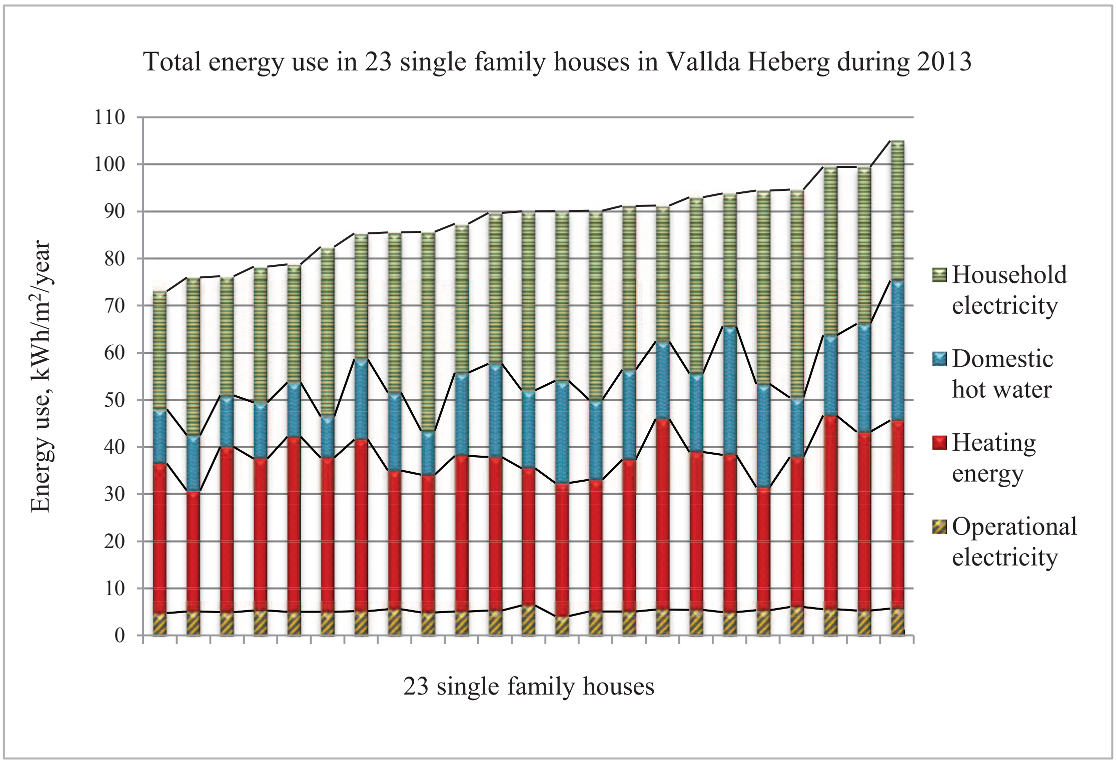

Energy performance and indoor climate investigations in the passive house residential area Vallda Heberg

Master of Science Thesis in the Master's Programme Structural Engineering and Building Technology

HÅKAN JIMMEFORS
JULIA ÖSTBERG

Department of Civil and Environmental Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2014

MASTER’S THESIS 2014:101

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Chalmers tekniska högskola 2014:101

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Cover:
The total energy use (heating energy, domestic hot water use, operational electricity and household electricity) in 23 of the single family houses in Vallda Heberg.

Chalmers Reproservice / Department of Civil and Environmental Engineering Göteborg, Sweden 2014

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ABSTRACT

Passive houses are becoming more common and the focus is usually put on the individual building. In the residential area Vallda Heberg, in the municipality of Kungsbacka in Sweden, all the buildings are built with passive house standard. The area consists of several different types of buildings; single family houses, apartment blocks, terrace houses, a retirement home and commercial buildings. All buildings are supplied with domestic hot water and heating energy from a local district heating system which is supplied with renewable energy generated on site.

The actual energy performance of the buildings has been studied for up to one year and the results have been compared to the design values. The variation in the specific energy use due to the user behaviour is large in the premises and the largest variations were found in the domestic hot water use. The single family houses (with a full year of measured values of the specific energy use) had a lower specific energy use than designed, while the other buildings, according to a prognosis, could have a larger energy use than designed. In the single family houses the actual heating energy was lower than designed while the domestic hot water use and the operational electricity were higher than designed. The assumed household electricity in the single family houses was underestimated in the design phase.

The measured indoor temperature in the premises is found to be in accordance with the recommendations of The Public Health Agency of Sweden and according to a survey most residents are satisfied with the indoor climate. The survey was sent to all the premises and the total response rate was 41 of 64. All questions referred to the perceived indoor climate during the winter season. While the most of residents perceived the indoor temperature as good, a common opinion was that the bathrooms were a bit cold while the bedrooms were experienced as too warm. The habits regarding airing were also investigated in the survey and large variations in this regard between the different types of premises could be seen.

Key words: Specific energy use, Domestic hot water, Indoor climate, Daylight, Vallda Heberg, Passive houses, Household electricity, Thermal comfort

Energiprestanda och inomhusklimatsutredning av passivhusområdet Vallda Heberg

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SAMMANFATTNING

Passivhus blir allt vanligare och fokus sätts ofta på den enskilda byggnaden. I bostadsområdet Vallda Heberg i Kungsbacka kommun, söder om Göteborg, är alla bostäder byggda med passivhusstandard och flera olika byggnadsformer finns representerade; villor, fyrfamiljshus, radhus, äldreboende och kommersiella byggnader. Alla byggnader förses med värme och varmvatten via ett lokalt fjärrvärmesystem där energin är genrerad från förnybara energikällor på plats i området.

Den uppmätta energianvändningen i de olika byggnaderna har studerats i upp till ett år, beroende på hur länge byggnaderna varit i bruk, och de uppmätta värdena jämfördes med projekteringsvärdena. Brukarbeteendets påverkan på energiprestandan är stor och de största variationerna fanns i varmvattenanvändningen. För byggnaderna med ett helt års mätdata var den uppmätta energianvändningen lägre än den projekterade medan prognoser indikerar en högre energianvändning än projekterat i de övriga byggnaderna. I helårsstudien var den uppmätta värmeanvändningen lägre än beräknat medan varmvattenanvändning och fastighetsel var något högre än projekterat. Den antagna hushållselen underskattades i projekteringen.

Inomhustemperaturen i bostäderna uppfyller kraven i Folkhälsomyndighetens Författningssamling och enligt en enkätundersökning var de flesta boende nöjda med sitt inomhusklimat. Enkäten skickades till alla bostäder i området och svarsfrekvensen var 41 av 64, alla frågor refererade till hur de upplevde sitt inomhusklimat under vinterhalvåret. De flesta svarande upplevde inomhustemperaturen generellt sett som bra, men en vanlig åsikt var att badrummen uppfattades som något kalla medan sovrummen något varma. Vädringsvanor undersöktes också i enkäten och det fanns stora variationer mellan vanorna i de olika boendeformerna.

Nyckelord: Specifik energianvändning, Varmvattenanvändning, Inomhusklimat, Dagsljus, Vallda Heberg, Passivhus, Hushållsel, Termisk komfort

Contents

Preface

In this study the energy use and the indoor climate in the buildings in the residential area Vallda Heberg has been investigated. The measured values of the energy use in all premises were used to compare the design values with the actual outcome. The perceived indoor climate in the premises and the user habits of the people living in the buildings were investigated with a survey.

This study is a part of a larger project with focus on the energy efficiency of the buildings, the indoor climate and the technical system in Vallda Heberg. The project is financed by a Swedish programme for buildings with very low energy demand, LÅGAN, the Swedish construction industry's organization for research and development, SBUF, NCC Construction Sweden AB and Eksta Bostads AB.

This sub-project was carried out by Håkan Jimmefors and Julia Östberg at NCC Construction Sweden AB in Gothenburg. The supervisors representing Chalmers were Angela Sasic and Magnus Österbring, the supervisor from NCC Construction Sweden AB was Göran Frenning. Thank you for your assistance and all good advices during the project.

The project manager of the main project is Elsa Fahlén at NCC Construction Sweden AB who has been very helpful and inspiring, thank you. Thanks also to Anders Ljungberg, Martin Jansson and Martin Sandberg at NCC for all information regarding Vallda Heberg, interesting conversations and good advices.

Gothenburg June 2014

Håkan Jimmefors
Julia Östberg

Notations

$A_{envelope}$	The area of the building envelope [m^2]
A_{temp}	The floor area of the heated part of the building [m^2]
$DVUT$	Design winter outdoor temperature [˚C]
DUT_{20}	Design outdoor temperature [˚C]
$E_{balanced,F09}$	The balanced energy demand in a building [$kWh/m^2A_{temp}/year$] according to FEBY 09
$E_{balanced,F12}$	The balanced energy demand in a building [$kWh/m^2A_{temp}/year$] according to FEBY 12
$E_{building}$	The specific energy demand in a building [$kWh/m^2A_{temp}/year$]
E_{el}, e_{el}	Delivered electricity [$kWh/m^2A_{temp}/year$] and the energy factor for electricity [-]
E_{dh}, e_{dh}	Delivered district heating [$kWh/m^2A_{temp}/year$] and the energy factor for district heating [-]
E_{dc}, e_{dc}	Delivered district cooling [$kWh/m^2A_{temp}/year$] and the energy factor for district cooling [-]
$E_{s,w}, e_{s,w}$	Delivered energy from sun or wind [$kWh/m^2A_{temp}/year$] and the energy factor for sun and wind [-]
E_{oth}	Other delivered energy such as bio fuel and natural gas [$kWh/m^2A_{temp}/year$]
$P_{building}$	Power demand of a building [W/m^2A_{temp}]
U_{mean}	The mean U-value of a building [W/m^2K]
v_a	Air velocity [m/s]
VFT_{DVUT}	Heat loss number for design outdoor winter temperature [$W/m^2/year$]
η	Efficiency of the heat exchanger [-]

1 Introduction

1.1 Background

There is a growing interest in energy efficient buildings and passive houses are becoming more and more common. A passive house is defined by its very low transmission losses, low air leakage through the building envelope and low ventilation losses, which is commonly achieved through an efficient heat exchange between exhaust and supply air. Passive houses are supposed to be heated mainly by the internal heat gains from people, their activity in the building and from solar radiation. There is usually some kind of complementary heating system installed to meet the requirements of the indoor climate during the heating season.

The focus on the energy demand in passive houses is usually put on the individual building. To be able to fulfil the future higher demands on the energy efficiency it will be necessary to change the perspective and find more overall solutions that make the entire area energy efficient and take advantage of the interaction between the buildings.

Vallda Heberg is a passive house certified residential area with on-site generation of heating energy from renewable energy sources. It is located 30 kilometres south of Gothenburg in the municipality of Kungsbacka in Sweden. The area consists of several different types of passive buildings; single family houses, apartment blocks, terrace houses for seniors, a retirement home and commercial buildings. A local district heating system that is connected to all of the buildings is supplied with heat from solar collectors and a pellet boiler in the area. The solar collectors are designed to cover 40% of the total heating demand in the buildings.

The contractor NCC Construction Sweden AB together with the client Eksta Bostads AB, LÅGAN (a Swedish programme for buildings with very low energy demand) and SBUF[1] (the Swedish construction industry's organization for research and development) have initiated a follow-up on the Vallda Heberg project with focus on the actual energy use, measured and perceived indoor climate and the overall system solution. This master thesis is a part of the follow-up project.

1.2 Purpose

The purpose of this project is to evaluate the energy use and the indoor climate in all the buildings in the residential are Vallda Heberg. Since different user behaviour leads to variations in the energy use, the measured energy use will be compared with the numbers obtained by calculations during the project design phase to see how well they correlate and based on that to come up with some general conclusions for future projects. The variation and distribution of the energy for heating, hot water, household electricity and operational electricity between different residents will also be compared.

Since there is a variation in the types of housing in the area there are also different family compositions present. The variations in terms of age and number of family members means that there is a variation of the residents' habits regarding airing,

[1] In Swedish: SBUF – Svenska Byggbranschens Utvecklingsfond

cooking, showering, physical activity etc., which affects the energy demand for heating and domestic hot water. Moreover, the thermal comfort varies between different people and changes with age. Due to these differences it is often difficult to accurately predict the actual energy demand for heating in the building during the design phase. This project provides data and information about how to predict user behaviour in future projects of similar type.

1.3 Method

There are measured data of the energy use, domestic hot water use, household electricity, operational electricity, indoor temperature and relative humidity available for all the premises. The measuring periods varies between the premises depending on how long the buildings have been in use and the data is stored by Eksta Bostads AB. The data will be analysed to find the fluctuation of the energy use between the different users and to find out how well the actual energy use agree with the theoretical calculations. Differences in indoor temperature will be compared with the heating energy to find out if there is a clear connection.

A survey of the perceived indoor climate during the winter season and the users habits that affects the energy demand will be performed with all the residents and with the employees at the retirement home. The results from the single family houses will be evaluated together with an earlier survey for the summer case for those houses. The purpose of the survey is also to give an explanation to some of the results from the measured data.

Three single family houses will have a more detailed investigation regarding air velocities, relative humidity, floor temperature, operative temperature and air temperature at two different heights. The daylight and the efficiency of the heat exchanger will also be measured. The results from these more complex measurements will be used to evaluate the indoor climate in the houses and the knowledge could be used in future projects.

1.4 Limitations

This master thesis is concentrated to the specific project Vallda Heberg and the focus is put on the actual energy use and indoor climate of all the buildings. A parallel master thesis project handles the follow-up of the overall technical system and the energy balance of the entire area. The title of that report is *Evaluation of the Solar-Assisted Block Heating System in a Passive House Residential Area.*

1.5 Questions

The main questions in this project are:

- How and why does the energy use fluctuate between the different users and how is the distribution between the heating energy, domestic hot water and operational energy in the different types of residents in the area?
- How good is the accuracy of the theoretical calculations of the energy demand compared to the measured energy use?
- How well does the assumption regarding the domestic hot water use correlate with the actual use in the premises?
- How well does the indoor climate fulfil the expected values and how is the indoor climate perceived by the people living in the building?

2 The Residential Area Vallda Heberg

Vallda Heberg is a passive house certified residential area with production of renewable energy and is located 30 kilometres south of Gothenburg in the municipality of Kungsbacka in Sweden.

2.1 General information

The residential area consists of several different types of passive buildings; 26 single family houses, four apartment blocks with four apartments in each block, six terrace houses for seniors with a total of 22 apartments and a retirement home with 64 small apartments. The area also contains a community room, two commercial buildings and five residential building plots that will be built on by the purchaser. The area sketch of Vallda Heberg with the different types of buildings is presented in Figure 2.1.

The main concept of the Vallda Heberg project is to build energy efficient buildings that are supplied with heat from renewable energy generated on site and distributed by a local district heating system. Vallda Heberg has a large educational value and has attracted much attention in Sweden because of the overall system thinking and the focus of an energy efficient area instead of a one-building perspective. The project is considered a pilot project that attempts to inspire and act as a role model for future projects.

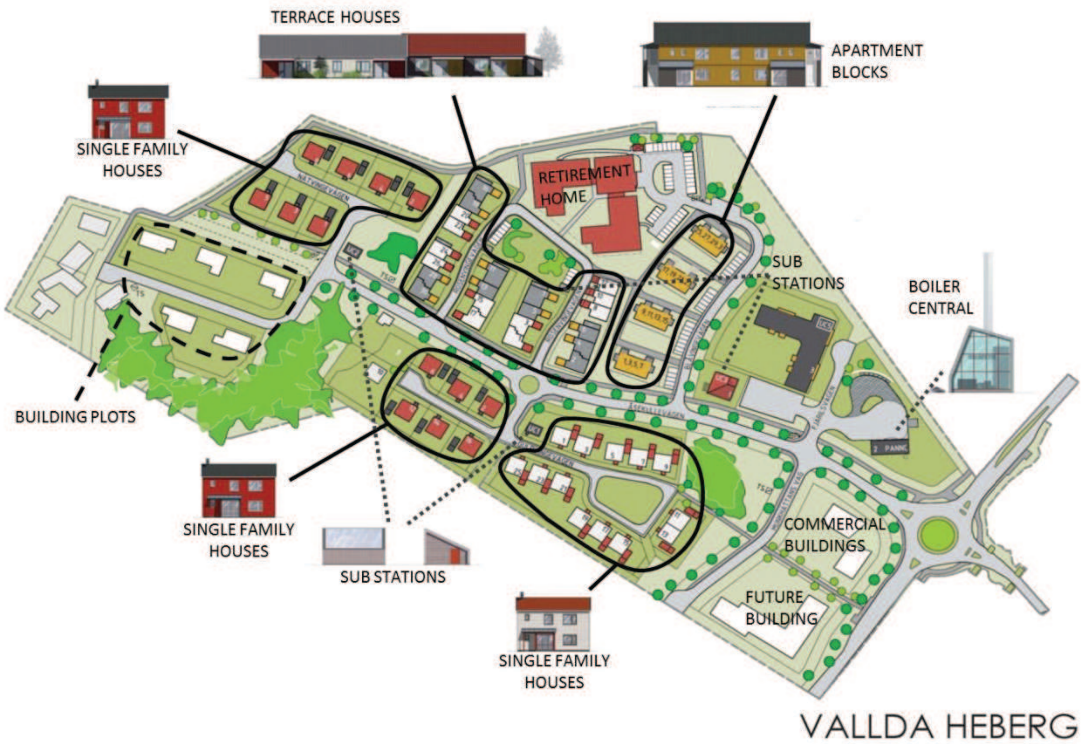

Figure 2.1 The residential area Vallda Heberg with the different types of living. (based on a sketch from Markgren Arkitektur AB)

The construction of Vallda Heberg started in 2011 and in the summer of 2014 the last two buildings, the commercial buildings that contains a gym, an office and a bakery, will be finished. All buildings in Vallda Heberg, including the commercial buildings, are built as passive houses according to the Swedish passive house standard.

2.2 Local district heating system

Vallda Heberg has its own district heating system that provides the buildings in the area with heat and domestic hot water. The aim is that 40% of the yearly heating energy in the area should be provided by solar heat and the remaining 60% by a biomass fuel boiler. The district heating system is divided into one pellet boiler central and four sub-stations. All sub-stations have flat plate solar collectors installed on the roofs and there are complementary flat plate solar collectors on the roofs of the four apartment blocks. The boiler central is equipped with 100 m^2 vacuum solar collectors placed at a 70˚ angle to fulfil the designed need of solar energy during spring and fall. The total area of the flat plate solar collectors in the area is 600 m^2.

The heat from the pellet boiler and the vacuum solar collectors is transferred by a well-insulated and anti-freeze treated water circuit to the four sub-stations. The system between the sub-stations and the buildings consists of a hot water circulation circuit that is used for both heating and domestic hot water in the buildings. A principal sketch of the district heating system is presented in Figure 2.2 below.

When the collected solar energy in the sub-station is not sufficient to keep the temperature at 60˚C in the hot water circulation circuit there is a need of heat from the pellet boiler central. The hot water from the pellet boiler central with the temperature of 80˚C is heat exchanged with the hot water circulation circuit in the sub-stations. The return temperature in the hot water circulation circuit is designed to never fall below 50˚C due to the risk of legionella bacteria (prescribed in the Swedish demands for buildings).

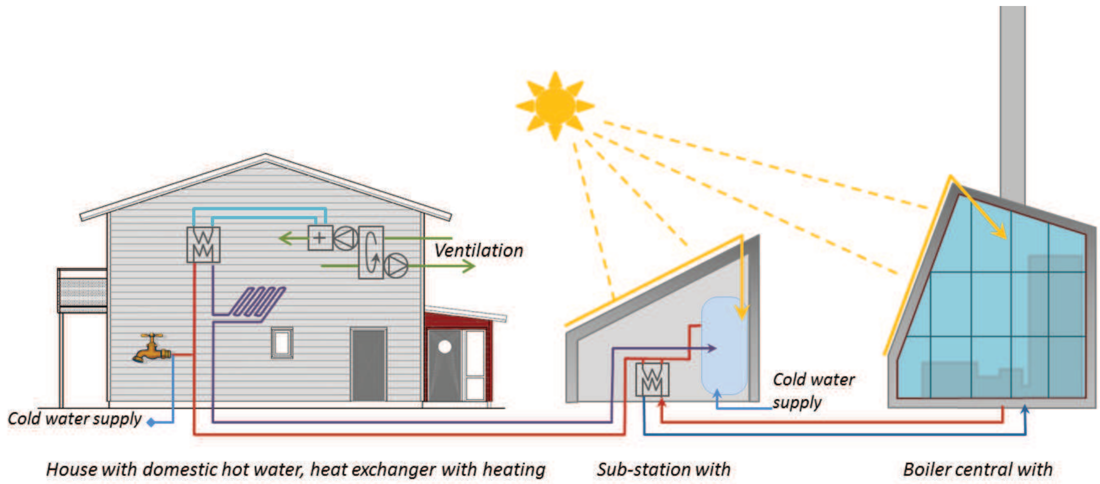

Figure 2.2 Principal sketch of the technical system in Vallda Heberg. (Based on figures from Markgren Arkitektur AB and Mats Abrahamssons Arkitektkontor AB)

Extra insulated pipes have been used in the area to decrease the energy loss in the distribution system. The system is prepared for expansion so that future buildings in the vicinity can connect to this district heating system as well.

3 Design criteria

All buildings in Vallda Heberg are built according to the Swedish passive house standard and the Swedish regulations in the law. This section describes the demands on the buildings.

3.1 Passive house technology

The passive house concept is defined as:

"A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by postheating or postcooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions (DIN 1946) - without a need for recirculated air." (Feist, 2006).

A passive house is usually built with a well-insulated and air tight building envelope and with an efficient heat exchange between supply and exhaust air. It is common that the building is heated by a heating coil in the supply air and no additional heating system is usually needed. All buildings in Vallda Heberg are built with this principle, the well-insulated and air tight building envelope provides low transmission losses and low air infiltration with outside air. The internal heat gains from people, electrical equipment and other activity in the building are used to heat the building. Solar shading is used to prevent overheating during the summer. In Vallda Heberg the balconies, carports and, in some cases, the eaves are designed to shade the windows from the sun during summer time. The solar shading is often designed to let the solar energy into the building during the winter season when the heating demand is larger, see Figure 3.1.

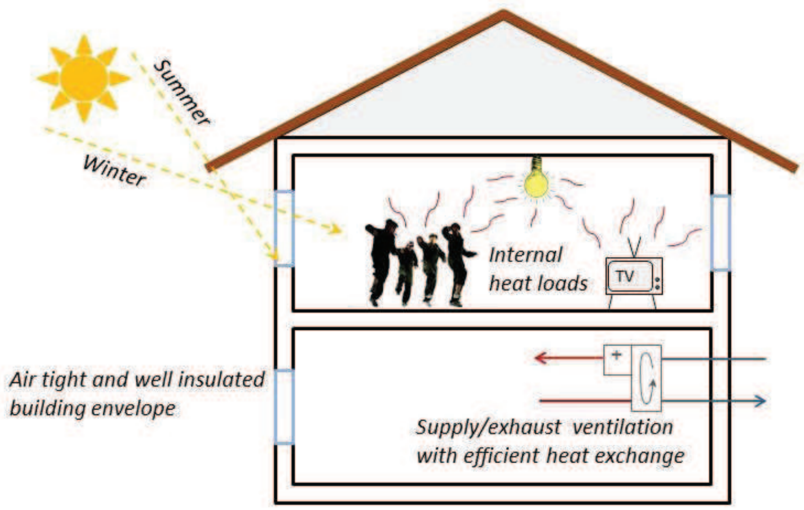

Figure 3.1 Principal sketch for the passive house concept

There are several other types of low energy buildings, for example plus-energy houses, zero-energy houses and mini-energy houses. This report only refers to passive houses.

3.2 The Swedish demands on passive houses

The demands on energy use and indoor climate for Swedish passive houses are determined by the Swedish forum for energy efficient buildings, FEBY[2]. The demands in the publications of FEBY pertain:

- Energy demand due to heating, domestic hot water use and operational electricity
- Heat losses due to transmission, air leakage and ventilation
- Noise reduction from ventilation
- Mean U-value of all windows and glazed doors

All the buildings in Vallda Heberg are designed according to the FEBY standard. The single family houses, the terrace houses and the retirement home are designed with the 2009 edition of FEBY (FEBY 09) and the apartment blocks are designed with the 2012 edition (FEBY 12).

3.2.1 Demands on energy performance

The passive house design requirements vary in different parts of Sweden due to variations in the climate. In the demands Sweden is divided into three climate zones as presented in Figure 3.2, the climate zones are the same as in the Swedish regulations that is described later in this chapter. Vallda Heberg is located in climate zone III and is marked with a dot in the figure below.

Figure 3.2 The three climate zones of Sweden. Vallda Heberg is marked as a dot and is located in climate zone III.

[2] In Swedish: FEBY - Forum för energieffektiva byggnader

3.2.1.1 The energy performance demands of the apartment blocks

The apartment blocks in Vallda Heberg are designed with the FEBY 12 standard. The energy performance demand of passive houses according to FEBY 12 refers to the heat loss number and the specific energy demand.

The heat loss number, VFT_{DVUT}[3], is defined as the sum of the heat losses from the building due to transmission, ventilation and infiltration. The calculation is performed at the indoor temperature 21℃ and the design winter outdoor temperature ($DVUT$) that depends on the location and the properties of building (FEBY, 2012). The demand for the heat loss number is presented in Table 3.1.

Table 3.1 The demands of the heat loss number due to FEBY 12. For buildings with an area smaller than 400 m^2 the maximum heat loss number can be increased with 2 W/m^2A_{temp}

	Zone I	Zone II	Zone III
Maximum VFT_{DVUT} , [W/m^2A_{temp}]	17	16	15

The specific energy demand, $E_{building}$, of the building includes heating, domestic hot water and operational electricity. The calculation of the specific energy demand is performed at the indoor temperature 21˚C and with a reduction of the solar heat load of at least 50 %. The demand is presented in Table 3.2 below.

Table 3.2 The demands for the specific energy demand due to FEBY 12. For non-electrically heated buildings with an area smaller than 400 m^2 the maximum specific energy demand can be increased with 5 kWh/m^2A_{temp}/year.

	Zone I	Zone II	Zone III
Maximum $E_{building}$, [kWh/m^2A_{temp}/year]	58	54	50

The specific energy demand is used for buildings with only one type of heating system. For a combined system (both electrical and non-electrical) the balanced energy demand, $E_{balanced,F12}$, should be used. The balanced energy demand is used to restrict the energy use and to promote low-grade energy sources such as district heating, solar energy and wind energy. Solar and wind energy produced on the building's property is not taken into account in the balanced energy demand.

In Vallda Heberg the operational energy comes from electricity and the balanced energy demand is therefore used. Since the solar energy is not produced on the

[3] In Swedish: VFT_{DVUT} - Värmeförlusttal vid dimensionerande utomhustemperatur

buildings' property the solar energy is also taken into account in the balanced energy demand.

The balanced energy demand is presented in Table 3.3 [kWh/m^{2}A$_{temp}$/year] and is calculated as:

$$E_{balanced,F12} = \sum(e_{el} * E_{el} + e_{dh} * E_{dh} + E_{dc} * e_{dc} + E_{oth}) \quad (3.1)$$

Where:

E_{el}, e_{el}	Delivered electricity [kWh/m^{2}A$_{temp}$/year] and the energy factor for electricity, $e_{el} = 2.5$
E_{dh}, e_{dh}	Delivered district heating [kWh/m^{2}A$_{temp}$/year] and the energy factor for district heating $e_{dh} = 0.8$
E_{dc}, e_{dc}	Delivered district cooling [kWh/m^{2}A$_{temp}$/year] and the energy factor for district cooling $e_{dc} = 0.4$
E_{oth}	Other delivered energy such as bio fuel and natural gas [kWh/m^{2}A$_{temp}$/year]

Table 3.3 The demands for the balanced energy demand due to FEBY 12. For buildings with an area smaller than 400 m^2 the maximum balanced energy demand can be increased with 5 kWh/m^{2}A$_{temp}$/year

	Zone I	Zone II	Zone III
Maximum $E_{balanced,F12}$ [kWh/m^{2}A$_{temp}$/year]	73	68	63

3.2.1.2 The energy performance demands of the single family houses, the terrace houses and the retirement home

The single family houses, the terrace houses and the retirement home in the Vallda Heberg are built according to FEBY 09, which was the current Swedish passive house standard when those buildings were designed.

The largest difference between the 2009 and the 2012 standards is that there is a maximum power demand in FEBY 09 instead of the maximum heat loss number in FEBY 12. There is no demand for the specific energy use in FEBY 09, only a recommendation.

The power demand, $P_{building}$, is calculated as the sum of the heat losses due to transmission and ventilation at design outdoor temperature. In the power demand calculations, unlike the heat loss number, the internal heat loads can be taken into account. The power demand is calculated at the indoor temperature 20˚C and the design outdoor temperature DUT$_{20}$ that depends on the location and the properties of the building. The demands of the power demand are presented in Table 3.4 below.

Table 3.4 The maximum power demand according to FEBY 09. For smaller one- or two family houses with an area smaller than 200 m^2 per residence the maximum power demand can be increased with 2 W/m^{2}A$_{temp}$

	Zone I	Zone II	Zone III
Maximum $P_{building}$ [W/m^{2}A$_{temp}$]	12	11	10

There is not a requirement of the energy demand in FEBY 09, there is only a recommended maximum that is presented in Table 3.5. The recommendation is expressed as balanced energy demand, [kWh/m^{2}A$_{temp}$/year], calculated from:

$$E_{balanced,F09} = \sum(e_{el} * E_{el} + e_{dh} * E_{dh} + e_{s,w} * E_{s,w}) \quad (3.2)$$

Where:

E_{el}, e_{el} Delivered electricity [kWh/m^{2}A$_{temp}$/year] and the energy factor for electricity, $e_{el} = 2.0$

E_{dh}, e_{dh} Delivered district heating [kWh/m^{2}A$_{temp}$/year] and the energy factor for district heating $e_{dh} = 1.0$

$E_{s,w}, e_{s,w}$ Delivered energy from sun or wind [kWh/m^{2}A$_{temp}$/year] and the energy factor for sun and wind $e_{s,w} = 0$

Since the solar energy is not generated on the buildings property the solar energy to the premises in Vallda Heberg is considered as district heating in the calculations.

Table 3.5 The recommended maximum for the balanced energy demand due to FEBY 09

	Zone I	Zone II	Zone III
Maximum $E_{balanced,F09}$ [kWh/m^{2}A$_{temp}$/year]	68	64	60

3.2.2 Demands on air leakage and U-values

The maximum air leakage through the building envelope according to FEBY 12 is 0.3 l/s/m^2 at ± 50 Pa. For smaller buildings with a shape factor (A$_{envelope}$/A$_{temp}$) larger than 1.7 the maximum air leakage is 0.5 l/s/m^2. In FEBY 09 the demand on the air leakage is maximum 0.3 l/s/m^2 for all buildings.

The mean U-value of windows and glazed doors is maximum 0.8 W/m^{2}K according to FEBY 12 and 0.9 W/m^{2}K in FEBY 09.

3.2.3 Demands on the indoor climate

The supply air temperature after the heating coil must not be higher than 52 ˚C and there is a recommendation that the indoor temperature during April-September should not exceed 26˚C for more than 10% of the time.

Noise from the ventilation shall pass at least the sound level B in living room and bedrooms.

3.3 The Swedish general requirements for all buildings

The Swedish National Board of Housing, Building and Planning[4], determines several regulations and advices regarding buildings (Boverket, 2014). These regulations are called BBR[5] and have the purpose to fulfil the design requirements and the technical specification requirements in the law of building and blanning, PBL. The contractor is obligated to follow these regulations. Among other demands BBR contains demands regarding the mean U-value of the building and the energy performance.

There are changes in the building related laws which means that BBR is continuously renewed and these updates are named with a BFS[6]- number, therefore it is important to write in the construction document what BFS that is applied. The energy investigations for the housing in Vallda Heberg were made with different editions; with changes until BFS 2010:5, BFS 2011:6 and BFS 2011:26, which means they have different specific energy demands (see Table 3.6 below) and mean U-value demands (see Table 3.7) for the different types of housing.

Table 3.6 Maximum specific energy demand for premises with non-electrical heating according to BBR.

	Zone I	Zone II	Zone III
$E_{building}$ (BFS 2010:5 and BFS 2011:6) [kWh/m^{2}A$_{temp}$/year]	150	130	110
$E_{building}$ (BFS 2011:26) [kWh/m^{2}A$_{temp}$/year]	130	110	90

[4] In Swedish: Boverket
[5] In Swedish: Boverkets Byggregler
[6] In Swedish: Boverkets Författningssamling

Table 3.7 Maximum mean U-value for the building envelope for buildings with non-electrical heating or electrical heating according to BBR.

	Zone I	Zone II	Zone III
U_{mean} (BFS 2010:5 and BFS 2011:6) [W/m^{2}K]	0.5	0.5	0.5
U_{mean} (BFS 2011:26) [W/m^{2}K]	0.4	0.4	0.4

Other listed demands concern airflow and domestic hot water. The ventilation systems should be designed for a minimum airflow corresponding to 0.35 l/s,m^{2}A$_{temp}$, when there are people in the building. When the building is empty, the demand is 0.10 l/s, m^{2}A$_{temp}$. The temperature of the domestic hot water should not be less than 50˚C and not higher than 60˚C.

4 Indoor Climate

4.1 Thermal climate

The human body tries to maintain a steady body temperature even though it is exposed to different thermal climates. To maintain the body heat balance the body temperature is regulated by automatic mechanisms in the body and by human behaviour. When the thermal climate affects the body (the temperature changes) the automatic mechanisms will operate by muscles, blood flow and sweat which will regulate the body temperature. Examples of human behaviour affecting the body temperature are by regulating the activity level, seeking shadow, opening a window, increasing or decreasing the amount of clothing etc.

The thermal climate is experienced differently by different people and there are a number of factors that affect how the surrounding thermal climate is perceived:

- Radiant temperature
- Air temperature
- Relative humidity
- Air velocity

The factors above affect heat exchange between the body and the surrounding. Radiation temperature directly affects the body heat balance. Air temperature affects the convective losses from the skin since the body heats the surrounding air. The relative humidity affect the evaporating of sweat to the air, the higher the relative humidity is the less sweat can evaporate into the air. The air velocity is affecting both convection and evaporation, with increased air velocity the convection and evaporation will increase due to the exchange of surrounding air. (Gavhed D., Holmér I. 2006)

Beside the factors described above there are individual factors that affect the experienced thermal climate; the clothing and activity level. The degree of clothing is measured in the unit [clo] and it tells the insulation ability of the clothing. 1 clo, which corresponds to 0.155 m^2K/W, is the amount of insulation where a person in rest maintains the thermal equilibrium in an environment at 21˚C and normal airflow. The activity level is measured in metabolic energy production, [met], where 1 met corresponds to an average person at rest with the energy production of 58 W/m^2, the area refers to surface area for human body. For an average person the surface area is around 1.8 m^2 according to ASHRAE[7] standard 55.

4.2 Thermal comfort

Thermal comfort is defined as the condition when a person feels comfortable and is satisfied with the thermal environment. Due to individual differences, it is impossible to find a thermal environment that will satisfy everybody. To measure how the thermal climate is experienced in a room, there is an index called the PMV-index, Predicted Mean Vote. This index predicts the mean response of a large group of people, with given physical activity and clothing, according to a seven-grade thermal sensation scale ranging from -3 to +3, where -3 is cold, +3 is hot and 0 is neutral

[7] ASHRAE - American Society of Heating, Refrigerating and Air-conditioning Engineers.

sensation. The comfort zone is defined as the values between -0.5 and +0.5 according to the European standard EN ISO 7730:2005[8].

With the PMV-index the Predicted Percentage Dissatisfied people, the PPD-index, can be calculated. The PPD-index is a quantitative measure of the reaction of a group of people at a specific situation, and is often used to investigate the thermal comfort for thermal environments. The range for the PPD-index is between 5% - 75% due to EN ISO 7730:2005, which state that the index should only be used for values of PMV between -2 and +2. The lowest amount of dissatisfied people, 5%, exists because there always will be a difference in people's opinion about thermal comfort.

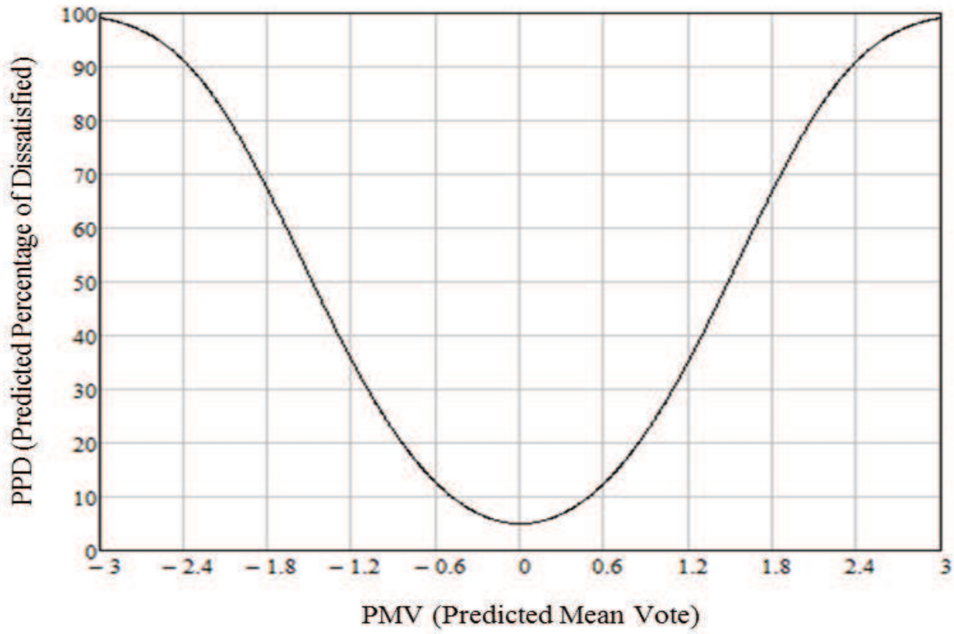

Figure 4.1 Relationship between the predicted percentage of dissatisfied people as a function of the predicted mean vote..

4.3 Thermal comfort in passive houses

The thermal environment in passive houses differs from that in regular houses. Since the air leakage and transmission losses are lower through the building envelope, there is a lower need of supplied energy to achieve thermal comfort. The indoor temperature usually increases between spring and autumn due to the extra heat from solar radiation, therefore it might be necessary to air during this season to reach a desirable indoor temperature. During the colder part of the year there is a higher heating demand that the internal heat loads are unable to fulfil. For normal houses there are often radiators under the windows while the passive houses in Vallda Heberg are heated by the supply air. Generally people's desired indoor temperature varies with the different seasons; during the summer season the desired indoor temperature are usually a bit higher than during the winter season.

[8] *EN ISO 7730:2005 - Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*

4.4 Daylight

An additional parameter for the indoor climate is the daylight comfort. To ensure there is enough daylight in a building, there are recommendations that the window glass area is about 10% of the floor area. When investigating the daylight, the illuminance is being measured, which is the amount of light falling on a surface. The amount of daylight that appears inside a building is measured as the daylight factor (DF) and is the relation between the internal and external illuminance.

The illuminance at the considered point is calculated as the sum of three components; direct light from the sky (SC), externally reflected light (ERC) and internally reflected light (IRC). ERC includes the light reflected on vertical surfaces outside the room which screens the sky. IRC is the contribution of the reflection that appears inside the room. (Löfberg, 1987)

When the daylight factor is measured the illuminance is measured both inside and outside the building. The measurements are done when there is an overcast sky which corresponds to an outside illuminance of approximately 12.000 Lux and where there is no shielding from trees, other houses etc. Due to the overcast sky the insolation to the room will be independent of the direction the windows are facing. The window area has to be free from any kind of shading, no curtains, blinds, flowers etc. It is important to have a stable weather and that the measuring, both outside and inside, takes place at the same time. The daylight is measured at the half depth of the room, 1 m from the wall and 0.8 m above the floor (Löfberg, 1987).

During the design phase of Vallda Heberg no daylight simulations were made, but in the master thesis *Daylight and thermal comfort in a residential passive house*[9] the daylight factor in the single family houses in Vallda Heberg was simulated. The master thesis was written during the construction phase of Vallda Heberg and did not affect the design of the houses. There are no demands on daylight factor in the buildings in Vallda Heberg, but measurement will be done in three single family houses to see how well the simulated daylight factor agrees with the measured values.

4.5 Measurement technology

When investigating the thermal climate in a building the basic physical quantities are measured:

- Air temperature
- Mean radiant temperature
- Humidity
- Air velocity
- Surface temperature

According to the European standard EN ISO 7726:2001[10] the measuring instruments are placed 1 m from the wall, in front of a window and at three different heights in the

[9] Written by Magnus Heier and Magnus Österbring at Chalmers University of Technology 2012
[10] *EN ISO 7726:2001 - Ergonomics of the thermal environment – Instruments for measuring physical quantities*

comfort zone. The instruments require a certain period of time to reach steady-state which is necessary to get accurate values of the indoor climate. Due to the small variations of the values it is important that the instruments are calibrated. When measuring the air velocity, the sensor has to be independent of the direction of the air movements. The mean radiant temperature is measured with a black-globe thermometer with a diameter of approximately 0.15 m, the smaller the diameter is the more sensitive the black-globe is for air velocity and air temperature which affect the accuracy of the radiation temperature.

Table 4.1 Characteristic values of the measuring instruments for the comfort class

Quantity	Measuring range	Accuracy (Required/Desirable)	Height:
Air temperature	10˚C to 40˚C	± 0.5˚C / ± 0.2˚C	0.1 m & 1.1m
Mean radiant temperature	10˚C to 40˚C	± 0.2˚C / ± 0.2˚C	1.1 m
Air velocity	0.05 to 1.0 m/s	± (0.05+0.05v_a[11]) m/s ± (0.02+0.07v_a) m/s	1.1 m
Absolute humidity	0.5 to 3.0 kPa	±0.15 kPa	1.1 m
Surface temperature	0˚C to 50˚C	± 1˚C / ± 0.5˚C	-

The measuring heights are recommended by the EN ISO 7726:2001 and refer to a seated person. The frequency of the momentary measurements in the measuring instruments is set to the shortest possible time. The absolute humidity is expressed as partial pressure of water vapour. The relative humidity is the ratio between the partial pressure of water vapour, p_a, in humid air and the water vapour saturation pressure, p_{as}, at the same temperature and total pressure.

In Vallda Heberg detailed measurements are made in three single family houses and the used measuring devices are showed in Figure 4.2 and their accuracies in Table 4.2.

[11] v_a is the air velocity

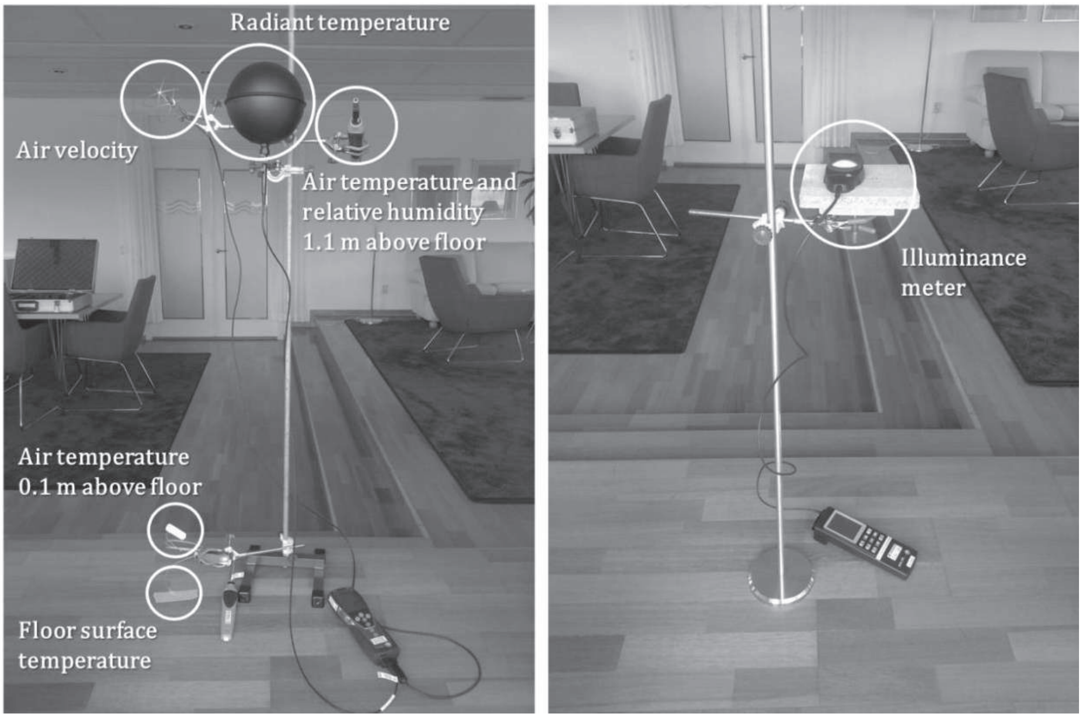

Figure 4.2 *The used measuring equipment. The left picture shows the devices for measuring air velocity, air temperature, radiant temperature and floor temperature. In the right picture the illuminance measurer is showed.*

Table 4.2 *The type and accuracies of the used measuring equipment. All accuracies are from the calibration certificates except for the air velocity which is not calibrated.*

Quantity	Instrument	Accuracy	Height:
Main measuring unit:	Testo 435-4 0563 4354	Depend on the sensors	-
Air temperature	Testo Wireless Handle 0554 0189	± 0.3˚C	1.1 m
Mean radiant temperature	Testo Globe Probe 0602 0743	± 0.4˚C	1.1 m
Air velocity	Testo Comfort Level Probe 0628 0109	± (0.03+0.04v_a) m/s	1.1 m
Relative humidity	Testo Wireless Probe 0554 0189	± 1.3% RH	1.1 m
Air temperature	Testo Wireless Handle 0554 0189 and Thermo Element Thread Type K	± 0.2˚C	0.1 m
Surface temperature			-

4.6 National board of statutes

When assessing the thermal indoor climate due to the detriment of human health, there are regulations in the Swedish Environmental Code. The Public Health Agency of Sweden gives advices in FoHMFS[12] 2014:17 which specify recommended values for the indoor climate that are shown in Table 4.3.

Table 4.3 Values for assessing detriment of human health (Carlsson, 2014).

	Recommended values:
Operative temperature	20 – 23℃
Differences in operative temperature measured 0.1m and 1.1m above the floor.	Less than 3℃
Air velocity (average)	Less than 0.15 m/s
Floor surface temperature	20 – 26 ℃

[12] FoHMFS – Folkhälsomyndighetens författningsansamling.

5 The Buildings in Vallda Heberg

All the premises in Vallda Heberg are equipped with a supply and exhaust air ventilation system with a rotating heat exchanger and a heating coil. The kitchen exhaust fans have a separate system and are not connected to the main ventilation system. The hot water circulation in the building is used as domestic hot water, comfort heating in the bathroom floor and it also heat exchanges with a glycol circuit that supplies the heating coil in the air handling unit with heat.

There are a washing machine, a dryer and a dishwasher in all the premises. The washing machines are connected to both the hot and the cold domestic water, the dishwashers are connected to the domestic hot water. In Sweden it is most common to only have cold water supply to the dishwasher and the washing machine, then the machines uses high-graded energy (electricity) to heat the water instead of, in this case, low-graded energy from renewable energy sources. The domestic hot water use is individually charged in all the premises. Only the single family houses have individual charging for the heating energy.

5.1 Single family houses

There are 26 single family houses in Vallda Heberg. The first single family houses in the area were finished during the spring 2012 and the last ones at the end of 2012. The single family houses are, unlike the other premises in the area, owned by the residents.

The area of the single family houses is 140 m^2 divided on two floors. On the first floor there is a kitchen, living room, laundry room and a toilet. On the second floor there are three bedrooms, a bathroom, a walk-in closet and a small living room. There is a vestibule that functions as an extra hall in the entrance and there is also a carport with a storage room in close connection to the building. In Figure 5.1 the layout of a typical single family house is shown, the dash-lined walls on the first and the second floor are optional walls that are not built in most of the houses in Vallda Heberg.

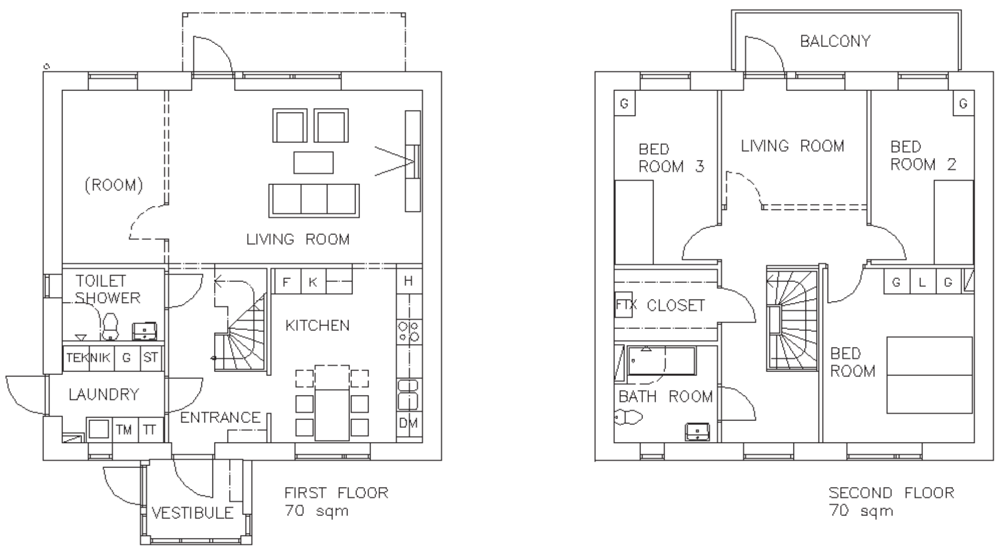

Figure 5.1 The layout of a typical single family house. The dash-lined walls are optional and are not built in most of the single family houses in Vallda Heberg. (Mats Abrahamsson Arkitektkontor AB)

The structural system of the single family houses is loadbearing timber stud walls with a timber roof truss structure on top. There is mineral wool insulation in the walls and the roof is a cold attic with blow-in wool insulation. The foundation is a concrete slab on the ground and the slab between the two floors is built with light weight composite timber beams. The U-values of the main elements of the building are presented in Table 5.1.

Table 5.1 The U-values of the main elements in the single family houses

Element	*W/m^2K*
External walls	0.11
Slab on the ground	0.08
Roof	0.05
Windows	0.70
Doors	0.80

The balcony and the carport are designed to be used as solar shading for some windows on the first floor. The facades are made of a horizontal timber panel as shown in Figure 5.2.

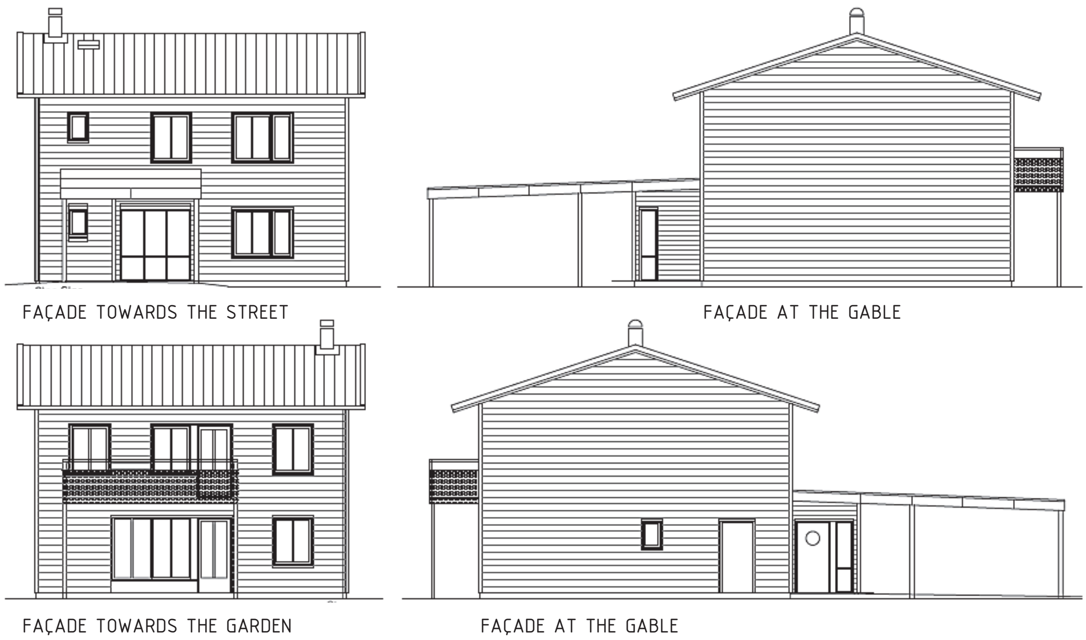

Figure 5.2 The facades of the single family houses in Vallda Heberg (Mats Abrahamsson Arkitektkontor AB)

The design ventilation air flow for the single family houses is 0.39 l/s,m^2 with supply air in bedrooms and living rooms and with exhaust air in bathrooms, kitchen, closet and laundry room. There is comfort floor heating in the bathroom on the first floor but not on the second floor.

5.1.1 Energy performance of the single family houses

To fulfil the demands of the passive house certification and the Swedish regulations the criterions in Table 5.2 should be fulfilled (except from the balanced energy demand that is only a recommendation in FEBY 09).

Table 5.2 Design values of the single family houses compared to demands in FEBY 09 and BBR (BFS 2010:5). Note that the balanced energy demand is only a recommendation in FEBY 09.

Criterions	*Design values*	*Demands in*	
Balanced energy demand, $E_{balanced}$ [kWh/m^{2}A$_{temp}$/year]	65	FEBY 09:	60
Design power demand $P_{building}$ [13] [W/m^{2}A$_{temp}$]	12	FEBY 09:	10+2
Mean U-value of windows and glazed doors [W/m^{2}K]	0.73	FEBY 09:	0.9
Air leakage thorough building envelope at ±50 Pa [l/s/m^2]	0.25	FEBY 09:	0.3
Specific energy demand, $E_{building}$ [kWh/m^{2}A$_{temp}$/year]	60	BBR:	110
Mean U-value of building envelope, U_{mean} [W/m^{2}K]	0.17	BBR:	0.5

The criterions fulfil the demands in FEBY 09 and the design is thereby approved as a passive house design.

During the construction of the single family houses the air leakage through the building envelope was measured in some of the houses. The measurements were made both by the contractor NCC Construction AB and by SP, the Technical Research Institute of Sweden. The results of the measured air leakage was 0.04 l/s/m^2.

The energy use in each single family house is measured by a heat meter in the return pipe for the hot water circulation and a flow meter in the domestic hot water pipe

[13] Due to the small area; 2 W/m^2 can be added to the standard demand in FEBY 09.

measure the hot water use. The operational electricity and the household electricity are also measured in all buildings.

5.2 Apartment blocks

There are four apartment blocks in Vallda Heberg and each block contains four apartments distributed on two floors. The tenants moved in during September-October 2013.

The floor layout and size of the apartment varies between the different blocks, the apartments have 2-4 rooms with a kitchen and the area varies between 67-95 m^2. In two blocks there are four apartments with three rooms in each apartment and in the other two blocks there are one four-room apartment and one two-room apartment on each floor. The floor plan of the first floor in one of the apartment blocks is showed in Figure 5.3. All apartments have a separate entrance with a vestibule and a small storage room in close connection to the entrance.

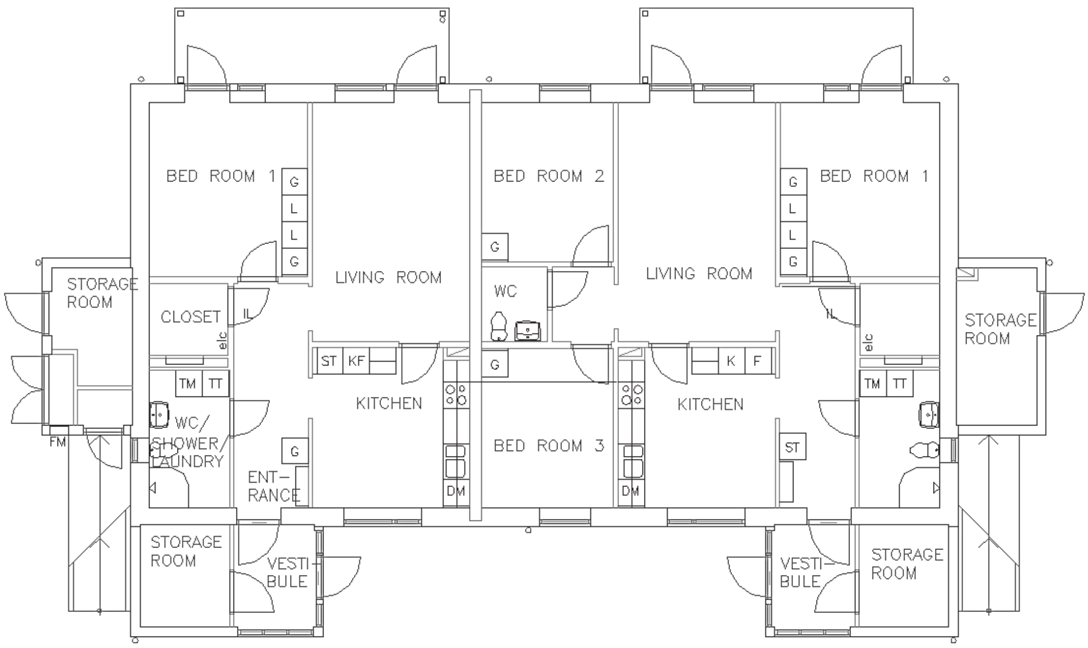

Figure 5.3 Floor plan of the first floor in one of the apartment blocks with two two-room apartments and two four-room apartments. (Mats Abrahamsson Arkitektkontor AB)

The structural system consists of steel beams and columns on a concrete slab with a concrete floor plate floor that separates the two storeys. A concrete wall separates the apartments in the vertical plane. There are timber framed external walls with mineral wool insulation, polyisocyanurate (PIR) insulation and another layer of mineral wool insulation. The roof structure is a cold attic with prefabricated timber roof trusses and blow-in wool insulation. The U-values of the main elements of the buildings are showed in Table 5.3.

Table 5.3 The U-values of the main elements of the apartment blocks

Element	W/m^2K
External walls	0.09
Slab on the ground	0.07
Roof	0.07
Windows	0.75
Glazed doors	0.80

Solar collectors cover the south side of the roofs of the apartment blocks, the solar collectors are connected to two different sub-stations in the area.

The façades of the apartment blocks consists of a vertical timber panel. The eaves are designed to shade the windows on the south side of the second floor during summer and to let the solar energy in during the winter. The balconies are designed to shade some of the windows on the first floor. This can be seen in Figure 5.4.

Figure 5.4 The facades of the apartment blocks (Mats Abrahamsson Arkitektkontor AB)

The designed mean air flow in the apartment blocks is 0,46 l/s/m^2.

5.2.1 Energy performance of the apartment blocks

The apartment blocks are designed according to FEBY 12 and BBR (BFS 2011:26) which means that all the requirements in Table 5.4 shall be fulfilled to be approved as a passive house design.

Table 5.4 Design values of the apartment blocks compared to the demands in FEBY 12 and BBR (BFS 2011:26).

Criterions	*Design values*	*Demands in*	
Balanced energy demand, $E_{balanced}$ [14] [kWh/m^{2}A$_{temp}$/year]	52	FEBY 12:	50+5
Heat loss number VFT_{DVUT} [15] [W/m^{2}A$_{temp}$]	16	FEBY 12:	15+2
Mean U-value of windows and glazed doors [W/m^{2}K]	0.77	FEBY 12:	0.8
Air leakage thorough building envelope at ±50 Pa [l/s/m^2]	0.25	FEBY 12:	0.3
Specific energy demand, $E_{building}$ [kWh/m^{2}A$_{temp}$/year]	52	BBR:	90
Mean U-value of building envelope, U_{mean} [W/m^{2}K]	0.17	BBR:	0.4

All requirements are fulfilled and the design is approved as a passive house design.

The heating energy use in each building body is measured by a heat meter in the building's return pipe for the hot water circulation circuit. The heating energy use is assumed to be equally distributed in the building. A flow meter in the domestic hot water pipe measures the hot water use in each apartment, all premises have individual billing of the domestic hot water.

[14] Due to the small area; 5 W/m^2 can be added to the balanced energy demand in FEBY 12.
[15] Due to the small area; 2 W/m^2 can be added to the heat loss number in FEBY 12.

5.3 Terrace houses for seniors

The terrace houses in Vallda Heberg were finished in May 2013, there are 22 apartments distributed in six terrace houses. The area of the apartments is 64-91 m^2 in one floor with 2-4 rooms and a kitchen. The tenants of the apartments in the terrace houses have to be at least 55 years old.

The layout of the apartments varies with the different sizes of the apartments. All apartments in the terrace houses have its own entrance with a vestibule, a carport, and a storage room. All apartments have an open floor plan between the kitchen and the living room. The floor plan varies between the different buildings, in Figure 5.5 the floor plan of one of the buildings is showed.

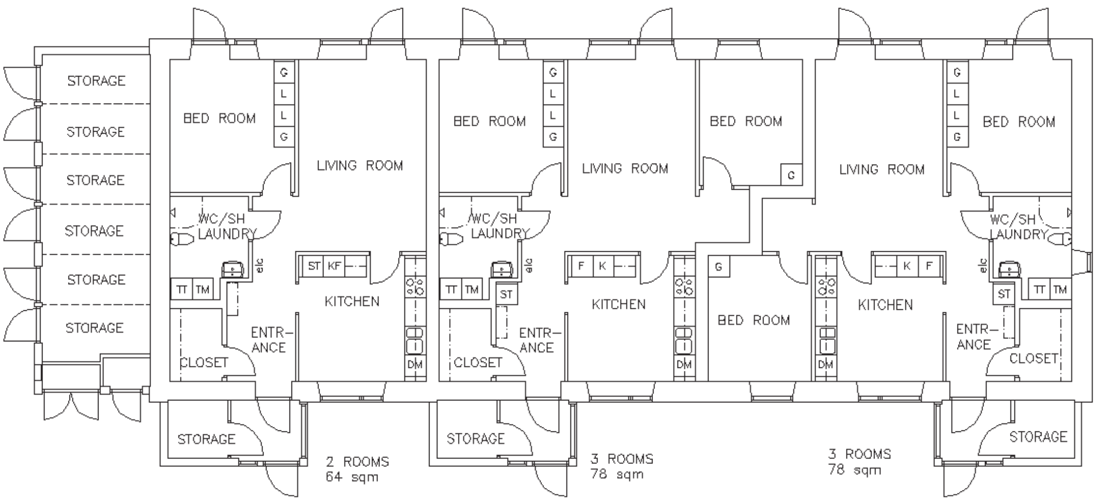

Figure 5.5 The floor plan of one of the terrace houses (Mats Abrahamsson Arkitektkontor AB)

The structural system consists of a concrete slab on the ground. The external walls are loadbearing timber stud walls with mineral wool insulation, a layer of graphite enhanced EPS insulation and a thinner timber stud wall with mineral wool on the inside. The roof is a cold attic structure with timber roof trusses and blow-in wool insulation. The U-values of the main elements of the building are showed in Table 5.5.

Table 5.5 The U-values of the main elements in the terrace houses

Element	*W/m^2K*
External walls	0.07
Slab on the ground	0.08
Roof	0.05
Windows	0.75
Glazed doors	0.80

The carports are used as solar shading for the terrace houses. The façade consists of vertical timber panels, sketches of the facades are showed in Figure 5.6.

Figure 5.6 The facades of one of the terrace houses (Mats Abrahamsson Arkitektkontor AB)

The design air flow to the apartments in the terrace houses varies between 0.39-0.47 $l/s/m^2$ and depends of the area of the apartment.

5.3.1 Energy performance of the terrace houses

The apartment blocks are designed according to FEBY 09 and BBR (BFS 2011:26) which means that all the requirements (except from the balanced energy demand that is only a recommendation) in Table 5.4 shall be fulfilled to achieve a passive house design.

Table 5.6 Design values of terrace houses compared to demands in FEBY 09 and BBR (BFS 2011:6). Note that the balanced energy demand is only a recommendation in FEBY 09.

Criterions	*Design values*	*Demands in*	
Balanced energy demand, $E_{balanced}$ [kWh/m^{2}A$_{temp}$/year]	65	FEBY 09:	60
Design power demand $P_{building}$ [W/m^{2}A$_{temp}$]	12	FEBY 09:	10+2
Mean U-value of windows and glazed doors [W/m^{2}K]	0.77	FEBY 09:	0.9
Air leakage thorough building envelope at ±50 Pa [l/s/m^2]	0.2	FEBY 09:	0.3
Specific energy demand, $E_{building}$ [kWh/m^{2}A$_{temp}$/year]	59	BBR:	110
Mean U-value of building envelope, U_{mean} [W/m^{2}K]	0.13	BBR:	0.5

All requirements are fulfilled and the design is approved as a passive house design.

The heating energy use in the terrace houses is measured by a heat meter in the return pipe of the hot water circulation circuit for the entire building body, the heating energy use is assumed to be equally distributed in the building. A flow meter in the domestic hot water pipe measures the hot water use in each apartment.

5.4 Retirement home

The retirement home in Vallda Heberg is the first passive house certified retirement home in Sweden and has been in use since October 2013. The retirement home consists of 64 small apartments divided into six departments on three floors. There are also social areas, kitchen, activity rooms, offices, dressing rooms and break rooms for the employees at the retirement home. The layout of the first floor is showed in Figure 5.7.

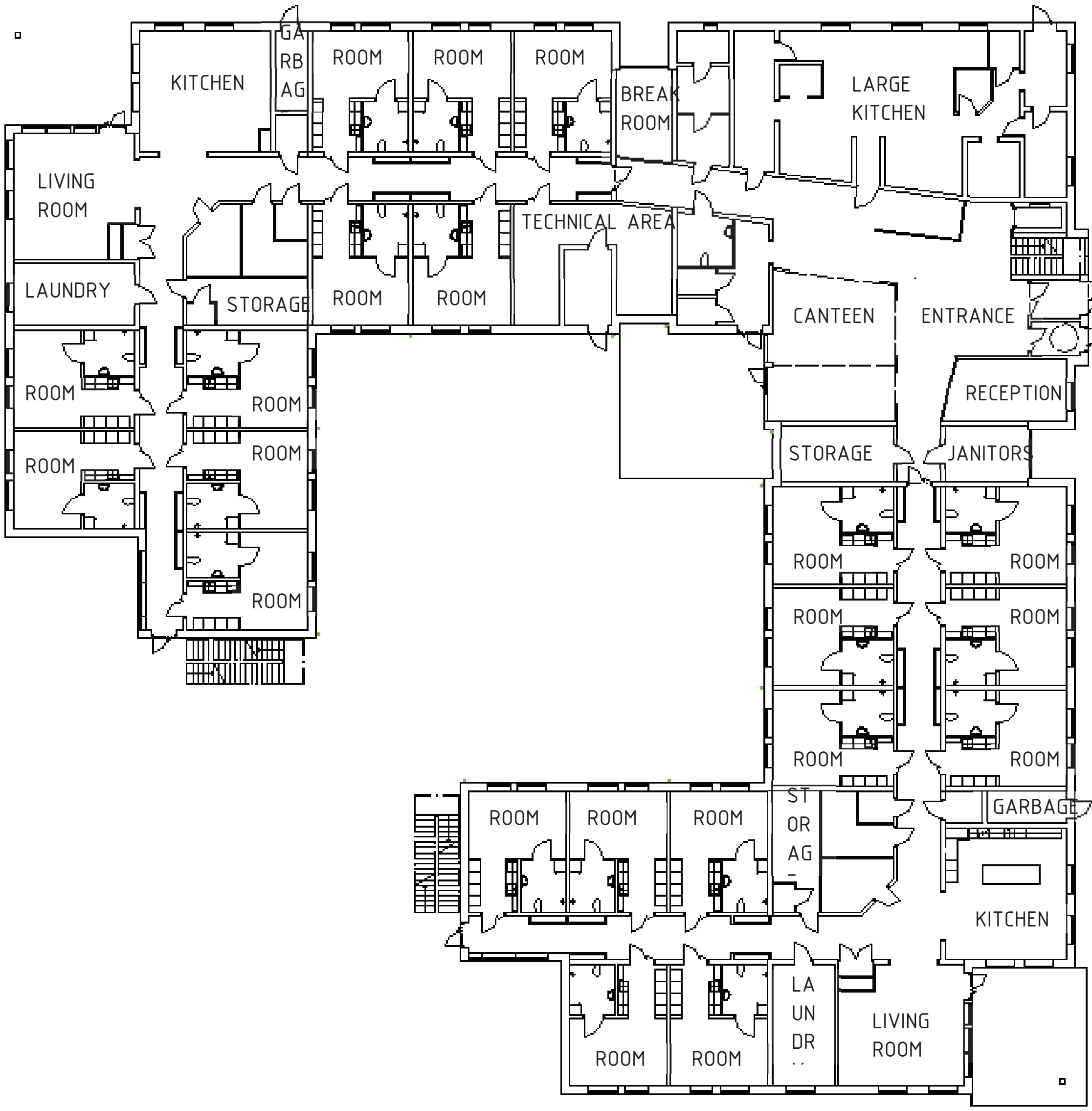

Figure 5.7 The floor plan of the first floor in the retirement home. The principle with two departments and one central social part is the same on all three floors. (Markgren Arkitektur AB)

The structural system consists of load bearing internal concrete walls on a concrete slab on the ground. The external walls have a timber stud framed part on the inside of the wall and one steel stud framed part in the outer part, both are insulated with rock wool insulation. The roof is built with light weight timber composite beams with a layer of insulation between the beams. The façade coating consists of fibre cement boards and timber panels. The U-values of the main elements in the retirement home is showed in Table 5.7.

Table 5.7 The U-values of the main elements in the retirement home

Element	*W/m²K*
External walls	0.09
Slab on the ground	0.11
Roof	0.08
Windows	0.84
Glazed doors	0.84

The residents in the retirement home are more sensitive of over temperatures during the summer season and the air handling unit is therefore equipped with both a heating and a cooling coil. All rooms are equipped with radiators to be able to regulate the temperature in each room separately. The attic is used as a technical room where all the air handling is performed. There are 550 m^2 solar cells on the roof of the retirement home to generate 40% of the buildings operational electricity and 100% of the electricity to the cooling machine. There are aluminium lamella solar shadings mounted above the windows at the retirement home to decrease the solar energy heat load to the building during the summer.

The design air flow to the retirement home is 0.76 $l/s/m^2$.

5.4.1 Energy performance of the retirement home

To fulfil the demands of the passive house certification and the Swedish regulations the criterions in Table 5.8 should be fulfilled (except from the balanced energy demand that is only a recommendation in FEBY 09).

The energy calculations are performed with the minimum temperature 22˚C and maximum temperature 25˚C.

Table 5.8 Design values of the retirement home compared to demands in FEBY 09 and BBR (BFS 2010:5). Note that the balanced energy demand is only a recommendation in FEBY 09.

Criterions	*Design values*	*Demands in*	
Balanced energy demand, $E_{balanced}$ [kWh/m^{2}A$_{temp}$/year]	57	FEBY 09:	60
Design power demand $P_{building}$ [W/m^{2}A$_{temp}$]	9.3	FEBY 09:	10
Mean U-value of windows and glazed doors [W/m^{2}K]	0.84	FEBY 09:	0.9
Air leakage thorough building envelope at ±50 Pa [l/s/m^2]	0.3	FEBY 09:	0.3
Specific energy demand, $E_{building}$ [kWh/m^{2}A$_{temp}$/year]	51	BBR :	110
Mean U-value of building envelope, U_{mean} [W/m^{2}K]	0.19	BBR:	0.5

The design fulfils the criterions and is approved as a passive house design.

6 Energy Simulations

During the design phase of Vallda Heberg the energy performance and the indoor climate were simulated in the program *IDA Indoor Climate and Energy (version 4.1-4.2)*. The input data for the simulations are a combination of numbers from SVEBY (see Section 6.1), regulations in FEBY and other assumptions. Thermal bridges were calculated with the program *HEAT2* version 6.1 and added to the simulations in *IDA Indoor Climate and Energy*, the thermal bridges are 15-26% of the total UA-value of the building envelope in the buildings in Vallda Heberg. The climate data that is used in the energy simulations is from Säve (10 km north from Gothenburg) which have a climate similar to the climate in Vallda Heberg.

The result from the energy simulations is the specific energy demand for each building that is presented in Chapter 5.

6.1 The development program SVEBY

The Construction and Real Estate business operates a development program called SVEBY[16] with the purpose to standardize and validate the energy performance in buildings. SVEBY determines user habits input data which is intended to be used as standardized input data to improve the energy calculations. The data that is being used are collected and accepted by a plurality of stakeholders in the building business. This is a good instrument to achieve a better control of the expected and actual energy use in a building. (SVEBY, 2014) Some categories that is listed in SVEBY of standardized habit input:

- Airing
- Sun screening (curtains, awning)
- Household electricity
- Domestic hot water use

In FEBY 12 the recommended input data from SVEBY are adapted.

6.2 Assumptions in the Vallda Heberg project

Several assumptions were made during the design phase, some of them will be compared to the actual measured result later in the report to see how well they correlate.

[16] In Swedish: SVEBY- Standardisera och Verifiera Energiprestanda i Byggnader

6.2.1 Input data from FEBY

In Table 6.1 the input data that is used from FEBY are presented.

Table 6.1 The assumptions made in the design phase of each house and is prescribed in FEBY

	Single family houses	Terrace houses	Apartment blocks	Retirement home
Swedish passive house standard:	FEBY 09	FEBY 09	FEBY 12	FEBY 09
Indoor temperature in energy calculations [˚C]	22	22	21	22-25
Indoor temperature in power calculations [˚C]	20	20	-	20
Domestic hot water [$kWh/m^2A_{temp}/year$]	15.4	15.4	20	20 [17]
Internal heat loads in energy calculations [W/m^2A_{temp}]	3.0	4.0	3.7	2.2
Internal heat loads in power calculations [W/m^2A_{temp}]	4.0	4.0	-	2.4
Energy losses due to airing [$kWh/m^2A_{temp}/year$]	0	0	0	4
Area per person – standard value [m^2/person]	41	41	41	-

The energy from the residents is assumed to be 47 W/person (the residents are assumed to be at home for 58% of the time and generate a mean power of 80 W/person). The energy loss due to airing is considered negligible.

The household electricity is assumed to be 1400 kWh/(year and household) + 400 kWh/(year and person) for single family houses according to FEBY 09. For the single family houses in Vallda Heberg this result in 2760 kWh per year and house. The terrace houses are calculated the same way and result in 2060-2308 kWh/year in the apartments depending on the area.

In FEBY 12 the assumed household electricity is prescribed as 30 kWh/m^2, this was adapted in the design phase of the apartment blocks.

[17] 20 kWh/m^2 on the area that consists of apartments. All other domestic hot water use is connected to the activity in the building and is not taken into account in the design phase.

The distribution of the household electricity over the year is not even and the design household electricity for a certain month can be calculated from a percentage factor prescribed in FEBY.

6.2.2 Input data from SVEBY

The input data from the SVEBY-programme was:

- Solar shading factor is 0.5 for all the buildings
- 70% of the household electricity can be credited as useful heat to the building

7 Results - Indoor Climate

This section contains the results from the indoor climate measurements that have been made in all the premises and in the retirement home. In the single family houses more detailed measurements have been made. This section also contains the results from the surveys which were sent to all the premises and the retirement home.

7.1 Indoor climate measurements

The indoor temperature and relative humidity are continuously measured in all premises. In this report different measuring periods of the indoor temperature will be used for the different types of premises since all of the buildings were not finished at the same time.

The measuring periods for the indoor temperatures in the premises are showed in Figure 7.1 below. In the single family houses the full year 2013 is measured, for the terrace houses the measuring period is for the six months August 2013 to January 2014. In the apartment blocks the measuring period is three months, December 2013 to February 2014 and in the retirement home the measurements started in Mars 2014 and were measured in the living room at different departments for one month.

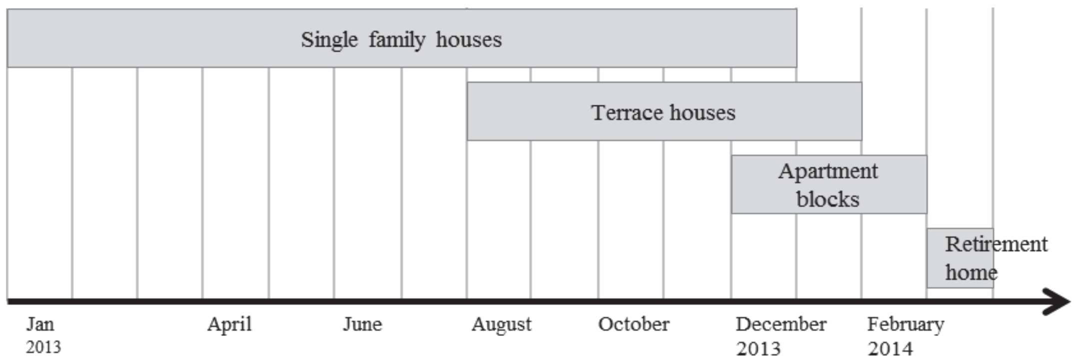

Figure 7.1 The measuring periods for the indoor temperatures in the premises.

The period of the indoor climate measurements for the terrace houses differs from the energy evaluation in Section 8 because the measuring of the indoor climate could start in august and represent one of the summer months.

The sensors are placed in the hall in the premises (protected from solar radiation) and the mean temperature and relative humidity of every hour is registered. There are a few hours during the measuring periods where the sensors did not register any values, this can be seen in diagrams and at the amount of registered hours of a specific period.

The way of controlling the indoor temperature differs between the different premises. In the single family houses, which are owned by the residents, it is possible to operate the ventilation system and set a desired indoor temperature. In the terrace houses and apartment blocks, which are rental apartments, the ventilation system is operated by Eksta Bostads AB who owns the property. However, the tenant can affect the indoor temperature if necessary by contacting Eksta Bostads AB.

7.1.1 The mean value of the indoor temperatures in the premises

The indoor temperature differs during the year due to the solar radiation and outdoor temperature. The mean value of the indoor temperature in all the premises during the winter and summer season is shown in Table 7.1 below. The winter season corresponds to the period December-February and the summer season corresponds to the period June-August. For the terrace houses August is the only measured month during the summer period and the temperature in the terrace houses in the table below is the mean indoor temperature in August.

Table 7.1 Mean value of the indoor temperature in the different premises

	Winter season, [˚C]	Summer season, [˚C]
Single family houses	21.3	23.6
Terrace houses	22.1	23.9
Apartment blocks	22.2	-

The measured hourly mean values of the indoor temperature for all the single family houses during August was between 22.5-25.9˚C and in the terrace houses it was between 22.6-26.9˚C. The mean hourly indoor temperature in the single family houses and terrace houses in August is showed in Figure 7.2 below.

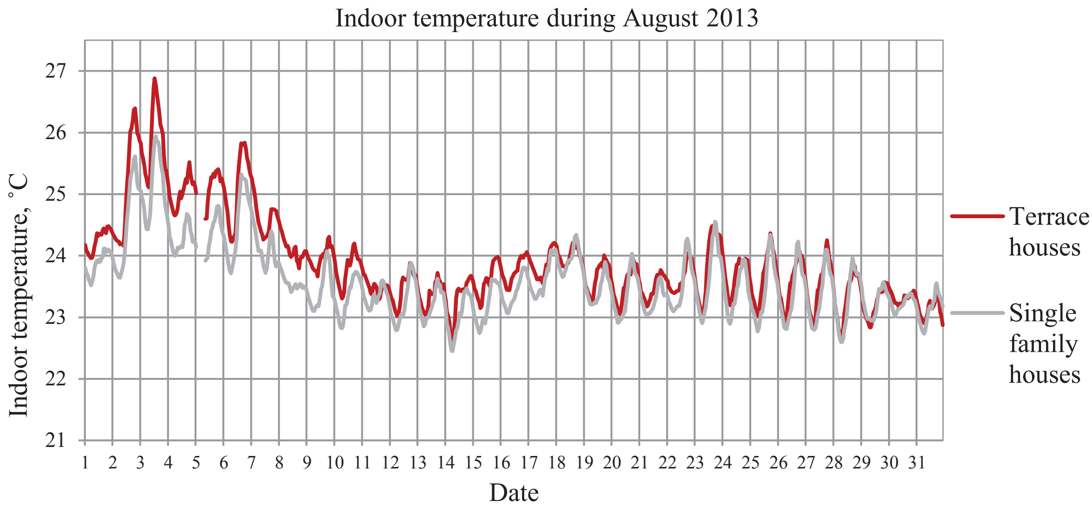

Figure 7.2 The mean value of the indoor temperature of every hour for all the premises is plotted for each kind of housing (single family houses and terrace houses) during August.

The warmest day in Vallda Heberg during 2013 was the 3rd of August when the outdoor temperature was 30.1˚C. The highest measured indoor temperature in the measuring period was 28.2 ˚C and occurred in one apartment in the terrace houses during the 3rd of August.

The mean value of the relative humidity in august was 53.9% in the single family houses and 52.8% in the terrace houses.

There is a difference between the mean indoor temperature in the different type of premises during the winter season. The mean value of the indoor temperature in January 2014 is showed in Figure 7.3.

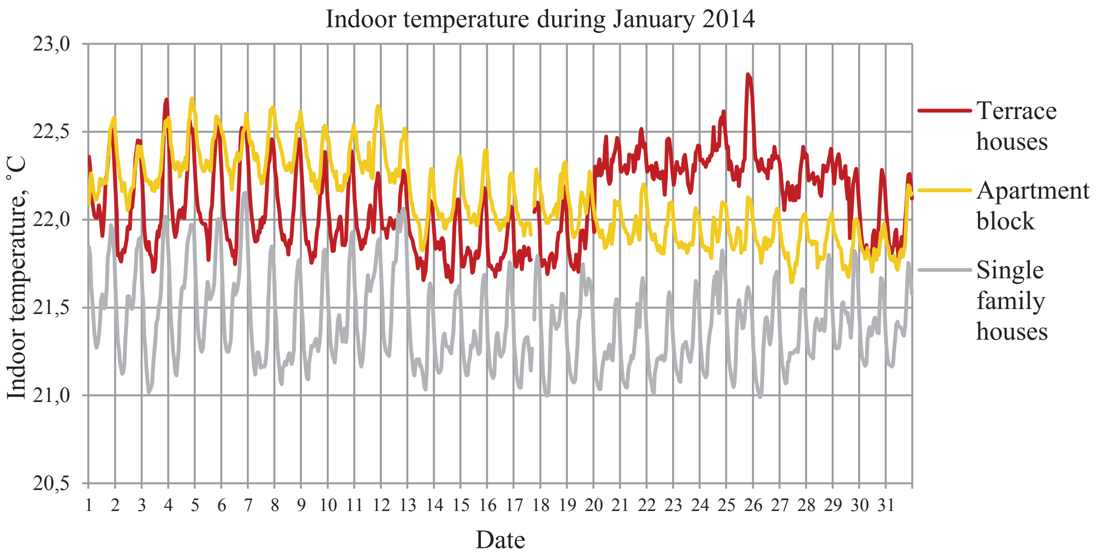

Figure 7.3 The mean value of the indoor temperature of every hour for all the premises is plotted for each kind of housing during January.

The Indoor temperature varies between 21.0-22.2˚C in the single family houses. In the terrace houses the variation was between 21.6-22.8˚C and in the apartment blocks it varied between 21.6-22.7˚C. The winter season 2013/2014 was relative mild and the mean outdoor temperature in January was -0.1˚C.

The mean value of the relative humidity in January was 31.3% in the single family houses, 27.5% in the terrace houses and 27.3% in the apartment blocks.

The mean indoor temperature is a bit lower in the single family houses (where the residents can control the indoor temperature) than in the terrace houses and the apartment blocks.

The measuring of the indoor temperature and relative humidity in the retirement home was performed in March 2014. The mean value of the indoor temperature in the living rooms was 23.0˚C and the relative humidity varied between 16.7 – 36.7%.

7.2 Measured indoor temperature in the premises

Duration charts have been made to visualize the indoor temperature distribution for each kind of housing. The measuring period is one year for the single family houses, six months for the terrace houses, and three months for the apartment blocks. In Table 7.2 below the distribution of the temperature duration for the different premises is showed.

Table 7.2 Results from the duration charts for the different premises.

	16.0-19.9 ˚C	20.0-24.0 ˚C	24.1-26.0 ˚C	26.1-29.0 ˚C
Single family houses [% of the year]	5.9 %	86.0 %	6.9 %	0.2%
Terrace houses [% of six month]	2.1%	88.8%	8.4%	0.7%
Apartment blocks [% of three months]	0.1%	96.8%	3.1%	0.0%

The indoor temperature higher than 26.0˚C in the single family houses and in the terrace houses occurred during the summer season. The highest indoor temperature in the apartment blocks during the measuring period was 25.9˚C. Note that no summer months was included in the measurements of the apartment blocks.

The indoor temperature varies in the range of the recommended values in FoHMFS and the high indoor temperature which occurs a few times in the summer are also in the range of what is acceptable as momentary indoor temperature according to FoHMFS.

7.2.1 Indoor temperature in the single family houses

The indoor temperature every hour and in all the single family houses is plotted as a normal distribution in Figure 7.4 below. Every registered temperature in all the houses during 2013 (184 050 values) is used to find the actual distribution of the indoor temperature of these houses, the temperatures are rounded to the closest 0.5˚C.

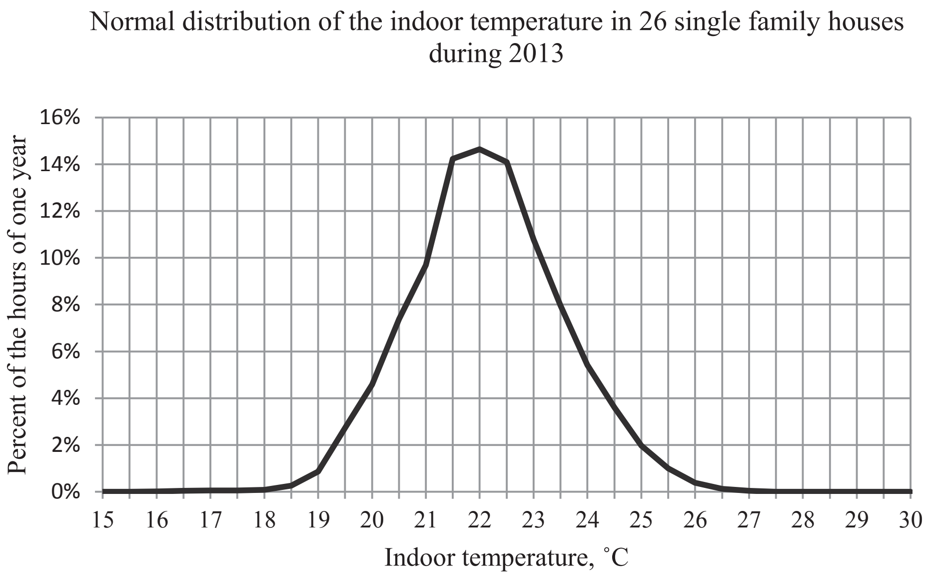

Figure 7.4 Distribution of the indoor temperature every hour in all the single family houses. The mean value is 22˚C and the standard deviation is 2˚C. All measured temperatures are rounded to 0.5˚C.

The indoor temperature was measured on both floors in three of the single family houses during Mars-September 2013. The temperature was measured in the living rooms on the first and the second floor with an interval of 30 minutes. In two of the houses the mean value of the indoor temperature is generally 0.5 ˚C higher on the second floor while the mean value of the indoor temperature is the same on both floors in the third house.

To visualize the variation of the indoor temperature between the different single family houses diagrams of the indoor temperature on the first floor was made for one summer month and one winter month.

Variations of the indoor temperature during August 2013 can be seen in Figure 7.5 and the variation in January 2014 is showed In Figure 7.6 below. To visualize the daily temperature variations in the premises two houses are showed with coloured lines in the figures below. The orange line represent a house with a higher average of indoor temperature, the green line represent a house with a lower average of the indoor temperature. The thick black line is the mean indoor temperature for all the single family houses.

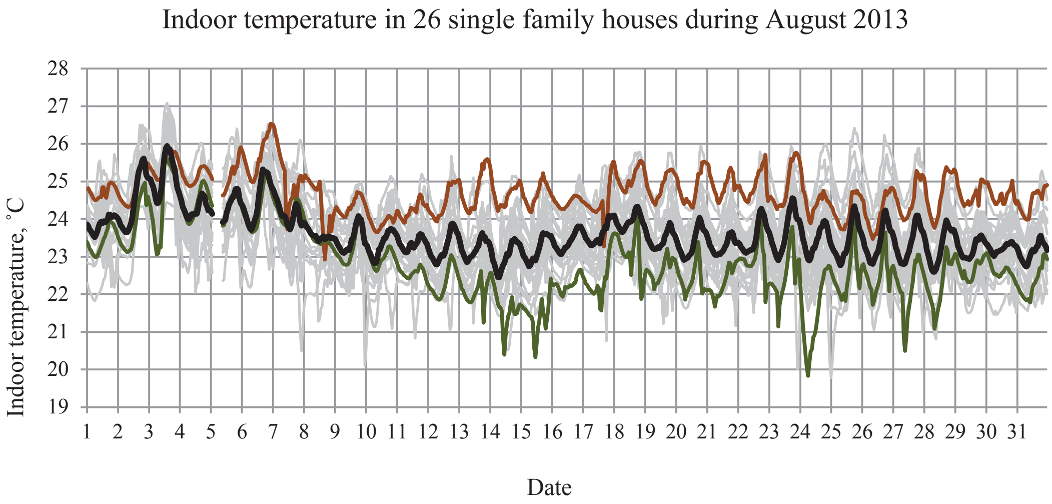

Figure 7.5 *Variations of the indoor temperature in the different single family houses during August 2013. The black line is the mean value of the temperatures and the coloured lines represents two houses with a high and a low mean indoor temperature.*

The variation of the indoor temperature between the houses during the winter season indicates that the residents choose to adjust the indoor temperature to achieve a satisfying thermal comfort.

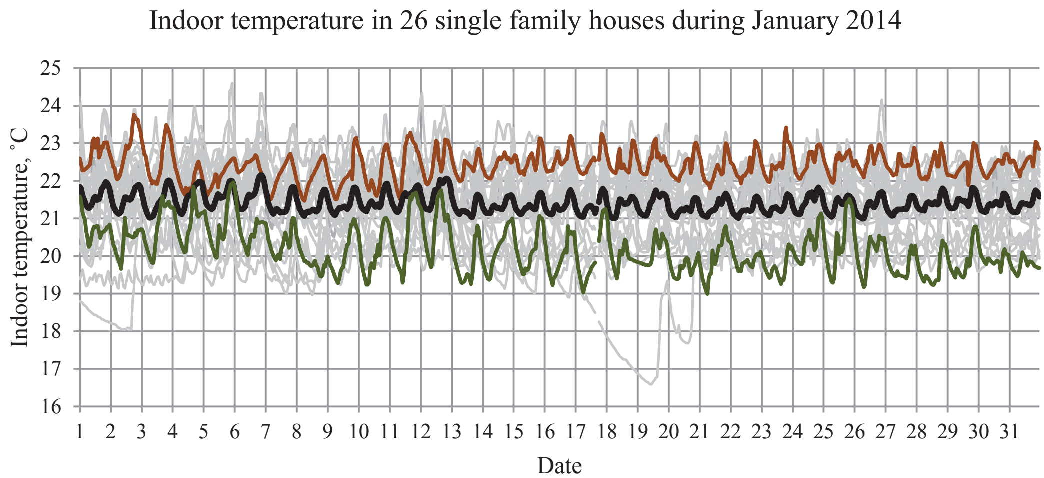

Figure 7.6 *Variations of the indoor temperature in the different single family houses during January 2014. The black line is the mean value of the temperatures and the coloured lines represents two houses with a high and a low mean indoor temperature.*

7.2.2 Indoor temperature in the apartment blocks

The temperatures in the apartment blocks during January 2014 are showed in Figure 7.7 below. There are two apartments with a very steady indoor temperature which could indicate that the apartment is not in use, one of them represented by the green line in the figure.

The variation of the temperature between the different apartments in the apartment blocks is small compared to the other types of buildings.

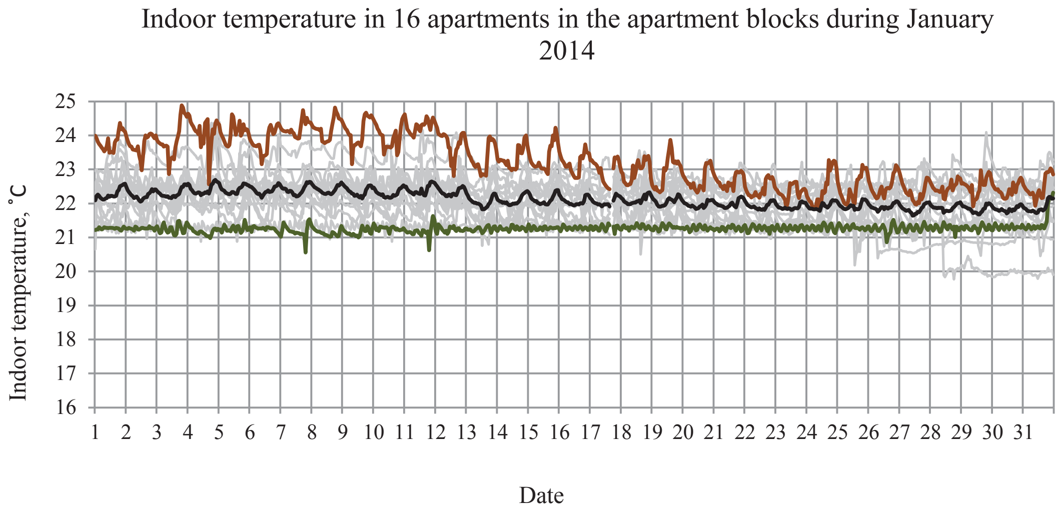

Figure 7.7 Variations of the indoor temperature in the different premises in the apartment blocks during January 2014. The black line is the mean value of the temperatures and the coloured lines represents two houses with a high and a low mean indoor temperature.

7.2.3 Indoor temperature in the terrace houses

The variation of the indoor temperatures in the terrace houses during August 2013 are showed in Figure 7.8 and the variation during January 2014 in Figure 7.9 below.

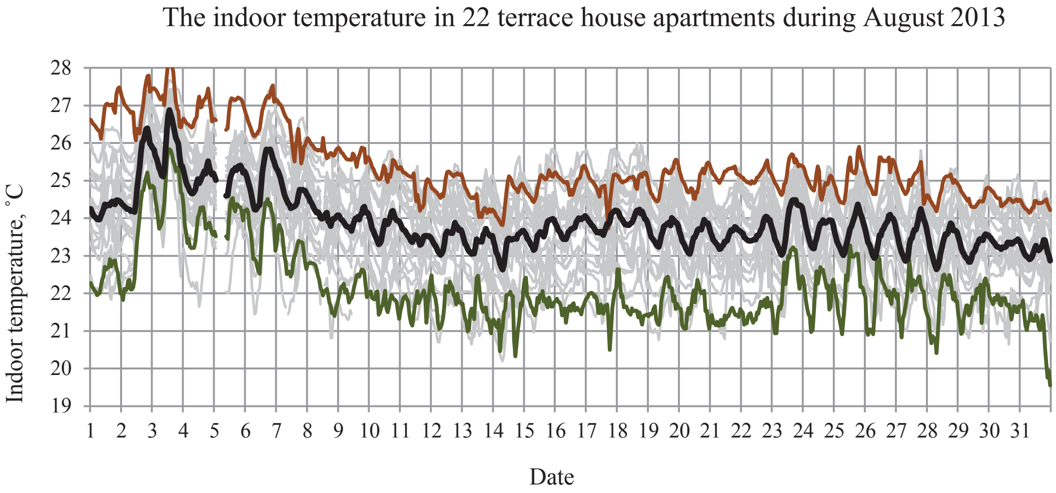

Figure 7.8 The variation of the indoor temperature in the terrace houses during August 2013. The black line is the mean value of the temperatures and the coloured lines represents two houses with a high and a low mean indoor temperature.

There is a gap in the temperature logs where some of the sensors in the houses did not register any temperatures. The apartment with the lowest indoor temperature in the figure below has large fluctuations and another apartment with a typical low temperature is marked with green instead.

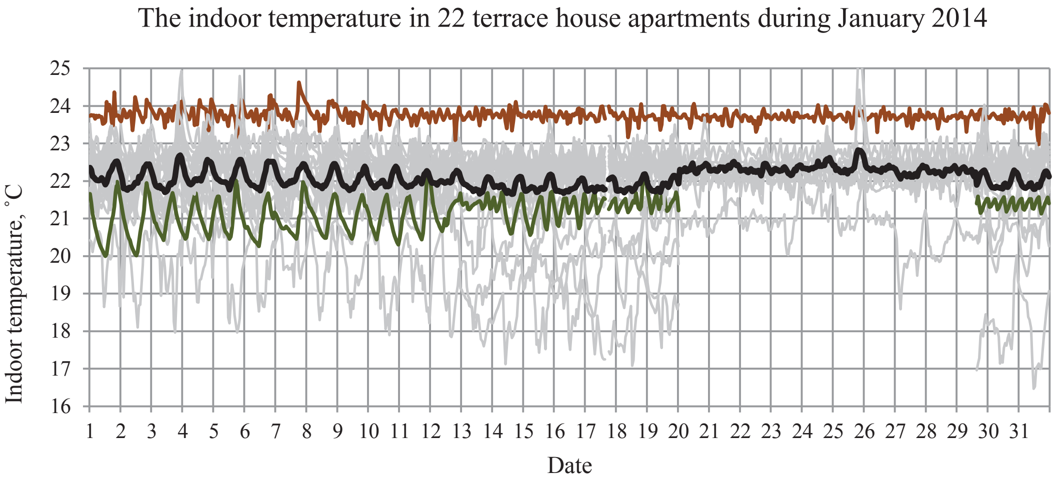

Figure 7.9 The variation of the indoor temperature in the terrace houses during January 2013. The black line is the mean value of the temperatures and the coloured lines represents two houses with a high and a low mean indoor temperature.

The variation of the indoor temperature in the terrace houses indicates that the residents have an opportunity to influence the indoor temperature although it is set by Eksta Bostads AB.

7.2.4 Detailed measurements in two single family houses

The indoor climate was measured in three single family houses, here referred to as house A, B and C. The measurement in house C failed since the values from that measurement never reached steady-state, the data from house C will therefore not be presented.

Measured parameters are operative temperature, air velocity, air temperature at 1.1 m and 0.1 m above floor height, relative humidity, floor temperature, daylight factor and the efficiency of the FTX heat exchanger. The measurements were performed according to the EN ISO 7730:2005 standard which is described in chapter 4.5.

The PMV (Predicted Mean Vote) and the PPD (Predicted Percentage Dissatisfied) is calculated with the ISO 7730:2005 standard (calculations are attached in Appendix A). The clothing level is set to 1.0 (basic clothing insulation, 0.155 W/m^2K), the metabolic energy production is set to 1.2 met (70 W/m^2) where the area refers to the surface of a person's skin. The rate of mechanical work is set to zero.

7.2.4.1 Conditions and results house A

Indoor climate measurements were made on a sunny day with light clouds and the outdoor air temperature varied between 3.7-6.0˚C. The residents were home most of the time but left the house for 75 minutes in the middle of the measurements. There were good conditions for measurement of the temperatures since the room had not been exposed to solar radiation that day. Temperature, humidity and velocity reached steady state after the residents had left the building. The conditions for the daylight measurement were not optimal since there were too light clouds and the outdoor illuminance was increasing a lot during the measurement. The result for the daylight factor showed in Table 7.3 is the mean daylight factor during 50 minutes when the outdoor illuminance varied between 8000 and 13000 lux. The other values in Table 7.3 are the values from when the steady state was reached when the residents had left the building.

Table 7.3 Results from the detailed measurements of the indoor climate in house A.

Radiant temperature [˚C]	20.9
Air temperature 1.1 m [˚C]	21.1
Air temperature 0.1 m [˚C]	20.5
Floor temperature [˚C]	20.3
Relative humidity [%]	33
Air velocity [m/s]	0.04
Daylight factor [%]	0.77

The calculated PMV is -0.096 and the PPD is 5.19%

7.2.4.2 Conditions and results house B

The measurements were made on a cloudy day with the outdoor temperature varying between 6.3-6.7 ˚C. The residents were home some parts of the measurements but left the house for 95 minutes, there were good conditions for all measurements. The numbers in Table 7.4 are from the time when the residents were out of the building and the indoor climate had reached steady state. The daylight factor in Table 7.4 is the mean value of the daylight factor during a total of 20 minutes when the outdoor illuminance varied between 8000 and 11500 lux.

Table 7.4 Results from the detailed measurements of the indoor climate in house B.

Radiant temperature [˚C]	20.9
Air temperature 1.1 m [˚C]	21.0
Air temperature 0.1 m [˚C]	20.6
Floor temperature [˚C]	20.9
Relative humidity [%]	38
Air velocity [m/s]	0.04
Daylight factor [%]	1.04

The reason to the higher floor temperature than the air temperature above the floor is unknown. The floor had not been exposed to any solar radiation and it is probably a measurement error.

The calculated PMV is -0.088 and the PPD is 5.16%

7.3 Summary of the results from the survey

Two surveys have been made to investigate how the indoor climate was perceived by the residents during the summer season 2013 and the winter season 2013/2014. Most of the questions in the surveys were taken from two other surveys, *Stockholm indoor climate survey* and the *MEBY survey*, which have been used in earlier projects to investigate the indoor climate. The purpose of using same questions is to later be able to compare the perceived indoor climate between different kinds of buildings.

The survey for the summer season was only made for the single family houses since they were the only buildings that were in use during the entire season. A survey for the winter season was made for all the premises with a few changes compared to the summer season survey, to improve the questions in the survey. A survey to the retirement home for the winter season was also made with customized questions for the staff who also answered how they perceived the opinions from the residents.

The response rate of the summer survey was 18 of 26 from the single family houses. The response rate of the winter survey was 17 of 26 from the single family houses and 20 of 22 from the terrace houses which makes the survey responses sufficient for an evaluation of the premises. The response rate of the apartment blocks was only 4 of 16 apartments which is considered too low to use as an evaluation for the apartment blocks, but is still interesting in the evaluation of the passive house residential area in Vallda Heberg. The survey to the retirement home was answered by the staff nurses on each department and the response rate was total four surveys.

7.3.1 Results of the surveys from the premises

The indoor temperature in the premises was generally perceived as satisfying during the winter season. In Figure 7.10 below, the answers from all of the buildings are showed together with the answers from the terrace houses.

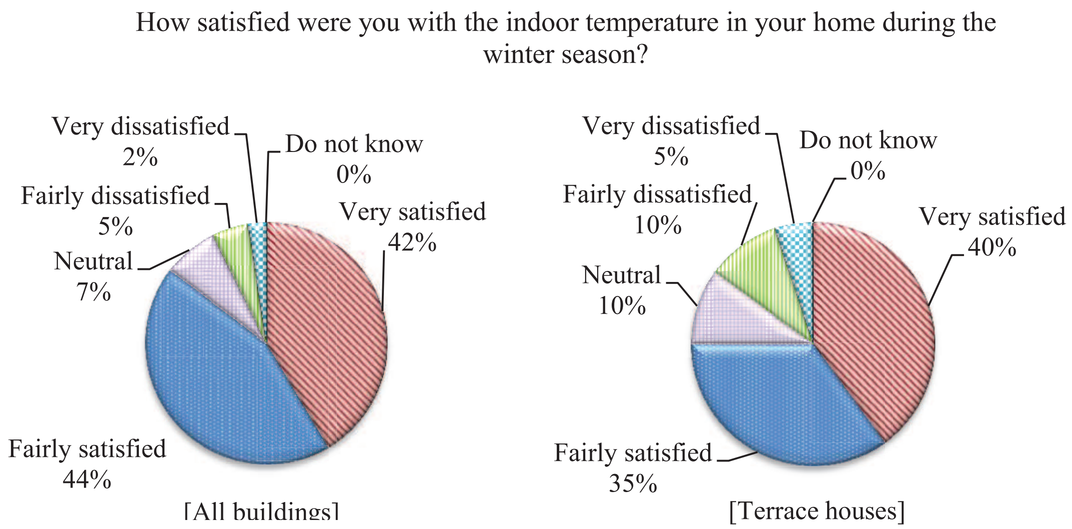

Figure 7.10 The perception of the indoor temperature during the winter season. All buildings are represented to the left and the terrace houses to the right.

The experienced indoor temperature during the summer and the winter season was generally perceived as satisfying for the singe family houses which can be seen in the Figure 7.11 below. Of the respondents there was a small part who answered that they were fairly dissatisfied with the indoor temperature during the summer season. A detailed perception of the indoor temperature during the two seasons for the single family houses are shown in Figure 7.11 below.

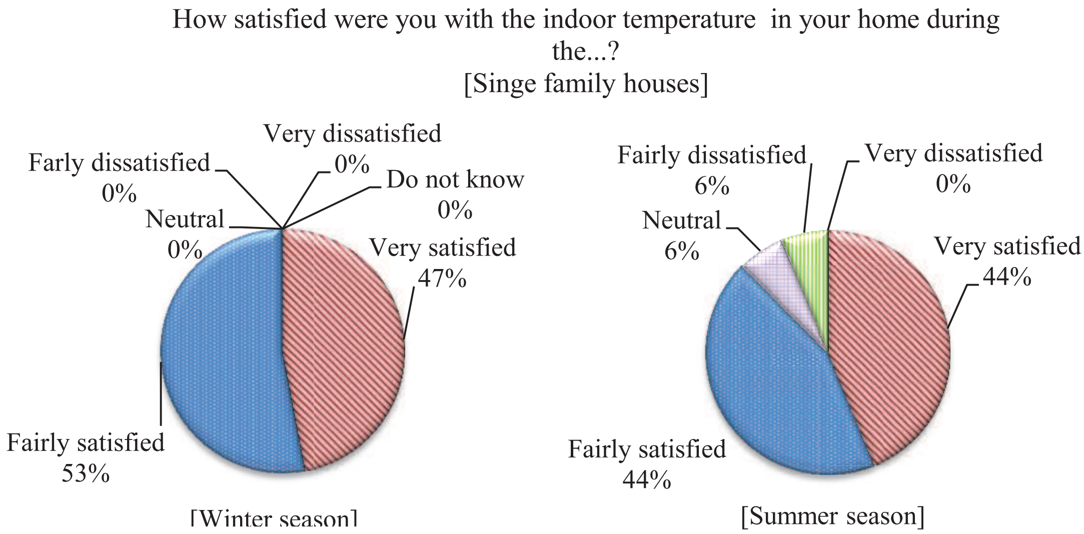

Figure 7.11 The perception of the indoor temperature in the single family houses during the winter and the summer season.

In the summer survey the question was “How well do you think the heating works in your home?” but was reformulated in the winter survey to clarify the sentence of the question.

There was a more detailed question about the indoor temperature in the survey; if the residents perceived any difference in the indoor temperature between different rooms. The survey tells that the residents in the terrace houses and the single family houses were satisfied with the temperature in the kitchen and living room but it indicate that some of the residents perceive the bathroom as cold and the bedroom too hot. In the single family houses the experienced indoor temperature was approximately the same for both seasons. The cold bathroom was referred to the one on the second floor in the single family houses. Figure 7.12 shows the perception in detail from the residents.

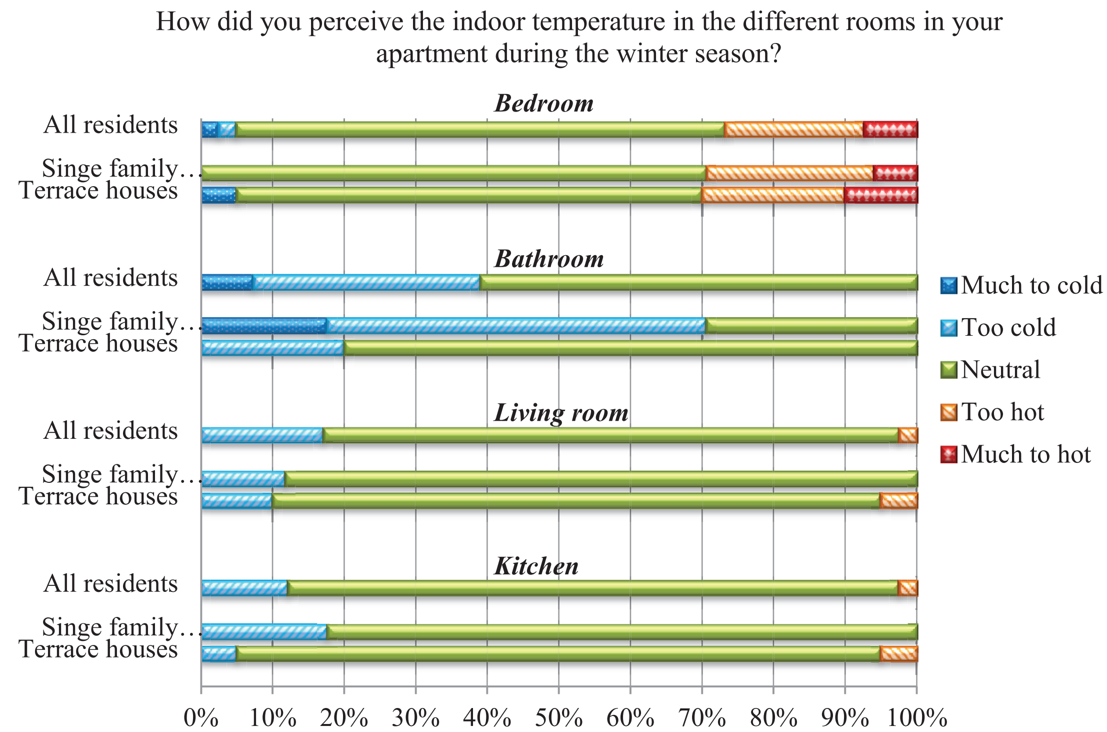

Figure 7.12 The perceived indoor temperature in different rooms during the winter season.

Another question in the survey was about airing habits. During the winter season there was a contrast in the habits of airing in the different kinds of housing, see Figure 7.13 below. Generally 27% of the respondents were airing daily while the corresponding number for the terrace houses were 50% (Figure 7.13) and for the single family houses only 6% (Figure 7.14).

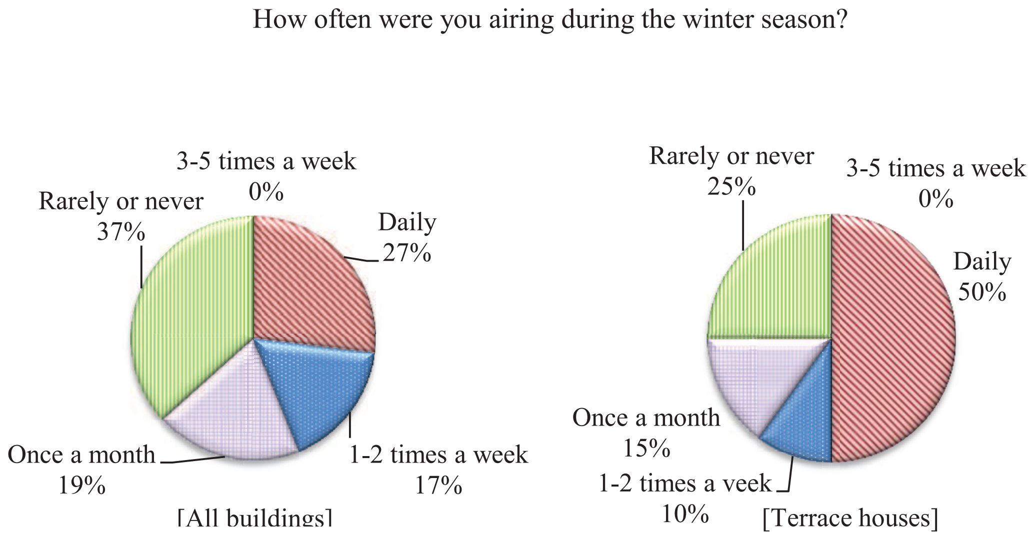

Figure 7.13 The habits regarding habits in the premises. To the left is all the buildings represented and to the right is the terrace houses represented.

There is a big difference in the habits regarding airing between the two seasons in the single family houses. According to the survey 94% of the respondents were airing daily during the summer season but only 6% during the winter season, this can be seen in the Figure 7.14 below. Note that more alternatives were added to the question in the winter survey.

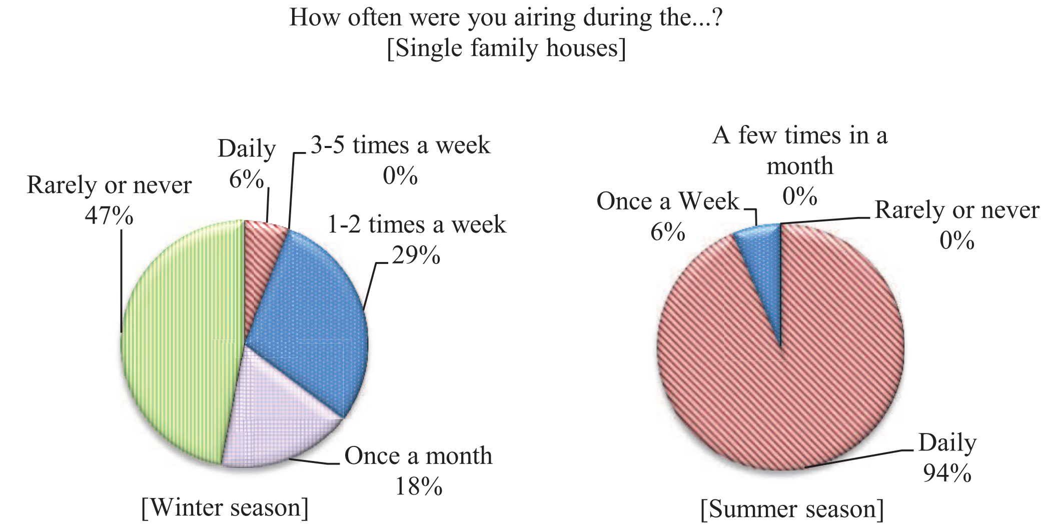

Figure 7.14 The habits regarding airing in the single family houses during the winter season and the summer season.

To investigate the experienced visual comfort in the home a question about the perceived daylight was included in the survey. During the winter season, for all the premises, 81% were satisfied with the daylight, see Figure 7.15 below. Of the respondents in the terrace houses 95% thought the daylight was acceptable, good or very good.

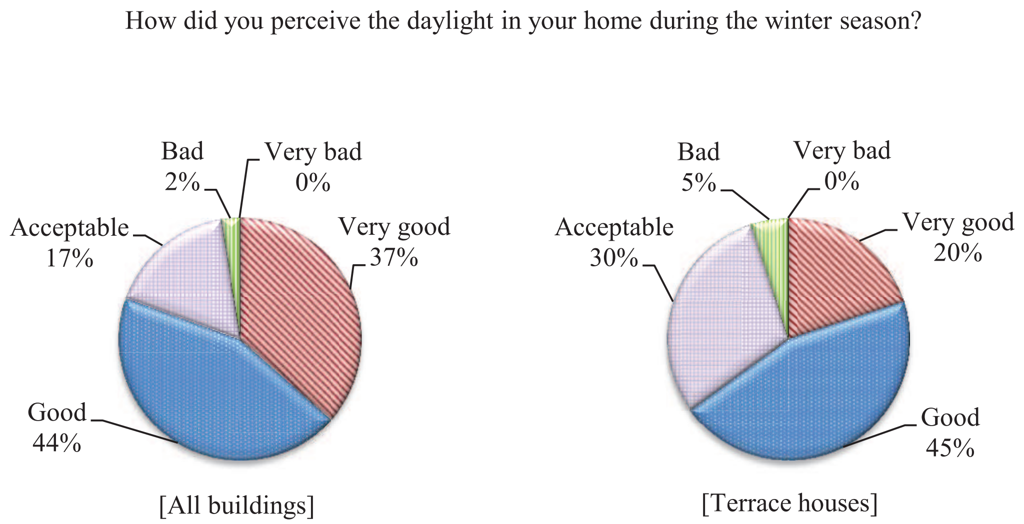

Figure 7.15 The perception of the daylight in the premises. To the left all buildings are represented and to the right the terrace houses are represented.

In the single family houses 100% of the respondents thought the daylight were acceptable, good or very good in their homes during both seasons, which can be seen in Figure 7.16 below.

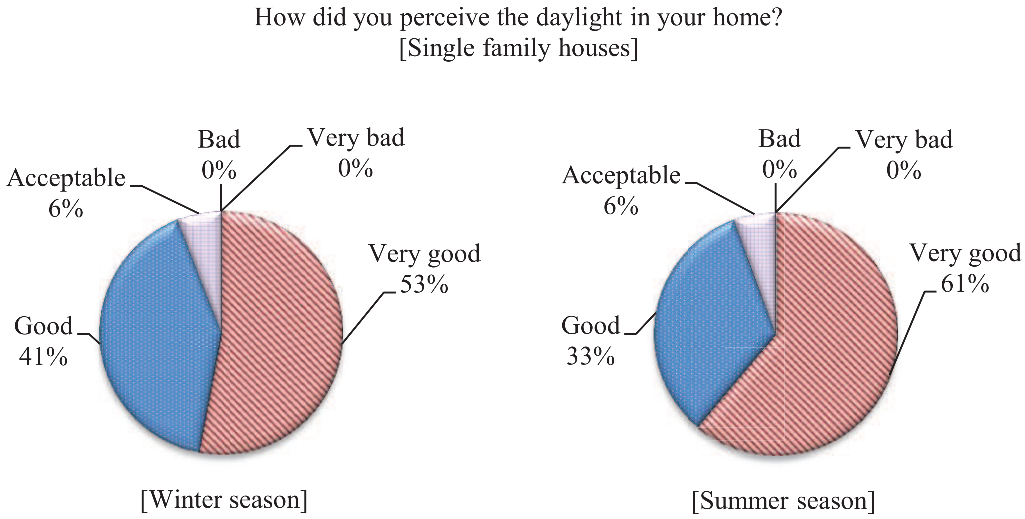

Figure 7.16 The perception of the daylight in the single family houses for both winter season and summer season.

7.3.2 Results from the survey, retirement home

The amount of received surveys from the retirement home is only four which means that there is an uncertainty in the result. Each survey have probably been filled-in by more than one staff nurse according to Niklas Christensson, energy controller at Eksta Bostads AB. The result of how the staff perceives how the residents experience the indoor climate is based on three surveys.

The indoor climate in the retirement home was generally perceived as slightly dissatisfying, expect from the daylight where the average response was good. The majority of the staff and the residents are dissatisfied with the indoor temperature. According to the survey the temperature seems to vary between the different apartments even though no windows are open. Some of the departments are perceived as warm.

All answers indicated that the staff is dissatisfied with the ventilation and the majority of the staff was airing a few times a week during the winter season. When they were airing, it was often by opening a door or a window a short while. It is pointed out by the staff that the "low airflow" will be a problem during the summer season when it is getting warmer and the offices will be uncomfortable. Two of three answers indicate that the residents also perceive the ventilation as dissatisfying.

The general opinion is also that the air is dry. After the answers from the survey and some results from the measuring were analysed, Eksta Bostads AB has decreased the indoor temperature to 22˚C. The temperature was at the beginning higher to dry out the slab on the ground and to keep an acceptable indoor temperature when the building was not fully occupied. Now, the relative humidity has increased due to the lower temperature which led to a higher satisfaction from the staff on the retirement home, according to Niklas Christensson.

7.4 Analysis of the indoor climate

The perception about the indoor climate differs between the single family houses and the terrace houses. It is hard to tell why but there could be several reasons. There are different generations living in the buildings, in the terrace houses the residents are seniors while there often lives a family with small kids in the single family houses. Due to the higher grade of satisfaction in the survey from the single family houses and the fact that they choose to buy a passive house, the interest for the passive house-concept and awareness of the environment might be higher in the younger generation.

Another aspect could be the behaviour or habits. The residents in the terrace houses seem to be airing regularly during the winter season even though it is not necessary, the residents might not have any earlier experience of mechanical ventilation.

During the winter season it is noted that the indoor temperature is a bit lower in the single family houses than in the terrace houses. The residents in the single family houses were satisfied with the temperature while the residents in the terrace houses wanted a higher indoor temperature according to Niklas Christensson. Due to the higher age of the residents in the terrace houses the users might have a lower metabolism and therefore prefer a higher indoor temperature.

When the residents own their house, as is the case with the single family houses, they take care of the building and set the indoor temperature by themselves, this seems to lead to a higher grade of satisfaction. The feeling of not being in control of their indoor temperature could result in a general dissatisfaction even though there is only a low level of dissatisfaction from the beginning.

The perception of the cold bathrooms is interesting. The bathroom floors are heated in the terrace houses and on the first floor of the single family houses. In the terrace houses 20% perceived the temperature of the bathroom as too cold, in the single family houses 72% of the respondents thought it were too cold. The respondents in the single family houses were often referring to the bathroom on the second floor, where there is no floor heating. This was also a perception during the summer season in the single family houses which indicates that it might is necessarily to install some kind of heating system in the bathroom on the second floor in future project, for example the same system as in the bathroom on the first floor.

In the survey it is not clear if the residents perceive the actual room or the floor as cold in the bathroom. The reason to the experienced cold bathrooms could depend on the surface material of the bathroom floors. The floor consists of clinker that has a larger thermal effucivity, which is a materials ability to absorb heat, than for example a linoleum carpet. If a person in the bathroom is barefoot the perception of a cold area will increase due to the heat transfer and the lower insulation on their feet.

8 The Measured Energy Use in Vallda Heberg

The actual energy use is continuously measured to be able to follow up the energy usage in all the buildings in Vallda Heberg. The single family houses is the only type of building that has been in use for a full year and the houses are thereby the only buildings that have reliable values of the actual energy use. For the apartment blocks, the terrace houses and the retirement home prognoses have been made to estimate the yearly energy use. The prognoses for the apartment blocks and the retirement home are based on the actual usage during December 2013-February 2014 in the buildings. Since the prognosis for the retirement home only includes winter months the energy demand of the cooling machine is not taken into account, neither the solar cells could be evaluated. The prognosis for the terrace houses is based on the six months September 2013-February 2014.

The prognoses are calculated from the percentage difference between the measured mean specific energy use and the designed value during the moths that is the basis of the prognoses. The domestic hot water use and the operational electricity use are assumed to be evenly distributed over the year while the monthly design values are used for the heating energy. The percentage difference in domestic hot water use, heating energy use and operational energy use is multiplied with the full year design value of the different energy categories to receive the value of the prognosis. The designed specific energy use for all buildings, the measured mean value for the single family houses and the prognoses for the other buildings are showed in Figure 8.1.

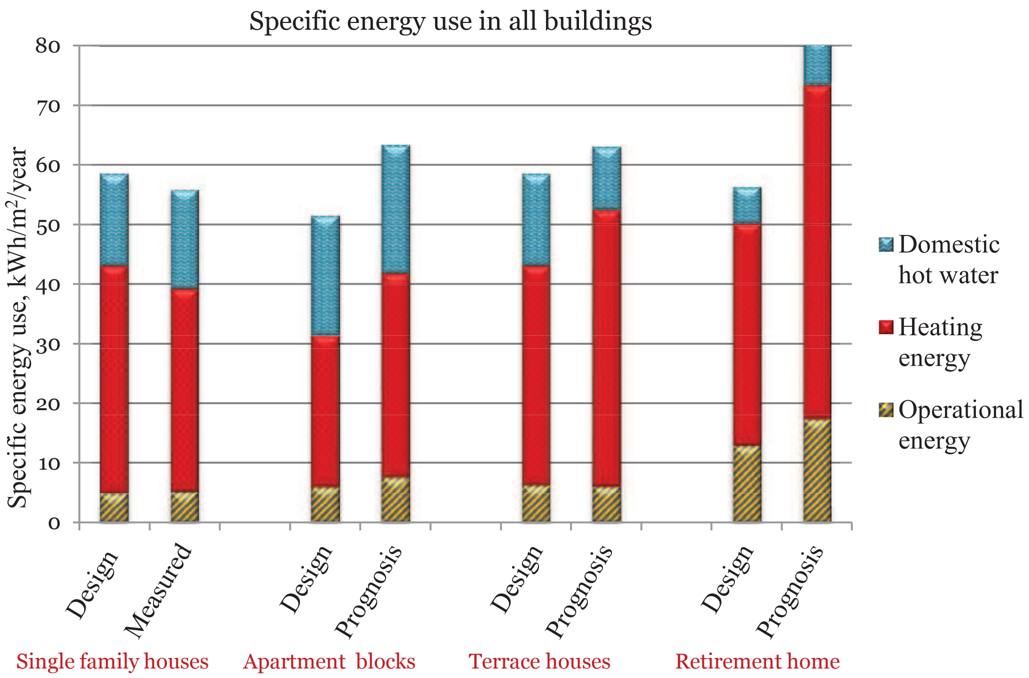

Figure 8.1 *The design values and the measured/prognosis values of the specific energy use in all buildings in Vallda Heberg. The prognoses are based on three winter moths and the cooling demand of the retirement home is therefore not considered.*

A prognosis is always a bit uncertain, but it gives a hint about the yearly energy use.

The reason for this detailed investigation of the energy performance in an early stage of the buildings gives an indication about the final energy performance but also an early feedback if the buildings do not seem to work the way they should.

In the following sections more detailed results regarding the energy use in the different types of buildings will be presented.

All the values of the heating energy use in this section are statistically adjusted due to the outdoor temperature and its duration for a normal year to be compared with the design values in a correct way.

The correction is based on the measured mean outdoor temperature of every 24 hours and the corresponding mean temperature during a *normal year*. The unit that is used in the comparison is [degree*days] where the temperature difference that is used is 17˚C minus the 24 hour mean value (17˚C is considered the temperature that the heating system should be able to heat the building to). During the summer season (April-October) 10˚C-13˚C is used instead of 17˚C due to the solar energy heat load. (SMHI, 2012)

The *normal year* and the mean 24-hour temperatures are from Kungsbacka, a few kilometres north-east from Vallda Heberg. The *normal year* is based on the mean temperatures in Kungsbacka during the years 1971-2000.

The amount of measured degree*days is divided with the amount of degree*days during the *normal year*. To achieve the statistically corrected heating energy the measured heating energy is divided with the calculated ratio of the degree*days.

8.1 Energy performance in the single family houses

The energy use in all the single family houses is measured, in this study the focus is the energy use during January-December 2013.

8.1.1 Specific energy use

In Figure 8.2 the heating energy, domestic hot water and operational electricity is showed for 25 of the houses. The 26th house was not in use the first 1.5 month of this year and is not considered in this comparison.

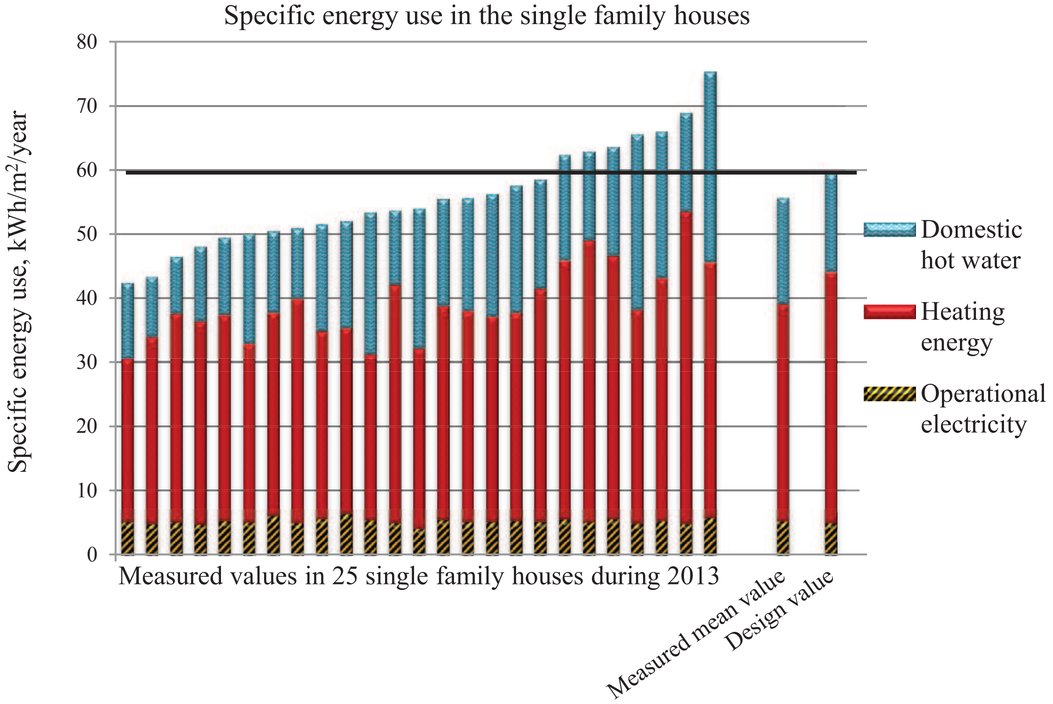

Figure 8.2 The measured specific energy use in 25 single family houses during 2013. The black horizontal line represents the design value.

There is a large difference in the specific energy use between the 25 identical houses, the largest variation is the use of domestic hot water. As showed in Table 8.1 the maximum usage of domestic hot water is more than three times larger than the lowest usage. There are also variations in the heating energy use and the operational energy use. The mean value of the specific energy use in the buildings is lower than the designed value. The mean heating energy is lower than designed while the mean use of domestic hot water and the mean operational energy is higher than expected.

Table 8.1 Variations in the three categories of energy in the specific energy use in the 25 single family houses (the maximum and minimum values are the maximum/minimum values in each category and are not necessarily from the same house).

	Design value	Mean value	Minimum value	Maximum value	Difference (max/min)
	[kWh/m^{2}A$_{temp}$/year]		[kWh/m^{2}A$_{temp}$/year]		[-]
Domestic hot water	15.4	16.6	9.3	29.6	318%
Heating energy	39.2	34.0	25.6	48.6	190%
Operational electricity	5.0	5.3	4.1	6.4	156%

It is not known how many people that lives in each house, but in most of the 17 premises that answered on the survey it lives 2 adults and 1-3 kids, the mean value is 2.1 adults and 1.6 kids. In the design phase 41m^2/person is used which results in 3.4 people in each house which seems to correlate well with the reality.

8.1.2 Household electricity

There are available data of the measured household electricity for 23 of the single family houses. The assumed household electricity in the energy calculations was 2760 kWh/year in the single family houses and the measured mean value is 4672 kWh/year. The lowest household electricity use was 3499 kWh/year and the highest use was 6182 kWh/year.

Note that the energy for heating of the water in the dishwashers and the washing machines in not included in the household electricity since the machines use the hot water from the district heating system.

If the household electricity is added to the specific energy use the total energy use is calculated. In Figure 8.3 the total energy use in the 23 houses with available measurements of the household electricity is showed.

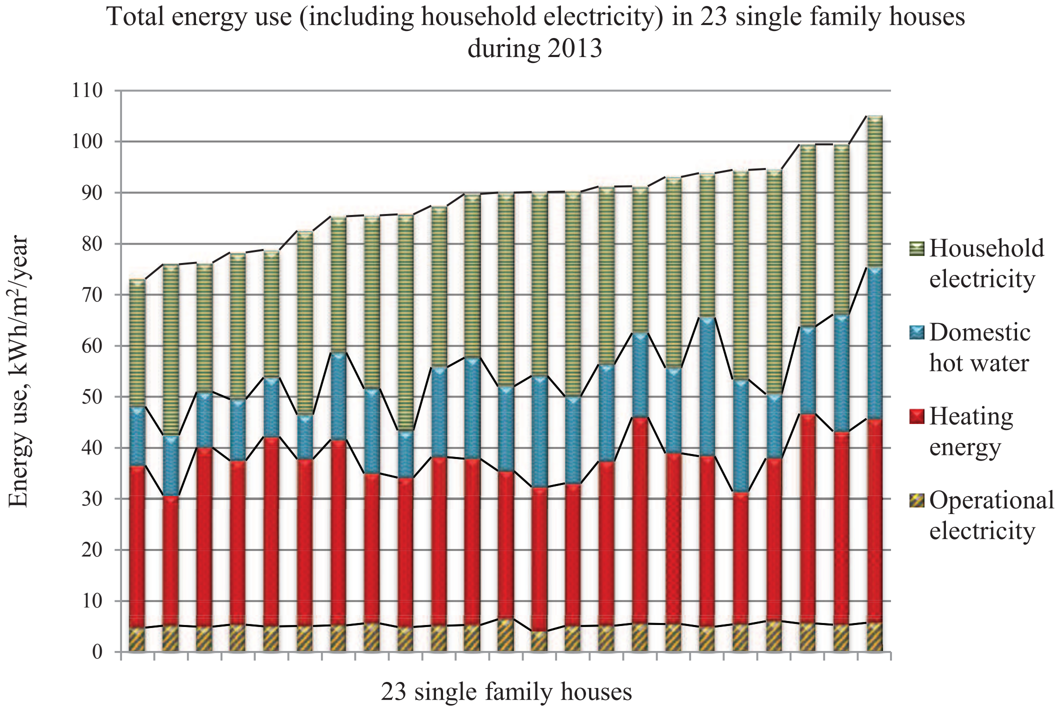

Figure 8.3 *The total energy use (household electricity, domestic hot water use, heating energy and operational energy) in 23 single family houses in Vallda Heberg during 2013.*

The connection between the indoor temperature, the heating energy and the household electricity was investigated to find out if there is a correlation. In the design phase 70% of the household electricity was credited as heat to the building, the household electricity is therefore an essential part of the heat supplied to the building. The heating energy, household electricity and the indoor temperature in 23 single family houses are showed in Figure 8.4 below.

The figure indicates a slightly higher indoor temperature in the buildings with a higher sum of the heating energy and household electricity use than in the buildings with a lower sum. The black line in the figure is the trend line of the variations of the indoor temperatures.

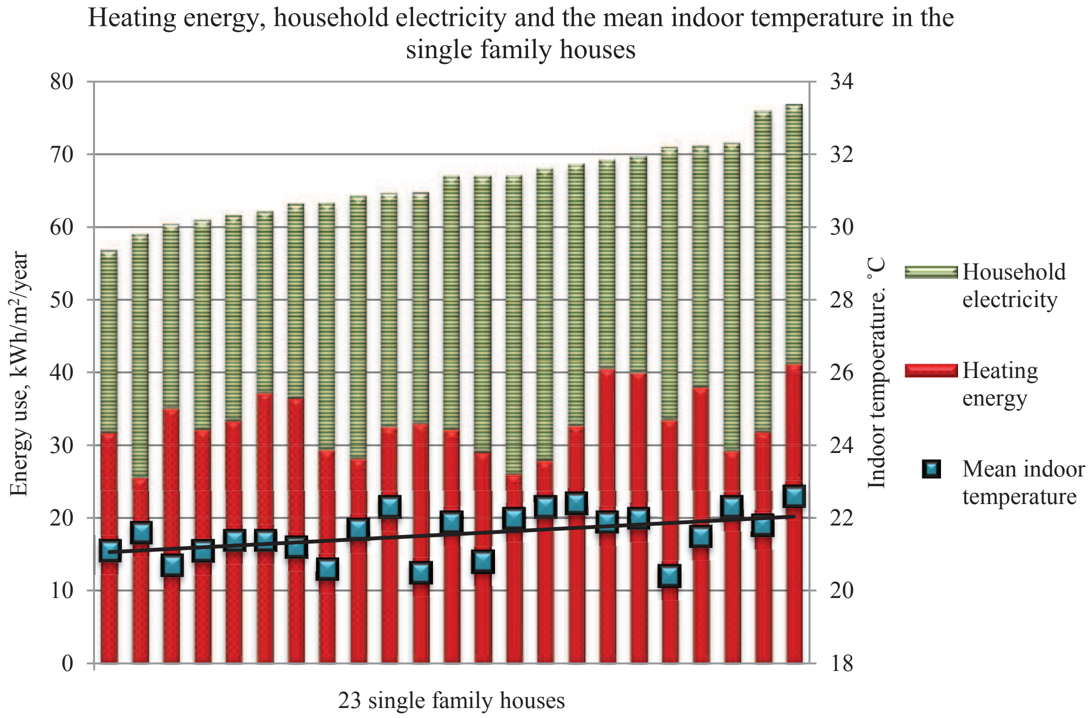

Figure 8.4 *The heating energy, the household electricity and the mean indoor temperature in the single family houses. The temperature is the mean temperature during the winter months January-March and October-December 2013. The black line is a trend line for the variation of the indoor temperature.*

8.1.3 Power demand in the single family houses

The power demand for heating in a building depends on the power loss to the surroundings through the building envelope, the ventilation and airing. The thermal conductivity of the building is the power of the losses per degree temperature difference between outside and inside, W/K. The design thermal conductivity of the single family houses is 112.7 W/K.

In Figure 8.5 the actual power demand in 16 houses is plotted with the outdoor temperature at the time. A 24 hour mean value of the power and the temperature are used for each house during the period January-December 2013. The slope of the white line represents the design thermal conductivity of the houses (112.7 W/K).

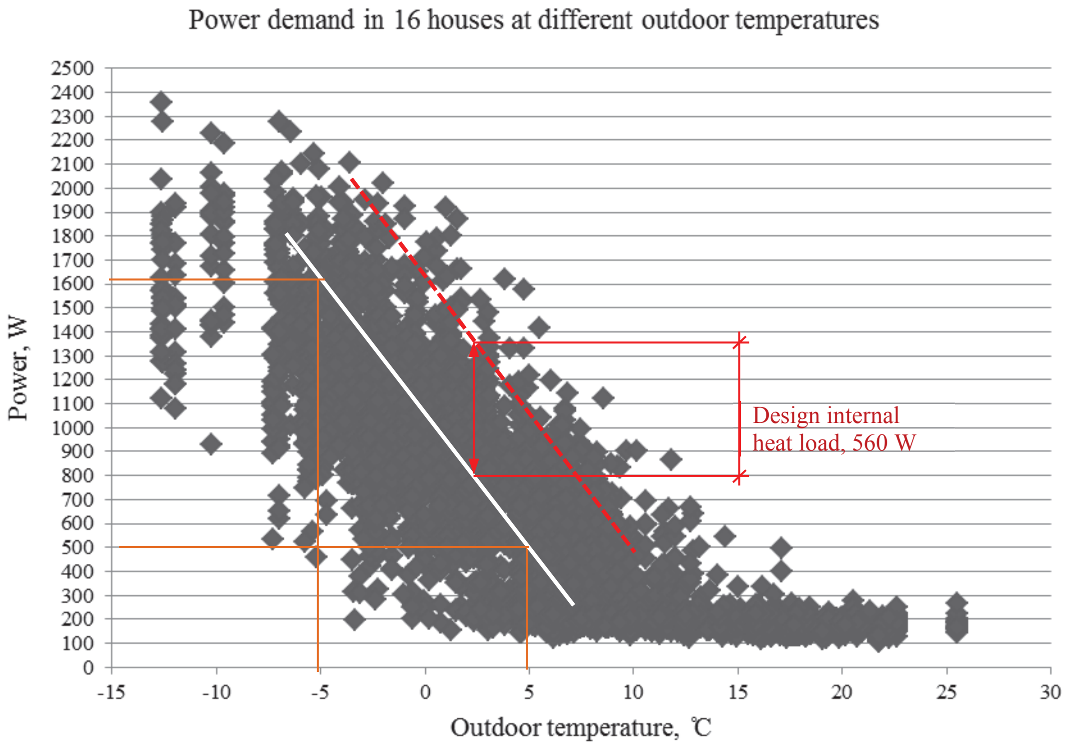

Figure 8.5 *The power demand in 16 houses plotted as squares for different outdoor temperatures. The white line represents the design thermal conductivity of the buildings and the distance from the white to the red line represents the design internal heat load.*

8.1.4 Efficiency of the heat exchanger in three single family houses

Although it was not the initial aim of the project the efficiency of the heat exchangers have been measured in three of the single family houses in order to make sure that the efficiency is as high as designed. NCC placed four temperature meters in the exhaust and supply air ducts on both sides of the heat exchanger during nine months (the end of May 2013 to the end of February 2014) and the measured data was used in this project to calculate the efficiency of the heat exchanger with equation (8.1). The air flows through the ducts were not measured but are assumed to be constant. The design value of the efficiency of the heat exchanger is 80%.

$$\eta = \frac{T_{supply} - T_{outdoor}}{T_{exhaust} - T_{outdoor}} \qquad (8.1)$$

In Figure 8.6 the efficiency of the heat exchanger in one of the houses is plotted with the outdoor temperature. The variations of the efficiency at the same temperatures depend on the heating demand in the house at that moment. The temperatures are measured every 15 minutes.

As shown Figure 8.6 the efficiency of the heat exchanger is less than 80% when the outdoor temperature is below 1˚C and can be up to 80% when the outdoor temperature is between 1-5˚C. When the outdoor temperature is higher than 5˚C the efficiency increases and reaches its maximum value of 84% when the outdoor temperature is 15˚C. The efficiency of 90-100% in the right part of the figure depends on the small differences between the exhaust, supply and outdoor temperatures which lead to calculation errors, the heat exchanger was not in use.

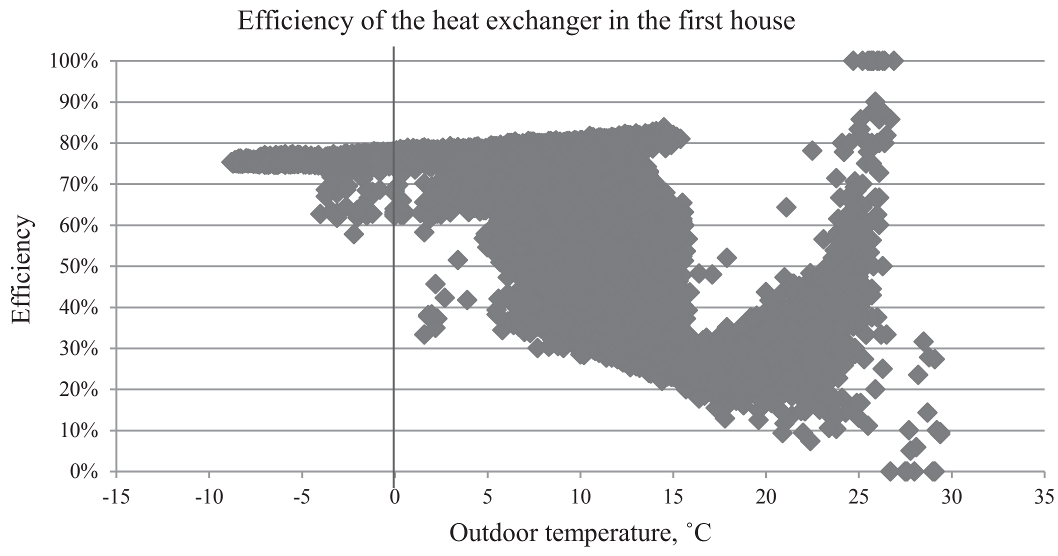

Figure 8.6 The efficiency of the heat exchanger in the first house.

The efficiency of the heat exchanger in the second house is showed in Figure 8.7. The heat exchanger in the second house has a lower efficiency that reaches 80% at around 6˚C instead of 1˚C in the first house.

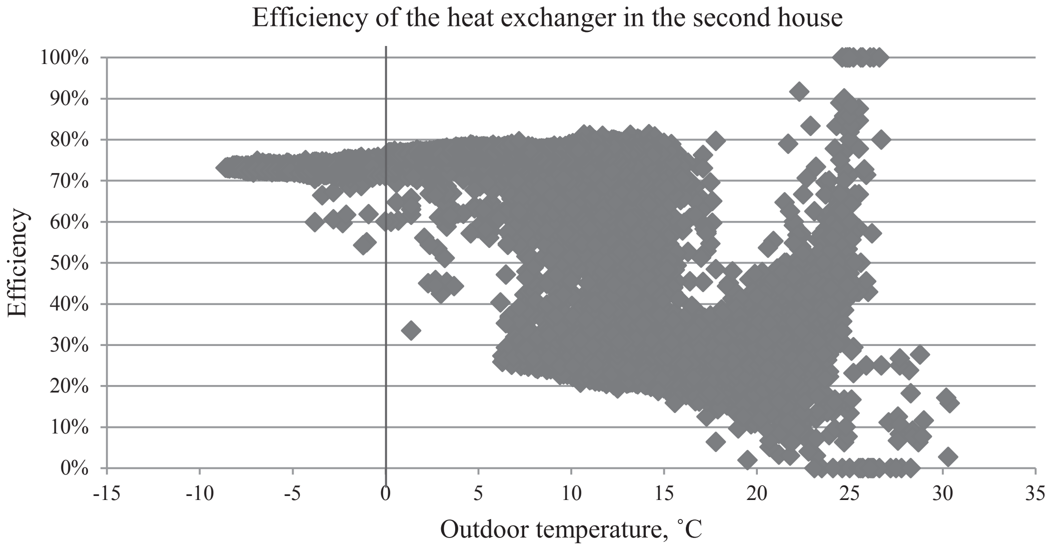

Figure 8.7 The efficiency of the heat exchanger in the second house. The efficiency is lower in this heat exchanger compared to the first house.

In the third measured house there was a software error in the air handling unit and the efficiency of the heat exchanger was lower than in the two other houses. The software error was repaired at the end of 2013 after which the efficiency appear to be similar to the two other heat exchangers.

8.1.5 Analysis of the results from the single family houses

The indoor temperature in the single family houses was 22˚C in the energy simulations during the design phase and the measured mean indoor temperature in the single family houses during the winter period was 21.3˚C. The lower indoor temperature than designed can be one of the reasons to the lower heating energy use.

The mean value of the household electricity was 69% larger than the design value and the internal heat loads is thereby higher than expected. This could be an explanation to the lower heating energy use than designed. The 69% higher household electricity corresponds to the heating load 9.5 kWh/m^2/year when assuming that 70% of the household electricity can be credited as heat. The heating energy use in the buildings were 5.2 kWh/m^2/year lower than expected. If the single family houses would have been designed with FEBY 12 instead of FEBY 09 the design household electricity would have been 4200 kWh/year (30 kWh/m^2/year) which agrees better with the actual mean household electricity use 4672 kWh/year (33.4 kWh/m^2) in the single family houses.

An indication of a correlation between the indoor temperature and the total use of heating energy and household electricity can be seen in the single family houses. No correlation can be seen between the indoor temperature and the heating energy only, which is reasonable since the heat from the household electricity is an essential heat load to the building. The variations in indoor temperature are small compared to the supplied heat and the users' habits seem to be the most important factor that affects the energy use.

Assumptions regarding the domestic hot water use in the design phase were reasonable even though there is a large variation in the domestic hot water use in the different houses.

The power demand in the houses appears reasonable and close to the design value. Variations in the power demand was also very similar in all buildings which indicate a good workmanship and an even quality of the houses.

8.2 Energy performance in the apartment blocks

Since the apartment blocks were moved into during September-November 2013 the energy performance of these buildings are studied for the period December 2013-February 2014.

8.2.1 Specific energy use

There is no data available of the domestic hot water use in three of the apartments, those apartments are not included in the results of the energy use below. In Figure 8.8 the specific energy use for the 13 apartments are showed together with their mean value and the design value.

Since there is no individual heat meter installed in the apartments the supplied heating energy to each building body is assumed to be evenly distributed over the heated floor area of that building. This means that it is probably a larger variation in the use of heating energy in reality than presented here. If the heating energy to each apartment was estimated from the proportions of the flow in the glycol circuit a much larger variation is calculated, but the accuracy of the flow meter is low and the heat distribution based on the flow is not reliable.

In one of the apartments the use of operational electricity was not measured due to an error, but since the variations in use between the apartments were small a mean value of operational electricity of all the other apartments was used as input data for that apartment in Figure 8.8.

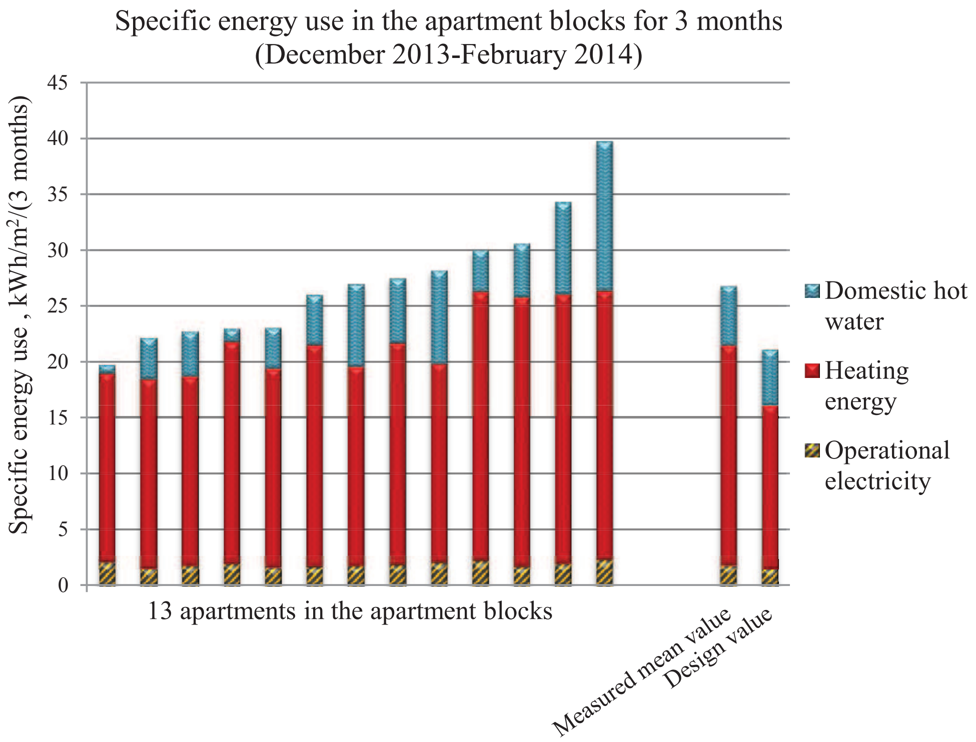

Figure 8.8 *The specific energy use in 13 of the apartments in the apartment blocks, the measured mean value and the design value.*

Large variations can be seen in the use of heating energy in the different apartment blocks. The mean value of the measured heating energy in the apartment blocks is 5 kWh/m^2/year larger than the design value, the mean values and the differences of the energy use are presented in Table 8.2 below.

Table 8.2 Variations in the three categories of energy in the specific energy use in the 13 apartments during December 2013-February 2014. (The maximum and minimum values are the maximum/minimum values in each category and are not necessarily from the same apartment).

	Design value	Mean value	Minimum value	Maximum value	Difference (max/min)
	[kWh/m^{2}A$_{temp}$/year]		[kWh/m^{2}A$_{temp}$/year]		[-]
Domestic hot water	5	5.4	0.8	13.4	1675%
Heating energy	14.7	19.7	17.0	24.1	142%
Operational electricity	1.5	1.8	1.6	2.3	144%

The domestic hot water use is approximately 17 times larger in the apartment with highest energy use compared to the apartment that uses the least energy. It is not known if the tenants in the apartments with very low domestic hot water use live full time in their apartment. The apartment that uses least domestic hot water also has a low use of household electricity which could indicate that the apartment is not used full time. The mean value of the domestic hot water use agrees well with the design assumptions.

8.2.2 Household electricity

The design household electricity for the apartment blocks is 30 kWh/m^2/year. The household electricity use for the months December, January and February is calculated with the percentage factor prescribed in FEBY and the design use for these three months is 9.3kWh/m^2. The mean value of the actual household electricity use is 9.2 kWh/m^2 and the usage varies between 2.6-15.6 kWh/m^2 in the apartments.

8.2.3 Analysis of the results in the apartment blocks

The design temperature in the energy calculations of the apartment blocks is 21˚C, the actual mean temperature in the apartments is 22.2˚C. This can be one of the explanations to the higher heating energy use than designed. The habits regarding airing is unknown in the apartment blocks, but that could also be one factor that explains the higher heating energy use.

The design household electricity agrees very well with the measured use during the three months.

The mean value of the domestic hot water use agrees well with the design values, but since two apartments do not seem to be used full time they keep the mean value down. 4 of 16 apartments use more than 50% more domestic hot water than designed.

8.3 Energy performance in the terrace houses

For the terrace houses the data of the energy use from September 2013 to February 2014 is studied.

8.3.1 Specific energy use

The results in Figure 8.9 are based in the specific energy use during the period September 2013-February 2014.

As in the apartment blocks only the heating energy to the building body is measured in the terrace houses. The supplied energy to each building body is assumed to be evenly distributed over the buildings area which means that there are probably larger variations in the heating energy in the reality than can be seen in Figure 8.9 below.

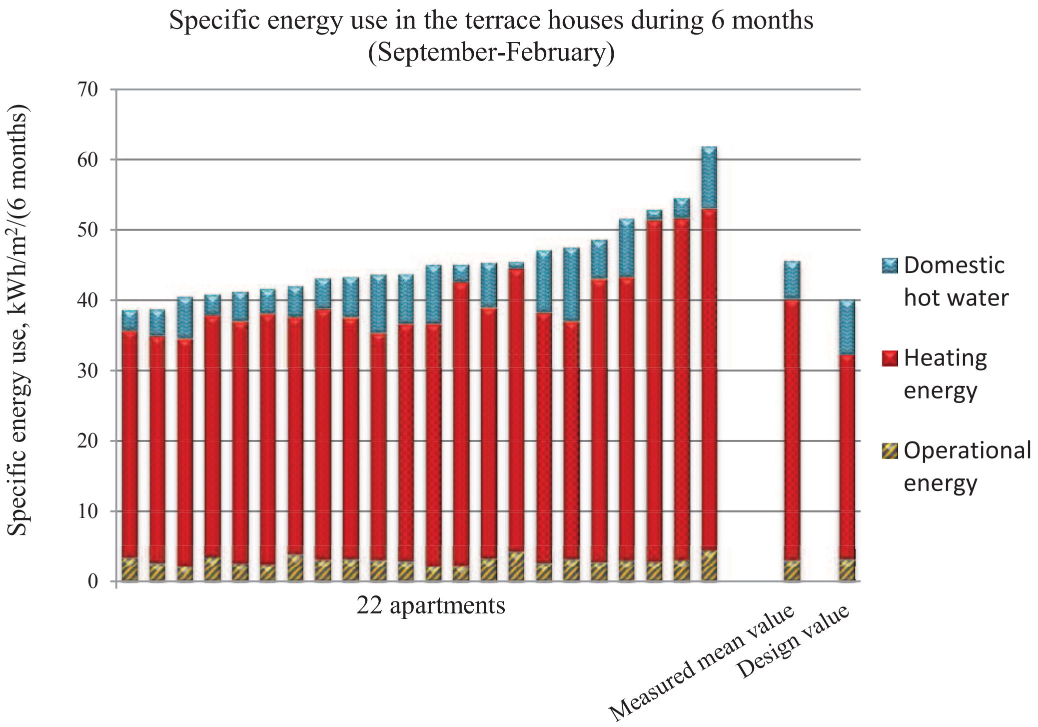

Figure 8.9 The specific energy use in the 22 terrace house apartments.

As presented in Figure 8.9 above all buildings have a higher heating energy use than designed while the mean value of the domestic hot water use is lower than expected. There are large variations in the domestic hot water use between the different apartments. The mean values and the differences of the energy use are presented in Table 8.3.

Table 8.3 Variations in the three categories of energy in the specific energy use in the 22 apartments in the terrace houses during September 2013-February 2014. (The maximum and minimum values are the maximum/minimum values in each category and are not necessarily from the same apartment).

	Design value	Mean value	Minimum value	Maximum value	Difference (max/min)
	[kWh/m^{2}A$_{temp}$/year]		[kWh/m^{2}A$_{temp}$/year]		[-]
Domestic hot water	7.7	5.3	0.9	10.4	1156%
Heating energy	29.2	37.2	32.4	48.5	150%
Operational electricity	3.2	3.1	2.3	4.5	196%

Of the 20 residences that answered the survey the mean value of number of people that lives in the apartment is 1.7. In the design phase 41m^2/person is used and the number of people in each apartment in the design calculations is 1.65-2.27 depending on the area of the apartment.

8.3.2 Household electricity

The design household electricity in the terrace houses is calculated the same way as for the single family houses and is 2060-2308 kWh/year in the apartments depending on the area. The mean value of the design household electricity, 2184 kWh/year, will be used in this comparison. The percentage factor prescribed in FEBY is used to find the design household electricity for the months September-February and the result is 1221 kWh. The mean value of the measured household electricity use for the six measured months is 1460 kWh, the smallest use is 727 kWh and the largest use is 2084 kWh.

8.3.3 Analysis of the results of the terrace houses

The mean indoor temperature in the terrace houses during December 2013 to February 2014 was 22.1˚C which agrees well with the temperature 22˚C in the energy simulations.

Results from the survey presented earlier shows that the habits regarding airing vary between the different types of buildings. 20 of the 22 premises that participated in the survey 50% answered that they were airing every day during the winter season. This is a possible explanation to the higher heating energy use than designed.

Assumptions regarding the number of people living in each apartment was slightly too high. The assumptions regarding the domestic hot water use was also too high.

The household electricity use in the terrace houses was higher than designed, the assumptions used in the design was the same as for the single family houses (prescribed in FEBY 09) where the household electricity was underestimated as well. If the terrace houses would have been designed with FEBY 12 (30 kWh/m^2/year) the mean household electricity would be assumed to be 1272 kWh, which also is lower than the measured mean value. The mean household electricity use in the terrace houses was 19.3 kWh/m^2/(6 months) and according to the distribution of the household electricity in FEBY 09 this should correspond to 55% of the yearly household electricity. A prognosis of the full year household electricity is thereby 35.1 kWh/m^2/year.

8.4 Energy performance in the retirement home

The activity in the retirement home building started during October 2013 and the data from December 2013 to February 2014 is used in the energy study.

8.4.1 Specific energy use

In Figure 8.10 the specific energy use and the design value for December 2013-February 2014 is showed together with a prognosis of the full year specific energy use. The retirement home have a cooling machine in the air handling unit and solar cells on the roof that should supply the building with operational electricity. This study is performed for three months without a cooling need and with a low solar energy supply.

The energy for cooling and the supplied solar energy are not included in the measured values or the design values of the specific energy use below. The magnitude of the designed solar energy and energy for the cooling machine is showed to the right in the figure, the solar energy is a negative value that should be subtracted from the specific energy use since the solar energy is generated on the building's property.

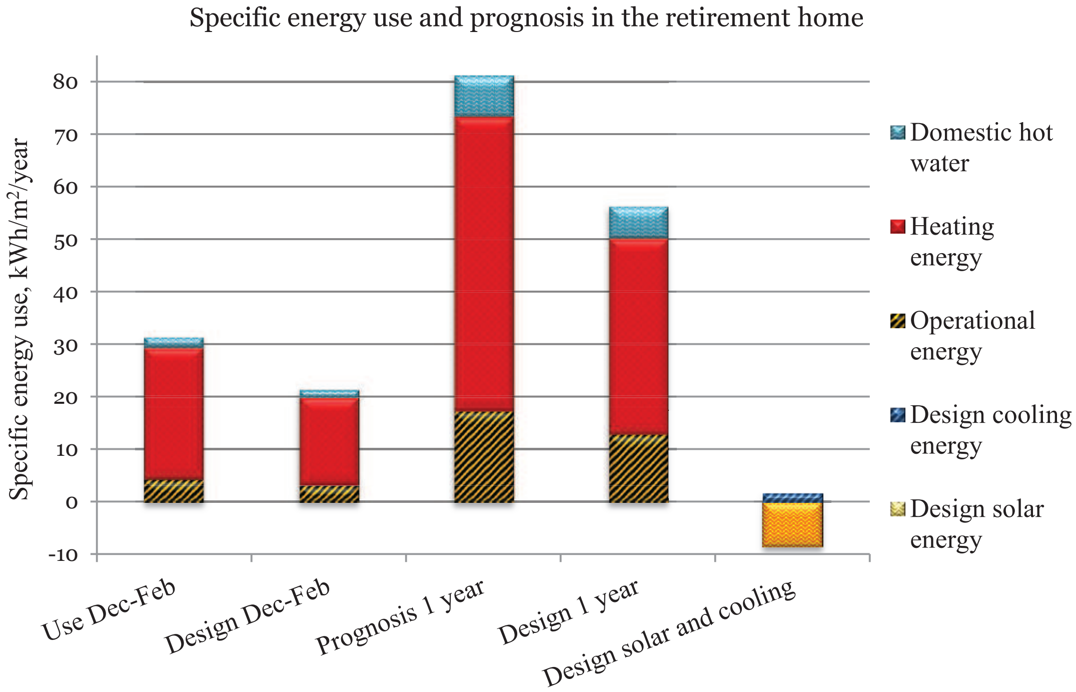

Figure 8.10 The specific energy use in the retirement home during December 2013-February 2014, the design value for the same period and a prognosis of the full year specific energy use. The design generated solar energy and the design cooling energy is represented by the bar to the right.

The household electricity in the retirement home is not investigated in this project since the electricity delivered to the building also includes electricity to the retirement home activities such as the industrial kitchen, social areas, office areas, staff break rooms etc.

Table 8.4 The measured specific energy use in the retirement home during December 2013-February 2014 compared to the design values.

	Design value	Measured value
	[kWh/m^2A_{temp}/year]	[kWh/m^2A_{temp}/year]
Domestic hot water	1.5	2.0
Heating energy	16.8	25.2
Operational electricity	3.2	4.3

8.4.2 Analysis of the results of the retirement home

The prognosis of the energy use in the retirement home indicates a higher specific energy use than designed. The retirement home is a large and complex building and there are no specific guidelines how to design a building with that kind of activity.

Differences between the measured and the designed specific energy use can depend on several factors. The mean indoor temperature in the measured parts of the retirement home is 23˚C, in the energy simulations the temperature was 22˚C. Another factor that affects the heating energy use is the metabolic rate of the residents which could have been overrated in this case, the remaining internal heat loads could also have been overrated. There are always uncertainties in a prognosis and a more detailed investigation of the energy performance after one year would give the precise results.

Since the prognosis indicates that the actual heating energy use is much higher than designed, there might be a reason to have a closer look on the technical system in the building to make sure that the air handling is performed correctly and with the designed efficiency.

8.5 Analysis of the domestic hot water use

In the design phase the domestic hot water use was assumed to be 15.4-20 kWh/m^2/year depending on which edition of FEBY that is used (see Section 5). The mean value of the domestic hot water use for all the premises in Vallda Heberg is 16.0 kWh/m^2/year. The mean value of the domestic hot water use in the different types of buildings is showed in Table 8.5, where the use in the apartment blocks and the terrace houses is based on the prognoses described in Section 8. As it can be seen, the variations in the domestic hot water use in the premises are large; 11 kWh/m^2/year.

Table 8.5 The domestic hot water use in the different types of buildings per square meter area and per residence compared to the design values. The mean values are balanced with the areas of the premises or the number of each type of residence.

	Single family houses	Apartment blocks	Terrace houses	Mean value
Mean actual use [kWh/m^2/year]	16.5	21.5	10.5	16.0
Median actual use [kWh/m^2/year]	16.6	18.7	9.8	-
Mean actual use [kWh/residence/year]	2310	1704	806	1642
Design value [kWh/m^2/year]	15.4	20.0	15.4	16.3

The apartment blocks have a higher mean domestic hot water use per area compared to the other premises, but the absolute use is lower than in the single family houses. Since the response rate for the apartment blocks was low it was not possible to tell the mean number of people living in the apartments. It would have been an interesting comparison to see if the mean domestic hot water use per person is approximately the same.

The fact that the washing machines and dishwashers use hot water was not taken into account during the design phase and it is therefore important to keep that in mind when comparing the measured hot water consumption with the design value.

When the specific energy use of a building is decided, the domestic hot water is an essential part. The domestic hot water use only depends on the habits of the people living in the building and has nothing to do with the building's properties. It can seem a bit strange that the domestic hot water use is included in the specific energy use while the household electricity, that actually provides some heat to the building, is not taken into account. It could be a good idea to either include both parameters in the specific energy use or exclude both.

9 Conclusions

The single family houses are the only buildings with measured data for a full year and the actual mean specific energy use is lower than expected; the heating energy use is lower than designed while the domestic hot water use and the operational electricity is slightly higher than designed. At the same time, the mean indoor temperature in the single family houses was lower than designed while the actual household electricity use were 69% higher than assumed during the design phase. Since 70% of the household electricity is assumed to credit the building as heat the household electricity is an essential part of the heat supplied to the building. The higher household electricity could thereby be one of the explanations to the lower heating energy use than designed.

Heat supplied to the building by the heating system and by the household electricity should both affect the indoor temperature. The correlation between the total supplied heat and the indoor temperature is not clear, but a trend-line indicates a slightly higher indoor temperature in the premises with higher supplied heating energy and household electricity. The heating energy demand in the buildings seems to be affected mostly by the users' habits.

For the terrace houses and the apartment blocks prognoses indicates a slightly higher specific energy use than designed, and the heating energy use is the factor that exceeds the design values the most. It is known that the mean indoor temperatures in both types of premises are higher than designed, which could be one of the explanations to the higher heating demand. Another important factor is the habits regarding airing; 50% of the residents in the terrace houses were airing daily during the winter season, which could also affect the heating energy use (the corresponding number for the apartments blocks is not known). To receive the precise specific energy use in these buildings, an investigation should be done when there are measured data available for a full year.

In a prognosis of the retirement home the heating energy use is noteworthy higher than expected and further investigations might be needed. The retirement home is a complex building and the first passive house certified retirement home in Sweden, thus no reference objects were thereby available. There are probably several explanations to the higher heating energy use; the internal heat loads might have been overestimated, there could be something wrong with the technical system or the building envelope and, of course, there are uncertainties in the prognosis.

Variations in the domestic hot water use between the premises in Vallda Heberg are large. In the future it might be a good idea to either exclude the domestic hot water use from the specific energy use or include the household electricity. Both are only affected by the users' habits and do not affect the building's properties.

The indoor temperature in the premises fulfils the demands set by The Public Health Agency of Sweden. The detailed measurements in two houses results in the PMV-index -0.088 and -0.096 which corresponds to the PPD-index 5.2%. According to the survey, people were generally satisfied with the indoor temperature during the winter season. A common opinion was that the bedrooms was too warm and the bathroom too cold. It is worth to note that the cold bathrooms in the single family houses were often referred to as bathrooms on the second floor that did not have any comfort floor heating.

The seniors in the terrace houses seem to prefer a higher indoor temperature compared to the families in the single family houses. The mean temperature in the terrace houses during December-February was 22.1˚C and the corresponding temperature in the single family houses was 21.1˚C. However, the residents in the single family houses were more satisfied with the indoor climate than the residents in the terrace houses, where some of them thought it was a bit too cold. The fact that the metabolism decreases with age and that the temperature for energy calculations is 21˚C (according to the newest Swedish passive house standard FEBY 12) it could be a reason to use a higher indoor temperature when designing future projects with senior residents.

10 Future challenges

The domestic hot water use is the part of the specific energy use that varies the most between the different premises in Vallda Heberg. The household electricity and the domestic hot water use are not related to the building but to the habits of the people living in the building. The specific energy use includes the domestic hot water use while the household electricity is not considered in the energy performance of the building. It can seem strange that these two quite similar aspects that both affect the total energy use of the building are treated differently. It might be a good idea to either include the household electricity to the specific energy demands or exclude the domestic hot water use.

Solar energy that is generated on the building's property can be subtracted from the specific energy use while solar energy generated outside the property is considered as delivered energy, even though it is generated very close to the property. If the perspective was changed from the building to the entire area more people might consider to build with a larger scale of renewable energy and the interaction between the buildings would improve the energy efficiency. The generated solar energy would be used in the building that needs it at the moment and would not be wasted if the building with the solar collectors did not need the heat for the moment.

One thing that could be a reason to investigate for future projects is the possibility and benefit of having an absence mode for the ventilation system. That would make it possible for the residents to decrease the air flow rate to the building, and thereby save energy, when they leave the building.

In the beginning of this project the purpose was to use the measured flow in the glycol circuit to estimate the heating energy use in each rental apartment. There were large variations in the flow between the apartments and studies on the single family houses showed that there are no clear connection between the flow in the glycol circuit and the supplied heating energy to the houses. In future projects it could be a reason to measure the heating energy use in each apartment, this would also allow individual charging of the heat to make the tenants more aware of their energy use.

11 References

The information regarding the area Vallda Heberg and the buildings is taken from the documentation on NCC servers and documentation binders from the design phase.

All measured data comes from the contractor Eksta Bostads AB.

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Figures

Figures without references in the caption was created by the authors.

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Appendix A – Calculation of PMV and PPD

House A

Air temperature:	$t_a := 21.1$	^oC
Air temperature in Kelvin:	$t_{aK} := t_a + 273 = 294.1$	K
Mean radiant temperature	$t_r := 20.9$	^oC
Relative air velocity:	$v_{ar} := 0.04$	m/s
Metabolic rate:	$M := 70$	W/m^2
Effective mechanical power:	$W_p := 0$	W/m^2
Clothing insulation:	$I_{cl} := 0.155$	m^2K/W
Raltive humidity	$RH := 0.33$	-

Water vapour saturation pressure: Pa

$$p_{as} := \frac{e^{\left(77.3450 + 0.0057 \cdot t_{aK} - \frac{7235}{t_{aK}}\right)}}{t_{aK}^{8.2}} = 2.472 \times 10^3$$

Water vapour partial pressure: $p_a := RH \cdot p_{as} = 815.734$ Pa

Clothing surface area factor: $f_{cl} := 1.05 + 0.645 \cdot I_{cl} = 1.15$ (I_{cl} is larger than 0.078 m^2K/W)

Convective heat transfer coefficient, W/m^2K:

$$12.1 \cdot \sqrt{v_{ar}} = 2.42$$

$t_{cl} := 26.35$ <u>Solved by iteration</u>

$$2.38 \cdot \left(\left| t_{cl} - t_a \right| \right)^{0.25} > 12.1 \cdot \sqrt{v_{ar}} = 1$$ 1= true, 0=false

$$h_c := 2.38 \cdot \left(\left| t_{cl} - t_a \right| \right)^{0.25} = 3.603$$

$$2.38 \cdot \left(\left| t_{cl} - t_a \right| \right)^{0.25} < 12.1 \cdot \sqrt{v_{ar}} = 0$$ 1= true, 0=false

$$h_{c2} := 12.1 \cdot \sqrt{v_{ar}}$$

Clothing surface temperature, ^{o} C:

$$t_{cl} := 35.7 - 0.028\cdot\left(M - W_p\right) - I_{cl}\cdot\left[3.96\cdot10^{-8}\cdot f_{cl}\cdot\left[\left(t_{cl} + 273\right)^4 - \left(t_r + 273\right)^4\right] + f_{cl}\cdot h_c\cdot\left(t_{cl} - t_a\right)\right]$$

$$t_{cl} = 26.352$$

Calculation of PMV

$$PMV := (0.303\cdot\exp(-0.36\cdot M) + 0.028)\cdot\left[\begin{array}{l}\left(M - W_p\right) - 3.05\cdot10^{-3}\cdot\left[5733 - 6.99\cdot\left(M - W_p\right) - p_a\right] \ldots \\ + -0.42\cdot\left[\left(M - W_p\right) - 58.15\right] - 1.7\cdot10^{-5}\cdot M\cdot\left(5867 - p_a\right) \ldots \\ + -0.0014\cdot M\cdot\left(34 - t_a\right) \ldots \\ + -3.96\cdot10^{-8}\cdot f_{cl}\cdot\left[\left(t_{cl} + 273\right)^4 - \left(t_r + 273\right)^4\right] \ldots \\ + -f_{cl}\cdot h_c\cdot\left(t_{cl} - t_a\right)\end{array}\right]$$

$$\boxed{PMV = -0.096}$$

Calculation of PPD

$$PPD := 100 - 95\cdot\exp\left(-0.03353\cdot PMV^4 - 0.2179\cdot PMV^2\right)$$

$$\boxed{PPD = 5.192}$$

House B

Air temperature:	$t_a := 21.0$	^oC
Air temperature in Kelvin:	$t_{aK} := t_a + 273 = 294$	K
Mean radiant temperature	$t_r := 20.9$	^oC
Relative air velocity:	$v_{ar} := 0.04$	m/s
Metabolic rate:	$M := 70$	W/m^2
Effective mechanical power:	$W_p := 0$	W/m^2
Clothing insulation:	$I_{cl} := 0.155$	m^2K/W
Reltive humidity	$RH := 0.38$	-

Water vapour saturation pressure: Pa

$$p_{as} := \frac{e^{\left(77.3450 + 0.0057 \cdot t_{aK} - \frac{7235}{t_{aK}}\right)}}{t_{aK}^{8.2}} = 2.457 \times 10^3$$

Water vapour partial pressure: $p_a := RH \cdot p_{as} = 933.572$ Pa

Clothing surface area factor: $f_{cl} := 1.05 + 0.645 \cdot I_{cl} = 1.15$

(I_{cl} is larger than 0.078 m^2K/W)

Convective heat transfer coefficient: W/m^2K

$$12.1 \cdot \sqrt{v_{ar}} = 2.42$$

$t_{cl} := 26.32$ <u>Solved by iteration</u>

$$2.38 \cdot \left(\left|t_{cl} - t_a\right|\right)^{0.25} > 12.1 \cdot \sqrt{v_{ar}} = 1$$ 1= true, 0=false

$$h_c := 2.38 \cdot \left(\left|t_{cl} - t_a\right|\right)^{0.25} = 3.615$$

$$2.38 \cdot \left(\left|t_{cl} - t_a\right|\right)^{0.25} < 12.1 \cdot \sqrt{v_{ar}} = 0$$ 1= true, 0=false

$$h_{c2} := 12.1 \cdot \sqrt{v_{ar}}$$

Clothing surface temperature: ^{o}C

$$t_{cl} := 35.7 - 0.028\cdot\left(M - W_p\right) - I_{cl}\cdot\left[3.96\cdot10^{-8}\cdot f_{cl}\cdot\left[\left(t_{cl} + 273\right)^4 - \left(t_r + 273\right)^4\right] + f_{cl}\cdot h_c\cdot\left(t_{cl} - t_a\right)\right]$$

$t_{cl} = ▮$

Calculation of PMV

$$PMV := (0.303\cdot\exp(-0.36\cdot M) + 0.028)\cdot\left[\begin{array}{l}\left(M - W_p\right) - 3.05\cdot10^{-3}\cdot\left[5733 - 6.99\cdot\left(M - W_p\right) - p_a\right] \ldots \\ + -0.42\cdot\left[\left(M - W_p\right) - 58.15\right] - 1.7\cdot10^{-5}\cdot M\cdot\left(5867 - p_a\right) \ldots \\ + -0.0014\cdot M\cdot\left(34 - t_a\right) \ldots \\ + -3.96\cdot10^{-8}\cdot f_{cl}\cdot\left[\left(t_{cl} + 273\right)^4 - \left(t_r + 273\right)^4\right] \ldots \\ + -f_{cl}\cdot h_c\cdot\left(t_{cl} - t_a\right)\end{array}\right]$$

$\boxed{PMV = -0.088}$

Calculation of PPD

$$PPD := 100 - 95\cdot\exp\left(-0.03353\cdot PMV^4 - 0.2179\cdot PMV^2\right)$$

$\boxed{PPD = 5.16}$

Appendix B – The survey, In Swedish

1. **Hur nöjd var du med inomhustemperaturen i din bostad under vinterhalvåret?**
   (sätt ett kryss vid alternativet som bäst speglar dina synpunkter)

Mycket nöjd	
Ganska nöjd	
Varken eller	
Ganska missnöjd	
Mycket missnöjd	
Vet ej	

2. **Tyckte du att det var för kallt eller för varmt i något rum i bostaden under vinterhalvåret?**

	Mycket för kallt	För kallt	Lagom	För varmt	Mycket för varmt
I kök					
I vardagsrum					
I badrum/toalett					
I sovrum					

3. **Besvärades du av att temperaturen varierade i bostaden beroende på temperaturförändringar utomhus under vinterhalvåret?**

Ja, ofta	
Ja, ibland	
Nej, sällan eller aldrig	

4. Hur upplevde du luftfuktigheten i din bostad under vinterhalvåret?

Torr luft	☐
Lagom fuktighet	☐
Fuktig luft	☐
Vet ej	☐

5. Hur bra tyckte du generellt sett att ventilationen fungerade i din bostad under vinterhalvåret?

Mycket nöjd	☐
Ganska nöjd	☐
Varken eller	☐
Ganska missnöjd	☐
Mycket missnöjd	☐
Vet ej	☐

6. Upplevde du under vinterhalvåret att din bostad hade..?

	Ja	Nej	Vet ej
Kalla golv			
Kalla väggar			

7. **Besvärades du av drag i din bostad under vinterhalvåret? Ange i så fall i vilket rum.** (Sätt ett kryss vid alternativ som speglar dina synpunkter, flera alternativ möjliga)

	X	I vilket/vilka rum?
Besväras ej av drag		
Besväras av drag vid golv		
Besväras av drag vid fönster		
Besväras av drag vid dörr		

8. **Hur ofta vädrade du under vinterhalvåret?**

Dagligen/nästan varje dag	
Ungefär 3-5 gånger i veckan	
Ungefär 1-2 gånger i veckan	
Någon gång i månaden	
Vädrar sällan eller aldrig	

9. **När du vädrade, vädrade du då oftast genom att…?**

Ha fönster/dörr öppet hela dagen	
Ha fönster/dörr öppet hela natten	
Ha fönster/dörr öppet några timmar	
Ha fönster/dörr öppet en kortare stund	
Korsdrag i några minuter	
Vädrar aldrig	

10. Använde du frånvarostyrningen för elektriciteten när du var borta från huset i ….?

	Ja	Nej
…några timmar		
…några dagar		
…flera veckor		

Jag använder aldrig frånvarostryningen: ☐

11. Hur tyckte du att dagsljuset var i din bostad under vinterhalvåret?

Mycket bra	
Bra	
Acceptabelt	
Dåligt	
Mycket dåligt	

12. Tyckte du att du fick för lite eller för mycket direkt solljus i bostaden under vinterhalvåret?

För mycket	
Något för mycket	
Lagom	
Något för lite	
För lite	

13. Hur brukade persiennerna i vardagsrum och kök vara ställda dagtid under vinterhalvåret?

Neddragna/öppna	
Neddragna/stängda	
Uppdragna	

14. Om dina persienner var neddragna (öppna eller stängda), varför var de neddragna? Flera alternativ är möjliga.

Skydda mot ljus	
Skydda mot värme/kyla	
Skydda mot insyn	

15. Besvärades du av störande ljud i din bostad under vinterhalvåret?

	Ja, ofta	Ja, ibland	Nej, sällan eller aldrig
Ljud från kranar, rör			
Ljud från ventilation			
A Ljud från grannar (flerbostadshus)			
n n Ljud utifrån, t.ex. trafik, människor etc. a			

Annat:____

16. Är det något annat i ditt inomhusklimat du har noterat? Finns det något som påverkar ditt boende som du skulle vilja få mer information om?

____
____
____
____
____

17. Hur många gånger använder ni tvättmaskinen i genomsnitt per vecka?

_____ tvättar per vecka

18. Hur många gånger används torktumlaren i genomsnitt per vecka?

_____omgångar i torktumlare per vecka

19. Hur många gånger använder ni diskmaskinen i genomsnitt per vecka?

_____ diskmaskiner per vecka

20. Hur många bor stadigvarande i din bostad? Räkna även med dig själv.

____ antal barn 0-12 år

____ antal ungdomar 13-18 år

____ antal vuxna 19-65 år

____ antal vuxna över 65 år

Har antalet förändrats under 2013/2014?_____________________________

21. Har bostaden stått tom under minst en vecka någon gång under 2013/2014?

Ja	☐
Nej	☐

I så fall i när?____

22. Vilken typ av bostad bor du i?

____ Villa (Guldvingevägen eller Nätvingevägen)

____ Radhus (Rosenvingevägen)

____ Fyrbohus (Blåvingevägen)

23. Har alla i hushållet samma uppfattning om inomhusklimatet?

Ja	☐
Nej	☐

Om nej, vilka andra uppfattningar finns?______________________________

24. Möjlighet till djupintervju?

Vi vill följa upp ett antal enkäter med djupintervjuer för att få mer kvalitativa svar på våra frågor kring inomhusmiljön. En sådan intervju kommer att ta ca 30 min. Får vi kontakta dig för en sådan intervju?

Ja	☐
Nej	☐

Om ja, ange namn och telefonnummer:

Namn: ______________________________

Telefonnummer: ______________________________

25. Intresserad av att medverka i en studie?

Vi vill ge möjlighet till några boende att under en arbetsveckas tid få sin dagliga värme- och varmvattenförbrukning presenterad för att se hur medvetenhet och ändrat beteende kan påverka energiförbrukningen.

Ja	☐
Nej	☐

Om ja, ange namn och telefonnummer:

Namn: ______________________________

Telefonnummer: ______________________________

E-post: ______________________________

Tilläggsfrågor till er som bor på <u>Guldvingevägen</u> och <u>Nätvingevägen</u>:

A. Tycker du att uppvärmningssystemet i bostaden ger dig stora eller små möjligheter att själv påverka temperaturen?

Stora möjligheter	☐
Vissa möjligheter	☐
Inga möjligheter	☐

B. Om du vädrar, ställer du då in temperaturen på minimum i ditt luftaggregat?

Ja	☐
Nej	☐

C. Ställer du ner temperaturen på ditt luftsaggregat om du reser bort..?

	Ja	Nej
…någon dag	☐	☐
…några dagar	☐	☐
…en vecka eller mer	☐	☐

D. Har ni själva reglerat något på ert luftaggregat under tiden ni bott i er bostad? (temperatur, flöden, etc.)

Ja	☐	I så fall vad?____
Nej	☐	

Appendix C – Answers from the survey - premises

1. How satisfied were you with the indoor temperature in your home during the winter season?

	All residences	Single family houses	Terrace houses
Very satisfied	41,5%	47,1%	40,0%
Fairly satisfied	43,9%	52,9%	35,0%
Neutral	7,3%	0,0%	10,0%
Farly dissatisfied	4,9%	0,0%	10,0%
Very dissatisfied	2,4%	0,0%	5,0%
Do not know	0,0%	0,0%	0,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

2. Did you experience that any room in your home was too hot or too cold during the winter season?

	All residences				Single family houses				Terrace houses			
	Kitchen	Living room	Bathroom	Bedroom	Kitchen	Living room	Bathroom	Bedroom	Kitchen	Living room	Bathroom	Bedroom
Much too cold	0%	0%	7%	2%	0%	0%	18%	0%	0%	0%	0%	5%
Too cold	12%	17%	32%	2%	18%	12%	53%	0%	5%	10%	20%	0%
Neutral	85%	80%	61%	68%	82%	88%	29%	71%	###	85%	80%	65%
Too warm	2%	2%	0%	20%	0%	0%	0%	24%	5%	5%	0%	20%
Much to warm	0%	0%	0%	7%	0%	0%	0%	6%	0%	0%	0%	10%
Frequency of answers	41 of 64				17 of 26				20 of 22			

3. Did indoor temperature variations due to the outdoor temperature variations bother you during the winter season?

	All residences	Single family houses	Terrace houses
Yes, often	7,3%	0,0%	15,0%
Yes, sometimes	31,7%	29,4%	30,0%
No, rarly or never	61,0%	70,6%	55,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

4. How did you experience the humidity in your home during the winter season?

	All residences	Single family houses	Terrace houses
Dry air	39,0%	23,5%	60,0%
Neutral	48,8%	64,7%	25,0%
Moist air	0,0%	0,0%	0,0%
Do not know	12,2%	11,8%	15,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

5. How well do you think the ventilation system worked in your home during the winter season?

	All residences	Single family houses	Terrace houses
Very satisfied	41,5%	47,1%	35,0%
Fairly satisfied	46,3%	52,9%	40,0%
Neutral	4,9%	0,0%	10,0%
Fairly dissatisfied	4,9%	0,0%	10,0%
Very dissatisfied	0,0%	0,0%	0,0%
Do not know	2,4%	0,0%	5,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

6. Did you experience cold floors or cold walls in your home?

	All residences		Single family houses		Terrace houses	
	Cold floors	Cold walls	Cold floors	Cold walls	Cold floors	Cold walls
Yes	41,5%	4,9%	41,2%	5,9%	50,0%	5,0%
No	53,7%	70,7%	52,9%	70,6%	45,0%	70,0%
Do not know	4,9%	24,4%	5,9%	23,5%	5,0%	25,0%
Frequency of answers	41 of 64		17 of 26		20 of 22	

7. Were you bothered by draught in your home during the winter season?

	All residences	Single family houses	Terrace houses
Not bothered by draught	84,6%	88,2%	72,2%
Bothered by draught at floors	5,1%	5,9%	5,6%
Bothered by draught at windows	7,7%	5,9%	11,1%
Bothered by draught at door	10,3%	0,0%	22,2%
Frequency of answers	39 of 64	17 of 26	18 of 22

The sum of the percentages above is not 100% in the total and the terrace houses since
One terrace house resident is bothered by draught at both windows and door
One terrace house resident is bothered by draught both at floor, windows and door

8. How often did you air your home during the winter season?

	All residences	Single family houses	Terrace houses
Every day/almost every day	26,8%	5,9%	50,0%
Appr. 3-5 times/week	0,0%	0,0%	0,0%
Appr. 1-2 times/week	17,1%	29,4%	10,0%
A few times/month	19,5%	17,6%	15,0%
Rarly or never	36,6%	47,1%	25,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

9. When you were airing, did you usually do it by having…

	All residences	Single family houses	Terrace houses
Open door/window all day	0,0%	0,0%	0,0%
Open door/window all night	12,2%	5,9%	20,0%
Open door/window a few hours	4,9%	5,9%	5,0%
Open door/window for a moment	56,1%	47,1%	65,0%
Drafts for a few minutes	29,3%	35,3%	25,0%
Never air	14,6%	11,8%	10,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

Several answers were possible, that is the reason the sum is over 100%

10. Do you use the absence control for the electricity when you left the building for…

	All residences	Single family houses	Terrace houses
… A few hours	19,5%	17,6%	15,0%
… A few days	19,5%	17,6%	15,0%
… A few weeks	12,2%	11,8%	5,0%
I never use it	75,6%	82,4%	75,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

Several answers were possible.

11. How did you experience the daylight in your home during the winter season?

	All residences	Single family houses	Terrace houses
Very good	36,6%	52,9%	20,0%
Good	43,9%	41,2%	45,0%
Acceptable	17,1%	5,9%	30,0%
Bad	2,4%	0,0%	5,0%
Very bad	0,0%	0,0%	0,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

12. From your opinion, did you get too much or too little direct sunlight during the winter season?

	All residences	Single family houses	Terrace houses
Too much	2,4%	0,0%	5,0%
Bit too much	0,0%	0,0%	0,0%
Neutral	75,6%	76,5%	70,0%
Bit too little	17,1%	23,5%	15,0%
Much too little	4,9%	0,0%	10,0%
Frequency of answers	41 of 64	17 of 26	20 of 22

13. How was the blinds placed in kitchen and living room daytime during the winter season?

	All residences	Single family houses	Terrace houses
Down but open	16,7%	18,8%	15,8%
Down and closed	0,0%	0,0%	0,0%
Up	83,3%	81,3%	84,2%
Frequency of answers	36 of 64	16 of 26	19 of 22

Some apartments do not have blinds

14. If the blinds were down, what was the reason?

	All residences	Single family houses	Terrace houses
Protect against light	27,3%	0,0%	50,0%
Protect against heat/cold	18,2%	0,0%	33,3%
Protect against INSYN?!	90,9%	100,0%	83,3%
Frequency of answers	11 of 64	4 of 26	6 of 22

Several answers were possible

15. Were you disturbed by noise in your home during the winter season?

	All residences				Single family houses				Terrace houses			
	Yes, often	Yes, sometimes	No, rarly or never	Frequency X of 64	Yes, often	Yes, sometimes	No, rarly or never	Frequency X of 26	Yes, often	Yes, sometimes	No, rarly or never	Frequency X of 22
Yes, noise from pipes, taps etc.	0%	8%	92%	39	0%	12%	88%	17	0%	0%	####	18
Yes, noise from ventialtion	0%	26%	74%	38	0%	41%	59%	17	0%	12%	88%	17
Yes, noise from neighbors	0%	6%	94%	35	0%	6%	94%	16	0%	0%	####	15
Yes, noise from utside such as trafic, people etc.	0%	15%	85%	39	0%	6%	94%	17	0%	22%	78%	18

16. Is there something else you have notised regarding your indoor climate?

The terrace houses:	Noise from the kitchen exhaust pipe when there is wind outside
	Draught from the supply air diffuser in the living room
	The wife in the house is often sneezy
The single family houses:	Disturbing noise from the fan
	Cold bathroom floor on the second floor
	Disturbing niose from frigde and freezer
Apartment blocks:	Difficult to close the doors
	Draught from the kitchen exhaust pipe

17. How many times do you use the washing machine in average per week

	All residences	Single family houses	Terrace houses
Average:	4.0	5.8	2.25

18. How many times do you use the dryer in average per week

	All residences	Single family houses	Terrace houses
Average:	2.7	3.7	1.6

19. How many times do you use the dishwasher in average per week

	All residences	Single family houses	Terrace houses
Average:	4.2	6.1	2.7

20. How many people live in your home, include yourself.

	All residences				Single family houses				Terrace houses			
	Kids 0-12 years	Kids 13-18 years	Adults 19-65	Adults over 65	Kids 0-12 years	Kids 13-18 years	Adults 19-65	Adults over 65	Kids 0-12 years	Kids 13-18 years	Adults 19-65	Adults over 65
Average:	0.74	0	1.27	0.61	1.65	0	2.06	0	0	0	0.45	1.25
Total average:	2.62				3.71				1.70			

23. Does everyone in the home have the same opinions about the indoor climate?

Yes	100%
No	0%

Additional questions to the single family houses only

A. Do you think that the heating system in your home give you big or small opportunities to affect the temperature?

Big oppotunities	35,3%
Some opportunities	58,8%
No opportunities	5,9%
Frequency of answers	17 of 26

B. If you are airing, do you lower the set temperature to minimum while airing?

Yes	0,0%
No	100,0%
Frequency of answers	16 of 26

C. Do you lower the set temperature on your air handlig unit if you leave the house for…

	Yes	No
… a day	5,9%	94,1%
… a few days	5,9%	94,1%
… a week or more	41,2%	58,8%
Frequency of answers	17 of 26	

D. Have you regulated something on your air handling unit?

Yes	88,2%
No	11,8%
Frequency of answers	17 of 26

Most people have changed the temperature, some have also changed the air flows (both temporarly when having guests and permanently)

Appendix D – Answers from the retirement home

1. How satisfied were you with the indoor temperature at your workplace during the winter season?

Very satisfied	0%
Fairly satisfied	25%
Neutral	0%
Farly dissatisfied	50%
Very dissatisfied	25%
Do not know	0%

2. Did you think the indoor climate varied between day and night?

Yes	0%
No	0%
Only Day shift	100%
Only night shift	0%

3. Were you bothered of temperaturevariation in your workingplace caused by outdoor variations during the winter season?

Yes, often	0%
Yes, sometimes	75%
No, rarly	0%
Do not know	25%

4. How well do you think the ventialtion system works at your workplace?

Very satisfied	0%
Fairly satisfied	0%
Neutral	0%
Farly dissatisfied	75%
Very dissatisfied	25%
Do not know	0%

5. How did you experience the air humity at your workplace during the winter season?

Dry air	100%
Neutral	0%
Moist air	0%
Do not know	0%

6. Do you experience that the indoor climate differs between the areas at your workingplace?

No	25%
Yes	75%

Cold in some of the apartments
Poor ventilated offices and in public areas
Dry air in public areas

7. How often did you air during the winter season?

Daily	0%
3-5 times/ week	25%
1-2 times/ week	50%
Once a month	0%
Rarely or never	25%

8. When you were airing, did you usually do it by…

Open all day	0%
Open all night	0%
Open a few hours	25%
Open a shorter while	75%
Draft for a few minutes	0%
Never airing	0%

9. How did you experience the daylight in your workplace during the winter season?

Very Good	25%
Good	50%
Acceptalbe	0%
Bad	25%
Very bad	0%

10. How many of the rooms were occupied at your department?

Avd:	8./11
Avd: C	8,5/10
Avd:	10./11
Avd: E	11. /11

The next questions are about the residents percieptions, the result are from three surveys filled in by the staff nurses.

1. What is your experience of the residents opinions about the…

A. Indoor temperature

Very satisfied	0%
Fairly satisfied	33%
Neutral	0%
Farly dissatisfied	0%
Very dissatisfied	67%
Do not know	0%

B. Ventilation

Very satisfied	0%
Fairly satisfied	0%
Neutral	33%
Farly dissatisfied	67%
Very dissatisfied	0%
Do not know	0%

C. Bothered by draft

Not bothered by draft	67%
Bothered by draft at floor	0%
Bothered by draft next to window	33%
Bothered by draft next to door	0%
Do not know	0%

D. air humidity

Dry air	67%
Neutral	0%
Moist air	0%
Do not know	33%

Other comments:

"Several people are bothered by the the dry air, it is warm on the upper floor. No circulation of the air"
"Temperature variations between apartments even thogh the windows are closed"
"One of the departments is experienced as dark"
"Need of better ventialtion in the kitchen and office rooms, will be real hot in the summer. Poor ventilated today"