University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study programme/specialisation: **City and Regional Planning**	**Spring Semester,2020** **Open**
Author: **Mehrdad Rahimi , Ayda Joudavi**	
Programme coordinator: Supervisor(s): **Professor Harald N.Røstvik**	
Title of master's thesis: **Solar Energy Potential in Urban Environments, Case of Stavanger**	
Credits: **30**	
Keywords: *Solar potential, Urban Environments, Solar analysis, Photovoltaic, BIPV, Positive Energy District (PED), Net-zero Energy*	Number of pages: ……99………… + supplemental material/other: ………… Stavanger, 15.06.2020…. date/year

Solar Energy Potential in Urban Environments, Case of Stavanger

Thesis for acquiring a Master of Science in City and Regional planning
University of **Stavanger**

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Spring 2020

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Abstract

Many cities around the globe are aiming for carbon-neutrality by 2050. Achieving this target requires a massive effort and innovative solutions, especially in the field of producing clean energy in large scales and close to the end-users. In this sense, the vast area of urban surfaces available for PV installations is a promising source of clean energy that can ease the transition towards low carbon urban environments.

The main aim of this study is to assess the solar energy potential for two urban blocks in the city of Stavanger, Norway. The study aims to find out how much clean solar energy could be generated by integrating BIPVs into different building skins in the scale of an urban neighborhood, and then to find out if this energy is sufficient to cover the neighborhood's energy demand.

For this purpose, an analysis of solar potential is carried out using ArcGIS and DL-light add-on for Sketchup, for two urban blocks at Øvre Holmegate and St.Olavs gate. Then the energy demand for each neighborhood is estimated based on existing statistics. Finally, the possibility of achieving a positive energy district (PED) is studied in four different scenarios.

- In 2020, considering current PV efficiencies and without energy-saving measures
- In 2020, considering current PV efficiencies and with 20% saving target achieved
- In 2030, considering improved PV efficiencies and without energy-saving measures
- In 2030, considering current PV efficiencies and with 32.5% saving target achieved

Findings suggest that in neither of the scenarios, the PED target could be reached, however with better PV efficiencies and bolder energy saving targets, the PED goal is not far to reach. The results also identify the better urban settings for maximizing the solar potential in the city of Stavanger.

Keywords: *Solar potential, Urban Environments, Solar analysis, Photovoltaic, BIPV, Positive Energy District (PED), Net-zero Energy*

Acknowledgments

We would like to express our gratitude and appreciation to our supervisor, **Professor Harald N. Røstvik** for his guidance, support, and encouragement not only throughout this thesis but also during the whole two years of this master's program. Furthermore, we would like to thank **Hassan Gholami,** a research fellow at the University of Stavanger who provided us with practical tips along with this study.

This thesis has been written in the time of a global pandemic and general lockdowns around the world, due to the COVID-19 outbreak. We would like to send our regards to the health workers everywhere, who are fighting against Coronavirus in the frontline.

Ayda & Mehrdad

List of Abbreviations

BAPV	Building Attached Photovoltaic
BIPV	Building Integrated Photovoltaic
CO_2e	Carbon dioxide equivalent
EU	European Union
GHG	Greenhouse Gases
GIS	Geographic information system
GW	Gigawatts = 1000 Megawatts
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kWh	Kilowatt-hour
kWh/m^2	Kilowatt hour per square meter
MW	Megawatt
MW	Megawatts = 1000 Kilowatts
NZE	Net-zero Energy
NZEB	Nearly Zero Energy Building
PED	Positive Energy District
PEN	Positive Energy Neighborhood
PV	Photovoltaic
ZEB	Zero Energy Building

Group Work

Two of the Master students in City and Regional Planning at the University of Stavanger, Ayda Joudavi, and Mehrdad Rahimi conducted this study together. The workload was divided almost equally between the two.

This thesis selects two urban blocks in the city of Stavanger as a case study to carry out comparative research. Each individual was taking responsibility for one of the selected sites. This included collecting data about the urban block, 3D modeling of the site in 3D software, carrying out the solar analysis, and analyzing the output data. Ayda was working on the urban block located in St. Olavs gate and Mehrdad was working on the urban block at Øvre Holmegate.

Regarding the writing of the thesis, the “Introduction”, “Discussion” and “Conclusion” chapters are written collaboratively by the two students. Ayda has written about solar energy, PV systems, and PED concept in the “Literature review” chapter, while Mehrdad has covered information about different models of assessing solar energy and similar studies in the same chapter. In the “Method” section, Ayda has covered the GIS methodology and Mehrdad has elaborated on the use of the “DL-light” software package in this study. Finally, each student has written about his or her assigned case study in the “Findings” chapter.

Conducting this study in four months was a massive workload that would not have been possible without full cooperation between the two students.

Chapter 01 | Introduction

1-1-Problem Statement

In a world that is aiming to move towards carbon neutrality, finding solutions to produce clean and renewable energy is crucial. Forecasts suggest that solar energy would lead the future energy mix due to considerable advances in the industry that has made it economically feasible. One of the main advantages of solar energy over other renewables is that it can be produced decentralized. Thanks to technological advances in Building Integrated/Attached Photovoltaics (BIPVs / BAPVs) over the past few decades, it is now possible to turn urban neighborhoods or a cluster of buildings to a solar power plant that can generate a fraction of their own energy need.

Whereas a significant fraction of energy need is located in urban environments, it is important to promote the deployment of photovoltaic (PV) systems on an urban scale. This requires an accurate assessment of local PV potential, which changes drastically in the urban landscape due to different exposure of urban surfaces to sunlight (Redweik, Catita, & Brito, 2013).

Urban environments are usually characterized by the complex built agglomerations, such as building volumes, diverse densities, and heights, landscape features e.g. vegetation, terrain and etc. The inter-relation among these will affect the optimal solar energy generating scenarios due to shading and reflection impacts. Therefore, solar potential analysis at the urban scales should take these constraints into account and be carried out in a more realistic way.

Assessing the solar potential of building rooftops is a well-practiced procedure; however, the vast potential of façade surfaces for collecting sunlight, especially in a modern cityscape, should not be neglected. In modern cities, facades constitute a much larger fraction of urban surfaces and are mostly devoid of building infrastructure (chimneys, elevator engines, ventilators). Besides, façade surfaces usually provide better maintenance conditions for PV panels since vertical surfaces do not collect so much dust and are rarely covered by snow in the winter (Redweik, Catita, & Brito, 2013).

Furthermore, the European Directive 2010/31/EU demands that all the new buildings shall be Nearly Zero Energy Buildings (NZEB) from 2020 onwards. This will require that local energy production should cover the local energy need and therefore much larger PV areas are needed than those that are available on standard urban rooftops (Scognamiglio & Røstvik, 2013).

Nowadays, PV systems are not solely means of generating clean energy anymore but also realized as an integrated architectural element. With current advances in BIPVs, architects have been able to integrate solar modules as building materials with aesthetic functions on roofs and façade surfaces that are more profitable as they can generate energy while working as cladding.

In dense urban environments, the efficient deployment of PV systems on façades and roofs is deeply affected by urban morphology due to shading from surrounding buildings and inter-building reflections (Redweik, Catita, & Brito, 2013). Therefore, the solar potential analysis should be carried out in the early stages of the urban planning process, to secure solar accessibility and enhance the efficient use of solar energy in new and existing urban developments.

The available area of urban surfaces can be converted to a very promising source of generating clean solar energy that can help to address the climate change issue. 3D solar potential maps are among the best way to communicate the vast potential of the whole neighborhood's surfaces for generating energy to the public and decision-makers. However, it seems that there is a gap in the literature when it comes to methods of generating 3D solar maps and this has to be studied further.

1-2- Research Aims

This study aims to address this gap by studying solar energy potential in urban environments in the city of Stavanger. The study uses **ArcGIS** and Environmental analysis software called "**DL-light**" to calculate the solar irradiance on urban surfaces and **solar energy production potential** in the scale of a cluster of buildings (an **urban block**) and assess how these buildings affect each other in terms of shading and reflection and how they impact the solar accessibility in public spaces.

Another aim of the study is to find out if it is possible to achieve a **Positive Energy District (PED)** goal by generating solar energy in the scale of an urban block (neighborhood) and how this should be reflected in urban planning and municipal regulations.

1-3- Research Questions

Following the research objectives, the study aims to find the answer to following main questions:

- **How much** solar energy can be generated by installing **PV systems** on buildings' envelope, on the scale of an **urban block** in the city of **Stavanger**?
- Is it possible to achieve the "**PED**" goal by generating solar energy in neighborhood scale, in **Stavanger**?

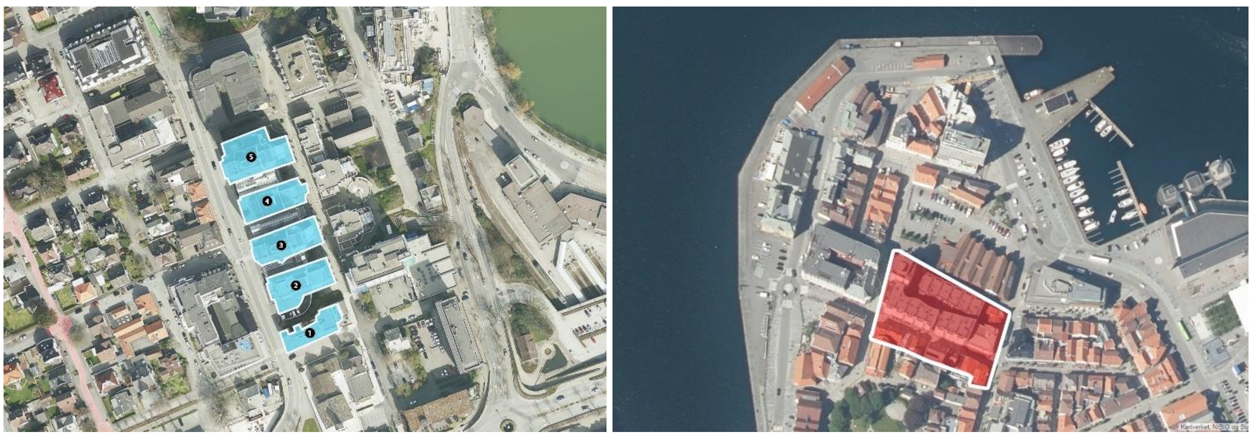
Finding answers to these two main questions requires seeking answers to a set of sub-questions. This process determines the steps that should be undertaken to conduct this study. The questions are:

- On average, how much is the **average solar radiation** on building surfaces (vertical and horizontal) in Stavanger in kWh/m^2 per year? And how much of urban surfaces are available for installing PV systems (within the research boundary)?
- What are the **efficiency of PV systems** and how much of the solar energy that building surfaces receive can be converted to electricity?

- How much is the **energy consumption** in Stavanger, divided by land-use (Residential, Commercial, other) in kWh/m^2? Therefore, how much energy is consumed in the selected urban districts over a year period?
- Finally, what percentage of energy consumption can be covered by solar-generated electricity?

1-4- Research Boundary

For limiting the scope, this study has used Stavanger city in Norway as the case study. Within the Stavanger city, two urban blocks with different characteristics have been chosen to enable authors to conduct comparative research. The urban block at "Øvre Holmegate" is low-rise and dense urban block that is located in Stavanger city center and includes both newly built buildings and protected old wooden house, and the urban block at "St. Olavs gate" is one of the few High-rise and dense developments in Stavanger city center. (Figure 1-1)



Urban block at St. Olavs gate, Eiganes — Urban block at Øvre Holmegate, Stavanger Sentrum

Figure 1-1- The two urban blocks selected for further studies

It would have been much comprehensive if two more urban blocks with "Low density, low-rise" and "Low density, and high-rise" characteristics were also included in the research, however, this was not achievable due to time constraints.

It should also be noted that for the aim of this research, only PV systems that can be installed on building skins e.g. BIPVs and BAPVs are considered. Other methods of generating solar energy on the urban scale, like centralized solar power plants, integrating solar with landscape features, and freestanding objects are excluded due to complications in the calculation process.

1-5- Research Method

A ***quantitative*** method has been selected to approach this study. The solar irradiance on urban surfaces (in kWh/m^2 per year) is analyzed using computer software called "DL-light" for the two urban blocks with different characteristics in a **comparative** study. Afterward, the amount of electricity that can be generated from available urban surfaces, assuming that they are covered with conventional PV systems, are calculated based on PVs efficiencies and the results for the two urban blocks are compared.

Finally, the current energy use of buildings in the study area is calculated based on the existing statistics, and results are compared with energy generation from PV systems to find out whether it is possible to achieve a PED goal. Four different scenarios are studied here:

1) Considering BIPPV efficiencies in the current year (2020), with no retrofitting measures adopted to improve buildings' energy use
2) Considering BIPV efficiencies in the current year (2020), while achieving 20% energy saving goal (energy saving targets are discussed further in chapter 4)
3) Considering BIPV efficiencies in 2030, with no retrofitting measures adopted to improve buildings' energy use
4) Considering BIPV efficiencies in 2030, while achieving 32.5% energy saving goal (energy saving targets are discussed further in chapter 4)

The results will indicate if using PV technologies are adequate to achieve PED goal or additional initiatives are required to do so. A simple solar analysis is also carried out on a larger scale for Stavanger Sentrum using ArcGIS both to validate the results from the solar analysis on urban blocks and to study the subject on a larger scale.

For data collection, a brief review of the existing literature was carried out to find out the best method to perform such an analysis. Information and data about buildings in each block that are required as input data in analysis software were collected through field observation and online resources like "Google street view", "Norge i bilder" and "KommuneKart" websites. Information about energy consumption in Stavanger, local documents, and current regulations were also collected from online resources including Statistics Norway, Stavanger municipality's website, etc.

1-6- Research Limits

Maybe, the most important challenge that authors faced while writing this thesis was the global pandemic due to COVID-19 outbreak that led to societal lockdowns and loss of many lives. The emotional pressure from this situation, alongside the closure of the university campus and not being able to access library and study rooms slowed down the progress of writing this thesis.

Another challenge was to find the appropriate software for carrying out solar analysis. One of the main aims of this study was to adopt a holistic approach toward solar analysis and to calculate solar irradiance on vertical surfaces and facades as well as rooftops. However, most of the studies in this field only considered insolation on rooftops in their analysis and therefore the well-described practiced methods were not suitable for this study. On the other hand, most of the software packages that are able to run such an analysis are licensed and usually very expensive. Nevertheless, among the few options, the "DL-Light" software package was chosen that offers a cheap license for students and has a more user-friendly platform than other options e.g. ArcGIS.

The next issue was the excessive computation times for running solar analysis tests for each month of the year. Although reasonable calculation time was one of the main factors in selecting the appropriate software package in the first place, the time consumed was still considerable. Running the solar analysis for each month of the year normally took between 10 to 12 hours on conventional PCs and this process had to be repeated for two urban blocks that were chosen as the study area. This means in total between 240 to 290 hours of time is spent only on ruing the tests for the two urban blocks! The same applies to the solar map produced in ArcGIS. Due to the extended analysis area, producing that map took 36 hours to complete.

Another challenge was to modify the 3D models so that they include the information that is needed for running solar analysis e.g. building materials. For this aim, the urban blocks that were selected as case studies were modeled in 3D in SketchUp software from scratch. The 3D model of the urban blocks was then placed in the site 3D model so that shading and reflection effects would be considered in the analysis.

Finally, most of the information regarding the local data, regulations, and guidelines e.g. data on buildings energy consumption or limitation on Installing PVs in protected urban areas, were only available in Norwegian. We managed to address this challenge with some help from our Norwegian classmates whom we should appreciate.

1-7- Thesis Structure

In chapter two, a brief overview of the existing literature on the subject of solar energy in urban environments is presented. Firs the importance of solar energy in the future energy mix and existing technologies to integrate solar energy with architecture are discussed. Then the concept of Positive Energy District (PEDs) is elaborated and finally, different models of assessing solar potential in urban environments are reviewed through studying two cases.

In chapter three, the research methodology is explained in detail. A step-by-step guide on how to carry out solar analysis using ArcGIS and “DL-light” software programs are provided in both neighborhood and urban block scale. The results from the analysis are presented in Chapter Four, “Findings”. The results for the two urban blocks are compared and preliminary conclusions are drawn. In this chapter, the answers to the research questions are also presented.

In chapter five, findings are discussed in regard to current debates around the subject and local regulations and guidelines about installing PVs in protected urban areas are criticized. In addition, the importance of considering solar potential as one of the key factors in urban planning and design has been appraised. Finally, in chapter six, conclusions are presented and some hints and opinions for further studies are suggested.

02 | Theoretical Background and Literature Review

2-1- Importance of Solar Energy in the Future Energy Mix

In his book “2052: A global forecast for the next forty years”, Jorgen Randers predicts that Solar energy will be the star in the future energy mix. He suggests that the share of renewables in the world’s electricity mix will increase from less than 20% in 2010 to more than 30% in 2030. Randers believes that although Hydro and wind power would initially have the largest share, beyond 2025 Solar PVs will take the lead and would become the principal source of electricity generation by 2050 (Randers, 2012).

The reason for this as he claims is declining production costs and decreasing investment risks. The cost of generating electricity from PVs has continued to decline by more than 10% per year. The cost of manufacturing PV panels is also falling while the efficiency for each panel is increasing continuously. Randers suggests that the average cost of PV will continue to drop by 5%-10% per year while their efficiency is expected to improve by 3%-4% per decade (Randers, 2012).

It is expected that by 2030 the cost of producing each kWh of solar electricity will drop drastically in major parts of the world, making it cheaper than any other alternative and preferred choice for both governments and private investors (Randers, 2012).

These forecasts are however challenged by a report from the International Energy Agency (IEA) that predicts solar energy would have a considerable share of the future energy mix but it is the wind energy that takes the lead by having about 35% share of the market (IEA, 2019). No matter which forecast comes true, the importance of solar energy should not be undermined.

In fact, increasing demand for electricity is considered as one of the most important reasons why global CO_2 emissions from the power sector have increased enormously in the past few years. Meanwhile, with everyday improvements in clean energy production technologies, electrification is becoming one of the frontiers to combat climate change (IEA, 2019).

In its world energy outlook towards 2040, IEA suggests two scenarios for future energy mix. The first scenario is assuming countries and states stick to their current policies and practices and in the second scenario, it has been assumed that countries will modify their regulations and plans to move faster towards sustainable development goals (IEA, 2019).

In the Stated Policies Scenario, it is expected that world electricity demand will grow at a rate of 2.1% per year towards 2040, which means electricity will have a 24% share of the total energy consumption in 2040 (IEA, 2019). Considering market conditions and technological advances in renewables, this increase in electricity demand is mostly going to be supplied by low carbon sources, e.g. wind and solar. Renewables are expected to have a 52% share of electricity generation by 2040 (IEA, 2019), however, coal remains a huge contributor. (Figure 2-1)

On the other hand, in the Sustainable Development Scenario, electricity with a 31% share of total energy consumption in 2040 will have a much more considerable role than the last scenario. The rise in electricity demand in this scenario is mainly due to vast electrification measures adopted e.g. in the transport section, industry, and heating. Since this scenario is aiming for reducing greenhouse gases (GHG) emissions, achieving it relies on accelerated efforts on renewables. It is suggested that renewables in this scenario will constitute more than two-thirds of total electricity production, among them solar and wind will have the largest share. This will expectedly result in reducing power sector CO2 emissions by three-quarters until 2040 (IEA, 2019)

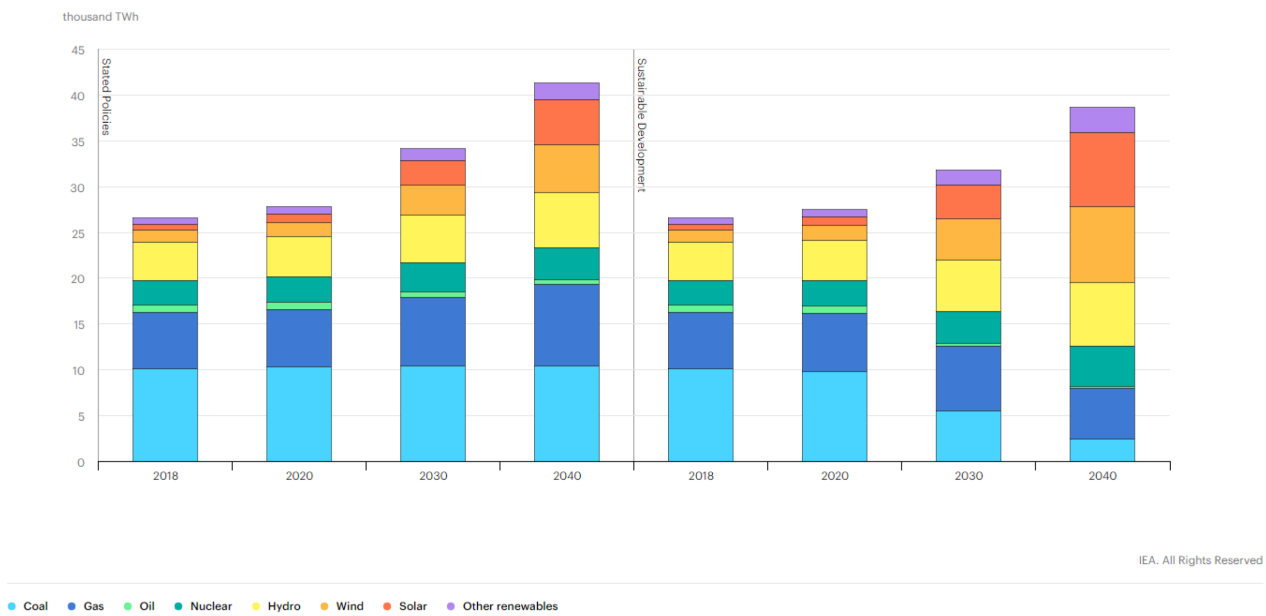


Figure 2-1- World energy outlook towards 2040, (IEA, 2019)
Stated Policies Scenario (left) and Sustainable Development Scenario (right)

Both scenarios suggest that solar will have a non-negligible share of the electricity production market by 2040. As it is shown in figure 2-2, IEA predicts that by 2035 solar PVs will be the dominant source of installed power generation capacity. The image clearly shows the rapid growth in the deployment of Solar PVs and the vast potential of this renewable source of energy.

The evolution in the PV industry and advances in BIPV and BAPV technologies have made this type of energy generation more accessible and acceptable to the public.

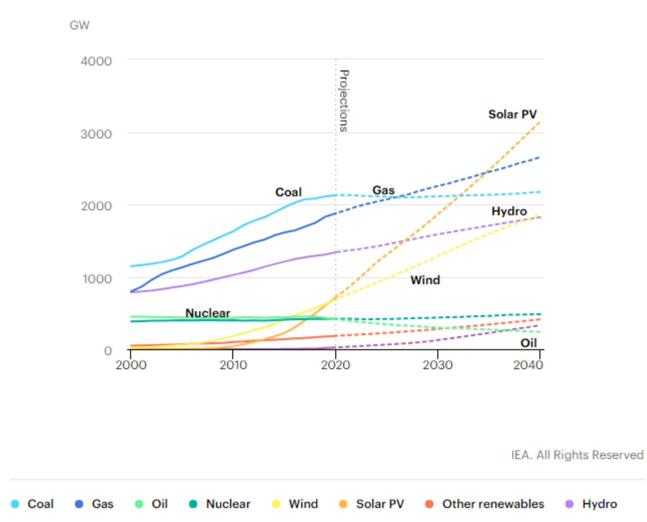


Figure 2-2- Installed Power generation capacity by the source in the stated policies scenario, 2000-2040, (IEA, 2019)

Finally, The International Renewable Energy Agency (IRENA) has also investigated the transitions in global energy trends towards 2050 in two different pathways. The same as IEA, IRENA also explores energy developments within both current policies pathway and a more climate change-oriented pathway that aims for an ambitious increase in adopting renewable sources and acceleration of energy efficiency in industry, transportation, and especially the building sector (IRENA, 2019).

IRENA claims that the decarbonization of the world's energy system is an essential step towards a more sustainable future and this should be sought by promoting deployment of the clean energy sources, particularly solar and wind energy (IRENA, 2019). In order to achieve global climate targets by 2050, the electricity sector should become carbon-free. Although this goal may seem idealistic, it is achievable via pursuing proper policies.

Among the many different low-carbon energy generation options, solar PVs are considered to have a major role in emission reductions by 2050. According to IRENA, by utilizing more than 8 500 GW of solar power by 2050, a significant decline of GHG emissions of approximately 4.9 Gt CO_2 can be expected (IRENA, 2019).

As stated earlier the PV industry has been able to gain the public interest due to declining costs, increasing efficiencies, and availability. Statistics show that PV installations are continuing to grow at a rapid pace globally (IRENA, 2019).

Figure 2-3 depicts the expected growth in solar PV capacity until 2050 (IRENA, 2019). The image clearly demonstrates the vast potential for a transition towards solar energy that comes with the better cost efficiency of PVs.
In the meantime, the ability to produce solar energy decentrally is a significant advantage. This means by installing PVs on buildings or at a neighborhood scale, solar energy can be produced in small or medium-sized power plants and closer to the end-users (European Commission (a), 2014). This way many issues including the costs of distribution grids and energy loss could be addressed.

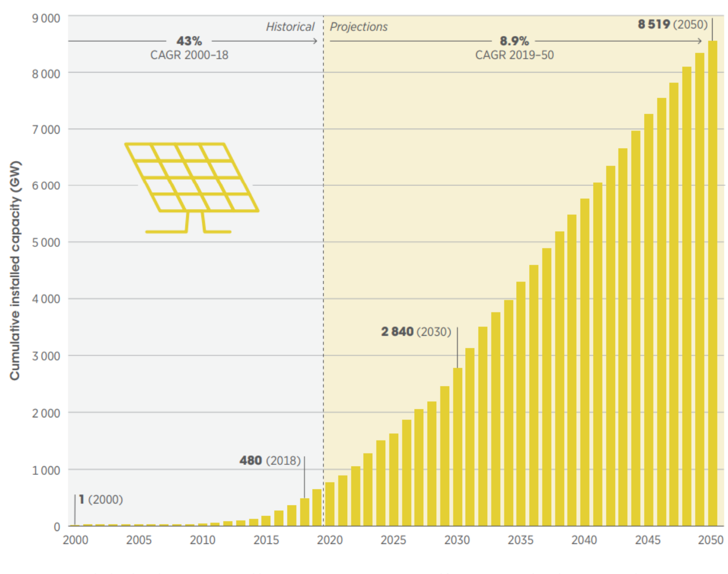


Figure 2-3- Cumulative Solar PV installed capacity, Projection until 2050, (IRENA, 2019)

Although integrating PV systems into architecture is well-practiced, the deployment of PVs in urban scale is rather new. Several studies have assessed the solar energy generation potential for several rooftops; however, the potential use of PVs on other building skins e.g. facades has been undermined. Considering the forecasted transition towards solar energy, urban planners need to become familiar with solar potential on an urban scale.

2-2- Solar Radiation in Norway

The amount of solar radiation that reaches the earth's surface at a certain place depends on its geographical location. The angle at which the sun rays strike the earth's surface and amount of time that it is exposed to sunlight determines how much insolation it receives. This means that solar radiation and consequently the potential generated solar energy is higher in tropical countries than countries with higher latitudes.

Considering that, it is expected that insolation in Norway, which is one of the northernmost countries in Europe and has a lower average of sunny days, would not be sufficient for the cost-beneficial production of solar energy. However, a study suggests that annual average daily global solar radiation in Norway is about 2.46 kWh/m2 (nearly 890 kWh/m^2 per year) (Hagos, D. A., Gebremedhin, A., & Zethraeus, B, 2014).

Norway has an elongated shape, and is stretched along the north-south axis and has a very variable climate; therefore, there is a huge difference in solar radiation in different parts of the country and at different times of the year. The monthly average daily global solar radiation in Norway varies between 0.1 and 0.35 kWh/m2 during the coldest month, January, and between 4 and 5.5 kWh/m2 during the peak summer, June, as shown in Figure 2-4 (Hagos, D. A., Gebremedhin, A., & Zethraeus, B, 2014). Considering this, it is important to analyze the solar potential for specific study locations to have a better understanding of solar energy efficiency.

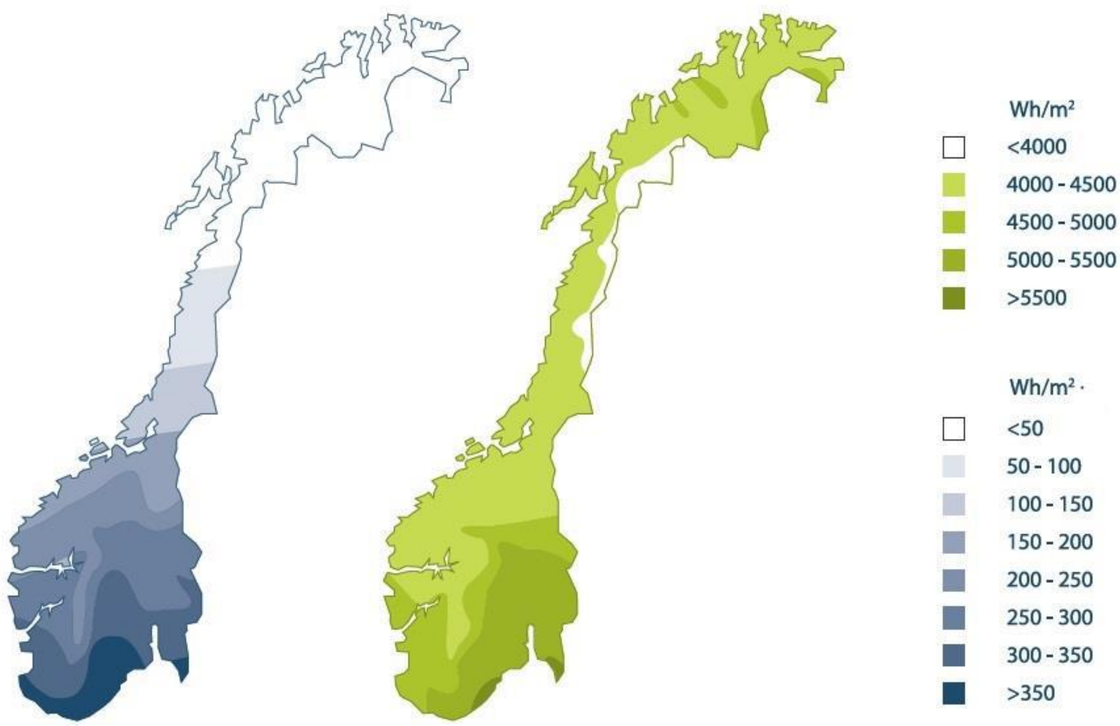


Figure 2-4- Global solar radiation per day for January (left map) and June (right map) in Norway. The legend shows expected values of Wh/m2 for each day, with the top legend being for June and the bottom for January (Hagos, D. A., Gebremedhin, A., & Zethraeus, B, 2014).

2-3- BIPVs and BAPVs

PV systems have made the conversion of sunlight to electricity possible. The evolution in the PV industry over the past few decades has been remarkable and PVs are now available in different shapes and formats. The flexibility of PV systems has led to their widespread application in different sectors, from transportation to buildings and architecture. Among the many different types of PV systems available to use on an urban scale, the ones that can be installed directly on buildings are those of interest in the current study.

Solar photovoltaic panels can be either attached or integrated into the building's envelope for producing electrical power. Based on the method of installation, these PV systems are classified as either building attached photovoltaics (BAPV) or building-integrated photovoltaics (BIPV).

BAPVs are the most common and well-practiced types of PV systems used in the building sector. Here, the PV modules are installed directly on the existing building skin (roof or façade) using a supportive mounting structure. The modules can be installed at different tilt angles for achieving the best performance due to local climatic conditions. BAPVs are mostly roof-mounted but they also can be installed on façades (Kumar, Sudhakar, & Samykano, 2019). The use of BAPVs has been somewhat criticized as it interrupts the building's look integrity and affects the cityscape if not installed properly.

BIPVs, on the other hand, are a rather new technology. In these PV systems, conventional façade or roof cladding material is replaced with PV modules that can fully or partially cover the building envelope and meanwhile generate electricity. BIPVs are mostly incorporated in the construction of new buildings, however, they can also be used on retrofitted existing buildings (BIPVNO, 2019).

The advantage of BIPVs over more common non-integrated systems is that its initial cost can be compensated by reducing the cost of purchased building material and labor force. The other advantage is that it would contribute to the building's monolith appearance.

Figure 2-5- application of BIPV and BAPV systems, Roof-mounted BAPV, Chiko Solar, Norway (right); BIPV on the facade of Oseana Art and Culture Center, Bergen, (BIPVNO, 2019)

2-4- Positive Energy District (PED) / Positive Energy Neighborhood (PEN)

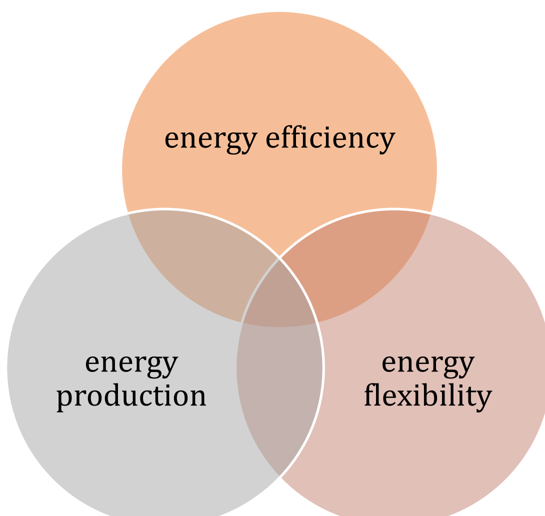
In response to the need for a transition, towards a more sustainable future in urban environments, the European Union (EU) introduced the concept of Positive Energy Districts / Neighborhoods (PED/PEN). This comprehensive approach reflects on technological advances, spatial design, city regulations, legal frameworks, and socio-economic perspectives (Urban Europe (a), 2020).

In this sense, a Positive Energy District is defined as “an urban neighborhood that with annual net-zero energy import and net-zero CO_2 emissions (Urban Europe (a), 2020)”. This means that the neighborhood can produce its own energy need over a course of a year via low-carbon technologies and achieve net-zero CO_2 emissions.

In other words, “Positive Energy Districts are referred to an urban area or a cluster of buildings net-zero greenhouse gas (GHG) emissions and actively engage in the local and regional surplus generation of renewable energy (Urban Europe (b), 2020)”.

According to the above definition, PED/PENs should have the following characteristics:

- PEDs should solely rely on renewable sources for generating the energy they need (energy production function)
- PEDs should prioritize energy efficiency and energy in order to best utilize the renewable energies available (energy efficiency function)
- PEDs should have a beneficial interaction with local and regional energy grid in order to achieve the net-zero energy import target (energy flexibility function) (Urban Europe (b), 2020)



Energy Production function requires that the energy need of an urban area should be supplied via renewable sources, low-carbon technologies e.g. solar and wind, both locally and regionally. This shall contribute to a considerable reduction of GHG emissions and the transition towards carbon neutrality.

Energy efficiency function aims for reducing the energy consumption in different sectors e.g. building, infrastructure, and transportation, within a PED. This also corresponds to other EU directive that requires all the new buildings from 2020 to be nearly zero-energy (NZEB) (European Commission (a), 2014). This function also reflects on increasing energy efficiency in existing building stock and encourages energy saving (Urban Europe (b), 2020).

Finally, the Energy flexibility function means that the urban neighborhood (PED) should interact with the regional energy system, by importing its energy need from the network when the local energy generation cannot cover the energy demand and exporting the additional surplus of renewable energy when demand is lower than production. This shall lead to annual net-zero energy import and enable carbon neutrality (Urban Europe (b), 2020).

The PED concept suggests that transition to a more sustainable future must shift from individual building solutions to neighborhoods and districts if the EU energy and climate targets are to be achieved. Sustainable urban development requires innovative solutions that are able to address social, economic, and environmental challenges comprehensively. By scaling up the level of impact, the PED concept moves the concentration of efforts from net-zero energy buildings toward positive energy neighborhoods. This new concept might better address the challenges of achieving NZEB targets in existing urban environments and ease the energy transition process.

2-5- Different models to analyze insolation in urban scale

Solar radiation is a clean, ample, and free source of energy. With fast technological advancements in the PV industry, the cost of solar energy systems is declining continuously while their efficiency is increasing. As mentioned earlier, several reports and authors have forecasted that solar energy would have a considerable share of the future energy mix. With more people living in cities, a significant fraction of energy demand is also taking place in urban environments. Therefore, there is a growing tendency to deploy PVs in urban areas.

Considering the availability of PV modules in different sizes and formats, they are gaining public interest, and slowly driving the decentralization of electricity in urban areas. This is an important step towards achieving EU energy concepts like NZEB and PED (Freitas, Catita, Redweik, & Brito, 2013).

Many cities across the world are already encouraging the use of solar energy in urban areas in their efforts towards becoming more sustainable. The potential deployment of solar energy can effectively transform neighborhoods and urban districts to small, local power plants, capable of procuring their own energy demand (Kodysh, Omitaomu, Bhaduri, & Neish, 2013).

However, the beneficial application of solar energy in urban areas can be somewhat challenging, and not all urban environments are suitable for PV installations. While in non-urban environments, the full attainment of solar energy is mostly affected by unfavorable weather conditions, in urban areas other restrictions like limited available area, shading from surroundings, and non-optimal surface orientations may affect energy yield from PVs.

Therefore, to promote the efficient application of PV systems in neighborhoods and urban districts, areas, or buildings with higher solar potential should be identified and their potential electricity yield should be assessed carefully. This requires the development of effective methods of analyzing and presenting solar potential in urban environments (Kodysh, Omitaomu, Bhaduri, & Neish, 2013).

Analyzing and depicting the solar potential in urban environments will probably result in better communicating the advantages of BIPV and BAPV systems to the end-users and raising the public interest. Moreover, it will contribute to the process of decision making for authorities by calculating all the available energy resources at a neighborhood scale and defining the most interesting areas for PV installations. This will help decision-makers to plan city developments the way to maximize the solar potential and move towards the PED target.

Preliminarily solar potential analysis tools and methods were mostly used to calculate the solar potential for non-urban scenarios, individual rooftops, or other 2D building-like geometries. Today's tools on the other hand are capable of carrying out much more sophisticated solar analysis for a 3D cityscape, due to great advances in computer powers and modeling techniques. New Computer-Aided Design (CAD) software enable the calculation and representation of solar potential in micro-scale e.g. a building or a group of buildings, while geographical information system (GIS) tools are now capable of performing such analysis at a macro scale and for large urban areas (Freitas, Catita, Redweik, & Brito, 2013).

Nevertheless, it should be noted that on the contrary to 2D approaches to solar analysis, that are straightforward and application of GIS tools are long-practiced and well developed, the calculation of solar radiation for a 3D urban model is still challenging (Freitas, Catita, Redweik, & Brito, 2013). In a 3D urban setting, buildings, structures, trees, and other landscape elements can also obstruct the solar radiation that reaches the buildings' envelope, therefore carrying out a reliable and detailed solar analysis relies on developing an analysis software that is capable of running such a test in a reasonable time and without excessive computation power.

Many different methods and software have been developed for this purpose, however, depending on the end-goal and the level of accuracy required, some would be more appropriate than others might. For instance, running a detailed solar analysis for a 3D urban area must account for complex shadowing scenarios and inter-reflection effects among buildings, particularly when vertical surfaces such as building facades are included in the analysis.

A study by (Freitas, Catita, Redweik, & Brito, 2013) has reviewed the existing methodologies that are capable of performing solar analysis on an urban scale and for large 3D urban models and has classified them into three main categories, as presented below.

- **All-in-one Models**
  Tools that are capable of treating solar radiation but also present design interfaces for 3D objects in a single software are here classified as all-in-one models. Although featuring user-friendly work environments, these models allow reliable quality assessments at small and medium scale e.g. one or a group of buildings. An example of that is TOWNSCOPE and SOLENE software tools (Freitas, Catita, Redweik, & Brito, 2013).

- **CAD plugin-based models**
  Contrarily to the models in the previous subsection, which receive the 3D objects but also have their own design modules, recently some CAD plugin-based 3D modeling software has been developed. They receive plugins from other software, are able to conduct radiation analysis, are very versatile in the non-urban/urban context analysis, and perform with great detail and user-friendly commands. Examples of that are Add-ons like Skelion and DL-light, which are installed on SketchUp software that is a common tool for 3D modeling used by architects and urban designers, and Autodesk Ecotect analysis that is a helpful environmental design tool.

- **GIS-based models**
  The most sophisticated models to predict the physical potential of the solar resource at the large scale of the urban fabric are in this category. They use sophisticated algorithms and coding in different programs like python and MatLab and mostly use ArcGIS to perform analysis. The results from these models are considered as the most accurate and reliable solar analysis data, however, adopting these models requires a certain level of expertise. Examples of that are models by Carneiro et al., and Jakubiec and Reinhart, and also V.sun module and SOL Algorithm (Freitas, Catita, Redweik, & Brito, 2013).

Among the different methods and tools that are mentioned above, this study adopts a CAD-plugin based Model for the aim of calculation solar potential. This is explained in detail in the next chapter; however, it is important to notice that the output data from these methods determine the amount of solar energy that is received by the urban surfaces. Conversion of solar radiation to electrical output from PV panels is a further step than can be performed either within the software itself or using a third party software used for analyzing and interpreting data like Microsoft Excel.

2-6- A brief review of Similar Studies

A brief review of the two similar studies is presented here. These cases have been reviewed to find out the methods that they have adopted and the steps that are undertaken to assess solar potential on an urban scale. The methods and results from these studies will contribute to defining a rational framework for the current research.

2-6-1- Solar energy potential on roofs and facades for the Campus of the University of Lisbon

In this study, a method for the calculation and visualization of the solar energy potential of a group of buildings in a 3D urban model is developed, that is aiming for integrating the potential of roofs and the façades. To assess this potential, a digital surface model (DSM) of the urban region is made from LiDAR data and solar radiation is calculated in ArcGIS based on climatic information. A shadow algorithm is developed to calculate shadow maps and sky view factor both for roofs and facades at once. Direct and diffuse solar radiation is obtained for the whole 3D model, including ground, roof, and facades with a spatial resolution of 1 m and a time resolution of 1 hour (Redweik, Catita, & Brito, 2013).

The method described above is called the SOL algorithm and it was applied to an area of about 160,000 m2 in the Campus of the University of Lisbon, including its nine main buildings. As expected, the results indicate that irradiation levels are much higher on the roofs and the ground than on vertical facades. South inclined roofs are particularly identified as a favorable area for the PV installation.

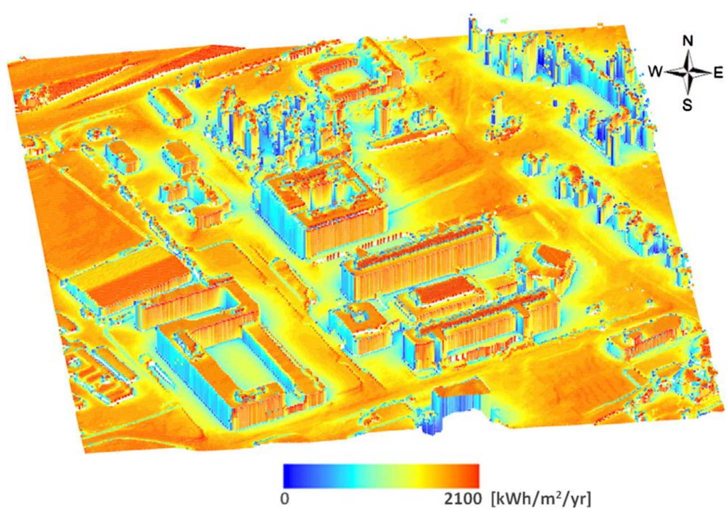


Figure 2-6- Annual global irradiation in the University Campus of Lisbon (Redweik, Catita, & Brito, 2013).

The SOL algorithm is being developed jointly in ArcGIS and MatLab and it enables the solar irradiation calculation on different surfaces of a 3D urban model (ground, roofs, and facades) for a specific period of time. This will allow monitoring the evolution of insolation throughout the year and brings some interesting facts into evidence regarding the PV potential in the study region.

The findings of this study indicate that, in the winter, the south-facing facades receive a larger amount of solar radiation per square meter than the roofs, while this equation reverses in the summer when roofs receive a larger share of insolation. The study also suggests that the solar radiation on roofs varies considerably between the seasons, while the solar potential of the best-oriented facades shows a much smaller variation (Redweik, Catita, & Brito, 2013).

The study also compares the insolation value for the different facades and suggests the most interesting facades for installing PV systems. Once the best-oriented facade has been identified, the detailed view of the 3D model can be used to identify the most favorable locations for the installation of a particular solar system. Findings indicate that vertical surfaces can be appropriate for large-scale deployment of PV systems since they produce more power during winter months and the early and later hours of the day when demand is higher. However, it emphasizes that roofs ought to have priority for the installation of solar power generation devices (Redweik, Catita, & Brito, 2013).

The results confirm that the annual irradiation on vertical facades is generally lower than roofs, but due to their very large area, the potential of facades is relevant for the overall solar potential of a building or an urban area. These results are also useful for the development of solar dissemination policies and urban planning.

2-6-2- Solar Energy integration in future urban plans, Case of Ibenbadis, Algeria

This study develops a concept for Energy-efficient urban planning through solar energy applications in the city of Ibenbadis, Algeria, based on Sustainable Solar Urban Planning algorithm designed by (Amado, M., & Poggi, F, 2012). The proposed algorithm is presented below.

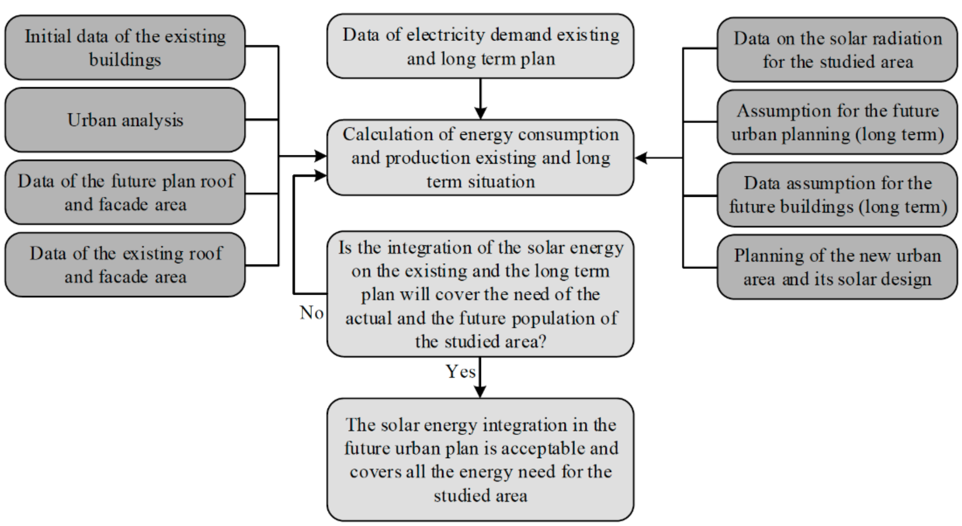


Figure 2-7- Energy efficient urban planning Research model, (Lauka, Haine, Gusca, & Blumberga, 2018)

In simple words, the study takes following four simple steps towards its research objective:

1. Analyzing the existing urban fabric, defining energy efficiency targets for the study region;
2. Collecting data on economic, social, environmental, climatic conditions especially solar radiation and energy demand in the study region;
3. Running the solar simulation and suggesting a new urban plan proposal for better solar energy production;
4. The new Urban model resulting in good environmental and energy performance.

The study selects a neighborhood in the city of Ibenbadis and extracts information and data about the current land-use, existing building envelope area, etc. Then the plans for development in the area are studied and a proposal is suggested based best solar performance of the neighborhood.

For this aim, first, a solar analysis of the exiting neighborhood is carried out using ArcGIS and then information about buildings' energy consumption, minimum usable roof area, the best roof tilt angle, efficient PV position, building orientation, and PV characteristics (type, performance ratio, and PV module efficiency) are collected. Table 1 shows buildings' average energy use by sector and table 2 shows predicted annual yield for PV systems in existing urban settings.

Table1 – Energy analysis of the city of Ibenbadis, (Lauka, Haine, Gusca, & Blumberga, 2018)

Electricity consumption by sector	Residential (Consumption per capita)	3 700 kWh/person/year
	Mixed-use :Residential/Commercial	180 kWh/m²/year
	Industrial and other specialized structures	311 kWh/m²/year

Table2 – PVs produced energy on existing roof areas, (Lauka, Haine, Gusca, & Blumberga, 2018)

Buildings (current use)	**Gross roof area (m²)**	**Total available roof area for PV installation (m²)**	**Mean annual global radiation on available roof area (MWh/y)**	**Predicted annual yield for PV systems on available roof area (MWh/y)**
Residential	17 600	12 320	23 408	2 282
Industrial and other specialized structures	0	0	0	0
service	1 760	1 232	2 341	228
Commercial	2 200	1 540	2 926	285
unclassifiable	500	350	665	64
Total	22 060	15 442	29 340	2 861

Then values for building energy consumption and potential solar energy generated are compared. The results show that energy production potential by integration solar PVs on the roofs of existing buildings for the city Ibenbadis is 2861 MWh/y whilst the annual consumption of electricity per capita is 3700 kWh/person per year. It means that considering the area population, the existing urban settings can provide renewable energy to 58% of inhabitants. It concludes that a traditional urban planning style (bad configuration of the roofs and bad orientation of the facades to solar radiation) hinders the full exploitation of the solar energy (Lauka, Haine, Gusca, & Blumberga, 2018).

The same steps are undertaken for future plans for developing the same neighborhood. The study uses predictions and forecasts at this stage to estimate the energy use and annual yield of PV systems in 2025. The results are summarized in the table below. Accordingly, the future urban plan is capable of producing 6 922 MWh /year from PVs installed on the roofs and facades of the buildings, which can cover energy needs for 4000 people.

Table 3 – PV energy production estimation on roofs and facades in new, (Lauka, Haine, Gusca, & Blumberga, 2018)

Buildings (current use)	**available roof area for PV installation (m^2)**	**Mean annual global radiation on roofs (MWh/y)**	**available façade area for PV installation (m^2)**	**Mean annual global radiation on facades (MWh/y)**	**Predicted annual yield for PV systems on available roof area (MWh/y)**
Residential	17 204	32 688	6 112	11 613	3 300
Industrial and other specialized structures	0	0	0	0	0
service	1 496	28 428	300	570	332
Commercial	1 870	35 538	664	262	372
Total	24 200	39 083	7 076	13 444	6 922

Consequently, the Solar Urban Planning model and its application in this study show that the NZEB target could be achieved if the transformation of the neighborhood takes place according to the model guidelines. The adopted model identifies unsuitable roof areas and inappropriate facade configurations that hinder the full exploitation of the solar potential in an efficient way. Accordingly, guidelines for more energy-efficient and better solar performing urban areas can be suggested. Efficient buildings orientation and engaging facades in energy generation procedures are essential for attaining the PED goal. (Lauka, Haine, Gusca, & Blumberga, 2018).

Presented research also shows that with the Solar Urban Planning method it is possible to improve urban qualities, accommodate more people and at the same time guarantee a better energy performance of the neighborhood, which contributes to the PED target.

03 | Methodology

3-1- Data Collection

This study adopts a quantitative approach to find answers to the main questions of the research. The first research question is about the amount of energy that can be produced by using PV systems on the scale of an urban block in the city of Stavanger. To find an answer to this question, one must initially answer a set of sub-questions:

- On average, how much solar energy does a surface (vertical and horizontal) receive in Stavanger in kWh/m^2 per year?
- What areas of urban surfaces are available for installing PV systems (BIPV) in selected urban blocks?
- Finally, what is the efficiency of PV systems, and how much of the solar energy that they receive can be converted to electricity?

The second research question is asking whether it is possible to achieve a PED goal by integrating PV systems in the existing urban fabric. Finding an answer to this question also requires seeking an answer to the following inquiries:

- How much is the energy consumption in Stavanger, divided by sector (Residential, Commercial, other) in kWh/m^2?
- What is the total area (BTA) of the selected sites, divided by land-use (Residential, Commercial, Other)?
- And consequently, how much energy is consumed in the selected areas over a year period based on data from the last two questions?

Seeking answers to the above-mentioned questions leads to the findings that should address the main research objectives. In the following, the steps taken to conduct this study are further elaborated.

The first step was to collect information about the two urban blocks that were selected earlier as the focus area through field observation. For each building in the selected urban block, some information about façades, roof, and building total area were collected and summarized in a table. An example of that is presented in figure 3-1; the rest can be reviewed in the appendix chapter.

Data gathered included façade cladding material and percentage of openings on the façade, roof cladding material and available area for PV installation, and the building area information divided by its land-use. Some of this information is essential for the solar irradiance calculations and are used as input data in the analysis software, the rest is used to find out whether it is possible to achieve a net-zero neighborhood.

It should be stated that due Coronavirus situation and general lockdown in Norway at the time of writing this thesis, we were not able to conduct the field observation for the urban block in Øvre Holmegata. The information for this area was collected using aerial images from “Norge I bilder” and Street view images from “Google maps”. In addition, municipal maps from Kommunekart were used to calculate floor area for both urban blocks.

BUILDING 04

FACADE	
MATERIAL	WOOD
COLOR	100%WHITE
ANGLE	90 °
WINDOWS PERCENTAGE	60%

ROOF	
ROOF TYPE	FLAT
MATERIAL	RUBBER ROOF
COLOR	GREY/10%REFLETIVE
USABLE AREA	80%

AREA	
FLOOR AREA	577 m²
NUMBER OF FLOORS	6
BRA - RESIDENTIAL	2885 m²
BRA - COMMERCIAL	467 m²
BRA - OTHER	110 m²
SUM BRA	**3462 m²**

Figure 3-1- Buildings information Data sheets sample

The next step is to select a method to carry out solar analysis. This study is aiming to consider the solar potential of PV systems both on roofs and façades, therefore it was important to choose an advanced and yet simple method/software that can run such an analysis in a reasonable time. As mentioned earlier, among the many different options, this study uses a new software named “DL-Light” for the solar analysis that is an add-on for SketchUp software. This is elaborated in detail further in this chapter.

Finally, the current energy use of buildings in the study area is calculated based on the existing official statistics, and results are compared to the energy generated from BIPVs to find out whether it is possible to achieve a net-zero energy neighborhood. Four different scenarios are studied here:

- Considering BIPVs efficiency in the current year (2020), with no retrofitting measures adopted to improve building energy efficiency
- Considering BIPVs efficiency in the current year (2020), also improved building energy efficiency by 20% (EU target for 2020)
- Considering BIPVs efficiency in 2030, with no retrofitting measures adopted to improve building energy efficiency
- Considering BIPVs efficiency in 2030 also improved building energy efficiency by 32.5% (EU target for 2030)

The research model adopted in this study is summarized in figure 3-2. The Numbers for PV efficiency developments towards 2030 and values for energy saving targets are explained further in the chapter.

Figure 3-2- Designed research model

3-1-1- Energy efficiency targets in the EU

According to a report by the International Energy Agency (IEA), increasing energy efficiency is one of the most important components in the fight against climate change (IEA (b), 2019). This has been reflected in national and international guidelines and directives that are aiming for a coordinated response to this issue. In 2012, the EU set a 20% energy efficiency target by 2020 under the Energy Efficiency Directive 2012/27/EU (European Commission (b), 2014). This goal suggested that the EU members should come up with their own national energy efficiency targets and publish annual reports on their progress towards this goal. The directive suggested that this energy efficiency should be developed throughout the full energy chain, from production to final consumption (European Commission (c), 2020). In 2018, a new amending Directive on Energy Efficiency (2018/2002) was agreed upon which was aiming for at least 32.5% energy efficiency target toward 2030 (European Commission (b), 2014).

Norway seems to follow the same directive in its climate actions, however, no specific number was found about energy efficiency targets for the city of Stavanger in the municipal climate and environmental plan. Meanwhile, in a 2020 report from Bergen municipality, it has been stated that this city could reduce its' energy consumption by 29% by using available technology and solutions (Bergen Kommune, 2020). Nevertheless, it has been assumed that the same numbers as the EU targets are applicable for the case of Stavanger as well.

3-1-2- Solar PV efficiency, trends, and forecasts

Solar PV efficiency is an indicator that measures the PV's ability to convert solar radiation into electricity. It is usually stated by a percentage and demonstrates the fraction of the received insolation that can be turned into electricity. In other words, for two PV modules with the same size and format but different efficiency rates, tested under the same conditions, the one with higher efficiency produces more electricity than the less efficient one. PV efficiency depends on many different factors e.g. cells' composition, surrounding components, environmental conditions, and more (Aggarwal, 2020).

For the public and general consumers, the PV efficiency is considered as one of the most important criteria for assessing the PV system's quality. However, it is not the only factor that should be considered while evaluating a PV system, other factors like total cost, climate durability, cell type, etc. are also important.

The PVs' efficiency has increased considerably since their invention. The National Renewable Energy Laboratory (NREL) is one of the main organizations that publish yearly report on Solar PV efficiency improvements by type. The newest report from NREL, presented in figure (3-3) shows the development of PV efficiency from 1976 to 2020 (NREL, 2020).

It is important to note that, NREL reports assess the PV efficiency in laboratory standards, meaning the best environmental conditions are applied to find out the maximum efficiency of the PV module. The actual PV efficiency value in real-world conditions is usually lower than what NREL suggests. The NREL also assesses the efficiency evolution for all types of PV modules.

The report suggests that the most efficient PV module available can reach up to 47% efficiency. However, the common PVs that are available in the market for general applications are mostly mono-crystalline modules, shown in this chart with dark blue lines. The report indicates that mono-crystalline PVs can reach up to 27.6% efficiency in laboratory conditions (NREL, 2020). The slope of the chart demonstrates the changes in crystalline PVs over the past few decades.

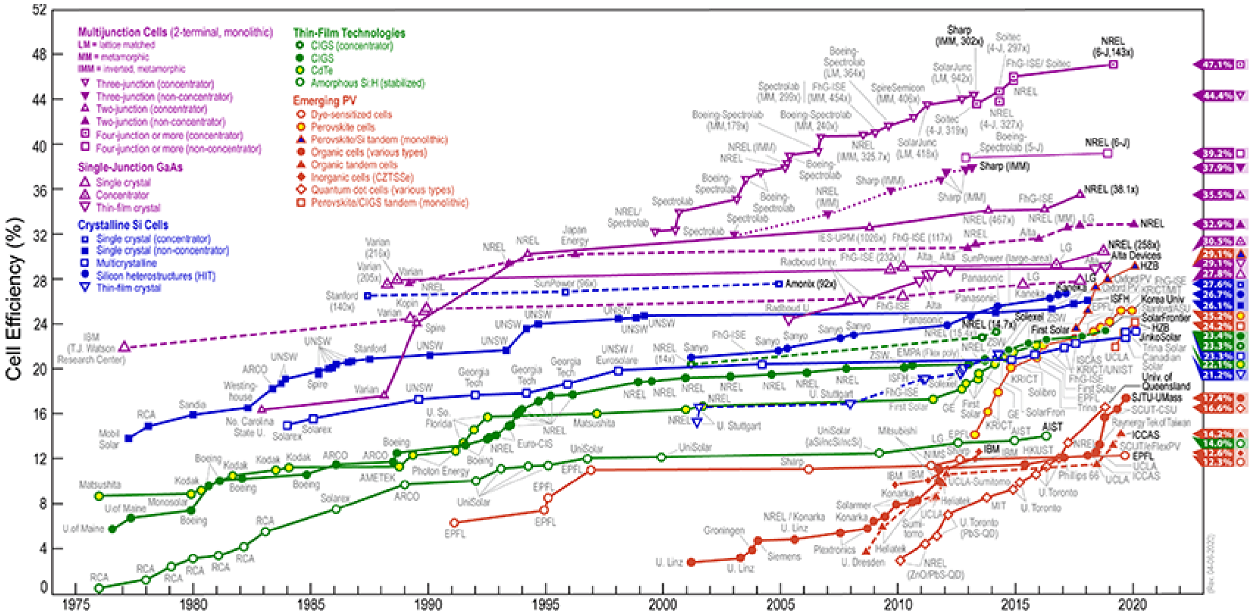


Figure 3-3- PV Module Efficiency improvements over time, (NREL, 2020)

According to a study by Fraunhofer Institute for Solar Energy Systems, best performing commercial modules are based on mono-crystalline silicon with 24.4% efficiency in the laboratory. However, in real-world conditions several factors like thermal function, snow cover, cloud cover might affect the PV efficiencies, therefore the average efficiency for commercial mono-crystalline PVs lies between 15 to 18% (Fraunhofer Institute, 2020).

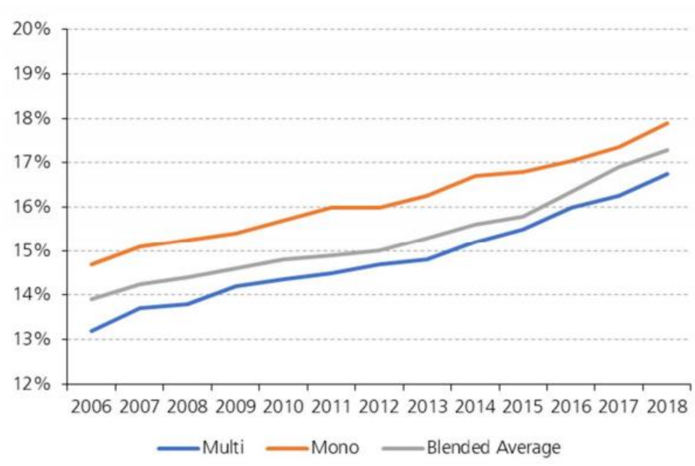


Figure 3-4- Average Crystalline-Silicon PV Module Efficiency, (Fraunhofer Institute, 2020)

Recently and due to developments in the BIPV industry, new types of modules have emerged. The ones that are of interest in the current study are transparent and semi-transparent PV modules that can replace windows and let the light through while generating electricity (ClearVue, 2018). According to one of the manufactures, this PV modules can currently reach up to 7% efficiency (ClearVue, 2018).

There are different forecasts on how PV efficiencies are going to develop towards 2030. While (Randers, 2012) suggest that PV efficiency is expected to develop by 3-4% per decade, more optimistic predictions are expecting better improvements. Based on the report from (Fraunhofer Institute, 2020) and past efficiency improvements data provided by (NREL, 2020), this study assumes that PV efficiencies will increase by 7-8% until 2030. This means that it has been assumed that conventional mono-crystalline PV will have 25% efficiency by 2030, while the efficiency value for transparent PV modules will rise to 15% in the same period.

3-2- GIS

Geographic Information System (GIS) is a tool for managing, analyzing, and visualizing geographical and spatial data (ESRI, What is GIS?, 2020). There are many types of GIS-based programs but the one that is used in the current study is ArcGIS. This software lets the user organize layers of geo-referenced information and enables determining patterns, relationships, and situations and helps the user make smarter decisions (ESRI, What is GIS?, 2020). In the current study, ArcGIS has been used to carry out the solar analysis for a large urban area in Stavanger Sentrum. Since ArcGIS is rather sophisticated software, the process of procuring an insolation map for Stavanger sentrum is described in this chapter. However, first, a brief introduction of how GIS works is presented.

3-2-1- Data input in GIS

As mentioned earlier, GIS produces maps based on different layers of input information. Some of these data are produced by high altitude satellite or low altitude aircrafts imagery (Falklev, 2017). Different approaches exist when it comes to air-borne imagery, but perhaps the most common one is using light detection and ranging (LiDAR) sensors. In this method, a signal is sent out and by measuring the time that reflected signal returns, the distance is measured (Falklev, 2017).

This method is used to generate high-resolution digital elevation models (DEMs), that demonstrate the topography of the earth's surface with great detail. Figure 3-5 shows how LiDAR data is provided.

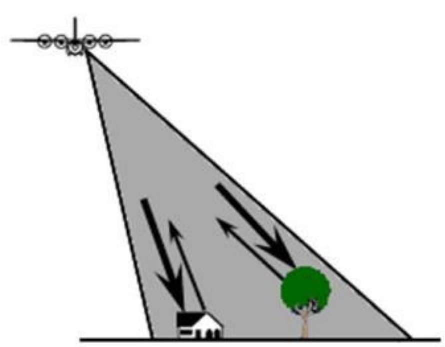


Figure 3-5- Illustration of airborne LiDAR, (Falklev, 2017)

Every map that is produced in GIS constitutes a combination of layers, where each layer contains a set of specific physical or non-physical information or data e.g. distribution of buildings on the terrain or population. The important point is every layer is geo-referenced, meaning that it holds information related to a specific location. In order to overlay information layers correctly, they should be placed on the right projection system (Falklev, 2017). For instance, Stavanger is located in the European Terrestrial Reference System (ETRS) of 1989, Universal Transverse Mercator (UTM) Zone 32 North, more commonly called UTM Z-32N.

There are two different types of layers in GIS, vector and raster layers. Raster layers are a 2D matrix of cells, arranged on a grid where each cell contains information e.g. global solar radiation or elevation. Raster is usually made using air-borne imagery and represents a real-world phenomenon (ESRI, What is raster data?, 2020).

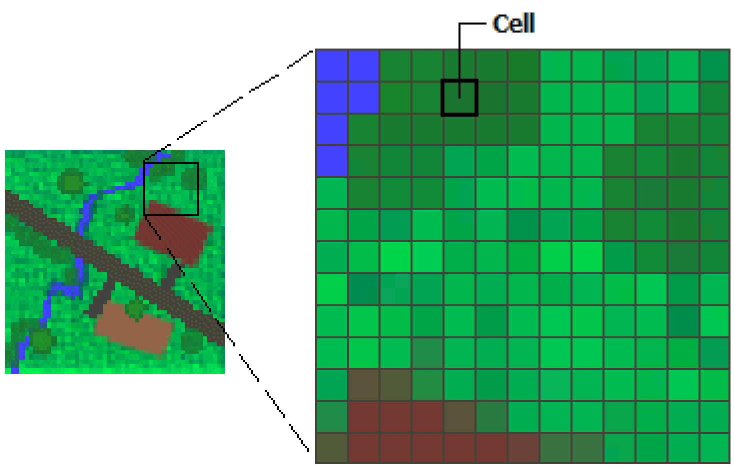


Figure 3-6- Illustration of a raster layer, (ESRI, What is raster data?, 2020)

On the other hand, vector layers include 2D information in geometrical shapes like polygons, lines, and points, where each shape represents a specific feature (Falklev, 2017). An example of that is presented in figure 3-7.

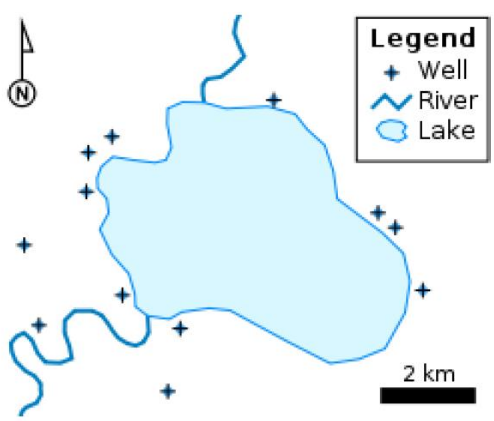


Figure 3-7- Illustration of a vector layer with distinctive features (Falklev, 2017)

3-2-2- Digital Elevation Model (DEM)

A digital elevation model (DEM) is usually a raster GIS layer that contains information about the elevation of the terrain. The most common method of creating a DEM layer is via LiDAR technique and photogrammetry. DEMs with higher resolutions provide more accurate data about elevation and are more reliable for running elevation-dependent analysis; however, they increase computation times considerably (Falklev, 2017).

In Norway, GeoNorge provides DEM rasters with different resolutions for the whole country. The resolution of a DEM is usually mentioned in its name i.e. DEM10. This means that each pixel of this raster contains information of a cell in size as 10x10 meters in the XY plane. For Stavanger, a DEM raster with 10x10 resolution was available in GeoNorge. However, due to its large size different DEMs, each covering an area of 1000X1000 meters were downloaded separately and combined in ArcGIS. The result showing the DEM raster of Stavanger sentrum is presented in figure 3-8.

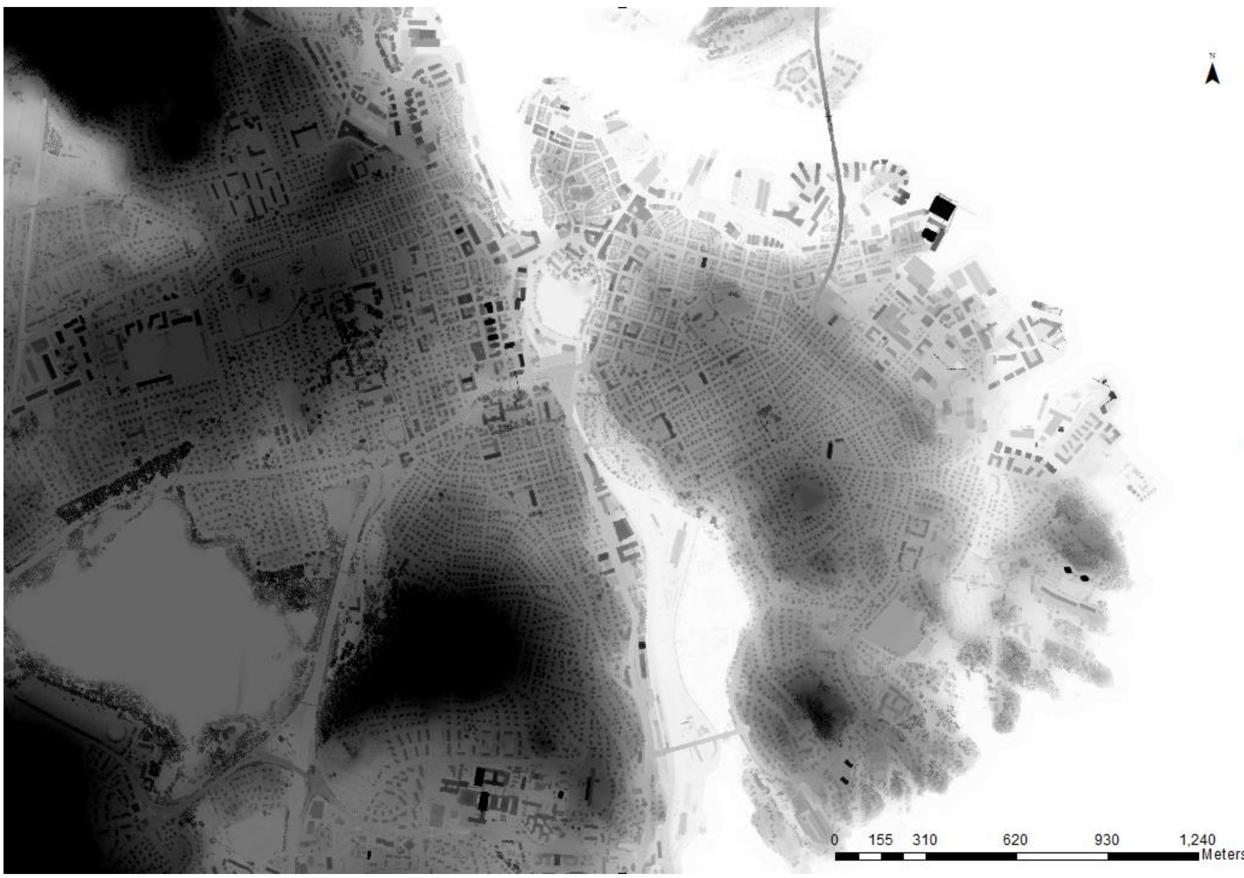


Figure 3-8- DEM10 of the Stavanger City center area. Created in ArcGIS. Projection: UTM Z-32N.

It is important to point out that there are two types of DEM; digital terrain model (DTM) and digital surface model (DSM) are presenting different elevation information. A DSM contains elevation information of the terrain and whatever is placed on it e.g. buildings and vegetation. While a DTM only represents the terrain surface (Falklev, 2017). This is illustrated in figure 3-9. In this study, a DTM raster is used.

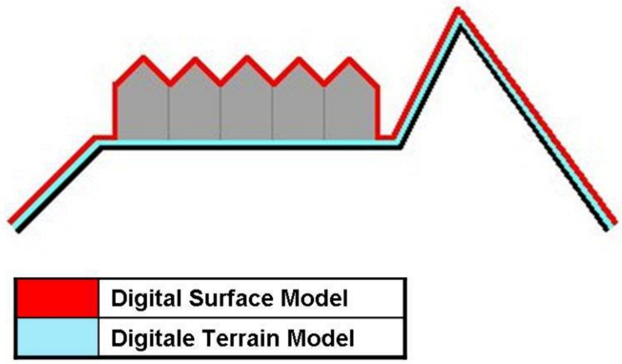


Figure 3-9- The difference between a DSM and DTM. (Defra 2017)

3-3- Solar Analysis for 2D urban models (Rooftops) using ArcGIS

ArcGIS Desktop version 10.5 is used, in order to run a solar analysis for horizontal surfaces in Stavanger Sentrum. To carry out the solar analysis, an ArcGIS tool called Solar Analyst is used. Solar Analyst tools enable the mapping and analyzing the effects of the sun over a geographic area for specific time periods (ESRI, An overview of the Solar Radiation tools, 2017).

Solar Analyst toolset contains three distinctive tools; Area Solar Radiation (ASR), Point Solar Radiation (PSR), and Solar Radiation Graphics (SRG). A detailed walkthrough guide of performing solar analysis in ArcGIS using Solar Analyst toolset is explained here.

3-3-1- Solar Analyst

Often, the solar radiation data is not available as a pre-made GIS layer for most geographical locations. This is mainly due to the great variation of insolation value in a landscape, due to distinctive topographical conditions and variability in elevation and slope and shadows (Falklev, 2017). Therefore, the solar analyst tool has been developed to enable GIS users to carry out a solar analysis.

Solar analyst tools can be found under Spatial Analyst extension, in the extension toolbox for ArcGIS. It contains three sub tools, ASR, PSR, and SRG for calculating solar radiation for a landscape at a specific geographical location. The solar analyst is a solar radiation-modeling tool that is capable of analyzing solar irradiance with great accuracy and with reasonable speed (Fu & Rich, 1999).

Area Solar radiation and Point solar radiation will do the same thing but on different scales. ASR tool is capable of calculating insolation for each cell of a DEM, while PSR does it only for a chosen cell. This means that running a solar test with PSR will probably result in less computation time. It is suitable for calculating insolation on a rooftop or a very small area. While for larger urban areas, the ASR tool must be used that calculates the insolation for all the cells in a raster layer (Falklev, 2017).

3-3-2- Viewshed, Sunmap, and Skymap

In order to analyze the solar radiation for a landscape, the solar analyst needs to initially calculate direct and diffuse irradiance by procuring viewshed, skymap, and sunmap diagrams. The SRG tool is used to calculate Viewshed, Skymaps, and Sunmaps for the chosen location (Falklev, 2017).

First, the Viewshed must be calculated using the SRG tool. According to (Fu & Rich, 1999), "A viewshed is the angular distribution of sky obstruction, i.e. how much of the sky that is obstructed from topographic elements at a certain location." This means that for each cell of a DEM, a viewshed is equal to an upward-looking hemispherical photograph, that depicts how much of the sky is blocked by topographic elements e.g. terrain. The viewshed is calculated based on DTM and therefore is not affected by landscape elements like trees and buildings. An example of viewshed is presented in figure 3-10.

Figure 3-10- Hemispherical viewshed photo with calculated viewshed (yellow inner line). (Falklev, 2017)

Figure 3-11 depicts the user interface of SRG too in ArcGIS. In this software dialogue, the input raster was chosen to be the DTM10 of a limited area around Stavanger city center (created and presented earlier in this chapter). This area was chosen for limiting the computation time in ArcGIS, and since it contains both selected urban block in this study. A sky size of 512x512 (suitable resolution for the viewshed) and calculation directions of 64 is set to represent all sky directions. These values are assigned based on guidelines from solar analyst developers (Fu & Rich, 1999).

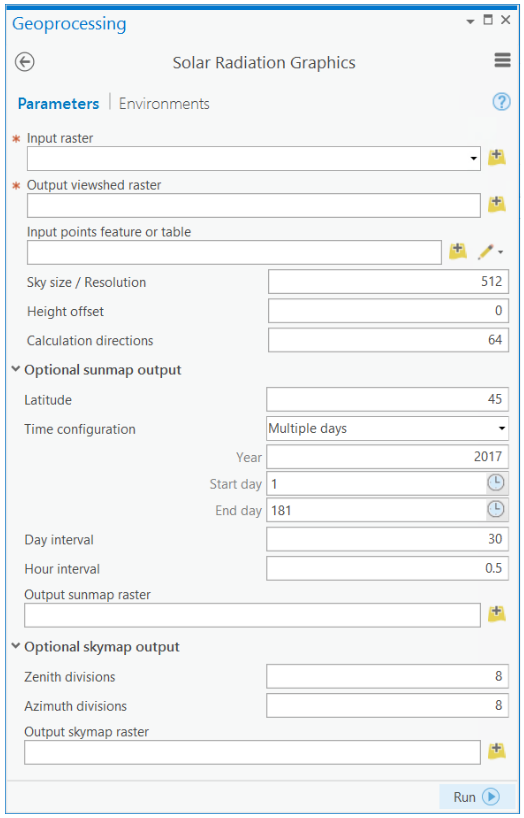


Figure 3-11- Tool screen for Solar Radiation Graphics, SRG, (Falklev, 2017)

The submap is also calculated in the same step. In the above-shown software dialogue box, the “Optional sunmap output” settings must be set. In order to calculate average solar radiation annually, the sunmap must be produced for a period of a whole year. According to (Fu & Rich, 1999), it should be also possible to differentiate between months of the year and times of the day. Therefore “Day interval” value is set to 30 and “Hour interval” is set 0.5 (Falklev, 2017).

Since the sun orbits the same path each half of the year, the time configuration is set to Start day=1 and end day=181, so that months like March and September would not cross each other. For optimal results, the time interval between the winter and summer solstice should be chosen, since the sun is at its highest and lowest positions at these times (Fu & Rich, 1999).

The Skymap is also calculated using the same SRG tool. Further down at the above-shown software dialogue, settings for skymap calculation can be found. For an optimal skymap calculation and base on (Fu & Rich, 1999) guidelines, zenith and azimuth division values were set to 18 and 16 respectively.

The first map created in SRG is the viewshed and it is presented in Figure 3-12. The viewshed indicates only minor sky block by terrain features, which might be as a result of low sun position in the sky for certain times of the day.

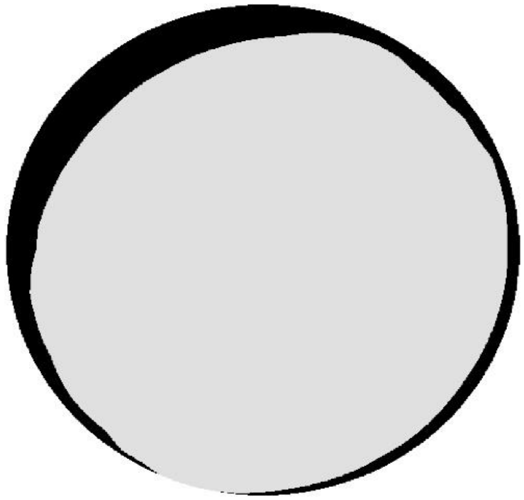


Figure 3-12- Viewshed of Stavanger Sentrum. Created in SRG.

Next, the sunmap is calculated. The sunmap depicts the sun path in the sky for each month of the year and each hour of the day, The sunmap should be calculated separately for the two half of the year. The calculation of a sunmap is based on time of day, latitude, and day of the year. The sun maps for the study area was procured but could not be saved due to a technical issue, therefore an example of sunmaps are presented in figure 3-13 and 3-14.

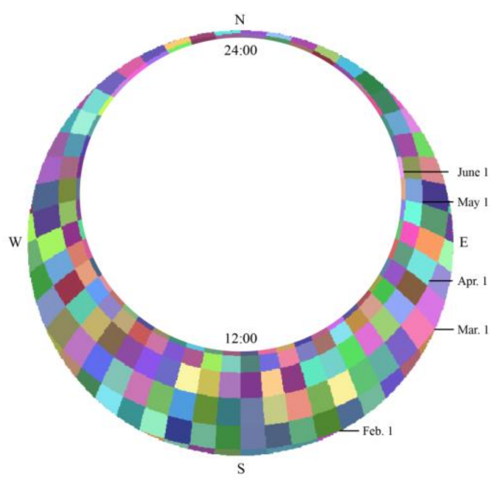


Figure 3-13- a sample Sunmap for the months January to June. The 1st of each month, as well as noon and midnight, are marked, Tromsøya, (Falklev, 2017).

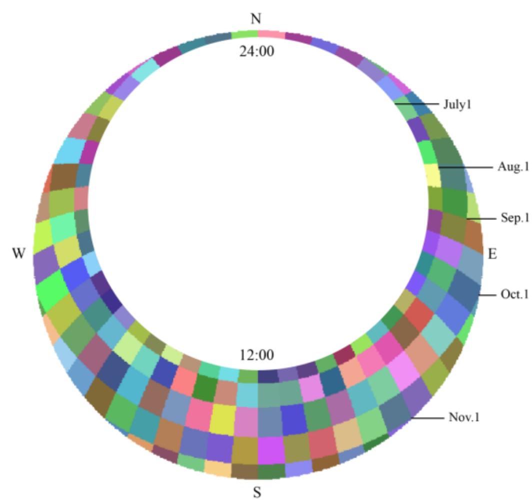


Figure 3-14-a sample Sunmap for the months July to December. The 1st of each month, as well as noon and midnight, are marked. Tromsøya, (Falklev, 2017)

The sunmap depicts the position of the sun in the sky at a specific time and at a certain time. The figure on the left displays months June (the inner circle) to January (the bottom circle close to the south mark), and Figure on the right displays July (the inner circle) to November (the bottom circle) (Falklev, 2017). Sunmaps are used to calculate the direct radiation.

Finally, skymap is calculated. Skymap calculation is used for assessing the diffuse radiation (radiation that is filtered by clouds and etc.). A skymap divides the sky into azimuth and zenith divisions and calculations are made for each of these sectors (Falklev, 2017). The skymap for the study area was made but it could not be saved due to a technical issue, therefore an example of sunmaps is presented in figure 3-15.

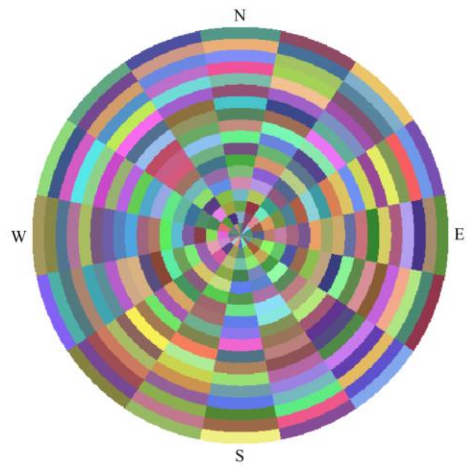


Figure 3-15- Skymap with 16 azimuth divisions and 18 zenith divisions. (Falklev, 2017)

The skymap and sunmaps should be overlaid by the viewshed, in order to enable the solar analyst to calculate global solar radiation. A sample of that is displayed in figures 3-16, 3-17, and 3-18. The viewshed covers some parts of both skymap and sunmaps. For the sunmaps the covered areas by viewshed represent the times of the year, the location does not receive direct radiations. For the skymap, the covered sectors by viewshed represent the sectors that cannot be a source of diffuse radiation (Fu & Rich, 1999).

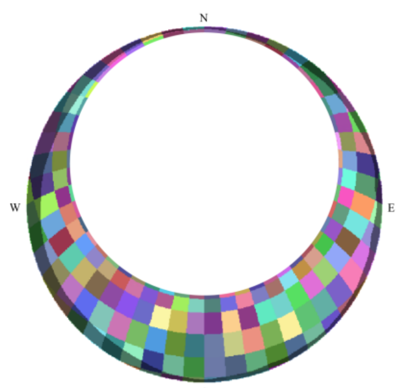


Figure 3-16- a sample Sunmap for January to June with overlaying viewshed. (Falklev, 2017)

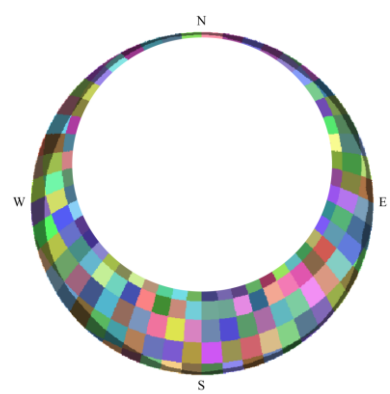


Figure 3-17- a sample of Sunmap for July to November with overlaying (Falklev, 2017)

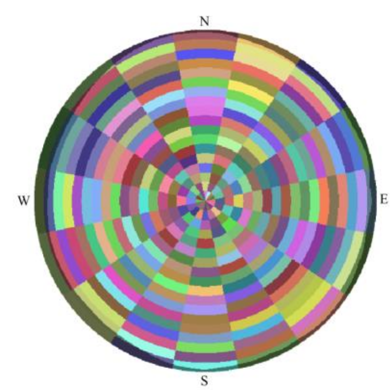


Figure 3-18- a sample of Skymap with 16 azimuth divisions and 18 zenith divisions, including overlaying viewshed. (Falklev, 2017)

When Diffuse and direct radiation values are calculated in SRG, the ASR tool is used to calculate annual average solar radiation for the selected urban area. It is important to point out that this method does not consider buildings inter-reflection effects.

3-4- Solar Analysis for 3D urban models using DL-Light

One of the main objectives of this study was to adopt a holistic approach towards solar energy analysis on an urban scale, therefore it was important to also include facades in energy analysis. Although it is evident that facades do not receive as much insolation as rooftops, since they form up a large fraction of urban surfaces, their potential for producing electricity must be studied more in detail.

As mentioned in the previous chapter, calculating solar irradiance on building facades has not been investigated properly and unlike the same analysis for rooftops, there is no prevailing method for carrying it out. Among the many different tools and methods that have been developed for calculating solar analysis for building surfaces, this study adopts a new software called “DL-LIGHT”.

This is a SketchUp plugin for studying natural light in architecture and urban projects, introduced by “De Luminæ” that is a technical and research company in natural and artificial lighting based in France. The software suite contains 17 metrics for analyzing light in architecture and urban planning, including a tool called “Watt”, that calculates solar irradiance on the selected outside surfaces of a 3D model in terms of W/m^2 over a period depending on the location and the climatic data.

This software package has several advantages over other methods that justify its choice. First, it has a user-friendly interface that makes it easy to use without needing extra knowledge in coding and programming. Second, it claims to calculate reflective irradiance as well, which is a huge advantage. Third, it does not need excessive computing times and it works very well with SketchUp 3D models.

In Norway, Norkart provides detailed 3D models of the urban environments in various file formats including SketchUp format. These models include both the terrain and the buildings. We have used the Norkart 3D models as the basis file for running the analysis in this thesis, however for several reasons we had to model the urban blocks that we had chosen earlier with a desirable amount of details and place them in Norkart 3D models. The main reasons for this decision are as follows;

- Norkart 3D models do not have enough accuracy when it comes to complex shapes, especially pitched roofs and tilted facades.
- Norkart 3D models do not include buildings’ cladding information.
- Norkart 3D models are consist of too many surfaces that will result in increased computation time.

Following the above-mentioned reasons, the chosen urban blocks were modeled from scratch in 3D using information from municipal maps and with the roof and façade cladding information included. This allowed us to save more computation time and modify the 3D models according to the input data we needed for the analysis software.

The "Watt" module will require some input data besides the 3D model to be able to calculate the solar spectrum irradiance (W/m^2) accurately. The main panel of the software is shown in figure 3-19. The software is able to calculate and present the solar irradiance data in three categories; Average, Total, and Maximum. Among these three, we are working with "average" data that represents the average daily irradiance for each surface for a selected period of time in Wh/m2 per day.

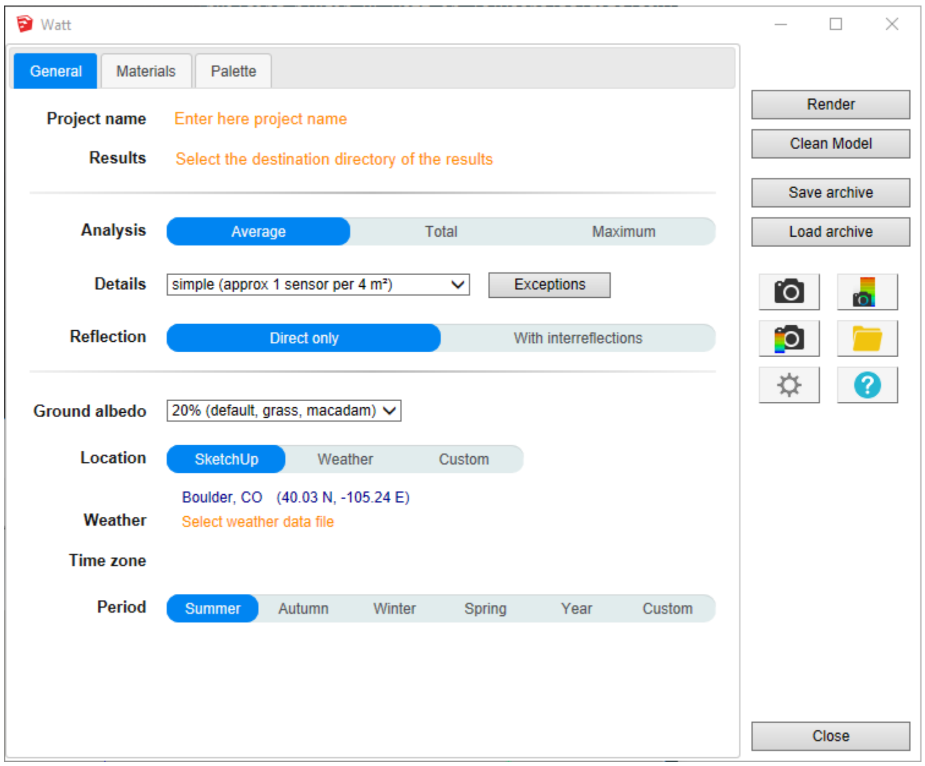


Figure 3-19- DL-Light Watt extension main panel

In the next step, the level of details for calculation should be determined. The software will allow the user to choose between a different number of sensors on each surface; where a higher number of sensors results in better accuracy and increased calculation time. For this study, we used "detailed" settings that are equal to approximately one sensor per m^2.

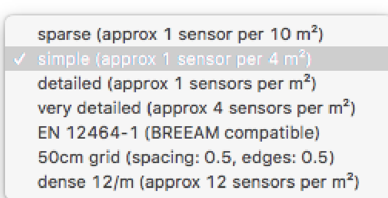


Figure 3-20- DL-Light Watt extension, level of details

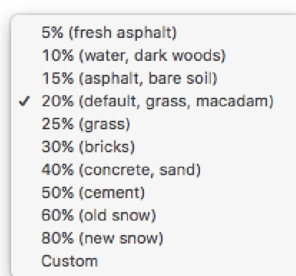


Figure 3-21- DL-Light Watt extension panel, ground albedo

The next steps are to choose whether the calculation should consider inter-reflections as well and to select a value as a ground albedo. Inter-reflections consider energy received from the sun and sky, and also reflected from surrounding surfaces such as ground, nearby buildings, facades, etc. This option requires the correct definition of materials optical characteristics and takes more time to calculate but the results are closer to real-world irradiance on surfaces. We chose the option to include inter-reflections in the calculation and selected 20% as the ground reflection value.

Then Project location should be determined by its latitude and longitude and weather data of the location should be loaded into the program. The weather data for Stavanger city for 2018 was retrieved from the “One Building” website that offers climate data of different cities around the world in a compatible format for DL-Light software.

The final step is to choose a period for which the irradiance should be calculated. Among the many different options, this study chose to calculate the energy received by the building envelope monthly. This way the changes in irradiance over the year can be depicted more accurately and the relation between the amount of energy received by horizontal and vertical surfaces can be better depicted.

Before running the analysis, buildings’ cladding materials should also be defined using the material pallet in the software. The program has its own material pallet with predefined samples but also allows users to define new materials as well. The Norkart models do not include buildings materials information, therefore 3D models were modified and selected buildings were modeled from scratch with the façade and roof cladding information, including their material and color according to the data that was extracted earlier.

After running the analysis, the results are presented in two different formats. The graphical representation uses a color spectrum and applies it to the analyzed surfaces. The color range indicates how much energy each part of the surface receives comparatively, where reddish surfaces are receiving more energy than the bluish ones. The results are also presented numerically in a table format, where each row indicates a unique surface, its’ area in [m2], and the average amount of energy it has received in [Wh/m2 per day]. The results of the analysis for the selected urban blocks are discussed in detail in the following chapter.

04 | Findings

After modifying the 3D models and inserting the prerequisite information in the analysis software, tests were run separately for each urban block and for each month of the year. Each test took between 10 to 12 hours to be completed and this was one of the main reasons to limit the study area to small city blocks and not the whole neighborhood. The results of the tests for each urban block are presented in detail below.

4-1- Solar analysis results for the urban block in Øvre Holmegata

The urban block selected in Øvre Holmegata, consists of 10 plots and 15 buildings and is stretched in the east-west direction. Located in the heart of Stavanger city center, the area is in a cultural heritage protected zone and any changes in buildings' appearance should be applied for and pre-checked with the municipality.

11 buildings in the selected area have a pitched roof and the rest have a flat roof. Most of the area has residential use while the first floor of most of the buildings is occupied for commercial purposes.

Figure 4-1- Selected urban block at Øvre Holmegata

The Buildings information data for this urban block including the façade cladding material and color, roof type, and cladding and finally building total area was collected via online services like Google street view and online municipal maps. For each building, an information sheet like the one in figure 4-2 was provided and the data were used in different stages of analysis. Building information sheets for this district is attached in Appendix 1.

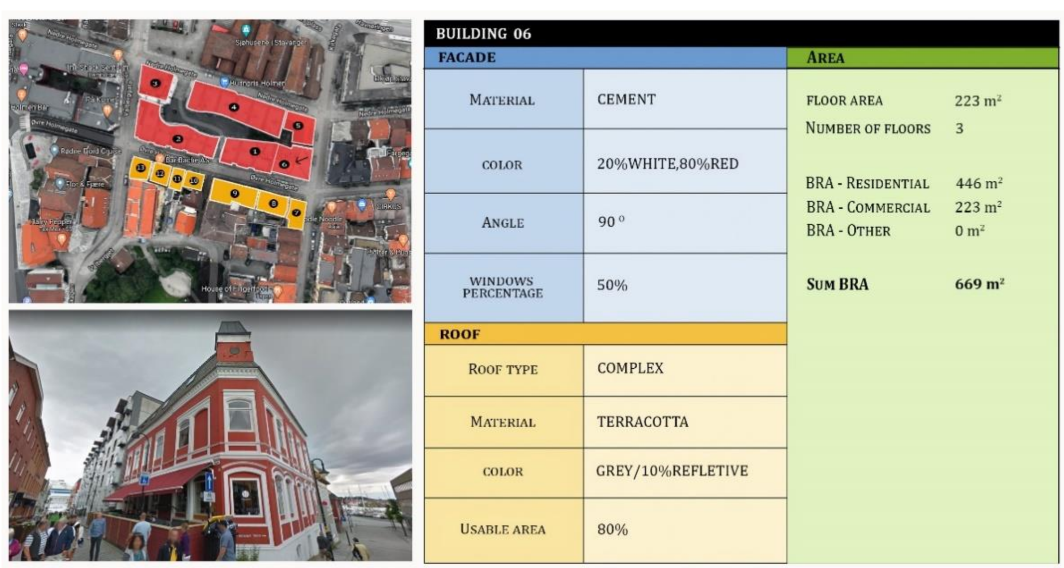


Figure 4-2- A sample of building information sheets for the urban block at Øvre Holmegata

The 3D model of the selected urban block was made from scratch in SketchUp software so that it includes all the data that is needed for the solar analysis program e.g. cladding materials and color. Afterward, the test was run for each month of the year according to the manual that was described in the previous chapter and the results were exported both in the form of a graphical image and a numerical table. The below figure depicts the average solar irradiance on building envelopes in the studied urban block throughout the year.

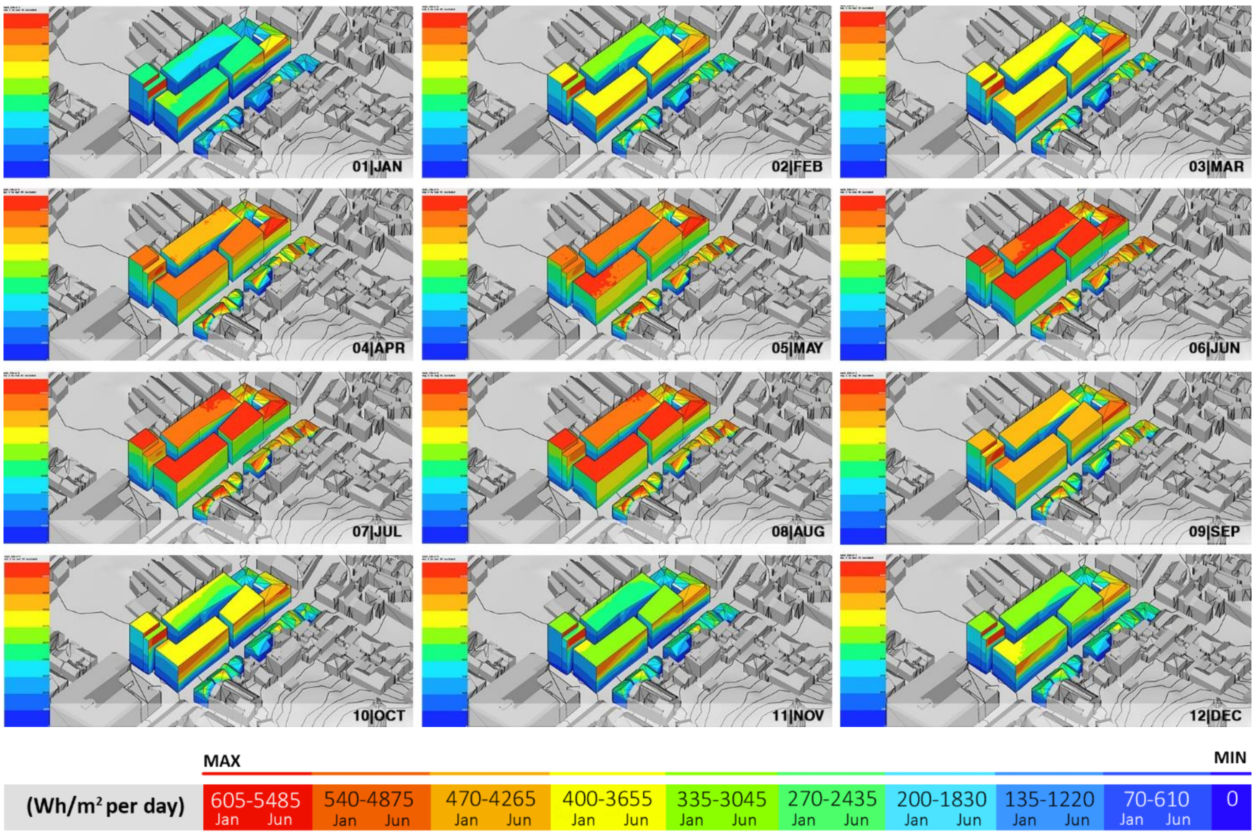


Figure 4-3- Insolation On different building skins at Øvre Holmegata

The image clearly demonstrates the change in solar irradiance on different building skins over a year period. The more reddish colors indicate a higher amount of solar irradiance and the more bluish colors show lower insolation. As expected, the solar irradiance on rooftops is much more considerable in spring and summer (April to September), while in winter and fall (October to March) the vertical surfaces and facades toward south and east receive more insolation compared to flat rooftops.

Another conclusion that can be drawn from the above photo is that the maximum insolation takes place between June to August and the least solar irradiance happens between November to January. This is important because it shows that the least energy can be produced during the period that the most energy is needed (mostly for heating). Therefore, if the Net zero-energy goal is to be achieved this difference in energy demand and production should be compensated for during the high insolation period.

In the following figures, insolation on south and east building facades is shown versus north and west facades for four selected months. As expected the results confirm that in general southern and eastern facades receive more solar energy compared to northern and western ones. The results also depict that generally pitched roofs have better solar performance than flat roofs.

Figure 4-4- Solar irradiance spectrum on South and East facades for selected months, Øvre Holmegata

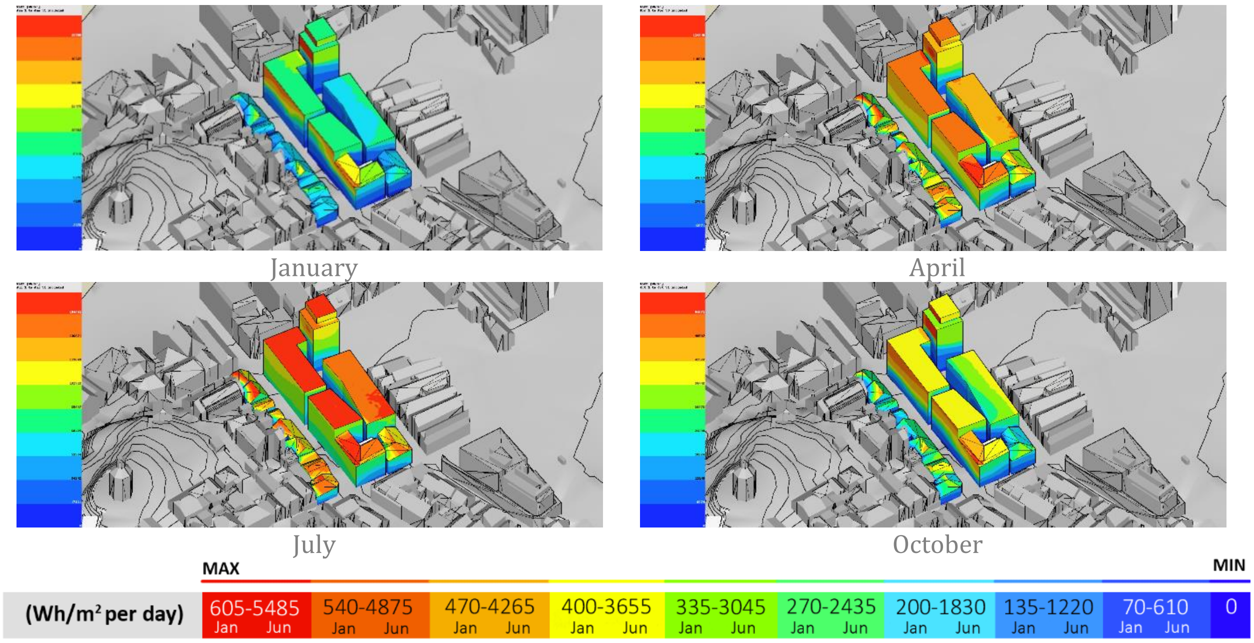
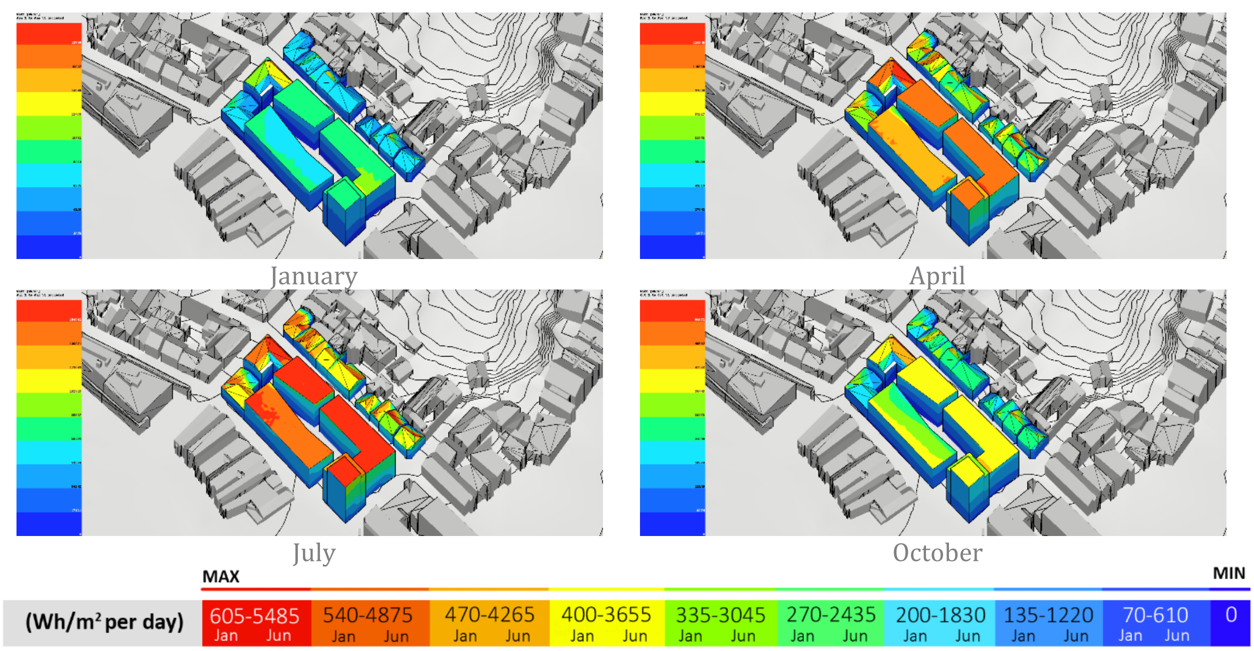
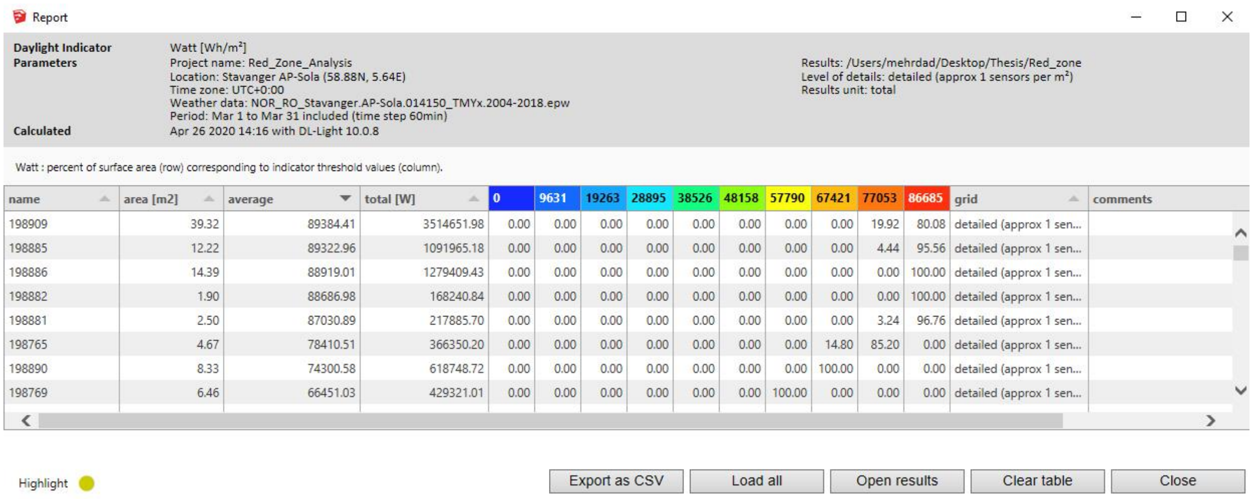


Figure 4-5- Solar irradiance spectrum on North and West facades for selected months, Øvre Holmegata



In addition to a graphical representation, for each month of the year, the numerical irradiance data were exported in the “CSV” file format and then imported to an Excel sheet. An example of the insolation data table exported from the software is presented in figure 4-6.



Report

Daylight Indicator: Watt [Wh/m²]

Parameters: Project name: Red_Zone_Analysis
Location: Stavanger AP-Sola (58.88N, 5.64E)
Time zone: UTC+0:00
Weather data: NOR_RO_Stavanger.AP-Sola.014150_TMYx.2004-2018.epw
Period: Mar 1 to Mar 31 included (time step 60min)

Calculated: Apr 26 2020 14:16 with DL-Light 10.0.8

Results: /Users/mehrdad/Desktop/Thesis/Red_zone
Level of details: detailed (approx 1 sensors per m²)
Results unit: total

Watt : percent of surface area (row) corresponding to indicator threshold values (column).

name	area [m2]	average	total [W]	0	9631	19263	28895	38526	48158	57790	67421	77053	86685	grid	comments
198909	39.32	89384.41	3514651.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.92	80.08	detailed (approx 1 sen...	
198885	12.22	89322.96	1091965.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.44	95.56	detailed (approx 1 sen...	
198886	14.39	88919.01	1279409.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	detailed (approx 1 sen...	
198882	1.90	88686.98	168240.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	detailed (approx 1 sen...	
198881	2.50	87030.89	217885.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.24	96.76	detailed (approx 1 sen...	
198765	4.67	78410.51	366350.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.80	85.20	0.00	detailed (approx 1 sen...	
198890	8.33	74300.58	618748.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	detailed (approx 1 sen...	
198769	6.46	66451.03	429321.01	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	detailed (approx 1 sen...	

Highlight

Export as CSV | Load all | Open results | Clear table | Close

Figure 4-6- Solar radiation on buildings’ envelope at Øvre Holmegata, report exported from DL-light

As shown in figure 4-6, the analysis software assigns a name to each surface in the 3D model, demonstrates the surface area, and calculates the solar irradiance for those surfaces. The whole surface does not necessarily receive the same insolation, for example, the area closer to the ground on south-facing facades receives less solar energy than the upper parts. Therefore, the software also shows what percentage of the surface area that falls in each category of insolation.

The results for each month of the year were imported into an excel sheet and summarized in table 4-1. To calculate the average solar irradiance on surfaces in a particular month the insolation value for different surfaces was added up together and divided by the number of surfaces in the model (the numbers in the second column). However, to make the final value closer to real-world value the surfaces that are shaded more than 60% of the year and have very low insolation value are excluded from this equation (the numbers in the third column).

Table 4-1- Average monthly and annual solar irradiance
on building envelope at Øvre Holmegata, kWh/m2 per year

Month of the year	**Average monthly** solar radiation [KWh/m^2]	**Average monthly** solar radiation [KWh/m^2] *excluding faces that are shaded more than 60% of the year*
January	57.51	63.75
February	146.37	162.27
March	345.48	382.99
April	638.66	708.00
May	834.67	925.29
June	951.55	1054.86
July	852.86	945.46
August	639.73	709.18
September	426.99	473.35
October	209.61	232.37
November	78.75	87.30
December	31.10	34.47
Average annual solar radiation (KWh/m^2/y)	**434.44**	**481.61**

The numbers demonstrate that on average each square meter of an urban surface in this urban block receives about 482 kWh/m² of solar energy in a year. The output data from analysis also shows that this urban block contains around 19 250 m² of surfaces (roofs and facades). However, a fraction of these surfaces is not suitable for installing PVs and are reserved for other purposes e.g. HVAC installations (mostly on roofs).

One of the information that was collected earlier on each building in the selected urban block was an estimation of usable are for PV installations on the roof. Based on that an average reduction factor of 15% was applied to sum area of surfaces and therefore with simple math presented in equation (1), this urban block receives more than 7 880 000 kWh solar energy in a year.

$$Total\ solar\ radiation = SR_a \times A_t \times R \qquad (1)$$

- SR_a = Average annual solar radiation in kWh/m²
- A_t =Total area of urban surfaces
- R =Reduction factor to estimate available area for PV installations (85%)

$$481.6\ \frac{kWh}{m^2} \times 19\ 250\ m^2 \times 85\% \approx \mathbf{7\ 880\ 000\ kWh}$$

To find out how much of this energy can be converted to electricity using BIPVs some other reduction factors have to be applied to this number. First of all, and due to estimations from building information sheets (presented in Appendix 1), it has been assumed that nearly 55% of the total area is solid non-transparent surfaces e.g. roof and facades that are suitable for conventional BIPVs and 45% are transparent surfaces e.g. windows and skylights, that should be covered with transparent PVs with lower efficiency. Therefore, the amount of energy that can be generated is calculated using the following equation

$$Total\ Solar\ energy\ generated = [SR_t \times BIPV_C \times E_C] + [SR_t \times BIPV_T \times E_T] \qquad (2)$$

- SR_t = Total Solar Radiation on building envelopes (7 880 000 kWh)
- $BIPV_C$ = Percentage of mono-crystalline PVs (55%)
- E_C = mono crystalline PV efficiency
- $BIPV_T$ = Percentage of Transparent PVs (45%)
- E_T = Transparent PV efficiency

In order to find out if the total solar power generated can cover the energy need of the same area, the buildings' energy consumption in the area should be calculated. For this aim, the average building energy-use in Stavanger by land-use is collected from Statistics Norway (SSB, 2012). The latest energy consumption data by land-use recorded for Stavanger dates back to 2012, the same year the EU energy savings directive was released and it is only available for residential land-use. Therefore, value for energy demand in other types of land-use is assumed and the change in energy use towards 2030 is calculated assuming that EU energy targets are pursued. The data is presented in the table below for 2012 and expected development until 2030.

Table 4-2- Building energy use by sector, Stavanger, (SSB, 2012)

	sector	**2012 Baseline [kWh/m²/year]**	**In 2020 with 20% energy savings [kWh/m²/year]**	**In 2030 with 32.5% energy savings [kWh/m²/year]**
Building energy consumption by sector, Stavanger, 2012	Residential	180	144	121.5
	Commercial	220	176	148.5
	Other	200	160	135

For the aim of this study, three different approaches have been assumed. First, the energy consumption in 2020 is the same as the 2012 baseline. Second, the EU goal of 20% energy saving by 2020 has been achieved already. Third, the expected energy saving goal of 2030 is going to be achieved. Based on these assumptions the following table summarizes the data on current and expected energy consumption in this urban block.

Table 4-3- development of buildings energy use by sector from 2012 baseline, Øvre Holmegata

Building current use	Gross floor area of the existing building (m^2)	Building energy consumption by sector (kWh/year) Without energy-saving measures	Building energy consumption by sector (kWh/year) with 20% energy saving	Building energy consumption by sector (kWh/year) with 32.5% energy saving
Residential	10 614	1 910 520	1 528 416	1 289 601
Commercial	2 586	568 920	455 136	384 021
Other (Parking, etc.)	110	22 000	17 600	14 850
Total	13 310	**2 501 440**	**2 001 152**	**1 688 472**

Following that, the four different scenarios are examined to see whether it is possible to achieve a PED goal by integrating solar energy generation at a neighborhood scale. The scenarios are as follows;

	2020 Conventional PV efficiency = 18% Clear PV efficiency = 7%	2030 Conventional PV efficiency = 25% Clear PV efficiency = 15%
Without energy-saving measures in the building sector	Scenario 1 *No Energy Savings*	Scenario 2 *No Energy Savings*
With energy-saving measures in the building sector	Scenario 3 *Energy Savings = 20%*	Scenario 4 *Energy Savings = 32.5%*

Figure 4-7- four different scenarios to assess PED target

1. In 2020 (current year); the average efficiency of a conventional mono-crystal PV panel in real-world conditions is between 15 to 18% and the efficiency for transparent PVs are only 7%. Therefore the amount of solar power that can be generated by covering the urban surfaces with BIPVs, in this urban block is calculated from equation (2);

$$[7\,880\,000\ kWh \times 55\% \times 18\%] + [7\,880\,000\ kWh \times 45\% \times 7\%] = \mathbf{1\,028\,340}\ kWh$$

   This means that with current technology only 1 028 340 kWh electricity can be produced using BIPVs. Assuming that no energy-saving measures are undertaken, the energy demand in the district is calculated in table 4-3 and equals to 2 501 440 kWh. Consequently, the generated energy covers only **41%** of energy use in the study area, and therefore net-zero energy goals cannot be achieved.

2. In 2020 (current year); the amount of solar energy that can be produced is the same as the first scenario as equals to 1 028 340 kWh. Assuming that retrofitting measures are adopted and 20% energy saving goal is achieved in the study area, the energy demand in the district is calculated in table 4-3 and equals to 2 001 152 kWh. This means that solar energy produced via integrating BIPVs into the urban block cover **51%** of energy demand.

3. In 2030, if the current trend in increasing the energy efficiency of PVs continues, it is expected that the mono-crystal PVs reach 25% efficiency and transparent PVs reach a 15% efficiency. Therefore the amount of solar power that can be generated by covering the urban surfaces with BIPVs, in this urban block is calculated from equation (2);

   $$[7\ 880\ 000\ kWh \times 55\% \times 25\%] + [7\ 880\ 000\ kWh \times 45\% \times 15\%] = \mathbf{1\ 615\ 400}\ kWh$$

   This means that in 2030, a total of 1 615 400 kWh electricity can be generated via integrating BIPVs in buildings. Assuming that no energy-saving measures are undertaken, the energy demand in the district is calculated in table 4-3 and equals to 2 501 440 kWh. Consequently, the generated energy covers only **64,5%** of energy use in the study area, and therefore net-zero energy goals cannot be achieved.

4. In 2030; the amount of solar energy that can be produced is the same as the third scenario as equals to 1 615 400 kWh. Assuming that retrofitting measures are adopted and 32,5% energy saving goal is achieved in the study area, the energy demand in the district is calculated in table 4-3 and equals to 1 688 472 kWh. This means that solar energy produced via integrating BIPVs into the urban block covers **95,6%** of the energy demand.

4-2- Solar analysis results for the urban block in St. Olavs gate

The urban block located in St. Olavs gate, consists of two plots and 5 buildings and is stretched in the north-south direction. The area is one of the few neighborhoods that reside high-rise buildings in Stavanger, and several new tall buildings are planned to be built in the same district as well. The selected urban block includes the two iconic 12 story residential buildings that are important components of the Stavanger skyline. The urban block has a mixed-use function and the first two floors are used as offices, gym, petrol station, and parking, while the upper floors are mostly residential.

Figure 4-8- Selected urban block at St. Olavs gate

The Buildings information data for this urban block including information about the façade cladding material and colors, roof type and its cladding, and finally buildings total area was collected through field observation and online municipal maps. For each building, an information sheet like the one in figure 4-9 was provided and the data were used in different stages of analysis. Building information sheets for each district is attached in appendix 2.

BUILDING 02			
FACADE		**AREA**	
MATERIAL	ALUMINUM CLADDING/ ALCOBAN	FLOOR AREA	- m²
COLOR	75%WHITE/25%BLUE	NUMBER OF FLOORS	7
ANGLE	90 °	BRA - RESIDENTIAL	0 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	2775 m²
ROOF		BRA - OTHER	750 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**3525 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

Figure 4-9- A sample of building information sheets for the urban block at St. Olavs gate

The 3D model of the selected urban block was made from scratch in SketchUp software so that it includes all the data that is needed for the solar analysis program e.g. cladding materials and color and to make the model simpler so that it would be less time consuming to analyze. Afterward, the test was run for each month of the year according to the manual that was described in the previous chapter and the results were exported both in form of a graphic image and a numerical table. The below figure depicts the average solar irradiance on building envelopes in the studied urban block throughout the year.

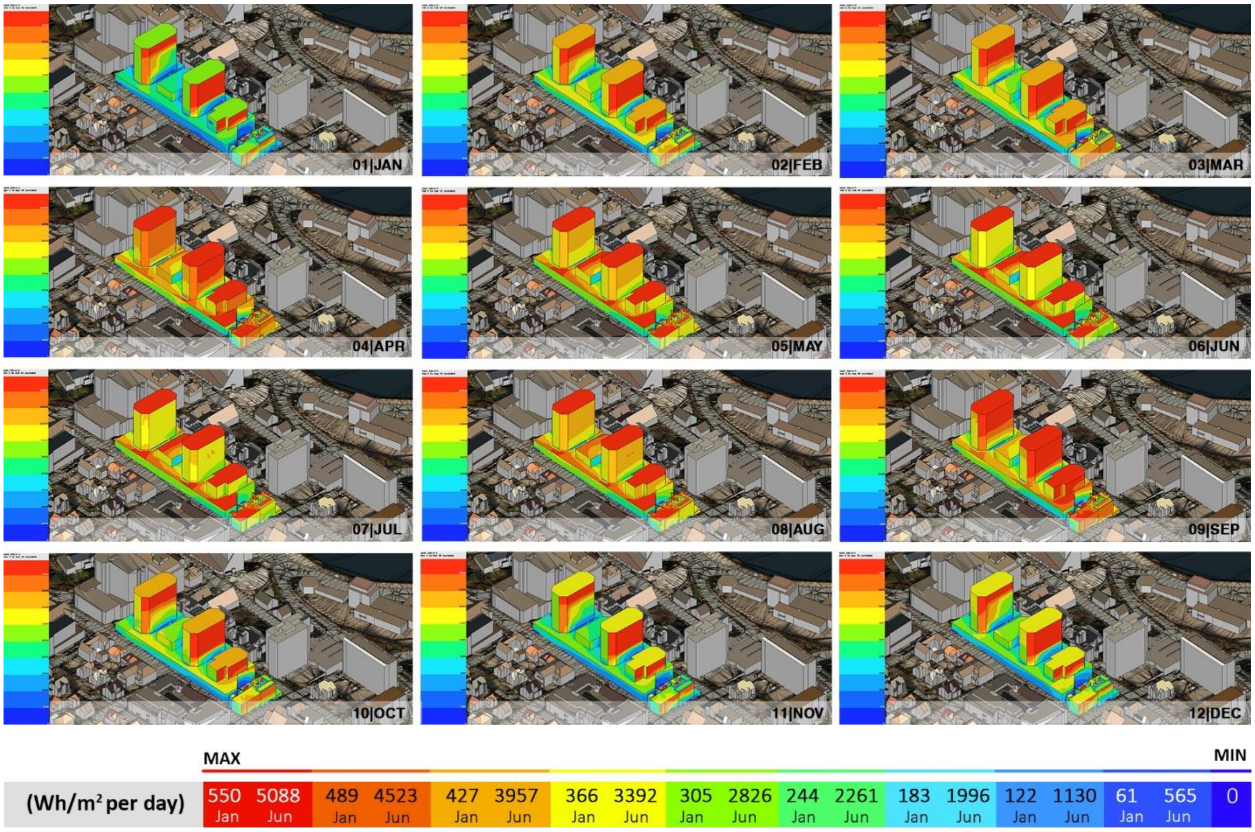


Figure 4-10- Insolation On different building skins, St. Olavs gate

The image clearly demonstrates the change in solar irradiance on different building skins over a year period. Like the latter, the image shows that the solar irradiance on rooftops is more significant in spring and summer (from April to September), while facades facing south and east receive more insolation relatively in winter and fall (from October to March). It can also be observed that in fall and winter (from October to March), due to sun low altitude and the block orientation (north-south), the buildings overcast shadows on each other and this notably affects the total average insolation.

Another conclusion that can be drawn from the above figure is that the maximum insolation takes place between June to August and the least solar irradiance happens between November to January. This is important because it shows that the least energy can be produced during the period that the most energy is needed (mostly for heating). Therefore, if the net-zero energy goal is to be achieved this difference in energy demand and production should be compensated for during the high insolation period.

The amount of insolation on different building skins is compared in the figures 4-11 and 4-12, for four selected months. The results confirm that in general southern and eastern facades receive more solar energy compared to northern and western ones. The figures also show that large facades toward the south that are not shaded may receive as much insolation as flat rooftops on specific periods of the year.

Figure 4-11- Solar irradiance spectrum on South and East facades for selected months, St. Olavs gate

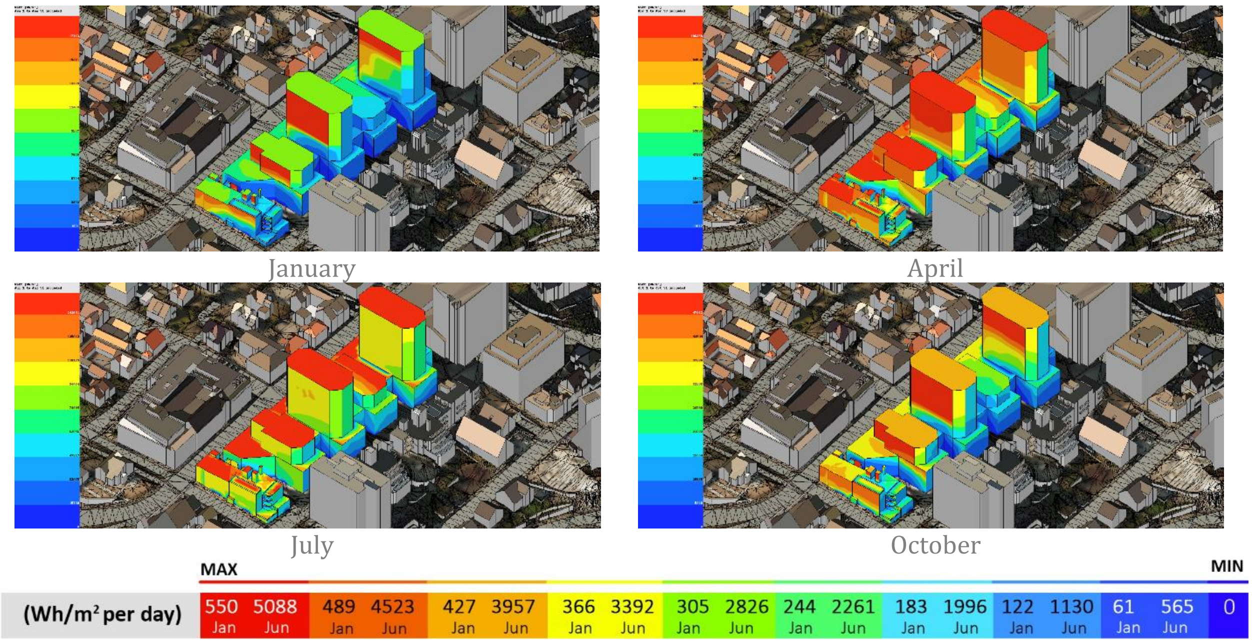
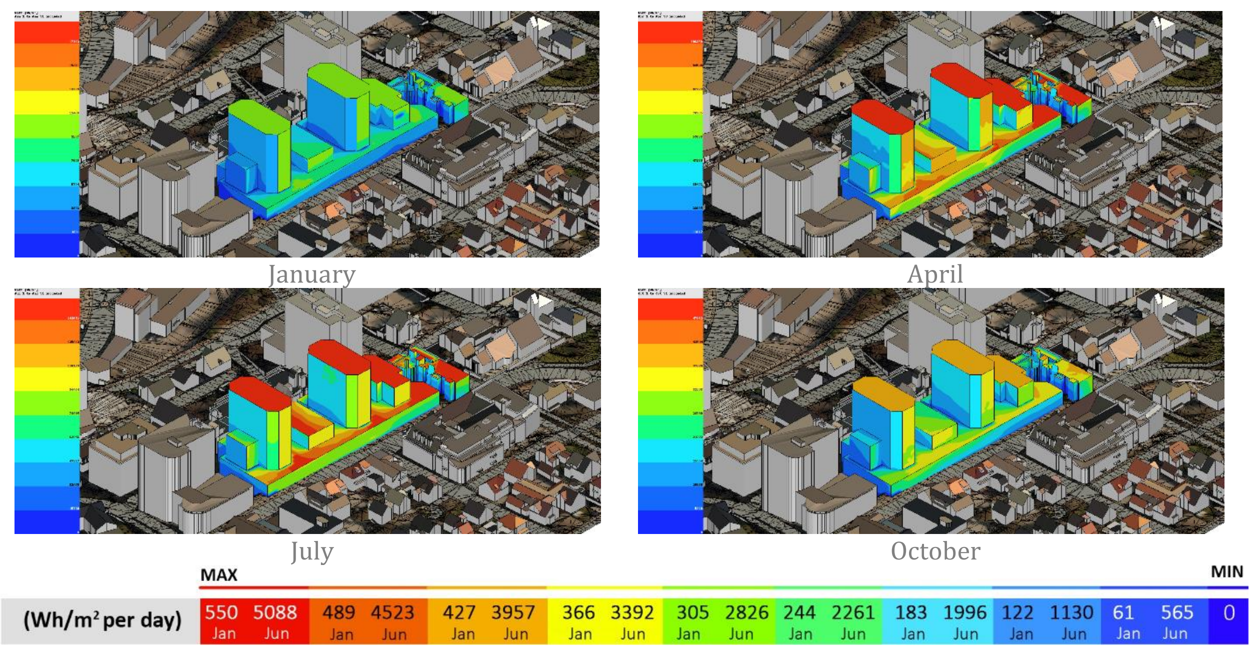
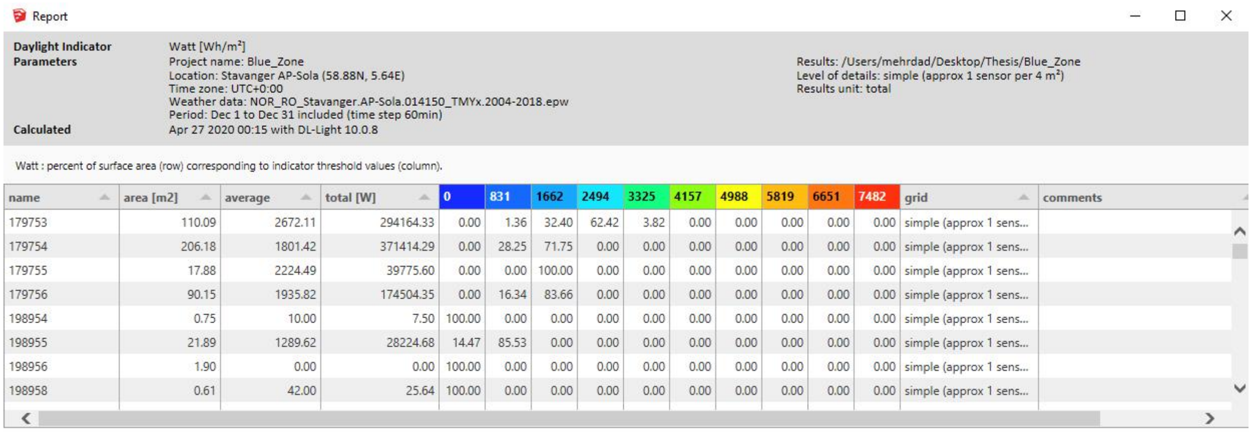


Figure 4-12- Solar irradiance spectrum on North and West facades for selected months, St. Olavs gate



In addition to a graphical representation, for each month of the year, the numerical irradiance data were exported in the “CSV” file format and then imported to an excel sheet. An example of the insolation data table is presented in figure 4-13.


Report

Daylight Indicator Watt [Wh/m²]
Parameters Project name: Blue_Zone
Location: Stavanger AP-Sola (58.88N, 5.64E)
Time zone: UTC+0:00
Weather data: NOR_RO_Stavanger.AP-Sola.014150_TMYx.2004-2018.epw
Period: Dec 1 to Dec 31 included (time step 60min)
Calculated Apr 27 2020 00:15 with DL-Light 10.0.8

Results: /Users/mehrdad/Desktop/Thesis/Blue_Zone
Level of details: simple (approx 1 sensor per 4 m²)
Results unit: total

Watt : percent of surface area (row) corresponding to indicator threshold values (column).

name	area [m2]	average	total [W]	0	831	1662	2494	3325	4157	4988	5819	6651	7482	grid	comments
179753	110.09	2672.11	294164.33	0.00	1.36	32.40	62.42	3.82	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
179754	206.18	1801.42	371414.29	0.00	28.25	71.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
179755	17.88	2224.49	39775.60	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
179756	90.15	1935.82	174504.35	0.00	16.34	83.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
198954	0.75	10.00	7.50	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
198955	21.89	1289.62	28224.68	14.47	85.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
198956	1.90	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	
198958	0.61	42.00	25.64	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	simple (approx 1 sens...	

Figure 4-13- Solar radiation on buildings' envelope at St. Olavs gate, report exported from DL-light

As described earlier the analysis software assigns a name to each surface in the 3D model, and for each surface, its' area and the amount of solar irradiance are calculated. The whole surface does not necessarily receive the same insolation as shown on the figures previously.

The results for each month of the year were imported into an excel sheet and summarized in table 4-4. To calculate the average solar irradiance on surfaces in a particular month the insolation value for different surfaces was added up together and then divided by the number of surfaces in the model. To make the final value closer to real-world conditions the surfaces that are shaded more than 60% of the year and have very low insolation value were excluded from this equation.

Table 4-4- Average monthly and annual solar irradiance on building envelope at St. Olavs gate, kWh/m2 per year

The month of the year	**Average monthly** solar radiation [KWh/m^2]	**Average monthly** solar radiation [KWh/m^2] *excluding faces that are shaded more than 60% of the year*
January	59.96	65.97
February	146.78	161.46
March	346.59	381.25
April	601.77	661.95
May	755.51	831.06
June	845.33	929.19
July	766.15	842.76
August	585.91	644.50
September	410.03	451.03
October	212.57	233.83
November	80.46	88.51
December	30.89	33.98
Average annual solar radiation (KWh/m^2/y)	**403.50**	**443.79**

The numbers from the above table indicate that on average each square meter of an urban surface in this urban block receives about 443,8 kWh of solar energy in a year. The data from excel also shows that this urban block contains around 33 500 m^2 of surfaces (roofs and facades). However, a fraction of these surfaces is not suitable for installing PVs and are reserved for other purposes e.g. HVAC installations (mostly on roofs) or setbacks in balconies that are mostly shaded.

One of the information that was collected earlier on each building in the selected urban block was an estimation of usable are for PV installations on the roof. Based on that an average reduction factor of 15% was applied to sum area of surfaces and therefore with simple math presented in equation (1), this urban block receives more than 12 637 205 kWh solar energy in a year.

$$Total\ solar\ radiation = SR_a \times A_t \times R \qquad (1)$$

- SR_a = Average annual solar radiation in kWh/m^2
- A_t =Total area of urban surfaces
- R =Reduction factor to estimate available area for PV installations (85%)

$$443.8\ \frac{kWh}{m^2} \times 33\ 500\ m^2 \times 85\% \approx \mathbf{12\ 637\ 205\ kWh}$$

To find out how much of this energy can be converted to electricity using BIPVs some other reduction factors have to be applied to this number. First of all, and due to estimations from building information sheets (presented in Appendix 2), it has been assumed that nearly 50% of the total area is solid non-transparent surfaces e.g. roof and facades that are suitable for conventional BIPVs and 50% are transparent surfaces e.g. windows and skylights, that should be covered with transparent PVs with lower efficiency. Therefore, the amount of energy that can be generated is calculated using the following equation

$$Total\ Solar\ energy\ generated = [SR_t \times BIPV_C \times E_C] + [SR_t \times BIPV_T \times E_T] \qquad (2)$$

- SR_t = Total Solar Radiation on building envelopes (12 637 205 kWh)
- $BIPV_C$ = Percentage of mono-crystalline PVs (50%)
- E_C = mono crystalline PV efficiency
- $BIPV_T$ = Percentage of Transparent PVs (50%)
- E_T = Transparent PV efficiency

Same steps as for the previous urban block is undertaken, in order to find out if the total solar power generated can cover the energy need of the same area. The buildings' energy consumption in the area was calculated based on the same data from (SSB, 2012), presented earlier in table 4-2. It is important to note again that the latest energy consumption data by land-use recorded for Stavanger dates back to 2012 and it is only available for residential land-use. Therefore, assumptions are made for energy demand values in other sectors.

For the aim of this study, three different approaches have been assumed. First, energy consumption in 2020 is the same as the 2012 baseline. Second, the EU goal of 20% energy saving by 2020 has been achieved already. Third, the expected energy saving goal of 2030 is going to be achieved. Based on these assumptions the following table summarizes the data on current and expected energy consumption in this urban block.

Table 4-5- development of buildings energy use by sector from 2012 baseline, St. Olavs gate

Building current use	Gross floor area of the existing building (m^2)	Building energy consumption by sector (kWh/year) Without energy-saving measures	Building energy consumption by sector (kWh/year) with 20% energy saving	Building energy consumption by sector (kWh/year) with 32.5% energy saving
Residential	18 060	3 250 800	2 600 640	2 194 290
Commercial	8 395	1 846 900	1 477 520	1 246 657
Other (Parking, etc.)	750	150 000	120 000	101 250
Total	27 205	5 247 700	4 198 160	3 542 197

Following that, the four different scenarios are examined to see whether it is possible to achieve a PED goal by integrating solar energy generation at the neighborhood scale. The Scenarios are as follows;

	2020 Conventional PV efficiency = 18% Clear PV efficiency = 7%	2030 Conventional PV efficiency = 25% Clear PV efficiency = 15%
Without energy-saving measures in the building sector	Scenario 1 *No Energy Savings*	Scenario 2 *No Energy Savings*
With energy-saving measures in the building sector	Scenario 3 *Energy Savings = 20%*	Scenario 4 *Energy Savings = 32.5%*

Figure 4-14- four different scenarios to assess PED target

1. In 2020 (current year); the average efficiency of a conventional mono-crystal PV panel in real-world conditions is between 15 to 18% and the efficiency for transparent PVs are only 7%. Therefore the amount of solar power that can be generated by covering the urban surfaces with BIPVs, in this urban block is calculated from equation (2);

$$[12\,637\,205\ kWh \times 50\% \times 18\%] + [12\,637\,205\ kWh \times 50\% \times 7\%] = \mathbf{1\,579\,650}\ kWh$$

This means that with current technology only 1 579 650 kWh electricity can be produced using BIPVs. Assuming that no energy-saving measures are undertaken, the energy demand in the district is calculated in table 4-4 and equals to 5 247 700 kWh. Consequently, the generated energy covers only **30%** of energy use in the study area, and therefore net-zero energy goals cannot be achieved.

2. In 2020 (current year); the amount of solar energy that can be produced is the same as the first scenario as equals to 1 579 650 kWh. Assuming that retrofitting measures are adopted and 20% energy saving goal is achieved in the study area, the energy demand in the district is calculated in table 4-4 and equals to 4 198 160 kWh. This means that solar energy produced via integrating BIPVs into the urban block cover **37,6%** of energy demand.

3. In 2030, if the current trend in increasing the energy efficiency of PVs continues, it is expected that the mono-crystal PVs reach 25% efficiency and transparent PVs reach a 15% efficiency. Therefore the amount of solar power that can be generated by covering the urban surfaces with BIPVs, in this urban block is calculated from equation (2);

$$[12\,637\,205\ kWh \times 50\% \times 25\%] + [12\,637\,205\ kWh \times 50\% \times 15\%] = \mathbf{2\,527\,441}\ kWh$$

This means that in 2030, a total of 2 527 441 kWh electricity can be generated via integrating BIPVs in buildings. Assuming that no energy-saving measures are undertaken, the energy demand in the district is calculated in table 4-4 and equals to 5 247 700 kWh. Consequently, the generated energy covers only **48%** of energy use in the study area, and therefore net-zero energy goals cannot be achieved.

4. In 2030; the amount of solar energy that can be produced is the same as the third scenario as equals to 2 527 441 kWh. Assuming that retrofitting measures are adopted and 32,5% energy saving goal is achieved in the study area, the energy demand in the district is calculated in table 4-3 and equals to 3 572 197 kWh. This means that solar energy produced via integrating BIPVs into the urban block covers **70%** of the energy demand.

Comparing the results for the two selected urban blocks reveals that the average solar irradiance on urban surfaces in the urban block located at Øvre Holmegate is slightly higher than the one in St. Olavs gate. While the average insolation in the first urban block is about 482 kWh/m^2 per year, the amount for the latter is only 443.8 kWh/m^2 per year.

This difference can be justified with two different arguments. First, the ratio of roof area to the facade area in the St. Olavs gate urban block is smaller than the same proportion for the Øvre Holmegate urban block. As has been stated earlier, In general roofs receive more solar energy than facades, and therefore, while calculating the average solar irradiance for both urban blocks, there are more surfaces with maximum insolation in the Øvre Holmegate urban block.

The second argument concerns the orientation and building height in the two urban blocks. The urban block in St. Olavs gate is stretched along the north-south axis and contains taller buildings. This will result in buildings overcasting shadows on each other and more shading time for this urban block and therefore lower average solar irradiance on urban surfaces.

Reviewing the results for the two urban blocks also suggests that achieving the net-zero neighborhood only by using BIPV technology is not possible in neither of the cases. However, the urban block in Øvre Holmegate offers better solar performance and therefore it would be easier to hit the Net-zero energy target in an urban block with the same characteristics.

The findings suggest that the integration of PV systems into urban areas should be considered in the early phases of urban design. The solar urban design concept affects both the planning procedures and buildings design and construction.

The estimation of potential energy production of existing building envelops also helps city planners and authorities to have an overview of how to place different activities in a cityscape, in order to make a balance between local energy demand and potential energy production and to move towards PED target.

4-3- Solar analysis results for Stavanger Sentrum District

What has been discussed so far in this chapter, answers both the research questions, however, in order to depict a more comprehensive image of the solar energy potential on an urban scale it is required to run the solar analysis for a larger urban area. Running such an analysis would not have been possible by using the "DL-light" software due to an enormous amount of time and data needed. Therefore, a more conventional method was adopted.

Insolation map for the Stavanger city center was produced in ArcGIS for a period of a full year that depicts the average solar radiation on rooftops and horizontal surfaces in Wh/m^2 per year. The output map from ArcGIS for a selected part of Stavanger is presented in figure 4-15. To be able to run the test in a reasonable amount of time, the analysis area was limited to the boundary known as the Stavanger Sentrum that also contains the two urban blocks that were selected for further studies.

It should be noted here that ArcGIS calculates solar irradiance only for horizontal surfaces e.g. rooftops and landscape. The output results are used to draw a larger picture of the solar potential in the city of Stavanger and also to validate the numbers that were calculated using "DL-light" software for the two urban blocks.

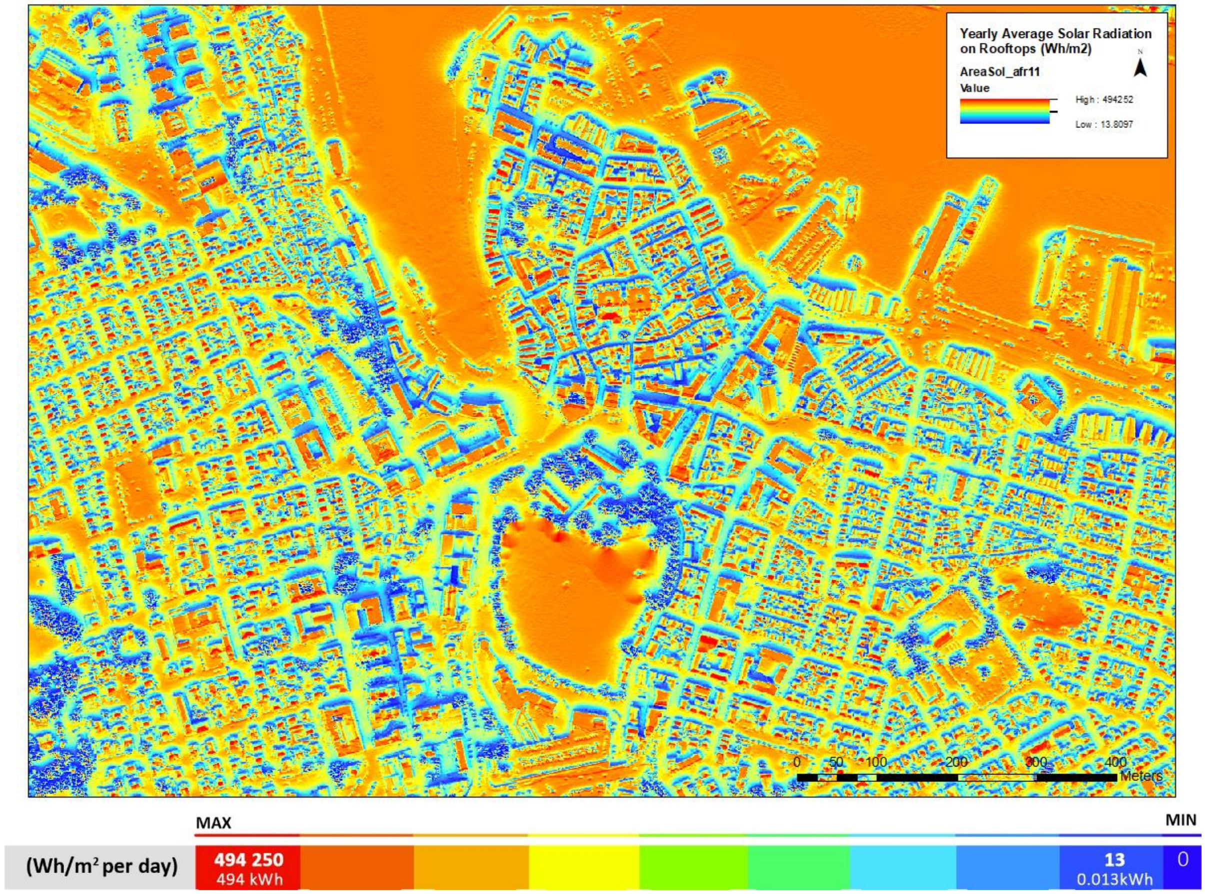


Figure4-15- annual average solar radiation on rooftops in Stavanger city center, Created in ArcGIS.

The colors in the image indicate the average amount of solar energy that horizontal surfaces receive, where the more reddish colors show a larger amount of solar irradiance and more bluish colors indicate lower amounts. As it is shown in the picture, in general rooftops have considerable solar potential regardless of building heights or urban density. This also confirms the results from earlier.

According to the map, the maximum value of the average yearly solar irradiation calculated for Stavanger is about 494 kWh/m^2 per year. Considering that on average facades would obviously receive less solar energy, this value also verifies the results from running the test for the two urban blocks.

The map also indicates the impact of density and building heights on the quality of natural light and the amount of solar energy received in the public spaces and landscape. It can be seen that streets and public spaces in dense neighborhoods receive much less solar irradiance. This means that installing PVs on landscape elements and gardens might not be an effective solution in these types of urban developments. The same applies to urban blocks with tall buildings e.g. the one on the St. Olavs gate, where the shadows from surrounding buildings affect the urban area to a large degree. If access to direct sunlight would be considered as one of the important qualities of public spaces in cold climates like Norway, then these two types of urban developments would definitely have poor functionality.

05 | Discussion

5-1- PVs and Protected urban areas

In May 2019, a piece of local news in Stavanger draw the national attention to the subject of installing photovoltaic in protected urban areas in Norway. The media covered a story about a homeowner in Stavanger that was forced to remove the installed PV panels from his house in Eiganes district, Stavanger. The homeowner came to know that it is essential to apply for such a change with the municipality right after he had installed the PVs (NRK, 2019). The office of cultural heritage management (Byantikvaren) in Stavanger municipality finally rejected his application, claiming that solar panels do not fit the timber façade of his house (Stavanger Aftenblad, 2020). This story has led to several discussions both in the society and in the professional setting about how solar panels and BIPVs should be treated in protected urban areas.

Figure 5-1- a house in Eiganes is forced to remove installed PV panels, (NRK, 2019)

According to the Planning and Building Act (plan- og bygningsloven) (Lovdata, 2014), solar PVs are considered as technical installations if mounted on buildings and therefore should be applied for to the municipality prior to installing (Hus & Bolig, 2019). However, in section 4-1 of the Building Regulations (byggesaksforskriften § 4-1) an exception is made for photovoltaic installations if the following criteria are met;

- Installing solar cell are not in conflict with municipal plans and regulations
- The technical requirement is met
- Solar cells are established within a single fire cell (Hus & Bolig, 2019)

This means that one can mount solar cells on their building without applying for it if all the above-mentioned criteria are in place.

In the case of Stavanger, the office of cultural heritage management (Byantikvar) is aiming to preserve the timber houses in old Stavanger (Gamle Stavanger) and therefore PV installations are accounted as having too much conflict with this approach. Stavanger timber town is the largest in Europe with over 8 000 timber houses built in the late 18s and early 19s (Stavanger Kommune, 2020). Stavanger municipality has adopted a very strict regulatory framework regarding any change or development in this area.

In September 2019, the University of Stavanger along with a non-profit organization called "Grønnby" hosted a meeting for professionals and different stakeholders to discuss possible solutions that might address this challenge (Grønnby, 2020), and many brilliant options were introduced including new PV technologies in different shapes and sizes that resemble the existing materials on buildings. However, the office of cultural heritage management (Byantikvar) is still insisting on its' last position about PV installations on timber houses and declaring that such a transformation is only allowed (Byantikvaren, StavangerKommune, 2020):

- On the roof surface that is away from public streets and is not visible from neighboring streets
- On the new buildings within the protected district that are not included as one in a uniform row of older buildings
- On Sheds, garages and (newer built) small extensions to the timber house
- And finally as free-standing elements in the gardens or landscape

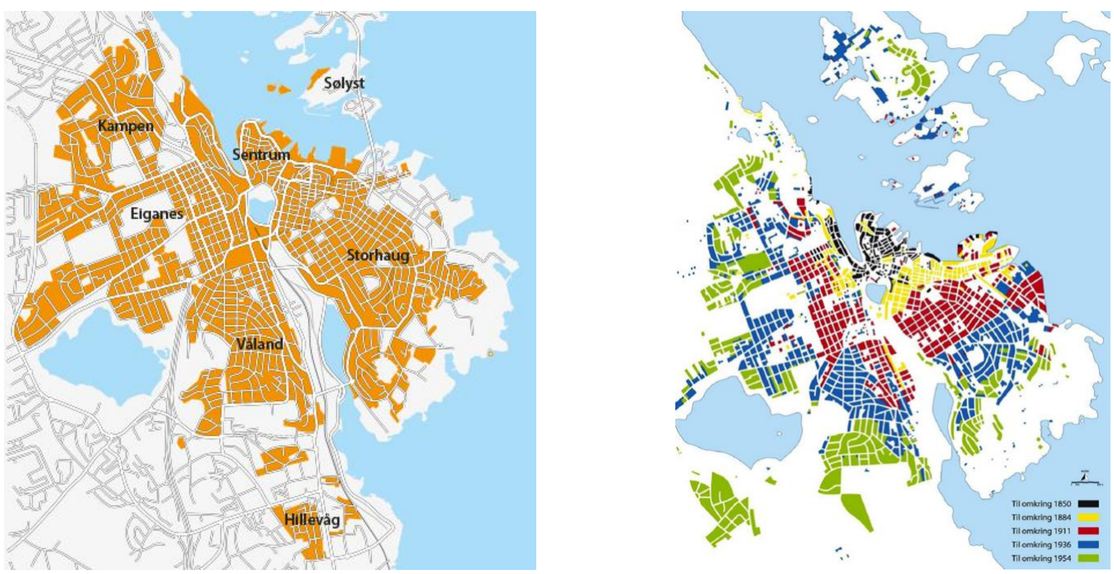


Figure 5-2- Protected urban area "Trehusbyen", Stavanger, (Stavanger Kommune, 2020)

Meanwhile, Stavanger municipality is aiming for an 80% reduction in its greenhouse gas emissions until 2030 (Stavanger City Council, 2018). Achieving this goal requires a massive effort in different sectors including moving towards cleaner energy production methods. In this manner, solar energy and specifically BPIVs and BAPVs are among the most obvious choices. The Photovoltaic industry is evolving rapidly and new options are available in the market with better efficiency, lower prices, and different forms and shapes.

Stavanger municipality's strict guidelines about PV installations in timber town do not seem to be aligned with its' climate goal. Excluding a considerable proportion of urban areas and setting restrictive regulations may discourage the population and hinder the progress toward a more green society.

One of the main motivations to conduct this study was to depict the vast potential of producing clean solar energy by integrating PV technologies into existing buildings and structures. The results clearly demonstrate that urban districts and neighborhoods can move towards the Net-zero energy goal and with day-to-day progress in the PV industry achieving this goal is not out of reach.

The results also may be inspiring for city management authorities to rethink their attitude towards the timber town in Stavanger. Facing the challenges of climate change requires bold decisions from politicians and city authorities and if the goal of an 80% reduction in GHG emissions is to be achieved by 2030, then generating solar energy via integrating PVs in existing urban structures should be considered as one of the most effective solutions.

5-2- Solar energy integration into urban planning

With more people living in cities and fast-paced urban growth all over the world, the energy consumption in the building sector is continuously growing and consequently, the amount of GHG emissions from urban living is increasing considerably. Many cities are already adopting new climate plans and moving towards reducing their emissions. An important component of many of these climate actions is to investigate the possibility of clean energy production within the city's jurisdiction boundaries.

In this sense, integrating solar energy into the built environment gains much credit. The vast area of urban surfaces available for PV installations demonstrates great potential for generating clean energy. Therefore, mapping and analyzing the solar potential of urban surfaces (roofs and facades), should become a common practice among urban planners, architects, and public authorities (Lobaccaro, Lisowska, Saretta, Bonomo, & Frontini, 2019).

It is expected that by 2050, 75% of the world's population will live in cities. Accommodating such a large population in urban areas requires higher densities and more complex built environments. Utilizing efficient solar systems and sunlight accessibility would definitely be challenging in this situation. Therefore the efficient deployment of PV systems in urban areas should be planned beforehand (Lobaccaro, Lisowska, Saretta, Bonomo, & Frontini, 2019).

With current advances in the PV industry and development of BIPVs, solar systems are now more than mere energy generation means. New BIPV modules have shown a great potential for integrating into different building skins, including facades. BIPV systems now can satisfy the aesthetical needs and act as building materials that reduce construction costs (Lobaccaro, Lisowska, Saretta, Bonomo, & Frontini, 2019).

The more complex an urban environment is, the more sophisticated the shading effects and optimal scenario for PV systems will become. Mutual effects of buildings on each other, including shadings and inter-reflections, are complicated issues that solar urban planning should deal with. The analysis of solar potential in large urban scale allows urban planners to identify the best alternatives for future developments and urban transformations, with better solar functionality (Lobaccaro, Lisowska, Saretta, Bonomo, & Frontini, 2019).

3D solar maps can also depict the vast solar potential of the available urban surfaces in the scale of neighborhood or city and better communicate the advantages of deploying BIPVs to the public and city planners.

EU regulations demand that all the buildings constructed after 2020, should follow the NZEB target. This requires buildings to cover almost all their energy demand by both generating energies from low carbon and renewable sources and reducing their consumption by adopting energy-saving measures. In designing a net-zero energy building or neighborhood, the designer should have a perception of the amount of clean energy that can be supplied on or off-site and the amount of energy demand (Scognamiglio & Røstvik, 2017).

In modern cityscapes, roofs are partially occupied with mechanical installations, and south-facing facades are reserved for maximizing the sunlight accessibility through windows and balconies. In the meantime, higher densities in contemporary urban environments mean less available roof area, and more shadow effects, therefore generating sufficient energy for achieving NZEB target in the scale of an individual building could be challenging. This issue might be addressed if the solar potential is utilized on a larger scale e.g. and urban district (Scognamiglio & Røstvik, 2017).

This is one of the reasons that the PED concept is recently gaining much more interest. This concept promotes sharing energy production between a cluster of buildings or on the scale of an urban neighborhood. The boundary could be defined with respect to energy supply infrastructure. This concept may lead to a beneficial balance between a group of buildings that may not be net-zero energy independently, but together form an NZE neighborhood (Scognamiglio & Røstvik, 2017).

When it comes to integrating solar energy into an urban environment, three options for placement of PV systems can be investigated; energy generation within the building footprint, on-site or off-site (Scognamiglio & Røstvik, 2017). These options are further discussed in figure 5-3.

When PV systems are placed within the building footprint, they are either attached or integrated into the building's envelope and should be designed at the architectural scale. If they are placed on-site, it means they are installed detached from the building and therefore could be designed at architecture or landscape scale. Moreover, if the PV system is installed off-site, the generated energy should be brought to the site through the network grid, and it should be designed at a landscape or urban scale (Scognamiglio & Røstvik, 2017).

Net ZEB Energy Supply Options (Balance Boundaries)	Renewable Energy Systems Design Options (Integration)
1. Within the Building Footprint (envelope integrated: on/in the envelope + external devices) Designed at the Architectural Scale	Building integrated (façades, roofs) Building attached/added (façades, roofs) External devices (sun-shading elements, "wings," canopies)
2. On-site (close to the building, or detached; e.g., a canopy, within the building site, in proximity relationship with the building, or belonging to the same functional system of the building) Designed at the Architectural Scale	a. Placed on a building other than the considered one (within the footprint: building integrated, building attached, external devices) b. Detached from any building (beyond the building physical footprint). They can exploit: – Other functions than the energy generation (multi-functionality) being integrated in functional urban or landscape equipment (e.g., a solar array integrated on parking lot); – The only energy generation function, being free standing (e.g., a solar array on the ground).
3. Off-site (renewable energy systems detached from the building, beyond the site's boundary; no proximity relationship with the building or the site) Designed at the Landscape Scale	a. They can exploit other functions than the energy generation (multi-functionality) being integrated in functional urban or landscape equipment (urban or landscape equipment; that is: an urban canopy, or a sound insulation barrier); b. They can exploit the only energy generation function, being free standing (e.g., a solar array on the ground).

Figure 5-3- Different NZEB supply options, (Scognamiglio & Røstvik, 2017)

The potential application of PV systems in protected urban areas and on listed buildings of cultural heritage importance is still challenging. New developments in the BIPV industry and the introduction of new PV modules that resemble the common cladding materials might be a solution to address strict municipal regulations in this regard.

On the other hand, on-site energy generation systems might also be profitable in this manner. While attaching technical installations to the listed buildings' envelope is often prohibited by municipal regulations, producing clean energy from free-standing or landscape-integrated PV systems might be a good solution (Scognamiglio & Røstvik, 2013).

Also as mentioned earlier, one of the benefits of performing solar analysis for existing urban blocks is to identify the types of urban developments that are having a better solar performance and can contribute to the PED target more effectively. The current study was not able to carry out solar analysis for all the practiced neighborhood typologies in Stavanger due to time constraints. However, a comparison between the two selected urban block was presented in the findings chapter, and the pros and cons of each urban block were pointed out.

In general, it can be stated that if buildings are obligated to generate their own energy need through solar energy, then low-rise buildings will have a better chance of achieving the NZEB target than the high-rise ones (Scognamiglio & Røstvik, 2017). A brief estimation of the relationship between energy demand and energy production potential in different building topologies is presented in figure 5-4;

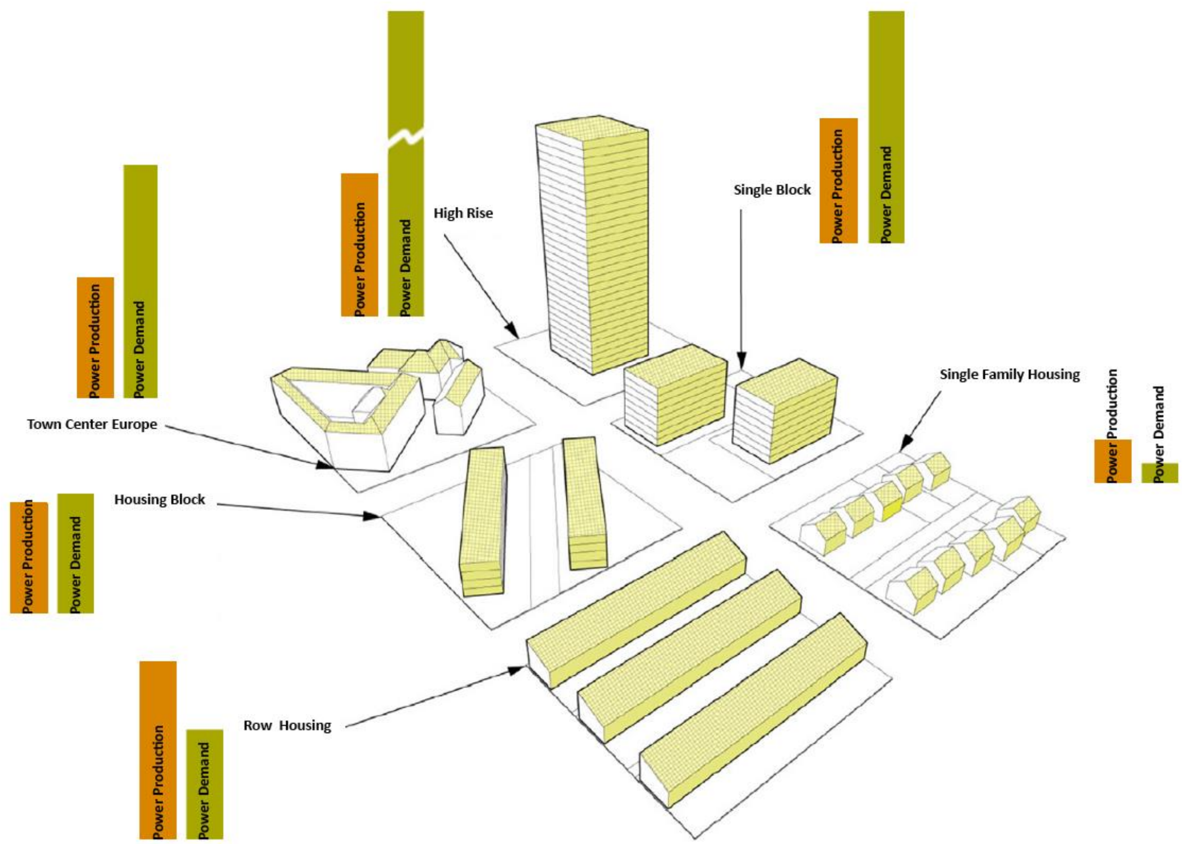


Figure 5-4- Net Zero Energy performance of different building typologies, (Scognamiglio & Røstvik, 2017)

Finally, a transition in the energy scenario is expected in the coming years, where a web of smaller energy generation systems slowly replaces the conventional centralized energy production. With EU directives asking member countries to move towards NZEB and PED targets, the buildings and urban neighborhoods are going to be converted into small power plants capable of procuring their own energy demand (Scognamiglio & Røstvik, 2013). Architects and planners then should be able to utilize the maximum energy yield from renewables in their design.

5-3- Solar energy as a design parameter in urban planning

In their 2012 paper, (Amado, M., & Poggi, F) presented the concept of solar urban planning. This concept is seeking an "operative methodology" in order to maximize the solar potential of an urban area and to achieve the NZEB target.

Presented in figure 5-5, this model is based on "assessing the solar potential of the existing urban area and then comparing it to the possible gains if the area is transformed using actions from the sustainable urban planning process" (Amado, M., & Poggi, F, 2012). In other words, the model suggests that in parallel to the urban planning process, a solar design process should also be carried out and its result should be reflected in defining new proposals for development in the area.

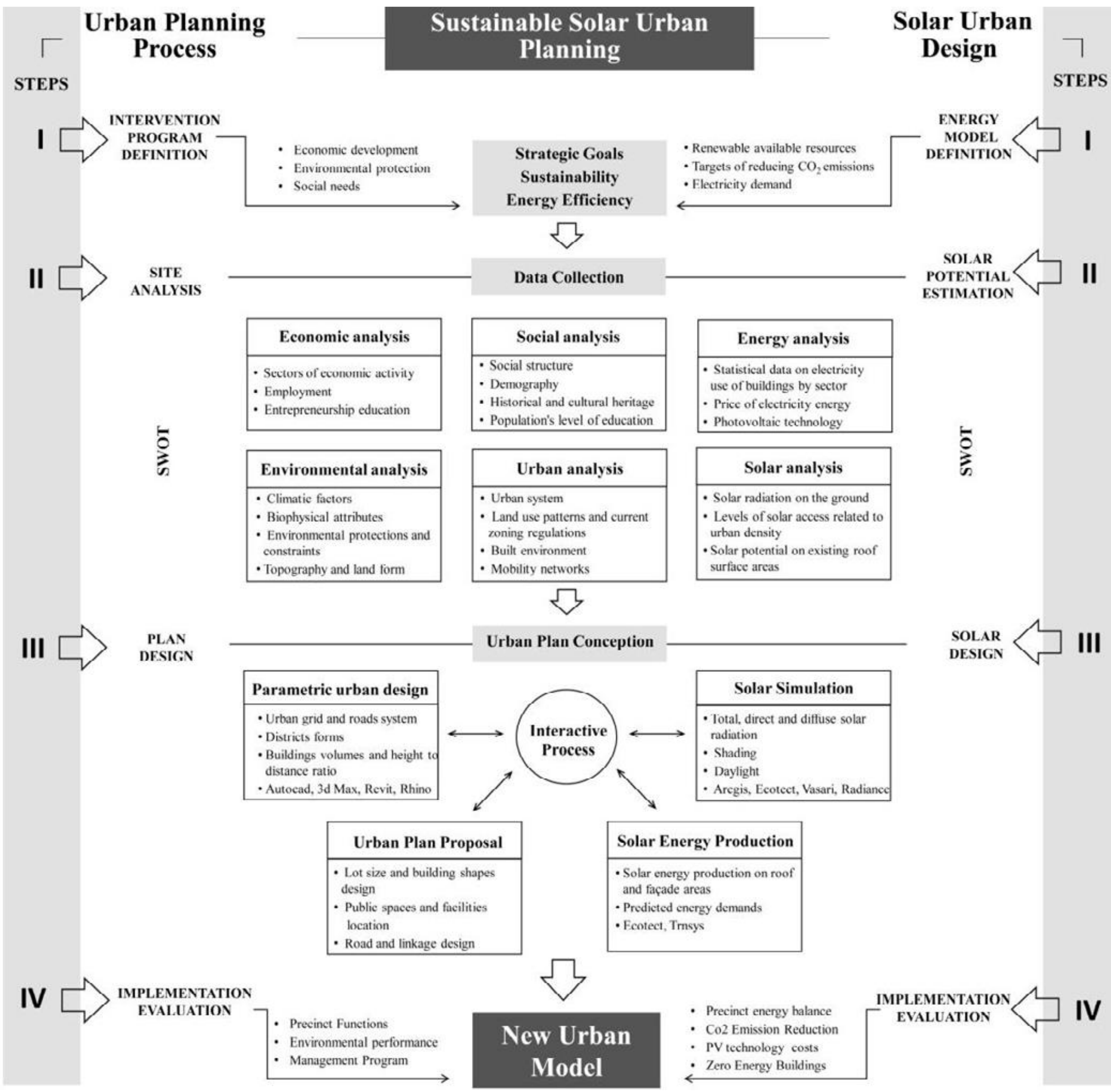


Figure 5-5- Sustainable Solar Urban Planning Model, (Amado, M., & Poggi, F, 2012)

By running solar analysis on exiting urban fabric, issues that might hinder the efficient exploitation of solar energy are identified. New proposals for transforming the area are developed by using parametric design tools and trying to maximize the solar potential. The result is tested again to see how much is gained. This process can be performed repeatedly until desirable results are achieved (Amado, M., & Poggi, F, 2012).

Increasing the solar performance of buildings and neighborhoods should be sought for both new and existing structures. Assessing the energy consumption of a district and studying its capacity to produce clean solar energy will result in a more realistic plan towards the NZEB and PED targets.

The end goal of solar urban planning is to improve solar access at the neighbourhood scale and promote the integration and application of PV systems in a large urban scale. This puts the future urban plans in line with sustainable development goals and contributes to the environmental stability of an urban area (Amado, M., & Poggi, F, 2012).

It should also be noted that achieving a sustainable urban form is only possible when it is supported by firm policies and local strategies. In this sense, clean energy production must be considered as one of the key components in the future urban plans, and identifying different methods and solutions for better production of solar energy should be pursued and encouraged.

To introduce the energy factor in the urban planning process, different tools and methods for analyzing solar potential on a large scale and integrating solar systems into urban districts should be developed and studied. The above-mentioned model is just an example of how this process could be conducted. Solar potential analysis should become an inseparable part of the urban planning process if the energy targets like PED and NZEB are to be achieved.

06 | Conclusion

6-1- Answering research questions

The first research question was asking, "How much solar energy can be generated by installing PV systems on buildings' envelope, on the scale of an urban block in the city of Stavanger?". Finding a concrete answer for this question that would be applicable for all the urban blocks in Stavanger city is not realistic, since the solar energy potential may vary considerably in urban blocks with different characteristics e.g. different height, density, orientation, and etc.

Therefore, this study chooses two urban blocks with distinctive characteristics as the case study and runs a solar analysis to find out their potential for producing solar energy. The tests have been running using CAD plugin-based software named "DL-light" which is a plugin for SketchUp. A 3D model of the selected urban blocks was made and imported into the site 3D model. Insolation on different building skins was calculated for each month of the year and for each urban block, using this software.

The results of the solar analysis indicate the annual average amount of solar energy that building envelope receives per square meter per year. For the urban block at Øvre Holmegate with low-rise high-density characteristics, that includes 11 buildings and 19 250 m2 of urban surfaces, the average solar irradiance is calculated as 482 kWh/m2 per year. Considering the applied 15% reduction factor, that estimates the suitable proportion of buildings envelope for PV installation, the total solar irradiance that this urban block receives is equal to 7 880 000 kWh (7 880 MW). Moreover, for the urban block at St. Olavs gate with high-rise high-density characteristics, which includes 5 buildings and 33 500 m2 of urban surfaces, the average solar irradiance is calculated as 443.8 kWh/m2 per year. Considering the applied 15% reduction factor the total solar irradiance that this urban block receives is equal to 12 637 205 kWh (12 637 MW).

In order to find out how much of this received solar radiation can be converted to electricity, it was assumed that the whole building envelopes are going to be covered with BIPVs, and then the efficiency values for conventional mono-crystalline modules and clear/transparent PV modules were applied. In this sense, two different scenarios were investigated:

1- In 2020 (current year), considering existing technology with current PV efficiencies; 18% for monocrystalline modules and 7% for clear/transparent modules
2- In 2030, considering the technological advances and improvement in PV efficiencies; 25% for monocrystalline modules and 15% for clear/transparent modules

Following that for each urban block, the amount of solar energy that can be generated assuming that the buildings are covered with BIPVs is calculated in the two scenarios. For the urban block at Øvre Holmegate, PV systems can produce 1 028 340 kWh solar energy in 2020 and 1 615 400 kWh in 2030. In the meantime, for the urban block at St. Olavs gate, PV systems can produce 1 579 650 kWh solar energy in 2020 and 2 527 440 kWh in 2030.

In conclusion, for better understanding and comprehensible comparison, the calculated values are converted to kWh/m2. Therefore, assuming the buildings are covered with BIPVs each square meter of buildings' envelope at the urban block in Øvre Holmegate can generate 53.5 kWh/m2 of solar energy in 2020 and 83.9 kWh/m2 in 2030. Meanwhile, each square meter of buildings' envelope at St. Olavs gate can generate 47.1 kWh/m2 of solar energy in 2020 and 75.4 kWh/m2 in 2030, and therefore the first research question is answered.

The second research question was asking, "Is it possible to achieve PED goal via generating solar energy in neighborhood scale, in Stavanger?". In order to find an answer to this question and ascertain if generated solar energy is enough to cover the district's energy needs, the first energy consumption in each urban block had to be calculated.

The latest statistics on building energy consumption for Stavanger are from 2012, and it is only available for residential land-use, therefore seeking an answer to this research question required many assumptions and estimations. In the first place, the amount of energy need in other types of land-use (e.g. commercial) was estimated based on other statistics on energy use in different sectors in Norway and similar studies. Then the energy consumption values for 2020 and 2030 were predicted using EU regulations that demanded member countries reduce their consumption through energy savings. Therefore, four different scenarios were studied here:

1- In 2020 (the current year), assuming the building energy consumption values have not been changed since 2012.
2- In 2020 (the current year), assuming the EU goal of 20% energy saving has been achieved.
3- In 2030, assuming the building energy consumption values have not been changed since 2012.
4- In 2030, assuming the EU goal of 32.5% energy saving has been achieved.

For each urban block, the total energy consumption value was calculated in the above-mentioned four scenarios and the results were then compared to the total amount of solar energy that each district can produce (data from last research question). The findings are the answer to the second research question.

For the urban block at Øvre Holmegate, the district energy consumption in 2020 and for the first scenario is calculated as 2 501 440 kWh and therefore solar energy would cover only 41% of the energy need. In the same year and for the second scenario that assumes 20% energy saving goal has been achieved, the total energy use would be 2 001 152 kWh and therefore solar energy would cover 51% of the energy need. In 2030, in the third scenario, the energy use is still the same as 2020, and therefore the solar energy generated (considering better PV efficiencies in 2030) would cover 64.5% of the energy need. And finally in 2030, following the fourth scenario and assuming 32.5% energy saving goal has been achieved the total energy use in the district would be 1 688 472 kWh and the solar energy generated can cover 95.6% of the districts' energy use.

For the urban block at St. Oalvs gate, the district energy consumption in 2020 and for the first scenario is calculated as 5 247 700 kWh and therefore solar energy would cover only 30% of the energy need. In the same year and for the second scenario that assumes 20% energy saving goal has been achieved, the total energy use would be 4 198 160 kWh and therefore solar energy would cover 37.6% of the energy need. In 2030, in the third scenario, the energy use is still the same as 2020, and therefore the solar energy generated (considering better PV efficiencies in 2030) would cover 48% of the energy need. And finally in 2030, following the fourth scenario and assuming 32.5% energy saving goal has been achieved the total energy use in the district would be 3 542 197 kWh and the solar energy generated can cover 70% of the districts' energy use.

Reviewing the results reveals that in the studied urban districts, the PED goal would be achieved neither in 2020 nor in 2030, solely via generating solar energy on an urban scale. However, the numbers are very promising and show the vast potential of exploiting solar energy in the neighborhoods. The findings suggest that if the solar energy generation in urban environments is coupled with other initiatives e.g. considerable energy savings in the buildings sector, achieving the PED goal is not out of reach.

Moreover, the findings suggest that solar potential should be considered as a key component in the future urban plans if the NZEB goal is to be achieved. Therefore it is essential for urban planners and city authorities to have an understanding of how to deploy solar energy effectively in the scale of a neighborhood or district, and how this would affect their designs and plans of developing or redeveloping urban areas.

6-2- Suggestions for further studies

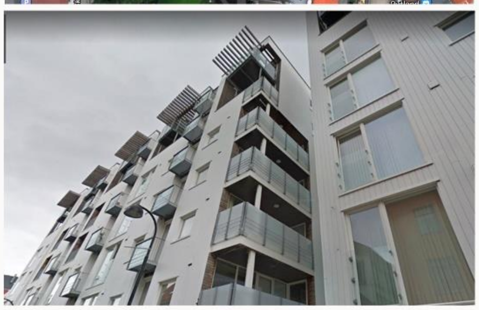
The current thesis has managed to depict the solar energy potential for two urban areas with different characteristics in the city of Stavanger, low-rise high-density urban block at Øvre Holmegate, and high-rise high-density urban block at St. Olavs gate. However, in order to grasp a more comprehensive picture of the solar energy generation opportunities in Stavanger city, other typologies of urban developments in the region should be studied as well. There are other types of urban fabrics with characteristics like low or medium densities (e.g. detached and semi-detached housing developments in Madla) and different heights (low, mid, or high-rise), that have not been included in this study due to time constraints.

Conducting similar studies for other types of practiced urban developments in the region would help the urban planners and city authorities to have a better understanding of the pros and cons of different development strategies regarding the potential use of solar energy in urban environments. Solar energy will definitely have a considerable role in achieving the NZEB goal and therefore it is essential for planners and designers to have an idea on how to maximize its exploitation in urban scale through considering the solar potential in the planning process.

Appendix

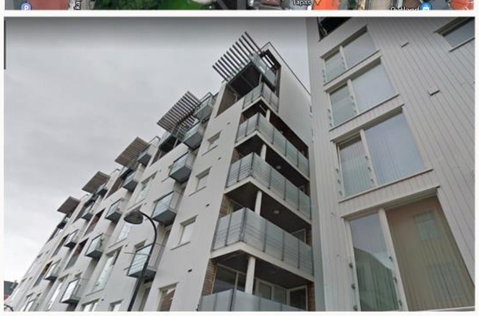
Appendix 1| Building Information Sheets for the urban block at Øvre Holmesgate

❖ Building 01



BUILDING 01			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	293 m²
COLOR	100%WHITE	NUMBER OF FLOORS	6
ANGLE	90 º	BRA - RESIDENTIAL	1465 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	293 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	FLAT	**SUM BRA**	**1758 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	80%		

❖ Building 02

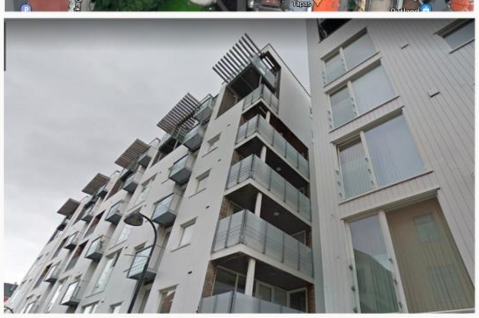


BUILDING 02			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	478 m²
COLOR	100%WHITE	NUMBER OF FLOORS	6
ANGLE	90 º	BRA - RESIDENTIAL	2390 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	478 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	FLAT	**SUM BRA**	**2868 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	80%		

❖ Building 03

BUILDING 03			
FACADE		**AREA**	
MATERIAL	WOOD,GLASS	FLOOR AREA	179 m²
COLOR	100%WHITE	NUMBER OF FLOORS	10
ANGLE	90 °	BRA - RESIDENTIAL	1611 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	179 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	FLAT	**SUM BRA**	**1790 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

❖ Building 04

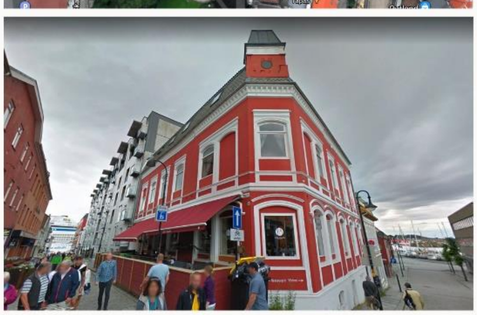


BUILDING 04			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	577 m²
COLOR	100%WHITE	NUMBER OF FLOORS	6
ANGLE	90 °	BRA - RESIDENTIAL	2885 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	467 m²
ROOF		BRA - OTHER	110 m²
ROOF TYPE	FLAT	**SUM BRA**	**3462 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	80%		

❖ Building 05

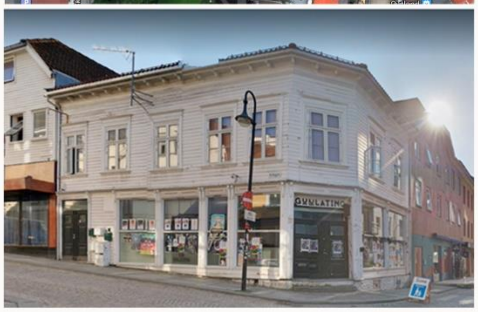
BUILDING 05			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	191 m²
COLOR	10%GREY,20%WHITE, 70%YELLOW	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	382 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	191 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**573 m²**
MATERIAL	TERRACOTTA		
COLOR	RED		
USABLE AREA	80%		

- Building 06



BUILDING 06			
FACADE		**AREA**	
MATERIAL	CEMENT	FLOOR AREA	223 m²
COLOR	20%WHITE,80%RED	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	446 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	223 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**669 m²**
MATERIAL	TERRACOTTA		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	80%		

- Building 07



BUILDING 07			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	115 m²
COLOR	100%WHITE	NUMBER OF FLOORS	2
ANGLE	90 º	BRA - RESIDENTIAL	115 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	115 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	PITCHED ROOF	**SUM BRA**	**230 m²**
MATERIAL	TERRACOTTA		
COLOR	DARK RED		
USABLE AREA	80%		

❖ Building 08

BUILDING 08			
FACADE		**AREA**	
MATERIAL	CEMENT	FLOOR AREA	140 m²
COLOR	80%RED,20%BLUE	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	280 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	140 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**420 m²**
MATERIAL	TERRACOTTA,RUBBER		
COLOR	LIGHT RED		
USABLE AREA	80%		

❖ Building 09

BUILDING 09			
FACADE		**AREA**	
MATERIAL	CEMENT	FLOOR AREA	209 m²
COLOR	5%BLACK,95%LIGHT BROWN	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	418 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	209 m²
		BRA - OTHER	0 m²
		SUM BRA	**627 m²**
ROOF			
ROOF TYPE	PITCHED ROOF		
MATERIAL	TERRACOTTA		
COLOR	70%LIGHT RED,30%BLACK		
USABLE AREA	80%		

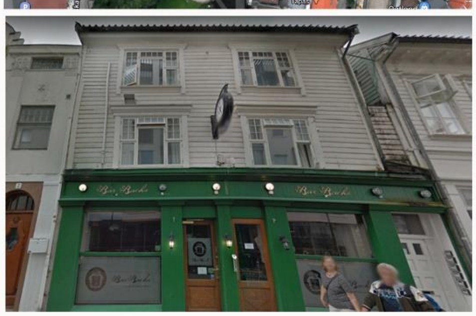
❖ Building 10

BUILDING 10			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	70 m²
COLOR	5%GREEN,95%WHITE	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	140 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	70 m²
		BRA - OTHER	0 m²
		SUM BRA	**210 m²**
ROOF			
ROOF TYPE	PITCHED ROOF		
MATERIAL	TERRACOTTA		
COLOR	DARK BROWN		
USABLE AREA	95%		

❖ Building 11

BUILDING 11			
FACADE		**AREA**	
MATERIAL	CEMENT	FLOOR AREA	62 m²
COLOR	100%WHITE	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	124 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	62 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	PITCHED ROOF	**SUM BRA**	**186 m²**
MATERIAL	TERRACOTTA		
COLOR	LIGHT GREY		
USABLE AREA	90%		

- ❖ Building 12



BUILDING 12			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	85 m²
COLOR	100%WHITE	NUMBER OF FLOORS	3
ANGLE	90 º	BRA - RESIDENTIAL	170 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	85 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	PITCHED ROOF	**SUM BRA**	**255 m²**
MATERIAL	TERRACOTTA		
COLOR	LIGHT BROWN		
USABLE AREA	90%		

- ❖ Building 13

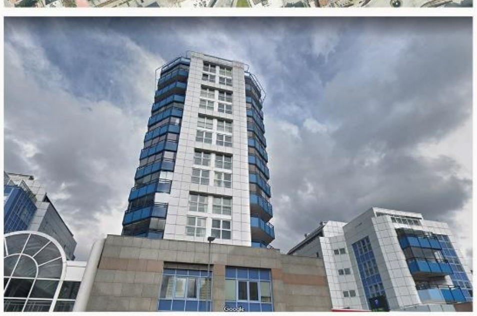
BUILDING 13			
FACADE		**AREA**	
MATERIAL	WOOD	FLOOR AREA	94 m²
COLOR	100%WHITE	NUMBER OF FLOORS	3
ANGLE	90 °	BRA - RESIDENTIAL	188 m²
WINDOWS PERCENTAGE	60%	BRA - COMMERCIAL	94 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	PITCHED ROOF	**SUM BRA**	**282 m²**
MATERIAL	TERRACOTTA		
COLOR	LIGHT BROWN		
USABLE AREA	90%		

Appendix 2| Building Information Sheets for the urban block at St. Olav gate

- Building 01

BUILDING 01			
FACADE		AREA	
MATERIAL	CEMENT	FLOOR AREA	606 m²
		NUMBER OF FLOORS	5
COLOR	BEIGE	BRA - RESIDENTIAL	0 m²
ANGLE	90 °	BRA - COMMERCIAL	3030 m²
		BRA - OTHER	0 m²
WINDOWS PERCENTAGE	35%	**SUM BRA**	**3030 m²**
ROOF			
ROOF TYPE	FLAT		
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

- Building 02

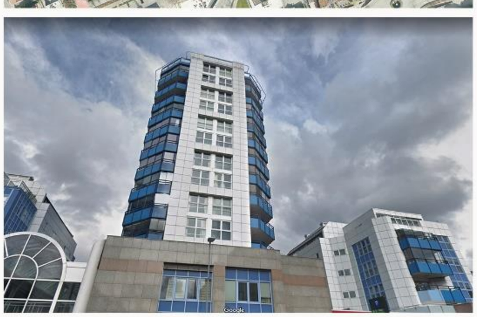


BUILDING 02			
FACADE		AREA	
MATERIAL	ALUMINUM CLADDING/ ALCOBAN	FLOOR AREA	- m²
		NUMBER OF FLOORS	7
COLOR	75%WHITE/25%BLUE	BRA - RESIDENTIAL	0 m²
ANGLE	90 °	BRA - COMMERCIAL	2775 m²
		BRA - OTHER	750 m²
WINDOWS PERCENTAGE	50%	**SUM BRA**	**3525 m²**
ROOF			
ROOF TYPE	COMPLEX		
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

❖ Building 03

BUILDING 03			
FACADE		**AREA**	
MATERIAL	ALUMINUM CLADDING/ ALCOBAN	FLOOR AREA	- m²
COLOR	75%WHITE/25%BLUE	NUMBER OF FLOORS	14
ANGLE	90 °	BRA - RESIDENTIAL	6720 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	1832 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**8552 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

❖ Building 04



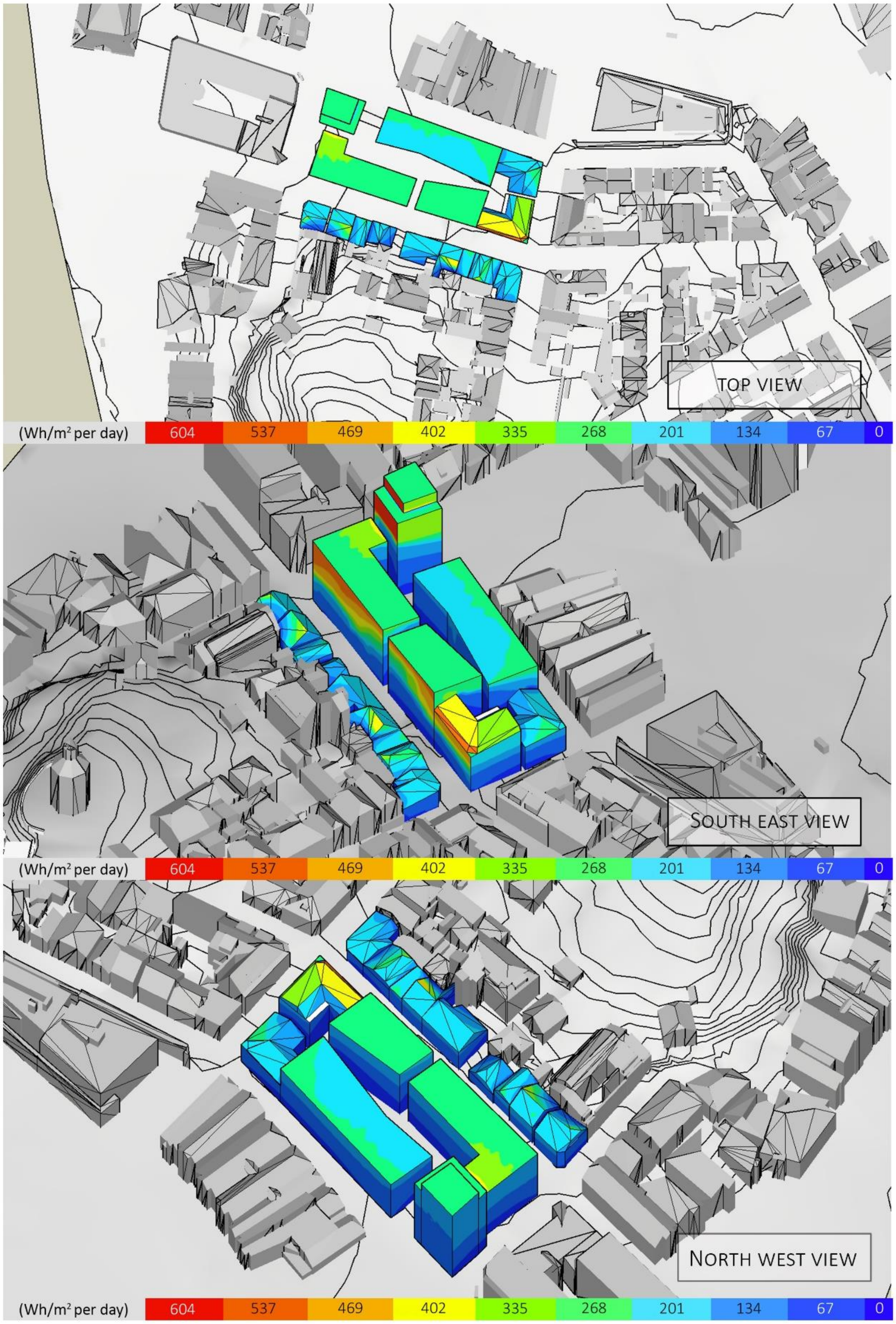
BUILDING 04			
FACADE		**AREA**	
MATERIAL	ALUMINUM CLADDING/ ALCOBAN	FLOOR AREA	- m²
COLOR	75%WHITE/25%BLUE	NUMBER OF FLOORS	6
ANGLE	90 °	BRA - RESIDENTIAL	2004 m²
WINDOWS PERCENTAGE	50%	BRA - COMMERCIAL	1739 m²
ROOF		BRA - OTHER	0 m²
ROOF TYPE	COMPLEX	**SUM BRA**	**3743 m²**
MATERIAL	RUBBER ROOF		
COLOR	GREY/10%REFLETIVE		
USABLE AREA	70%		

❖ Building 05

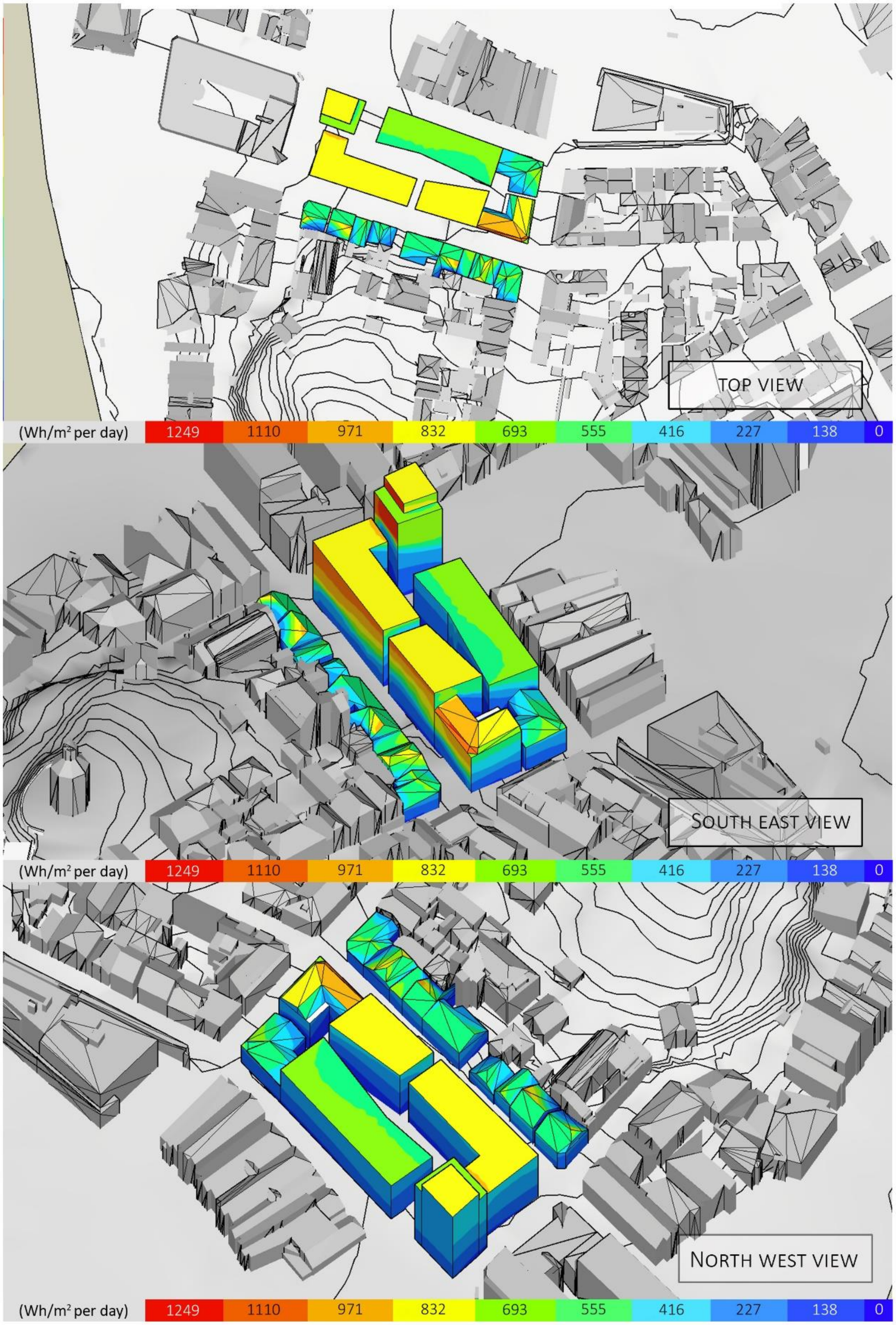
BUILDING 05		
FACADE		**AREA**
MATERIAL	ALUMINUM CLADDING/ ALCOBAN	FLOOR AREA - m^2
COLOR	75%WHITE/25%BLUE	NUMBER OF FLOORS 13
ANGLE	90 °	BRA - RESIDENTIAL 6561 m^2
		BRA - COMMERCIAL 1794 m^2
		BRA - OTHER 0 m^2
WINDOWS PERCENTAGE	50%	**SUM BRA 8355 m^2**
ROOF		
ROOF TYPE	COMPLEX	
MATERIAL	RUBBER ROOF	
COLOR	GREY/10%REFLETIVE	
USABLE AREA	70%	

Appendix 3| Solar Analysis maps for the urban block at Øvre Holmesgate

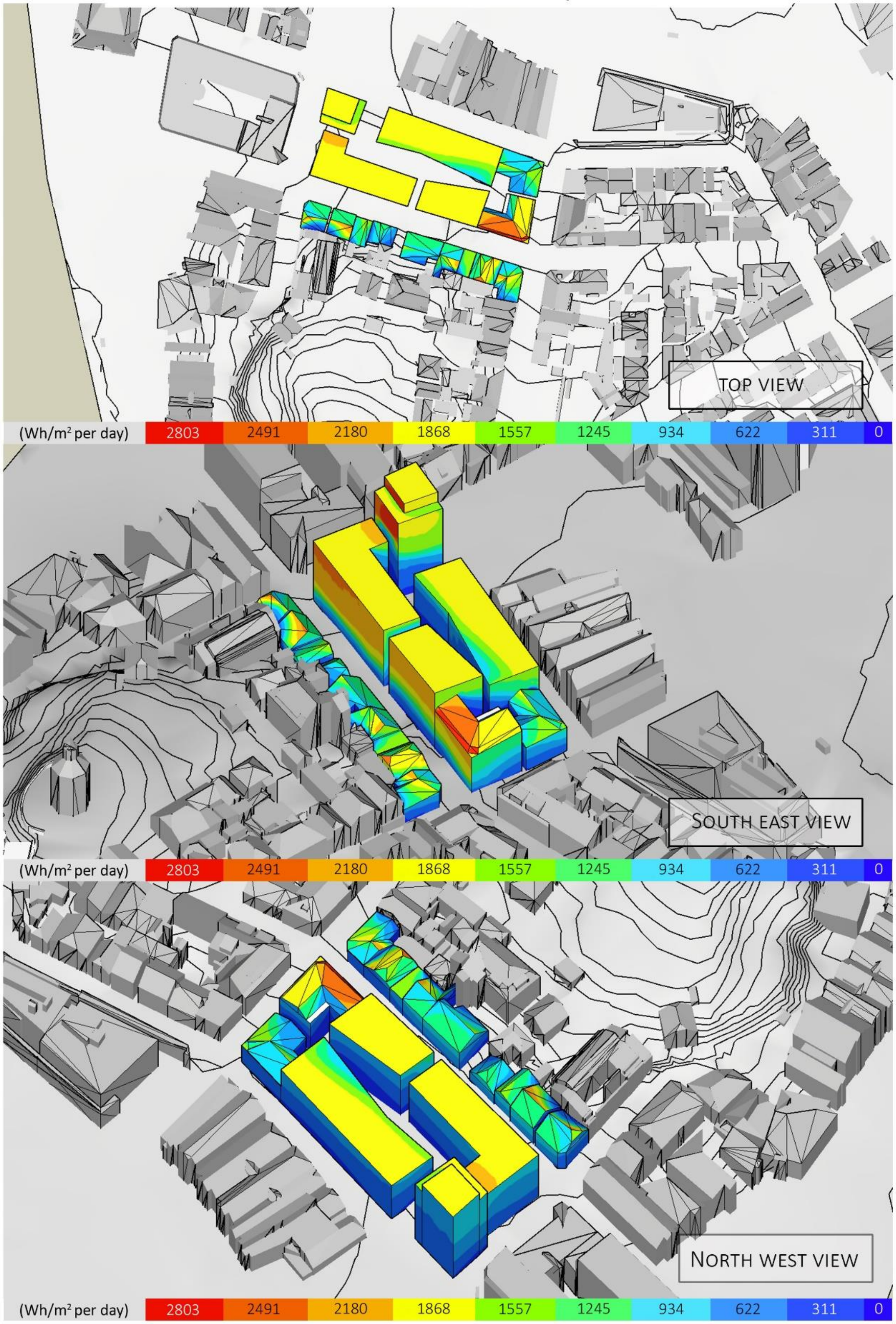
SOLAR ANALYSIS MAP:ØVRE HOLMEGATE,JAN 1 TO JAN 31



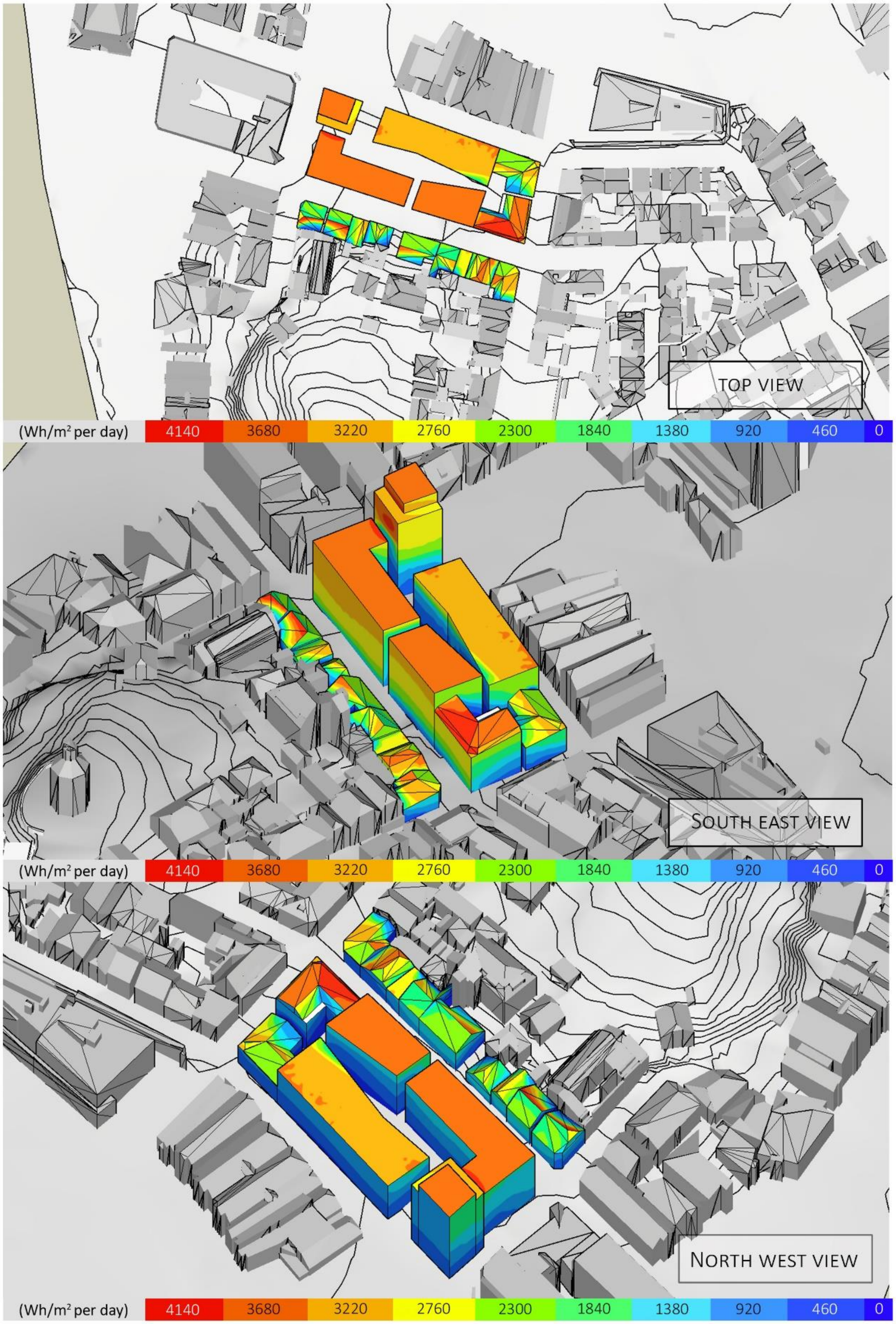
Solar Analysis map:Øvre Holmegate,Feb 1 to Feb 28



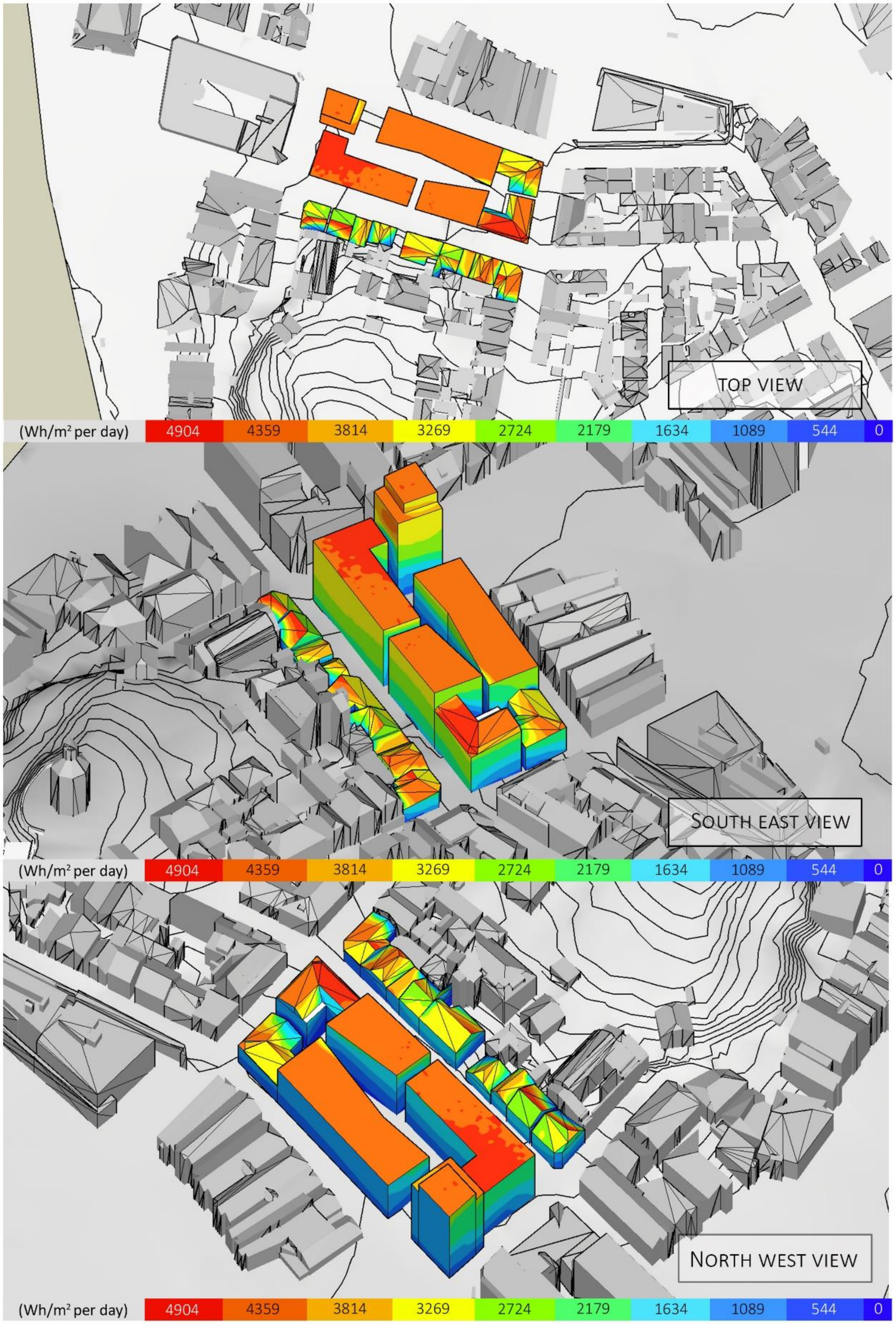
Solar Analysis map:Øvre Holmegate,Mar 1 to Mar 31



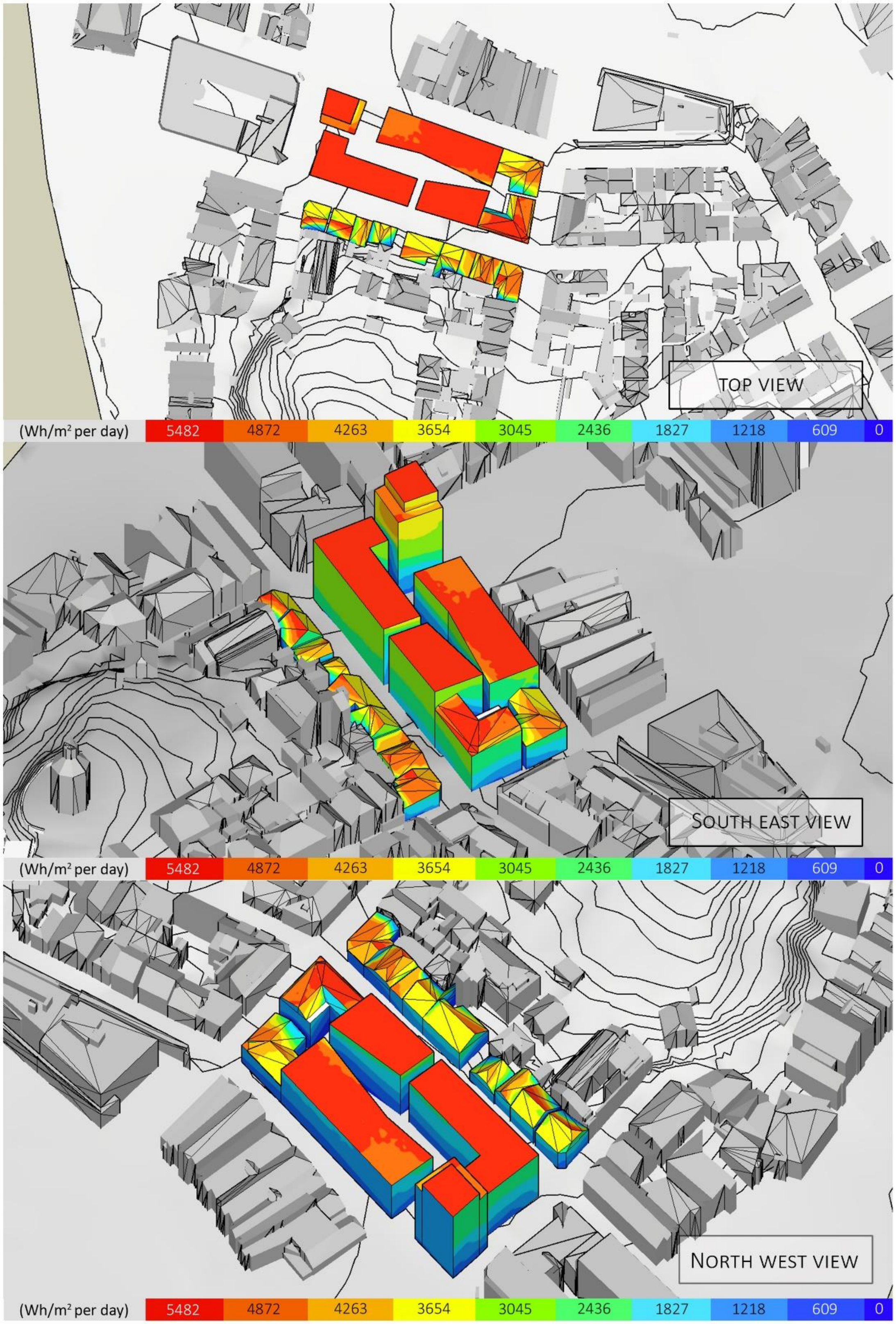
Solar Analysis map:Øvre Holmegate,Apr 1 to Apr 30



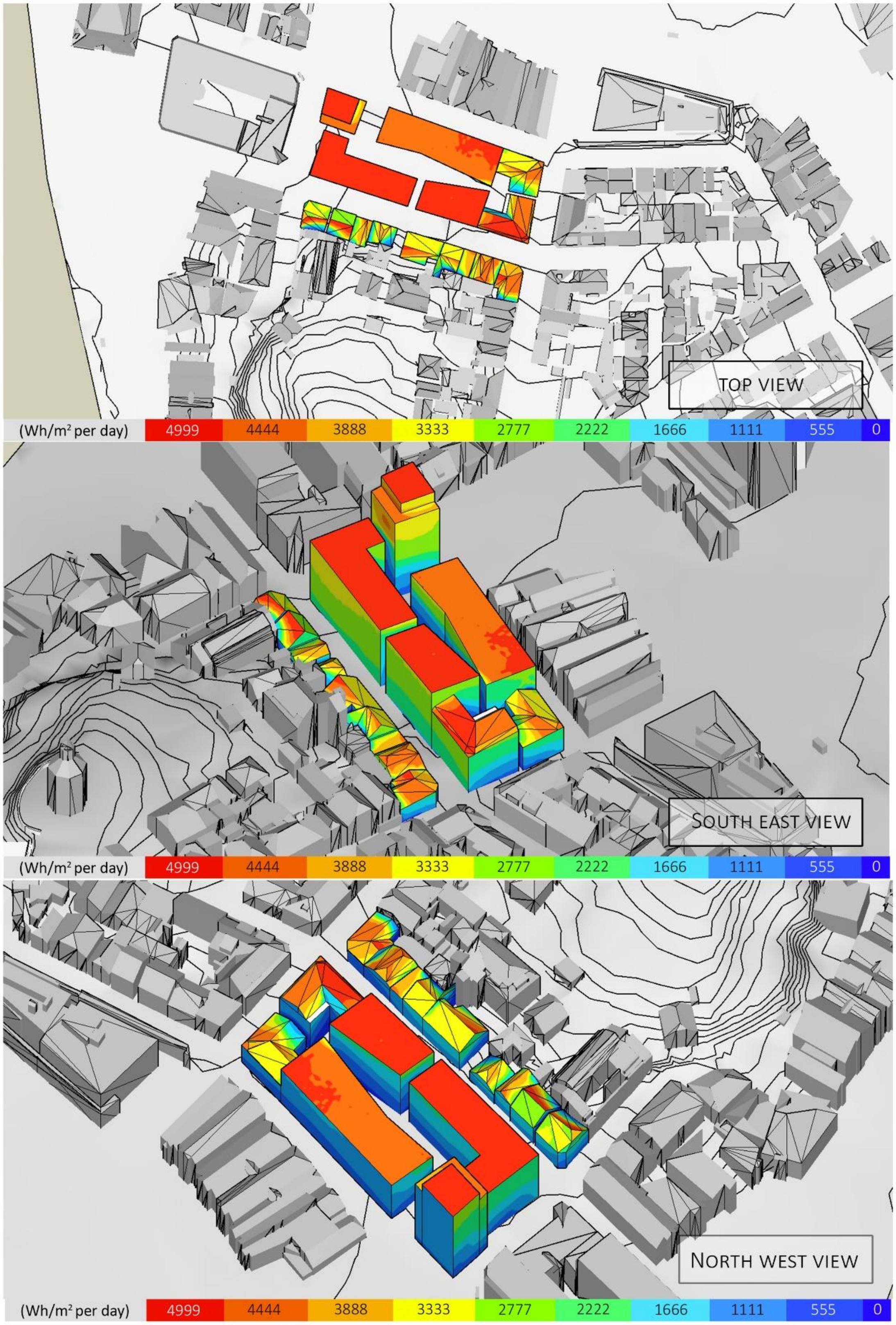
Solar Analysis map:Øvre Holmegate,May 1 to May 31



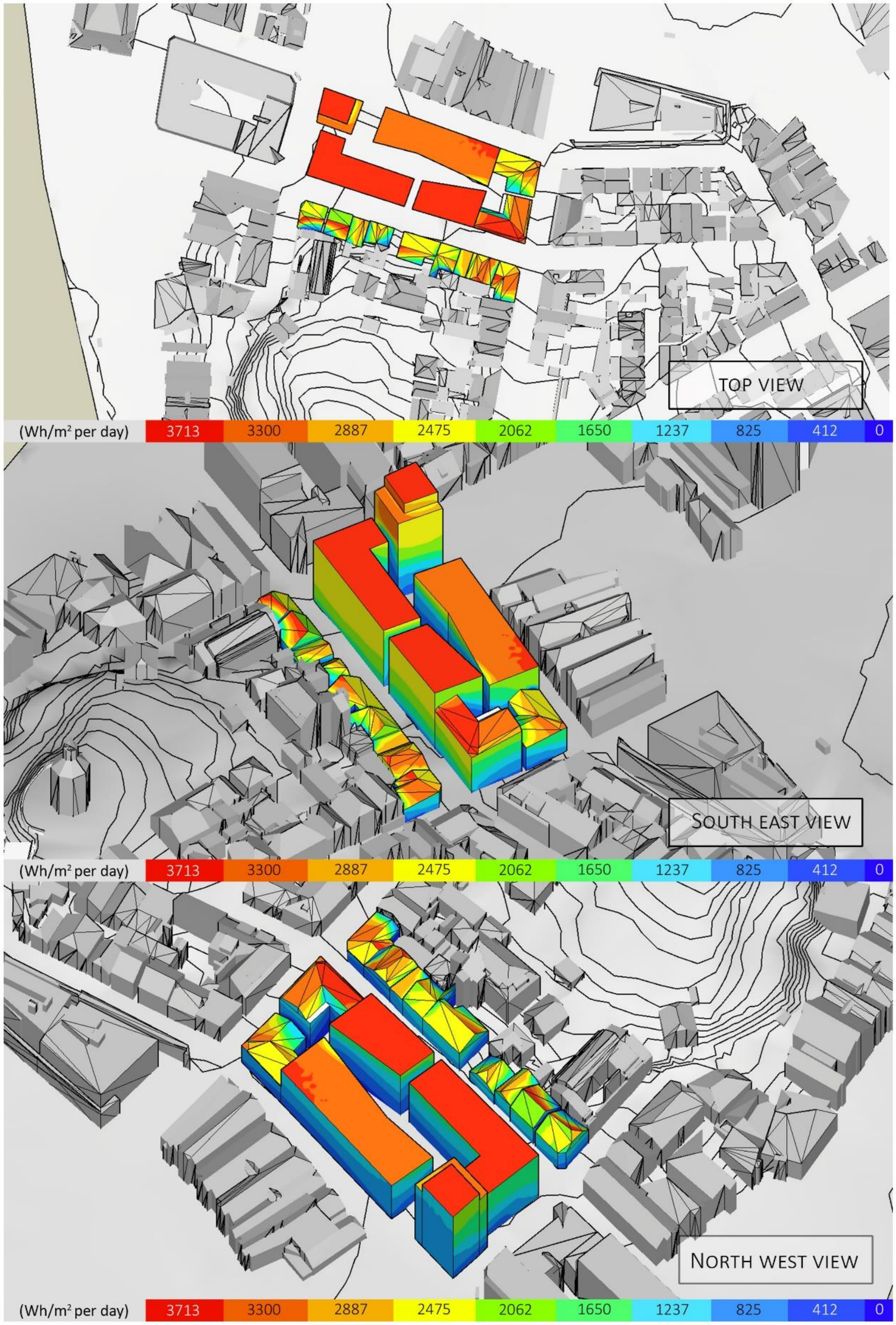
SOLAR ANALYSIS MAP:ØVRE HOLMEGATE,Jun 1 TO JUN 30



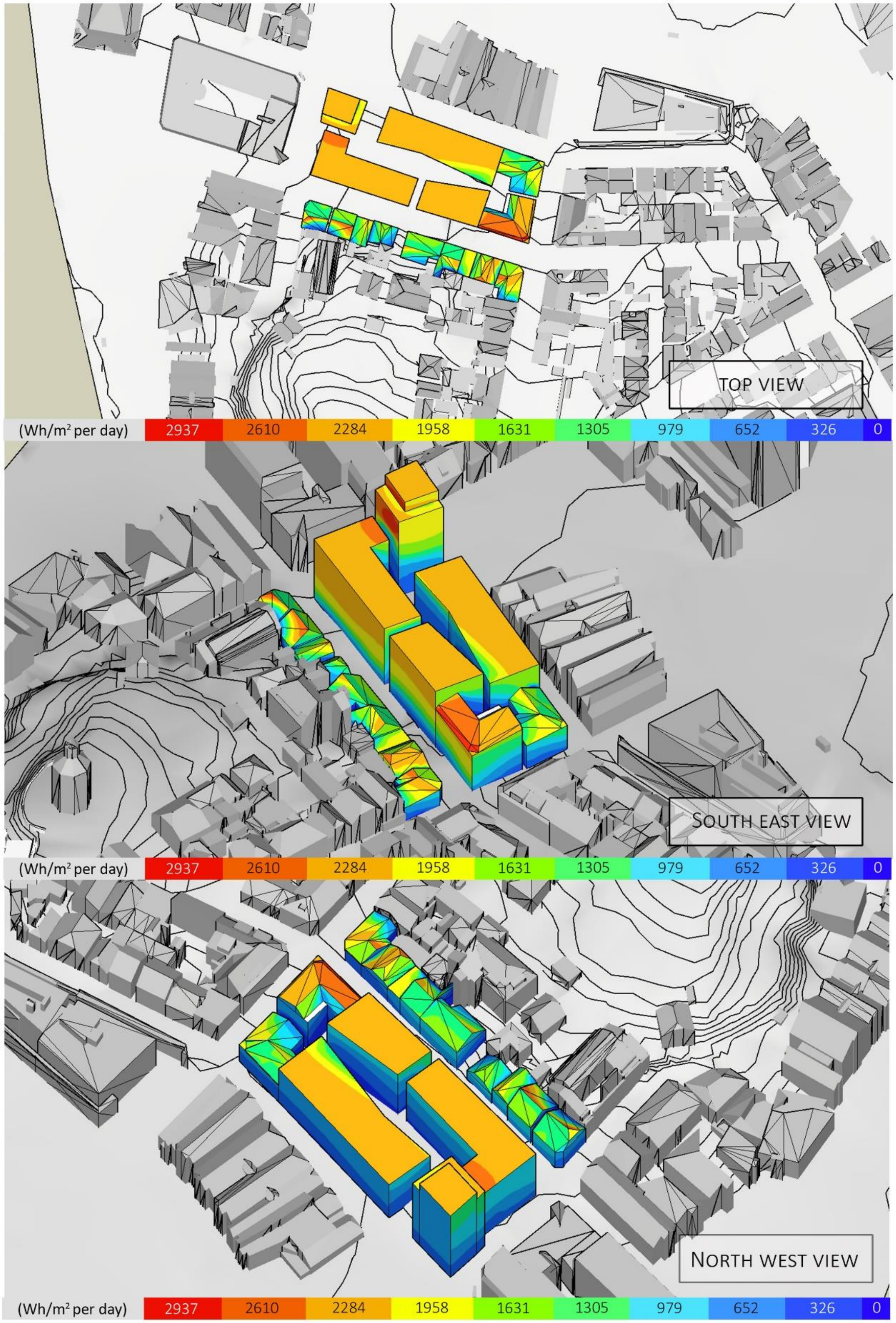
SOLAR ANALYSIS MAP:ØVRE HOLMEGATE,July 1 TO July 31



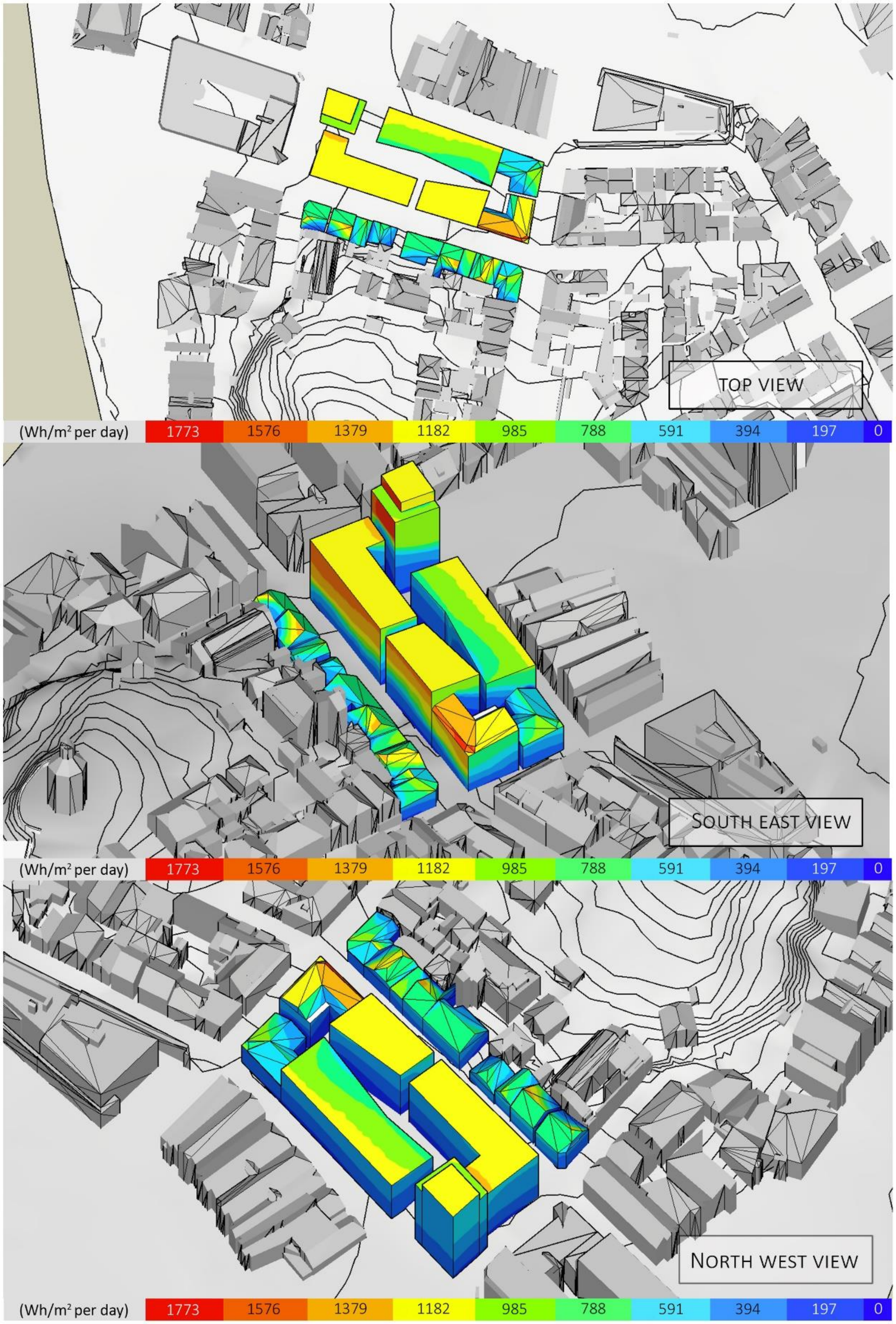
SOLAR ANALYSIS MAP:ØVRE HOLMEGATE,Aug 1 TO Aug 31



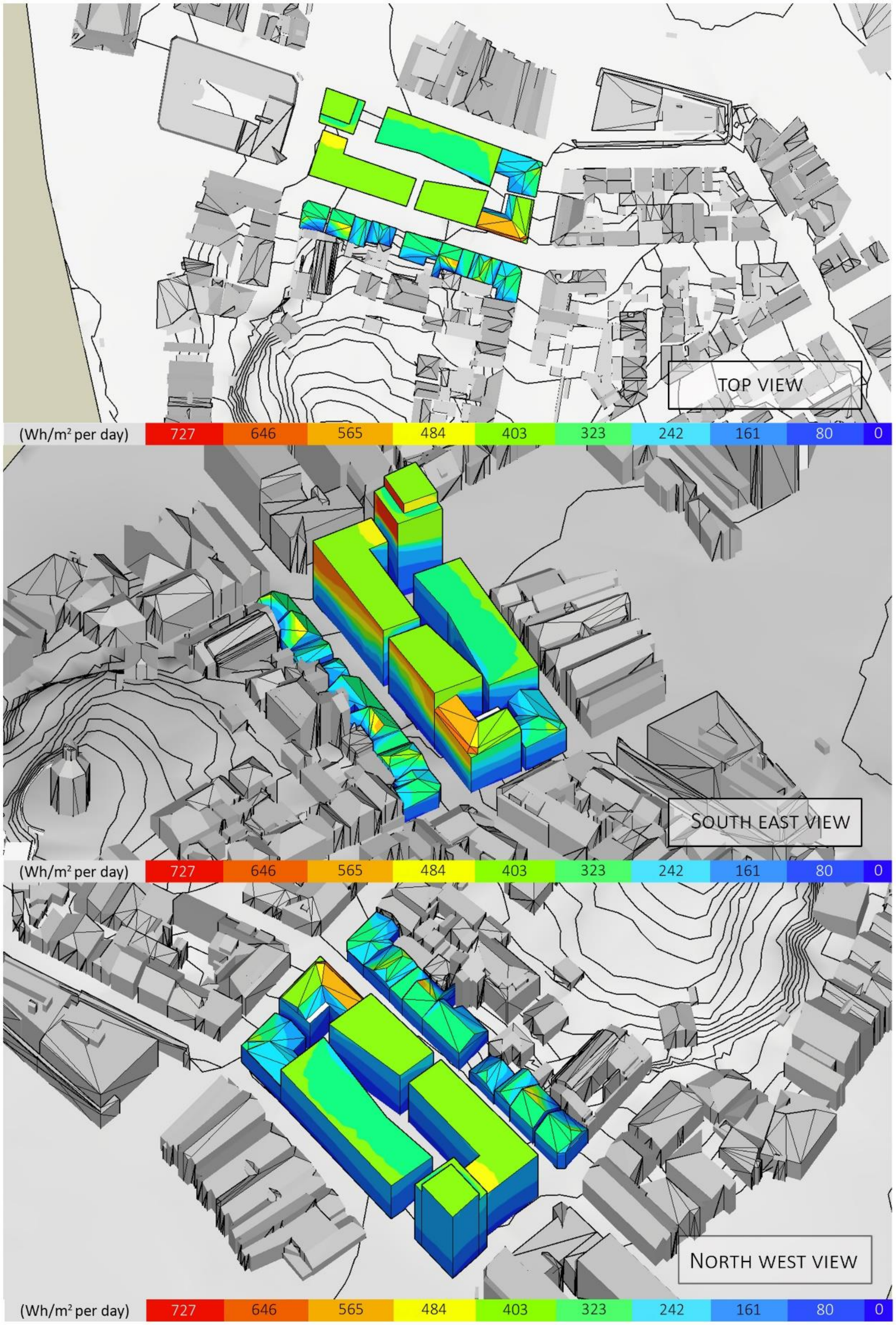
SOLAR ANALYSIS MAP:ØVRE HOLMEGATE,Sep 1 TO Sep 30



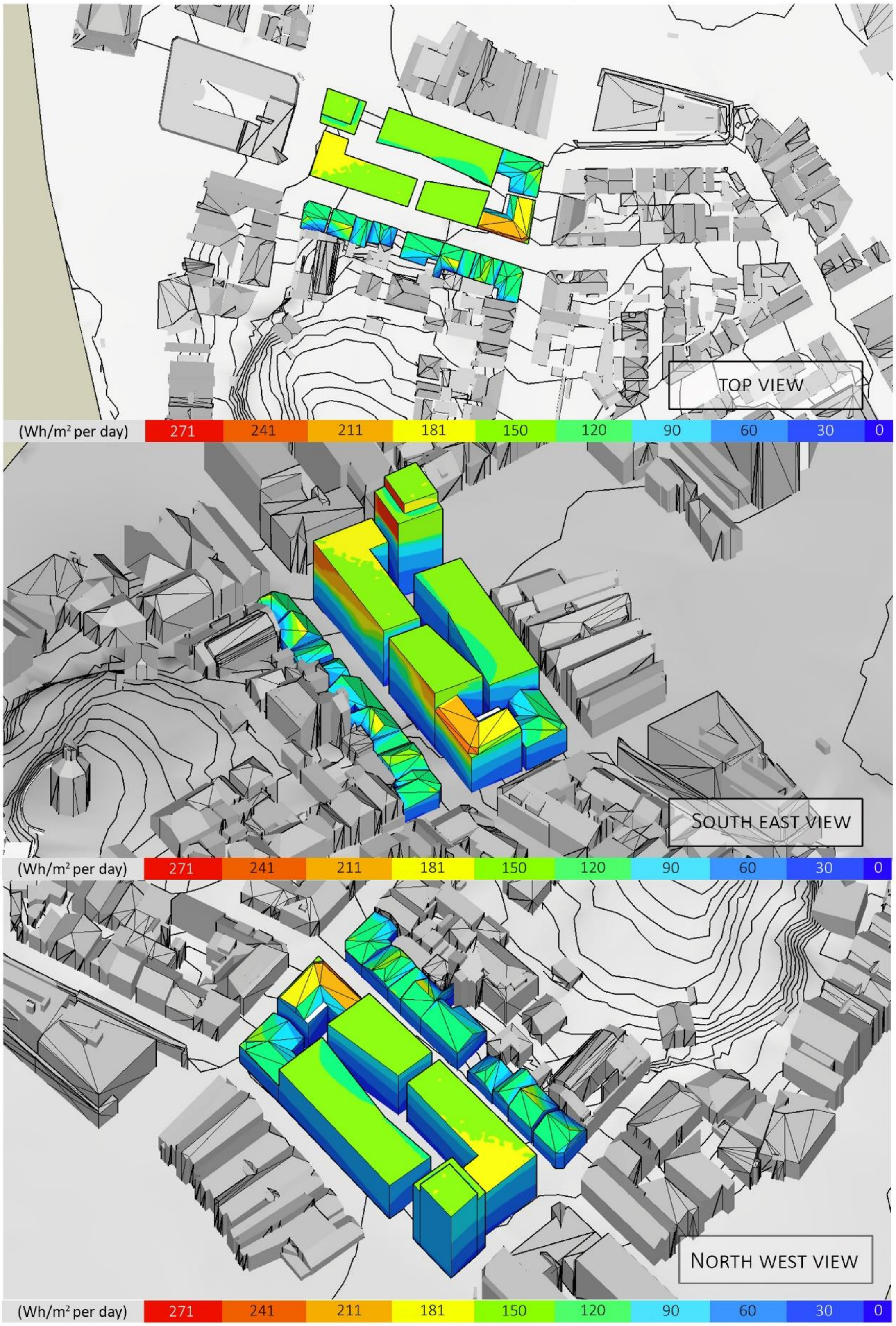
Solar Analysis map:Øvre Holmegate,Oct 1 to Oct 31



Solar Analysis map:Øvre Holmegate,Nov 1 to Nov 30

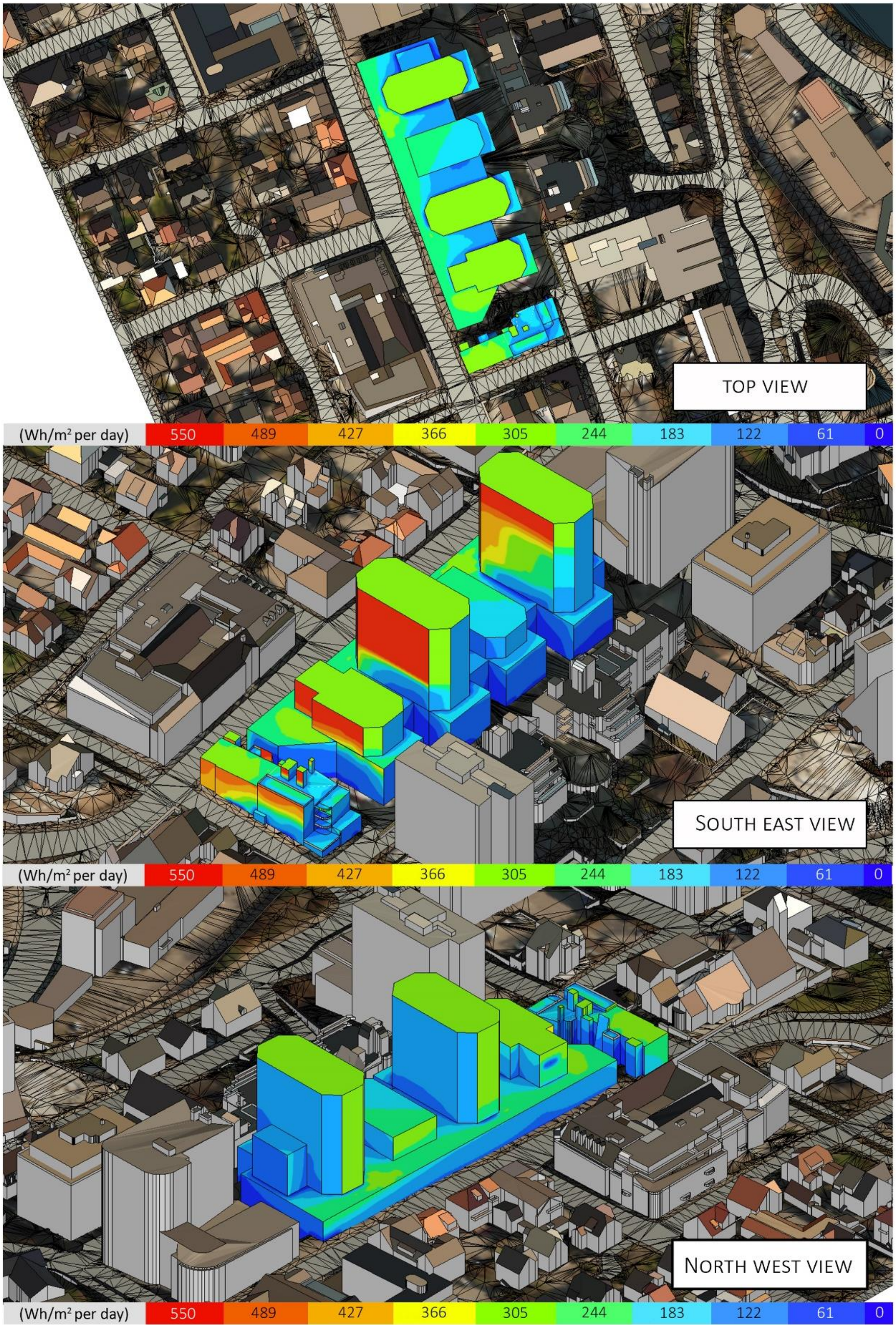


Solar Analysis map:Øvre Holmegate,Dec 1 to Dec 31

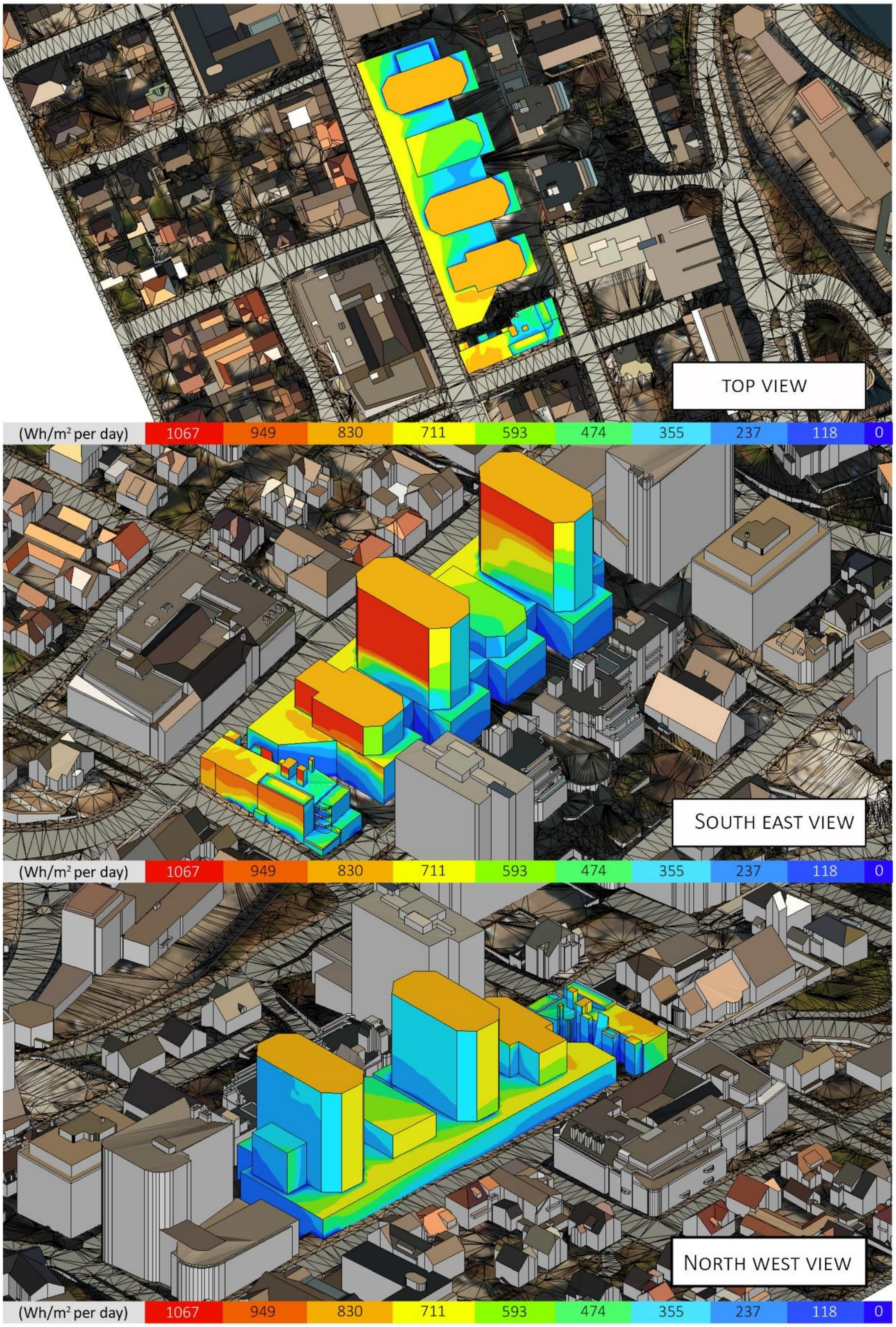


Appendix 4| Solar Analysis maps for the urban block at St. Olavs gate

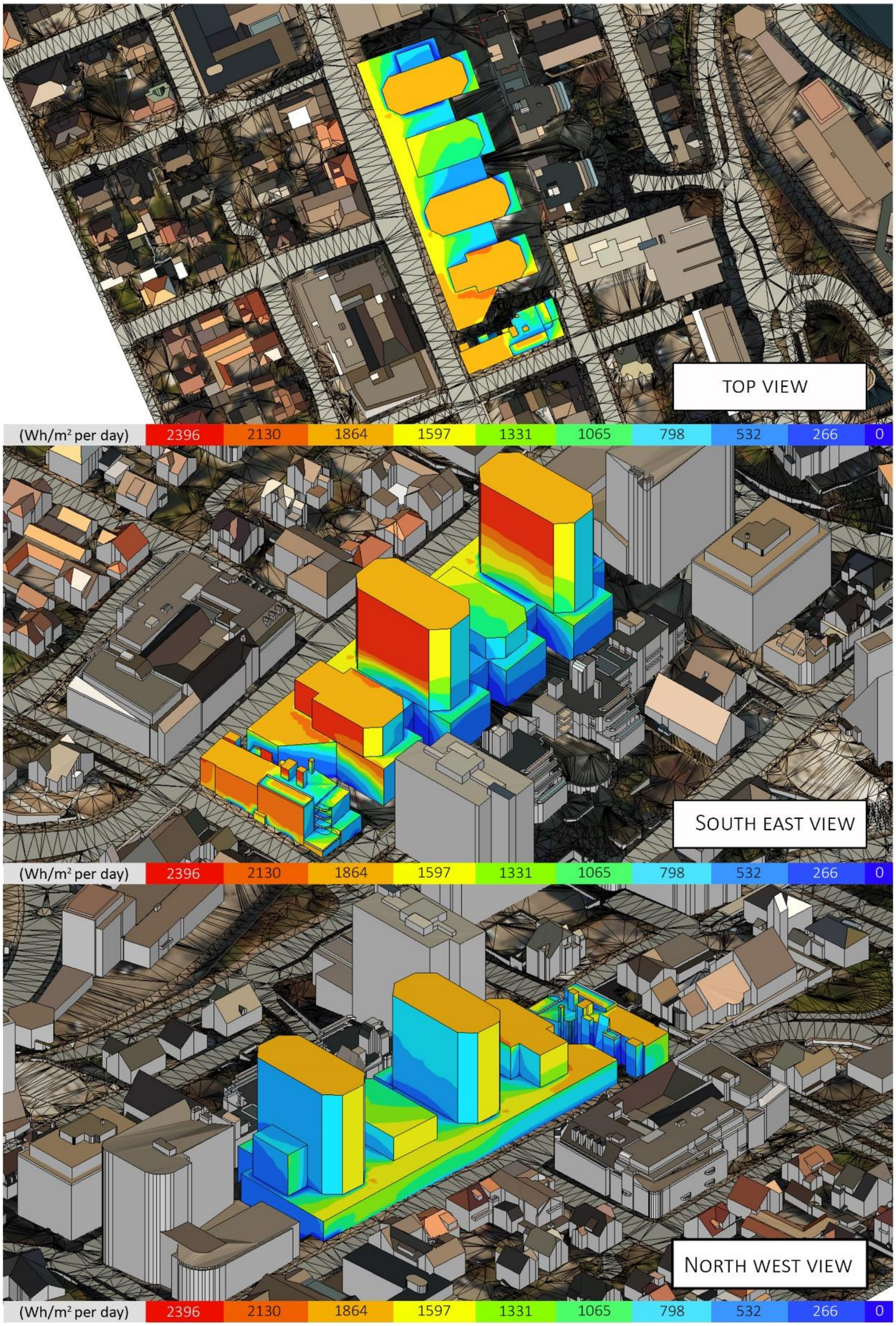
SOLAR ANALYSIS MAP:St.Olav Gate,Jan 1 TO Jan 31



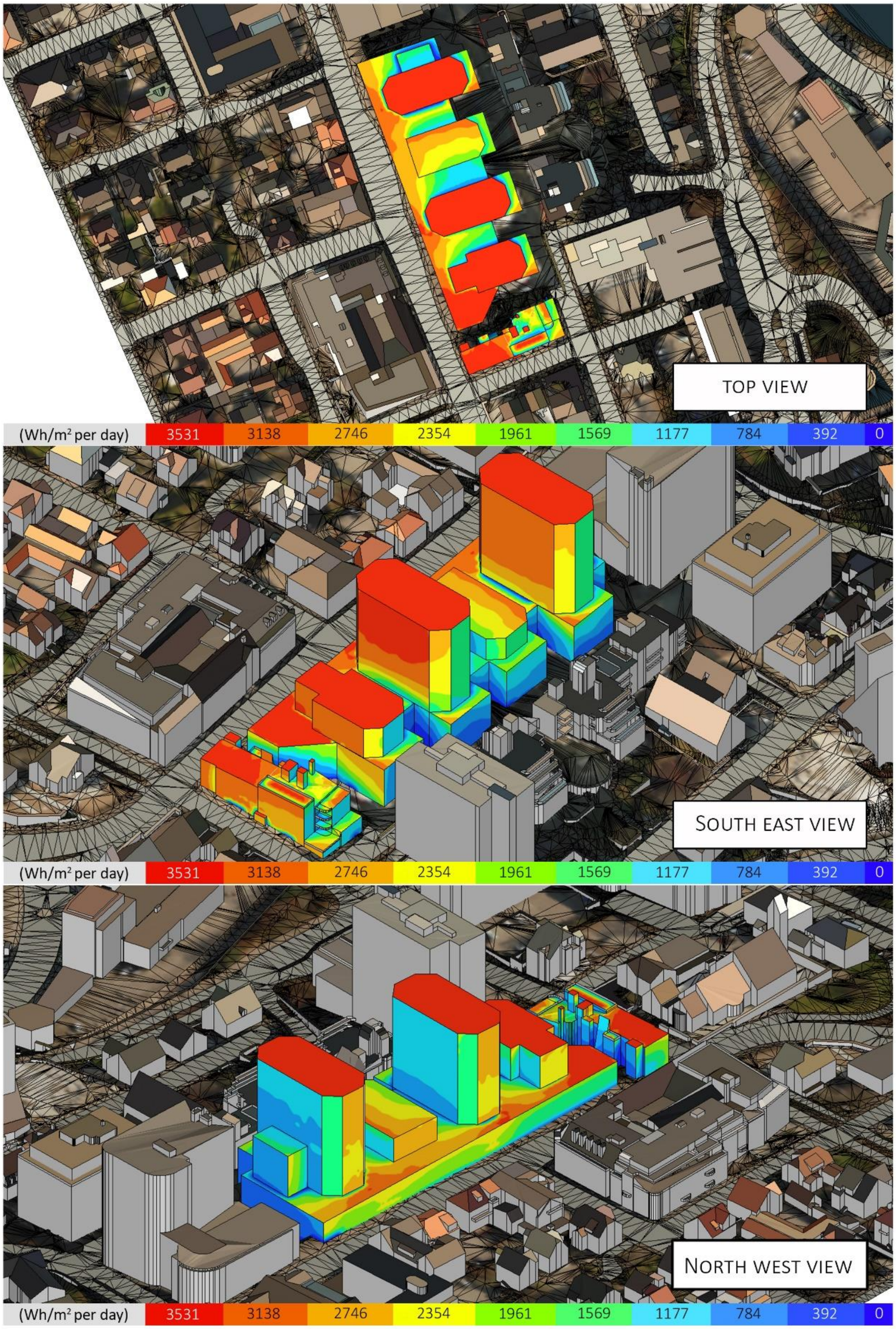
Solar Analysis map:St.Olav Gate , Feb 1 to Feb 28



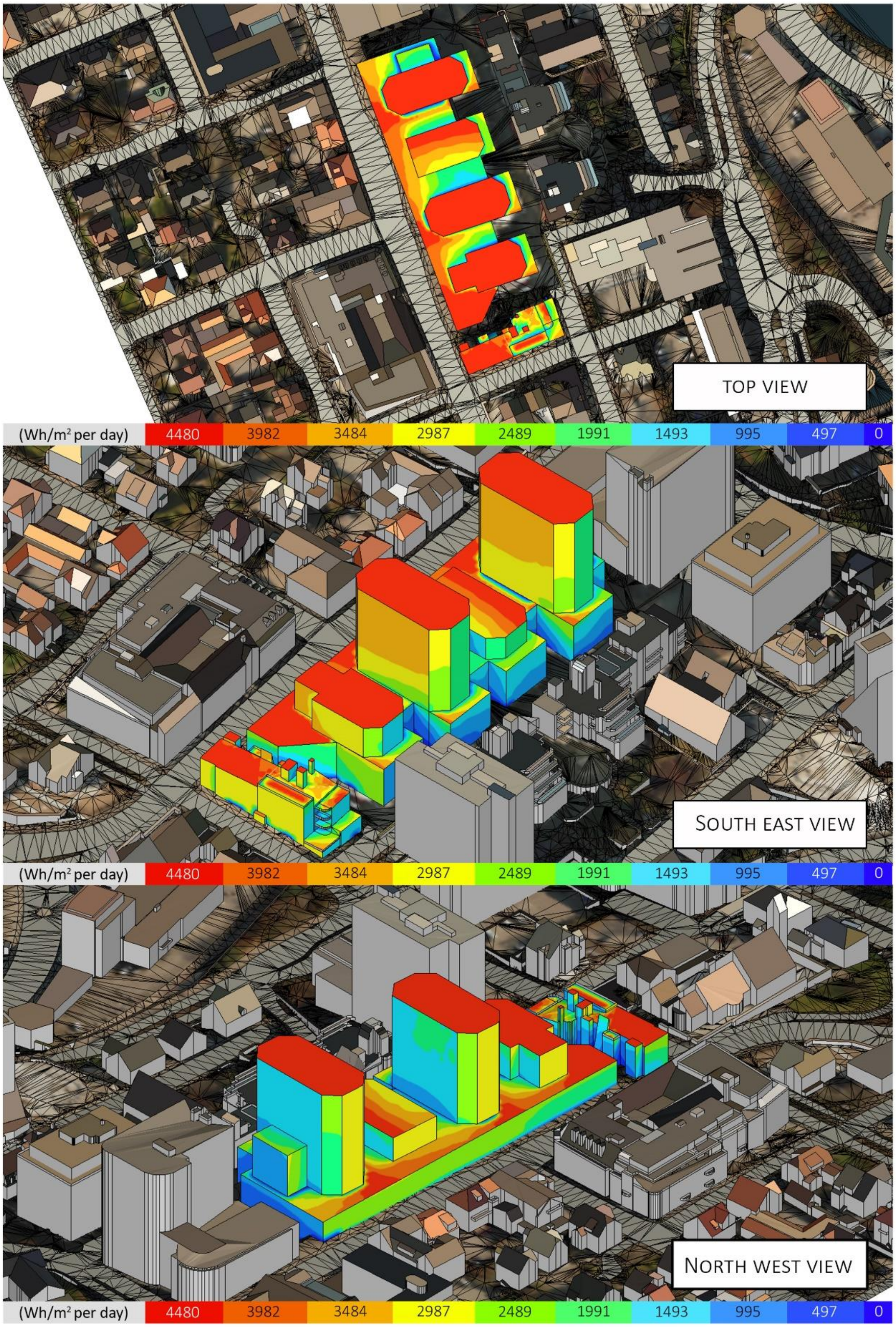
Solar Analysis map:St.Olav Gate , Mar 1 to Mar 31



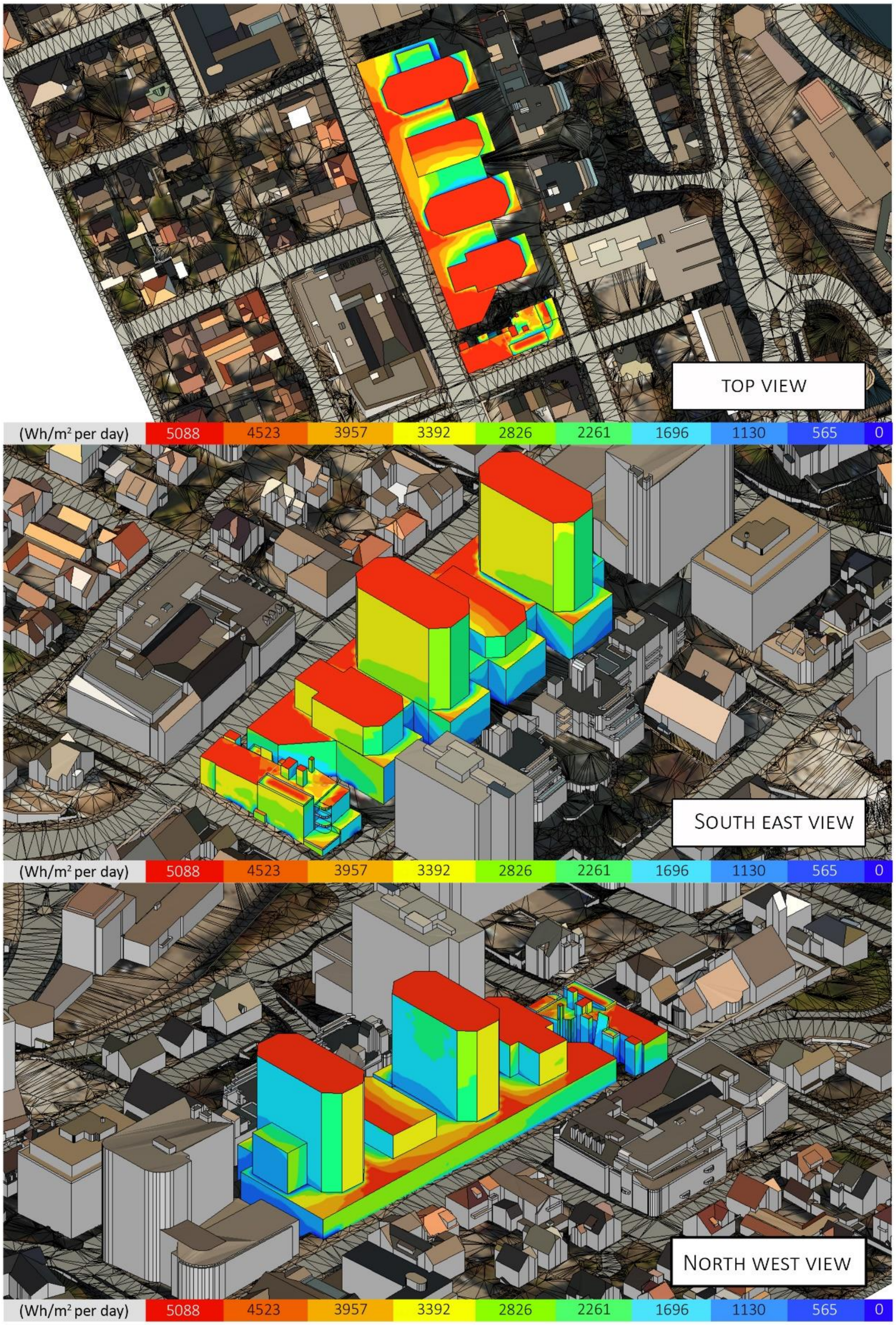
Solar Analysis map:St.Olav Gate , Apr 1 to Apr 30



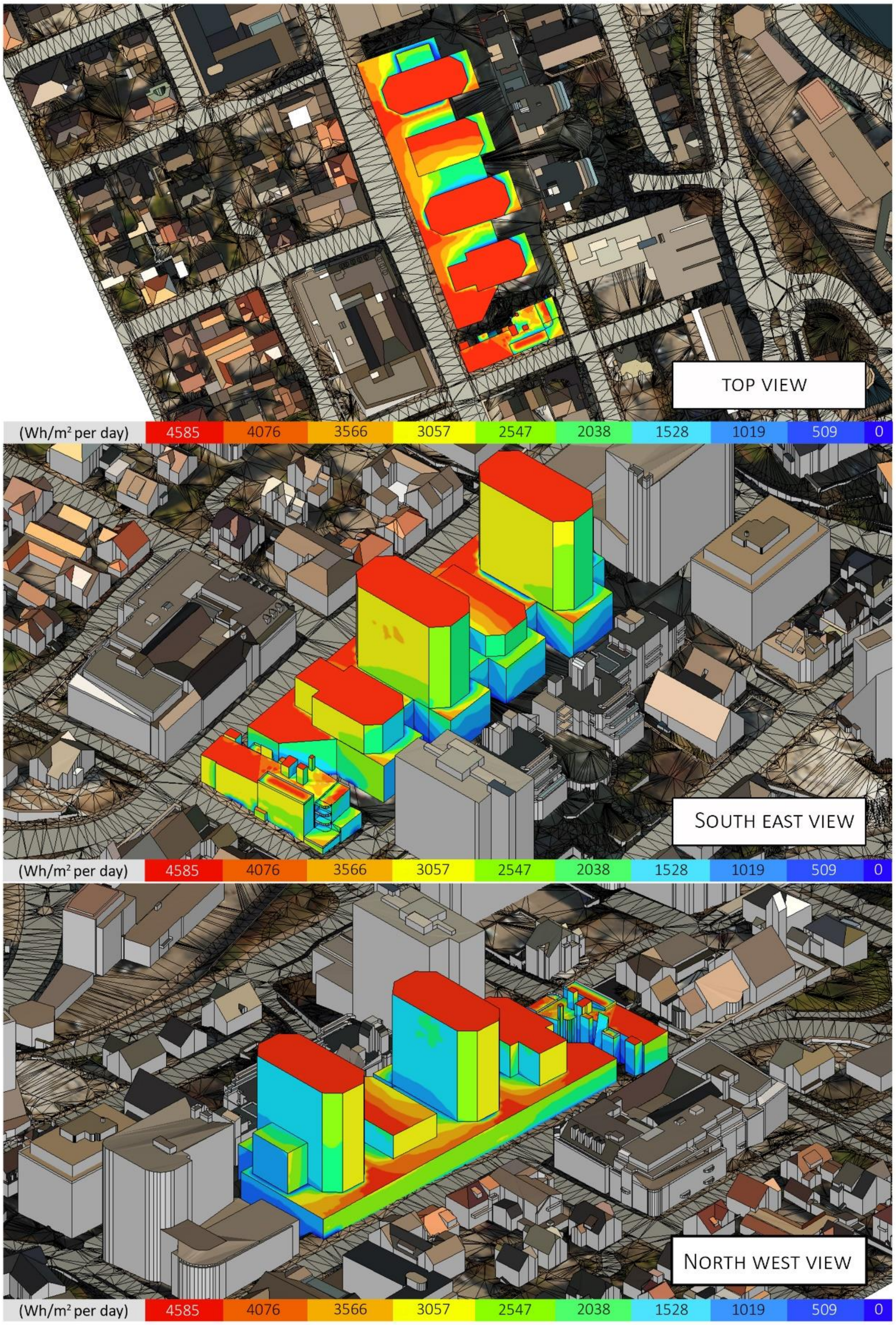
Solar Analysis map:St.Olav Gate , May 1 to May 31



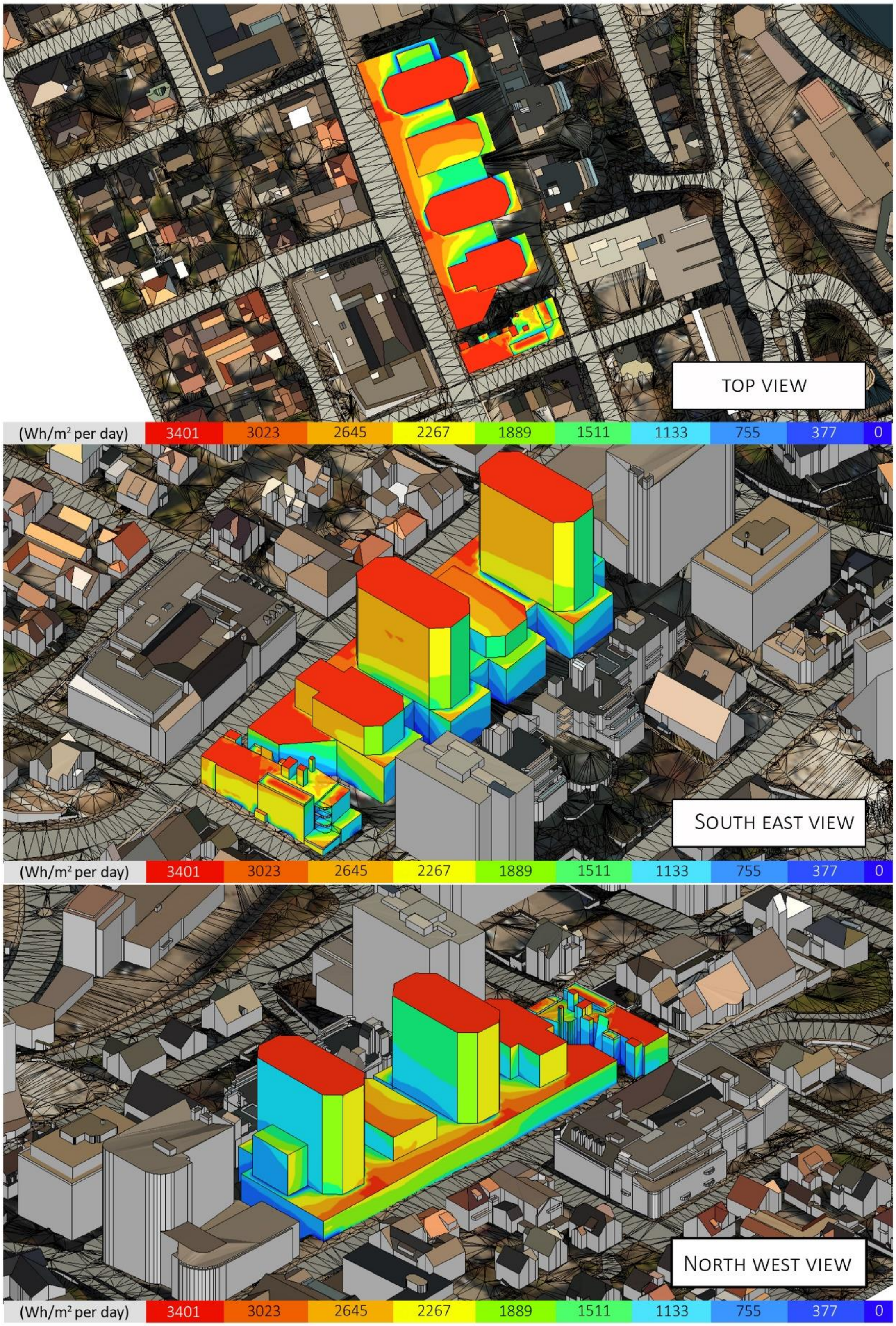
Solar Analysis map:St.Olav Gate , Jun 1 to Jun 30



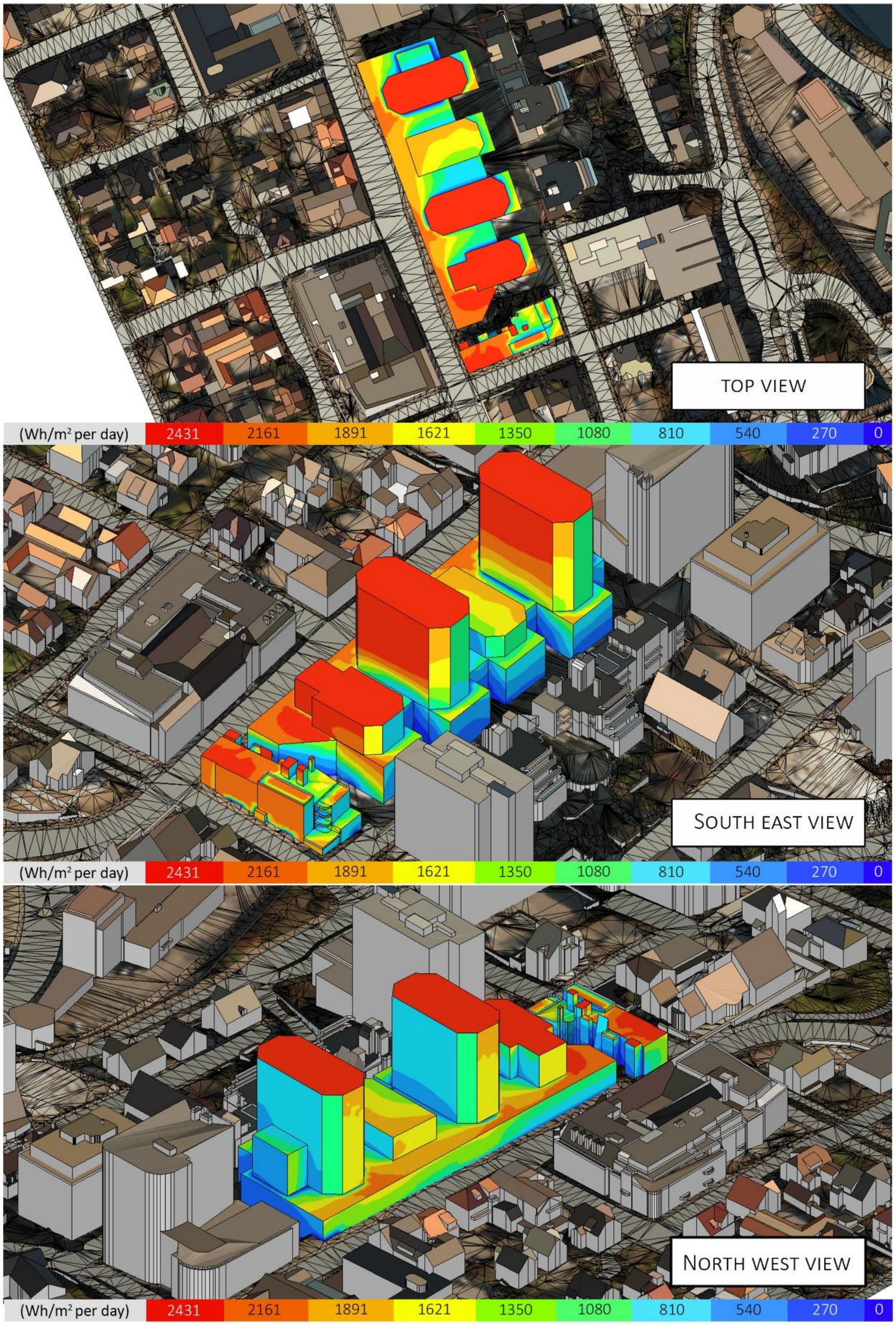
Solar Analysis map:St.Olav Gate , Jul 1 to Jul 31



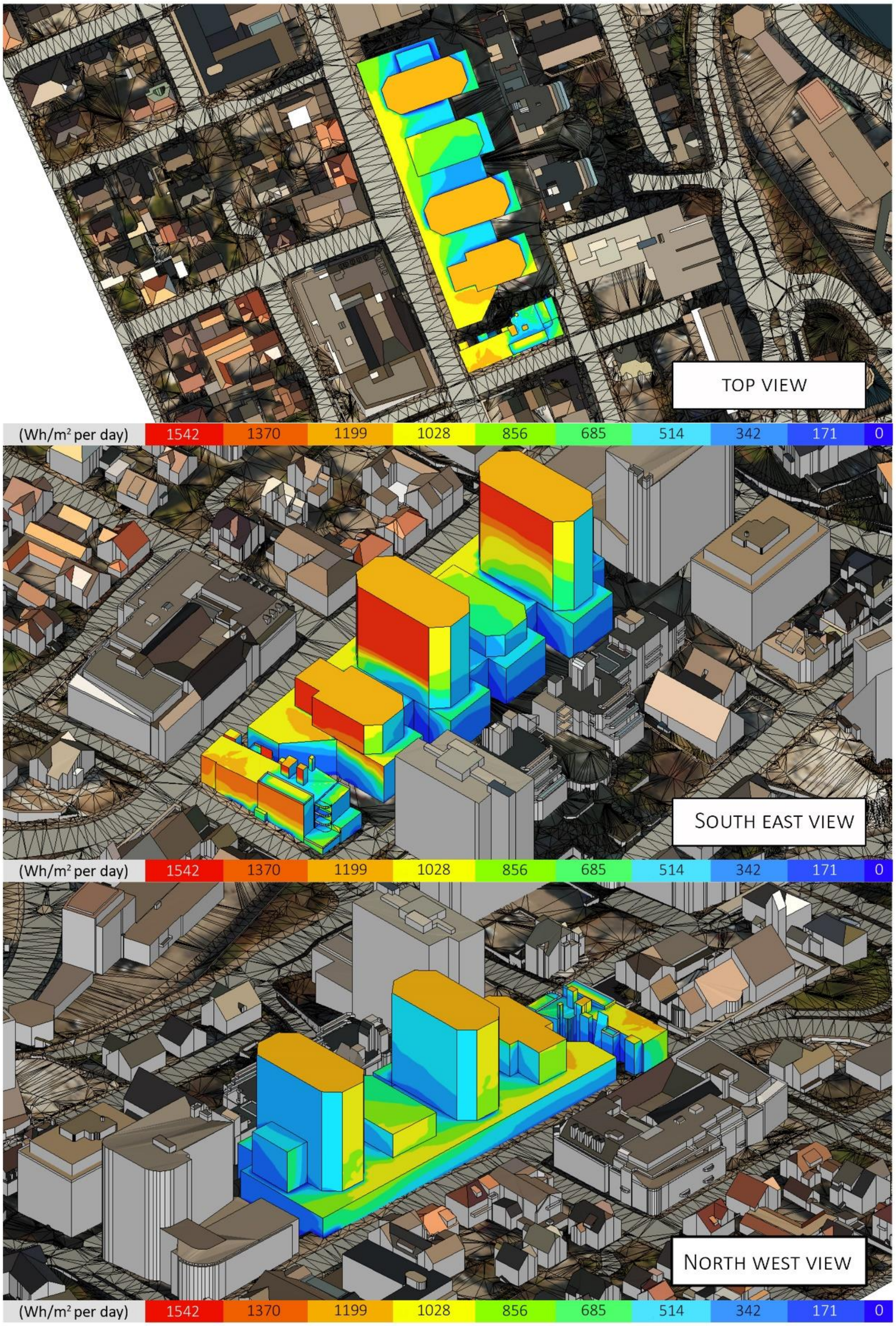
Solar Analysis map:St.Olav Gate , Aug 1 to Aug 31



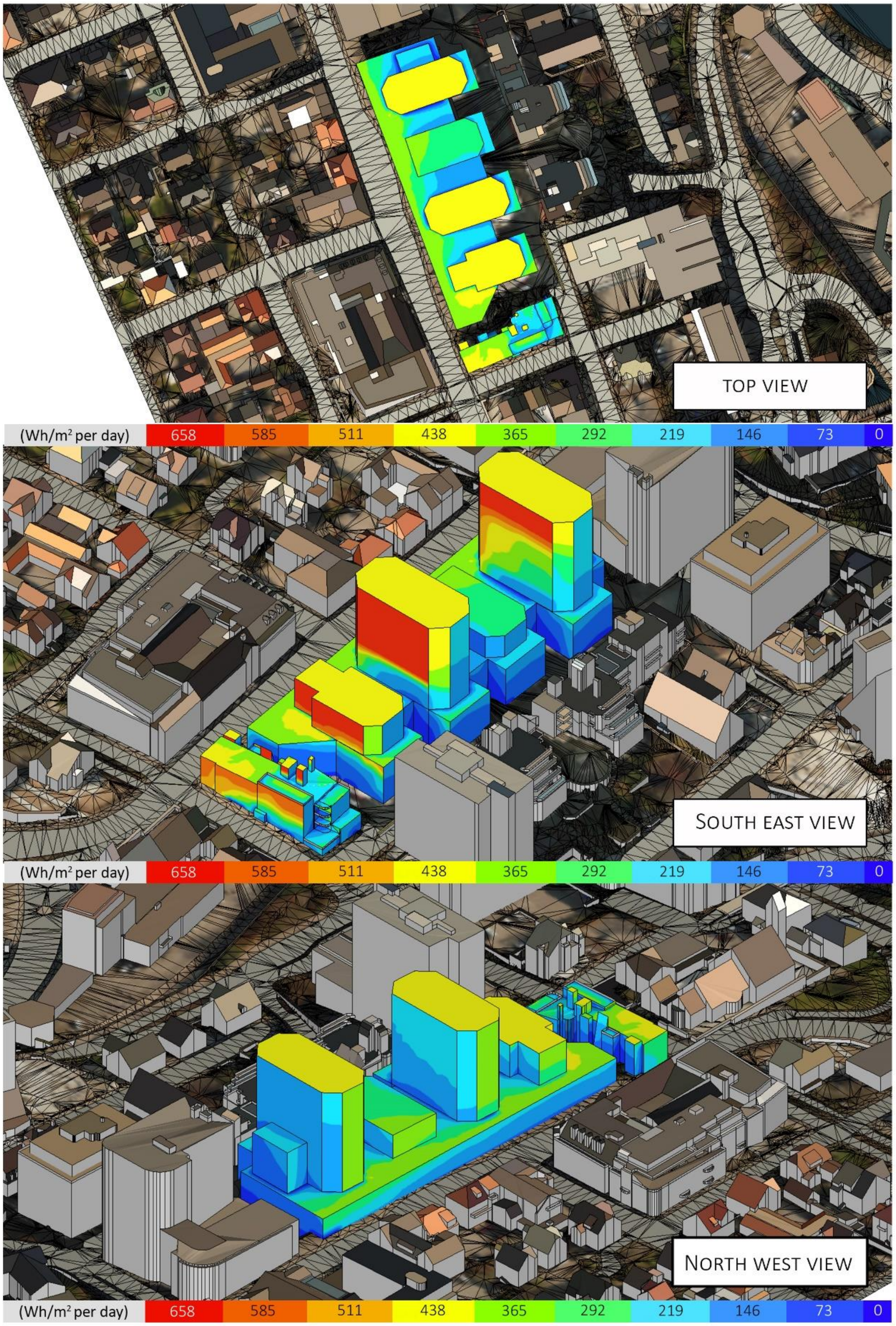
Solar Analysis map:St.Olav Gate , Sep 1 to Sep 30



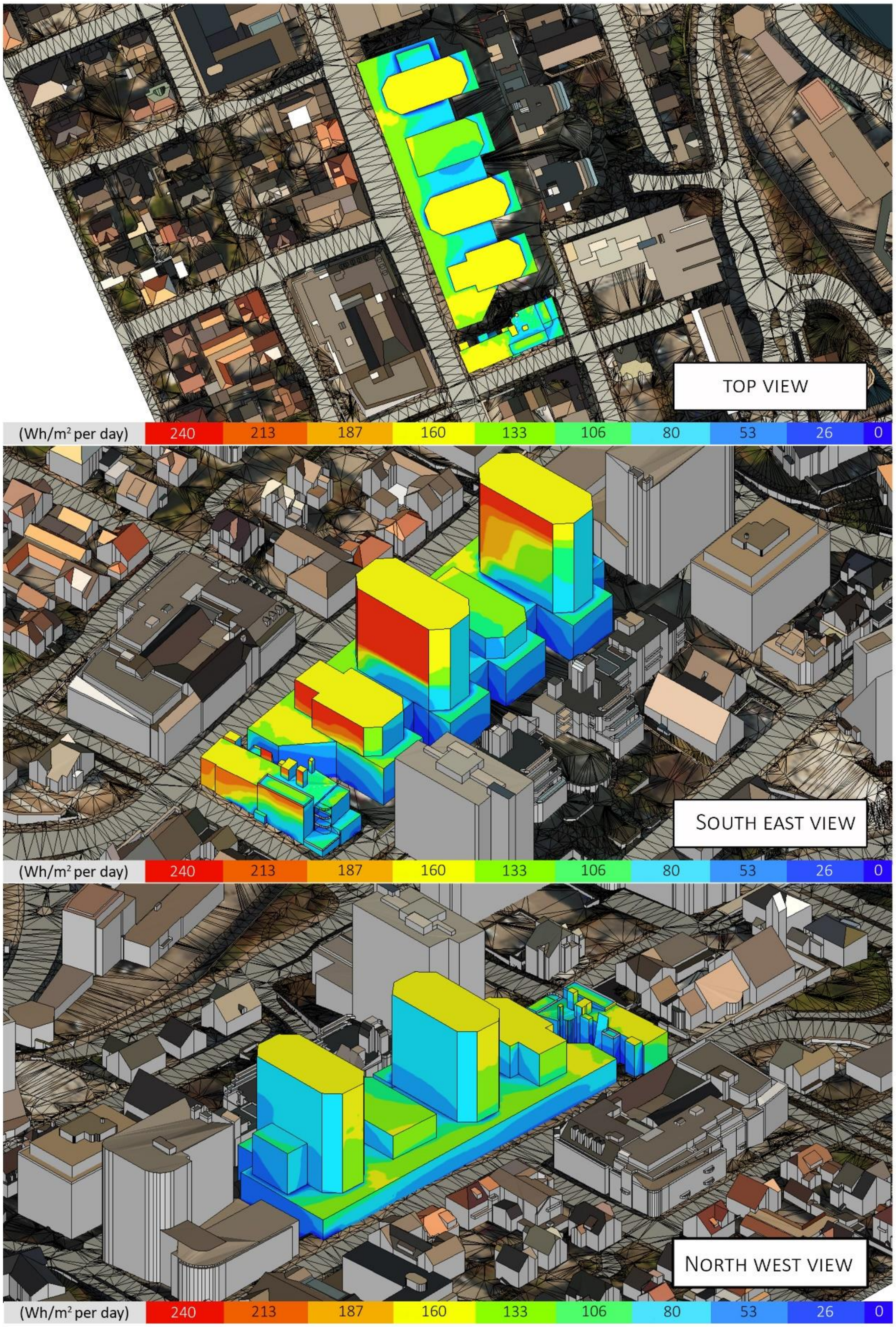
Solar Analysis map:St.Olav Gate , Oct 1 to Oct 31



Solar Analysis map:St.Olav Gate , Nov 1 to Nov 30



Solar Analysis map:St.Olav Gate , Dec 1 to Dec 31



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