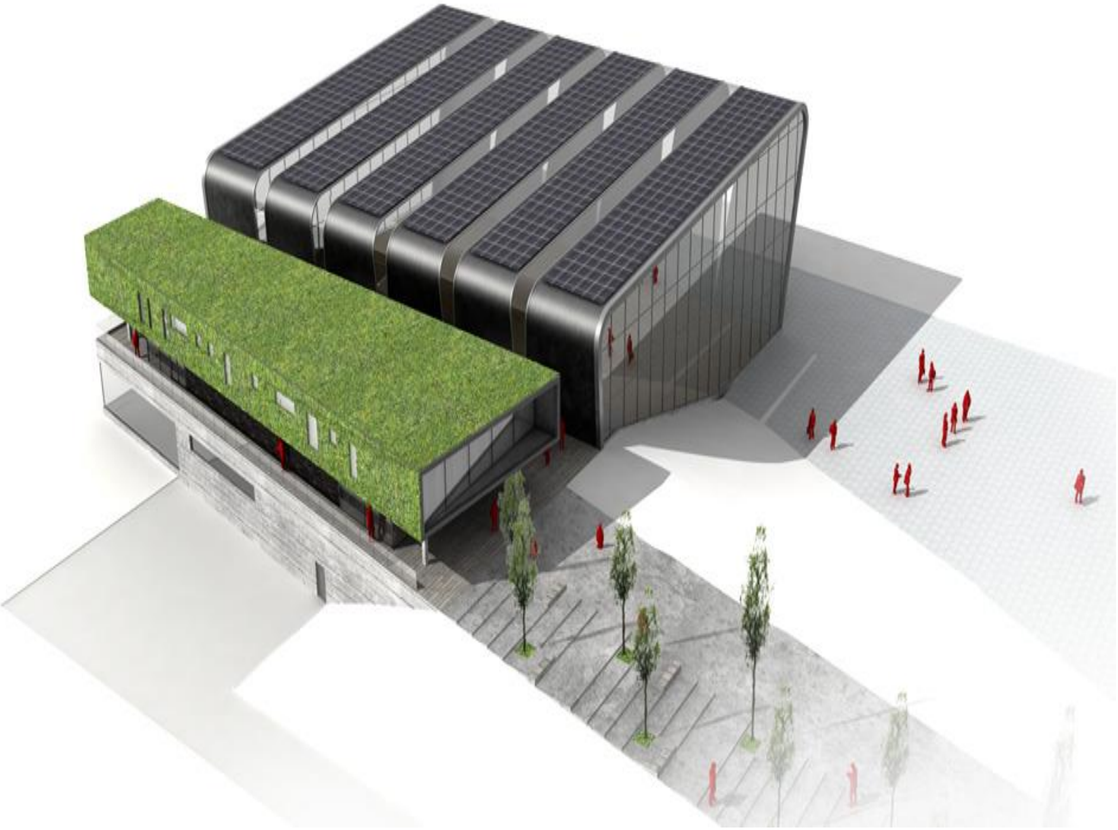

# Energy-efficient sports hall with renewable energy production

## Retrofitting a sports hall in Landskrona

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Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

# Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

## Master Programme in Energy-efficient and Environmental Building Design

This international programme provides knowledge, skills and competencies within the area of energy-efficient and environmental building design in cold climates. The goal is to train highly skilled professionals, who will significantly contribute to and influence the design, building or renovation of energy-efficient buildings, taking into consideration the architecture and environment, the inhabitants' behaviour and needs, their health and comfort as well as the overall economy.

The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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# Abstract

In today's society, much energy is used and all energy use (e.g. heat, electricity) affects the environment. Greenhouse gas emissions from energy affect the climate of the earth and increase the natural greenhouse effect. Environmental impact because of energy use causes both local and global problems.

Efficient energy use in buildings is a prerequisite for dealing with climate issues and in the long term, securing our energy supply. Increased energy prices and major climate change make the issue of energy efficiency both economically and environmentally interesting.

In this degree project, the possibility to refurbish a new sports hall to meet the nearly zero- and plus-energy requirements with today's construction technology is being investigated. The possibility was investigated for a sports hall in Landskrona.

In order to be able to carry out energy retrofitting, an energy audit was realized. The first step was to realize an inventory of the building equipment. From this analysis, building behavior and energy use were modeled using IDA ICE simulation software. A comparison with real measured energy use showed reasonable agreement. Retrofitting by increasing the insulation of the building envelope was investigated as well as the possibility of adding solar energy. Each retrofit solution was evaluated calculating the LCC based on investment costs and energy savings. The results show that the addition of insulation materials to walls, roof and floor, adjustment of heating set point would have a significant impact on reducing the energy demand in the sports hall, also the result of calculations of energy use shows that it is possible to make a sports hall that meets the requirements of nearly zero and plus energy buildings and earn money at the same time if all of these measures have been implemented. The work is carried out as a case study.

# Preface

My deepest gratitude and appreciation goes to my academic supervisor Åke Blomsterberg senior researcher in the department of Energy and Building Design, Architecture and Built Environment of Lund University and at WSP, for giving me the chance to do this research and for his continuous support, guidance, valuable feedback, and optimistic spirit he provided me throughout this research.

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*Helsingborg October 2017*

*Mohammed Al-Husinawi*

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# Abbreviations

| | |
|---|---|
| AHU | Air Handing Unit |
| BIPV | Building Integrated Photovoltaics |
| IDA ICE | IDA Indoor Climate and Energy |
| DHW | Domestic Hot Water |
| EPS | Expanded Polystyrene |
| U-value | Heat loss coefficient |
| PV | Photovoltaic cell |
| VAV | Variable air volume |
| MSEK | Millions of Swedish Kronor |
| LCC | Life Cycle Cost |
| NPV | Net Present Value |
| VAT | Value Added Tax |
| g-value | solar heat gain coefficient |
| $\lambda$ | thermal conductivity |
| VK | Entrance |

# 1 Introduction

In recent years, the excessive emission of greenhouse, gas $CO_2$, causing global warming, already poses a serious threat to human survival and the demand for energy is high on the global environmental agenda. The resulting increase in energy demand for private and public consumption and economic activity with uncontrollable urbanization means that there is an urgent need for energy efficient urban planning and construction. Alleviate and reduce the effects contributed by these activities is a major challenge to city planners, designers, architects and the construction industry, especially in terms of population and urban growth and associated demands for houses, offices, shops, factories and roads. It is therefore important to encourage the environmentally sound management of urban areas through more energy and resource efficient eco-design, architecture and construction methods, taking into account the objectives of sustainable development.

Modern energy-efficiency standards for buildings provide significantly improved comfort and indoor air quality conditions, as well as much lower energy demands in comparison with conventional buildings. Such buildings should be built with paying extremely close attention to details and advocating rigorous design and construction, for example according to principles developed by Passive house Institute.
The concern for high energy use in the building sector has risen decades ago in the end of the past century. Since the time when the first low energy house was launched in Germany in 1990, thousands of passive and low-energy buildings have been built around the world. Despite the cold climate, using this building strategy in Sweden is also achievable. However, the buildings should not only be energy-efficient, but also comfortable for occupants. High requirements on airtightness and thermal insulation raise the problems of proper ventilation and overheating. In addition, as traditional Swedish building practice lies in wide utilization of wooden structures, condensation and other moisture problems are coming to the forefront. That is why designing a low energy house is a complex task requiring integrated design approach, well-considered solutions and analysing a wide range of parameters and properties in order to satisfy low energy use standards and life quality of inhabitants.

## 1.1 Background

In any sport hall energy use expenses are only second to the expenses the facility incurs due to labour. Energy costs account for approximately thirty percent of the total operational costs for a sport hall (1). Heating is the highest energy part in any sports hall accounting for close to or even over sixty percent of the energy use of the hall. Lighting is the second highest energy part in a sports hall accounting for twenty five percent of the energy used in a sports hall (2). This report seeks to show how reduction of energy can be achieved in an existing sports hall bearing in mind the specific energy requirements of sports facilities generally. The study seeks also to show how a photovoltaic system placed on the roof of a sports hall can be properly and efficiently utilized to increase the use of renewable energy in the specific sports hall. Further the report seeks to compare and explore the reliability of solar energy for sports complexes with the aim of recommending or commenting on its suitability as an alternative energy source for the type of buildings.

Achieving low energy use for sports halls constructed decades ago require renovation on the building to meet the new standards set by regulation and practice. Energy savings in existing buildings can therefore only be achieved through renovations aimed at achieving a reduction in the energy consumption in such a building. Energy use can be greatly reduced if owners of buildings make energy improvements that are sensible and financially sound as part of their renovations performed regularly. The energy savings can be achieved best and most cost-effectively when the work is done at the same time as the general building renovation. The utility value and the quality of buildings is improved by energy renovations. Energy improvements can further make the building healthier and better to work in by improving the daylight conditions and the indoor climate of the building. The improvements can also be said to play a major role in increasing the market value of the building being so improved. The value of building stock is said to be raised by the making of the building to be more energy sufficient by minimizing the amount of energy necessary to run the building in question.
Energy renovation should however take into account the architectural perspective of the building being renovated. This is because such renovations can result in the improvement of the architecture of the building. Such building improvements should also take into consideration the environmental objectives for reuse and sustainability in the building industry. The improvements should generally be done in accordance with environmental laws and with the intention of having the least negative impact on the surrounding environment as can be possibility achieved.

A reduction of energy use in a sport hall and any renovation carried out to achieve this should consider the areas and factors that affect energy use in a sport hall. Total heating energy used, which is required for building, is calculated based on these heat gains and heat losses. The process of renovation should be founded on basic concepts as energy use. These concepts include the fact that energy like matter cannot be destroyed just transformed from one form to another, the fact that at all times the energy in any building has to be balanced and the fact that there are many types of energy. To save money and energy, it is important to note that the renovations should be geared towards keeping heat indoors as much as possible. The renovation of any sports hall should focus on the lighting system, the heating system, pipework insulation, the building fabric or envelope and the ventilation and cooling system among other systems.

## 1.2 Problem motivation

The buildings are the main cause of global warming because they use about 48 % of all energy see Figure 1.2. Therefore the building sector offers high potential for energy savings. About 40 % of those 48 % of energy is for operating building HVAC and equipment etc. and the remainder is for construction (creating materials, transportation and erection) (Courtesy of Architecture 2030).

It is practically feasible and necessary to reduce the energy demand and the environmental impact of the building in many existing buildings and consequently the total energy demands and the environmental impacts at a national level. This can be done planning building renovations and new buildings carefully and take advantage of all means available, including renewable energy during their use phase.

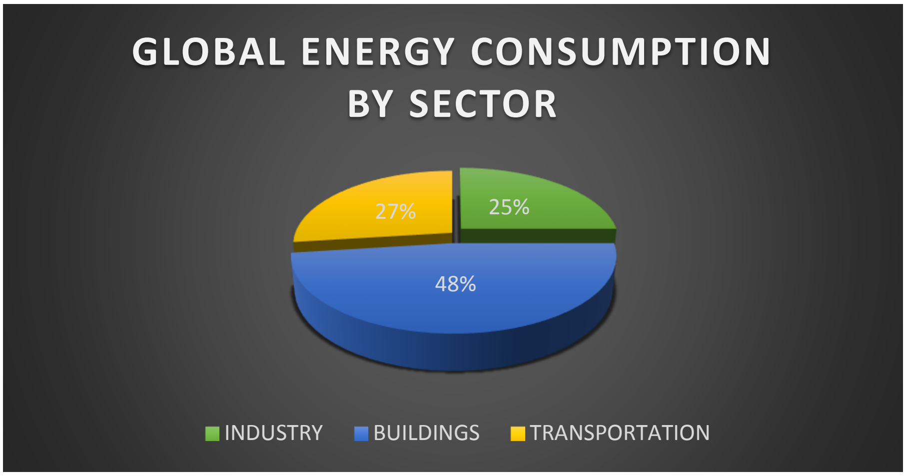


*Figure 1.2.1. Global energy consumption by Sector* (3)

There are around one and a half million sports facilities in Europe. They are representing eight percent of the overall building stock. Most of them were built before 1980 and need refurbishment because no considerable changes have been made to reduce the use of energy and increase the use or renewable energy. The aim could even be to create zero and plus energy buildings.

A previous Swedish study has addressed this topic, the thesis project “Fitness center as zero and plus energy building - energy and indoor climate simulations (4). They evaluated new energy efficient technologies and integration of solar technologies. The project investigated whether it is possible to get a new construction of a Sports Hall to qualify for a zero or plus energy building. A great deal of energy use depends on the set point values of temperature, relative humidity, carbon dioxide and airflow. Therefore this study was conducted for an existing sports hall.

## 1.3 Aim and objectives

The main objective of this study is to reduce the energy use for a sports hall and to analyse a photovoltaic system on the roof area or other available area to increase the use of renewable energy. The energy use will be lowered by improving the building envelope. The aim is to reduce the Life Cycle Cost by reducing the annual operational costs during the lifespan. Also the study of HVAC system will be taken into account and solutions will be propose by giving clear suggestions of how they best can be implemented to obtain the desired satisfaction level of the occupants.

An aim of this thesis is to analyse the reduction potential of energy use specifically by refurbishment of a sports hall in case Landskrona towards nearly zero and plus energy building standard.

## Research questions

- Which renovation solution would be most suitable for achieving low energy use in an existing sports hall? economy?
- How should a photovoltaic solar cells system and solar thermal collectors be placed and sized to be profitable for an existing sports hall?

## 1.4 Thesis structure

The present study begins with a theoretical chapter that deals with different definitions of low energy buildings, energy balance records, thermal comfort, building installations and the authors' interpretation of the concept of plus energy building. Description of the method of the thesis work is presented and the software used is described. The prerequisites and user profiles for the specific building and the user are presented. Here are the requirements for indoor climate as well as a description of the building envelope, technical systems and a detailed description accounting of input data for energy simulation.

The results and analysis show the annual energy use for the three scenarios of retrofit of the building. Solar system will be proposed and investigated from an economic perspective. Analyses of the results are performed throughout the entire chapter. The life cycle costs for the buildings are presented and an economic analysis of the respective building construction is made. Finally the final results of the study are presumed and are highlighted future research opportunities regarding possible probabilities and obstacles.

# 2 Literature Review

The relevant literature and current research on energy use and its environmental and climate impacts were studied in order to provide a sufficiently deep concept about low energy house strategies and renovation projects which are integrating solar photovoltaic technologies. Building Integrated Photovoltaics Systems were reviewed in order to get a more detailed view of how to install renewable energy on the building envelope.

Low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation to lower heating and cooling energy. They may also use passive solar building design techniques or active solar technologies.

An energy-plus-house a house that on average over the year supplies more energy from renewable energy sources than it uses from external sources. This is achieved using combination of small power generators and low-energy building techniques such as passive solar building design, insulation and careful site selection and placement. Many energy-plus houses are almost indistinguishable from a traditional home, since they simply use the most energy-efficient solutions (appliances, fixtures, etc.) throughout the house. In some developed countries power distribution companies have to buy surplus electricity from energy-plus homes, and with that approach house can even earn money for owner(5).

A nearly zero energy building is a building with zero net energy use, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site (5). Refurbishment of existing building conversion reduces the building's energy use can be implemented in various ways, including integrated design, energy efficiency installation, and reduced plug load and energy conservation programs. Reduced energy use makes it easier and cheaper to meet the building's energy needs with renewable energy sources (5). Well-designed and well-built new buildings are the best way to reduce heating, cooling, ventilation and lighting loads (5). The most effective way to ensure that energy efficiency is built into the design and construction process is by introducing and implementing building energy efficiency codes(5).

There are a number of long-term benefits to moving towards a nearly zero and plus energy building, including lower environmental impact, lower operating and maintenance costs, better electricity in power outage and natural disasters and improved energy security.

## 2.1 The thermal envelope and insulation

The thermal envelope is what serves to shield the living space from the outdoors. It includes the wall, roof and floor, insulation, air/vapour retarders, windows and weather stripping and caulking. The envelope is indeed one of the most crucial parts in the conservation of energy. The envelopes for most old buildings and sport halls in specific have had the energy performance highly neglected. Most buildings are still leaky way without sufficient insulation or exterior shade control. Bearing in mind that heating and cooling account for almost a third of the energy consumption globally, it has become important to optimize building envelopes in a manner that results in long term reduction in energy utilization in buildings (6). The building envelope determines the energy consumption by the specific building in terms of lighting and heating. The building envelope performs many different functions, offering security, fire protection, privacy, comfort and shelter from weather, as well as benefits such as aesthetics, ventilation and views to the outdoors (6).

An energy efficient envelop should maximize the availability of sunlight for lighting and heating and thereby reducing the reliance on heating and lighting systems during sunlight hours, without causing overheating. Efficient glazing, shading, reflective surfaces and natural ventilation can similarly be relied on to reduce the energy use through cooling (6). Recent innovation in dynamic window technology could enable greater passive heating in winter and shading in summer, once the technology is mature and becomes economically viable.

Insulation reduce energy loss through the walls and the floor and all other services forming part of the external area of the sport hall. Proper insulation reduces heat loss in cold weather, keeps out excess heat in hot weather, and helps maintain a comfortable indoor environment without incurring maintenance costs (6).

In essence insulation ensures that heat is kept within the sport hall and this is an effective way of conserving energy. However this challenge is not experienced with new buildings which are built to meet the minimum standards laid down by energy regulations. This means that there is room to improve the insulation of older sport halls in specific to meet the new set minimum standards while at the same time reducing the energy consumption. While insulation measures can be more expensive and disruptive than other energy efficiency actions, improvements will result in a warmer more welcoming hall that is more energy efficient (7).

## 2.2 Airtightness

The airtightness of a building's envelope is a critical factor in its thermal performance and durability. Undesirable air movement (infiltration) through the envelope can occur through different unintentional paths such as cracks around windows and doors or improperly sealed construction joints. They are caused by wind pressure and temperature differences across the building envelope due to differences in air density between warm and cold air. This can cause condensation. Physical damage of the envelope components from condensation (e.g., corrosion of metals, rotting of wood etc.) and reduced thermal insulating value of the envelope resulting in excessive heat losses and increased heating energy requirements. To avoid these negative impacts, a building's envelope must be sufficiently air- and moisture-tight. Depending on the envelope type, different approaches to achieve air and moisture tightness are required.

Building envelopes under the low energy house standard are required to be extremely airtight compared to conventional buildings. Air barriers careful sealing of every construction joint in the building envelope and sealing of all service penetrations through it are all used to achieve this (8). Airtightness minimizes the amount of warm - or cool- air that can pass through the structure, enabling the mechanical ventilation system to recover the heat before discharging the air external.

## 2.3 Indoor environmental quality enhancement

The Indoor Environmental Quality (IEQ) category in e.g. LEED standards, (V4 for Building Design and Construction) is one of the five environmental categories created to provide comfort, well-being, and productivity of occupants. The LEED IEQ category addresses design and construction guidelines especially indoor air quality (IAQ), thermal quality, and lighting quality (9).

Indoor Air Quality seeks to reduce volatile organic compounds (VOC's), and other air pollutants such as microbial contaminants. Buildings rely on a properly designed HVAC system to provide adequate ventilation and air filtration as well as isolate operations (kitchens, dry cleaners, etc.) from other occupancies.

During the design and construction process choosing construction materials and interior finish products with zero or low emissions will improve IAQ. Many building materials and cleaning/maintenance products emit toxic gases, such as VOC's and formaldehyde. These gases can have a detrimental impact on occupants' health and productivity as well. Avoiding these products will increase a building's IEQ. Personal temperature and airflow control over the HVAC system coupled with a properly designed building envelope will also aid in increasing a building's thermal quality. Creating a high performance luminous environment through the careful integration of natural and artificial light sources will improve on the lighting quality of a structure (10).

Thermal comfort is often listed by occupants as one of the most important requirements for any building in surveys of user satisfaction in buildings, it was found that having the "right temperature” was one of the most important considerations (11). Additionally, it was determined that air freshness was an important requirement. Even the subjective feeling of air freshness was found to be closely linked to the air temperature. Therefore, two important requirements of user satisfaction with the indoor environment are closely related to temperature.

Creating a comfortable indoor environment is also important because occupants will react to any perceived discomfort by taking actions to restore their comfort. Sometimes these actions will come with an energy cost for example, using a shading device and turning on lights is a costly way to eliminate glare due to the presence of solar radiation is also a costly way to alleviate discomfort. Therefore it is important to recognize that low energy standard that increases occupant discomfort may be no more sustainable than one that encourages energy use (12).

The principle purpose of heating, ventilation, and air-conditioning (HVAC) is to provide conditions for human thermal comfort (ASHRAE Handbook of Fundamentals, 2005). ASHRAE Standard 55(2004) defines thermal comfort as “that state of mind which expresses satisfaction with the thermal environment". Although this broad definition has been subject to deep inquiry and philosophical debate (13), it nevertheless emphasizes that the judgement of comfort is a cognitive process that is influenced by a combination of physical, psychological, and physiological factors. In general, comfort is attained when body temperature is held within a narrow range, skin moisture is low, and the physiological effort of regulation is minimized (ASHRAE Handbook of Fundamentals, 2005). There are no information available for sports halls

## 2.4 Windows

Windows are one of the most significant components of the building envelope, and therefore of the entire building. Although windows have always been used as architectural components for providing outdoor view and natural light, it has only been in recent years that the benefits of windows and their effect on the satisfaction, health, and productivity of the building occupants have been recognized (14). This is reflected in the current trend of designing commercial buildings with glass facades. In addition to these more immediate human-related needs, there is also an urgent need for significant improvements in building energy performance Windows have also several functions, including giving access to the building, providing outlook, letting in daylight and offering safety egress. In most cases, windows should emit as much light as possible without causing glare problems, but heat gain needs to be minimised in summer and maximised in winter. Appropriate choices of sizing, orientation and glazing are essential to balance the flows of heat and natural light. These rating systems require high-quality design in order to deliver superior daylight, views, comfort, ventilation, and energy performance all of which are directly related to fenestration systems(15). In addition, sustainable building design requires consideration of passive and active solar energy systems; good performance of these systems cannot be achieved unless the integration of solar technologies is considered from the early design stage. The systems' performance is directly related with the location form and orientation of the building and, thus, affect the quality of the indoor environment.

The typical home loses more than 30 percent of its heat through windows and windows have a large impact on thermal comfort because of their effect on the mean radiant temperature (MRT) (16). Even modern windows insulate less than a wall. Therefore, an energy efficient house in a heating dominated climate (Scandinavia's climate) should in general not have too many windows. For window, there are several parameters that affect the building's energy use including U value, solar energy transmittance (g-value) and the light transmittance (LT) value. Glass properties differ considerably and it is important to choose the right kind of glass. One way to improve the U value of the glass structures is to have the noble gases argon or krypton in the space between the panes of glass (17). Another way is low emissivity of glass is using Low-e coatings  to minimize the amount of ultraviolet and infrared light that can pass through glass without compromising the amount of visible light that is transmitted.

In most cases windows should let in as much light as possible but heat gain needs to be minimized in the summer and maximized in the winter. Appropriate choices of sizing, orientation and glazing are essential to balance the flows of heat and natural light.

## 2.5 Lighting System

Lighting plays a key role in the energy balance of any building. Older lighting systems in sport halls may have an excessive energy use. Older sport arenas may have high lighting levels for television broadcast but these levels of lighting are not really required with the modern broadcasting equipment in use. The systems should be replaced with more efficient systems that consider the issue of broadcasting but utilize lower energy that the earlier systems. Most lighting should be high-frequency fluorescent tube or compact fluorescent fittings (18). There are very few uses for which incandescent bulbs are justifiable. In those minimal cases low voltage tungsten halogen bulbs can be sparingly used to create the intended effect but their use should never be in large numbers. The lighting system should be one that allows for faster switch on and off, one that allows for step control and ensure minimal loss of energy when one of the bulbs is not working. With properly designed lighting schemes, it is possible to improve the effectiveness of the lighting both in terms of quality and quantity without utilizing high levels of energy. The lighting system in the specific sport hall can be replaced with a low energy lighting system that utilizes passive infra-red controls (18). The controls ensures that when someone enters the building, lights are automatically turned on and the lights will remain on as long as the building is occupied but will go off once the building or the specific rooms therein are no longer occupied. The PIR system ensures that lights are on only when the facility is occupied and light levels are low. Lights are no longer left on unnecessarily. The fluorescent fittings installed are of ‘high frequency’ specification. These are twenty percent to forty percent more efficient than standard fluorescent units (18).

There are specific areas in a sport hall that should be highly illuminated. These places are the playing area and the auxiliary area (18). The illumination necessary is provided for by the several guidelines and laws on this area but the amount of energy to be utilized in illuminating these areas is dependent on the height of the sporting hall, the location of the playing area in the hall, and the location and elevation of the bulbs or lamps used to illuminate. The main task of the renovation and implementation of a low energy lighting system should be achieving a high efficiency lighting system at low energy demands (18) and utilizing daylight.

## 2.6 Heating, Ventilation and Air Conditioning (HVAC) system

The heating system in any sport hall is based on Heat normally transferred through conduction, through convection and through radiation (16). Several solutions have been suggested that would improve the heating systems of sport halls ensuring that the necessary levels of heat are maintained but in a manner that conserves and reduces the use of energy in the sport hall. A central heating system from district heating used in large sport halls with constant need for heating are better compared older and larger plants used in the older sport halls. This system results in substantial saving in energy consumption (16). However localized and locally controlled heating systems are more energy conservative especially for sport halls were heating is not constant and heating is provided on demand. For instance gas fired radiant tubes have proven to be more efficient and use low energy when utilized in high bay sport halls.
Under floor heating has been suggested as a solution to raising the room temperature in sport halls to the required temperature for the comfort of occupants and users of the hall (19).

A warm air system with a complete heat and ventilation provision can also be used to heat and ventilate a sport hall in an energy efficient way. The system can include air recirculation options and a heat exchanger to help capture heat gains from occupants. Heat is usually from a district heating system. The warm air system is more suitable for sport halls that do not require radiant heat and can be used in such halls to cater for both ventilation and heating. Careful control of the ventilation process can minimize the energy use and by implication the running costs especially for small to medium sized sport halls. The installation and utilization of this system however requires an examination of the temperature stratification or a large temperature gradient in a room especially those with high ceilings. Where air velocity is high, a draught in the playing area of the sport hall may affect specific games and the noise from the supply of air may be distracting for other sports. The system makes it possible to fit the heat and ventilation systems in one room and ensures sufficient supply of fresh air (16).

Heat recovery is also an essential aspect of heating and energy conservation in sport halls. The heat recovery system is meant to collect moist stale air from specific rooms in a sport hall such as changing rooms and washrooms and discharging it to the outside through a heat exchanger. In the process the system ensures sufficient supply of fresh air in to the sport hall (16). The fresh air picks the heat left in the exchanger and supplies it to the specific rooms. The recommendation by Sport Scotland of ten air changes per hour has been found to be sufficient and the systems installed should operate with this level as the minimum (19).

## 2.7 Solar energy

Renewable electricity generation from technologies that are commercially available today in combination with a more flexible electric system is more than adequate to supply high percent of total electricity generation in the future (7).
Renewable energy source especially solar energy can be relied on in recent year to power buildings in an attempt to supply renewable energy that is both cost effective and environmentally sound. Solar power has emerged as one of the quickly growing and reliable source of electricity (7). Generation of electricity from solar energy has several advantages over generation of electricity from other sources. The main advantage is how solar energy is not limited as is with energy generated from fossil sources which are limited and bound to run out. Although there is variability in the amount and timing of sunlight over the day, season and year, a properly sized and configured system can be designed to be highly reliable while providing long-term, fixed price electricity supply (7). Electricity generated from a solar production system has less impact on the environment. Solar produced electricity can be used to adequately supplement the electricity from the electric transmission grid. Another advantage of solar electricity is as the size and generating capacity of a solar system are a function of the number of solar modules installed, applications of solar technology are readily scalable and versatile (7).

Solar is an inexhaustible source of energy. Over the past thirty years advancements have been made aimed at making solar energy usable in the form of electricity (7). From the time solar energy was converted into electricity, the cost of producing solar energy into electricity has reduced to nearly 1/300 of what it used to be. Solar energy is currently used in two forms, thermal and photovoltaic. Thermal solar energy can be used to heat hot water for buildings, water in pools and the washrooms, warm up the building, and heat up the air in the building plus any other aspect of a sport hall that needs to be heated. Photovoltaic solar power provides electricity without any moving parts or machines. Photovoltaic system are often made of silicon cells the second most abundant element in the earth's crust. Photovoltaic solar power is converted to electricity when sunlight strikes the semiconductor material and creates an electric current. The system is made up of small cells which convert sunlight into electric current. Cells wired together form a module, and modules wired together form a panel. A group of panels is called an array, and several arrays form an array field (7).

Photovoltaic solar energy has several advantages making it one of the most promising source of renewable energy. It is non-polluting, has no moving parts that could break down, requires little maintenance and no supervision, and has a life of 20-30 years with low running costs. It is especially unique because no large-scale installation is required (7). It has advantages over wind power, thermal solar power and hydropower. There are only two main disadvantages in using solar energy in general. Solar power is dependent on sunlight and exposure of the building in question to sunlight whose intensity and availability varies depending of geographical location, the availability of clouds, the season of the year and the time of the day. The initial cost of acquiring the necessary equipment to set up the solar energy system can be quite high (7).

For successful utilization of solar energy in sports halls and sport facilities, it is necessary to focus on supply over energy requirements. Although the installed system may have a certain amount of energy to supply, this should not be used to indicate the actual energy that the system will supply (7). The production of energy by the system can be affected by several factors once installed including the shading, the location of the sport hall, the tilt of the system, and how much sun it receives throughout the year. Concentration on energy production will lead to the provision of the suitable factors to ensure maximum production energy which would not be achieved if the main focus is placed on the capacity of the system being acquired.

The development of a financial model will help in reducing the cost of acquiring the system and minimize the period it takes for the system to pay back (7).

The utilization of solar energy in sport halls will require the installation of solar panels on the buildings facing the sun. The installation of a solar power system however starts with the conduction of a power audit. An energy audit will give you a clear picture of how your facility is using energy now. It can provide actionable steps to reduce energy waste through conservation and technology improvements. Because it measures your current energy load, the audit is an important starting point for scoping a potential on-site project in relation to your system goals (7).

The installation process also involves the confirmation of the goals the system is meant to achieve. This will involve identifying which aspects of the energy demands of the sport hall are to be provided for by the solar power system (7). It involves deciding whether the solar system will be the primary source of energy for the hall or if it will be supplementary to the electric grid. The determination and confirmation of the goals to be met influence the amount of energy the system needs to generate. The conducting of a feasibility study has also been said to be an essential step before the installation of the solar power system. The feasibility study will confirm the basic fits for the sport hall and will answer essential questions such as the size and location within the hall and the facility in general where the system will be placed, the connection of the solar system to the existing electrical system, and data monitoring to be involved in the system (7).

The solar panels should be installed in a place that maximizes exposure to sunlight in order to increase the energy production of the system (7). Therefore, solar panels are often installed on the roof of a building. Where the weight of the solar panels is an issue to be considered before they are placed on the roof, a choice can be made between the traditional crystalline silicon solar panels and the thin film cells solar panels. Where the parking lots to the sport hall are uncovered then carport-like installations of the solar panels can be considered. However this should be informed by the fact that the racking structure will increase the cost of installing the entire system (7). Solar energy is more and more used in sport facilities. The Solar Energy Industries Association (SEIA), reported that in 2014 the total accumulative solar capacity in pro sports facilities hit 21.7 MW in the USA. The report showed that twenty five stadiums and sport halls as well as twelve racecourses used solar energy one way or another. Topping the solar list was Indianapolis Speedway, home of the

Indianapolis 500, with 9000 kW of solar power capacity. Indianapolis Speedway has the largest sports solar farm in the world, enough to power 1,000 US homes.

## 2.8 Inspiring Projects

One of the main reasons for studying the successful projects is getting a clear impression in order to realize high quality solar energy solutions in architecture and gain new information meaningful ways about the energy roof and facades, BIPV integration. The author has chosen three successful projects One of them is a commercial and the rest are public.

### 2.8.1 Rockwool International Office Building “Center 2” Hedehusene, Denmark

The project located in Hedehusene, Denmark. International Office Building “Center 2” was built in 1973 and was renovated with Rockwool Solutions in 2013 and new facades, floors and ceilings, new windows with 3 layers of glass, new ventilation system with higher efficiency and heat recovery, new heating system (heat pumps), new water based solar collectors and new photovoltaic system were implemented(20). The primary energy demand in the building was reduced from 264 kWh/ ($m^2$·yr.) to 41 kWh/ ($m^2$·yr.). The reduction is 84% of the primary energy and in the table below the U-values of the building components are presented, see Table 2.2.1 (20).

*Table 2.2.1, U-values of building components before and after renovation (Thomsen & Rose)*

| Building components | U-value before renovation/ (W/($m^2$·K)) | U-value after renovation/ (W/($m^2$·K)) |
|---|---|---|
| Walls | 0.17 | 0.08 |
| Roof/attic | 0.14 | 0.14 |
| Windows | 2.4 | 0.75 |
| Ground floor | 0.17 | 0.06 |

### 2.8.2 Centre for Interactive Research on Sustainability (CIRS), Vancouver, Canada

The project was first conceived in 1999 by Dr. John Robinson, a professor at University of British Columbia as an opportunity to create a sustainability showcase in the province of British Columbia. The refurbishments were completed in 2011 in order to push the envelope of sustainable design by integrating passive design strategies with the most advanced sustainable technologies of the time to achieve a high level of performance. The essential strategies implemented in the building were construction with high insulation at walls, roof and floor slab, with double glazing and low-e coating and exterior shading devices with integrating photovoltaics system. The building services were also implemented with the waste heat recovery from adjacent building, heat pump with 30 geo-exchange wells and displacement ventilation and natural cross ventilation.

The primary energy demand in the building was reduced from 169 kWh/ ($m^2$·yr.) to 76 kWh/ ($m^2$·yr.). The reduction is 45% of the primary energy and $CO_2$ Emissions is 16.8 Kg/ ($m^2$·yr.)(21).

### 2.8.3 Derelict factory building transformed into energy-plus building in Hannover, Niedersachsen

The building was built in 1959 as a factory building in Hannover, Niedersachsen. The refurbishment was implemented, transformed derelict factory building to an office building during 2009-2011 and aimed at scientifically monitoring the refurbishment of a special non-residential building. Low energy house strategies was used with comprehensive renovation by using high insulation at walls, roof and floor slab, with triple glazing and the use of a heating system adapted to the reduced heating needs and the integration of a ventilation system with highly efficient heat recovery have reduced the heating energy requirement by more than 90% from around 270 kWh/ ($m^2$·yr.) to approximately 25 kWh/ ($m^2$·yr.). A photovoltaic collector has been installed on the roof and the evacuated tube collectors on the upper facade. The solar electricity in the building is completely used for heating and air-conditioning. The solar electricity production is greater than the user requirements (22).

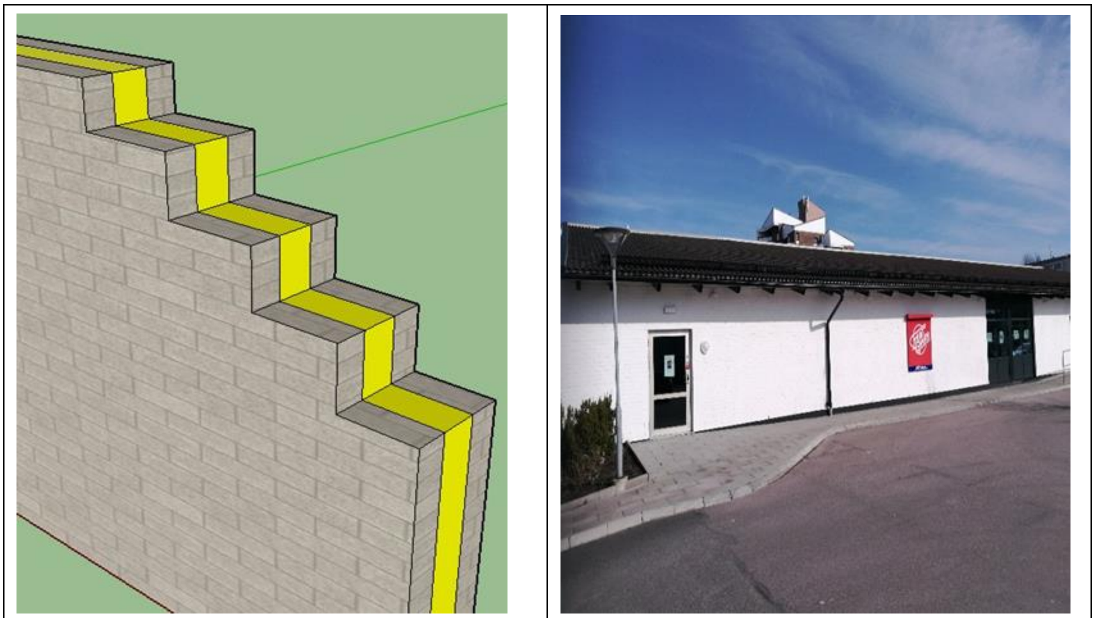
# 3 Description of the Case Study Building

The building which was used for this study is a fairly typical sports hall with gyms and aerobics. The building was originally built in the eighties and was turned into Sports hall in 2014. The Sports hall has been chosen to investigate the potential for energy savings and implementation of renewable energy. In a first approach, the information that was known about the site before this study, was that it was located in the north side of Landskrona, Sweden. The building had one floor and had approximately been built in a square shape. The floor area was 2874 m².

*Figure 3.1. The building site in Landskrona*

## 3.1 Building components

The exterior wall consisted of three layers: Brick, 120mm, 140mm mineral wool and Brick, 120mm Figure 3.1.1. The roof of the sports hall had three parts of roofs, one roof towards the south with tilt 14 degree Figure 3.1.1. consists of roof tile and insulation layer 100 mm and the second roof towards the north with tilt 4 degree consists of roof tile and insulation layer 100mm and the third new part of roof over café and VK (Entrance), is recently built towards the east consists of roof tile and insulation layer 300 mm. The floor is made of concrete slab on ground 120 mm and 50 mm insulation layer under the floor, along the border of the slab and there is no insulation layer under central of the slab, and the new part of floor below café and VK, is made of concrete slab 120mm and insulation layer (Sundolitt) 200 mm under the concrete slab. The “jympa” room (see also floor plan in Figure 3.1.2.) had an addition construction above the slab, assumed 20 mm insulation. All of the windows are two pane glazing, clear and the glass facade is also two pane glazing, clear Figure 3.1.2. Partitions are made of two layer gypsum board12.5 mm, insulation layers 95 mm and two layers gypsum board 12.5.



The wall construction

The tilt roof towards the south

*Figure 3.1.1. Sports hall components (photo Mohammed Al-Husinawi)*

The floor in JYMPA | The glass facade

*Figure 3.1.2. Sports hall components (photo Mohammed Al-Husinawi)*

## 3.2 Electric lighting

Electric lighting: It is considered that lights are switched on from 06:00 am to 09:00 pm Monday to Thursday, from 06 am to 08:00 pm Friday, from 08:30 am to 04:00 pm Saturday, while the Sunday from 08:30 am to 08:00 pm in the gym while the rest of the sports hall were controlled by the present sensors, and internal heat gains from lighting were set to 3.4W/m$^2$ (28). Efficient lighting devices were assumed with a luminous efficacy of 40 lm/W. Because of daylighting is not sufficient the light output was controlled according to the available daylight. When the area (work plan) illuminance was below 100 lux the lights were set on power. When the area (work plane) illuminance exceeded 350 lux the lights were turned off.

Lighting in JYMPA

Lighting in GYM

*Figure 3.2.1. Lighting inside sports hall (photo Mohammed Al-Husinawi)*

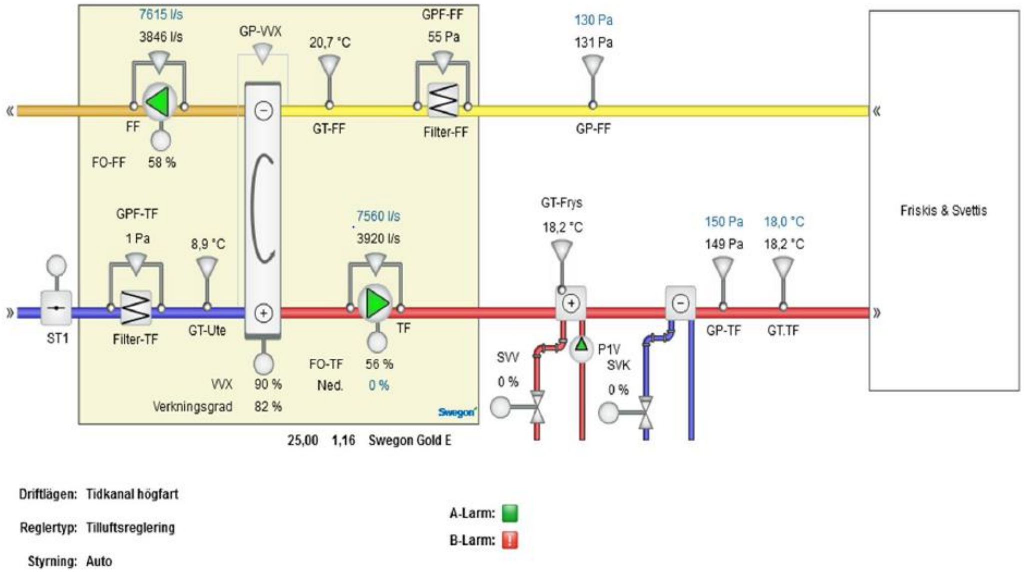
## 3.3 HVAC

In the sports hall, the heating system consists of radiators and the system are fed by a district heating system. Ventilation has to provide acceptable indoor air quality and prevent health hazards or any other pollutants. However, in air supported structures the purpose of ventilation is not to provide indoor climate only. The air in ventilation is used for heating in winter time and cooling during the summer. AHUs uses rotary heat exchanger with a high efficiency, heat recovery is 80-90%. The cooling demand is met by the cooling coils of the building’s AHUs. CAV and VAV system operates according to the occupancy schedule, from air handling unit located behind the building, through the ducting network. In addition, climate sensors by temperature 20-25 ˚C and CO2 700-1000 ppm were placed to gain better control of the desired indoor conditions achieved through the Variable Air Volume (VAV) system in the activity rooms (JYMPA, SPINING and GYM), controlled by the number of people, presence sensors, temperature and CO2 inside the sports hall. The rest of sports hall are ventilated by a Constant Air Volume system (CAV). The total supply air flow is the sum of the hygienic fresh air of 7 l/s person + 0. 35 l / (s · m²). Table 3.3.1 presented CAV and VAV systems with supply air and return air flow in different zones were taken from Landskronahem’s document, more information presented in Appendix 10.7.

Table 3.3.1. Supply air and return air flow in different zones

| AIR FLOW FOR CASE STUDY SPORTS HALL | | | | | |
|---|---|---|---|---|---|
| Item | Supply air flow/(l/s) | Exhaust air flow/(l/s) | Item | Supply air flow/(l/s) | Exhaust air flow/(l/s) |
| LOKAL | 40 | 40 | SPINNING | 300-1750 | 300-1750 |
| INCHECH/VÄNT1,2 | 400 | | OMKL HERR | 270 | |
| CAFÉ/REC/PENTRY | 30 | 35 | DUCSH HER | | 240 |
| JYMPA 2 | 250-1050 | 250-1050 | OMKL DAM | 270 | 240 |
| JYMPA 1 | 450-1800 | 450-1800 | WC/WC/WC WC/WC/STAD | | 15/15/15/15/15/30 |
| GYM | 300-1200 | 450-2100 | EXP. | 40 | 40 |
| GYM1 | 150-300 | | BARN | 20 | 20 |

Maximum ventilation supply airflow in the sports hall is approximately 7560 l / s(29), which corresponds to 7 l / (s · m²) in the whole sports hall achieved by AHUs in figure 3.3.1 . Maximum ventilation exhaust airflow in the sports hall is approximately 7615 l / s(29), which corresponds to 7.05 l / (s · m²). Minimal ventilation supply airflow in the sports hall is approximately 2960 l / s, which corresponds to 2.7 l / (s · m²) in the whole sports hall achieved by AHUs in figure 3.3.1. Minimal ventilation exhaust airflow in the sports hall is approximately 3015 l / s, which corresponds to 2.8  l / (s · m²).



Driftlägen: Tidkanal högfart

Reglertyp: Tilluftsreglering

Styrning: Auto

A-Larm: 🟩

B-Larm: 🟥

*Figure 3.3.1. Map of HVAC*

# 4 Method

The reference building (case study building) has to be carefully defined and simulated in the software “IDA ICE” in order to find the energy performance and indoor climate conditions. Furthermore climate analysis will be performed and energy calculations for both base case and improvements will be made in the software “IDA ICE”. Solar system will be proposed by using Grasshopper and investigated from an economic perspective (LCC).

## 4.1 Software used in the thesis

### 4.1.1 IDA Indoor Climate and Energy

IDA Indoor Climate and Energy is a program developed by EQUA Simulation AB (EQUA Simulation, 2012). The program is a dynamic calculation program used to study the climate in several zones and to make the calculation of energy use during a year in a building. The program is used by engineers, HVAC engineers, manufacturers and researchers, etc. The program is offered in two versions: standard and expert. The program is suitable for use where heating and ventilation system needs to be simulated. The program is validated towards ASHRAE 140, CEN Standard EN 15255 and 15265, 2007, CEN Standard EN 1379, International Energy Agency SHC Task 34, Technical Memorandum 33 (TM33), LEED and BREEAM and DGNB.

### 4.1.2 SketchUp

SketchUp is a computer program for a wide range of drawing applications such as architectural interior design, architecture, civil and mechanical engineering, film, and video game design and was developed by Start-up Company at Last Software of Boulder, Colorado.

### 4.1.3 Grasshopper Rhinoceros

Grasshopper is a graphical algorithm editor tightly integrated with Rhino’s 3D modelling tools. Rhinoceros is a 3D modelling application used widely for computer aided design. Archsim. Archsim is a plug-in for Grasshopper developed by Timur Dogan, based on Energy Plus. Energy Plus is a widely used, extensively tested, building energy simulation program used to model energy, HVAC system, calculated performance and financial metrics of renewable energy systems and water use in buildings. Archsim supports advanced daylighting and shading controls, ventilation modules such as wind and stack natural ventilation, airflow-networks, photovoltaics and phase changing materials.

## 4.2 Collected documents

Documents have to be collected to complete onsite observations. The main pieces of information that are worth collecting are the following, on a decreasing level of importance. Onsite contacts: Property Manager, Facility Managers, Technical Managers, Maintenance Responsible.
The technical visit: to complete the information included in the documents collected, a visit on site is necessary. A first part of this visit is to identify the technical equipment of the building. Information is collected by every means available onsite: direct observations, discussion with the technical manager, identification sheets and technical documents.

## 4.3 Boundary conditions - Climate Analysis and Surrounding Conditions

Landskrona, like the rest of southern Sweden, has a coastal climate with slightly warm summers and cold winters. Despite its northern location, the climate is surprisingly mild compared to other locations in similar latitudes, or even somewhat further south, mainly because of the Gulf Stream. Because of its northern latitude, daylight extends 17 hours in midsummer, to only around 7 hours in midwinter (wikipedia).

Since climatic conditions have such a large impact on the building, author is going to present the most important climatic conditions during the year to give some perspective of the building, climate and surrounding conditions in regard to the objectives of this thesis.

Figure 4.3.1.1. Average temperature range during a year between (-2 to 20), Figure 4.3.1.2. Average relative Humidity range during a year between (60%-90%) and Figure 4.3.1.3. Average daily shy cover range during a year between (55%-85%).

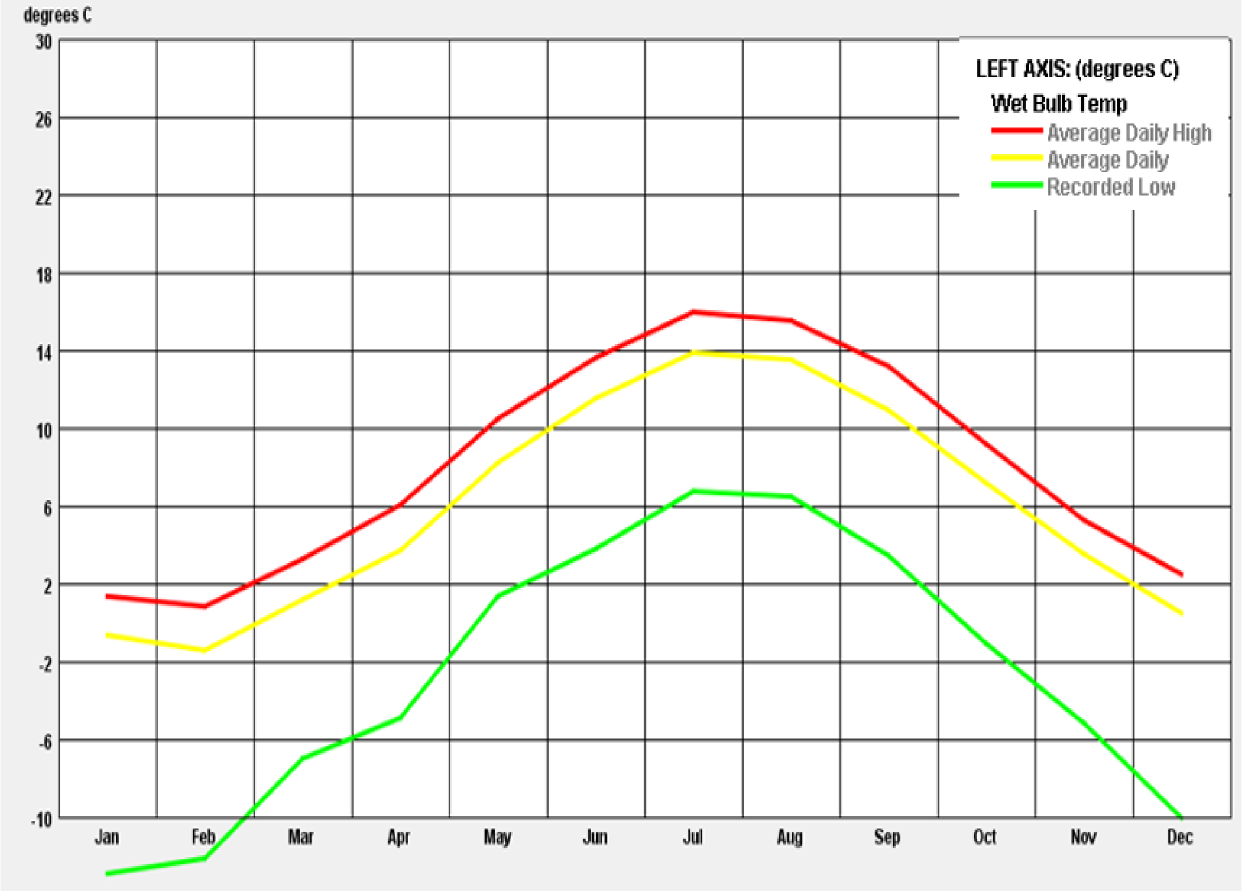


*Figure 4.3.1.1. Temperature range during a year*

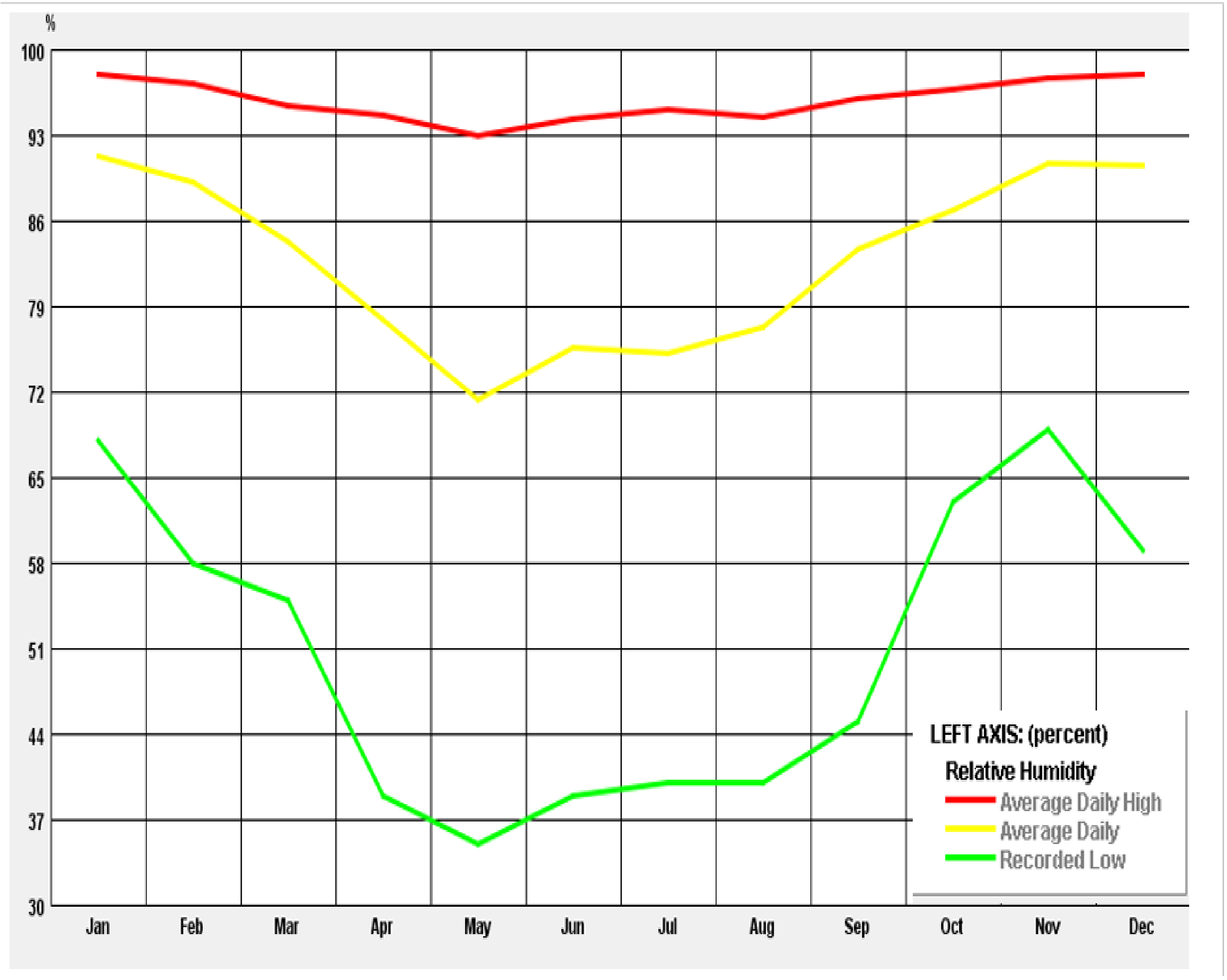


*Figure 4.3.1.2. Relative Humidity range during a year*

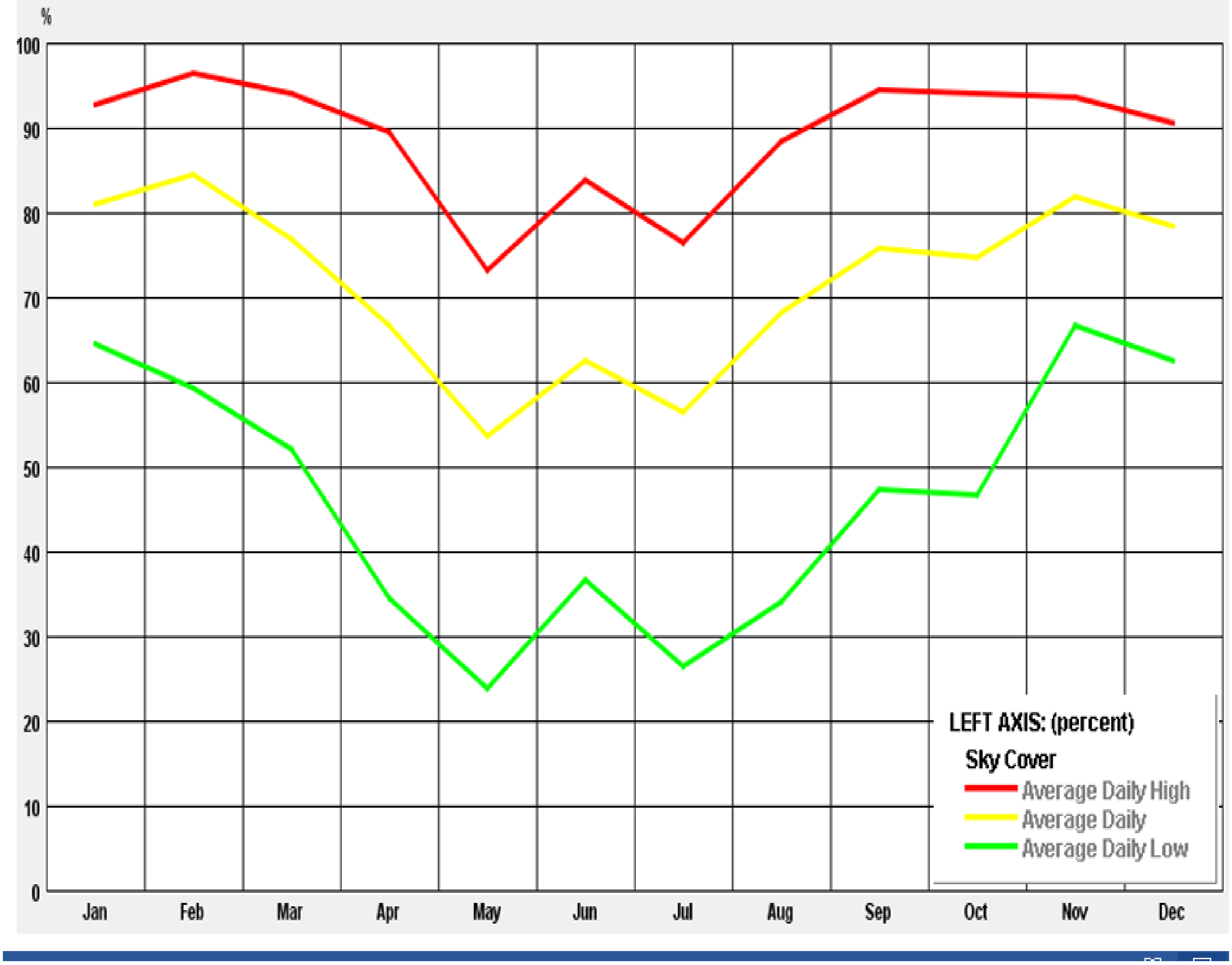


*Figure 4.3.1.3. Shy cover range during a year*

Local shading by the surroundings and incident solar radiation on the building was investigated to determine the potential locations for solar system placement. Annual conditions were studied in Grasshopper Ladybug using Lund weather file.
An initial shading analysis showed that the examined roof towards south is not affected by surrounding shadows during the summer and winter. Figure 4.3.1.4 shows urban shading conditions during the equinox.

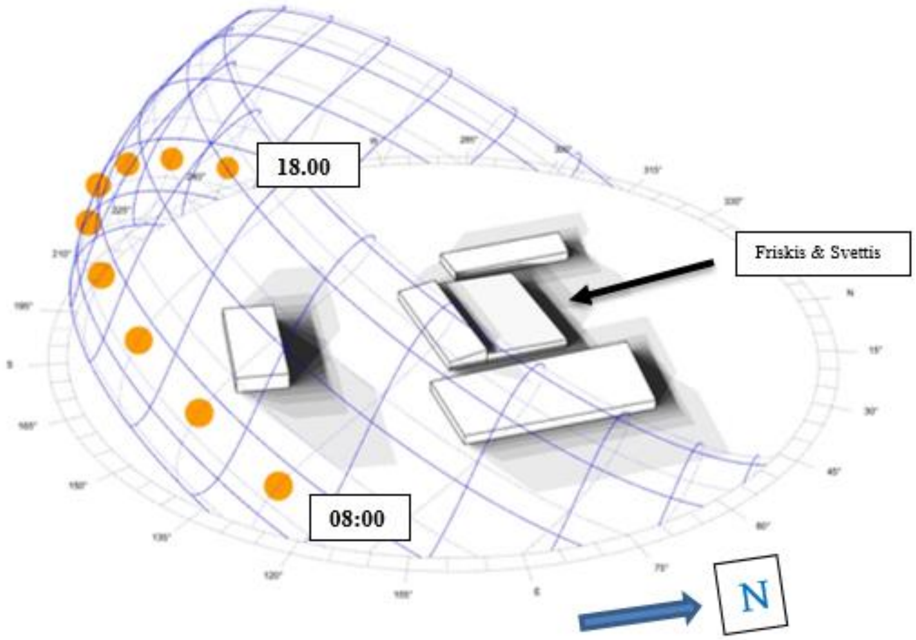


*Figure 4.3.1.4. Urban shading Shadow analysis- 21st of September between 08:00-18:00 (during the equinox).*

A solar irradiation was performed for whole year in “Grasshopper Ladybug” and the examining location showed the highest incident occurs during the months of March to August. Radiation studies allow to look at how much heat will have an incident with different facades and roof and elements of building and also to determine where the building will have the extreme conditions in regarding to daylight factors and lighting levels went inside the building. It is not only looking at outside but it is also to understand interior layout of the building in order to place heat producing rooms and the functions. In the following figure 4.3.1.5, annual solar irradiation on the building’s roof and façade can be seen. The irradiation values for roof vary between 971-1055 kWh/ ($m^2 \cdot a$).

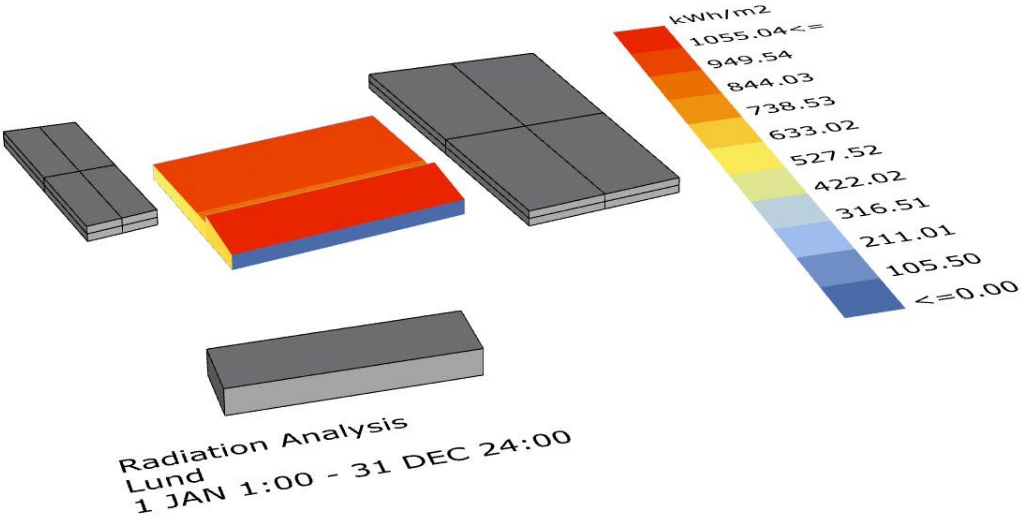


*Figure 4.3.1.5. Solar irradiation distribution on sports hall (calculation performed for a whole year)*

## 4.4 Energy calculation input data

In order to estimate the current status of the energy use of the reference sports hall, 3D models and floor plan of the building was built in the software IDA ICE (as seen in Figure 4.4.1, 4.4.2); properties for the building envelope and occupants' behavior were assigned. The building constructions and U-values were calculated by analyzing the building at site and drawings review.

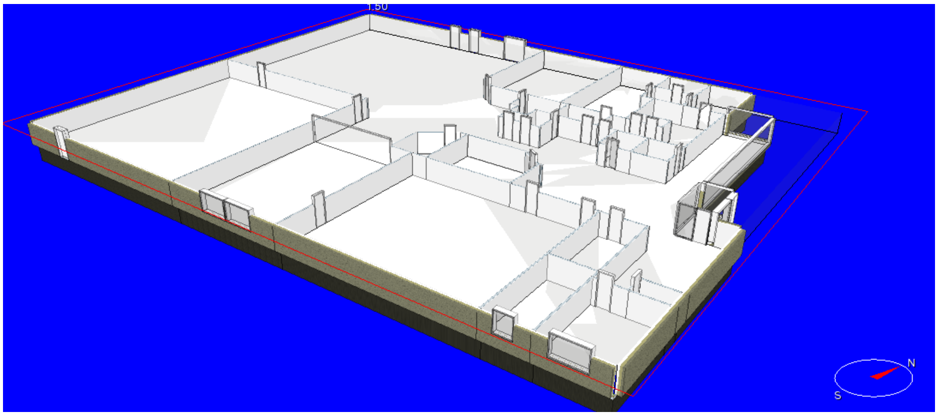


*Figure 4.4.1 IDA ICE simulation model Sports Hall*

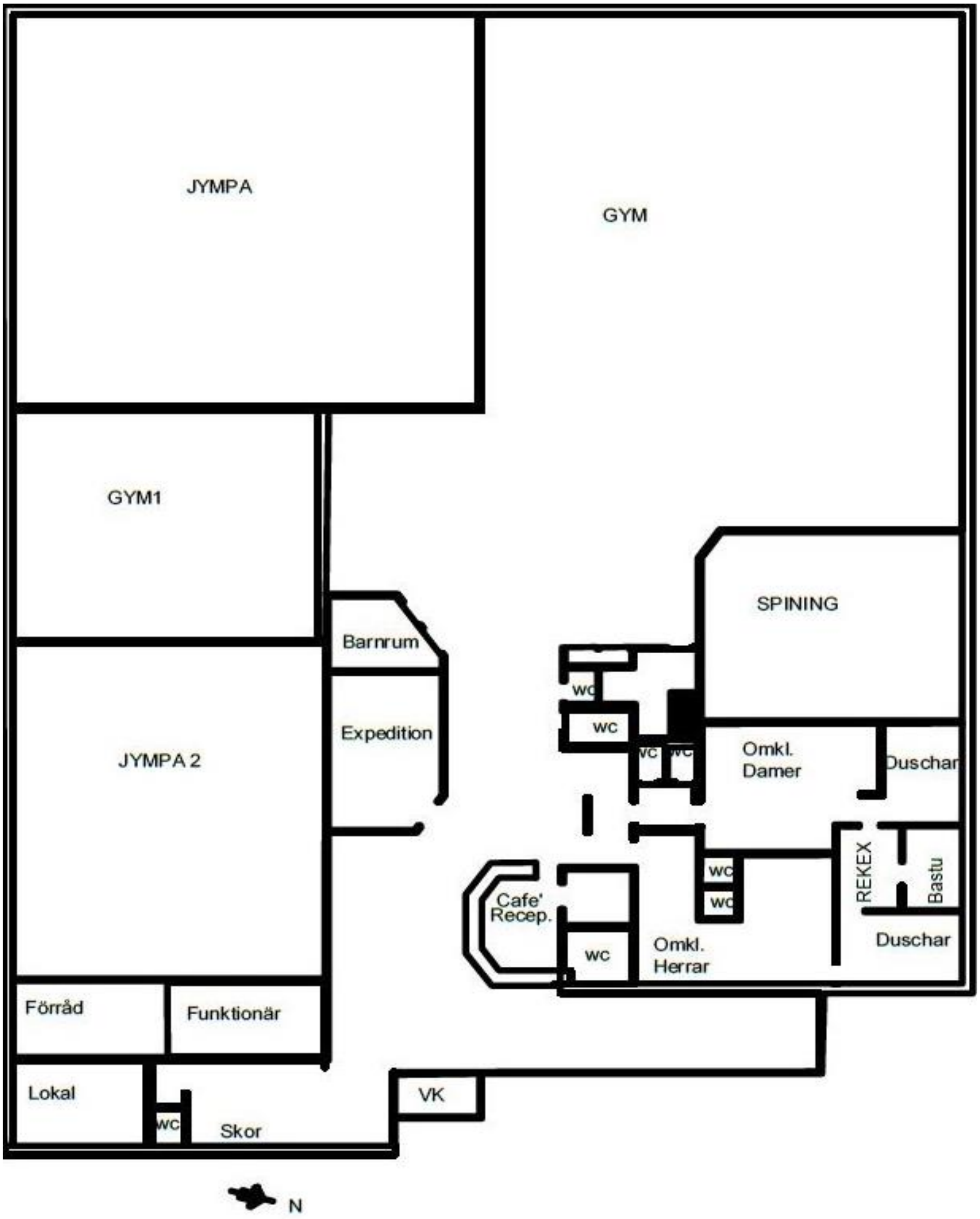


*Figure 4.4.2 Floor Plan- Sports Hall*

Input data for internal gains: lighting were estimated 3. 4 W/ $m^2$. Efficient lighting devices were assumed with a luminous efficacy of 40 lm/W and facility electricity and other factors for constructions were estimated according to collected data and analysis of drawings and contacts with Landskronahem. The input data for the base case are presented in Table 4.4.1. As the sports hall is a quite old building, the thermal bridges in IDA ICE were considered as "typical", which indicate 25% of transmission losses by thermal bridges.

*Table 4.4.1 IDA ICE Input data for base case*

| **IDA ICE Input data for base case** | | |
|---|---|---|
| **Building** | | |
| **Location** | Landskrona | |
| **Weather files** | Malmö Sturup | |
| **Orientation** | 10˚ towards southeast | |
| **Heated floor area/$m^2$** | 1400 | |
| **Construction** | | |
| The area of windows /m<br>The area of the glass wall /m | 11<br>40.4 | Towards south<br>Towards east |
| Window U-value /(W/($m^2$·K)) | 1.3 | |
| Glass facade U-value /(W/($m^2$·K)) | 1.3 | |
| External wall U-value /(W/($m^2$·K)) | 0.22 | |
| Entrance door U-value /(W/($m^2$·K)) | 1.08 | |
| External roof U-value /(W/($m^2$·K)) | 0.34 | |
| Ground floor (average) U-value /(W/($m^2$·K)) | 0.7 | |
| Airtightness /(l/(s·$m^2$))<br>Outside area towards air | 0.3 | At 50 Pa |
| Thermal bridges | Typical (25% of transmission losses) | Estimated |
| **Installation system** | | ***Schedules*** |
| District heating, heating set point/˚C | 20 | Always on |
| Cooling set point/˚C | 25 | Always on |
| Mech. Max supply air /(l/(s·$m^2$)) | 7<br>0.35 | Always on |

| | | |
|---|---|---|
| Mech. min supply air /(l/(s·m²)) | | |
| Mech. max rate exhaust air /(l/(s·m²))<br>Mech. min exhaust air /(l/(s·m²)) | 7.05<br>0.35 | Always on |
| DHW/(kWh/m²) district | 10$^{(16)}$ | Always on |
| Level of $CO_2$ ppm (vol) | 700-1000 | Always on |
| **Internal gains** | | ***Schedules*** |
| Lightning/(W/m²) | 3.4 | 13.14 h/Day |
| Occupants/(participants/sports hall) | 30.17($^{appendix\ 10.6)}$ | 12h/(day/participants) |

The sports hall opening hours (training hours) explains number of participates and time pass of each activity rooms, more information presented in Appendix 10.6

## 4.5 Retrofits and measures

In order to reduce energy use in the sports hall (scenario 1), heating setback 2 °C lower than the constant heating temperature 20 °C, was introduced during nights (between 21:00 and 06:00), when occupants are not present and a slightly lower indoor temperature would not supply discomfort for humans. The first retrofit package (scenario 2), involved increasing insulation in the wall, was performed keeping the brick wall untouched, and the insulation was applied outside the brick wall and thin wall plaster. Adding insulation on the facade is a simple way to improve the building envelope by reducing thermal bridges. In the second retrofit package (scenario 3), the existing roof construction was renovated by increasing insulation in the roof, aiming at the reduction of the thermal transmittance between the internal and the external environments Table 4.5.1, i.e. the U-value. See Table 4.5.2. The last improvement was to use all the available roof area for PV installation. This change aimed to reduce the amount of energy bought from the grid, since a significant part of the electricity consumption could be supplied locally by the solar panels. Afterward LCC analysis was conducted to determine the economic feasibility of the system.

*Table 4.5.1 Improvement cases*

| Simulation Case | Description |
|---|---|
| Base case | The reference building, without changes. |
| Scenario 1 | Heating night setback 2 degrees lower than the constant heating temperature 20 °C |
| Scenario 2 | Added wall insulation EPS (λ=0.34 (W/m K)) of 20 cm thickness to reach U-value 0.09(W/m².K)) (The U-value was reduced considerably, and FEBY standard was achieved) and thin wall plaster (λ=0.17 (W/m K)) + heating night setback 2 degrees. |
| Scenario 3 | Added roof insulation EPS (λ=0.34 (W/m K)) of 30 cm thickness to reach U-value 0.09(W/m².K)) (The U-value was reduced considerably, and FEBY standard was achieved) and added wall insulation EPS (λ=0.34 (W/m K)) of 20 cm thickness to reach U-value 0.09(W/m².K)) and thin wall plaster (λ=0.17 (W/m K))+ heating night setback 2 degrees |

*Table 4.5.2.U-values of building components before and after renovation.*

| Building components | U-value before renovation (Base case)/ (W/(m²·K)) | U-value after renovation (Scenario 3)/ (W/(m²·K)) |
|---|---|---|
| Walls | 0.22 | 0.09 |
| Roof | 0.3 | 0.09 |
| Roof over Café and VK | 0.117 | 0.117 |
| Windows | 1.3 | 1.3 |
| Ground floor(average) | 0.7 | 0.7 |
| Ground floor under Café and VK | 0.17 | 0.17 |

Roof integration with PV means installing solar photovoltaic cells on the roof to supply the electricity need of the building, depending on the maximum available area. This change aimed to reduce the amount of energy bought from the grid, since a significant part of the electricity consumption could be supplied locally by the solar panels. Solar system energy output was performed in software Archsim for Grasshopper for Diva. The photovoltaic systems considered only on the roof with slope 14° faced south and installed on the available 436 $m^2$ roof area, the photovoltaic system was designed accordingly, taking into account location (a specific weather file was used- Lund) and system design parameters (available surface area, photovoltaic module and inverter performance characteristics). As photovoltaic system is building integrated, the modules' tilt is 14° for the roof system and there is no row spacing between them. For the roof system, the azimuth is 170°. The photovoltaic system consisted of seven rows, every PV (ET Solar P660250WW with performance warranty 25 years) row consisting of twenty sex modules connected in serial connection with total 252 PV corresponded to 73 kWp capacity. Output data for photovoltaic system, presented in the script in Appendix 10.5.

Solar thermal was performed with SAM (System Advisor Model) software, designed accordingly, taking into account location (a specific weather file was used- Copenhagen). Solar thermal production considered only on the roof with slope 14° faced south and installed on the available 40 m$^2$ roof area. The modules' tilt is 14° for the roof system and there is no row spacing between them.

## 4.6 LCC Method

Life Cycle Costing (LCC) is a technique used for the assessment and evaluation of a building or an asset in general along its whole life in terms of its monetary value. The method is used, mainly to combine the initial cost (the building envelope retrofit and PV installation) with the running cost of the building during a period of time. The initial cost includes the investment cost for the refurbishment, materials, workmanship and possible evacuation or compensation costs. The running cost includes the yearly cost for district heating usage, building electricity usage and the inverters replacement. Finally, the comparison between the life cycle costs of two alternatives base case and scenario four combining solar system investment.
The total LCC can be defined as:

$$LCC = \Sigma \text{ Initial cost} + \Sigma \text{ NPV running costs}$$

Initial costs are calculated, while the running costs are calculated at present day, year zero, which is the time of investment, using the net present value, taking into account the nominal interest rate and annual rate of price increase. All costs are added over the entire life span of the PV system, which in this case is 25 years. Future costs were calculated being discounted to today's value, using the NPV formula which was the sum of present values for the incoming and outgoing cash flows, over the time of 25 years, as described below. The time period of 25 years was chosen equal to the linear performance warranty of the PV modules.

$$NPV = A1 \cdot \frac{1-(1+g)^{n}.(1+i)^{-n}}{i-g}$$

Where *A1* is the first year running cost, *g* is the annual rate of price increase (electricity, heating etc.), *i* is the annual interest rate and *N* is the calculated period of time.

It is impossible to predict future financial rates. The author estimated future financial rate through review of some projects and lectures (23). So the numbers are just approximations.

*Table 4.6.1: Prerequisites for the LCC analysis*

| | |
|---|---|
| Calculation time/years | 25 |
| Annual real rate of interest | 3 % |
| Annual real price increase of electricity | 2 % |
| Inflation | 2 % |
| Annual real district heating price increase | 1 % |
| Annual real PV-panel price increase | – 2 % |
| Annual price increase for maintenance | 1 % |

## 4.7 Electricity and materials Prices

The electricity buying price in Sweden corresponds to 1.22 SEK/kWh and in case of surplus solar electricity which is sold back to the grid, 0.5 SEK/kWh and district heating buying prices have seasonal variations and the cold season has the highest kWh price due to higher heat demand. (Compricer, 2016)(24), table 4.7.1. and Table 4.7.2. Show these prices.

*Table 4.7.1. Electricity and district heat pricing*

| | *Buy(SEK)* | *Sell(SEK)* | *District heating* | *Buy (SEK)(25)* |
|---|---|---|---|---|
| *Electricity price* | *0.5* | *0.5* | *November-march* | *0.725* |
| *Transmission* | *0,25* | *X* | *April and May* | *0.5* |

| | | | | |
|---|---|---|---|---|
| *El. certificate* | *0.05* | *X* | *September and October* | *0.5* |
| *Energy Tax* | *0.3* | *X* | *June-August* | *0.3* |
| *VAT* | *0.2* | *X* | | |

*Table 4.7.2. Pricing for wall, window and roof improvements.*

| Item | Total area/m$^2$ | Price /(SEK/m$^2$) | Source |
|---|---|---|---|
| Wall (Materials + Labour) | 330 | 762.12 | Wikells Kalkylprogram |
| Roof (Materials + Labour) | 1070 | 846.56 | Wikells Kalkylprogram |
| PV - ET Solar P660250WW | 73 (kWp) | 11000 | Nordic Solar Sweden AB(26) (2017), |
| STC - Heliodyne Gobi 408 013 | 23.4(kWp) | 12000 | Silicon Solar(27) (2017) |
| Solar inverter- Fronius Symo 20.0-3-M | 4 | 27500 | Solar Purag(28) |

# 5 Results

## 5.1 Energy Performance of the Building

The result from the base case ((the annual total building energy use is 143 484 kWh or 49.9 kWh/(m$^2$.a) and the cooling needs are 1569 kWh or 0.5 kWh/(m$^2$.a)) of the annual total building energy use (appendix 10.1)) was compared to the energy declaration (bills: 146 000 kWh) from Friskis & Svettis in Landskrona. The base case (simulation) result was 1.7 % lower than the energy declaration (bills), which only consisted of space heating demand, DHW and building electricity use (Energy Use 2016). See figure 5.1.1 below.

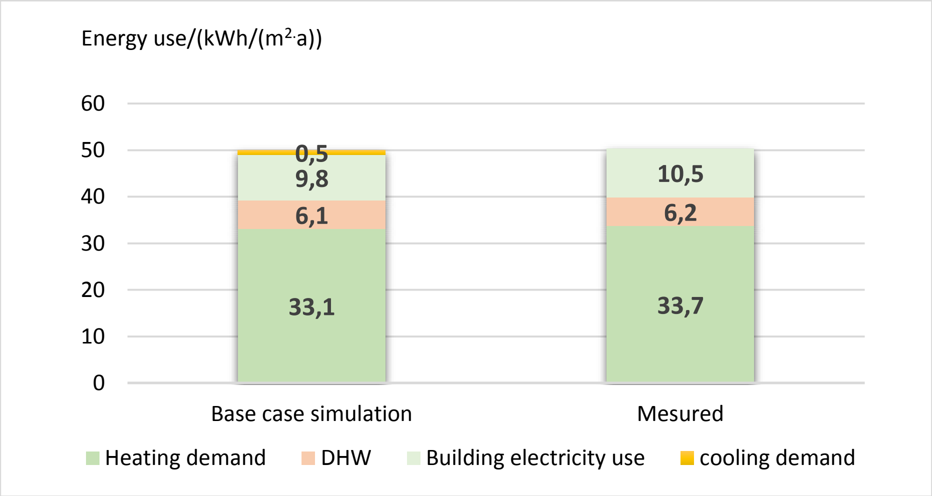


*Figure 5.1.1 Measured energy use and simulation energy use for the existing building*

The result presented in the figure and table below in scenario1 (see appendix 10.2), shows that the heating night setback strategy would reduce the heating demand by approximately 4,8%. It was considered for all further simulations and it will not be mentioned again. This means that the constant heating set point temperature is 20°C, expect for time between 21:00-06:00, when the heating temperature is 18°C. The result presented in figure 5.1.2 and table 5.1 in scenario1 (appendix 10.3), shows that with added wall insulation EPS of 20 cm thickness  the heating demand would decrease by approximately 13.8% and in scenario3 (appendix 10.4), shows that with added roof insulation EPS of 30 cm thickness respectively would reduce the heating demand by approximately 31.7%. Furthermore the results for the different parametric studies presented (the different scenarios) shows the impact of each of the proposed improvements on the heating demand in the building in order to reach the maximal redaction of energy need would reduce the heating demand by approximately 31.7%. See figure 5.1.2 below.

*Table 5.1. The annual total building energy use with different scenarios*

| Cases | Energy /kWh | Energy/(kWh/m²) | Saving/% |
|---|---|---|---|
| Base case (simulation) | 143 484 | 49.9 | 0 |
| Scenario 1 | 136 966 | 47.6 | 4.8 |
| Scenario 2 | 123505 | 43 | 13.8 |
| Scenario 3 | 98 028 | 34.1 | 31.7 |

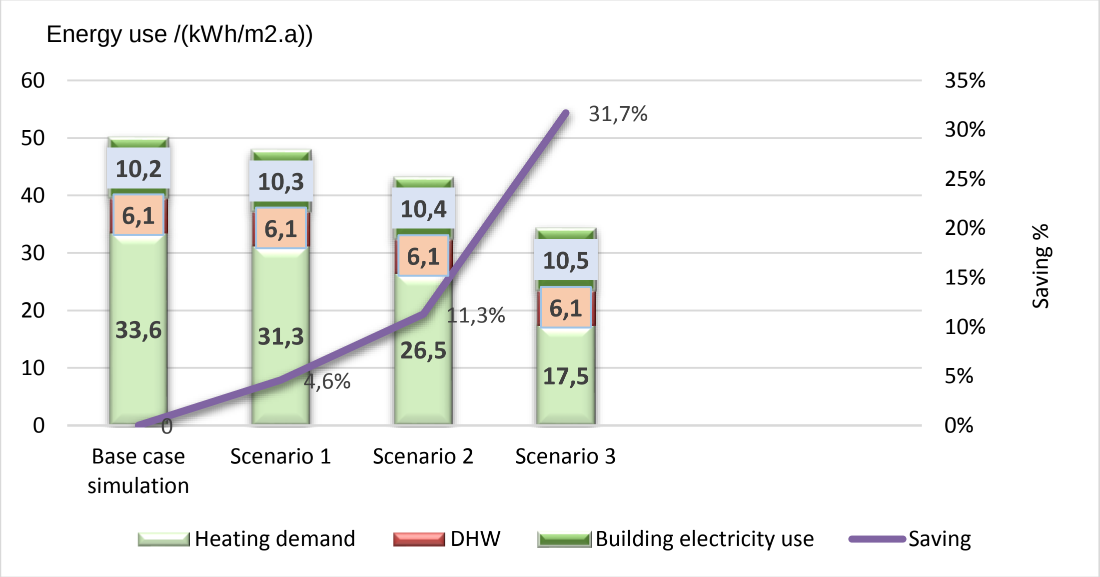


*Figure 5.1.2 Energy Use for the Building with different scenarios*

The annual total building energy use is 98 028 kWh (34, 1 kWh/m$^2$.a) Scenario 3 after improvements. The monthly building electricity need and DHW can be seen in Table 5.1.1, figure 5.1.3 and Table 5.1.2, figure 5.1.4.

*Table 5.1.1 Monthly total building electricity need (Scenario3 simulation)*

| **Electricity Need/ kWh** | | | | | |
|---|---|---|---|---|---|
| January | February | March | April | May | June |
| 10 952 | 10 442 | 10 089 | 7 687 | 6 690 | 5 910 |
| July | August | September | October | November | December |
| 5 841 | 6 139 | 5 766 | 7 617 | 9 152 | 10 579 |

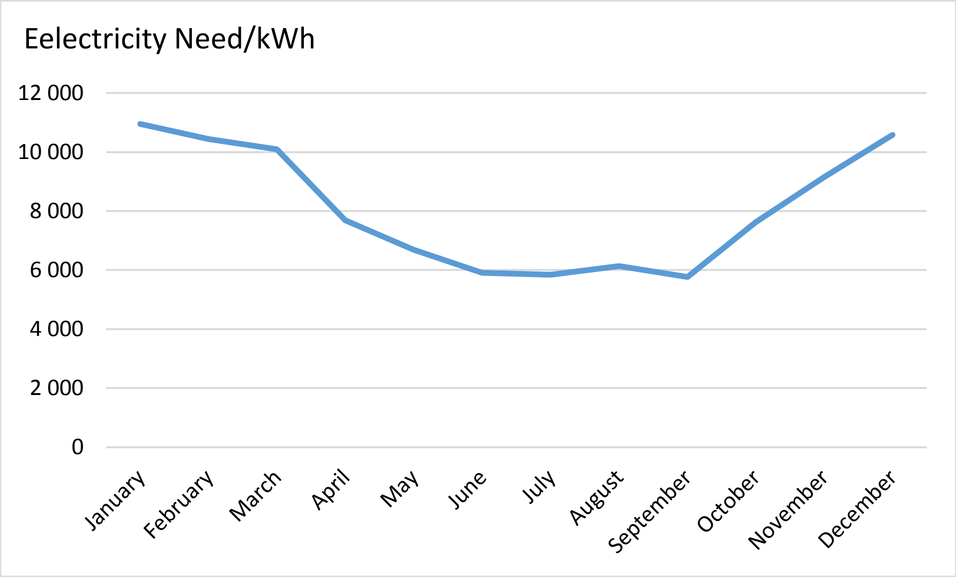


*Figure 5.1.3 Monthly total building electricity need (Scenario3 simulation)*

*Table 5.1.2 Monthly total DHW need (Scenario 3 simulation)*

| **DHW/ kWh** | | | | | |
|---|---|---|---|---|---|
| January | February | March | April | May | June |
| 1702 | 1531 | 1712 | 1609 | 1716 | 1651 |
| July | August | September | October | November | December |
| 1671 | 1716 | 1620 | 1702 | 1655 | 1667 |

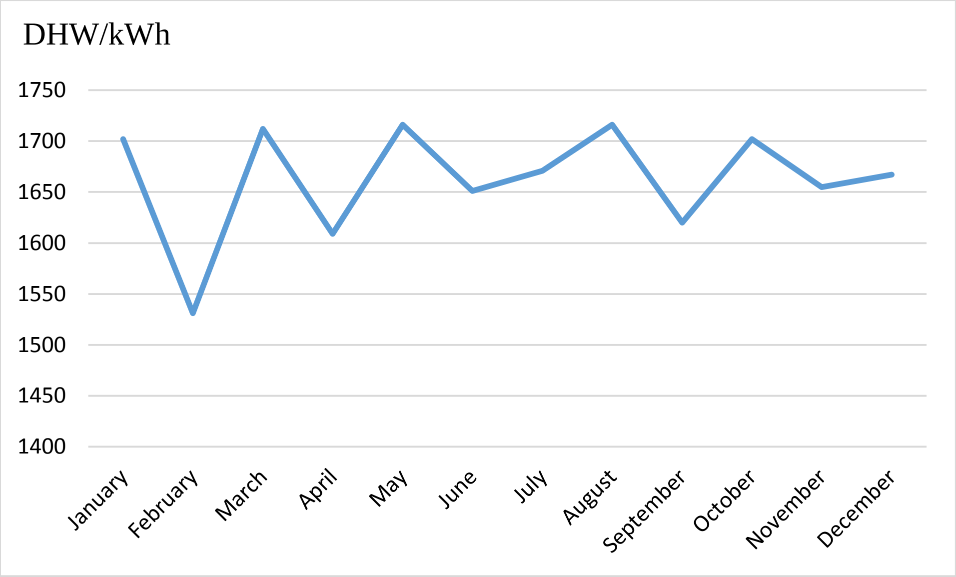


*Figure 5.1.4 Monthly total DHW need (Scenario 3 simulation)*

## 5.2 Energy output of solar electricity and thermal systems

The results of the simulations relate to energy output of building integrated solar photovoltaic and thermal systems present in table 5.2.1, figure table 5.2.1 and 5.2.2, figure 5.2.2. The annual total building electricity supply is 72200 kWh/year, while the annual use of electricity is 98 028 kWh/year.

*Table 5.2.1 Monthly total photovoltaic system supply*

| Electricity Supply/ kWh | | | | | |
|---|---|---|---|---|---|
| January | February | March | April | May | June |
| 1400 | 2200 | 5500 | 9200 | 10800 | 10900 |
| July | August | September | October | November | December |
| 10800 | 8900 | 6200 | 3900 | 1400 | 1000 |

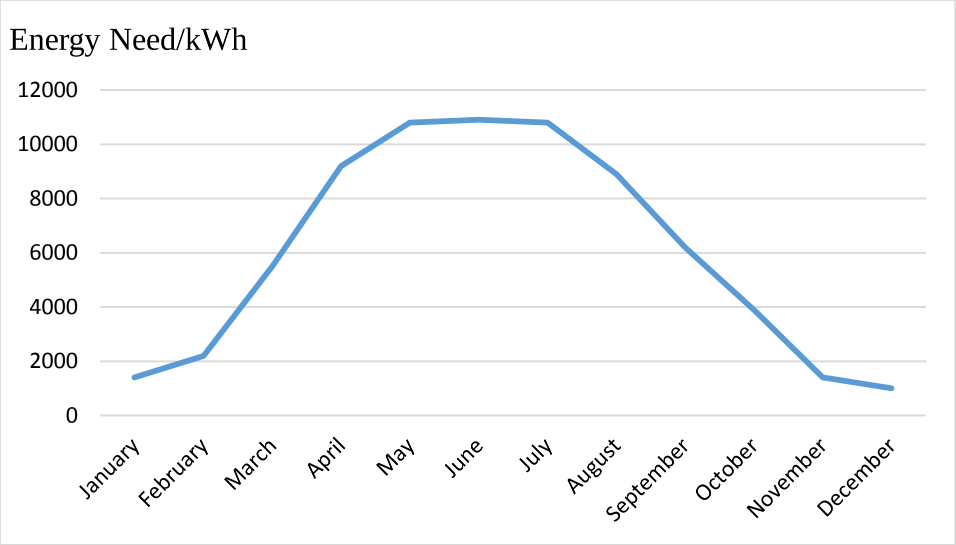


*Figure 5.2.1 Monthly total photovoltaic system supply*

*Table 5.2.2 Monthly total DHW supply*

| **DHW Supply/ kWh** | | | | | |
|---|---|---|---|---|---|
| January | February | March | April | May | June |
| 92 | 278 | 798 | 1389 | 1968 | 1882 |
| July | August | September | October | November | December |
| 1892 | 1645 | 1044 | 509 | 139 | 51 |

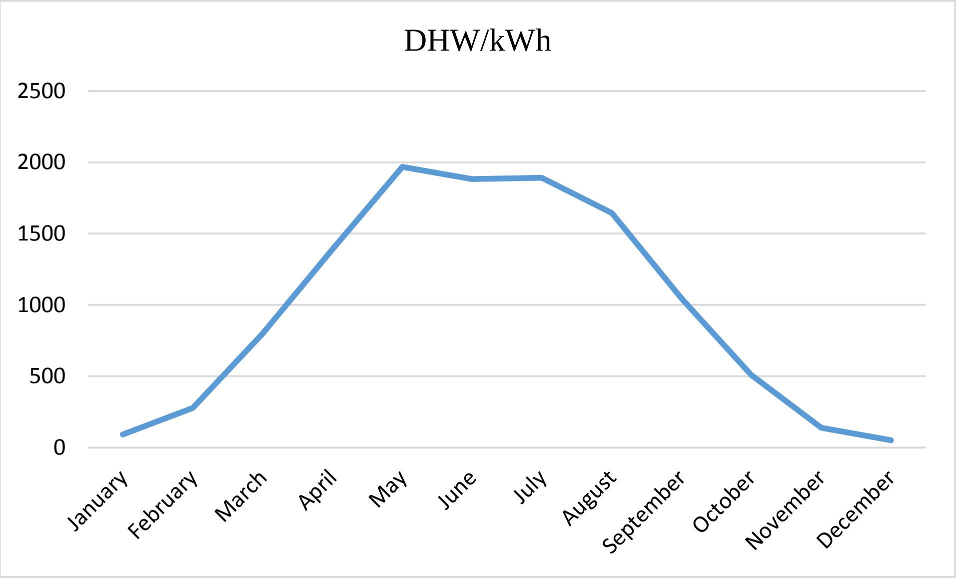


*Figure 5.2.2 Monthly total DHW supply*

According to Figure 5.2.1. The supply covers 69% of energy need i.e. the Solar Fraction, which is calculated as the proportion between the supply provided by the solar technology and the total building electricity required. As it appears, there is an oversupply during the summer months, which means that the oversupply kWh would have to be sold to the grid.

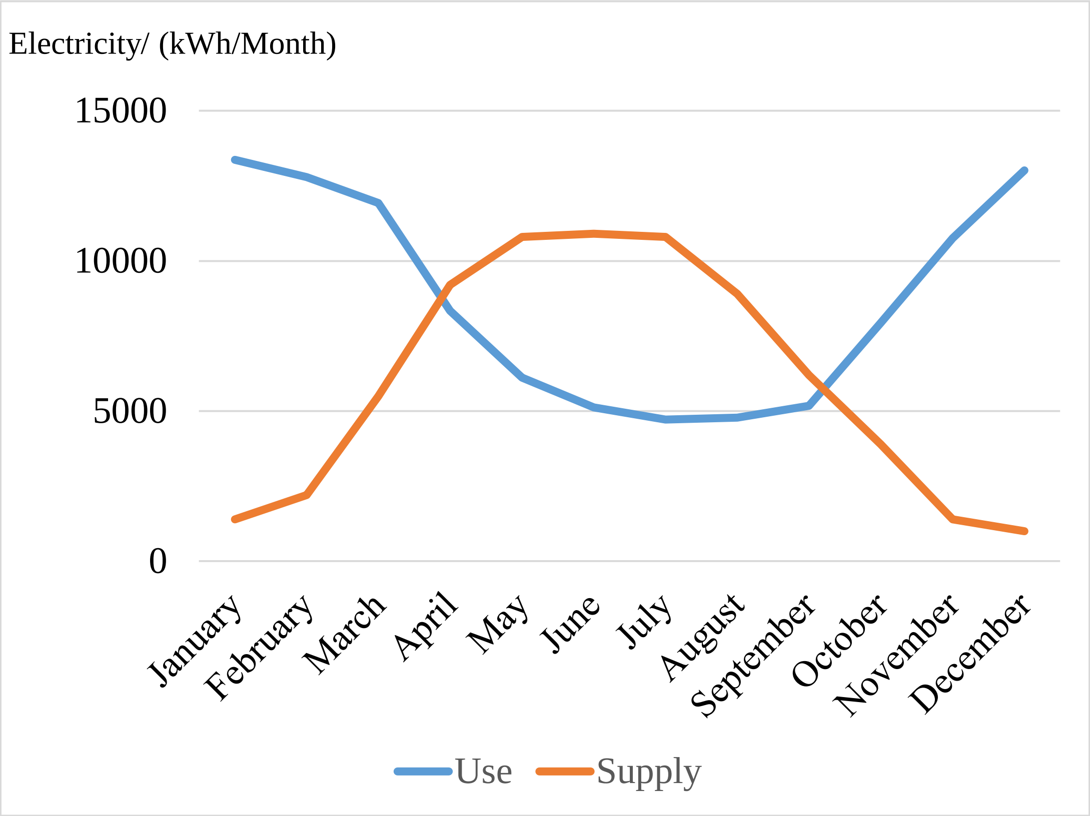


*Figure 5.2.1 Monthly total photovoltaic system supply*

The optimum conditions for solar thermal system were found to have a flow rate 0.09 kg/s and 1.3 $m^3$ solar tank with height to diameter ratio of 2. The highest solar fraction value.

According to Figure 5.2.2. The output for the total annual energy (hot water) from the solar thermal system is 11678 kWh/year, while the annual energy use, 21677 kWh/year that covers 53.8% of DHW use.

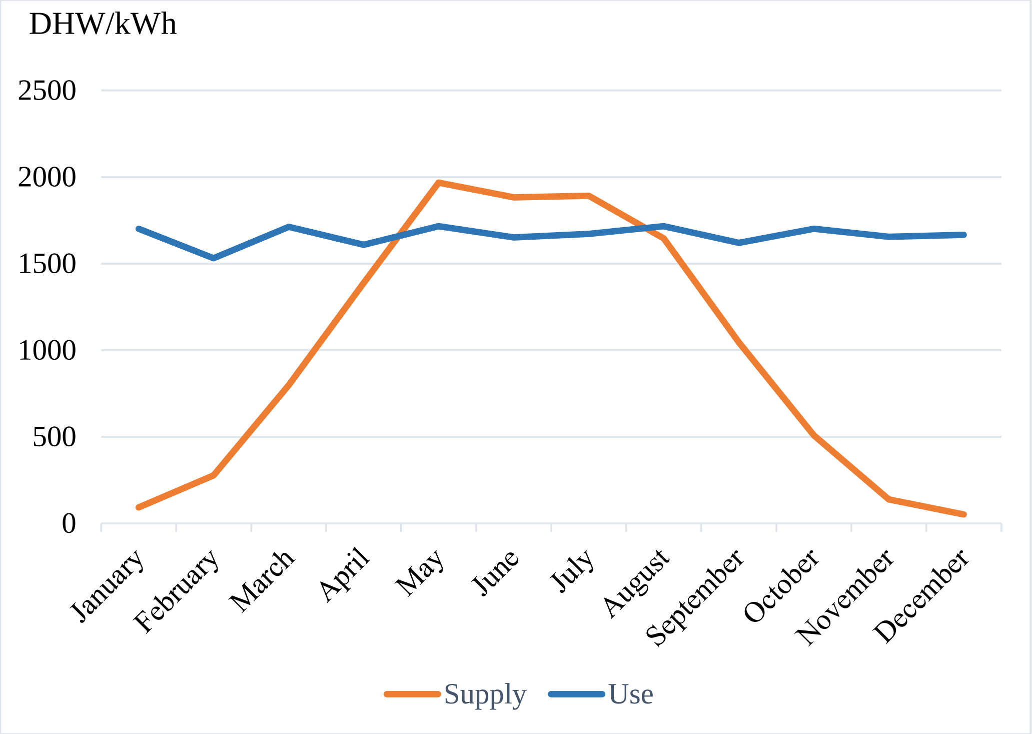


*Figure 5.2.2 Monthly total DHW supply*

The above graphs show the supply from Solar system (Combining the photovoltaic system and solar thermal energy) is 83878 kWh/year, would result in covering 85.6% of energy need energy present in table 5.2.3.

Table 5.2.3 show that the result from the retrofit will be a nearly zero energy and plus energy building

| | Energy need (kWh/year) | Supply (kWh/year) | Covering the energy need **%** |
|---|---|---|---|
| Existing case | 143 484 | **0** | **0** |
| Improved case | 98 028 | 83878 | 85.6 |

## 5.3 Life Cycle Cost

The NPV was calculated for the three scenarios alternatives (excl. PV) of improvements over 25 years, as mentioned before in 4.2.4 and compared with the NPV for the existing building referred to as base case, which included only the running costs for energy need, for 25 years. Next step was NPV calculations for scenario three combining solar system investment compared to the NPV for the existing building.

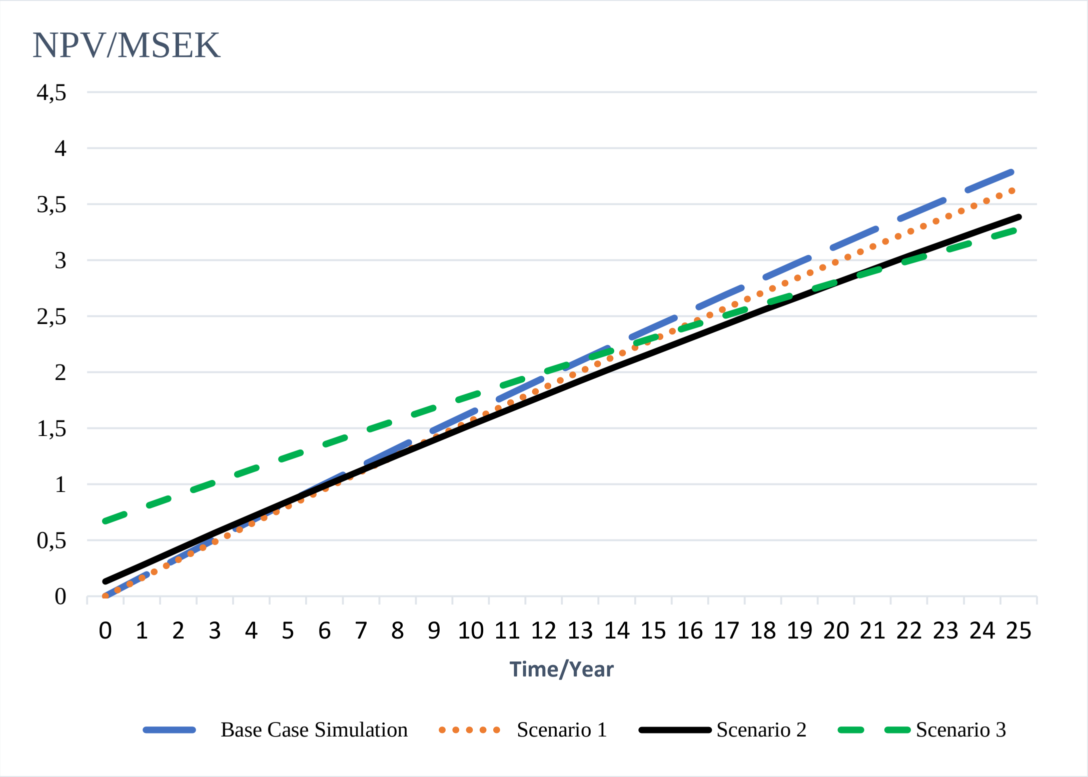


*Figure 5.3.1. NPV comparison between the existing and the improved cases over 25 years.*

Figure 5.3.1. Shows the impact of each of the proposed improvements on the LCC after a period of 25 years. Each of the changes were made progressively, gradually adding to the previous one, until the final, most profitable solution was reached.

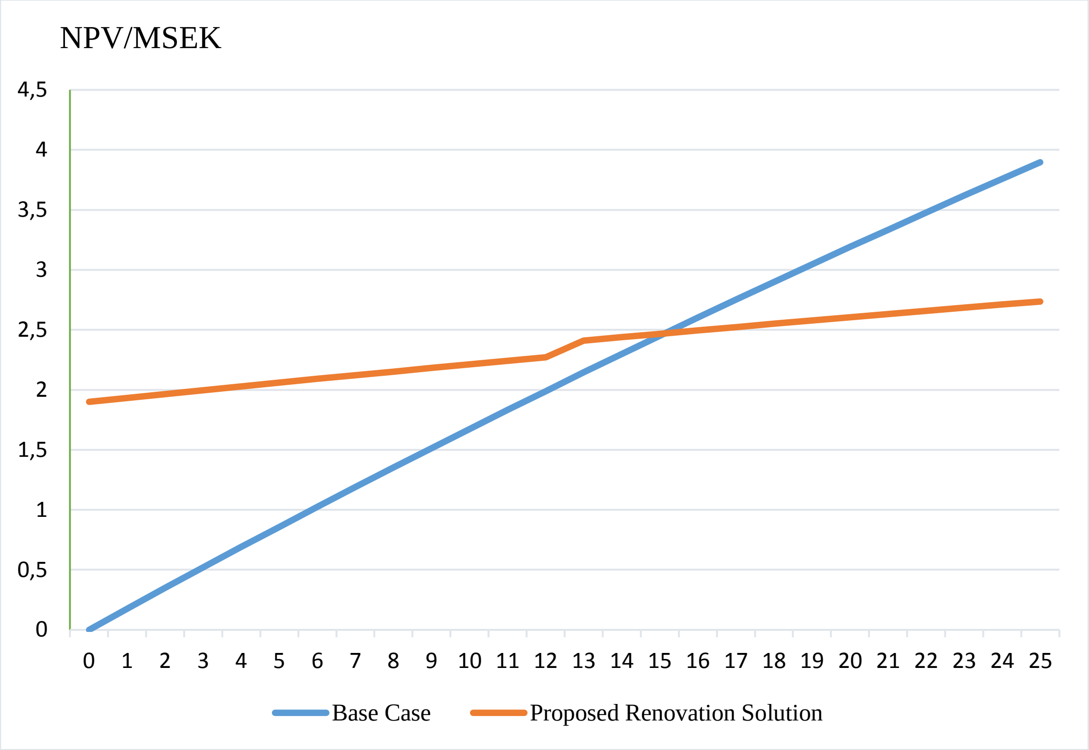


*Figure 5.3.2. NPV comparison between the existing and the improved case (Scenario 3 added PV investment) over 25 years*

According to Figure 5.3.2. NPV comparison between the existing and the improved case (Scenario 3 added PV investment) over 25 years. A total investment cost of 1.9 MSEK, compared to the existing case with renovation after 25 years. It can be seen that the for scenario three combined with solar system investment has a payback time of 15 years and total savings of 1.16 MSEK during the period of 25 years.

# 6 Discussion

Currently, space heating and cooling together with water heating are estimated to account for nearly 78% of energy use in the sports hall (Figure 5.1.1). Concerning the measures for reducing the energy use, the highest proportion (58%) of the energy is used for heating needs (Figure 5.1.1). Focusing only on the energy reduction, by applying energy-efficient measures without considering the cost required, it can be concluded that the most energy-efficient scenario is scenario 3. Obviously, it was expected to be the best scenario while it is the combination of two energy-efficient scenarios each causing a reduction in the required energy. Applying scenario 1, the total energy need was reduced from 49.9 kWh/m$^2$ kWh to 47.6 kWh/m$^2$, achieving 4.8% energy saving and the total energy consumed. Applying scenario 2, the total energy need was reduced from 49.9 kWh/m$^2$ kWh to 43 kWh/m$^2$, achieving 13.8% energy saving. The combination of all previous scenarios (Scenario 3) shows that energy demands decrease significantly according to which changes on building envelope were applied, and proved to be the most energy-efficient and economical. The major reduction can be detected in heating needs where a reduction of 48% occurs. The main reason of this effectiveness is because it managed to reduce the heating needs, which are the main source of using energy in the building, Therefore, a 31.7 % reduction on the total used energy is achieved, by applying measures on building envelope. They therefore represent the largest opportunity to reduce buildings energy use, improve energy efficiency and reduce $CO_2$ emissions.
The minimized energy, that has to be covered by renewable energy sources, is 83878 kWh/year. So, the renewable energy technologies in total supply approximately 85.6% of the quantity of the energy used and it can be observed that the PV system supply the highest quantity of energy during April to September. The maximum energy output was detected in May, because the solar irradiance is very high and the ambient temperature is not so high. Thus, the PVs have the maximum efficiency. It can be seen from the Figure 5.3.1. that by renovating the roof, a significant reduction in both the energy use and LCC can be achieved. More specifically, the biggest financial benefit was achieved with this measure, saving 1.16 million SEK. This is mainly because the thermal losses of the building have decreased significantly and therefore, the operational costs for heating are much lower and applying renewable energy sources. There is a thing that is worthy to mention that renewable energy sources cover a large part of energy demand for cooling, appliances and lighting today in the building.

According to Figure 5.3.2. NPV comparison between the existing and the improved case (Scenario 3 added PV investment) over 25 years, a total investment cost of 1.9 MSEK, compared to the existing case with renovation after 25 years, would result in savings of 1.16 MSEK.

Nevertheless, the PV panels cannot function every hour during a day due to different daily weather conditions. For this reason, it is necessary to have grid purchases.
To evaluate precisely the real energy consumption of a given building, measuring precisely consumptions, temperatures, and the impact of each occupier on the energy use over a year is the most adapted method. A compromise can be found between this and the presented energy audit methodology, with namely several visits onsite, infrared measurements, light and temperature probes placed over several days, more advanced and detailed occupier interviews, etc.

The author has studied the described measures due to that certain measures cannot be performed as windows replacement or upgrading of AHUs because they have been recently implemented and not feasible economically. It would have been desirable to insulate the ground floor but it is not possible for practical reasons. The daylight analysis was not treated for this dissertation in the sports hall. Moisture analysis for the sports hall was not performed. For the solar energy assessment, the effect of snow was neglected. Occupants were collected in different periods. It is impossible to predict future financial rates and the prices are fluctuated. This result in uncertainties in the LCC calculations.

# 7 Conclusions

Enhancement of the envelope of the building may reduce the heat demand and significantly reduce the annual operating costs. In addition, it also created a better environment reducing carbon dioxide emissions. The choice of energy saving measures must be evaluated economically to determine if they are beneficial to the building. By taking this into consideration, realistic energy-saving measures can be identified.

In general, the renewable energy system (PV and solar collectors) can cover all building energy needs for building electricity and hot water, from April to September, and the electricity surplus can be sold to the grid. But during the other months, most of the energy is delivered by the grid. Therefore, energy supply from renewable energy sources covers a smaller amount of building energy use. After the best scenario 3 (energy-efficient measures combined with renewable energy sources), the retrofitting of the current sports hall will be achieved to become a nearly net zero and plus-energy building (the renewable energy technologies in total supply approximately 85.6% of the quantity of the energy need).

Measures can most likely be actively taken to reduce the energy use by many sports halls across the country in a manner that does not compromise on the quality of space, achieving the highest energy supply from renewable energy sources). Solar energy can reduce the reliance on the electric grid and reduce the energy cost incurred by the sport halls. Apart from the installation of the solar power system, sunlight can be used to light and heat the sport hall depending on the envelope of the sport hall. Once converted to electricity, sunlight can be used to power 85.6% of energy need that use in the most of the appliances and systems in a sport hall. The study on a selected sports hall shows that with proper conditioning and structuring of a sports hall, solar energy can be relied on as an exercise of green energy for a sport halls.

Photovoltaic solar energy has several advantages making it one of the most promising source of renewable energy. It is non-polluting, has no moving parts that could break down, requires little maintenance and no supervision, and has a life of 20-30 years with low running costs. It is especially unique because no large-scale installation is required. In that sense it has advantages over wind power, thermal solar power and hydropower.

Finally, some energy will still be required for daily operation of a building, even if the most energy efficient measures are applied and all economically interesting measures are taken to reduce energy use. These improvements are nevertheless seen as an expense of time, resource and economic point of view. In addition, a very accurate evaluation of the energy consumption is mandatory for evaluating the building's retrofitting potential. The interest in this energy use method must then be limited to analyzing the equipment quality and its use, pointing out default values, errors or low-performance equipment, and to emphasize what consumptions are considered to be alarming in comparison to construction.

This report contains recommendations for saving energy in literature review. These tips can help manufacturers and owners to reduce the amount of heat energy consumption. By using energy-efficient envelopes and equipment, it is possible to save a significant amount of energy without losing comfort and reducing as much amount of waste energy.

# 8 Further Research

The mentioned approaches are not unique and it has been seen that results can be affected by variation in input data. For a higher level of accuracy in the results, more complex and detailed measurements and calculations would have to be used. A study is nevertheless limited by time and resources constraints. The approach presented here aims to give a first understanding of a building in terms of energy use and retrofitting potentiality. This approach is to be seen as a first step which can lead to an entire energy retrofitting project. For energy saving of sports hall, further research is proposed: Deeper studies can investigate different renovation solutions regarding new building design technologies and artificial intelligence. Heat and moisture supply in hard physical training could be investigated specifically for different exercise activities.

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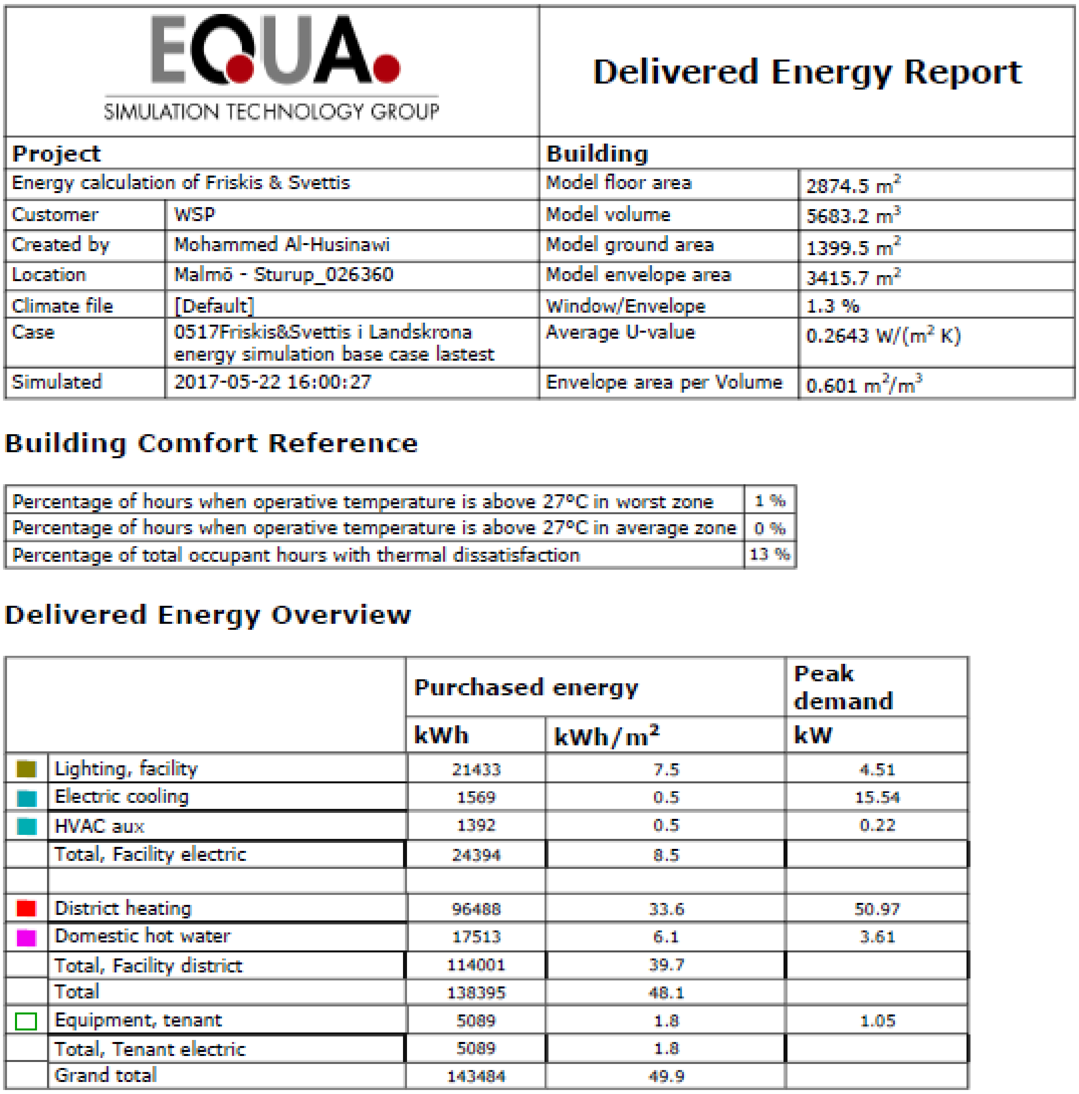
# 10 Appendix.

## 10.1 Base case simulation



EQUA
SIMULATION TECHNOLOGY GROUP

**Delivered Energy Report**

| **Project** | | **Building** | |
|---|---|---|---|
| Energy calculation of Friskis & Svettis | | Model floor area | 2874.5 m² |
| Customer | WSP | Model volume | 5683.2 m³ |
| Created by | Mohammed Al-Husinawi | Model ground area | 1399.5 m² |
| Location | Malmö - Sturup_026360 | Model envelope area | 3415.7 m² |
| Climate file | [Default] | Window/Envelope | 1.3 % |
| Case | 0517Friskis&Svettis i Landskrona energy simulation base case lastest | Average U-value | 0.2643 W/(m² K) |
| Simulated | 2017-05-22 16:00:27 | Envelope area per Volume | 0.601 m²/m³ |

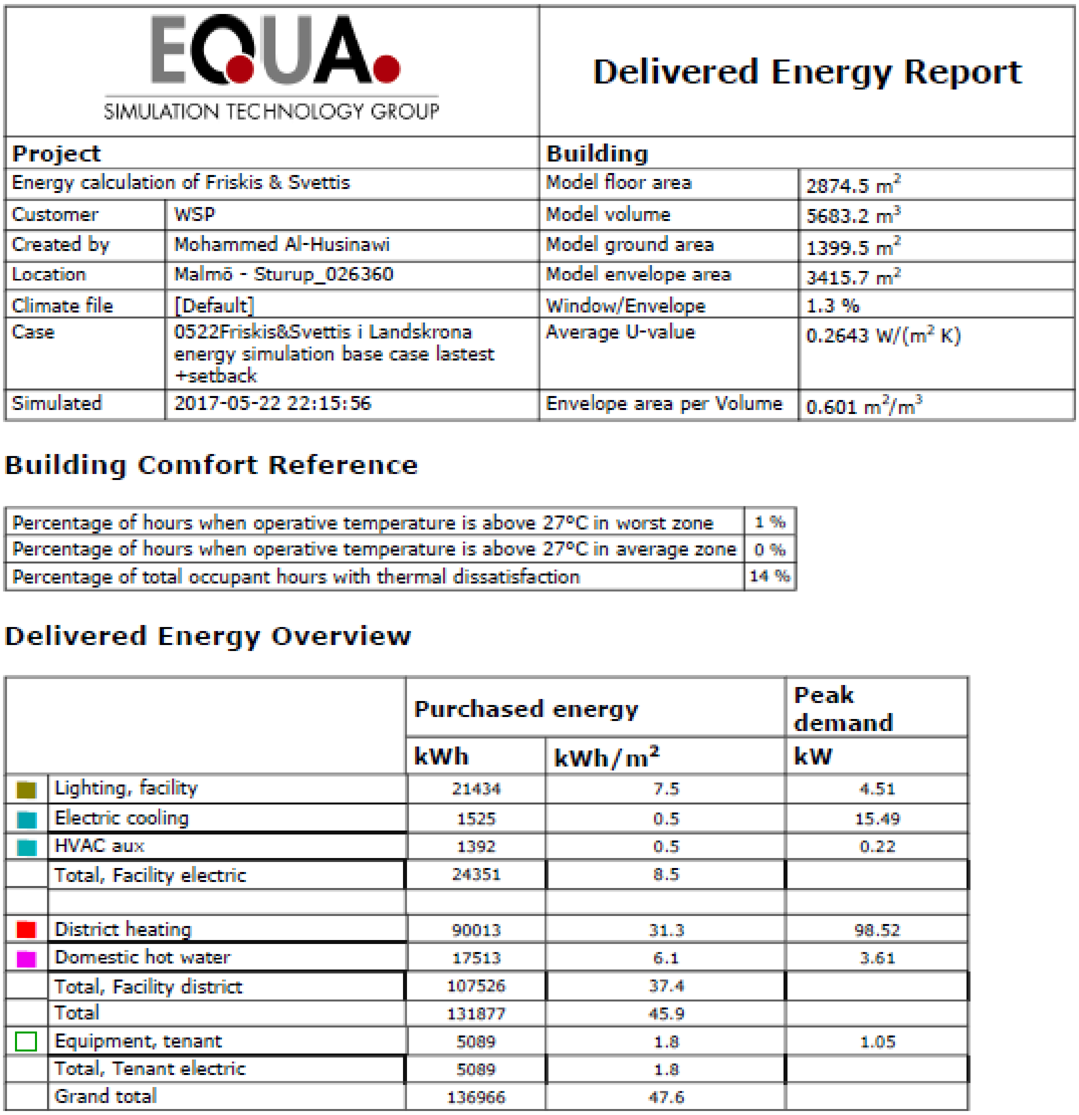
**Building Comfort Reference**

| | |
|---|---|
| Percentage of hours when operative temperature is above 27°C in worst zone | 1 % |
| Percentage of hours when operative temperature is above 27°C in average zone | 0 % |
| Percentage of total occupant hours with thermal dissatisfaction | 13 % |

**Delivered Energy Overview**

| | | **Purchased energy** | | **Peak demand** |
|---|---|---|---|---|
| | | **kWh** | **kWh/m²** | **kW** |
| 🟫 | Lighting, facility | 21433 | 7.5 | 4.51 |
| 🟦 | Electric cooling | 1569 | 0.5 | 15.54 |
| 🟦 | HVAC aux | 1392 | 0.5 | 0.22 |
| | Total, Facility electric | 24394 | 8.5 | |
| | | | | |
| 🟥 | District heating | 96488 | 33.6 | 50.97 |
| 🟪 | Domestic hot water | 17513 | 6.1 | 3.61 |
| | Total, Facility district | 114001 | 39.7 | |
| | Total | 138395 | 48.1 | |
| ☐ | Equipment, tenant | 5089 | 1.8 | 1.05 |
| | Total, Tenant electric | 5089 | 1.8 | |
| | Grand total | 143484 | 49.9 | |

## 10.2 Scenario 1



EQUA
SIMULATION TECHNOLOGY GROUP

### Delivered Energy Report

| **Project** | | **Building** | |
|---|---|---|---|
| Energy calculation of Friskis & Svettis | | Model floor area | 2874.5 m$^2$ |
| Customer | WSP | Model volume | 5683.2 m$^3$ |
| Created by | Mohammed Al-Husinawi | Model ground area | 1399.5 m$^2$ |
| Location | Malmö - Sturup_026360 | Model envelope area | 3415.7 m$^2$ |
| Climate file | [Default] | Window/Envelope | 1.3 % |
| Case | 0522Friskis&Svettis i Landskrona energy simulation base case lastest +setback | Average U-value | 0.2643 W/(m$^2$ K) |
| Simulated | 2017-05-22 22:15:56 | Envelope area per Volume | 0.601 m$^2$/m$^3$ |

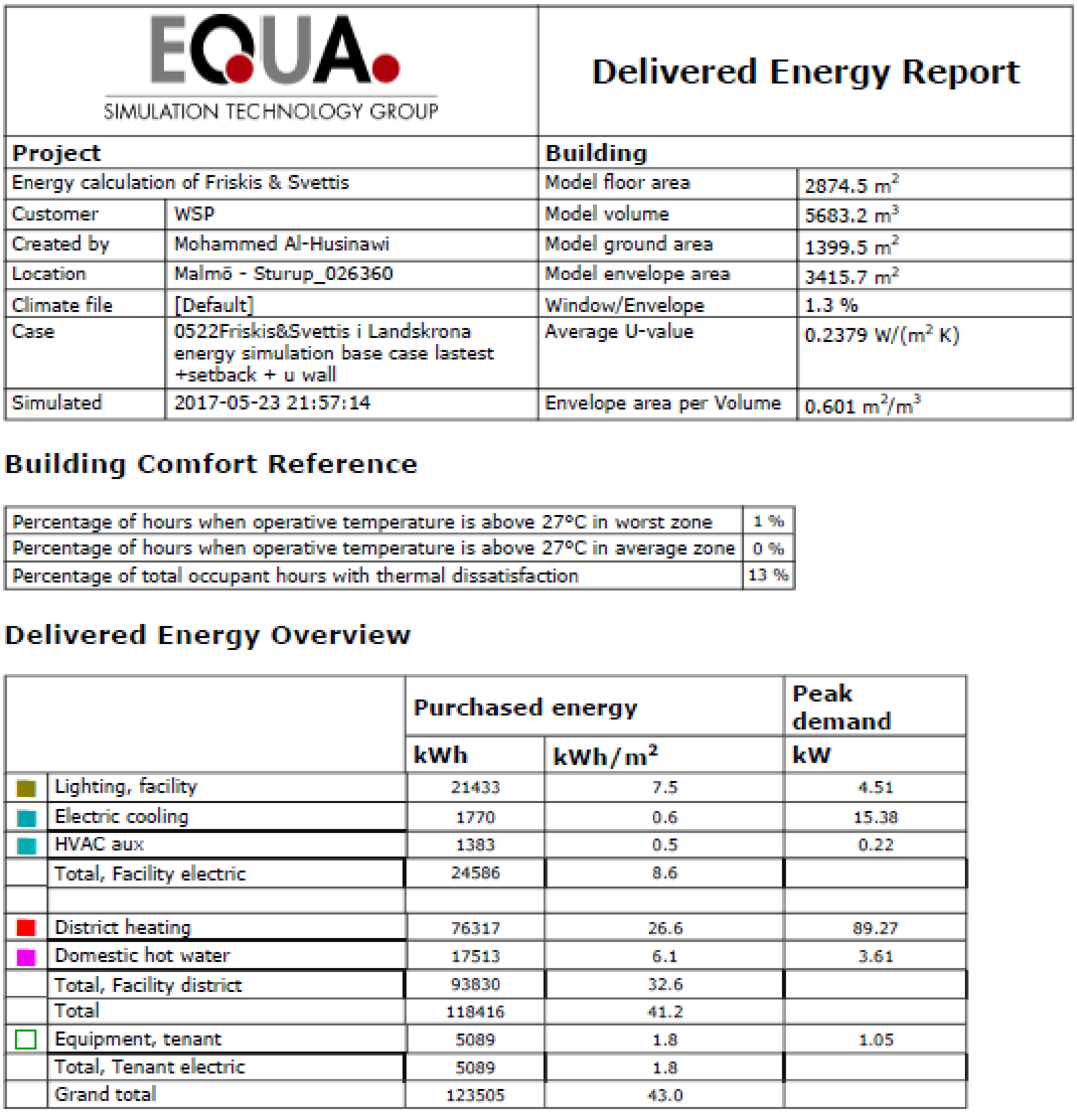
### Building Comfort Reference

| | |
|---|---|
| Percentage of hours when operative temperature is above 27°C in worst zone | 1 % |
| Percentage of hours when operative temperature is above 27°C in average zone | 0 % |
| Percentage of total occupant hours with thermal dissatisfaction | 14 % |

### Delivered Energy Overview

| | | **Purchased energy** | | **Peak demand** |
|---|---|---|---|---|
| | | **kWh** | **kWh/m²** | **kW** |
| 🟫 | Lighting, facility | 21434 | 7.5 | 4.51 |
| 🟦 | Electric cooling | 1525 | 0.5 | 15.49 |
| 🟦 | HVAC aux | 1392 | 0.5 | 0.22 |
| | Total, Facility electric | 24351 | 8.5 | |
| | | | | |
| 🟥 | District heating | 90013 | 31.3 | 98.52 |
| 🟪 | Domestic hot water | 17513 | 6.1 | 3.61 |
| | Total, Facility district | 107526 | 37.4 | |
| | Total | 131877 | 45.9 | |
| ☐ | Equipment, tenant | 5089 | 1.8 | 1.05 |
| | Total, Tenant electric | 5089 | 1.8 | |
| | Grand total | 136966 | 47.6 | |

# 10.3 Scenario 2



EQUA SIMULATION TECHNOLOGY GROUP

## Delivered Energy Report

| **Project** | | **Building** | |
|---|---|---|---|
| Energy calculation of Friskis & Svettis | | Model floor area | 2874.5 $m^2$ |
| Customer | WSP | Model volume | 5683.2 $m^3$ |
| Created by | Mohammed Al-Husinawi | Model ground area | 1399.5 $m^2$ |
| Location | Malmö - Sturup_026360 | Model envelope area | 3415.7 $m^2$ |
| Climate file | [Default] | Window/Envelope | 1.3 % |
| Case | 0522Friskis&Svettis i Landskrona energy simulation base case lastest +setback + u wall | Average U-value | 0.2379 W/($m^2$ K) |
| Simulated | 2017-05-23 21:57:14 | Envelope area per Volume | 0.601 $m^2/m^3$ |

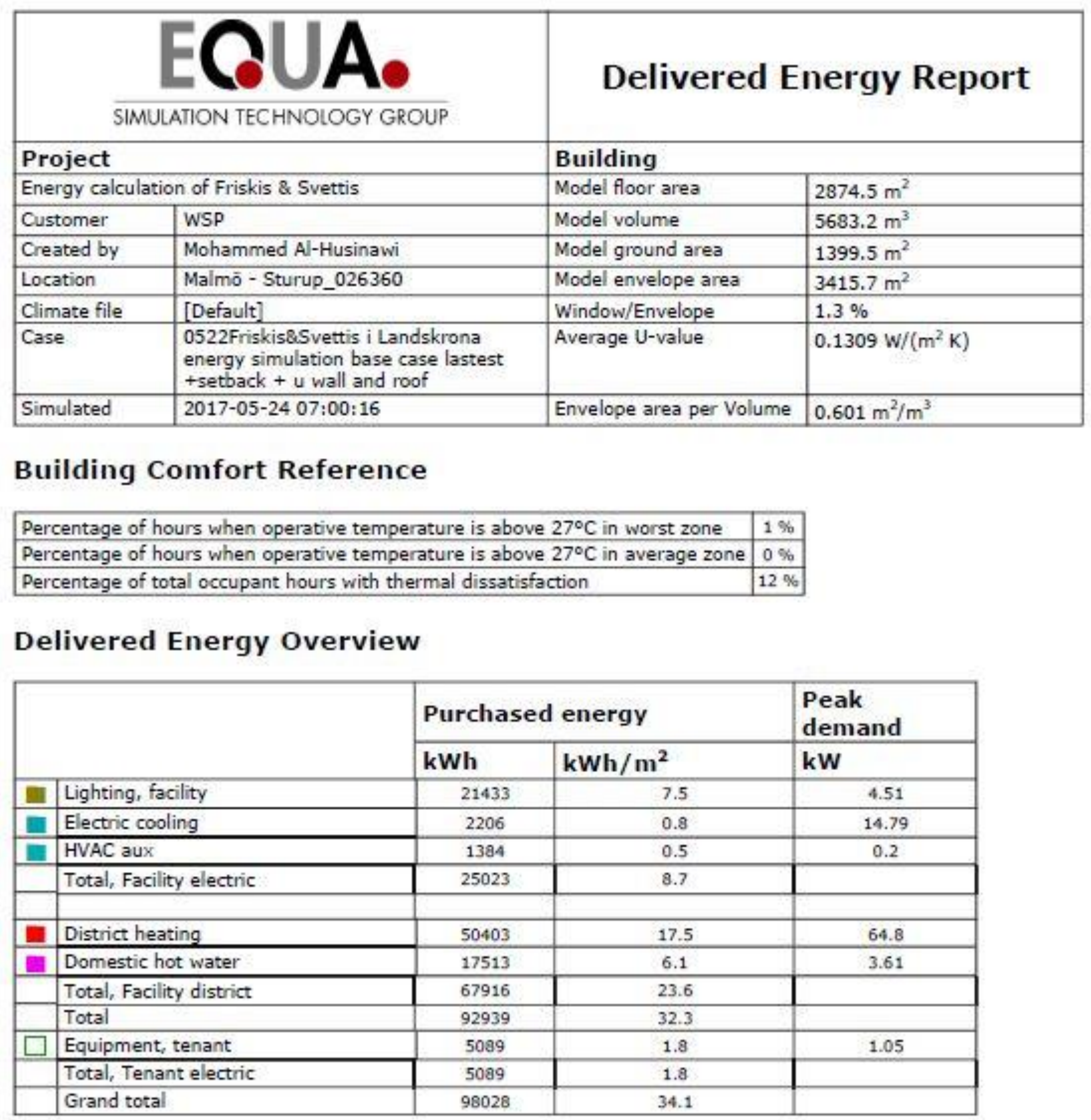
### Building Comfort Reference

| | |
|---|---|
| Percentage of hours when operative temperature is above 27°C in worst zone | 1 % |
| Percentage of hours when operative temperature is above 27°C in average zone | 0 % |
| Percentage of total occupant hours with thermal dissatisfaction | 13 % |

### Delivered Energy Overview

| | | **Purchased energy** | | **Peak demand** |
|---|---|---|---|---|
| | | **kWh** | **kWh/m²** | **kW** |
| 🟨 | Lighting, facility | 21433 | 7.5 | 4.51 |
| 🟦 | Electric cooling | 1770 | 0.6 | 15.38 |
| 🟦 | HVAC aux | 1383 | 0.5 | 0.22 |
| | Total, Facility electric | 24586 | 8.6 | |
| | | | | |
| 🟥 | District heating | 76317 | 26.6 | 89.27 |
| 🟪 | Domestic hot water | 17513 | 6.1 | 3.61 |
| | Total, Facility district | 93830 | 32.6 | |
| | Total | 118416 | 41.2 | |
| □ | Equipment, tenant | 5089 | 1.8 | 1.05 |
| | Total, Tenant electric | 5089 | 1.8 | |
| | Grand total | 123505 | 43.0 | |

## 10.4 Scenario 3



EQUA. SIMULATION TECHNOLOGY GROUP

**Delivered Energy Report**

| **Project** | | **Building** | |
|---|---|---|---|
| Energy calculation of Friskis & Svettis | | Model floor area | 2874.5 m$^2$ |
| Customer | WSP | Model volume | 5683.2 m$^3$ |
| Created by | Mohammed Al-Husinawi | Model ground area | 1399.5 m$^2$ |
| Location | Malmö - Sturup_026360 | Model envelope area | 3415.7 m$^2$ |
| Climate file | [Default] | Window/Envelope | 1.3 % |
| Case | 0522Friskis&Svettis i Landskrona energy simulation base case lastest +setback + u wall and roof | Average U-value | 0.1309 W/(m$^2$ K) |
| Simulated | 2017-05-24 07:00:16 | Envelope area per Volume | 0.601 m$^2$/m$^3$ |

**Building Comfort Reference**

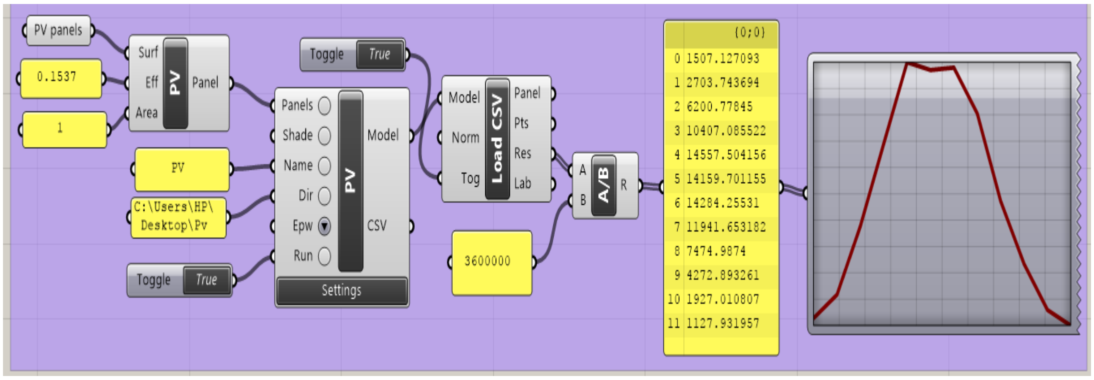
| | |
|---|---|
| Percentage of hours when operative temperature is above 27°C in worst zone | 1 % |
| Percentage of hours when operative temperature is above 27°C in average zone | 0 % |
| Percentage of total occupant hours with thermal dissatisfaction | 12 % |

**Delivered Energy Overview**

| | | **Purchased energy** | | **Peak demand** |
|---|---|---|---|---|
| | | **kWh** | **kWh/m$^2$** | **kW** |
| 🟫 | Lighting, facility | 21433 | 7.5 | 4.51 |
| 🟦 | Electric cooling | 2206 | 0.8 | 14.79 |
| 🟦 | HVAC aux | 1384 | 0.5 | 0.2 |
| | Total, Facility electric | 25023 | 8.7 | |
| | | | | |
| 🟥 | District heating | 50403 | 17.5 | 64.8 |
| 🟪 | Domestic hot water | 17513 | 6.1 | 3.61 |
| | Total, Facility district | 67916 | 23.6 | |
| | Total | 92939 | 32.3 | |
| ☐ | Equipment, tenant | 5089 | 1.8 | 1.05 |
| | Total, Tenant electric | 5089 | 1.8 | |
| | Grand total | 98028 | 34.1 | |

## 10.5 Production data script for photovoltaic system.

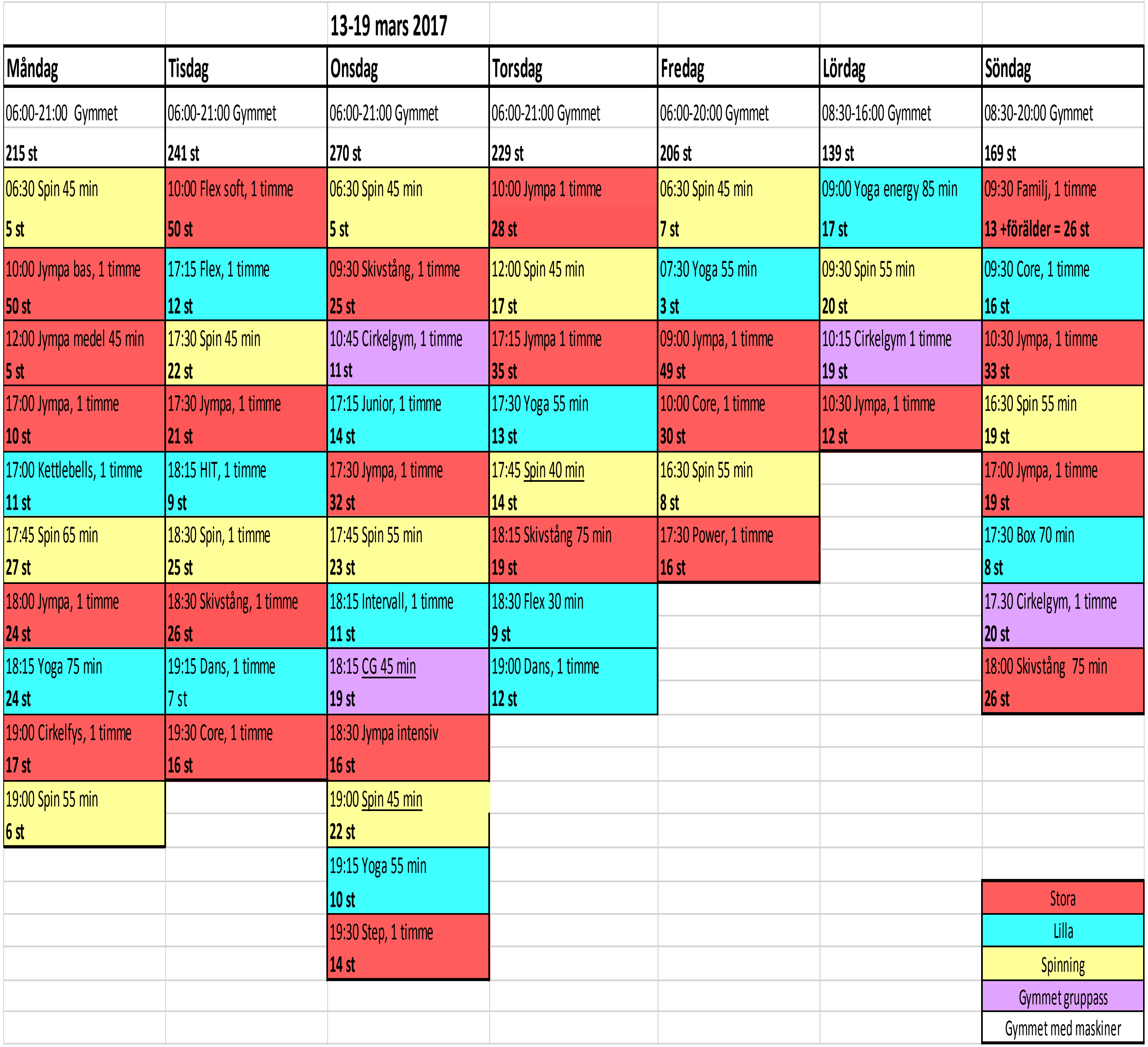
The PV component is connected to PV panel which is defined by Brep panel to enter the area of PV and efficiency. PV component is also connected to Toggle to run simulation and load CSV to load the results. Use the quick graph to see production during the year.



```
             {0;0}
 0 1507.127093
 1 2703.743694
 2 6200.77845
 3 10407.085522
 4 14557.504156
 5 14159.701155
 6 14284.25531
 7 11941.653182
 8 7474.9874
 9 4272.893261
10 1927.010807
11 1127.931957
```

## 10.6 The human activity

Table below presents the number of people and how long the sessions are in and which rooms they are.



13-19 mars 2017

| Måndag | Tisdag | Onsdag | Torsdag | Fredag | Lördag | Söndag |
|---|---|---|---|---|---|---|
| 06:00-21:00 Gymmet | 06:00-21:00 Gymmet | 06:00-21:00 Gymmet | 06:00-21:00 Gymmet | 06:00-20:00 Gymmet | 08:30-16:00 Gymmet | 08:30-20:00 Gymmet |
| **215 st** | **241 st** | **270 st** | **229 st** | **206 st** | **139 st** | **169 st** |
| 🟨 06:30 Spin 45 min<br>**5 st** | 🟥 10:00 Flex soft, 1 timme<br>**50 st** | 🟨 06:30 Spin 45 min<br>**5 st** | 🟥 10:00 Jympa 1 timme<br>**28 st** | 🟨 06:30 Spin 45 min<br>**7 st** | 🟦 09:00 Yoga energy 85 min<br>**17 st** | 🟥 09:30 Familj, 1 timme<br>**13 +förälder = 26 st** |
| 🟥 10:00 Jympa bas, 1 timme<br>**50 st** | 🟦 17:15 Flex, 1 timme<br>**12 st** | 🟥 09:30 Skivstång, 1 timme<br>**25 st** | 🟨 12:00 Spin 45 min<br>**17 st** | 🟦 07:30 Yoga 55 min<br>**3 st** | 🟨 09:30 Spin 55 min<br>**20 st** | 🟦 09:30 Core, 1 timme<br>**16 st** |
| 🟥 12:00 Jympa medel 45 min<br>**5 st** | 🟨 17:30 Spin 45 min<br>**22 st** | 🟪 10:45 Cirkelgym, 1 timme<br>**11 st** | 🟥 17:15 Jympa 1 timme<br>**35 st** | 🟥 09:00 Jympa, 1 timme<br>**49 st** | 🟪 10:15 Cirkelgym 1 timme<br>**19 st** | 🟥 10:30 Jympa, 1 timme<br>**33 st** |
| 🟥 17:00 Jympa, 1 timme<br>**10 st** | 🟥 17:30 Jympa, 1 timme<br>**21 st** | 🟦 17:15 Junior, 1 timme<br>**14 st** | 🟦 17:30 Yoga 55 min<br>**13 st** | 🟥 10:00 Core, 1 timme<br>**30 st** | 🟥 10:30 Jympa, 1 timme<br>**12 st** | 🟨 16:30 Spin 55 min<br>**19 st** |
| 🟦 17:00 Kettlebells, 1 timme<br>**11 st** | 🟦 18:15 HIT, 1 timme<br>**9 st** | 🟥 17:30 Jympa, 1 timme<br>**32 st** | 🟨 17:45 Spin 40 min<br>**14 st** | 🟨 16:30 Spin 55 min<br>**8 st** | | 🟥 17:00 Jympa, 1 timme<br>**19 st** |
| 🟨 17:45 Spin 65 min<br>**27 st** | 🟨 18:30 Spin, 1 timme<br>**25 st** | 🟨 17:45 Spin 55 min<br>**23 st** | 🟥 18:15 Skivstång 75 min<br>**19 st** | 🟥 17:30 Power, 1 timme<br>**16 st** | | 🟦 17:30 Box 70 min<br>**8 st** |
| 🟥 18:00 Jympa, 1 timme<br>**24 st** | 🟥 18:30 Skivstång, 1 timme<br>**26 st** | 🟦 18:15 Intervall, 1 timme<br>**11 st** | 🟦 18:30 Flex 30 min<br>**9 st** | | | 🟪 17.30 Cirkelgym, 1 timme<br>**20 st** |
| 🟦 18:15 Yoga 75 min<br>**24 st** | 🟦 19:15 Dans, 1 timme<br>7 st | 🟪 18:15 CG 45 min<br>**19 st** | 🟦 19:00 Dans, 1 timme<br>**12 st** | | | 🟥 18:00 Skivstång 75 min<br>**26 st** |
| 🟥 19:00 Cirkelfys, 1 timme<br>**17 st** | 🟥 19:30 Core, 1 timme<br>**16 st** | 🟥 18:30 Jympa intensiv<br>**16 st** | | | | |
| 🟨 19:00 Spin 55 min<br>**6 st** | | 🟨 19:00 Spin 45 min<br>**22 st** | | | | |
| | | 🟦 19:15 Yoga 55 min<br>**10 st** | | | | |
| | | 🟥 19:30 Step, 1 timme<br>**14 st** | | | | |

| | |
|---|---|
| 🟥 | Stora |
| 🟦 | Lilla |
| 🟨 | Spinning |
| 🟪 | Gymmet gruppass |
| ⬜ | Gymmet med maskiner |

## 10.7 Air flow protocol

Measurement of partial flow air flow for supply air and exhaust air. The information is from Skanska (contact person: Joakim Bentsen).

| Room No. | Room name | Supply air flow/(l/s) Calculated | Supply air flow/(l/s) Kept | Number of measure | Exhaust air flow/(l/s) Calculated | Exhaust air flow/(l/s) Kept |
|---|---|---|---|---|---|---|
| 1 | Skor | | | | 35 | 36 |
| 2 | WC | | | | 15 | 13 |
| 3 | Lokal | 40 | 40 | 2 | 40 | 38 |
| 4 | Invänt. 1 | 150 | 151 | 2 | | |
| 5 | Invänt. 2 | 250 | 252 | 2 | | |
| 6 | CAFE/SITT | 150 | 150 | 2 | | |
| 7 | CAFE/REC | 30 | 30 | 2 | | |
| 8 | HWC | | | 2 | 25 | 26 |
| 9 | Penttry | | | | 35 | 36 |
| 10 | Jympa 2 | 250-1050 | 1052 | 4 | 250-1050 | 1051 |
| 11 | Förråd | | | | 20 | 20 |
| 12 | Funk. | 40 | 40 | 2 | 40 | 40 |
| 13 | Exp. | 40 | 40 | 2 | 40 | 40 |
| 14 | Barn rum | 20 | 20 | 2 | 20 | 20 |
| 15 | Gym1 | 300-1200 | 1203 | 4 | 450-2100 | 2100 |
| 16 | Gym2 | 150-500 | 503 | 4 | | |
| 17 | Jymp 1 | 450-1800 | 1806 | 4 | 450-1800 | 1807 |
| 18 | Spinning | 300-1750 | 1754 | 4 | 300-1750 | 1752 |
| 19 | Städ | | | | 30 | 31 |
| 20 | ELC | | | | 15 | 15 |
| 21 | WC | | | | 15 | 15 |
| 22 | WC | | | | 15 | 15 |
| 23 | WC | | | | 15 | 15 |
| 24 | WC | | | | 15 | 15 |
| 25 | WC | | | | 15 | 14 |
| 26 | OMKL.Herr | 270 | 274 | | | |
| 27 | OMKL, Dam | 270 | 272 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | Ducsh Herr | | | | 240 | 242 |
| 29 | Ducsh Dam | | | | 240 | 243 |
| 30 | WC | | | | 15 | 15 |
| 31 | WC | | | | 15 | 15 |
| | | | | | | 15 |
| | Sum | | 7587 | | | 7629 |

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