

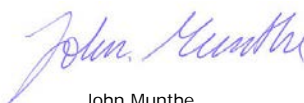
# **Framtidens trähus - energieffektiva med god innemiljö**

Documentation of the project's  
operational stage

Measured Energy Performance and  
the Environmental Assessment

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<b>Title and subtitle of the report</b> Framtidens trähus - energieffektiva med god innemiljö Documentation of the project's operational stage Measured Energy Performance and the Environmental Assessment	
<b>Summary</b> For the first time in Sweden an eight storey high building has been constructed in timber according to the voluntary Swedish passive house criteria. Within the Vinnova (the Swedish Governmental Agency for Innovation Systems) research project “Framtidens trähus – energieffektiva med god innemiljö” IVL has the aim to perform an environmental evaluation and document the development of the energy-efficient multi-family housing built in timber construction. Two buildings, built in Växjö, are owned by the Rental Housing Company in Växjö (“Hyresbostäder i Växjö”). Only building A1 was analysed, which lies on the north-western part of the building site called Southern Portvakten (“Portvakten Söder”). In the first report “Framtidens trähus – energieffektiva med god innemiljö. Documentation of project’s development, planning, and building phases. Building’s energy performance” [1] the project’s development, planning, and building phases were presented. In this report, results of the qualitative and quantitative evaluation of the Southern Portvakten building in Växjö are presented. It includes results of the evaluation of the measured energy performance, user and operational experiences during the first year in operation, as well as the building’s environmental performance analysed with LCA.	
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## **Foreword**

This report is a result of the research project “Framtidens trähus – energieffektiva med god innemiljö” funded by Vinnova, The Swedish Governmental Agency for Innovation Systems. IVL Swedish Environmental Research Institute leads a work package which focuses on environmental evaluation of a multifamily building built in timber construction according to the voluntary Swedish passive house criteria. The building is located in Växjö, Sweden.

This report documents the results from the building’s energy use during the first fifteen months in operation as well as the building’s environmental analysis. A separate document “Framtidens trähus – energieffektiva med god innemiljö. Documentation of project’s development, planning, and building phases. Building’s energy performance” describes the results from the key moments during the development, planning, and building phases of the project.

Maria Wall, from the Division of Energy and Building Design at LTH has contributed with valuable support and comments in writing this report. Rental Housing Company in Växjö (“Hyresbostäder i Växjö”) delivered measured energy data for the Southern Portvakten buildings, while Tommy Wesslund from Wesslunds VVS-Teknik provided valuable input on experiences with the buildings’ ventilation systems. Stefan Olsson from the Energy Agency of South East Sweden has been involved in the analysis of the measured energy performance. The evaluation of the project and the technique that was used in the buildings was made possible thanks to the contribution of the involved project team, whereas the inhabitants provided a valuable input on the experienced indoor air quality by answering the sent out questionnaire.

We would like to use the opportunity and thank everyone that has contributed in collecting and providing the relevant data for this report.

Stockholm, April 2013.

## Sammanfattning

I projektet "Framtidens Trähus - Energieffektiva med god inomhusmiljö" har IVL som mål att miljömässigt utveckla och utvärdera energieffektiva och sunda bostäder i trä genom att delta i uppförandet av Kvarteret Portvaken i Växjö från idéstadium via byggnation och idrifttagning. Portvaken har kombinerat träbyggnadsteknik med koncept för mycket låg energianvändning och två byggnader som ägs av Hyresbostäder i Växjö har uppförts med tekniken. Inom detta projekt analyserades byggnad (A1), som ligger på den nordvästra delen av byggplatsen som kallas Portvaken Söder. Tidigare har rapporten "Framtidens trähus – energieffektiva med god inomhusmiljö. Documentation of project's development, planning, and building phases. Building's energy performance" [1] publicerats som beskriver projektets utvecklings-, planerings- och byggfaser. I denna rapport redovisas uppföljningen av byggnad (A1) med kvalitativa och kvantitativa analyser av uppmätta energiprestanda, brukar- och drifterfarenheter samt beräkning av byggnadens miljöprestanda genom livscykelanalys (LCA) med verkliga driftdata. Även byggnad B1 har analyserats för uppmätt energiprestanda samt brukar- och drifterfarenheter för att kunna jämföra med resultaten från byggnaden A1. I energiprestandan har energianvändning uppmätts för uppvärmning, varmvattenanvändning, elanvändning (hushålls- och fastighetsel), återvunnen energi från avloppsvattenvärmepumpen och inomhustemperaturen registrerats i några representativa lägenheter. Under den analyserade perioden var den uppmätta energianvändningen för uppvärmning (normaliserad) mer än dubbel så hög jämfört med beräknade värden ( $22,2 \text{ kWh/m}^2$  jämfört med  $8,9 \text{ kWh/m}^2$ ). Förklaringen tros ligga i injusteringsproblem av tekniska system, låg uthyrningsgrad och hur brukarna nyttjat lägenheterna under den analyserade perioden. Den köpta volymen av tappvarmvatten är nästan hälften av svenska genomsnittet för 2009, vilket är i linje med den beräknade mängden som ges i de svenska frivilliga passivhuskriterierna [12]. Om uppmätt energianvändning för uppvärmning och varmvatten justeras till 100% uthyrningsgrad motsvarar denna siffra en fjärdedel av den energi som används i ett genomsnittligt svenskt flerfamiljshus (under perioden 2005-2009) [27]. Fastighetsel, som förutom el för belysning av gemensamma utrymmen och hiss inbegriper el för fläktar och pumpar, utgör en betydande post, motsvarande nästan 20% av den totala energi som används i byggnaden A1. Under den analyserade perioden motsvarar det dubbelt så mycket jämfört med rekommendationerna i de svenska frivilliga passivhuskriterierna. Inomhustemperaturer under sommarperioden, vilket var ett bekymmer under projektets utvecklingsfas, visade goda resultat under mätperioden. Inomhustemperaturen var jämn i de övervakade lägenheterna oavsett deras läge och beläggning (uthyrningsgrad). Effektiviteten av avloppsvärmepumpen kunde inte bedömas på grund av den låga uthyrningsgraden av huset. Den totala viktade köpta energin i Portvaken Söder var  $61,1 \text{ kWh/m}^2\text{a}$  (Byggnad A1) och  $45 \text{ kWh/m}^2\text{a}$  (Byggnad B1), vilket var lägre för båda byggandena jämfört med andra energisnåla flerbostadshus, som Värnamo, Frillesås, Lidköping, och de renoverade lägenheterna i Brogården i Alingsås. Skillnaden i uppmätt energiprestanda mellan byggnaderna A1 och B2 kan förklaras av hur elanvändningen för fastighetselen i de två byggnaderna mäts. Elmätaren för fastighetselen i byggnaden A1 registrerar även el som används i förrådet (separat byggnad) där pumpar för vattencirkulationen för båda byggnaderna är belägna.

Livscykelanalysen av Portvaken Söders byggnad visar att den minskade energianvändningen för uppvärmning gör att hushållsansvändning nu står för den procentuellt största andelen av primärenergianvändningen sett på 60 års drift. En lösning skulle kunna vara att installera solceller för att minska denna miljöpåverkan, men då ska analysen också inkludera miljöpåverkan från produktion och drift av solceller. Den

minskade energianvändningen för uppvärmning får vidare effekten att den procentuella andelen av den totala miljöpåverkan från produktion av byggmaterial ökar.

En slutsats från utvärderingen är att analys av energiprestanda under första årets drift bör undvikas. Ytterligare en vintersäsong bör förlöpa för justering av system under en mer normal uthyrningsgrad av lägenheter. Detta blir särskilt viktigt för lågenergihus där energiåtervinning från människor och apparater ingår i energikonceptet. Även avloppsvärmeväxlaren kräver att byggnaden är fullt belagd för att kunna fungera optimalt.

## Summary

Within the project “Framtidens trähus – energieffektiva med god inomhusmiljö” IVL has the aim to document the development and perform an environmental evaluation of the energy-efficient multi-family housing built in timber construction. This was done by participating in the development, construction and follow-up of the Southern Portvakten (“Portvakten Söder”) housing area in Växjö. The two buildings, are owned by the Rental Housing Company in Växjö (“Hyresbostäder i Växjö”). Within the project building A1, which lies on the north-western part of the building site, was analysed. The first report “Framtidens trähus – energieffektiva med god inomhusmiljö. Documentation of project's development, planning, and building phases. Building's energy performance” [1] contains a presentation of the project's development, planning, and building phases. In this report, results are presented from the qualitative and quantitative evaluation of the Southern Portvakten building A1, which was analyzed for measured energy performance, user and operational experiences as well as calculation of the environmental performance through life cycle assessment (LCA) with real operational data. Building B1 was also analyzed for the measured energy performance and user and operational experiences in order to allow comparison of the results to the performance of the building A1. For the evaluation of the energy performance, the following parameters were measured and analyzed: energy use for space heating, hot water use, electricity use (household and common electricity), energy recovered from the waste water heat exchanger, and indoor temperatures in selected apartments. During the analysed period, measured energy use for space heating was more than twice as high ( $22.2 \text{ kWh/m}^2$  for a normal year in Building A1) as the calculated values ( $8.9 \text{ kWh/m}^2$  for a normal year). This can be explained with several factors, including technical system adjustments, low occupancy level, and occupants' behaviour during the analysed period. The bought volume of domestic hot water is almost half the Swedish average in 2009, but is in line with the calculated amount according to the Equation provided in the Swedish voluntary passive house criteria [12]. Still, measured energy use for heating and hot water, adjusted to 100% occupancy level, result in less than one fourth of the energy used in an average Swedish multifamily building (for the period 2005-2009) [27]. Electricity use for common areas, which besides the electricity for lighting of common areas and elevator includes the electricity for fans and pumps, represents a significant energy use post, amounting to almost 20% of the total energy used in Building A1. This was twice the recommended amount in the Swedish voluntary criteria for passive houses. Indoor temperatures during the summer period, which was a concern during the project's development stage, showed good results during the monitored period. The indoor temperature was quite even in the monitored apartments regardless of their orientation and occupancy. The efficiency of the waste water heat exchanger was not fully assessed due to the low occupancy level. The total weighed bought energy in Southern Portvakten was  $61.1 \text{ kWh/m}^2\text{a}$  (Building A1) and  $45 \text{ kWh/m}^2\text{a}$  (Building B1), which was for both buildings lower compared to other low energy apartment buildings in e.g. Värnamo, Frillesås, Lidköping, and the renovated apartments in Brogården in Alingsås. The difference in the measured energy performance between the buildings A1 and B2 can be explained by the way electricity use for common areas of the two buildings is measured. The electricity meter for common areas in building A1 registers also electricity used in the storage area (a separate building) where the water circulation system pumps for both buildings are located.

The Life Cycle Assessment of the Southern Portvakten building shows that due to the decreased need of energy for space heating in low energy buildings, it is the household

electricity use that constitutes the single biggest post for the use of primary energy during the 60 years of operation. Part of the need could be solved by installing solar cells on the building's roof (which is already prepared for such an installation), but then the LCA should also include the environmental impacts from the production and operation of the solar cells. The decreased need of energy for space heating further have the effect that the share of the total environmental impact from the production of materials increases.

Analysis of energy use in the first year of operation should be avoided in demonstration building where new systems have been installed. At least one heating season should be allowed for system adjustments and the analysis should preferably be carried out with full occupancy of the building in order to reach the full effect of different aspects, like free heat from people and appliances, and a real use of different energy categories, as household electricity, common indoor electricity, and domestic hot water (in that case even waste water heat exchanger could be properly evaluated).

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Figure 1.1 Southern Portvakten buildings (Building A1 to the left and Building B1 to the right)

## 1 Introduction

Within the Vinnova research project “Framtidens trähus – energieffektiva med god inomhusmiljö” IVL Swedish Environmental Research Institute (IVL) has the aim to perform an environmental evaluation and document the development and first year in operation of the energy-efficient multi-family buildings built in timber construction. In the first report “Framtidens trähus – energieffektiva med god inomhusmiljö. Documentation of project’s development, planning, and building phases. Building’s energy performance” [1] the project’s development, planning, and building phases are presented. The report presents results from energy simulations, as well as describes building elements and installed technical systems and solutions, for Building A1, located at the north-west part of the building site. The report can be downloaded from the project’s web-page <http://www.framtidenstrahus.se/>

This report summarizes the experiences and measurement results from the first year in operation of the Southern Portvakten Buildings A1 and B1. Energy performance results are compared to the calculated values for Building A1, which was analysed and presented in the first report. Results from an evaluation performed with the project’s team and inhabitants are also presented. The evaluation was performed in the form of two questionnaires that are analysed in connection to the experiences reported during the first year in operation. Environmental performance of the Building A1 and a comparison with two other buildings is also presented in this report.

### 1.1 Framework

The project “Framtidens trähus – energieffektiva med god inomhusmiljö” is financed by Vinnova, The Swedish Governmental Agency for Innovation Systems. The project is comprised of five sub-projects where the Environmental Assessment is one of them, led by IVL. Other sub-projects include 1) System for energy efficiency and good indoor environment, 2) Moisture safety in building and operational stages, 3) Interaction between wood and indoor environment, and 4) Calculation tools. The project is assigned a Scientific

Council and an Industrial Council. The task of the Scientific Council is to ensure that project is carried out in a scientific sound manner while the Industrial Council ensures that the topics addressed are relevant for the industry and the results achieved can be used in practice.

## 1.2 Aim

The aim of the Vinnova research project “Framtidens trähus– energieffektiva med god innemiljö” is to evaluate and document the development of energy efficient multi-family housing built in timber construction. Within the research project IVL has the task to perform an environmental assessment of the Southern Portvakt building, built in Växjö. It is a complex task divided into several stages which are reported in separate reports.

This report presents results and experiences from the operational stage, including measured energy performance results for one year and documentation of experiences during the first 15 months in operation. Experiences include results from the performed questionnaires with the project team members and the inhabitants, and interviews of professionals involved in the maintenance of the technologies applied at the Southern Portvakt buildings. The report, in addition, presents results from the environmental assessment, where the building A1 is compared with two similar buildings; one that is built with the technique used for Limnologen and one with an energy performance according to the building regulations in Sweden.

The report is a complement to the previous report on documentation from the development, planning, and building phases “Framtidens trähus – energieffektiva med god innemiljö. Documentation of project's development, planning, and building phases. Building's energy performance” [1].

Results from both reports are summarized and presented in the final project's report.

## 1.3 Project limitations (boundaries)

Major project limitations are given in the first report “Framtidens trähus – energieffektiva med god innemiljö. Documentation of project's development, planning, and building phases. Building's energy performance” [1].

This report focuses on the analysis of available measured energy use data and experiences given by the project team members and the inhabitants collected in separate questionnaires. The Vinnova research project is not a part of the Southern Portvakt building project so the decisions made in the project could not be significantly affected. As a result not all measuring devices were installed that are necessary for a detailed analysis of the energy performance data. Also, the author of the report did not have a direct possibility to access the measurement data but the data was received from the Rental Housing Company in Växjö on a monthly basis. Some of the measurement units were not digitally connected to the head office and to get hold of the data it was necessary to read them manually. Thus some of the measured values were read rarely or only once during the monitoring period. As a result it was not possible to perform a detailed analysis of all the data.

## 2 Background

The Southern Portvakten Buildings A1 and B1 are two eight-story high apartment buildings built in Växjö following the Swedish voluntary passive house criteria. They are unique buildings in Europe where high buildings have been constructed in prefabricated timber elements with technology that secures high energy efficiency.

The buildings were finished in 2009 and since 1 October 2009 IVL has followed, for 15 months, the first operational period, recording experiences as well as analysing energy measurement data.

More about the project, developments in the field, and carried out similar projects can be found in the first report “Framtidens trähus – energieffektiva med god innemiljö. Documentation of project's development, planning, and building phases. Building's energy performance” [1].

Since the beginning of the project, when the Southern Portvakten buildings were very unique, several similar projects in Europe have been initiated and completed. Timber as a material has been recognized as a good resource with respect to the environmental impacts and CO<sub>2</sub> emissions [2] at the same time as fire protection systems have been developed. Still, in different countries different regulations apply, specifically concerning fire protection. Fire safety is widely considered as one of the most significant obstacles for increasing the use of wood in construction [3]. In some countries, like Germany, building over 5 floors high buildings require a one and a half hour fire resistance which can be achieved only by using hybrid construction combining for instance timber with concrete, and using cladding materials as gypsum and fibre-cement sheeting. In recent popular literature one can find interesting examples of new buildings. To mention, the “Urban housing”, Murray Grove, in London, UK, which is similar in construction as Southern Portvakten having the ground floor in concrete and eight floors in timber [4].

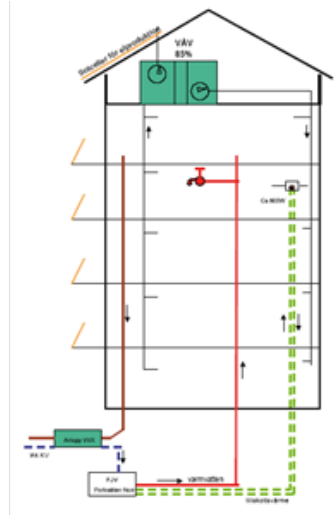


Figure 2.1 Sketch of the planned passive house apartment building Southern Portvakten

Source <http://www.hyresbostaderivaxjo.se/Documents/Hyresbostader/Documents/Princip%20passivhus.pdf>

## 3 Method

### 3.1 Energy performance

For the acquiring and analysing the material presented in this report several methods were used.

The energy measurement data was assembled on a monthly basis by the IT Coordinator at the Rental Housing Company in Växjö. Several meetings were held together with the Energy Agency for Southeast Sweden, Rental Housing Company in Växjö, and IVL to analyse the data. Experiences with the installed equipment that had an effect on the measurement data were noted and commented.

Data that was followed and analysed include electricity use (household and common electricity), energy required for space heating, hot water use, heat recovery of the waste water heat exchanger, and indoor temperatures in selected apartments. Information about the program for energy measurements and which apartments were selected for more detailed analysis can be found in the report *"Framtidens trähus – energieffektiva med god inommiljö. Documentation of project's development, planning, and building phases. Building's energy performance"* [1] (pages 57 and 58).

Measured data for space heating was revised to the normal year, according to degree days, using climate data obtained from Swedish Meteorological and Hydrological Institute (SMHI). The local outdoor temperatures were measured on site and reported by a partner in the project. The normalization was done in order to be able to compare calculated to measured results and analyse the data in connection to the Swedish voluntary criteria for passive houses and other housing projects.

Project's evaluation was done with the professionals that were involved in the project as well as the inhabitants, using questionnaires and interviews.

At the evaluation meeting organized by the Växjö Municipality Company (Växjö Kommunföretag) a questionnaire was distributed to the team members that were involved in the Southern Portvakten project. The goal was to assemble the experiences and opinions about the project. The questionnaire can be found in Appendix 1 (in Swedish).

After one year in operation a questionnaire was sent to the inhabitants. The questionnaire was based on the Engvall/USK Formulär Energi 02 where the permission to use it was received from Eje Sandberg from Aton Teknikkonsult. It was extended with a few relevant questions for a passive house housing project and complemented with a question by the Rental Housing Company in Växjö. The questionnaire was sent to the inhabitants of both buildings at Southern Portvakten. The questionnaire can be found in Appendix 2 (in Swedish).

Both questionnaires were analysed and results are presented in this report.

After more than one year in operation the author of the report visited Southern Portvaktens buildings and talked to the consultant involved in designing the ventilation system. His experiences with the installed system are summarized in the report.

### 3.2 Environmental performance

To assess external environmental consequences a life cycle approach is required. The family of methods used to analyse this scope is referred to as system analytic tools. Life cycle assessment (LCA) is the most used such tool and defined in the international standards EN-ISO 14040 and EN-ISO 14044. LCA is recognised by EC for instance in respect to the Construction Product Regulation (CPR) and its basic work requirement BWR7 'Sustainable Use of natural resources'. Based on the European standardisation mandate M/350 the work in CEN/TC 350 develops a suite of standards for assessment of building products and construction works that also include LCA-methodology.

Environmental Life Cycle Assessment (LCA) is the calculation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle (EN-ISO 14044). Environmental inputs and outputs refer to demand for natural resources and to emissions and solid waste. The life cycle consists of the consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. LCA is sometimes called a "cradle-to-grave" assessment.

An LCA is divided into four phases. In accordance with the current terminology of the EN-ISO standards, the phases are called goal and scope definition, inventory analysis, impact assessment, and interpretation, see Figure 3.1.

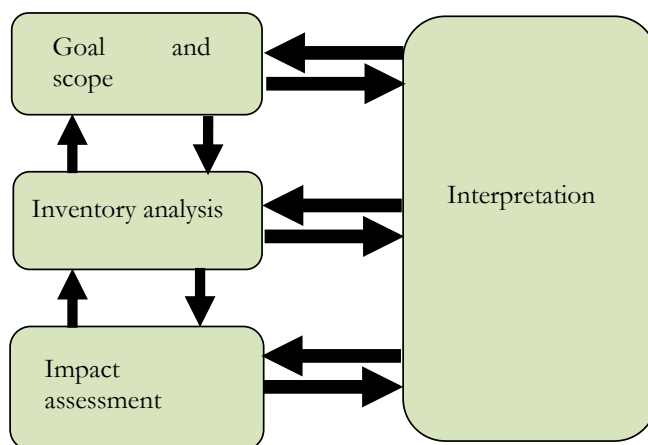


Figure 3.1 Phases of LCA

The environmental performance with the results is presented in section 4.2.

## 4 Results

Energy performance of both Southern Potvakt buildings (A1 and B1) was followed during the first fifteen months in operation. In this report results for the period 1<sup>st</sup> of January to the 31<sup>st</sup> of December 2010 are presented. During the first few months in operation some system problems were experienced and the number of rented apartments was low. Due to the ending of the Vinnova project the last data that could be analysed is from December 2010. For this reason it was decided to analyse the energy performance for the period of one whole year, January - December 2010.

### 4.1 Energy Performance

#### 4.1.1 Occupancy level during the monitored period

The occupancy level of the Southern Portvakt buildings during the analysed period varied. In total there are 64 apartments available for renting in the two buildings, distributed as 32 apartments in each of the buildings. In January 2010 there were 13 apartments leased, whereas in December 2010 23 apartments were rented out in each of the buildings. On average, Building A1 had 17.5 apartments occupied, while Building B1 had 16.8 apartments occupied during the whole year. The occupancy level has a big influence on the peak load and energy use for space heating. In low energy buildings with heat recovery a large relative influence in the heating need has the so called “free” heat from people and utilities. Since all the apartments are connected to the same heating and ventilation system the amount of free heat was lower during the monitored period than if the buildings were fully occupied. In the calculation of the peak load for the building A1 4 W/m<sup>2</sup> of the living space of free heat were included for full occupancy levels, which is permitted according to the voluntary Swedish Passive house criteria [12]. In order to understand better the measured energy results in relation to the occupancy levels and the influence of free heat on building's energy performance an additional analysis was done. Results are presented in Chapter 4.1.9.

One of the main reasons for low occupancy rate might be the level of rent. From 1 January 2010 a two room apartment (one bedroom and living room, 60 – 64m<sup>2</sup>) was in the range of 6500 – 7261 SEK, a three room apartment (78 – 81m<sup>2</sup>) was 8399 – 8830 SEK and four room apartments (94-96m<sup>2</sup>) were rented out for 9800 – 10284 SEK. The price does not include the costs for electricity and water use. These are individually measured and invoiced according to the use [7].

#### 4.1.2 Normalization of the results

Measured energy use for space heating of the building A1, which is affected by the local weather conditions, was revised according to the degree days for a normal year. This is done due to the possibility that the measured year was climatically different than a normal year and the analysed data can give unreliable results for the long term. A normal year is calculated from a 30 year period as an average value. The important factor is degree days, where degree days of the measured year are compared to the degree days of a normal year. A correction factor is then calculated on a monthly basis and used for adjusting the measured energy data.

Degree days only take into account how the outside temperature affects the building's heating needs. They are based on the outside temperatures and are calculated as a difference between the actual outside temperature and +17°C. The differences are summarized into monthly values. During the summer months the degree days are calculated only if the average daily temperatures are under a certain value for following months [8]:

April	12°C
May-July	10°C
August	11°C
September	12°C
October	13°C

The adjustment of the degree days of the measured year is done with a correction factor that indicates how much warmer or colder the measured year has been compared to a normal year. The number of degree days of a measured month is divided by degree days for the same month for a normal year. The resulted deviation from the value of 1 gives an answer how the measured year was compared to a normal year. If the result is above 1 the year was colder and if the result is below 1 the year was warmer for the calculated value. This correction factor is then used to adjust the energy consumption results to a normal year [9].

#### 4.1.3 Calculated space heating demand, normalized results

The energy performance calculations were done in the dynamic simulation program DEROB-LTH and are presented in the report "*Framtidens trähus – energieffektiva med god innemiljö. Documentation of project's development, planning, and building phases. Building's energy performance*" [1]. For the DEROB-LTH simulation program the best available climate file, from the database Meteonorm, was used, for the location of Jönköping airport. The climate file contains normalized detailed data for a 30 year period. The Meteonorm database [10] is provided by the Swiss company Meteotest [11]. In order to be able to compare the simulated energy performance results with the measured values several steps were necessary to be made. A correction factor on a monthly basis was calculated from a comparison between the degree days data for a Meteonorm normal year taken from the climatic file used in DEROB-LTH and SMHIs normal year values for the same location (Jönköping airport). In this way the simulated energy performance results could be adjusted to the SMHIs climate data.

Since the Southern Portvakten buildings are located in Växjö the measured values are connected to the local climate conditions. In order to be able to compare the measured to the calculated energy demand for space heating a correction factor for each month is calculated between Jönköping degree days and Växjö degree days for a normal year.

The calculated space heating demand for Building A1 is 9.5 kWh/m<sup>2</sup>. Heating demand for each month is adjusted using the calculated correction factors, first correcting the Meteonorm climate data to the SMHIs climate data for Jönköping and then adjusting the data to the Växjö location. The normalized and location adjusted calculated space heating demand for Building A1 is 8.9 kWh/m<sup>2</sup>.

#### 4.1.4 Measured energy use for space heating, normalized results

In Building A1 during 2010 energy use for space heating was measured to be 25.7 kWh/m<sup>2</sup>, while in Building B1 the average use was 23.1 kWh/m<sup>2</sup>.

In order to be able to compare to other buildings or draw conclusions about energy use for space heating the measured figures are adjusted to the normal year, according to the correction factor calculated from the degree days data received from SMHI for the year 2010 and a normal year (Table 1).

During the winter months of the analysed period (1 Jan -31 Dec 2010) it was colder than in a normal year while the summer months were warmer. Therefore the measured values for energy used for space heating are adjusted to the normal year climate conditions in Växjö, using monthly correction factors. In the Table 1 the correction factor for which the results are adjusted is presented.

Table 1 Correction factor for adjusting to normal year

	Växjö degree days for 2010	Växjö degree days for a normal year	Correction factor
January	728	589	0.81
February	590	531	0.90
March	519	501	0.97
April	327	354	1.08
May	201	140	0.70
June	0	13	0
July	0	0	0
August	13	6	0.46
September	138	146	1.06
October	354	299	0.84
November	488	442	0.91
December	758	556	0.73
<b>Year</b>	<b>4116</b>	<b>3577</b>	<b>0.87</b>

**Adjusted to the normal year in Växjö the energy use for space heating in Building A1 was 22.2 kWh/m<sup>2</sup>, while in Building B1 it was 20.2 kWh/m<sup>2</sup>.**

Space heating is provided by air, mostly from the energy provided by the exchange of heat from the outgoing air to the incoming fresh air in the heat exchanger. Since not all necessary heat can be provided by the heat exchanger the extra energy needed for space heating is provided by the batteries where the energy carrier is hot water from the district heating system. There are two types of batteries, one is the central battery located after the central heat exchanger (for the incoming fresh air) and the other type are individual batteries (in total 32 in each building) located in the bathroom of every apartment. Individual batteries allow for individual adjustments of the desired indoor temperatures. Depending on the adjustments of the central heating battery one can regulate which battery type gets the biggest heating load. Figures 4.1 and 4.2 show how the heating system was adjusted in the two buildings over the one year period. During the first heating season January – May most of the heating was done by the individual batteries. In April and May



there was practically no heating by the central battery but the heating need was supplied by the individual batteries. In building B1 in December 2010 the system was adjusted to almost equally provide the heating need by the central battery and the individual batteries (Figure 4.2).

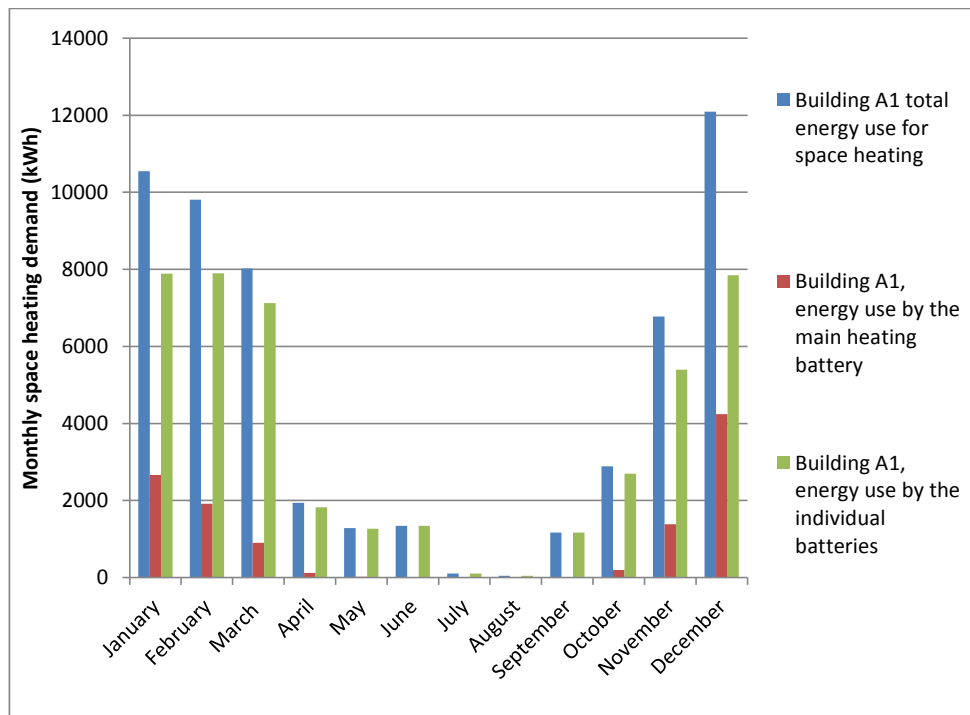


Figure 4.1 Monthly space heating demand in Building A1, normalized values

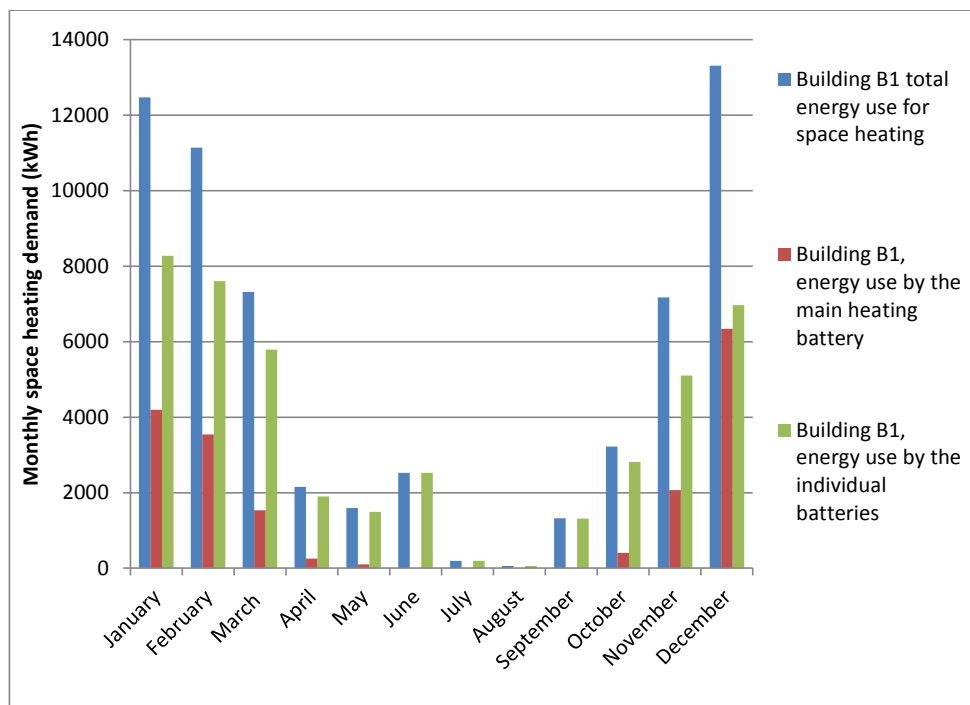


Figure 4.2 Monthly space heating demand in Building B1, normalized values

In Figure 4.3 energy use for space heating during the period 1 January to 31 December 2010, in Buildings A1 and B1, are presented in relation to the average outdoor daily temperatures.

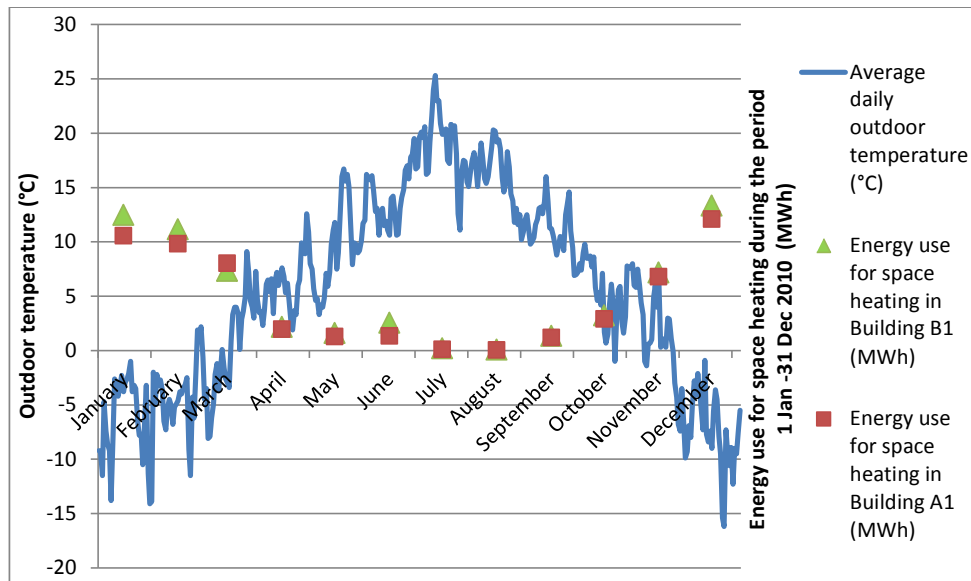


Figure 4.3 Monthly energy use for space heating in Buildings A1 and B1 in relation to average outdoor temperatures in 2010

#### 4.1.5 Household electricity use

The Swedish voluntary criteria for passive houses gives a template for calculation of household electricity for multifamily buildings with energy efficient white goods [12]:

$$\text{Total EI} = 1040 \text{ kWh/}(\text{year, household}) + 300 \text{ kWh/}(\text{year, person}). \quad \text{Equation 4-1}$$

According to the housing company regulations the number of inhabitants per apartment is not registered. The apartments are leased to one person. Therefore it is not possible to know how many people live in the apartments, besides assessing the answers given in the questionnaire to the inhabitants. According to the 19 responses received from the inhabitants (1 per household) there are in total 35 inhabitants living in those apartments (on average that would equal to 1.84 inhabitants per apartment). That means than on average, for the whole building, according to the Equation 4-1, the electricity use should be 1592 kWh/apartment, year or 20.9 kWh/m<sup>2</sup> living area.

In the Building A1 the average household electricity use per m<sup>2</sup> of living area during the period 1 January – 31 December 2010 was 14.7 kWh/m<sup>2</sup>, year while in Building B1 the usage was on average 15.6 kWh/m<sup>2</sup>, year. Since the occupancy level of the two buildings was 55% and 52% respectively, the average household electricity use was adjusted to 100% occupancy rate and equals to 26.7 kWh/m<sup>2</sup>,year for Building A1, and 30.1 kWh/m<sup>2</sup>,year for Building B1.

In total 12 apartments were followed during the analysed period, 6 from each building. Individual electricity use between the apartments was quite different which among other things was due to the fact that some of the apartments were not occupied (rented out)

during the whole period. Some apartments were empty during the whole year 2010 while others were occupied 50-90% of the time. Only one of the analysed apartments had a higher household electricity use than average, which recorded 42 kWh/m<sup>2</sup> year (the apartment was occupied during the whole analysed period), see Figure 4.4. If one would calculate backwards (using Equation 4-1) the number of people that this electricity use would correspond to would result in annual electricity use of more than 7 people. Still, compared to 42.9 kWh/m<sup>2</sup> which was the mean value of the annual household electricity use in the passive house apartment buildings in Frillesås [28], this figure is not very high. An apartment with the highest household electricity use in Frillesås recorded over 70 kWh/m<sup>2</sup>. On the other hand in the passive house renovation project Brogården in Alingsås the mean value of annual use of household electricity was 20.5 kWh/m<sup>2</sup>, but the variation between different apartments was great, being from 6.5 kWh/m<sup>2</sup> to 56.1 kWh/m<sup>2</sup> [28]. A literature study, performed in 2002 on household electricity use [14], identified user behaviour as an important aspect that has an influence on the amount of energy used, but which was rarely included in the previous analysis of energy use. This has however changed in the recent years where user behaviour is seen as an aspect that has great influence on energy use. In the European Directive on the Energy Performance of Buildings [13] installing metering for measuring household electricity use is seen as a measure to reducing the total energy use in buildings. Metering allows people to follow their energy use.

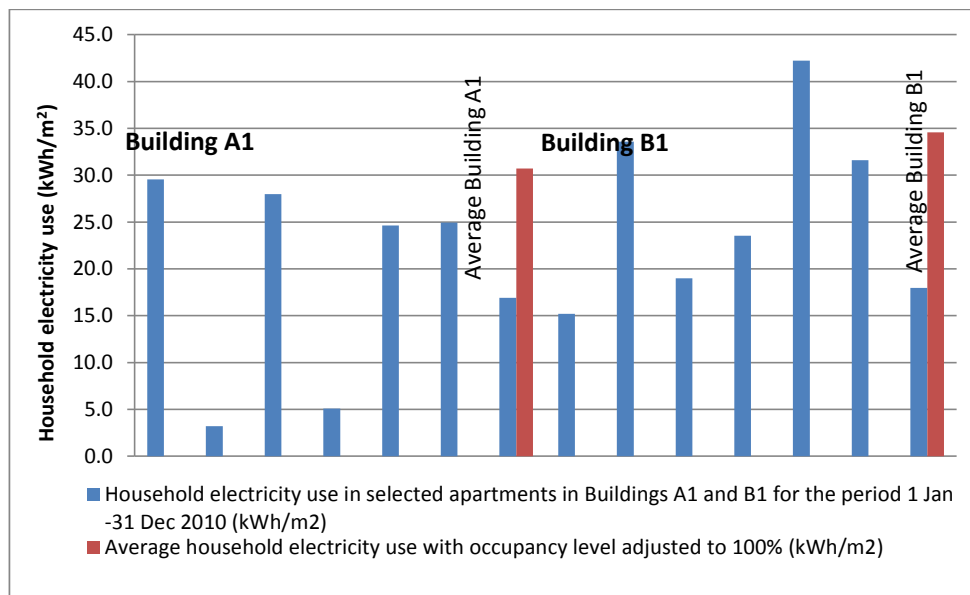


Figure 4.4 Bought household electricity in the 12 monitored apartments of the Buildings A1 and B1.

#### 4.1.6 Domestic hot water use

In the voluntary Swedish passive house criteria for the calculation of the annual domestic hot water use one can use the Equation 4-2:

$$V_{hw} = 18 \text{ m}^3 / \text{person}$$

Equation 4-2

In case payment incentives are used to motivate the inhabitants to use less hot water one can count for 20% less use in practice. This means that inhabitants pay for as much water as they use. In case energy efficient (water saving) faucets are used water use can be reduced by 30%, where in combination with payment incentives a total of 36% less hot water use can be expected [12].

This can be used as a reference for analysing the water use in the Southern Portvakten buildings.

In the Southern Portvakten buildings, water saving faucets have been installed and the inhabitants pay for the amount of water they use. Therefore one could count that the water use could be 36% lower than in conventional buildings.

In order to transfer the amount of DHW used into energy in kWh the Equation 4-3 is used:

$$Q_{dhw} = 1.16 \text{ kWh/}^{\circ}\text{C} * 47^{\circ}\text{C} * X \text{ m}^3_{dhw} \quad [\text{kWh}] \quad \text{Equation 4-3}$$

where:

it takes 1.16 kWh/°C to raise every °C of cold water (assuming that it is on average 10 °C) to the desired domestic hot water temperature (57°C)

$X \text{ m}^3_{dhw}$  is the amount of domestic hot water used by every household

**During the analysed period the total domestic hot water use in Building A1 was 358.5m<sup>3</sup> (19545 kWh) while in Building B1 it was 362.5 m<sup>3</sup> (19764 kWh). Adjusted to the occupancy level of 100% the bought volume of the domestic hot water would be 652 m<sup>3</sup> and 697 m<sup>3</sup> respectively.** If we assume that on average 1.84 people lived in the apartments during the analysed period (as a result from the questionnaire performed) and in Building A1 17.5 apartments were on average rented out, this equals to average annual use of 11.2 m<sup>3</sup>/person (611 kWh) domestic hot water per person. In Building B1 the use would be 11.7 m<sup>3</sup>/person (638 kWh). Since in the buildings the energy efficient faucets are installed and the inhabitants pay for the amount they use a 36% higher consumption could have been expected in conventional buildings (around 17.5m<sup>3</sup>).

For the analysed apartments in Building A1, that were occupied during the studied period, domestic hot water use was from 14 m<sup>3</sup> to 20 m<sup>3</sup> per apartment per year. In the Building B1 only one apartment had higher hot water use; 28.7 m<sup>3</sup> per year. It is a four room apartment and one would expect that a family with a child/children lives there. In case 3 people lived there the calculated use would be 34.6 m<sup>3</sup>/year. For comparison in the Oxtorget apartment buildings the bought volume of domestic hot water varied from 1.5 m<sup>3</sup>/year to 68.1 m<sup>3</sup>/year whereas in the Frillesås apartment buildings the annual use varied from 9 – 71 m<sup>3</sup>/year [28].

#### 4.1.7 Electricity use for common areas and fan electricity

Electricity use for common areas and fan electricity can be only manually read. This was done only once in January 2011. There was no measuring device for the electricity used only by the fans for the central ventilation system so all indoor electricity for common areas (electricity for fans and pumps, elevator, and indoor lights) is read by one measuring device. **In the Building A1 on average it is needed 2105 kWh (13.5 kWh/m<sup>2</sup>) per month while in Building B1 1796 kWh (7.7 kWh/m<sup>2</sup>) is used on average since the moment the building was put into use.** The measuring device for Building A1 registers also electricity use in the storage area (a separate building) where the pumps for the water circulation system are located. Thus one can explain the difference in the use between the two buildings even though Building B1 is bigger in size. Parking and electricity chargers for car heating are recorded by a separate measuring device.

#### 4.1.8 Efficiency of the waste water heat exchanger

A part of the energy from the waste water is recovered using a water heat exchanger that is connected to the waste water pipes going from both buildings. Therefore the amount of reused energy is directly dependent on the occupancy level of both buildings, but also on the age group since households with children tend to use more water than a single elderly person. **The total amount of energy recovered from waste water in the Southern Portvakten buildings was during the analysed period measured 0.62 kWh/m<sup>2</sup>,year which is 2.43% of the amount of domestic hot water used during the year.**

#### 4.1.9 Additional analysis - different occupancy levels and internal heat gains

The EN ISO 13790:2008 standard gives calculation procedures for internal heat gains, which member countries, like Sweden, are bound to implement as a national standard. For residential buildings the standard defines the sum of internal heat gains from people, lighting and devices that for residential buildings corresponds to the criteria of constant values of 4 W/m<sup>2</sup> [30]. In the Swedish voluntary passive house criteria, the same value of 4 W/m<sup>2</sup> is given as a maximum value for internal heat gains that can be used for calculating the peak load of residential buildings. Dokka [31] suggests that the effect of the internal heat gains (in percent) is greater when the space heating load is very low, and thus an important factor to consider when designing low energy buildings. By using the internal heat gain of 4 W/m<sup>2</sup>, as interpreted in the Swedish [12], Norwegian [31], and Finish [30] low energy building design guidelines instead of 2.1 W/m<sup>2</sup>, used as a standard value in the Passive House Design Package of the German Passive House criteria (PHPP)[31][32], one could have an effect of moving the same building from the Oslo climate conditions (as typical Norwegian climate) to Zurich (as typical Central European climate). At the same time, the national levels for internal heat gains for conventional housing buildings were proposed to be 7.9 W/m<sup>2</sup> in Norway [31] and 7.8 W/m<sup>2</sup> in Finland [30].

When calculating peak load and space heating demand for the first passive houses in Sweden, Wall [16] used values for internal heat gains by four occupants (two adults and two children) and appliances as 4.3 W/m<sup>2</sup>, two occupants (adults) and appliances as 3.4 W/m<sup>2</sup> and no occupants, just appliances, as 1.7 W/m<sup>2</sup>. Internal heat gains were studied in more detail under the International Energy Agency (IEA) Solar heating and Cooling Programme Task 28 Sustainable Solar Housing [33].

In the Southern Portvakten building internal heat gains are recognized and used for calculations from several heating sources:

1. People
2. Household electricity (lighting and appliances in the apartments)
3. Common electricity use
4. District heating and domestic hot water circulation system

Internal free heat gains from solar energy were not studied in detail mainly due to the solar control glass used for the windows at the Southern Portvakten buildings. Studies show that the effect of solar radiation has minor influence on peak load compared to the effect of free heat from people [16]. This is especially the case with energy efficient glazing [34]. However solar gains can have a great influence on the space heating demand, depending on the glass used for the windows as well as size and orientation of the windows [34]. Most importantly DEROB calculates separately solar heat gains by using the data in the climate file, location, orientation, geometry and properties of the building as well as shading by the surrounding objects [35].

#### *Internal heat gains from people*

In the voluntary Swedish passive house criteria a template is given for calculating the internal heat gains by people, where one could use the value of 47 W/person as average daily free heat emitted by a person. An average person with moderate activities emits 80 W per day [36]. If one assumes that on average a person spends 14 hours at home, this would result in average daily free heat of 47 W/person. According to the questionnaire performed with the tenants after one year in operation, on average 1.8 people live in each apartment. This figure corresponds to the template for calculation of the number of inhabitants given in the voluntary passive house criteria [12].

DEROB-LTH performs energy simulations using data, defined by the user, for the HVAC schedules for each building volume specified. Parameters influencing the energy performance and indoor air quality of the building can be controlled. These parameters include max power for heating and cooling (W), temperature setpoints for heating and cooling (°C), internal loads (W), inflow and outflow (l/s), open window (%), and openings between internal volumes of the building (%). Therefore for each volume in the building internal heat gains were calculated for several cases:

1. Fully occupied building (with 1.8 person/ apartment)
2. Half occupied building (with 0.9 person/ apartment)
3. Empty building

The summary of internal heat gains can be seen in Table 2.

#### *Internal heat gains from household electricity*

Waste heat from household electricity that could be used in the static energy balance is assumed to be 80% of the bought electricity [12]. Using the template given in the Swedish voluntary passive house criteria [12] annual household electricity demand depends on a constant electricity demand from appliances and lighting and the number of occupants who with their activities influence the electricity use. The electricity use varies during the year and is higher during the winter months. The criteria give a template for calculating the household electricity use for each month. This also has an effect on the available internal free heat. Due to the way internal heat gains are defined in the DEROB-LTH program household electricity and free heat are calculated per apartment and occupancy level (Table

2). When occupancy level is zero, steady household electricity is assumed to be half of the constant electricity demand defined in the voluntary passive house criteria, since a minimum number of appliances are turned on.

#### *Internal gains from common electricity*

The voluntary Swedish passive house criteria propose a max common electricity use, in apartment buildings, of 10 kWh/m<sup>2</sup> a [12]. This includes fixed lighting in common areas and technical rooms, energy used in heating cables, pumps, fans, motors, control and monitoring equipment and the like. Also, externally locally placed devices that supplies the building, such as pumps and fans for free cooling, are included [29].

In the calculations of internal heat gains electricity use for common areas is assumed to be constant since it is difficult to predict how much a more or less frequent use of the elevator affects the internal free gains. Likewise the free heat from the pumps for the water circulation system is not included since they are located outside the building shell. Therefore for the calculation of the free heat from common electricity half of the maximum amount is used, 5 kWh/m<sup>2</sup>. As in the case of household electricity static energy balance is assumed to be 80% of the bought electricity usable for internal heat gains. For the DEROB-LTH program, the heat gain from common electricity is allocated to the staircase volume.

#### *Internal heat gains from district heating and DHW circulation system*

DHW is provided by the district heating system. The hot water circulation system has some losses between the substation and the end user since it runs all the time securing that hot water is available when the faucet is used. Also, while the hot water is running it emits some energy that can be used as free heat. Further waste water also emits some usable heat. Some references refer to 20% of waste heat from DHW that can be used as free heat gain [36]. This could not be confirmed with other sources so the measured losses in the district heating system including the DHW system are being used. Since the substation, where one of the measuring devices is located, is outside the building shell we assume that half of the measured losses have occurred in the building shell and are used as free heat. For the half inhabited building this corresponds to 0.22 W/m<sup>2</sup> and is for the DEROB-LTH program allocated to all volumes proportionally to their size. The increase in free heat from the DHW circulation system does not increase proportionally with the number of inhabitants as the hot water circulation system works at all times. Likewise if the building had no occupants the internal heat gains would decrease for the amount of hot water not used, but the free heat from the DHW circulation system would be constant. A summary of all the internal heat gains are presented in Table 2.



Table 2 Internal heat gains used for energy simulations

		Fully occupied building with 1.8 people per apartment	Half occupied building with 0.9 people per apartment	No apartments are rented out
Internal heat gains from people (per apartment), W		84.6	42.3	0
Internal heat gains from household electricity (per apartment and period of the year), W	Nov-March	164.5	136.4	54.1
	April-May	135.6	112.5	44.6
	June-Aug	108.7	90.1	35.8
	Sept – Oct	132	109.5	43.5
Internal heat gains from common electricity (allocated to the staircase), W		136.4	136.4	136.4
Internal heat gains from district heating and DHW system (allocated to all volumes, apartments and the staircase), W/m <sup>2</sup>		0.3	0.2	0.2
Maximum internal heat load according to the Swedish PH voluntary criteria (allocated to all volumes in relation to their size), W/m <sup>2</sup> living area		4		

Energy simulation results show that internal heat gains have the largest effect on space heating demand, as expected (Figure 4.5). There is a significant difference between the effect of internal heat gains when the building is half occupied and if the building is empty. This is due to the fact that people affect the level of internal heat gains by both personal heat and by using household appliances and electricity which in return emits some free heat.

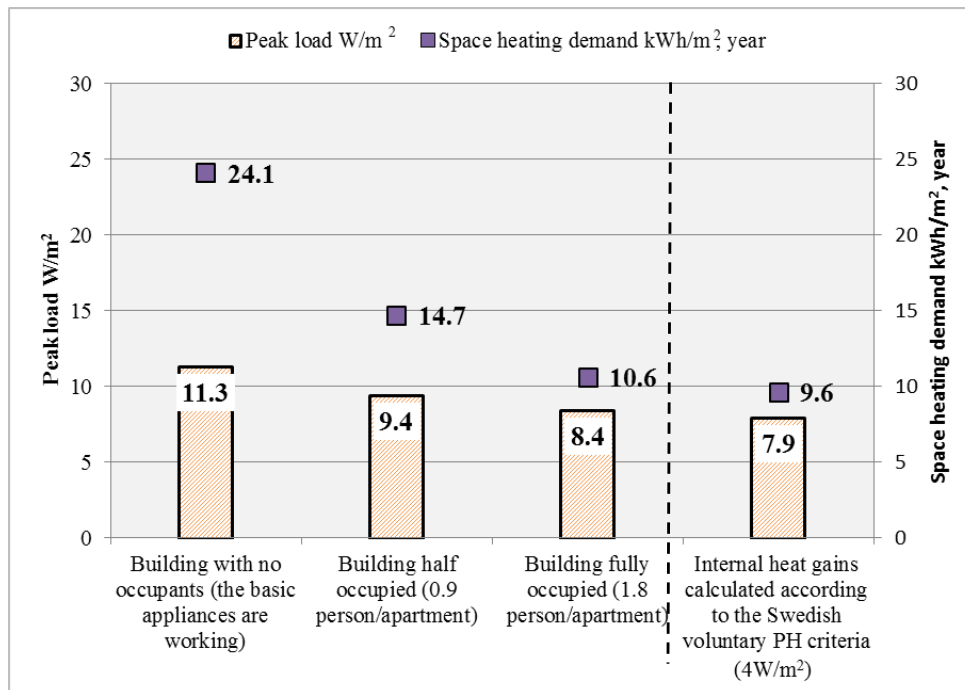


Figure 4.5 The effect of different levels of internal heat gains on peak load and space heating demand

The difference between the maximum value of 4 W/m² living area, which can be used for free heat according to the Swedish voluntary Passive House criteria, and the manually calculated effect of 1.8 people living in each apartment is not high. Still, one should perhaps make a difference in the level of internal heat gains for apartment buildings that have centralized technical systems and common areas with electricity use, and detached houses where applied technical systems are usually within the building shell.

#### 4.1.10 Total energy use

The total energy use in the Southern Portvakten Buildings A1 and B1 is 47.6 kWh/m² and 37.6 kWh/m² respectively, excluding household electricity (Figure 4.6). Energy use for space heating is revised to a normal year. Since the occupancy rate in the two buildings was on average 55% and 52% respectively the domestic hot water and household electricity do not represent a real proportional figure to other values, like energy use for the water circulation system.

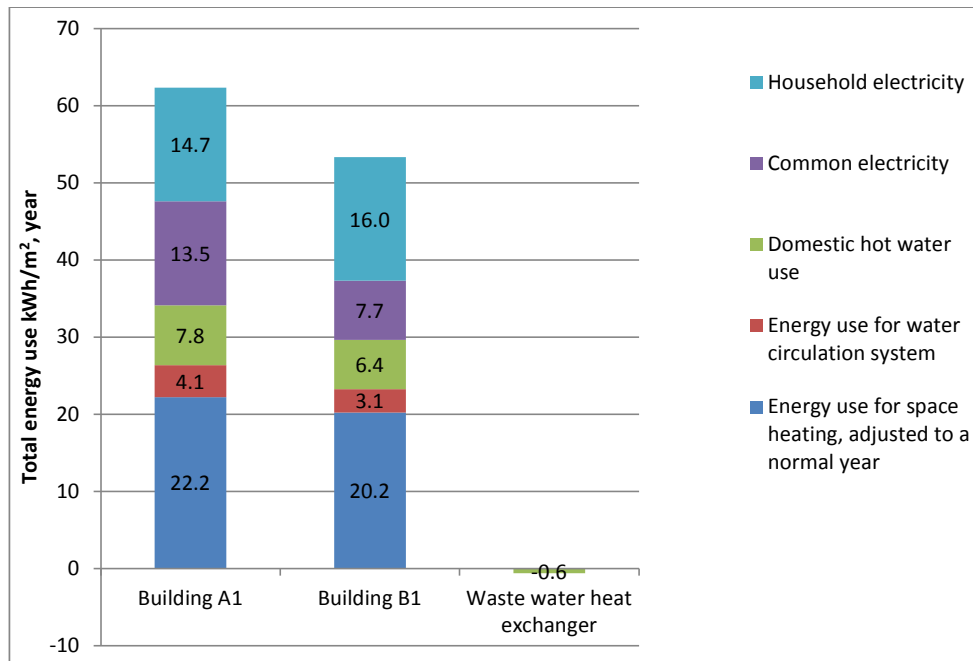


Figure 4.6 Total energy use by buildings A1 and B1, space heating revised to a normal year

Figure 4.7 shows the comparison of the measured energy performance to the calculated energy performance of the half occupied building. Values for DHW use (as described in the section 4.1.6), household electricity use, and common electricity were calculated using templates from the voluntary Passive house criteria. Value for the DHW circulation system energy use is the same as measured.

Calculated values for space heating demand are revised to a normal year. They are significantly lower than the measured values. On the other hand DHW use is very close to the calculated values, while household electricity is lower. On the other hand common electricity use is higher than expected. In Figure 4.7, for the calculated common electricity demand it is the same as if the building was fully occupied, and equals the maximum recommended energy use in the voluntary Swedish passive house criteria.

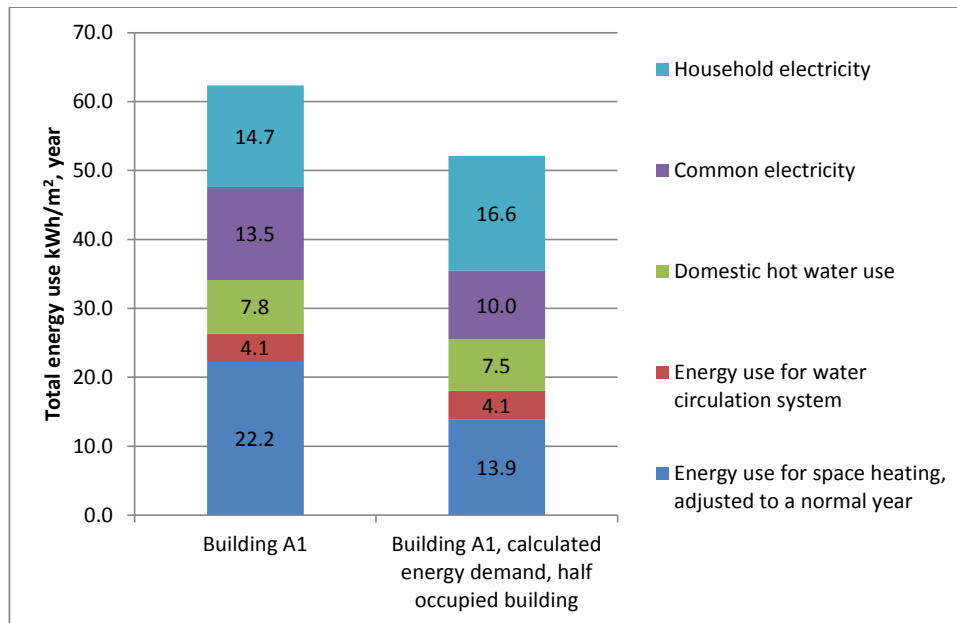


Figure 4.7 Energy performance comparison to the calculated energy performance of a half occupied Building A1

In Figure 4.8, the amount of domestic hot water and household electricity use, and space heating demand is revised to 100% occupancy rate. In a study performed by Maria Wall [16] where she investigated the effect of 2 occupants (2 adults), 4 occupants (2 adults and 2 children), and no occupants on the space heating demand and peak load, the energy simulation results showed a significant effect of the free heat from the occupants on the building's energy demand. Space heating demand was almost 2.5 times higher if the apartment was not occupied than if a family of 4 lived there. She also compared the effect of free heat from people and solar gains. A family with four occupants had more influence on the space heating demand and peak load than solar gains did. The effects of internal free heat on space heating demand is presented in section 4.1.9, where the energy simulations show that a fully occupied building has 27.9% less space heating demand than if the building was half occupied.

In the revision of the measured energy use to 100% occupancy levels energy use for common electricity was not adjusted to the full occupancy level since it is difficult to predict how much electricity would be needed for the elevator with a higher building occupancy rate.

Total energy use revised to the normal year and adjusted to 100% occupancy rate in Building A1 is 47.8 kWh/m² while in building B1 is 37.6 kWh/m², excluding household electricity (Figure 10), which is less than half defined as maximum in the Swedish building regulations for the third climate zone (110 kWh/m²). This is almost the same as the Building A1's measured total energy performance of 47.6 kWh/m², for the half occupied building. The reduction in space heating demand due to higher occupancy level is almost equal in the increase in DHW use.

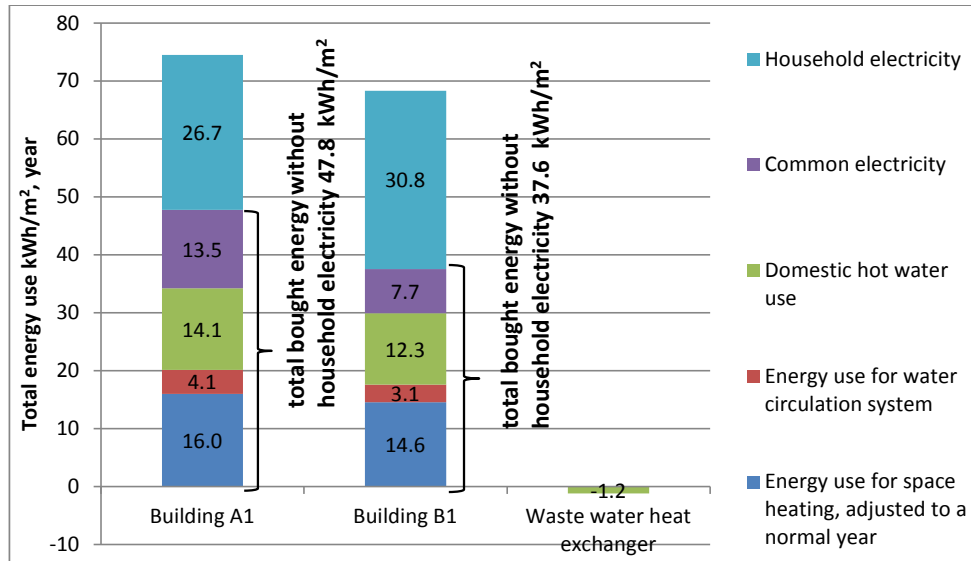


Figure 4.8 Total energy use by buildings A1 and B1, space heating revised to normal year, and occupancy level to 100%, for space heating, DHW, and household electricity

#### 4.1.11 Weighed bought energy

The Swedish voluntary passive house criteria [12] give instruction on calculating weighed total measured/bought annual energy. For the Swedish third climate zone maximum recommended bought energy should be 60 kWh/m²a which comes from the Equation 4-4.

$$Q_{\text{weighted}} = \sum (e_{el} \cdot Q_{el} + e_{dh} \cdot Q_{dh} + e_{bf} \cdot Q_{bf} + e_{s,w} \cdot Q_{s,w}) \leq Q_{\text{requirement}} \quad \text{kWh/m}^2\text{a} \quad \text{Equation 4-4}$$

Where:

- $Q_{\text{weighted}}$  Bought energy, weighed (kWh/m²a)
- $e_{el}$  Energy correction factor for electricity
- $e_{dh}$  Energy correction factor for district heating
- $e_{bf}$  Energy correction factor for bio fuels
- $e_{s,w}$  Energy correction factor for solar systems or wind power plants
- $Q_{el}$  Delivered energy, electricity (kWh/m²a)
- $Q_{dh}$  Delivered energy, district heating (kWh/m²a)
- $Q_{bf}$  Delivered energy, bio fuels (kWh/m²a)
- $Q_{s,w}$  Delivered energy, solar systems and wind power plants (kWh/m²a)

Since at the time the latest voluntary criteria were updated (October 2009) there were no national energy correction factors for all climate zones it was recommended to use those that are developed for the third Swedish Climate Zone by the Swedish Building Regulations [29] where  $e_{el}=2$ ,  $e_{dh}=e_{bf}=1$  and  $e_{s,w}=0$  and limit the bought energy for housing and offices to 60 kWh/m²a.

Applied to the Southern Portvakten buildings the total weighed bought energy would equal to 61.1 kWh/m²a for Building A1 while for Building B1 it would equal to 45 kWh/m²a. Adjusted to 100% occupancy level this would correspond to

**61.2kWh/m<sup>2</sup>a for building A1 and 45.2 kWh/m<sup>2</sup> for Building B1. Household electricity is not included in this calculation.**

The voluntary criteria give also an alternative simplified recommendation for housing, schools, and children day care where for the same climate zone (third) total bought energy should not exceed 50 kWh/m<sup>2</sup>a. This is for buildings that are heated with other means than electricity. Using this method, measured energy use, without household electricity, adjusted to 100% occupancy level, at the Southern Portvakten buildings equal 47.8 kWh/m<sup>2</sup>a for Building A1 and 37.6 kWh/m<sup>2</sup>a for Building B1.

According to the first year's measurement, Building B1 would fulfil the recommendations for total bought weighed energy given in the voluntary Swedish passive house criteria.

#### **4.1.12 Indoor temperatures**

Average indoor temperatures in the 12 apartments, 6 in each building, were analysed for the monitored period. It was interesting to examine the difference in indoor temperatures in apartments due to their orientation (north-east and the south-west), floor (located on different building floors), and changes in the outdoor temperatures as well as exposure to solar radiation. Different apartment orientations have an influence on the amount of solar energy that enters the apartments, and thus provides "free" extra heat. The comparison is relevant both for summer and winter conditions. Apartments on three floors were selected: the bottom floor, the fourth floor, and the eighth floor. Indoor temperatures were collected for both Southern Portvakten buildings. In this way it is possible to try and assess if and how much the shading from the buildings has an influence on the indoor temperatures.

Due to the technical limitations of the measuring devices it was not possible to collect hourly or daily indoor temperatures for the whole analysed period and therefore monthly average temperatures were used. For the summer period (June-August) two apartments were chosen and average daily temperatures were recorded. This was done for the apartments on the top floor of the Building A1, with different orientations, one towards south-west and the other towards north-east.

During the analysed period not all analysed apartments were occupied, so the results cannot be directly compared. For those that were empty we were able to assess the real effect of different periods since there was no free heat from people and equipment that can affect the results.

**During the period 1 January – 31 December 2010, the average monthly indoor temperature in the analysed apartments of the Building A1 varied between 19.3 and 25.9 °C, whereas outdoor temperatures were in the average monthly range of -7.4 to 18.8 °C (Figure 4.9).** Even though apartments are located in different parts of the building, indoor temperatures did not vary significantly from each other. This is, of course, influenced by the central ventilation system.

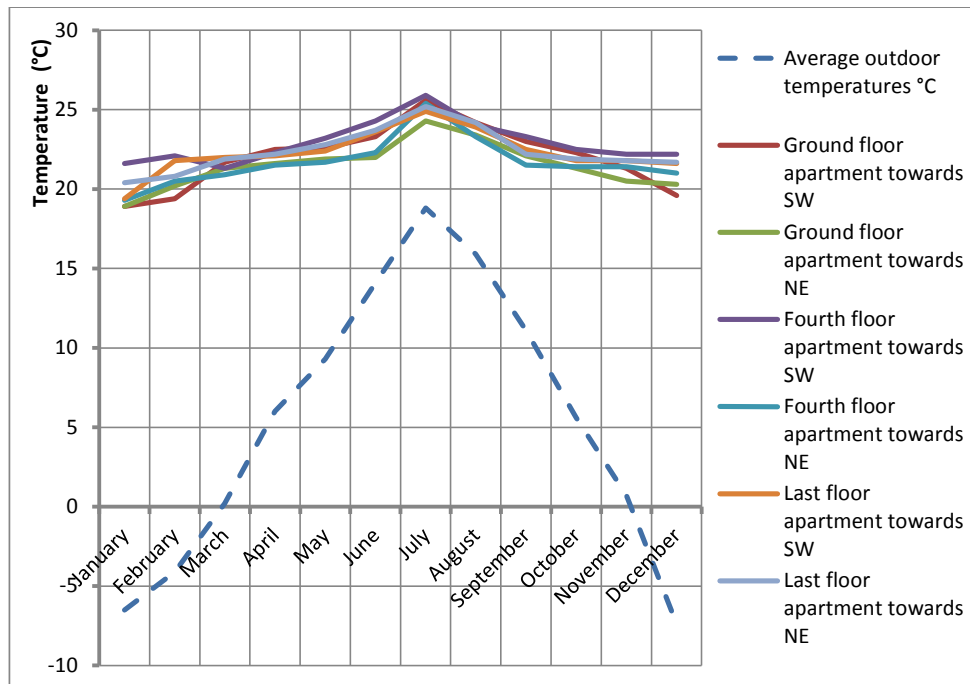


Figure 4.9 Building A1 average monthly indoor temperatures in selected apartments in relation to the average outdoor temperatures

In July when the highest outdoor temperatures were recorded, the highest average indoor temperature in Building A1 was measured in the apartment at the fourth floor towards south-west, 25.9°C. According to other parameters (electricity and water use) the apartment was only partly used during that month. The consumption for all three parameters (household electricity, domestic hot water, and cold water) was around half the consumption during June or August. For this reason one might also conclude that the high average indoor temperature is a result of not manually airing the apartment during the warm periods. The recorded measurement, however, does not show the highest achieved indoor temperature and for how long the high indoor temperature lasted.

In the north-eastern apartment, at the same floor, the average recorded temperature was 25.4°C. This apartment was, however, not inhabited during the whole first year which means that it was not manually aired, and there was no “free” heat from the people and equipment. The lowest average indoor temperature in this apartment was recorded 19.3 °C in January 2010.

The apartment at the top floor towards south-west was most probably occupied during the whole month of July (since the electricity and water use were steady) and has highest recorded average daily indoor temperature; 27.4 °C in July 2010. This temperature was recorded only for one day whereas the day before and the day after it was 26.5 °C. Outdoor temperature was also the highest daily average for the whole period, 25.3 °C. Average monthly indoor temperature was 24.9 °C. Interestingly, the apartment towards north-east

at the same floor had the same highest recorded temperature of 27.4 °C, which stayed for 3 days in a row. Electricity and water use was also recorded for those three days which means that the apartment was used. The same apartment had the highest use of cold water registered during July, which was almost 30% higher than the month before or after. Figure 4.10 shows that indoor temperatures during the summer are to a large extent not affected by the fluctuations of the outdoor temperatures. Lowest average indoor temperature during the analysed period was 22 °C while outdoor it was 10°C. It is not surprising that passive houses or low energy houses are sometimes referred to as thermoses, since they keep the indoor temperature quite stable for fluctuations of outdoor conditions.

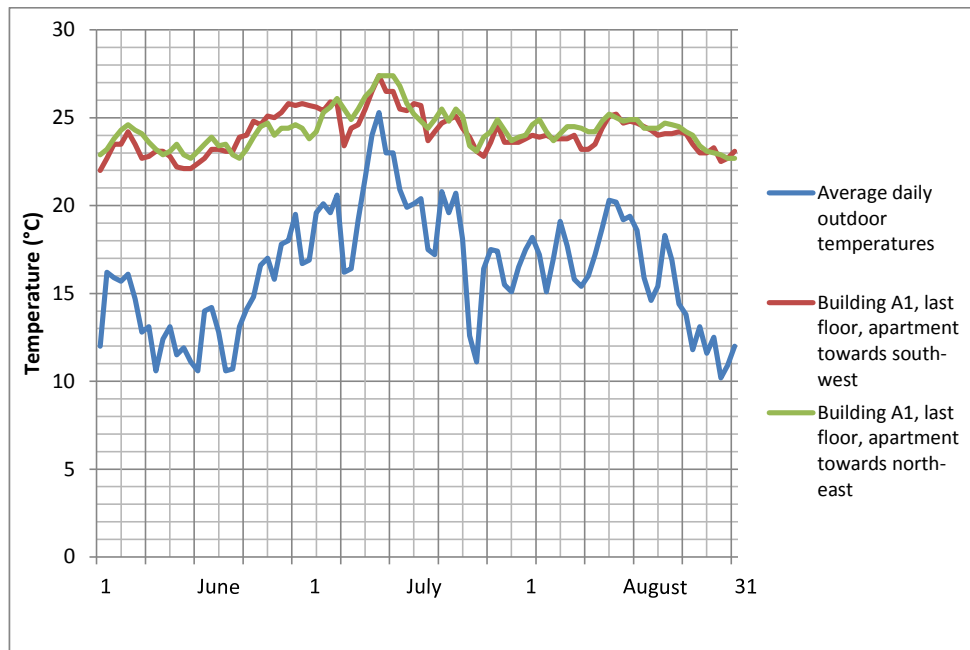


Figure 4.10 Measured average daily indoor temperatures at the top floor in relation to the outdoor temperatures.

On average apartments in Building A1 towards south-west are for 0.5 °C warmer than apartments towards north-east. Two of the analysed apartments that are oriented towards north-east were not occupied during the whole studied period.

In the Building B1 apartments towards north-west had in general recorded slightly higher indoor temperatures than apartments towards south-east, even though the first are shadowed by Building A1 and are not exposed towards the western or southern sun. During the studied period all apartments were occupied, except one towards south-east that was empty almost half of the time, and one towards north-west that was not inhabited during the first three months.



## 4.2 Environmental Performance

Southern Portvakten Building A1 was compared to if the building was built using the technique used for Limnologen, with the same construction principle (prefabricated timber elements), but with worse thermal properties of the building envelope, and different technical systems for heating and ventilation. The Building A1 was also compared to if it was constructed as Limnologen but with the energy performance which corresponds to the national requirements for energy performance of buildings that are not heated with direct electricity, 110 kWh/m<sup>2</sup>.

### 4.2.1 Goal and scope of the LCA

In the first phase the purpose of the study is described. This description includes the intended application and audience, and the reasons for carrying out the study. Furthermore, the scope of the study is described. This includes a description of the limitations of the study, the functions of the systems investigated, the functional unit, the systems investigated, the system boundaries, the allocation approaches, the data requirements and data quality requirements, the key assumptions, the impact assessment method, the interpretation method, and the type of reporting.

### 4.2.2 Inventory analysis

In the inventory analysis, data are collected and interpreted, calculations are made and the inventory results are calculated and presented. Mass flows and environmental inputs and outputs are calculated and presented.

### 4.2.3 Life cycle impact assessment

In the life cycle impact assessment (LCIA), the production system is examined from an environmental perspective using category indicators. The LCIA also provides information for the interpretation phase.

The LCIA phase shall include the following mandatory elements:

- selection of impact categories, category indicators and characterization models
- assignment of LCI results to the selected impact categories (classification)
- calculation of category indicator results (characterization)

The following elements are optional:

- calculating the magnitude of category indicator results relative to a reference value (normalisation)
- grouping
- weighting
- data quality analysis

In the terminology of EN-ISO 14044, the reason to why an environmental impact is considered to be a problem is the category endpoint. The category indicator is the

quantified representation of the environmental impact. The characterisation factor,  $W_{ij}$ , describes the potential contribution to the impact category  $i$  from the input or output of substance  $j$  per unit mass of  $j$ . The total contribution to the impact category from the life cycle,  $C_i$ , is calculated as in the Equation 4-5:

$$C_i = \sum E_j \cdot W_{ij} \quad \text{Equation 4-5}$$

where

$E_j$  is the amount of the output  $j$  and  
 $W_{ij}$  is the characterisation factor for this output.

The LCA method is suitable for studying global and certain regional environmental impacts.

In recent development of the impact assessment part of an LCA a site dependent approach is applied, or sometimes even a site specific assessment that will increase the environmental relevance of the LCA result. Current development and state of the art concerning impact assessment in LCA is outlined in Finnveden et al.[17]

#### 4.2.4 Functional unit

The functional unit of an LCA defines the quantification of the function of the products. The functional unit chosen for the environmental assessment is 1 m<sup>2</sup> internal area (BRA-area within the external walls of the building which includes the partition walls, staircases, and corridors).

#### 4.2.5 Type of LCA

We distinguish between two types of methods for LCA: attributional and consequential LCA. In this study attributional LCA methodology is used, which is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. The calculation of emissions from electricity production, for example, differs between the two types of LCA: an attributional LCA includes data on the average electricity production in the area where the electricity is used; a consequential LCA typically includes data on the electricity production actually affected by a change in the electricity use. The choice between these two types of LCA is discussed in detail by Ekvall et al.[18].

#### 4.2.6 System boundaries

##### Geographical boundaries

The purpose of the study is to analyse the Southern Portvakten building in Växjö, Sweden. As mentioned in section 1.2 above, this building is compared with two similar buildings; one that is built with the technique used for Limnologen, also situated in Växjö, and one with an energy performance according to the building regulations in Sweden. Production of raw materials may however take place elsewhere, which has been taken into account by expanding the geographical boundary to include the production of raw materials where the production actually occurs.

What electricity production is associated with the electricity use? In an accounting LCA, the electricity is typically regarded as being produced in a system with a mix of technologies for electricity production. The emissions from the production of 1 kWh of electricity are then defined as the average emissions from this mix.

To calculate the average emissions, we need to define the geographical or organisational boundaries of the system where the electricity is produced. There is no objective way of defining these boundaries; the electricity system is that which is perceived to be the electricity system. Here, we have chosen to use Nordic average data for the production of the electricity used by the buildings, see further discussion in section 4.2.7 below. The emissions of greenhouse gases, measured as carbon dioxide equivalents, used for the Nordic electricity production mix is 97.3 grams per kWh [6].

### **Boundaries in time**

The time limit used for the environmental assessment is 60 years. This means that apart from the construction phase, operation and maintenance for the 60 first years of the building's life time is included. However, the deconstruction phase is not included.

How the production of electricity will develop within the coming 60 years is difficult to predict. Any estimate regarding the future electricity production mix as well as the production technologies would be impaired by large uncertainties and for this reason we have chosen not to make any estimation about the future electricity production. Instead, we have chosen to use data on today's electricity production (see above) for the whole period.

### **Boundaries within the life cycle**

Boundaries within the life cycle describe *where* in the life cycle the environmental impact is accounted for as inputs or outputs and *how* aggregated the data presented are.

The environmental impact is accounted for in the process where they are generated.

For practical reasons, some extracting processes have been summarised with other production processes downstream into aggregated "cradle-to-gate" data sets, presented as one process. This is often due to the way data are presented in the literature source. This is the case for the data on production of raw materials and components taken from the Ecoinvent database that has been used.

### **Production of electricity and fuels**

Electricity production and the conversion of energy resources into fuels are included in the life cycle system. This means that emissions and natural resource demand from electricity and fuel production are included, see Figure 4.11.

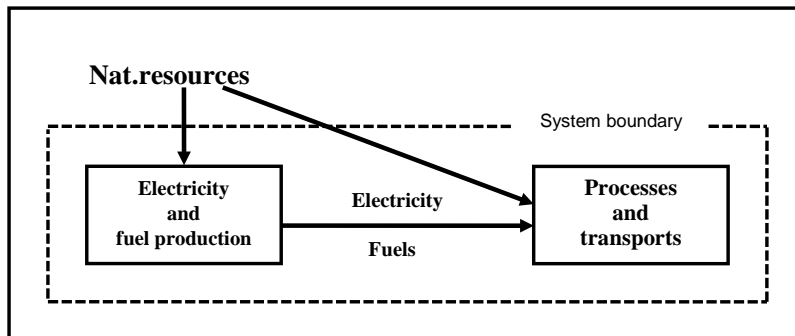


Figure 4.11 Illustration of system boundary regarding electricity production.

Here, the *inflows* to the system are, instead of electricity, the energy resources including crude oil, coal, hydropower, uranium etc., used for the electricity production.

Electricity demand is thus defined as an *internal parameter* of the system. It is the same for fuels; the fuel used by a process is accounted for as an internal parameter. Thus, the internal parameters are all energy carriers, while the inflows to the system are natural resources such as crude oil, hard coal, natural gas, etc.

#### Boundaries towards nature

The cradle of the life cycle is nature. The boundary between nature and the product life cycle is crossed when the materials (*e.g.* crude oil) are extracted from the ground.

The grave of the life cycle is the soil (after human activity has ceased, and landfill gas emissions and leakage production are minimal), the air (*e.g.* emissions from combustion of fuels) or water (*e.g.* water emissions from wastewater treatment). In this project however, the buildings have not been followed to the grave, see discussion above under section “Boundaries in time”.

Neither is the management of waste that arises during construction included. This has been excluded since this amount of waste is small compared to the amount of waste that arises during deconstruction of the building.

### 4.2.7 Key assumptions

#### Electricity production

There is a large difference between the environmental impacts of different electricity production technologies. The choice of electricity scenario therefore requires careful consideration.

In an accounting LCA, the electricity is typically regarded as being produced in a system with a mix of technologies for electricity production. The emissions from the production of 1 kWh of electricity are then defined as the average emissions from this mix.

To calculate the average emissions, we need to define the geographical or organisational boundaries of the system where the electricity is produced. There is no objective way of

defining these boundaries; the electricity system is that which is perceived to be the electricity system. Here we use regional boundaries, because this is a very well established way of perceiving geographical boundaries. This means that the electricity production is assumed to be the mix in the region where the electricity is used.

The electricity production for the data on most of the raw materials is however already included in the data sets from the Ecoinvent database used for the project (see Chapter 4.2.8).

### **District heating**

The net for district heating is not common for the whole region in the same way as the electricity net. Instead the district heating is local and the fuels used for the production of district heating vary between the different producers. In order not to make this study too dependent on the location of the studied buildings, the data used for the production of the district heat supplied to the buildings are Swedish average data.

## **4.2.8 Data sources**

### **Production of building materials**

For most of the different building materials, data from the Ecoinvent database in the GaBi professional database have been used. These data already include electricity production. For more information about the electricity production mix that has been used for each of the materials, we refer to the GaBi software metadata [20].

### **Energy data**

As stated in Chapter 4.2.7 above, the data used for the production of the electricity used by the buildings are Nordic average data. These data are based on Gode et al, 2011 [6]. Also the data used for the production of district heating are based on Gode et al and corresponds to Swedish average data for district heating.

### **Transport data**

The transport distances that have been used are based on estimates. For the fuel consumption and the emissions associated with the transports, data from the Gabi professional database has been used.

## **4.2.9 Inventory analysis**

### **Use of primary energy**

The total use of primary energy has been calculated in the Gabi professional software. The imbedded energy can be recovered through incineration of the energy-containing material when the building is de-constructed. However, the waste management is not included in this project. For this reason, the imbedded energy in the buildings has been calculated manually based on the information received through the inventory data sheets in order to separate this amount of energy from the total amount of primary energy used.

The result for the use of primary energy is presented in section 4.2.11.

#### **4.2.10 Impact assessment**

The impact category included in this study is global climate change, measured in kg CO<sub>2</sub>-equivalents. The methodology used for global climate change as well as the characterisation results is described below.

##### **Global climate change**

The global climate change is a problem for many reasons. One is that a higher average temperature in the seawater results in flooding of low-lying, often densely populated coastal areas. This effect is aggravated if part of the glacial ice cap in the Antarctic melts. Global climate change is likely to result in changes in the weather pattern on a regional scale. Such changes can have severe effects on natural ecosystems as well as the food production.

Global climate change is caused by increases in the atmospheric concentration of chemical substances that absorb infrared radiation. These substances reduce the energy flow from Earth in a way that is similar to the radiative functions of a glass greenhouse.

The IPCC is the leading body for the assessment of climate change, established by the United Nations Environmental Program (UNEP) and the World Meteorological Organisation (WMO) in 1988 to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation.

According to the fourth assessment report by the Intergovernmental Panel on Climate Change, the warming of the climate system is unequivocal [21]. This is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. It is very likely that the observed increased average global temperature is due to human activities. Most certainly, the majority of the observed increase of the global temperature is due to anthropogenic greenhouse gas emissions (GHG). The global GHG emissions, due to human activities, have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Carbon dioxide (CO<sub>2</sub>) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004. The rate of growth of CO<sub>2</sub>-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 Gt CO<sub>2</sub>-eq per year) than during the previous period of 1970-1994 (0.43 Gt CO<sub>2</sub>-eq per year).

In the impact category "Global climate change", the category indicator is the degree to which the substances emitted from the system investigated contribute to the increased radiative forcing. The characterisation factor stands for the extent to which an emitted mass unit of a given substance can absorb infrared radiation compared to a mass unit of CO<sub>2</sub>. As the degree of persistence of these substances is different, their global climate change potential (GWP) will depend on the time horizon considered. Thus there exist

values for 20, 100 and 500 years. In this study the time horizon 100 years has been chosen. The time scale of 100 years is often chosen as a "surveyable" time period in LCA.

The total contribution to the global climate change potential from the life cycle is calculated as:

$$GWP = \sum GWP_j * E_j \quad \text{Equation 4-6}$$

where

$E_j$  is the amount of the output  $j$  and  
 $GWP_j$  is the characterisation factor for this output.

The characterisation factor is measured in *kg CO<sub>2</sub>-equivalents per kg of the emitted substance*, and thus, the unit of the category indicator is *kg CO<sub>2</sub>-equivalents*.

The characterisation factors used for global warming are taken from the International Panel of Climate Change report [21].

#### 4.2.11 Use of primary energy, results

The use of primary energy is presented in Figure 4.12 - 4.15 below. The difference between the Southern Portvakt building and a corresponding building built with the technique used for Limnologen is mainly due to the use of energy used for heating. As it can be seen from the Figures below, the difference between the Southern Portvakt building and a corresponding building built with the technique used for Limnologen is quite small. This is primarily due to the fact that the calculated energy performance for the building built with the technique used for Limnologen is only 12.5 kWh/m<sup>2</sup>, year higher than the corresponding for the Portvakt building. When comparing the Southern Portvakt building with a conventional building with an energy performance of 110 kWh/m<sup>2</sup>, year, which is the energy requirement for buildings that are not electrically heated in Sweden [22], the difference is much more obvious. However, the results show that the focus for primary energy use changes when building low energy buildings; from space heating demand to household electricity use and material as well as building component production. Of the total amount of primary energy used for construction and operation, the share used for the operation phase decreases from 80% for the conventional building to 75% for the Portvakt building due to the decreased amount of energy used for space heating, see Figure 4.14 below.

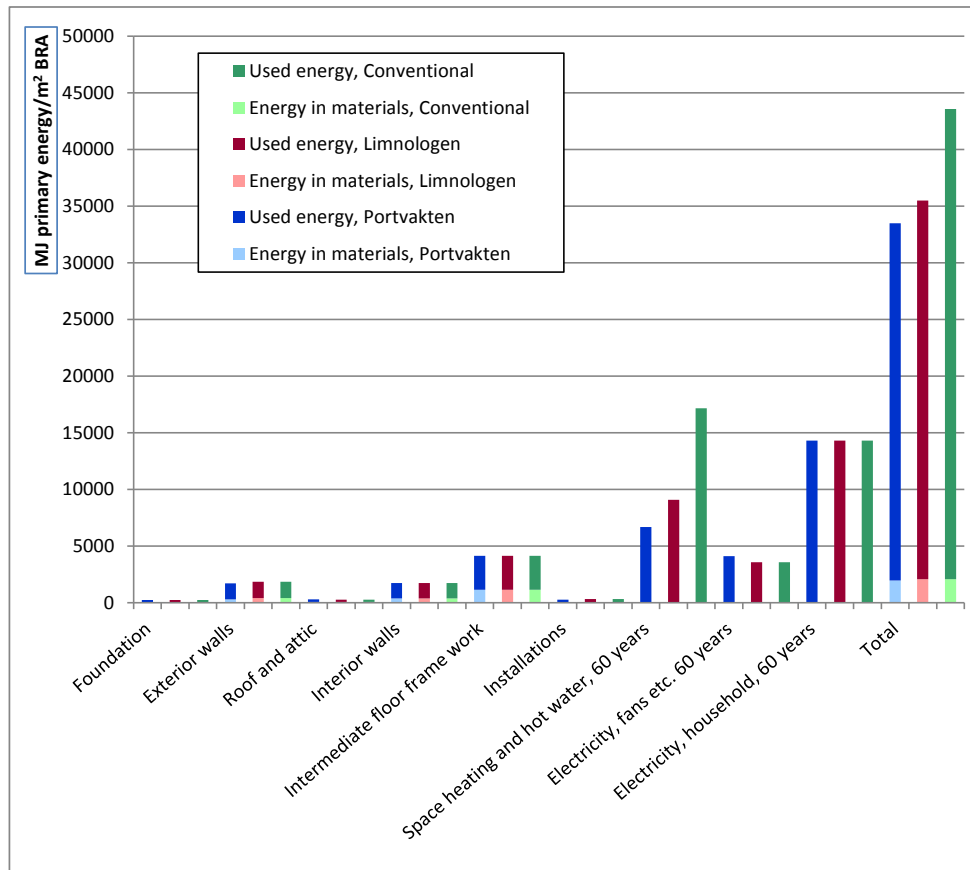


Figure 4.12 Use of primary energy, including 60 years of operation [MJ/m² BRA]



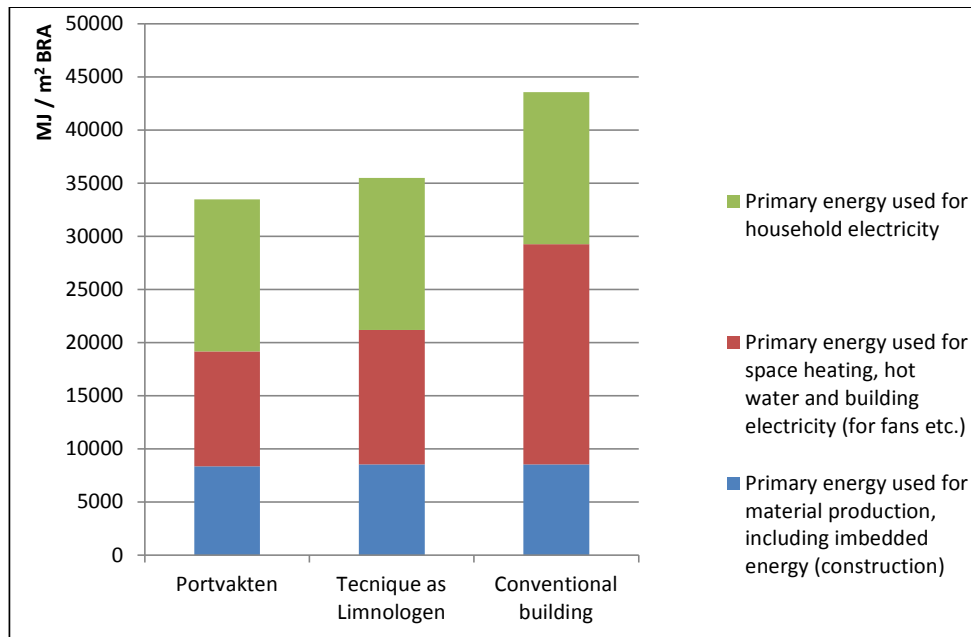


Figure 4.13 Use of primary energy for construction and 60 years of operation [MJ/m² BRA]

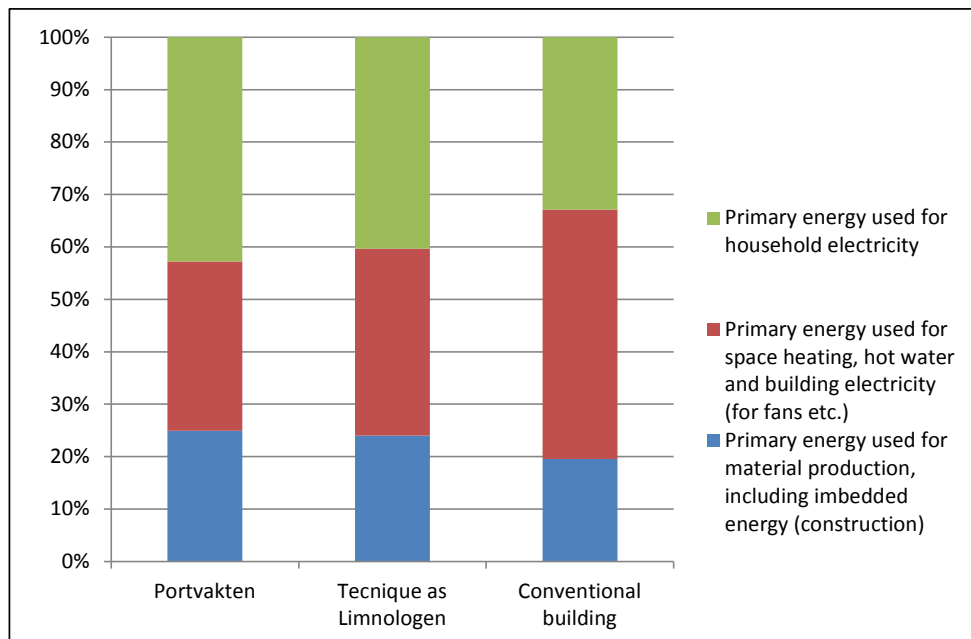


Figure 4.14 Share of the primary energy use arising from material production, space heating, hot water and building electricity and household electricity.

In Figure 4.15 below, the accumulated use of primary energy is presented for the 60 years of operation. It is clear that the difference increases for each year, especially the difference between the Southern Portvakten building and a corresponding conventional building.

After 30 years of operation, the use of primary energy for the conventional building (110 kWh/m<sup>2</sup>, year) is 25% higher than for the Southern Portvakten building and after 60 years of operation it is 30% higher.

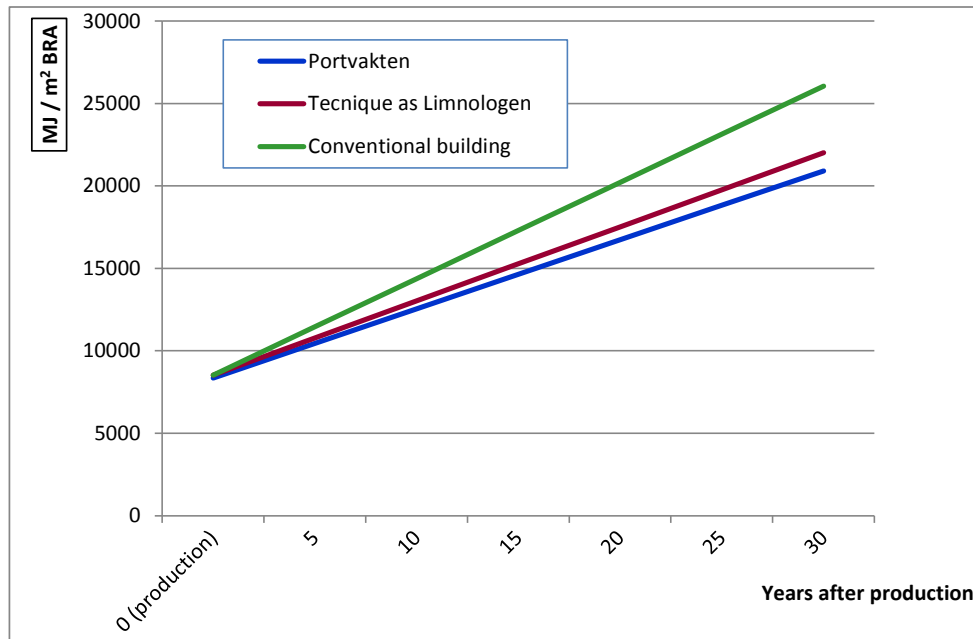


Figure 4.15 Use of primary energy, accumulated over 60 years of operation

#### 4.2.12 Global climate change

The potential contribution to global climate change is presented below (Figure 4.16 – 4.19). As it can be seen, the largest difference between the Southern Portvakten building and a corresponding building built with the technique used for Limnologen is mainly due to the use of energy for heating and hot water. When comparing with a conventional building (110 kWh/m<sup>2</sup>, year), the difference is more obvious. With a minor increase in the environmental impact from the building materials and the building production of a low energy building, a significant reduction in the environmental impact can be achieved from lowering the space heating demand. Still, it is the use of energy during the 60 years of operation that has the greatest potential impact on global climate change. This of course depends on the energy sources, and would in other countries, where the energy mix is based more on fossil fuel, have a greater impact.

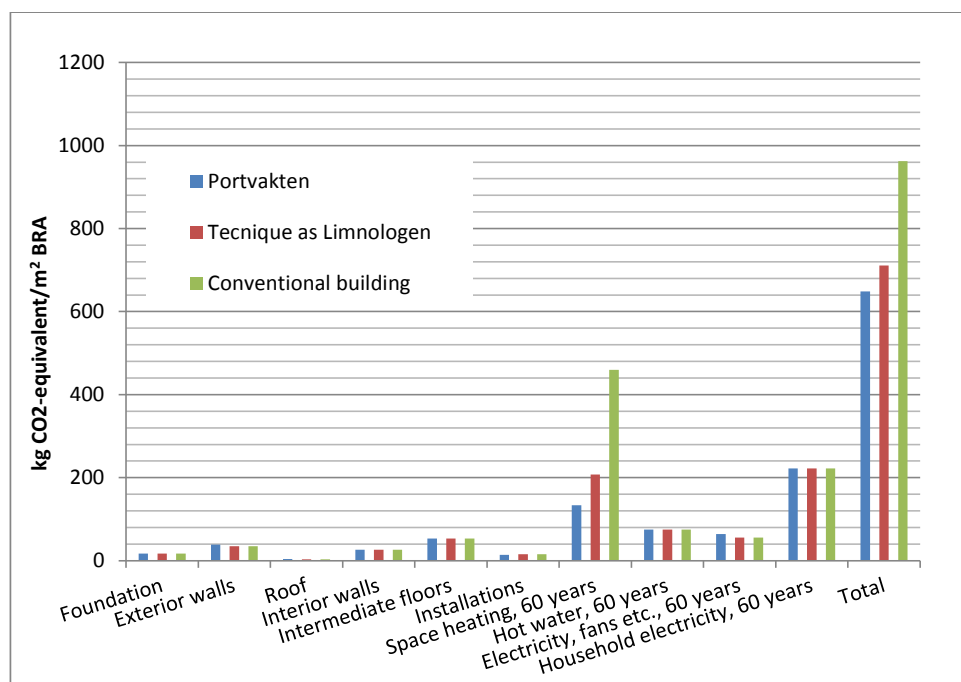


Figure 4.16 Potential contribution to global climate change, including 60 years of operation [kg CO<sub>2</sub>-eq / m<sup>2</sup> BRA]

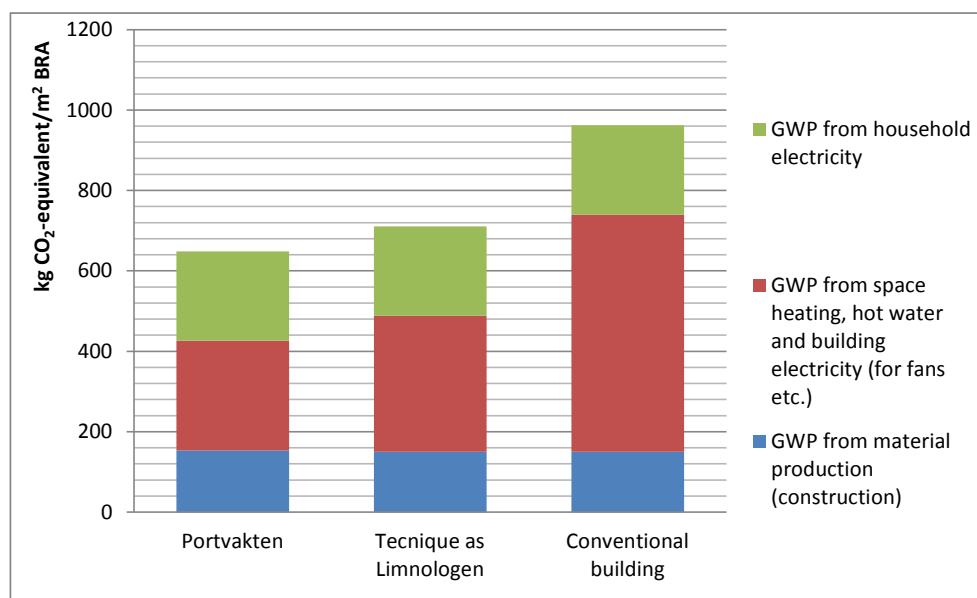


Figure 4.17 Potential contribution to global climate change for construction and 60 years of operation [kg CO<sub>2</sub>-eq / m<sup>2</sup> BRA]

In the same way as for the use of primary energy, the focus for the potential contribution to global climate change changes when building low energy buildings; from space heating demand to household electricity use and material as well as building component production. Of the total potential contribution to global climate change for construction and operation, the share used for the operation phase decreases from 84% for the conventional building to 76% for the Portvaktén building due to the decreased amount of energy used for space heating, see Figure 4.18 below.

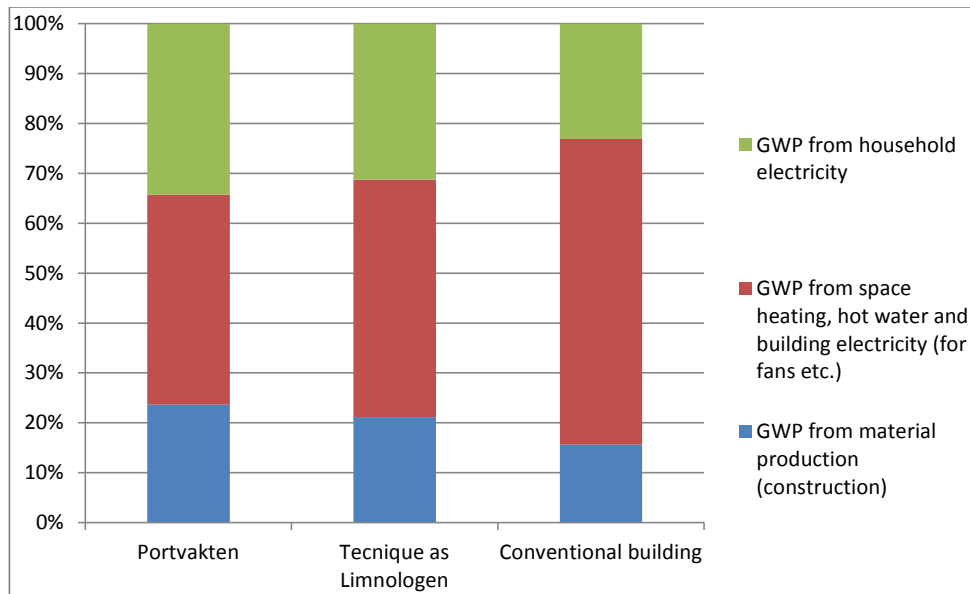


Figure 4.18 Share of potential contribution to global climate change arising from material production, space heating, hot water and building electricity and household electricity.

After 30 years of operation, the potential contribution to global warming is 39% higher for the conventional building than for the Southern Portvaktén building (Figure 4.19) and after 60 years of operation, it is as much as 48% higher for the conventional building.

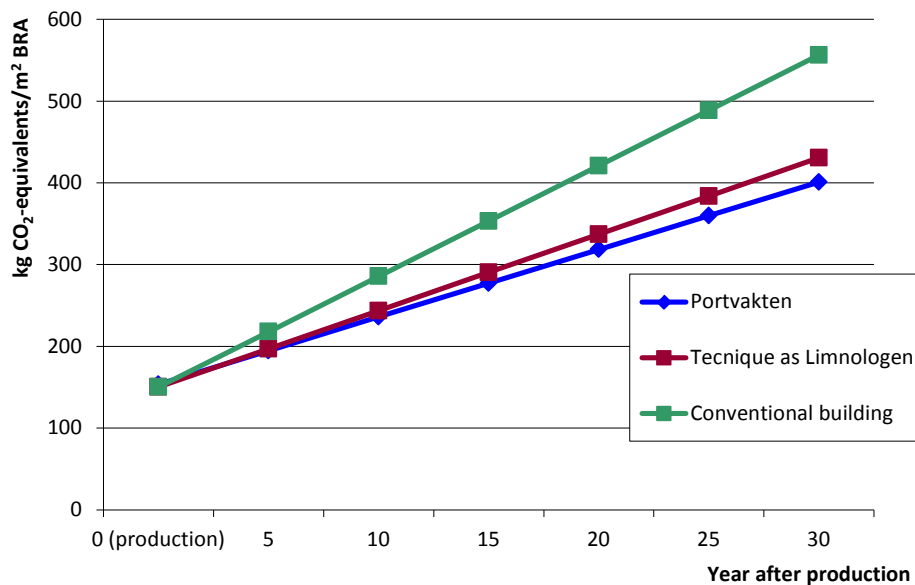


Figure 4.19 Potential contribution to global climate change, accumulated over the first 30 years of operation

## 4.3 Qualitative project evaluation

In order to be able to get a comprehensive picture of the quality of the indoor environment and experiences with the installed systems, a qualitative study was performed. Two questionnaires were carried out, one with the project group and the other with the inhabitants. In addition, during the first year in operation, experiences with the functioning of the systems were noted during meetings with the Rental Housing Company in Växjö and the Energy Agency for Southeast Sweden, as well as by interviewing specific consultants. In this chapter results from the questionnaires and the experiences are presented while the discussion in connection to the measured data is given in the Chapter 5 below.

### 4.3.1 Project team

In august 2010, after almost a year in operation of the two Southern Portvaktén buildings, a meeting was organized to evaluate the experiences from building high rise buildings in timber construction. In total 15 companies were invited. During the last few years three building areas in Växjö were built in timber construction that were under the scope of the evaluation; Limnologen, Building M (Hus M), and Southern Portvaktén. At the meeting, experiences were presented and a dialogue took place. In the end a questionnaire was given to the participants that were involved in the Southern Portvaktén building process to fill in. Seven participants answered the questionnaire. They had fairly or very much influence in the decision making processes during the project. Results from the questionnaire are presented below where the share of the answers is given as number of answers/total number of people that answered the question:

- Most of the seven participants (4/7) that answered the questionnaire are fairly satisfied with the project results whereas 3 are very satisfied. Still, there are several things that they would like to have done different:
  - Expose more timber architecturally in the building
  - Have closer cooperation between different building installation professionals during the building's planning stage
  - Plan better the operational (use) stage
  - Have a greater influence in development of the heating system towards having 100% water as the carrier for the heating, instead of air as it is today
- The involvement in the project has to a large extent improved the understanding and opinion about passive houses of the project participants (5/7).
- Forms of cooperation, mounting of the construction with weather protection, airtightness, engagement of everyone involved were the things that were identified as particularly good experiences in the project.
- The cooperation among participants in the project group during the development, and planning phases was evaluated evenly as fairly good and very good (3/6) whereas the cooperation during the construction phase was evaluated as very good (6/6). One participant did not give a response. Several aspects of cooperation among the participants were identified as different compared to a conventional project:
  - The cooperation was open and honest
  - Everyone involved from the early project stages
  - Development phase was different than in a conventional project
  - There was more cooperation among project participants
  - The heating, ventilation, and water system professionals were involved in the process very early
- The involvement in the project has to a large extent contributed to developing new solutions that were implemented in the project (6/7 participants have answered that the project has very much influenced the development of new solutions in their field). Out of those they have named several systems/solutions that they think should be used in future projects:
  - Prefabricated timber elements
  - Heat exchanger in connection to good air tightness of the building's envelope
  - The tent that protects the building during construction
  - High prefabrication rate
- To the question what the participants have learned most during the project that they will take with them for the future projects they responded:
  - cooperation among project participants (2/7)
  - The heating unit solution (1/7)
  - Timber load bearing construction (1/7)
  - Engagement among the project team members (2/7)
  - Passive house thinking (1/7)
- The biggest problems they have experienced in the project were:
  - Fulfilling expectations for the rent levels for the inhabitants
  - Coordination between water-ventilation-steering=heating
  - Keeping the red thread throughout the project
  - Fulfilling the requirements for airtightness of the building's envelope

- Distribution of heat, fine tuning of the system in the operational stage
  - Keeping the costs down
- Finally, out of seven responded questionnaires four participants would *maybe* like to live in the Southern Portvakten buildings, whereas two gave a positive response and one would not like to live there.

#### 4.3.2 Empirical experiences during the first year of the operational stage

During the first year in operation meetings were held with Hyresbostäder in Växjö and the Energy Agency for Southeast Sweden to analyse the energy measurement data and follow up the empirical experiences with the installation systems installed in the two buildings. Some of the experiences are noted here as well as the interview with the consultant involved in the design of the ventilation system.

The heat exchanger was specifically designed for the Southern Portvakten buildings and connected to the ventilation and heating system that operates with hot water from the district heating system as the energy carrier. In the very beginning of the heating season it was noticed that there was no heating in the apartments. It turned out that there was air in the water circulation system of the district heating system and since the main battery is located at the top of the building no heating (hot water from the district heating system) could be provided to the battery. During that period some of the apartments were provided with electrical heaters, so the energy used for heating was actually registered as the household electricity use. This period was not included in the analysed period for measured energy consumption presented in Chapter 4.

In addition the main heating battery located after the heat exchanger, at the top of the building, experienced problems with icing of the heat exchanger during the cold months and by-pass was used. The amount of air coming through the by-pass was several times adjusted, from 100% of air going through by-pass in the beginning of the heating season to 30% and later on to outdoor temperature related adjustments (at certain outdoor temperatures the by-pass is used for a certain amount of incoming air). The amount of air passing through the by-pass is self-regulated by the temperature of the outgoing air from the heat exchanger and the incoming air. This temperature should be minimum 0°C to avoid the icing of the heat exchanger. Another change in the settings is the temperature of the air which is blown from the heat exchanger into the ventilation system since the heat exchanger gave higher efficiency than initially thought due to the higher temperature of the outgoing air. The new temperature was set to 18°C which results in less supply energy needed by the individual batteries located in the apartments.

Towards the end of the first heating season another adjustment was made with the central heating battery after the heat exchanger which was set to be in operation until the outside temperature is +9°C. This means that for temperatures below +9°C, if necessary, the heating battery worked by heating the air coming from the heat exchanger up to +18°C. When the outside temperature is above +9°C the central heating battery is turned off and the air is preheated only by the effect of the heat exchanger and the individual batteries in the apartments. If the air that is pre-heated in the heat exchanger by the outgoing air is too warm, the temperature is regulated by introducing the fresh air through the by-pass. Then

the air is distributed to the apartments where the individual batteries regulate the temperature to the desired level.<sup>1</sup>

After the project's evaluation meeting with the professionals involved in the Southern Portvakten project contact was made with Tommy Wesslund, from Wesslunds VVS-Teknik AB, the consultant who was involved in the design of the ventilation system for the Southern Portvakten buildings. He was also involved in monitoring the system's operation and adjusting it to improve its performance, during the first year in operation.

Problems were registered with the shunt unit connected to the district heating system and the central battery for heating located at the top of the building (Figure 4.20). According to the consultant, in the dimensioning of the generator (during the design stage) it was missed to include the de-frosting of the heat exchanger which resulted in weak shunt units. Once the de-frosting cycle begins, during the cold days, the air in the ventilation system is cold – the hot water from the district heating system does not get to the heating battery to heat the incoming air, due to the weak shunt unit. The shunt unit will be changed to improve the hot water flow.



Figure 4.20 Shunt Unit with the central heating battery and the heat exchanger in the background

Another problem is the low power of the individual batteries in the apartments so when individual adjustments are made to increase the heat supply (when the inhabitant desires higher indoor temperature) it takes a long time for the system to respond. The problem was especially registered in the apartments at the top of the building.

Additional concern that was registered was the need to have high incoming temperature of the water in the district heating system in order to transfer enough heat to the air distributed to the apartments. At an outdoor temperature of -20 °C the water temperature has to be +70°C, and with indoor air temperature of +20°C the water in the return system from the heat exchanger to the substation is cooled to +50 °C. As a result the return water from the substation in the district heating system is too warm, which creates a problem for the district heating company.

**The consultant concluded that the solution of having air born heating in apartment buildings is not a good solution when it is connected to district heating system or heat pumps and in his opinion should be avoided in the future, unless the technique develops to solve the identified problems. In addition it is difficult to regulate indoor temperatures room per room, and as a result one gets an average comfort in the apartment, with temperatures never right in any of the rooms.**

<sup>1</sup> Taken from the report "Framtidens trähus – energieffektiva med god inomhusmiljö. Documentation of project's development, planning, and building phases. Building's energy performance"



### 4.3.3 Inhabitants

In order to gain an input on how inhabitants experience living in a low energy building, built in timber construction using passive house technologies, it was decided to send out a comprehensive questionnaire. After analysing different questionnaires that were previously used in similar projects in Sweden it was decided to use the Engvall/USK form Energy 02 as the basis [15]. An approval for using the form was received from Eje Sandberg, Aton Teknikkonsult. A few questions were added to the form, which were relevant for the type of building. The full questionnaire can be found in the Appendix A, Chapter 9.2.

In October 2010, when the questionnaire was sent, in total 39 apartments in both Southern Portvakten buildings were rented out (out of available 64). Inhabitants had two weeks to answer the questionnaire. In total 19 responses were received.

The questionnaire had five sections:

- Heating and temperature
- Ventilation
- Noise and light
- Energy
- Background questions

During the winter the temperature in the apartments was on average experienced as cold to adequate. In only one apartment the temperature was experienced as too cold in all rooms, whereas several experienced it too cold in some of the rooms. On average the kitchen was experienced as the warmest room, while sleeping rooms and the living room were felt as the coldest. During the summer months indoor temperature was experienced as *average* to *warm*, whereas only in one apartment, oriented towards the west in Building A1, indoor temperature was experienced as *too warm*. In the Building A1 apartments towards the south were experienced warmer than apartments towards the north whereas in the building B1 it was the opposite. Most of the inhabitants (10/19) are sometimes affected by the temperature variations indoors due to the outdoor temperature changes. Three out of eighteen responses noted that the heating system offered them *good* possibilities to personally affect the indoor temperatures, where two of them lived less than half a year in the building, missing the first heating season and the warmest recorded month in 2010, July. Seven responses were negative and gave answers *very bad* or *no possibility* for affecting the indoor temperatures personally. Whereas most inhabitants are not affected by draught in their apartments there are some that marked that they experience draught at the air supply duct in the living room, bedroom and bathroom (even though there is no air supply in the bathroom). Half of the inhabitants (8/16) experience thermal comfort in the apartments during the summer months as *acceptable*, whereas only one experienced it *very bad* (the same that mentioned that it was too warm during the summer months). Two out of three that thought that the thermal comfort was *very good* live in apartments oriented towards the north, whereas one lives in an apartment located towards south-west in the Building A1. During the winter months those that thought that the thermal comfort was *very bad* live in apartments towards the south (2/16), whereas most (12/16) experience the indoor thermal comfort as *acceptable* or *rather good*.

The air quality in the apartments was on average experienced as *rather good* and *very good*. No one experienced the air quality to be *very bad* in any of the rooms, where only one inhabitant experienced that the air in the bathroom was *rather bad*.

The inhabitants are *often* or *sometimes* troubled by the condensation that is created on the outside of the windows (9/18 and 6/18). Own kitchen smells (14/19) and dry air in the apartment (9/19) are the following two things that bother the inhabitants whereas 5/19 are bothered with kitchen smells from neighbouring apartments.

Most people (14/18) air (manually ventilate by opening the windows or the balcony door) the apartment *every day* during the heating season (September –April), whereas only one airs a *few times per month*. They have a window open somewhere in the apartment either for *some hours* or *some minutes*, mostly for *10 cm or more* (9/18). Those that experience the apartment *too cold* or *rather cold* during the winter months have also mentioned that they manually ventilate the apartment *every day for several minutes* during the same period. Twelve out of seventeen people think that the ventilation system gives them *rather bad*, *very bad*, or *no possibility* to affect the indoor air quality, whereas four thought it was *acceptable*.

The apartments are experienced as *rather silent* or *very silent* (14/18) whereas only one thought that the apartment was *rather sound filled*.

Almost everyone thinks that their apartments have an *acceptable* amount of daylight (18/19) and are not bothered by the solar control glass on the windows (13/19), whereas only one reported that he/she is bothered by the glass during the winter period. Four inhabitants did not notice that there was a solar control glass on the windows. Two experience *little* or *too little* light during the winter, whereas three experience *slightly too much* light and one *slightly too little* light during the summer months. The amount of sunlight on the balconies is mostly experienced as *acceptable* (12/19) whereas some, whose balconies are oriented to the south, experience there is *too much* sunlight and some, oriented towards the north or east, experience that the balconies get *slightly little* or *too little* sunlight (4/19).

On average people wash 5.3 washing machines per month where the span goes from 2 to 12.5 machines.

Most of the people that answered live with someone whereas 6/19 live alone. On average people that responded the questionnaire lived for 8.6 months in the Southern Portvakten buildings, ranging from 1.5 to 16 months. Most respondents were 25-34 or above 65 years old (12/19). The reason that the buildings have a *good location* and *apartments have a big balcony* were the most common reasons for moving into them (12 and 9 respectfully), where there was also a high awareness of *low energy use* (8) (multiple responses were possible). Finally, most people are *satisfied* or *very satisfied* that they moved into the Southern Portvakten buildings (11/18 and 4/18), while three experience it *worse* than their previous place of living. High rent was often given as an additional remark. Noise from the traffic was also noted as disturbing as well as draught from the ventilation or limited possibility to adjust the temperature outside the +16°C and +22°C frame.

## 5 Discussion

The empirical experiences and measurement results from the Southern Portvakten buildings are analysed in relation to each other. Energy measurement results are to a large extent affected by the number of inhabitants and apartments occupied, adjustments of the ventilation and heating system, as well as user habits including the manual ventilation of their apartments during the winter period.

From the very beginning of the project's planning stage it was decided to build apartments in timber prefabricated construction following the Swedish voluntary passive house criteria. The research project "Framtidens trähus – energieffektiva med god inommiljö" followed the project's planning, development, and building stages, provided scientific input, but did not have any influence on the decision making during the project.

The energy use for space heating was measured to be more than twice higher (22.2 kWh/m<sup>2</sup> for a normal year in Building A1) than the calculated values (8.9 kWh/m<sup>2</sup> for a normal year). Energy simulations for a half occupied building result in 13.9 kWh/m<sup>2</sup> space heating demand (normalized value) which is lower than the measured values. There are several reasons for this, such as low occupancy level especially during the first heating season (from 31% in November 2009 to 50% in May 2010), icing of the heat exchanger which led to the several changes in the settings of the by-pass (from 100% to 30% of the incoming air), and many adjustments of the heating and ventilation system. Energy simulations during the project's development stage showed that 25% less efficiency of the heat exchanger can result in 118% higher space heating demand, which almost alone can explain the measurement results [1]. In addition, most inhabitants, that responded to the questionnaire, manually ventilate the apartment every day (14 out of 18 that responded to the questionnaire) during the winter period, which can have large effects on the energy used for space heating. Thus, the second heating season could be much better for the assessment, even though the occupancy level of 63 - 72% (September - December 2010) would still give slightly misleading results. It would be best, though, if a follow-up of the energy use is done in 5 or 10 years, when the heating and ventilation systems are adjusted to their full potential and buildings are fully inhabited.

Average energy use for space heating and domestic hot water in Swedish multi-family housing for the period 2005-2009 is presented in Table 3.

Table 3 Average energy use in Swedish multi-family buildings [27]

	2005	2006	2007	2008	2009
Average energy use for space heating and domestic hot water in all Swedish multi-family housing in kWh/m <sup>2</sup> <sup>i</sup>	157	156	151	145	148.1
Average energy use of district heating in multifamily buildings built after the year 2001, using district heating only, in climate zone III, in kWh/m <sup>2</sup>	119±13	127±12	135±12	124±12	131±11
Average energy use of district heating for all multifamily buildings in Sweden in kWh/m <sup>2</sup>					155
Building-specific energy use requirements for III climate zone, in kWh/ m <sup>2</sup> Atemp and year <sup>ii</sup>	110				

<sup>i</sup> The average consumption is influenced by the year of construction, type of building, and heating source and includes all multi-family buildings in Sweden.

<sup>ii</sup> Minimum energy efficiency requirements for new residential buildings with heating other than electric heating, according to the Swedish Building Regulations in 2008 [22]

While the measured energy use in Southern Portvakten buildings is higher than the calculated it is still much lower than in conventional buildings. According to the measurements during the first year in operation, adjusted to the 100% occupancy level, the Southern Portvakten buildings use less than a fourth of the energy for space heating and domestic hot water compared to an average Swedish multifamily building during the period 2005-2009. Compared to multifamily buildings, where district heating is the energy carrier, Southern Portvakten buildings used during the studied period (2010) only 16% of the average energy use for heating recorded in 2009, or a half compared to building-specific energy use requirements defined in the Swedish building Regulations for residential buildings heated with other heating source than electric (here domestic hot water and common electricity have a big influence).

Even though the energy used for space heating was twice than the one expected, the inhabitants still experienced the apartments as cold to adequate, where the coldest rooms were the living room and the bedrooms. Those are the rooms where the fresh pre-heated air is introduced into the apartments. Despite the feeling of coldness most inhabitants manually ventilate the apartments on a regular basis, every day. In majority they feel that the ventilation system does not give them good possibilities for affecting the indoor air quality, even though at the same time they experience the air quality in the apartments on average as rather good or very good.

The regular manual ventilation of the apartments indicates that either the inhabitants are not aware of the fact that the air is exchanged by the ventilation system all the time, they do it because they are just used to it, or they really feel that they lack fresh air. Most of the responses to the questionnaire identified that they are either *often* or *sometimes* disturbed by the cooking smells in their own apartment. The low effect of the kitchen ventilation hood can in that case explain the need for manual ventilation. Inhabitants are given instructions regarding the building and the systems installed when they sign the lease contract, but

possibly due to the so much information that is given in connection to the new apartment it is easy to forget all the details about the special technique installed in the building. One could repeat the instructions once the inhabitants have settled in.

The annual bought volume of domestic hot water was measured for each apartment but the number of people living in each apartment is not registered. Calculating from the questionnaire responses on average 1.84 people live in each apartment. Analysing the annual volume of bought hot water the average annual consumption results in 11.2 m<sup>3</sup>/person in Building A1, and 11.7 m<sup>3</sup>/person in Building B1. This is in line with the calculation using the Equation 2 given in the voluntary Swedish Passive house criteria which results in 11.52 m<sup>3</sup>/person,year, including the saving effect of the energy efficient faucets (water saving) in combination with payment incentives for the users. Compared to the Swedish average of domestic hot water use, which reported to be 21.2 m<sup>3</sup>/person, in 2009, the bought volume of domestic hot water in the Southern Portvakten buildings is low [24]. Experiences in four demonstration projects followed by Ulla Janson show high variations of the bought volume of domestic hot water where the mean value lies at 10.9 m<sup>3</sup>/person, year [28].

Electricity use for common indoor areas presents a significant amount of total energy used in the two buildings during the first year (19.7% in Building A1 and 13.1% in Building B1), even though the occupancy level was low. According to the Swedish voluntary criteria for passive houses electricity for indoor common areas is recommended as max 10 kWh/m<sup>2</sup> [12] for multi-family buildings, which in relation to the advised total bought energy for the third climate zone in Sweden would be 16.7%. A 100% occupancy level would affect the electricity used by the elevator but other parameters like fans and pumps, and indoor lighting would stay the same. Since the substation unit lies in the storage building, which is a separate building, the effect of the pumps has to be high. The main heating battery lies at the top of the building and due to the need to have hot water constantly delivered to the heating battery the effect of the pump is high. This has a direct effect on the energy measured for common areas.

A waste water heat exchanger was a technology interesting to test at the Southern Portvakten site. The efficiency of the heat exchanger to a large extent depends on the occupancy level. It always functions when the water is used, but in order to have the full efficiency it is necessary that the water is constantly used, since the fresh water is preheated by the waste water coming from the faucets. This means that someone has to be using the water just after someone else has used it in order to give time for the heat from the waste water to be transferred to the cold fresh water. When the occupancy level is low then it is less likely that such chain of events would occur, except during the rush hours in the morning when people are going to work. In addition, in order to have the most effect it is best if the waste water heat exchanger is close to the source. In case the waste water heat exchanger is located outside the building shell, which is the case with Portvakten buildings, heat losses occur in the pipes between the building and the heat exchanger in both directions (outgoing, waste water direction and ingoing, fresh water direction). It is a question then if such a system is suitable for apartment buildings, especially when it is located outside the building shell, or should the system be developed more on an individual level, with small units where the effect of the heat exchange is felt instantly back at the source?

Summer indoor temperatures were a big concern during the project's planning and development stages. Calculations showed concerning high indoor temperatures. This was partly due to the limitations of the simulation program DEROB-LTH to simulate the whole building, so instead one apartment was chosen for the detailed summer simulation. In that way the ventilation system in the simulation program could not take into account the whole air capacity of the building, but instead simulated only the exchange of air in the chosen apartment. During the summer of 2010 the highest measured daily average indoor temperature was 27.4 °C, registered in the chosen apartments of both buildings. The average indoor temperature was above 26°C for four days in the Building A1 while in the Building B1 it was for six days in a row above 26°C. Still, since the available figures are for average daily temperatures, it is difficult to assess if and for how long did the indoor temperature go above the 28°C limit defined in the recommendations issued by the National Board of Health and Welfare [26]. Indoor temperatures were very steady in relation to the changes of the outdoor temperatures. Whereas the outdoor temperature changed several times from 10°C to 25 °C during the period June – August 2010 (having average temperatures 14.1 °C in June, 18.8 °C in July, and 15.9 °C in August), indoor temperatures varied between 22°C and 27.4 °C (with average monthly indoor temperatures 23.6 °C in June, 24.9 °C in July, and 23.9 °C in August in Building A1). A little amount of energy was registered that was used for space heating by the individual batteries in the apartments (0.12 kWh/m<sup>2</sup> in Building A1 and 0.17 kWh/m<sup>2</sup> in Building B1 for all three months together). An influence on the measured indoor temperatures has also the climate year for 2010. Comparing the degree days 2010 was warmer in June and colder in August than a normal year. Nevertheless indoor thermal comfort during the summer of 2010 was experienced as acceptable by half of the inhabitants that answered the questionnaire, where only one respondent experienced the indoor comfort as very bad.

Most inhabitants notice and are sometimes or often troubled by the condensation on the outer pane of the windows. This was discussed at the project planning meetings when it was noted that experience, from other low energy buildings, shows occurrence of condensation on the outside of the energy efficient windows [28]. Research shows that the amount of condensation on the outer window pane is reduced if there is a fixed horizontal shading above the window [23][25]. The original building design had 60 cm deep fixed shadings above the windows as a sun protection. Unfortunately due to the difficulty to fix the shadings to the moisture sensitive timber construction, which would in addition create thermal bridges, the shadings were discarded. Solar control glass was chosen as a solution for the sun protection while there was no solution for the condensation. Interestingly most people are not bothered by the solar control glass or didn't even notice that the glass was shaded. There was only one that was bothered by the less light due to solar control glass during the winter period. The reason for this might be that since all windows have solar control glass it is difficult to compare to a clear glass and notice the difference.

The first year in operation was a very educational year for heating and ventilation installation professionals involved in the project as well as the Rental Housing Company that owns the buildings. Since the heating and ventilation system was quite new, during the first heating season system adjustments were often made. One of the professionals involved in the project concluded that the chosen system solution should not be used in the future projects for apartment buildings due to the incompatibility of the chosen systems. The solution of having air born heating in apartment buildings is not a good solution when it is connected to district heating system or heat pumps and, in the opinion

of the consultant, should be avoided in the future. In addition it is difficult to regulate indoor temperatures room per room, and as a result one gets an average comfort in the apartment, with temperatures never right in any of the rooms. Still, perhaps in the future the components for this solution might be improved to meet the technical performance requirements needed for good functioning.

High energy efficiency of massive timber buildings has big potential in reducing (for 48%) the potential impact to global climate change over a period of 60 years, compared to a massive timber building built to satisfy Swedish national requirements for energy performance of buildings. Saving in space heating and hot water creates the biggest post that contributes to the results. Still, when building low energy buildings the new focus becomes household electricity as a single aspect that contributes the most to potential climate change. Studies were not done to show what would be the difference in the environmental impact if the building was built with conventional materials and technical systems. Then a greater difference in the environmental impact of the different construction materials would occur.

The Portvakten building has been compared to two other cases, one if it was built with technique and equipment as Limnologen and the other as if it fulfilled the national requirements for energy performance (conventional building). Building's construction remained the same, timber prefabricated elements with the ground floor in concrete. Significant savings in primary energy use can be achieved when the building is built as a low energy building, compared to a conventional building. The focus for the environmental impact changes when building low energy buildings; from space heating demand to household electricity use and material and building component production. For as well as the use of primary energy as the potential contribution to global warming, the use of household electricity is the single biggest post during the 60 years of operation of the low energy building. Since the building has the possibility to install solar cells for producing electricity on site this would be a good solution to use local renewable energy sources and minimize the need for purchasing electricity. Over the 60 year period this could be a realistic solution to implement.

Compared to other passive house and low energy house projects in Sweden, Southern Portvakten buildings show good results. Total weighed bought energy in Southern Portvakten was 61.1 kWh/m<sup>2</sup>a (Building A1) and 45 kWh/m<sup>2</sup>a (Building B1) whereas in Värnamo (apartment buildings) it was 69.4 kWh/m<sup>2</sup>a, Frillesås (apartment buildings) 67.2 kWh/m<sup>2</sup>a, Lidköping (single-family house) 63.9 kWh/m<sup>2</sup>a, and Alingsås (renovated apartment building) 89.1 kWh/m<sup>2</sup>a [28]. Even so, Southern Portvakten buildings are 8 floors high, built as independent multi-storey buildings with centralized systems, different in size and type than other comparative buildings. There is still a lack of built and analysed multi-storey low energy buildings that can be used for a better comparison.

## 6 Conclusions

It is possible to successfully build low energy, air tight buildings in timber prefabricated construction. Even though the measured energy performance is much higher than the calculated values, during the analysed period, it is expected that the Southern Portvakten buildings will have a better energy performance once they are fully occupied, the buildings' mechanical systems are working properly and the inhabitants' behaviour changes to less manual airing during the winter months.

There was a lack of previous experience with the selected system solution for ventilation and heating which created some challenges for the professionals involved. District heating is a preferable option from an environmental perspective, but the experiences from this project have shown that using the system for preheating the air is not optimal due to the small demand level for a low energy building and inadequate dimensioning of the technical solution. Both the installation professionals and the inhabitants were experiencing the problems with adjusting the system to the desired use and temperature levels. Development is needed regarding heat exchangers and control systems for multi-storey low energy apartment buildings, especially where the heat exchanger is located at the top of the building, and the energy carrier for the heating battery is hot water from the district heating system.

One should allow at least one heating season to pass before the energy performance analysis of a new building is done. Full system operation and preferably full occupancy of the building is important in order to be able to assess the effects of different aspects, like free heat from people and appliances, and a real use of different energy categories, like household electricity, common indoor electricity, and domestic hot water (in that case even waste water heat exchanger could be properly evaluated).

Solar control glass does not bother the inhabitants, but the lack of fixed shading that might minimize the condensation on the outside of the windows does. There is no significant difference in indoor temperatures in the apartments facing the southwest or northeast. Even shading of the adjacent building has no greater influence. This might be thanks to the solar control glass but also due to the central ventilation system that constantly exchanges the indoor air. There was a concern that the use of solar control glass might influence the low free solar heat during the winter months but recent studies show that in a Swedish climate solar radiation cannot be utilized for space heating during the winter months [16] [28].

The future work with low energy buildings lies to a great extent in communication with the users of the buildings. One aspect is changing user habits and the other is lowering household electricity use. It is rather difficult to change people's habits to avoid regular manual ventilation of the apartments, even during the winter months. Perhaps several educational packages during the first year after the inhabitants move into the building should be carried out in order to make sure that they learn how to use the building in the most optimal way. The environmental analysis showed a clear need to address the household electricity use as it is responsible for the highest primary energy use over the 60 year period. Development of low energy, smart, household appliances and gadgets is also needed to lower the household electricity use.



In future studies it would be interesting to investigate the effect of manual ventilation on the building's energy performance, the ventilation system and the heat exchanger in more detail, since high attention is paid on good airtightness of the building shell during the construction period.

One should be very careful when planning which energy measuring devices are installed with respect to user friendliness and easiness to read and evaluate the data. Advanced Building Information Modelling (BIM) systems should be used, as they have high potential for additional building energy savings. This is a market still under development.

Overall, the Southern Portvakten buildings are a good example of multi-storey low energy buildings built in timber prefabricated construction and will serve for a long time as an example and benchmark for many professionals and researchers in the future low energy projects.

Since the amount of energy available is limited, it is important to reduce the total amount of energy used in order to increase the possibilities to reach the goals set within the European Union to reduce the use of fossil energy and thereby to reduce the global climate change. As the results from this study shows, the reduction of as well the use of primary energy and the potential impact to global climate change due to a reduced use of energy during operation is much higher than the increase due to e.g. more material in the low energy building, which motivates to stimulate low energy building construction from an environmental point of view.

## 7 Recommendations and use

This report should be used in connection to the first report “*Framtidens trähus – energieffektiva med god innemiljö. Documentation of project’s development, planning, and building phases. Building’s energy performance*” [1], where critical points during the Southern Portvaktén project’s development, planning, and building phases are documented. The first report also includes calculated energy performance results that are used for the analysis of the measured data presented in this report.

Experiences from the first operational year, measured energy performance, and environmental performance assessment of the Southern Portvaktén buildings, that are documented in this report, can be used as references for other similar projects and guidelines when planning future projects.

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## 9 Appendix

### 9.1 Questionnaire for the project team members

#### ENKÄT OM ERFARENHETER FRÅN PROJEKTET PORTVAKTEN SÖDER

Inom Vinnova projektet "Framtidens trähus – energieffektiva med god inommiljö" har IVL följt projektet Portvakten Söder. För att utvärdera utvecklings-, projekterings- och byggprocessen behövs era synpunkter. Vi är tacksamma om Du vill fylla i enkäten och kommentera med dina egna ord där det behövs. Lämna in formuläret efter mötet.

1. Är Du nöjd med resultaten från projektet?

Ja, mycket  
nöjd  
☐

Ja, ganska nöjd  
☐

Varken eller  
☐

Nej, inte så nöjd  
☐

Nej, inte alls  
nöjd  
☐

2. Vad skulle Du göra annorlunda?

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3. Hur mycket har projektet påverkat att Du har kommit fram till nya lösningar som användes i Portvakten Söder?

Väldigt mycket  
☐

Inte så mycket  
☐

Inte alls  
☐

4. Vilken teknisk lösning tycker Du är speciellt bra och som Du skulle vilja se i framtida projekt?

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5. Vilken lösning, av olika skäl, kunde inte genomföras men som Du skulle vilja se i framtida projekt?

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6. Vad har Du lärt Dig mest i projektet och som Du kommer att använda i framtida projekt?

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7. Har projektet ändrat Din uppfattning om Passivhus?

Ja, det har blivit bättre  
☐

Varken eller  
☐

Nej, inte alls  
☐

8. Vad har Du upplevt som största problemet i projektet?

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9. Vad tycker Du gick sällsynt bra?

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10. Hur har Du upplevt arbete i projektgruppen?

	Mycket bra	Ganska bra	Acceptabla/varken bra eller dåliga	Ganska dålig	Mycket dålig
Under utvecklings fasen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Under projekterings fasen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Under bygg fasen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. Hur mycket inflytande hade Du i beslutsfattande?

Mycket	Ganska	Lite	Ingen
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

12. När det gäller arbete i projektgruppen vad var skillnad från andra projekt?

---

13. Skulle Du vilja bo i Portvakten Söder?

Ja	Kanske	Nej	Ja bor där
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

14. Har Du någon ytterligare som rör Din erfarenhet från projektet som Du vill Framföra kan Du göra det här. Du kan även med egna ord komplettera Dina svar.

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Tack för hjälpen!

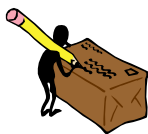
## 9.2 Questionnaire for the inhabitants of the Southern Portvakten buildings

# Enkät om Ditt inomhusklimat

## Energi



Frågorna besvaras genom att Du sätter ett kryss i rutan för det svarsalternativ som passar Dig bäst.



Skicka in det ifyllda formuläret så fört som möjligt. Gärna redan idag. Använd det bifogade svarskuvert.



Om du har några frågor kan du ringa till Ivana Kildsgaard på 0859856341

Lghnr . . . . .

*Vi är tacksamma för Din medverkan. Ditt medverkande är frivillig och Din respons är konfidentiell.*

*Enkäten är baserat på Engvall/USK Formulär Energi 02*



Vi är intresserade av att få veta hur Du trivs i Din bostad och hur du upplever Ditt inomhusklimat

### VÄRME OCH TEMPERATUR

1. Tycker Du att det är för kallt eller för varmt i något rum i lägenheten under vinterhalvåret?

	mycket för kallt	för kallt	lagom	för varmt	mycket för varmt
I kök	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I vardagsrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I badrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I sovrum (mindre) *	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I sovrum (större)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

\* där den finns

2. Tycker Du att det är för kallt eller för varmt i något rum i lägenheten under sommarhalvåret?

	mycket för kallt	för kallt	lagom	för varmt	mycket för varmt
I kök	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I vardagsrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I badrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I sovrum (mindre) *	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I sovrum (större)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

\* där den finns

3. Besväras Du att temperaturen varierar i lägenheten beroende på temperaturförändringar utomhus?

☐ Ja, ofta  
aldrig

☐ Ja, ibland

☐ Nej, sällan eller

4. Tycker Du att uppvärmningssystemet i lägenheten ger Dig bra eller dåliga möjligheter att själv påverka temperaturen?

Mycket bra	Ganska bra	Acceptabla/varken bra eller dåliga	Ganska dålig	Mycket dålig	Finns inga möjligheter
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. Tycker Du att Din lägenhet har...

	ja	nej	vet ej
Kalla golv	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kalla väggar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. Besväras Du av drag i Din lägenhet? Ange i så fall i vilket rum och varifrån det drar. Flera alternativ kan anges.

	Besväras ej av drag	Besväras av drag: Vid golv	Vid fönster	Vid balkong dörr	Vid entré dörr	Vid ventilations- inblåsning
Kök	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vardagsrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Badrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sovrum (mindre) *	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sovrum (större)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hall	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

\* där den finns

7. Hur tycker Du värmekomforten i stort sett är i Din lägenhet under...?

	Mycket bra	Ganska bra	Acceptabla/ varken bra eller dåliga	Ganska dålig	Mycket dålig
Sommarhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vinterhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## VENTILATION

8. Hur tycker Du att luftkvaliteten i stort sett är i ... ?

	Mycket bra	Ganska bra	Acceptabla/ varken bra eller dåliga	Ganska dålig	Mycket dålig
Kök	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vardagsrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Badrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sovrum (mindre) *	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sovrum (större)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Hall ☐ ☐ ☐ ☐ ☐

\* där den finns

9. Hur bedömer Du i allmänhet luften i Din lägenhet?

Är luften torr eller fuktig...

	mycket torr	ganska torr	varken eller	ganska fuktig	mycket fuktig
vinterhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sommarhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Är luften ren eller dammig...

	mycket ren	ganska ren	varken eller	ganska dammig	mycket dammig
vinterhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sommarhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Är luften frisk eller unken...

	mycket frisk	ganska frisk	varken eller	ganska unken	mycket unken
vinterhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sommarhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

10. Besväras Du av följande olägenheter i Din lägenhet? Markera hur ofta Du besväras av...

	Ja, ofta	Ja, ibland	Nej, aldrig
Eget matos som sprids i lägenheten	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Matos från grannlägenheter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tobaksrök eller annan lukt från grannlägenheter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lukter utifrån, t.ex. bilavgaser, grillkök, och industrier	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Torr luft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Svärhet att få tvätt/fuktiga handdukar torra i badrum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kondens mellan fönsterrutor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kondens på insidan av fönstren	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kondens på utsidan av fönstren	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. Om du har allergiska besvär (astma, hösnuva och/eller allergiska eksem), hur förändras ditt allergiska tillstånd när du vistas mycket i din bostad?

Tillståndet förbättras	Tillståndet varken förbättras eller försämras	Tillståndet försämras	Jag har inga allergiska besvär
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ ☐ ☐ ☐

12. Har du under de tre senaste månaderna haft besvär (klåda/sveda/irritation i ögonen, irriterad /täppt/rinnande näsa, heshet/halstorrhet, hosta eller torr/rodnande hud i ansiktet) som du tror kan bero på inomhusmiljön i din bostad?

Ja, ofta (varje vecka) ☐ Ja, ibland ☐ Nej, sällan eller aldrig ☐

13. Tycker Du att ventilationssystemet i lägenheten ger dig bra eller dåliga möjligheter att själva påverka luftkvaliteten?

Mycket bra ☐ Ganska bra ☐ Acceptabelt/ varken bra eller dåliga ☐ Ganska dålig ☐ Mycket dålig ☐ Finns inga möjligheter ☐

14. Hur ofta vädrar Du vanligtvis under eldningssäsongen (dvs september-april)?

Vädrar dagligen/nästan varje dag ☐ Vädrar ungefär 1 gång i veckan ☐ Vädrar någon gång i månaden ☐ Vädrar sällan eller aldrig ☐

15. Hur länge brukar Du ha öppet när du vädrar?

Har ständigt öppet någonstans ☐ Har öppet någonstans hela dagen ☐ Har öppet någonstans hela natten ☐ Har öppet någonstans några timmar ☐ Har öppet någonstans några minuter ☐ Vädrar sällan eller aldrig ☐

16. När Du vädrar hur stor öppning brukar Du ha på det fönster/balkongdörr som du oftast öppnar?

Mindre än 1cm öppning ☐ 2-4 cm öppning ☐ 5-9 cm öppning ☐ 10 cm öppning eller mer ☐ Vädrar sällan eller aldrig ☐

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## LJUD OCH LJUS

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17. Besväras Du av störande ljud i Din lägenhet?

Ljud från kranar, rör eller ledningar ☐ Ja, ofta ☐ Ja, ibland ☐ Nej, sällan eller aldrig ☐

Ljud från ventilationen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ljud från grannlägenheter, trapphus eller hiss	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ljud utifrån, t.ex. från trafik, industri eller människor utomhus	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

18. Tycker Du att det är för mycket ljud i Din lägenhet eller är det en tyst lägenhet?

Mycket tyst	Ganska tyst	Acceptabel/ varken tyst eller ljudfylld	Ganska ljudfylld	Mycket ljudfylld
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

19. Tycker Du att din lägenhet är för ljus eller för mörk?

Mycket för ljus	För ljus	Lagom	För mörk	Mycket för mörk
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

20. Tycker Du att du får för lite eller för mycket direkt solljus i lägenheten under ...?

	För mycket	Något för mycket	Lagom	Något för lite	För lite
vinterhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sommarhalvåret	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

21. Besvärar Du av mörkare glas på fönstren?

Inte alls	Ja, under sommarhalvåret	Ja, under vinterhalvåret	Ja, under hela året	Har inte upptäckt att dem är mörkare
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

22. Tycker Du att du får mycket eller för lite sol på Din balkong sommartid?

För mycket	Något för mycket	Lagom	Något för lite	För lite
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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### ENERGIFRÅGOR

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23. Du fick en termometer tillsammans med frågeformuläret. Använd den för att mäta vilken temperatur det är just nu i vardagsrummet. Termometern placeras på innervägg i ögonhöjd.

Termometern visar på ..... °C i vardagsrummet.

24. Vilken temperatur skulle Du vilja ha just nu i vardagsrummet?

..... °C

25. Då inomhusklimatet varierar under en månad och tid på dygnet ber vi Dig även fylla i datum och klockslag när Du mätte temperaturen.

Datum den ...../..... Klockan .....

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## BAKGRUNDSFRÅGOR

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26. Hur stor är Din lägenhet?

2 rum och kök ☐

3 rum och kök ☐

27. Vilket våningsplan ligger lägenheten på?

Bottenvåning ☐

1 trappa upp ☐

2 trappor upp ☐

3 trappor upp ☐

4 trappor upp ☐

5 trappor upp ☐

6 trappor upp ☐

7 trappor upp ☐

28. Hur många maskiner tvätt kör Du eller någon annan i hushållet sammanlagt under en normal månad?

I lägenheten ..... St

29. Hur många bor stadigvarande i Din lägenhet? Räkna även med Dig själv.

.....antal vuxna

.....antal barn 0 – 6 år

.....antal barn 7 – 17 år

30. Hur länge har Du bott i lägenheten?

..... månader

31. Hur gammal är Du?

24 år eller yngre ☐

25 – 34 år ☐

35 – 44 år ☐

45 – 54 år ☐

55 – 64 år ☐

65 år eller äldre ☐

32. Är Du man eller kvinna?

Man ☐  
Kvinna ☐

33. Röker Du?

Ja ☐  
Nej ☐

OCH TILL SIST...

34. Vi vill veta varför Du har flyttad till Portvakten Söder.

Eftersom det är en Passivhus, dvs sparar energi ☐  
Bra läge ☐  
Ny byggnad ☐  
Har stor balkong ☐  
Bra läge ☐  
Annat: ☐  
\_\_\_\_\_

35. Jämfört med Din tidigare bostad är Du nöjd med att bo i Portvakten Söder?

Inte alls	Nej, det är sämre	Ingen åsikt	Ja, jag är nöjd	Ja, jag är mycket nöjd
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Har Du någon ytterligare som rör Din lägenhet, dess inomhusmiljö eller förvaltning som Du vill Framföra kan Du göra det här. Du kan även med egna ord komplettera Dina svar.

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TACK FÖR HJÄLPEN!