Energy Audit in Educational Buildings

Case study of Fridhemsskolan in Gävle

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Abstract

The global share from buildings towards energy usage in residential and commercial buildings have been increasing constantly reaching between 20% to 40% in developed countries and has overtook the other major sectors: industrial and transportation. Energy demand reduction in the building sector is important for Sweden to achieve national energy aims for reduced energy use in the future. For this reason, energy efficiency measures in buildings today is one of the main objective for energy policy towards 2020 goals.

This project moves on the same path to find energy efficiency potential in Fridhemsskolan buildings in Gävle, Sweden by performing energy audit using IDA-ICE software to simulate energy performance for the buildings under study. In addition, measurements have been made on three of the school buildings named Hus 1, Hus 2 and Hus 3.

The results include different energy efficiency retrofits on each building and economic analysis of these retrofits for each building individually and for the whole buildings together. The presented measures are reducing working hours of the ventilation system in Hus 2, change of CAV system with VAV system in (Hus 1 and Hus 2) and lights changing to LED, s efficient lights and building envelope improvement which includes walls and roof extra insulation and windows replacement.

Replacement of the CAV system in Hus 1 and Hus 2 were not economically beneficial when considering their high cost compared to energy reduction that can be achieved by applying them. On the other hand, energy retrofits analysis showed that combination of the following energy efficiency measures is the most effective and profitable: extra insulation (walls and roof), windows replacement and lights change to LED in the three buildings. In addition to these measure is reducing running hours of the ventilation system in Hus 2.

Implementation of the recommended energy efficiency measures will save 120, 737 kWh/ year of the district heating and 21, 962 kWh/year electricity consumption with capital investment of 417, 396 SEK and 98, 957 SEK/ year cost saving with payback period of 4.2 years. These figures represent 40.3% and 18.1% reduction in district heating and electricity energy use respectively.

Since reducing working hours of ventilation system measure has no capital investment and have the highest figure of energy reduction it reduces payback period significantly. In case the amount of money saved by this measure doesn't consider; payback period for the other measures which require capital investment will be 13.5 years and the energy saving in terms of cost will be 30, 874 SEK/ year.

Key words: energy audit, building energy performance, energy retrofits technology, energy efficiency measures in building, IDA-ICE.

Preface

First of all, I would like to show my deepest gratitude to my supervisor, Arman Ameen, for his great support during carry out of this thesis. He has shared all his knowledge which has been very useful and has been always available when needed.

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Last but not least, I would like to express my very deep gratefulness and thanks to my friends and family especially my father for providing me with all support and motivation throughout this year of study.

This accomplishment would not have been possible without them.

Nomenclature

Latin and Greek

Symbol	Description	Units
$\dot{q}$	Heat transfer rate	W
K	Thermal conductivity	W/m.K
dT/dx	Temperature gradient in the direction of heat flow	K/m
R	Thermal resistance	m²K/W
l	Materials thickness	m
hc	Convective heat transfer coefficient	W/m²K
Tw	Temperature of the solid surface	K
$T\propto$	Temperature of the fluid	K
σ	Stefan-Boltzmann constant$\approx$5,699·10-8	W/m²K⁴
T	Absolute temperature of the blackbody	K
q12	Radiant heat-transfer rate	W
hr	Radiation heat transfer coefficient	W/m²K
T1	Temperature of the surface 1	K
T2	Temperature of the surface 2	K
Tm	Mean temperature of T1 & T2	K
U	Thermal transmission coefficient	W/m²K
Rsi	Indoor surface resistance	m²K/W
Rse	Outdoor surface resistance	m²K/W

Abbreviations

Letters	Description
HVAC	Heating, ventilation and air conditioning
GHG	Greenhouse gas
NPV	Net present value
BCR	Benefit-cost ratio
OOR	Overall rate of return
IRR	Internal rate of return
SPP	Simple payback period
AHU	Air handling unit
DH	District heating
IAQ	Indoor air quality
IEQ	Indoor environment quality
ACH	Air change per hour
HRE	Heat recovery exchanger
HE	Heat exchanger
NPI	Normalize performance indicator
PPD	Predicted percentage of dissatisfied

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1 Introduction

1.1 Background

The growing increase of the world energy use has already highlighted the concerns about energy supply difficulties, energy resource depletion and environmental impact (global warming, ozone layer depletion, climate change, etc.). The International Energy Agency has collected alarming data on energy usage tendencies. During the period (1984– 2004) primary energy use has increased by 49% and CO_2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively.

Current estimates show that this trend will keep going. Energy use by nations with emerging economies (South America, Southeast Asia, Middle East and Africa) will grow at an average annual rate of 3.2% and will exceed by 2020 that for the developed countries (North America, Western Europe, Australia, New Zealand and Japan) at an average growing rate of 1.1%. In China, during 20-year energy use was doubled at an average growth rate of 3.7%. These highlight the global policy efforts to invert this tendency by improving energy efficiency [1].

In 2008, global energy supply accounted almost for 144, 000 TWh; about 81% of this supply was made up of fossil fuels. Oil had the largest portion with 33% of the supply, followed by coal and gas with 27% and 21% respectively. Supplies from renewable energy, including hydro power have increased in the last decade to 13% share. The rest 6% of the energy supply was nuclear power. Meeting this world's energy demand is significantly important for international economic growth and countries development [2].

Energy end usage is usually divided into three main sectors: industry, transport and other which include agricultural, service and residential sector. The service sector includes all the public and commercial buildings such as schools, restaurants, museums, hotels, etc. with various profile of uses and energy services (domestic hot water, HVAC, lighting, refrigeration, etc.). The demand of services and the energy usage increases with the growth of both economic and population. In USA, service sector energy use has extended from 11% to 18% from 1950s [1].

1.2 Energy in Sweden

Final energy use in Sweden can be divided into three sector users' which are industrial, transport and residential and service sectors. Industrial sector uses biofuels and electricity while transport sector mainly uses oil products such as diesel, petrol and aviation fuel. The residential and service sector use of energy based on district heating, electricity and biofuels or oil [3].

In 2013, the final energy use in total for all sectors accounted for 375 TWh. Residential and service sector and industrial amounted for 174 TWh and 144 TWh respectively, while energy usage in transport sector accounted for 85 TWh, as represent in Figure 1-1. Energy use in residential and service sector is affected in short-term basically by outdoor temperature which implies large proportion of energy usage for heating purpose.
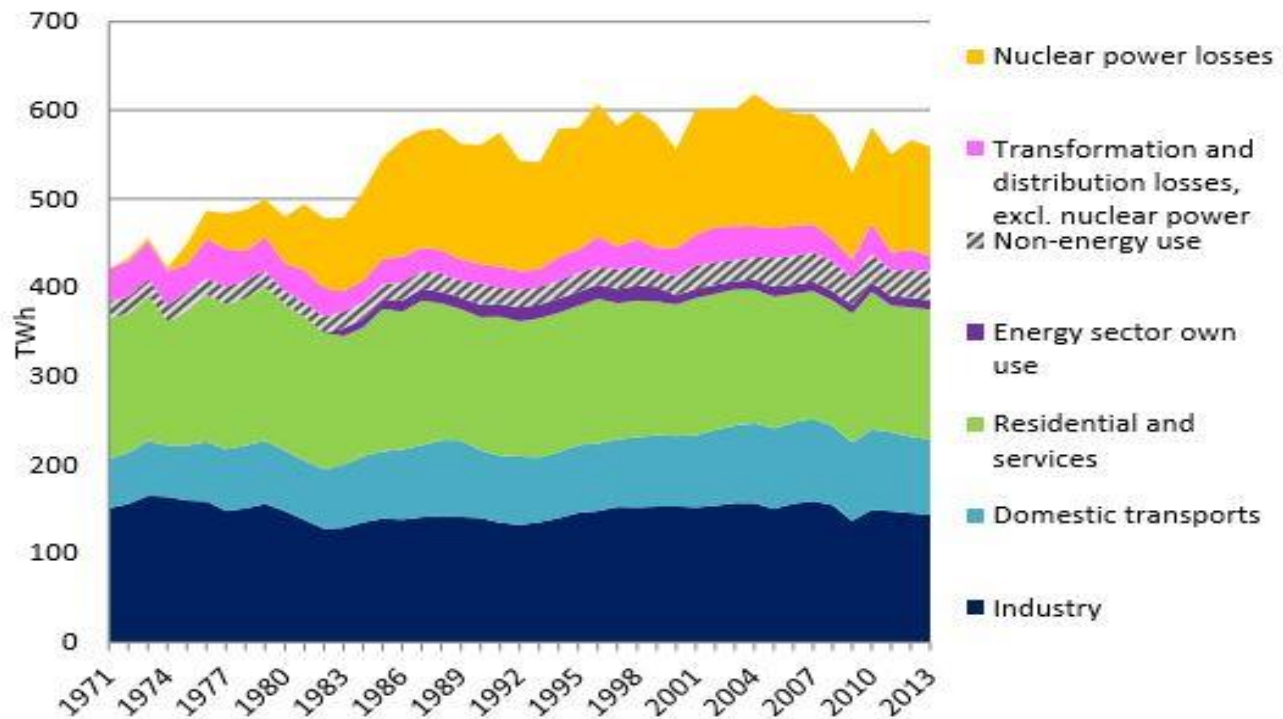
Source: Swedish Energy Agency and Statistics Sweden.

Figure 1-1. Total energy use, by final energy, losses etc., 1971 – 2013, TWh

1.3 Energy use in buildings

In 2004, Buildings accounted for 37% of final energy use in Europe, higher than industry (28%) and transport (32%). In UK, 39% was the portion of energy use in buildings, slightly higher than European figure. This is due to move away from heavy industry towards activities in service sector. The figure in Spain was 23% of the final energy use in buildings, but it's expected to rise as result of economic growth. Service sector in USA energy usage has extended from 11% to 18% from the 1950s [1].

In Sweden, Service and residential sector amounted for almost 40% of Sweden entire energy use. Non-residential buildings and households accounted for around 90% of the energy use in this sector and energy use for hot water and heating for them equalled to 80 TWh, which is 55% of the whole energy use within the sector; the most common form of energy to fulfil these purposes is district heating with consumption of 18 TWh [3].

Building and transport sector are responsible for the highest energy consumption and greenhouse gas emissions within EU and they are not cover by emission trading scheme (ETS). This show important need for effective measurement in these two sectors to mitigate the environmental climate change challenge. The building sector, because of both its energy demand and the long useful life of buildings make it the most critical between these sectors. [4].

Buildings sector has good opportunities to minimize energy usage by improvements in operation, design and renovation technology. 73% of energy consumption for north European household is related to heating system which represent the biggest part of the total energy usage. Therefore, energy efficiency measures in heating system has a high potential for energy usage reduction [5]. To find out energy efficient measures to be implemented in a specific building requires the analysis of energy flow of a building which is the main aim of the energy audit [6].

In Europe, educational buildings represent 20% of the whole non-residential floor space. The school sector uses high portion of energy for heating and electricity, therefore improving energy efficiency is essential. Schools final energy use in USA, UK and Spain amount for 13%, 4% and 10% of the total energy use respectively. Moreover, electricity energy usage patterns in schools have changes considerably in the last decades due to increasing of using computers for educational purposes, 71% increase of computers number per square meter.

Good indoor comfort and air quality are important for right educational development bearing in mind the long periods that students spend in schools, so achieving suitable comfort levels is considered necessary. This mean acting on the existing educational buildings is vital, not only to accomplish the EU 2020 targets but also to enhance the educational performance of future generations [7].

As this thesis is performed on commercial building (school buildings), the study [8] demonstrate the key possible retrofit technology that can be applied in such buildings. These technologies can be grouped in three categories which are supply management, demand management and change of energy usage patterns, i.e. human factors. For the demand side management, it includes retrofit technologies and strategies to decrease building heating and cooling demand, usage of energy efficient equipment and low energy application. Retrofitting of building envelope and use of advanced technologies such as windows shading, air tightness, etc are used to reduce building heating and cooling demand. low energy technologies might include heat recovery, natural ventilation, advanced control schemes, etc. The supply side include retrofit technologies such as photovoltaic system, solar collectors for hot water, wind energy, etc.

1.4 Literature Review

This literature review will demonstrate the main goal of this research, which is decreasing the energy usage of Fridhemsskolan buildings located in Gävle through energy audit. Both the important of the energy audit and how it can be done will be determine in this literature review also. Furthermore, this study within this literature review will focus also in the aim and objectives of this research which is illustrated in more details in the next section (1.5) of this study. key words such as energy audit, energy efficiency, retrofit, commercial building energy and energy trends were used for searching for peer reviewed articles and journals to conduct this literature review.

The previous presented statistics in the background section show the importance of the building energy usage reduction which is considered as priority indicated in European Directive 2010/31/EU (EU Parliament 2010) and according to the Energy Efficiency Plan of the European Commission (2011). Although energy use figure for buildings is high; building sector have the greatest energy - saving potential [9]. Between public buildings types, a wide stock classified by a continuous use is the ones built for learning activates and they are affected by high energy

usage due to internal environmental quality required for young people. However, to reach an accurate retrofit at any level; first it is important to perform an energy audit to identify the feasible interventions for the energy use reduction possibilities and their costs [10], this was also mentioned in the study [11] which states:

 "An energy audit is a key feature of successful management of the energy issue in any building, as it represents a starting point for implementing energy issues in management procedures. An energy audit aims at assessing the present energy situation in a building."

The previous literature show the value of this research and why it's worth performing energy audit for buildings to achieve overall EU target for 2020 which aim for 20% reduction in greenhouse gas emissions, 20% increase in renewable energy sources' share of final energy consumption and 20% increase in energy efficiency over 1990 levels.

When energy audit is performed for buildings, the heat balance components of buildings should be studied and measured [11]; these components are:

- Transmission through wall, roofs and floors.
- Ventilation.
- Infiltration.
- Internal Gains from equipment, people, lights, etc.

Study [12] illustrated results obtained by performing energy audit on the faculty of engineering department building in Jordan. The study proposed energy efficiency measures regarding the lighting which are replacement of used lights by energy efficient lights, using occupancy sensor and dimmers which are devices used to control the brightness of the light. Applying these measures will lead to 20% to 40% energy saving in the electricity for each measurement of them. Furthermore, by replacing of single pane glass windows with double glass windows will reduce heat loss through building envelope by 10% to 12%, and the fact that around 60% of heat losses occurs through the standard single pane windows. The last measurement will lead to significant saving in the heating bills.

Other studies showed great results from energy auditing of buildings e.g. study [9] which performed on teaching building of the Faculty of Economics of the University of Coimbra concluded that by applying the proposed energy measures after the energy audit a reduction of 26 MWh/ year in the electricity could be achieve, equalled to (€2663/year) and at the same time an amount of 3,704 kg CO_2/year will be prevented.

Another case study [6] of energy audit for a Portuguese school building based on the information collected during the audit, some energy efficiency measures were identified that can be applied in the school building. Those founded measures were related to electricity and involve control equipment, efficient lights, power factor improvement and optimization of electricity contract with the supplier. Implementation of the identified measures will result in decreasing the electricity usage in the building around 31, 100 kWh/year which is equals to annual drop of 14, 620 kg CO_2e and saving of 28% of the yearly electricity bill which is around 4, 000 €. Furthermore, suggestion about evaluation and analyse of other efficiency measures like integration of solar collectors for hot water and changing of existing taps by efficient ones with a regulator to decrease water usage.

Study of [13] simulated educational building using dynamic software (TRNSYS 17) to model the whole building components such as building envelope, school students occupancy profile and HVAC system. The study reported that the dynamic model of the school is the best tool to achieve a comprehensive analysis of an energy saving measure. For this reason, an approach to improve energy performance of the building was evaluated by way of the developed dynamic model. Finally, the proposed retrofit focused on the heating system renovation instead of building envelope improvement because of high price of the external insulation and replacement of widows, due to large external area and windows number in the school. Results showed that using air-source heat pump instead of boiler decrease the primary energy need for heating by 46%.

The same pervious dynamic model was also used in study of [14]to enhance the energy performance of secondary school building in Italy. By analysing the actual condition in terms of energy use, measures were addressed to enhance both air tightness and building envelope insulation. The measures applied to the model were installation of new windows with lower U-value (1.2 W/m^2 K), installation of heat recovery for the ventilation system (0.7 sensible effectiveness) and internal insulation of the roof and attic floor. Combination of building envelope measures alone (new windows and insulation) entails 44% reduction of heating consumption.

Many studies were performed on educational buildings for both energy and indoor environment quality (IEQ). Study published by ref [15] in Luxemburg presents the result of an energy use analysis and savings potential on 68 school buildings. The study exposed that simple retrofits as insulation and air tightness can decrease the energy demand. The author estimates saving of 1% of the national fuel oil and gas consumption annually.

Study of [16] showed an energy audit results performed on 135 Hellenic school's buildings and analysis of several energy conservation refurbishments while maintaining acceptable IEQ. The analysis showed that 63% of the buildings were not well insulated while just 23% had 2 pane glazing windows. The study also revealed that 24% and 22% were concerned by enhancement of the heating and lighting systems respectively.

Furthermore, retrofit of existing school building in Italy was implemented by study of [17] within framework of "the School of the Future project, funded by 7th Framework Programme". The main objective is to demonstrate the technical and economic feasibility of major energy renovation to improve the energy performance of the existing building stock. The founded measures involve façades and roof external insulation, insulation of part of the ground floor, windows replacement with external shading device (moveable), renovation of the whole heating system, remote energy management system design and installation for the municipality schools, PV plant installation on the roof and mechanical ventilation system for classrooms. The last measure was implemented to satisfy the IEQ requirement. Implementation of the insulation and windows replacement on the west and north oriented façades resulted in decreasing actual energy use required for heating purposes by 42%.

Investment on energy efficiency measures involve large number of factors. The choice of retrofit measures is balance between benefits that can be gained due to implementation of the retrofit measures and capital investment. Economic analysis can facilitate the comparison among different retrofit measures, it can identify also which alternatives are energy efficient

and cost-effective. A diversity of economic analysis methods can be used to for the purposes mentioned previously. Some of them are net present value (NPV), Benefit-cost ratio (BCR), Overall rate of return (ORR), Internal rate of return (IRR) and Simple payback period (SPP) which can be used to assess the economic feasibility of one retrofit measures. The most used one to make a decision is the pay-back period which was used in this research to evaluate the proposed energy efficiency measurements and prioritise them accordingly [8].

Building retrofit effectiveness depend on building- specific information like building type, age, size, geographical location, energy sources, building envelope, occupancy schedule etc. for a specific project. Another important element that affect building retrofit success is human factors; some studies showed that 10 -20% of domestic use of energy in Nordic countries can be reduced from occupant behaviour changes only [8].

All the studies presented in this literature review illustrates that there are great opportunities to reduce energyuse in school buildings through energy audit. Energy audit allows identification of possible measures and retrofit technologies to achieve the goals of this research.

1.5   Aims and Objectives

The overall aim of this thesis is to perform an energy audit using IDA-ICE software to simulate energy performance of Fridhemsskolan buildings to find the reason behind the high-energy consumption, then to propose energy efficiency measures to achieve the goal of reducing the energy usage in the school buildings. The study was proposed by Gavlefigheter company which manages and owns real state for trade, industry and municipal activates in Gävle. According to the company energy management system the school energy usage is more than the average compared to other school with the same criteria in Gävle municipality.

Specifically, with the context of the buildings energy audit, the objectives of this research are:

- Perform energy survey and energy analysis for the school buildings.
- Determine the possibilities of energy efficiency measures to reduce the energy usage by analysing the results from simulation.
- Measures evaluation and cost assessment.
- Formulate recommendations about the proposed measures.

1.6   Case study building - Fidehmskolan

The school is located in central Gävle, Sweden, it consists of several buildings named Hus 1, Hus 2…, Hus 9 as shown in Figure 1-2. This thesis is performed on Hus 1, Hus 2 and Hus 3.

Hus 1 consist of classrooms, groupwork classes, store room, toilets and staff and administration offices. Hus 2 consist of dining hall, kitchen, washing room, workshop class and sewing classroom and toilets. Finally, Hus 3 consist of gym hall, changing room with showers and toilets. The school opening hours from 6:00 am to 5:00 pm Monday to Friday. The school have 360 students and about 60 administration and teaching staff members.
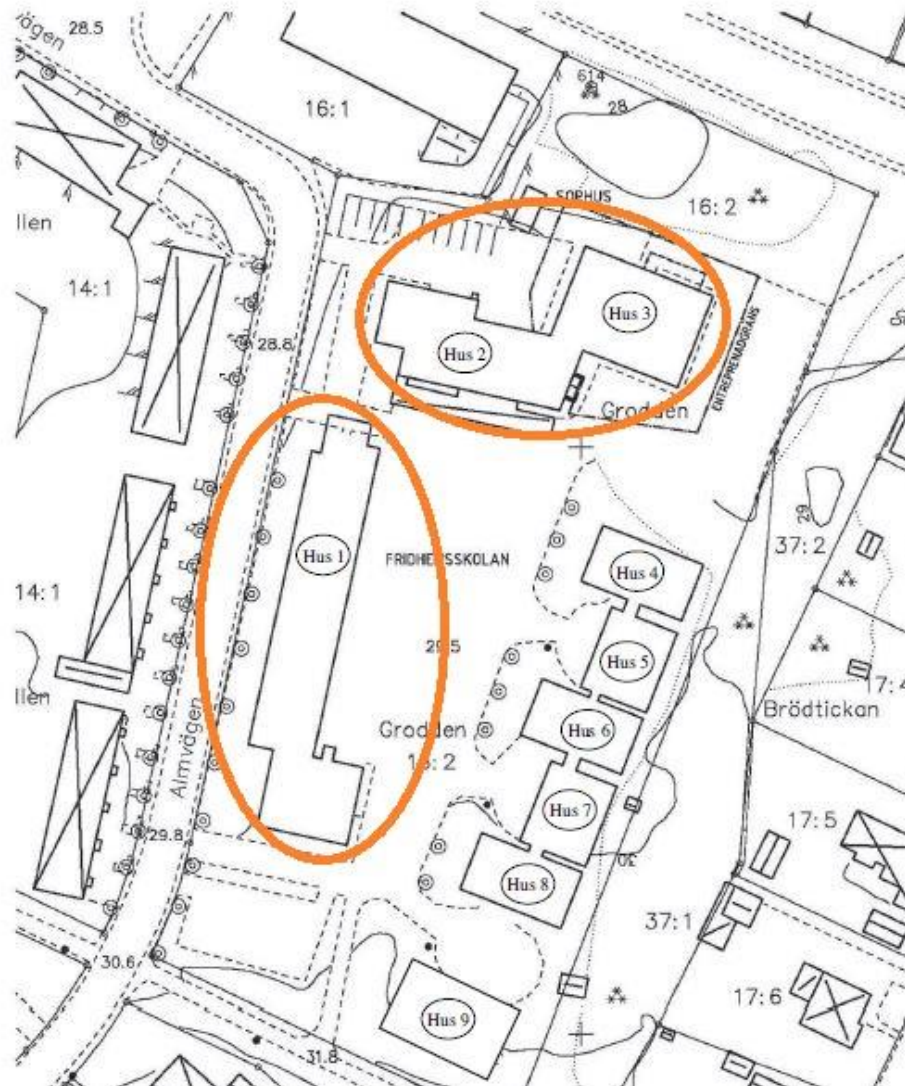
Figure 1-2. Fridhemskolan buildings

1.7 Approach

The study begins with on-site visit to take the required measurements and to collect the necessary information such as (lights, ventilation, construction materials, plan drawing, energy bills, etc.) for the energy audit, then all gathered information was used as input data on IDA-ICE to build baseline models and simulate energy usage in the three buildings under study. Finally, some energy efficiency measures were applied to reduce the school energy usage after analysing the simulation results. Figure 1-3 shows a simplified structure of the approach
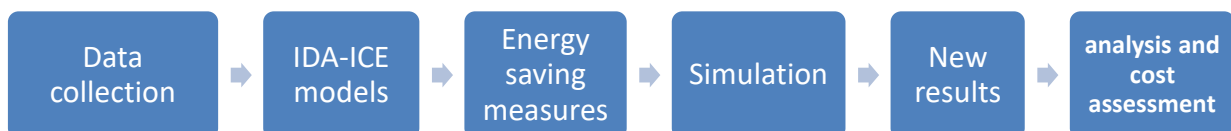
Figure 1-3. Simple structure of the approach

2 Theory

2.1 Energy Audit

An energy audit can be defined as a method of determining the types and cost of energy use in buildings, assessing where a building consume energy, and finding opportunities to decrease this usage. There are four basic level of energy audit which are [18]:

Type 0 – The Benchmarking Audit

This audit involves making a detailed preliminary analysis of energy usage and cost, and identifying benchmarking indices such as Btu per square foot per year and energy cost in dollars per square foot per year bases on energy bills.

Type 1 – The Walk-through Audit

From its name, it a tour to visually check each system using energy. It includes an assessment of energy usage data to analyse energy consumption trends and amounts. It also provides comparisons between similar facilities based on industry averages. It considered the least costly audit and result in a list of low-cost saving potential through improvement of operation and maintenance practice.

Type 2 – Standard Audit

In this audit, more detailed review and analysis of the operational characteristics, systems and equipment is performed to calculate energy uses and losses. On site measurement and testing is also performed as part of energy analysis to quantify energy use and efficiency of different systems. To analyse efficiencies, energy calculation and costs saving based on changes to each system, standard energy engineering calculation is used. furthermore, economic analysis of recommended changes or measures is included in this type of audit.

Type 3 – Computer Simulation

Computer simulation audit include "detail of energy use by function and more comprehensive evaluation of energy use patterns." [18]. This is achieved by use of computer simulation software. The auditor will create a model of building system that will account for weather and other variables and estimate yearly energy usage. The main goal here is to build a baseline for comparison that is reliable with the actual energy usage of the subject under study. After finishing the baseline, the auditor will then try to improve efficiency of various systems by implementing different changes on the baseline model. Then the effect of these changes will be measured and compared to the base model. This type of audit also takes into account interaction between systems to avoid overestimation of savings.

2.2 IDA-ICE

Nowadays simulation software is used often to estimate and analyse buildings performance and HVAC systems. IDA-ICE is "is a dynamic simulation tool providing simultaneous dynamic simulation of heat transfer and air flow by creating a mathematical model to calculate the heating and cooling load in a building, and predict the thermal comfort and indoor air quality based on building properties defined by the user" [5].

IDA-ICE 4 validation was performed by some studies, depending on the set indoor temperature, heat balance between all supplied heat and heat losses is calculated by using finite difference method, timesteps simulation and transient calculations. The main negative side of IDA-ICE is the risk of program crashes occurrence and possibility of errors in developing the mathematical model throughout the simulation [5].

2.3 Building Energy Balance

A brief explanation of building energy balance is used here to illustrate building energy saving potential by implementing existing technologies, such as energy saving ventilation systems and efficient building envelope components. Energy balance of building is the relationship between the energy that is supplied to the building and energy loss from it. Energy is supplied to building for various application and purposes. Space heating and cooling is needed to maintain thermal comfort indoor when the temperature outside is either low or high. Energy for space heating is required to balance the heat losses through building envelope and through ventilation. Hot water is required for hand washing, dish washing, showering, etc. Electricity is needed for lighting, household appliances and building utilities (system air handling units, circulation pumps, elevators etc.) [19].
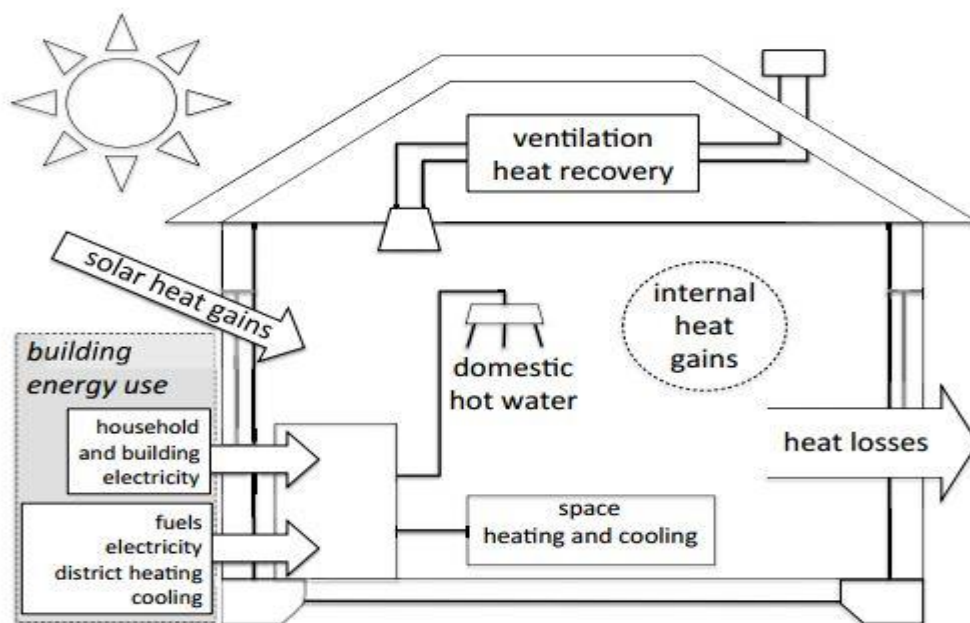
Figure 2-1. Energy Balance of a building component

Figure 2-1 above shows the energy supply and losses that effect a building's energy balance. Building envelope heat losses consist of heat transmission through floor, roof, walls and doors, and heat losses due to air leakage which is known as infiltration. Ventilation system has heat losses also. The heat in the exhaust air from building can be recovered partially by supplying it to the fresh air through heat recovery system. Heat is also supplied to the building by solar heat gains through windows and internal heat gains which generated inside from appliances and human existence [19].

2.4 Heat Transfer
Heat transfer is the science that looks to estimate the energy transfer that can take place between materials bodies when there is temperature difference between them. Heat transfer also predict the exchange rate under specified condition. The fundamental when determining the design of

building is the study of heat transfer and for the design of the building technical system to provide the thermal comfort the heat losses is considered the core key. Heat transfer through three different ways: conduction, convection and radiation [20].

2.4.1 Conduction

Heat transfer by conduction occurs between solid/stationary fluids due temperature difference of inter-molecular interactions. Conductive heat transfer is defined in Fourier's law as:

$$\dot{q} = -k \times A \times \frac{dT}{dx}$$ Eq.2-1

Where $\dot{q}$ = heat-transfer rate [W]
A = heat transferring area [m²]
k = thermal conductivity of the material [W/m K]
dT/dx = temperature gradient in the direction of heat flow [K/m]

Material thermal conductivity is a thermodynamic property and it have constant value. Heat conduction is proportional to K-value. Thermal resistance of material layer is how good the material allow heat to transfer by conduction through it and depends on the thickness of the material and its thermal conductivity. The following equation illustrated this relation.

$$R = \frac{l}{k}$$ Eq.2-2

Where R = conductive thermal resistance [m² K/W]
l = thickness of the layer [m]
k = thermal conductivity of the material [W/m K]

So, materials with lower thermal conductivity will result in high thermal resistance thus good insulators for the building to reduction heat transfer through building envelope.

2.4.2 Convection

Heat transfer by convection occurs when a fluid is in contact with solid body which has different temperature than the surroundings. Natural convection can happen if there is no outside influence and the media movement depends on the density difference driven by buoyancy forces.
Overall effect of convection is express by Newton's law:

$$\dot{q} = hc \times A \times (Tw - T\infty)$$ Eq.2-3

Where $\dot{q}$ = heat-transfer rate [W]
A = heat transferring area [m²]
hc = convective heat transfer coefficient [W/m² K]
Tw = temperature of the solid surface [K]
$T\infty$ = temperature of the fluid [K]
Thermal resistance in this case is related to convective heat transfer coefficient as

$$R = \frac{l}{hc}$$ Eq.2-4

Where R = convective thermal resistance [m^2 K/W]
hc = convective heat transfer coefficient [W/m^2 K]

2.4.3 Radiation

Anybody with temperature higher than 0 K emit thermal radiation and this radiation is absorbed by the surrounding surfaces. The difference between these (emission and absorption) in a body results in net heat transfer, which affect the temperature of the body. The radiation mechanism is an electromagnetic radiation.

The total radiation energy exit (emitted and reflected) from a body's surface is called Radiosity, **J** [W/m^2] and the radiation energy that received by a surface is called Irradiation, **G** [W/m^2].

Blackbody is considered to be an ideal radiator which absorb all the radiation and the energy emitted is expressed by Stefan-Boltzmann equation

$$\dot{q}_{emitted} = \sigma \times A \times T^4 \qquad\qquad \text{Eq.2-5}$$

Where

$\dot{q}_{emitted}$ = blackbody emitted radiation [W]
A = heat transfer area [m^2]
T = absolute temperature of the blackbody [K]

However, in reality the emissivity value is below black value and not all the emitted radiation would reach other surfaces, part of it would be lost to surrounding. By taking onto account these factors the equation will be as follow:

$$q_{12} = \varepsilon_1 \times F_{12} \times \sigma \times A \, (T_1^4 - T_2^4) \qquad\qquad \text{Eq.2-6}$$
$$q_{12} \approx A \times \varepsilon_1 \times \sigma \times (4T^3{}_m) \, (T_1 - T_2) \approx A \, hr \, (T_1 - T_2) \qquad\qquad \text{Eq.2-7}$$

Where q_{12} = radiant heat-transfer rate [W]
ε_1 = emissivity of the grey body
F_{12} = view factor, the fraction of the radiation which leaves the surface 1 and reaches the surface 2
A = heat transferring area [m^2]
hr = radiation heat transfer coefficient [W/m^2 K]
T_1 = temperature of the surface 1 [K]
T_2 = temperature of the surface 2 [K]
T_m = mean temperature of T_1 and T_2 [K]

2.4.4 U-value

Thermal transmission or U-value is used to calculate the heat flow through building construction materials due to temperature differences. U-values depends on the summation of the thermal resistances of the construction materials and surfaces (outside and inside) resistances also.

$$U = \frac{1}{Rsi + \sum R + Rse} \qquad\qquad \text{Eq.2-8}$$

Where

R_{si} = indoor's surface resistance [m^{2}K/W]
R_{se} = outdoor's surface resistance [m^{2}K/W]

The lower the U-value of the construction materials means better insulation thus lower heat losses through it, as U-value means heat flow in watts (W) per square meter of component as result of degree temperature difference across it.

2.5   Ventilation System

The main purpose of the ventilation system is to establish acceptable thermal comfort and indoor air quality (IAQ). There are different types of ventilation system, for example, natural ventilation, mechanical and combined ventilation (natural and mechanical). Depending on some factors such as outdoor climate, IAQ requirements and cost one type is chosen over the others. Ventilation airflow supplied to building can be constant air volume (CAV) or variable air volume (VAV). The VAV is preferable in industrial, commercial, school and office buildings due to continuous change of occupancy levels during a day and random fluctuations in CO_2 concentration [21].

2.6   Energy condition of Fridhemskolan

The school have two primary energy sources electricity and district heating. Electricity is used for lighting, appliances, equipment's and AHU's, while DH is required for space heating and tap hot water. The monthly energy usage report of the last three year for both electricity and district heating was provided by Gavlefighteter company (Figure 2-2 and Figure 2-3).

From this report, total energy use per year and energy balance of the school between electricity and district heating is calculated (Figure 2-4). From energy balance, it's clear that the district heating consumption has the biggest share with more than 60% of the total consumption.
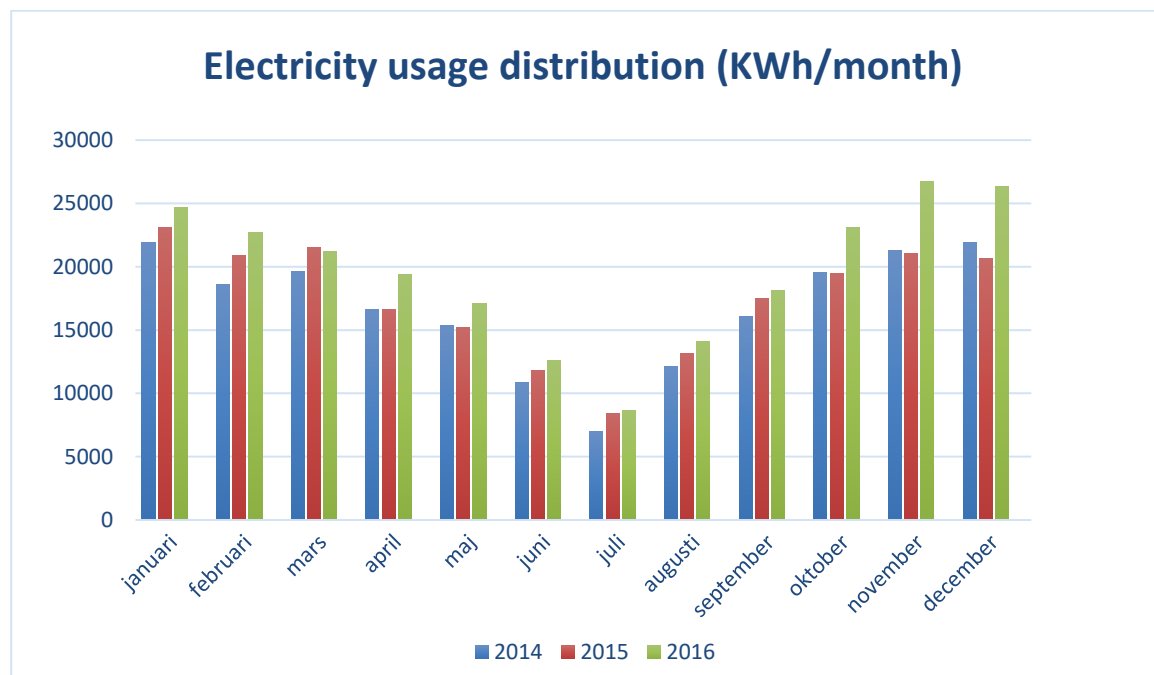
Figure 2-2. Monthly electricity consumption

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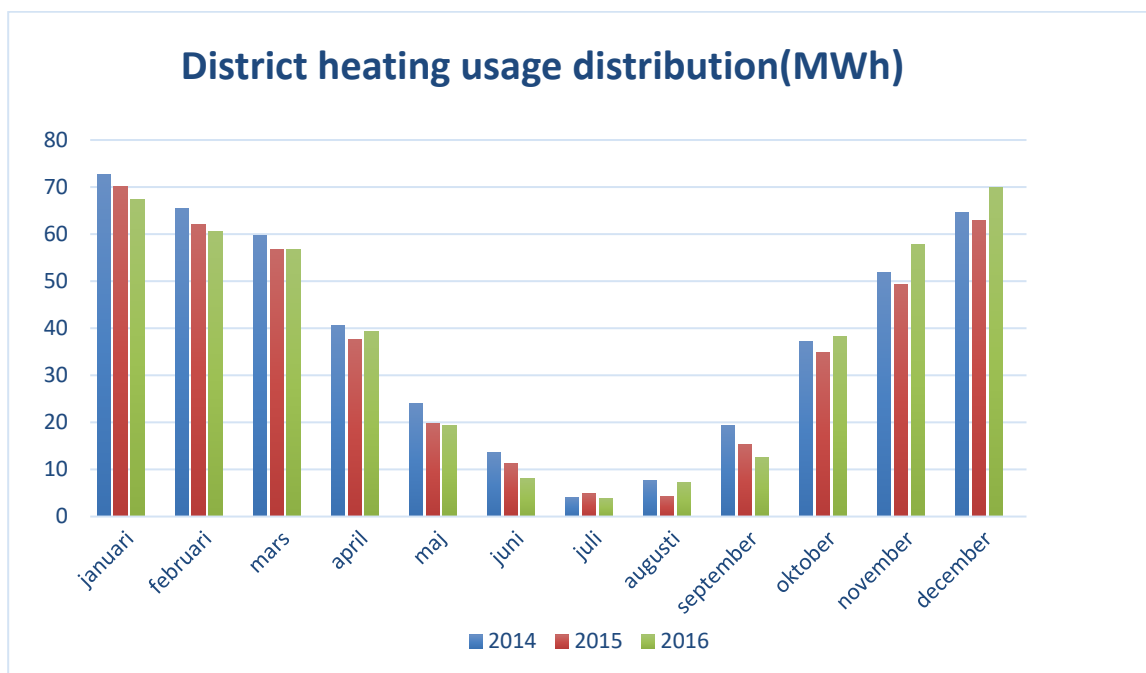
Figure 2-3. Monthly district heating consumption

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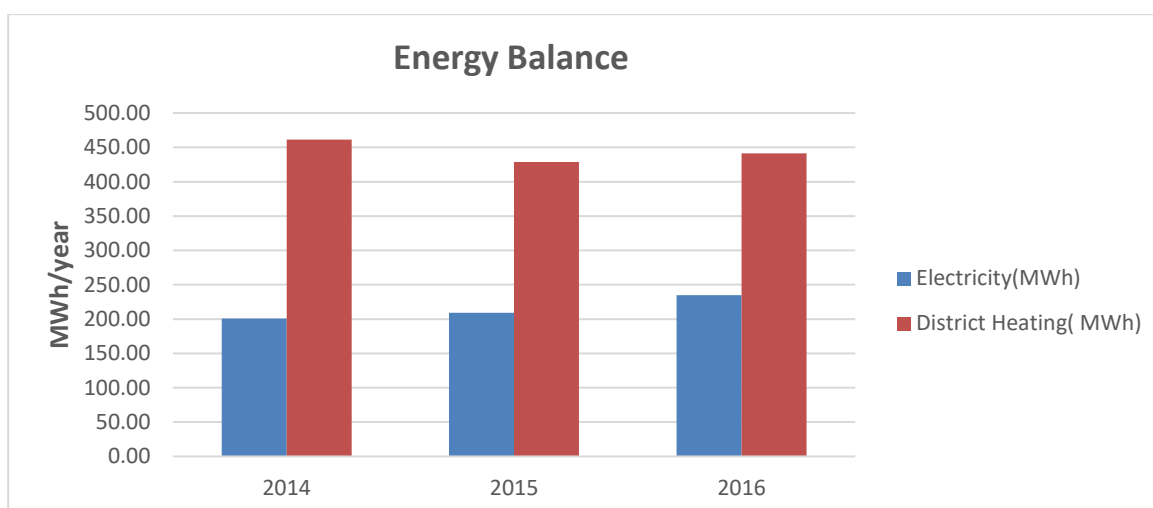
Figure 2-4. Comparison between electricity and DH usage for the last three years

Table 2-1. Total & average energy use of electricity and DH for the last three years

Energy Source	2014	2015	2016	Average
Electricity(MWh)	200.89	209.4	234.8	215.03
DHW(MWh)	461.31	428.89	441.3	443.83

2.6.1 Energy Prices

It's very important to know the cost of the energy used in the school buildings to calculate the energy saving in terms of money (SEK) for both electricity and DH. It will also make it possible

to evaluate energy saving measures economically. The monthly electricity bills were provided by Gavlefighteter company, while the DH price was taken from study [22] which was about energy retrofits of buildings in Gävlelborg region.

Electricity bill for one month can be found on appendix 8-1. It consists of two parts one part is paid to (GavleEnergi Elhandel) and the other part is paid (GavleEnergi AB). The payment made for the first company is related to the monthly amount of electricity consumption, while payment for the second company includes fixed subscription fees, power transmission fees, high and low load fees.

For simplicity, the paid fees which is related to the monthly power consumption will be considered to calculate electricity saving in SEK. These fees are the following:

1. Price (Elpris) = 38.90 Öre/kWh.
2. Energy tax (Energiskatt) = 29.20 Öre /kWh.
3. Transmission fees (Elöverföring) = 5.8 Öre/kWh.
4. Moms= 25%.

So, the electricity saving in **SEK/year** is calculated as shown in equation

$$Electricty\ saving(SEK) = a + b + c + d \qquad \text{Eq.2-9}$$

Where:
a = Electricity saving (kWh/year) * Elpris.
b = Electricity saving (kWh/year) * Energiskatt.
c = Electricity saving (kWh/year) * Elöverföring.
d= (a+b+c) * Moms.

The DH price was approximately 0.65 kWh/year [16]. So, the saving of the DH in SEK/year is calculated according to Eq.2-10 below.

$$DH\ saving(SEK/year) = DH\ saving\left(\frac{kWh}{year}\right) * DH\ price\left(\frac{SEK}{kWh}\right) \qquad \text{Eq.2-10}$$

3 Method

As mentioned before the aim of this thesis is to perform energy audit on Fridhemsskolan buildings to reduce the annual energy usage on it, in order to comply with overall EU target for 2020; which target to 20% increase energy efficacy over 1990 levels. Type-3 (computer simulation) of energy audit that stated before in the theory chapter (see section 2.1) was followed to accomplish the aim of this thesis by using IDA-ICE software to simulate energy performance of the buildings under study.

By analysing the simulation result and heat balance of the buildings, some energy savings potential and their correspondence cost was proposed in order to achieve the main goal of this thesis.

3.1 Materials

Two types of devices were used for measuring the actual ventilation rates inside the buildings for supply and exhaust air flow rates. The first one is Thermo-anemometer which is used to measure the speed in meter per second (accuracy $\pm3\%$[1]) of the supply air flow by placing the device pin perpendicular to the airflow, numbers of readings were taken on air outlets (grill) and air ducts. Then an average of the readings was calculated and used to find the airflow in litter per second according to equations (3-1) and (3-2) depending on the type and shape of the air outlet and where measurements took place. Figure 3-1 shows the thermo-anemometer device.

$$Q = V * A * 1000 \qquad\qquad\qquad \text{Eq.3-1}$$

Where:
Q= Airflow (l/s) in duct.
V= Average speed (m/s).
A= Cross sectional area of duct in m^2, ($A = \pi d^2/4$), d =Diameter of duct.

$$Q = V * A * C * 1000 \qquad\qquad\qquad \text{Eq.3-2}$$

Where:
Q= Airflow (l/s) from air outlet
V= Average speed (m/s).
A= area of air outlet(m^2).
C= 0.6 (Experience value).

The reduction (0.6) in above equation was used to reduce the area of air outlet because the air outlet is consisting of grilled bladed network. The second device is airflow hood capture (uncertainty $\pm6\%$) [22] which was used to measure the airflow (supply/exhaust) directly in litter per second Figure 3-1, it used by putting the hood directly on the air outlet. The air flow for each room inside the three buildings supply and exhaust can be found in Appendix 8-1.

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[1]http://www.tsi.com

Figure 3-1. Airflow measurements devices, Thermo-anemometer on the left and airflow hood on the right

3.2 Procedures

3.2.1 Data collection and on-site measurements

The study stared with collecting of the required documents from Gavlefastigheter company such as energy bills, annual energy use, architectural, construction and ventilation drawings. Then several on site measurements in school buildings under study were performed to measure the actual air flow rate in each room inside the buildings using devices mentioned above.

Due to unavailability of drawing regarding windows and doors dimensions manual measuring and checking was performed to know windows dimension and type of windows glazing in each room. Then, the rating power and number of lights and appliances in the buildings were checked visually in each building and documented in Appendix 8-1. Also, information about number of students, teacher and administration staff, working hours and operation of the school were collected during site visit. This type of procedures about data collection and measurements on site was performed in study [11] [12] (see section 1.3).

3.2.2 IDA-ICE baseline models building

Firstly, building models started by importing architectural drawings of each building into IDA-ICE to create the building body. Then, zones were defined according to the drawing; which represent different rooms inside the buildings corresponded to the real situation. Appendix 8-2 shows plan drawing and how zones and building body was created.

The following represent how the input data defined in IDA-ICE models as per the European standard 15265-2006 recommended format of input data for energy simulation [23].

- **Buildings location and climate data**
  Location of Söderhamn (Sweden) is used for simulation of the school buildings. The ASHRAE weather file for Söderhamn is used as an input data for the simulation, Since Gavle file is not found in the software.

- **Buildings Descriptions**
  Buildings construction materials with their thermal conductivity and overall U- value
  for each structure are shown in Table 3-1. Appendix 8-2 (Fig 8-10 to Fig 8-13) show
  how floors, roofs, and external wall materials determined in IDA-ICE. The floor, walls,
  roof and windows area are presented in Table 3-2.

Table 3-1. Construction materials specification for Hus 1,2 and 3

Building	Construction	Materials	Thickness (mm)	Thermal conductivity (W/K m)	U-value (W/m².K)
Hus 1 and Hus 3	**External walls**	Gypsum	25	0.22	0.17
		Mineral wool[2]	190	0.036	
		Gypsum	9.5	0.22	
		Frames cc60, Insulation	34	0.044	
	Roof	Wood	23	0.14	0.15
		Air gap	45	0.25	
		Chip board	3.2	0.13	
		Mineral wool	220	0.036	
		Gypsum	12.5	0..22	
		Frames cc600, Insulation	28	0.044	
	Floor	Concrete	100	1.7	0.31
		Cellplast	80		
		MAKDAM	150	0.2	
Hus 2	**External walls**	Wood	23	0.14	0.14
		Air gap	45	0.25	
		Frames cc60, Insulation	45	0.044	
		Gypsum	9.5	0.22	
		Mineral wool	190	0.036	
		Gypsum	12.5	0.22	
		Protect F	15.4	0.7	
	Roof	Wood	23	0.14	0.102
		Air gap	45	0.25	
		Frames cc600, Insulation	28	0.044	
		Chip board	3.2	0.13	
		Mineral wool	270	0.036	
		Gypsum	12.5	0..22	
		Frames cc600, Insulation	45	0.044	
	Floor	Concrete	100	1.7	0.31
		Cellplast	80		
		MAKDAM	150	0.2	

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[2] Mineral wool simulated as light insulation which have the same thermal conductivity.

Table 3-2 Building envelope for Hus 1, 2 and 3

Building	Floor area (m²)	External walls area (m²)	Roof area (m²)	windows area (m²)
Hus 1	816.54	492.72	816.54	98.91
Hus 2	414.48	392.66	427.54	60.7
Hus 3	345.63	314.53	345.63	24.41

Hus 1 rooms have different ceiling height (floor to suspended) some of them 2.5 m and others 3 m. Rooms in Hus 2 rooms have height of 2.5 m except the dining room which is 3.2m height. For Hus 3 the rooms height is also 2.5 m except the gym area which is 5.6 m height.

3 pane glazing windows in Hus 1 and Hus 2 have U-value of 1.9 $W/m^2 K$, a G factor or solar heat gain coefficient equal to (0.68) and solar transmittance equal to (0.6). 2 pane glazing windows in Hus 3 have U-value of 2.9 $W/m^2 K$, a G factor or solar heat gain coefficient equal to (0.76) and solar transmittance equal to (0.7).

The average overall U-value for Hus 1,2 and 3 are (0.249 $W/m^2 K$), (0.242 $W/m^2 K$) and (0.249 $W/m^2 K$) respectively.

- **Description of HVAC system**

The HVAC system was modelled by standard air handling unit (AHU) with heat recovery exchanger and heating coils. Each building has its own AHU for ventilation. There were two types of heat exchanger one is regenerative heat exchanger (rotary heat exchanger) which is used in AHU's of Hus 1 and Hus 3, the other type is direct heat exchanger (plate heat exchanger) in the AHU of Hus 2.

The effectiveness of the heat exchanger was defined 0.7 for both type, which is the minimum value required by the Swedish building code [24]. AHUs in Hus 1 and Hus 2 are constant air volume (CAV) system while the one on Hus 3 is variable air volume (VAV) system.

- **Internal temperature, ventilation and infiltration rate**
The thermal comfort condition and ventilation rates were identified in the models according the actual setting of the temperature inside set by Gavlefastigheter company and measurements on site of the ventilation rates. The heating and ventilation system were working to keep the indoor temperature at 20°C. Ventilation control system was set to work from 6:00am till 4:00pm (to 5:00pm in Hus 3only) Monday to Friday. The heating system was working always.

For more accurate results of energy consumption for each zone different supply and exhaust air flow rate in litter per second was defined according the measurements taken on site. Infiltration rate is another input which has been assumed as value of an air tightness equal to 0.5ACH at pressure difference of 50 Pa which is the minimum value according to the Swedish building regulations [22].

- **Internal heat gain and occupancy**
  The occupancy (Students, teachers and administrative staff) contribute to the sensible and latent heat in the zones. The activity level of the occupants generally was 1.6 metabolic equivalents (MET) and in the gym class was equal to 6 MET. The balance between the two types of gains (sensible and latent) calculated by the software.

  The occupants' presence in the school buildings from Monday to Friday 6:00am to 4:00pm. Schedule for them were different in each building depending on the nature of the building. Due to the movement of the students during the day between the classes, gym, outdoor activities and dining rooms some assumptions were made for each building for occupancy schedule with help of the school personnel. Appendix 8-2 Appendix 8-2 (Fig 8-2 to Fig 8-5) contain occupants schedule in main rooms and classes.

  Appliances (household)contribute to the internal gain also and their schedule also were different from one to another based on the frequent use of it. Appliances in the classrooms schedule were defined with help of the teachers, while others in kitchen hall were set with help of the workers there according to their use. 60% of the appliances power was defined as their share to the internal gain.

  Another source of the internal gains is the lighting. Due to the presence of at least two or three students anytime, the lighting schedule was defined always on during the working hours. 60% of their rated power was calculated as internal gain in IDA-ICE.

- **Ground Specification**

  " The ground was modelled according to ISO-13370 for determining the heat transfer between building and ground. In ISO- 13370 a 0.5 m layer of earth and a 0.1 m layer of insulation were assumed beneath the ground floor level of the buildings" according to study [5].

- **Heating system**
  Heating system was modelled as ideal heaters for each zone with district heating as energy carrier. The energy required for cooling was not accounted since there was no cooling equipment in the school.

3.3 Assumptions and limitation

Due to lake of some data and information some assumptions were made which can be accounted as limitation for the study. Those assumptions are the following:

- The construction drawing of Hus 1 were not found in the company files and even in the archives section in Gävle city hall so, the external walls, floor and roof materials were assumed to be the same as Hus 3.
- Schedule of the appliances was defined in the model according to questionnaire response of the personnel in the school.
- Occupants schedule was very hard to be defined exactly due to high mobility and movement between the classes and outside yard and changing of the classes schedule, so some assumptions were made here with the help of the school personnel.

- Domestic hot water consumption which is heated by DH was not available, so its assumed to be 45% of the total water consumption (cold + hot) which is available in cubic meter for the whole school building, then it was divided by the total area of the school and defined in IDA-ICE as (0.14 m^3/m^2.year) for each building.
- Since no measurement used to check the thermal bridges it was assumed to be typical.

3.4 Validation of the baseline models

Since there was no meter to measure the district heating consumption for each building separately; to validate the built-up models the average consumption of DH for the last three years (443.83 MWh/Year) was divided by the total area (m2) of the whole school buildings to find the consumption in (MWh/m2.year) as shown in eq.3-3 this value is called normalize performance indicator (NPI) [25], then this value was used to find reference value according to eq.3-4. The reference value was used for comparison with the simulation results to validate baseline models.

$$NPI = \frac{average\ consumption}{Total\ area} = \frac{443.83}{3073.6} = 0.144\ \frac{MWh}{m^2.year} \qquad \text{Eq.3-3}$$

where
Total area = area of the whole school (Hus1 to Hus 9)

$$Reference\ Value = NPI * Area = 0.144 * 2004.18 = 288.6\ MWh/year \qquad \text{Eq.3-4}$$

Where:
Area= Area of Hus 1,2 and 3

3.5 Energy Balance and energy saving measures

After performing the simulation energy balance obtained for each building. Then by analysing the energy balance which part of the building that causes high portion of energy losses were determined. After that number of retrofit measures were applied to the baseline models and simulated again to examine their effect on the energy consumption. Four scenarios of energy saving measures presented in the results chapter were studied, analysed and evaluated according to their cost.

4 Results

4.1 Validation Baseline models'

As illustrated before in the method section, the reference value was used to verify the simulation results in Table 4-1 as shown Table 4-2. These results were extracted from the delivered energy to each building in IDA-ICE, appendix 8-4 shows simulation results in terms of delivered energy to each Hus in more details, the built-up models are also available in the same appendix.

Table 4-1. IDA-ICE simulation results for Hus 1,2 and 3

Building	Baseline Model Simulation Results	
	DH (MWh/Year)	Electricity(MWh/Year)
Hus 1	133.26	56.51
Hus 2	142.83	56.84
Hus 3	23.25	7.69
Total	**304.84**	**121.04**

Table 4-2. Verification of the baseline models' consumption in comparison with the reference value

Energy Source	Reference Value MWh/year	Simulation Results MWh/year	Error
DH	288.6	304.84	5.3%

$$Error = \frac{(Simulation\ Results - Reference\ Value)}{Simulation\ Result} = \frac{(304.84 - 288.6)}{304.84} = 5.3\% \qquad \text{Eq.4-1}$$

The table above show that the simulation results are 5.3% deviated from the reference value which is used for validation. In this way, simulated energy use for the models is consistent and close to real value.

Another method to verify baseline model is by adding the obtained simulation results above to results of another study which is performed in the rest of the school buildings (Hus 4, Hus 5...., Hus 9). Then by comparing the total simulation result for the whole school buildings with average consumption in Table 2-1. Table 4-3 illustrate the result from both studies and deviation (error) from average consumption.

Table 4-3. Verification of the simulation results based on another study

Energy Source	Study (1) results[3] MWh/year	Study (2) results[4] MWh/year	Total MWh/year	Average consumption MWh/year	Error
DH	299	157	456	443	2.8%
Electricity	121	89	210	215	2.4%

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3 Result of this study which is performed on Hus 1, Hus 2 and Hus 3.
4 Results from another study which is performed on Hus 4 to Hus 9.

4.2   Energy Balance

After verifying the baseline models, to perform energy audit the main objective of this study, firstly it was important to study building energy balance component as mentioned in study [11] (see section 1.3). Analysing of the energy balance allowed identification of where high energy use and losses occurs. Then by implementing some of the retrofit measures stated before in study [8] (see section 1.3) the heat and electricity demand can be reduced.

Figure 4-1, Figure 4-2 and Figure 4-3 shows the energy balance in each building. From these figures, it clear to observe that high share of heat losses is caused by building envelope in all the buildings which mean there is need to improve building envelope insulation. Similarly, there is high percentage of DH consumption to heat the supply air especially in Hus 2. More details about the heat losses are available in Appendix 8-4.
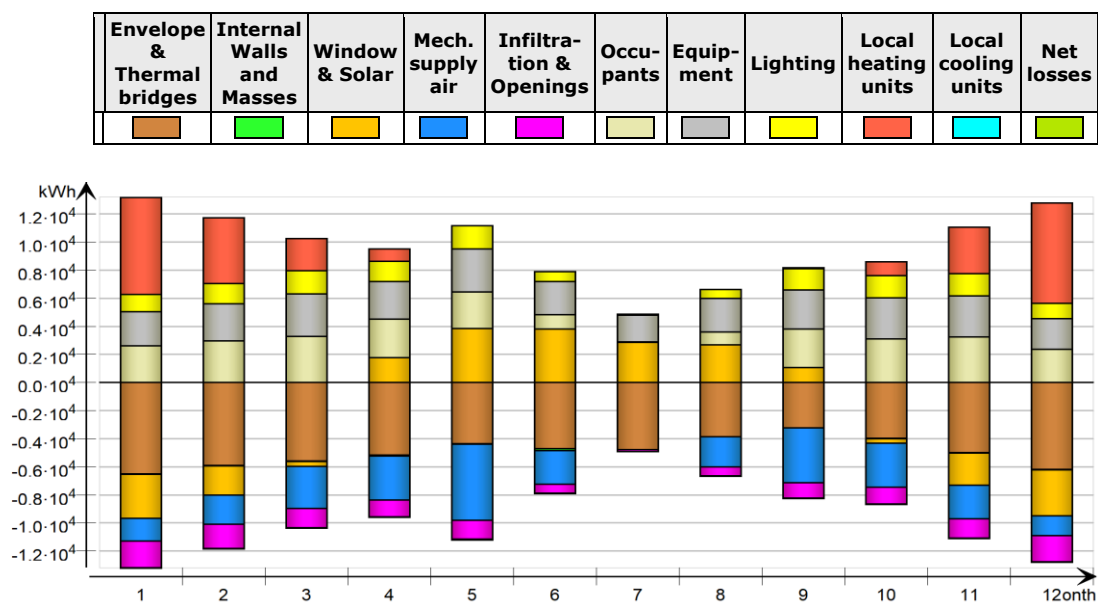

Figure 4-1. Hus 1 energy balance
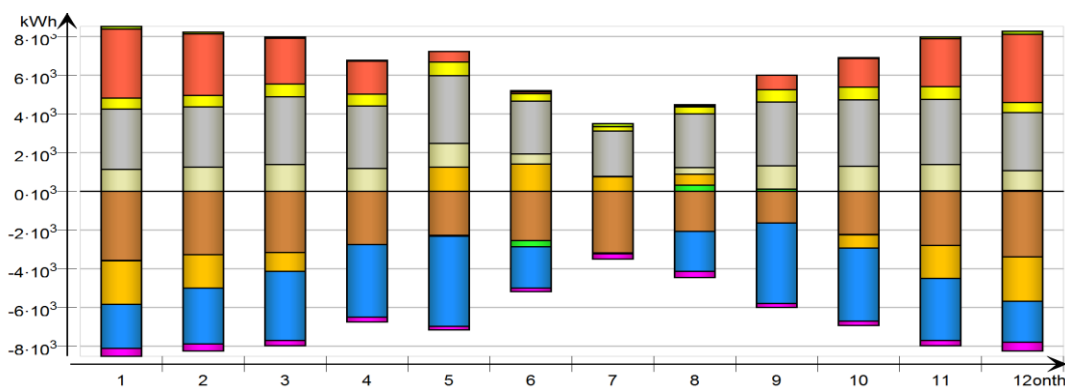
Figure 4-2. Hus 2 energy balance

24
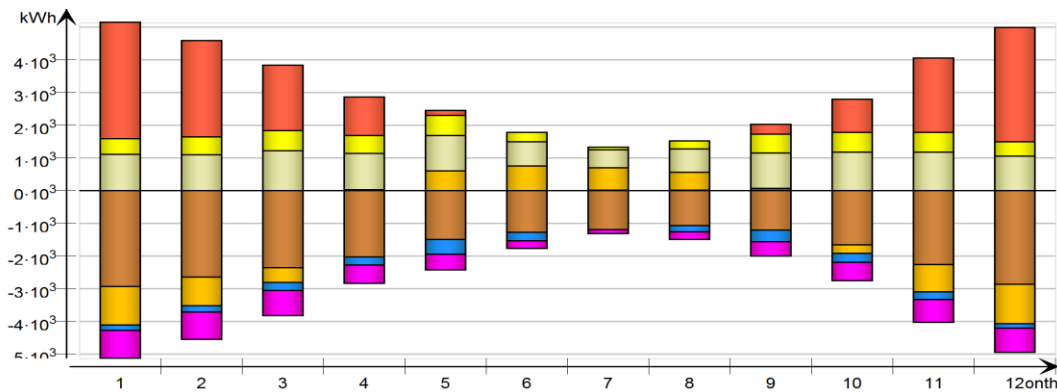
Figure 4-3. Hus 3 energy balance

4.3 Baseline models Thermal comfort

ISO 7730 assessment method is used by IDA-ICE software to determine the thermal comfort level achieved. Predicted percentage of dissatisfied occupancy (PPD) calculations and thermal comfort analyses are based on Fanger's models [5].

IDA-ICE simulation showed the (PPD) for each building. Table 4-4 shows average PPD obtained by IDA-ICE in each building. Regarding the CO_2 level; since the software provided it for each room separately inside each building Table 4-5 represent CO_2 level for three rooms (categorized with high frequent use by occupant's) as an example from each building.

Table 4-4. Average PPD in baseline models

Baseline Models	Hus 1	Hus 2	Hus 3
PPD%	14	20	17

The results above show that the value of PDD in Hus 2 and Hus 3 is higher than the (EN ISO 7730) standard regulation of 15% [5].

Table 4-5. CO_2 level in three selected room (baseline models)

Room No.	Type	Location	CO_2 vol.(ppm)
2/105	classroom	Hus 1	1149
2/206	Dining room	Hus 2	691
2/214	Gym hall	Hus 3	1892

CO_2 level indicated in the table above show that the level is higher specially in the gym room than the permissible concentration of CO_2 in the closed spaces according to World Health Organization (WHO) which is 1000 ppm.

4.4 Energy Saving-measures

After analysing energy balance for each building, some retrofit measures were applied to each baseline model and simulated again to see their effect on the energy use especially for the DH which have the highest portion of consumption.

Regarding electricity use reduction, some technology retrofits with their potential saving were presented also. Energy saving is achieved through different scenarios, each scenario is presented with its potential energy saving and the amount of cost correspond to the achieved saving.

4.4.1 Scenario 1

During project work one site visit was done after working hours of the school to check for unnecessary energy use. The visit revealed that AHU of Hus 2 was running continuously after working hours which means energy being wasted without need. Although it was programmed to work from 6:00 am to 4:00 pm every day from Monday to Friday, but the control system was malfunctioning.

The simulation result for Hus 2 in Table 4-1 was with current situation (continuous running) of AHU which implies enormous amount of DH and electricity consumption. In this scenario, the working time of AHU was adjusted in IDA-ICE to work from 6:00 am to 4:00 pm every day from Monday to Friday and simulated again. Table 4-6 shows the saving in DH and electricity by implementing this scenario.

Table 4-6. Potential energy saving of scenario 1

Building	DH Saving (kWh/year)	El Saving (kWh/year)	DH Saving (SEK/year)	El Saving (SEK/year)
Hus 2	91, 831	9, 030	59, 690	8, 420

4.4.2 Scenario 2

As it was illustrated before that high portion of the heat losses where due to building envelope which results in large DH consumption. This heat losses (heat transmission losses) can be reduced by improving building envelope insulation with extra 200 mm glass mineral wool (0.035 W/K m) on roofs and walls and by replacing windows with ones that have a U-value of 1 W/m^2. K

These retrofit measures resulted in reducing heat flow (losses) through building construction and windows. Table 4-7 below shows the potential saving in DH in kWh/year and SEK/year by applying insulation.

Table 4-8 presents the effect of windows replacement on the DH consumption and cost.

Table 4-7. Predicted energy saving with implementation of Insulation

Building	**Walls & roofs Insulation (200 mm Glass mineral wool)**	
	DH Saving (kWh/year)	**DH saving (SEK/year)**
Hus 1	7, 350	4, 778
Hus 2	3, 463	2, 251
Hus 3	4, 736	3, 078
Total	**15, 549**	**10, 107**

Table 4-8. Estimation of energy saving by windows replacement

Building	Windows U= 1 W/m² K	
	DH Saving (kWh/year)	DH Saving (SEK/year)
Hus 1	6, 665	4, 332
Hus 2	3, 392	2, 205
Hus 3	3, 300	2, 145
Total	**13, 357**	**8, 682**

4.4.3 Scenario 3

The type of the AHU's used is Hus 1 and Hus 2 is constant air volume (CAV) which is not appropriate for school application due to high occupancy level change and associated random change of CO_2 level. This make the VAV system with CO_2 more applicable in this case as stated in study [21]. Another advantage of the VAV system it reduces the electrical energy used by fans also, because it supplies of air according to the requirement not continuously like CAV system. It also decreased the amount of DH consumed in the heating coils to increase the temperature of the supply air due to change in the airflow rate. Hus 3 was already served by VAV with CO_2 system.

In this scenario, the CAV system was changed in the model of Hus 1 and Hus 2 by AHU's with VAV system from Swegon company. According to the technical data provided by Swegon the heat exchanger effectiveness can go up to 84.1% for plate heat exchanger and 81.3% for rotary heat exchanger; if there is balance between the total supply air and exhaust air flow rates. The plate heat exchanger was chosen for Hus 2 to prevent the smell from the Kitchen area. Technical data of the AHU's is available in appendix 4-1. Table 4-9 show energy reduction in each Hus due to implementation of this scenario.

Table 4-9. Energy Saving potential with AHU change, EL=electricity

Building	DH Saving kWh/year	El Saving kWh/year	DH Saving SEK/year	El Saving SEK/year
Hus 1	1, 992	367	1, 295	342
Hus 2	4, 092	599	2, 660	559
Total	**6, 084**	**966**	**3, 955**	**901**

4.4.4 Scenario 4

The types of the lights used in the buildings is fluorescent lights bulb which is not efficient and it's almost on during the whole working hours. The most rated used power of lights in the school is 36W T8 florescent light (332 lamps) in the studied buildings which have 2500 luminous flux5[26]. This can be replaced with 16.5T8/LED lamps (Philips) which have the same

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5. **Luminous flux** is the portion of the lamps power which is perceived as light by the human eye.

luminous flux [27]. Table 4-10 below show the savings in the electricity that can be achieved by changing to LED lights and the cost related to the savings.

Table 4-10. Electricity saving by using efficient LED lights

Building	EL Saving kWh/year	El Saving SEK/year
Hus 1	9, 458	8, 819
Hus 2	1, 210	1, 128
Hus 3	2, 264	2, 111
Total	**12, 932**	**12, 058**

4.5   Extra Saving

4.5.1   Air Curtains

Due to the high mobility of the students between Hus 1 and outside activates in the school yard; it observed that outdoors frequent use is very high (open and close) sometime its even open for a while. This behaviour was simulated in the base model by assuming an opening schedule for the outdoors as shown in appendix 8-2 (Figure 8-6). Energy losses due to this behaviour is portion of opening and infiltration losses illustrated in Figure 4-4. This energy loss can be decreased by using air curtain[6] to prevent infiltration of outdoor air inside the building.

To estimate energy reduction which can be achieved by the air curtain the model was simulated again with outdoors schedule always closed to see the difference in DH consumption with baseline model. Air curtain can save up to 70 % of this energy (difference) according to the study [28]. Eq.6 shows how the saving with the air curtain was calculated. Table 4-11 illustrated potential energy reduction.

Table 4-11. Predicated energy saving by using air curtains

Simulation	DH consumption (kWh/Year)
Baseline model	133, 264
Outdoor closed	127, 835
With Air curtains	3, 800

$$Air\ curtain\ Saving = 0.7 * (133264 - 127835) = 3,800\ kWh/year \qquad \text{Eq.4-2}$$

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6. **Air curtain** is device consist of casement and fan which supply a jet of air. It can be found in many applications one of them is the preservation of thermal comfort and air quality in specific zones of commercial and public buildings. In building, air curtains are mounted on top of doors to provide aerodynamic sealing [28] [29].

All zones

multizone report: output object in 811 baseline model final

kWh (sensible only)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-6498.6	-37.3	-3132.9	-1600.3	-1906.5	2630.3	2432.0	1235.8	6914.5	0.0	-15.9
2	-5900.2	-26.0	-2060.9	-2052.4	-1720.2	2978.0	2665.2	1446.4	4700.8	0.0	-19.5
3	-5585.8	-28.0	-330.1	-2965.3	-1353.7	3296.1	3050.7	1661.2	2288.7	0.0	-27.0
4	-5151.6	-69.9	1758.9	-3109.0	-1184.2	2755.7	2686.7	1449.7	907.4	0.0	-27.7
5	-4368.3	-32.7	3861.1	-5428.7	-1327.0	2614.7	3060.4	1661.3	14.2	0.0	-47.3
6	-4709.1	-114.8	3808.4	-2392.6	-633.3	1043.9	2353.4	700.0	-0.0	0.0	-21.5
7	-4782.7	18.6	2879.5	-0.1	-134.3	47.0	1905.1	78.2	0.0	0.0	-1.4
8	-3867.3	6.0	2698.6	-2134.0	-617.0	914.1	2400.3	632.5	0.0	0.0	-19.4
9	-3229.8	18.4	1049.2	-3910.0	-1063.6	2761.1	2800.6	1520.0	83.4	0.0	-34.3
10	-3978.9	-13.1	-323.8	-3122.9	-1174.1	3110.0	2936.0	1591.0	1004.4	0.0	-27.9
11	-4998.7	-14.7	-2295.2	-2398.7	-1359.1	3249.4	2925.1	1589.4	3330.1	0.0	-22.6
12	-6199.8	-31.2	-3262.6	-1407.2	-1871.0	2353.6	2210.5	1094.3	7150.4	0.0	-14.2
Total	-59270.7	-324.7	4650.1	-30521.4	-14343.8	27753.9	31425.9	14660.0	26393.8	0.0	-278.7

Figure 4-4. Outdoor heat losses due to infiltration and opening

4.6   Energy saving measures impact on thermal comfort

As mentioned before in many studies the important of IAQ and thermal comfort in educational buildings, the effect of each scenario on these two factors is presented in Table 4-12 and Table 4-13 below.

Table 4-12.Changes in the average PPD with each scenario

	PPD%		
Energy saving measures	**Hus 1**	**Hus 2**	**Hus 3**
Scenario 1		23	
Scenario 2 (walls and roof Insulation)	15	20	16
Scenario 2(windows replacement)	15	20	17
Scenario 3	14	23	_
Scenario 4	11	20	17

Table 4-13. CO₂ level after implementing each scenario

Room	CO₂ vol.(ppm)				
	Scenario 1	Scenario 2 (Insulation)	Scenario 2 (Windows)	Scenario3	Scenario 4
classroom	_	1150	1142	1153	830
Dining room	904	689	688	904	691
Gym hall	_	1899	1888	_	1889

4.7 Economic assessment

From the results obtained above energy usage reduction potential is great, but implementation of these measures must be evaluated according to their cost and benefits as it's one of the objectives of this study.

The decision about the investment on the suggested energy saving measures depend on many factors and the most used one is payback period which is performed here to prioritize the proposed energy saving measures. As the choice of which energy measures to implement is balance between its benefits and the capital investment.

All the scenarios were analysed here according to their capital cost, annual saving and payback period for each building separately and for all of them together as illustrated in Table 4-14. Investment in Swedish kronor, annual energy and payback period of saving scenarios in each studied building and for the Whole buildings together. The Payback period was calculated as shown in the equation below [18].

$$Payback\ Peroid = \frac{Investment\ Cost(SEK)}{Total\ Saving\ (SEK/year)}$$

Eq.4-3

Where:
Total Saving = DH saving (SEK/year) +Electricity saving (SEK/year).
Investment cost = energy saving measure cost.

Table 4-14. Investment in Swedish kronor, annual energy and payback period of saving scenarios in each studied building and for the Whole buildings together

	Scenario 1	Scenario 2[7] (Insulation)	Scenario 2[8] (Windows)	Scenario 3[9]	Scenario 4[10]
Hus 1					
Annual energy saving (SEK/yrs)	*	4, 778	4, 332	1, 637	8, 819
Investment cost (SEK)	*	62, 321	121, 602	185, 000	29, 420
Payback Period	*	13	28	113	3
Hus 2					
Annual energy saving (SEK/yr)	68, 111	2251	2, 205	3, 218	1, 128
Investment cost (SEK)	0	29, 977	78, 910	200, 000	19, 798
Payback Period	0	13	36	63	18
Hus 3					
Annual energy saving (SEK/yr)	*	3, 078	2, 145	*	2, 111
Investment cost (SEK)	*	31, 424	31, 733	*	12, 212
Payback Period	*	10	15	*	6
All buildings (Hus 1,2&3)					
Annual energy saving (SEK/yr)	*	10, 107	8, 682	4, 855	12, 058
Investment cost (SEK)	*	123, 721	232, 245	385, 000	61, 430
Payback Period	*	12	27	79	5

Investment cost for different scenarios is calculated as follow:

$$\text{Insulation Investment} = \text{Cost of insulation} * (roof \text{ area} + \text{wall area}) \qquad \text{Eq.4-4}$$

$$\text{Windows Investment} = \text{Cost of windows} * \text{Windows area} \qquad \text{Eq.4-5}$$

$$\text{Lights Investment} = \text{Cost of LED lamps} * \text{Number of lamp} \qquad \text{Eq.4-6}$$

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7 Cost of glass mineral wool insulation= 47.6 SEK/m^2 [30].
8 Cost of windows= 1300 SEK/m^2 [31].
9 Cost of AHU(VAV) for Hus 1= 185, 000 SEK, Cost of AHU(VAV) for Hus 2= 200, 000 SEK [32].
10 Cost of LED lights= 185 SEK/lamp [27].

5 Discussion

5.1 Method and IDA-ICE models

The method which is followed on this thesis by creating a dynamic model for the buildings under study then applying different kinds of energy efficiency measures to study their effect on the energy use was implemented by study [13] [14]. Furthermore, study [13] mentioned that creating a dynamic model is the best way to perform energy analyses of the energy efficiency measures. On other hand, creating the models had some limitation which can be considered as drawbacks such as assuming values for losses through thermal bridges, infiltration rate and domestic hot water consumption.

The results obtained from the simulation results on IDA-ICE showed that the baseline models are valid to be used for the study with an error of 5.3 % in DH demand. This deviation could be result of uncertainties and assumptions made in the method chapter which is considered as limitations. In addition to that, other factor such as the behaviour of the occupant's regarding the opening of the windows wasn't considered also in the simulation results.

Electricity consumption of each building individually was not available either. In addition to that household appliances working schedules couldn't be specified exactly which is another limitation for electricity use estimation. lights were also assumed to be on almost on the entire working hours of the school.

The only to validate electricity consumption is to add the electricity usage in the studied buildings models with the consumption of the other buildings (from another study which is performed on the rest of the buildings) and compare with the annual electricity use from the bills. This have also shown 2.4 % deviation from the real value which can be considered acceptable.
.

5.2 Results

5.2.1 Energy saving-measures and profitability

- **Scenario 1**
  One of the most important findings was the first saving measure in Scenario 1 which should be implement directly since there zero capital investment. The control system (timer) of the Hus 2 AHU which was not functioning and resulted in continuous running thus a huge amount of wasted energy. Significant reduction of energy use will be achieved by setting the time control again on the AHU; 30.7 % and 7.5% reduction in district heating and electricity consumption respectively which correspond to 68, 111 SEK/year saving.

- **Scenario 2**
  Building envelope insulation cost can be considered very high compared to the relatively low energy reduction that could be attained. In addition to that district heating price (0.65 SEK/kWh) was an important factor that influence the profitability of building envelope retrofits. Number of simulations were made with extra insulation of the walls, floors and roof but the cost of it was very expensive. So, the best solution to optimize building envelope insulation cost was adding extra insulation on walls and roofs only for all the buildings which appears to be the most effective insulation measure. Figure 5-1 show the comparison between implementing of this measure on each

building individually and for all of them in terms of energy saving, energy cost reduction and payback period. This improvement cost 123, 721 SEK with payback period of 12 years and it reduce the annual district heating consumption by 5.2%.
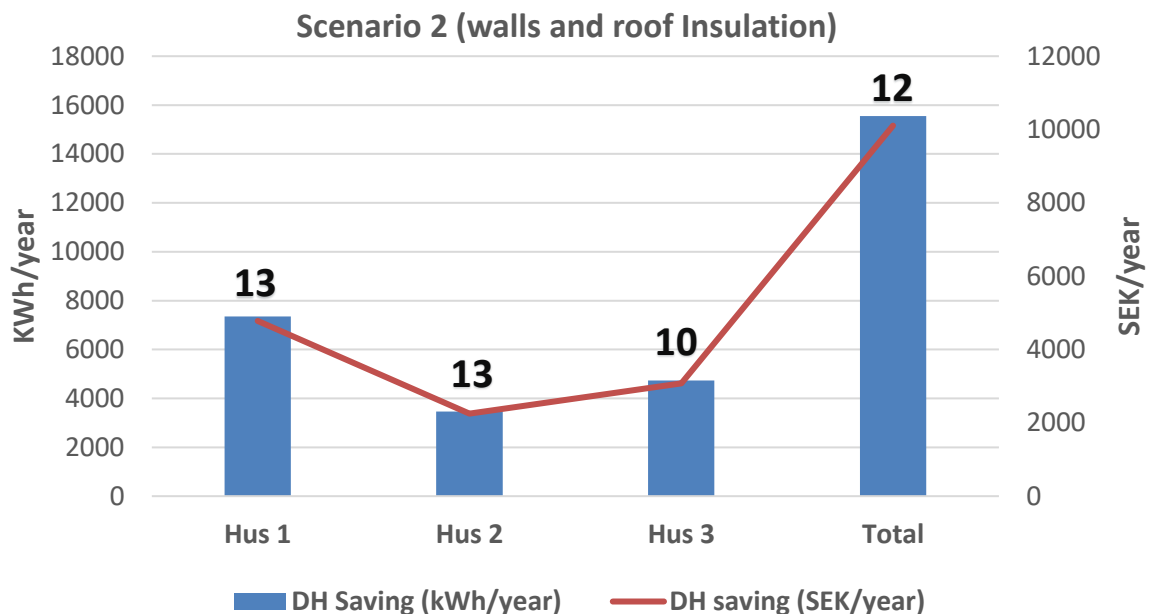

Figure 5-1. Comparison of saved energy, saved energy cost and payback periods by implementation of insulation in each building and all buildings together. (Numbers above each column represent payback period)

Windows used in the building are considered quite energy efficient but the simulation showed that it implies high heat transmission losses. Replacing of the windows in the three buildings cost is substantially high and have a long payback period of 27 year as presented in figure below. However, implementing this measure in all the buildings is the most convenient solution since this scenario cost for individual building is very high compared to the saving specially Hus 1 and Hus 2, thus resulting in a long payback period as shown in Figure 5-2.
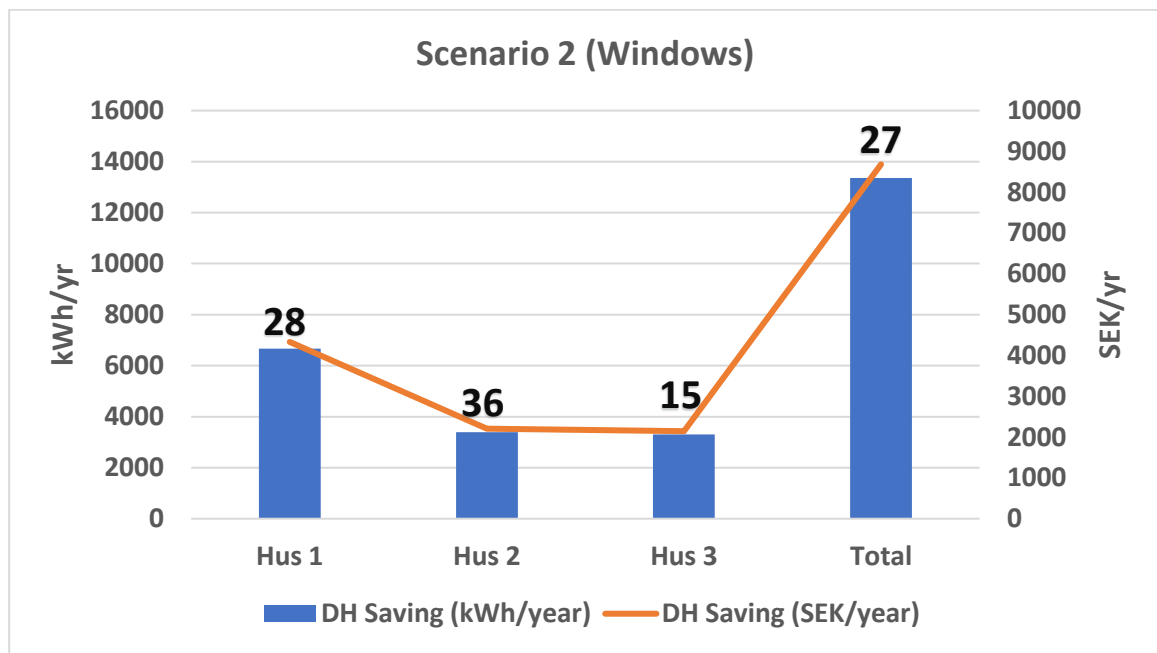
Figure 5-2. Comparison of windows replacement in each building and all the buildings together in terms of saved (KWh/year), (SEK/year) and payback period. (Numbers above each column represent payback period)

- **Scenario 3**

  CAV ventilation system of Hus 1 and Hus 2 is not recommended to be used in the school application as stated in [21]. By changing to VAV system in those mentioned buildings, simulation show that energy reduction potential for both DH and electricity is very low which make this measure not worth implementation. In addition to that the capital investment of the new AHU's is quite expensive and the payback period is even longer (see Figure 5-3 below) than the life time of the them.
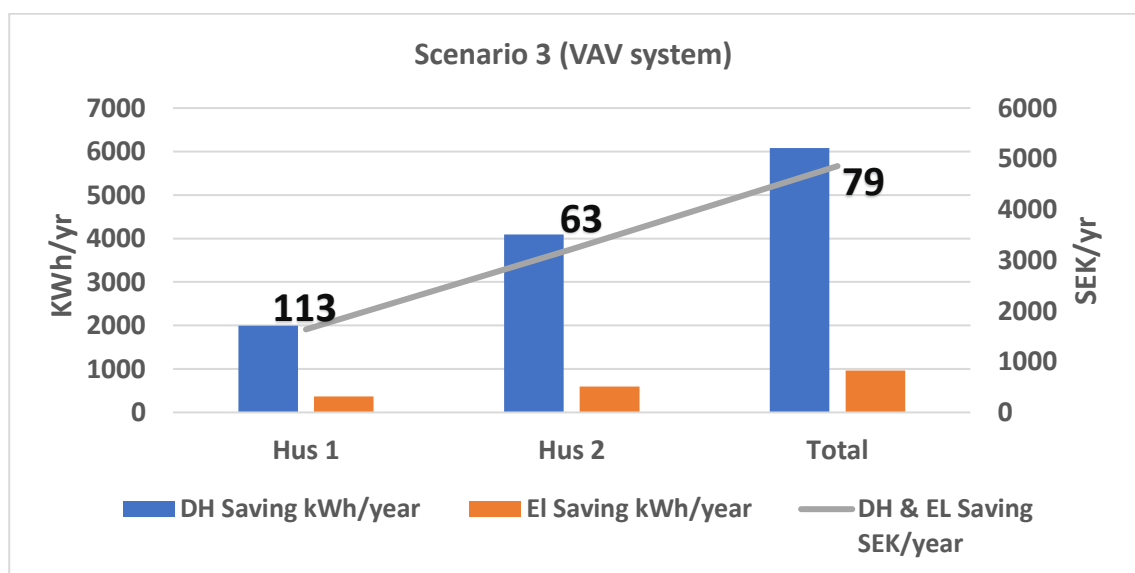

Figure 5-3. Comparison of Ventilation replacement in each building and all the buildings together in terms of saved (KWh/year), (SEK/year) and payback period. (Numbers above each column represent payback period

- **Scenario 4**

  In contract to district heating price, high electricity price had a significant impact on the cost-effectiveness of lights technology upgrade. Electricity consumption reduction by changing lights to LED technology is promising and worth to be impalement in all the building together or at least in Hus 1 where the lights electricity consumption is high. The saving potential in Hus 1 by applying this measure is 9, 458 kWh/ year with 3 years payback period, but if it's applied on all the buildings the payback period increases to 5 years as represented in Figure 5-4 with 12, 931 kWh/year electricity use reduction which is equal to 12, 058 SEK/years electricity cost saving.
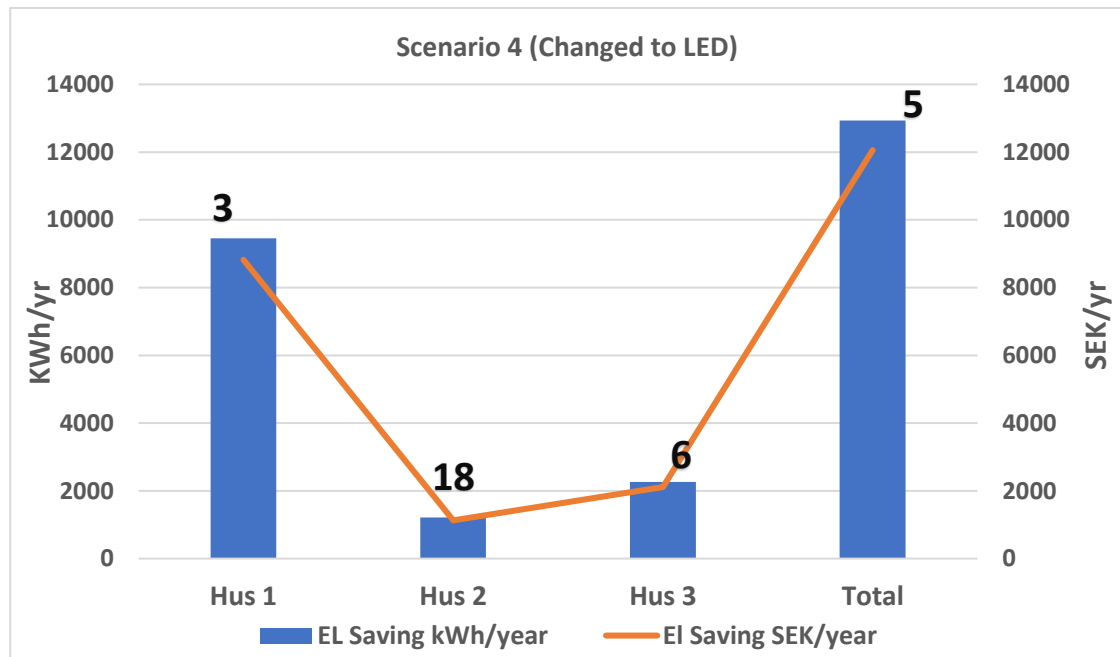

Figure 5-4. Comparison of using LED lights in each building and all the buildings together in terms of saved (KWh/year), (SEK/year) and payback period. (Numbers above each column represent payback period

Building envelope retrofits measure was expected to be low and cost-effective as have been mentioned in the study [8] which state that the building fabric retrofit measures have less investment cost compared to other measures. This difference can be due to the buildings specific information stated in the same study [8] such as size, geographical location, age, etc. which determine the effectiveness of the retrofits.

The cost of the installation of the suggested measurement were not taken into account in the economic assessment of these measures which will increase the investment capital. To reach the actual value this cost should be calculated also.

Generally speaking, simple payback period which is used to evaluate the saving measures have some disadvantages because it doesn't take into account other important factors such as expected energy price increase, interest rate and expected life of the improvement. These factors can increase the profitability of the proposed energy saving measures more and make it more reliable and consistent to be implement.

To conclude, implementation of the recommended energy saving measures which appear from the discussion above to be the most cost-effective measures are reducing working time of AHU in Hus 2, insulation of the building roof and walls, replacement of windows and changing to LED efficient lights in all the three buildings. These measures will save in total 120, 737 kWh/ year of DH energy and 21, 961 kWh/year of electricity. In terms of economic value saving of 98, 957 SEK/ year will be reach with a related cost of 417, 396 SEK.

5.2.2 Thermal Comfort and CO_2 level

Implementation of the energy efficiency measures didn't have a significant impact on the CO_2 level inside the rooms that have been chosen for the analysis. Although it was expected that scenario 3 (VAV system) will decrease CO_2 level and improve air quality as it's recommended for this purpose according to [21]. Regarding the thermal comfort, simulation results showed that the PPD change slightly in some cases after implementing of the energy efficiency measures. Never the less, two cases needs to be point out, first changing of the lights in Hus 1 decreased PPD to 11% (3% decrease) this is because the average operative temperature inside the building zones was reduced due to less heat gain from the new lights Less rated power). In Hus 2 reducing of the AHU working hours and changing of the ventilation system to VAV increased PPD to 23% (3% increase), according to the simulation, the reason for this was the percentage of hours when operative temperature is above 27°C raised up from 12% to 20%.

Generally, Hus 1 showed acceptable percentage of thermal comfort in all scenarios according to the (EN ISO 7730) standard regulation of 15% [5], While Hus 2 presented high level of discomfort. Hus 3 was slightly higher than acceptable limit for thermal comfort by 2%. In a real building, windows would not be closed all the time as assumed in all the models, which lead to elevated temperature inside the rooms causing this discomfort specially in Hus 2. Opening of the windows in real life specially in summer period can bring fresh cool air which can lower the temperature inside buildings rooms leading to better thermal comfort.

6 Conclusion

An energy audit has been conducted in Fridhemsskolan building in Gävle; based on the information collected during this work, the project has shown that the school buildings under study have a great potential to reduce their DH and electricity energy use by 40.3% and 18.1% respectively, if the recommended measures in the discussion chapter are implemented. By this the main objective why this study was performed is accomplished. As some of these retrofits might not have great economic beneficial (long payback period) such as scenario 1 for both insulation and windows replacement, the combination of different retrofits as suggested would lower the effect of the non-profitable options.

However, depending on the available budget for retrofits and the underlying motivation (economic benefit at long term) the implementation of the proposed measures can be spread over time, as all the measures can be applied independently.

Regarding the thermal comfort, the improved models after implementation of the energy efficiency measures didn't show considerable different from the baseline model, except the case of Hus 2 which show an increase in the degree of thermal discomfort due to implementation of scenario 1 and scenario 3.

6.1 Outlook

The applied method can be improved by using temperature loggers to measure the indoor temperature in different places of the studied three building. Blown door method also might be used to assess the real airtightness of the buildings construction.

Furthermore, an infrared camera could be used to identify thermal bridges and air leaks. These three techniques measures will improve the built-up models since the measured parameters are considered important factors that can lead to more accurate bassline models and thus precise results.

More investigation about using air curtain to reduce heat losses due to infiltration should be done to to know which types of air curtain and which velocity should the air jet supply to suit the condition of the school. Althought the associated fans energy consumption should be calculated to know if it worth implemtation when saving in the DH compare to added electricity consumption .

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8 Appendix

Appendix 8-1

FAKTURASPECIFIKATION   Sida: 2/3

Fakturanr/OCR   21659571117

Gävle Energi Elhandel

Elhandel avtal 2020189 Gästrike inköp Kommunavtal 1 apr 2007 - 31 dec 2022
Fakturaperiod 1 nov 2016 - 30 nov 2016

Beräknad årsförbrukning 229062 kWh

Elpris	26734 kWh	38,90 öre/kWh	10 399,52 kr
Energiskatt	26734 kWh	29,20 öre/kWh	7 806,33 kr
Moms 25 % på 18 205,85 kr			4 551,46 kr

Gävle Energi AB fakturerar på uppdrag av Gävle Energi Elhandel
Gävle Energi Elhandel har överlåtit fordran till Gävle Energi AB

Summa Elhandel   **22 757,31 kr**

Gävle Energi AB

Elnät avtal 1041144 Nätavtal
Fakturaperiod 1 nov 2016 - 30 nov 2016
Beräknad årsförbrukning 229062 kWh

Eff lågsp. Abonnemangsavgift	30 dagar	4 000,00 kr/år	327,87 kr
Eff lågsp. Elöverföring	26734 kWh	5,80 öre/kWh	1 550,57 kr
Eff lågsp. Effekt höglast	93,667 kW	77,00 kr/kW	7 212,36 kr
Eff lågsp. Effekt låglast	50 kW	23,00 kr/kW	1 150,00 kr
Moms 25 % på 10 240,80 kr			2 560,20 kr

Summa Elnät   **12 801,00 kr**

Figure 8-1. Energy Bill from November

Appendix 8-1

Ventilation rates

Table 8-1. Supply and exhaust air flow rates in Hus 1

	Hus 1 ventilation rates		
	Room No.	**Q.supply (l/s)**	**Q.Exhaust (l/s)**
Plan 1	1/101	0.00	0.00
	1/102	0.00	21.00
	1/103	0.00	10.00
	1/104	86.74	0.00
	1/105	531.57	212.30
	1/106	0.00	0.00
	1/107	0.00	0.00
	1/108	0.00	28.50
	1/109	86.74	0.00
	1/110	361.37	181.50
	1/111	0.00	26.50
	1/112	0.00	0.00
	1/113	0.00	23.50
	1/114	145.41	0.00
	1/115	361.37	181.50
	1/116	0.00	28.50
	1/117	0.00	0.00
	1/118	0.00	0.00
	1/119	95.03	0.00
	1/120	361.37	0.00
	1/121	0.00	36.00
	1/122	0.00	0.00
	1/123	0.00	26.00
	1/124	145.41	0.00
	1/125	361.37	181.50
	1/126	0.00	20.50
	1/127	0.00	0.00
	1/128	0.00	12.50
	1/129	86.74	0.00
	1/130	84.81	203.20
	1/131	0.00	24.00
	1/132	0.00	0.00
	1/133	0.00	19.50
	1/134	155.43	0.00
	1/135	0.00	36.00
	1/136	0.00	27.60
	1/137	0.00	0.00
	1/138	69.96	25.00
	1/139	0.00	25.00
	1/140	0.00	0.00
	1/141	0.00	20.00
	1/142	0.00	20.00
	1/143	202.06	0.00
	1/144	0.00	43.80
	1/145	35.88	64.40
	1/146	458.49	209.30
	1/147	65.11	26.50
	1/148	0.00	0.00
	1/149	0.00	26.50
	1/150	43.50	0.00
	1/151	0.00	0.00
Total		**3738.40**	**1760.60**

Table 8-2. Supply and exhaust air flow rates in Hus 2

	Room No.	Q.Supply (l/s)	Q.Exhaust(l/s)
	Hus 2 ventilation rates		
Plan 2	2/201	0.00	0.00
	2/202a	68.33	0.00
	2/202b	0.00	18.50
	2/203	0.00	17.50
	2/204	0.00	17.50
	2/205	0.00	0.00
	2/206	550.30	21.50
	2/207	0.00	0.00
	2/208	0.00	0.00
	2/209	0.00	21.70
	2/210	20.00	0.00
	2/211	10.10	0.00
	2/212	0.00	16.50
	2/213	0.00	17.50
	2/214	0.00	0.00
	2/215	25.00	0.00
	2/216	0.00	18.00
	2/217	0.00	0.00
	2/218	211.01	105.50
	2/219	0.00	15.50
	2/220	0.00	17.50
	2/221	0.00	19.00
	2/222	0.00	0.00
	2/223	17.00	0.00
	2/224	0.00	19.00
	2/225	0.00	9.00
	2/226	204.98	101.20
	2/227	6.50	17.00
	2/228	19.50	21.00
Total		**1132.71**	**473.40**

	Room No.	Q.supply (l/s)	Q.Exhaust(l/s)
	Hus 2 ventilation rates		
Plan 1	2/101	0.00	0.00
	2/102	0.00	0.00
	2/103	0.00	42.00
	2/104	104.01	0.00
	2/105	0.00	0.00
	2/106	0.00	10.00
	2/107	0.00	24.50
	2/108	0.00	10.00
	2/109	0.00	0.00
	2/110	0.00	0.00
	2/111	0.00	30.50
	2/112a&b	0.00	25.00
	2/113	0.00	18.00
	2/114	0.00	16.00
	2/115	0.00	15.00
	2/116	0.00	7.00
	2/117	0.00	17.00
	2/118	72.22	0.00
	2/119	0.00	58.00
	2/120	0.00	8.00
	2/121	0.00	0.00
	2/122	20.00	0.00
	2/123	47.00	0.00
Total		**243.23**	**281.00**

Table 8-3. Supply and exhaust air flow rates

	Hus 3 ventilation rates		
	Room No.	Q. Supply (l/s)	Q. Exhaust (l/s)
Plan 1	3/101	0.00	0.00
	3/102	0.00	18.00
	3/103	8.00	0.00
	3/104	0.00	0.00
	3/105	0.00	0.00
	3/106	136.50	0.00
	3/107	0.00	16.50
	3/108	0.00	17.50
	3/108a	0.00	136.40
	3/109	0.00	0.00
	3/110(S.1)	137.00	0.00
	3/111	0.00	16.50
	3/111a	0.00	136.40
	3/112	0.00	17.50
	3/113	0.00	0.00
	3/114	308.03	0.00
	3/115a	0.00	0.00
	3/115b	0.00	236.20
	3/116	0.00	18.00
	3/117	0.00	17.50
	3/118	0.00	0.00
Total		589.53	630.5

Lighting

Table 8-4.Lights rated power and number used in each room inside Hus 1

	Room No.	No. of light	Rated Power(W)
	Hus 1 (lighting)		
Plan 1	1/102	2	75
		2	40
	1/103	2	18
	1/104	2	36
		4	18
	1/105	18	36
	1/106	2	40
	1/107	2	9
	1/108	1	40
	1/109	2	36
	1/109a	4	18
	1/110	18	36
	1/111	2	40
	1/112	2	9
	1/113	1	40
	1/114	2	40
	1/114a	4	18
	1/115	18	36
	1/116	2	36
	1/117	2	9
	1/118	1	53
	1/119	2	40
		4	18
	1/120	18	36
	1/121	1	36
	1/122	2	9
	1/123	1	42
	1/124	2	36
		4	18
	1/125	18	36
	1/126	2	36
	1/127	2	9
	1/128	1	75
	1/129	2	36
		4	18
	1/130	18	36
	1/131	2	36
	1/132	2	9
	1/133	1	42
	1/134	8	18
	1/135	2	9
	1/136	1	42
	1/137	2	9
	1/138	4	36
	1/139	2	18
	1/140	2	36
	1/141	1	42
	1/143	6	36
	1/144	2	36
	1/145	1	58
		8	28
	1/146	18	36
	1/147	4	36

Table 8-5.Lights rated power and number used in each room inside Hus 2

	Hus 2 (lighting)		
	Room No.	**No.of lights**	**Rated power(W)**
	2/201	2	9
	2/202a	12	14
	2/202b	2	36
	2/203	1	75
	2/204	2	75
	2/206	24	28
	2/207	4	28
		4	36
		2	18
	2/208	2	28
	2/209	2	28
	2/210	2	28
	2/211	2	28
Plan 2	2/212	1	60
	2/213	1	40
	2/214	2	9
	2/215	4	18
	2/216	1	40
	2/217	1	40
	2/218	34	36
	2/219	1	60
	2/220	4	36
	2/221	4	36
	2/222	2	9
	2/223	4	18
	2/224	1	75
	2/225	1	75
	2/226	30	36
	2/227	2	40
	2/228	2	28

	Hus 2 (lighting)		
	Room No.	**No.of lights**	**Rated power(W)**
	2/101	4	18
	2/102	2	18
	2/103	6	36
	2/104	6	36
	2/106	2	36
	2/107	2	36
	2/108	2	36
	2/109	6	40
	2/110	2	40
		4	28
Plan 1	2/111	8	18
	2/112a	4	18
	2/112b	4	18
	2/113	1	75
	2/114	1	75
	2/115	1	75
	2/116	1	75
	2/117	2	18
	2/118	4	36
	2/119	4	18
	2/120	1	36
	2/121	2	36
	2/122	2	40
	2/123	4	36

Table 8-6.Lights rated power and number used in each room inside Hus 3

	Room No.	No. of lights	Rated Power(W)
	Hus 3 (lighting)		
Plan 1	3/101	1	75
	3/103	2	18
	3/104	2	18
	3/104	1	75
	3/106	12	36
	3/106	2	18
	3/107	1	75
	3/108	4	36
	3/108a	2	36
	3/108a	6	18
	3/109	2	18
	3/110	12	36
	3/110	2	18
	3/111	4	36
	3/111a	2	36
	3/111a	6	18
	3/112	2	75
	3/113	2	36
	3/114	24	36
	3/116	4	36

Appliances

Table 8-7. Appliances information in Hus 1

List of appliances in Hus 1			
No.	Name	Power (W)	No. of Units
1	Washing machine	3300	1
2	Oven	10000	2
3	Fridge and freezer	160	3
4	Projector	235	5
5	Dishwasher	1700	3
6	PC	120	21
7	Cloth dryer	1500	5
8	Printer	50	2
9	Microwave	3000	1

Table 8-8. Appliances information in Hus 2

List of Appliances in Hus 2
No.	Name	Power (W)	No. of Units
1	Fridge and Freezer	225	1
2	Food heaters	2400	2
3	Food heaters	3000	1
4	Freezer	770	2
5	Electrothermy	9000	1
6	Heater and hood	900	1
7	Fridge and Freezer	330	3
8	Drill machine	550	1
9	Bandsaw machine	1500	1
10	Rikt och planhyvel	1250	2
11	Fridge and Freezer	110	1
12	Microwave	3000	1

Appendix 8-2.
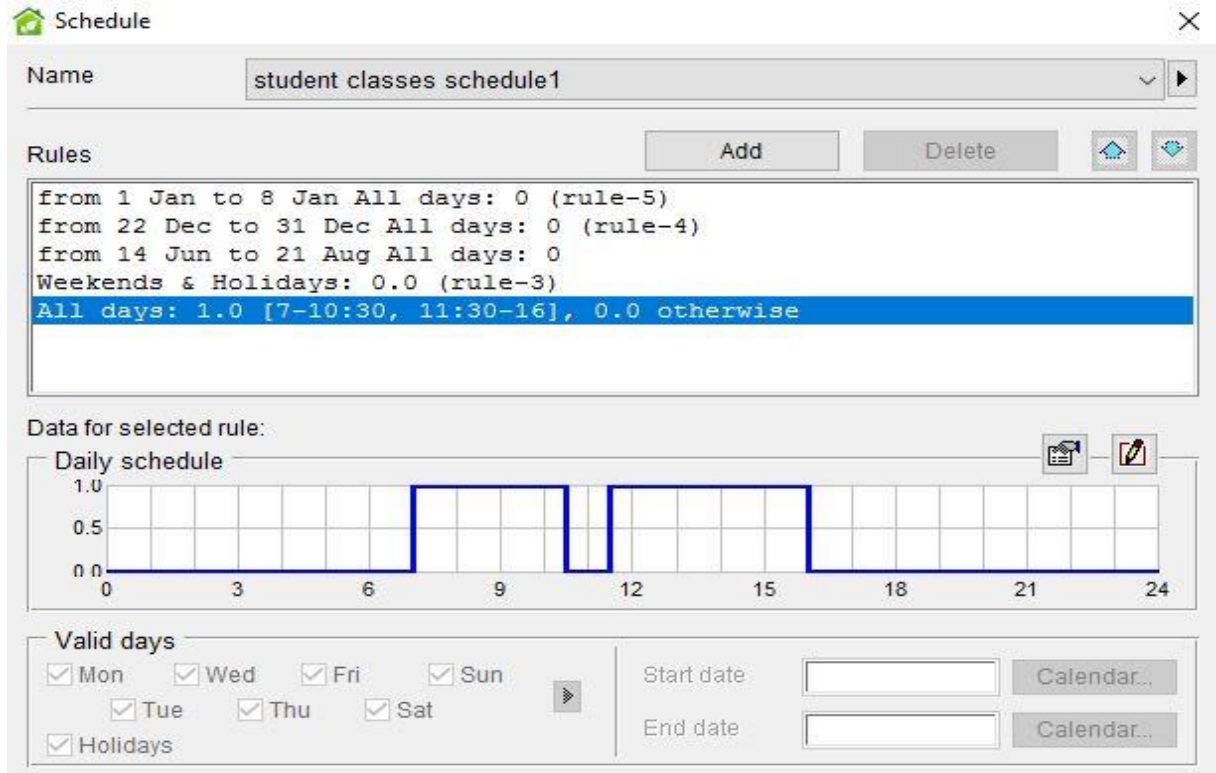
Figure 8-2. Classrooms occupant's schedule in Hus 1
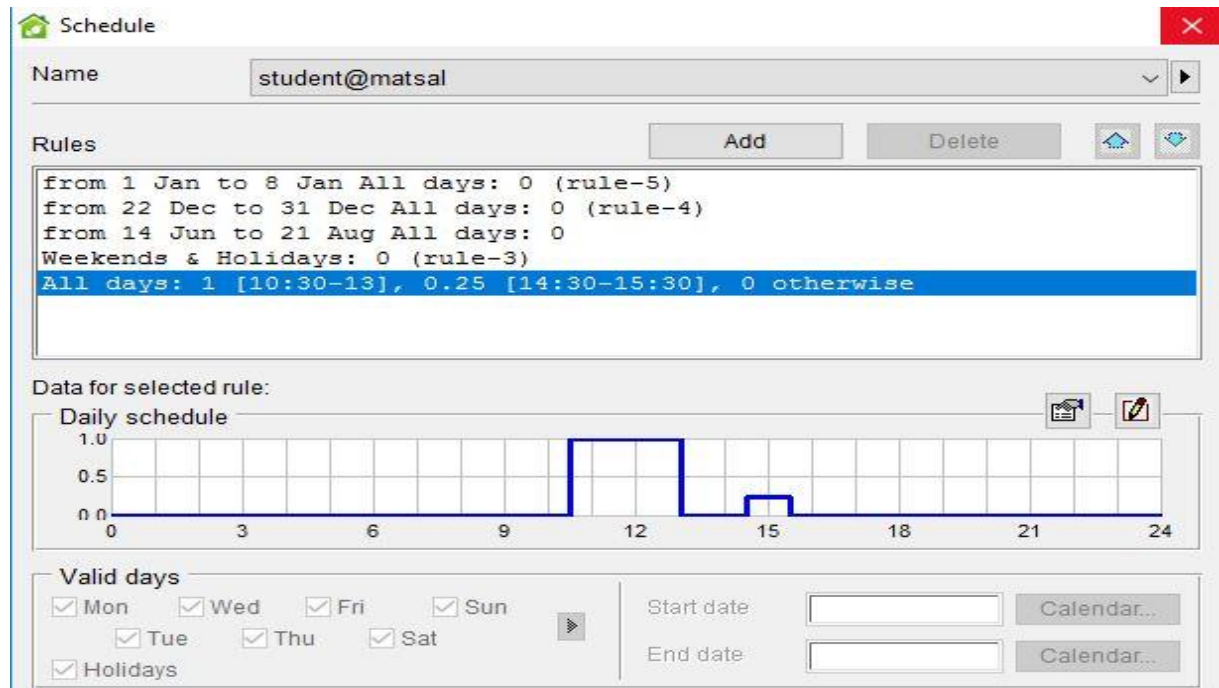
Figure 8-3. Dining room occupant's schedule in Hus 2
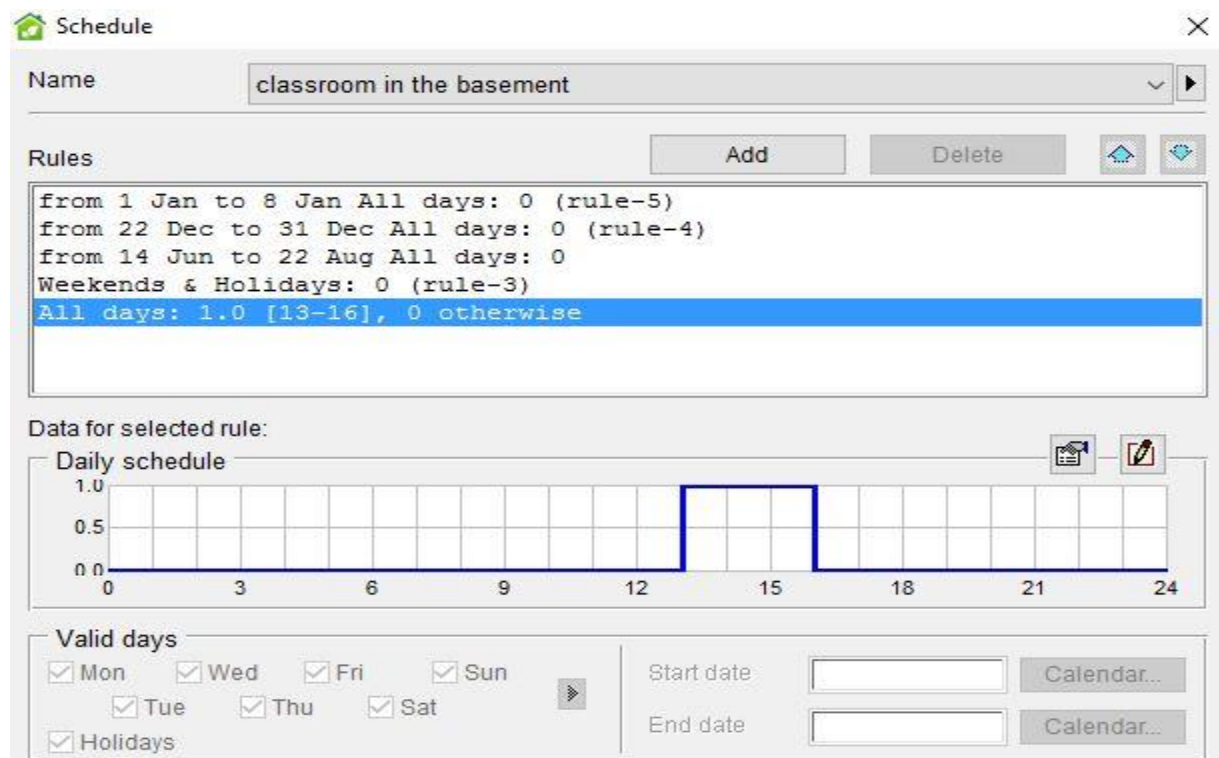
Figure 8-4. Basement classroom occupant's schedule in Hus 2
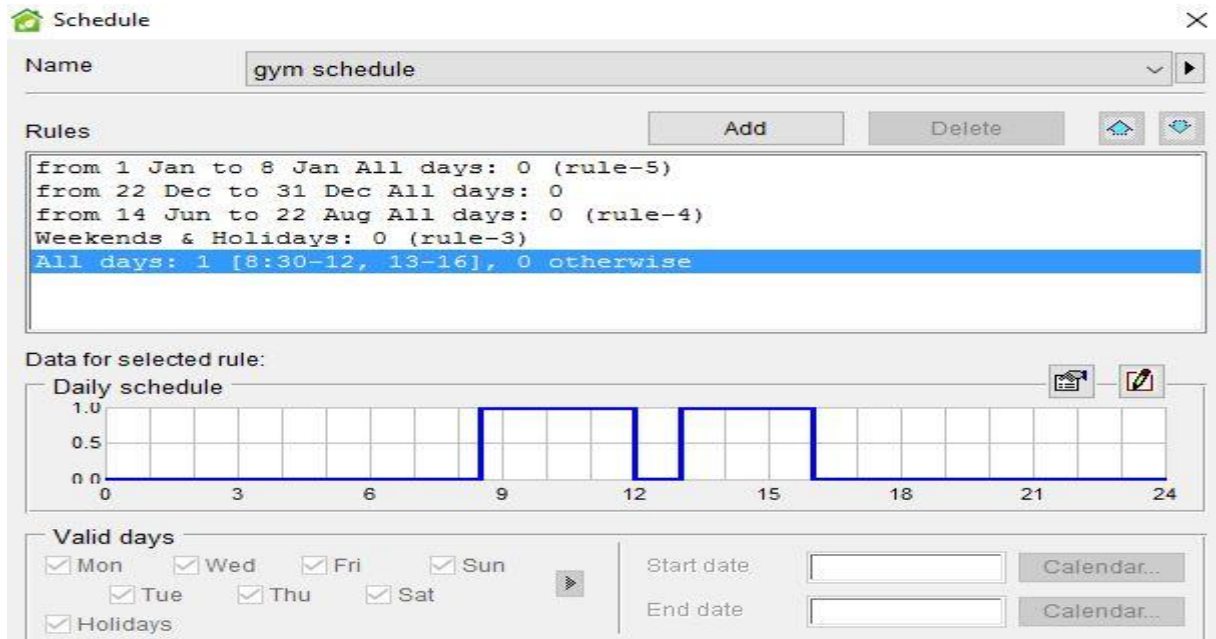
Figure 8-5. Gym occupant's schedule in Hus 3
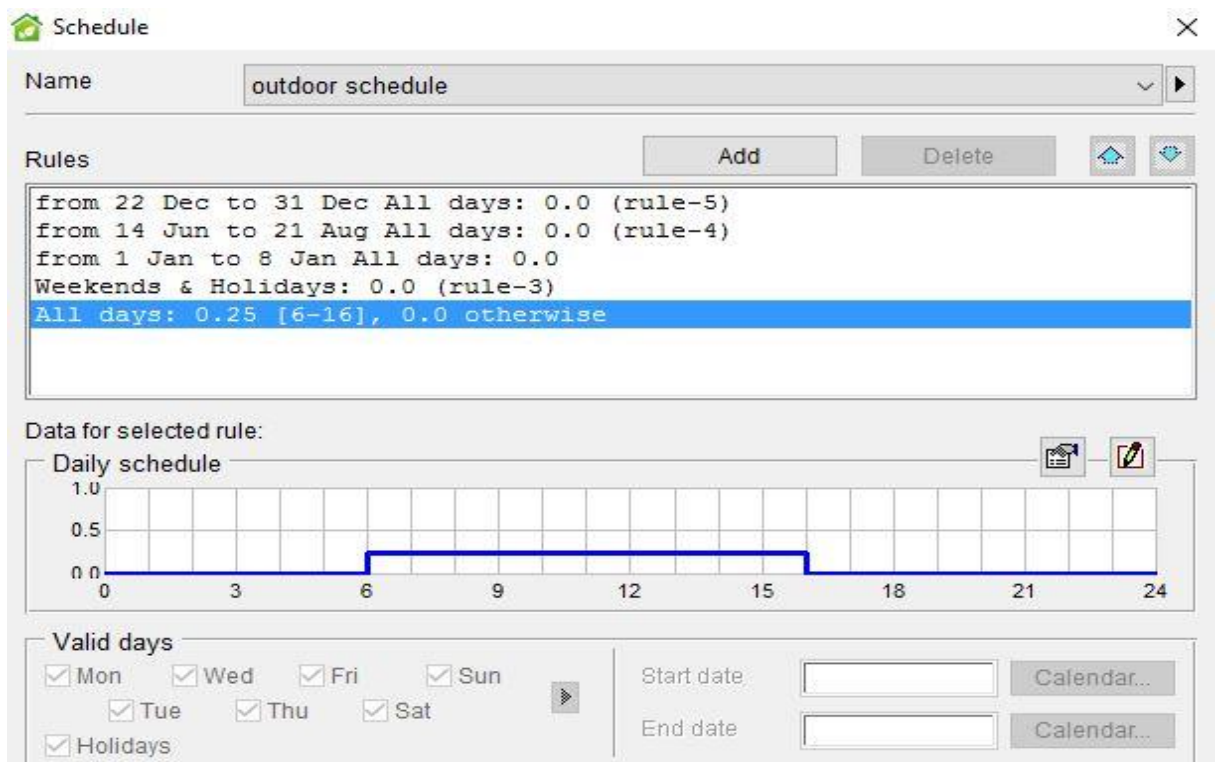
Figure 8-6. Air curtains Schedule.

Appendix 8-3

Plans drawing and construction materials

Figure 8-7. Hus 1 (Plan 2)
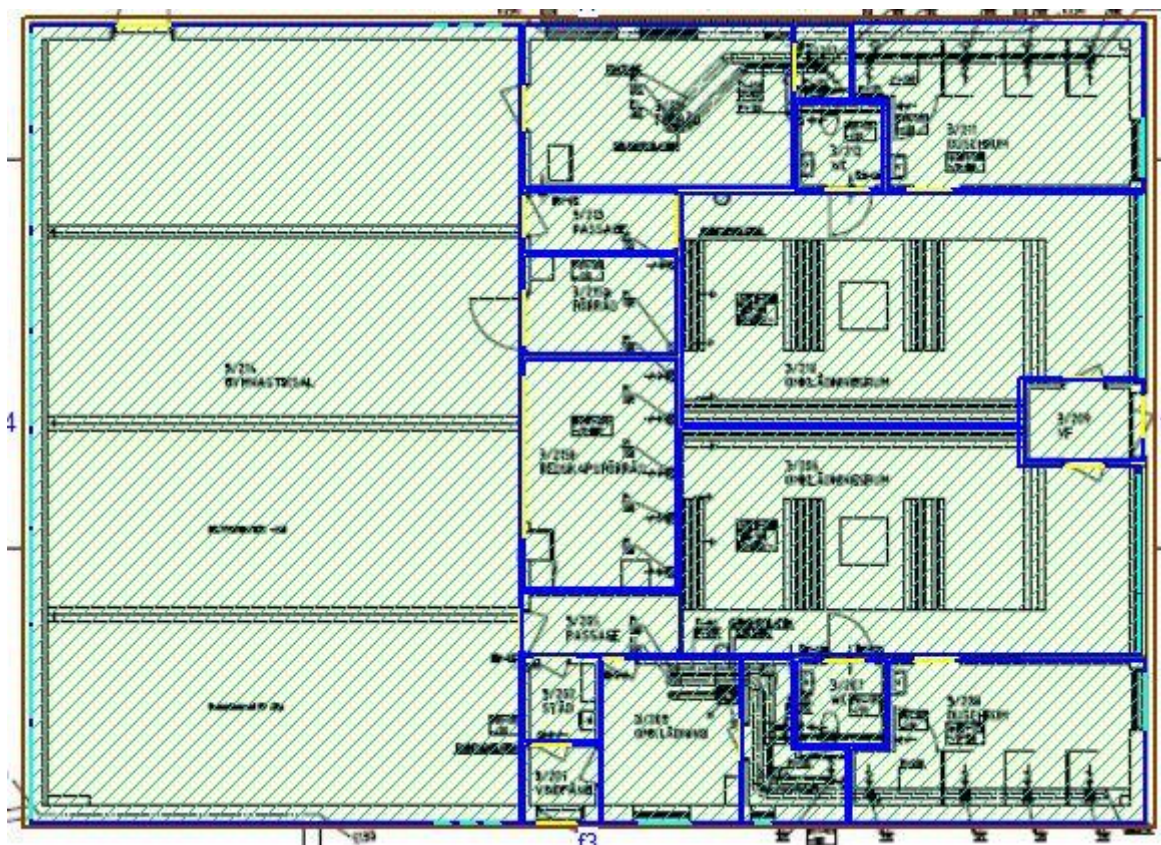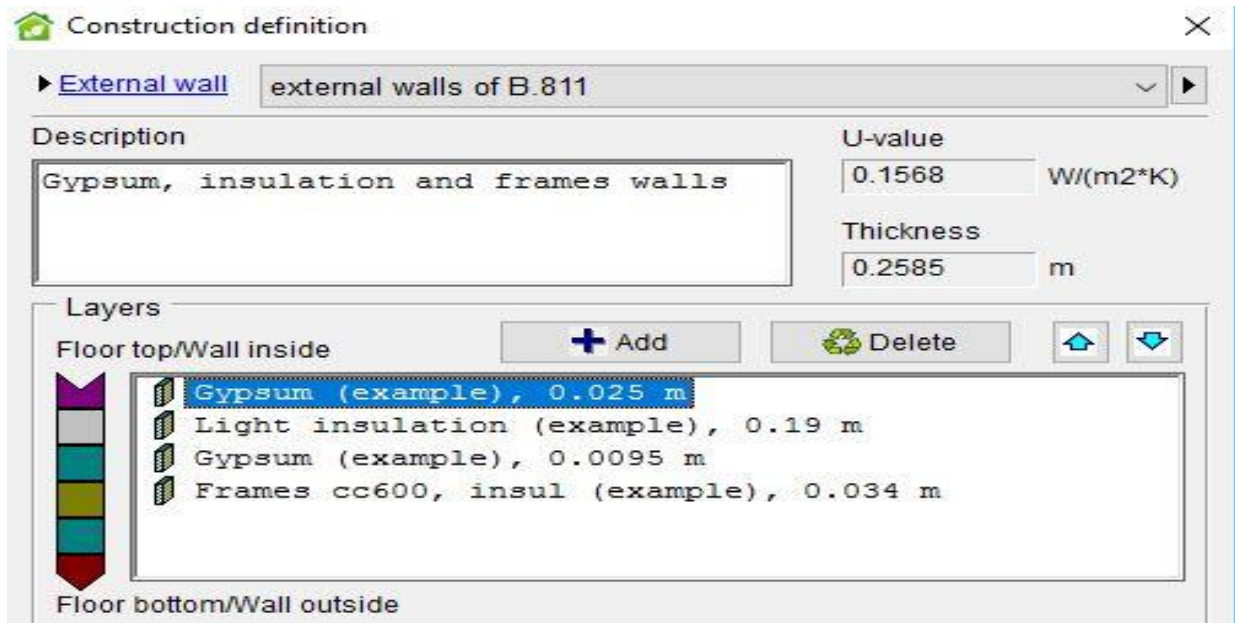
Figure 8-8. Hus 2 (Plan 1)

Figure 8-9. Hus 2 (Plan 2)

Figure 8-10. Hus 3 (Plan 2)
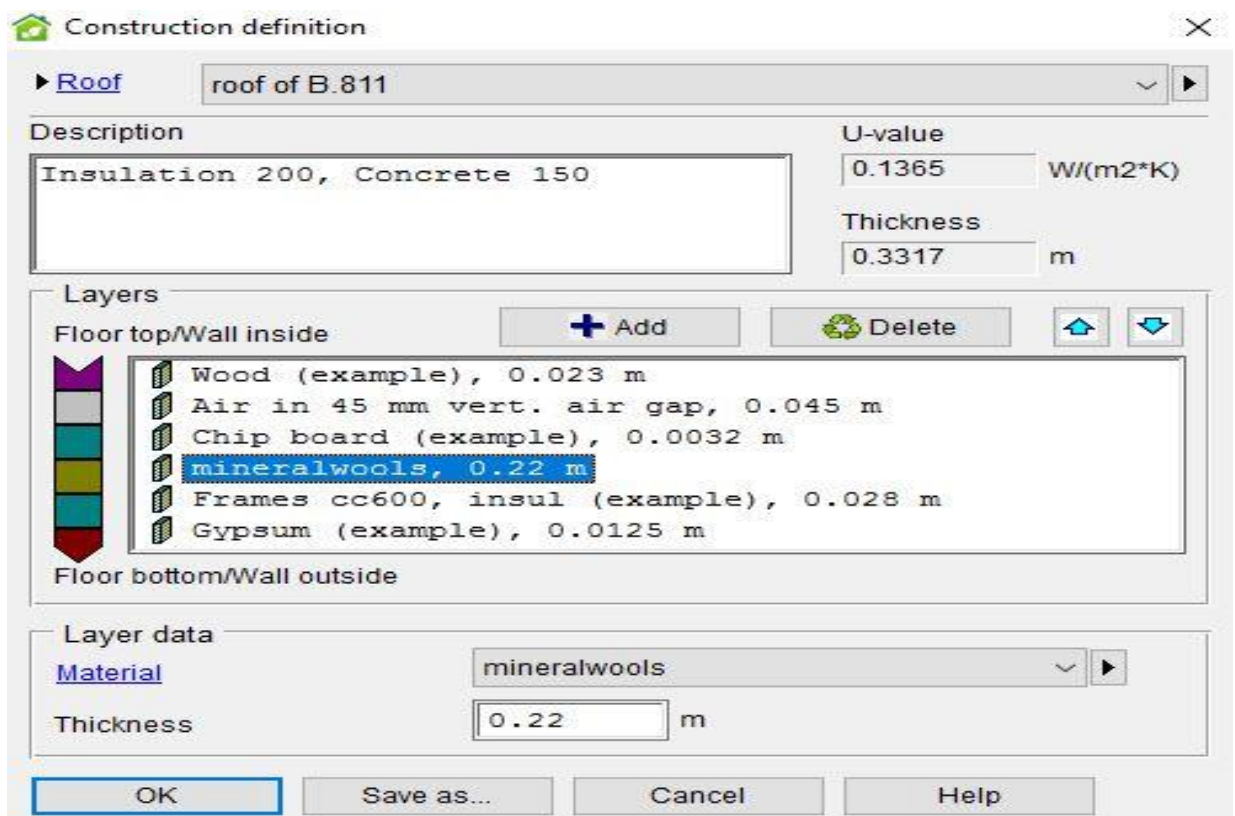
Figure 8-11. External walls construction materials in Hus 1&3.

Figure 8-12. Roof construction materials in Hus 1&3

Figure 8-13. External walls construction materials in Hus 2

Figure 8-14. Roof construction materials in Hus 2

Buildings Models

Figure 8-15. Hus 1 baseline model
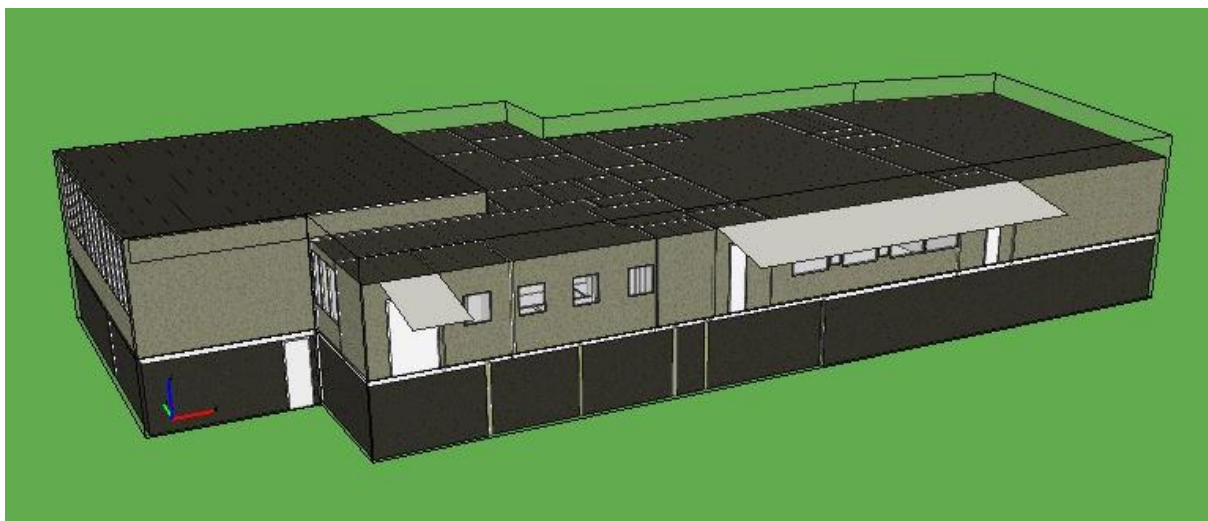
Figure 8-16. Hus 2 baseline model
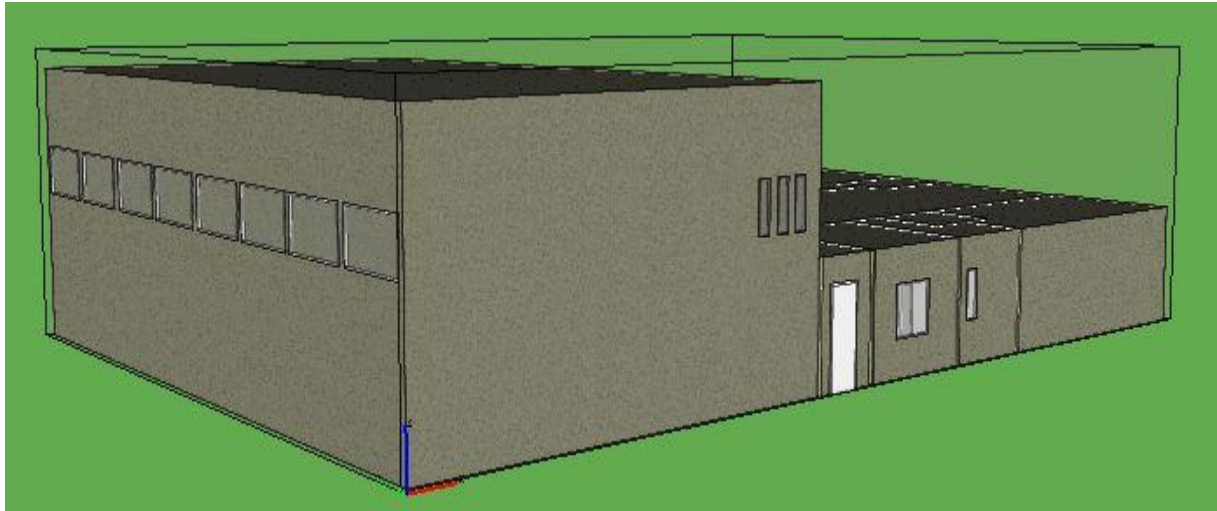
Figure 8-17. Hus 3 baseline model

Table 8-9. Delivered Energy in Hus 1

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	14660	17.9	7.25
HVAC aux	10423	12.8	5.25
Total, Facility electric	25083	30.7	
District cooling	0	0.0	0.0
District heating	133264	163.2	209.3
Total, Facility district	133264	163.2	
Total	158347	193.9	
Equipment, tenant	31425	38.5	21.18
Total, Tenant electric	31425	38.5	
Grand total	189772	232.4	

Table 8-10. Delivered Energy in Hus 2

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	6618	7.9	3.02
HVAC aux	12875	15.3	1.95
Total, Facility electric	19493	23.2	
District cooling	0	0.0	0.0
District heating	142831	169.6	70.82
Total, Facility district	142831	169.6	
Total	162324	192.8	
Equipment, tenant	37345	44.4	19.4
Total, Tenant electric	37345	44.4	
Grand total	199669	237.1	

Table 8-11. Delivered Energy in Hus 3

		Purchased energy		Peak demand
		kWh	kWh/m²	kW
■	Lighting, facility	5598	16.2	3.05
■	HVAC aux	2093	6.1	1.15
	Total, Facility electric	7691	22.3	
■	District cooling	0	0.0	0.0
■	District heating	23250	67.3	30.54
	Total, Facility district	23250	67.3	
	Total	30941	89.5	

Table 8-12. Hus 1 envelope transmission (kWh)

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-1563.9	-2557.6	-1248.8	-3635.3	-47.4	-1161.2
2	-1364.2	-2237.6	-1280.0	-3295.6	-41.2	-1043.6
3	-1159.7	-1879.4	-1632.5	-3016.1	-35.9	-934.4
4	-957.6	-1488.5	-1896.8	-2726.3	-30.8	-826.7
5	-685.2	-978.9	-2026.9	-2379.2	-24.2	-691.0
6	-644.3	-903.3	-2517.4	-2258.8	-24.2	-664.2
7	-791.3	-1186.6	-2027.8	-2713.6	-29.5	-805.9
8	-662.9	-1036.0	-1527.2	-2258.6	-24.6	-662.7
9	-697.2	-1143.3	-785.6	-2058.2	-22.8	-615.9
10	-891.6	-1522.8	-874.4	-2336.4	-28.3	-705.2
11	-1229.2	-2047.0	-830.8	-2923.4	-37.1	-913.6
12	-1563.1	-2578.5	-945.9	-3617.8	-47.6	-1147.3
Total	**-12210.1**	**-19559.5**	**-17594.0**	**-33219.1**	**-393.6**	**-10171.7**

Table 8-13. Hus 2 envelope transmission (kWh)

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-797.3	-964.2	-581.4	-2696.5	-151.4	-748.5
2	-727.3	-840.6	-588.2	-2468.0	-130.7	-671.6
3	-695.5	-701.6	-715.6	-2250.8	-110.0	-596.5
4	-609.4	-532.7	-714.7	-1965.2	-86.7	-507.1
5	-486.2	-274.4	-795.6	-1512.8	-54.2	-361.4
6	-537.3	-288.4	-1035.0	-1466.7	-55.7	-345.6
7	-725.0	-467.8	-1156.8	-2075.9	-91.1	-521.5
8	-548.3	-379.9	-570.2	-1759.2	-72.7	-438.4
9	-392.7	-380.0	-330.6	-1411.9	-60.7	-353.6
10	-489.2	-566.5	-422.7	-1737.5	-81.8	-444.1
11	-618.0	-767.4	-432.6	-2210.9	-119.3	-589.5
12	-766.3	-970.0	-487.2	-2679.3	-152.7	-740.0
Total	**-7392.4**	**-7133.5**	**-7830.5**	**-24234.8**	**-1166.9**	**-6317.8**

Table 8-14. Hus 3 envelope transmission (kWh)

Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-891.6	-1010.6	-441.4	-1457.8	-93.8	-498.2
2	-773.5	-878.1	-467.6	-1313.0	-80.3	-445.0
3	-631.9	-707.3	-576.0	-1150.0	-64.3	-385.1
4	-491.9	-518.1	-648.3	-995.5	-47.7	-325.6
5	-275.8	-245.2	-721.2	-758.8	-25.5	-233.7
6	-200.6	-146.5	-718.6	-617.9	-18.9	-189.8
7	-197.5	-157.7	-628.8	-614.0	-19.6	-189.7
8	-190.4	-189.7	-500.9	-581.5	-18.0	-176.2
9	-318.9	-368.7	-272.8	-701.8	-31.8	-223.5
10	-461.0	-556.3	-314.3	-861.7	-45.2	-279.4
11	-683.9	-795.1	-325.7	-1146.2	-70.8	-383.2
12	-892.7	-1022.8	-369.8	-1450.1	-94.6	-492.1
Total	**-6009.7**	**-6596.0**	**-5985.4**	**-11648.4**	**-610.5**	**-3821.4**

Appendix 8-5

VAV air handling unit's technical data from Swegon company in Gävle

Page 1 of 11

Swegon

ProUnit
2017-07-10

Version: 41 / 2017.6.27
cee2bde5-4918-4c4e-aee9-426ed74c8cdc.pru

Technical specification

Project	**Fridhemsskolan Gävle, student HIG**		
Atmospheric pressure		101325	Pa
Air density		1.200	kg/m³
Sound power to duct, measured according to ISO 5136			
Noise reduction for function section included to duct.			
Sound power emitted to surroundings, measured according to ISO 3741			
Components are arranged according to airflow direction			

Hus 1
GOLD RX
Manufactured by Swegon

Unit size		40	
Supply air flow		3.740	m³/s
Static pressure drop			
Outdoor air duct			Pa
Supply air duct		200	Pa
Extract air flow		1.760	m³/s
Static pressure drop			
Extract air duct		200	Pa
Exhaust air duct			Pa
Design outdoor temperature, summer		26.0	°C
Lowest design outdoor air temperature		-20.0	°C
Supply air temperature, summer		26.8	°C
Supply air temperature, winter		20.0	°C
Specific fan power efficiency rating, SFPv (clean filters)		1.27	kW/(m³/s)

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319
A+
A
B
D
E
Report to performance data
A+ 2016

Eurovent energy efficiency class A+ 2016

Checking against Commission Regulation (EU) No 1253/2014

ErP
fulfillment
The air handling unit meets the requirements in 2016
The air handling unit meets the requirements in 2018

Casing option: 1mm – 52mm
Casing leakage according to EN 1886:2007: L2 at -400 Pa and +400 Pa
With computer-based IQlogic control system
52mm double skin panel insulated with mineral wool with external paint finish
Electrical connections   3-phase, 5-wire, 400 V-10/+15%, 50 Hz, 20 A

Swegon

ProUnit
2017-07-10

Version: 41 / 2017.6.27
cee2bde5-4918-4c4e-aee9-426ed74c8cdc.pru

Supply air

1	**Damper with actuator, TBSA-4-140-060-1-1**		
	Motor with spring return action, 24V		
	Tightness class 3 to EN 1751		
	Static pressure drop	3	Pa

1	**End section, outdoor air**		
	Static pressure drop	13	Pa

1	**Air handling system, GOLD, GOLD40ERX111111**		

Accessories

6	Support foot for base frame, TBXZ-1-36
6	Rubber plate for support foot, TBXZ-1-37
1	Hand terminal GOLD ver E without WLAN

1	**Filter**		
	Filter class F7		
	3x(592x592x520-10), 3x(592x287x520-10)mm		
	Velocity in the filter section	2.20	m/s
	Recommended design pressure drop	123	Pa
	Initial pressure drop	73	Pa
	Final pressure drop	173	Pa

1	**Rotary heat exchanger**			
	Rotary heat exchanger of type RECOnomic			
	Standard aluminium			
	Speed controlled			
	Pressure drop, supply air		223	Pa
	Pressure drop, extract air		78	Pa
	Extra pressure drop in extract air side (damper)			
	to ensure the right flow direction		78	Pa
	Purging flow including leakage		0.183	m³/s
	Temperature efficiency of supply air	(81.3% at the same airflow)	45.0	%
	Annual energy efficiency, dry conditions		52.7	%
	Humidity efficiency, supply air, winter		20.5	%
	Supply air enthalpy ratio, vinter		40.5	%

	Supply air side, winter	In	Out	
	Air temperature	-20.0	-1.1	°C
	Relative humidity	80	36	%
	Capacity		93.40	kW

	Extract air side, winter	In	Out	
	Air temperature	22.0	-18.1	°C
	Relative humidity	25	100	%

1	**Fan section**
	Fan of type GOLD Wing+
	Direct drive with speed controlled EC motor

AHU Design
Technical specification

Swegon'

Project: Fridhemsskolan Gävle, student HIG
Unit name: Hus 7 PX balance - Design data

Date: 10/07/2017
3 / 1.0.20170613.5
Unit ID: AD-10000024073

Functional sections viewed in the direction of air flow	Velocity m/s	Air Temperature in/out Winter °C	Air Temperature in/out Summer °C	Power kW	Design Pressure drop Pa	Noise Level dB(A)
Outdoor air duct					-0	61
Damper, duct mounted					-3	
End section					-5	
Filter	1.26				-90	
Counter flow heat exchanger	1.25	-24.0/-2.2	25.6/25.1		-122	
Fan				1.19	444	
End section					-6	
Heating coil, water, duct mounted		-1.6/20.0		44.34	-18	
Supply air duct					-200	77
Extract air duct					-200	62
End section					-5	
Filter	1.26				-70	
Counter flow heat exchanger	1.25	22.0/0.2	25.0/25.5		-122	
Fan				1.09	406	
End section					-6	
Damper, duct mounted					-3	
Exhaust air duct					-0	80

Sound power to duct, measured according to ISO 5136
Noise reduction for function section included to duct.
Sound power emitted to surroundings, measured according to ISO 3741

Frequency band	63	125	250	500	1k	2k	4k	8k		All	
To supply air duct	77	72	73	75	72	70	68	68	dB	77	dB(A)
To outdoor air duct	71	66	68	55	49	45	44	48	dB	61	dB(A)
To extract air duct	70	65	68	54	48	45	47	51	dB	62	dB(A)
To exhaust air duct	77	72	74	76	73	72	70	70	dB	80	dB(A)
To surroundings	70	62	55	59	44	43	40	43	dB	57	dB(A)

GOLD-Unit with control system

Components are arranged according to airflow direction

Quantity		Supply air	
1	Damper, duct mounted, TBSA-4-120-050-1-1		
	Damper motor: With spring return		
	Damper blade: Uninsulated		
	Static pressure drop	3	Pa
1	End section, outdoor air		
	Static pressure drop	5	Pa

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