TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

MASTER-/DIPLOMARBEIT

ASPECTS OF INTRODUCING ENERGY EFFICIENCY IN GOVERNMENT HOUSING PROJECTS IN CROATIA

ausgeführt zum Zwecke der Erlangung des akademischen Grades
eines Diplom-Ingenieurs / Diplom-Ingenieurin
unter der Leitung

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Wien, Januar 2012 eigenhändige Unterschrift

Ich habe zur Kenntnis genommen, dass ich zur Drucklegung meiner Arbeit unter der Bezeichnung

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Acknowledgments

First, I like to thank my advisor Prof. DI dr. techn. Ardeshir Mahdavi whose support, scientific guidance and helpful suggestions made this thesis possible.

Furthermore, I thank the members of the Department of Building Physics and Building Ecology, who were always ready to answer my questions, with special thanks to Univ.Ass. Dipl.-Ing. Dr.techn. Kristina Orehounig.

Above all, I want to express my gratitude to my parents, who made it possible for me to study in Vienna and helped me during the time of my studies. I would also like to thank my sister, for her ever- present encouragement and moral support.

Abstract

Latest data available shows that in the last decade, energy demand in households in Croatia is on a constant rise, with yearly increase of 4 %. Within that, in total energy demand of households, heating demands contribute with more than 50 %, offering significant room for energy consumption reductions. Rapid development of the real estate market in recent years induced the government to develop a model of subsidies housing that would make apartment owning more affordable. This included significant financial investments, but without a clear strategy, as large number of those apartments remained unsold, the main goal of the project was not achieved.

Therefore, this research analyses two scenarios that include better thermal envelope of selected buildings. Based on dynamic energy simulations, proposed improvements of the building envelope are compared to the current thermal performance of two selected buildings.

This comparison allows one to make heating cost estimations based on the heating energy consumption, but it also enables making carbon dioxide emission projections. Focusing on those two parameters, that are directly influenced by heating energy consumption, this research aims to prove that better thermal performance of buildings raises the environmental quality, but also reduces the costs of living, which should be the goals in projects that are directly financed by the government.

Contents

1.0 Introduction

1.1. Overview

Within Croatia's efforts to join the EU in the last decade, large number of new laws and regulations had to be modified in order to meet the standards set by the EU. One of the biggest and most demanding chapters was, and still is, energy development policy. As the studies show, Croatia, as well as other developing countries, has the biggest energy demand in the building sector, with 3, 9% yearly rise between 1992-2004 (*Domac et al. 2003).*

This research will focus on the residential sector as one of the biggest consumers in overall energy consumption. Focus is on thermal behavior of apartment buildings built within the government housing program started in 2002. As part of this project, apartment buildings have been built all over the country, but most of them in capital city, Zagreb. Research is based on dynamic energy simulations, made by specialized software tool, possible of performing simulations on hourly bases.
Two large apartment buildings were selected for thermal behavior analyses. For each of the two buildings, three simulation scenarios were made. First scenario included simulations of buildings based on the exact building documentation, including exact floor plans and material properties details as they are actually built. Second scenario included simulations with improvements in the building envelope that would result in lower energy demands. Finally, third scenario included improvements in the building envelope that meet passive building standards in construction material properties. After having the relevant results from all three cases, it was possible to make a valid comparison based on simulations made.

Research goal was to show that, when it comes to government financing of housing projects, grater care of energy efficiency had to be taken into account. Objective was to prove that better thermal performance in buildings results not only in heating cost reduction, but also has a significant impact on the environment, which is presented in carbon dioxide (CO_2) emission analyses.

1.2. Motivation

As in the rest of the EU countries, energy consumption in Croatia is on a constant rise in the past years.

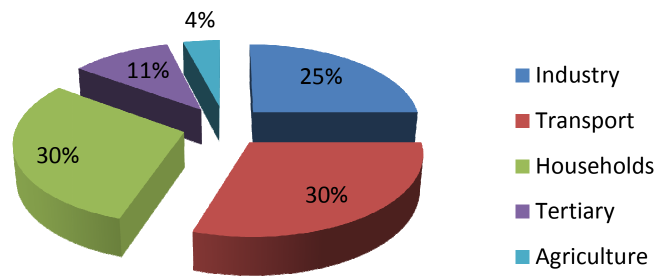


Figure 1.1.; Energy consumption by sector for Croatia, 2004.(HEP 2007)

According to the latest data available (HEP 2007)41% of overall energy consumption goes to the building sector, followed by transportation sector with 30,6% and industry sector with 21,7% of overall final energy consumption. Only this basic information is showing that there is a clear need for addressing the problem of energy saving with grater care. As part of Croatia's efforts to join the EU, set to happen in July 2013, list of regulations, laws and procedures must be implemented in order to follow the strict EU agenda in energy efficiency. Crucial point for this research lies in the fact that Croatia was facing rapid price growth in real-estate in recent decade, with residential and apartment housing prices booming, often unrealistic. This created the need for making housing and house owning more affordable, so government stepped in, offering a housing model that will primarily induce housing prices to drop.

Government model included apartment buildings in all parts of Croatia, offering housing to those who cannot afford high prices on jet developing market. For the program significant founds were invested, but obviously without a clear strategy. One would expect that more attention was given to energy efficiency, as the government officially stated that energy efficient building and reduction of CO_2 related to it are key points for the future, according to *the Energy development strategy for Republic of Croatia*.

This paper will show that additional efforts in energy efficiency result in a lower living cost for the residents, which was the intention of the government in the first place, but also that the impact on the environment would be smaller if a different approach was taken.

Adding to this the lack of research in field of energy efficiency in buildings, and having in mind that only in recent years this problem has been addressed with greater importance, it is my hope that results presented within this thesis will also contribute to highlighting the importance of energy efficient building.

1.3. Background

In the last decade, housing projects financed by the government had the intention of decreasing rising housing prices by building a significant number of new apartments and putting them on the market. The initial idea was to make living and apartment owning affordable to younger population; like families with children or young people looking for their first apartment. Project was very well accepted from the beginning, so only in first two years more than 3000 apartments were built all over the country. For the first year of the program, 19 million Euros of government founding was provided, making it one of the biggest infrastructural investments in Croatia at the time. Upper price for apartments within this program was initially set to only 700 Euro/m^2, which was well below the market price at the time, with prices on the real-estate market often going above 2000 Euro/m^2. Additional benefit of this program was a long pay-off period offered by the banks, which opens a new perspective when analyzing the program in general.

After gaining independence in 1991, energy demand in Croatia has been increasing dramatically, with final overall energy consumption rising by 3,3% each year. Within that, one of the highest growing rates was noticed in households, with 3, 9% annual rise *(HEP 2007*).

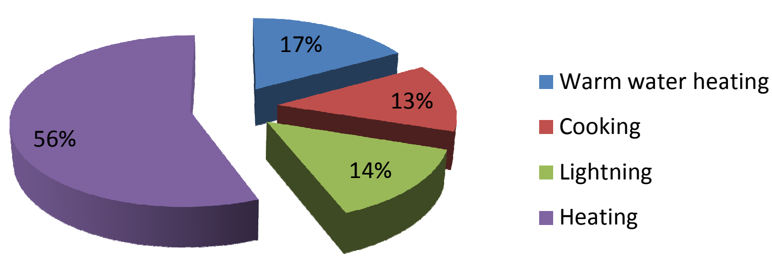
After the adaptation of technical regulations, concerning heat energy savings and thermal regulation in buildings, level of thermal protection in buildings has improved, and annual heating energy consumption for new buildings was limited between 51,31 $kwh\ m^{-2}$ and 95,01 $kwh\ m^{-2}$ for residential buildings, and 16,42 $kwh\ m^{-2}$ and 30,40 $kwh\ m^{-2}$ for non-residential buildings. This was the first step of implementing the

2002/91 EC Directive on energy performance of buildings, which was adopted from the EU legacy.

Within efforts to induce energy efficiency, State Energy Agency issued a handbook on energy efficiency implementation in households, with emphasis on:

- Implementation of EU legacy in energy efficiency, thermal insulation, energy savings and renewable energy sources
- Improvements in thermal performance in buildings
- Increasing efficiency of heating, cooling and ventilating systems
- Better control of energy consumption in existing and new buildings
- Implementation of energy certification in buildings
- Continues education and promotion on energy efficiency related issues

According to Croatian National Energy Company (*HEP 2007*), around 83% of all households in Croatia have the annual energy consumption somewhere between 150-200 $kwh\ m^{-2}a^{-1}$. The report points out that all residential buildings in Croatia have irrationally high heating energy demands, with increasing cooling energy demand in recent years.



Fig*ure 1.2; Average consumption of final energy in residential sector for Croatia (HEP 2007)*

In the last decade, with energy prices on constant rise, the average energy supply from domestic resources dropped from 65% to 50% only, showing that overall energy stability of the country is far from ideal. Biggest growth was noticed in natural gas demand, as most new constructed buildings were gas heated.

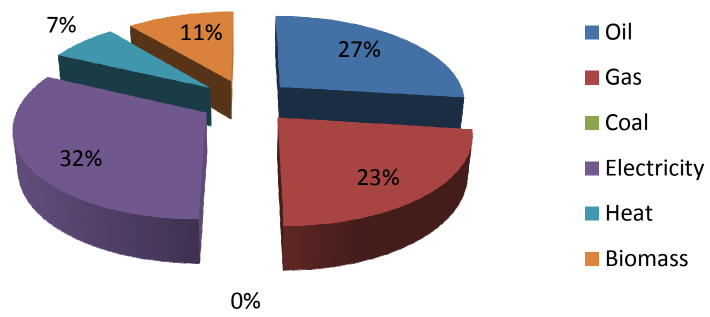


Figure 1.3 ; Final energy consumption in households by energy carrier for Croatia 2004. (HEP 2007)

From the graph (Figure 1.3) it is visible that oil and electricity are still leading heating energy carriers, with biomass heating represented in only 11% according to the data available. Heating demand for residential buildings in Croatia contributes with 40%-60% in overall energy consumption, and it is above the EU average.
For heating processes in buildings, the most important factor is duration of the heating season, followed by demanding temperature of space. Influencing factors are also; heating system technology, ratio between heated and unheated space and building envelope. For cooling in buildings, same parameters have a vital role, with additional consideration to electrical power.

Rapid development of the building sector, not only increased the energy demand, but had a significant influence on the environment. From year 1992, final CO_2 emission in Croatia has increased by 54%**,** again with the high increase in household sector, with more than 60%. If we single out the carbon dioxide emission, more than 35% of overall emission in Croatia is related to the building sector, which is a clear sign that energy efficient measures must be implemented from planning stages of every project.

After signing the Kyoto protocol in 2007, Croatia agreed to reduce greenhouse gas emission by 5% in period from 2008-2012 in comparison to the reference year 1990. Several relevant reports on implementation of this protocol showed that Croatia is facing serious difficulties in meeting those demands. Just in the year 2003, 6.6 % increase of CO_2 emission was recorded in comparison to the previous year 2002, which means that the values allowed by the Kyoto protocol were exceeded.

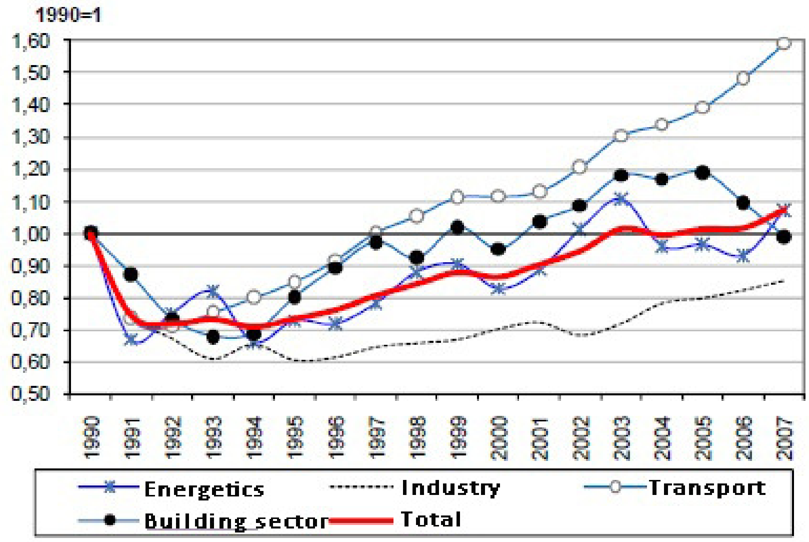


Figure 1.4; Carbon dioxide emission in Croatia from 1990.-2007,
(European commission 2010)

Graph shows that CO_2 emission related to building sector was at its peak between 2002-2005, which at the time when the project documentation for selected buildings was made.

1.3.1 Legal legacy in energy efficiency in Croatia

Within the process of joining the EU started in 2002 Republic of Croatia had to start with the implementation of EU regulations in energy efficiency. First step was implementing the EU Directive on energy savings that was voted in 2002 and had to be integrated into the Croatian laws until 2006. Due to the fact that more than 40% of energy is consumed by households, the Directive required that focus has to be on energy efficiency in buildings. The major reduction in CO_2 emissions, according to this document, was supposed to happen by rising standards in energy efficiency in new building projects, and by increasing energy efficiency in reconstruction projects on existing buildings with over 1000 m^2 in the first stages.

Beside the EU Directive, there were number of other laws and regulations regarding energy efficiency in buildings that were implemented in Croatian legal system;

- **Energy law** (2001/2004/2007) is the first official paper that underlines the orientation towards efficient use of energy as well as continues reduction of negative impacts on the environment.
- **Low on energy efficiency and environment protection fond** (2003) defines the establishment of a found that is in charge of preparing financial frame for developing and implementing programs and projects in fields of sustainable development, energy efficiency and renewable energy sources.
- **Building construction law** (2003/2004) defines energy saving and thermal insulation as one of the six key demands in construction.

Urban development and construction law emphasizes the importance of energy efficiency and sets an obligation of energy certification in all buildings. According to the regulations, all participants in construction projects are obligated to ensure energy savings and thermal insulation, so that depending on the climate and other influencing parameters, energy consumption In buildings is not higher than the value stated by law, and that at the same time all residents must have satisfying thermal conditions at all time.

According to Croatian norms (*NN 113/2008, 89/2009*), energetic summary of a building includes:

- Transmission heat losses and heat losses due to aeration from inner to outer space
- Transmission heat losses and heat losses due to aeration or heat gains to neighboring zones
- Usable internal heat gains from inner heat sources
- Usable sun heat gains
- Heat losses within the heating system
- Energy gains within the heating system

These norms are in accordance with the legacy in most EU countries. To continue, within the frame of 2006/32/EC directive, steps that needed to me made in order to decrease pay off time in energy efficient building were defined. Following this legal act, all EU countries including Croatia, must increase their efforts in finding the most affordable solutions that bring the biggest energy savings within the minimum pay off period for investments related.

Latest law voted by the Croatian government, concerning energy efficiency in buildings, was (2010/31/EU) - *The Energy Performance of Buildings Directive* (EPBD). One of the key goals of this document is to induce energy efficient measures in order to improve thermal performance of buildings in private and public sector.
Key points for EPBD directive are;

- 20% decrease in greenhouse gas emission by year 2020 with reference to year 1990; or 30% if accepted depending on the economy of the developing countries
- 20% of brutto energy needs provided from renewable energy sources in 2020
- 9% decrease In direct energy consumption until 2016 by implementing energy efficiency measures

1.3.2 Financing of energy efficient projects in Croatia

With the Implementation of *National environment protection and energy efficiency fond* (FZOEU), problem of financing energy efficiency projects has been addressed properly. The propose of the fond was to induce implementation of those activities and measures in energy efficiency, which bring significant improvements for the society, and would not be implemented otherwise by the investor due to the fact they are not bankable or for any other reason

The FZOEU fond offers financing models in areas of;

- energy efficiency in buildings and sustainable development
- energy efficiency in industry, service sector and public sector
- energy efficiency in transport sector in order to decrease CO_2 emissions
- solar energy exploitation
- energy efficiency in centralized heating systems
- use of geothermal energy
- energy exploitation from small hydro plants

- usage of wind energy
- congregation processes

However, creation of such a found did not increase the number of green projects in the building sector as it was initially expected; it proved to be a formal support with no real effect.

Even though housing projects described above were also financed by the government, they were not a part of this found. For financing public housing, the state implemented a different financing model. As part of that model, government set a price of 700 Euro/m^2 that covered costs of project documentation, construction costs, and all other costs related to the building process. This however, was not the final price offered on the market, because the state government issued a law that allows the local authorities to sell the apartments at the price that is not higher that 30% of the price of construction. From this, it is visible that the main idea was to offer the lowest price possible, even if that meant neglecting the quality of the building process. As the price limit was set low, building sites were often poorly located, which resulted in little interest from the buyers.

As mentioned, project was intended to lower housing prices so people who were buying their first apartment or people with lower income were given the advantage in purchase. In accordance with the government, banks offered loans with a long pay off period of up to 31 years with a low fixed interest rate of 5% that was made tax free.

1.3.3 Level of information about energy efficiency in Croatia

Research made in Croatia by the Energy institute Hrvoje Požar (*J. Domac 2003),* is the first survey of this kind, addressing public attitudes, perceptions and knowledge about renewable energy sources and energy efficiency. Results of this survey clearly show that citizens support the use of those energy technologies and sources of energy, which lessen the negative environmental impact, even in the case of higher energy production costs. Survey shows that citizens are relatively poorly informed about the general aspects related to the production, consumption of energy and also about specific aspects related to the use of renewable energy sources.

From the survey it was visible that there is a close connection between level of information about energy efficiency and the amount of money spent on energy. It has been noticed that people who spent more than 30 Euros per month on car fuel, are well more informed then those spending less. The same tendency was noticed among those who spent more than 30 Euros per month on electrical bills, as they were also better informed than those spending less.

Furthermore, research also proved that people with higher university education are significantly better informed then those with finished high school.

When asked to choose one of the most common ways that people save energy in households, it was visible that the level of engagement in that mater is average. More than 55% of the people answered that they never, or rarely, use thermal insulation as a measure to save energy. Further 50% of them never or rarely turn off heating or air condition when possible with intention to save energy.

Table 1.1; Survey on energy saving measures in households on daily bases (J. Domac et al. 2003)

How often do you use the following measures to save energy in your household on daily bases?	Never %	Really %	Often %	Regularly %	No answer %
Turning off heating/air condition	21.6	28.6	35.0	14.8	0.0
Turning off lightning	11.6	22.9	43.0	22.4	0.1
Buying energy efficient house appliances	18.0	31.7	35.5	14.8	0.1
Using warm water effectively	13.6	24.9	34.8	26.7	0.1
Rare use of hose appliances	19.2	40.5	26.9	13.4	0.1
Thermal insulation improvements	**26.8**	**28.9**	**27.7**	**16.4**	**0.2**
Using public transportation more often	24.2	29.1	19.0	27.1	0.6
Some other way	0.0	0.0	0.0	0.4	99.6

Survey showed that more than 65% of the people support additional strict regulations in energy savings in households, as they believe it will have a major impact on energetic balance of Croatia. Also, more than 71 % declared their support for introducing additional eco taxes in industry.

Table 1.2: Survey on general measures to stimulate energy saving in households (J. Domac et al. 2003)

Do you support the following measures to stimulate energy saving	Support %	Do not support %	Don't know %	No answer %
Eco tax on energy for industry	71.3	21.1	7.5	0.1
Eco tax for energy for households	34.0	57.4	8.5	0.1
Implementing strict rules on savings in households	65.2	27.6	7.0	0.2
Restrictions in car usage	61.3	32.4	6.2	0.1
Stricter rules on energy saving in industry	87.4	7.8	4.8	0.1
Subsidies for energy efficient products	90.5	5.9	3.5	0.1
Providing regular information from the responsible institutions	93.3	3.5	3.2	0.1

Within the same survey, people were asked to rate their level of knowledge about some key issues related to energy efficiency; when asked to rate their level of information about the future plans of energy development of Croatia, more than 60% rated their level of knowledge in that matter as low or very low.

Survey also included questions regarding the connection between economic development of Croatia and environmental protection; almost 70% of the people are sure that in Croatia, ecology related topics are not present enough in the media. More than 45% said that Croatia needs new laws and legislations on environmental protection, when additional 22. 3% is not sure if the current laws should be changed or not.

Results of this survey offer a clear justification for trying to address the problem of energy efficiency in buildings with the intention to improve the overall awareness of benefits that energy efficient construction brings.

2.0 Approach

2.1. Objective

The goal of this research was to show a different prospective on a major housing project built in Croatia. The intention was to point out some shortcomings in thermal performance of buildings built within this project, and to prove the discordance between the stated purpose of this project and the actual outcome. This was made based on energy simulations of two buildings that have been selected because they represent the same building approach as most of the other buildings within the program. After modeling and performing the simulations of the current state of buildings, it was necessary to propose some improvements that would result in better thermal performance. Focus in this research is just on heating energy demands, as biggest energy consumer in buildings (Figure 1.2). Heating demands that were calculated, based on the detailed simulation models, were used to determine the living costs and CO_2 emission, which are directly related to heating energy demands. These two factors were analyzed due to the fact that living cost affect the residents directly and are often a decisive factor when purchasing a new flat. Carbon emission, however, is a factor that is important on a grater scale and affects grater population. Results of the research will show that there are various factors that influence the final heating energy demand, and that with simple variations of some of those factors, like building orientation, great savings in energy consumption can be achieved. Results of this research can be used to make some conclusions on a bigger scale, as the buildings analyzed have similar thermal properties with other buildings built within the program. The fact that this research includes heating energy demand represented in living cost, might contribute to greater interest in this topic.

2.2. Building documentation

Simulations are made based on the original documentation gained from the National Real-Estate Agency (APN) . Agency was established with the intention to participate on the real-estate market in behalf of the Government of Croatia within the country borders. Agency is therefore responsible for government subsidized housing projects, and it is acting as an investor in behalf of the Croatian government. APN is also in charge for planning and project development of housing projects financed by the state, according to the needs on the market, which are closely observed through the network of regional centers all over the country.

Documentation that was used for this research included detailed floor plans of selected buildings, as well as list of materials and constructions together with the relevant physical properties. On-site visits were made to prove the congruence of the documentation with the actual situation on the site.

2.3. EDSL TAS simulation program

To get relevant results regarding the performance of selected apartment buildings, EDSL TAS (*Thermal analyses software*) software was selected. This software is one of the most used building modeling and simulation tool, capable of performing dynamic building simulations even on most complex buildings. Besides calculation of heating and cooling loads, it is capable of performing deeper analyses that include; heat transfer, heat loses between construction elements, and many other things related.

TAS software consists of three segments. First is the 3D modeler that enables the modeling of the building according to its geometrical properties, and were zones to certain spaces are assigned, according to the space conditions. This segment includes modeling of windows and doors, but also surrounding buildings, when needed. Second segment is the Building simulator; in this segment all data regarding the materials and material properties of construction elements is inputted. Here it is also possible do define other important parameters like, weather conditions, internal conditions in buildings and heating or cooling schedules. Third segment of the software is the result viewer, which allows in depth analyses of the model made. Here, it is possible to define the type of results the user needs In order to get more concise results.

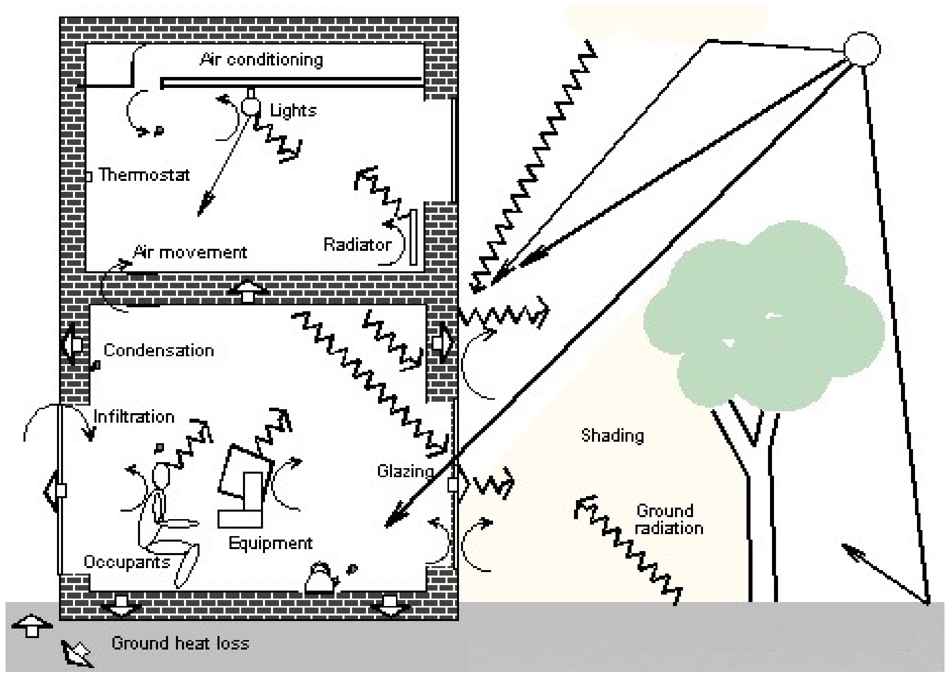


Figure 2.1 ; Heat transfer mechanisms in buildings (EDSL TAS manual 2011)

2.4. Climate data

By official standards, climate in Zagreb is defined as Oceanic climate but near the boundary to the humid continental climate. Summers are warm with average temperatures of 22C, when in winter the average temperature is -0,5 C, but can drop up to -10 on the coldest day.

In this research, weather file gained for the city of Zagreb was imported into the EDSL TAS simulation tool. This file contains relevant climate data to perform dynamics simulations.

Table 2.1; Average yearly weather values for Zagreb (Meteorological and Hydrological service of Croatia 2011)

	Average temp. C°	**Aps. Max C°**	**Aps. Min C°**	**Num. of days**	**Num. of days**	**Num. of days**
January	-0.1	19.4	-24.3	4 ($t_{min} \leq -10^oC$)	8 ($t_{max} < 0^oC$)	24 ($t_{min} < 0^oC$)
February	2.0	22.2	-27.3	2 ($t_{min} \leq -10^oC$)	4 ($t_{max} < 0^oC$)	19 ($t_{min} < 0^oC$)
March	6.2	26.0	-18.3	0 ($t_{min} \leq -10^oC$)	1 ($t_{max} < 0^oC$)	12 ($t_{min} < 0^oC$)
April	11.0	29.4	-4.4	2 ($t_{min} < 0^oC$)	-	1 ($t_{max} \geq 25^oC$)
May	15.8	33.2	-1.8	0 ($t_{min} < 0^oC$)	-	7 ($t_{max} \geq 25^oC$)
June	19.2	37.6	2.5	15 ($t_{min} < 0^oC$)	-	3 ($t_{max} \geq 25^oC$)
July	20.8	40.4	5.4	22 ($t_{max} \geq 25^oC$)	-	7 ($t_{max} \geq 30^o$)
August	20.1	39.8	3.7	20 ($t_{max} \geq 25^oC$)	-	6 ($t_{max} \geq 30^o$)
September	16.0	33.5	-0.6	8 ($t_{max} \geq 25^oC$)	-	1 ($t_{max} \geq 30^o$)
October	10.8	28.3	-5.6	2 ($t_{min} < 0^oC$)	-	1 ($t_{max} \geq 25^oC$)
November	5.7	25.4	-13.5	0 ($t_{min} \leq -10^oC$)	1 ($t_{max} < 0^oC$)	9 ($t_{min} < 0^oC$)
December	1.3	22.5	-19.8	1 ($t_{min} \leq -10^oC$)	6 ($t_{max} < 0^oC$)	21 ($t_{min} < 0^oC$)

2.5. Zoning in EDSL TAS

TAS simulation program has the possibility of defining spaces in building models as zones. In TAS, zone defines an area within the building In which air temperature and humidity are assumed to be uniform. Different zones are usually assigned to spaces that have different properties, or if it is necessary to make a separate analyses for certain spaces. Within internal conditions it is possible define ventilation rate, infiltration rate, occupancy sensible load, equipment gains, light gains, and thermostat. For each zone it is possible to define thermostat conditions by assigning upper and lower temperature value when the heating turns on or off.

2.6. Residents profile

It was mention in the opening chapter that buildings in city part Špansko are mostly inhabited with younger population, often young families with one or two children. For most of them, this was their first home after starting a family life. Good road connections, schools, kindergartens and shops, offer a good life quality, and make it possible for the residents to find everything they need for their everyday life within the block.

Assumptions on the residents' behavior were made based on the list of residents that was provided from the National Real estate agency (APN). No additional research concerning residents' behavior has been made.

Simulations are therefore based on the assumption that most flats are inhabited with two to four residents, as stated on the residents list, and that majority of them are employed. This was important due to the fact that heating schedule was set in a way that the heating was turned off in certain parts of the day; when it was assumed that the flats were empty. Other factors that might influence the heating profile, like equipment in apartments, were taken with standard values and are listed later in the text (Table 2.8).

Small deviations between the values used in the simulation models and actual conditions in buildings are possible, but they do not influence the results in a grater scale.

2.7. Heating demand simulations

Three scenarios for thermal envelopes have been simulated for this research. First case included simulations of buildings as there were built, with material selection and U-values as stated in project documentation available. This simulation scenario had the purpose to show the actual condition of buildings in terms of thermal behavior. Simulation results obtained from this scenario were then used as a reference for further retrofitting that was made in the building envelope in other two scenarios, with purpose to achieve better thermal performance. Second simulation scenario included improved building envelope, based on the results from the analyses of the first scenario. Materials with better conduction values have been selected, and insulation on all walls has been improved. Changes in the building envelope were made with the intention to improve the thermal performance of the building by making simple interventions, which do not include rearrangement of the main construction elements, or rearrangement of the existing floor plans. Furthermore, all construction elements, like doors and windows were kept as in current condition; only better thermal properties were assigned to them.

Third scenario involved thermal performance analyses with material selection that would satisfy passive standards conductance values for construction elements. This scenario included application of shading systems and increased indoor ventilation as standard for passive building. Proposed improvements in the building envelope for the third scenario were made based on analyses of first two simulation scenarios.

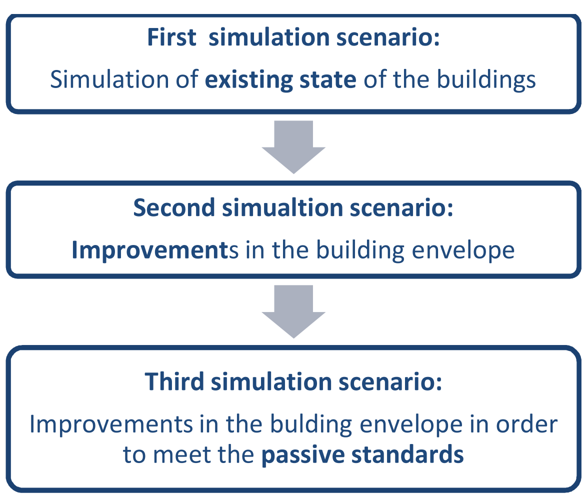


Figure 2.2; Flow chart of simulations scenarios for both buildings

All three scenarios were simulated with same internal conditions, with just ventilation rate in passive case set higher than in other cases as mentioned before.

Following Internal condition parameters, as important factor for the simulations, were taken into account; human sensible gain, human latent gain, light gain, equipment gain.

Human sensible gain represents the heat gain into the certain zone due to the metabolism of the occupant, and is represented in watts per unit of floor area. Human latent gain; heat or moisture gain into the certain zone due to the metabolism of the occupants. Light gain; the heat gain into a certain zone due to artificial lightning, also expressed in watts per unit of floor area. Equipment gain; heat gain into the zone due to equipment usage, expressed in watts per floor area.

As simulated buildings are residential, heating schedules and thermostat settings were assigned to the model, simulating actual living conditions as close as possible. Other spaces in the building have been modeled with internal conditions that represent the actually situation on site; basement area, staircases and hall areas were set as unheated spaces with higher ventilation rates. Attic area was also modeled as unheated, with increased infiltration rate, as there are possible leakages in the roof construction.

2.8. Carbon dioxide emission calculation

Along with reduction of heating costs, better thermal performance decreases the impact of gas emission on the environment. For selected buildings carbon dioxide emission was calculated based on *International Guidance for Climate Change guidance* .Procedure of calculating gas emissions that are a product of fuel combustion, is based on the following points;

- Determining the fuel consumption
- Determining the amount of energy that would be released by fuel combustion, by multiplying the amount of energy with lower end calorific values of specific fuel

Total amount of energy gained from a specific energy source was calculated by multiplying useful heating energy with efficiency coefficient of the heating system:

$$\mathbf{Q_T} = \frac{\mathbf{Q_k}}{\eta_t} \quad (1)$$

- $\mathbf{Q_T}$ **- total heating energy**
- $\mathbf{Q_k}$**- useful heating energy**
- η_t **- efficiency coefficient of the heating system**

Total heating energy that was calculated was then multiplied by the emission factors for CO_2, and with correction factors for uncompleted combustion of fuel.

$$m_{CO_2} = C_f \mathbf{Q_k} \zeta_b \quad (2)$$

- m_{CO_2} **-** $\mathbf{CO_2}$ **emission**
- C_f **– carbon emission factor for specific fuel**
- $\mathbf{Q_k}$ **- useful heating energy**
- ζ_b **- carbon burnout factor for specific fuel**

2.9. Site selection

Within Zagreb, there are two large sites that were selected for subsidies housing project; one in the eastern part of the city, and the other one in the western part, with good connections to both high way and city center. This research analyses the one in the west part of the city .

Besides government housing, this new city block, Špansko, was developing fast in recent years, as it was attractive due to good connectivity and it was still affordable in comparison to some other blocks closer to the center. Construction of new apartment blocks was accompanied by rapid development of shops, cafes, schools and kindergartens, offering better living standard for the residents.

Picture (Figure 2.3) below shows the plan of the newly built site, with two selected buildings marked in color; Building 1 marked orange, and Building 2 marked green. Whole neighborhood was built on the same building principles, with almost the same construction materials. As it can be noticed on the plan below, two buildings with different orientations were selected, as orientation of the building can have a significant influence on the final energy demand.

Figure 2.3 ; location of the buildings within the newly built site; Building 1 marked orange, Building 2 marked green

Selected buildings are surrounded by other residential buildings at a relatively close range. This was important because of the shadow effect that can be created by the surroundings, which influences the solar gains for the selected buildings. Therefore, surrounding buildings have been modeled in TAS simulation program as well, but just using the outside dimensions, to simulate the possible shadow effect.

2.9.1 Building 1 description

Building 1, marked green on the picture above is 56,5m long and 34,0 m wide consists of two detached parts ; oriented southwest- northeast, with 10 m distance between them. The space between is a courtyard, but two detached parts are considered to be one building, and were therefore modeled as such.

All together, ***Building 1*** offers 95 residential apartments that are vertically divided between 6 upper floors, ground floor and basement area. Floors 1 ,3 ,5 have the same floor plan, meaning the apartment arrangements on those floors are unique. Floors 2,4,6 also have the identical floor plan, with some minor differences in comparison to floors 1,3,5 Total building high is 23, 4 m, with netto floor area of 9859,65 m².

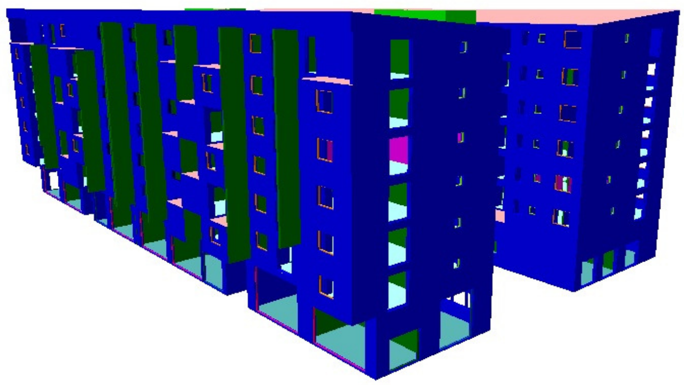


Figure 2.4 ; Simulation model of Building 1

Figure 2.5; Picture of building 1, north facade

Main construction element used was reinforced concrete, with bearing walls placed on repeating distance of 620 cm. Bearing wall thickness for all floors was 20 cm, while longitudinal walls are made of 30 cm thick brick. All walls in basement, garage and storage areas have cement finish. Foundations were made of reinforced concrete, 45 cm thick.

Apartment floors were made of wood, with tiles on kitchen and bathroom floors. Building is heated with floor gas heating system, separate for each apartment. All apartment rooms are predicted to be ventilated naturally, which was also taken into account in the simulation models.

2.9.2 Building 2 description

Building 2 is 56,5m long and 14, 08 m wide. Ground floor area was planed leisure area intended for cafes or shops, and each of the higher five floors has additional 9 residential apartments. Basement area includes parking spaces and storage rooms, with additional storage and garbage rooms placed on ground floor, which are all included into the simulation model. Most of the apartments are oriented north-south, with a small angle to the west providing higher solar gains. Apartments on first three floors, including the ground floor, are all about the same size, with almost the same room arrangement. Floors 4 and 5 are occupied with bigger apartments then those on lower floors.

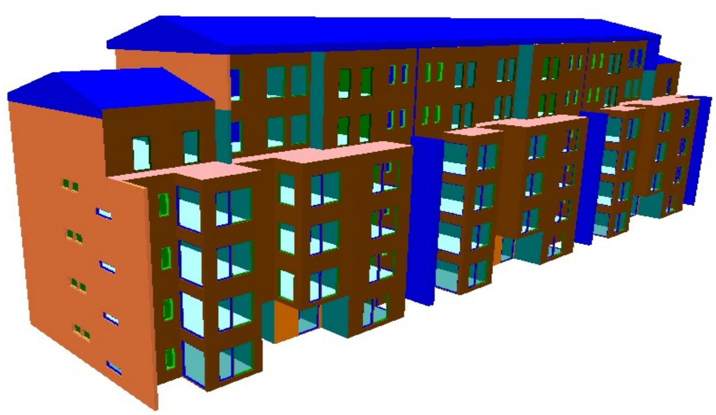


Figure 2.6 ; Simulation model of Building 2

Figure 2.7 ;Picture of Building 2, South facade

Main construction material was reinforced concrete, with wall and slab thickness of 18 cm. Netto floor high is 275 cm. Concrete and brick constructions were insulated with expanded polystyrene. Inner walls in the apartments were made of brick and aerated concrete, with cement plaster finish. Apartment floors in living room area, as well as in sleeping area, were made of lime wood. Floors in the bathroom and in the kitchen area are made of granite tiles.

Building 2 offers the total of 3100,7 m² living area in 45 apartments, with additional 382,6 m² of garage space in the basement area. The whole building has a volume of 16.751,00 m³.

2.10 Thermal properties of selected buildings

As the main construction material was concrete, its thermal properties had a significant impact on overall thermal performance of the building.

In Croatian norms, there is a distinction in construction regulations for different regions of the country so the table below is showing the list of highest U-values allowed for construction elements for continental part of the country, where the buildings are placed.

Table 2.2 ; List of U-values for specific construction elements according to the Croatian norms (HRN EN ISO 6946:2002 0)

Construction element	U-Value $Wm^{-2}K^{-1}$
Outside walls, walls to garage, attic	**0,80**
Walls to unheated space	**1,30**
Walls to ground floor	**0,80**
Floor to ground	**0,65**
Slabs between heated floors	**1,40**
Slabs to unheated space	**0,70**
Slabs to unheated basement	**0,50**
Roofs above heated space	**0,40**

Table (Table 2.2) shows that for Building 1, outside walls have conduction value of 0, 60 $Wm^{-2}K^{-1}$, which was according to the regulations at the time of construction. Inside walls that have no bearing function, had the conductance value of 0.80 $Wm^{-2}K^{-1}$, and are made of block brick with cement finishing, with total thickness of 20 cm. Walls in contact to the ground offer better hydro isolation, resulting in U-value of 0, 60 $\mathrm{Wm^{-2}K^{-1}}$. From the table it is visible that the conductance values calculated are according to the norms, but close to the highest values allowed.

Table 2.3; Thermal properties of construction elements for Building 1

Construction element	U value $Wm^{-2}K^{-1}$
Floor to the ground	**1,2**
Outside walls to the ground	**0,60**
Outside walls	**0,60**
Inside walls between apartments	**1,35**
Inside walls to staircase and storage rooms	**0,80**
Roof	**0,36**
Slab to attic	**0,41**

Important construction elements, in terms of thermal behavior, are windows and doors. All built in windows were wooden, but better material selection would contribute to better thermal performance as big heat losses can occur through the windows. Current windows for both buildings reach the U-value of 1, 8 W$m^{-2}K^{-1}$. Glazing for the windows and balcony doors have the U-value of 1,36 W$m^{-2}K^{-1}$ and therefore offer significant room for improvement.

Table 2.4; Thermal properties of construction elements for Building 2

Construction element	**U-Value** W$\boldsymbol{m^{-2}K^{-1}}$
Outside wall and walls to unheated space	**0,60**
Inner walls and walls to unheated staircase	**1,73**
Inner walls between apartments	**0,35**
Floors to the ground	**1,1**
Slabs between floors	**1,16**
Slab to unheated attic	**0,43**
Roof	**0,61**

List of construction elements for Building 2 shows that some U-values calculated were higher than values allowed by the norms, and that some construction elements have higher conductance values then those in Building 1, which is visible when comparing both tables given (Table 2.2 and table 2.3). It can be noticed that in both buildings, floors that are in contact with ground, as well as inner walls are poorly insulated.

2.11 Simulation of buildings

Both buildings are on the geographically same site, and are similar in terms of size and construction materials. Visible from the table in previous chapter construction U-values are fairly good and are in accordance to the building legislation at that time. However, from the results that will be presented in detail later, it is obvious that with a different material selection, significant improvements in thermal properties could have been achieved.

2.11.1 Zoning in Building 1

First building, in text addressed as **Building 1,** consists of two parts that are separated by a courtyard between. As this separation can has an influence on the results of the energy demand calculations, simulation model was made so there is a division between the two parts; so in further text there is a distinction between **Building 1 North** for the part of the building oriented more to the north, and **Building 1 South** oriented more to the south.

Building has a total length of over 50 m, so zones were assigned in respect to the placement and orientation within the floor plan. This means that each floor had two zones assigned to it, respecting the orientation, which made possible to analyze the differences in thermal behavior for every part of the building separately.

Thus, each floor has one zone assigned to the apartments oriented east, labeled **E**, and one zone for apartments oriented West, labeled **W**. As the building has 6 floors all together, apartments in the building are divided between 12 zones in total.

For example; first floor is divided between two zones with labeling as follows: **B N 1E** marked red on the figure below, and **B 1 N W** marked blue. This labeling defines east part of first floor, for north oriented part of building 1.

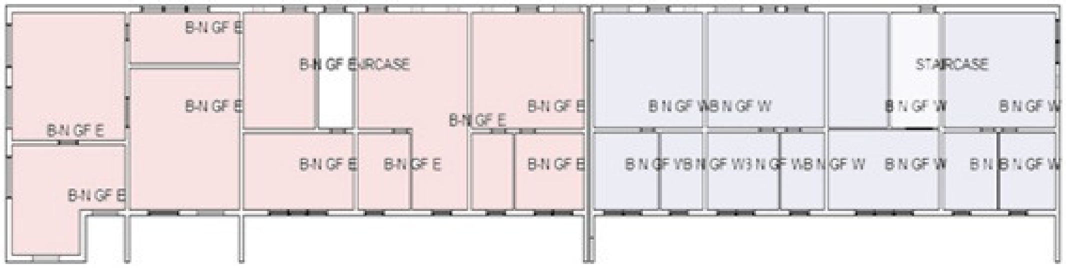


Figure 2.8; Zoning for Building 1, example for Ground floor

Table 2.5 ; Zones in Building 1 North, with associated floor areas and volumes

Name of the zone	Floor Area (m^2)	Volume (m^3)
B-N GF E	260,35	1002,37
B N GF W	204,23	786,30
B N 1 E	197,68	504,09
B N 1 W	172,05	438,73
B N 2 E	223,06	568,80
B N 2 W	196,91	502,13
B N 3 E	207,43	528,96
B N 3 W	183,34	467,52
B N 4 E	223,41	569,71
B N 4 W	197,74	504,25
B N 5 E	207,43	528,96
B N 5 W	183,34	467,52
B N 6 E	208,41	531,45
B N 6 W	159,05	405,58
BASEMENT	1024,81	2613,28
STAIRCASE	278,24	900,38
ROOF	1087,93	451,69

Same zoning method and labeling was used for south part of the building; list of zones is given in the table.

Table 2.6 ; zones in Building 1 South, with associated floor areas and volumes

Name of the zone	Floor Area (m²)	Volume (m³)
B S GF E	238,02	916,39
B S GF W	196,28	755,71
B S 1 E	222,32	566,94
B S 1 W	192,39	490,59
B S 2 E	228,54	582,80
B S 2 W	201,13	512,88
B S 3 E	222,70	567,90
B S 3 W	192,39	490,59
B S 4 E	227,08	579,07
B S 4 W	200,20	510,63
B S 5 E	222,70	567,90
B S 5 W	192,39	490,59
B S 6 E	215,72	550,09
B S 6 W	188,29	480,15
BASEMENT	1024,81	2613,28
ROOF	1087,93	451,69
STAIRCASE	294,40	924,77

2.11.2 Zoning in Building 2

Second building is smaller than the first one, and consists of only one part. Zoning for this building was also made with respect to apartment's orientation. Similar like in Building 1, each floor was divided, but now into three parts; East, Middle, and West, following the building raster. This division is represented in the following labeling for each floor; E, Midd, W. Respecting this labeling, first floor was divided in three zones as follows; 1st floor E marked red, 1st floor Midd marked green , 1st floor W marked blue (Figure 2.9).

Figure 2.9; Zoning for Building 2, example of the ground floor

Table 2.7 ; zones in Building 2, with associated floor areas and volumes

Name of the Zone	Floor Area (m^2)	Volume (m^3)
GF W	139,261	382,968
GF MIDD	140,567	386,559
GF E	142,842	392,816
1st floor E	176,044	484,122
2nd floor W	172,012	473,033
2nd floor MIDD	172,294	473,809
2nd floor E	176,044	484,122
3rd floor W	172,012	473,033
3rd floor MIDD	172,294	473,809
3rd floor E	176,044	484,122
4th floor W	134,22	369,104
4th floor MIDD	132,91	365,501
4th floor E	137,89	379,197
5th floor W	81,47	224,043
5th floor MIDD	112,821	310,258
5th floor E	50,831	139,786
Staircase	28,863	601,666
Hall	417,557	1148,281
Basement	647,07	2167,686
Roof space	560,052	563,341
1st floor W	172,012	473,033
1st floor midd	172,294	473,809

As the temperature conditions are not the same for the whole building, zones Staircase, Basement, Hall and Roof are assigned as those areas of the building have different conditions and are modeled as unheated spaces.

2.11.3 Internal conditions

As buildings 1 and 2 are both residential, and were constructed in a similar way, same internal conditions have been applied in first two simulation scenarios. Having in mind that the buildings are newly constructed, for apartment rooms in both buildings ventilation rate rate of 0,4 air changes per hour was assigned. Infiltration, ventilation and air movement between zones in building are important because they cause transfer of heat between air masses, which is represented by mass flow, temperature difference and the heat capacity of air. In apartments, heat gains that are emitted by the metabolic processes of residents are taken into account with the occupant sensible gain set to 2 Wm^{-2}Heat gains that are emitted from the equipment in the apartments, were calculated with a value of 1 Wm^{-2}, so that the total internal gains do not exceed 5 Wm^{-2} as it is defined by Croatian standards . For apartment areas, thermostat is set to turn on when inside temperature drops below 20 C°, offering sufficient thermal comfort.

In hall area, basement and roof spaces, conditions were set differently than in apartment zones; they were assigned with different internal conditions values and were modeled as unheated space.

Table 2.8 ; Internal conditions for all apartment zones in Buildings 1 and 2

	Values	**Units**
Ventilation	0,4	(ach)
Lighting Gain	2	(W/m²)
Occupancy Sensible Gain	2	(W/m²)
Equipment Sensible Gain	1	(W/m²)

2.12 Improvements in building envelope

Simulation results of the current state of buildings have showed that material selection and material properties were offering significant room for improvement. To achieve better thermal performance, the most effective way was to increase the thickness of the insulation.

As mentioned before, these buildings had thermal insulation that is mostly in accordance to the building standards required at the time of the construction; however it was already then known that new legislations are coming in force within a very short time after construction. As described, the proposed improvements will be analyzed based on two scenarios. Improvements in the building envelope were simple, and do not include rearrangement of any construction parts, or rearrangement of floor plans.

2.12.1 Scenario 1 improvements

To make better comparisons of the final results, both buildings used the same materials with corresponding U-values for certain construction elements in the improved scenario. Improvements include thicker insulation on the outside walls, with 10cm insulation, instead of existing 6cm for Building 2, and 8 cm for Building 1. The same insulation type was added as in the existing state, but just with better properties and different thickness. List of construction elements and according U-values is given below.

Table 2.9 ; List of U-values for construction elements in Scenario 1

Construction element	**U value,** $Wm^{-2}K^{-1}$
Floor to the ground	0,4
Outside walls to the ground	0,35
Outside walls	0,40
Inside walls to staircase and storage rooms	0,50
Roof	0,30
Doors	0,8
Glazing	0,8

From the table above (Table 2.11) it is visible that biggest improvements in thermal properties of construction elements were made for ground floor construction and for the roof construction. This two construction elements proved to be the weakest points in the thermal envelope, so just by improving those to elements, significant savings can be made.

2.12.2 Scenario 2 improvements

Second scenario included selection of insulation so that conductance values would satisfy passive standards in buildings.

This scenario, however, does not include other solutions that are common for passive buildings, but the focus was only on the construction element materials. For this scenario, thickens of insulating materials was increased up to 20 cm for the outside wall, and up to 12 cm stone wool for the floors in contact to ground. Additionally, slabs to the attic space have been insulated with 23 cm thick insulation, as big heat losses have been recorded in the roof area. Good roof insulation can contribute the most in better thermal performance of any building, 30 cm insulation was added to for the roof construction.

Table 2.10; List of U-values of construction elements for Scenario 2

Construction element	U value $Wm^{-2}K^{-1}$
Floor to the ground	**0,12**
Outside walls to the ground	**0,10**
Outside walls	**0,15**
Inside walls to staircase and storage rooms	**0,12**
Roof	**0,11**
Doors	**0,8**
Glazing	**0,8**

Table above shows the U-values of construction elements after the improvement in the insulation. New U-values calculated satisfy the passive requirements for constructions elements according to the Croatian standards.

3.0 Results and discussion

3.1. Building 1 current state

Results of the simulations showed that total heating demand calculated for **Building 1 North** was 159 224 (kWh a^{-1}), which is represented in 56,38 kWh $a^{-1}m^{-2}$. Distribution of the monthly heating loads per area is show in the graph below (figure 3.1)

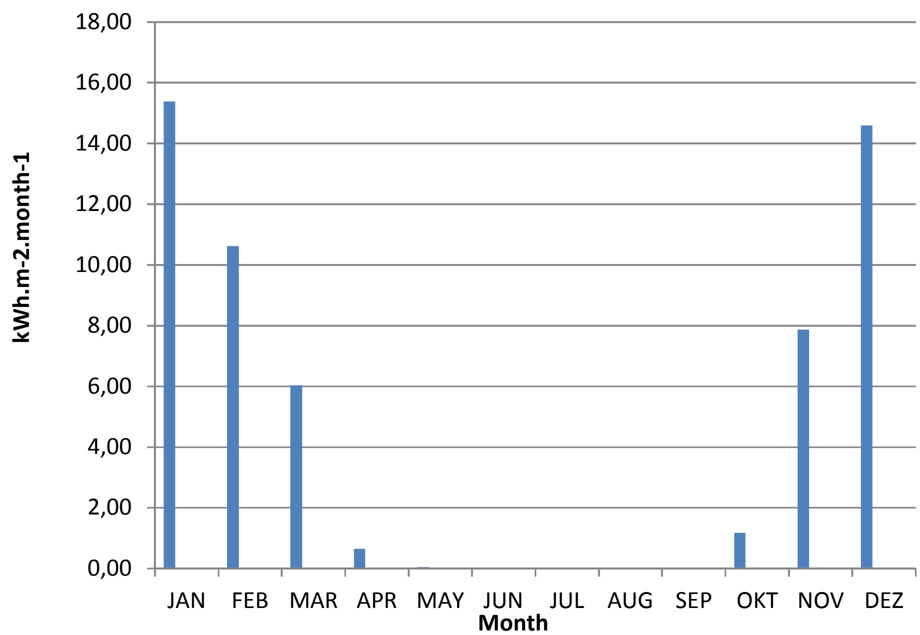


Figure 3.1; Monthly heating load distribution for Building 1 , current state

As expected, the biggest heating loads were recorded in months of January and December, when the heating season is at its peak, and external temperatures are the lowest.

As the building had the thermostat set to turn on when the inside temperature drops below 20 C°, separated are the results for heating demand on the coldest day of the year 26.December ,according to the simulation model. Observing the heating loads just on the coldest day, it was possible to analyze heating demand distribution within the building. Following the division into different zones, , graph below shows the heating profiles on the coldest day of the year for each of the zones assigned.

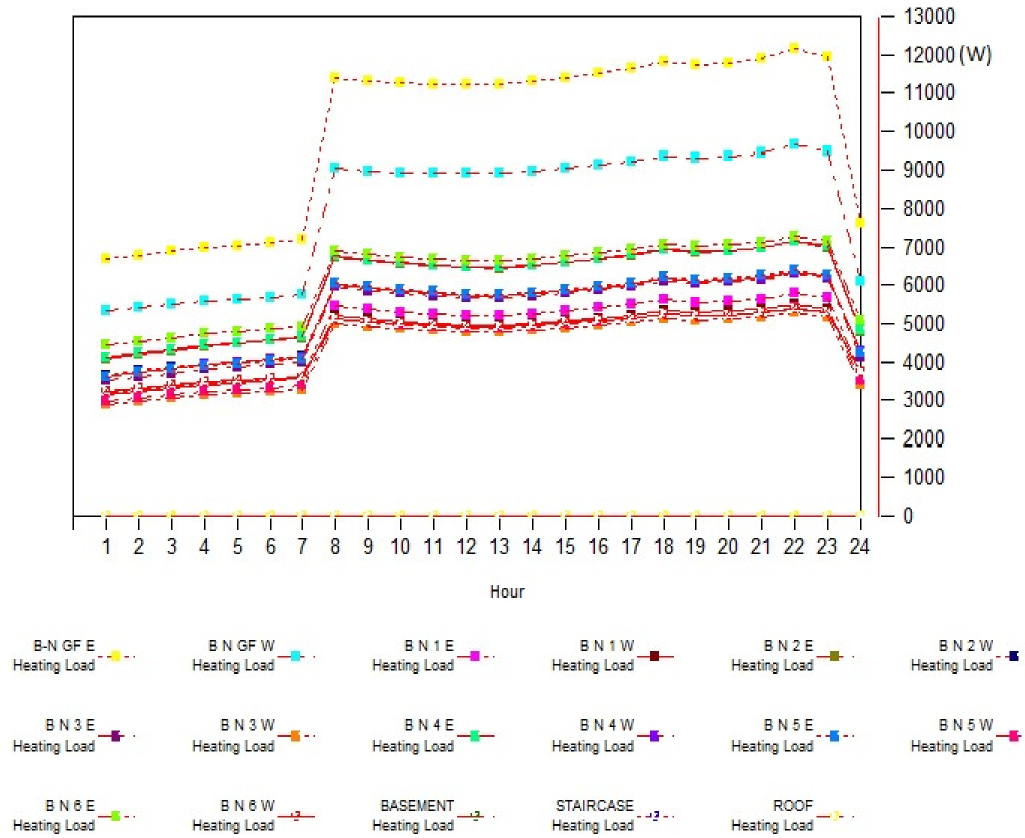


Figure 3.2; Heating load break down on the coldest day of the year for each zone, Building 1 North

Shown on the graph (Figure 3.2) , it is possible to see that the biggest heating load was recorded in the zone- Ground floor East (marked yellow on figure 3.2), as this zone was assigned to big shop areas. High heating loads on ground floor can be explained by large window, which are 2, 5 m high and therefore contribute to higher heating demands in the winter time.

It was also visible that all zones that are assigned to apartment area have roughly the same heating demand, where only a small difference was noticed between apartments oriented east, compared to those oriented west. Heating load distribution for the coldest day of the year also showed the effects of the thermostat which was set to turn off during the night time.

From the graph (Figure 3.2) it is possible to read out that if the shop areas on the ground floor were ignored, biggest heat load is recorded in the apartments on the 4th and 6th floor oriented East.

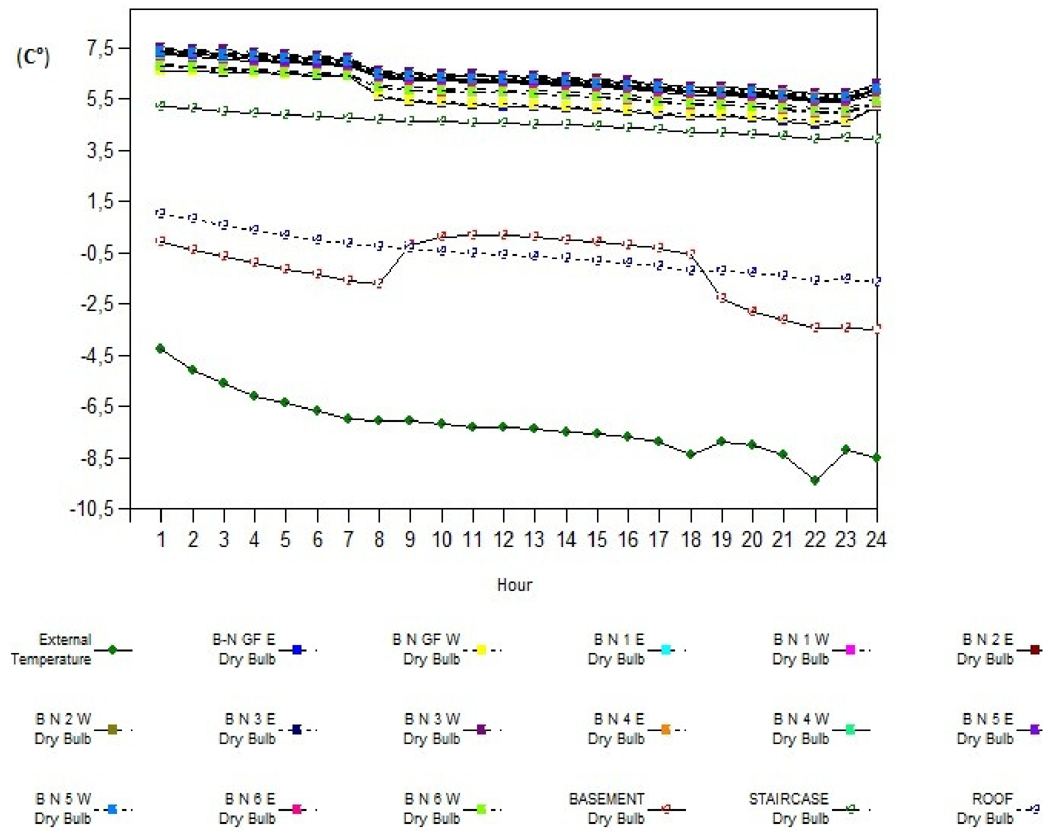


Figure 3.3; Dry bulb temperatures for each zone on the coldest day of the year, without thermostat, Building 1North

As first scenario represents the current state of the buildings, it was possible to simulate and see how these buildings are performing in conditions without thermostat, when there is no heating. These results gave better information on how well is the building performing in terms of thermal comfort. Shown on the graph (figure 3.3)are dry bulb temperatures for each zone on the coldest day on the year ; here it was noticed that inside temperatures in all zones were higher than 3, 5C° , with the exception of the basement and roof area, where temperatures dropped slightly below 0 C° during the night hours on the coldest day. It was noticed, that the indoor temperatures were similar in all zones, varying to 1, 5 C° depending on the orientation and the size of the zones.

Analyses also showed that inside temperature for apartment areas varies from 5,5 C° to 7,5 C° in conditions without heating (Figures 3.3 and 3.4), showing that there is significant room for improvement in terms of thermal comfort.

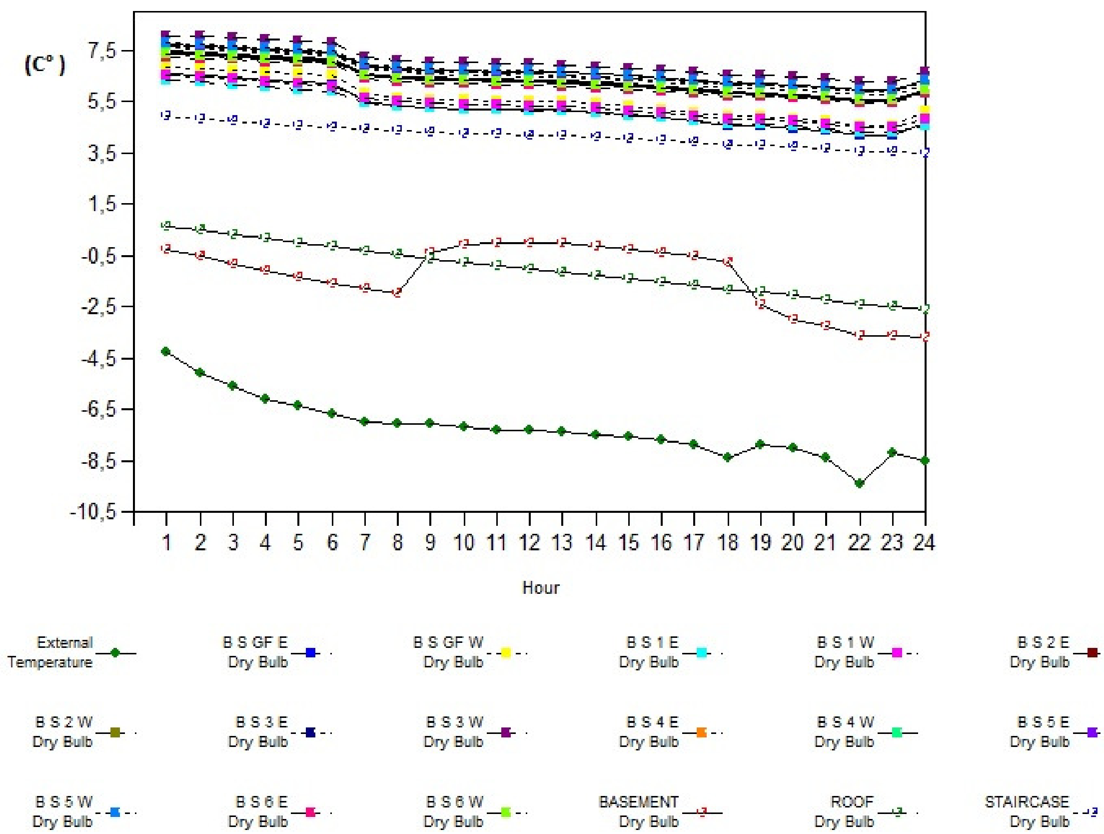


Figure 3.4 ; Dry bulb temperatures for each zone on the coldest day of the year, without thermostat, Building 1 South

Dry bulb temperatures in the **South oriented** part of the building were in average higher on the coldest day of the year. Temperatures recorded never dropped below **5 C°** in the apartment area, which is up to 1,5 C° higher than in the north part of the building.

For part of Building 1 oriented south, overall heating demand for the whole building is 149 111 (kWha^{-1}), resulting in 50,72 (kWh a^{-1}m^{-2}). Even though the same construction elements and materials with the same properties have been used, heating demand is lower than in the northern part, which can again be explained by the orientation of the building.

Compared to the heating load distribution of the north part, it was recorded that south part had no heating loads for the month of September, where as in north part inside temperatures in apartment zones drop below 20 C° on some days in May, resulting in minimal heating loads.

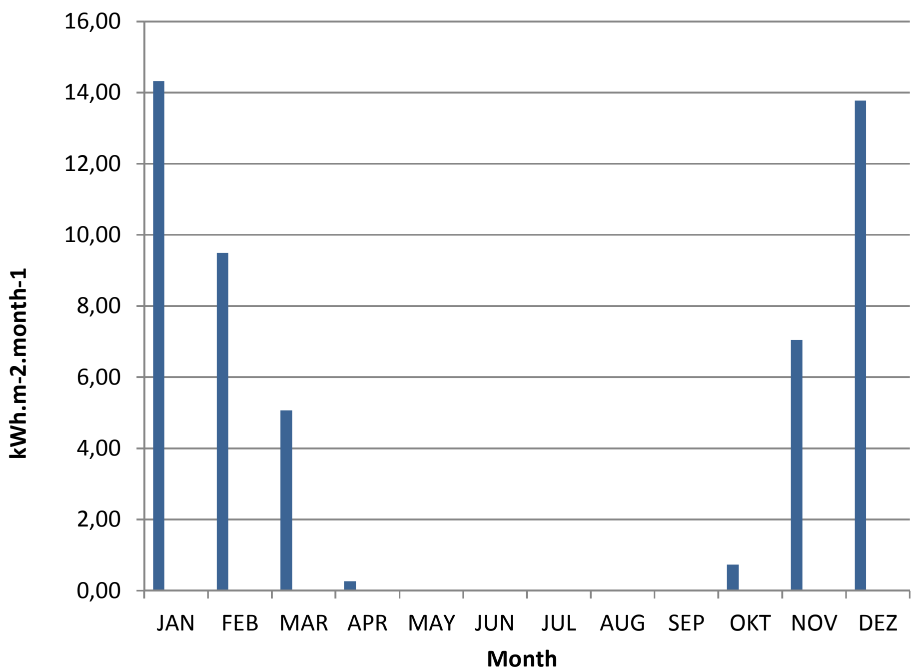


Figure 3.5; Monthly heating load distribution for Building 1-South

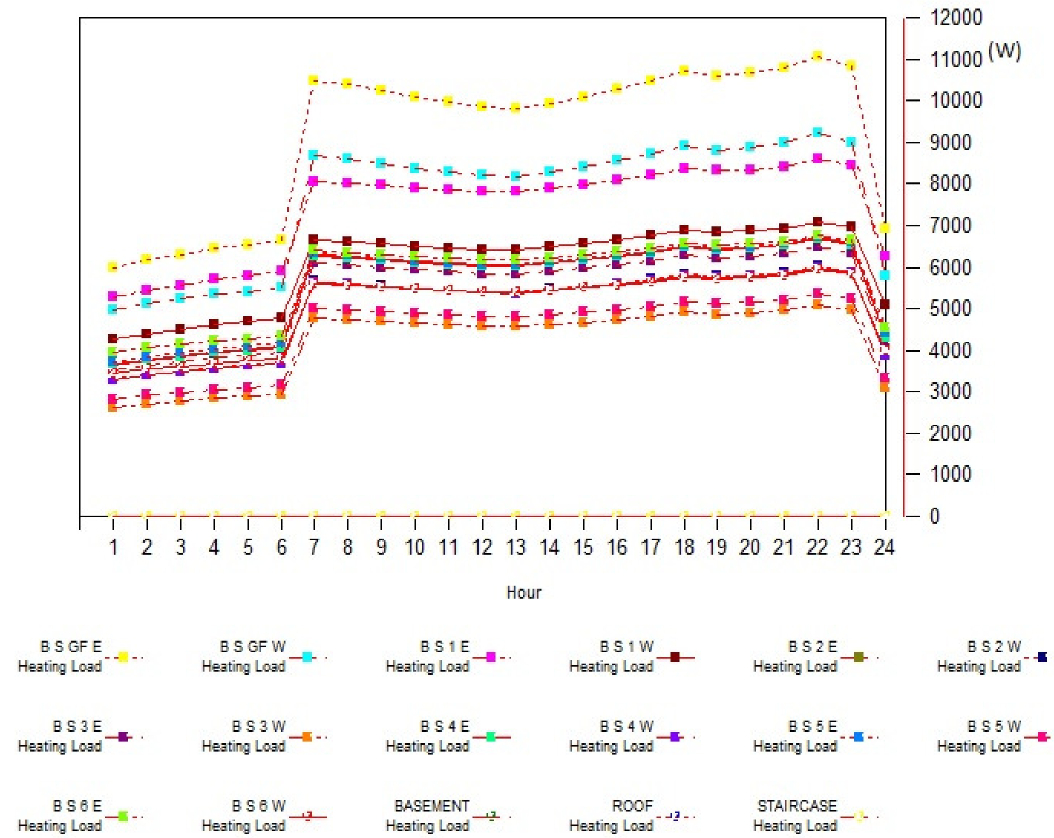


Figure 3.6; Heating load break down on the coldest day of the year for each zone, Building 1 south

From the graph (Figure 3.6) it was visible that apartments oriented more to the east have a slightly higher energy demand 1. Lowest hating demands were recorded on 3rd and 5th with orientation to the west. Influence that orientation of the apartment has on heating loads is best visible on the first floor, where the difference between apartments oriented east (marked purple) and those oriented west (marked black) within the same floor was significant.

Table 3.1; Heating loads overview for Building

	Area of heated zones (m2)	**All year heating load ($kWh\ a^{-1} m^{-2}$)**	**Overall annual heating load ($kWh\ a^{-1}$)**
Building 1-South	2940	**50, 72**	149 111
Building 1-North	2824	**56, 38**	159 224

3.1.1. Building 1-Scenario 1

In previous sections improvements that were made in the building envelope have been described in detail, together with the U-values of the construction elements used. For **Building 1** improvements resulted in significantly better thermal performance. Annual heating load for the North oriented part was reduced to 83 121 (kWh.a^{-1}) or 29, 43 (kWh. a^{-1}. m^{-2}), which was a **47.8 %** improvement compared to the existing state. For South oriented part of ***Building 1*** heating load was reduced to 82 027 (kWh.a^{-1}) or 27, 90 (kWh. a^{-1}. m^{-2}), resulting in **44.9 %** improvement in comparison to the existing state. Simulation showed that improvements had a better influence on the North oriented part, as the reduction in heating loads was 3% better compared to reduction recorded in South oriented part of Building 1. From the monthly distribution of heating loads it was noticed that implemented improvements resulted in minimal loads for the month of October, reducing the heating season to five month.

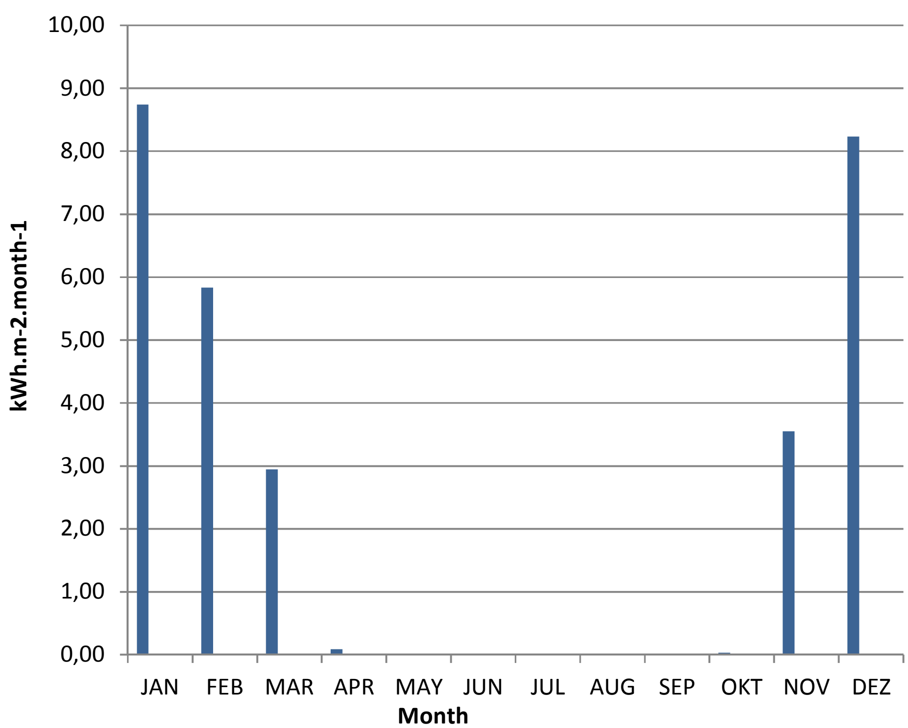


Figure 3.7; Monthly distribution of heating loads for Building 1-North, Scenario 1

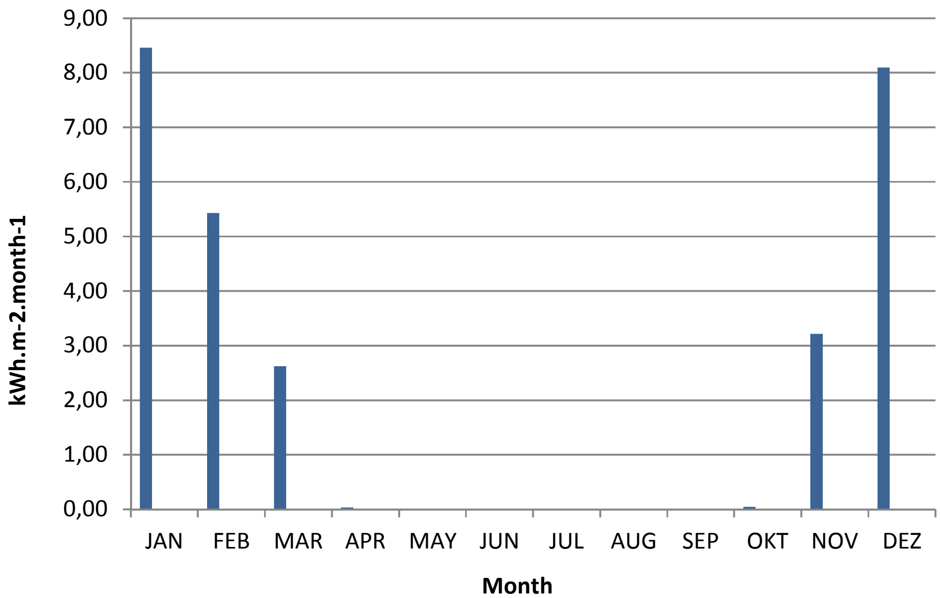


Figure 3.8; Monthly distribution of heating loads for Building 1 South, Scenario 1

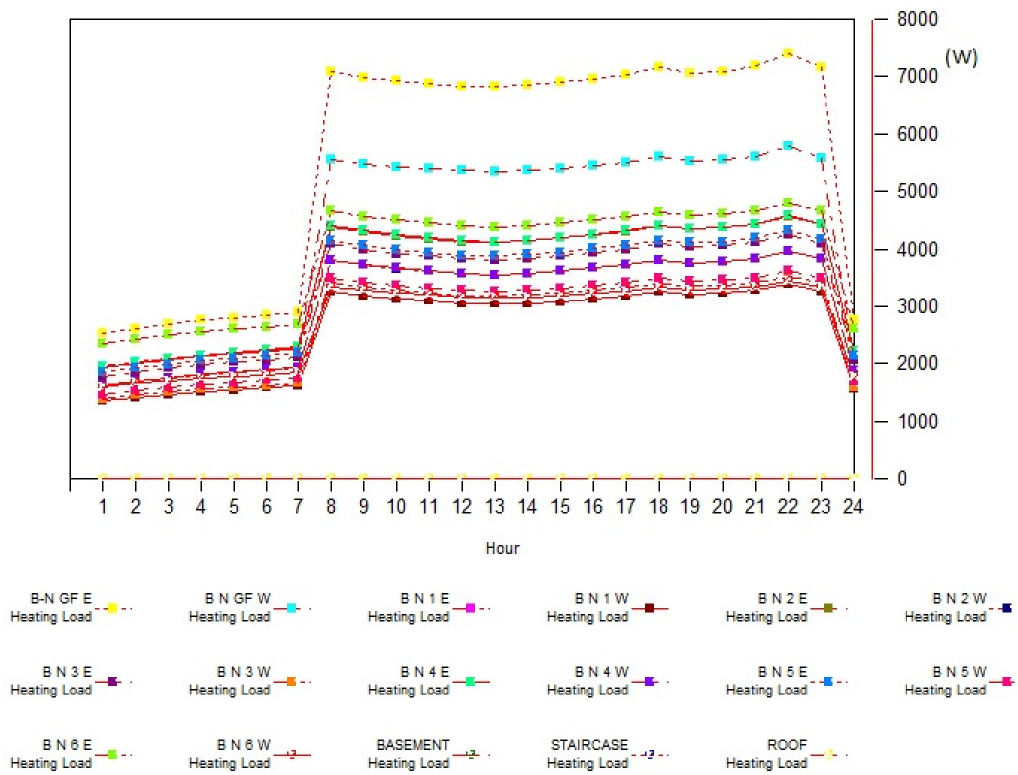


Figure 3.9; Heating load break down for the coldest day of the year-Building 1 North, Scenario 1

Heating load break down for each zone in North part (Figure3.9), showed that there were still differences related with the orientation of the zone, as east oriented zones had bigger heating demands. As in current state scenario**,** high heating loads were recorded in the shop areas on the ground floor.

Simulation results for Scenario 1 showed that lower heating demands were recorded on 2nd and 3rd floor, and are in average up to 30 % lower that the values calculated for 6th floor apartments oriented east.

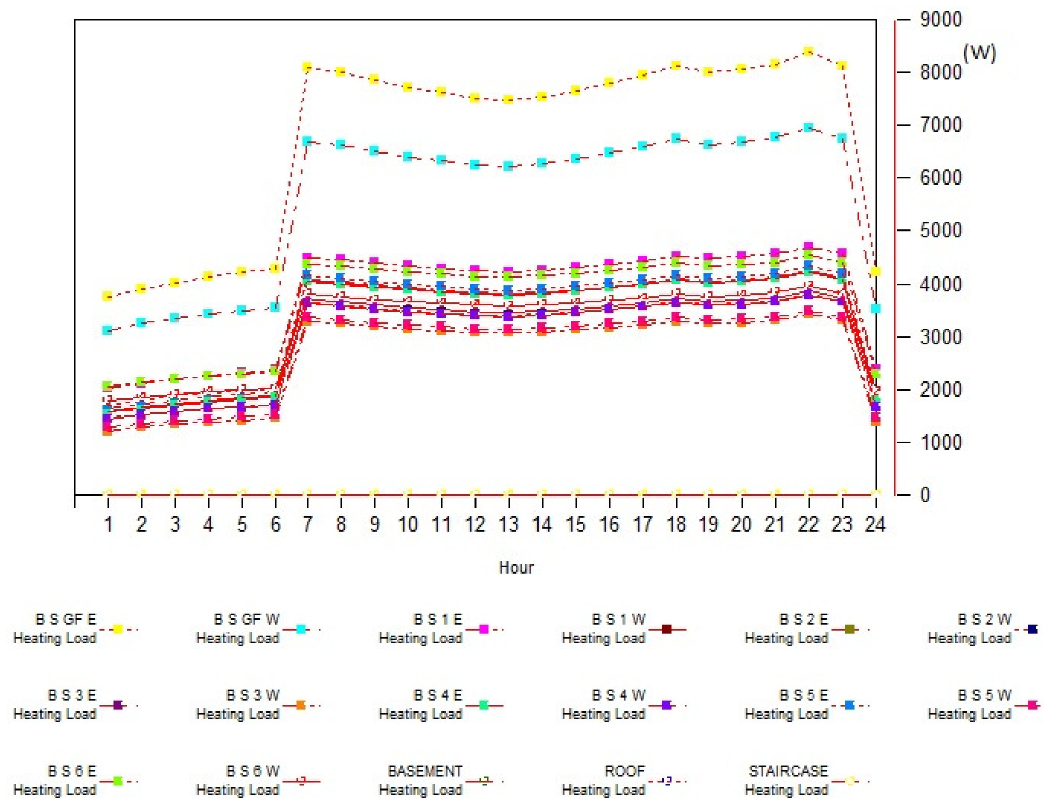


Figure 3.10; Heating load break down for the coldest day of the year-Building 1 South, Scenario 1

Load breakdown for the south part of **Building 1**, showed that the overall loads values were very similar as in north part; however the distribution between zones was different. South part of the 1st floor East (marked pink in Figure 3.10) had the biggest load of all apartment areas; compared to the north part the highest load was recorded in the zone on the 4th floor east.

Table 3.2; Heating loads overview for Building 1 after improvements, Scenario 1

	Energy consumption , current state (kWh.a-1.m-2):	Energy consumption, Scenario 1 (kWh.a-1.m-2)	% improvement, Current state to Scenario 1
Building 1 South	50,72	**27, 90**	44.9
Building 1 North	56,38	**29, 43**	47.8

3.1.2. Building 1- Scenario 2

After implementing standards for passive constructions, building thermal envelope was performing notably better than compared to the existing state. Results showed that even though passive standards and conditions for building constructions were satisfied in terms of conductance , the heating load dropped below 15 (kWh $a^{-1}\ m^{-2}$) ,which is considered passive, in south part of building 1 and Building2, where the north part of Building 1 remained above the value of 15 (kWh $a^{-1}\ m^{-2}$) . The final consumption could have been even lower is some more invasive solutions were implemented; like changing the orientation of the building, or changing the size of the windows on the north side façade . For **Building 1-North** heating demand dropped to 52 952 (kWh a^{-1}) or 18, 75 (kWh $a^{-1}m^{-2}$) which is a **66.74 %** improvement compared to the current state.

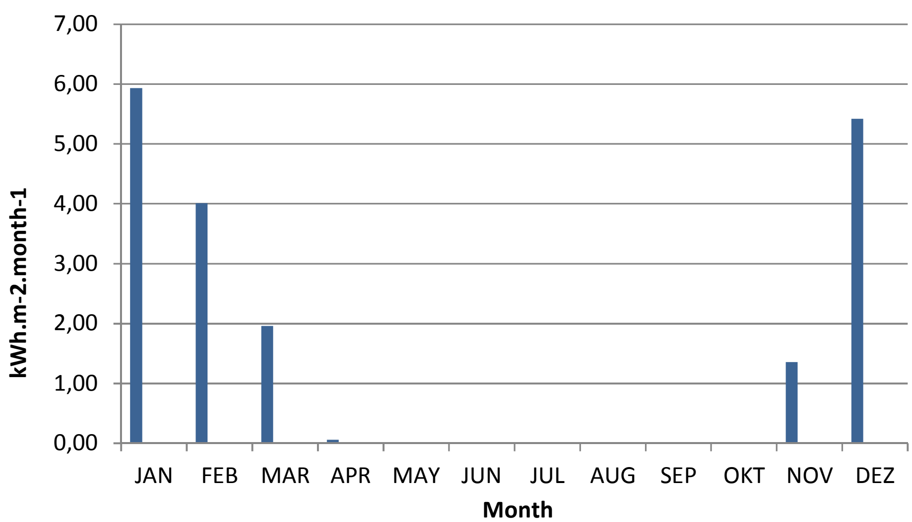


Figure 3.11; Monthly distribution of heating loads for Building 1-North, Scenario 2

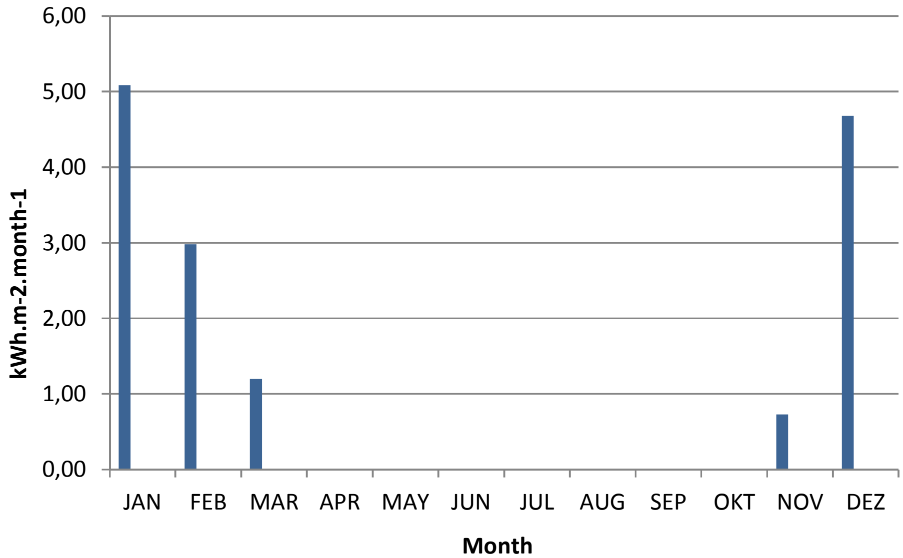


Figure 3.12; Monthly distribution of heating loads for Building 1-South, Scenario 2

In case of south building, heating loads were lower than those in north part of the building, for some 4 (kWh. a^{-1}. m^{-2}) in average**.** Yearly heating load calculated for south part was 43 119 (kWh a^{-1}) or 14, 67 (kWh $a^{-1}m^{-2}$), resulting in significant **71. 08 %** improvement compared to the existing state . Again, it was noticed that for the month of April heating demand was minimal, compared to the Scenario 1, where minimal heating loads existed even in May. Finally, the table below summarizes the effects that implemented improvements in Scenario 2 had on overall heating demand for **Building 1**.

Table 3.3; Heating loads overview for Building 1 after improvements, Scenario 2

	Area of heated zones m²	Energy consumption Current state (kWh $a^{-1}m^{-2}$)	Energy consumption Scenario 2 (kWh $a^{-1}m^{-2}$)	% improvement, passive to improved
Building 1 South	2940	50,72	**14, 67**	71. 08
Building 1 North	2824	56,38	**18, 75**	66.74

3.2. Building 2 current state

Building two had a different orientation that Building 1, as well as some differences in the building envelope, so the simulations of the current condition showed it had lower heating energy demand. The overall heating load for the whole year was 133 073 (kWh a^{-1}) or 50, 54 (kWh $a^{-1}m^{-2}$).

Graph below shows that heating demands in month of April, May and October were minimal. This interesting if heating demand distribution is compared to Building 1 showing a significant difference in heating demand for October

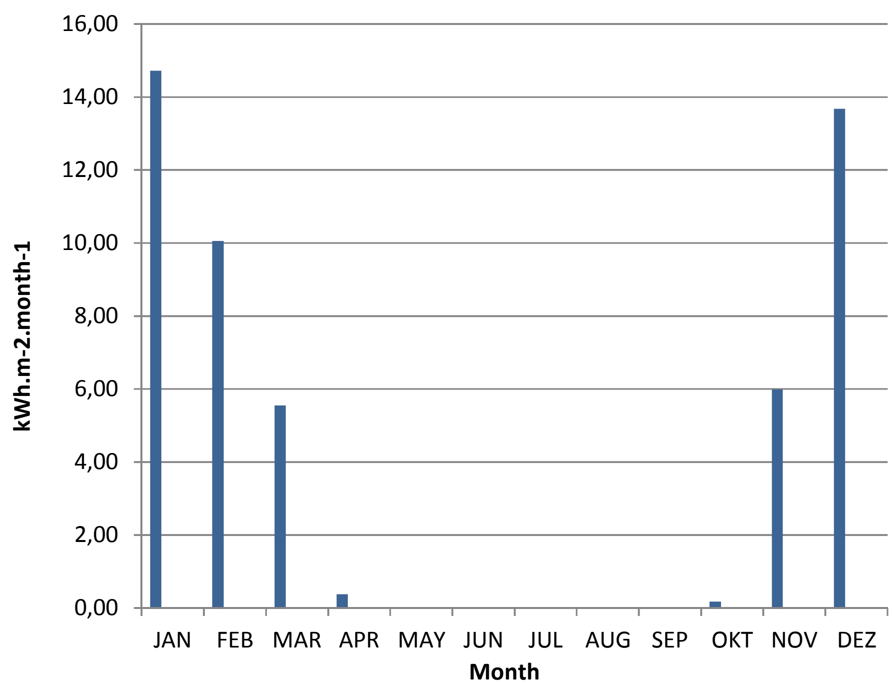


Figure 3.13; Monthly distribution of heating loads for Building 2, current state

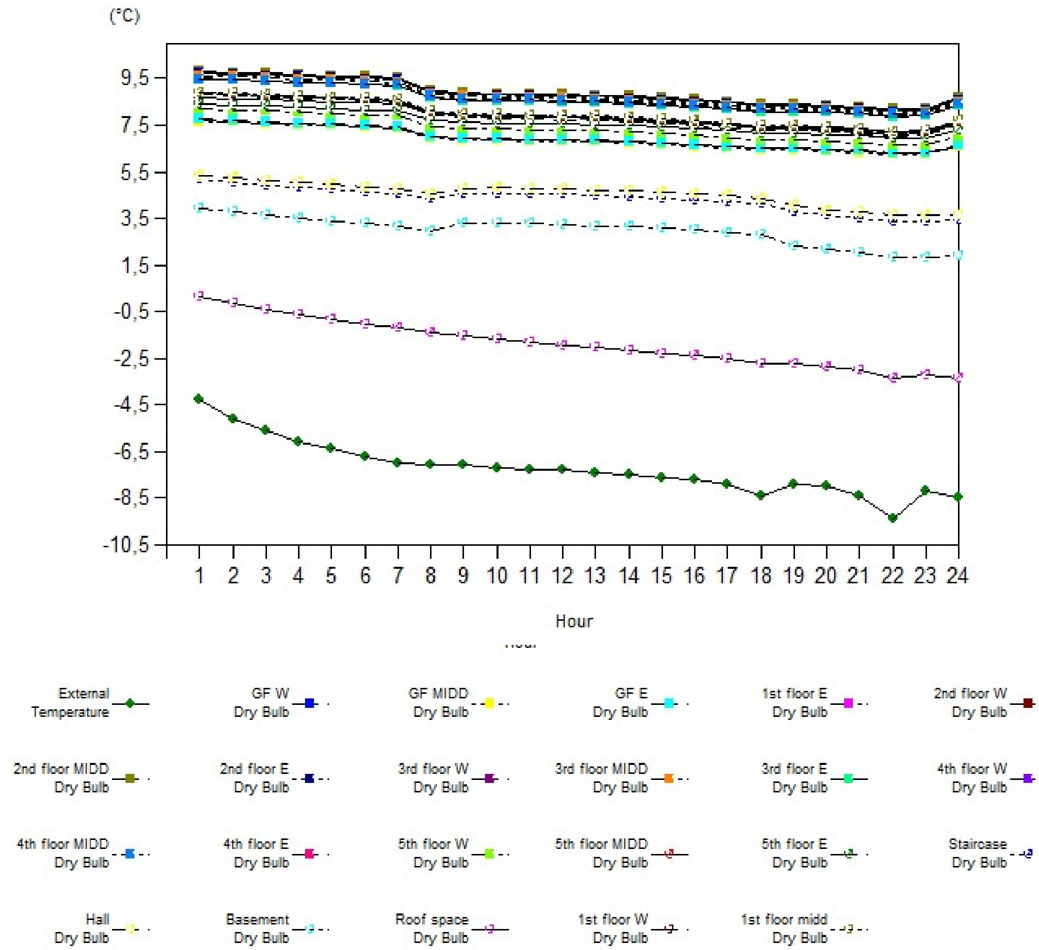


Figure 3.14; Dry bulb temperature for the coldest day of the year without thermostat; current state

Dry bulb temperatures in conditions without thermostat, showed that temperature in all apartment zones never dropped below 5,3 C°, meaning that Building 2 is performing slightly better than building 1, where indoor temperatures were in average 2,0 C° lower (Figure 3.14). Again, this can be explained by better orientation of the building, but also it might be a result of some differences in construction elements.

Heating loads analyses for the coldest day, when the thermostat is set to 20 C°, again showed the difference in heating demands depending on the orientation; best visible on the 5th floor, where differences between west and east oriented zones can be noticed on the graph (Figure

3.15). For the middle part of the 5th floor the heating load was higher due to the face that the area assigned to this zone is much bigger than areas assigned to zones 5th floor W and 5th floor E.

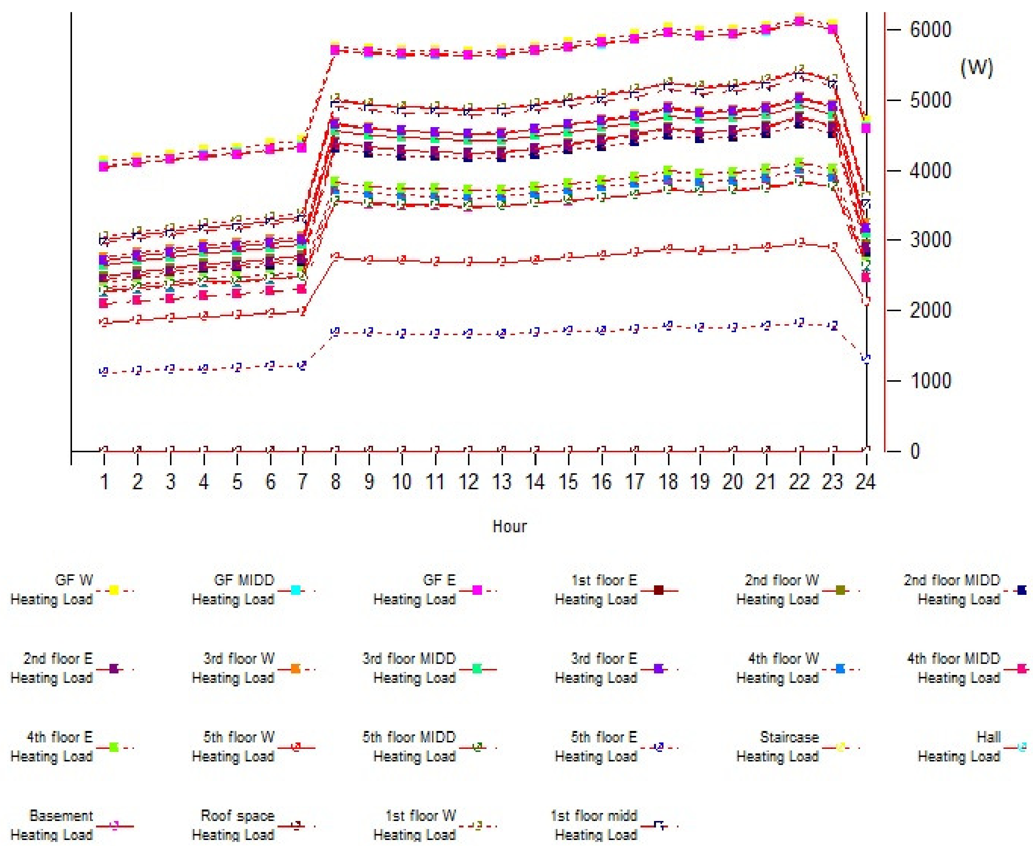


Figure 3.15; Heating load break down for the coldest day of the year-Building 2, current state

3.2.1 Building 2 – Scenario 1

Improved building envelope resulted in overall heating loads decrease by 35, 08%, resulting in whole year heating load of 133 073 (kWh a^{-1}) or 24, 03(kWh $a^{-1}m^{-2}$).

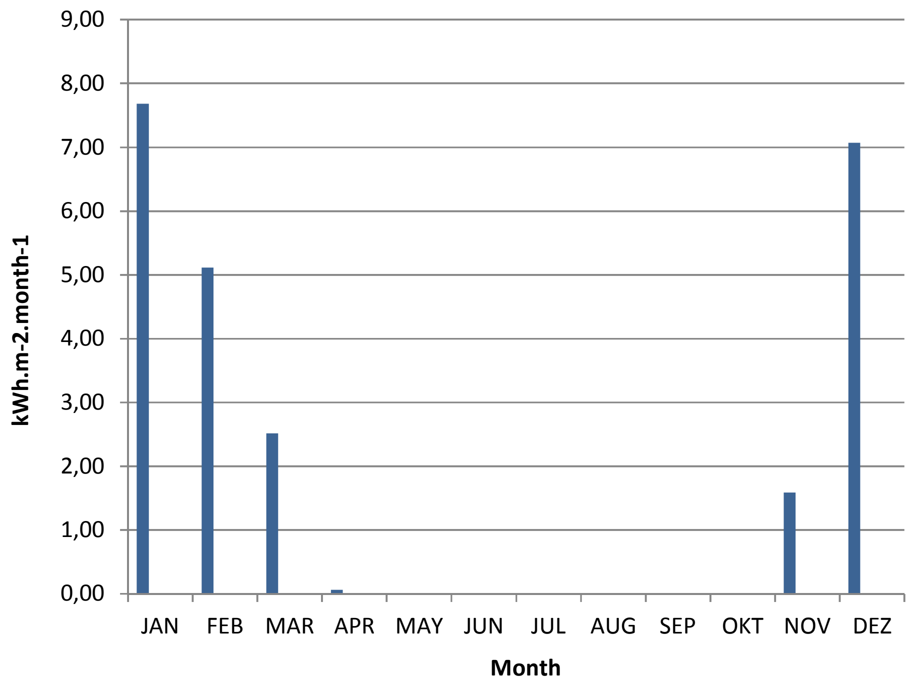


Figure 3.16; Monthly distribution of heating loads for Building 2, Scenario 1

From the graph below it is possible to read out that on the coldest day of the year, highest heating demand was recorded in the apartments on the 3rd floor east (Figure 3.17). Again, differences were the biggest on the 5th floor, where depending on the orientation heating loads within one floor vary up to 1 kW in total for roughly the same area.

High heating demand was noticed on the first floor, but as it is above the storage room, this can have a cooling effect on the apartments. Simulations showed that apartments on the 4th floor have lower heating demands then those on the 2nd and 3rd floor, probably due the heat flow between floor slabs.

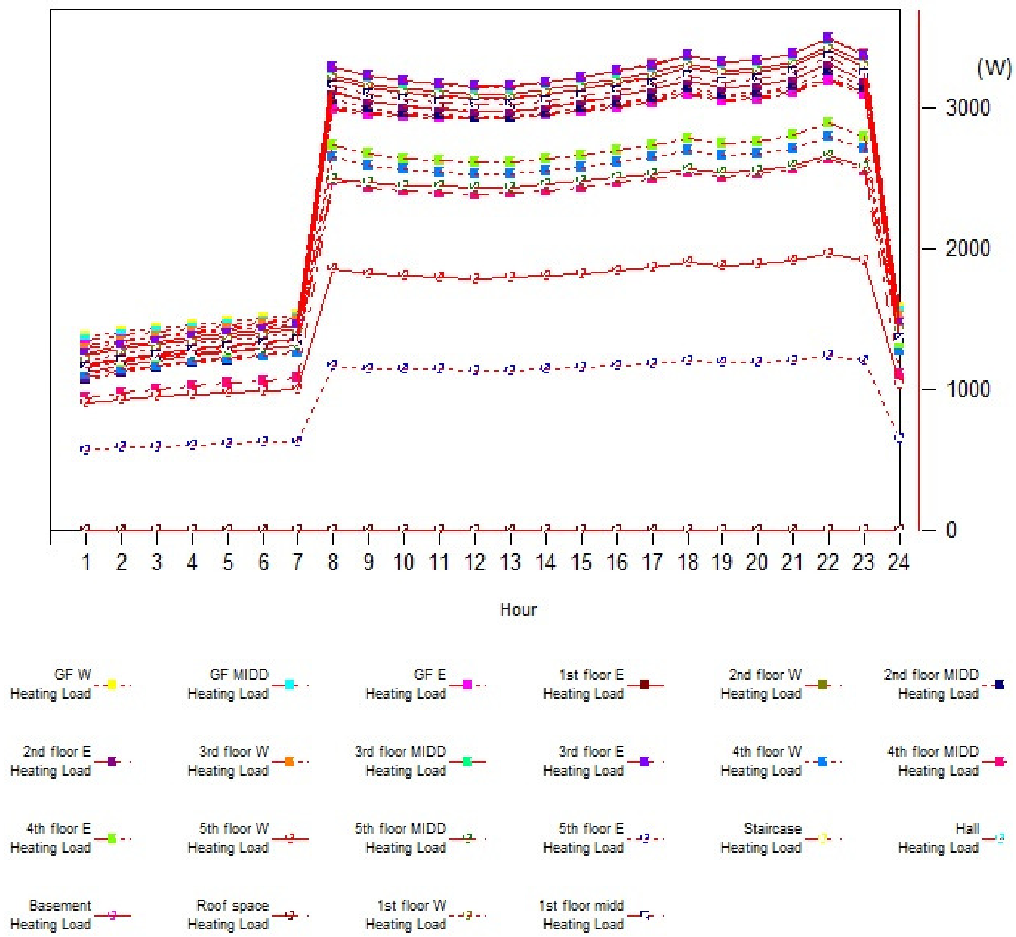


Figure 3.17; Heating load break down for the coldest day of the year-Building 2, Scenario 1

3.2.2 Building 2 –Scenario 2

After meeting the standards for conduction values in passive buildings, heating load for **Building 2** also dropped, as expected, to 10,33 (kWh $a^{-1}m^{-2}$) or 27 187 (kWh a^{-1}) in total. Same as in Building 1 South , heating load dropped below expected 15 (kWh $a^{-1}m^{-2}$).

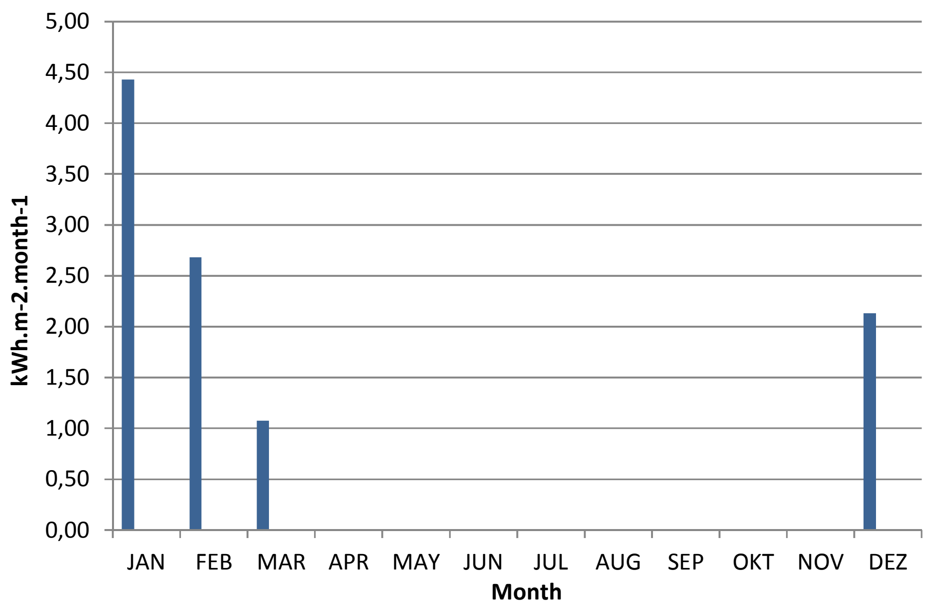


Figure 3.18; Monthly distribution of heating loads for Building 2, Scenario 2

Heating load distribution through the year showed that implementing passive standards in building constructions resulted in significant drop in heating loads as the heating demand was almost 80 % lower than in the current state scenario. Heating loads for the month of October were eliminated which was not the case so far, and even in November there were only minimum heating demands recorded. It is noticeable from the graph (Figure 3.18) that biggest heating demands have been calculated in January, with values almost doubled than in December.

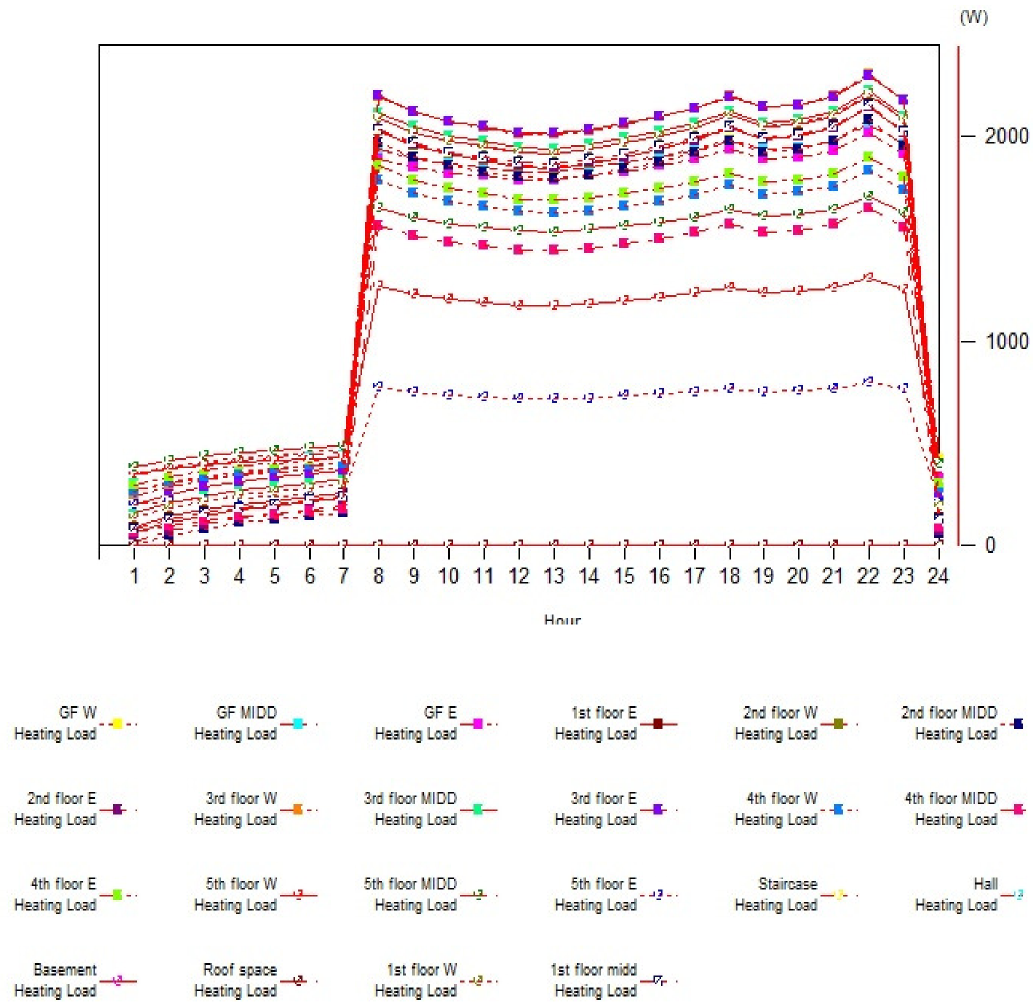


Figure 3.19; Heating load break down for the coldest day of the year-Building 2, Scenario2

Heating load break down for each zone showed that biggest heat loads are on the first and second floor, again with biggest variations on the 5th floor. As on all graphs that are showing the heating break down for the coldest day of the year, it is important to notice the sudden increase in loads that is recorded between 7-23 hours. This happens due to thermostat settings, as the simulation models were made with the assumption that heating is on during that time, as explained in previous chapters.

3.3 Carbon dioxide emission calculation

Besides the clear benefits that improvements of the building envelope had in regard to heating demand and overall thermal performance, another important parameter that is directly influenced by the changes made, is the CO_2 emission. Carbon emission calculations were made for each of the three scenarios analyzed. This gives valuable information about the impact that heating demands of can have on the environment. Carbon emission was calculated based on the heating load values gained for each of the cases analyzed. The calculation method has been described in chapter, but some further values were needed to get the final result. According to the documentation available, buildings are equipped with floor radiating systems, so calculations were made with coefficient of performance (COP) of 0,7. Selected COP value of 0, 7 means that one unit of energy consumed by the heating system, delivers 0,7 units of heating energy. This shows that selected heating system is not very efficient, as conventional heat pumps that are much more efficient have COP from 2 to 5. Simulated buildings are heated with natural gas so it was necessary to determine the specific CO_2 emission depending on the heating fuel used.

Table 3.4; Specific energetic values for different fuels

Fuel	Specific Carbon Content ($kg_C kgfuel^{-1}$)	Specific Energy Content ($kW\ kgfuel^{-1}$)	Specific CO_2 Emission ($kg_{CO2}\ kgfuel^{-1}$)	Specific CO_2 Emission ($kg_{CO2}\ kWh^{-1}$)
Coal	0.75	7.5	2.3	0.37
Gasoline	0.9	12.5	3.3	0.27
Light Oil	0.7	11.7	2.6	0.26
Diesel	0.86	11.8	3.2	0.24
LPG - Liquid Petroleum Gas	0.82	12.3	3.0	0.24
Natural Gas, Methane	**0.75**	**12**	**2.8**	**0.23**

3.4 Carbon dioxide emissions for selected buildings

Based on the formula described in chapter 2.8, below is the calculation procedure that was made for Building 1- North, for Scenario 1. All other emission values are calculated the same way; where just total heating energy value changes, depending on the simulation results.

$$\mathbf{Q_T} = \frac{\mathbf{Q_k}}{\mathbf{\eta_t}} \qquad (1)$$

$$\mathbf{Q_k} = \mathbf{Q_T} * \mathbf{\eta_t} \qquad (2)$$

$$\mathbf{Q_k} = \mathbf{159\ 224\ (W) * 0,7 = 111\ 456 (W)} \qquad (3)$$

$$\boldsymbol{m_{CO_2}} = \boldsymbol{C_f}\mathbf{Q_k}\boldsymbol{\zeta}_\mathbf{b} \qquad (4)$$

$$\mathbf{m_{CO_2}} = \mathbf{0,236}\ \left(\frac{\mathbf{kg}CO_2}{\mathbf{kWh}}\right) * \mathbf{111\ 456(W)} * \boldsymbol{\zeta}_\mathbf{b} \qquad (5)$$

$$\boldsymbol{m_{CO_2}} = \mathbf{24\ 633}(\boldsymbol{kg}\ CO_2\ ) \qquad (6)$$

For the yearly heating demand of 159 224 (kWh a^{-1}) for North oriented part of the building, annual CO_2 emission equals 26,3 tons annually**.** South oriented part of the building had a similar CO_2 emission based on the current state scenario, resulting in 24,6 tons annually . After making the described improvements in the building envelope for Scenario 1, carbon emission dropped significantly by almost a half. For North oriented part carbon emission was reduced to 13,7 tons, and for South part of the building emissions dropped to 13,5 tones.

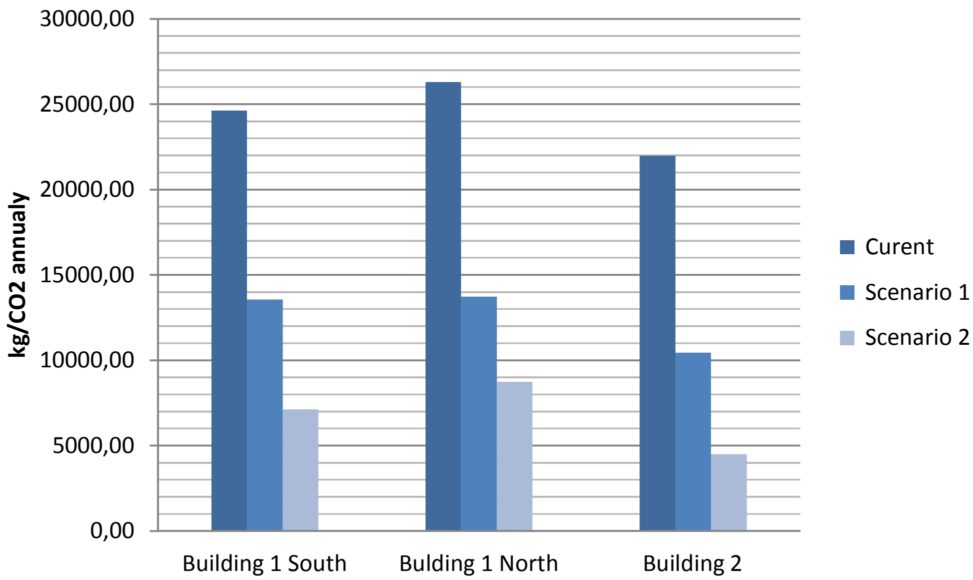


Figure 3.19; Carbon emission for each building

For the passive standard Scenario 2, reduction in carbon emissions was even higher than initially expected, rising up to 80% . For Building 1-North calculated emission equals 8,7 tons annually , and for south oriented part 7,1 tons per year. Difference noticed here was a consequence of lower heating demand calculated in southern part of the building. Comparing these values to the values in current state scenario, there is 79.5 % improvement in carbon emissions for the north part, and 56% improvement for the south part.

Biggest reductions were calculated for Building 2, where the proposed improvements in Scenario 2 resulted in 79.6 % less carbon emission compared to the current state (Figure 3.19).

Interesting is also the comparison between improved Scenario 1 and passive Scenario 2 for Building 1; it was noticed that improvements made in those two scenarios had a more significant impact on North part of Building 1 as the carbon reduction was 11% higher than for the South part of Building 1.

Table 3.5 ; Annual CO_2 emission for each building

	CO2 emission, current state [kgCO_2]	*CO2 emission Scenario 1 [kgCO_2]*	*CO2 emission Scenario2 [kgCO_2]*	*improvement Scenario 1 to current*	*improvement Scenario 2 to current*
Building 1 South	24633,14	13550,86	7123,26	44.99%	71.08%
Building 1 North	26303,80	13731,59	8747,67	47.80%	66.74%
Building2	21983,66	10452,37	4491,29	52.45%	79.57%

3.5 Heating costs analyses

Based on the heating demand results for two selected buildings, it was possible to calculate heating costs for each building, dependent on three scenarios analyzed. Same as in carbon emission calculations, efficiency of the heating system was taken into account, with the COP value of 0,7,

As it was already mentioned and described in the text, all buildings have gas floor heating, so all calculations were made based on the current price of natural gas in Croatia, which is **0,42 Euro/m3**. In Zagreb, where buildings are situated, natural gas provided form the city gas has an average caloric value of **10 kWh/ m3**, resulting in 0,13 m3 of gas for 1 kwh of heating energy.

Table 3.6; Annual heating costs in € for each scenario

	Current state	**Scenario 1**	**Scenario 2**
Building 1 South	8051,99	4429,46	2328,43
Building 1 North	8598,10	4488,53	2859,41
Building 2	7185,94	3416,63	1468,10

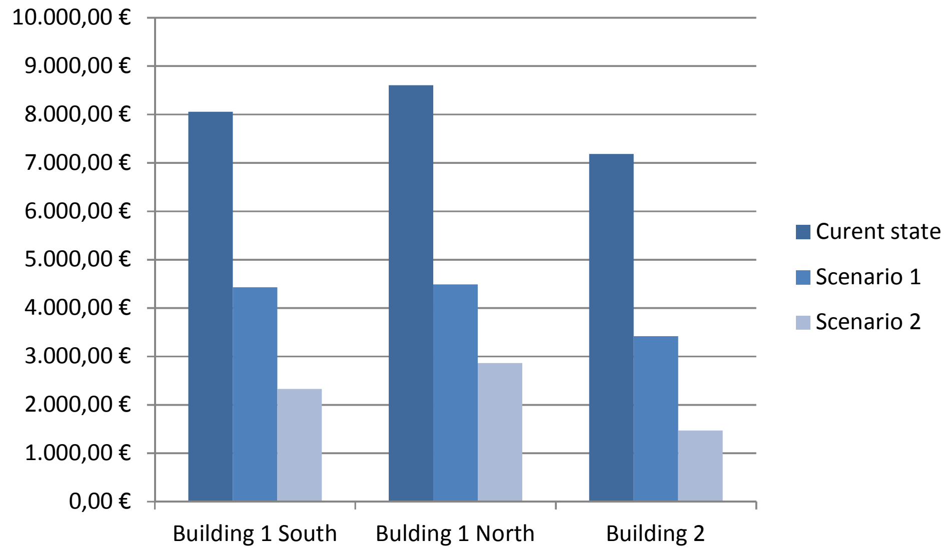


Figure 3.20; Total annual heating costs for each building

Tables above show that the heating cost savings are significant in both improvement scenarios. For building 1 and Building 2 savings go up to 37% compared between current and improved state. The difference is even more drastic comparing Scenario 2 with Scenario 3 for both buildings. In this case for Building 1 North 52, 25% save has been calculated, for Building 1 south 56.72%, and for Building 2 58.57%.

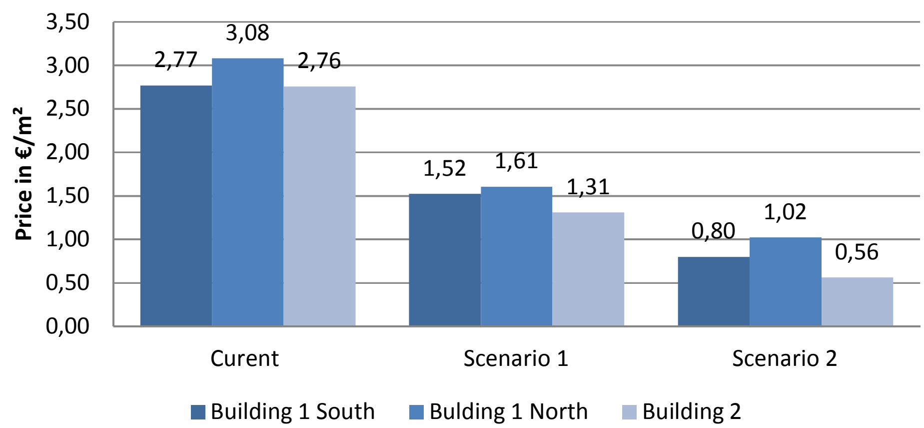


Figure 3.21 ; Annual price of heating for m² for each scenario

Apartment sizes vary within the buildings, so better representation of the heating cost is given in price of heating per m^2 for each of the scenarios. This way it is possible to make simple calculations of the annual costs for heating just by multiplying the values with the size of the apartment.

As average apartment in buildings has 70 m^2, annual costs of heating for apartment that size would be 210 € for Building 1 North in the current state. With implementation of measures presented in Scenario 2, heating costs for the same building are cut dramatically to only 70 € per year.

It was expected, due to differences in heating demand between south and north oriented parts of building 1, that the costs would be lower for south oriented part. Observing just the Scenario 2 results, calculations showed that in south oriented part of Building 1, heating costs are 20 % lower than in North part (Figure 3. 21)

As mentioned before, apartments have been offered on the market with a long pay off period of maximum 31 years. Under the assumption that an average family lives in one apartment for some 15 years; it brings a new perspective on the heating costs. For Building 1, taking the current price of gas into account, in 15 years heating cost sum up to 3200 € for 70 m^2, apartment. Comparing that to just 1700 € in Scenario 1 or 1100 € for Scenario 2, it is clear that proposed improvements save up to 65% in heating cost during 15 years.

4.0 Conclusion

4.1 Contribution

In Croatia, more than 30% of overall energy consumption is consumed by the building sector, and in the last decade further increase was noticed due to rapid growth of the real estate market. Furthermore, in total energy consumption in households, heating energy demands contribute with 56%. Only this basic numbers show the clear need to create a new building practice that includes energy efficient solutions that would contribute in decreasing the overall energy consumption.

This is also important having in mind that Croatia is facing difficulties in meeting the Kyoto protocol agenda, as the CO_2 emission reduction is a direct consequence of lower energy demand in building sector. In this research, it was confirmed that better thermal envelope can decrease carbon emissions up to 70%-80 % , depending on the scenario. Huge potential of reducing carbon emission, which was proved on these two buildings, becomes even more important having in mind that similar construction methods were used for almost 3000 other apartments built within the government housing program. Besides the general benefits of lower energy consumption, results presented in this paper showed that better thermal performance of the building envelope has a significant influence on the heating costs. Moreover, better thermal performance impacts the quality of living, which was not directly addressed within this paper. Results showed that only by introducing improvements that were presented as Scenario 1 contributes to 40 % decrease in heating costs on yearly bases. More radical savings can be achieved by following the passive construction requirements, as heating cost can be reduced by up to 70 %. This proved that sustainable and energy efficient building practice induces the social component of the buildings analyzed, as it is to expect that lower living cost can be a decisive for the buyers. Deeper analyses of the results also indicated the impact that building orientation has on the heating demands. It was noticed that just by better planning process some savings could have been made just by orienting the building differently. This point is also interesting from the buyers' perspective, knowing that apartments oriented south can consume up to 10 % less heating energy then those oriented differently. Same was noticed when comparing apartments oriented west to those oriented east, as west oriented have lower heating demands.

However it is clear that a deeper analysis of the human behavior in the buildings is needed in order to get more relevant results. Current results are calculated on certain assumptions based on the list of residents provided by the national real-estate agency, therefore in case of different behavior of the residents than assumed here , some alterations in the final results are possible.

Current thermal performance of selected buildings can be described as satisfactory, having in mind that the average energy consumption for households in Croatia is still very high, between 150-200 kWh $a^{-1}m^{-2}$ but that however, does not change the fact that this concept of government housing was carried out poorly.

This statement is based on couple of crucial points; Housing offered within this program was intended to make living more affordable to those with a lower purchase power, but poor thermal properties for new buildings resulted in higher heating costs. Also the goal of this project was to induce the real estate market by offering lower prices. As the demand for subsides housing was not as high as expected, prices did not drop. To continue, government stated the intention to induce energy efficient building in order to reduce the carbon footprint, but it was showed with this research that they failed to do so in a project they self financed. It is clear that energy efficient building practice in Croatia is still in its early developing stages. Compared to the countries in region, like Slovenia or Austria, Croatia still has a long way to go to make sustainable building a necessity and not an exception. Reaching this goal becomes even more difficult with the government not recognizing the clear benefits of energy efficient building practice.

4.2 Future research

This research was made on two buildings that were built as part of government's housing project. As this project includes a large number of buildings build in the last decade, future efforts should be concentrated on analyzing a larger number of buildings in order to get more relevant results. Also as these buildings were built all over country, it would be necessary to select buildings from different regions of Croatia, as they are in a different climatic environment. To continue, a relevant research on the occupants behavior would be needed, as internal conditions, that are influenced by the users behavior, can impact the simulations results significantly.

At the end, as the intention of the government project was to attract people with lower financial status to live in this buildings, it would be interesting to make a questioner within the certain target groups, about the willingness to live in an apartment just based on the lower living costs, putting all other decision making factors a side.

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6.0 List of tables and figures

6.1 List of tables

6.2 List of figures