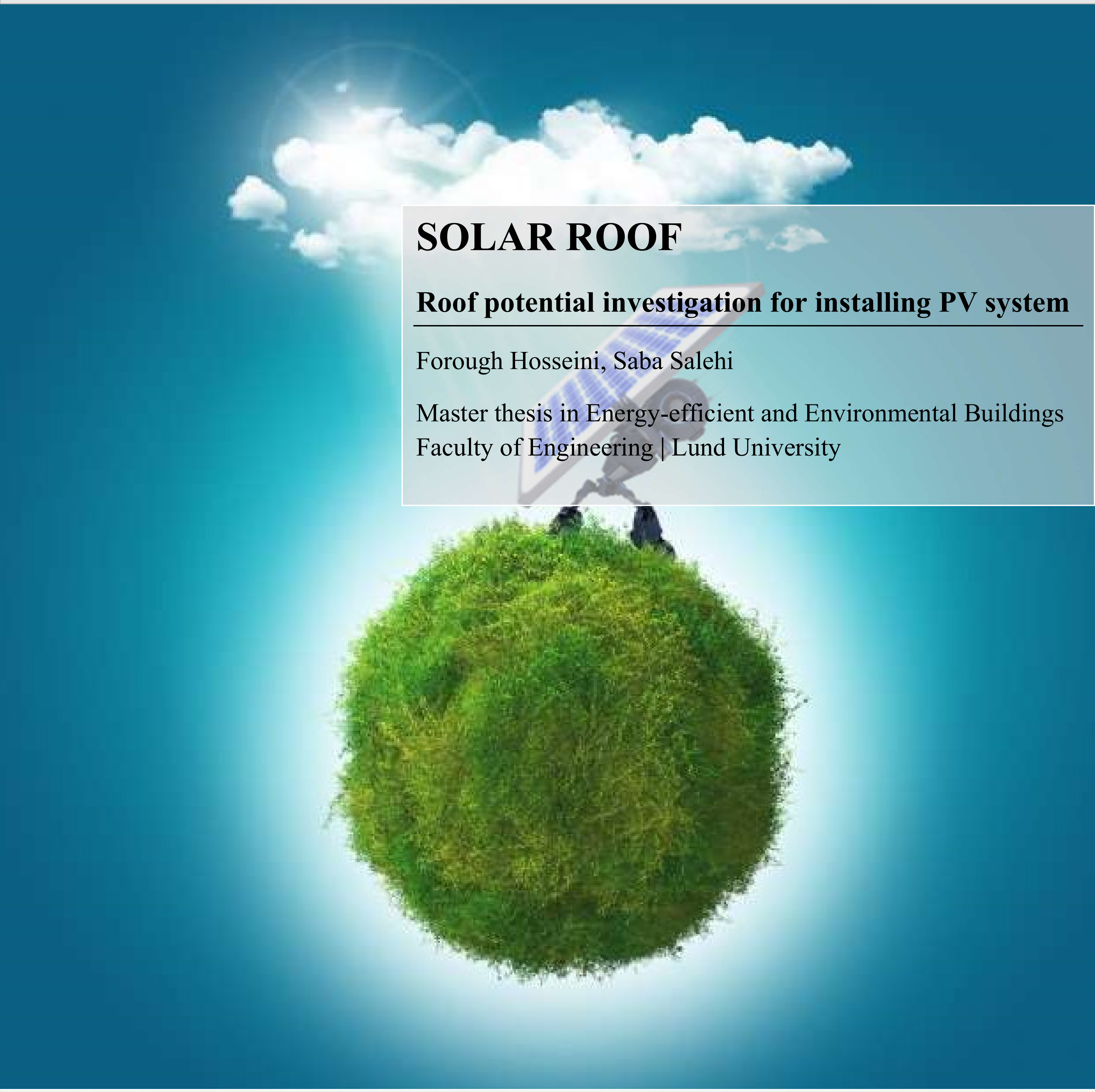

SOLAR ROOF

Roof potential investigation for installing PV system

Forough Hosseini, Saba Salehi

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 centers 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.

Examiner: Henrik Davidsson (Energy and Building Design)

Supervisor: Dennis Johansson (Installation and air conditioning theory), Peter Kovács (RISE), Ricardo Bernardo (Energy and Building Design)

Keywords: Roof solar potential, PV system, Ventilation system

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Abstract

By increasing the amount of CO_2 emissions to the atmosphere because of using fossil fuel and the limitation of non-renewable energy sources, solar photovoltaics technology has been growing steadily and is thought to play an important role in the realm of future energies.

The objective of this thesis is to investigate the potential of the rooftops for installing PV system on a small scale of 30 multifamily houses in Gothenburg divided into four categories of age, location, roof type, and ventilation system.

The results of this study are based on simulations from PV*SOL software. The solar potential in this study were investigated by two designing approaches: first, applying the PV modules on the total available area on the roof and considering the total electricity demand in the building, the second approach was to design a PV system for each building for the best roof area by taking into account all possible shading on the roof and the roof direction. Furthermore, the electricity demand was considered only for the building's common electricity. A deep-in analysis for shading effects was performed in this study to determine the importance of shading on the PV systems output.

The investment payback time of each system was investigated for both current and predicted electricity price by performing Life Cycle Cost (LCC) analysis. Additionally, Life Cycle Assessment (LCA) of the PV system was investigated in terms of two aspects: environmental impact and energy payback time.

The result of this study indicated that the profitability of the systems is directly depended on the amount of electricity demand in the buildings. The ventilation type of the building for designing a PV system on the rooftop had a significant role in the system output and profitability. The buildings with FTX ventilation system which demanded the highest amount of electricity had the shortest investment payback time. The most significant effect of the building's location was on shading analysis results. However, the output of the system did not show any difference between the tilted or the flat roofs. By designing the systems based on the second approach the average size of the PV systems decreased by 40 %, while the demand for buying electricity from the grid for both common and household electricity increased only by 10 %. The output of the designed system indicated that designing PV system for household electricity demand was not profitable. The average investment payback time for current and predicted electricity price was calculated as 28 and 22 years, respectively and the average energy payback time was determined as 1.5 years.

Preface

This study was carried out as the final part of the master programme in Energy Efficient Building Design at Lund University.

We would like to express our gratitude our main supervisor Dennis Johansson for his supervision, advice, and support during the process of this master thesis. We also would like to thank Ricardo Bernardo for his help during the project.

We would take the opportunity to thank Peter Kovács from RISE for his substantial guidance and support, as well as Jenny von Platten for her contribution in providing the "Gripen" data base used in this study.

Finally, we gratefully acknowledge the support from our family and friends through this project.

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Abbreviations

PV	Photovoltaic
RISE	Research Institutes of Sweden
EST	Effektiva SolcellsTak (efficient solar roof)
3D	3 Dimension
CdTe	Cadmium Telluride
a-Si	Amorphous Silicon
CIGS	Copper Indium Gallium Selenide
BAPV	Building Applied Photovoltaic
BIPV	Building Integrated Photovoltaic
MPP	Maximum PowerPoint
HVAC	Heating, Ventilation and Air Conditioning
VAT	Value Added to Tax
EPBT	Energy Payback time
O	Old
M	Million-program
Y	Young
S	Natural ventilation in English (Självdrag in Swedish)
F	Exhaust air ventilation in English (Frånluft in Swedish)
FVP	Exhaust air ventilation with heat recovery in English (Frånluft med Värmeåtervinning in Swedish)
FT	Exhaust and supply air ventilation in English (Från- och Tilluft in Swedish)
FTX	Exhaust and supply air ventilation with a heat exchanger in English
NPV	Net Present Value
LCC	Life Cycle cost
PBP	Payback period
LCA	Life cycle Analysis

1 Introduction

The limited resource of fossil fuels threatens human life, activities, and economies, which depend on this energy to a large extent. However, non-renewable sources of energy and fossil fuels have extensive effects on the economy and disadvantages to the environment; therefore, investing more in renewable energy is essential (Kalogirou, 2004).

Additionally, the growing trend of the population increases concerns in regard to meeting the energy demand for future generations. In this regard, the primary matter is supplying energy for future generations which has become more vital by industrial progress (Kalogirou, 2004). Furthermore, people prefer to have control over their cost of living and be independent of government or other energy provider companies. These reasons lead to the popularity of using solar energy as a type of energy that can provide the opportunity for buildings' owners to have a better control over their buildings' energy demand (Mulder et al., 2010).

The sun is a sustainable source that can provide energy effectively and is easily accessible with low CO_2 emissions. The irradiation that reaches the Earth can provide a surplus of the Earth’s energy needs. The sun as a green source of energy, is the foremost alternative for the replacement of fossil fuel (Gray et al., 2014).

Solar energy attracts both specialists and politicians and exploits of this energy have recently surged drastically around the world, which causes noticeable progress in solar energy usage (Zahedi, 2011).There is a similar trend for the government of Sweden to supply the country’s energy demand by using renewable energy. Sweden's goal is to meet its demand of 100 percent using green energy in 2040. In this regard, solar energy is one of these sources being considered (Swedish Energy Agency, 2020).

1.1 Gothenburg city

Gothenburg is the second biggest city in Sweden and the capital of Västra Götaland County. The population in the city is approximately 570 000. Gothenburg is located by the Kattegat sea, on the west coast of Sweden.

Gothenburg was built during the 1600s. During the 1900s, the city grew to an industrial and modern city. A typical housing construction in Gothenburg and the other cities in Sweden is belong to the million homes program. During the 60s, the habitation requirement increased as a result of the second world war and population increment, Sweden also were shadowed by this condition. The Swedish government solution to this issue was a project known as ¨Miljon programmet¨. The aim was to build one million homes with the help of several private and nonprivate firms around that decade (Hall and Vidén, 2005).

Recently, sustainability and energy shortages has become an indisputable global concern, and Sweden has been acting actively in this respect, which is in contrast to the contemporary condition of many of the Million Programme buildings. Although the renewal cost of the project is enormous, reconstructing these buildings have a severe environmental impact. Therefore the renovation option was chosen that includes improvement in ventilation, installing insulation and PV system, by carrying out these acts, the buildings' energy use decreases up to new energy-efficient constructions (Green and Paulsson, 2019).

1.2 RISE and EST project

RISE, which stands for a Research Institutes of Sweden, is an independent non-profit, State-owned research institute. RISE's mission is to discover facilities and possibilities for a sustainable future in Sweden.

The company provides a foundation for researchers, companies, and universities to collaborate in various fields to solve social and environmental issues.

One of the RISE's work tasks is to coordinate with the Optimized Refurbishment for Efficient Solar Roof (EST) project to analyze simultaneous roof renovation and solar panels installation. The project runs from August 2018 to December 2020 (RISE - Research Institutes of Sweden, Box 857, SE-501 15 Borås, Sweden, n.d.). EST project aims to gain new knowledge and find constructive solutions for roof renovation with solar cells in multi-dwelling buildings and premises. The goals of the project are:

- To contribute to a faster, efficient align with considering the quality development in the roof renovation with solar panels market.
- validating a new development and industrial participation in the area.

The project is funded by National Swedish Energy Agency via the research program E2B2 and participating organizations and companies

1.3 Aim and object

The purpose of this project is to calculate the rooftops' potential of supplying solar electricity for the total electricity demand in multi-family buildings. The maximum potential was investigated by applying PV panels on the total available roof area.

The project presents a generic study of the solar potential for existing buildings' roofs in which the following points were analysed:

- Objects that fragment the roofs, such as different ventilation types and windows on the top of the roofs
- Surroundings' impact on a PV installation by shading it
- Life cycle assessment of PV panels
- Life cycle cost study regarding PV panels
- Possibility to classify roofs based on different parameters.

1.4 Limitation

This study is subjected to some primary limitations which are mentioned as follows:

- Determining the renovation options and methods for the roofs with PV installation is a part of the EST project. However, because of the limited information available about buildings construction and condition, this part was omitted in this study
- A restricted number of thirty buildings were selected to study because of the time limit.
- By following the EST projects, only residential buildings were considered.
- Due to the focus on Gothenburg in the EST project, only buildings in Gothenburg were studied.
- The precision was limited to the level of what could be found with Google Maps since the 3D-drawings were not accessible.
- For the studied building, only the information of yearly electricity usage was available, therefore for all the buildings, a general hourly profile was considered. Since the information about the existence of the laundry room for buildings was not available, the average electricity use was assumed for this study.

2 Technical background

This chapter discusses briefly the PV performance, its type, and installation. Limitation that this technology faces, how building type or tilt affects this technology, stand-alone and grid-connected system, and the economic aspect of these facilities are also explained in this part.

2.1 PV Panels

Without changing the present share of fossil fuel in providing for the energy demand, the world will suffer from its irreparable consequences such as global warming and rise in CO2 levels. To impede the situation, governments make efforts to find possible ways to convert renewable energy into a suitable type of energy (Elibol et al., 2017). In this regard, solar energy becomes impressive since PV panels can change solar radiation to electricity without a medium (Pandey et al., 2016). The basic unit to quantify PV panels is a cell, several cells create a module, and a sequence of modules is named an array (Sommerfeldt et al., 2016).

PV panels improve each day, recently, silicon became known as the best element to manufacture the panels because of its specific characteristics such as high resistance, availability in a large amount, environmentally friendly attribute, and flexibility to use on a large or small scale (Nogueira et al., 2015).

2.1.1 Common module

PV panels are available in different types and materials consisting of crystalline silicon, thin-film, organic or polymer, hybrid PV, and dye-sensitized, but among all models crystalline silicon and its products (monocrystalline, polycrystalline and GaAs) are more popular business models (Pandey et al., 2016). Moreover, monocrystalline panels despite their higher price are the most common type due to having better quality and higher efficiency, as it can provide the same amount of energy in comparison with polycrystalline but by a smaller system (energy sage, 2020).

A brief comparison of three well-known PV technologies (multi-crystalline, thin-film, and latest laboratory discoveries) can give a better point of view to choose a proper module. Multi-crystalline or silicon wafer divides into polycrystalline and monocrystalline material with 18 % and 21 % efficiency, respectively (Ise, 2019). Thin-film common types are cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium selenide (CIGS) (Sommerfeldt et al., 2016). The thin film has approximately 9 % to 18 % efficiency. Finally, laboratory-based technology multi-junction solar cells with efficiency of more than 40 % have the highest value, but reachable by concentrators, therefore it is not applicable as building PV function (Ise, 2019).

The prevailing buildings' PV module has almost 1m x 1.6m size and peak power between 250 and 350 Wp and 15 % to 22 % efficiency based on its material.

2.2 System type

PV technology's performance wildly depends on the weather conditions and panels' orientation and tilt, so investigating these points can lead to choosing a proper system (JNTUH College of Engineering, Jagtial, Nachupally, Karimnagar, Telangana State, India, 2017). Moreover, the choice of system type depends on the electricity use and supply profiles in the building. As it is well-known, a PV system supplying profile shows a higher generation during the day and decreases to zero in dark hours. On the other hand, energy demands are dissimilar for different buildings, such as office, industrial, and dwelling. Therefore, to match the supply and demand, designing a proper type of system is essential (Benda et al., 2018). System types are explained as followed:

Stand alone: A stand-alone PV system is designed to operate independently of the grid and is usually used in areas with no access to an electrical grid. These systems can contain only PV modules and a certain dc or ac load, or batteries can be added up to the system to store the supplied electricity. By using the battery, the electricity is stored as the form of dc power which can be used directly in low voltage electric devices or it can be converted to ac voltage by an inverter to run ac loads (Al-Juboori, 2016).

Grid-connected: This system copes with wasting energy by conveying the overproduction of electricity to the grid. To clarify, the owners can sell the overproduction to the electricity production company, then buy the lack of energy during the time PV can not support the demand (Mulder et al., 2010). New research in Sweden shows a growing interest in installing PV panels, especially grid-connected systems (Palm, 2018). It could be the consequence of grid-connected sooner payback time and its lower environmental effect (Goel and Sharma, 2017).

2.3 PV panels installation methods on roof

There are two different techniques for installing PV systems on the roofs. Building Applied PV (BAPV) and Building Integrated PV (BIPV).

Building Applied PV (BAPV): In BAPV technique each row of panels supports a prefabricated rail (Contreras, 2019). Figure 2-1 shows this mounting technique for both tilted and flat roofs. Installation on the tilted roof can be done by concerning a distance from the surface of the roof to obtain ventilation for panels.

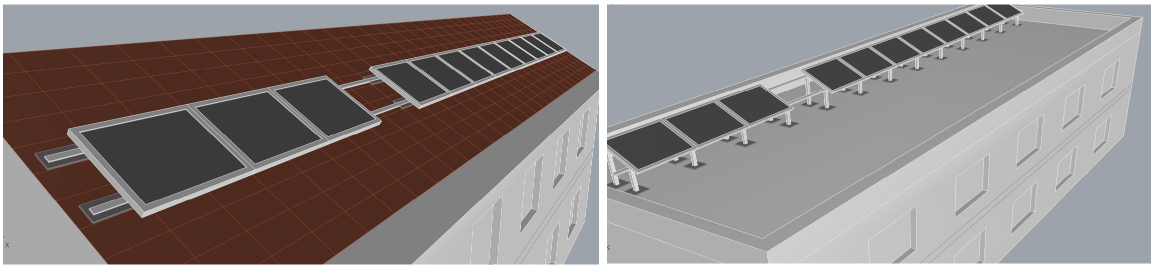

Figure 2-1: BAPV technic on both tilted and flat roofs from left to right respectively.

Building Integrated PV (BIPV): This model is the building integrated photovoltaic (BIPV) in which panels become a part of buildings by replacing the regular components. The BIPV advantages are acting like an insulation by blocking solar panels, mitigating environmental impact by less material, and increasing the aesthetic view of the buildings. However, for existing buildings, its cost is high (Lu et al., 2019). Figure 2-2 shows a roof with a BIPV system.

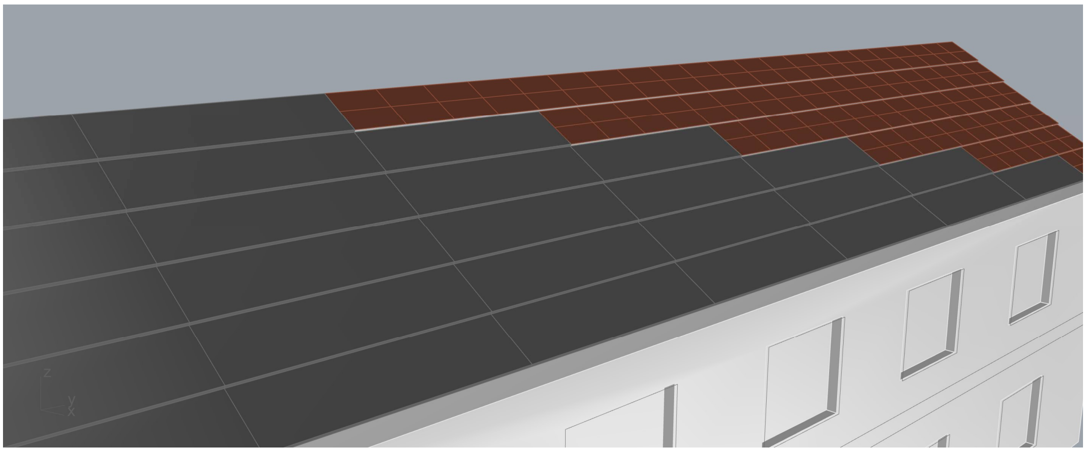

Figure 2-2: A sample of a BIPV system.

2.4 Photovoltaic modules and inverter efficiency

To achieve the goal of vast spreading solar energy clarifying the financial issue of this technology is a dominant prospect to convince all, especially prosumers. In this respect, determining the life span of solar energy main segments such as panels and inverter are the first step.

Solar panels: When solar panels maintenance is posed, two matters should contemplate lifetime and degradation. New generation solar panels' lifetime is around 25 to 30 years, which does not mean the solar panel will not generate energy anymore but meets its useful lifetime. This fact relates to the solar panels' relative reduction efficiency per year, which is 0.8 % of the total PV generation in a year (and it is 0.5 % for better PV panels), so panels will be operate at around 82 % of its first efficiency after 25 years. Moreover, PV degradation induces companies to propose two kinds of warranty, which are manufacture and performance (energy sage, 2016).

Inverters: Inverter production has been progressed alongside the PV panels with a life expectancy of fewer than 15 years, but still is responsible for the majority of systems breakdown and imposes a high cost on consumers (Sangwongwanich et al., 2018).

Inverters operate based on different methods such as Maximum Power Point Tracking MPPT or reactive power injection. In the first method, inverters produce the maximum power by forcing PV panels to work at Maximum PowerPoint MPP (LEONICS, 2020). Besides, the second strategy is to control the power extract from PV not to impose a sudden change. For instance, if the system has an unforeseen power reduction, power will be injected to balance the system (Das et al., 2016).

2.5 Photovoltaic modules in Sweden

In the last forty years, Sweden's electricity demand has been provided by nuclear power, but the goal to depend 100 % on renewable energy sources, causes Sweden to be fond of solar energy. In this respect, the government reduces the price and tax of PV panels to pave the way for operating it. Moreover, buildings, particularly roofs, are recognized as the most proper location for installing panels in Sweden since it omits the cost of depending on the grid utility and paying tax. Also, among all installing possibilities, it would be more eco-friendly if PV panels add to existing constructions (Sommerfeldt et al., 2016). It means the majority of the investors are prosumers who are the users that produce energy themselves (Parag and Sovacool, 2016).

Despite the public beliefs of Sweden's low access to solar radiation, the radiation in the majority of Sweden is similar to the north of Germany, while Germany is a pioneer in extracting solar energy. Annual solar radiation in Sweden is approximately between 900 and 1 200 kWh/m2 in a year and 1 000 kWh/m2 on average. This amount can produce 680 to 900 kWh/m2 electricity in a year (800 kWh/m2 on average), employing 1 kWp solar panels with optimum tilt and a 75 % performance ratio. Furthermore, the PV panels' installation tilt is crucial for generating maximum possible electricity, and Sweden's range is 35o to 45 o from south to north (Sommerfeldt et al., 2016).

Life cycle cost: Although there has been an attempted to reduce the price of PV panels, their installing expenses are still high, which lead to a longer payback time. Besides, Sweden's policy regarding electricity tariffs in the future is not predictable, but it is low-cost now, which leads to low economic justification for applying PV panels. Additionally, the annual solar irradiation in Sweden is approximately as much as the UK and northern Germany that have the highest market and installation capacity of PV panels respectively in the year 2014 (Sommerfeldt et al., 2016).

2.6 Electricity in Sweden

In Sweden, the electricity load of the buildings is divided in two parts of household, and building's common electricity. Building’s common electricity use includes HVAC system, outside and stairwell lighting, elevator and laundry rooms, heating, and hot water system (Sommerfeldt et al., 2016). Household electricity includes cooking, inside lighting, and electric equipment (Johansson and Bagge, n.d.).

It should be mentioned, around 90 % of multifamily houses and 80 % of none residential building heating demands including, space heating and hot water are supplied, by the district heating system (EUROHEAT&power, 2019).

Electricity price: Electricity price in Sweden is calculated on several levels and involves many expenses that all should be considered to have a precise cost for electricity. These costs will be explained briefly.

- **Electricity spot price:** The spot price is calculated hourly every year by Nord pool company and can be collected from the Nord pool site based on the origins of the city (NOERD POOL, 2020).
- **Measurement fee:** is a monthly fixed charge that applies to the applicants who have production and consumption in the same facility (Göteborg Energy, 2020a).
- **Electricity transmission:** is a variable price for transporting electricity through the electricity grid. This price is depended on the amount of electricity usage by the appliance (Göteborg Energy Nät AB, 2020).
- **Electricity transmission compensation:** is a fee that is paid by energy companies to the electricity producers that also have an agreement for consumption with the same company. Another requirement is that the generated electricity can not exceed the electricity used over a year. This price is depended on the size of the PV system (Göteborg Energy Nät AB, 2020).
- **Trading surcharge:** is an additional fee to the electricity market price for buying electricity from grid per kWh (Göteborg Energy, 2020a).
- **Direct capital subsidy:** It refers to Sweden’s governmental support for installing PV panels, which was started from 2009. By the year 2020 government have been decided to covers 20 % of total installation cost (Lindahl et al., 2018).
- **The green electricity certificate system:** The certificate provides an income for PV panels owner in 15 years. They will gain one certificate per MWh of electricity production (Energimyndigheten, 2019a).
- **Guarantees of origin:** It is an electrical engineering and computer science domain protocol that intends to guarantee the source of the renewable energy that produces the electricity. It will be provided for energy producers by the government per MWh generated energy (Energimyndigheten, 2019b).
- **Subscription fee:** is a fixed annual fee for having access to the electricity grid. The price depends on the size of the meter fuse (Göteborg Energy, 2020a)**.**
- **Energy tax:** is a fixed fee that applies to energy in Sweden. The current value since Janauary 2020 is 0.353 SEK/kWh (Göteborg Energy Nät AB, 2020).
- **Tax credit:** refers to the tax reduction for the surplus electricity that is fed to the grid. With this credit, the producers would be able to have a current income of 0.6 SEK/kWh for the electricity that they sell to the grid. To be eligible to get this credit the following conditions are required:

- the grid connection for both buying and selling electricity should be the same,
- the grid connection point fuse should not exceed 100 amperes for selling,
- the utility companies should confirm that the electricity consumers are connected to the grid,
- the maximum amount of produced electricity per year that is eligible for the tax reduction is equal to the amount a consumer buys from the grid,
- finally, the electricity fed into the grid cannot exceed 30 000 kWh per year (Lindahl et al., 2018).

- **VAT:** Abbreviation of Value Added to Tax and is equal to 25 % (TMF Group, 2019). VAT applies to all expenses except green electricity certificate, the guarantee of origin, and tax reduction (Lindahl et al., 2018).

Turnkey cost: Turnkey cost is all expenses of a product or a service that must be covered before the product or service can be presented in the market. It sometimes includes only the actual manufacture (known as direct cost) or the executive (known as indirect cost) expenses. However, in some conditions, it provides both direct and indirect prices (Investopedia, 2019).

The turnkey cost of a grid-connected PV system excluding VAT in multifamily houses in 2018 was 14.02 and 13.21 SEK/Wp for 20 to 50 kWp and 50 to 100 kWp system, respectively (Lindahl et al., 2018).

2.7 PV system design considerations

For installing PV panels, several aspects should be considered, some are general, and others are specifically related to the location that is selected to apply the PV system.

2.7.1 Buildings age

Building's age is one of the initial factors that should be considered in designing the PV system since the age of the building has a direct effect on the building's need for renovation as well as its electricity demand profile (Brounen et al., 2012).

2.7.2 Location

A construction location's vicinity should be taken into consideration because of shading and pollution. Dens area influences PV system efficiency in many aspects, such as environment's shading that can block irradiations access to a roof (Moraitis et al., 2018). On the other hand, in the less crowded zones, the most disturbing issue against irradiations can be trees.

2.7.3 Roof type

Gable: This report is focused on 4 types of gable roofs which are box, open, intersecting, and dormer, which are shown in Figure 2-3 from left to right respectively. In dormer type windows can be used for both ventilation and a fixed window for view and design.

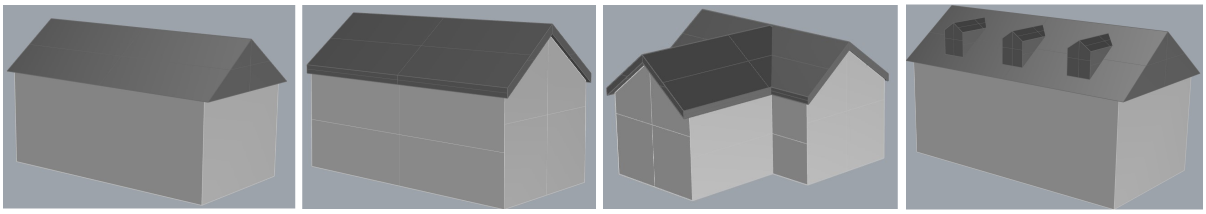

Figure 2-3: Different gable roof types that call box, open, intersection, and dormer from left to right.

Hip: Simple and pyramid hip roof from left to right are shown in Figure 2-4. The difference between the box gable and simple hip roof is, in the simple hip roof, all four outer shells of the roof have a pitch.

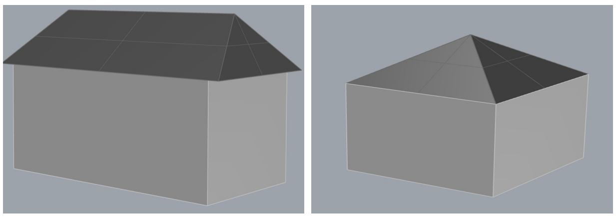

Figure 2-4: Two different hip roofs, simple, and pyramid.

Butterfly: As can be seen in Figure 2-5, the pitch of the butterfly roofs is opposite of the open gable.

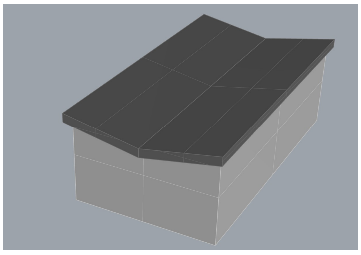

Figure 2-5: Butterfly roof shape.

Shed: As illustrated in Figure 2-6 shed roof has tilted only in one direction.

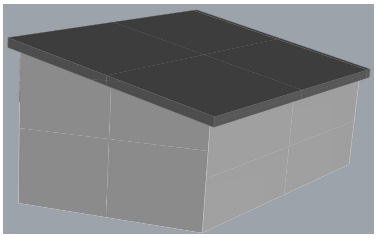

Figure 2-6: Type of shed roof.

2.7.4 Roof installation

Obstacles on top of the roof affect the PV output by reducing the area of installation and increasing shading on the roof. Therefore, identification of these obstacles and modelling them clarify the impact of each obstacle type. The roof obstacles variation in this study are windows (including both vertical and dormer windows), ventilations' construction (like chimneys, mechanical ventilation room, and ...), air duct, and other roof installation like roof parapet. To classify practically ventilation components' effects were separated from the other types since they were common in all buildings of different ages or locations.

Windows: The roof windows frame stands out from the surface of the roof. Therefore, they reduce the useful area for installing PV panels on top of the roof.

Construction installations: Based on structure of the roof and the mechanical system of the buildings, different installation on the roofs exist. In addition to the architectural design of a building that creates limitation for installing PV panels on the roof (like dormer windows), the main impediments for installing PV panels on the rooftop are ventilation construction. These constructions are different in shape, size, and height for each ventilation type.

2.8 Ventilation types

The type of buildings' ventilation system imposes a certain electricity demand on the building. On the other hand, each ventilation system requires, different installation on the roof. Since these aspects are significant factors in designing a PV system different common ventilation types in Sweden, and their performance and structure are explained in this chapter.

- **Natural ventilation (Självdrag in Swedish - S):** The operation of this form depends on the chimney effect principle in which supply air from envelope leakage and windows gets heated through fireplace, radiator, electric heater, and so on, then flows up from the chimney and ventilates a building. Therefore, in this type, the more the temperature is different between inside and outside, the more ventilation flow will be and its function is better in taller buildings according to the chimney effect. In contrast with the cold windy season, buildings with natural ventilation perform less efficient in the absence of outside and inside temperature difference and raise window opening demand. The disadvantages of the buildings with this ventilation system are that supplied-air is not controllable and impossible to filter; in the case of interfering with the supply air, a huge pressure drops will disrupt natural ventilation. However, Lack of mechanical ventilation brings about two advantages to the system: low electricity use and operation with low sounds (VENTILATION.SE, 2020). On the other hand, no heat recovery is usually possible for this system. A scheme of this ventilation is shown in Figure 2-7 in which the blue and red arrows are supply and exhaust air direction respectively. According to Figure 2-7, the natural ventilation needs rather long chimneys on roofs, therefore, they will shade and fragment roofs.

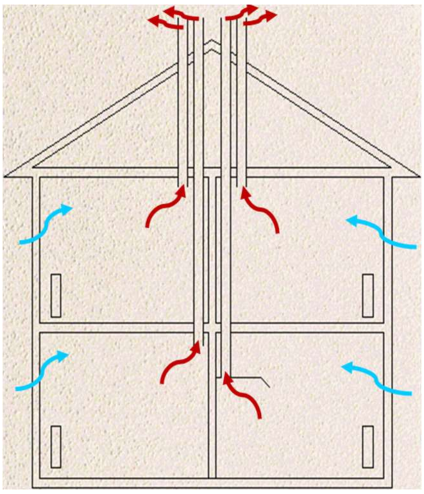

Figure 2-7: Natural ventilation with its supply and exhaust air direction in blue and red arrows respectively.

Although the natural ventilation system has not been rejected by Swedish regulation and it was popular since 1976, it is not common anymore due to its low air quality and energy losses that are the result of a lack of heat recovery (ENERGY BUILDING, 2020).

- **Exhaust air ventilation (Frånluft in Swedish - F):** In this system, the supply air is provided for a building through openings similar to the natural ventilation system. But the exhaust air pulls out with the help of a fan which is usually located in the attic or on the roof. This fan is connected to diffusers located in the kitchen, storage, restroom, and wardrobes. The operation of the fan is constant and works 24 hours per day (HOUSE ENERGY, 2013).
  In comparison with the natural ventilation, filtering supply air is possible in exhaust air ventilation with the existence of the fan, but the 24 hours operation of the fan causes this system to have a high electricity use and creates unpleasant noise. Another drawback of the system is that the fan curved under pressure such as an open window in the kitchen removes the supply airflow in the bedrooms (VENTILATION.SE, 2020). In buildings with this ventilation system an exhaust heat pump may be added to save heat, it can be installed in the basement or attic or on the roof. Figure 2-8 illustrates an exhaust air ventilation system that includes: the supply air direction from envelope leakage and windows with blue arrows, the outlet air direction with red arrows, and the fan of the system on the roof. Another significant issue regarding this system is the several numbers of chimneys that occupy the available area for installing PV panels on the roof and also create shading.

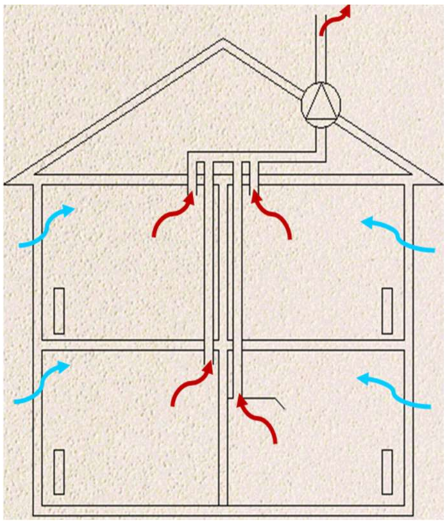

Figure 2-8: Exhaust air ventilation with supply and exhaust direction besides the fan for exhaust.

- **Exhaust air ventilation with heat recovery (Frånluft med Värmeåtervinning in Swedish - FVP):** It is a mechanical exhaust air ventilation with better energy performance than Exhaust air ventilation since it has heat recovery. It pulls the exhaust air and implements heat recovery by adding an exhaust air heat pump. In this system, exhaust air is controlled mechanically and ensures adequate ventilation through a constant exhaust airflow, however, the electricity use of this ventilation system is high (POLARPUMPEN, 2017). Moreover, if the exhaust heat pump is installed on the roofs, it would occupy the roofs' surface and limits the area for installing PV panels.

- **Exhaust and supply air ventilation (Från- och Tilluft in Swedish - FT):** It is a mechanical ventilation system, which improves the indoor air quality by preheating and filtering supply air and pulling the exhaust air out. Bedrooms and living room have priority to supply air, and exhaust air devices are usually located in the rooms with higher air contaminant like kitchen and restrooms (VENTILATION.SE, 2020). Figure 2-9 shows the mechanical ventilation of this system in detail with inlet and outlet directions that represent in the same colores as other types. This type of ventilation can deduct the electricity demand of the building by preheating and filtering the outdoor air. However, the location of the mechanical room can be in the basement or attic or on the roof. In a case of locating on the roof, it occupies a relatively large area of the roof and causes shading more than other types of ventilation systems.

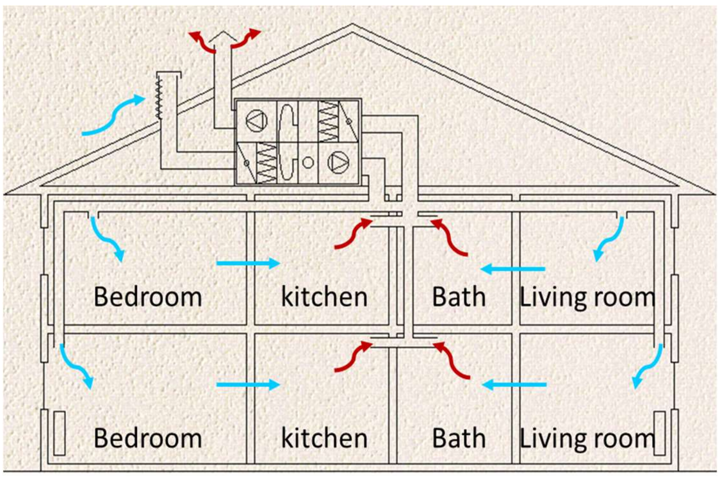

Figure 2-9: Exhaust and supply air ventilation with its details, mechanical ventilation system besides the direction of inlet and outlet in blue and red, respectively.

- **Exhaust and supply air ventilation with a heat exchanger (FTX):** This system is like Exhaust and supplies air ventilation that heat exchanger is added to it so, performs more sufficiently and economically since it uses the wasted energy of exhaust air to heat the supply air. Also, FTX can provide passive cooling and proper indoor air quality in all rooms, but its drawback is high maintenance expenses and initial cost (VENTILATION.SE, 2020). Figure 2-10 shows the FTX system duct in a house in which the inlet duct has blue and outlet has yellow colors. It should be mentioned that the extract devices are usually installed in the most polluted rooms like the bathroom and kitchen (Swegon Group AB, 2020). The total electricity demand of buildings with this system is rather low since it contained heat recovery. But if this system locates on the roof, the area that will occupy is higher than other types because this ventilation type needs a mechanical room, which also causes more shading.

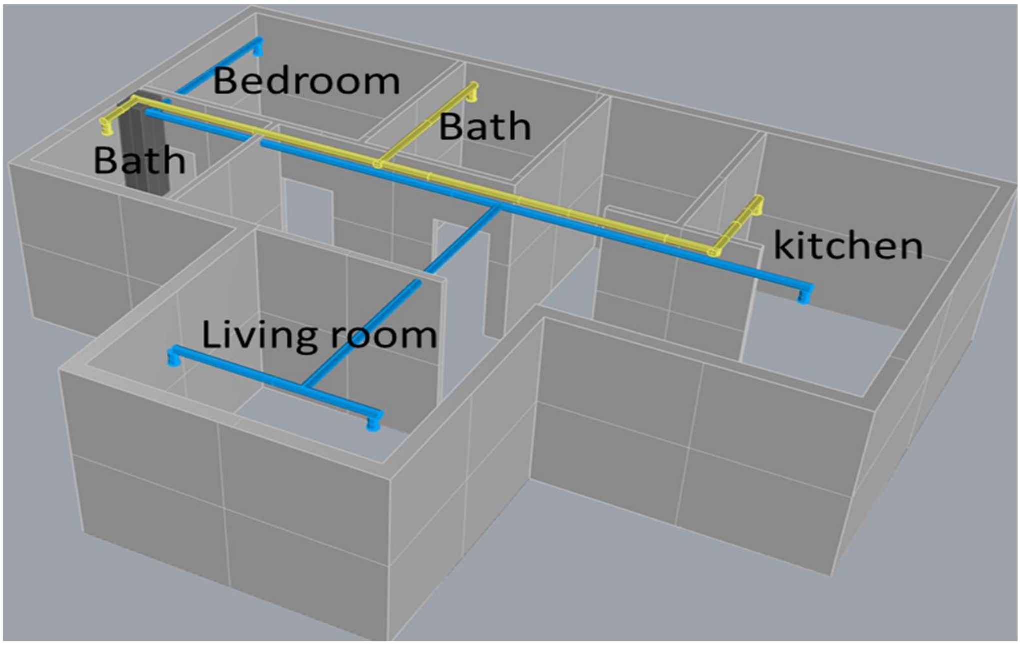

Figure 2-10: Exhaust and supply air ventilation with a heat exchanger duct system in a house, blue ducts convey supply air and yellow one the exhaust.

2.9 Life Cycle Assessment of PV panels

One of the critical issue regarding PV panels' market as a growing trend is the average lifespan of this technology which is between 25 and 30. Therefore, it is expected that PV panels' waste reaches 3 and 9.5 million tons in 2035 and 2050, respectively. This estimation is the result of the previous installations that have already reached their life span and current installations that will reach by 2035 and 2050 (Mak, 2016).

Despite all matters, PV panels are one of the cleanest means of producing energy during their lifetime since they have a significant low CO2 emission and any other pollutions. The environmental impacts of the PV system could be investigated more deeply through its energy payback time (EPBT). EPT of PV panels is the year in which the green electricity that is generated by a PV system can compensate for the total renewable and non-renewable energy that was used to manufacture PV panels. For roof-mounted silicon-based panels' EPBT was estimated to be around 2.5 to 3 years in Chicago in the year 2000. Moreover, the greenhouse gas emission for installing PV panels on the roof is approximately between 46 and 63 g CO2 eq./kWh (Yue et al., 2014).

A comparison between Chinese and European silicon-based panels illustrates that the cumulative energy for Chinese production is higher than the other models. Furthermore, the research regarding using Chinese and European silicon-based PV panels in Sweden shows the amount of green electricity that generates during the life span (30 years) of each model per their cumulative energy is roughly from 3.7 to 4.1 for European and 2.9 for Chinese model (Sommerfeldt et al., 2016).

3 Methodology

With the aim of investigating the solar potential of the roofs, including the obstacles, as introduced in section 1.3, a case study of thirty existing buildings was chosen.

Since this study is contributed as a sub-study of the EST project, conducting meetings with supervisors and RISE representatives to observe the calculation and results in every step was a fundamental feature of this study. Figure 3-1 illustrates the general work process of this study.

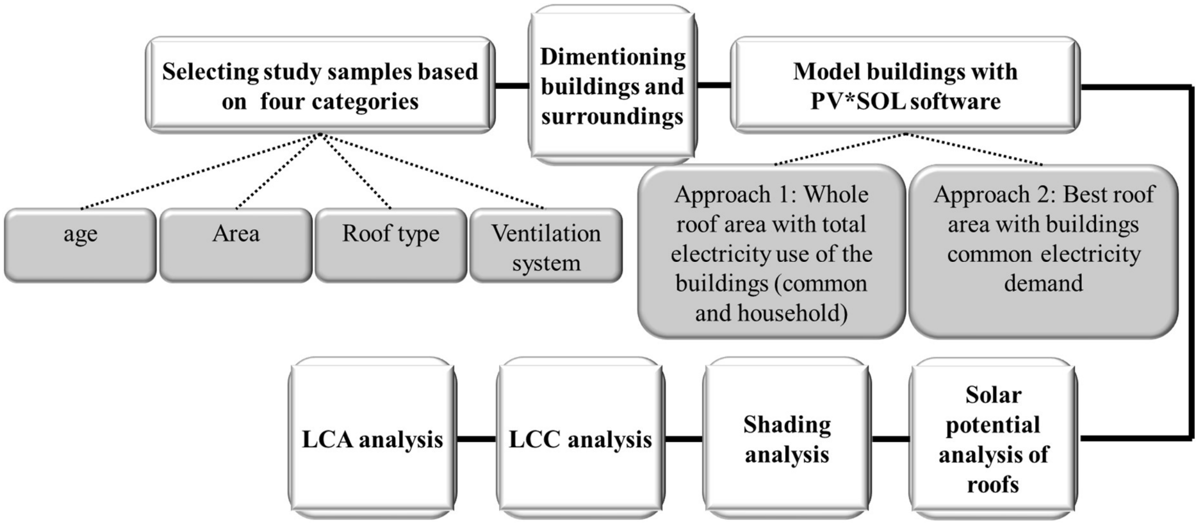

Figure 3-1:Summary to the method of the project.

3.1 Selecting study samples

The first step in Figure 3-1 is to make the choice of the buildings. To have a decent classification, four significant aspects that can affect the roof potential were considered, as shown briefly in Figure 3-2.

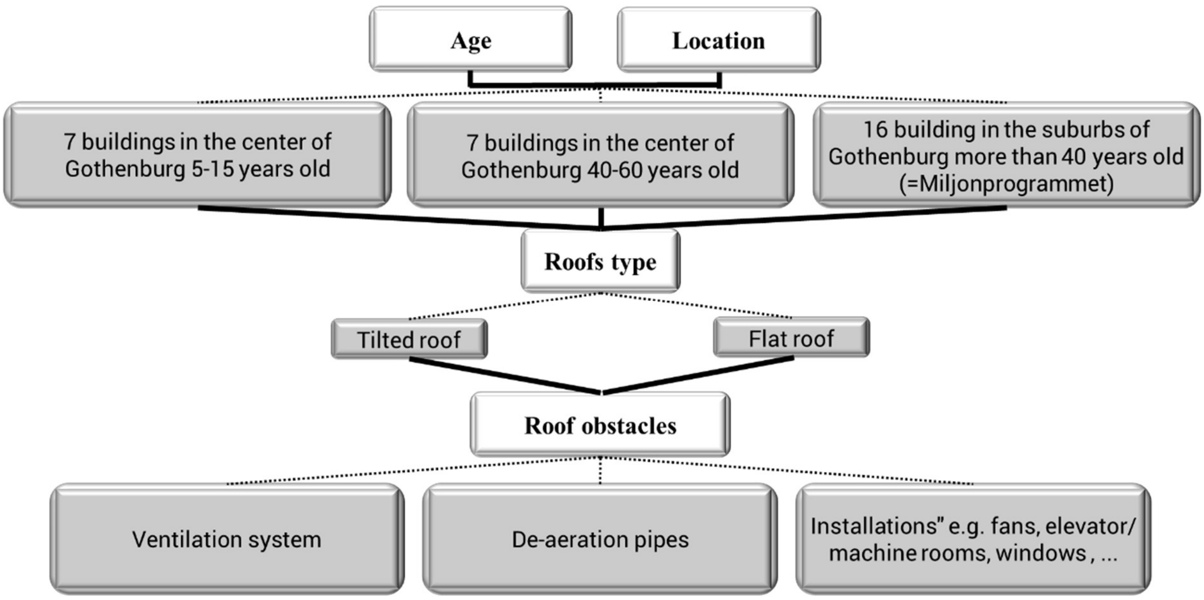

Figure 3-2: Building classification summary.

The needed information about buildings in the three age categories, as shown in Figure 3-3 were obtained from "Gripen" data base (Boverkets databas över energideklarationer).

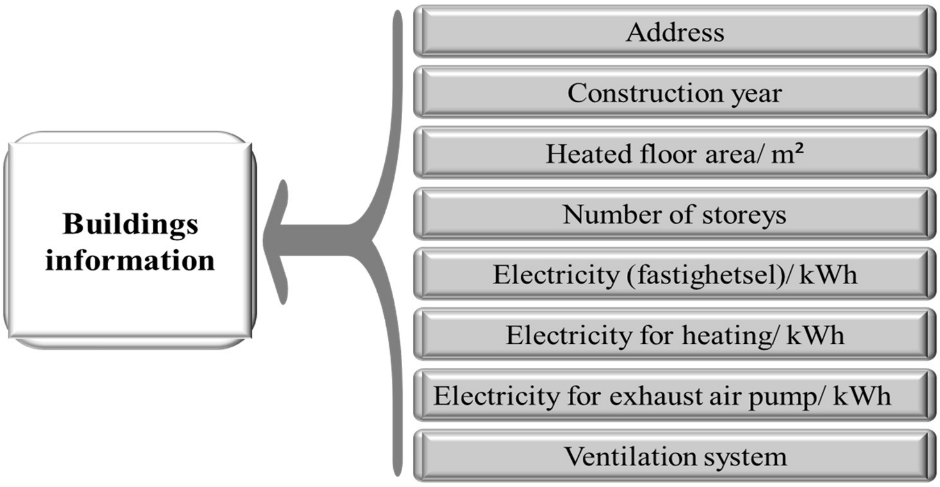

Figure 3-3: Buildings' first information.

195 buildings were assessed based on their location, roof type, ventilation type, and age. Furthermore, 30 buildings were selected for the following classifications, considering for having equal distribution of these parameters.

3.1.1 Class of age

The first indicator in the building's categorization was considered as the year of construction. To study how the age of the building can affect the electricity demand and the output of the PV system, the study samples were divided into young and old buildings. Seven buildings which were constructed after the year 2005 were collected as young buildings. Buildings with age over 40 were selected as the old buildings since for the building at this age, the probability of demand for renovation is quite high. On the other hand, among the old buildings, the ones belong to the million-program were considered a separate group. This division was based on the particular importance of this group for RISE. Sixteen buildings were selected in the million-program class, and seven buildings were chosen for the rest of the old buildings. Further, they will be referred with the abbreviations from O1 to O7 as old buildings, M1 to M16 as million program buildings, and Y1 to Y7, as young buildings.

3.1.2 Class of location

Buildings were selected in both center and suburb regions of Gothenburg, with the aim to study the effect of the environment on the PV system's output. Seventeen buildings were selected in the center and thirteen buildings in the suburbs.

3.1.3 Class of roof type

To calculate potential based on the roof type, roofs were broken down into flat and tilted (encompass gable, hip, butterfly, and shed). As installing the PV system, tilted roofs impose a certain option of azimuth and angle for roof mounted-PV panels in contrast with the flat roof that provides a better opportunity to choose the optimum azimuth and installation angle. Among the chosen buildings, 22 of them are with tilted roofs, and 8 of them have flat roofs.

3.1.4 Ventilation system

A building's ventilation system requires a specific structure based on its function, which is explained for the existing ventilation system in section 2.8 of this report. Each type of ventilation system not only has its specific electricity demand but also affects the potential of the roofs regarding the available area to install the modules. In this report, the ventilation system groups are referred to as "S" for natural ventilation with seven buildings, "F" for exhaust air ventilation consists of eight buildings, "FVP" for extract air ventilation with heat recovery consists of five buildings, "FT" for mechanical exhaust and supply air with five buildings, and" FTX" for mechanical ventilation with heat exchanger consist of five buildings. This category serves as a useful classification since it can give information for future decisions regarding renovation integrating PV system installation. Ventilation system category is also a specific indication for each building.

3.2 Dimensioning

Modelling the buildings and the effective environment around them with accurate dimensions were essential to get the correct results for shading analysis, and the system generated electric energy.

Since the drawings for buildings were not accessible, all the dimensions, i.e., width, length, height, roof height, and tilt were determined with the help of "google earth pro and the map section in PV*SOL software.

The buildings with all the details on the roof consisting of windows, De-aeration pipes, ventilation system, and construction installations were modelled in PV*SOL-premium 3D. The surrounding buildings and trees were also added to the model for reflecting the effect of environmental shading.

3.3 Modelling buildings with PV*SOL

This chapter explains the methods of modelling buildings and PV systems with related software and approaches for performing the classification.

Weather data: The weather-data in this study was selected from the PV*SOL database, for Gothenburg city with latitude 57.7° and longitude 12°, period 1991 to 2010, and hourly resolution.

Electricity usage: Three different electricity use profiles considered in this study are as follows:

- The hourly usage profile for building's common electricity consumption. As the information about the existence of laundry room for buildings was not available, two usage profiles for with and without laundry rooms were calculated (Sommerfeldt et al., 2016), and the average were used in the simulation.
- The hourly profile for heat pump system with space heating and domestic hot water (water/water). This profile was applied for buildings outside the district heating system.
- Household electricity demand. The electricity used for individual households was not available in "Gripen" database. Therefore the household electricity usage for the total heated floor area of the buildings was calculated by the average of 27 to 35 kWh/m^2 electricity use buildings in Sweden (Johansson and Bagge, n.d.). Since the electricity use in Sweden is higher in winter times (Johansson and Bagge, n.d.) the profile with low summer proportion, was used from PV*SOL database profiles.

Losses: In the PV system, the energy losses through system components affect the performance of the system. The losses in the cables vary for different sizes from 0.2 % to 1.7 % (Ekici, 2017). The system's design is another factor that affects the total losses in the cables, in which the overall loss should not be more than 3 %. (Photovoltaic-software, 2020). In this study, considering the systems as a well-designed one, the total loss due to cabling was set as 2 % (Ekici, 2017).

It should be mentioned that the losses due to panels quality, inverters and module array mismatch were calculated with the software for each assembly system and configuration.

Applying PV panels on the roofs:

- **Tilted roof:** The installation type on the tilted roof was chosen as "flush mounting with rear ventilation." The distance between modules was set as 2 cm in vertical and horizontal.
- **Flat roofs:** Finding the optimum tilt and azimuth is a critical step for installing the PV system. Although, on the rooftops with limited area and building's dimension, the effect of modules array mutual shadings is significant. Considering these limitations, the best tilt to avoid covering the panels with snow, rain, and dust and mutual shading considered as 10° to 12° with facing towards south or east-west (SPRIT, 2020) depending on the building's direction to get the maximum possible output.

3.3.1 Approaches

Two different approaches were considered in this study:

The first approach was according to the EST project goals to find the maximum potential of rooftops solar electricity supply in which both the effect of current and future electricity prices was investigated. This approach provides some complementary information for renovation decision-making and future policy of electricity prices

The second approach was conducted based on designing the PV system for the best area of the roofs by considering the shadings effects and roof direction, only for covering the building's common electricity consumption.

3.4 Roofs potential calculation

The potential of the roofs for producing solar electricity was assessed in several aspects:

- the ratio of obstacles area per roof area to determine the effect of structures on the roofs regarding the occupied space. The obstacle areas are shown schematically with black hatches in Figure 3-4.
- the ratio of generation area to the roof area, to calculate the available area for installing the PV modules. This function was a parallel calculation with obstacle area to study the effect of obstacle shapes on installing the module arrays. The available generation areas are shown schematically with blue hatches in Figure 3-4. The grey hatches are considered as unavailable area for installing PV system due to shape and size of the PV modules and obstacles on the roof.
- the ratio of electricity demand covered by the PV system to the total building's electricity demand; to calculate the ability of installed PV systems in providing for the buildings' electricity demand. This ratio was referred to as the "solar fraction" in this report.
- the ratio of electricity demand covered by the PV system to the total electricity generated by the PV system; to calculate the portion of the total demand that was used directly in the buildings. This ratio was referred to as the "self- consumption" in this report. Moreover, with this function, the amount of electricity that was fed to the grid was also concluded.
- yield reduction due to the shading for assessing the effect of shading on the systems' annual yield.

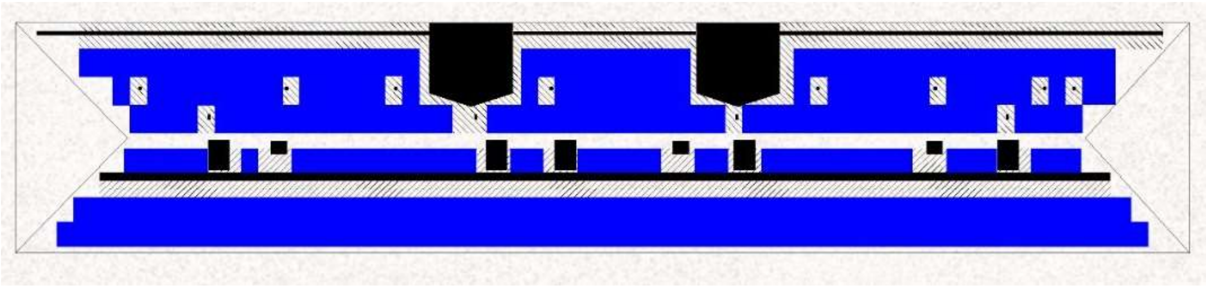

Figure 3-4: A schematic drawing of a rooftop with PV panels an obstacles on the roof for installing the PV system. The figure shows the obstacles on the roof with black hatches, the available generation area with blue, and unavailable area for installing PV panels with grey hatches.

3.4.1 Roof potential calculation summary

Figure 3-5 is a summary of the potential calculation method based on four categories.

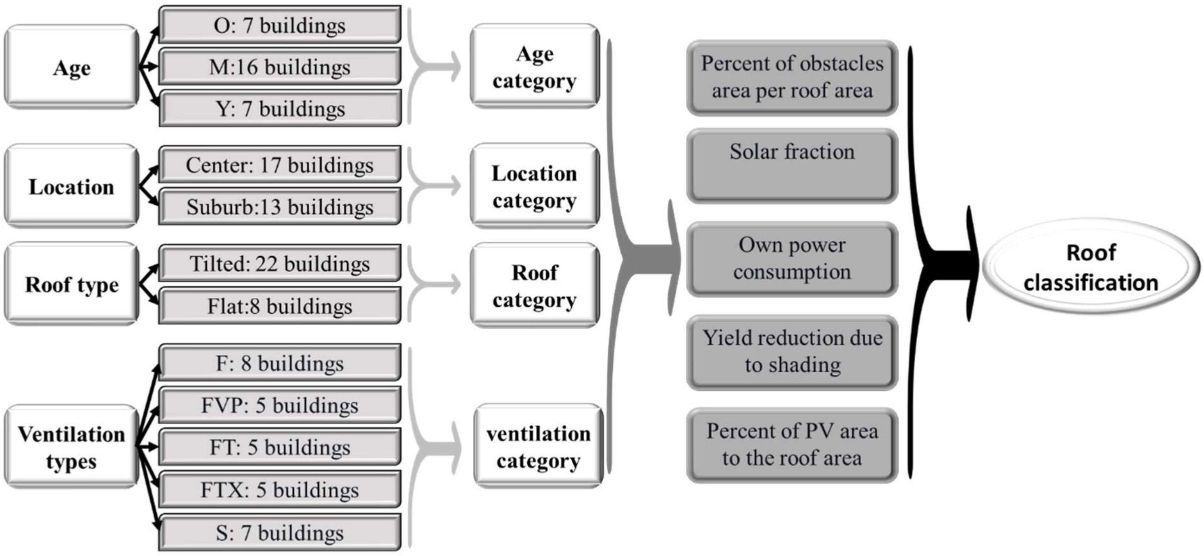

Figure 3-5: Roof potential method calculation summary.

3.5 Shading analysis

The effect of shading on reducing the PV system's electricity production is a significant factor that should be considered during the designing of the system and economic decision-making (Teo et al., 2018). The shading impact varies for different systems depending on the modules type, materials of modules structure, bypass diode placement, system configuration (Bimenyimana et al., 2017).

Therefore, studying the factors that create shading on the PV system and the severity of this effect would give helpful ideas regarding the productivity of the system's designing and building renovation options.

It should be mentioned that mutual shading is another essential issue that should be considered. However, in this study, the mutual shading was minimized in the installation design step; therefore, the results of shadings analysis were carried out without this effect.

3.5.1 Shading concepts

Shading analysis was performed in two concepts: one for the shading frequency as the percentage of the annual reduction of the direct irradiance on the module under clear sky conditions, and another for the factors of creating the shading.

To assess the frequency of shading effects, the output of each system calculated when the modules with more than 10 % shading as a rule of thumb, were removed from module arrays. Results were compared with system's output before removing these panels in terms of energy production (kWh) per generation area.

The study on factors of shading was conducted for two sources.

- environment shading, which is including the adjacent trees and buildings
- ventilation systems installations on rooftops

For environmental sources, all buildings were modeled without installations on roofs; in other words, the effect of the structure was removed from the analysis results. The system's "yield reduction due to shading" factor was calculated for the buildings located in the city center and suburbs.

In the next step, all the surroundings were omitted from the simulation to investigate the effect of the ventilation systems structures on creating shadings on the PV system. Then the system's "yield reduction due to shading" factor was compared for the five ventilation systems.

3.6 Life cycle cost assessment

To calculate the profitability of the installing PV system on roofs the costs and incomes were assessed for each system.

The costs for PV system installation consist of the investment cost and the electricity price. The average investment cost for grid-connected PV systems in residential buildings according to the database of the direct capital subsidy program was considered 17 500 SEK/kWp for systems smaller than 50 kWp and 16 500 SEK/kWp for the systems bigger than 50 kWp. These prices are including VAT (Lindahl et al., 2018). The cost for buying electricity from the grid includes trading surcharge, electricity transmission charges, subscription, fixed grid charge, tax, green electricity certificate, and guaranty of origin, are added to the electricity spot price. Further, a fixed grid charge for the electricity provided by PV system usage is also included in the total cost (Göteborg Energy, 2020b).

The income of selling the electricity to the grid consists of electricity spot prices besides tax deduction, transmission compensation, and green electricity certificate (Göteborg Energy, 2020b).

Table 3-1 shows the prices for the items used in this study for calculating the electricity price.

Table 3-1: The electricity components' prices and units.

Electricity price component	Unit	Price
Electricity spot price*	SEK/kWh	hourly 2019
Trading surcharge	SEK/kWh	0.019
Electricity transmission	SEK/kWh	0.153
Electricity tax	SEK/kWh	0.353
Green electricity certificate	SEK/kWh	0.01
Guaranty of origin	SEK/kWh	0.005
Subscription	SEK/two weeks	145
Fixed grid charge	SEK/year	1 500

* nord pool market data hourly prices for the year 2019

Figure 3-6 shows the average prices for selling and buying the electricity from grade as well as the saving price by using the electricity from PV system. The prices presented in Figure 3-6 are based on average spot price of 0.405 SEK/kWh from nord pool market data hourly prices for the year 2019. In this study, for each electricity usage profile, the hourly prices were used.

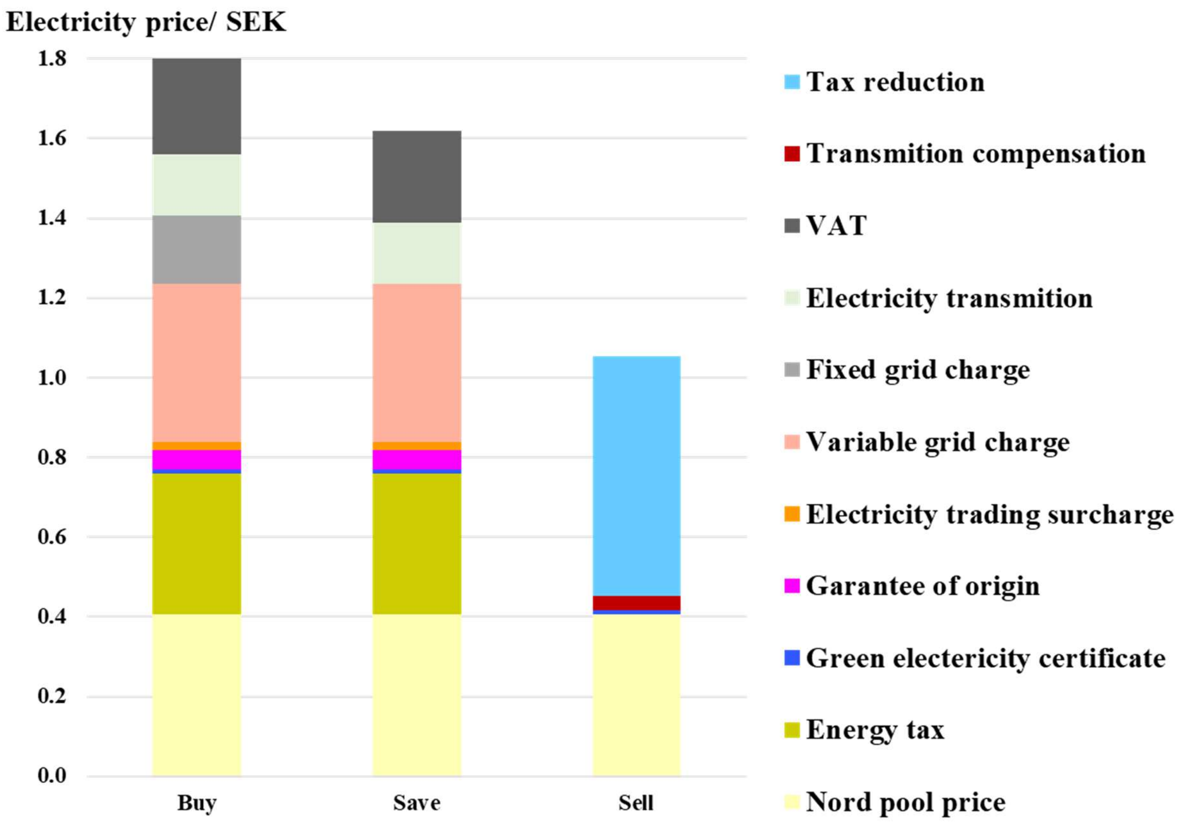

Figure 3-6: Average price for selling and buying electricity in detail. From left to right, the first column is the price for buying electricity, second is the amount that can be saved in a case of using electricity from a PV system and the third one is the electricity price for selling to the grid per kWh. The vertical axis is the price of 1 kWh.

3.6.1 NPV calculation

To assess the profitability of PV systems for approach one, the net present value of the installing PV system in 30 years life span was calculated. For this purpose, the hourly prices of selling, buying and self-usage electricity for the first year and the investment cost were calculated for each building, with the help of bellow equations.

$$A_1 = P(1 + i)^N$$

$$NPV = A_1\left(\frac{1-(1+g)^N(1+i)^{-N}}{i-g}\right)$$

$P = present\ value$

$A_1 = first\ year\ cost$

$\mathrm{i} = intrest\ rate$

$g = \mathrm{electricity\ growth\ rate}$

$\mathrm{N} = life\ span$

NPV_{total}= Investment costs + Electricity cost –Income from selling electricity
All the components of the formula above have the units of Swedish krona (SEK).

The first line of equations is for calculating first-year expenses, and the second is for calculating 30 years of prices. The rest is an explanation of items in the formula. Furthermore, the payback time of investment calculated for each building.

Although NPV can show whether a system is profitable or not, the year that a system starts to have payback is also remarkable which is known as the payback period (PBP). On the other hand, PBP is the time that the NPV will be equal to zero. Moreover, the sooner a system's PBP is, the better it performs (Pillai and Naser, 2018).

The input data for calculating NPV in the mentioned formula are shown in Table 3-2. Moreover, the forecast for electricity prices showing an increasing trend. Therefore, in this study, an alternative study of payback time was done for the average 3.7 % growth rate based on estimated price in (Statista, 2020) up to the year 2050.

Table 3-2: NPV inputs' unite and value.

NPV calculation input	Unit	Value
Electricity growth rate	%	8
Alternative electricity growth rate	%	3.7
Interest rate	%	1.45

3.7 Life Cycle Assessment

LCA analysis of PV panels was done for both cradles to grave environmental impacts and Energy Payback Time (EPBT) for roof-mounted grid-connected monocrystalline PV panels. The explanation about each of them is given followingly.

3.7.1 Environmental Impacts

In this study, six most effective environmental impacts consist of Global warming, Ozone depletion, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, and Photochemical oxidant formation were chosen to evaluate the PV systems effect during their cradle to grave life spans by employing shadow cost weighting method. To calculate the environmental impacts, the shadow cost method is used to unite the unit of the impacts and weight them. Shadow cost strategy is a practical way to present the environmental impacts of a product or activity by allocating the cost of compensating the effect of their impacts, which are different for each product (de Bruyn et al., 2010).

Besides, shadow cost calculates for various periods of a product life span. These periods are cradle to cradle and cradle to grave. The former one is the period of manufacture and using a product till recycling. However, the latter one also, contains the disposal of a product's materials. In this study, the monocrystalline PV panels' environmental impacts are presented from cradle to grave.

The impacts, as well as the shadow cost value, are listed in Table 3-3. It should be mentioned that the functional unit of the impacts is per kWh produced energy.

Table 3-3: In this table, the first column is the environmental impact name, the second is the unit of these impacts, next is the value of these impacts, and the last one is the shadow cost of each impact.

Impacts	Unit	Impacts value/ (kWh produced energy)*	Shadow cost (£/ kg pollutants)*
Global warming	kg CO2 eq	0.85	0.025
Ozone depletion	kg CFC-11-eq	1	30
Terrestrial acidification	kg SO2 eq	1	5
Fresh water eutrophication	kg PO4 eq	0.8	11
Marine eutrophication	kg N eq	0.3	7
Photochemical oxidant formation	kg NMVOC eq	1	5

* Environmental impact of PV panels (Linjord et al., 2017).

* Shadow cost value (de Bruyn et al., 2010).

Impacts values are gathered according to the study which was done in Norway on a life cycle assessment of PV panels (both BIPV and BAPV) (Linjord et al., 2017). And shadow cost value is gathered from the shadow price handbook of the Valuation and weighting of emissions and environmental impacts (de Bruyn et al., 2010).

3.7.2 Energy Payback Time (EPBT)

EPBT presents the environmental impacts by calculating the time that it takes for the green electricity that produces by a PV system to compensate for the energy that was used for manufacturing PV panels. The embodied energy for manufacturing a product is required. In this project, 4.87 GJ cumulative energy for 1 square meter of PV panel was considered (Bahlawan et al., 2020). to calculate the total cumulative energy for each building the formula bellow was used:

Total cumulative energy of a system (GJ) = Cumulative energy for 1m^2 panels (GJ/m^2) * total area of a system (m^2)

Furthermore, the average yearly generated electricity by the installed PV system were calculated to find the time, this energy gets equal to the embodied energy, which is presented as EPBT. In the next step the energy payback time was calculated with the equation below for each building:

$$\text{EPBT of a system (Year)} = \frac{\text{Total cumulative energy of a system (GJ)}}{\text{Green electricity generates with PV system in one year (GJ/Year)}}$$

4 Result

This chapter presents the results of calculations and simulation based on the methods explained in the previous chapter. Section 4.1 is assessing the results of “approach 1” as the total solar potential of the roofs. The results of “approach 2” are given in section 4.2 as the potential of designed systems. In section 4.3, the results of these two approaches are compared. This chapter is continued with the results of the shading analysis in section 4.3. Finally, the LCC and LCA calculations are presented in sections 4.4 and 4.5.

The box plot diagram was chosen to give a graphic presentation of the results. In each diagram, the boxes are highlighting were the most values are set. The vertical lines are extending from the boxes to the minimum and the maximum values of the data if these values are not outliers. Two shorter horizontal lines mark the ends of the whiskers, and outliers’ data are marked by “●”. The horizontal line inside the box presenting the Median, and the average is marked by “×” in the box.

4.1 Roofs’ potential-Approach 1

In this section, the relation between the groups in each category is presented. Table 4-1 shows the PV*SOL simulations and the calculated results for the total potential of the roof.

*Table 4-1: PV*SOL software simulation and calculated results of Approach 1.*

Age	Roof type	Location	Ventilation type	Generator output (kwp)	Total electricity use/ (kWh/year)	Covered by PV power/ (kWh/year)	Covered by grid/ (kWh/year)	Grid Feed-in / (kWh/year)	Obstacle area%	Generation area/%	Solar fraction/ %	Self usage/ %	Yield Reduction due to Shading/ %
Million-program 1	Tilted	Suburb	F	92	89 022	29 307	59 716	44 546	2	78	33	40	4
Million-program 2	Tilted	Suburb	S	89	39 119	14 213	24 906	54 714	1	67	36	21	8
Million-program 3	Tilted	Suburb	S	86	56 546	19 045	37 501	48 477	2	78	34	28	6
Million-program 4	Tilted	Suburb	F	101	126 147	38 668	87 479	38 898	9	61	31	50	5
Million-program 5	Flat	Suburb	FT	86	123 003	36 973	86 030	39 155	2	60	30	49	4
Million-program 6	Flat	Center	F	76	82 368	22 321	60 048	32 426	0	73	27	41	21
Million-program 7	Tilted	Suburb	F	84	265 648	48 654	216 995	16 369	1	86	18	75	3
Million-program 8	Flat	Center	FT	42	377 780	31 607	346 173	381	1	71	8	99	2
Million-program 9	Flat	Suburb	FVP	23	21 516	5 669	15 847	6 957	7	52	26	45	41
Million-program 10	Flat	Center	F	31	290 303	24 003	266 300	314	2	47	8	99	9
Million-program 11	Tilted	Suburb	FVP	102	368 131	71 522	296 609	8 991	13	56	19	89	5
Million-program 12	Tilted	Suburb	F	204	429 313	103 888	325 426	70 624	0	69	24	60	1
Million-program 13	Tilted	Suburb	F	54	152 253	33 212	119 041	11 128	3	73	22	75	2
Million-program 14	Tilted	Suburb	FT	94	428 841	57 431	371 411	8 810	20	56	13	87	18
Million-program 15	Tilted	Suburb	F	78	93 096	28 499	64 597	34 586	5	79	31	45	3
Million-program 16	Tilted	Suburb	FVP	125	819 527	100 052	719 475	2 059	3	63	12	98	2
Old 1	Tilted	Center	S	45	45 140	12 484	32 662	23 207	4	58	28	35	7
Old 2	Tilted	Center	S	91	67 114	21 032	46 093	53 916	9	77	31	28	2
Old 3	Tilted	Center	FtX	62	381 425	50 562	330 867	698	12	67	13	99	2
Old 4	Tilted	Center	FtX	224	1 604 672	177 143	1 427 542	3 985	3	68	11	98	4
Old 5	Tilted	Center	FtX	37	177 516	24 884	152 632	2 660	23	50	14	90	16
Old 6	Tilted	Center	FT	245	866 790	156 531	710 261	49 594	10	53	18	76	2
Old 7	Tilted	Center	FT	206	385 483	90 256	295 230	57 877	1	67	23	61	11
Young 1	Tilted	Center	S	63	60 824	18 129	42 695	32 694	11	51	30	36	8
Young 2	Tilted	Center	S	47	27 553	9 310	18 243	25 925	8	67	34	26	7
Young 3	Tilted	Center	S	6	6 542	1 704	4 838	1 925	10	40	26	47	26
Young 4	Tilted	Center	FTX	29	102 864	17 229	85 635	1 983	28	30	17	90	13
Young 5	Flat	Center	FTX	30	700 160	25 698	674 462	0	1	55	4	100	8
Young 6	Flat	Center	FVP	31	332 903	25 231	307 672	35	2	58	8	100	13
Young 7	Flat	Center	FVP	239	686 597	129 989	556 608	29 058	48	83	19	82	27

4.1.1 The relation between ventilation types

The results are presented for this category in 5 different groups, based on ventilation system types. The buildings are divided into 5 groups, as shown in Table 4-2.

Table 4-2: Buildings ventilation system types.

Ventilation system types	Number of buildings
F	8
FVP	5
FT	5
FTX	5
S	7

Total electricity use: The ratio of total electricity demand (common and household) to the heated floor area is illustrated in Figure 4-1. As the results indicate, electricity demand in the buildings with FTX system is the highest. The second highest electricity use is in buildings with FVP system. Electricity demand in buildings with F and FT system is almost the same. The lowest electricity use was calculated for the buildings with S system.

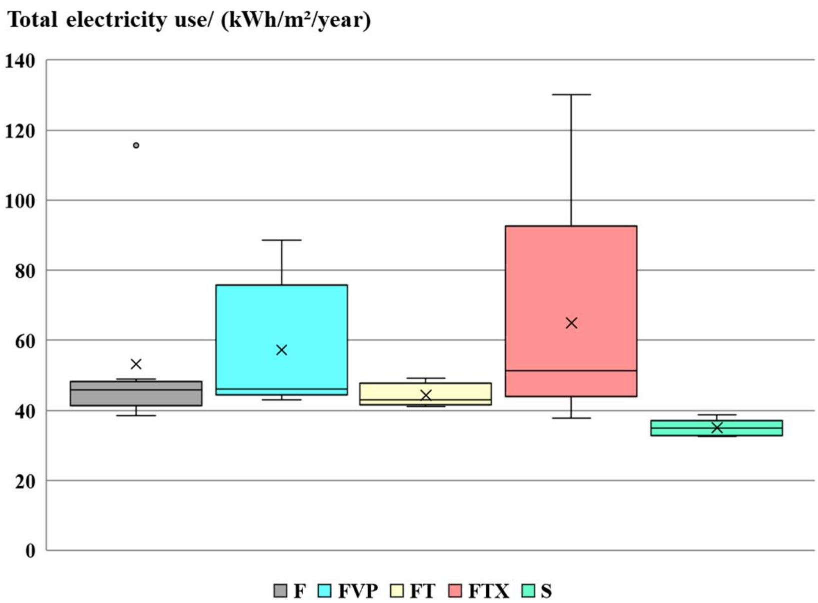

Figure 4-1: Total electricity use in the buildings, based on 5 different ventilation types. The vertical axis shows the electricity use per heated floor area in kWh/m^2, and the horizontal axis presents the ventilation types.

Generation area: The ratio of total available area for mounting the PV arrays to the total roof area is shown in Figure 4-2. The highest available rooftops for installing the PV system belong to the buildings with F and S system, respectively. The buildings with the FTX system have the lowest available area.

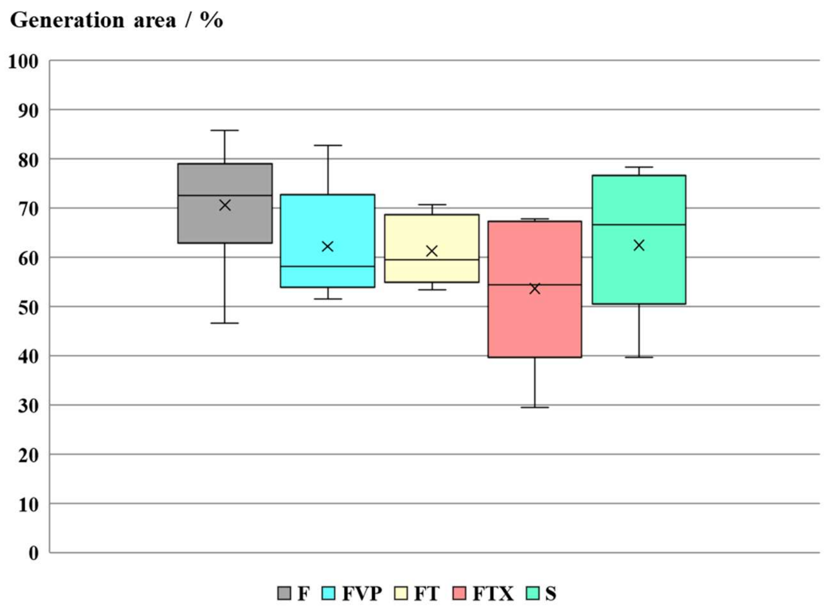

Figure 4-2: The ratio of available area for installing PV panels to the roof area, based on 5 different ventilation types. The vertical axis is the generation area in percent, and the horizontal axis presents the ventilation types

Obstacles area: the ratio of the total area occupied by installations on the roofs to the total roof area is shown in Figure 4-3. Buildings with F system has the highest Median obstacle ratio. This value is the lowest in the buildings with the FT system.

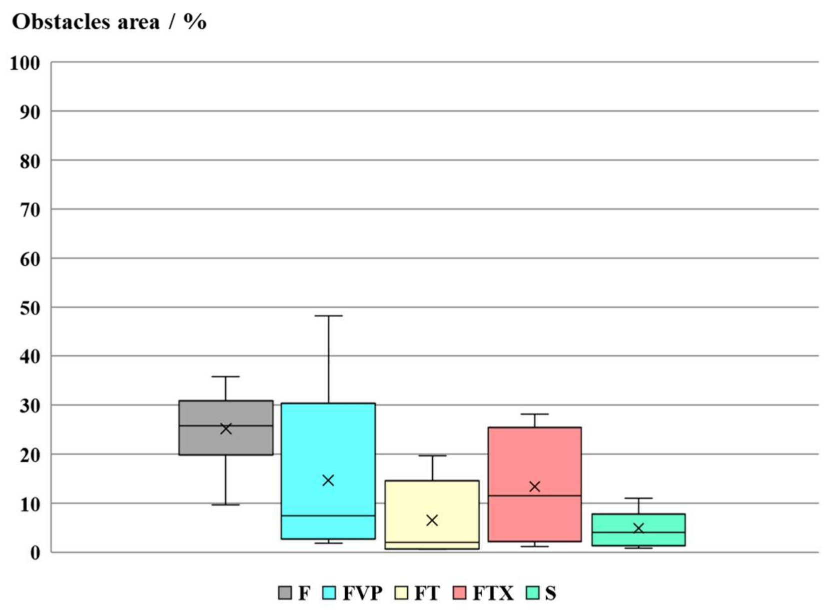

Figure 4-3: Ratio of roofs' obstacles area to total roof area based on ventilation types. The vertical axis shows the obstacles area in percent, and the horizontal axis presents the ventilation types.

Self-usage: Figure 4-4 presents the amount of generated electricity by the PV system, which was directly used in the buildings. This factor has the highest value in the buildings with the FTX ventilation system and the lowest value in the buildings with S system. With this factor, the amount of supplied electricity to the grids can also be concluded as a complementary factor.

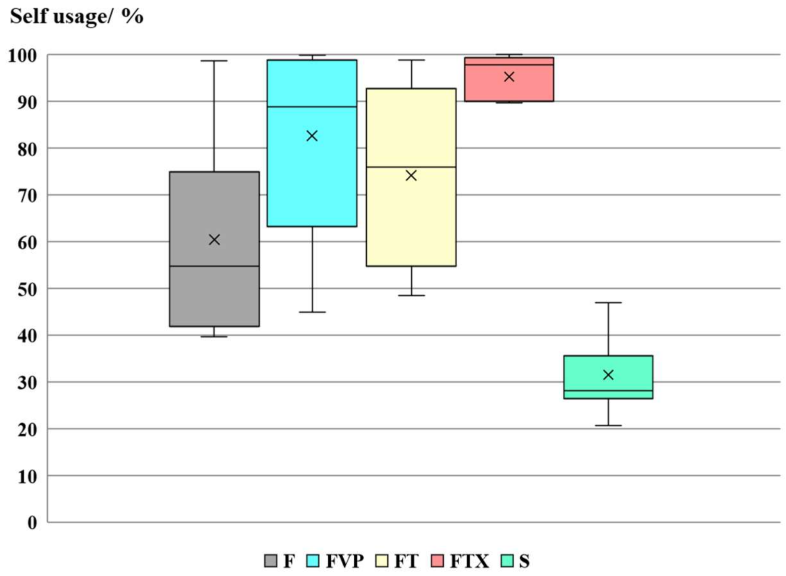

Figure 4-4: The percentage of total electricity generated by the PV system, which was used directly in the buildings based on 5 ventilation system types. The vertical axis illustrates the self-usage in percent, and the axis presents the ventilation types.

Solar fraction: The solar fraction factor indicates the amount of electricity demand of the buildings, which was covered by supplied electricity from the PV system.

Figure 4-5 shows solar fraction based on ventilation system types. As shown in the graph, 12 % to 31 % of total electricity demands in the buildings are covered by PV systems. This factor has the highest value in the building with S system and the lowest value in FTX group.

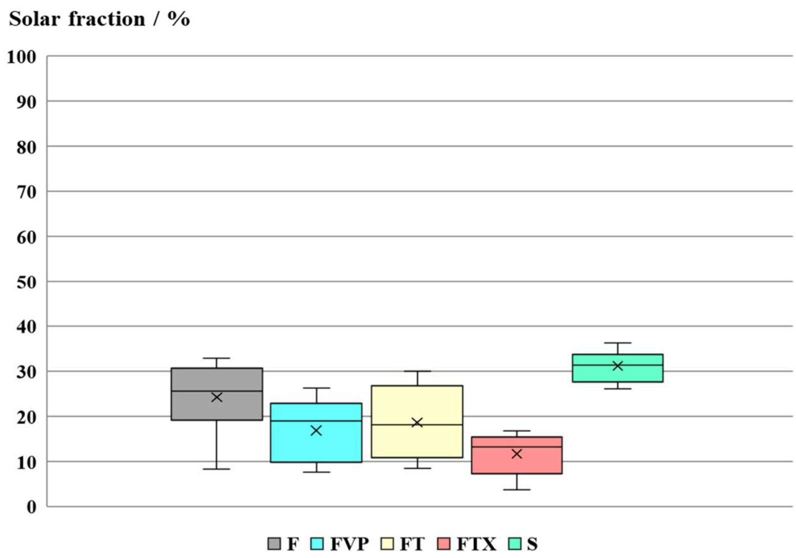

Figure 4-5: Solar fraction (buildings' electricity demand covered by PV system per total consumption) based on ventilation types. The vertical axis is the solar fraction in percent and the horizontal axis presents the ventilation types.

4.1.2 The relation between age of the buildings

The following graphs in this section are the result of the systems' potential based on the age of the buildings.

Buildings in this category were divided into 3 groups, as shown in Table 4-3.

Table 4-3: Buildings division group based on age.

Buildings age group	Number of buildings
Young	7
Old	16
Million-program	7

Generation area: The ratio of the total available area for installing the PV arrays to the total roof area was calculated for each group of the age category. As Figure 4-6 displays, from 55 % to 67 % of the rooftops are available for installing the PV system. However, young buildings have lower value in comparison to other groups.

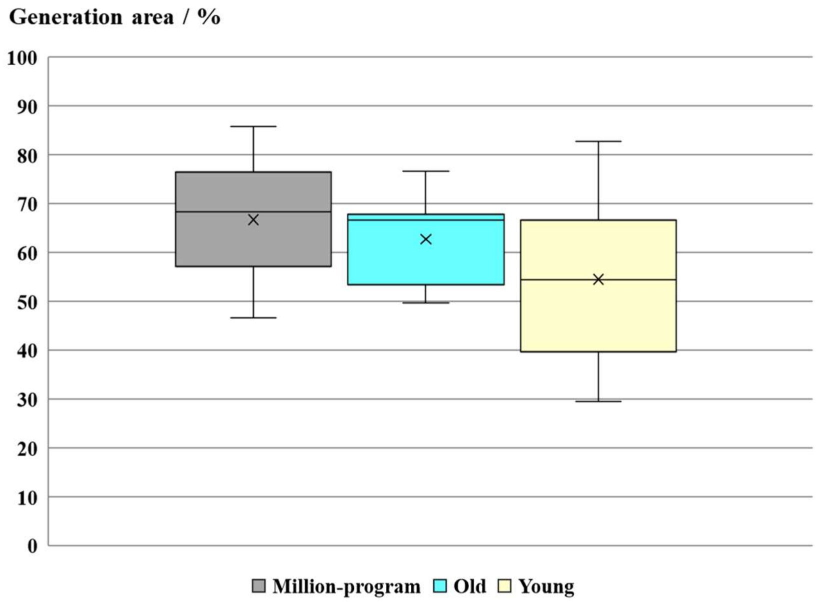

Figure 4-6: The ratio of available area for installing PV panels to the roof area for 3 groups of age category. The vertical axis is the generation area in percent, and the horizontal presents the groups of the age category.

Obstacles area: the ratio of the total area occupied by installations on the roofs to the total roof area is illustrated in Figure 4-7, the Median value of this ratio indicates that buildings in the million-program group had the lowest installation on the roof while for the old and young buildings groups this value is almost the same.

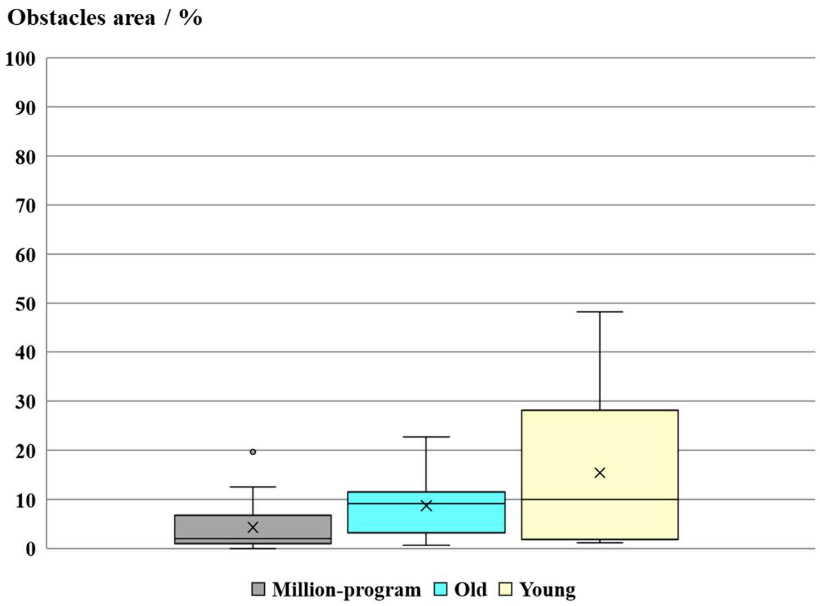

Figure 4-7: Ratio of roofs' obstacles area to the total roof area for 3 groups of age category. The vertical axis shows the obstacles area in percent, and the horizontal axis is the box plots of the age categories.

Total electricity use: The ratio of total electricity demand (common and household) to the total heated floor area for each group of age is shown in Figure 4-8. The Median values show higher electricity use for young buildings. 3 outliers values in the million-program group are noticeable in this graph. The difference between the maximum value in the groups is considerable. For buildings over 40 years old, i.e., million-program and old group, the maximum yearly electricity usage is 64 kWh/m² and 55 kWh/m² respectively, while the maximum electricity use for young buildings was calculated up to 130 kWh/m².

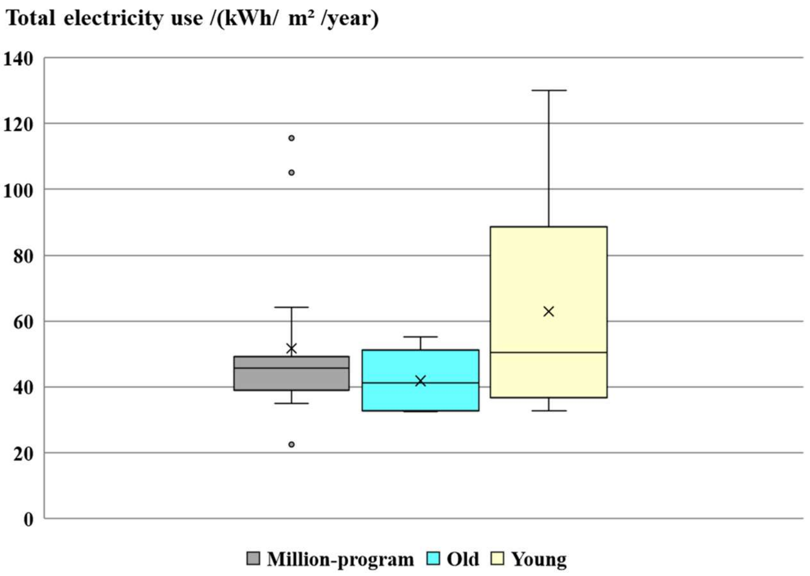

Figure 4-8: Total electricity use in the buildings for 3 groups of age category. The vertical axis shows the consumption per total heated floor area of the buildings in kWh/m². and the horizontal presents the groups of age category.

Self-usage: The amount of supplied electricity which was used directly in the buildings, based on the buildings ‘age is shown in Figure 4-9. The median values indicate that this factor for buildings in the million-program group is the lowest. Buildings in young and old groups show a similar result.

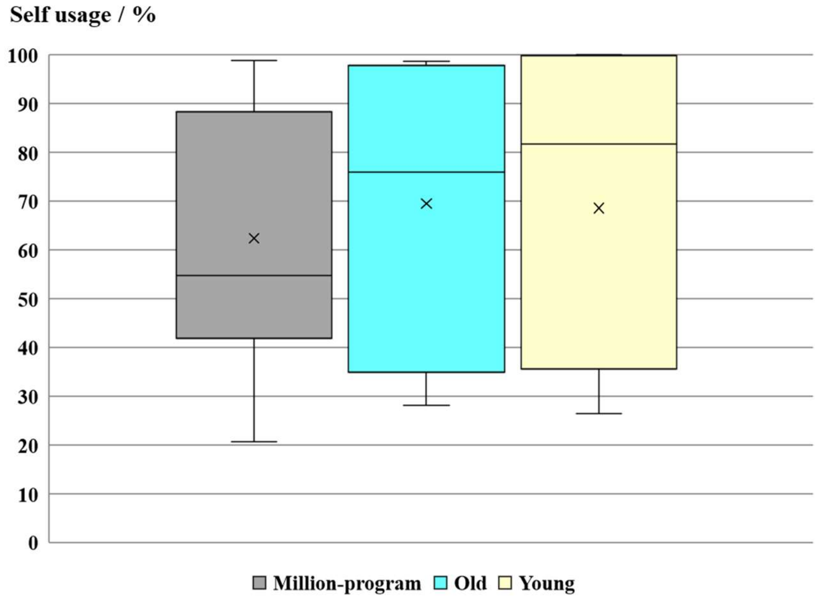

Figure 4-9: The percentage of total electricity generated by the PV system, which was used directly in the buildings for 3 groups of the age category. The vertical axis illustrates the self-usage in percent, and horizontal presents the groups of age category.

Solar fraction: The amount of electricity demand of the buildings which was covered by supplied electricity from PV systems is presented in Figure 4-10 for each group. Solar fraction for the million-program group is higher compared to the other groups.

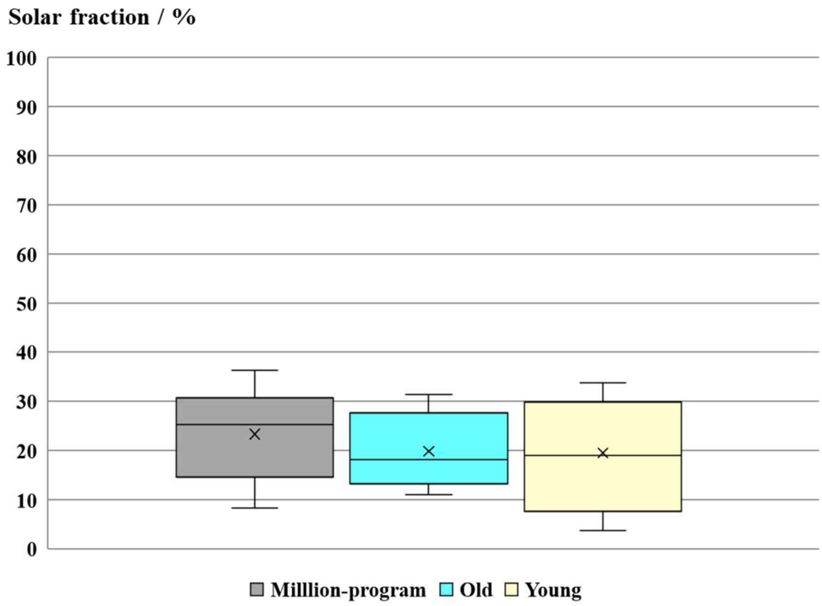

Figure 4-10: Solar fraction (buildings demand cover by PV per total consumption) comparison area for 3 groups of age category. The vertical axis is the solar fraction in percent, and the horizontal axis presents the groups of the age category.

4.1.3 The relation between the location of buildings

In this section, the output of the systems is investigated based on their location. This category divides buildings into two groups, as shown in Table 4-4.

Table 4-4: Buildings division based on location category.

Buildings location group	Number of buildings
Center	17
Suburb	13

Generation area: The ratio of the total available area for mounting the PV arrays to the total roof area is shown in Figure 4-11. The median value in this graph indicates that for the buildings in the center, the available installation area is 10 % less than the suburban buildings.

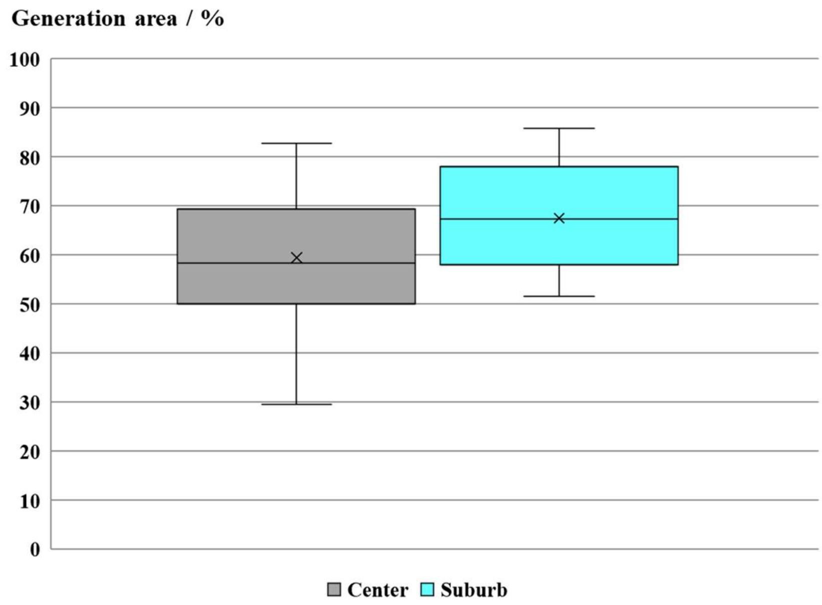

Figure 4-11: The ratio of available area for installing PV panels to the roof area for buildings in the center and suburb. The vertical axis is the generation area in percent, and the horizontal axis presents the locations.

Obstacles area: Figure 4-12, shows the ratio of the total area of obstacles in the roofs to the roof area. This ratio indicates that less than 10 % average of the roofs area is occupied with the installations. The median value is higher in the center group. The outliers in both groups are notable.

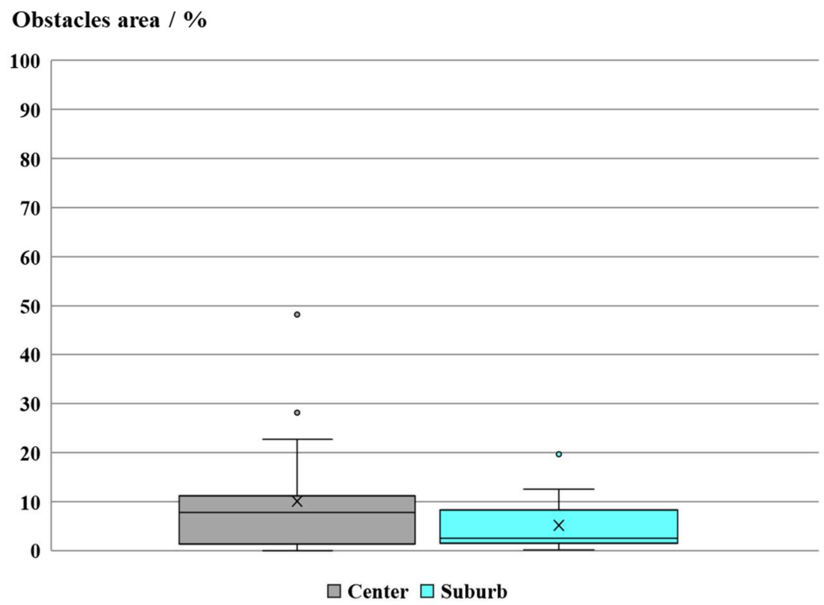

Figure 4-12: Percentage of roofs' obstacles area to total roof area based on the location (the center and suburb) of buildings. The vertical axis shows the obstacles area in percent, and the horizontal axis is the box plots of the locations.

Total electricity generation: The total electricity generation per roof area for the buildings in the center and suburbs are compared in Figure 4-13. The median value of generation per roof area for buildings located in the center of city is 88 kWh/m² which is almost 15 % less than the suburban buildings.

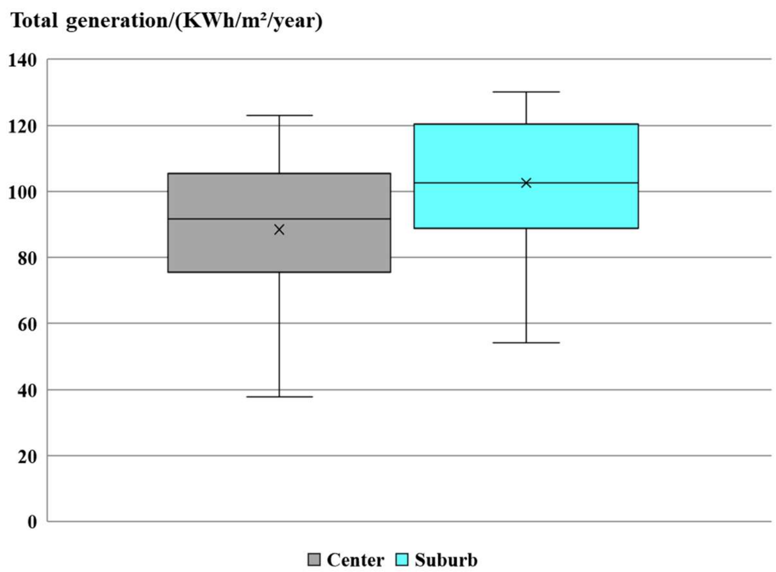

Figure 4-13: Total electricity use per heated floor area for buildings in the center and suburb. The vertical axis refers to the total electricity use, and the horizontal axis presents the locations.

Self-usage: The amount of generated electricity which was used directly in the buildings based on the buildings 'location is shown in Figure 4-14. The median value in this graph for buildings located in the center is 82 % while for suburban building the self-usage ratio is 50 %.

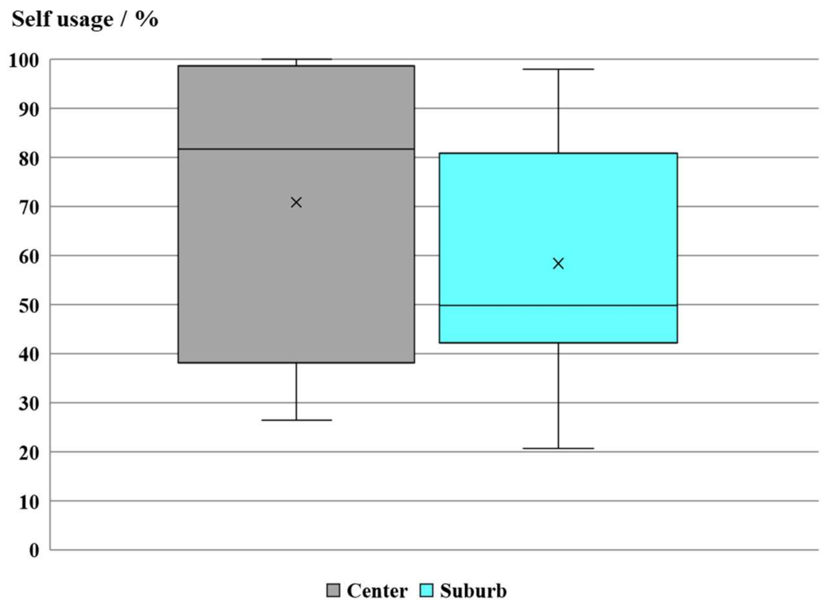

Figure 4-14: The percentage of total electricity generated by the PV system, which was used directly in the buildings, based on the location. The vertical axis illustrates the self-use in percent, and the horizontal axis presents the locations.

Solar fraction: This factor specifies the amount of electricity demand of the buildings, which was covered by supplied electricity from the PV system. As shown in Figure 4-15 difference between median solar fraction in the center and suburb is 10 %.

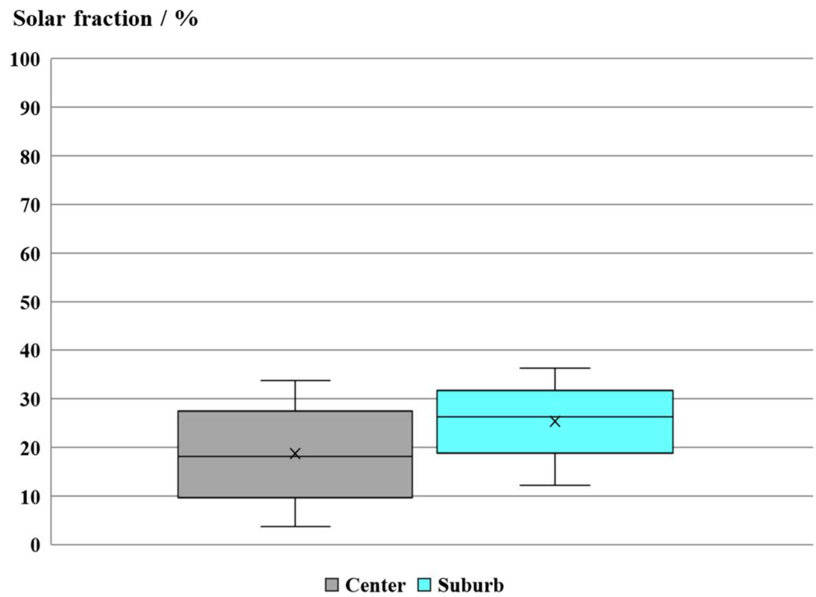

Figure 4-15: Solar fraction (buildings demand cover by PV per total consumption) comparison based on locations of the buildings. The vertical axis is the solar fraction in percent, and the horizontal axis is the box plots of the locations.

4.1.4 The relation between roof types

In this section, the effect of roof types on the systems output and potential is investigated. The buildings in this category are presented in two groups, as shown in Table 4-5.

Table 4-5: Buildings division based on roof types category.

Buildings division based on roof types	Number of buildings
Tilted	22
Flat	8

Generation area: Figure 4-16 shows the available area on the roof for installing the PV arrays as the ratio of the total roof area. The median value in these two groups is 57 % for flat roofs and 66 % for tilted roofs. The distribution of the result for tilted roofs is notable.

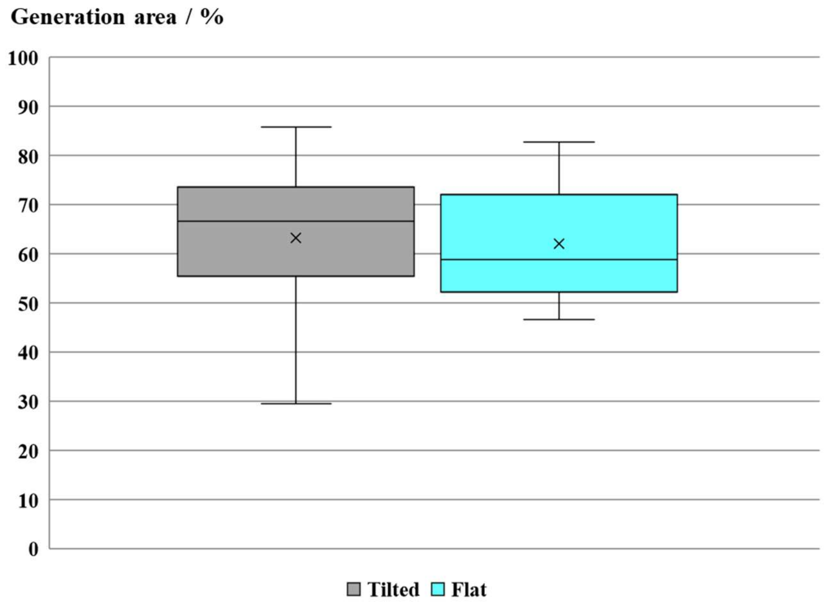

Figure 4-16: The ratio of available area for installing PV panels to the roof area based on tilted and flat roofs. The vertical axis is the generation area in percent, and the horizontal axis presents the roof types.

Obstacles area: The ratio of installation on the roof to the total roof area for tilted and flat roofs is shown in Figure 4-17. Outliers are seen in both groups, and the maximum ratio in Tilted groups is significantly higher than the flat group.

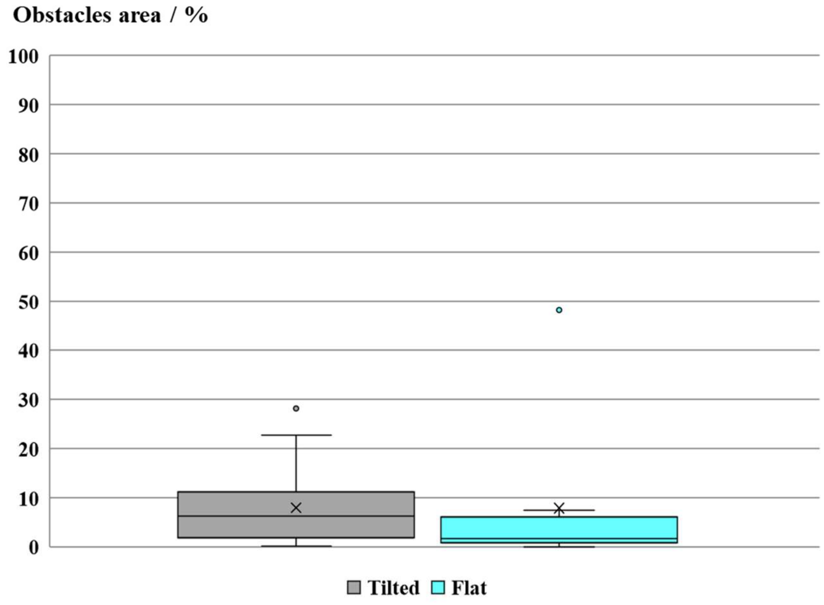

Figure 4-17: Ratio of roofs' obstacles area to total roof area based on the roof type. The vertical axis shows the obstacles area in percent, and the horizontal axis presents the roof types.

Total generation: Total electricity generation per roof area is shown in Figure 4-18; the median value of this ratio shows the generated electricity in both tilted and flat roofs was similar.

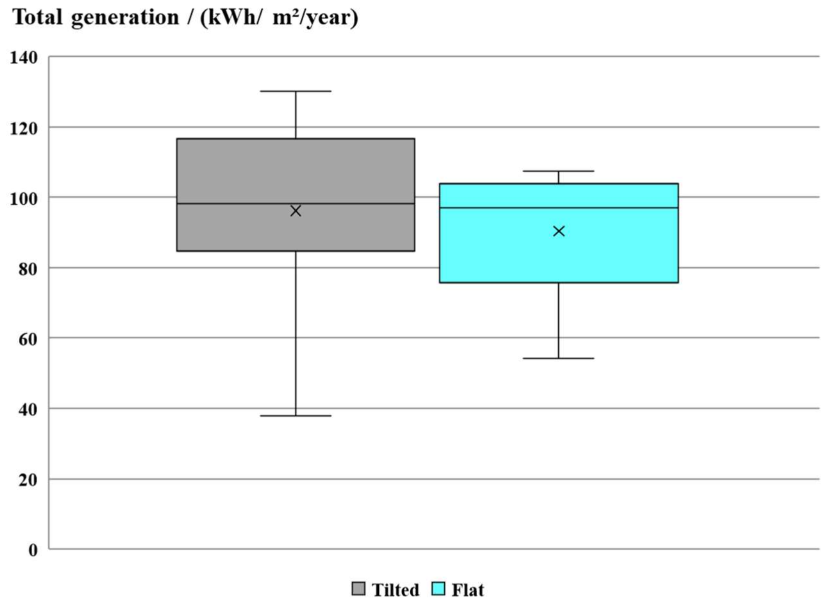

Figure 4-18: Total generated electricity per roof area *based on the roof types*. The vertical axis refers to the total generation, and the horizontal axis presents the *roof types.*

Self-usage: The percentage of supplied electricity that is directly used in the buildings with flat and tiled roofs is shown in Figure 4-19. The median value indicates that 90 % of generated electricity was directly used in the buildings with the flat roof, while this value is 61 % when the building's roof is tilted. For both groups, this factor was calculated up to 100 %.

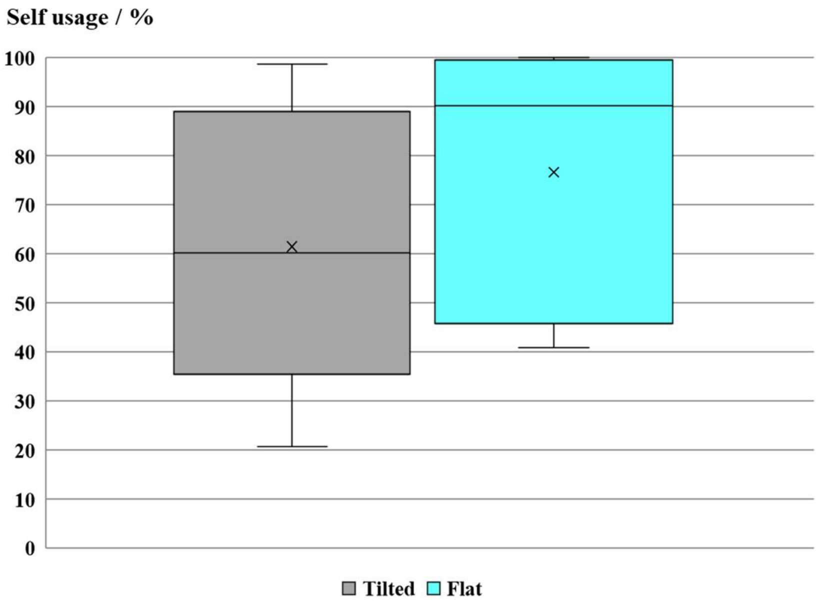

Figure 4-19: The percentage of total electricity generated by the PV system, which was used directly in the buildings, based on roof types. The vertical axis illustrates the self-consumption in percent, and the horizontal axis presents the roof types

Solar fraction: the ratio of total electricity need in the buildings with different roof types are shown in Figure 4-20. This ratio shows 7.3 % higher value in the buildings with the tilted roof.

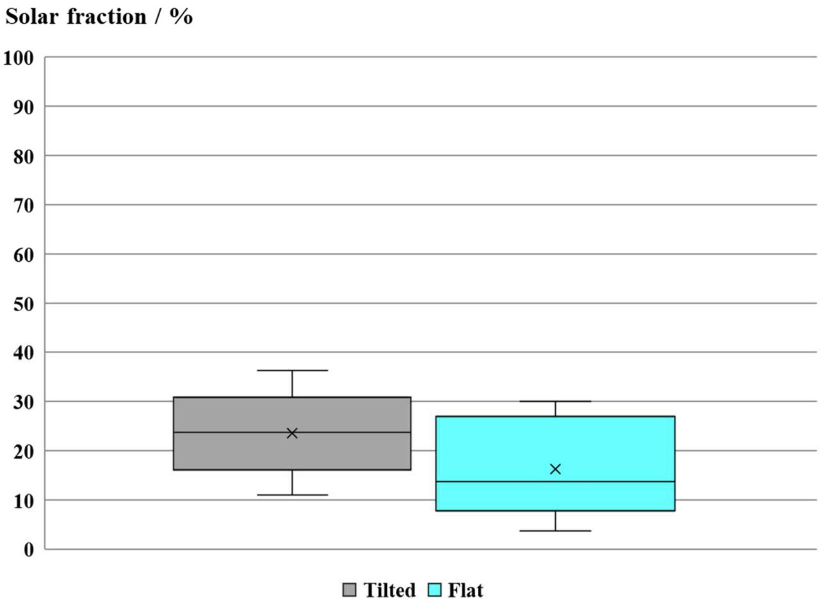

Figure 4-20: Solar fraction (buildings demand cover by PV per total consumption) comparison based on roof types (tilted and flat) of buildings. The vertical axis is the solar fraction in percent, and the horizontal axis presents the roof types.

4.2 Roofs' potential-approach 2

Table 4-6 Shows the PV*SOL simulations results and calculated results for all 30 buildings based on the best roof area and building common electricity demand (see section 3.2.1).

*Table 4-6: PV*SOL software simulation and calculated results of Approach 2.*

Age	Roof type	Location	Ventilation type	Generator output (kwp)	Total electricity use/ (kWh/year)	Covered by PV power/ (kWh/year)	Covered by grid/ (kWh/year)	Grid Feed-in / (kWh/year)	Obstacle area%	Generation area/%	Solar fraction/ %	Self usage/ %	Yield Reduction due to Shading/ %
Million-program 1	Flat	Center	F	48	27 205	11 288	15 917	25 027	2	77	41	31	4
Million-program 2	Tilted	Suburb	F	50	4 335	2 177	2 158	44 681	1	63	50	5	6
Million-program 3	Flat	Center	FT	48	9 273	4 146	5 127	35 684	2	73	45	10	4
Million-program 4	Flat	Suburb	FVP	55	40 529	16 335	24 194	37 371	9	59	40	30	4
Million-program 5	Flat	Center	F	53	45 594	18 283	27 311	28 789	2	58	40	39	4
Million-program 6	Tilted	Suburb	FT	38	30 027	10 426	19 602	20 549	0	53	35	34	16
Million-program 7	Tilted	Suburb	F	40	52 103	17 563	34 540	21 719	1	79	34	45	3
Million-program 8	Tilted	Suburb	FVP	35	123 518	27 697	95 821	3 819	1	58	22	88	2
Million-program 9	Tilted	Suburb	F	23	17 008	4 940	12 069	7 686	7	52	29	39	41
Million-program 10	Tilted	Suburb	S	24	212 463	20 452	192 011	434	2	37	10	98	10
Million-program 11	Tilted	Suburb	S	98	189 945	58 380	131 565	21 141	13	54	31	73	2
Million-program 12	Tilted	Suburb	F	103	98 147	38 497	59 650	48 588	0	69	39	44	1
Million-program 13	Flat	Suburb	FT	27	49 333	15 077	34 256	4 913	3	73	31	75	2
Million-program 14	Tilted	Suburb	FVP	70	119 714	34 628	85 087	20 570	20	42	29	63	8
Million-program 15	Tilted	Suburb	F	36	30 174	11 101	19 075	23 957	5	77	37	32	2
Million-program 16	Tilted	Suburb	F	69	577 947	53 566	524 381	9	3	63	9	100	2
Old 1	Tilted	Center	S	20	1 822	793	1 029	15 334	4	58	44	5	7
Old 2	Tilted	Center	S	91	3 533	1 380	2 165	73 568	9	77	39	2	2
Old 3	Tilted	Center	FTX	62	236 531	48 541	187 994	2 720	12	67	21	95	2
Old 4	Tilted	Center	FTX	220	704 688	159 105	545 592	21 014	3	68	26	100	4
Old 5	Tilted	Center	FTX	31	70 078	18 756	51 322	7 631	23	37	27	71	7
Old 6	Tilted	Center	FT	212	231 199	79 917	151 282	113 255	10	53	35	41	2
Old 7	Tilted	Center	FT	103	99 854	36 060	63 795	47 827	1	44	84	100	2
Young 1	Tilted	Center	S	51	11 964	5 247	6 717	38 565	11	48	44	12	8
Young 2	Tilted	Center	S	23	1 469	705	764	19 708	8	63	48	3	6
Young 3	Tilted	Center	S	2	991	369	622	1 045	10	31	37	26	19
Young 4	Tilted	Center	FTX	22	39 579	11 770	27 809	4 704	28	23	30	71	4
Young 5	Flat	Center	FTX	30	533 194	25 832	507 362	0	1	55	5	100	8
Young 6	Flat	Center	FVP	31	216 498	24 989	191 509	277	2	53	12	99	6
Young 7	Flat	Center	FVP	115	348 409	79 958	268 452	12 493	48	40	23	86	10

4.3 Comparison of two designing approaches

In this section, the output and solar potential of the PV systems, calculated for “approach 1” and “approach 2,” is compared together.

4.3.1 Comparison of electricity use profile for two approaches.

Figure 4-21 illustrates the total electricity demands in the building. As the diagram shows, 55 % of the total electricity use in the buildings belongs to the building’s common electricity use.

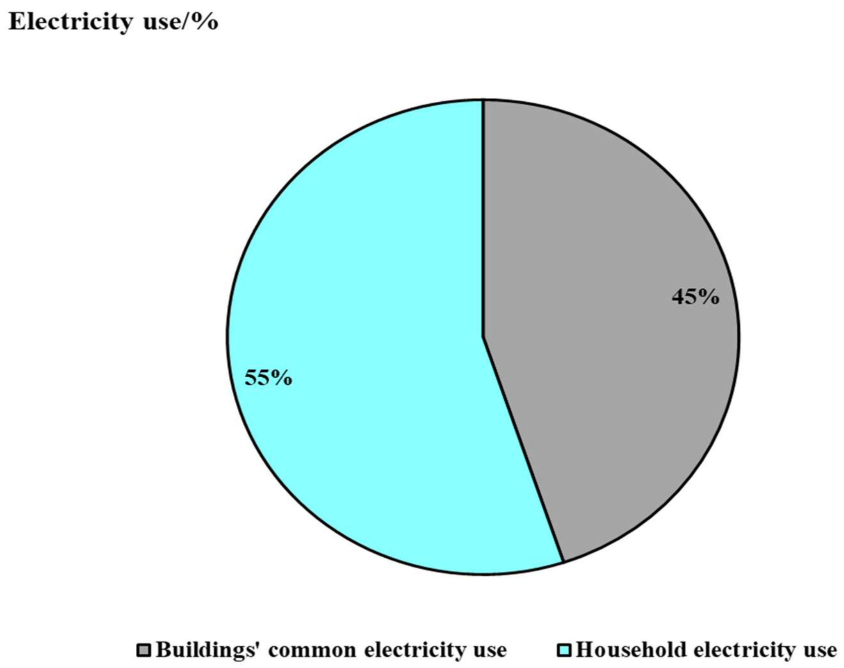

Figure 4-21: Total electricity use in the buildings divided into the building’s common electricity and household electricity.

The changes in systems ‘generator power (kWp) and self-use factor, as well as the amount of electricity for feeding to the grid by designing the systems are shown in Figure 4-22.

By designing the systems based on second approach, as explained in section 3.3.1, the generator output is reducing by 41 %. While the needed electricity from the grid increase by 10 %. The supplied electricity for selling to the grid is also increased by 3 %.

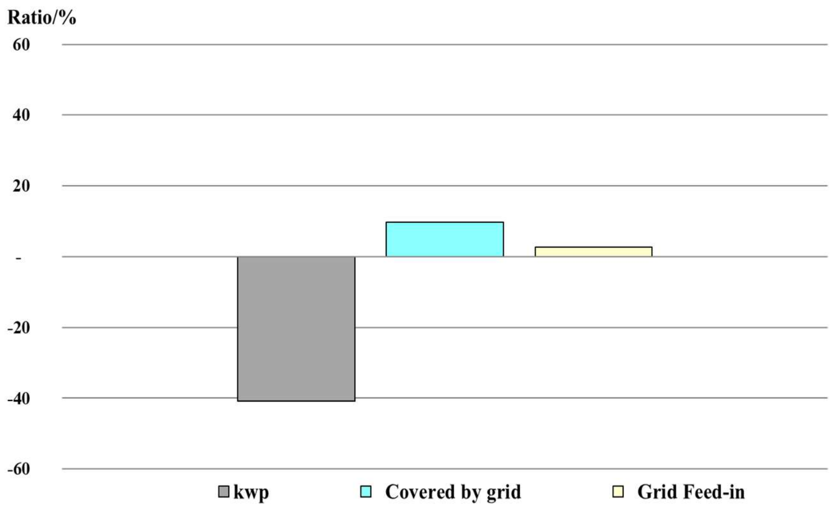

Figure 4-22: The changes in the average generator output and potential by designing the system based approach 2 in this study. The vertical axis shows the ratio of the change, and the horizontal axis shows the generator output, electricity demand covered by the grid and surplus of supplied electricity

4.4 Shading analysis result

The effect of shading on the systems' output is presented in terms of "Yield reduction due to shadings." Which signifies the total reduction in the level of irradiated energy. Figure 4-23 shows how each shading factors affect full-load irradiation energy. the total reduction because of every possible shade on the system is 9 %.

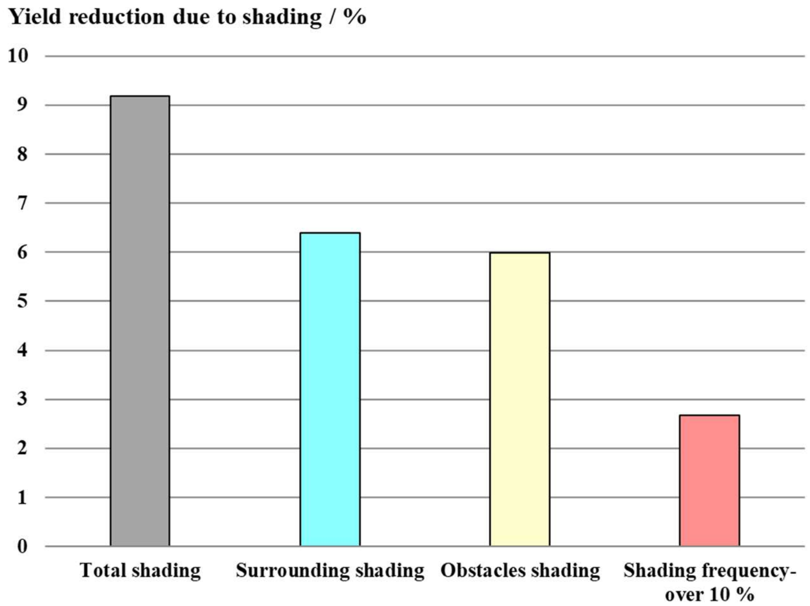

Figure 4-23: The percentage of annual yields reduction in systems for all shading factors. The vertical axis shows Yield reduction due to the shading factor, and the horizontal axis is the shading factor.

Surrounding shading: the shadings which were created only by nearby buildings and trees reduce the annual yield by 6.4 %

Obstacles shading: the shadings created by the installation on the roofs regardless of the surrounding effects set 6 % annual yield reduction in the systems.

Shading frequency: calculating the effect of shading frequency on PV arrays indicates that 2.7 % of the total reduction in the systems is the effect of shadings with higher than 10 % frequency.

4.5 Life cycle cost

This section presents the profitability of the systems in terms of net present value and the investment payback time over 30 years. The payback time was calculated for the current electricity price with 0.8 % growth rate as well as predicted price with 3.7 % growth rate. The amount of electricity usage in the buildings showed a significant effect on the financing results. Since in the ventilation type and age category the electricity demand for each group is exclusive, the results of financial calculations are presented with these two categories.

NPV factor: The net present value of each system according to investment cost, electricity cost, and income from selling electricity to the grid was calculated for 30 years and is shown in Figure 4-24 and Figure 4-25. The NPV factor is the total NPV for one square meter of the heated floor area that was normalized with the maximum NPV value. The NPV factor for young buildings shows the highest value in the age category.

In the ventilation type category, the buildings with exhaust air and heat pump ventilation system have the highest NPV factor median while the buildings with exhaust and supply ventilation systems have the lowest value.

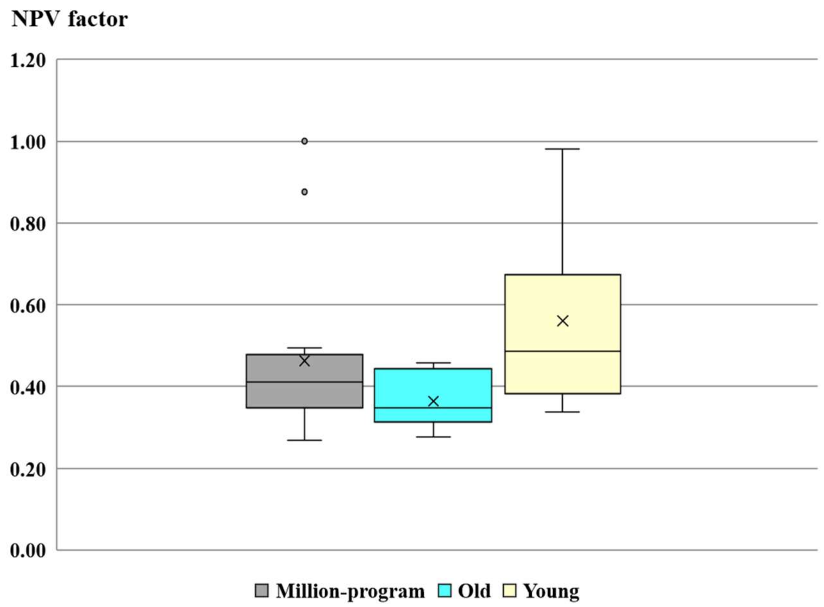

Figure 4-24: Normalized NPV (total cost of each building normalization based on maximum) based on 3 different age categories. The vertical axis is the normalized NPV, and the horizontal axis is the box plots of the 3 different age categories.

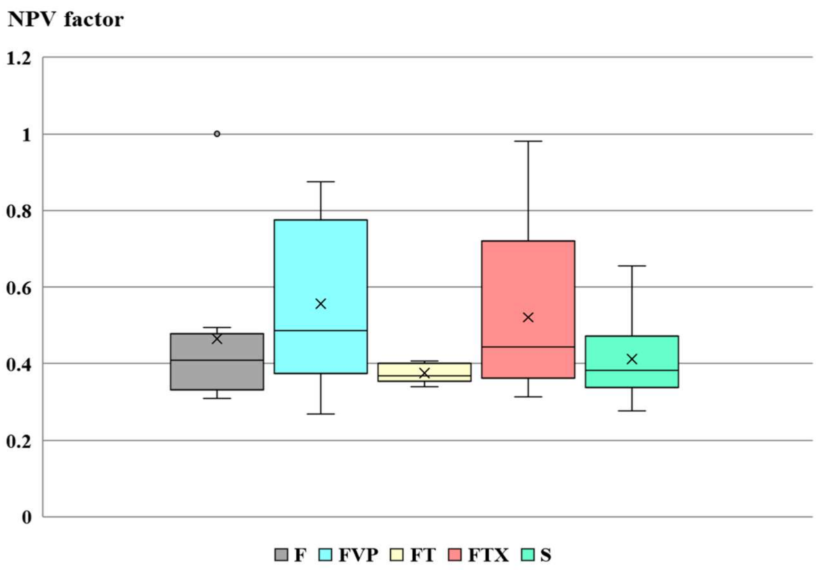

Figure 4-25: Normalized NPV (total cost of each building normalization based on maximum) based on 5 different ventilation categories. The vertical axis is the normalized NPV, and the horizontal axis is the box plots of the 5 different ventilation categories.

Payback time: The investment payback time based on current electricity price is presented in Figure 4-26 and Figure 4-27. Afterward, the payback time based on predicted electricity price is shown in Figure 4-28 and Figure 4-29.

As Figure 4-26 shows, the median payback time based on current electricity prices for every ventilation system is more than 25 years. Buildings with exhaust air ventilation system and natural ventilation did not have profit in 30 years. Figure 4-27 shows that young buildings will not be profitable for 30 years.

Figure 4-28 and Figure 4-29 show that by considering the predicted growth rate for electricity price, the payback time will occur during 18 to 25 years for most of the building. For buildings with natural ventilation, this time is over 25 years.

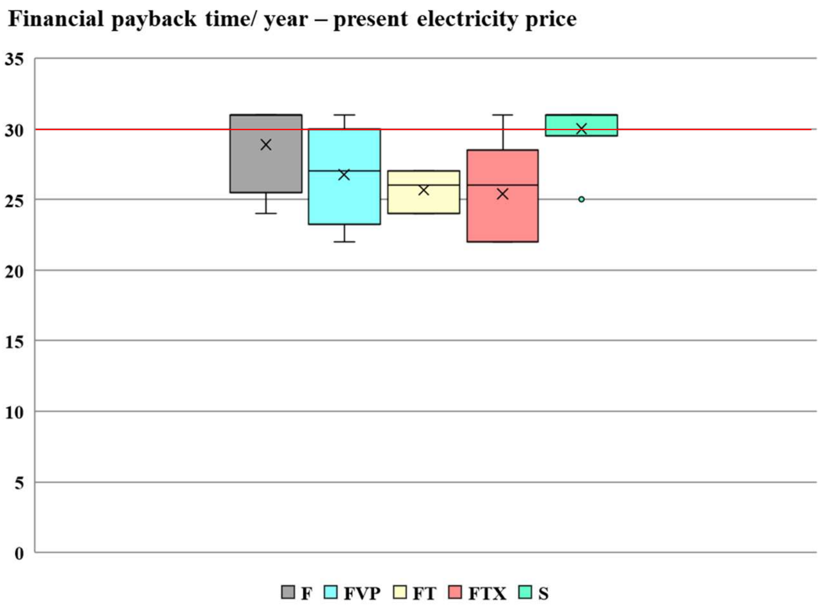

Figure 4-26: Financial payback time based on ventilation system types category for present electricity price. The vertical axis is the payback time for the present electricity price, and the horizontal axis is the box plots of the 5 different ventilation categories.

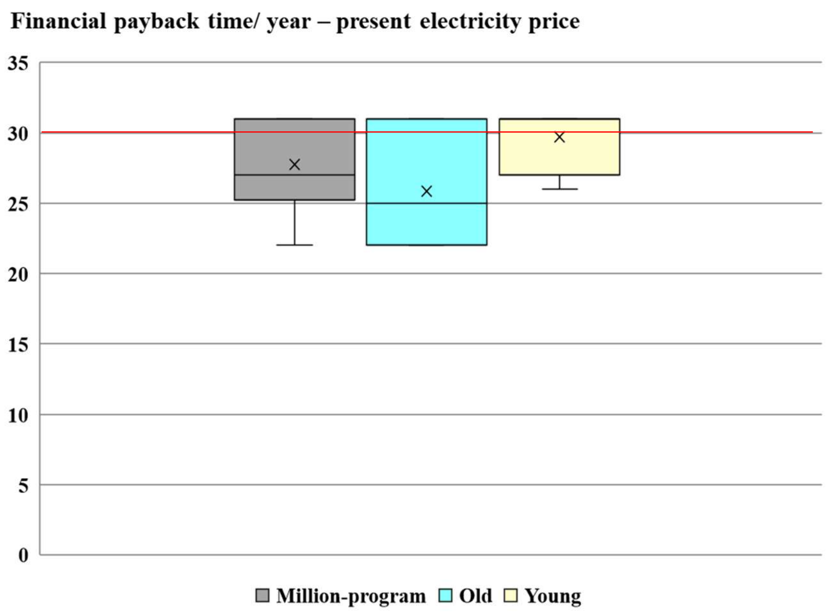

Figure 4-27: Financial payback time based on age category for the present electricity price. The vertical axis is the payback time for the present electricity price, and the horizontal axis is the box plots of the 3 different age categories.

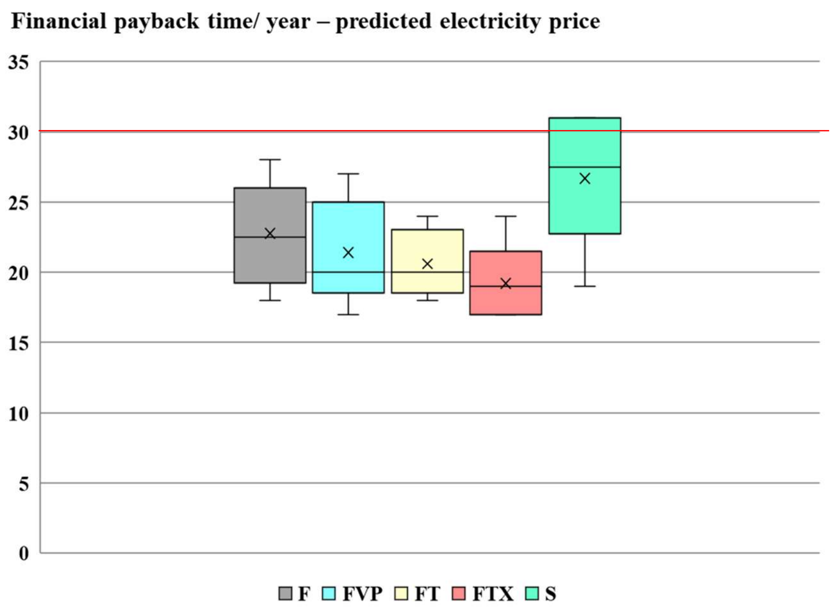

Figure 4-28: Financial payback time based on ventilation system types category for predicted electricity price. The vertical axis is the payback time for predicted electricity price, and the horizontal axis is the box plots of the 5 different ventilation categories.

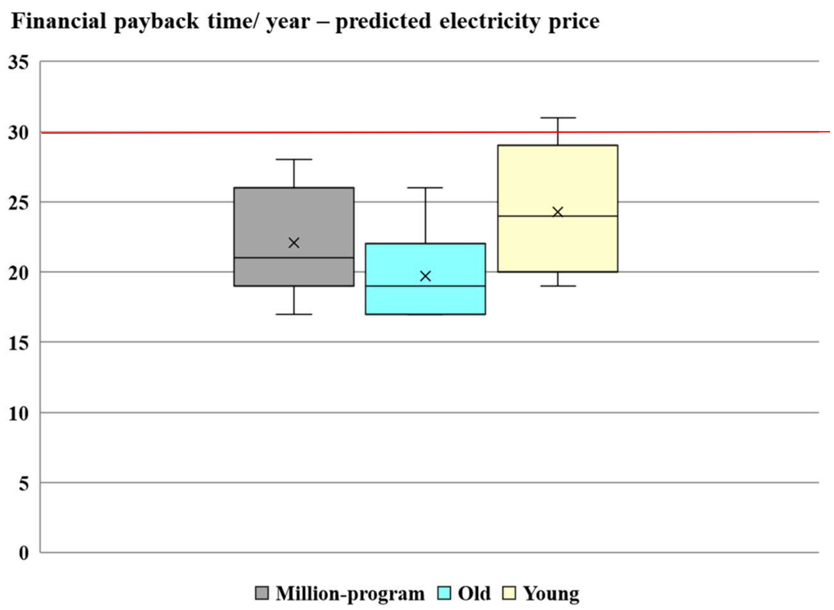

Figure 4-29: Financial payback time based on age category for the present electricity price. The vertical axis is the payback time for predicted electricity price, and the horizontal axis is the groups of age category.

4.6 Life cycle assessment

In this section, the environmental impacts of producing PV panels are presented in terms of LCA factor and energy payback time.

LCA factor: the effect of manufacturing PV panels on 5 environment impacts, as explained in section 3.6, are presented in Figure 4-30 and Figure 4-31 for the age and ventilation type categories. The median LCA factor for all the ventilation types is almost the same, while in the FVP group, the minimum value is the lowest. This difference in this factor is more evident in the groups of age category. The old building is having a higher effect on the environment.

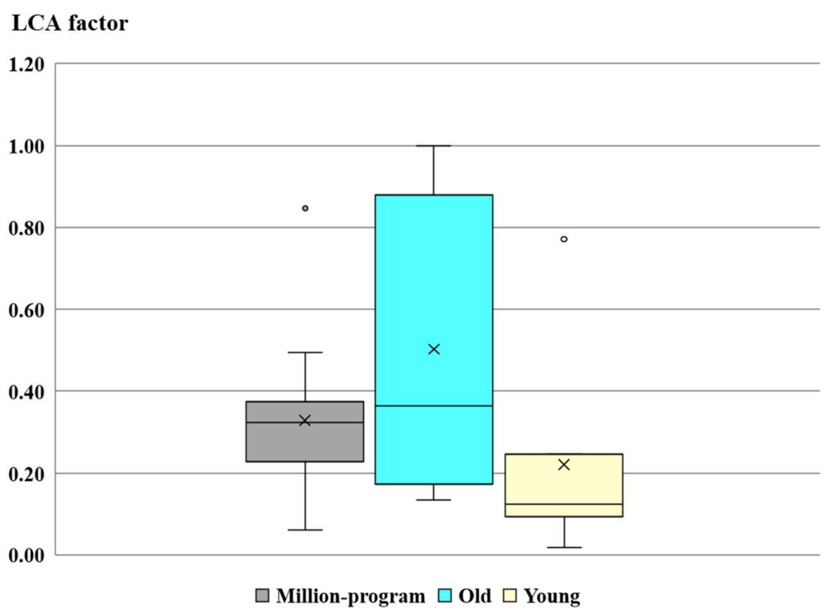

Figure 4-30: Normalized LCA based on 3 different age categories. The vertical axis is the normalized LCA, and the horizontal axis is presenting the groups of age categories.

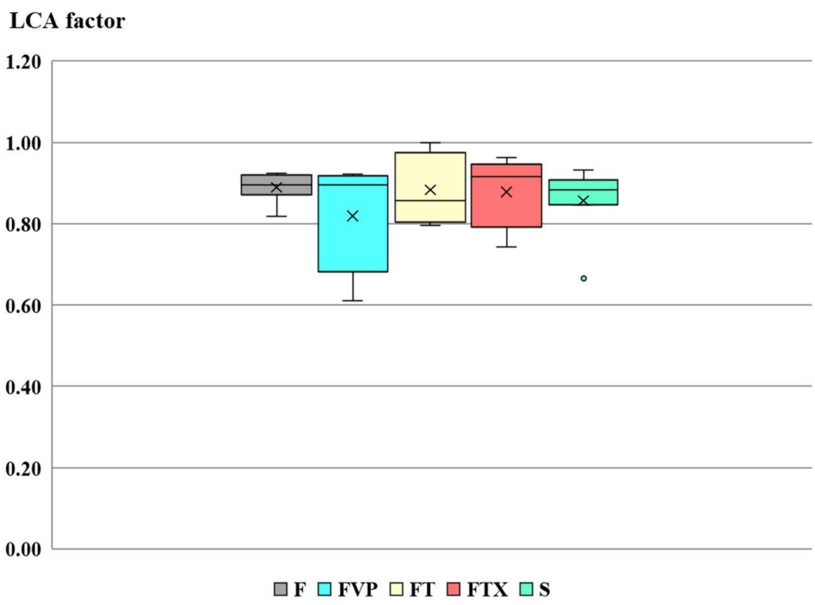

Figure 4-31: Normalized LCA based on 5 different ventilation categories. The vertical axis is the normalized LCA, and the horizontal axis is ventilation types.

Energy payback time: the calculated time in which the generated electricity by each PV system is starting to make up for the used electricity in the production phase is shown in Figure 4-32 and Figure 4-33. As the results indicate the median time is around 1.5 years for each group.

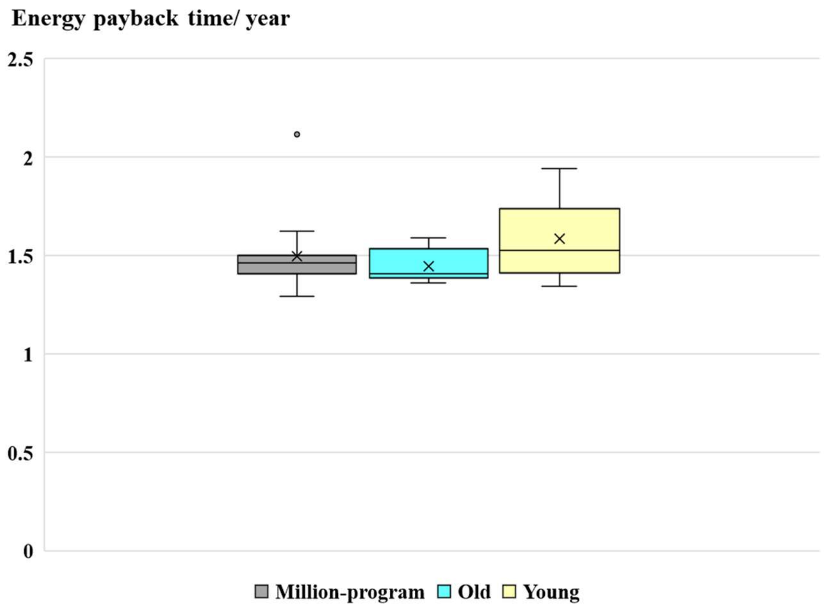

Figure 4-32: Energy payback time per year based on 3 different age categories. The vertical axis indicates the year of energy payback time and the horizontal axis is the box plots of the 3 different age categories.

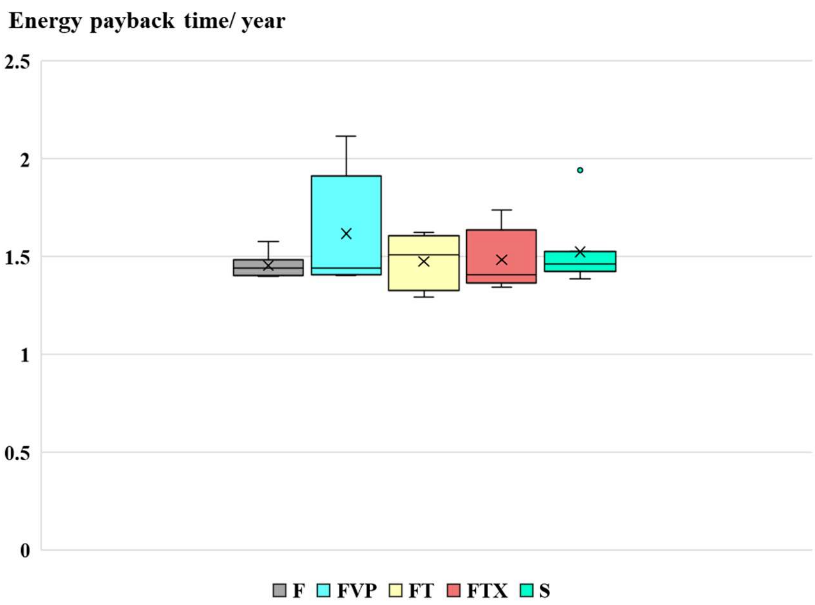

Figure 4-33: Energy payback time per year based on 5 different ventilation types. The vertical axis indicates the year, and the horizontal axis presents ventilation types.

5 Discussion and Conclusion

This chapter discusses the results presented in chapter 4 of this paper.

5.1 Ventilation classification

The aim of calculating obstacle area and generation area on the roofs for each ventilation type was to assess how the ventilation system can affect the roof's potential of supplying solar electricity as a function of available area for installing the system. For all the studied buildings, the average of the available area was 55 % to 70 % of the total roof area. While the F and S ventilation system had the largest available area, the obstacle area on these two ventilations showed significantly different results. S ventilation had the lowest roof area occupied with obstacles, which is a probable effect of the high available generation ratio. However, the obstacle area on the roofs with the F ventilation system was the highest among all the other ventilation systems. The major cause of this result was the structure and shape of these obstacles, which means not only the area of obstacles is essential, the possibility of mounting PV panels around these obstacles is an adequate factor.

The FTX systems had the lowest available generation area due to the substantial mechanical room on the roofs.

Since in this study, the individual effect of architecture design on the roofs was not considered, the wide range of calculated available area in each group of ventilation systems was notable. It means the architecture design beside the mechanical design of the system should be considered, to be able to introduce a classification based on the ventilation type.

Solar fraction calculated for each system would indicate the ability of the system regarding providing the electricity demand. On the other hand, to have a more precise interpretation of the results, knowing the amount of total generated electricity that is used directly in the buildings and the electricity demand for different ventilation types are other fundamental features. Although, in the S ventilation systems, the solar fraction is the highest among the other types, the self-usage factor is only 32 %. It means almost 70 % of the produced electricity should be sent to the grid. While the FTX system, which has the lowest solar fraction (12 %), the average 95 % of supplied electricity is directly used in the building and only 5 % could be sold to the grid. Therefore, considering the low income from selling electricity compared to the cost of installing PV system, the efficiency of the system is debatable.

5.2 Roof type

Comparing the total generation (kWh/year) of the PV system on the flat and tilted roof showed that the same average electricity production per roof area for each type can be reached. Since in this study, the PV modules were mounted on flat roofs based on the best direction and angle to get the maximum output. One possible conclusion of these results is that the buildings with the tilted roof, are initially designed with the optimum direction due to sun movement for daylight and heating issues. However, to have a particular declaration, a deep-in study regarding the direction of the buildings is required.

Additionally, to carry out the efficiency of the system in roof type categorization, solar fraction and self-consumption were calculated. These factors are describing as a function of the building's total electricity demand. However, as the result of this study indicates, the electricity demand in buildings mainly related to the electricity usage of the ventilation system and the heated floor area in the building. Therefore, the roof type can not be a significant indicator in classifying the rooftop's potential for installing the PV system.

5.3 Age

Assessing the obstacle area on the roof indicated that the million project program buildings had quite fewer obstacle areas on the roof in comparing to the other groups. The available area for installing PV panels on old buildings, including million project program buildings are 10 % more than young buildings.

The ratio of the total electricity demand for the heated floor area for each building suggests that electricity consumption in young buildings are higher than the old buildings. Therefore, with the lower available generation area on the roof and higher electricity usage, more than 80 % of electricity production is directly used in young buildings, while for old buildings, this value is less than 70 %. Furthermore, by calculating solar fraction in this category shown in the "million program buildings," the PV system could cover a higher part of the building's electricity demand.

5.4 Location

Calculating the ratio of the total electricity generation to the roof area indicates that buildings located in the suburbs supply more electricity compared to the building in the center. However, only 50 % of the total supplied electricity in suburban buildings is directly used in the building. While in the center, this amount is up to 80 %.

On the other hand, with fewer obstacles on the roof in suburban buildings, the available area on the roof for PV system installation is higher. Therefore, a higher proportion of the electricity demand could be covered in suburban buildings compared with the buildings in the center.

5.5 Designed systems

As it was calculated in this study, household electricity is 55 % of total electricity usage in the buildings. When the systems are designed for the best roof area and the only common electricity demand, the results illustrate that while the average size of the PV systems is decreasing by 40 %, the demand for buying electricity from the grid for both common and household electricity is only increasing by 10 %. This result is a direct cause of the consumption profile for household electricity. The household electricity usage in Sweden is high during the winters, and in the evenings, the exact times that the electricity generation in PV systems is minimum. At the same time, an increase of 5 % in feeding electricity to the grid can be seen.

5.6 Shading analysis

Shading analysis for the effects of existing installation on the roofs indicated that the structure of the ventilation system in S, F, and FT type ventilation caused less than 5 % reduction in annual yield due to the shading. The FTX ventilation system causes the highest yield reduction among all the ventilation types. Tacking to account, the significant difference in the obstacle area for S and F emphasizes the fact that not only the occupied area on the roof is essential, the shape and height of these obstacles are equally considerable.

Studying the annual yield reduction for each system, while the effect of the environment was added to the shading effects, clarified that the environment shading could increase this reduction by up to 5 %.

Shading analysis for the location of buildings indicated that when the effect of the environment is only considered, regardless of the installations on the roofs, buildings in the suburb had five times lower reduction of annual yield compared with the center buildings.

When considering the effect of shading on designing a PV system, it is essential to consider not only the area of the shaded panels but also the density of shading. As the results of shading analysis indicate, by removing the panels with shading frequency of more than 10 %, the average annual yield reduction is decreasing almost to half.

5.7 Financial and environmental impacts

The most important decision regarding PV panels is to choose the right size of a system. However, the average LCC and LCA value can not clarify for consumers to choose the right size since it does not contain the effect of valuable green energy that a system can make. Therefore, a more in-depth investigation regarding the LCA of a system is required to find out the time that PV generation nullifies the environmental impact of a system.

Calculating the net present value of each system over 30 years for one square meter in each building indicated that this value for the young buildings is higher comparing the old buildings. By comparing the results of the electricity usage of the buildings based on their age category with their NPV factors, it can be concluded that the profitability of the systems is depended directly on the amount of electricity demand in the buildings. Furthermore, by investigating these values for ventilation classification, the results indicate that the ventilation types with higher electricity use have a higher NPV factor.

As the LCA of PV panels was affected by the number of installing panels, therefore all the results of the normalized LCA represent the available generation area of each category. For instance, the normalized LCA of the Million and old buildings is higher than young buildings which can be the result of more available generation areas of these age categories. The lowest impacts of the buildings with FTX ventilation can be induced as the highest obstacles area this ventilation type occupies on the roof. Finally, Buildings with S and F ventilation have approximately the same LCA results as well as F med and FT with the highest impact value.

Moreover, the result of EPBT shows that in the system with a higher median LCA factor the EPBT median value is lower. However, it can be concluded from these results the smallest system does not have the lowest EPBT. Also, the EPBT of a system depends on both system size which is in direct relation with cumulative energy, and the green electrical energy it can generate. In another word, both cumulative and generated electrical energy can affect the EPBT.

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Appendix

Address of Installation	Project Name
Kavaljersgatan 10. Gothenburg	Million-program 1

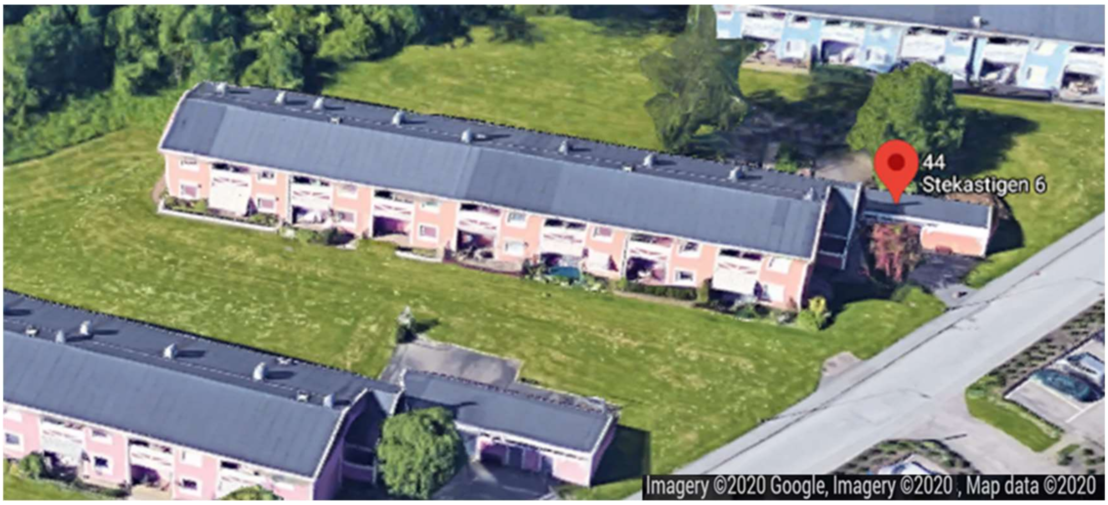
PV System-million-program 1		
PV system factors	**PV system output**	**Unit**
PV Generator Output	91.98	kWp
PV Generator Surface	472.1	m^2
Number of PV Modules	283	-
Number of Inverters	6	-

The yield-million-program 1		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	73 855	kWh
Direct Own Use	29 310	kWh
Grid Feed-in	44 546	kWh
Self usage	39.7	%
Solar Fraction	32.9	%
Spec. Annual Yield	802.99	kWh/kWp
Performance Ratio (PR)	86.6	%
Yield Reduction due to Shading	3.3	%/Year
CO_2 Emissions avoided	34 712	kg / year

Energy use of the building-million-program 1		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	27 203	kWh
Household. load profile with low summer proportion	61 628	kWh
Load Peak	171.9	kW

Appliances-million-program 1		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	88 831	kWh/Year
Standby energy use (Inverter)	191	kWh/Year
Total electricity use	89 022	kWh/Year
Covered by PV power	29 307	kWh/Year
Energy from Grid	59 716	kWh/Year
Solar Fraction	33	%

Address of Installation	Project Name
STEKASTIGEN 6. Gothenburg	Million-program 2



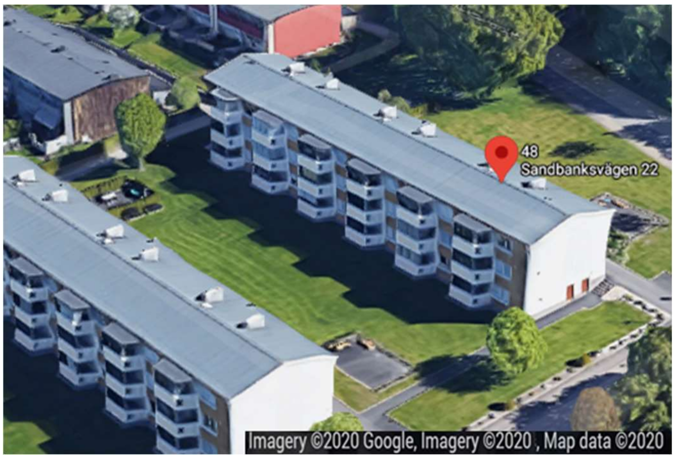
PV System-million-program 2		
PV system factors	**PV system output**	**Unit**
PV Generator Output	88.73	kWp
PV Generator Surface	455.5	m^2
Number of PV Modules	273	-
Number of Inverters	5	-

The yield-million-program 2		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	68 927	kWh
Direct Own Use	14 213	kWh
Grid Feed-in	54 714	kWh
Self usage	20.6	%
Solar Fraction	36.3	%
Spec. Annual Yield	776.86	kWh/kWp
Performance Ratio (PR)	83.8	%
Yield Reduction due to Shading	8.4	%/Year
CO_2 Emissions avoided	32 396	kg / year

Energy use of the building-million-program 2		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	4331	kWh
Household. load profile with low summer proportion	34 782	kWh
Load Peak	96.4	kW

Appliances-million-program 2		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	39 113	kWh/Year
Standby energy use (Inverter)	6	kWh/Year
Total electricity use	39 119	kWh/Year
Covered by PV power	14 213	kWh/Year
Energy from Grid	24 906	kWh/Year
Solar Fraction	36	%

Address of Installation	**Project Name**
SANDBANKSVÄGEN 22. Gothenburg	Million-program 3



PV System-million-program 3		
PV system factors	**PV system output**	**Unit**
PV Generator Output	86.45	kWp
PV Generator Surface	443.8	m²
Number of PV Modules	266	-
Number of Inverters	8	-

The yield-million-program 3		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	67 530	kWh
Direct Own Use	19 054	kWh
Grid Feed-in	48 477	kWh
Self usage	28.2	%
Solar Fraction	33.7	%
Spec. Annual Yield	781.14	kWh/kWp
Performance Ratio (PR)	83.5	%
Yield Reduction due to Shading	6.3	%/Year
CO_2 Emissions avoided	31 739	kg / year

Energy use of the building-million-program 3		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	8 815	kWh
Household. load profile with low summer proportion	47 244	kWh
Load Peak	131.2	kW

Appliances-million-program 3		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	56 059	kWh/Year
Standby energy use (Inverter)	487	kWh/Year
Total electricity use	56 546	kWh/Year
Covered by PV power	19 045	kWh/Year
Energy from Grid	37 501	kWh/Year
Solar Fraction	34	%

Address of Installation	**Project Name**
SMYCKEGATAN 89. Gothenburg	Million-program 4

PV System-million-program 4		
PV system factors	**PV system output**	**Unit**
PV Generator Output	101.08	kWp
PV Generator Surface	518.9	m²
Number of PV Modules	311	-
Number of Inverters	3	-

The yield-million-program 4		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	77 567	kWh
Direct Own Use	38 669	kWh
Grid Feed-in	38 898	kWh
Self usage	49.9	%
Solar Fraction	30.7	%
Spec. Annual Yield	767.42	kWh/kWp
Performance Ratio (PR)	85.4	%
Yield Reduction due to Shading	4.8	%/Year
CO_2 Emissions avoided	36 456	kg / year

Energy use of the building-million-program 4		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	40 500	kWh
Household. load profile with low summer proportion	85 591	kWh
Load Peak	238.8	kW

Appliances-million-program 4		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	126 091	kWh/Year
Standby energy use (Inverter)	56	kWh/Year
Total electricity use	126 147	kWh/Year
Covered by PV power	38 668	kWh/Year
Energy from Grid	87 479	kWh/Year
Solar Fraction	31	%

Address of Installation	**Project Name**
VÄSTRA ANDERSGÅRDSGATAN 6. Gothenburg	Million-program 5

PV System-million-program 5		
PV system factors	**PV system output**	**Unit**
PV Generator Output	86.13	kWp
PV Generator Surface	442.1	m²
Number of PV Modules	265	-
Number of Inverters	5	-

The yield-million-program 5		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	76 128	kWh
Direct Own Use	36 973	kWh
Grid Feed-in	39 155	kWh
Self usage	48.6	%
Solar Fraction	30.1	%
Spec. Annual Yield	883.93	kWh/kWp
Performance Ratio (PR)	87.7	%
Yield Reduction due to Shading	3.5	%/Year
CO_2 Emissions avoided	35 780	kg / year

Energy use of the building-million-program 5		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	45 590	kWh
Household. load profile with low summer proportion	77 407	kWh
Load Peak	216.4	kW

Appliances-million-program 5		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	122 997	kWh/Year
Standby energy use (Inverter)	6	kWh/Year
Total electricity use	123 003	kWh/Year
Covered by PV power	36 973	kWh/Year
Energy from grid	86 030	kWh/Year
Solar Fraction	30	%

Address of Installation	Project Name
Kjellmansgatan 7. Gothenburg	Million-program 6

PV System-million-program 6		
PV system factors	**PV system output**	**Unit**
PV Generator Output	75.73	kWp
PV Generator Surface	388.7	m²
Number of PV Modules	233	-
Number of Inverters	4	-

The yield-million-program 6		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	54 747	kWh
Direct Own Use	22 321	kWh
Grid Feed-in	32 426	kWh
Self usage	40.8	%
Solar Fraction	27.1	%
Spec. Annual Yield	722.98	kWh/kWp
Performance Ratio (PR)	72.7	%
Yield Reduction due to Shading	20.9	%/Year
CO_2 Emissions avoided	25 731	kg / year

Energy use of the building-million-program 6		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	30 000	kWh
Household. load profile with low summer proportion	52 297	kWh
Load Peak	147.1	kW

Appliances-million-program 6		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	82 297	kWh/Year
Standby energy use (Inverter)	71	kWh/Year
Total electricity use	82 368	kWh/Year
Covered by PV power	22 321	kWh/Year
Energy from grid	60 048	kWh/Year
Solar Fraction	27	%

Address of Installation	Project Name
Norra Säterigatan 10. Gothenburg	Million-program 7

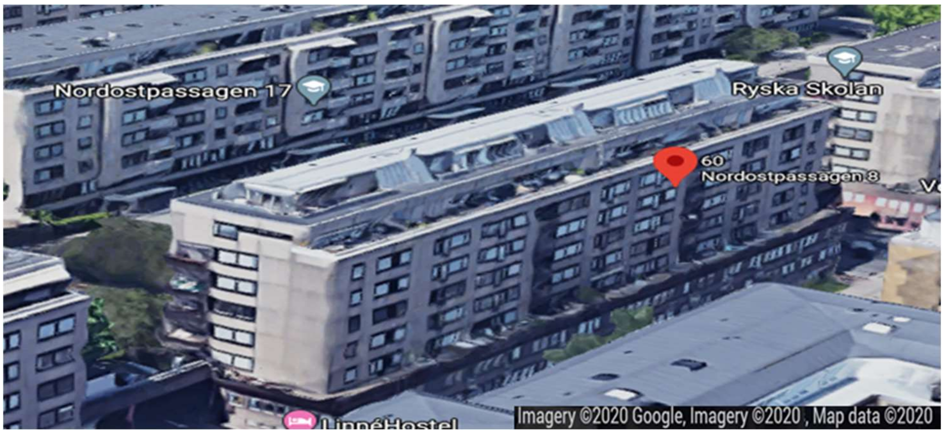
PV System-million-program 7		
PV system factors	**PV system output**	**Unit**
PV Generator Output	83.53	kWp
PV Generator Surface	428.8	m²
Number of PV Modules	257	-
Number of Inverters	5	-

The yield-million-program 7		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	65 022	kWh
Direct Own Use	48 654	kWh
Grid Feed-in	16 369	kWh
Self usage	74.8	%
Solar Fraction	18.3	%
Spec. Annual Yield	778.48	kWh/kWp
Performance Ratio (PR)	86.9	%
Yield Reduction due to Shading	3.4	%/Year
CO_2 Emissions avoided	30 560	kg / year

Energy use of the building-million-program 7		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	52 100	kWh
Household. load profile with low summer proportion	213 466	kWh
Load Peak	594.7	kW

Appliances-million-program 7		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	265 566	kWh/Year
Standby energy use (Inverter)	82	kWh/Year
Total electricity use	265 648	kWh/Year
Covered by PV power	48 654	kWh/Year
Energy from grid	216 995	kWh/Year
Solar Fraction	18	%

Address of Installation	**Project Name**
Nordostpassagen 8. Gothenburg	Million-program 8



PV System-million-program 8		
PV system factors	**PV system output**	**Unit**
PV Generator Output	42.25	kWp
PV Generator Surface	216.9	m²
Number of PV Modules	130	-
Number of Inverters	1	-

The yield-million-program 8		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	31 988	kWh
Direct Own Use	31 607	kWh
Grid Feed-in	381	kWh
Self usage	98.8	%
Solar Fraction	8.4	%
Spec. Annual Yield	757.12	kWh/kWp
Performance Ratio (PR)	88.9	%
Yield Reduction due to Shading	1.9	%/Year
CO_2 Emissions avoided	15 034	kg / year

Energy use of the building-million-program 8		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	123 500	kWh
Household. load profile with low summer proportion	254 262	kWh
Load Peak	713.2	kW

Appliances-million-program 8		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	377 762	kWh/Year
Standby energy use (Inverter)	18	kWh/Year
Total electricity use	377 780	kWh/Year
Covered by PV power	31 607	kWh/Year
Energy from grid	346 173	kWh/Year
Solar Fraction	8	%

Address of Installation	**Project Name**
Gröna Annas gata 17. Gothenburg	Million-program 9

PV System-million-program 9		
PV system factors	**PV system output**	**Unit**
PV Generator Output	23.4	kWp
PV Generator Surface	120.1	m²
Number of PV Modules	72	-
Number of Inverters	1	-

The yield-million-program 9		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	12 625	kWh
Direct Own Use	5 669	kWh
Grid Feed-in	6 957	kWh
Self usage	44.9	%
Solar Fraction	26.3	%
Spec. Annual Yield	539.55	kWh/kWp
Performance Ratio (PR)	59.3	%
Yield Reduction due to Shading	40.7	%/Year
CO_2 Emissions avoided	5 934	kg / year

Energy use of the building-million-program 9		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	8 951	kWh
Household. load profile with low summer proportion	4 508	kWh
Exhust	8 056	kWh
Load Peak	14.1	kW

Appliances-million-program 9		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	21 515	kWh/Year
Standby energy use (Inverter)	1	kWh/Year
Total electricity use	21 516	kWh/Year
Covered by PV power	5 669	kWh/Year
Energy from grid	15 847	kWh/Year
Solar Fraction	26	%

Address of Installation	**Project Name**
Mäster Johansgatan 17. Gothenburg	Million-program 10

PV System-million-program 10		
PV system factors	**PV system output**	**Unit**
PV Generator Output	31.2	kWp
PV Generator Surface	160.2	m^2
Number of PV Modules	96	-
Number of Inverters	2	-

The yield-million-program 10		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	24 317	kWh
Direct Own Use	24 003	kWh
Grid Feed-in	314	kWh
Self usage	98.7	%
Solar Fraction	8.3	%
Spec. Annual Yield	779.38	kWh/kWp
Performance Ratio (PR)	82.4	%
Yield Reduction due to Shading	8.8	%/Year
CO_2 Emissions avoided	11 429	kg / year

Energy use of the building-million-program 10		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	113 350	kWh
Heat Pump System with Space Heating and Domestic Hot Water (water/water)	99 097	kWh
Household. load profile with low summer proportion	77 841	kWh
Load Peak	231.4	kW

Appliances-million-program 10		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	290 288	kWh/Year
Standby energy use (Inverter)	15	kWh/Year
Total electricity use	290 303	kWh/Year
Covered by PV power	24 003	kWh/Year
Energy from grid	266 300	kWh/Year
Solar Fraction	8	%

Address of Installation	Project Name
Stackmolnsgatan 13. Gothenburg	Million-program 11

PV System-million-program 11		
PV system factors	**PV system output**	**Unit**
PV Generator Output	101.73	kWp
PV Generator Surface	522.2	m²
Number of PV Modules	313	-
Number of Inverters	5	-

The yield-million-program 11		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	80 514	kWh
Direct Own Use	71 523	kWh
Grid Feed-in	8 991	kWh
Self usage	88.8	%
Solar Fraction	19.4	%
Spec. Annual Yield	791.49	kWh/kWp
Performance Ratio (PR)	85.8	%
Yield Reduction due to Shading	4.6	%/Year
CO_2 Emissions avoided	37 842	kg / year

Energy use of the building-million-program 11		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	143 968	kWh
Household. load profile with low summer proportion	178 126	kWh
Exhust	45 968	
Load Peak	505.3	kW

Appliances-million-program 11		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	368 062	kWh/Year
Standby energy use (Inverter)	69	kWh/Year
Total electricity use	368 131	kWh/Year
Covered by PV power	71 522	kWh/Year
Energy from grid	296 609	kWh/Year
Solar Fraction	19	%

Address of Installation	**Project Name**
Nebulosagatan 10. Gothenburg	Million-program 12

PV System-million-program 12		
PV system factors	**PV system output**	**Unit**
PV Generator Output	204.29	kWp
PV Generator Surface	1 099.4	m²
Number of PV Modules	659	-
Number of Inverters	6	-

The yield-million-program 12		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	174 513	kWh
Direct Own Use	103 889	kWh
Grid Feed-in	70 624	kWh
Self usage	59.5	%
Solar Fraction	24.2	%
Spec. Annual Yield	854.24	kWh/kWp
Performance Ratio (PR)	91.0	%
Yield Reduction due to Shading	1.1	%/Year
CO_2 Emissions avoided	82 021	kg / year

Energy use of the building-million-program 12		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	98 092	kWh
Household. load profile with low summer proportion	331 111	kWh
Load Peak	921	kW

Appliances-million-program 12		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	429 203	kWh/Year
Standby energy use (Inverter)	110	kWh/Year
Total electricity use	429 313	kWh/Year
Covered by PV power	103 888	kWh/Year
Energy from grid	325 426	kWh/Year
Solar Fraction	24	%

Address of Installation	Project Name
Kåserigatan 2. Gothenburg	Million-program 13

PV System-million-program 13		
PV system factors	**PV system output**	**Unit**
PV Generator Output	54.28	kWp
PV Generator Surface	278.6	m²
Number of PV Modules	167	-
Number of Inverters	3	-

The yield-million-program 13		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	44 340	kWh
Direct Own Use	33 213	kWh
Grid Feed-in	11 128	kWh
Self usage	74.9	%
Solar Fraction	21.8	%
Spec. Annual Yield	816.96	kWh/kWp
Performance Ratio (PR)	89.1	%
Yield Reduction due to Shading	1.5	%/Year
CO_2 Emissions avoided	20 840	kg / year

Energy use of the building-million-program 13		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	49 330	kWh
Household. load profile with low summer proportion	102 920	kWh
Load Peak	287.2	kW

Appliances-million-program 13		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	152 250	kWh/Year
Standby energy use (Inverter)	3	kWh/Year
Total electricity use	152 253	kWh/Year
Covered by PV power	33 212	kWh/Year
Energy from grid	119 041	kWh/Year
Solar Fraction	22	%

Address of Installation	Project Name
Näverlursgatan 26. Gothenburg	Million-program 14

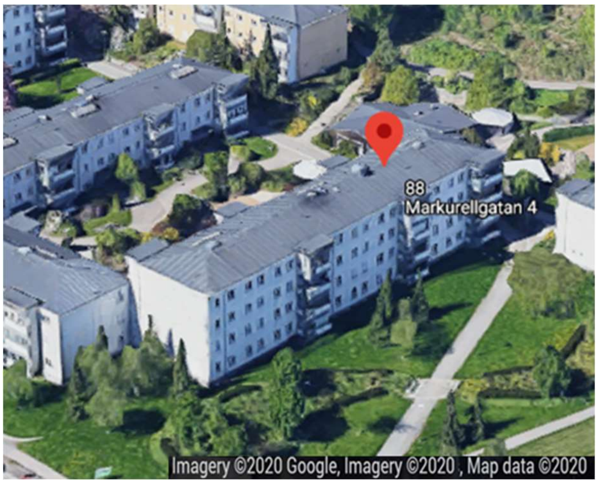
PV System-million-program 14		
PV system factors	**PV system output**	**Unit**
PV Generator Output	94.25	kWp
PV Generator Surface	483.8	m^2
Number of PV Modules	290	-
Number of Inverters	2	-

The yield-million-program 14		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	66 241	kWh
Direct Own Use	57 431	kWh
Grid Feed-in	8 810	kWh
Self usage	86.7	%
Solar Fraction	13.4	%
Spec. Annual Yield	702.83	kWh/kWp
Performance Ratio (PR)	74.6	%
Yield Reduction due to Shading	18.0	%/Year
CO_2 Emissions avoided	31 133	kg / year

Energy use of the building-million-program 14		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	119 664	kWh
Household. load profile with low summer proportion	309 132	kWh
Load Peak	864.8	kW

Appliances-million-program 14		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	428 796	kWh/Year
Standby energy use (Inverter)	45	kWh/Year
Total electricity use	428 841	kWh/Year
Covered by PV power	57 431	kWh/Year
Energy from grid	371 411	kWh/Year
Solar Fraction	13	%

Address of Installation	Project Name
Markurellgatan 4. Hisings Backa. Gothenburg	Million-program 15



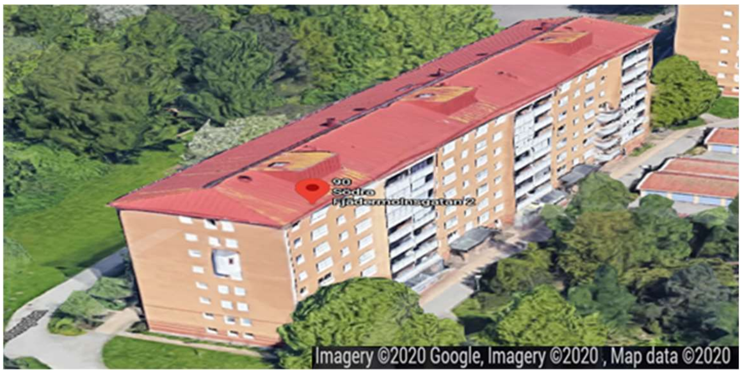
PV System-million-program 15		
PV system factors	**PV system output**	**Unit**
PV Generator Output	78.33	kWp
PV Generator Surface	402.1	m^2
Number of PV Modules	241	-
Number of Inverters	2	-

The yield-million-program 15		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	63 085	kWh
Direct Own Use	28 499	kWh
Grid Feed-in	34 586	kWh
Self usage	45.2	%
Solar Fraction	30.6	%
Spec. Annual Yield	805.43	kWh/kWp
Performance Ratio (PR)	89.8	%
Yield Reduction due to Shading	2.8	%/Year
CO_2 Emissions avoided	29 650	kg / year

Energy use of the building-million-program 15		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	30 100	kWh
Household. load profile with low summer proportion	62 961	kWh
Load Peak	176.6	kW

Appliances-million-program 15		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	93 061	kWh/Year
Standby energy use (Inverter)	35	kWh/Year
Total electricity use	93 096	kWh/Year
Covered by PV power	28 499	kWh/Year
Energy from grid	64 597	kWh/Year
Solar Fraction	31	%

Address of Installation	**Project Name**
Södra Fjädermolnsgatan 2. Gothenburg	Million-program 16



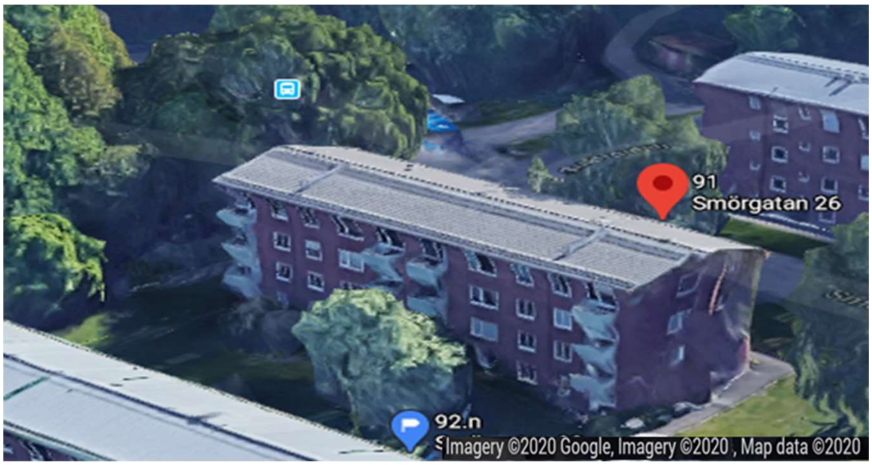
PV System-million-program 16		
PV system factors	**PV system output**	**Unit**
PV Generator Output	125.45	kWp
PV Generator Surface	644.0	m²
Number of PV Modules	386	-
Number of Inverters	2	-

The yield-million-program 16		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	102 111	kWh
Direct Own Use	100 052	kWh
Grid Feed-in	2 059	kWh
Self usage	98.0	%
Solar Fraction	12.2	%
Spec. Annual Yield	813.96	kWh/kWp
Performance Ratio (PR)	88.8	%
Yield Reduction due to Shading	2.0	%/Year
CO_2 Emissions avoided	47 992	kg / year

Energy use of the building-million-program 16		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	320 636	kWh
Heat Pump System with Space Heating and Domestic Hot Water (water/water)	161 500	kWh
Household. load profile with low summer proportion	241 552	kWh
Exhaust	95 800	kWh
Load Peak	716.1	kW

Appliances-million-program 16		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	819 488	kWh/Year
Standby energy use (Inverter)	39	kWh/Year
Total electricity use	819 527	kWh/Year
Covered by PV power	100 052	kWh/Year
Energy from grid	719 475	kWh/Year
Solar Fraction	12	%

Address of Installation	Project Name
Smörgatan 26. Gothenburg	Old 1



PV System-old 1		
PV system factors	**PV system output**	**Unit**
PV Generator Output	45.5	kWp
PV Generator Surface	233.6	m²
Number of PV Modules	140	-
Number of Inverters	7	-

The yield- old 1		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	35 691	kWh
Direct Own Use	12 484	kWh
Grid Feed-in	23 207	kWh
Self usage	35.0	%
Solar Fraction	27.7	%
Spec. Annual Yield	784.41	kWh/kWp
Performance Ratio (PR)	84.7	%
Yield Reduction due to Shading	6.5	%/Year
CO_2 Emissions avoided	16 775	kg / year

Energy use of the building- old 1		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	1 808	kWh
Household. load profile with low summer proportion	43 028	kWh
Load Peak	119.2	kW

Appliances- old 1		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	44 836	kWh/Year
Standby energy use (Inverter)	304	kWh/Year
Total electricity use	45 140	kWh/Year
Covered by PV power	12 484	kWh/Year
Energy from grid	32 662	kWh/Year
Solar Fraction	28	%

Address of Installation	**Project Name**
Smörgatan 20. Gothenburg	Old 2

PV System- Old 2		
PV system factors	**PV system output**	**Unit**
PV Generator Output	91	kWp
PV Generator Surface	467.1	m²
Number of PV Modules	280	-
Number of Inverters	12	-

The yield- Old 2		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	74 948	kWh
Direct Own Use	21 032	kWh
Grid Feed-in	53 916	kWh
Self usage	28.1	%
Solar Fraction	31.3	%
Spec. Annual Yield	823.60	kWh/kWp
Performance Ratio (PR)	87.9	%
Yield Reduction due to Shading	2.3	%/Year
CO_2 Emissions avoided	35 225	kg / year

Energy use of the building- Old 2		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	2 984	kWh
Household. load profile with low summer proportion	63 581	kWh
Load Peak	176.2	kW

Appliances- Old 2		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	66 565	kWh/Year
Standby energy use (Inverter)	549	kWh/Year
Total electricity use	67 114	kWh/Year
Covered by PV power	21 032	kWh/Year
Energy from grid	46 093	kWh/Year
Solar Fraction	31	%

Address of Installation	Project Name
Västergatan 20. Gothenburg	Old 3

PV System-old 3		
PV system factors	**PV system output**	**Unit**
PV Generator Output	62.4	kWp
PV Generator Surface	320.3	m²
Number of PV Modules	192	-
Number of Inverters	9	-

The yield- old 3		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	51 253	kWh
Direct Own Use	50 562	kWh
Grid Feed-in	698	kWh
Self usage	98.7	%
Solar Fraction	13.3	%
Spec. Annual Yield	821.36	kWh/kWp
Performance Ratio (PR)	88.4	%
Yield Reduction due to Shading	1.6	%/Year
CO_2 Emissions avoided	24 089	kg / year

Energy use of the building- old 3		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	163 033	kWh
Household. load profile with low summer proportion	144 894	kWh
Exhaust	73 279	kWh
Load Peak	422.1	kW

Appliances- old 3		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	381 206	kWh/Year
Standby energy use (Inverter)	219	kWh/Year
Total electricity use	381 425	kWh/Year
Covered by PV power	50 562	kWh/Year
Energy from grid	330 867	kWh/Year
Solar Fraction	13	%

Address of Installation	Project Name
Gyllenkrooksgatan 10A. Gothenburg	Old 4

PV System-old 4		
PV system factors	**PV system output**	**Unit**
PV Generator Output	223.6	kWp
PV Generator Surface	1 147.8	m^2
Number of PV Modules	688	-
Number of Inverters	23	-

The yield-old 4		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	181 117	kWh
Direct Own Use	177 143	kWh
Grid Feed-in	3 985	kWh
Self usage	97.8	%
Solar Fraction	11.0	%
Spec. Annual Yield	810.01	kWh/kWp
Performance Ratio (PR)	86.4	%
Yield Reduction due to Shading	3.8	%/Year
CO_2 Emissions avoided	85 125	kg / year

Energy use of the building- old 4		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	704 200	kWh
Household. load profile with low summer proportion	899 930	kWh
Load Peak	2545.4	kW

Appliances- old 4		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	1 604 130	kWh/Year
Standby energy use (Inverter)	544	kWh/Year
Total electricity use	1 604 674	kWh/Year
Covered by PV power	177 143	kWh/Year
Energy from grid	1 427 542	kWh/Year
Solar Fraction	11	%

Address of Installation	Project Name
FÖRENINGSGATAN 14	Old 5

PV System-million- old 5		
PV system factors	**PV system output**	**Unit**
PV Generator Output	37.05	kWp
PV Generator Surface	190.2	m^2
Number of PV Modules	114	-
Number of Inverters	2	-

The yield- old 5		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	27 543	kWh
Direct Own Use	24 884	kWh
Grid Feed-in	2 660	kWh
Self usage	90.3	%
Solar Fraction	14.0	%
Spec. Annual Yield	743.41	kWh/kWp
Performance Ratio (PR)	77.6	%
Yield Reduction due to Shading	15.5	%/Year
CO_2 Emissions avoided	12 945	kg / year

Energy use of the building- old 5		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	70 050	kWh
Household. load profile with low summer proportion	107 415	kWh
Load Peak	302.7	kW

Appliances- old 5		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	177 465	kWh/Year
Standby energy use (Inverter)	51	kWh/Year
Total electricity use	177 516	kWh/Year
Covered by PV power	24 884	kWh/Year
Energy from grid	152 632	kWh/Year
Solar Fraction	14	%

Address of Installation	Project Name
Nilssonsberg 27. Gothenburg	Old 6

PV System- old 6		
PV system factors	**PV system output**	**Unit**
PV Generator Output	245.38	kWp
PV Generator Surface	1 259.6	m²
Number of PV Modules	755	-
Number of Inverters	9	-

The yield- old 6		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	206 124	kWh
Direct Own Use	156 531	kWh
Grid Feed-in	49 594	kWh
Self usage	75.9	%
Solar Fraction	18.1	%
Spec. Annual Yield	840.04	kWh/kWp
Performance Ratio (PR)	89.4	%
Yield Reduction due to Shading	1.6	%/Year
CO_2 Emissions avoided	96 878	kg / year

Energy use of the- old 6		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	231 000	kWh
Household. load profile with low summer proportion	635 666	kWh
Load Peak	1 777	kW

Appliances- old 6		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	866 666	kWh/Year
Standby energy use (Inverter)	124	kWh/Year
Total electricity use	866 790	kWh/Year
Covered by PV power	156 531	kWh/Year
Energy from grid	710 261	kWh/Year
Solar Fraction	18	%

Address of Installation	Project Name
Carl Grimbergsgatan 31. Gothenburg	Old 7

PV System-old 7		
PV system factors	**PV system output**	**Unit**
PV Generator Output	206.38	kWp
PV Generator Surface	1 059.4	m²
Number of PV Modules	635	-
Number of Inverters	7	-

The yield- old 7		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	148 131	kWh
Direct Own Use	90 256	kWh
Grid Feed-in	57 877	kWh
Self usage	60.9	%
Solar Fraction	23.4	%
Spec. Annual Yield	717.78	kWh/kWp
Performance Ratio (PR)	80.5	%
Yield Reduction due to Shading	11.1	%/Year
CO_2 Emissions avoided	69 622	kg / year

Energy use of the- old 7		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	99 800	kWh
Household. load profile with low summer proportion	285 572	kWh
Load Peak	798	kW

Appliances- old 7		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	385 372	kWh/Year
Standby energy use (Inverter)	111	kWh/Year
Total electricity use	385 483	kWh/Year
Covered by PV power	90 256	kWh/Year
Energy from grid	295 230	kWh/Year
Solar Fraction	23	%

Address of Installation	**Project Name**
Kompassgatan 13A. Gothenburg	Young 1

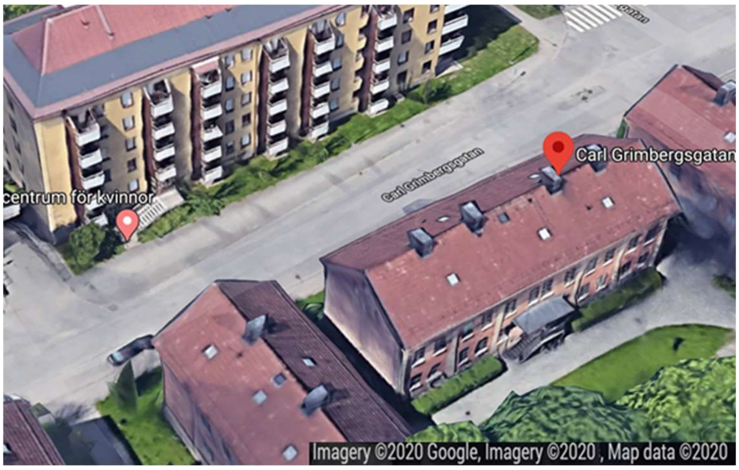
PV System- Young 1		
PV system factors	**PV system output**	**Unit**
PV Generator Output	63.38	kWp
PV Generator Surface	325.3	m²
Number of PV Modules	195	-
Number of Inverters	5	-

The yield- Young 1		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	50 822	kWh
Direct Own Use	18 130	kWh
Grid Feed-in	32 694	kWh
Self usage	35.7	%
Solar Fraction	29.8	%
Spec. Annual Yield	801.92	kWh/kWp
Performance Ratio (PR)	83.1	%
Yield Reduction due to Shading	8.4	%/Year
CO_2 Emissions avoided	23 886	kg / year

Energy use of the building- Young 1		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	11 960	kWh
Household. load profile with low summer proportion	48 794	kWh
Load Peak	135.8	kW

Appliances- Young 1		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	60 754	kWh/Year
Standby energy use (Inverter)	70	kWh/Year
Total electricity use	60 824	kWh/Year
Covered by PV power	18 129	kWh/Year
Energy from grid	42 695	kWh/Year
Solar Fraction	30	%

Address of Installation	Project Name
CARL GRIMBERGSGATAN 32. Gothenburg	Young 2



PV System- Young 2		
PV system factors	**PV system output**	**Unit**
PV Generator Output	47.13	kWp
PV Generator Surface	241.9	m^2
Number of PV Modules	145	-
Number of Inverters	2	-

The yield- Young 2		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	35 235	kWh
Direct Own Use	9 310	kWh
Grid Feed-in	25 925	kWh
Self usage	26.4	%
Solar Fraction	33.8	%
Spec. Annual Yield	747.69	kWh/kWp
Performance Ratio (PR)	83.9	%
Yield Reduction due to Shading	7.3	%/Year
CO_2 Emissions avoided	16 560	kg / year

Energy use of the building- Young 2		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	1 455	kWh
Household. load profile with low summer proportion	26 071	kWh
Load Peak	72.2	kW

Appliances- Young 2		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	27 526	kWh/Year
Standby energy use (Inverter)	27	kWh/Year
Total electricity use	27 553	kWh/Year
Covered by PV power	9 310	kWh/Year
Energy from grid	18 243	kWh/Year
Solar Fraction	34	%

Address of Installation	Project Name
SEMINARIEGATAN 3. Gothenburg	Young 3

PV System- Young 3		
PV system factors	**PV system output**	**Unit**
PV Generator Output	6.18	kWp
PV Generator Surface	31.7	m²
Number of PV Modules	19	-
Number of Inverters	4	-

The yield- Young 3		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	3 629	kWh
Direct Own Use	1 705	kWh
Grid Feed-in	1 925	kWh
Self usage	47.0	%
Solar Fraction	26.1	%
Spec. Annual Yield	587.63	kWh/kWp
Performance Ratio (PR)	66.2	%
Yield Reduction due to Shading	25.6	%/Year
CO_2 Emissions avoided	1 705	kg / year

Energy use of the building- Young 3		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	975	kWh
Household. load profile with low summer proportion	5 518	kWh
Load Peak	15.3	kW

Appliances- Young 3		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	6 493	kWh/Year
Standby energy use (Inverter)	49	kWh/Year
Total electricity use	6 542	kWh/Year
Covered by PV power	1 704	kWh/Year
Energy from grid	4 838	kWh/Year
Solar Fraction	26	%

Address of Installation	Project Name
UTLANDAGATAN 12. Gothenburg	Young 4

PV System- Young 4		
PV system factors	**PV system output**	**Unit**
PV Generator Output	29.25	kWp
PV Generator Surface	150.1	m²
Number of PV Modules	90	-
Number of Inverters	6	-

The yield- Young 4		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	19 212	kWh
Direct Own Use	17 231	kWh
Grid Feed-in	1 983	kWh
Self usage	89.7	%
Solar Fraction	16.8	%
Spec. Annual Yield	656.83	kWh/kWp
Performance Ratio (PR)	75.9	%
Yield Reduction due to Shading	13.0	%/Year
CO_2 Emissions avoided	9 030	kg / year

Energy use of the building- Young 4		
Energy use division	**Energy use amount**	**Unit**
Heat Pump System with Space Heating and Domestic Hot Water (water/water)	8 500	kWh
Buildings common energy use	31 005	kWh
Household. load profile with low summer proportion	63 271	kWh
Load Peak	177.7	kW

Appliances- Young 4		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	102 776	kWh/Year
Standby energy use (Inverter)	88	kWh/Year
Total electricity use	102 864	kWh/Year
Covered by PV power	17 229	kWh/Year
Energy from grid	85 635	kWh/Year
Solar Fraction	17	%

Address of Installation	Project Name
SMÖRGATAN 102. Gothenburg	Young 5

PV System- Young 5		
PV system factors	**PV system output**	**Unit**
PV Generator Output	30.23	kWp
PV Generator Surface	155.2	m²
Number of PV Modules	93	-
Number of Inverters	3	-

The yield- Young 5		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	25 699	kWh
Direct Own Use	25 700	kWh
Grid Feed-in	0	kWh
Self usage	100.0	%
Solar Fraction	3.7	%
Spec. Annual Yield	850.25	kWh/kWp
Performance Ratio (PR)	82.7	%
Yield Reduction due to Shading	7.8	%/Year
CO_2 Emissions avoided	12 079	kg / year

Energy use of the building- Young 5		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	288 504	kWh
Heat Pump System with Space Heating and Domestic Hot Water (water/water)	201 654	kWh
Household. load profile with low summer proportion	166 966	kWh
Exhaust	42 956	kWh
Load Peak	500.6	kW

Appliances- Young 5		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	700 080	kWh/Year
Standby energy use (Inverter)	80	kWh/Year
Total electricity use	700 160	kWh/Year
Covered by PV power	25 698	kWh/Year
Energy from grid	674 462	kWh/Year
Solar Fraction	4	%

Address of Installation	Project Name
SMÖRGATAN 106. Gothenburg	Young 6

PV System- Young 6		
PV system factors	**PV system output**	**Unit**
PV Generator Output	31.2	kWp
PV Generator Surface	160.2	m²
Number of PV Modules	96	-
Number of Inverters	2	-

The yield- Young 6		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	25 267	kWh
Direct Own Use	25 232	kWh
Grid Feed-in	35	kWh
Self usage	99.9	%
Solar Fraction	7.6	%
Spec. Annual Yield	809.83	kWh/kWp
Performance Ratio (PR)	78.8	%
Yield Reduction due to Shading	12.5	%/Year
CO_2 Emissions avoided	11 875	kg / year

Energy use of the building- Young 6		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	130 715	kWh
Heat Pump System with Space Heating and Domestic Hot Water (water/water)	85 755	kWh
Household. load profile with low summer proportion	116 405	kWh
Load Peak	337	kW

Appliances- Young 6		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	332 875	kWh/Year
Standby energy use (Inverter)	28	kWh/Year
Total electricity use	332 903	kWh/Year
Covered by PV power	25 231	kWh/Year
Energy from grid	307 672	kWh/Year
Solar Fraction	8	%

Address of Installation	Project Name
ARVID HEDVALLS BACKE 5. Gothenburg	Young 7

PV System- Young 7		
PV system factors	**PV system output**	**Unit**
PV Generator Output	238.55	kWp
PV Generator Surface	1 224.6	m²
Number of PV Modules	734	-
Number of Inverters	6	-

The yield- Young 7		
PV system factors	**Yield output**	**Units**
PV Generator Energy (AC grid)	159 048	kWh
Direct Own Use	129 992	kWh
Grid Feed-in	29 058	kWh
Self usage	81.7	%
Solar Fraction	18.9	%
Spec. Annual Yield	666.73	kWh/kWp
Performance Ratio (PR)	67.7	%
Yield Reduction due to Shading	26.5	%/Year
CO_2 Emissions avoided	74 753	kg / year

Energy use of the building- Young 7		
Energy use division	**Energy use amount**	**Unit**
Buildings common energy use	291 002	kWh
Household. load profile with low summer proportion	338 148	kWh
Exhaust	57 300	kWh
Load Peak	961.6	kW

Appliances- Young 7		
PV system feature based on appliances in building	**PV system output**	**Unit**
Appliances energy use	686 450	kWh/Year
Standby energy use (Inverter)	147	kWh/Year
Total electricity use	686 597	kWh/Year
Covered by PV power	129 989	kWh/Year
Energy from grid	556 608	kWh/Year
Solar Fraction	19	%

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