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Energy audit in Fridhemsskolan

A preschool in Gävle municipality

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Abstract

This thesis is about the energy audit in Fridhemsskolan which is an educational facility. Fridhemsskolan is a preschool for children in Gävle municipality for children up to the age of six years and comprise of nine buildings in total. The project begins with an energy survey on the school facilities which ranges from checking the ventilation system, lightning system, number of occupants, equipment's types and so on. The next step was to use a simulation program software called indoor climate and energy (IDA ICE) to create the base model for the building and input the data collected during the energy survey directly into the software and simulate it for a period of one year. After creating the base model, the total electricity use of the building was around 89 MWh/year while the district heating was 157 MWh/year.

The energy conservation opportunities in Fridhemsskolan for the building was divide into two categories and these are referred to as non-retrofitting (no or minimal cost) and retrofitting (with cost) recommendations. The non-retrofitting involves reducing the indoor temperature and with this approach; the district heating consumption was reduced to 147.6 MWh/year which amount to 9.34 MWh/year in savings for the district heating while the electricity consumption was reduced to 86.4 MWh/year which amount to 2.6 MWh/year in savings for the electricity.

Retrofitting (with cost) recommendations involves looking at the base model and see where some improvements can be carried out. In this research, the roof of the building has more energy losses and retrofitting with cost analysis was performed on that part of the building envelope.

After retrofit, the district heating consumption was reduced to 142 MWh/year which is about 15 MWh/year in saving for the district heating while the electricity consumption was reduced to 26 MWh/year which also amount to 63 MWh/year saving in electricity consumption. The reason for this sharp decrease in the electrical consumption was because, the electrical radiators in the base model of the building was replaced with ideal heaters that uses district heating as the energy carrier and 170 mm of mineral wool was also added to the roof.

Finally the research further looks at the thermal comfort and the indoor air quality of the occupants in the building by analysing the data on both thermal comfort and the indoor air quality to see if the value obtained are within the acceptable range. In most cases the value is within the acceptable range like in the case of carbon dioxide (CO_2) concentration in the

occupied zone, the value obtained after reducing the indoor temperature was less than 1000 parts-per-million (ppm) and that shows that the carbon dioxide (CO_2) concentration is within an acceptable level in the room. The thermal comfort of the occupants in the occupied zone was within the acceptable limit. However, lowering indoor temperature increases the PPD for both buildings. The percentage of the total occupant hours with thermal dissatisfaction increases to 13% from 14 % for Hus 9 and from 13% to 15% for Hus (4-8).

Nomenclature

Latin and Greek

Symbol	Description	Units
U	Thermal conductivity	W/m.K
R	Thermal resistance	m^2 K/W
l	Materials thickness	m
R_{in}	Inside surface resistance	m^2 K/W
R_{out}	Outside suface resistance	m^2 K/W
δ	Thickness of the material	m
h	Heat transfer coefficient	W/mK
T	Temperature	K
q_i	Rate of sensible and latent heat release	W
Q	Heat energy	W
C_p	The air isobaric specific heat capacity	J/KgK
h_{fg}	Enthalpy of evaporation	KJ/Kg
i	The incident on the interior surface	W/m^2
ρ	Air density	Kg/m^3
V_b	Volume	m^3

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1.0 Introduction

1.1 Background

Energy consumption by humankind have grown over the years. It started with the invention of fire. Humankind depend on wood burning to cook and to provide warmth and light for several thousands of years. As civilisation get more advanced, the necessity for energy turn out to be greater challenges and additional sources were sought after. In the 20th century, coal has been the major source of energy use and this has further put its use into further applications. The oil crises of 1979 further tripled the prices of oil. The high price put a lot of strain on non-producing countries. This strain was major felt in Europe because, it put great strain on the amount the consumer of energy should spend. Oil discovery extend the competition for manufacturing beyond the industrialized countries own territory. The struggles for the shares in the oil export market put massive pressure on the fossil fuel reserve.

In the famous curve published by Hubbert in 1953, shows that, the oil reserve of the world is consumed at a faster rate and in an unsustainable way. If this trend continues, the oil maybe exhausted before the century is over. It is of great importance to find an alternative source of energy to replace fossil fuel or reduce fossil fuel consumption. The depletion of fossil fuel resources should be regarded as positive sign, because it will put more pressure on energy consumers to reduce the excessive energy consumption trend. From the Figure 1-1 below on the world energy consumption, the world energy consumption continued to increase year by year because of the increase in population and thus, increasing the energy consumption per capita.

In 1900, it was estimated that the world energy consumption was 22 EJ (exajoule) and by 1960 it has increased to 128 EJ (exajoule) and by year 2000 it has increased to almost 564 EJ (exajoule) [1]. Comparing the carbon dioxide (CO_2) emissions growth with the growth in energy use, both on per capita basis in Figure 1-2, the CO_2 emissions increased very slowly than the energy consumption from 1970 to 1990. The lines further diverged, and this divergence occurs because of the change in the fuel mix (more nuclear and more natural gas, relative to coal) during this period. As from year 2000 upward, these two lines tends to be approximately parallel, which indicates that there is no further CO_2 saving which result in the greater use of coal again [2].

Year	Coal EJ	Oil EJ	Natural Gas EJ	Renewable Energy EJ	Total EJ	Population Millions	Energy kW/capita
1860	3.8	0.0	0.0	0.0	3.8	1000	3.8
1900	20.8	0.8	0.3	0.0	21.9	1700	12.8
1920	35.8	3.8	0.9	0.0	40.5	1900	21.3
1940	42.1	11.2	3.1	0.0	56.4	2000	28.2
1960	60.0	40.2	17.9	10	128.1	2400	53.4
1972	66.0	115	46	26	253	2500	101.2
1985	115.0	216	77	33	441	3884	113.5
2000	170.0	195	143	56	564	5780	97.6
2020	259.0	106	125	100	590	8846	66.7

Figure 1-1: World energy consumption: past present and future Source (Al-Shemmeri, 2011)

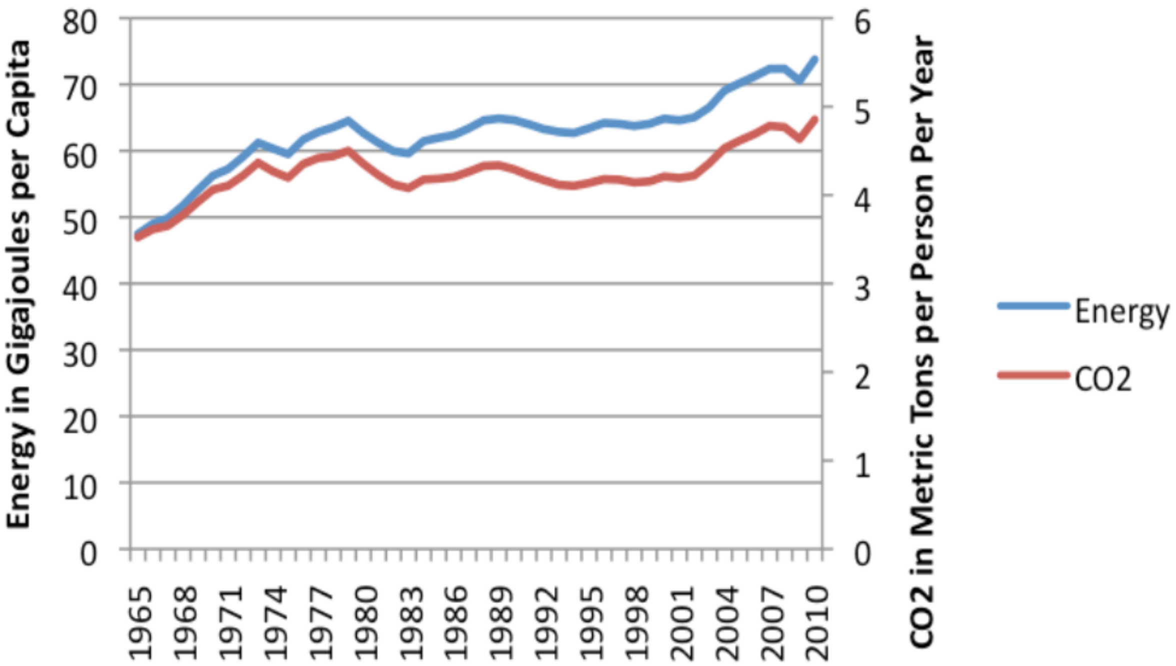

Figure 1-2: World per capita energy consumption and CO_2 Source (Tverberg 2012).

1.2 Overview of the energy mix in Sweden

The energy demand in Sweden is partially met by some imported energy. Nuclear power is used mostly for electricity production in nuclear reactors. Fossil fuels like oil and natural gas are mainly used in the transportation sector and it partially combined with some domestic renewable energy source such as biofuel. The energy demand in Sweden has been quite stable since the mid-1990s, but the total energy use has been reducing over the years. As of 2014, the aggregate of the energy supply in Sweden was around 555 TWh (Terawatt hour). Nuclear power represents (33%) of the total supply while crude oil and petroleum products account for (24%), biofuel (23%), hydropower (11%) and wind power took a portion 2% of the total production. Wind power accounts for 10% of the total production for electricity as of 2014, while hydropower and nuclear power took a portion of (34%) and (47%) respectively [3].

Taking further look at the energy usage by sector in Sweden in Figure 1-3 below, the building sectors uses more energy than any other sectors. This is then followed by the industrial sector and then the transport sector. The energy usage by buildings are in the form of heating and for hot water and that is why it is of utmost importance to have a look on this sector to see if there will be possibilities to cut down the energy use by using energy efficiency measures.

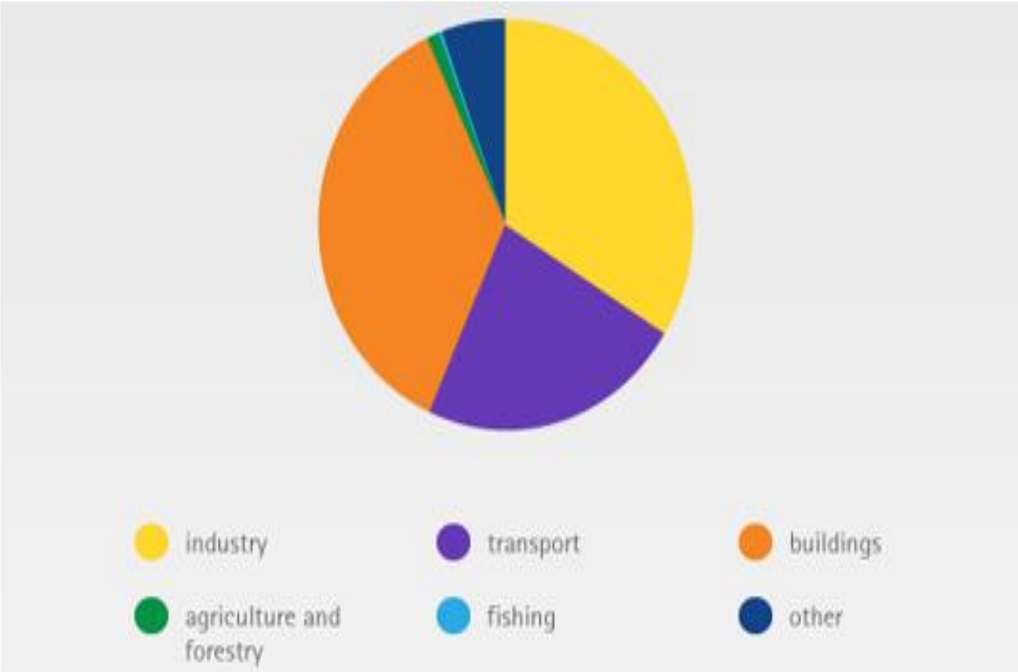

Figure 1-3: Swedish energy consumption by sector in 2012 (IEA 2012)

1.3 Energy efficient buildings

Buildings accounts for about 30-45% of the world energy demand. The growth in the energy usage and CO_2 emissions in the built environment has made energy efficiency and saving opportunities a mandatory objective for energy policies in most countries. Buildings which are classified as energy efficient buildings are designed to use a lesser amount of energy. Buildings can be made energy efficient by using insulation materials that are of high quality standard which in turn will reduce the heat loss and will make the building to be airtight without compromising the thermal comfort of the occupants in the building [4]. Classification of energy efficient buildings are based on their building performance or the amount of energy the building is using, and this classification are explained as follows [5].

- Standard Building are buildings that are built to meet only the minimum building standard energy efficiency requirements.
- Low Energy Building are buildings that consumes just half of the energy needed by a standard building. The energy efficiency in a low energy building are achieved by improving the insulation in the building envelopes and by using ventilation system with heat recovery. The yearly energy consumption for heating a low energy building is around 50-60 kWh.
- Passive buildings are known to consume less than a quarter of the energy that is used by a standard building. It is kept warm by using the heat that is generated in the building. The passive building contains no separate heating system apart from the normal heat recovery ventilation system.
- Zero energy building are buildings that has total zero energy consumption and zero carbon emissions annually. This type of building can be independent of the energy grid supply.
- Plus energy building are buildings that are based on the concept of having the attributes of passive building energy efficiency level and at the same time have integrated active energy supply systems that can make use of solar or wind energy. During the summer the building sells excess electricity that is produced to the national grid and are bought back during the winter period.

1.4 Building energy usage

Buildings accounts for 40% of the total energy use in Sweden. The building sector in Sweden consists of households, public administrations, commercial, agriculture, forestry, fishing and construction. Public administration and commercial building are mainly of non-residential buildings. Non-residential buildings and Households account for about 90% of the energy use in the sector.

The gross total energy use in the building sector in 2013 was around 147 TWh (Terawatt hour). Figure 1-4 below, shows how the energy use in the building sector decreased between 2000 and 2009, before increasing again in 2010.The increase in year 2010 was due to the colder weather conditions in that year. In 2013 the energy use in the building sector was back again to its normal level as it was in year 2010 [6].

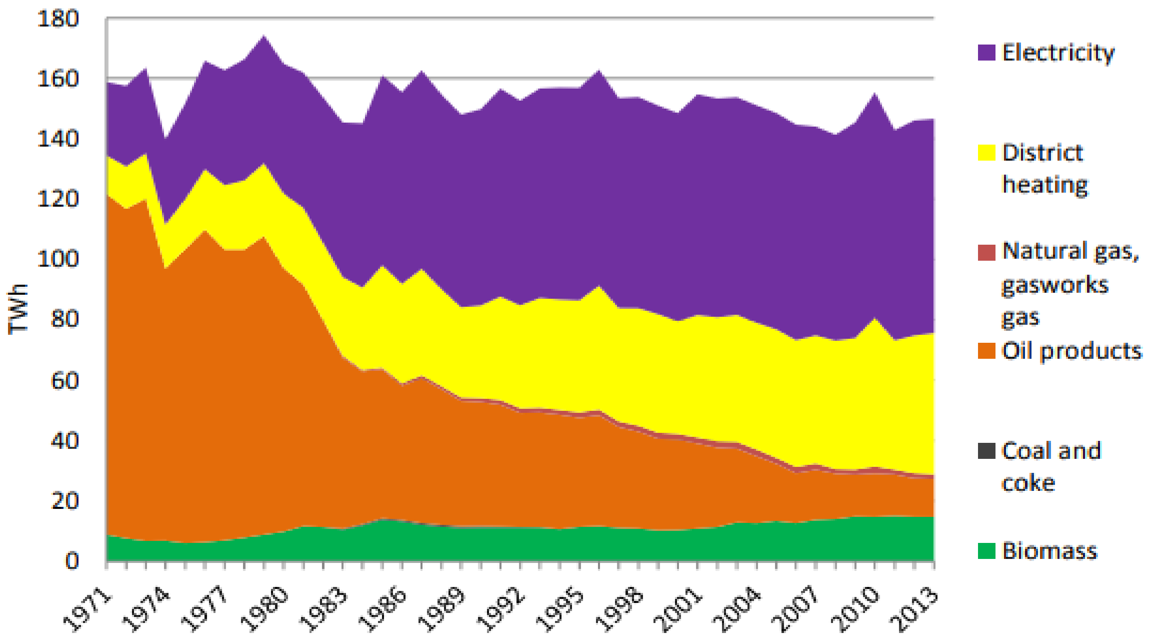

Figure 1-4: Final energy use in the building sector by energy carrier from 1971-2013 Source: Swedish Energy Agency and Statistics Sweden

Furthermore, substantial improvements have been carried out to improve the energy efficiency of new buildings. Unfortunately, most of the building in existence are more than 20 years old and does not conform with the current energy efficiency construction standards (IEA, 2008). Energy retrofits of this existing buildings will be essential or vital for some years to come if the total energy efficiency of the building stock is to meet the required standard. Investing to enhance the energy efficiency of buildings offer an instant and quite foreseeable positive cash flow which will result in lower energy consumption [7].

1.5 Energy performance of building.

The first step in analysing the energy use of a building is to look at the energy performance of that building. To know the energy performance of a building, the building normalized performance indicator is estimated by diving the total annual energy consumption of the building to that of total floor area of the building. This is express in kWh/m². year [8]. After estimating the building normalized performance indicator, the value obtained usually describes the amount of energy that the building is using per unit of the floor area under some certain conditions. The building normalized performance indicator will be used later in this thesis to check the building performance of the school by looking at the energy consumption per unit of the floor area.

To better understand the energy performance of a building, simulation software is used to investigate the energy usage of the building. During the assessment of the building, the building can produce some energy conservation opportunities which can be referred to as non-retrofitting (no or minimal cost) and retrofitting (with cost) recommendations. This classification will be applied to the energy audit that will be performed on the school building in Fridhemsskolan to see if there are any energy conservation opportunities that require no or minimal cost or retrofitting with cost recommendations [9].

Retrofitting can help to improve the energy performance of building and are more cost effective than building a new facility. Performing energy conservation retrofits on existing building can helps to reduce energy consumption. Energy conservation should not be the only reason for retrofitting an existing building but should aim at creating a high building performance by applying the integrated, whole building design process, to the project during the planning phase to ensure that all the important design objectives are met. Meeting the design objectives will ensure that, the building will be less costly to operate, increase the worth of the building and will contribute to a better, healthier, and more comfortable environment for people to live and work in. It also offers better indoor air quality, decreasing moisture penetration, and improving the occupant health and productivity. Retrofitting an existing building should include sustainability initiatives that will reduce the cost of operation and the environmental impacts. It should also increase the building adaptability, durability, and resiliency [10].

The building energy performance certificate is another way to access the energy performance of buildings. The building energy performance certificate (EPC) shows the energy efficiency ratings of building as stipulated by the European Union directive 2002/91/EC. The aim of the building energy performance certificate is to reduce the energy consumption and CO_2 emissions. The building energy performance certificate is shown in Figure 1-5 below. The energy efficiency on the left-hand side indicates a measure of the total energy use while the right-hand side indicates the environmental impact that are related to the use of energy in that building.

In the chart, each illustration has two indicators: one of the indicator is showing the actual rating and next to it is the potential ranking which is said to be the benchmark for that type of building. This rating can be represented graphically on scale from A to G where A represents the most efficient energy performance and G represents the least efficient energy performance. The building energy performance certificate does not only help to save money but also help to contribute to environmental improvement [11].

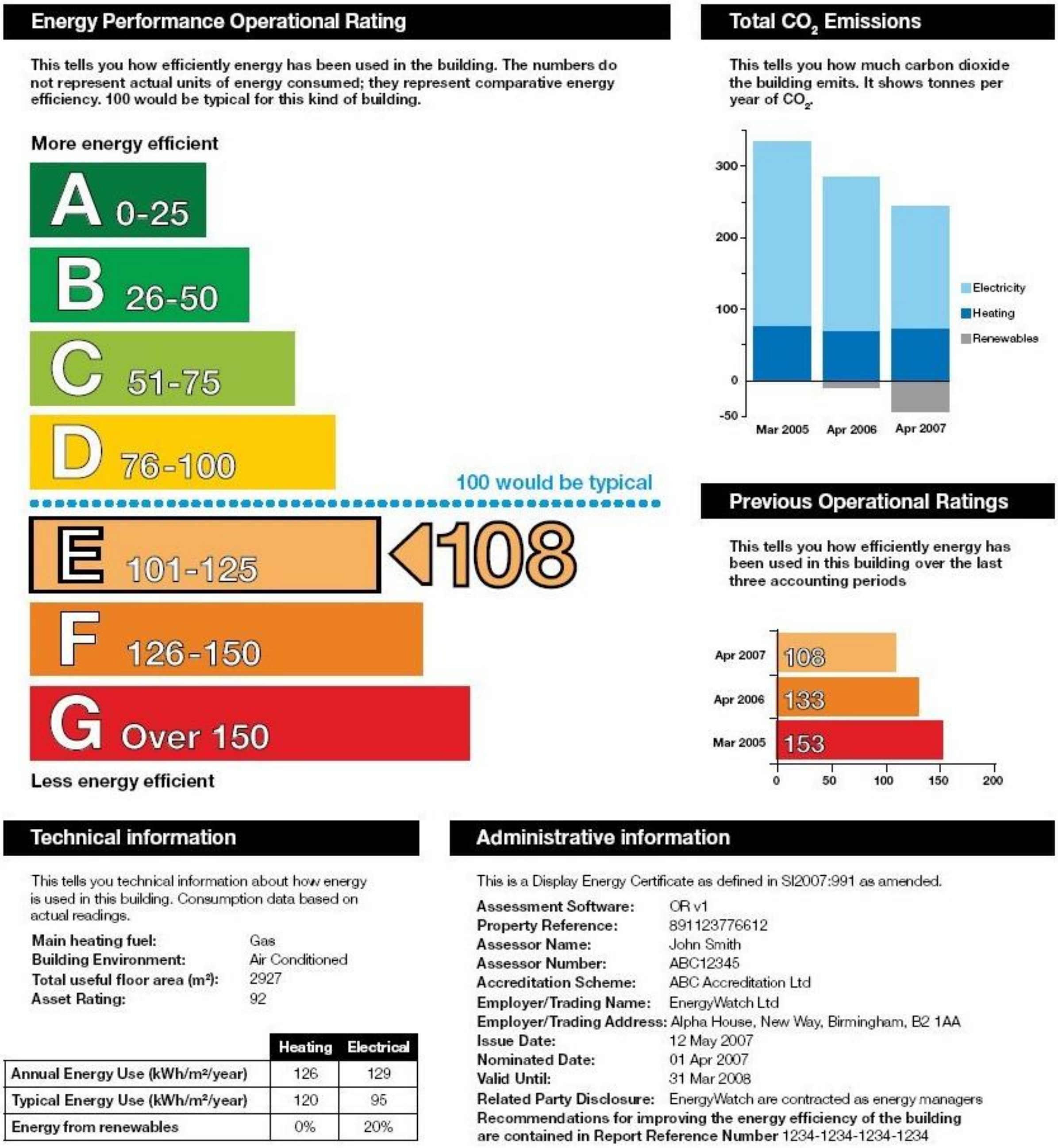

Figure 1-5: building energy performance certificate (Al-Shemmeri, 2011)

1.6 Literature review

Prior to the commencement of the thesis, some peer review scientific articles are reviewed. Those peer review scientific article gives some insight about the energy theory that will be of utmost importance to this thesis.

The research conducted into the embodied energy of a building shows an increase in the overall energy use in a building life. Building that have low or zero operational energy but high initial embodied energy cannot be regarded as the best option. The tool used for the analysis of the overall energy use in a building can be referred to as the Life Cycle Energy Analysis. Life Cycle Energy is used to analyse all the various stage of building life. The stage ranges from pre-use, use, and end-of-life of the building itself [12].

Energy analysis and refurbishment of building envelopes was another way of finding energy potential savings in building. This approach was used in the Zagreb University buildings. The approach centred at the material components of the building. Among other things that was considered during the audit was the thermal bridges and the building envelopes such as the walls, roofs, windows and the doors. In some instances, measures were taken to replace the windows and the doors with more energy efficient ones. Suitable thermal bridges were chosen to replace the existing ones and with all these measures, greater reduction in energy use in the Zagreb University buildings was achieved. Another important measure that was taken was the use of wind-protection door which can help to reduce the air flow rate ventilation losses [13].

Energy audit of schools by means of cluster analysis shows that, high level of energy use in school building does not only apply to Italian schools alone but also to most European countries as whole with emphasis primarily placed on two aspects. The first aspect is on the high level of energy use and the second aspect is an in-adequate level of comfort (both thermal and air quality). The study furthers shows that, the use of data mining techniques, such as the K-means clustering method can help reduce the energy use in school building. Clustering method referred to a process whereby large samples are divided into homogeneous and smaller groups based on the attribute or similarities of the buildings such as heated area, age of the building and heating system, envelope insulation, number of classrooms, students and occupancy profile. The European Commission these days are promoting the refurbishments of existing buildings by implementing a cost-optimal analysis of diverse retrofit enhancements, starting from a reference building, which must have a characteristics or similarities of a building category [14].

According to the study done on the faculty of Engineering and Technology at the University of Jordan. The study shows two different scenarios. The first scenario was carry out energy audit of the building without applying any measures and the second scenario was to apply energy efficiency measures. These gives significant reduction in the energy use of the department. The method or concept adopted can be regarded as level one and level two energy audit because there was no simulation that was carried out. The study further reveals that a window with larger area facing south, east and west can save more energy in the winter and reduce the heating cost. The use of double glazing while reducing the area of glazing north can save money and energy. Furthermore, considerable reduction in energy use in the department was achieved by using double glazing windows. These gives a reduction of around 10–12% in the cost of heating the department. The energy use in the lighting system of the department was reduced by using energy efficient bulb together with occupancy sensors in the class rooms, offices and other facilities, which comes on when there is need for lightning. With all these measures carried out during the study, there was greater reduction in the operating cost of the building [15].

Most of the studies that have been reviewed so far are limited to level two of energy auditing. Energy audit of building can further go to level three and level three of energy audit involve the use of simulation software to investigate the energy use in a building. During the assessment of the building, the building produces some energy conservation opportunities which was referred to as non-retrofitting (no or minimal cost) and retrofitting (with cost) recommendations. The non-retrofitting energy conservation opportunities total annual energy use that was saved was said to be around 6.5% while retrofitting energy conservation opportunities was said to be around 52% of the total energy use annually [9]. This interesting classification will be applied to the energy audit that will be done on the school in Fridhemsskolan to see if there are energy conservation opportunities that require no or minimal cost or retrofitting with cost.

Lighting system has been a major area of interest in building energy audit. Reduced energy use in lightning system will amount to an increase in energy savings and thus reduced the energy use of that building. The use of lightning control strategy has an energy saving potential of around 50%. If it is combined with dimmable general lighting, the energy saving potential can be increased to around 59% [16]. For this reason, attention will be paid to the lighting system in Fridhemsskolan to see if there will be some energy saving potential on the lightning system

The study towards nearly zero-energy buildings clearly identifies that; there must be collective policy making among members of the European Union to achieve lower energy use in building. Furthermore, energy efficiency and renewable energy requirements should be integrated; conversion of investment into energy savings should reflect economic value. Lastly, commitment should be made towards nearly zero-energy target. Measures that have important attributes on energy usage in a building can be further grouped into building envelopes, internal condition and building services [17].

Conducting an energy efficiency measures on building envelopes, internal condition and building services can increase the energy saving in a building. Another important part is the climatic condition of the location or region. Different climatic condition will require different approach in designing the building envelopes to fit the local climatic condition of the area or region. Furthermore, some criteria are developed to evaluate the thermal performance of building envelopes. The various criteria include overall thermal transfer value for region with subtropical climates (OTTV), evaluation of energy and thermal performance which can be applied in region with hot summer and cold winter climatic condition (EETP), envelope thermal transfer value (ETTV) which can be applied to region with tropical climate and lastly, the bioclimatic approach, by making use of passive design approaches for different climatic region. The reason for designing the building envelopes according to the climatic condition of a region is to reduce the amount of summer heat that is gain and the heat that will be loss through the building envelope in the winter so that, the corresponding heating and cooling needed in the building will not be more than what is required [18].

The study on the market barriers on energy conservation proposes different ways to reduce the market barriers on energy conservation. The first step in overcoming the barrier is to check the consumer attitude towards energy use which suggest must be changed to reduce the energy use in building. If these barriers can be considered properly, it can help to reduce the energy use by buildings [19].

Measuring the efficiency of intensive industries across European countries using data envelopment analysis consider multiple inputs and outputs to attain higher energy saving in an industry. This was attained by identifying the energy efficiency trend of an industry by differentiating between the overall effects of the efficiency and changes that may arises due technological changes. This approach can be used in the building sector to reduce the energy use in buildings [20].

1.7 Aim and objectives of the thesis

The aim of the research or thesis is to conduct an energy audit of the buildings in Fridhemsskolan using indoor climate and energy software (IDA ICE) to simulate the energy usage for a period of one year and then compare the result with energy bills for validation. After comparing the result of the simulation with energy bills obtained from Gavlefastigheter to an energy efficiency measure will be proposed to reduce the energy usage in buildings. The objectives of the thesis or research are to

- Conduct energy survey and energy analysis of the building number (4,5,6,7,8 and 9) in Fridhemsskolan.
- Propose energy efficiency measures that can be used to reduce the energy usage of the buildings based on the energy simulation results.
- Analyse and evaluate the cost of these measures. Propose further recommendations to improve the building performance.

1.8 Object (Fridhemsskolan)

The energy audit to be carried out was done in Fridhemsskolan which is an educational facility that is located in Almvägen 62, 80269 in Gävle municipality, Sweden. Fridhemsskolan is a preschool for children and for student up to grade 6. The total number pupils in the school are 350. The research will be performed on Hus (4,5,6,7,8 and 9). Each building has its own air handling unit (AHU) for the ventilation system. The heating system is supplied via district heating for some parts of the building heating is supplied via electrical heating. Furthermore, most of the rooms in the school consist of classrooms for teaching, group-work classes, kitchen, toilets and storage rooms. The opening hours for the school is from 06:00 to 17:00, Monday to Friday. The building situation plan is shown in the Figure 1-6 below.

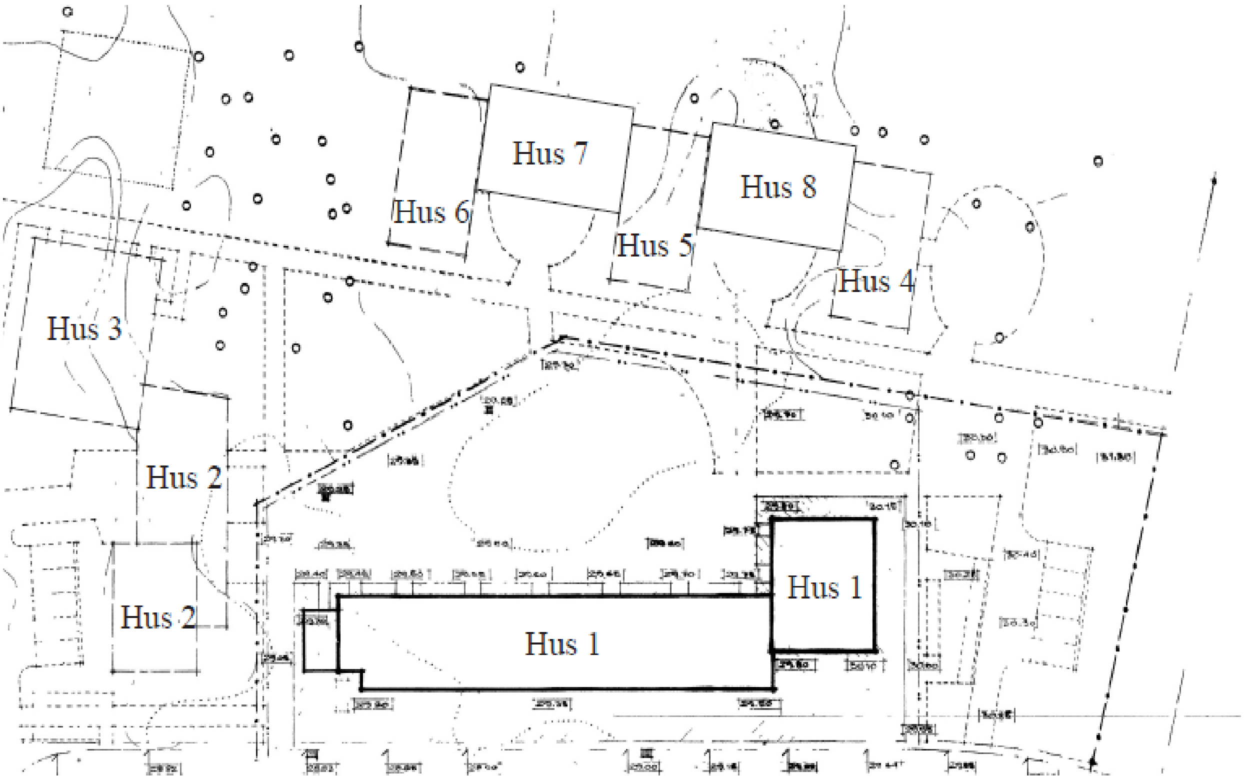

Figure 1-6: Situation plan for building or Hus 1-9 in Fridhemsskolan (source Gavlefastigheter)

1.9 Approach

The approach used for this research start with an onsite visit to the facility to take some measurements and at the same time take some vital information about the (lighting system, ventilation system, energy bills, wall construction, building plan, working schedule of the occupants etc.). The data collected was input into the indoor climate and energy software (IDA ICE) to create a base model for the building and this was used to simulate the energy use pattern of Hus (4,5,6,7,8 and 9) for a period of one year. After the completion of the base model, some energy efficiency measures are applied to the school building to reduce the energy usage based on the result obtained from the simulation.

2. Theory

2.1 Energy audit

The term “energy audit” can have different meanings depending on the energy service company. Energy audit in buildings can be a short walk-through of the facility to a more comprehensive analysis which can include hourly computer simulation. Generally, there are four types of energy audits and they are briefly described below [21].

2.1.1 Walk-through energy audit

The walk-through energy audit involves a short on-site visit to the facility. Some areas are pointed out to see where simple or no cost can provide an instant reduction in energy use or operating-cost savings. This are sometimes referred to as operating and maintenance (O&M) measures. An example of operating and maintenance includes setting back heating set-point temperatures, insulating exposed hot water or steam pipes, replacing broken windows, and adjusting boiler fuel–air ratio.

2.1.2 Utility Cost Analysis

The sole aim of the utility cost analysis it’s to carefully examine the operating cost of the building or facility that the energy audit will be carried on.The first thing to do in using utitlity cost analysis is to obtained utitlity data over some period of years and evaluate it in order to identify energy use pattern of the building or facility, peak demand,effects of weather and the potential for energy savings. In order to carry out the analysis,it is recommended that a work-through survey is carried out first so that the auditor will get familiar with the facility and the enegy system.

It is important to note that the utility rate structure that is used in the facility is clearly unerdstood by the energy auditor because of the of the following reasons stated below:

- The utility charges should be checked and verified so that, there are no mistakes made during the calculation of the monthly bills. For commercial buildings , the utility rate structures can be quite difficult with ratchet charges and power factor penalties [21].
- To find out the most dominant charges in utility bills. For example, peak demand charges can consistute the largest portion of the utitlity bill if ratchet rates are used [20].
- To know if the facility can profit from using other types of rate structures to purchase less expensive fuel and reduce its operating cost [21].

Furthermore, Utility Cost Analysis can be use to determine if the facility will require energy retrofit by analyzing the utility data [21].

2.1.3 Standard Energy Audit

The standard audit gives a detailed energy analysis for the energy systems of a particular building or facility. In addition to the walk-through audit and the utility cost analysis that have been described above, the standard energy audit invoves developing a baseline for the energy use pattern of the facility or the building and then, evealuate the energy savings and the cost-effectiveness carefully of some of the selcted energy conservation measures. Furthermore, some simple tools are used in the standard energy audit in order to develop the baseline energy models and to foresee the energy savings of energy efficiency measures. The tools that are commonly used are the degree-day methods and linear regression models. Furthermore, a simple payback analysis are done to determine the cost-effectiveness of energy conservation measures [21].

2.1.4 Detailed Energy Audit

Detailed energy audit is a comprehensive energy audit type, but it required longtime to be completed. Detailed energy audit requires the use of instruments to measure the energy use for the whole building. (for example, lighting systems, office equipment, fans, chillers, etc.). Detailed energy audit may involve the use of computer simulation programs to analyse and recommend energy retrofits for the building or the facility [21].

2.2 The heating and cooling loads in a building

2.2.1 Heating load in a building

If the air inside a building is warmer than the air outside, the building tends to lose heat through its envelope into the surrounding. Nevertheless, there can be some certain solar energy gain which can be through the windows and other heat gain can comes because of internal energy sources [22]. The total heat loss from a building is given by the following equation.

$$Q_{heat} = Q_{tr} + Q_{inf} - Q_{sol} - Q_{int} \text{ [W]}$$

Where

Q_{tr} = Building transmission heat loss

Q_{inf} = Building heat loss due to cold infiltration

Q_{sol} = Heat gain due to solar radiation absorbed in the building

Q_{int} = Heat gain from internal sources

2.2.1.1 Transmission heat loss in a building

Losses due to transmission are because of the heat that is passing through the building envelopes such as the windows, floors ceilings walls and so on. Furthermore, transmission losses equation in a building is given by the equation below

$$Q_{tr} = U_b A_b (t_i - t_o) \text{ [W]}$$

Where

U_b = The average overall heat transfer coefficient of a building in $[W/m^2\ K]$

A_b = The total exterior surface area of a building in $[m^2]$

t_i & t_o = The air temperature inside and outside the building in [°C]

But the average overall heat transfer coefficient of a building (U_b) is

$$U_b = \frac{\sum(A_i U_i)}{\sum A_i} \text{ [W/m}^2\text{ K]}$$

Where

A_i = The surface area of the building. $[m^2]$

U_i = The total heat transfer coefficient of a component of building envelopes .

$[W/m^2\ K]$

2.2.1.2 Infiltration heat loss in a building

The Infiltration heat loss in a building is equivalent to the total sensible heat and latent that is used in heating the cold air to room temperature and evaporates its moisture. Infiltration heat loss in a building is expressed as follows:

$$\mathcal{Q}_{\mathrm{inf}} = \mathcal{Q}_{\mathrm{sens}} + \mathcal{Q}_{\mathrm{lat}} = \mathrm{Z}\rho\mathcal{V}_{\mathrm{b}}\Big(\mathrm{C}_{\mathrm{p}}\,(t_i - t_{\mathrm{o}}) + (\mathcal{W}_i - \mathcal{W}_{\mathrm{o}})h_{\mathrm{fg}}\Big)\ [\mathrm{W}]$$

Where

$\mathcal{Q}_{\mathrm{sens}}$ & $\mathcal{Q}_{\mathrm{lat}}$ = The sensible heat and latent heat of the air [kW]

Z = The air exchange rate in l/s

ρ = The air density 1.2 [kg m^3]

$\mathcal{V}_{\mathrm{b}}$ = The volume of the building in [m^3]

C_{p} = The air isobaric specific heat capacity [J/kg K]

t_i & t_o = The air temperature inside and outside the building [°C]

$\mathcal{W}_i$ & $\mathcal{W}_{\mathrm{o}}$ = The humidity ratio of indoor and outdoor air [W/m^2 K]

h_{fg} = The enthalpy of evaporation [kJ/kg]

2.2.1.3 Heat gain in a building due to solar radiation absorbed

Consequently, the heat that is gain in a building because of the solar radiation absorbed by the building can also be calculated as follow.

$$\mathcal{Q}_{\mathrm{sol}} = \sum\Big((\tau\alpha)_{\mathrm{eff}}\ I_{\mathrm{sol}}\,\mathrm{A}\Big)\mathrm{i}\ [\mathrm{W}]$$

Where

$(\tau\alpha)_{\mathrm{eff}}$ = The effective product of transmissivity (τ)and absorptivity (α)of the room's interior surface

I_{sol} = The solar intensity of radiation

i = The incident on the interior surface [W/m^2]

A = The interior surface area in [m^2]

2.1.1.4 Heat gain from an internal source

The heat that is gain from the internal sources can come from the occupants of the building or people that are present in the building and it can also come from the equipment's or appliances that are used in the building itself [22]. The heat gain from internal source can be expressed as follows:

$Q\text{int} = \sum(\text{q}in i)$ [W]

Where

q_i = The rate of sensible and latent heat release from an internal heat source

n_i = The number of internal heat source of one kind.

2.1.1.5 The annual heating load of a building

Building annual heating load differs from time to time and this is due to variation in local climatic conditions, building design and material that is used during the construction of the building [22]. The annual heating load per meter square of floor surface area is expressed in (kWh/m² per year). The equation for the annual heating load can be expressed as follow

$Q_{\text{heat, year}} = \int_{\text{heat}}, \delta\tau$ [kWh]

Where

Q_{heat} = Heat transfer rate [kW]

$\delta\tau$ = Time or time intervals [s] or [h]

2.2.2 Cooling load of a building

During the summer when the outside air is warmer than the inside air, heat transfer takes place through the building envelopes onto the interior part of the building. However, there is also heat gain from solar radiation and at the same time internal heat source. [22]

$Q_{\text{cool}} = Q_{\text{sol}} + Q_{\text{tr}} - Q_{\text{inf}} + Q_{\text{int}}$ [W]

Where

Q_{tr} = The building transmission heat gain.

Q_{inf} = The building heat gain due to hot air infiltration.

Q_{sol} = The heat gains due to solar radiation absorption.

Q_{int} = The heat gain from internal sources.

2.2.2.1 Transmission heat gain in building

Transmission heat gain in building due to cooling can be express as follow:

$$Q_{tr} = (t_i - t_o) \sum(U_i)\, A_i \text{ [W]}$$

Where

t_i & t_o = The air temperature inside and outside the building. [°C]

U_i = The heat transfer coefficient of an individual part of the building envelope. [W/m^2 K]

A_i = The surface area of the component. [m^2]

2.2.3 Thermal insulation in building

Thermal insulation in building envelopes can help reduce heat loss. Some part of the building that should be insulted includes: external walls, roof or top floor ceiling, window frame, basement ceiling, heating system, hot piping and heat storage units. Materials that have thermal conductivity (k) ranging from 0.035-0.045 W/m*K are said to be suitable for insulation. Example of these type materials are Styrofoam, polystyrene, polyurethane, mineral and glass wool. Thermal bridges in building have lower thermal resistance compared to surrounding structural elements. Thermal bridges should be excluded from the building during the design and construction stages [22].

The heat transfer rate from an indoor air to outdoor air across the wall can be express with the equation below:

$$Q = U\, A\, (t_i - t_o) \text{ [W]}$$

where

U = The overall heat transfer coefficient for the heat transfer across the wall. [W/m^{2}K]

A = The wall surface area. [m^2]

t_i & t_o = The air temperature inside and outside the building. [°C]

The Overall heat transfer coefficient between the indoor air and outdoor air across uninsulated plane can be express as

$$\text{U} = \left(\frac{1}{\text{h}i} - \frac{\delta}{\text{k}} + \frac{1}{\text{ho}}\right)^{-1} \ [\text{W/m}^2\text{K}]$$

Where

h_i & h_o = Heat transfer coefficient (on the inner surface and the outer surface) [W/m²K]

δ = Thickness of the material [m]

k = Thermal conductivity of the material [W/m K]

2.2.3.1 The total thermal resistance of uninsulated wall

$$R = \frac{1}{\text{U}} \ [\text{m}^2 \ \text{K/W}]$$

Where

$$\text{U} = \left(\frac{1}{\text{h}i} - \frac{\delta}{\text{k}} + \frac{1}{\text{ho}}\right)^{-1} \ [\text{W/m}^2\text{K}]$$

h_i & h_o = Heat transfer coefficient (on the inner surface and the outer surface)

2.2.3.2 The Overall heat transfer coefficient of an insulated wall

$$\text{Uins} = \left(\frac{1}{\text{h}i} - \frac{\delta}{\text{k}} + \left(\frac{\delta}{\text{k}}\right)\text{ins} + \frac{1}{\text{ho}}\right) \ [\text{W/m}^2\text{K}]$$

Where

h_i & h_o = Heat transfer coefficient (on the inner surface and the outer surface) [W/m²K]

δ = Thickness of the material [m]

k = Thermal conductivity of the material [W/m K]

2.2.3.3 The total thermal resistance of an insulated wall

$$R\text{ins} = \frac{1}{\text{Uins} = \left(\frac{1}{\text{h}i} - \frac{\delta}{\text{k}} + \left(\frac{\delta}{\text{k}}\right)\text{ins} + \frac{1}{\text{ho}}\right)} \ [\text{m}^2\text{K/W}]$$

$$R\text{ins} = R + (\delta/\text{k})\text{ins}$$

2.2.3.4 Thickness of insulation needed to reduce heat loss rate

$\delta_{ins} = k_{ins} (R_{ins} - R)$ [m]

Where

δ_{ins} = The thickness of insulation material

R_{ins} = The thermal resistance of an insulated wall [m^2K/W]

R = The total thermal resistance of uninsulated wall [m^2K/W]

Meanwhile the total difference between the Q-values for an uninsulated and insulated wall is associated to the thermal resistance of the uninsulated and insulated wall as shown below

$$\Delta Q = A(t_i - t_o)(U - U_{ins}) = A(t_i - t_o)(1/R - 1/R_{ins}) \quad [W]$$

Thus, the total heat transfer coefficient for the whole building can be calculated as follows

$$U_{tot} = \frac{\sum (U A)_i}{\sum A_i} = \frac{(UA)_w + (UA)_{wd} + UA)_r + (UA)_f}{(A_w + A_{wd} + A_r + A_f)} \quad [W/m^2K]$$

Where

U_i = The overall heat transfer coefficient of the building envelopes [W/m^2K]

A_i = The surface area of building component [m^2]

A_w = The area of the wall [m^2]

A_{wd} = The area of the window [m^2]

A_r = The area of the roof [m^2]

A_f = The area of the floor [m^2]

2.3 The ventilation system

The sole aim of having ventilation system in a building is to provide healthy air for breathing by diluting the pollutants originating in the building and then removing the pollutants from it. This means that a good ventilation system should provide adequate level of thermal comfort and indoor air quality.

There are three ways of ventilating a building and this include natural ventilation, mechanical ventilation and mix mode ventilation [23]. In addition to that, indoor air quality, cost and the outdoor climatic condition are other factors that can influence the type of ventilation system that will be used in a building. The ventilation airflow that is supplied to a building can either be constant air volume (CAV) or variable air volume (VAV). Variable air volume is more applicable in commercial buildings because space in commercial buildings are divided into various zones. Each zone will require or demands different air temperature to keep the occupants with desirable thermal comfort [24].

2.4 Energy consumption pattern in Fridhemsskolan

The two-primary source of energy to the school (Fridhemsskolan) are district heating and electricity. District heating is used for space heating and tap hot water while electricity is used for air handling unit, lighting, equipment and appliances. Although some electric radiators are used in some part of the building. District heating and electricity usage for a period of three years was provided by Gavlefastigheter and this can be seen in Figure 2-7 and Figure 2-8 respectively. From the Figure 2-9 below, the trend in the energy consumption is increasing every year for both the district heating and the electricity.

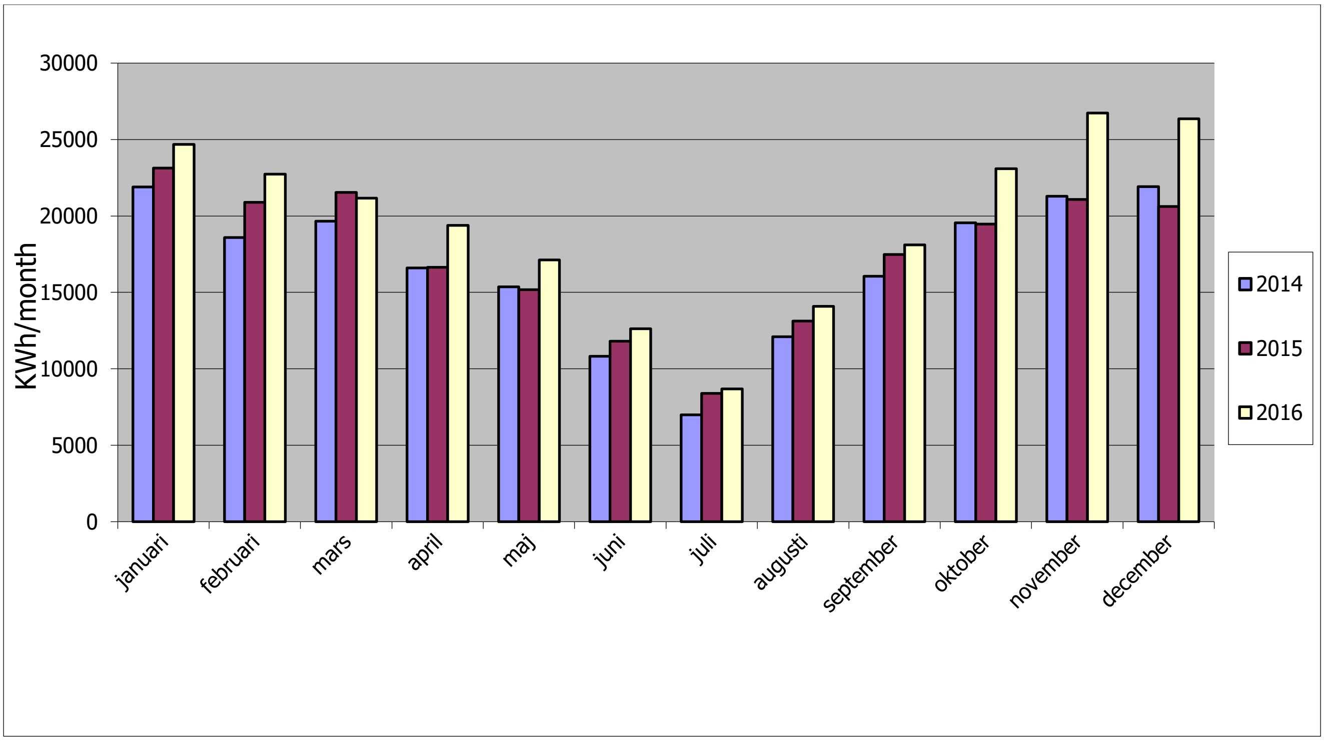

Figure 2-7: Monthly electricity usage in Fridhemsskolan for three years period Source: (Gavlefastigheter)

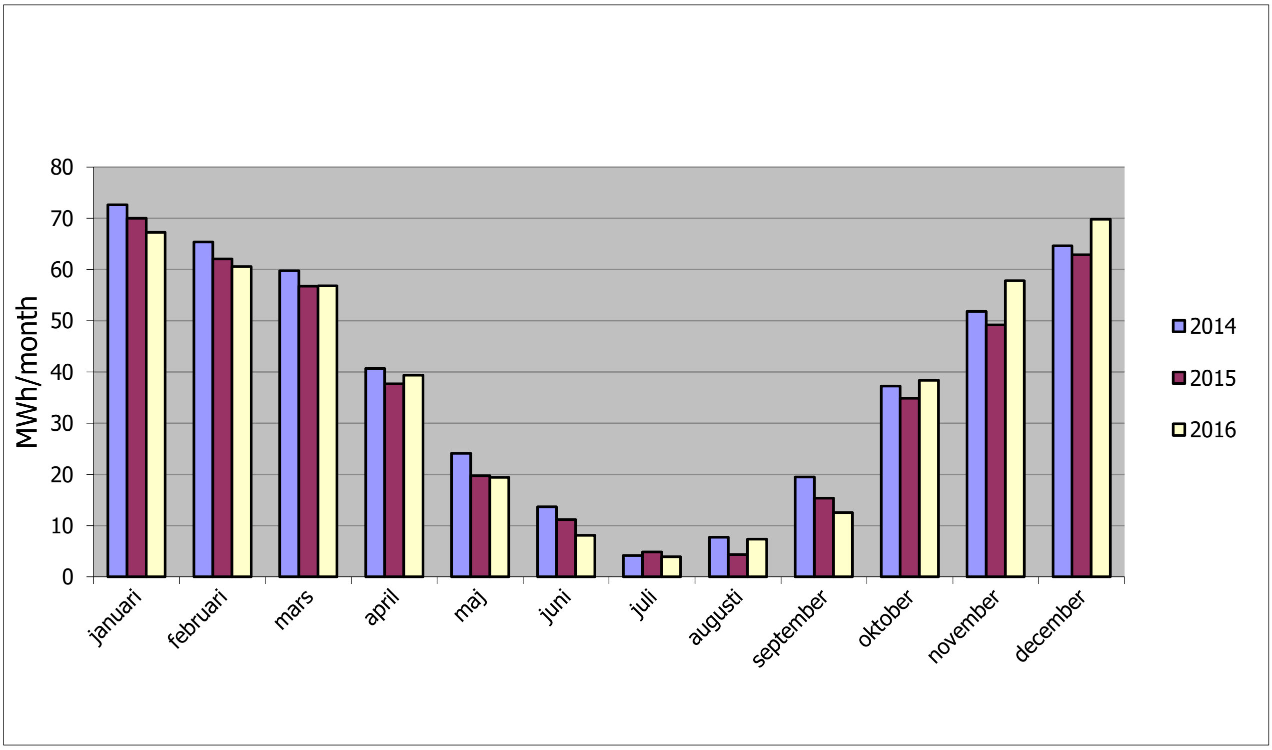

Figure 2-8: Monthly District heating usage in Fridhemsskolan for three years period Source: (Gavlefastigheter)

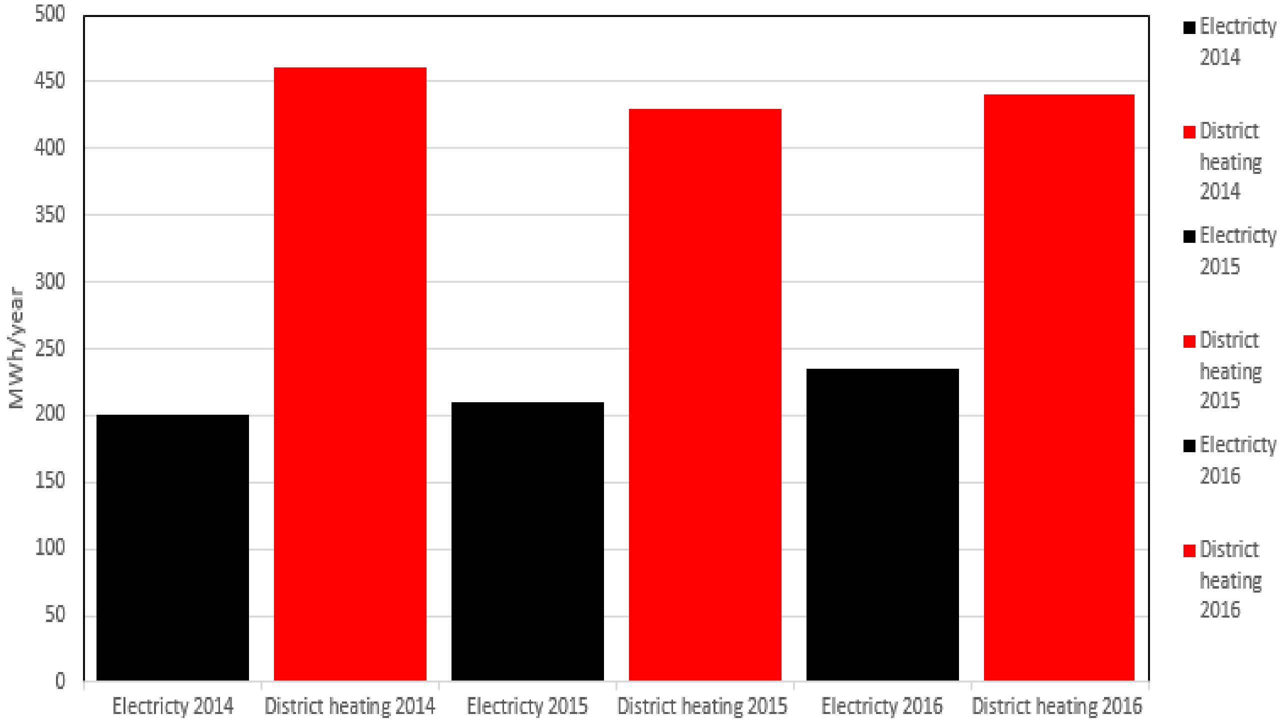

Figure 2-9: Showing the energy balance for the building in (Hus 1-9)in Fridhemsskolan

3.0 Method

As it has been mentioned previously in section 1.7 of this thesis, the aim is to perform energy audit on the school building in Fridhemsskolan using Indoor Climate and Energy (IDA ICE) software to simulate the energy use for a year and see where some energy efficiency measures can be applied to reduce the energy usage in the school building.

The report format and the data input for the energy simulation for this research follows the guidelines recommended by the European standard 15265-2006. The subsequent presentation of input data conforms with the guidance in the standard [25].

3.1 Measuring device

The following devices are used during the energy survey to carry out some measurements and this include

- The anemometer air velocity meter was used to measure the air velocity and the volumetric flow rate using a single probe with multiple sensors. It can measure the air velocity within the range of (0 to 30 m/s) and the accuracy range is between ±3% of the reading, while the volumetric flow rate range is a function of the actual velocity, pressure, duct size and the and K factor.

Figure 3-1: Anemometer for measuring air velocity meter and volumetric flowrate.

- This is an airflow meter which can be used to measure the exhaust airflow in a ventilation system within the range of 2 to 65 l/s

Figure 3-2: Airflow meter for measuring airflow rate.

Both devices mentioned above was use during the onsite visit to measure the actual ventilation flowrate within the building and sometimes the air velocity. When the ventilation flowrate cannot be measure directly; the anemometer air velocity meter was used to take the speed of the flow. The average speed is recorded and the area of object too was recorded and the flow rate is now calculated using the equation below

$$Q = \mathrm{V} * \mathrm{A}$$

Where

$Q =$ Airflow rate in $[\mathrm{m}^3/\mathrm{s}]$

$\mathrm{V} =$ Average velocity of the flow in $[\mathrm{m/s}]$

$\mathrm{A} =$ Area of the object depending if the shape circular or rectangular $[\mathrm{m}^2]$

$\mathrm{A} = \frac{\pi \mathrm{r}^2}{4}$ If the shape the duct is circular and $\mathrm{r} =$ radius of the object $[\mathrm{m}^2]$

$\mathrm{A} = \mathrm{L} * \mathrm{W}$ if the shape of the duct is rectangular and $\mathrm{L} =$ length and $\mathrm{W} =$ width $[\mathrm{m}^2]$

3.2 Data collection procedure and on-site visit

The research started with the data collection of necessary building documents from Gavlefastigheter and this include the construction drawings, ventilation drawings, energy bills, architectural drawings and yearly energy consumption for both district heating and electricity. Several onsite visits were done and during each visit, some measurements on the school building was performed and this include measuring the actual flowrate in each classroom, number of lamps with their ratings, number of equipment or appliances in each classroom with their ratings, the working hours for the air handling unit the number of radiator in each room and the number of electric radiators with their ratings. The measurements for the windows and doors was done manually because the drawing for it was unavailable or could not be provided by Gavlefastigheter. Some important information was also obtained from the staff of the school which include the time schedule for the occupants, the school working hours, number of pupils in each classroom and the total number of students and staff in the whole school.

3.3 Building locations, weather data, building description and the ground properties.

The school building to be simulated is located in Almvägen 62, 80269 in Gävle municipality, Sweden. The weather description is characterised by a cold climate. The ASHRAE IWEC2 Weather File for SODERHAMN was used as input data in the simulation model. The reason why SODERHAMN was used for the weather file was because Gävle cannot be found in the software. SODERHAMN shares the same climatic condition with Gävle and is in the same region.

The surface floor area for Hus (4-8) is 942.7 m^2 while Hus (9) surface floor area is 207.6 m^2. This can be seen in Appendix 8.1 and 8.2 respectively. The height of the building is 3m from the ground surface. The general information about the external wall for Hus (4-8) and Hus (9) can be seen in the Figure 3-1 and Figure 3-2. The external wall construction can also be seen Appendix 8.3 and 8.4 respectively.

Table 3-1: Showing the insulation material, thickness of insulation material, thermal conductivity and the U-value for Hus (4-8)

External wall (4-8)			
Insulation Material	Thickness (Meter)	Thermal Conductivity (W/m K) (λ)	U-Value Hus(4-8) (W/m² K)
Gypsum	0.025	0.22	**0.1481**
mineral wool	0.19	0.036	
Gypsum*	0.0095	0.22	
Air in vertical gap	0.043	0.25	
frames cc6000, Insulation	0.043	0.044	

Table 3-2: Showing the insulation material, thickness of insulation material, thermal conductivity and the U-value for Hus (9)

External wall (9)			
Insulation Material	Thickness (Meter)	Thermal Conductivity (W/m K) (λ)	U-Value Hus (9) (W/m² K)
Gypsum	0.025	0.22	**0.1527**
Mineral wool	0.19	0.036	
Gypsum*	0.0095	0.22	
Air in vertical gap	0.043	0.25	
frames cc6000, Insulation	0.034	0.044	

The windows in Hus (4-8) and Hus (9) are three panes glazing clear without shading. The area of the windows in Hus (4-8) are not the same throughout the building because, the windows are of different dimension and size. The same thing goes for all the window in Hus (9). The general information about the roof construction for Hus (4-9) can be seen in Figure 3-3. The roof construction details can also be seen in Appendix 8.5 and 8.6 respectively. The roof in Hus (4-9) has a U-value 0.6013. The external floor construction can also be seen in Figure 3-4.

Table 3-3: Showing the insulation material, thickness of insulation material, thermal conductivity and the U-value for Hus (4-9)

Roof in Hus (4-9)			
Insulation Material	Thickness (Meter)	Thermal Conductivity (W/m K) (λ)	U-Value Hus (9) (W/m² K)
Wood	0.023	0.140	**0.6013**
Chip board	0.0032	0.130	
Mineral wool	0.022	0.03	
frames cc6000, Insulation	0.028	0.04	
Gypsum	0.0125	0.22	

Table 3-4: Showing the insulation material, thickness of insulation material, thermal conductivity and the U-value for Hus (4-9) external floor.

External Floor Hus (4-9)			
Insulation Material	Thickness (Meter)	Thermal Conductivity (W/m K) (λ)	U-Value Hus (4-9) (W/m² K)
Concrete	0.1	0.3	**0.3184**
Cellplast	0.08	0.037	
Makadam	0.15	0.2	

The ground properties were modelled according the ISO-1370 and this will help to determine the heat transfer between the building and the ground.

3.4 The building internal temperature, ventilation and infiltration rate

The ventilation specifications and the thermal condition are chosen to conform with the values that was defined in EN-15251 for the category I of the indoor environment in the school classroom when it is occupied between 07:00 to 16:00 [25]. The design of the airflow rate works according to the working schedule for the ventilation system in the school. The working schedule for the ventilation system can be seen in Appendix 8.8. At full occupancy, there are

17 occupants in each classroom. According to the European standard EN-15251, it recommends 10 l/s (litre per seconds) per person as the ventilation rate for indoor environment category I and 1 l/(s*m^2) (litre per seconds meter square) when the buildings are less low polluting [25]. In this research, the ventilation rate for each room and the building was measured and input directly to the Indoor Climate and Energy (IDA ICE). The value for the ventilation rate in each building can be seen in Appendix 8.9. The infiltration rate was made to be wind driven flow with air tightness of 0.5 l/(s*m^2) (litre per seconds meter square) at a pressure of 50 Pa (Pascal). The pressure coefficient for the building was set to semi auto fill. This can also be seen in Appendix 8.10.

3.5 The Internal heat gains, occupancy and the (HVAC) system

The internal heat gains occur when heat is transferred directly to the room air by people, equipment and lightning and the same time heat is transferred indirectly from the walls, floors and ceiling of the room.

There are 17 occupants in each classroom and they contribute to both the latent and sensible heat load in the classrooms. The activity level of the occupants are 1.0 met (1 met = 58.15 W/m^2) (watt per square meter) and the overall heat produced per occupant was approximately 104 W (watt). The sensible and latent heat balance is calculated by the software [25]. The occupants of the building are present from Monday to Friday from 06:00 to 18:00 with a break in between and an hour lunch break in the noon. Saturdays, Sundays and public holidays are free days and are not included. The metabolic rate and the clothing insulation is modelled according to ASHRAE Standard 55-2013 [26]. In this research the clothing insulation is between 0.6 and 1.1 Clo and 1.0 met. The Appendix 8.11 shows the number of occupants in each classroom and the time schedule for the occupants in the classroom.

The HVAC system is modelled as a standard air handling unit with time schedule and this can be seen in Appendix 8.12. The air handling unit system uses CAV systems (constant air volume) which means that the airflow supply is constant but with a variable temperature to meet the classrooms need. In the air handling unit system, the cooling coil air side effectiveness is set to zero because only heating is required not cooling. The air handling unit system works according to the school working hours which is from 6:00 to 18:00.

3.6 The lightning system and domestic hot water

The lightning systems are modelled according to the ratings on the lamps and input directly to the indoor climate and energy (IDA ICE). The lightning system are switched on Monday to Friday between 06:00 to 18:00 every day but are off on Saturday, Sundays and public holidays. The lightning system also have time schedule and can be seen in Appendix 8.13. The lightning system are switched off outside the school working hours. The luminous efficiency and convective fraction for the lamps is calculated automatically by the indoor climate and energy (IDA ICE).

The domestic hot water usage was modelled based on the assumption that 45% of the total water usage in the building goes directly to the domestic hot water. The water usage for the year 2015 was taking from the monthly water usage provided by Gavlefastigheter. The monthly water usage can be seen in Appendix 8.14. The domestic hot water can now be calculated as follows:

Average domestic hot water use = water use for a year × 0.45/ total area of the building

$967.6\,m^3 \cdot \frac{0.45}{3073.6\,m^2} = 0.14\ \frac{m^3}{m^2}$ hot water usage m^3 / m^2 area of the building

3.7 Indoor climate and energy (IDA ICE) Simulation software

The indoor climate and energy (IDA ICE) is an energy simulation software that can be used to analyse the thermal comfort, indoor air quality and energy usage in a building. It also covers more advanced phenomena for example, an integrated airflow and thermal models, CO_2 modelling and vertical temperature gradients. The mathematical models are defined in terms of equations in a formal language called neutral model format (NMF). This makes it easier to change and upgrade the program modules [25].

3.7.1 Simulated cases

The simulated cases for this research work can be categorized into three and the procedure on how the simulation was done will be later explain,

- The first simulation scenario is to simulate for the base model with all the information that was collected during the onsite visit
- The second simulation scenario is to apply non-retrofitting energy efficiency measure with no cost by reducing the indoor temperature.

- The third simulation scenario is to apply retrofitting with cost recommendation by applying more insulation to some part of the building envelopes and then carry out a simulation.

3.7.2 Procedure for modelling the (IDA ICE) base model for the building.

All the data collected during onsite visit with schedules was used as an input data to create the baseline model of the school using the Indoor climate and energy Simulation software (IDA ICE). Furthermore, some assumptions was made and the following steps by steps defined the procedure for creating the baseline model for the school building.

- **Zone setting**

  The process of zone setting of the building begins by importing the architectural drawings into the indoor climate and energy simulation program (IDA ICE) by using AutoCAD or bitmap import function. Afterwards, the building plan is fitted with the right dimension, scaled and then divided into zones as it can be seen in Figure 3-3 and Figure 3-4.

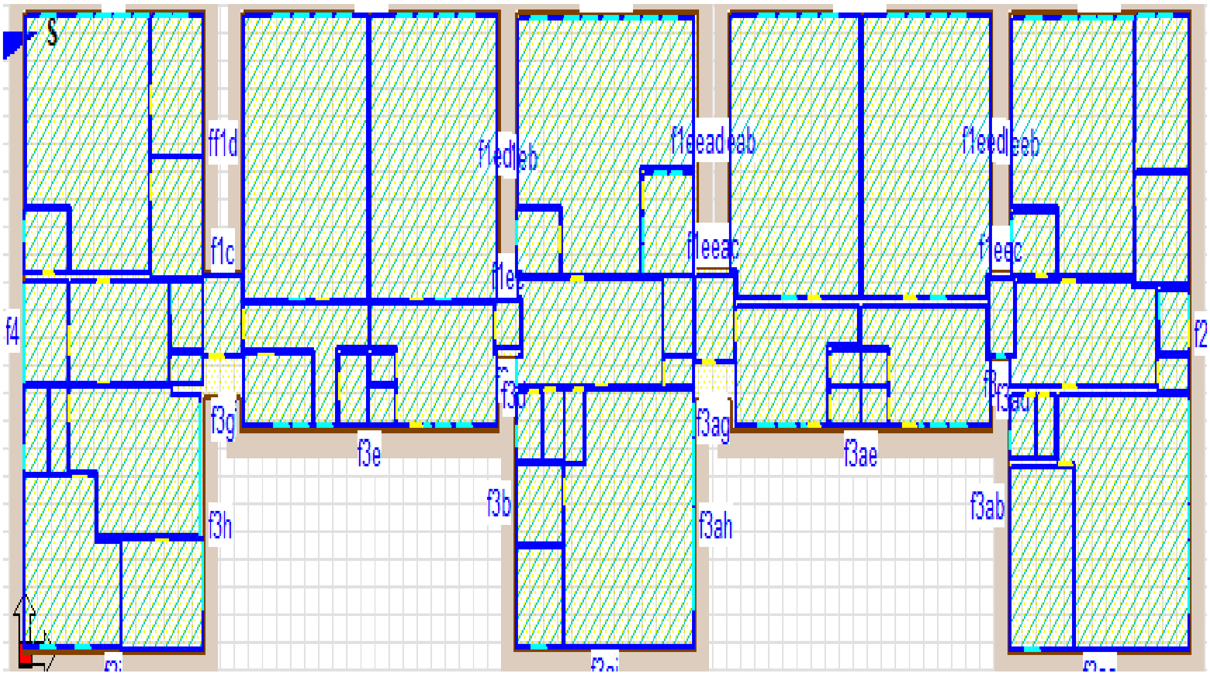

Figure 3-3: Showing the zone setting for (Hus) 4,5,6,7 and 8

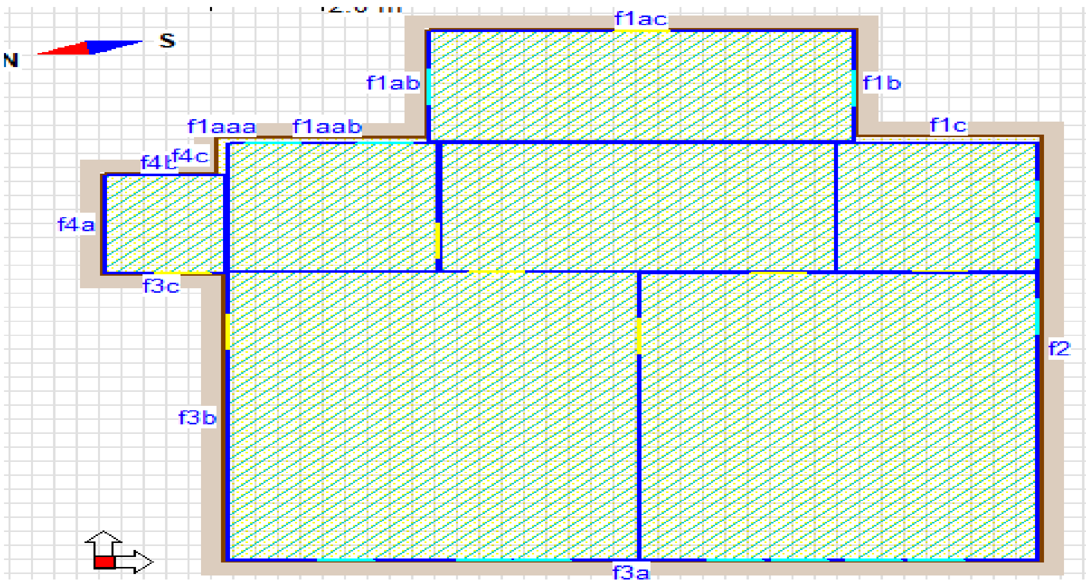

Figure 3-4: Showing the zone setting for (Hus) 4,5,6,7 and 8

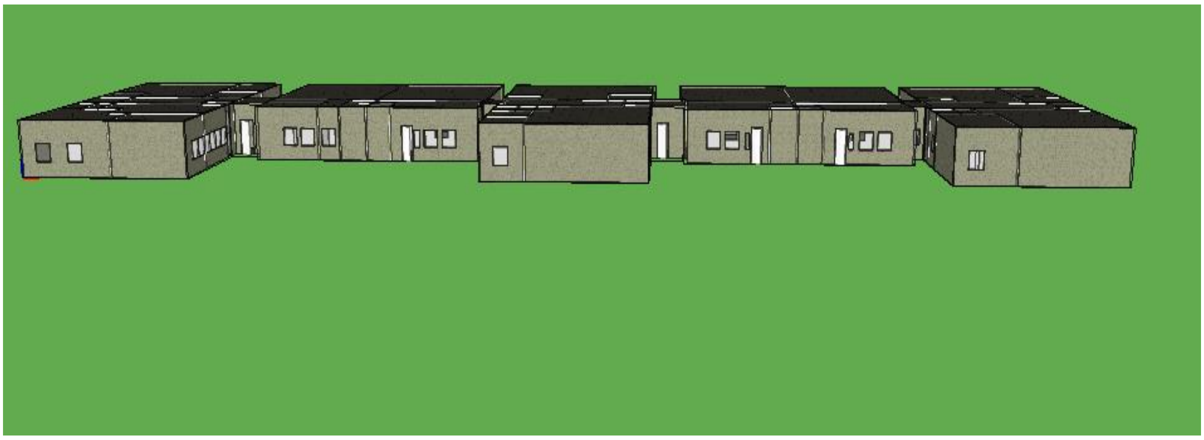

Figure 3-5: Overview of building (Hus) 4,5,6,7, and 8 from the building base model.

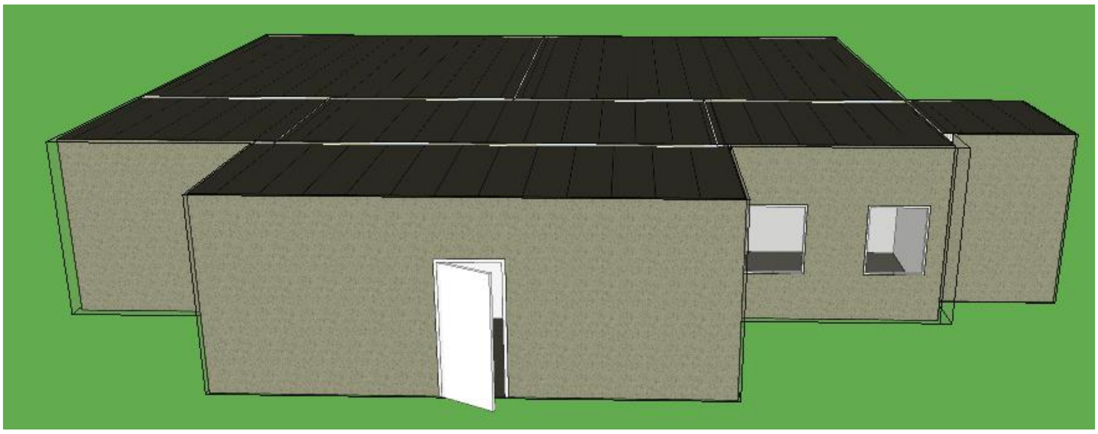

Figure 3-6: Overview of building (Hus) 9 from the building base model heating system

The heating system for the building was modelled as ideal heaters or electric radiators. In Hus (4,5,6,), the heating system was modelled as ideal heaters with district heating as the energy carrier while Hus(7&8) heating system was modelled as electric radiator with ratings obtained on the radiator and input directly on the indoor climate and energy (IDA ICE) Simulation software and the energy carrier for electric radiator is the electricity. All the buildings (from Hus (4-9) uses hydronic space heating system with the radiators spread all over the classrooms and in some special rooms in the building.

- **Ground properties**
  As it has been mentioned earlier in section 3.3, the ground properties were modelled according the ISO-1370 and this will determine the heat transfer between the building and the ground. The ground properties were modelled as 0.5 m layer of earth and 0.1m layer of insulation were used below the ground level of the building floor [27].
- **Ventilation rates for the base model**
  The ventilation rates for each zone in the building was set according to the data collected during the onsite energy survey.
- **The building envelopes for the base model**
  The building envelopes for the base model was modelled according the construction drawing obtained from Gavlefastigheter and this can be seen section 3.4. The windows for the building are 3 panes glazing clear.
- **Climate and location setting for the base model**
  As it has been mentioned earlier in section 3.3, the climate and location setting for the base model was set according to the ASHRAE IWEC2 Weather File for SODERHAMN. The reason for this was that, Gävle weather file cannot be found in the software but SODERHAMN shares the same climatic condition with Gävle and are in the same region.
- **The Air handling units**
  The air handling unit used for the base model is a standard air handling unit with a schedule. In the air handling unit system, the cooling coil air side effectiveness was set to zero because only heating is required not cooling. The air handling unit in Hus 4,5,6,7 has a rotary heat exchanger with heat recovery system while the air handling unit in Hus 7 and 8 uses a flat plate heat exchanger with a heat recovery heat bank. The effectives were set to 76% because, the field tests conducted by the Swedish energy agency on heat exchanger with heat recovery shows an average of 76% based on Swedish climatic conditions and this value has been used in various studies in Sweden

and the same value will be used for the effectiveness of the heat exchanger with heat recovery for the base model [28].

3.8 Assumptions and Limitation

Some data's and information's are not readily available and therefore some assumptions have to be made which constitute the basis for limitation for this thesis or study. These assumptions include

- The thermal bridges were assumed to be typical because there is no measurement that can be used to check the thermal bridges.
- The schedule for the occupants was difficult to defined because of the students and staff moving from one class to another.
- The schedule for the equipment in the base model was defined by asking the staff on how often those equipment is used in the school. The response gotten was used to create the schedule for the equipment.
- The assumption made on the domestic hot water usage in the base model was that,45% of the total water usage in the school building was hot water with the heating source coming from the district heating. The total value for the domestic hot water use was estimated to be 0.14 m^3/m^2 for a year.
- The infiltration rate was assumed to be at an air tightness of 0.5 ACH (air change per hour) and at a differential pressure of 50 Pa (pascal) based on the study [28].
- Measuring the total district heating and electricity consumption supplied to each building was not possible in this study because there were no measuring devices to take the measurements directly from the source; rather, an estimated value of the total electricity and district heating consumption for the building was done using the formula called building normalized performance indicator. This is done by diving the total annual energy consumption of the building to the total floor area of the building [29].

$$\text{BNPI} = \frac{\text{Total yearly energy consumption of the building}}{\text{Total floor area of the building}}$$

Building normalized performance for the district heating Usage

$$\frac{445.0999828}{3073.6} = \frac{0.145\ \text{MWh}}{\text{m}^2.\,\text{year}}$$

Building normalized performance for the electricity usage

$$\frac{205.1425}{3073.6} = \frac{0.07\ \ \text{MWh}}{\text{m}^2.\,\text{year}}$$

Total district heating supplied to Hus $(4-9) = 0.145 \times$ total area for Hus$(4-9)$

Where total area for Hus$(4-9)$ extracted from the base model $= 1150.3\ \text{m}^2$

$0.145 \times 1150.3\ = 166\ \text{MWh/year}$

Total electricity supplied to Hus $(4-9)$

$0.07 * 1150.3 = 81\ \text{MWh/year}$

After obtaining the estimated district heating and electricity consumption for the building using the building normalized performance indicator, this value will now be compared with the simulation result from the base model to validate the base model simulation and at the same time, the energy bills will also be used to validate the simulated result from the base model and this will be further discussed on the result section of the study or research.

3.9 The building energy balance and energy saving opportunities

After running the simulation for the base model, the next step is to analyse the building energy balance to see which part of the building has higher energy losses. After proper analysis of the energy balance, energy efficiency measures like retrofitting and non/retrofitting measures will be applied to the base model and simulated again and then re-examined to see if there is a change in the energy consumption pattern of the building after applying those measures.

4.0 Result

4.1 Validation of the building base model

The result of the simulation from the base model can be validated in two ways and this include

- Comparing the result of simulation from the base model with the whole energy bill for the whole school. For this to be done; the result of the simulation for the rest of the building will be needed too and this will be the result from (Hus 1-3)
- Another way to compare the result of the simulation of the base model is to compare it with the value of the building normalized performance indicator which was obtained for both the district heating and the electricity consumption in Hus (4-9).

4.1.1 Validating the base model with the energy bill

Table 4-1: Average value for the district heating and electricity in 2014-2015

Months	District Heating (MWh)	Electricity (MWh)
Jan	71.4	22.5
Feb	63.7	19.7
Mar	58.3	20.6
Apr	39.2	16.6
May	21.9	15.2
Jun	12.4	11.3
Jul	4.5	7.7
Aug	6.0	12.6
Sep	17.4	16.8
Oct	36.1	19.5
Nov	50.5	21.2
Dec	63.6	21.3
Total	445.1	205.1

Table 4-2: Result of simulation from the base model

Building	District Heating (MWh/year)	Electricity (MWh/year)
Hus 9	32	4
Hus 4-8	126	85
Total	157	89

The result of the base model simulation for Hus (9) and Hus (4-8) can also be seen in Appendix 8.15 in Table 8.1 and Table 8.2 in terms of the energy delivered to each building which was obtained in Indoor climate and energy (IDA ICE) Simulation software.

Table 4-3: Result of simulation of the case study for the rest of the school

Building	District Heating (MWh/year)	Electricity (MWh/year)
Hus 1	133.26	56.51
Hus 2	142.84	56.84
Hus 3	23.25	7.69
Total	299.35	121.04

By comparing the results from the base model simulation with the actual district heating and electrical usage in the energy bill, there will be some percentage error and the total percentage error is thus calculated as follow

District heating

- Total district heating usage for Hus $(1 - 9)$ from the base model $= 456.35\ \mathrm{MWh/year}$
- Total district heating from energy bill for Hus $(1 - 9) = 445.1\ \mathrm{MWh/year}$
- $= 456.35\ \mathrm{MWh/year} - 445.1\ \mathrm{MWh/year} = 11.25\ \mathrm{MWh/year}$
- Total percentage error $11.25/445.1 = 0.00253 = 2.5\%$

Electricity

- Total electricity usage for Hus (1-9) from the base model = 210.04 MWh/year
- Total electricity usage from energy bill for Hus (1-9) = 205.1 MWh/year
- $= 210.04\ \mathrm{MWh/year} - 205.1\ \mathrm{MWh/year} = 4.94\ \mathrm{MWh/year}$
- Percentage error $= 4.94/205.1 = 0.0241 = 2.41\%$

Table 4-4: Result of the percentage error for Hus (1-9) when compared with the energy bills (1-9)

Building	District Heating (% error)	Electricity (% error)
Hus (1-9)	2.5	2.41

Since the value obtained for the district heating and electricity usage are within $\pm 10\%$ range, thus the result for the base model simulation is acceptable when compared with the energy bills.

4.1.2 Validating the base model with the building normalized performance indicator.

Table 4-5: Result from the building normalized performance indicator for Hus (4-9)

Building Normalized Performance Indicator for Hus (4-9)		
Building	District Heating energy supply (MWh/year)	Electricity (MWh/year)
Hus (4-9)	166	81

District heating

- Total district heating usage for Hus $(4-9)$ from the base model $= 157$ MWh/year
- Total District heating estimation usage from the building normalized performance indicator for Hus $(4-9) = 166$ MWh/year
- $= 166$ MWh/year $- 157$ MWh/year $= 9$ MWh/year
- Percentage error $= 9/166 = 0.054 = 5.4\%$

Electricity

- Total electricity usage for Hus $(4-9)$ from the base model $= 89$ MWh/year
- Total electricity usage estimation from the building normalized performance indicator for Hus $(4-9) = 81$ MWh/year
- $= 89$ MWh/year – 81 MWh/year $= 8$ MWh/year
- Percentage error $= 8/81 = 0.0241 = 0.098 = 9.9\%$

Table 4-6: Result of the percentage error for Hus (4-9) when compared with the building normalized performance indicator.

Building	District Heating (% error)	Electricity (% error)
Hus (4-9)	5.4	9.9

Since the value obtained for the district heating and electricity usage are within $\pm 10\%$ range, thus the result for the base model simulation is acceptable too using building normalized performance indicator.

4.2 Indoor air quality and thermal comfort from the base model

The base model for the indoor air quality and thermal comfort for the building was modelled or defined according to the European standard EN-15251 in the indoor climate and energy (IDA ICE) simulation software.

4.2.1 Thermal comfort for the base model

IDA-ICE integrates ISO 7730 and other standards in evaluating thermal comfort. The results of comfort are based on Fangers. From the results, the predicated percentage of dissatisfied (PPD) was 12 % of the base model Hus 9 and 13% of Hus (4-9). However, the percentage of hours when operative temperature is above 27 ℃ is 1% for both Hus 9 and Hus (4-9). Table 4-7 show the average PPD for the base models. In the both models the PPD is within the accepted standard of ISO 7730 of less than 15%.

Table 4-7: Result of the average PPD the base model for Hus (4-9)

Building	Predicted Percentage of dissatisfied (PPD %)
Hus (9)	12
Hus (4-9)	13

4.2.2 Indoor air quality

Table 4-8 & 4-9 below show the respective monthly average carbon dioxide (CO_2) concentration for Hus (4-8) and Hus (9). The monthly average (CO_2) concentration for Hus (4-8) and Hus (9) are within the acceptable range of 1000 parts-per-million (ppm). The maximum CO_2 level for Hus (4-8) is 939.4 ppm and 753.9 ppm for Hus 9. These are recorded in different months.

Table 4-8: Average Carbon dioxide concentration for Hus (4-8) from the base model.

Months	CO_2, ppm (vol)
January	906.7
February	842.8
March	893.3
April	905.1
May	871.9
June	643.3
July	400
August	571.3
September	939.4
October	875.8
November	857.9
December	745.9

Table 4-9: Average Carbon dioxide concentration for Hus (9) from the base model.

Months	CO_2, ppm (vol)
January	570.3
February	658
March	680.8
April	732.6
May	753.9
June	490.6
July	400
August	611.8
September	775
October	718.8
November	697.1
December	589.3

4.3 The building energy balance from the baseline model.

According to the building energy balance from the baseline model in Figure 4-1 and Figure 4-2 for both Hus (4-8) and Hus (9). The highest losses occur in the building envelope and the thermal bridges for both buildings. The overview of the energy balance for the zones can also be seen in Appendix 8.16 for both Hus (4-8) and Hus (9).

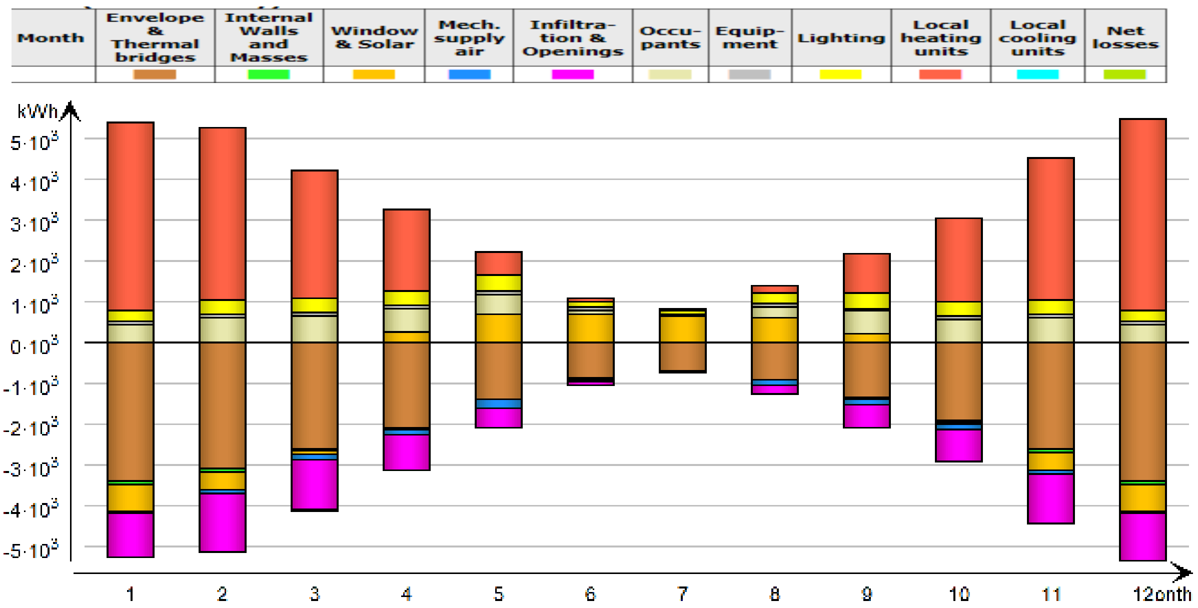

Figure 4-1: Energy balance for Hus (9)

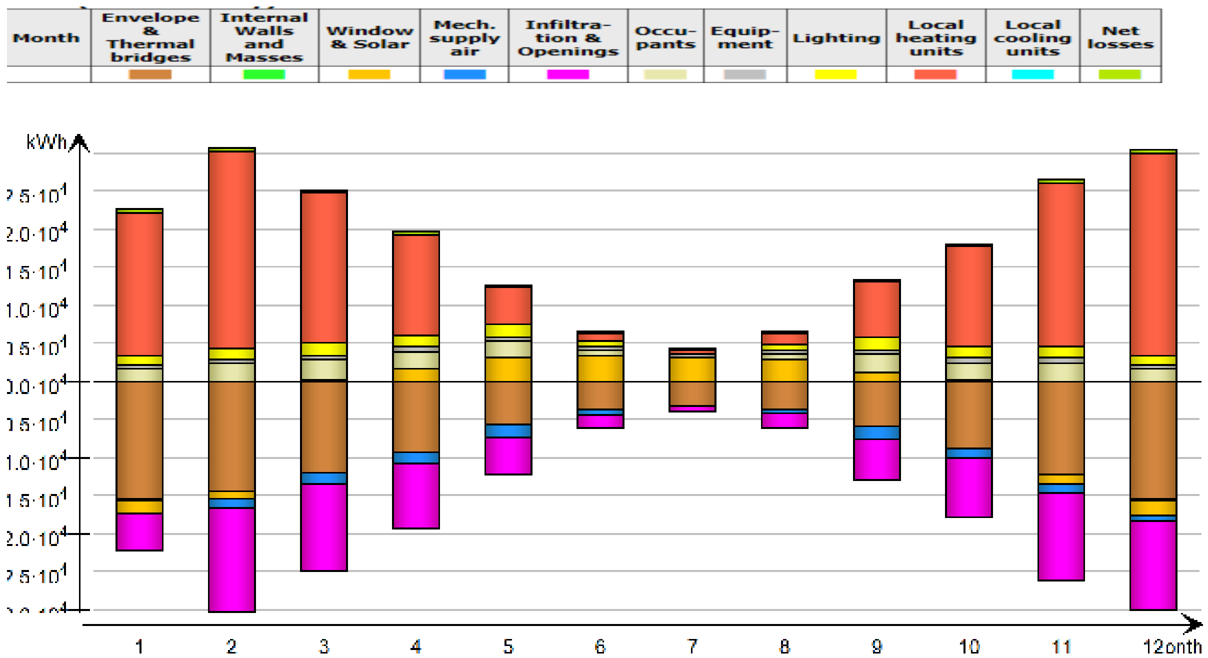

Figure 4-2: Energy balance for Hus (4-8)

Further analysis of the building envelope transmissions from the baseline model will help to show how the losses in the building envelope are distributed for both Hus (9) and Hus (4-8) this can be seen in Figure 4-3 and Figure 4-4 below. The envelope transmission from the baseline model for Hus (9) and Hus (4-8) shows the roof has more losses than any other parts of the building envelopes.

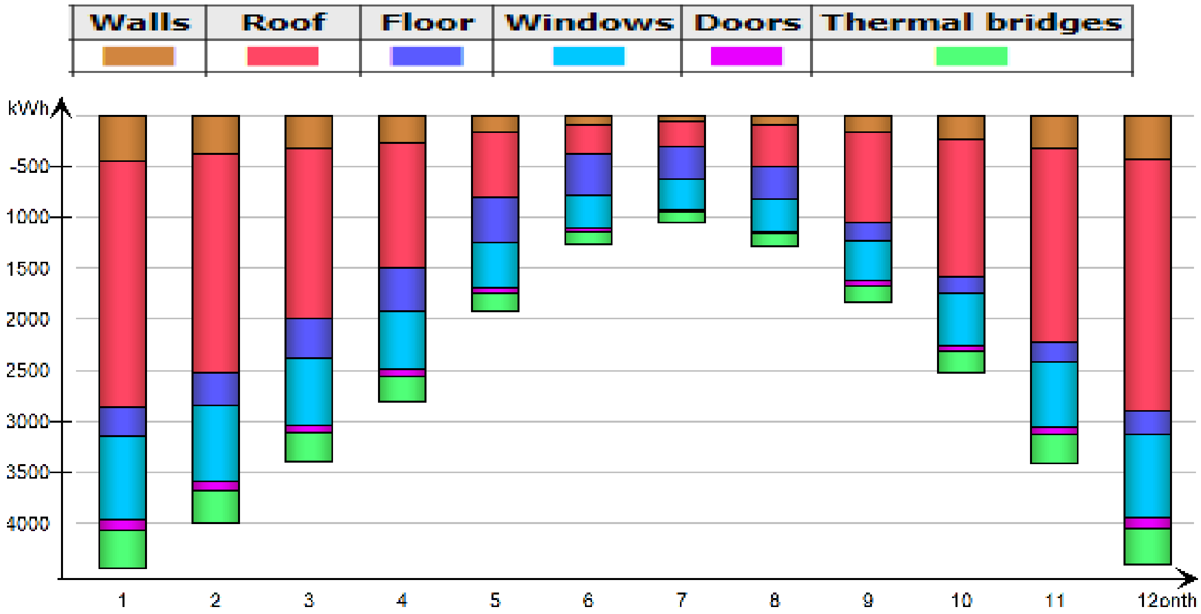

Figure 4-3: The building Envelope transmission for Hus (9) from the base model

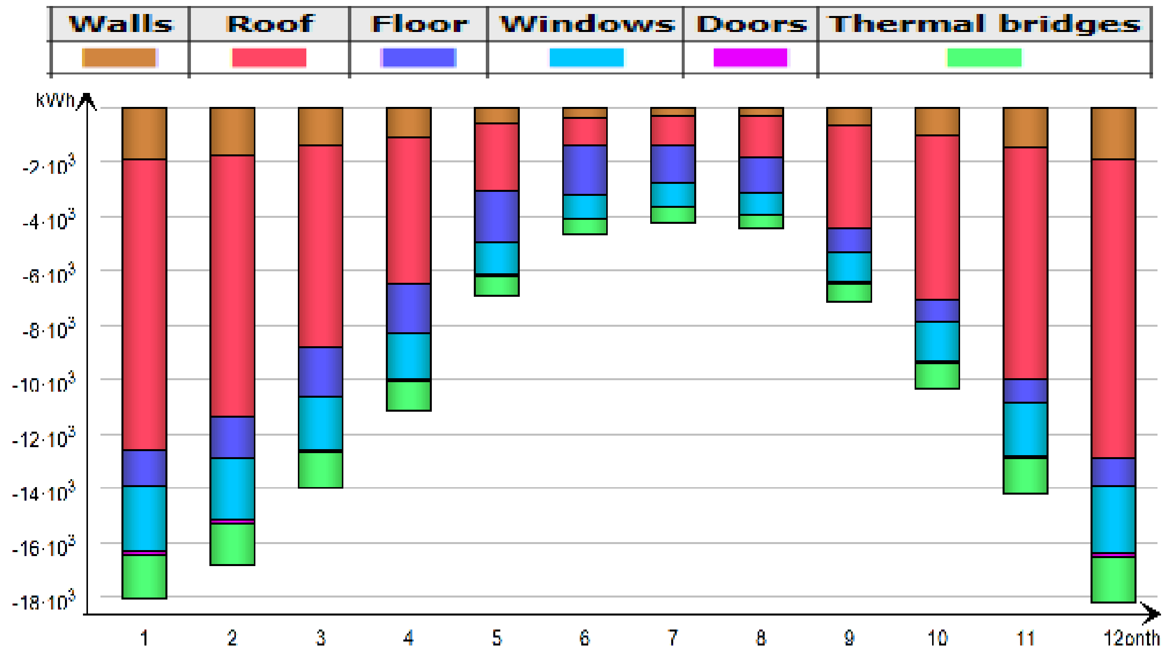

Figure 4-4: The building Envelope transmission for Hus (4-8) from the base model

4.4 The energy savings opportunities

The first scenario is to apply non-retrofitting energy efficiency measure with no cost by reducing the indoor temperature while the second scenario is to apply retrofitting with cost recommendations by analysing the building energy balance and see where there is energy saving opportunities. The building energy balance for this study has shown that, there is more saving potentials the building envelopes and further analysis of the envelope transmission shows the roof has more heat losses than any other part of the building envelope.

4.4.1 Non-retrofitting by reducing the indoor temperature

Non-retrofitting (with no cost) is referred to as an energy saving potential in a building that require no investment cost to carry out. In this study, this will be done by setting the temperature controller setpoint in the building from (19ºC-20ºC) to (18ºC-19ºC) in the indoor climate and energy (IDA ICE). Careful consideration must be taken because reducing the indoor temperature should not compromise the thermal comfort of the occupants in that building. The thermal comfort and the indoor air quality of the occupants in the indoor climate and energy (IDA ICE) was modelled using the European standard EN-15251 which will be used to show that the thermal comfort and air quality of the occupants are not compromised by reducing the indoor temperature.

Table 4-10: The energy use after reducing the indoor temperature

Building	District heating after reducing the indoor temperature (MWh/year)	Electricity after reducing the indoor temperature (MWh/year)
Hus (9)	29	4.9
Hus (4-8)	117	81.5
Total	147	86.4

Table 4-10 above shows the total energy use of the building after reducing the indoor temperature. The price for the district heating was estimated be around 0.63 SEK/ kWh [33].

However, the Savings in district heating (SEK/year) is therefore calculated as seen below:

Savings in district heating (SEK/year)

- $\text{Savings in district heating (kWh/year)} * \text{ District heating cost (SEK/kWh)}$
- $\text{District heating use before reducing the indoor temperature} = 157 \text{ MWh/year}$
- $\text{District heating use after reducing the indoor temperature} = 147.6 \text{ MWh/year}$
- $\text{Energy saving in district heating use} = 157 - 147.6 = 9.34 \text{ MWh/year}$
- $\text{Savings in district heating } \left(\frac{\text{SEK}}{\text{year}}\right) = 630\text{kr/MWh} * 9.34 \text{ MWh/year}$

  $= 5{,}884 \text{ SEK/year}$
- $9.34/157 = 5.9 = 6\%$

Decreasing the indoor temperature will amount to a saving of 9.34 MWh/year in the district heating without no investment and this will amount to 5884 SEK/year. It should be noted that, the estimated saving in Swedish Krona (SEK) for the district does not include the energy tax and moms. Figure 4-5 below shows the energy saving for the district heating use after reducing the indoor temperature.

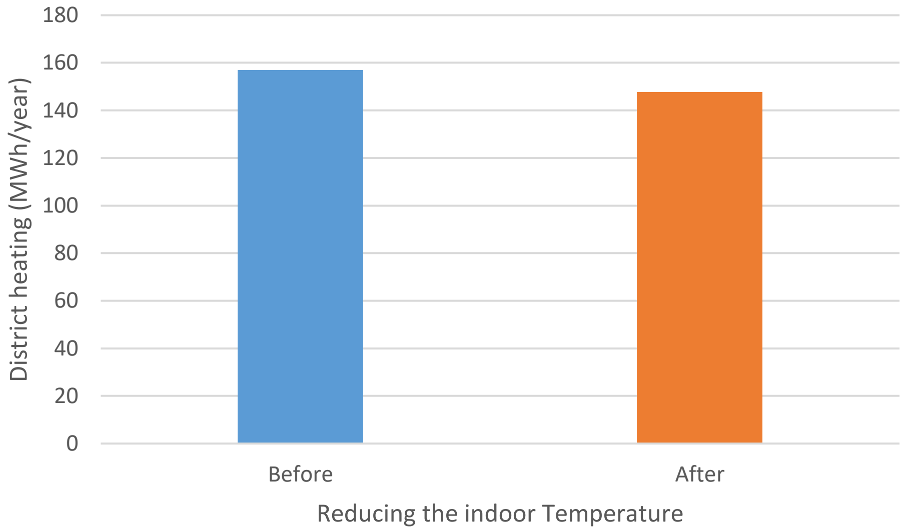

Figure 4-5: Energy savings in district heating use after reducing the indoor temperature

Savings in Electricity (SEK/year)

- Savings in electricity (kWh/year) $*$ electricity cost (SEK/kWh)
- Electricity cost take from the energy bill 0.389 SEK/kwh
- Electricity use before reducing the indoor temperature $= 89$ MWh/year
- Electricity use after reducing the indoor temperature $= 86.4$ MWh/year
- Energy saving in electricity use $= 89$ MWh/year $- 86.4$ MWh/year $= 2.6$ MWh/year
- Savings in Electricity (SEK/year) $= 2.6$ MWh/year $*$ 389 SEK/MWh $= 1{,}011$ SEK/year
- $2.6/89 = 0.029 = 3\%$

Decreasing the indoor temperature will amount to a saving of 2.6 MWh/year in the electricity without no investment and this will amount to 1,011 SEK/year. It should be noted that, the estimated saving in Swedish Krona (SEK) for the electricity does not include the energy tax and moms. Figure 4-6 below shows the energy saving for the electricity use after reducing the indoor temperature.

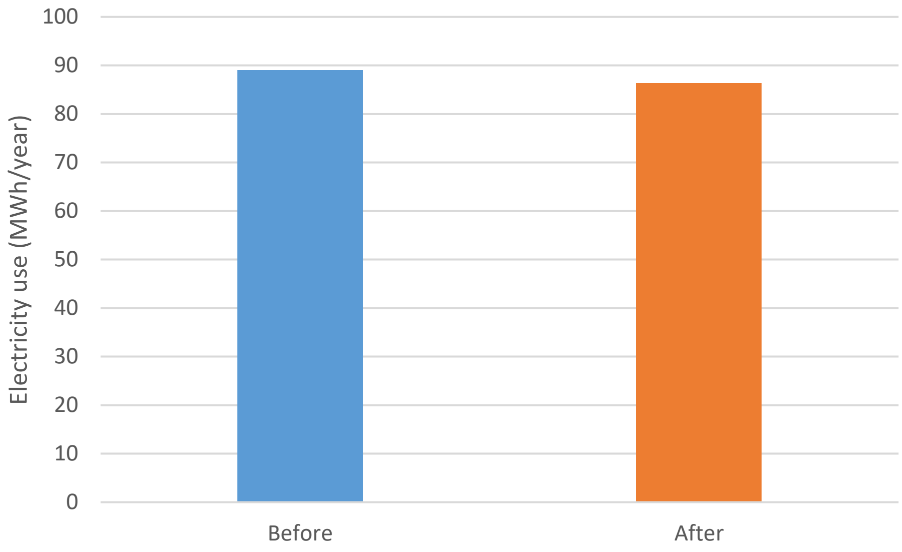

Figure 4-6: Energy savings in electricity use after reducing the indoor temperature

4.4.2 Thermal comfort of the occupants after reducing the indoor temperature

Lowering indoor temperature increases the PPD for both buildings. The percentage of the total occupant hours with thermal dissatisfaction increases to 13% from 14 % for Hus 9 and from 13% to 15% for Hus (4-8). Table 4-11 shows the comparison with the base model when temperature is lowered.

Table 4-11: Result of the average PDD after reducing the temperature for Hus (4-9)

Building	PDD (%)
Hus (9)	14
Hus (4-9)	15

4.4.3 Indoor air quality of the occupants after reducing the indoor temperature

As it has been mentioned before, the indoor air quality in an occupied room or zone is associated with relative humidity, air age in the room and the carbon dioxide ($CO_{2,}$). This study will only be concern with the level of the carbon dioxide (CO_2) concentration in the room after reducing the indoor temperature to see if the level of carbon dioxide (CO_2) is above the 1000 parts-per-million (ppm). Table 4-12 & 4-13 show the average carbon dioxide (CO_2) concentrations for Hus (4-8) and Hus (9) which was obtained after reducing the indoor temperature. The monthly average carbon dioxide (CO_2) concentrations in Hus (4-8) and Hus (9) in the occupied zone are within an acceptable range of 1000 parts-per-million (ppm) [32].

Table 4-12: Average Carbon dioxide concentration in Hus (4-8) after reducing the indoor temperature

Months	CO_2, ppm (vol)
January	911.0
February	843.5
March	893.2
April	904.6
May	870.9
June	644
July	400
August	571
September	938.7
October	875.2
November	859.2
December	746.7

Table 4-13: Average Carbon dioxide concentration in Hus (9) after reducing the indoor temperature

Months	CO_2, ppm (vol)
January	574.8
February	661.5
March	705.5
April	756.8
May	790.8
June	497.7
July	400
August	634.1
September	814.7
October	745.5
November	702.1
December	590.8

4.4.4 Retrofitting (with cost) recommendations

Retrofitting with cost involves changing or adding some material in the building that can help to reduce the energy consumption in the building and at the same time will give a desirable pay back after retrofitting. Implementing retrofit in Hus (4-9) will require the analysis of the envelope transmission from the base model. This will be significant because the envelope transmission will show which part of the building envelope is having more heat losses and the value for the heat losses can be seen in Appendix 8.17. The part of the building in Hus (4-8) and Hus (9) that will require retrofitting is the roof. Furthermore, Hus (4-8) electrical radiators will be replace with ideal heaters because it is cheaper to heat with district heating than electricity. The cost per square meter of mineral wool was estimated to be (48.10 SEK) [34]. The result of the energy use from the simulation software after retrofitting of Hus (4-9) can be found in Appendix 8.18 and in Table 4-14.

Table 4-14: The energy use in Hus (4-9) after retrofitting of the roof

Building	District heating use after adding 170 mm mineral wool to the roof (MWh/year)	Electricity use after adding 170 mm mineral wool to the roof (MWh/year)
Hus (9)	22.0	5.0
Hus (4-8)	120.0	21.0
Total	142.0	26.0

Savings in district heating (SEK/year)

- Savings in district heating(kWh/year) $*$ District heating cost (SEK/kWh)
- District heating use before retrofitting $= 157$ MWh/year
- District heating use after retrofitting $= 142$ MWh/year
- Energy saving in district use $= 157 - 142 = 15$ MWh/year
- Savings in district heating (SEK/year) $= 630$ MWh/year $*$ 15 MWh/year $= 9{,}450$ SEK/year
- $\frac{15}{157} \approx 0.096 \approx 9.6\% \approx 10\%$

Retrofitting of the roof and changing of the electrical radiators to district heating will amount to a saving 15 MWh/year of district heating which is around 10% and will result in a saving of 9,450 SEK/year

Savings in Electricity (SEK/year)

- Savings in electricity (kWh/year) $*$ electricity cost (SEK/kWh)
- Electricity cost take from the energy bill 0.389 SEK/kwh
- Electricity use before retrofitting $= 89$ MWh/year
- Electricity use after retrofitting $= 26$ MWh/year
- Energy saving in electricity use $= 89$ MWh/year $-$ 26 MWh/year $= 63$ MWh/year
- Savings in Electricity (SEK/year) $= 63$ MWh/year $*$ 389 SEK/MWh $= 24{,}507$ SEK/year
- $= 63/89 \approx 0.707 \approx 71\%$

Retrofitting of the roof and changing of the electrical radiator to ideal heater that uses district heating will amount to a saving of 63 MWh/year of electricity which is around 71% and will result in a saving of 24,507 SEK/year. The 71% saving in electricity was because the electrical heating system in the building was change to district heating system.

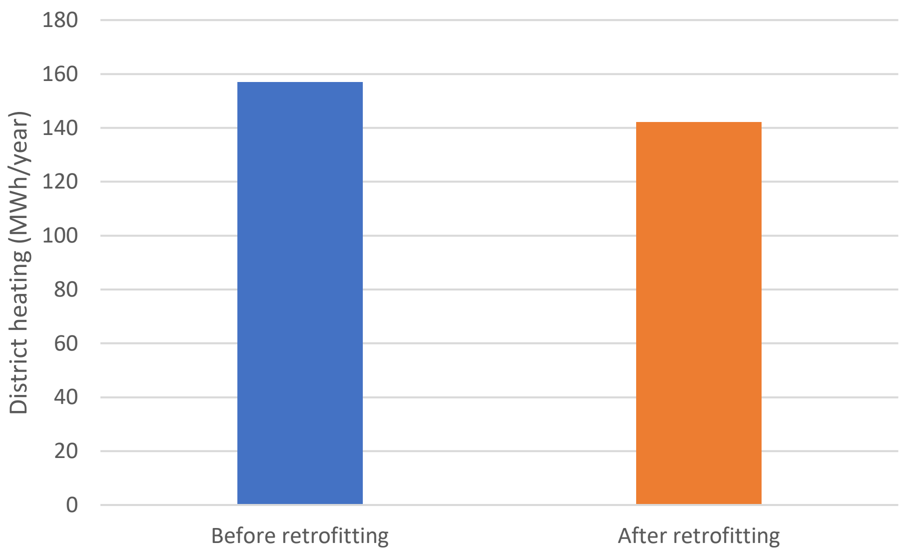

Figure 4-7: Energy savings in district heating use after retrofitting of the roof

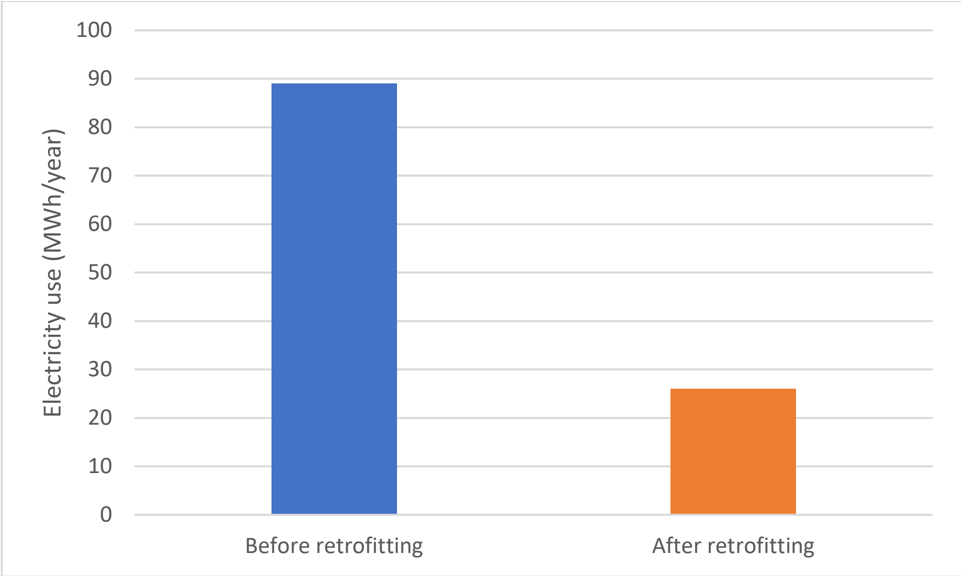

Figure 4-8: Energy savings in electricity use after retrofitting of the roof

The Figure 4-7 above shows the energy saving for the district heating after retrofitting procedure has been carried out on the roof of the building. This was achieved by adding 170mm of mineral wool as insulation material to the roof of the building and a total of 15 MWh/year for district heating was saved and the at same time, 63 MWh/year of electricity was also saved in the building and this can also be seen in Figure 4-8 above.

4.5 Cost analysis for retrofitting of the roof

The cost analysis for retrofitting of the roof is based on pay back method. The payback method is thus calculated as the ratio of the initial cost to that of the invested cash inflow per period or yearly

$$\text{Payback period} = \frac{\text{Initial investment on new inulation material}}{\text{Total energy savings on district heating and electricty per year}}$$

- $\text{Savings on electricity per year after retrofitting} = 24{,}507\ \text{SEK/year}$
- $\text{Savings on district heating per year after retrofitting} = 9,450\ \text{SEK/year}$
- $\text{Cost of mineral wool} = Price/m^2 \times roof\ area = (41.8\ \text{SEK}) \times 1150.3 = 48{,}082\ \text{SEK}$
- $\text{Payback period} = 48{,}082/33{,}957 = 1.5\ \text{years}$

The payback period after retrofitting of the roof its approximately one and half year and it should be noted that the cost for the workmanship was excluded because different company that will repair the roof will charge different prices for the renovation.

5.0 Discussion and Conclusion

Given that the building is more than 50 years old; it is normal for the energy balance in this type of building to exhibit or have high U-value. The cost of renovation is another factor in deciding which method is more profitable in renovating the roof. It will be cost-efficient to complement the insulation material already installed on the roof vis-a-vis replace all the electrical radiators with ideal heaters. Given that cost of district heating is relatively lower than that of electricity; switching to ideal heater will reduce the cost of electricity significantly.

Since it is not possible to measure the exact amount of electricity or district heating that is supplied to Hus (4-9), the method of building normalized performance indicator was used to calculate the district heating that is supplied to each building and then compared to the base model from the simulation; a desirable result of less than + 10% or -10% percentage was obtained.

Comparing the base model with the energy bill that was supplied by Gavlefastigheter also gives a desirable result. This study further looks at the thermal comfort of the occupants since one of the energy saving measures proposed was to reduce the indoor temperature. The study further shows that, changing the indoor air temperature is not viable from thermal comfort point of view. The indoor air quality is another aspect that was consider in this study. Analysis of the indoor air quality for Hus (4-9) shows that the carbon dioxide (CO_2) concentration in the building does not exceed the 1000 parts-per-million (ppm) limit in the occupied zone or room after applying the energy efficiency measures.

The energy audit conducted in Hus (4-9) in Fridhemsskolan in Gävle shows greater potential to reduce both electrical and district heating usage based on the energy efficiency measures that was proposed during the research. By reducing the indoor temperature, there is saving of 6% in district usage and 3% in electricity respectively, without compromising the thermal comfort of the occupants. Complementing insulation to the roof will result in saving of 10% in district heating and 71% in electricity as depicted in Figure 4-7 and 4-8.

6.0 Further recommendation

The climatic condition is another factor that influence higher energy consumption in this kind of building during the colder season. The use of electric heater is another major concern for the building but that can also be resolve by replacing it with district heating and four of the air handling unit in Hus 7 and 8 are obsolete and should be faced out or replaced. There should be basis to compare the carbon dioxide CO_2 concentration for the occupied zone. Having a measured value of the CO_2 concentration and value from the simulation to compare will give more accurate result of the CO_2 level in each occupied zone in the building.

7.0 References

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8.0 Appendix

8.1 The floor area for Hus (4-8)

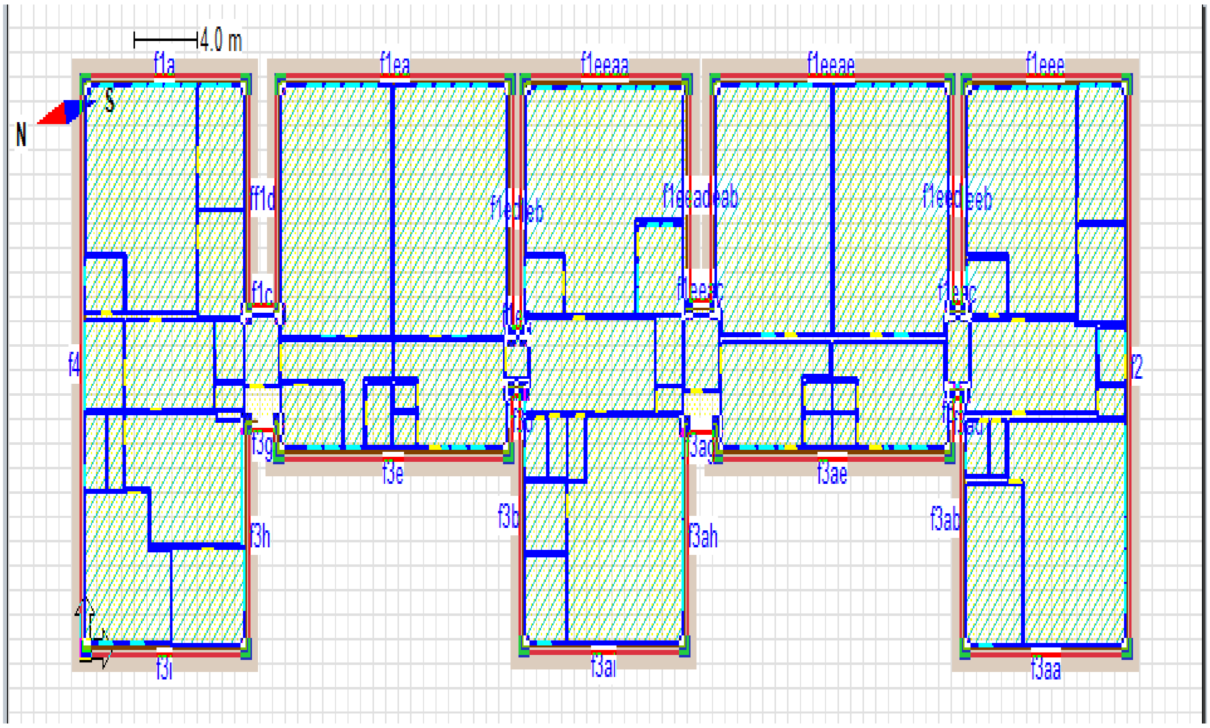


Fig 8-1: The total floor area of Hus (4-8) (942.7 m²)

8.2 The floor area for Hus (9)

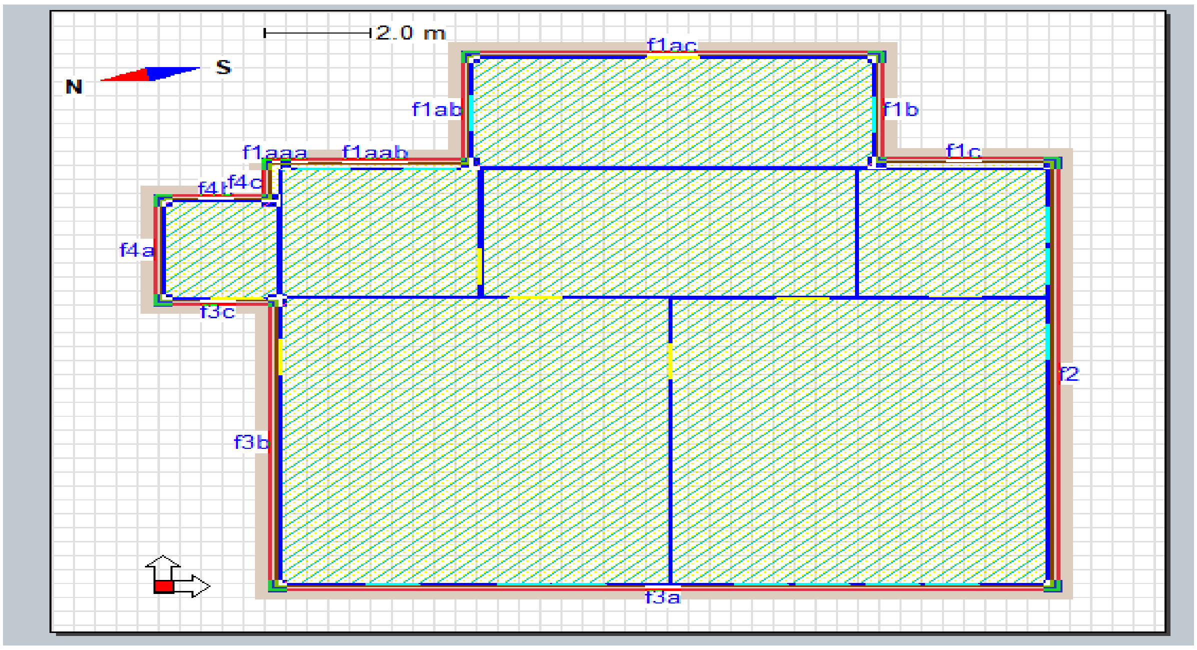


Fig 8-2: The total floor area of Hus (9) (207.6 m²)

8.3 The construction for the external wall

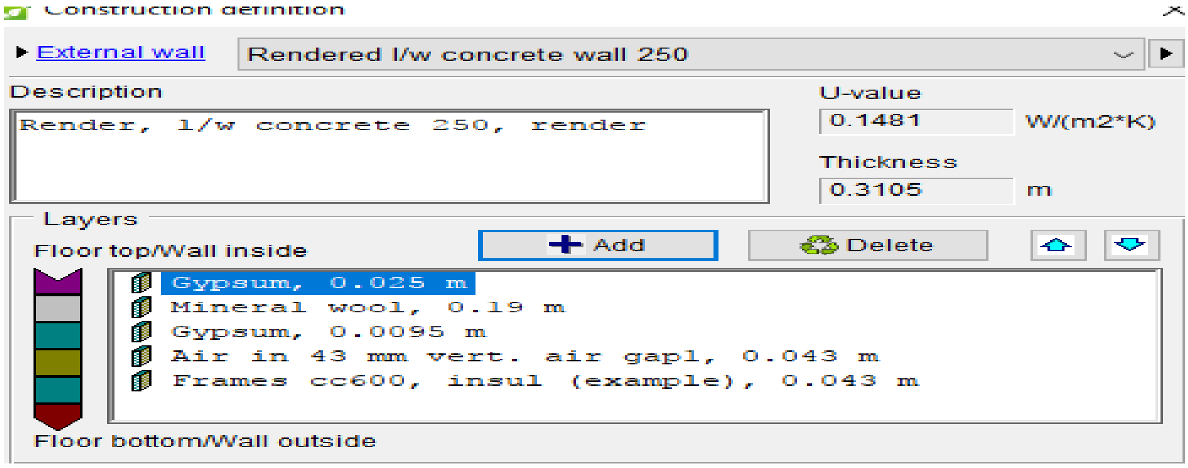


Fig 8-3: the external wall construction for Hus (4-8)

8.4 The construction for the external wall

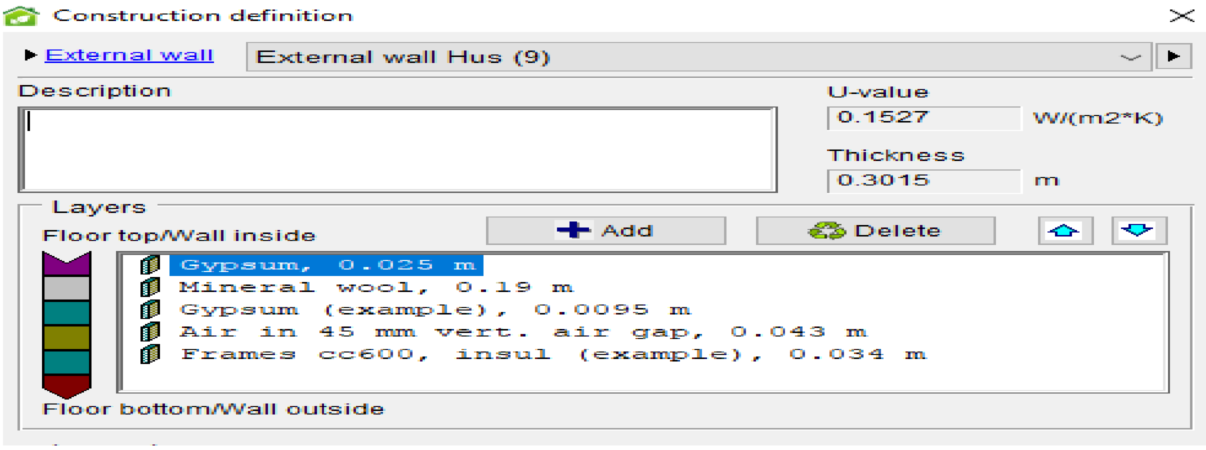


Fig 8-4: The external wall construction for Hus (9)

8.5 The roof construction

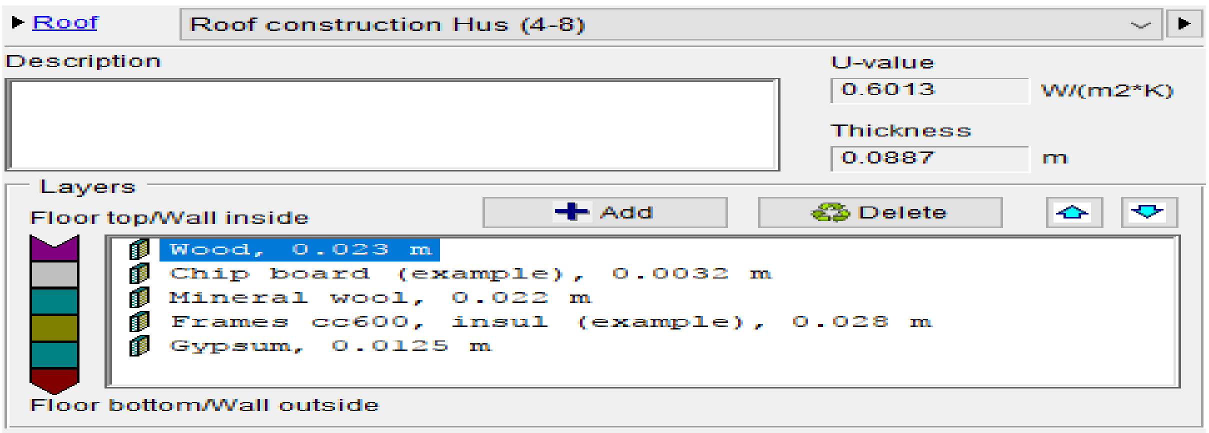


Fig 8-5: The roof construction for Hus (4-8)

8.6 The roof construction

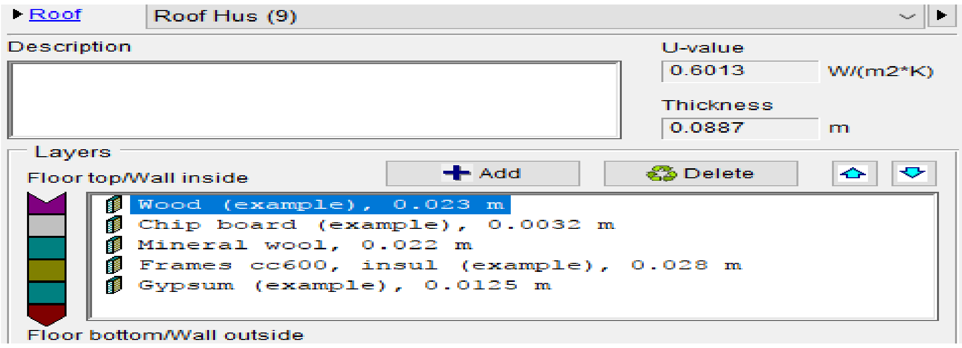


Fig 8-6: The roof construction for Hus (9)

8.7 The external floor construction

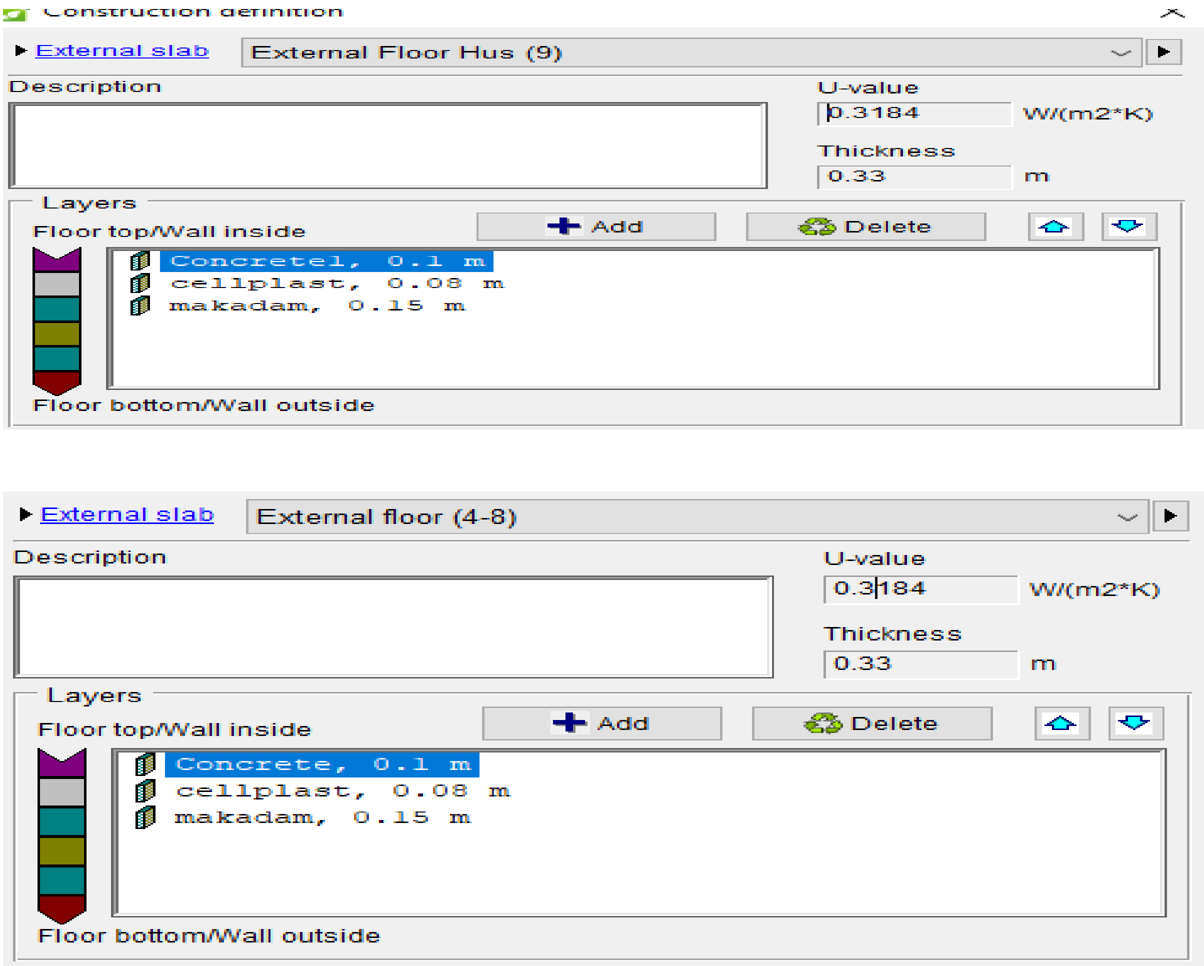


Fig 8-7 showing the external floor construction for Hus (9) and Hus (4-8)

8.8 Time schedule for the ventilation system

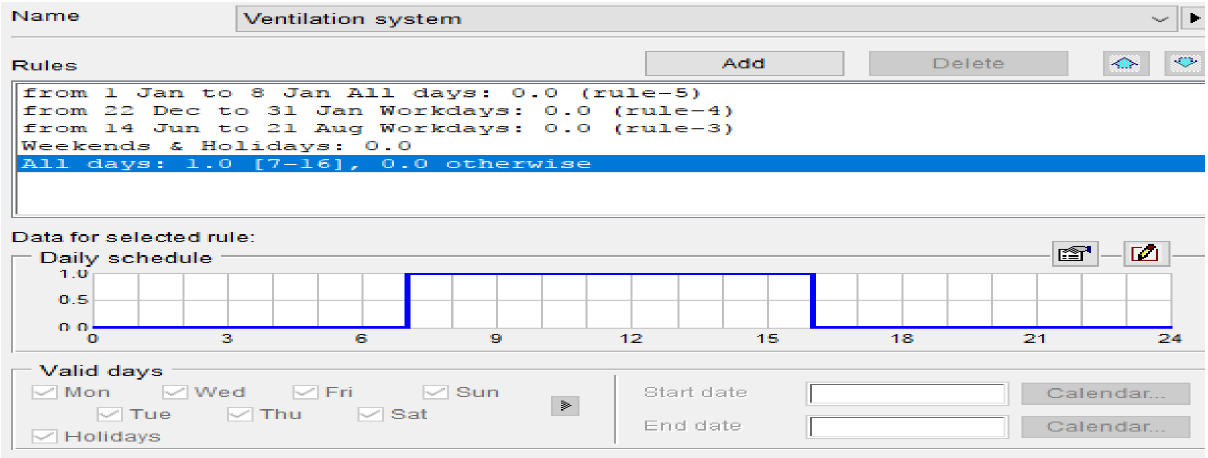


Fig 8-8: showing the time schedule for the ventilation system in Hus (4-9)

8.9 The ventilation rate for each of the building

Table showing the ventilation rate in Hus 4

Room number	Supply air (l/sm^2)	Return air (l/sm^2)
4/101	0	0
4/102a	4.882	0
4/102	0	0.6143
4/103	0	7.932
4/104	0	8.514
4/105	0	4.321
4/106	0	2.222
4/107	3.843	4.91
4/108	4.048	4.261
4/109	0	0
4/110	0	0
4/112	0	5.488

Table showing the ventilation rate in Hus 5

Room number	Supply air (l/sm^2)	Return air (l/sm^2)
5/101	0	0
5/101a	0	0
5/102	0	0
5/103	0	14.92
5/104	0	12.78
5/105	0	10
5/106	0	5.313
5/107	7.955	6.273
5/108	13.01	10.03
5/109	0	16.2
5/111	0	9.471
5/112	0	13.15
5/113	16.58	15.69

Table showing the ventilation rate in Hus 6

Room number	Supply air (l/sm²)	Return air (l/sm²)
6/101	0	0
6/101a	0	0
6/102	0.7661	0
6/103	0	15.78
6/104	0	9.657
6/105	0	7.091
6/106	0	4.942
6/107	8.647	12.14
6/108	0.7222	7.475
6/109	0	6.692
6/110	0	3.811
6/111	0	12.37
6/112	0	13.89
6/113	0	0

Table showing the ventilation rate in Hus 7

Room number	Supply air (l/sm²)	Return air (l/sm²)
7/101	0	0
7/102	2.975	0
7/103	3.545	2.236
7/104	0	7.372
7/105	0	0
7/106	1.088	5.912
7/107	0	15.79
7/108	0	9.29

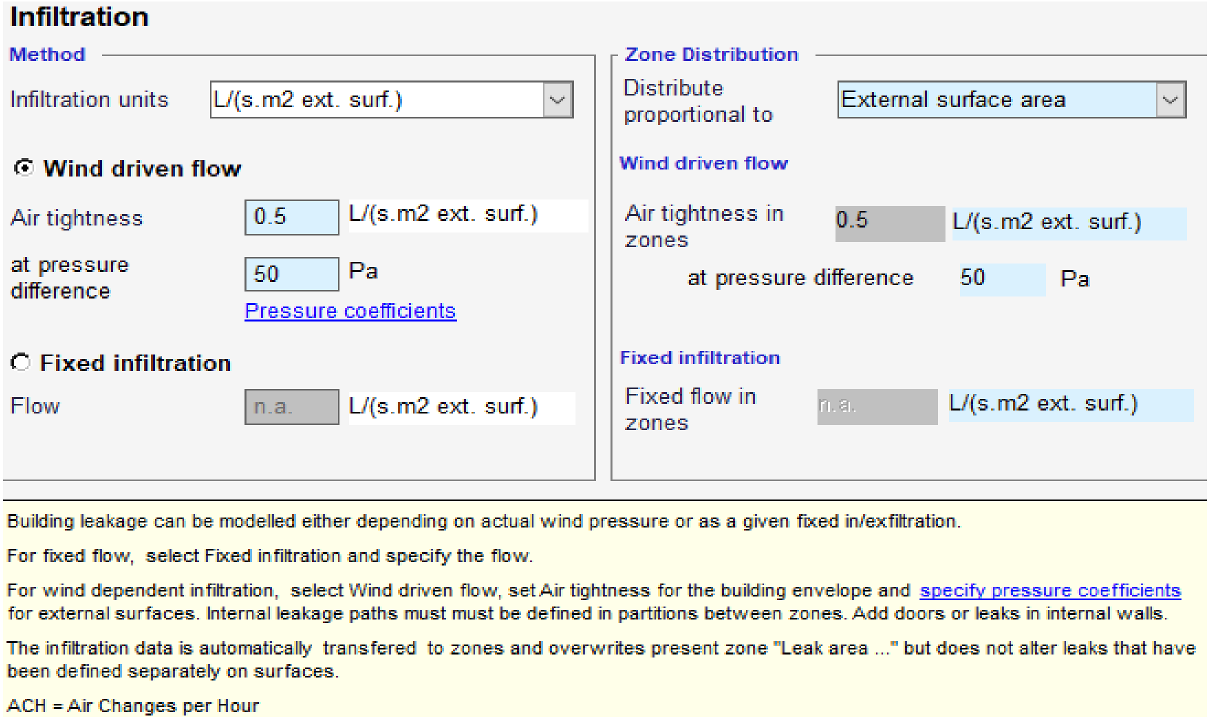
Table showing the ventilation rate in Hus 8

Room number	Supply air (l/sm²)	Return air (l/sm²)
8/101	1.422	0
8/102	0	13.87
8/103	3.03	1.84
8/104	0	16.03
8/105	0.8706	0
8/106	5.252	1.304
8/107	0	16.21
8/108	0	15.32
Hallway	0	0

Table showing the ventilation rate in Hus 9

Room number	Supply air (l/sm²)	Return air (l/sm²)
9/101/106/107 /108/109	0.708	2.355
9/102	2.752	0.4313
9/103	1.212	0
9/103	0.4171	0
9/105	1.764	0
9/110	0	0
9/111	0	0

8.10 The infiltration rate with pressure coefficient



Face \ Angle	0	45	90	135	180	225	270	315	Face azi...
Building body									
f1aaa	0.4	0.2	-0.6	-0.5	-0.3	-0.5	-0.6	0.2	100.0
f1aab	0.4	0.1	-0.3	-0.35	-0.2	-0.35	-0.3	0.1	100.0
f1ab	0.4	0.1	-0.3	-0.35	-0.2	-0.35	-0.3	0.1	10.0
f1ac	0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06	100.0
f1b	0.4	0.1	-0.3	-0.35	-0.2	-0.35	-0.3	0.1	190.0
f1c	0.4	0.1	-0.3	-0.35	-0.2	-0.35	-0.3	0.1	100.0
f2	0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06	190.0
f3a	0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06	280.0
f3b	0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06	10.0
f3c	0.4	0.2	-0.6	-0.5	-0.3	-0.5	-0.6	0.2	280.0
f4a	0.4	0.2	-0.6	-0.5	-0.3	-0.5	-0.6	0.2	10.0
f4b	0.4	0.2	-0.6	-0.5	-0.3	-0.5	-0.6	0.2	100.0
f4c	0.4	0.2	-0.6	-0.5	-0.3	-0.5	-0.6	0.2	10.0
Crawl space	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Roof	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	100.0

Fig 8-9: showing the wind driven infiltration with semi exposed pressure coefficients.

8.11 The number of occupants with the time schedule

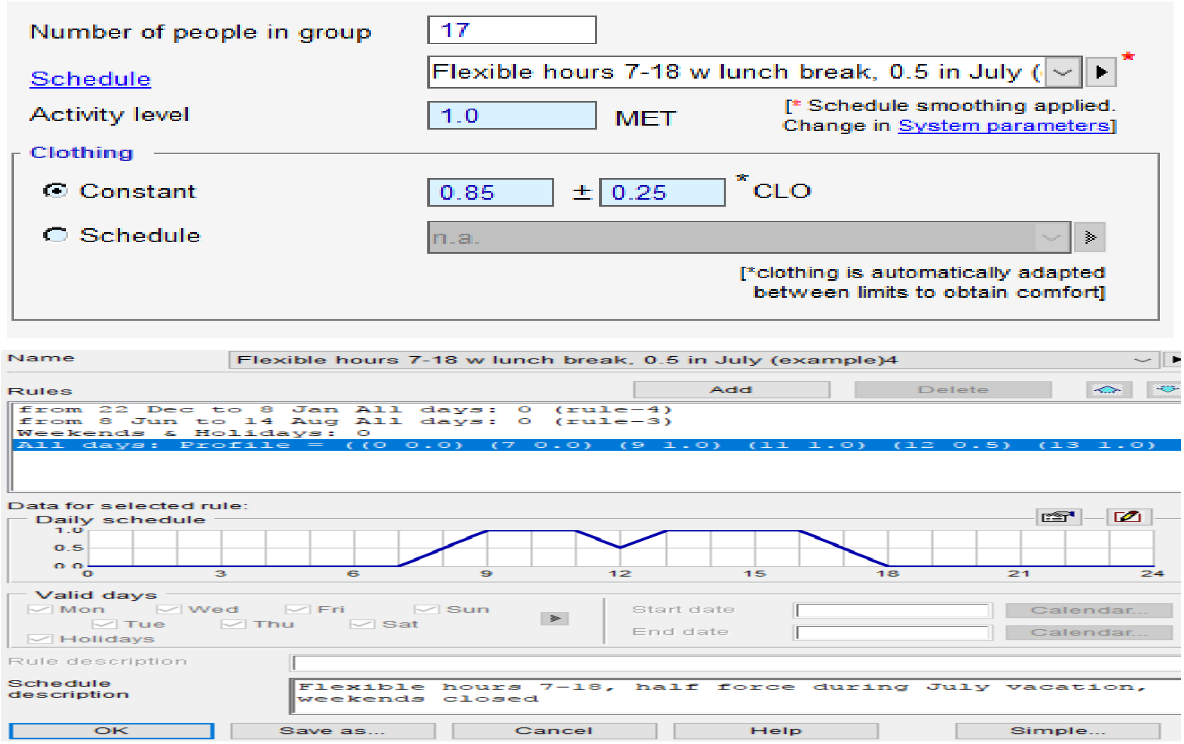


Fig 8-10: showing the number of occupants with the time schedule

8.12 The air handling unit with time schedule

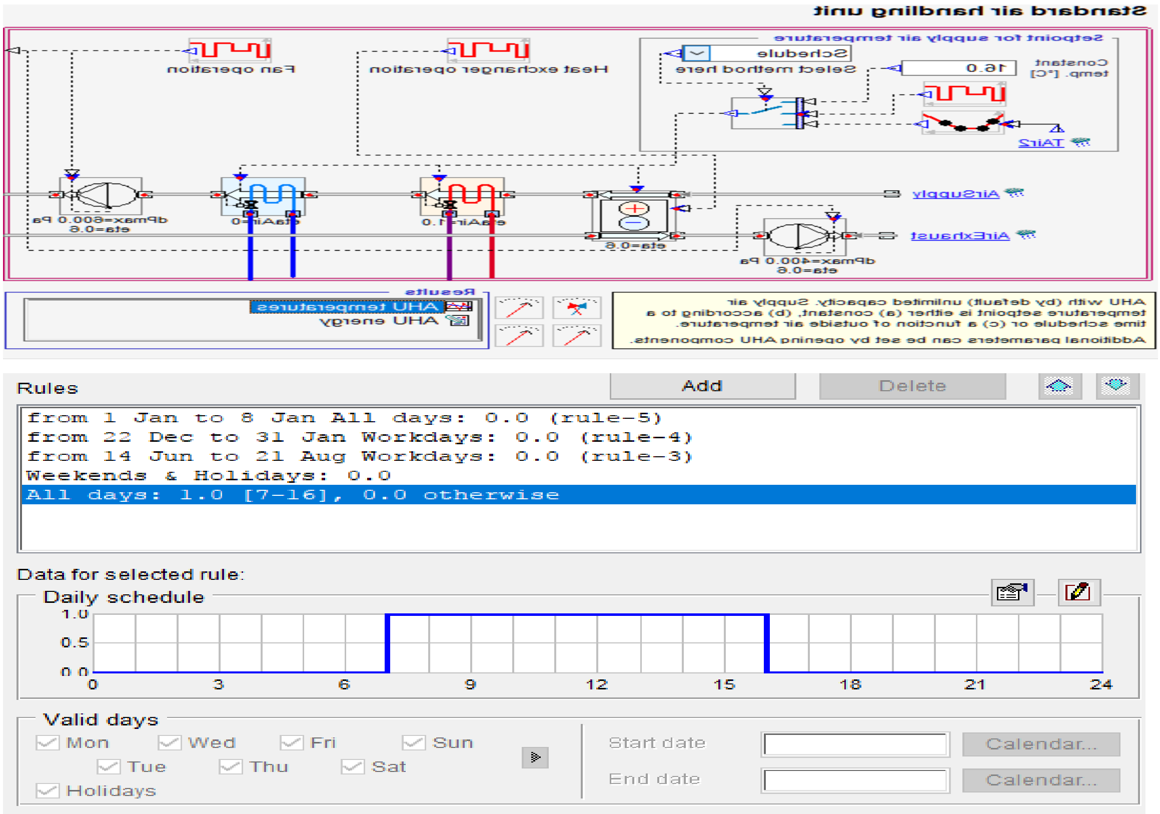


Fig 8-11: showing the air handling unit with time schedule

8.13 The lighting system with types and ratings in each zone

Zone	Power (W)	Types	Number of Lamps
4/102	36	Philips TL-D 36W 840	4
4/102*	18	Philips TL-D 18W 840	2
4/103	18	Philips TL-D 18W 840	2
4/104	50	Philips Eco classic 4H	1
4/105	50	Philips Eco classic 4H	1
4/106	40	Philips Eco classic	1
4/107	36	Philips TL-D 36W 840	18
4/108	36	Philips TL-D 36W 840	18
4/112	10	Luma	1
5/101	36	Philips TL-D 36W 840	2
5/101*	36	Philips TL-D 18W 840	2
5/102	36	Philips TL-D 36W 840	6
5/103	36	Philips TL-D 36W 840	2
5/104	75	Classtone	1
5/105	75	Classtone	1
5/106	18	Philips TL-D 18W 840	2
5/107	36	Philips TL-D 36W 840	18
5/108	36	Philips TL-D 36W 840	16
5/108*	18	Philips TL-D 18W 840	8
5/111	11	Master pl 11/827	3

5/112	18	Philips TL-D 18W 840	2
5/113	18	Philips TL-D 18W 840	2
6/101	18	Philips TL-D 18W 840	2
6/101a	18	Philips TL-D 18W 840	2
6/102	36	Philips TL-D 36W 840	4
6/103	18	Philips TL-D 18W 840	2
6/104	42	Philips Eco classic	1
6/105	42	Philips Eco classic	1
6/106	18	Philips TL-D 18W 840	2
6/107	36	Philips TL-D 36W 840	10
6/108	60	Classtone	2
6/108*	36	Philips TL-D 36W 840	10
6/108**	18	Philips TL-D 18W 840	8
6/109	36	Philips TL-D 36W 840	2
6/110	36	Philips TL-D 36W 840	2
6/111	36	Philips TL-D 36W 840	4
6/112	36	Philips TL-D 36W 840	2
6/112*	18	Philips TL-D 18W 840	8
7/101	36	Philips TL-D 36W 840	4
7/102	36	Philips TL-D 36W 840	2
7/103	36	Philips TL-D 36W 840	22
7/104	40	Luma	2
7/105	36	Philips TL-D 36W 840	9
7/106	36	Philips TL-D 36W 840	16
7/107	9	Pls 9w	2

7/108	11	Pls 11w	3
8/101	36	Philips TL-D 36W 840	6
8/102	44	Philips Eco classic	1
8/103	36	Philips TL-D 36W 840	16
8/104	44	Philips Eco classic	1
8/105	36	Philips TL-D 36W 840	6
8/106	36	Philips TL-D 36W 840	16
8/107	44	Philips Eco classic	1
8/108	44	Philips Eco classic	1
9/101	28	TL5 HE 28w	2
9/102	36	Radium NL 36w 840	12
9/103	36	Radium NL 36w 840	4
9/104	36	Radium NL 36w 840	12
9/105	28	OSRAM FH 28W 830	4
9/106	50	Philips Eco classic	1
9/107	50	Philips Eco classic 4H	1
9/108	50	Philips Eco classic 4H	1
9/109	50	Philips Eco classic 4H	1

Fig 8-12: showing the zone, ratings and number of lamps and bulbs in each zone in Hus (4-9)

8.14 Monthly domestic water use

	2014	2015
januari	94,5	75,6
februari	72,6	78,4
mars	91,5	77,2
april	89,5	73,6
maj	73,7	76,1
juni	61,1	73,6
juli	35,4	76,1
augusti	35,4	76,1
september	91,3	73,6
oktober	89,5	102,1
november	86,6	103,7
december	75,6	81,7
Summa År	896,6	967,6
Ackumulerat	348,1	304,8

Fig 8-13: showing the monthly water usage for two years. Source Gavlefastigheter

8.15 Overview of the energy delivered to each building

Table 8-1 showing the delivered energy to Hus (9)

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	3527	17.5	1.92
	HVAC aux	452	2.2	0.3
	Total, Facility electric	3979	19.7	
	District cooling	0	0.0	0.0
	District heating	31820	157.6	20.9
	Total, Facility district	31820	157.6	
	Total	35799	177.3	
	Equipment, tenant	853	4.2	0.54
	Total, Tenant electric	853	4.2	
	Grand total	36652	181.5	

Table 8-2 showing the delivered energy to Hus (4-8)

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	14650	16.6	9.04
	HVAC aux	9189	10.4	5.69
	Electric heating	56315	63.7	18.84
	Total, Facility electric	80154	90.7	
	District cooling	0	0.0	0.0
	District heating	126013	142.5	196.0
	Total, Facility district	126013	142.5	
	Total	206167	233.2	
	Equipment, tenant	6370	7.2	7.35
	Total, Tenant electric	6370	7.2	
	Grand total	212537	240.4	

8.16 Overview of the zones energy balance of the baseline model

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-3427.1	-90.3	-636.8	-60.4	-1057.5	421.5	71.7	266.9	4604.4	0.0	-7.2
2	-3113.0	-62.5	-445.3	-89.9	-1450.4	585.1	72.5	343.4	4227.4	0.0	-10.3
3	-2615.1	-56.6	-104.1	-118.5	-1235.8	620.8	77.5	376.0	3117.4	0.0	-12.6
4	-2115.8	-53.0	257.1	-126.5	-858.7	541.7	75.0	343.4	1995.4	0.0	-12.9
5	-1391.4	-38.0	656.1	-190.6	-501.1	505.3	77.3	359.8	574.0	0.0	-19.4
6	-888.5	-27.0	687.8	-43.3	-84.7	88.3	58.4	156.6	81.0	0.0	-4.6
7	-717.4	-13.7	633.4	0.0	-31.8	0.0	55.1	74.4	19.4	0.0	-0.1
8	-917.4	-22.1	575.5	-132.8	-227.3	282.5	67.4	266.4	142.0	0.0	-14.4
9	-1365.4	-31.9	189.4	-160.9	-551.9	555.4	75.0	359.7	976.0	0.0	-15.9
10	-1918.6	-44.3	-73.1	-119.8	-785.5	559.1	77.5	343.3	2014.6	0.0	-12.5
11	-2636.2	-55.6	-451.1	-103.0	-1198.1	604.4	75.0	359.7	3466.1	0.0	-11.4
12	-3405.2	-85.3	-668.1	-53.5	-1175.0	432.9	70.3	277.6	4692.7	0.0	-6.3
Total	-24511.3	-580.4	620.6	-1199.4	-9157.7	5196.9	852.6	3527.2	25910.5	0.0	-127.6
During heating (7739.0 h)	-18275.4	-279.7	-2976.2	-316.9	-8052.9	2369.4	428.4	1842.4	25790.1	0.0	-63.0
During cooling (722.9 h)	-5169.1	-294.4	3427.0	-718.7	-867.8	2066.4	343.2	1324.4	0.0	0.0	-53.8
Rest of time	-1066.8	-6.3	169.8	-163.8	-237.0	761.2	81.0	360.4	120.4	0.0	-10.8

Fig 8-14: The overview of the heat losses in the baseline for Hus (9)

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-15448.8	-123.8	-1864.0	0.1	-4985.7	1704.1	503.7	1118.4	18840.5	0.0	365.6
2	-14349.4	-98.4	-1118.5	-1091.1	-13772.3	2280.0	564.1	1526.7	25652.2	0.0	489.0
3	-11878.3	-84.0	276.0	-1429.8	-11507.5	2475.4	598.4	1670.6	19543.8	0.0	402.5
4	-9346.9	-76.8	1587.5	-1370.1	-8543.6	2211.4	570.2	1529.7	13188.4	0.0	307.8
5	-5672.5	-62.4	3076.4	-1766.9	-4886.3	2191.3	598.1	1601.2	4769.2	0.0	190.0
6	-3703.7	-66.3	3323.5	-787.4	-1731.6	773.8	425.5	633.4	1019.2	0.0	149.8
7	-3321.2	-4.5	3025.1	0.0	-797.1	8.9	406.6	84.5	462.3	0.0	164.2
8	-3597.7	-26.3	2797.5	-728.0	-1942.0	817.3	469.4	636.7	1433.5	0.0	165.3
9	-5997.2	-47.3	1213.3	-1661.1	-5428.6	2325.2	577.6	1598.6	7233.3	0.0	220.4
10	-8739.0	-54.2	230.5	-1402.5	-7715.1	2263.1	590.1	1532.1	13037.4	0.0	308.4
11	-12107.6	-83.0	-1300.4	-1294.1	-11358.1	2385.8	578.2	1598.7	21223.2	0.0	425.0
12	-15458.3	-105.0	-2084.4	-676.6	-11808.0	1648.9	488.5	1118.3	26479.3	0.0	503.1
Total	-109620.5	-832.0	9162.7	-12207.5	-84475.9	21085.1	6370.4	14648.8	152882.2	0.0	3690.9
During heating (5976.0 h)	-81195.4	167.2	-5054.3	-6260.4	-77208.7	9755.0	3244.0	8226.0	146171.3	0.0	2683.4
During cooling (2412.0 h)	-18601.7	-1218.3	12743.4	-4001.4	-4167.4	7412.2	2724.0	4310.7	284.8	0.0	639.8
Rest of time	-9823.4	219.1	1473.6	-1945.7	-3099.8	3917.9	402.4	2112.1	6426.1	0.0	367.7

Fig 8-15: The overview of heat losses in the baseline model for Hus (4-8)

8.17 Overview of the evenlop transmission for the basline model

Table 8-3: envelope transmission for Hus (9) (kWh)

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-1945.7	-10647.6	-1320.7	-2390.9	-143.6	-1655.2
2	-1766.2	-9612.0	-1536.0	-2262.0	-127.0	-1529.0
3	-1411.6	-7453.6	-1807.0	-1918.1	-104.2	-1282.6
4	-1122.0	-5369.0	-1832.5	-1648.2	-84.6	-1087.6
5	-623.9	-2463.5	-1875.0	-1188.3	-55.1	-753.1
6	-387.3	-1010.7	-1787.9	-883.6	-36.2	-548.7
7	-298.2	-1101.3	-1428.6	-853.0	-32.2	-521.3
8	-331.7	-1534.9	-1266.8	-817.4	-32.7	-490.5
9	-682.5	-3797.7	-853.0	-1093.6	-57.4	-706.7
10	-1006.7	-6043.8	-796.1	-1461.5	-81.4	-953.7
11	-1488.9	-8512.6	-907.1	-1918.8	-109.9	-1279.6
12	-1917.5	-11000.5	-996.3	-2459.8	-144.6	-1661.4
Total	-12982.2	-68547.1	-16407.0	-18895.1	-1009.0	-12469.3
During heating	-9610.9	-56792.5	-6255.8	-13784.6	-791.7	-9134.6
During cooling	-2406.4	-4769.0	-9384.1	-3525.8	-114.0	-2139.3
Rest of time	-964.9	-6985.6	-767.1	-1584.7	-103.3	-1195.4

Table 8-4: envelope transmission for Hus (4-8) (kWh)

kWh

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-443.3	-2422.7	-281.9	-807.7	-109.4	-368.2
2	-382.9	-2141.7	-323.5	-741.7	-89.7	-327.1
3	-318.1	-1669.1	-399.5	-644.9	-78.7	-282.3
4	-263.3	-1231.5	-424.7	-567.5	-67.6	-245.8
5	-159.9	-636.6	-447.9	-448.5	-45.1	-180.4
6	-94.4	-289.9	-396.2	-332.1	-24.4	-129.0
7	-62.2	-248.2	-312.9	-299.5	-19.8	-111.5
8	-90.2	-419.2	-310.5	-316.2	-26.6	-117.1
9	-164.2	-883.3	-186.2	-392.3	-47.0	-163.8
10	-229.9	-1361.3	-157.4	-501.5	-64.8	-215.1
11	-330.7	-1897.3	-184.3	-638.6	-81.2	-278.7
12	-432.5	-2466.7	-229.3	-808.6	-106.5	-361.4
Total	-2971.6	-15667.5	-3654.3	-6499.1	-760.9	-2780.4
During heating	-2132.8	-13479.7	-1012.2	-4677.9	-681.7	-2163.5
During cooling	-732.6	-1482.6	-2485.8	-1524.7	-64.8	-510.4
Rest of time	-106.2	-705.2	-156.3	-296.5	-14.4	-106.5

8.18 Overview of the energy use after reducing the indoor temperature

Table 8-5: Energy usage in Hus (9) after reducing the indoor temperature

Month	Facility electric		Facility district		Tenant electric
	Lighting, facility (kWh)	HVAC aux (kWh)	District cooling (kWh)	District heating (kWh)	Equipment, tenant (kWh)
1	266.8	40.6	0.0	5075.0	71.7
2	343.3	56.8	0.0	5006.0	72.5
3	376.0	62.1	0.0	3654.0	77.5
4	343.4	56.7	0.0	2333.0	75.0
5	359.8	59.2	0.0	678.3	77.6
6	156.7	21.5	0.0	105.2	58.4
7	74.3	0.0	0.0	59.6	55.1
8	266.2	21.5	0.0	198.8	67.4
9	359.8	59.3	0.0	1081.0	75.0
10	343.3	56.7	0.0	2261.0	77.6
11	359.6	59.5	0.0	4014.0	75.0
12	277.5	40.6	0.0	5300.0	70.3
Total	3526.7	534.6	0.0	29765.9	852.9

Table 8-6: Energy usage for Hus (4-8) after reducing the indoor temperature

Month	Facility electric			Facility district		Tenant electric
	Lighting, facility (kWh)	HVAC aux (kWh)	Electric heating (kWh)	District cooling (kWh)	District heating (kWh)	Equipment, tenant (kWh)
1	1118.0	0.0	8674.0	0.0	10606.0	503.5
2	1527.0	1045.0	7732.0	0.0	21799.0	564.1
3	1671.0	1152.0	5991.0	0.0	15957.0	598.3
4	1530.0	1056.0	4190.0	0.0	10478.0	570.3
5	1601.0	1116.0	1620.0	0.0	3517.0	597.9
6	633.4	408.1	550.3	0.0	557.9	425.3
7	84.5	0.0	286.3	0.0	329.2	406.7
8	636.7	406.5	495.8	0.0	1124.0	469.3
9	1599.0	1114.0	2248.0	0.0	5266.0	577.6
10	1532.0	1057.0	4143.0	0.0	9783.0	590.1
11	1599.0	1101.0	6450.0	0.0	17371.0	578.2
12	1118.0	744.9	8847.0	0.0	21111.0	488.6
Total	14649.6	9200.6	51227.4	0.0	117899.1	6369.9