings. This "green" estate is located practically in the middle of town, near the student quarter Moholt.

2.4 CLIMATIC DATA OF TRONDHEIM

- Trondheim (Norway, 63°25'N, 10°27'E) has a subarctic climate that has severe winters, no dry season, with cool, short summers and strong seasonality; according to the Holdridge life zones system of bioclimatic classification Trondheim is situated in or near the boreal wet forest biome.[13]

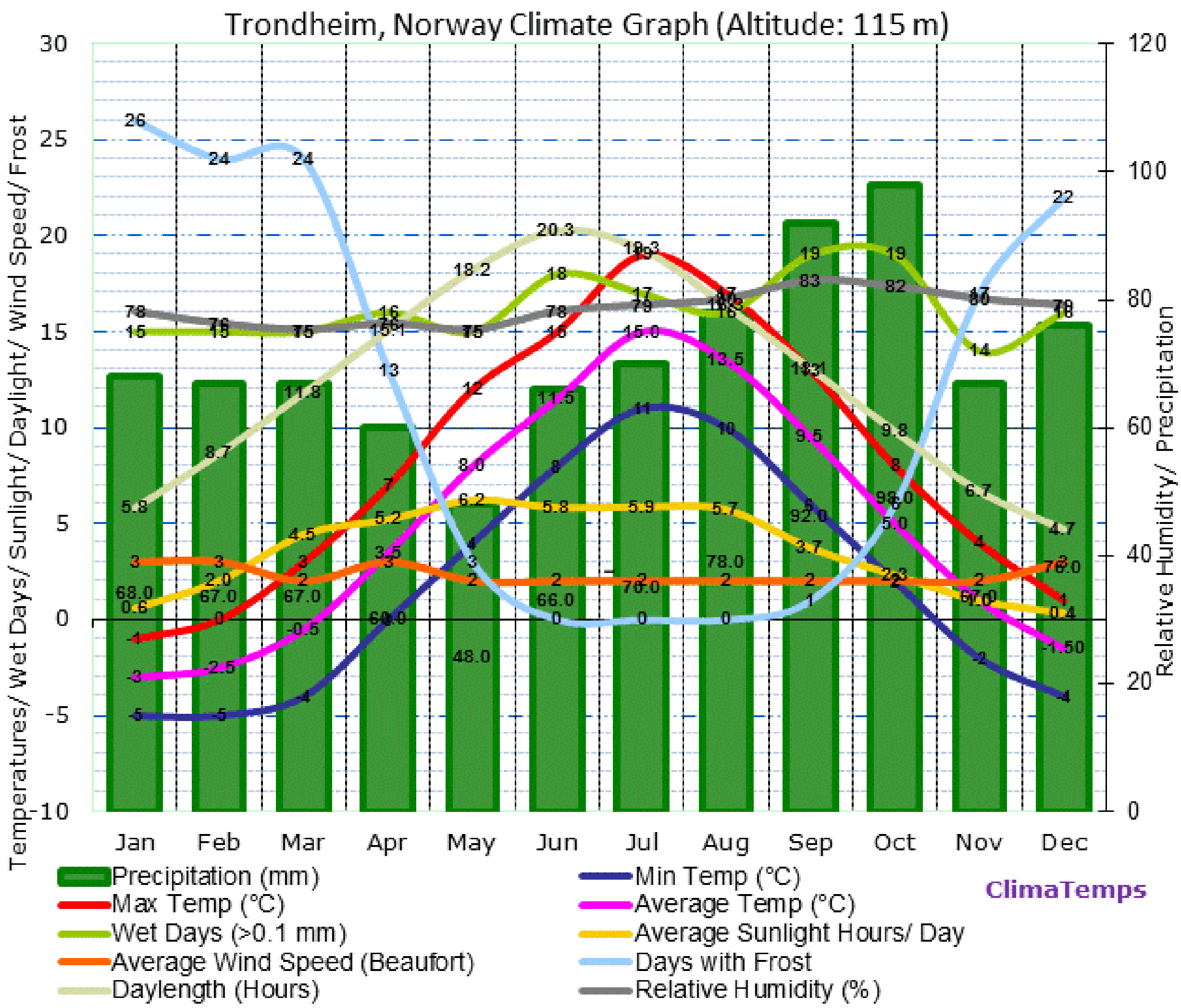


Figure 14. Climate of Trondheim during a year [13]

- The average annual temperature is 5°C
- Average monthly temperatures vary by 18 °C. This indicates that the continental type is oceanic, subtype semicontinental.

- In the winter time records indicate temperatures by day reach 0°C ,on average falling to -4.7°C overnight.
- In spring time temperatures climb reaching 7.3°C generally in the afternoon with overnight lows of 0°C.
- During summer average high temperatures are 17°C and average low temperatures are 9.7°C .
- When autumn comes - temperatures decrease achieving average highs of 8.3°C during the day and lows of 2°C generally not long time after sunrise [13].

2.5 CONSTRUCTION OF THE BUILDING

Heat loss of the building is directly proportional to the surface of the envelope. For this reason, every designer should strive to ensure that the building shape factor A/V (the ratio of surface area to volume envelope of the building) was as low as possible. Accordingly, the shape of the building should be similar in shape to a sphere (the most optimal solution is a cube).

Passive buildings should also be simple in its construction roof in order to maintain a low ratio of the building.

The test object corresponds to the above assumptions because the aspect ratio of the building is 0,4533 m^2/m^3.

The design of the building envelope included in the soil, which baffles foundation, is based mainly on the concrete. Also the mandatory isolation is applied to vertical and horizontal partitions, which protects walls against water capillary penetration. To be insulated from the outside compartments PVC foil and heavy insulation is used.

Overall heat transfer coefficients for external walls in the basement is 0.2446 [$W/(m^2 \cdot K)$], for floors on the ground 0.245 [$W/(m^2 \cdot K)$].

The design of the building envelope over the ground, or partitions carrier, are based mainly on a wooden frame filled with insulation. To be insulated partitions used a layer of glass wool with a thickness 20 cm. The external wall also has the inner and outer side layer of gypsum thick 13 mm. Overall heat transfer coefficients for external walls over the ground is equal to 0.149 [$W/(m^2 \cdot K)$].

In the external walls are glazed window openings and doors. Glazing in the building occupy about 17 square meters of exterior area of the building (9.2% of whole area) . Overall heat transfer coefficients for windows and doors are taken from the project of the building and are equal to 0.8 [W/(m²·K)].

The internal walls of the model in question are divided into five types: internal walls/partitions with thicknesses of 98mm and 68mm, internal walls between the two buildings (above ground and below ground) and ceilings between the floors.

Partitions are made from wooden frame with glass wool and layer of gypsum, the walls between two buildings are more complicated, constructed with two layers of glass wool with air gap between them. These walls are more thick than partition walls (Table 3).

Type	**Name**	**U, $W/m^2 \cdot K$**	**Thickness, m**
External wall	Over Ground	0.149	0.246
	Under Ground	0.245	0.393
	Roof	0.061	0.625
	floor in basement	0.245	0.798
	External door	0.802	0.056
Internal wall	Internal door	0.884	0.050
	Between two buildings over the ground	0.152	0.272
	Between two buildings under the ground	3.154	0.250
	98mm	0.405	0.098
	68mm	0.641	0.068
	floor	0.127	0.400

Table 3. General information about walls

The ceiling between two floors is constructed like joist ceiling. The elements of the supporting wooden roof beam may be a beam of solid wood or prefabricated, for example, OSB and laminated wood. Beams from the top is secured sheathing boards or planks, and from the bottom - the ceiling with drywall.

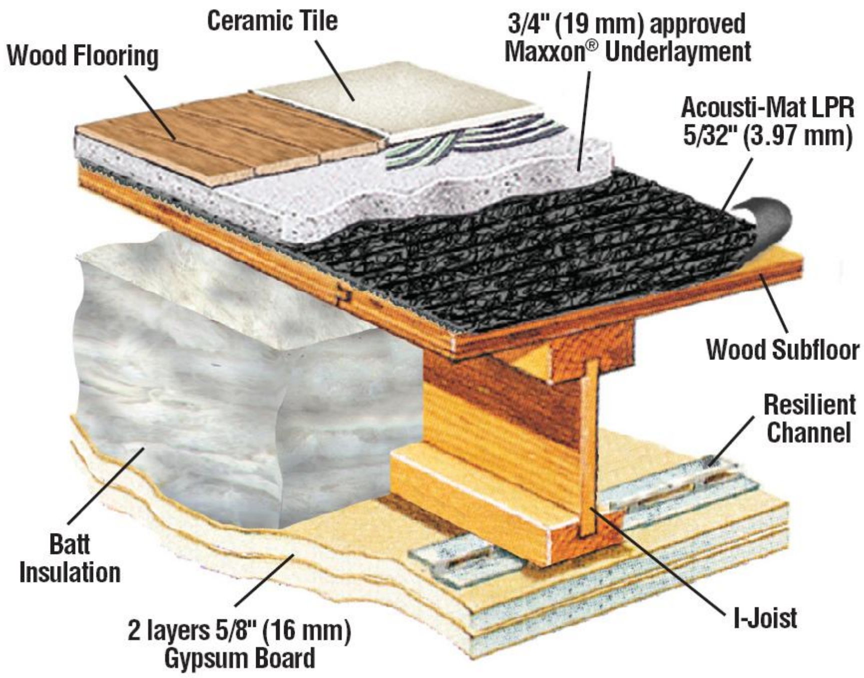


Figure 15. Contruction of ceiling

As the last will be discussed construction of the roof. The thickness of the roof is almost 63cm. The roof also is the partition with the lowest overall heat transfer coefficients throughout the building. The precise design of the roof is presented in the form of a census layers introduced to the IDA ICE (Figure 16).

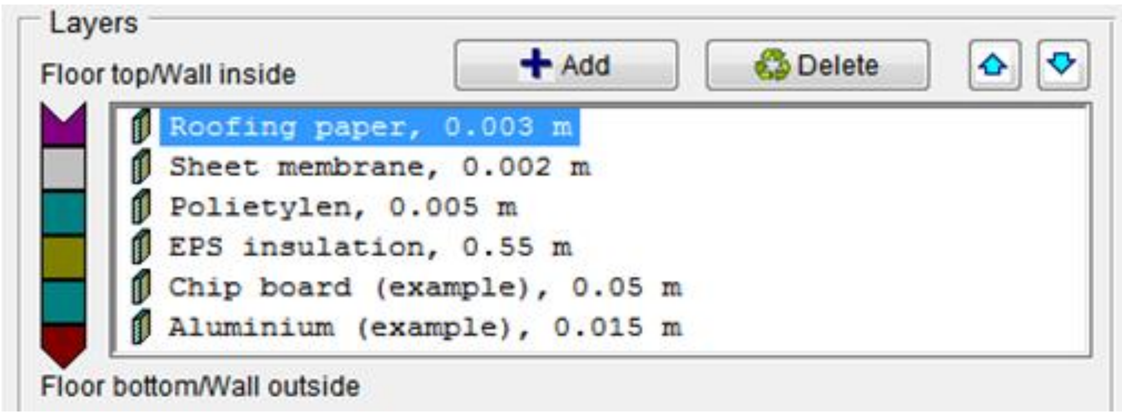


Figure 16. Layers of the ceiling from IDA ICE

The thickness of the insulating layer is the result of the fact that the roof is a light baffle layer which due to beneath the rooms must meet certain requirements. It is necessary to ensure that the interiors have suitable microclimate and protection from rain, excessive heat losses, wind, noise and other external factors.

The roof structure (in addition to its basic function of carrier) should be primarily designed to meet two basic conditions:

• the maximum extent possible to reduce heat loss through the roof

• eliminate any probability of condensation on cold surfaces coverage.

2.6 ZONES

As mentioned earlier, the building consists of eleven zones. Nine of them is heated, two - located in the basement - not.

List of parameters concerning zones is presented in Table 4.

	Name	Floor area, m2	Supply air, L/sm2	Return air, L/sm2	Occupants, no./m2	Lights, W/m2	Equip., W/m2	External windows area, m2	Volume, m3	Walls above ground, m2	Walls below ground, m2
Under ground	Main basement	36.840	0.309	0.151	0.0000	0	0.0	0.000	110.50	0.000	22.96
	Basement	8.921	0.000	1.121	0.0000	0	0.0	0.000	26.76	0.000	8.59
Ground floor	Stairs 1	5.078	0.000	0.000	0.0139	2	1.8	0.000	15.23	0.000	0.00
	Hall	7.849	0.000	0.991	0.0139	2	1.8	1.024	23.55	4.461	0.00
	Living room	32.680	0.264	0.306	0.0139	2	1.8	9.172	98.06	14.921	0.00
First floor	Room 3	6.736	1.072	0.000	0.0139	2	1.8	2.488	20.21	6.071	0.00
	Bathroom	6.274	0.000	2.391	0.0139	2	1.8	0.000	18.82	0.000	0.00
	Room 2	11.510	1.255	0.000	0.0139	2	1.8	2.071	34.54	6.497	0.00
	Room 1	7.573	0.954	0.000	0.0139	2	1.8	0.959	22.72	6.217	0.00
	Hall 2	7.498	0.963	0.000	0.0139	2	1.8	1.237	22.49	5.912	0.00
	Stairs 2	5.268	0.000	1.476	0.0139	2	1.8	0.000	15.80	0.000	0.00

Table 4. General parameters of zones in modeled building from IDA ICE

In every zone there is heat setpoint equal to 21ºC, cooling setpoint = 23ºC, the constant parameters for every zone are air handling unit and established system CAV.

The exact distribution of zones in a building is depicted in Figures 17-19 from IDA ICE.

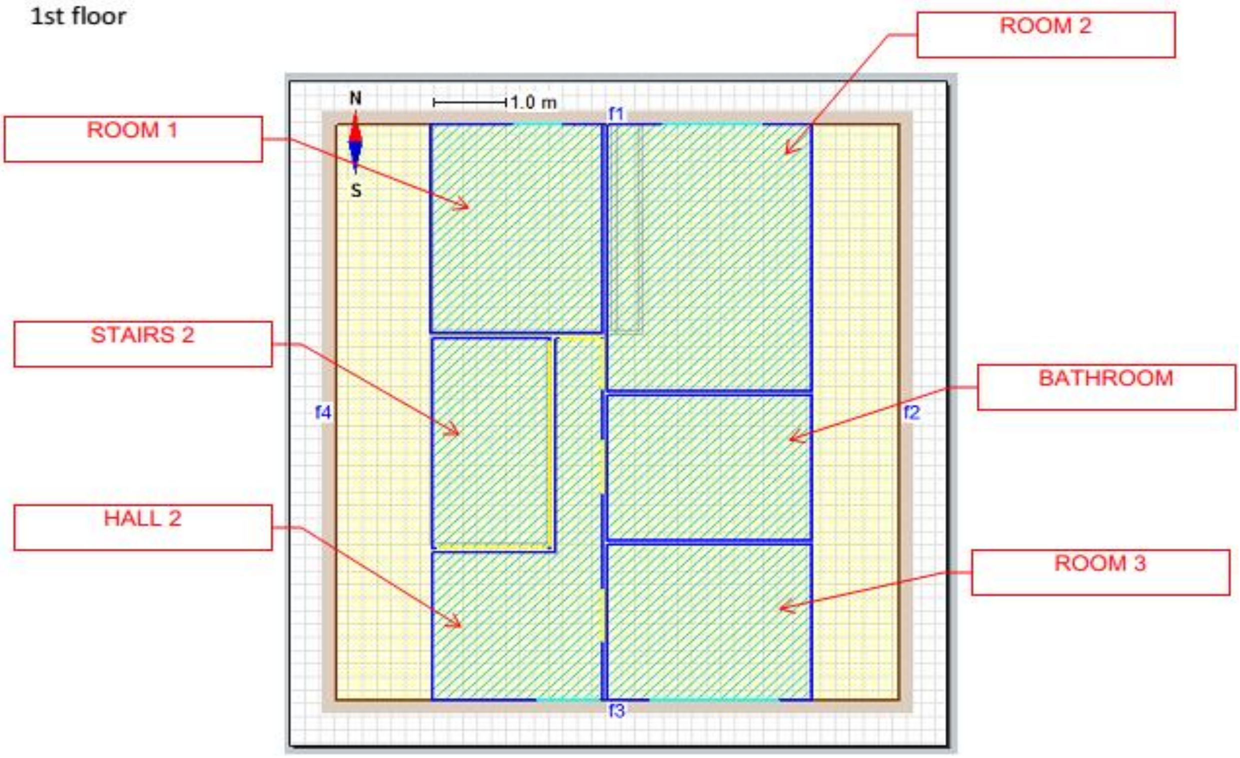


Figure 17. First floor plan

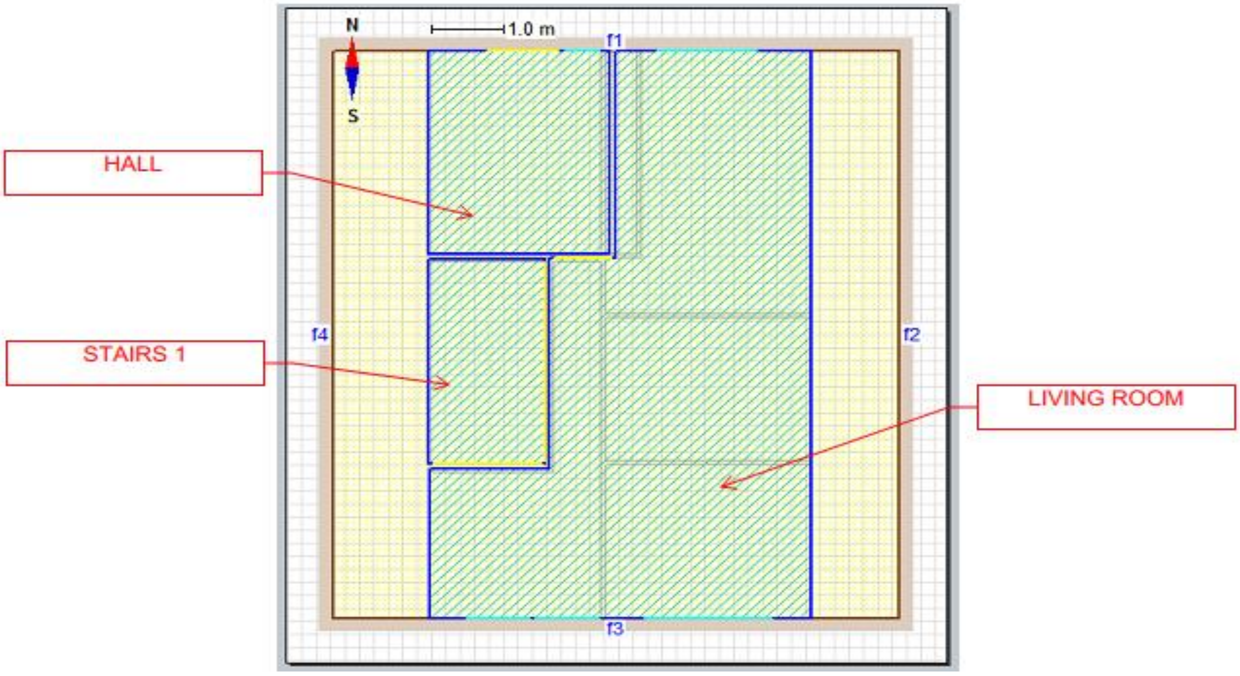


Figure 18. Ground floor plan

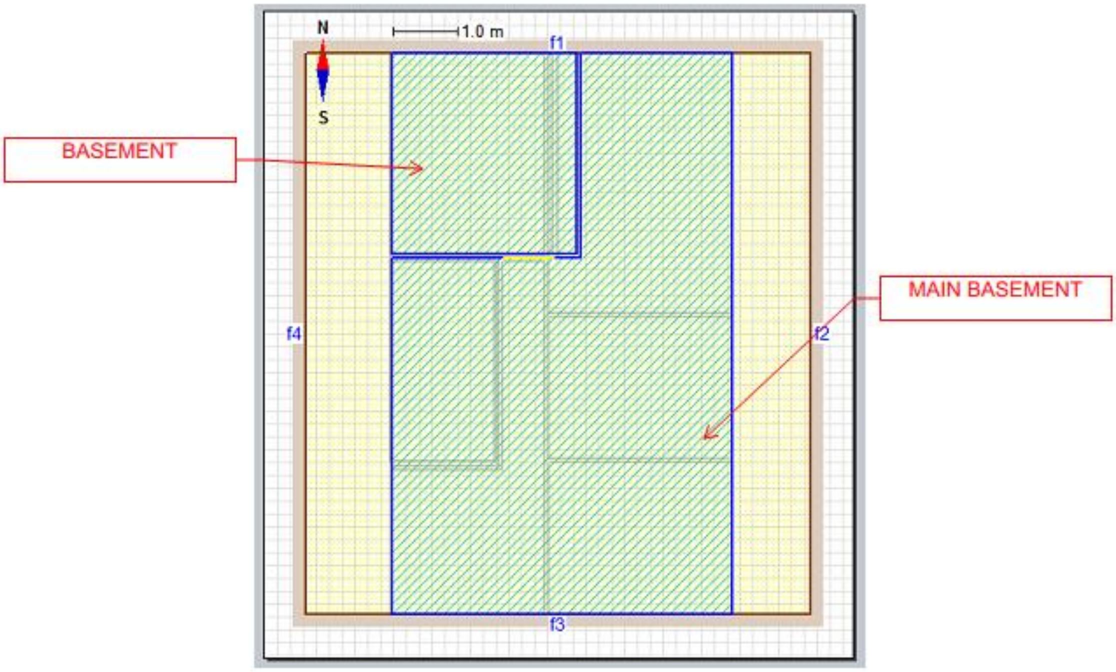


Figure 19. Basement plan

2.7 HEATERS

Heaters in the building have been selected on the basis of the results of calculations of individual temperature situations in the IDA ICE. In this simulations were used radiators from Purmo company.

The heating elements were chosen from a catalog, based on the calculated previously required power and established supply and return temperatures, which are respectively 60 and 40°C. The use of such high performance heating may be surprising, however, when there was a low temperature heating eg. 40/30 degrees size of radiators exceeded the size of partitions and radiators could not be applied.

Dimensions and types of heaters are summarized in Table 5 with the division into different temperature situations and cases with open and closed doors.

tuation	***Zone***	**Door**	**21ºC**				**19/21ºC**				**19/21ºC (holidays)**			
			heating power, [W]	**height, mm**	**lenght, mm**	**type**	**heating power, [W]**	**height, mm**	**lenght, mm**	**type**	**heating power, [W]**	**height, mm**	**lenght, mm**	**type**
1 radiator per floor	Living room	closed	668	500	1000	Compact 22	2063	600	2000	Compact 33	2064	600	2000	Compact 33
		open	669	500	1000	Compact 22	2054	600	2000	Compact 33	2061	600	2000	Compact 33
	Hall 2	closed	338	500	500	Compact 22	1154	550	1600	Compact 22	1142	550	1600	Compact 22
		open	506	550	700	Compact 22	1595	550	1600	Compact 33	1610	550	1600	Compact 33
1 radiator per room	Hall	closed	159	300	600	Compact 11	403	300	900	Compact 22	393	550	900	Compact 11
		open	218	550	500	Compact 11	395	550	900	Compact 11	400	550	900	Compact 11
	Living room	closed	514	550	700	Compact 22	1694	600	1600	Compact 33	1661	500	1800	Compact 33
		open	464	550	800	Compact 21s	1679	500	1800	Compact 33	1698	500	1800	Compact 33
	Room 1	closed	101	300	400	Compact 11	250	450	400	Compact 22	248	450	400	Compact 22
		open	102	300	400	Compact 11	271	500	400	Compact 22	273	500	400	Compact 22
	Room 2	closed	159	300	600	Compact 11	372	450	600	Compact 22	378	450	600	Compact 22
		open	158	300	600	Compact 11	398	500	600	Compact 22	407	500	600	Compact 22
	Room 3	closed	134	300	400	Compact 21s	292	450	500	Compact 22	294	450	500	Compact 22
		open	135	300	400	Compact 21s	334	500	500	Compact 22	338	500	500	Compact 22
	Hall 2	closed	135	300	400	Compact 21s	761	600	1600	Compact 11	754	500	1100	Compact 22
		open	139	300	400	Compact 21s	817	500	1200	Compact 22	816	500	1200	Compact 22

Table 5. Dimensions and types of heaters.

2.8 PRESENTATION OF CASES

In this thesis the impact of the deployment of the radiators in the building for energy efficiency and thermal comfort of users is studied. In order to diversify testing it was introduced to the IDA ICE an additional breakdown situation: due to the thermal conditions in the building and on the assumption that in the model interior doors are always open or closed (Figure 20).

- **The division due to the temperature conditions in the room:**

21°C - In this situation there is constant temperature in heated zones equal to 21°C during the whole year.

19/21°C - This situation is a modified temperature fluctuations throughout the day. At the time of the day (from 7 am to 23 pm) the temperature is kept at 21°C, and at night (from 24 pm to 6 am) the temperature of room air is lowered to 19°C.

19/21°C (holidays) - the last one checked possibility is similar to the previously discussed, with the difference that within a year there is a week (exactly in the Christmas period) of reduction the indoor temperature to 16°C. This is due to the assumption that users leave the building for a week Christmas period.

- **The division based on the complexity of the heating system:**

Each of the above situation has been tested for changes in energy efficiency and thermal comfort of users, if a standard heating loop (**with one heater in each room**) will be replaced by a simplified solution (**one heater works on one floor**).

Heaters in the simplified scheme are located in strategic locations in the building. On the ground floor heater in the living room is located on the southern wall under the window, while the floor is heated from the hallway (zone: Hall 2).

- **The division based on opening the door:**

Door between rooms in examined building are either completely open.

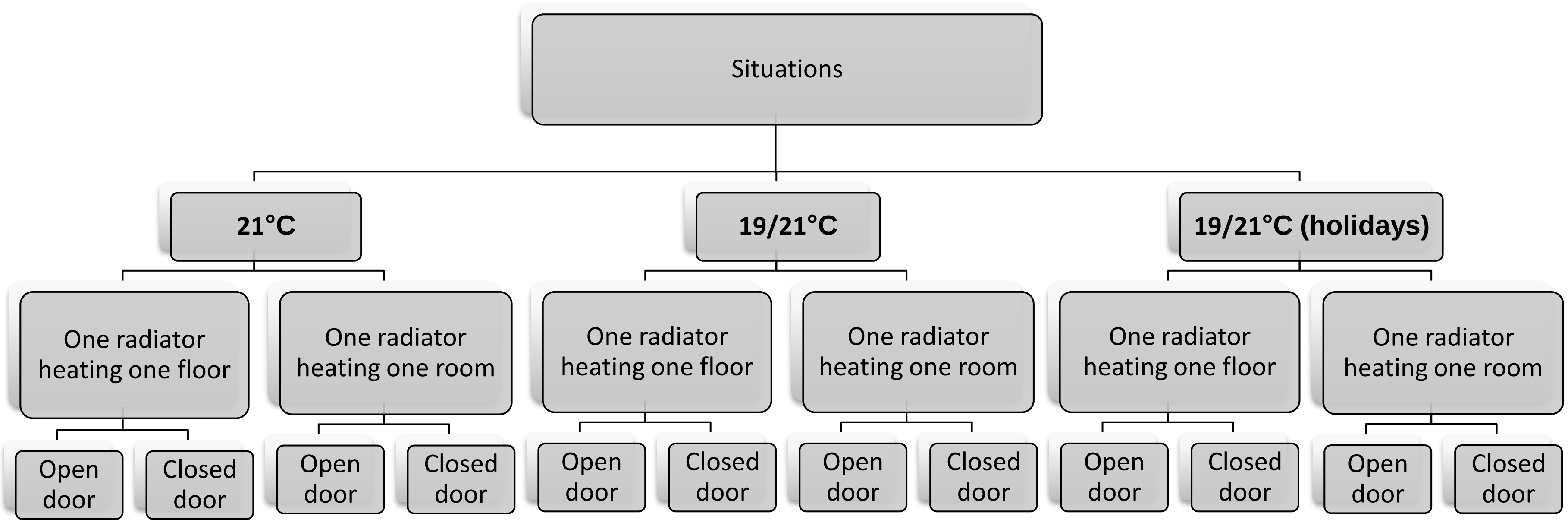


Figure 20. Scheme of assumptions for the tested building

The thesis uses the abbreviations of the situation, such as:

- **1F = one radiator is heating one floor**
- **1R = one radiator is heating one room**

3. RESULTS OF SIMULATIONS

This chapter will present the results of individual simulations respectively for each of the previously discussed situations.

3.1 SIMULATIONS WITH IDEAL HEATER

The first was conducted simulation with ideal heater for extreme conditions (heating load) and for a typical meteorological year (energy).
This simulation was performed to validate the introduction of the model into ICE IDA programme. The comparison was made based on the simulation results of the program SIMIEN.

month	AHU heating coil power, W	Ideal heaters and other local units, W
January	180.1	863.3
February	127.9	621.4
March	40.2	386.7
April	9.0	215.5
May	0.0	121.1
June	0.0	38.8
July	0.0	9.9
August	0.0	27.3
September	0.1	106.3
October	6.3	305.5
November	54.6	596.7
December	70.4	796.1
mean	**40.3**	**339.5**
mean*8760.0 h	**352737.3**	**2974036.2**

Table 6. Results of simulation for 21ºC with ideal heater (heating load) - IDA ICE.

In SIMIEN simulation, which was made in extreme conditions the tested model needed approximately 18 kWh/m^2 of heating power during one year.

In IDA ICE simulation, for extreme conditions , the building needs almost the same value of heating power during a year, which is equal to 17.95 kWh/m^2.

This value was calculated by summing the total annual for AHU heating coil power and ideal heaters and other local units and changed into kW. After that, the value was divided by model envelope area. The calculations were shown below:

$$352737.3\ \mathrm{Wh} + 2974036.2\ \mathrm{Wh} = 3326773{,}5\ \mathrm{Wh/year}$$

$$3326.77\frac{\mathrm{kWh}}{\mathrm{year}} \cdot \frac{1}{185.3\ \mathrm{m}^2} = \mathbf{17{,}95}\ \frac{\mathbf{kWh}}{\mathbf{m^2}}\ \textbf{during one year}$$

Based on the simulation results and some simple calculations can be shown that tested object is entered correctly (slight differences in the results are due to the inability to exactly the same set of parameters in both programs).

3.2 SIMULATIONS FOR 21°C

In this case, a constant daily temperature of indoor air, equal to 21 degrees Celsius, four simulations were conducted.

The first two of which were carried out spinning the assumption that there is a standard heating loop, the difference appears in the size of the door opening.

The second type of simulation was carried out under the assumption that there is one heater on one floor. In the tables below compares the most important parameters, ie. the demand for heat individual rooms, operative temperature and the minimum and maximum values of average temperatures throughout the year.

ZONE	minimal temperature. °C				max. temperature. °C			
	1 radiator per room		1 radiator per floor		1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors
Main basement	15.7	15.9	15.6	15.8	24.6	25.5	24.6	25.4
Basement	15.3	13.7	15.2	13.7	23.8	22.6	23.8	22.6
Stairs 1	21	20.9	20.9	20.9	35.9	36.4	35.9	36.4
Hall	21.6	21.3	20.6	20.6	36.1	36.5	36	36.5
Living room	21.2	21.1	21.2	21.2	36.8	37.2	36.7	37.2
Room 3	21.2	21.2	20.5	17	35.6	40.2	35.5	40.2
Bathroom	21.3	21.4	21.2	20.9	33.5	33.5	33.4	33.5
Room 2	21.2	21.2	20.5	17.8	32.8	30.7	32.7	30.6
Room 1	21.2	21.2	20.5	17.8	32.9	30.4	32.8	30.4
Hall 2	21.3	21.3	21.3	21.3	34	34.6	33.9	34.6
Stairs 2	21.2	21.2	21.2	21.3	34.3	34.9	34.3	34.9
Average	**20.2**	**20.0**	**19.9**	**18.9**	**32.8**	**33.0**	**32.7**	**32.9**

Table 7. Summary results of the simulation of minimum and maximum temperature in rooms (energy 21) ICE

At the blue marked the lowest of any minimum temperatures, while the red - the highest values of the maximum.

Based on the above statement it can be concluded that the least optimal solution is the version with the door closed.

In a situation when the heater is located in each occupied space, the minimum temperature difference is not significant. However, if we take into consideration the situation with one heater on the whole floor, the temperature differences between rooms (with the door closed) they are so high that they can cause thermal discomfort.
Such significant temperature difference is a result of impossibility of the air flow between rooms, because of the closed door.

The high maximum temperatures are the result of a lack of cooling founded in the building and are not taken into account when considering thermal comfort (for all other pending cases).

ZONE	**Operative temperature in room. °C**			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Stairs 1	26.9	32.7	26.4	32.9
Hall	25.4	25.4	25.1	25.1
Living room	21.1	21	21	21
Room 3	21.1	21	20.2	17.3
Bathroom	23.6	23.1	23.1	21
Room 2	22.8	21.1	22.6	16.8
Room 1	22.9	21.2	22.7	16.7
Hall 2	21.2	21.3	21.3	21.4
Stairs 2	23.9	25.5	24.1	25
Average	**23.21**	**23.59**	**22.94**	**21.91**

Table 8. Summary results of the simulation of operative temperature in rooms (energy 21) - IDA ICE

Table 8 summarizes the operative temperature in zones. The table does not contain information about the spaces in the basement, because by definition they are unheated and users rarely staying there.

The above table confirms previous conclusions that the worst option in terms of thermal solution is closed transitions. It was also observed that the most comfortable temperature distribution occurs when the passages are open and the heater heats the entire floor.

ZONE	Room unit heat. W			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Hall	217.8	158.8	0	0
Living room	464	513.9	668.8	668
Room 3	134.8	133.5	0	0
Bathroom	25.65	26.14	27.92	57.35
Room 2	157.4	158.7	0	0
Room 1	101.7	100.3	0	0
Hall 2	138.9	134.7	505.5	337.5
TOTAL	1240.25	1226.04	1202.22	1062.85

Table 9. Summary results of the simulation room unit heat (energy 21) - IDA ICE

Based on the results of Table 9, it was found that the option with a simplified heating system has a lower heat demand than with standard heating loop.
There is no information about Room Unit Heat in zones: Stairs 1 and Stairs 2, because there are no heaters. The power needed for these zones is added respectively tozones: Living room and Hall 2.

In that case, it was found that in a situation where we assume to maintain a constant temperature equal to 21 degrees Celsius (during whole year), most preferred in terms of thermal comfort and energy efficiency, will be simplified heating solution (the doors must remain open).

3.3 SIMULATIONS FOR 19/21°C

Similarly to the previous subparagraph carried out four simulations (division depending on the complexity of the heating system as well as in open or closed doorways). For the next event the temperature is variable throughout the day and during the day is 21ºC and 19 ºC at night.

ZONE	minimal temperature. °C			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Main basement	15.5	15.7	15.5	15.7
Basement	15.1	13.7	15.1	13.6
Stairs 1	19.6	19.6	19.6	19.6
Hall	19.8	19.8	19.3	19.3
Living room	19.8	19.8	19.8	19.8
Room 3	19.9	19.8	19.5	16.9
Bathroom	20.7	21.0	20.4	20.3
Room 2	20.1	19.9	19.8	17.8
Room 1	20.1	19.9	19.8	17.7
Hall 2	20.2	20.2	20.0	19.8
Stairs 2	20.3	20.3	20.1	19.9
Average	**19.2**	**19.1**	**19.0**	**18.2**

Table 10. Summary results of the simulation of minimum temperature in rooms (energy 19/21) - IDA ICE

ZONE	Operative temperature in room. °C			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Stairs 1	26.5	32.9	26.5	32.9
Hall	20.7	20.6	24.8	24.7
Living room	20.9	20.7	20.8	20.8
Room 3	20.7	20.6	19.6	17.3
Bathroom	20.9	21	20.8	20.5
Room 2	20.8	20.6	22.3	16.8
Room 1	20.8	20.7	22.4	16.7
Hall 2	21.1	21	21	21.1
Stairs 2	20.8	20.9	20.7	20.8
Average	**21.47**	**22.11**	**22.10**	**21.29**

Table 11. Summary results of the simulation of operative temperature in rooms (energy 19/21) - IDA ICE

ZONE	Room unit heat. W			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Hall	394.4	402.7	0	0
Living room	1679	1694	2054	2063
Room 3	333.3	292	0	0
Bathroom	339.1	387.2	423.3	585.2
Room 2	397.4	371.5	0	0
Room 1	270.9	249.6	0	0
Hall 2	816.3	760.8	1595	1154
TOTAL	4230.4	4157.8	4072.3	3802.2

Table 12. Summary results of the simulation room unit heat (energy 19/21) - IDA ICE

The tables 10 - 12 confirm the positive impact of changes in the standard system for simplified as a result, thermal comfort is ensured and energy efficiency of the building increases.

Since the temperature change occurs within days, in the Figure 21 summarizes the values of the operative temperature depending on the time of day, to determine at what time and in which case there is the greatest discomfort to the ambient temperature.

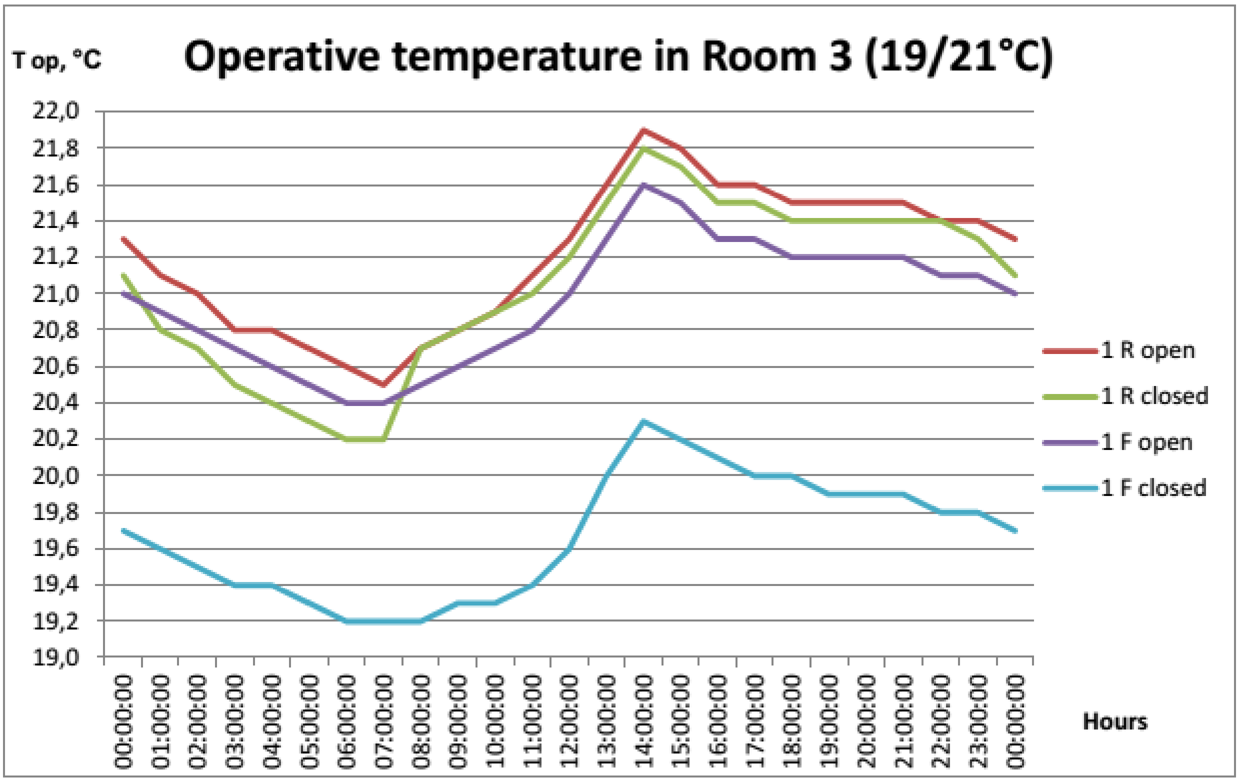


Figure 21. Changes of operative temperature in Room 3 during one day - 9.01.2015

In this case also it confirmed the theory that the most optimal solution is to heat one level by one heater (open passages).

Daily temperature distribution after closing the doors is significantly lower which can cause excessive cooling sensation in users.

In contrast with standard loop felt during the day temperatures greatly exceed a predetermined value 21 degrees , it means discomfort.

3.4 SIMULATIONS FOR 19/21°C (HOLIDAYS)

The last type of simulation is the most complicated in terms of temperature from all previously pending cases. Temperature changes not only during the day, but also is reduced to 16 degrees during the absence of users (one week of Christmas break).

In tables 13 - 15 there are characteristic parameters based on which it can be deduced, in which case users thermal comfort will be at the highest level.

ZONE	minimal temperature. °C			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Main basement	15.5	15.7	15.4	15.7
Basement	15.1	13.6	15.0	13.6
Stairs 1	17.4	17.4	17.4	17.3
Hall	17.0	17.1	17.0	16.9
Living room	17.3	17.3	17.3	17.2
Room 3	17.9	17.4	17.9	16.9
Bathroom	18.5	18.9	18.5	18.7
Room 2	18.4	18.6	18.4	17.8
Room 1	18.3	18.4	18.3	17.6
Hall 2	18.2	18.2	18.3	18.1
Stairs 2	18.2	18.2	18.2	18.1
Average	**17.4**	**17.3**	**17.4**	**17.1**

Table 13. Summary results of the simulation of minimum temperature in rooms (energy 19/21 - holidays) - IDA ICE

As you can see, the values of minimum temperature, which are occurring in areas, are too low to determine which situation is most enjoyable thermally - none of above options is successfull.

In order to decide whether the assumption that for a week of indoor air temperature has to be lowered to about 16 degrees, is necessary to check the other parameters such as: amount of heat to warm the room and the operative temperature.

ZONE	Room unit heat. W			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Hall	399.7	392.4	0.0	0.0
Living room	1698.0	1661.0	2061.0	2064.0
Room 3	337.9	293.2	0.0	0.0
Bathroom	343.1	382.5	417.0	578.1
Room 2	406.1	377.8	0.0	0.0
Room 1	272.9	247.9	0.0	0.0
Hall 2	815.9	753.8	1610.0	1142.0
TOTAL	**4273.6**	**4108.6**	**4088**	**3784.1**

Table 14. Summary results of the simulation room unit heat (energy 19/21 - holidays) - IDA ICE

The highest values of room unit heat occur in a situation where every room has its own separate heater. This may be due to oversizing radiators because of easier heat flow between rooms (open doors).

The lowest value shows the situation with one heater on the floor and difficult heat flow between the rooms due to the closure of door.

ZONE	Operative temperature in room. °C			
	1 radiator per room		1 radiator per floor	
	Open doors	Closed doors	Open doors	Closed doors
Stairs 1	26.4	32.9	26.4	33.0
Hall	20.7	20.7	24.8	24.7
Living room	20.8	20.9	20.8	20.8
Room 3	20.7	20.5	19.6	17.3
Bathroom	20.9	20.9	20.8	20.5
Room 2	20.8	20.7	22.3	16.8
Room 1	20.8	20.7	22.3	16.6
Hall 2	21.0	21.1	21.1	21.1
Stairs 2	20.8	20.8	20.8	20.8
Average	**21.43**	**22.13**	**22.10**	**21.29**

Table 15. Summary results of the simulation of operative temperature in rooms (energy 19/21 - holidays) - IDA ICE

The best way to be sure which option is the most comfortable is to check operative temperature, but not only the average value (Table 15) but also the temperature distribution within two weeks, including Christmas time (Figure 22).

The time simulation is made from 21st of December 2015 year to 8th of January 2016, it means that IDA ICE simulated with theoretical data.

Figure 22 shows temperature distribution in zone: Room 3. This zone was taken to examination because of its southern (more extreme in way of thermal conditions) location.

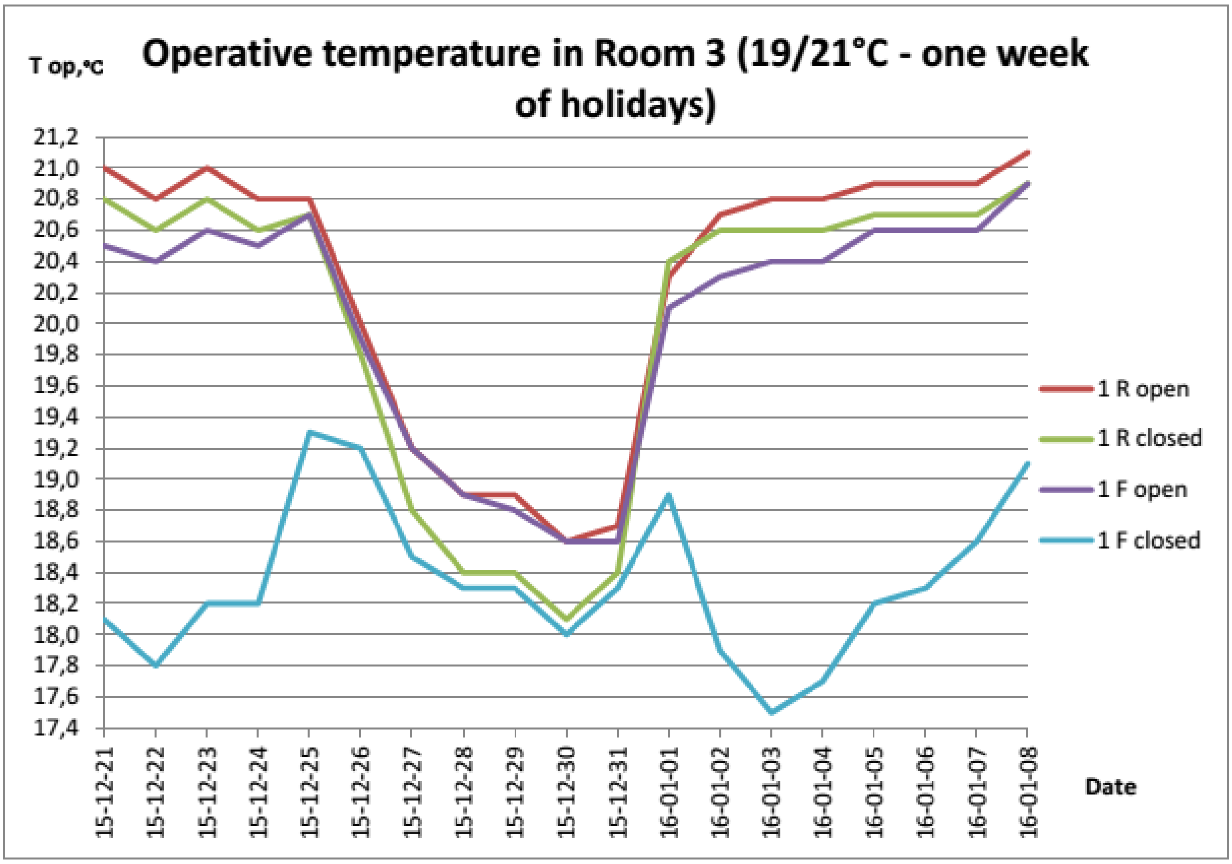


Figure 22. Changes of operative temperature in Room 3 during two weeks - 21.12.2015 - 08.01.2016

The chart above indicates a very clear difference between the situation with the lack of heat flow (one heater per floor) and the other less extreme temperature.

The heater during the holiday season is switched off. Following the temperature drop depends on the insulated building (which in this case has no impact because the level of isolation is not changed, the simulation), the room temperature before turning off the heating, and the heat flow between rooms.

Another statement indicates potential user dissatisfaction with the use of the simplified heating system with closed doors.

4. LOSSES FROM PIPES

Heating system are not only heaters but also pipes, heating source and valves. The results of simplified calculations of losses from distribution pipes in the heating medium systems: standard and simplified will be presented in this chapter.

4.1 CALCULATION PROCEDURE

Calculation of heat losses from pipes is performing the following calculation:

- Calculate and determine the temperature of the heat carrier, the temperature in the room temperature outer surface of the conduit, surrounding soil (from lines routed in the ground)
- Calculation of the heat loss in the conduit under the operating conditions
- Determine the temperature at the end of the cable (term drop in temperature)
- Selection of the thickness and type of insulation

• The heat loss to the environment from the guide wire heating element may be calculated by the formula:

$$Q_{loss} = \frac{l \cdot (t_{av} - t_e)}{R}$$

where,

Q_{loss} - heat loss to the environment from the guide wire heating element, W

l - length of the section, mm

t_{av} - the average temperature of the heating medium in the concerned section, K

t_e - standard ambient temperature, K

R - the sum of the resistance of heat transfer between the outside and the heating medium, mK/W

- The total resistance of the heat can be calculated from the relationship:

$$\sum_{i=1}^{n} R_i = R_a + R_S + R_\lambda + R_e$$

where:

R_a - The resistance to heat transfer on the inside of the pipe

R_S - The thermal resistance in the wall of the pipe

R_λ - The conduction resistance of insulation

R_e - The resistance to heat transfer on the outside of the cable to the ambient air

- Calculation of heat transfer resistance on the side of the heat carrier

$$R_a = \frac{1}{\pi \cdot d_{in} \cdot h_a}$$

where:

d_{in} - the inner diameter, m

h_a - the heat transfer coefficient on the inside conduit, W/m^2K

The heat transfer resistance on the side of the carrier depends largely on the speed of the water flow. The higher - the greater h_a, and thereby lower the resistance value. The heat transfer coefficient [h_a] ranges from 250 to laminar flow to as much as 10000 for turbulent flow. The installation conditions at speeds flow rate of 1m/s conditions are turbulent, thus the value of R_a is negligibly small.

- The Resistance of heat transfer conduit single layer (or insulation pipe)

$$R_\lambda = \frac{1}{2\pi\lambda} \ln \frac{d_{ex}}{d_{in}}$$

where:

λ - thermal conductivity of the material

d_{ex} - exterior diameter, m

d_{in} - diameter of inner material, m

- The resistance of heat transfer from the outer surface of the

$$R_e = \frac{1}{\pi \cdot d_{ex} \cdot h_e}$$

where:

h_e - the heat transfer coefficient on the outside wire

d_{ex} - the diameter of the outer conductor

Heat transfer from the conductor to the environment is done by radiation and convection, which is why he value can be calculated with the following formula:

$$h_e = h_f + h_k$$

where:

h_f - heat transfer coefficient on the road radiation

h_k - coefficient of heat transfer by convection

The heat transfer coefficient by radiation following equation:

$$h_f = \varepsilon \cdot \sigma \frac{(\frac{\tau_e}{100})^4 + (\frac{t_e}{100})^4}{\tau_e - t_e}$$

where:

ε - The emissivity of the outer surface of the tube (assumes values from 0-1 for steel = 0.77)

σ - The Boltzmann constant value = 5,67x10-8, W/m^2K^4

τ_e - surface temperature wire

t_e - ambient temperature

The heat transfer coefficient by convection described by the equation

$$h_k = 1{,}25 \cdot \sqrt[4]{\frac{\tau_e - t_e}{d_{ex}^{ins}}}$$

where:

t_e - ambient temperature, K

τ_e - conductor surface temperature, K

d_{ex}^{ins} - the outer diameter of insulation, m

4.2 RESULTS

In this part of the study were presented results of calculations of heat loss from bare wires to the environment.

Calculations were performed manually in excel based on central heating system design for standard situations and simplified heat distribution.

STANDARD HEATING LOOP

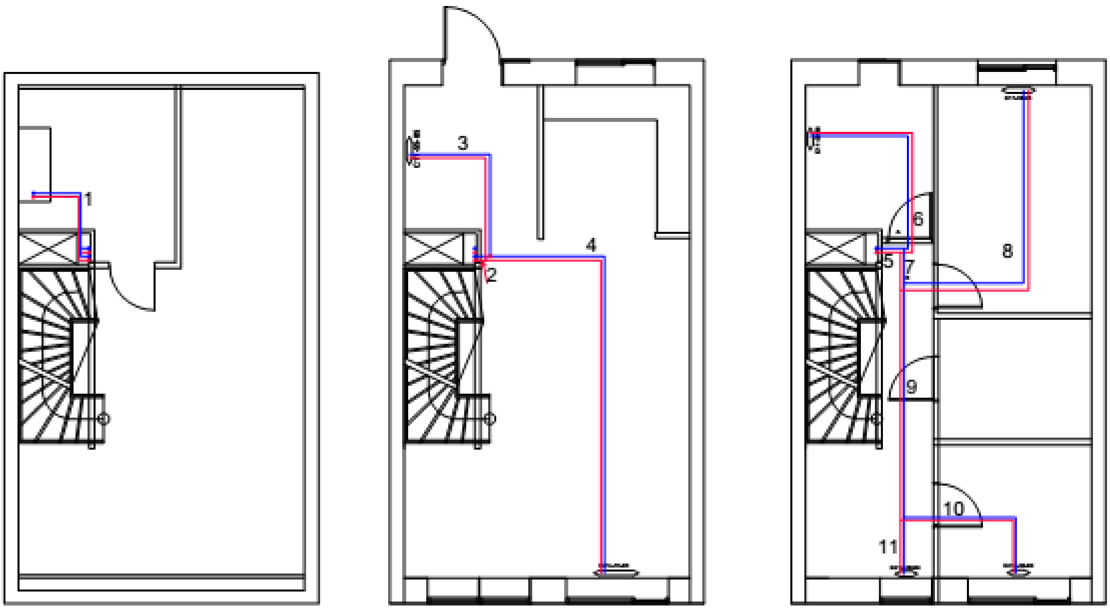


Figure 23. The distribution system design of the heating medium in the standard system respectively in the basement, ground floor and on the floor

In Figure 23 there is shown the distribution of the heating medium in the standard system, where one heater heats one room. Red color indicated supply lines, while the blue - return. Numbers at the lines indicate the numbering of plots, according to the calculations summarized in Table 17.

Parameter	Unit	Value
ha	W/m^{2}K	400
λ steal	W/(mK)	50
ε	-	0.77
σ	W/m^{2}K^4	5.67E-08
λ insulation	W/(mK)	0.035

Table 16. Constant values used in the calculation

Temperature	zone	No. of pipe	Q [W]	m [kg/s]	l [m]	d [mm]	d ex [mm]	d in [mm]	thickness of the wall [mm]	R [Pa/m]	w [m/s]	σ insul [mm]
21°C		1	1199.9	0.014319	3.09	20	26.9	22.3	2.3	1.86	0.04	20
		2	672.7	0.008027	1.15	20	26.9	22.3	2.3	0.72	0.02	20
	Hall	3	158.8	0.001895	3.31	15	21.3	17.3	2	0.29	0.01	20
	Livingroom	4	513.9	0.006132	7.74	15	21.3	17.3	2	1.8	0.03	20
		5	527.2	0.006291	4.05	15	21.3	17.3	2	1.87	0.03	20
	Room 1	6	100.3	0.001197	4.26	15	21.3	17.3	2	0.15	0.01	20
		7	426.9	0.005094	0.67	15	21.3	17.3	2	1.33	0.02	20
	Room 2	8	158.7	0.001894	5.95	15	21.3	17.3	2	0.29	0.01	20
		9	268.2	0.0032	4.07	15	21.3	17.3	2	0.64	0.01	20
	room 3	10	133.5	0.001593	1.1	15	21.3	17.3	2	0.23	0.01	20
	Hall 2	11	134.7	0.001607	3.07	15	21.3	17.3	2	0.23	0.01	20
19/21°C		1	3770.6	0.044995	3.09	32	42.4	37.2	2.6	1.23	0.04	30
		2	2096.7	0.02502	1.15	25	33.7	28.5	2.6	1.65	0.04	30
	Hall	3	402.7	0.004805	3.31	15	21.3	17.3	2	1.21	0.02	20
	Livingroom	4	1694	0.020215	7.74	20	26.9	22.3	2.3	3.35	0.05	20
		5	1673.9	0.019975	4.05	20	26.9	22.3	2.3	3.28	0.05	20
	Room 1	6	249.6	0.002979	4.26	15	21.3	17.3	2	0.57	0.01	20
		7	1424.3	0.016996	0.67	20	26.9	22.3	2.3	2.49	0.04	20
	Room 2	8	371.5	0.004433	5.95	15	21.3	17.3	2	1.07	0.02	20
		9	1052.8	0.012563	4.07	20	26.9	22.3	2.3	1.5	0.03	20
	room 3	10	292	0.003484	1.1	15	21.3	17.3	2	0.73	0.02	20
	Hall 2	11	760.8	0.009079	3.07	20	26.9	22.3	2.3	0.88	0.02	20
19/21°C (holidays)		1	3726.1	0.044464	3.09	32	42.4	37.2	2.6	1.2	0.04	30
		2	2053.4	0.024504	1.15	25	33.7	28.5	2.6	1.59	0.04	30
	Hall	3	392.4	0.004683	3.31	15	21.3	17.3	2	1.16	0.02	20
	Livingroom	4	1661	0.019821	7.74	20	26.9	22.3	2.3	3.25	0.05	20
		5	1672.7	0.019961	4.05	20	26.9	22.3	2.3	3.28	0.05	20
	Room 1	6	247.9	0.002958	4.26	15	21.3	17.3	2	0.57	0.01	20
		7	1424.8	0.017002	0.67	20	26.9	22.3	2.3	2.49	0.04	20
	Room 2	8	377.8	0.004508	5.95	15	21.3	17.3	2	1.09	0.02	20
		9	1047	0.012494	4.07	20	26.9	22.3	2.3	1.48	0.03	20
	room 3	10	293.2	0.003499	1.1	15	21.3	17.3	2	0.73	0.02	20
	Hall 2	11	753.8	0.008995	3.07	20	26.9	22.3	2.3	0.86	0.02	20

Table 17. The selection of pipe diameters

Summary of the results of calculations of losses of the wires is presented in Tables 18 and 19. The tables do not include the division into situations with the door open / closed, due to the lack of impact of this factor on the results of the calculations.

Temperature	zone	No. of pipe	No insulation									
			Q loss	**R**	**Ra**	**Rλ**	**Re**	**he**	**hf**	**hk**	**τe**	**q**
21°C		1	49.71	1.80	0.0357	0.0006	1.7662	6.6998	3.44E-07	6.70	316.35	11390.42
		2	18.50	1.80	0.0357	0.0006	1.7662	6.6998	3.44E-07	6.70	316.35	11390.42
	Hall	3	44.25	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
	Livingroom	4	103.48	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
		5	54.15	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
	Room 1	6	56.95	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
		7	8.96	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
	Room 2	8	79.55	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
		9	54.41	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
	room 3	10	14.71	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
	Hall 2	11	41.04	2.17	0.0460	0.0007	2.1225	7.0409	3.54E-07	7.04	315.59	11417.32
19/21°C		1	74.80	1.24	0.0214	0.0004	1.2175	6.1660	3.07E-07	6.17	318.25	11755.49
		2	23.07	1.50	0.0279	0.0005	1.4669	6.4390	3.21E-07	6.44	316.88	11755.49
	Hall	3	46.16	2.15	0.0460	0.0007	2.1046	7.1008	3.4E-07	7.10	315.33	11811.02
	Livingroom	4	129.90	1.79	0.0357	0.0006	1.7513	6.7568	3.3E-07	6.76	316.12	11783.19
		5	67.97	1.79	0.0357	0.0006	1.7513	6.7568	3.3E-07	6.76	316.12	11783.19
	Room 1	6	59.41	2.15	0.0460	0.0007	2.1046	7.1008	3.4E-07	7.10	315.33	11811.02
		7	11.24	1.79	0.0357	0.0006	1.7513	6.7568	3.3E-07	6.76	316.12	11783.19
	Room 2	8	82.97	2.15	0.0460	0.0007	2.1046	7.1008	3.4E-07	7.10	315.33	11811.02
		9	68.30	1.79	0.0357	0.0006	1.7513	6.7568	3.3E-07	6.76	316.12	11783.19
	room 3	10	15.34	2.15	0.0460	0.0007	2.1046	7.1008	3.4E-07	7.10	315.33	11811.02
	Hall 2	11	51.52	1.79	0.0357	0.0006	1.7513	6.7568	3.3E-07	6.76	316.12	11783.19
19/21°C (holidays)		1	77.92	1.23	0.0214	0.0004	1.2076	6.2168	2.95E-07	6.22	318.09	12147.34
		2	24.03	1.48	0.0279	0.0005	1.4549	6.4920	3.09E-07	6.49	316.67	12147.34
	Hall	3	48.08	2.13	0.0460	0.0007	2.0874	7.1592	3.26E-07	7.16	315.07	12204.72
	Livingroom	4	135.31	1.77	0.0357	0.0006	1.7370	6.8124	3.17E-07	6.81	315.88	12175.96
		5	84.64	1.48	0.0279	0.0005	1.4549	6.4920	3.09E-07	6.49	316.67	12147.34
	Room 1	6	61.88	2.13	0.0460	0.0007	2.0874	7.1592	3.26E-07	7.16	315.07	12204.72
		7	11.71	1.77	0.0357	0.0006	1.7370	6.8124	3.17E-07	6.81	315.88	12175.96
	Room 2	8	86.43	2.13	0.0460	0.0007	2.0874	7.1592	3.26E-07	7.16	315.07	12204.72
		9	71.15	1.77	0.0357	0.0006	1.7370	6.8124	3.17E-07	6.81	315.88	12175.96
	room 3	10	15.98	2.13	0.0460	0.0007	2.0874	7.1592	3.26E-07	7.16	315.07	12204.72
	Hall 2	11	53.67	1.77	0.0357	0.0006	1.7370	6.8124	3.17E-07	6.81	315.88	12175.96

Table 18. The results of calculations for standard situation without insulated pipes

The division results in two tables based on the assumption of two situations: the ducts are insulated, and the lack of insulation cables.

Temperature	**zone**	**No. of pipe**	Insulation									
			Q loss	**R**	**Ra**	**Rλ**	**Re**	**he**	**hf**	**hk**	**τe**	**q**
21°C		1	26.67	3.36	0.0296	2.5284	0.8015	8.4674	-4E-08	8.47	195.40	50.52
		2	9.93	3.36	0.0296	2.5284	0.8015	8.4674	-4E-08	8.47	195.40	50.52
	Hall	3	24.72	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
	Livingroom	4	57.80	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
		5	30.24	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
	Room 1	6	31.81	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
		7	5.00	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
	Room 2	8	44.43	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
		9	30.39	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
	room 3	10	8.21	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
	Hall 2	11	22.93	3.88	0.0374	3.0117	0.8344	9.2373	-3E-08	9.24	170.98	50.53
19/21°C		1	29.69	3.12	0.0188	2.4335	0.6702	6.5600	-8.4E-08	6.56	238.23	34.90
		2	9.55	3.61	0.0236	2.8957	0.6917	7.2238	-6E-08	7.22	222.10	34.90
	Hall	3	25.62	3.88	0.0374	3.0117	0.8273	9.3159	-2.8E-08	9.32	165.74	52.27
	Livingroom	4	69.26	3.35	0.0296	2.5284	0.7948	8.5394	-3.7E-08	8.54	191.00	52.27
		5	36.24	3.35	0.0296	2.5284	0.7948	8.5394	-3.7E-08	8.54	191.00	52.27
	Room 1	6	32.97	3.88	0.0374	3.0117	0.8273	9.3159	-2.8E-08	9.32	165.74	52.27
		7	6.00	3.35	0.0296	2.5284	0.7948	8.5394	-3.7E-08	8.54	191.00	52.27
	Room 2	8	46.05	3.88	0.0374	3.0117	0.8273	9.3159	-2.8E-08	9.32	165.74	52.27
		9	36.42	3.35	0.0296	2.5284	0.7948	8.5394	-3.7E-08	8.54	191.00	52.27
	room 3	10	8.51	3.88	0.0374	3.0117	0.8273	9.3159	-2.8E-08	9.32	165.74	52.27
	Hall 2	11	27.47	3.35	0.0296	2.5284	0.7948	8.5394	-3.7E-08	8.54	191.00	52.27
19/21°C (holidays)		1	30.73	3.12	0.0188	2.4335	0.6647	6.6140	-8E-08	6.61	235.40	36.06
		2	9.89	3.61	0.0236	2.8957	0.6861	7.2833	-5.7E-08	7.28	218.73	36.06
	Hall	3	26.52	3.87	0.0374	3.0117	0.8206	9.3926	-2.6E-08	9.39	160.49	54.01
	Livingroom	4	71.70	3.35	0.0296	2.5284	0.7883	8.6097	-3.5E-08	8.61	186.59	54.01
		5	34.82	3.61	0.0236	2.8957	0.6861	7.2833	-5.7E-08	7.28	218.73	36.06
	Room 1	6	34.13	3.87	0.0374	3.0117	0.8206	9.3926	-2.6E-08	9.39	160.49	54.01
		7	6.21	3.35	0.0296	2.5284	0.7883	8.6097	-3.5E-08	8.61	186.59	54.01
	Room 2	8	47.67	3.87	0.0374	3.0117	0.8206	9.3926	-2.6E-08	9.39	160.49	54.01
		9	37.70	3.35	0.0296	2.5284	0.7883	8.6097	-3.5E-08	8.61	186.59	54.01
	room 3	10	8.81	3.87	0.0374	3.0117	0.8206	9.3926	-2.6E-08	9.39	160.49	54.01
	Hall 2	11	28.44	3.35	0.0296	2.5284	0.7883	8.6097	-3.5E-08	8.61	186.59	54.01

Table 19. The results of calculations for standard situation with insulation on pipes

SIPLIFIED HEATING LOOP

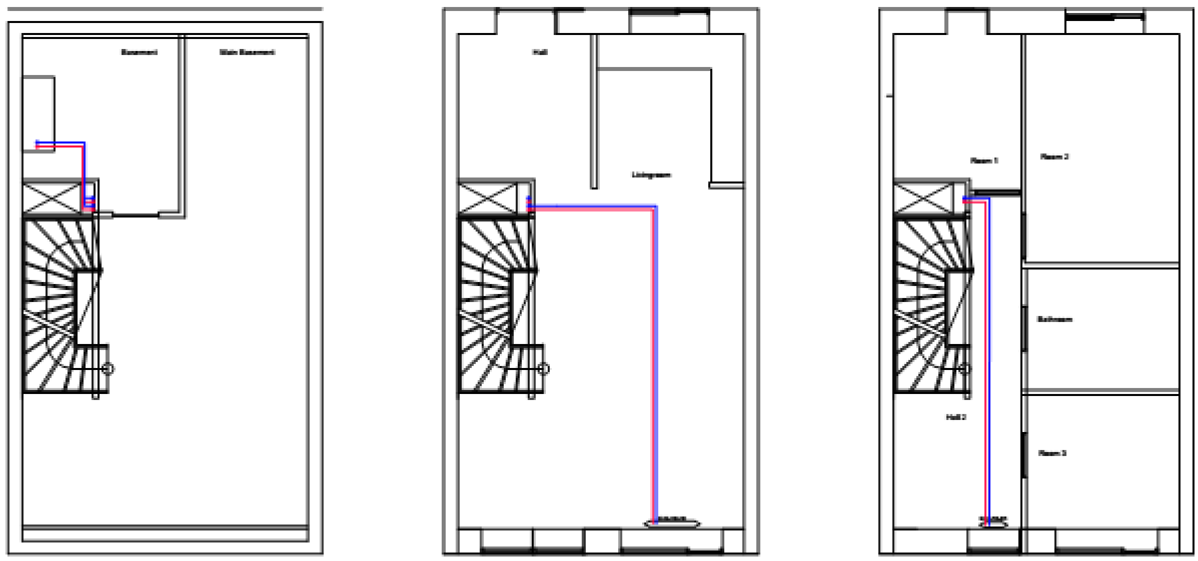


Figure 24. The distribution system design of the heating medium in the simplified system respectively in the basement, ground floor and on the floor

In Figure 24 there is shown the distribution of the heating medium in the simplified system, where one heater heats one floor. Red color indicated supply lines, while the blue - return.

Table 20 summarizes the results of the selection of pipe diameters.

Temperature	No. of pipe	Q [W]	m [kg/s]	l [m]	d [mm]	d ex [mm]	d in [mm]	thickness of the wall [mm]	R [Pa/m]	w [m/s]	σ insul [mm]
21°C	1 (main)	1005.5	0.011999	3.09	20	26.9	22.3	2.3	1.39	0.03	20
	2 (living room)	668	0.007971	8.85	20	26.9	22.3	2.3	0.71	0.02	20
	3 (hall 2)	337.5	0.004027	9.86	15	21.3	17.3	2	0.91	0.02	20
19/21°C	1 (main)	3217	0.038389	3.09	32	42.4	37.2	2.6	0.93	0.04	30
	2 (living room)	2063	0.024618	8.85	25	33.7	28.5	2.6	1.6	0.04	30
	3 (hall 2)	1154	0.013771	9.86	20	26.9	22.3	2.3	1.75	0.04	20
19/21°C (holidays)	1 (main)	3671	0.043807	3.09	32	42.4	37.2	2.6	1.17	0.04	30
	2 (living room)	2061	0.024594	8.85	25	33.7	28.5	2.6	1.6	0.04	30
	3 (hall 2)	1610	0.019212	9.86	20	26.9	22.3	2.3	3.07	0.05	20

Table 20. The results of the selection of pipe diameters for simplified heating system.

The increase in the diameters in the case of a simplified heating system is due to higher mass flows flowing through the conduits. In a system with one heater on the floors, the required capacities are much greater than for standard (single radiator in the standard system has much less power than the one in the simplified).

Temp.	No. of pipe	Q strat	R	Ra	Rλ	Re	he	hf	hk	τe	q
21°C	1 (main)	49.715	1.802	0.036	0.000597	1.766	6.700	3.44E-07	6.70	316.35	11390.42
	2 (living room)	142.387	1.802	0.036	0.000597	1.766	6.700	3.44E-07	6.70	316.35	11390.42
	3 (hall 2)	131.820	2.169	0.046	0.000662	2.122	7.041	3.54E-07	7.04	315.59	11417.32
19/21°C	1 (main)	74.797	1.239	0.021	0.000416	1.218	6.166	3.07E-07	6.17	318.25	11755.49
	2 (living room)	177.549	1.495	0.028	0.000533	1.467	6.439	3.21E-07	6.44	316.88	11755.49
	3 (hall 2)	165.475	1.788	0.036	0.000597	1.751	6.757	3.3E-07	6.76	316.12	11783.19
19/21°C (holidays)	1 (main)	77.916	1.229	0.021	0.000416	1.208	6.217	2.95E-07	6.22	318.09	12147.34
	2 (living room)	184.948	1.483	0.028	0.000533	1.455	6.492	3.09E-07	6.49	316.67	12147.34
	3 (hall 2)	172.370	1.773	0.036	0.000597	1.737	6.812	3.17E-07	6.81	315.88	12175.96

Table 21. The results of calculations for simplified situation without insulated pipes

Temp.	No. of pipe	Q strat	R	Ra	Rλ	Re	he	hf	hk	τe	q
21°C	1 (main)	26.673	3.360	0.030	2.528393	0.802	8.467	-4E-08	8.47	195.40	50.52
	2 (living room)	76.394	3.360	0.030	2.528393	0.802	8.467	-4E-08	8.47	195.40	50.52
	3 (hall 2)	73.631	3.883	0.037	3.011671	0.834	9.237	-3E-08	9.24	170.98	50.53
19/21°C	1 (main)	29.688	3.122	0.019	2.433477	0.670	6.560	-8.4E-08	6.56	238.23	34.90
	2 (living room)	73.523	3.611	0.024	2.895729	0.692	7.224	-6E-08	7.22	222.10	34.90
	3 (hall 2)	88.225	3.353	0.030	2.528393	0.795	8.539	-3.7E-08	8.54	191.00	52.27
19/21°C (holidays)	1 (main)	30.732	3.117	0.019	2.433477	0.665	6.614	-8E-08	6.61	235.40	36.06
	2 (living room)	76.093	3.605	0.024	2.895729	0.686	7.283	-5.7E-08	7.28	218.73	36.06
	3 (hall 2)	91.343	3.346	0.030	2.528393	0.788	8.610	-3.5E-08	8.61	186.59	54.01

Table 22. The results of calculations for simplified situation with insulation on pipes

On the basis of calculations it can be concluded that in both cases (standard / simplified) heating loops, the isolation of pipes resulted in a reduction of heat losses by about 50% with respect to the distribution without insulated pipes.

In the case of a simplified distribution of heat, heat loss from the tubes to the rooms are considerably lower than the solution heated with each room individually. This is due to the size of the installation, which in the standard version is very extensive, in the floor almost all the rooms are wires.

Precise comparisons of losses for the studied situation is presented in Table 23.

No insulation			Insulated pipes	
temp.	**1R**	**1F**	**1R**	**1F**
21ºC	525.71	323.92	292.14	176.70
19/21 ºC	630.69	417.82	327.77	191.44
19/21 ºC (holidays)	670.80	435.23	336.62	198.17

Table 23. The comparison of the results for the tested situations.

The smallest loss of the wires are in a situation of simplified distributing the heat and insulation of cables (for the assumed constant temperature of 21 degrees in the premises) and the largest for a standard solution in situations with variable temperature (with Christmas break) in the absence of insulation on distribution lines.

5. ANALYSIS OF RESULTS

This section summarizes and compares together all the examined situations in order to determine which one is the most thermally comfortable for users and how the energy efficiency depending on the situation. At the end, it will be considered the relationship between energy efficiency and thermal comfort.

5.1 THERMAL COMFORT - A COMPARISON OF ALL SOLUTIONS

As previously mentioned, thermal comfort depends on three types of factors:
- human factors (ie, insulating clothing, physical activity level and duration of stay in the room), - parameters describing the state of the room air (temperature, humidity and speed)
- parameters describing the room (radiation temperature and the temperature of the surface of the partitions).

Table 24 summarizes the results of a simulation of the IDA program ICE. Parameter under consideration is the lowest sensed temperature of the test areas of the building based on the assumed conditions (21ºC, 19/21ºC, 19/21ºC (holidays)), of heating the applied solution (standard / simplified) as well as the size of the door opening.

Zone	Simulations for 21°C					Simulations for 19 - 21°C					Simulations for 21°C (one week of holidays 16°C)				
	without radiators	with radiators				without radiators	with radiators				without radiators	with radiators			
		1 radiator per floor		1 radiator per room			1 radiator per floor		1 radiator per room			1 radiator per floor		1 radiator per room	
		Open doors	Closed doors	Open doors	Closed doors		Open doors	Closed doors	Open doors	Closed doors		Open doors	Closed doors	Open doors	Closed doors
Hall	20.8	20.5	20.3	21.6	21.3	20.2	19.4	19.4	20.2	20.2	17.8	17.0	16.9	17.0	17.0
Livingroom	20.8	21.1	20.7	21.2	21.1	18.9	19.6	19.6	19.6	19.6	18.0	17.2	17.2	17.2	17.3
Stairs 1	21.0	20.8	20.5	20.9	20.8	19.2	19.4	19.4	19.4	19.4	18.2	17.4	17.3	17.4	17.4
Stairs 2	21.0	21.2	20.9	21.2	21.2	19.5	19.9	19.7	20.0	20.0	18.5	18.2	18.1	18.2	18.2
Hall 2	21.0	21.3	21.0	21.3	21.3	19.4	19.8	19.7	20.0	19.9	18.5	18.2	18.1	18.2	18.2
Room 1	20.9	20.5	16.1	21.2	21.2	19.3	19.4	16.0	19.9	19.8	18.5	18.3	17.6	18.3	18.4
Room 2	20.9	20.4	16.3	21.2	21.2	19.3	19.4	16.2	19.8	19.8	18.6	18.4	17.7	18.4	18.5
Room 3	20.9	20.4	15.7	21.1	21.1	19.0	19.2	15.5	19.7	19.6	18.1	17.9	16.8	17.9	17.3

Table 24. The comparison of minimal temperature for tested situations.

Based on the results shown in Table 24, it can be concluded that the lowest minimum temperatures occur in areas where the passage is closed assuming a simplified system heat distribution. Such low temperatures can contribute to thermal discomfort for residents / users, especially when they go out of the room in which the heater is located (eg. Hall 2), to the bedroom with the door closed (eg. Room 3).

For a fixed constant temperature equal to 21 degrees, the temperature difference between inside and outside hall 2 and Room 3 is 5.3 degrees. It is a very large temperature difference likely to cause health problems for users.

The most convenient solution seems to be to apply a simplified system of heat distribution, but only if left open pass between zones. It have to be considered that in this case, the only way the power supplied to the heater, can heat the other areas.

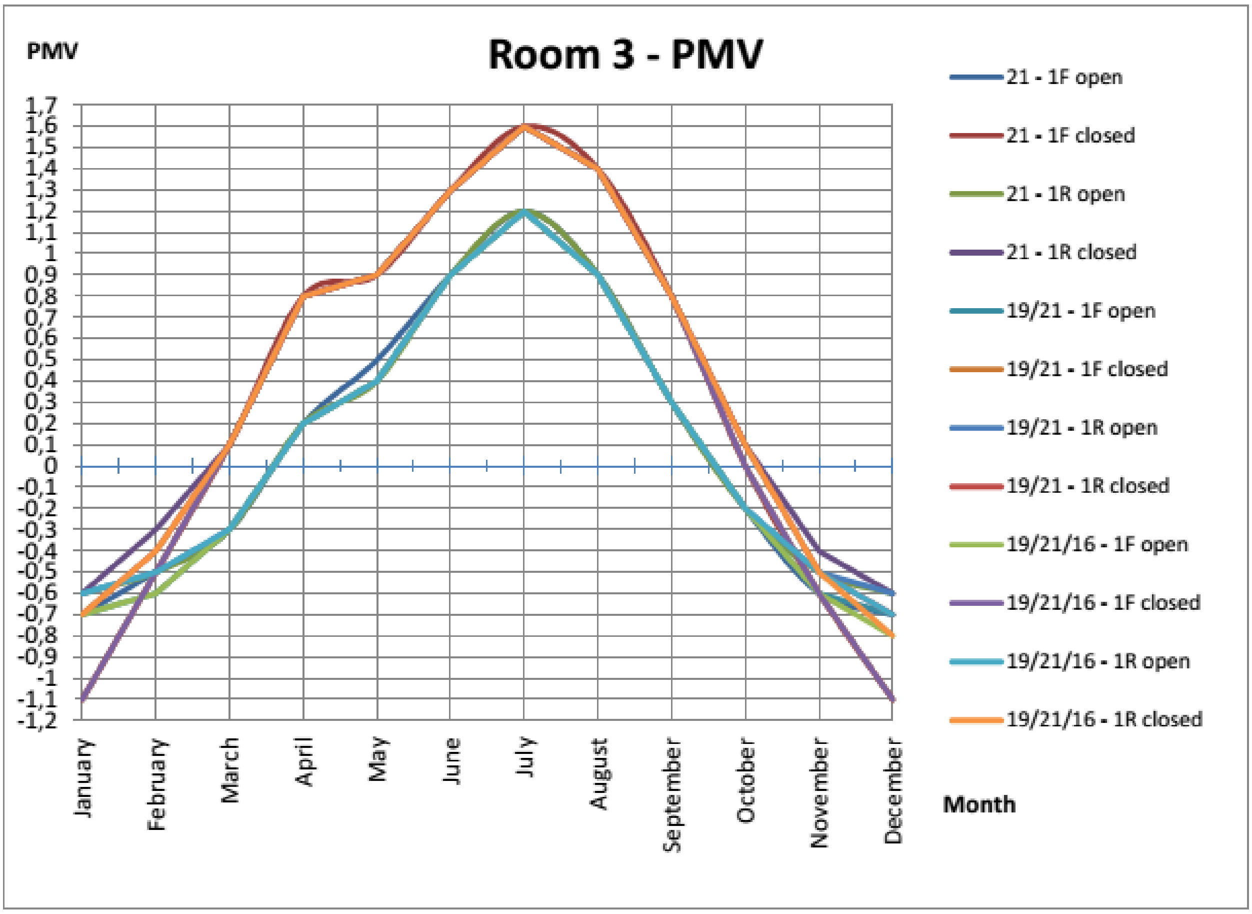


Figure 25. Comparison of PMV in tested sytuations, during one year for Room 3.

Figure 25 shows a comparison of average monthly Predicted Mean Vote Index value for the zone: Room3, depending on the established situation.

The graph shows that in the summer months, users in most situations assess the environment as a slightly warm, it is caused by a lack of cooling in the building. However, in the winter, especially when the heat flow between the rooms is locked and the premises are heated using a heater on the floor, users experience greater discomfort from the cold.

Based on the data from the table 25 it can confirm the thesis that heating solution in a simplified manner and closing the door will displeasure Members in connection with the felt air temperature in the studied areas.

month	Simulations for 21°C				Simulations for 19 - 21°C				Simulations for 21°C (one week of holidays 16°C)			
	1 radiator per floor		1 radiator per room		1 radiator per floor		1 radiator per room		1 radiator per floor		1 radiator per room	
	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors	Open doors	Closed doors
January	15.4	30.9	13.0	12.9	15.9	30.9	13.8	14.6	15.9	30.9	13.8	14.5
February	11.9	12.7	10.6	9.8	12.4	12.8	11.3	10.6	12.4	12.8	11.3	10.6
March	8.5	11.9	8.2	11.9	8.7	12.0	8.4	11.9	8.7	11.9	8.4	11.9
April	10.5	29.2	10.5	29.2	10.4	29.0	10.4	28.9	10.4	28.9	10.3	28.8
May	13.6	28.6	13.4	29.1	13.6	28.0	13.4	28.3	13.2	28.1	13.3	28.4
June	26.0	41.0	25.7	41.4	25.1	40.3	25.0	40.4	25.1	40.5	24.8	40.2
July	36.5	53.1	36.5	53.5	35.7	52.1	35.6	51.9	35.8	52.3	35.7	52.0
August	29.5	46.9	29.6	47.0	28.4	46.2	28.4	46.1	28.8	45.9	28.3	45.9
September	10.9	24.5	10.7	24.7	10.6	24.2	10.6	24.0	10.6	24.3	10.6	24.1
October	7.8	10.8	7.6	10.6	7.9	10.7	7.7	10.6	7.9	10.7	7.7	10.6
November	12.1	15.3	10.9	10.1	12.5	15.2	11.3	10.9	12.5	15.2	11.3	10.9
December	15.1	29.0	12.9	13.0	15.4	29.0	13.4	14.3	18.4	30.5	16.7	18.2
min	7.8	10.8	7.6	9.8	7.9	10.7	7.7	10.6	7.9	10.7	7.7	10.6
max	36.5	53.1	36.5	53.5	35.7	52.1	35.6	51.9	35.8	52.3	35.7	52
average	16.5	27.8	15.8	24.4	16.4	27.5	15.8	24.4	16.6	27.7	16.0	24.7

Table 25. The comparison of PPD for tested situations in Room 3.

Marked in red are the highest values of PPD indicating a large dissatisfaction. These sensations from residents occur in the summer months (due to lack of cooling - which is not considered in this work) and in the situation "1F closed" for each situation temperature.

The worst evaluation has version of the constant temperature, because of the highest temperature differences between rooms.

The color blue represents the lowest value of PPD common in periods February-March and October-November. This is due to the external temperature, which at the time of reaching the medium close to 0 degrees. With such a high insulation of the building, heat loss from the building on the outside are negligible and maintenance of the established temperature does not cause problems.

The lowest value of PPD is in the standard case of heating, with one heater for one room. In this situation, opening / closing doors almost do not affect the feeling of comfort in the building.

Table 25 also appears green color, which is the optimum value for comfort. The argument is backing the distribution of PPD during the year, the situation of maintaining an open door by using simplified heat distribution, which in terms of value differs only little from that of the lowest values PPD, but in terms of cost and energy differences are significant, in favor of "1F open" situation.

5.2 ENERGY EFFICIENCY

In this thesis the impact of a change in heat distribution (with standard heating loop simplified) on energy efficiency of the building is considered. To find it out through a series of simulations in extreme conditions for the assumptions mentioned in previous chapters. Based on the results obtained in the comparison projected annual consumption (Table 26).

Situation		kWh/m^2
21	1F open	12.68
	1F closed	12.82
	1R open	13.65
	1R closed	13.51
19/21	1F open	14.06
	1F closed	13.36
	1R open	14.11
	1R closed	14.44
19/21*	1F open	13.42
	1F closed	13.12
	1R open	13.83
	1R closed	13.89

Table 26. The comparison of annual energy consumption for checked situation, kWh/m^2.

Changing the heat distribution system to a simplified standard reduces annual energy consumption in the building, but the difference is small (in the same room temperature). The greatest annual consumption was observed, assuming the variable air temperature in the room during the day, in an energy distribution with a standard and a closed door. The smallest maintained constant while the temperature and the simplified heating loops.

5.3 CONCLUSION

In this section has been inspected whether and what relationship exists between energy efficiency of the object and the thermal comfort of the building users.
The most reliable way to verify this relationship seems to be a comparison of the annual energy consumption with indicator PPD. This combination is presented in Table 27.

Situation		kWh/m2	PPD
21	1F open	12.68	16.5
	1F closed	12.82	27.8
	1R open	13.65	15.8
	1R closed	13.51	24.4
19/21	1F open	14.06	16.4
	1F closed	13.36	27.5
	1R open	14.11	15.8
	1R closed	14.44	24.4
19/21*	1F open	13.42	16.6
	1F closed	13.12	27.7
	1R open	13.83	16
	1R closed	13.89	24.7

Table 27. The comparison of annual energy consumption for checked situation with PPD index.

It has been observed that a change in the assumed air temperature in the room has no effect on altering perception of comfort for the user, while the energy consumption already.

Between the minimum and the maximum, contained in Table 27, the difference is 1.76 kWh/m^2 per year, or during the year, while maintaining a constant temperature = 21 degrees will save 326 kWh.

Both checked the parameters (comfort and energy efficiency) depend on assumptions considered but do not depend on each other.

The use of the simplified heat distribution rather than the standard heating loop will save further kWh for energy consumption, but in order to began to affect the change of thermal comfort, enter another assumption - open / closed door between zones.

In a situation where there is a distribution of one radiator on the floor and blocked the flow of heat between the rooms, there is an increase of dissatisfied users, caused by too much perceptible difference in temperature between the room with the heater (which is at 21 degrees - Hall 2) and the room behind the door (eg. room 3 with a temperature of 15.7ºC).

It was also examined the impact of assumptions insulation of the distribution pipes. It turned out that the use of insulation reduced heat loss from the pipes of almost 50% but using a low-temperature heating such losses are so small that they do not have practically no influence on the energy efficiency and thermal comfort of users

6. SUMMARY

The whole thesis was designed to investigate the relationship between energy efficiency and thermal comfort with regard to the way heat distribution in the passive house as well as control efficiency. In order to verify the assumed also performed simulations in the IDA Indoor Climate and Energy, which is a modern tool for simulation.

When conducting the analysis of the influence, founded the air temperature in the building, the impact of heat distribution method, as well as closing the door openings and pipe insulation, on energy efficiency and thermal comfort in the test building (located in Trondheim, Norway).

Considered temperature situations were divided into:

- Stable temperature equal to 21ºC
- Room temperature variable during the day - during the day and hour 7 am to 11 pm, the temperature is 21 degrees whereas at night - would fall to 19 degrees.
- The last case, the most complicated, similarly as in the previous case that varies in temperature during the day, but in addition, during the year (at Christmas - 25.12 to 31.12), the temperature would drop to 16 degrees because of the absence inhabitants.

Among the above-mentioned objectives in terms of comfort, most preferably dropped situation where temperature change followed only during the day. The most unfavorable in this respect turned out to be an option with the temperature at a constant level.

The most efficient option is to maintain a constant air temperature in the room. This is due to the increased energy demand, which occurs when you need to increase the temperature from 19ºC (night) to 21ºC (day).

Another factor that could have a potential impact on thermal comfort and energy efficiency model was the way the distribution of heat in the building.
Two possibilities were taken into consideration:
- Standard system - where one radiator falls on one room, two-pipe system
- Simplified layout - lines also carried out a two-pipe system, and the heaters are located one on the floor.

With the introduction of this assumption, it turned out that a change in the distribution of heat does not have too much impact on altering perception of comfort but only if we make the assumption unhindered flow of air masses (warm) between the two rooms.
Otherwise (assuming no heat flow) streamlined solution causes a strong feeling of thermal discomfort caused by excessive fluctuations in temperature between the rooms.
This is where there is the need to adopt and verify the assumptions next - door open / closed.

The last inspected the condition insulate distribution lines to the radiator heating medium.
In the absence of pipe insulation heat loss to the environment they were almost twice as high as when the pipes were insulated. This could affect the feeling of comfort in the case of high-temperature heating.

Based on these studies it was concluded that the best solution due to thermal comfort, energy efficiency, and even the economic aspect is to simplify the heating distribution system with mandatory leaving the door open and establish a constant temperature equal to 21ºC in the analyzed object.

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MAPS:

- Map 1. Normal annual temperature in Norway,
  Source: http://met.no/?module=Articles;action=Article.publicShow;ID=486
- Map 2. Location of building in Trondheim
  (http://www.miljobyen.no/assets/img/seksjoner/kart.png)

FIGURES:

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