Simulation and Calibration of Passive Houses in Trondheim

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NTNU

Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

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MASTER THESIS

for

Student Turgay Coskun

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Simulation and Calibration of Passive Houses in Trondheim

Simulering og kalibrering av passiv bolig i Trondheim

Background and objective

In Trondheim, a residential building area has been built based on the passive house standard. The area of 28 000 m^2 consists of row houses, detached houses, and blocks. Part of the flats has been in use for a few years. The area is connected to the district heating system. This passive house area is the most north passive house area in Norway. Much data including building documentation and energy bills are available for the study. In addition, an occupant survey was performed. It is important to analyze such data to increase the knowledge of this building type. The aim of the study is to simulate and calibrate passive houses located in Trondheim. Information about the flats and their use should be combine into the building energy simulation tool to increase quality of the building simulation model. EnergyPlus can be used to simulate the building energy performance. GenOpt together with EnergyPlus or some other optimization tool could be implemented for the calibration. Application of the statistical methods and optimization methods can help in this work. Based on the results, a comparative analysis on possible energy use should be performed.

This master thesis has aim to calibrate building energy simulation model of the passive houses by using energy bills, documentation, and occupant survey. The student can use EnergyPlus or some other relevant building energy simulation program.

The following tasks are to be considered:
1. Literature review on building energy use in residential buildings and driving variables of residential building energy use. Literature review on calibration of building energy simulations. Review on different simulation and optimization tools could be also good.
2. Lear a building energy simulation tool that can be used for this thesis. Develop simulation models of the passive houses based on the available data.
3. Develop a methodology for the model calibration. The methodology can be based on the statistical methods, optimization methods, self-developed based on the literature review.
4. Perform the sensitivity analysis of the building simulation model. Calibrate the model. Identify the driving variables of the energy use in this building type.

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5. Analyse the results by comparing, the calibration output and the real energy use. Discuss issues with the model calibration. Identify data that might be important for model calibration.
6. Make a draft for a journal paper.

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 14. January 2014

Olav Bolland
Department Head

Natasa Nord
Academic Supervisor

Research Advisor:
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Preface

This report represents my Master Thesis, conducted the one semester in the Erasmus program at NTNU. This thesis is written at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology, NTNU, in Trondheim, Norway, the spring 2015.

We wanted to achieve calibration of passive houses which located at Miljøbyen Granåsen in Trondheim, Norway.

The objective of this thesis was to access the simulation of the energy use in the passive houses. This master thesis has also objective to analyze energy use of the passive house area in Trondheim.

The thesis has been quite challenging since the gathering of all necessary data.

This project can be a sample for other studies, which aims to calibrate of a passive house.

I would like to thank everybody who has provided relevant data and support for this project.

A special thanks go to my supervisor, Prof. Natasa Nord from NTNU for great guidance and good cooperation.

Turgay Coşkun
Trondheim, Norway
July 2015

Abstract

Energy use of the world is increase with rise in population. Building energy consumption is an important part of the energy use in the world. In last decades there are a lot of actions to decrease energy use by buildings. Low energy houses and passive buildings are the projects to increase building energy performance.

In this thesis, passive houses will be investigated with respect energy use and comfort level of the houses.

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1. Introduction

All over the world, energy use increase with the rising of the population of the worlds. The main energy consumption areas are industry, transportation and buildings. This situation arises some concerns; energy supply difficulties and environmental aspects. The energy sources of the world are limited and people search new energy sources and develop new technologies to meet the energy requirements. By the environmental aspects; ozone layer depletion, global warming and climate change are main concerns of the people [1].

Buildings are one of the major areas of the energy consumption. In developed countries, buildings sector, both residential and commercial make contribution between 20%-40% to the total energy consumption and this is an important ratio. Also, the percentage of energy use in buildings is rise by the growth of population and increase in the demand of comfort levels. So that situation has acted the governments and they put some policies to decrease energy use of the houses by the increase of energy efficiency in buildings [1].

1.1 Problem background

The number of residential building has an increase all over the world by the increase of population. The energy consumption of the buildings is in direct proportion to the rise the number of buildings.

Most of the houses use consumption materials like oil, coal and gas in the last decades to supply energy to the buildings for space heating and other services. This situation makes contribution on the greenhouse effect. This contribution will be rise in the future if there is no precaution in the means of energy efficiency in the buildings.

On the other hand, the energy sources of the world also have limited. Limited energy sources of the world push people to find new energy sources for their houses. One of the possible energy sources is renewable energy. Wind power, sun, hydro power and geothermal energy some of the examples for the renewable energy sources.

Energy use in residential building comes one of the major problem all over the worlds in the last decades. So, people try to find some solutions to decrease the energy use in residential building. Only way to succeed that is to increase energy efficiency of the houses. This can be carried out in three steps. First step is design and construction. In this step, there must be

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studies to decrease energy loss from the building. Second step is to integrate effective energy supply systems to the houses. Third step is related with end-users. In this step, occupants need to be rise awareness of the importance energy-efficiency in the houses. The last step is very important to succeed energy efficiency in residential buildings.

There are lots of project to decrease energy consumption of the residential buildings. In general means, low energy houses and passive houses are some of them. EU project, Concerto Eco-City is one of them. The main aim of that project is to show energy solutions in buildings. Planning, construction and operation are the phases of energy solutions in buildings.

Green city Granåsen is one of the projects of the EU Concerto-City. This is a passive house project. This building project carried out in Trondheim and included detached and terraced houses. All homes in the green city Granåsen were built by passive standard [30].

The objective of this study is calibration of the detached houses in Green city Granasen by comparing the measured energy use with simulation outputs. The simulation of the houses was carried out by using EnergyPlus program.

The goal of this project is to discuss the contribution of the end-users on the energy consumption of houses. Also, the percentage of equipments, lighting and DHW in the energy use of the houses will be discussed in detail.

1.2 The objective and scope of thesis

The objective of this study was to investigate calibration issues of the passive houses in Mijobsen Granesan.

In 2012, passive house project in Trondheim was completed and most of the houses started to use from this year. It is a sample for passive house project for that area. In general view, passive houses are supported as energy efficient buildings. But this idea not supported totally in Norway and there is some discussion about the passive house technology.

The overall goal of this study is to show how the contributions of occupant behaviour on the energy consumption of houses. To achieve this goal, simulation of the houses carried out, results are gathered and the measured energy use of the houses analyzed.

Comparison between real energy use and simulation results was made to investigate the occupant behaviour and issues in the energy use calibration.

In this paper, 15 detached houses were analysed. All houses are connected to the district heating system.

1.3 The master thesis structure

The thesis structure divided into eight chapters according to subject.

Chapter 1 show us the general view of the thesis. It contains problem definition, the goal and objectives of the thesis. Chapter 2 represents literature review and research process.

In Chapter 3, the characteristic of detached houses are defined. Chapter 4 is methodology section. In this chapter, simulation and calibration methodologies are clearly defined.

In Chapter 5, the measured energy use for houses is analyzed. The consumption of electricity and district heating energy is showed effectively by using graphs. Also, an occupant survey which was made with end-users is assignment. Chapter 6 represents the comparison of calibration outputs with real energy use. Chapter 7 shows the assignment of the results.

1.4 The thesis limitations

Monthly electricity and district heating values are gathered from the building users. Data for some months were missing for some houses and reading date of the values were not consequent for all the houses. Further some houses had not so much measurement data, so they were not highly relevant for a good analysis.

The capacity of radiators, list and schedule of the equipments and number of occupants in the houses were not known exactly. These are important parameters to simulate energy use in the houses correctly.

There are some limitations related with simulation programs. Some of the construction materials doesn't find in software. This makes differences between real building and simulation model in the means of heat transfer from walls and floors.

2. Literature review

2.1 Energy use in residential buildings

The energy need of world is rise by the increase of industrialization and urbanization. Industry, transportation and buildings are the main energy consumption areas all over the world [1].

Buildings are one of the major areas of the energy consumption. In developed countries, buildings sector, both residential and commercial make contribution between 20%-40% to the total energy consumption [1].

The percentage of residential energy consumption in the national energy consumption can be seen in Figure 1 [2].
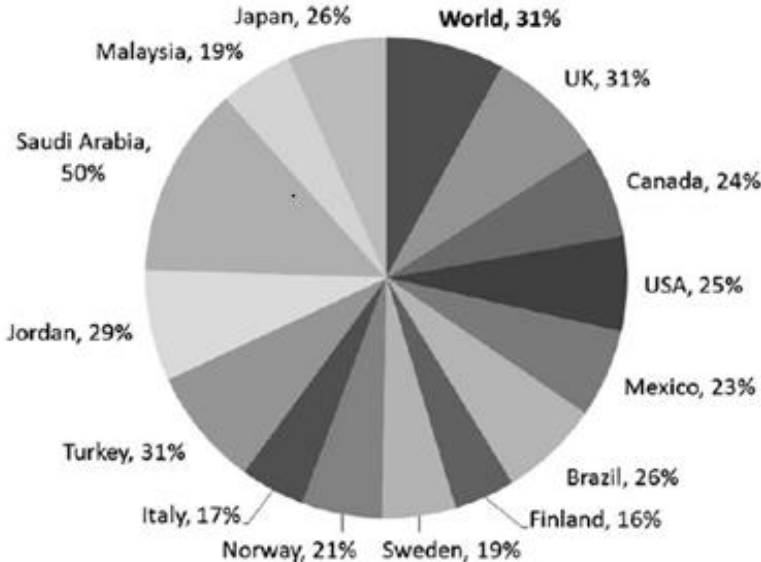
Figure 1: Percentage of residential energy consumption in the national energy consumption [2]

Energy use in residential buildings can be investigated into two main part; electricity and space heating. Most of the systems in the buildings; ventilation, air-conditioning, lighting and sometimes heating can be carried out by using electricity.

Energy use for heating systems show changes with respect to climate. Residential energy use for space heating is dominated in cold climates. [9] EuroAce figure out that 57% of the energy consumed in building is used for space heating. Other part of the energy is used for hot water (25%), lighting and electrical appliances (11%) and cooking (7%) [3].

2.1.1 Energy Use in Norwegian Residential Buildings

Unander made a study in 2003 and investigate the energy consumption of residential buildings of three Scandinavian countries between the years 1973 and 1998. The countries are Denmark, Sweden and Norway. According to his study, the residential energy consumption of Norway is lower than other countries in 1973. After this year, energy consumption of Norway dramatically increases up to 1990 while other countries show decrease between these years. The main factor for that increase between these years is to rise in demand for space heating by the increase of the income level. Unander realized that the floor area per capita increased from 1970 to 1998 for Norwegian people by the increase of income level. Another reason for this development is that the growth of Norway after 1970. Unander (2003) states that use of electricity for space heating was only 42% in 1973 and this value reached 65% in 1998 [4].

Energy saving by end-users in Norway between 1973 and 1990 was negligible. There are two reason of that situation. One of them is that increasing in the heating comfort level of the houses. Another one is low electricity prices and heating system in Norway mainly based on electricity not other fuels. After 1990, Norway gave more attention to energy saving subjects and as a result of that the price of electricity significantly increased after this year [4].

There is a study which shows the energy use in Norway by using graphs. In Figure 2, energy use by different sectors is given between the years 1976 and 2010. According to graph, energy use of most of the sectors shows an increase from 1976 to 2010. Especially, energy consumption in transportation and service industries is shows a significant increase.
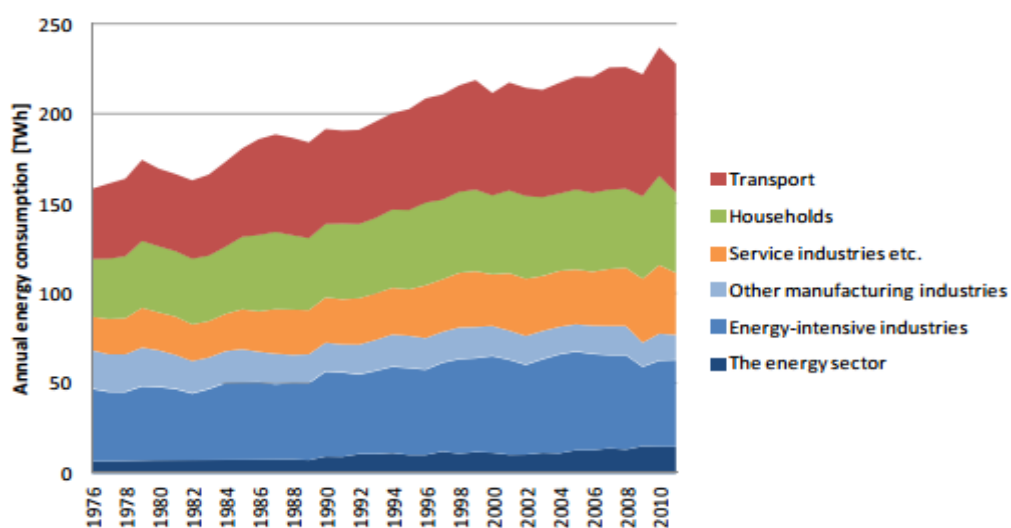
Figure 2: Energy consumption by sector in mainland Norway. Source: (SSB, 2012)

In Norway, 40% of the final delivered energy consumes by building stock and 22% of this energy related with residential buildings. 80 % of the final energy in buildings is supplied by electricity in Norway for heating purposes [5]. In Figure 3, types of energy are used between the 1975 and 2005 in residential is shown. According to Figure 3, main energy source for Norway buildings is electricity.
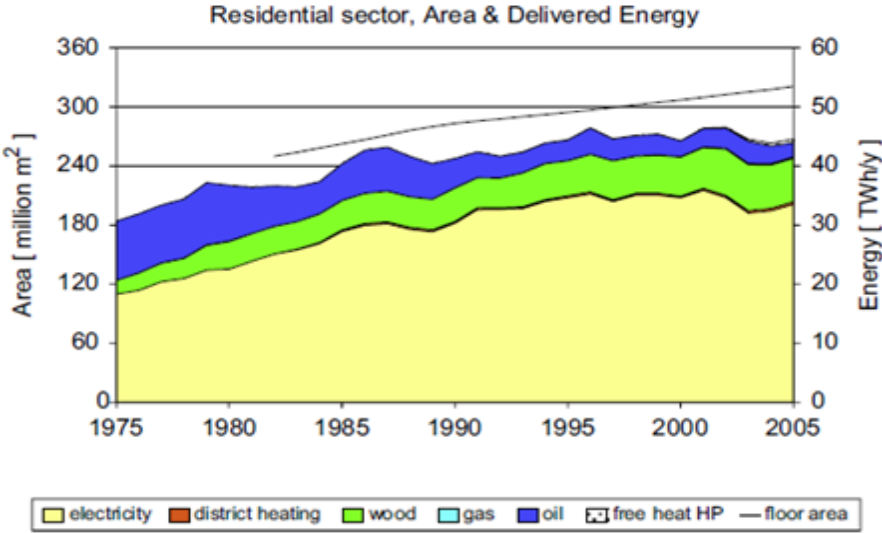
Figure 3: Delivered energy types for residential sector in Norway [5]

In Figure 4, household energy consumption between the years 1976 and 2010 is given. From the graph, it can be said that main energy source in household is electricity. Electricity consumption shows approximately 100 % increase from 1976 to 2010. In contrast to that, oil consumption in the house shows a dramatically decrease from 1976 to 2010.
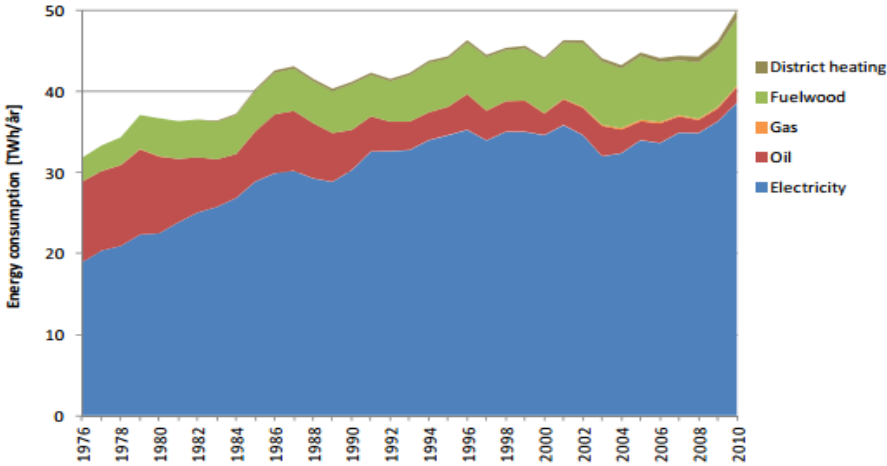
Figure 4: Household energy consumption between 1976 and 2010 (SSB, 2012)

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Harold Wilhite (1996) investigates the household energy use behaviour in Norway and in Japan. The energy use habits of Norwegian people are listed in Table 1 [6].

Activity	Norway
Space heat	Area Heating
	Lax temperature setback habits
Lighting	Incandescent in living areas
	Table, floor and spot lighting
	Fluorescent in bathrooms, kitchens
Bathing	Either shower or bath
	No reuse of bathwater
Clothes	Ample use of hot water
	Never use of bathwater
Dish	Hot water use is usual
Washing	Basin usual for wash

Energy use in the house is divided some categories. Figure 5 shows the breakdown of end-use energy consumption in households. Approximately 70% of energy consumption in the building belongs to district heating.
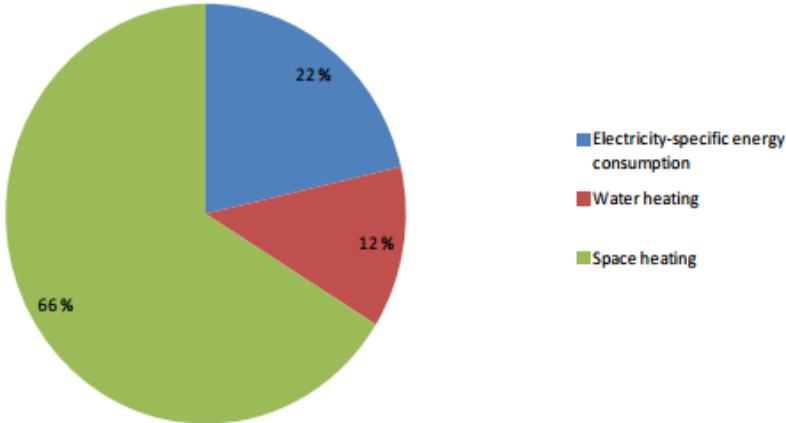
Figure 5: Breakdown of end-use energy consumption in households

(Norwegian Water Resources and Energy Directorate, 2012)

2.1.2 Heating System in Norwegian Buildings

The main energy resource of the Norway is hydropower. Approximately 99% of the electricity supply from hydropower [5]. These means that, electricity production in Norway based on a renewable source and environmental friendly. So there is no restriction in the means of energy demand and energy use in buildings. As a result of this, energy use increases year by year. While there is a rise in energy demand, the energy source is limited due to protection of the remaining natural waterfalls [5]. Sartori (2009) states that Norway is become an electricity importer country between 1996 and 2005 due to increase of electricity

consumption more than national power. As a result of that energy saving concept gains importance in Norway.

Heating system plays a significant role in energy use of Norwegian building stock. Most of the dwellings in Norway, approximately 70%, use space heaters and floor cables to use electricity directly. Only 12% of dwellings equipped with a hydronic system. Almost 93% of dwellings use direct electricity for space heating [5]. In Norway, there is a habit and they heat all of the rooms of the house except bedrooms. So this allows occupants move from one room to another room freely without feeling any discomfort [6].

2.2 Passive Houses

Energy consumption in the world shows a rapid increase in last decades. Production of energy and price, limitation of energy sources and global warming issues urgent countries to save energy. Developed countries agreed in Kyoto Protocol to limit their greenhouse gas emissions in 1997. Building sector one of the primary energy consumption areas. After that protocol, building sector becomes an important target for energy and GHG emission reduction activities [7]. There are three types of buildings: the standard building, the low energy building and the passive house [8]. Sartori and Hestnes and Badescu and Sicre make definition of these building types.

- Conventional (standard) building: "Refers to a building built according to the common practice of a specific country in a specific period, meeting the minimal legally required energy standards." [8]
- Low energy building: "Refers to a building built according to special design criteria aimed at minimising the building's operating energy." [8]
- Passive house: "A type of low-energy building; design is oriented to make maximum exploitation of passive technologies (eventually adopting also some active solar technology), assuring a comfortable indoor climate during summer and winter without needing any conventional heating or cooling system." [8]

The passive houses can be defined as demand for space heating is lower than $15kWh/m^2$.

In Norway there are two standards for building requirements. They are The Norwegian building code and the building standards. The Norwegian building code is named as the planning and building act (TEK). Standards Norway (SN) is a private end independent standards organization.

Technical requirements of Passive houses are listed in Table 2 and 3.

Table 2: Insulation and U-value requirements from passive house standard

Construction	Insulation	U-value (W/m^2K)
Outer walls	300-450 mm mineral wool	0,12
Roof	450-550 mm mineral wool	0,07-0,10
Ground Floor	300-350 mm exp. polystyrene	0,07-0,10
Normalized cold bridge	-	0,03

Table 3: Window requirements from passive house standard

Type	U-value	air change/h (N50)
Insulated frame and triple energy glass with argon in the cavity	0,8 W/m^2K	0,6

2.3 Calibration of Building Energy Simulation

Calibration process carried out by the compare of simulated results with measured data. Energy simulation tools are used in calibration process. The main aim of the calibration is that increase the building energy performance.

Simulation steps defined with respect to gathered data. First simulation carried out with respect to standards. Passive house standards are used in first simulation. In later simulations; building documentation and end-user survey are used to define simulation parameters.

3. Passive house project - Miljobyen Granåsen

In this chapter, the area of Granåsen and passive houses in there will be investigated in a detail. The aim of this chapter is to define the characteristic of the passive houses in Granåsen. The area found in the south of Trondheim. *(http://arkitektur.no/miljobyen-granasen-eneboliger)*

Location of green city can be seen in Figure 6.
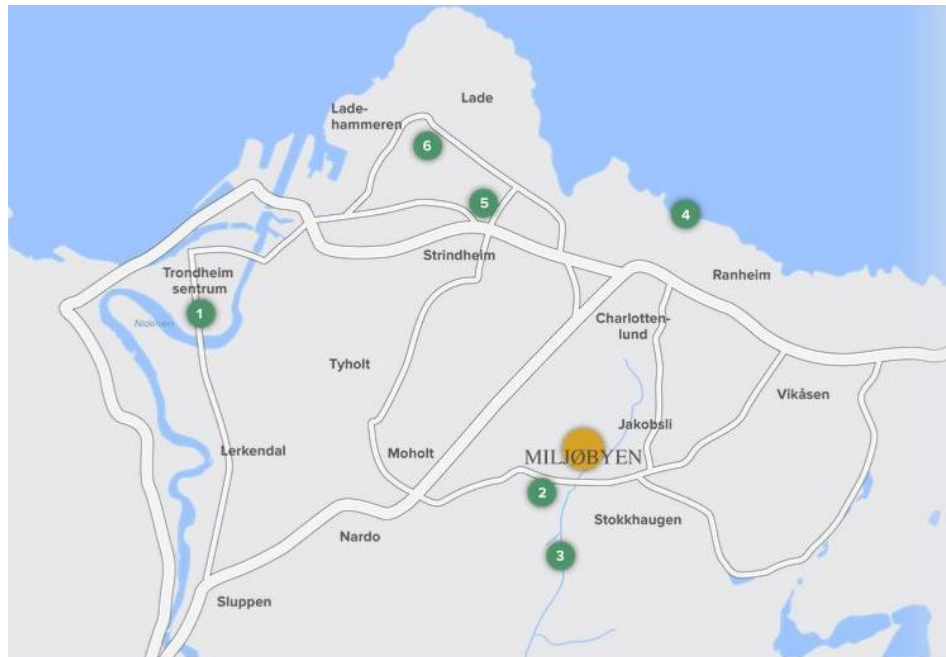
Figure 6: Location of the green city Granasen (www.miljobyen.no)

3.1 Building Documentation

At 2012, the construction of 17 passive houses were completed in south of Trondheim. All of them constructed as detached houses. In later time, the 80 townhouses and 210 apartments were built in the area.

Three different construction plans were used for detached houses and they were called as A1, A2 and A3. Each of them has same heated area, approximately 180 m^2. The figure below shows the houses. *(http://arkitektur.no/miljobyen-granasen-eneboliger)*.

Figure 7: Detached houses

Figure 8: A Facade of Detached House

http://www.arkitektur.no/miljobyen-granasen?iid=386121&pid=NAL-EcoProject-Pictures.Native-InnerFile-File&r_n_d=186809_&adjust=1&x=564&y=383&from=0

3.2 Weather data

One of the main parameters in the analysis of buildings is that climate of the area. Norway is very close to North Pole. So the weather is extremely cold, especially in winter, so adjusting of the thermal comfort in the houses is very hard.

Measured energy use data for houses were recorded during the year 2012 and some of the months from 2013. So, in our study, the climate date for 2012 was used. There are some parameters which affect energy use in houses. Daylight and benefit from sunlight two of them. In Norway, the daylight for summer months is very long; sometimes it reached 20 hours in a day. In a contrast, in winter days, the daylight takes only 6 hours. In the southern of Norway, the sunset doesn't occur during two months in mid of summer. (*http://www.weatheronline.co.uk/reports/climate/Norway.htm*)

Temperature

Outdoor temperature is given in Figure 3.
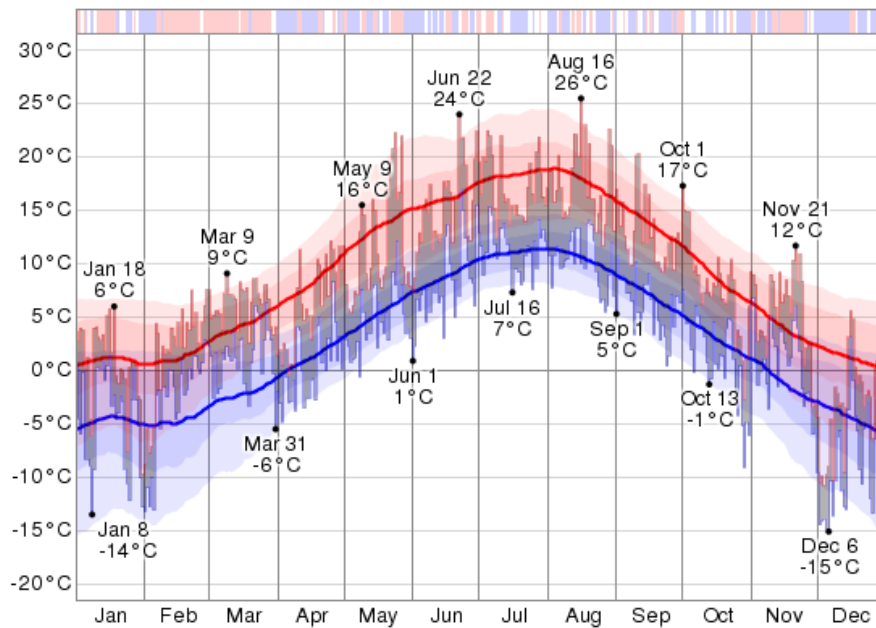
Figure 9: Outdoor temperature values for Trondheim for the year 2012
(**https://weatherspark.com/history/28896/2012/Stj-rdal-Nord-Trondelag-Norway**)

The daily low (blue) and high (red) temperature during 2012 with the area between them shaded gray and superimposed over the corresponding averages (thick lines), and with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile). The bar at the top of the graph is red where both the daily high and low are above average, blue where they are both below average and white otherwise.

The *hottest day* of 2012 was August 16, with a high temperature of 26°C. For reference, on that day the average high temperature is 18°C and the high temperature exceeds 23°C only one day in ten. The *hottest month* of 2012 was August with an average daily high temperature of 18°C.

Relative to the average, the hottest day was November 21. The high temperature that day was 12°C, compared to the average of 3°C, a difference of 9°C. In relative terms the warmest month was March, with an average high temperature of 6°C, compared to a typical value of 4°C.

The longest *warm spell* was from February 9 to February 26, constituting 18 consecutive days with warmer than average high temperatures. The month of March had the largest fraction of warmer than average days with 84% days with higher than average high temperatures.

The *coldest day* of 2012 was December 6, with a low temperature of -15°C. For reference, on that day the average low temperature is -3°C and the low temperature drops below -11°C only one day in ten. The *coldest month* of 2012 was December with an average daily low temperature of -8°C.

Relative to the average, the coldest day was December 6. The low temperature that day was -15°C, compared to the average of -3°C, a difference of 12°C. In relative terms the coldest month was December, with an average low temperature of -8°C, compared to an typical value of -4°C.

The longest *cold spell* was from November 28 to December 15, constituting 18 consecutive days with cooler than average low temperatures. The month of April had the largest fraction of cooler than average days with 73% days with lower than average low temperatures.

The longest *freezing spell* was from November 29 to December 15, constituting 17 consecutive days with temperatures strictly below freezing.

Humidity

Humidity is an important factor in determining how weather conditions feel to a person experiencing them. Hot and humid days feel even hotter than hot and dry days because the high level of water content in humid air discourages the evaporation of sweat from a person's skin.

When reading the graph below, keep in mind that the hottest part of the day tends to be the least humid, so the daily low (brown) traces are more relevant for understanding daytime

comfort than the daily high (blue) traces, which typically occur during the night. Applying that observation, the *least humid month* of 2012 was May with an average daily low humidity of 49%, and the *most humid month* was October with an average daily low humidity of 66%.

But it is important to keep in mind that humidity does not tell the whole picture and the dew point is often a better measure of how comfortable a person will find a given set of weather conditions. Please see the next section for continued discussion of this point.
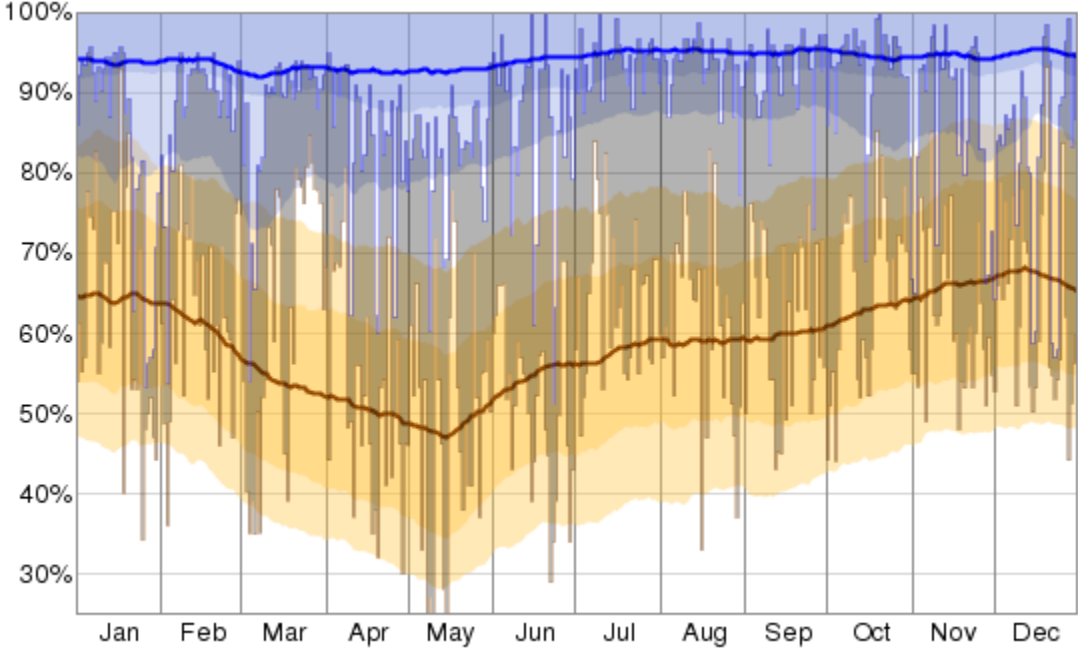
Figure 10: Humidity values for Trondheim for the year 2012

(https://weatherspark.com/history/28896/2012/Stj-rdal-Nord-Trondelag-Norway)

The daily low (brown) and high (blue) relative humidity during 2012 with the area between them shaded gray and superimposed over the corresponding averages (thick lines), and with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

3.3 Reference model

3.3.1 Building characteristics of detached houses

The table shows us the elements requirements for passive house NS3700:2010.

Table 4: Minimum element requirements, house and heat loss calculations

	Requirements for building components, components and leakage rate connectors. ENOVA [b]	Values used in calculationsof row houses, fields B2 Environmental town Granås (Requirement level)
U-value exterior wall [a]	≤ 0,15 W/(m²K)	0,12 W/(m²K) / 350 mm iso
U-value roof [a]	≤ 0,13 W/(m²K)	0,09 W/(m²K) / 500 mm iso
U-value floor [a]	≤ 0,15 W/(m²K)	0,12 W/(m²K) / 300 mm iso
U-value window [a]	≤ 0,80 W/(m²K)	0,80 W/(m²K)/ 3-lags iso frame
U-value door [a]	≤ 0,80 W/(m²K)	0,80 W/(m²K)
Normalized thermal bridge	≤ 0,03 W/(m²K)	0,02 W/(m²K) (calculated)
Annual average temperature efficiency	≥ 80 %	83 %
SFP ventilation factor	≤ 1,5 kW/(m³/s)	1,5 kW/(m³/s)
Leakage rate at 50 Pa, n50	≤ 0,60 h	0,60 h
Ventilation Airflow	≥ 1,20 m³/(h m²)	1,20 m³/(h m²)
Lighting	11,4 kWh/(m² h)	11,4 kWh/(m² h)
Equipment	17,5 kWh/(m² h)	17,5 kWh/(m² h)
Hot water consumption	30,0 kWh/(m² h)	30,0 kWh/(m² h)

a) U-values are calculated as the average value for the various building components.
b) A building where building parts, components and leakage rate is within the minimum requirements (Enova) will not necessarily satisfyrequirements related to heat loss figures and the highest estimated net energy for heating.

3.4.1.1 Construction details

Some U-values and insulation thickness are given before than this part of the thesis. All of them taken from standards. In this part, u-values of the model which is used in simulation are listed in this part.

3.4.1.1.1 Exterior Walls

In this project, we accept all of the exterior walls are constructed similar in ground, first and second floor. Table 5-7 gives detailed information about structure of walls. All are constructed with well insulation and small U-values.

External Walls	
Number of Layers	4
Insulation thickness	400 mm
U-value	0.098 W/m^2-K

3.4.1.1.2 Roof and Ceiling

Table 6: Construction of Roof

Roof	
Number of Layers	2
Insulation thickness	500 mm
U-value	0.085 W/m^2-K

Table 7: Construction of Floor (Ceiling)

Floor (Ceiling)	
Number of Layers	2
Insulation thickness	270 mm
U-value	0.089 W/m^2-K

3.4.1.1.3 Windows and doors

Passive house window consists of three layers of glass. Argon gas is used to fill the gap between the layers. The frames are insulated.

Table 8: Construction of Windows

Windows	
Number of Layers	3
Insulation Gas	Argon
U-value	1.488 W/m^2-K

4. Measured energy use in detached houses

The green city area contains detached and terraced houses. In this thesis, detached houses are the main object and will be analyzed.

There are 17 detached passive houses. Monthly electricity and district heating consumption of the houses recorded. All measurements were collected for the building users.

4.1 Energy use for detached houses

The green city area contains 17 detached houses. Not all of the houses analyzed there because some of the data were missing for some houses. In first step, we analyzed 15 houses. The energy consumption of the houses investigated from March 2012 to September 2013. All of the houses investigated individually.

In second step, energy consumption between May 2012 and April 2013 is determined. Only 11 houses investigated in this step because they have enough data to asses.

4.1.1 Building Electricity use

Figure 11 shows the monthly electricity consumption of the 15 houses. Most of the houses started to use beginning of March 2012.
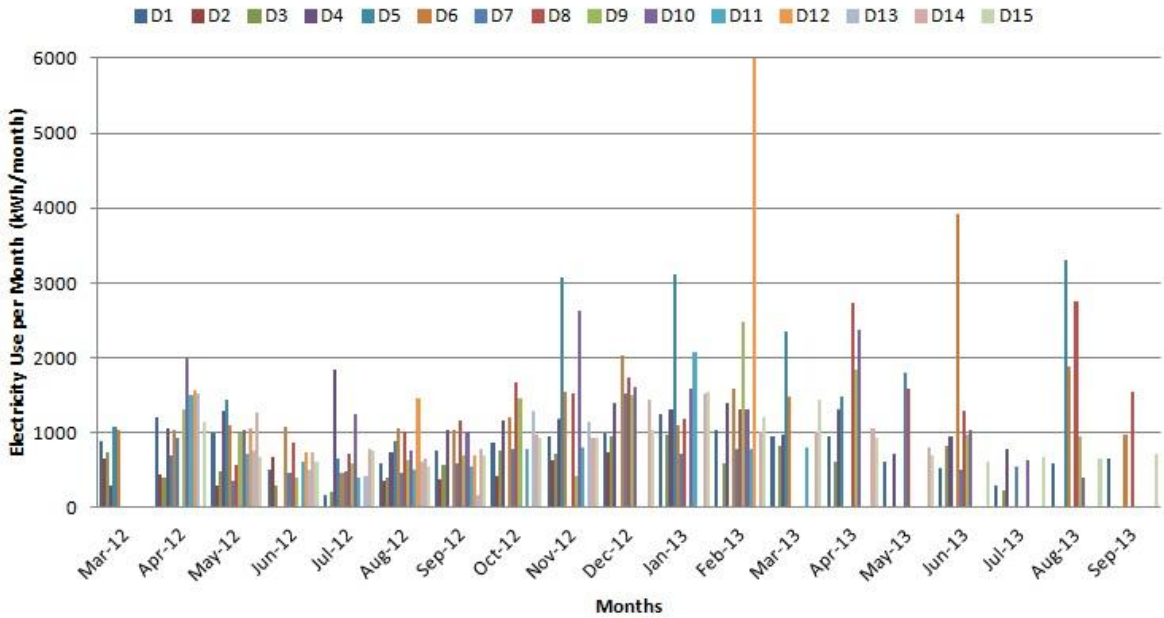
Figure 11: Monthly electricity consumption

Improvement of the measured data

As it can be seen from Figure 11, some months were not recorded for some houses. Energy use for missing months generally added to next months. To make development in the measured values, missing months are filled with respect to measured months. Figure 13 and 14 shows the values after improvement.
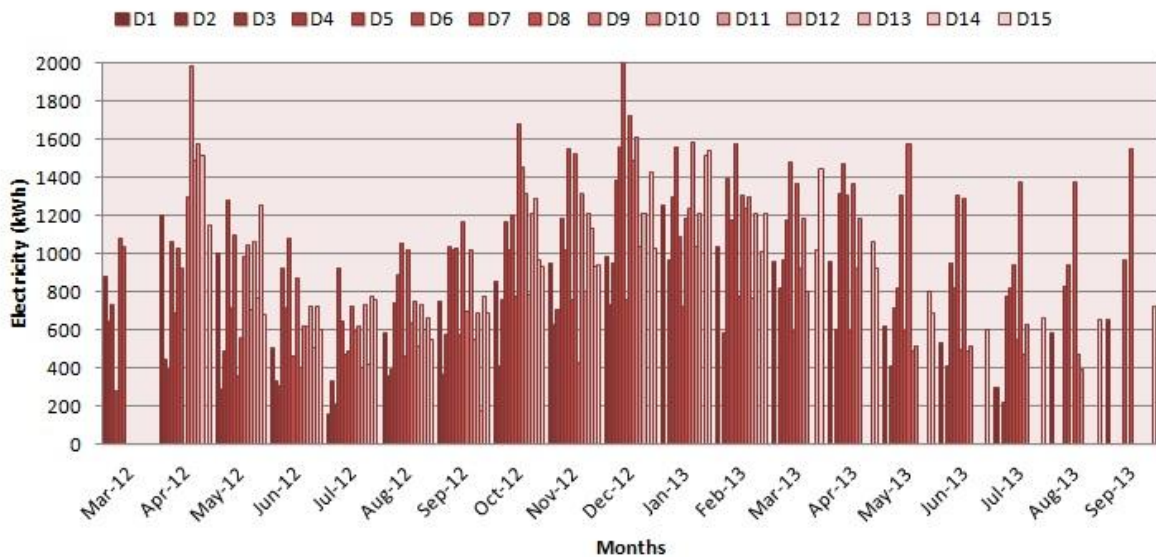
Figure 13: Electricity consumption after improvement
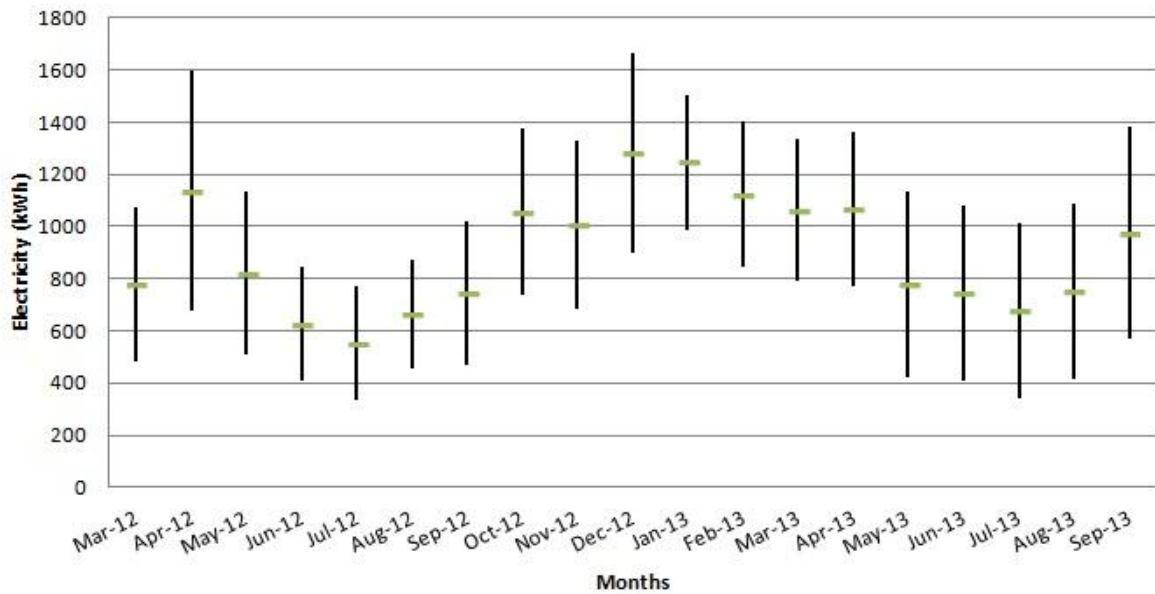
Figure 14: Standard Deviation for electricity consumption after first improvement

Figure 14 show us the improvements on measured values are logical. After improvement on measured values, deviation of months is decrease.

4.1.2 Heating energy use

Heating energy consumption of the houses is given in Figure 15. As it seen from the Figure 15, some months values are not recorded. This missing data added to next month.
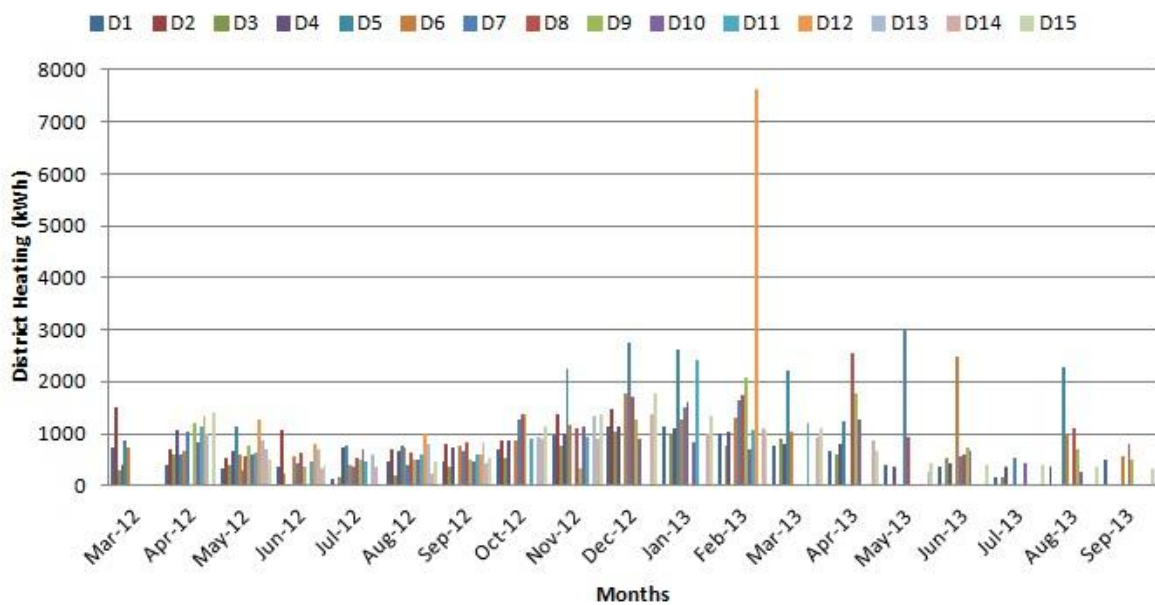
Figure 15: Monthly district heating consumption
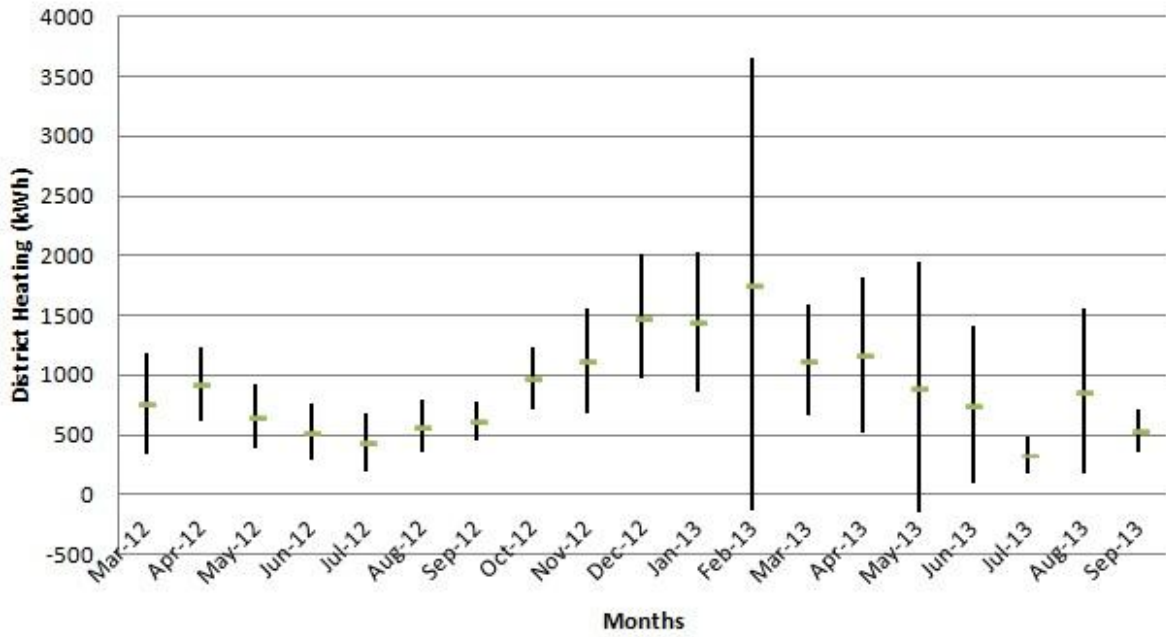
Figure 16: Standard Deviation for district heating

According to Figure 16, standard deviation on February is very high. We need to improve measured values to decrease standard deviation.

Improvement of the measured data
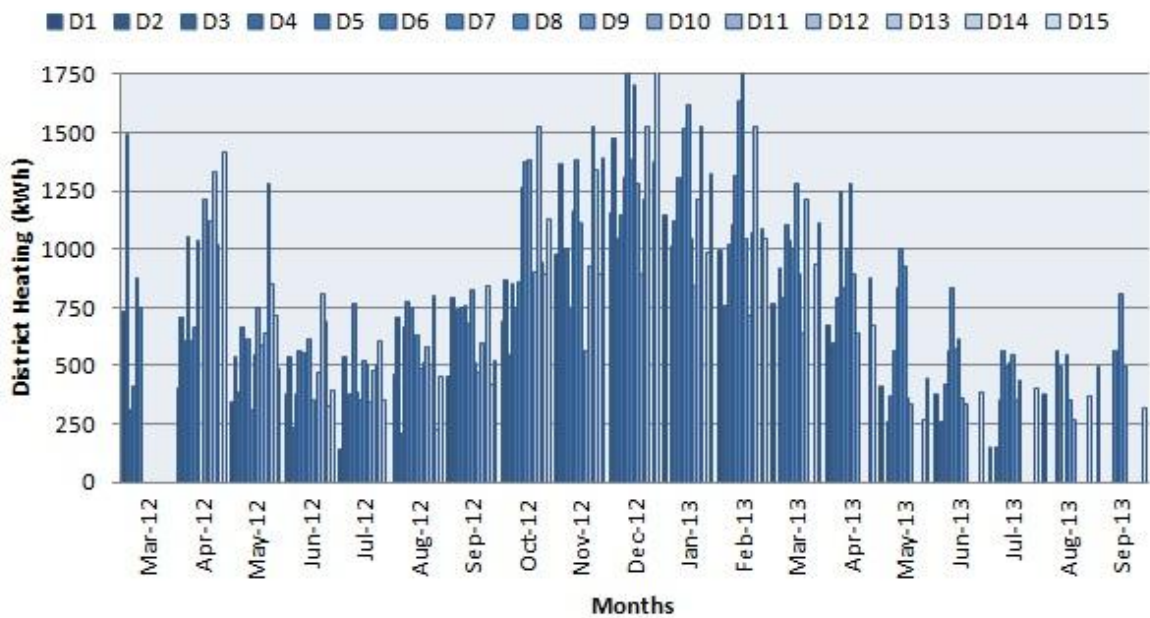
Figure 17: Monthly district heating consumption after improvement
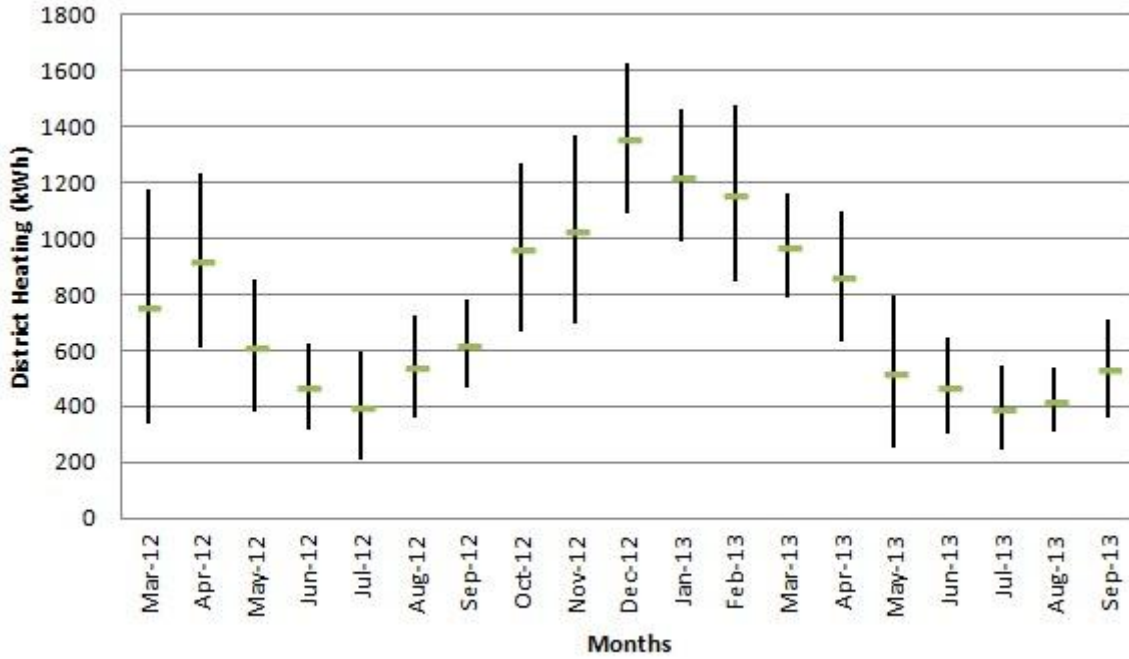
Figure 18: Standard Deviation for district heating after improvement

Annual Energy Consumption

In this section, one year period, from May 2012 to April 2013, energy consumption of the 11 houses was analyzed. Other 4 houses have missing data so we ignore them in this part.
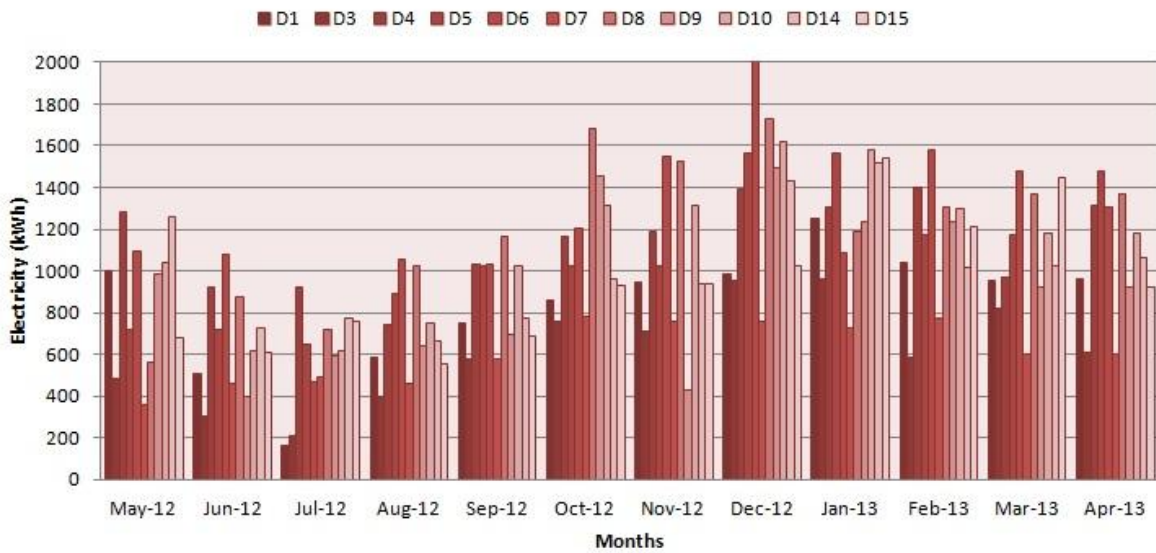
Figure 19: 1 year period electricity consumption
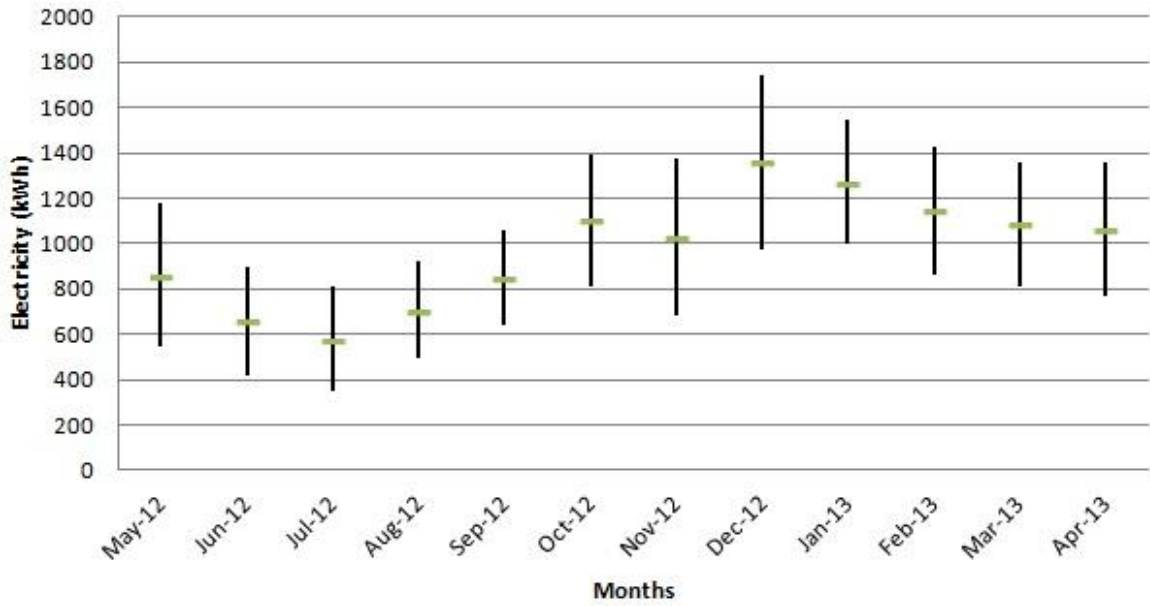
Figure 20: Standard Deviation for 1 year period electricity consumption
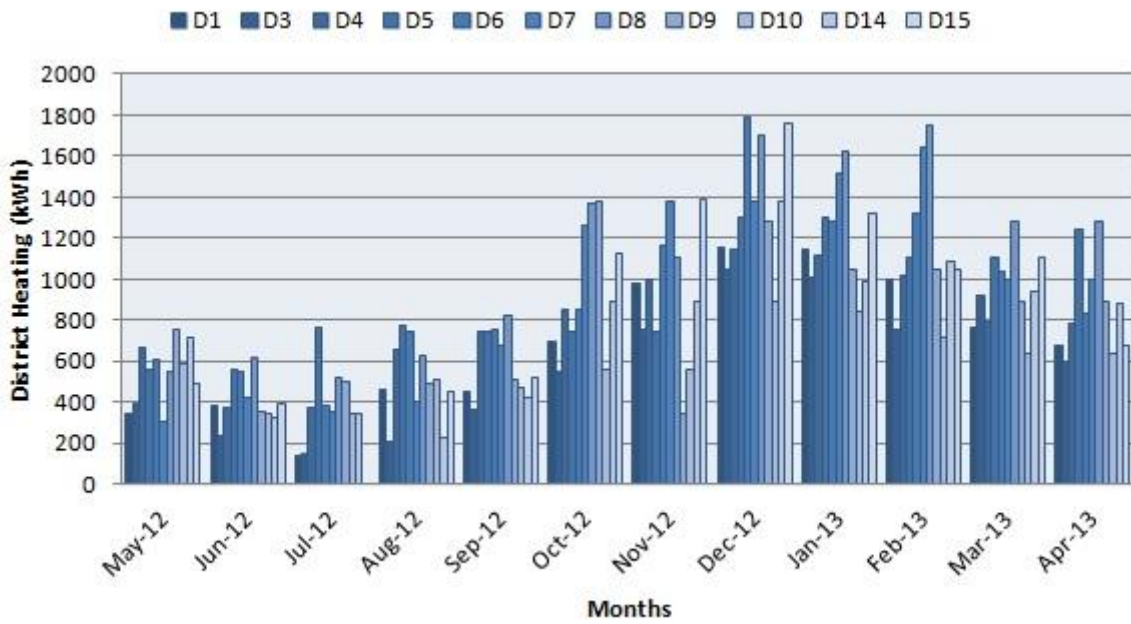
Figure 21: 1 year period district heating consumption

When we look at the one year period of electricity and district heating energy use values, it can be said that electricity consumption of the houses are top at December. Differences between the monthly values are not clear in electricity use in contrast to district heating values. As a normal condition, district heating values are high between the months October and April. Actually, simplification in values is not a correct way to asses' consumption values. But, it gives some idea about the energy use of the houses.

Total Energy Consumption of Detached Houses (one year period)

Table 9: Annual energy consumption of the houses

	Masurement Period		Consumption (kWh)	
			Electricity	District Heating
D1	05/03/2012	01/03/2013	10179	7871
D2	05/03/2012	05/03/2013	5545	11480
D3	09/03/2012	05/03/2013	7072	6383
D4	19/03/2012	05/03/2013	12697	9419
D5	16/03/2012	01/04/2013	13292	11205
D6	16/03/2012	07/03/2013	14248	10866
D7	26/03/2012	05/03/2013	7077	10388
D8	08/05/2012	01/05/2013	14502	13260
D9	23/03/2012	01/03/2013	10462	8922
D10	21/03/2012	03/03/2013	13173	6659
D11	21/03/2012	02/04/2013	9525	10432
D12	21/03/2012	06/03/2013	11585	12668
D13	01/05/2012	14/05/2013	10418	12156
D14	25/04/2012	01/05/2013	12145	9085
D15	29/03/2012	03/04/2013	11528	11036
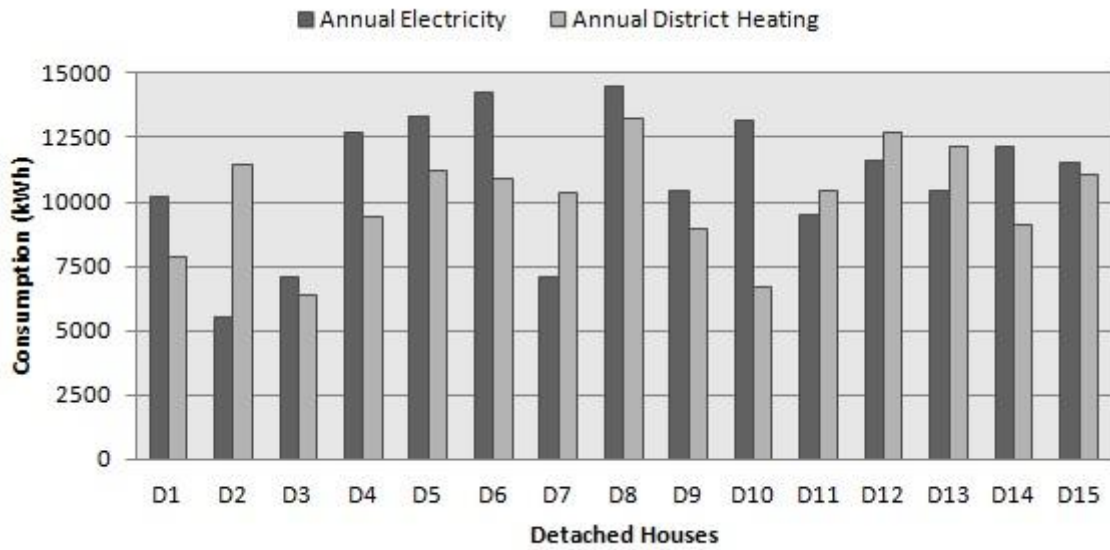
Figure 23: Annual electricity and district heating consumption

Figure 24: Distribution of energy consumption

4.2 Occupant survey with end-users

Most of the houses started to use from 2012. An occupant survey was made with end-users to define correctly all aspects of the houses. The questions asked to end-user are listed below. According to survey, most of the family consist of 4 people; mother, father and 2 children.

5. How do you perceive the temperature is winter?

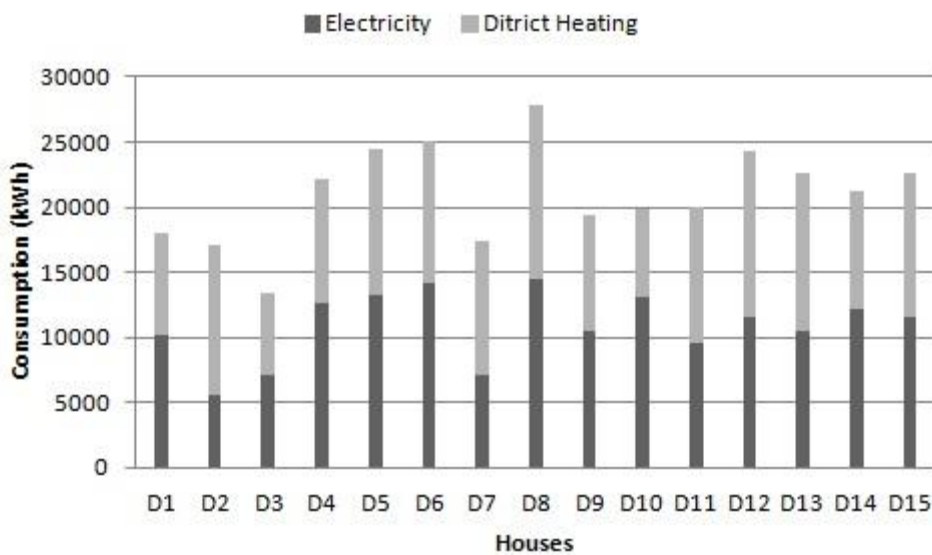|	hot	warm	something hot	just fit	something cool	cool	cold	Eq.
Living / dining room	3.6%	0.0%	3.6%	89.3%	3.6%	0.0%	0.0%	28
Bedroom	0.0%	10.7%	39.3%	46.4%	3.6%	0.0%	0.0%	28
Bathroom	0.0%	0.0%	3.6%	96.4%	0.0%	0.0%	0.0%	28
Total								28

7. How do you perceive the temperature is about summer?

	hot	warm	something hot	just fit	something cool	cool	cold	Eq.
Living / dining room	3.6%	21.4%	25.0%	50.0%	0.0%	0.0%	0.0%	28
Bedroom	14.3%	46.4%	28.6%	10.7%	0.0%	0.0%	0.0%	28
Bathroom	0.0%	7.1%	17.9%	75.0%	0.0%	0.0%	0.0%	28
Total								28

Question 5 and 7 shows the indoor climate at different season. For winter season, there is no problem related with indoor climate. But for summer season, there is overheating problem in bedroom. According to question 12, heating solution for living room and bedroom is pleased. But for bathroom, only half of the residences are pleased.

12. How satisfied or dissatisfied are you with heating the solution in the following rooms?

	very dissatisfied	unhappy	neither	pleased	very satisfied	Eq.
Living / dining room	0.0%	3.8%	3.8%	80.8%	11.5%	26
Bedroom	0.0%	3.8%	3.8%	76.9%	15.4%	26
Bathroom	3.8%	19.2%	23.1%	50.0%	3.8%	26
Total						26

16. To what extent are your expectations to your residence fulfilled when it comes to these conditions?

	Far below expectation	Anything under expectation	As expected	Anything above expectation	Far above expectations	Eq.
Energy savings	29.6%	25.9%	37.0%	7.4%	0.0%	27
Air quality	0.0%	14.8%	29.6%	51.9%	3.7%	27
Room temp. in the winter	0.0%	3.7%	51.9%	33.3%	11.1%	27
Room temp. in summer	3.7%	18.5%	55.6%	22.2%	0.0%	27
Daylight in your home	3.7%	18.5%	55.6%	18.5%	3.7%	27
Total						27

23. Which fan speed / airflow ventilation system is usually set?

	MIN	NORMAL	MAX	Eq.
At night	25.9%	70.4%	3.7%	27
In the presence day	14.8%	85.2%	0.0%	27
In the absence of day (work / school))	22.2%	77.8%	0.0%	27
For longer absences (vacation))	63.0%	37.0%	0.0%	27

24. What temperature of the air from the ventilation system is usually set?

	Additional heating is turned off	10-15 °C	16-20 °C	21-25 °C	26-30 °C	do not know	Eq.
At night	25.9%	7.4%	40.7%	14.8%	0.0%	11.1%	27
In the presence day	25.9%	0.0%	40.7%	22.2%	0.0%	11.1%	27
In the absence of day (work / school)	25.9%	0.0%	48.1%	14.8%	0.0%	11.1%	27
For longer absences (vacation)	29.6%	3.7%	40.7%	14.8%	0.0%	11.1%	27
Total							27

29. In which time periods are the following heat sources turned on so that they emit heat?

	All year	The entire winter	Only the coldest days	Is declined throughout the year	have not	don't know	Eq.
Radiator 1st floor	11.1%	66.7%	18.5%	3.7%	0.0%	0.0%	27
Radiator on the 2nd floor (if applicable)	7.4%	44.4%	29.6%	18.5%	0.0%	0.0%	27
Under floor heating time (if any)	28.0%	32.0%	0.0%	0.0%	40.0%	0.0%	25
Floor heating in bathrooms	88.9%	11.1%	0.0%	0.0%	0.0%	0.0%	27
Total							27

30. Used other heat sources in addition to those that were installed when moving? If so, which?

	Percent	total
No, no other heat sources used	84.6%	22
Fan heater	3.8%	1
electric radiator	7.7%	2
Oil	0.0%	0
Other	3.8%	1
Equivalent		26

31. Enter typical room temperatures in winter.

	Lower than 16 °C	16-18 °C	19-21 °C	22-24 °C	Higher than 24 °C	Don't know	Eq.
Living/Dining Room	0.0%	3.7%	44.4%	48.1%	3.7%	0.0%	27
Bedroom	11.1%	22.2%	51.9%	11.1%	0.0%	3.7%	27
Bathroom	0.0%	0.0%	25.9%	66.7%	7.4%	0.0%	27
Total							27

41. What type of technology is the lighting in the following room is in mainly based on?

	LED	Energy saving light	Halogen bulbs	Fluorescent	Incandescent bulbs	Don't know	Eq.
Entrance	37.0%	48.1%	22.2%	0.0%	0.0%	0.0%	27
Living room	48.1%	33.3%	44.4%	0.0%	11.1%	0.0%	27
Bedroom	26.9%	38.5%	34.6%	0.0%	11.5%	0.0%	26
Bathroom	51.9%	18.5%	22.2%	33.3%	3.7%	0.0%	27
Outside light	7.4%	51.9%	7.4%	0.0%	11.1%	22.2%	27
Total							27

49. Specify the age and number of occupants in the dwellings?

	0	1	2	3	4 or more	Eq.
Under 12 year	8.3%	16.7%	58.3%	12.5%	4.2%	24
12 - 20 year	70.0%	30.0%	0.0%	0.0%	0.0%	10
21 - 65 year	0.0%	11.1%	81.5%	7.4%	0.0%	27
Over 65 year	85.7%	0.0%	14.3%	0.0%	0.0%	7
Total						27

50. Enter the number of people who are usually at home on weekdays at different times.

	0	1	2	3	4 or more	Eq.
Day (Cl. 8-16)	73.1%	15.4%	11.5%	0.0%	0.0%	26
In the afternoon (Cl. 16-24)	0.0%	14.8%	11.1%	7.4%	66.7%	27
At night (Cl. 24-8)	0.0%	7.7%	11.5%	11.5%	69.2%	26
Total						27

5. Comparison of calibration output and real energy use

In first step, energy demand of the houses is defined according to first simulation. In this step, all of the zones heated by electricity.

Electricity	4888.19 kWh
District Heating	16354.33 kWh

After defining energy demand, a reference model is figure out. The specifications of reference model are listed in Table 6.

Ventilation System	Only natural ventilation
Lighting	2 W/m^2 – 100 lux
Internal Equipments	3 W/m^2
DHW	Instantaneous hot water only
Heating	Underfloor heating in bathrooms and entrance Fan coil units in living room
Heating set point temperatures	20°C for common areas 18°C for storage areas

5.1 Analysis of the measured energy use and simulated values

In calibration process, measured and simulated values are compared. In this thesis, there are 15 detached houses and energy uses of the houses are different from each other. A problem arises at this point. Which house will be taken as reference house? In Figure 25, simulated values compared with average energy use of the houses.
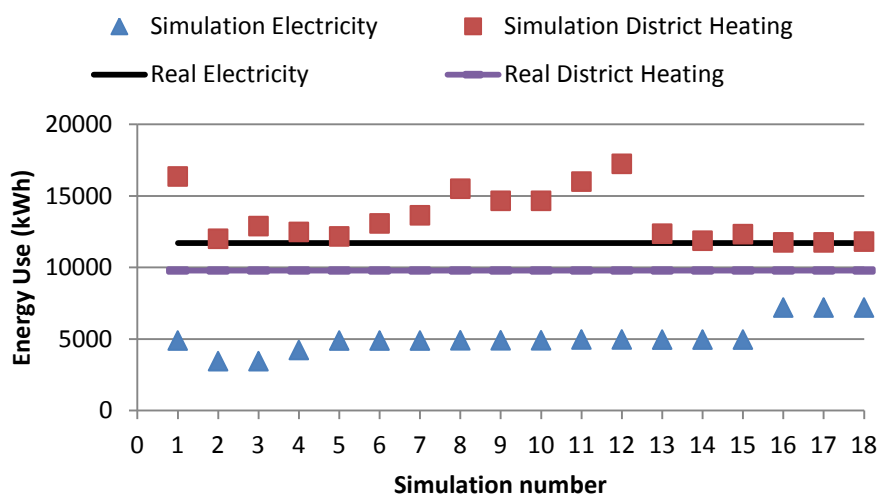

Figure 25: Comparison of simulated values with average of measured values

As it can be seen in Figure 25, there is big difference between measured and simulated values. Simulated district heating value shows a decrease from 1st simulation to last simulation. Simulation parameters are adjusted from 1st simulation to last simulation and it reached to actual parameters. In contrast use of electricity is increase from 1st simulation to last simulation.

6. Conclusion

Energy use of the Granasen investigated detail. All of the houses have same heating area but energy use values different from each others. The main reason of that is occupant behaviour.

Simulation of the houses is rise the energy performance of the buildings. Simulation of the buildings gives idea about the behaviour of the building. This idea can be used before or after the construction of the buildings.

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