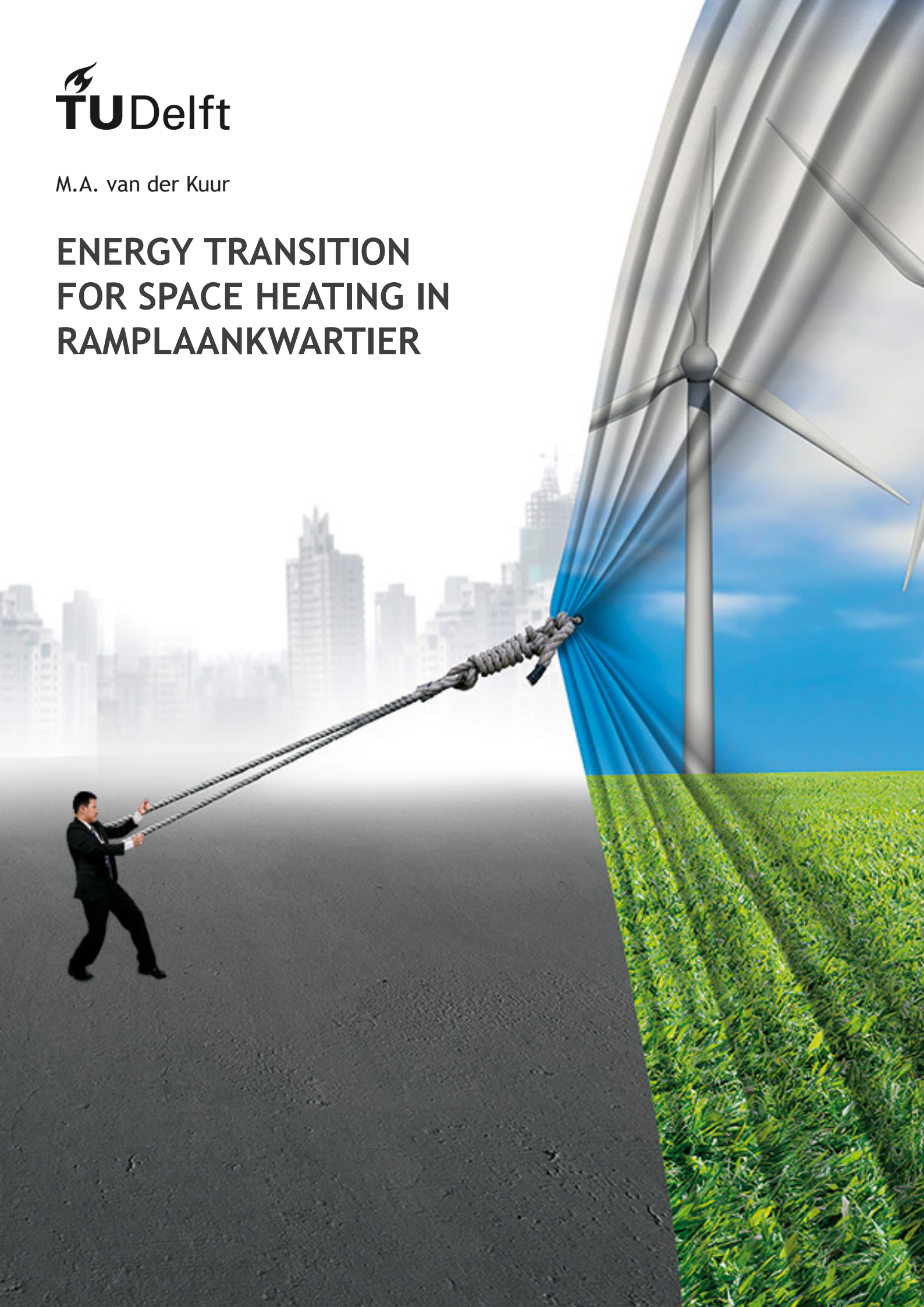
TU Delft

M.A. van der Kuur

ENERGY TRANSITION FOR SPACE HEATING IN RAMPLAANKWARTIER



TU Delft

Energy transition for space heating in Ramplaankwartier

Technical configurations & visualisations of the implementation of a solar powered self- sufficient energy system for space heating in selected urban blocks located in Haarlem.

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(https://www.thesustainablecity.ae/)

PREFACE

Dear reader,

During one of the courses of my master program the concept and necessity of energy storage was brought to my attention. It came as a shock to me that I never heard and thought of this principle before. Immediately the importance of the integration of energy storage in the coming energy transition century came to mind. The interest in the energy transition combined with the growing national importance quickly made me decide my that the subject of my graduation should be about an energy storage integrated energy transition for the current built environment.

In consultation with my first mentor Sabine Jansen, the graduation project focused on creating a renewable self-sufficient energy system for an existing neighborhood in the Dutch city of Haarlem. This neighborhood is used as a case study by the Smart Urban Isle project, of which the TU Delft is a research partner, to research the spatial and energy characteristics of an energy transition performed at different scales. In consultation with second mentor Daniela Maiullari, specialized in urban design, the scale of the energy transition project was demarcated at an urban block scale including 113 buildings.

The amount of newly acquired knowledge during the graduation research is enormous but is only a tip of the iceberg. The importance of more research on related topics is the key for successful energy transition projects and its spatial integration in the existing built environment, is the resulting overarching sense that remains after working on this subject for over a year. The challenges and scale the energy transition brings, made my choice to work and specialize further on this subject after graduation, a convincing, exiting and super challenging choice.

Successfully completing this graduation project would have not been possible without the help of my mentors Sabine & Daniela. Always providing feedback and positively stimulating the process, was an important factor in successfully finishing this project.

ABSTRACT

This research is about the spatial integration of a self-sufficient renewable energy system in selected urban blocks in the neighbourhood Ramplaankwartier in Haarlem, providing the heat demand of the residential buildings located in these selected urban blocks. Solar energy production and thermal energy storage are the selected energy production and storage methods included in this report. These methods are the result of a literature study and its demarcation results. Based on a spatial analysis resulting in energy potentials, ten configurations are set up for the integration of a renewable energy systems. These configurations are divided over three categories with different principles for an energy transition project:

(A) 100% gas replacement using the commonly applied placement of panels on roofs.
(B) 100% gas replacement using an analysis of energy potentials
(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

These ten configuration were assessed on their quantifiable spatial & energy characteristics using a set of selected/modified spatial & energy indicators. Secondly a perceptual analysis was employed on a pilot group of inhabitants during an information night. During a presentation of the configuration results questionnaires were filled in by inhabitants.

The results of the quantifiable and perceptual analysis are compared using the the following criteria: energy potential, spatial impact, inhabitants acceptance, amount of m^2 used energy production panels & necessary additional technologies. The configuration (C.4), using PVT + large scale heat pump + pit thermal energy storage, is the optimal solution of the investigated energy solutions.

Purely based on the energy characteristics replacing 100% of the gas use, the best option would be (combination of configurations C.3 & C.4) using PVT + large scale heat pump + latent thermal energy storage.

If spatial/visual impact in the public space of an energy transition project is not possible or there is an aim for zero spatial/visual impact of stakeholders, then the B.1 or C.2 configuration, using flat-plate collectors + pit thermal energy storage (without covered parking), is the best option.

This thesis hopes to contribute to speeding up the process of energy transition projects, replacing the gas produced heat demand with a renewable produced heat demand, for the existing built environments in the Netherlands.

Keywords: *Solar energy production, thermal energy storage, energy transition, heat pump, gas, heat demand, configurations, energy potentials, selected urban blocks, spatial design, climate change, inhabitants Ramplaankwartier, Haarlem, Netherlands.*

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1 INTRODUCTION

1.1 Background

1.1.1 Underlying problem

With the world running out of fossil fuels and CO_2 emissions (Figure 1.1) increasing the greenhouse effect, the necessity for a transition to a renewable energy supply is growing. The energy transition this century from fossil fuels to renewable recourses in all sectors is unavoidable. The reason why the energy transition is a necessity is simply because the world is running out of fossil fuels. Oil is expected to be depleted first, in approximately in 40 years. The current stock of gas is also expected to be depleted in 40 up to 70 years (Shafiee & Topal, 2009). The predictions about the amount of time there is left before the world runs dry is diverge and opinions of specialists differ. Different calculation models are used to determine the depletion period, resulting in different outcomes (Shafiee & Topal, 2009). The fact remains that the energy management we got used to, will drastically change.



Figure 1.1: *Air pollution due to coal-fired power plants and pollution.*

The total primary energy demand of the Netherlands is 3250 PJ. The total energy demand of residential buildings in the Netherlands is 417,1 PJ, which is mostly caused by the high heat demand of our residential buildings. 71,7% of the total energy demand of the residential buildings (299,2 PJ) is produced using natural gas (RVO Nederland, n.d.). The Dutch government pronounced that a transition of the current energy system towards a sustainable energy self-sufficient system must be achieved in 2050. Solving the transition for our heat production without the use of gas in an earlier stage then 2050 is a big step towards the goals for 2050 (Kamp,2015).

1.1.2 Disadvantages of fossil fuel dependency

Speeding up the process of our energy transition will have significant advantages compared to the scenario where we wait until the world runs out of fossil fuels and an energy transition is forced upon mankind.

Firstly the supply and demand of fossil fuels between countries cause political tensions between countries (Sijmons, 2014). The Dutch dependency on countries like Russia to provide us with gas, increases with the increasing resistance against gas extraction in the province Groningen. This dependability on other countries is not considered desirable.

Secondly fossil fuels speed up the global warming because they emit carbon dioxide when they are burned (Sijmons, 2014). Burning all the currently known fossil fuel stocks will lead to an temperature increase on earth of 5,3 degrees (Sijmons, 2017). Resulting in melting polar caps raising the sea level and extreme droughts creating life-threatening living conditions.

There might be a third argument that can be used to speed up the energy transition process, careful approach and planning. There is still time to find inventive methods for a smoothly transition of our energy system. Carefully using this time to prevent future problems and growing resistance, is advised. A relatively new research field of space and energy integration might provide welcome developments that can contribute to the energy transition process.



Figure 1.2: *(by Noun project)*

1.1.3 Energy transition & spatial inmpact

As a results of the underlying problems & derived goals, the Dutch government has published the “energieagenda” that describes a guideline for the energy transition including the spatial challenges the energy transition brings (Ministerie van economische zaken, 2016). Alternative renewable energy production methods making use of the sun, wind, geothermal wells and biomass are developing in fast speed. Compared to the fossil fuel powered energy system there is an important difference noticeable. Renewable energy production techniques compared to the gas powered energy system, have a spatial footprint and are therefore area dependent (Figure 1.3)(Kelly & Gartland, 2016).

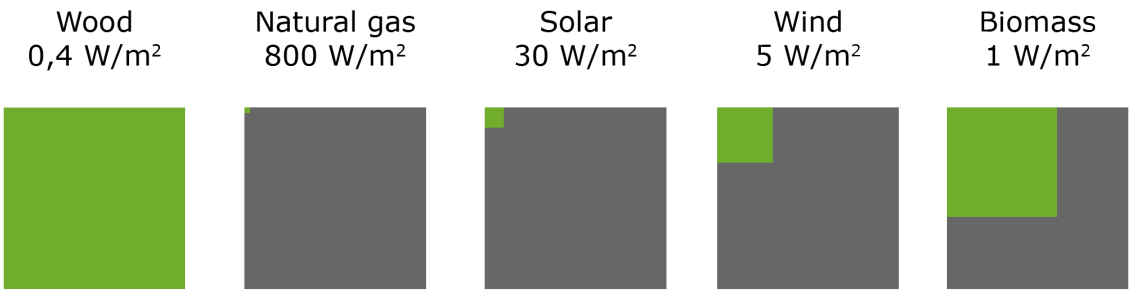


Figure 1.3: *Spatial footprint renewable energy production (Chen, 2013)*

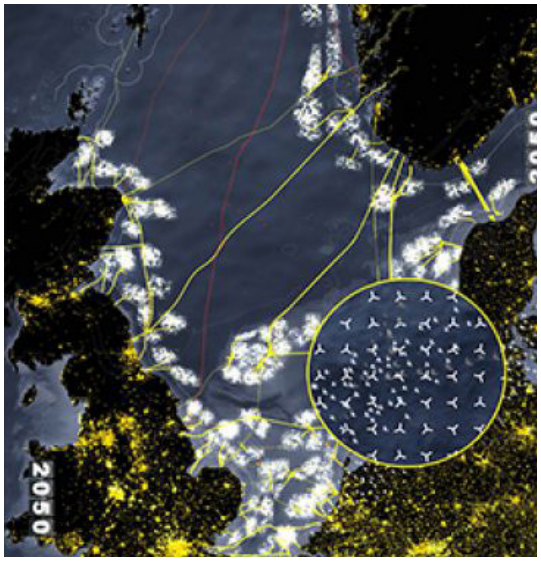


Figure 1.4: *Proposed by IADR energy system in the northsea in 2050 (IADR, 2016)*

1.1.4 Large scale energy transition & spatial impact

Creativity in implementing this large spatial footprint in our world is growing quickly. In the "2050 – an energetic odyssey" made by IADR, the north sea is transformed into a wind farm that will produce the energy demand on land (Figure 1.4). The goal of the visualization research is creating a dialogue and awareness about the immense task the making of sufficient renewable energy production includes. Only placing wind mills in sea is too short sighted, there is also a necessity for transportation and storage (IADR, 2016). On the first hand placing the large spatial footprint in sea seems a smart option because it appears to be a seemingly unused space.

If on sea integration of large scale energy systems already looks like a case of spatial planning between many different actors, imagine what a large task the implementation of renewable energy technologies on land will include.

"But the North Sea is not empty. Our story is set in the most intensively used coastal waters in the world. With fishery and shipping routes cutting right across, it contains designated nature reserves and military zones, oil rigs the size of skyscrapers, countless oil and gas pipelines and there are already several wind farms" (IADR, 2016)

As discussed in 1.1.1, the quickly forgotten characteristic about the energy transition is the fact that heat supply plays a large role in the success of a transition. The electricity demand is much smaller compared to the heat demand, which is not ideal with electrical output most renewable energy production systems provide.

The Dutch government created a start nota that is the first step towards a national environmental vision. This environmental vision researches the use of space for different functions and their integral influence on each other. These results will be used by the Dutch government to determine which policy direction to follow. This vision is of great importance because of the dense living environment and the spatial limitations. The overarching goal of the environmental vision is providing a liveable and healthy living environment (Rijksoverheid, 2017).

1.1.5 Local scale energy transition & spatial impact

Providing the heat demand for our residential buildings needs to be done more locally because the output of a renewable energy system for heating is subject to thermal energy losses. Transporting heat over long distances is ill-advised. Integrating large solar farms on land is already an often used solution to provide cities large percentages of the heat demand in Denmark & Germany, Figure 1.5.

Figure 1.5: *Pit storage, Vojen-Denmark (State of green)*



Renewable energy technologies integrated in our living environment encounters heavy resistance from residents. Visual and spatial deterioration of their living environment is a quick used argument to appeal against the implantation of these technologies around their building. The fact that the energy transition is unavoidable combined with insufficient free space in the Netherlands, creates a new research field combining energy and space. The energy sector providing the necessary technologies and urban planners are tasked with the immense challenge to successfully change our energy system in the dense Dutch built environment.

"Spatial planning and spatial design are therefore of great importance to the energy sector. Conversely, the energy transition will be a huge challenge for administrators, planners and designers. The energy transition is not only a technical challenge but also a landscape challenge, and thus a cultural one. The transition will take place in unison, or otherwise it will not take place at all."
(Sijmons, 2014)

1.2 Research framework

1.2.1 Problem statement

A renewable self-sufficient energy based system for supplying the heat demand for the built environment will consist of renewable energy generation, distribution and storage technologies. The spatial footprint of a renewable powered energy system is much bigger than the existing energy system due to new energy system configurations with technologies needing much more space. Energy production and consumption need to be adjusted to each other leading to more local of energy production, causing changes in our spatial planning. This will result in a new urban design and a different experience of our living environment. The spatial impact of renewable energy systems is often not included in in the analysis of these systems.

1.2.2 Objective

The objective of this research is to explore the technical possibilities of supplying space heating with solar renewable energy and to explore the spatial impact of implementing a self-sufficient renewable energy system for space heating in selected urban blocks in Ramplaankwartier in Haarlem.

1.2.3 Case study description

SUI project

This master thesis contributes to the "smart urban isle" (SUI) project of which the TU Delft is a research partner. The project aims to supply the energy demand using locally produced renewable energy. One of the SUI project case studies is the existing neighbourhood Ramplaankwartier located in Haarlem. The scale of this graduation thesis is the urban scale of a block structure in the neighbourhood Ramplaankwartier located in Haarlem. Ramplaankwartier is a neighbourhood in the Netherlands involved in the research of the SUI project. Further information about the SUI project can be found on the following website: https://jpi-urbaneurope.eu/project/smart-urban-isle/

1.2.4 Reserach questions

Main research question:

How can a renewable self-sufficient energy system for space heating be spatially integrated in selected urban blocks of the neighbourhood Ramplaankwartier?

Sub research questions:

Q1. What is the current state of a renewable energy supply for the built environment and which technologies and systems are relevant for this study?

- **(Q1.1)** What are the current developments in the energy transition of the built environment?
- **(Q1.2)** What are the relevant technologies for a solar based energy system supplying space heating & domestic hot water?
- **(Q1.3)** Which reference projects are related to this graduation thesis and what are its characteristics?

Q2. What information on the case study area is needed for the development of an energy system (technical configuration design) and what are their values/properties?

- **(Q2.1)** What is the current average energy label and average heat demand for space heating and domestic hot water?
- **(Q2.2)** What are the spatial characteristics of the selected urban blocks which are relevant for the implementation of renewable energy generation and storage?
- **(Q2.3)** What are the weather conditions in Ramplaankwartier?
- **(Q2.4)** What is the view of the inhabitants on the land use of their living enviroment and what is their view on the implementation of renewable energy production technologies.

Q3. What is the heat demand and what are the energy potentials for the new self-sufficient energy system?

- **(Q3.1)** What is the heat demand that needs to be supplied for the selected urban blocks in Ramplaankwartier after feasible renovations?
- **(Q3.2)** How can the energy and spatial characteristics of relevant technologies be calculated?
- **(Q3.3)** What are the energy potentials based on the spatial characteristics of the selected urban blocks in Ramplaankwartier?

Q4. Which indicators can be used to assess the performance of the new self-sufficient energy system and its spatial impact?

- **(Q4.1)** Which spatial indicators can be used for the assessment?
- **(Q4.2)** Which energy indicators can be used for the assessment?

Q5. Which renewable energy based configurations with different ambitions can be developed for the selected urban blocks and what could their energy performance be?

- **(Q5.1)** Which energy system configurations (using commonly applied placement of panels) are possible that could cover the full heat demand with solar produced heat, using the commonly applied placement of panels on roofs and how could they be spatially integrated?
- **(Q5.2)** Which energy system configurations (using the analysis results of the spatial impact of renewable technologies, chapter 4) are possible that could cover the full heat demand with solar produced heat and how could they be spatially integrated?
- **(Q5.3)** What are the energy potentials with minor spatial impact & the inhabitants interests and wishes for an energy transition in their neighbourhood. Which energy system configurations are possible making use of these potentials & whishes and how could they be spatially integrated?

Q6. How do the energy systems, including spatial integration, perform on the defined indicators?

Q7. Which general conclusions/guidelines for other Dutch neighbourhoods can be extracted from this research?

1.2.5 Methodology

Overview methodology
The method of the study consists of, see Figure 1.6:

Chapter 2: Literature review & questionnaire inhabitants

Chapter 3: Case study analysis based on existing studies and research. (Jansen, 2011& SUI porject)

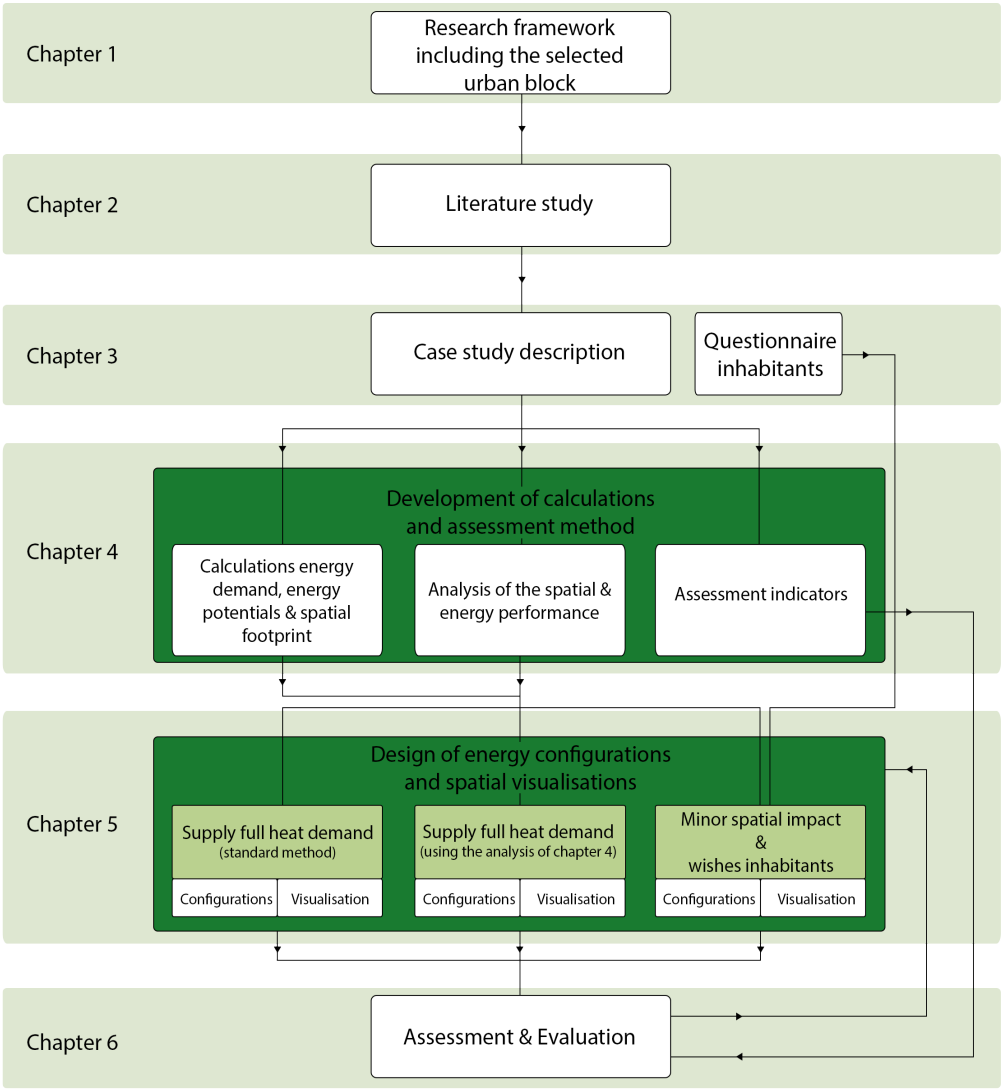
Chapter 4:

- Development of calculations for energy potentials and the spatial footprint of technologies, based on the performed literature study and case study analysis.
- Analysis of the spatial and energy performance of renewable technologies in the selected urban blocks.
- Development of an assessment method meant for the configuration(s) and visualisation(s) outcome, based on the performed literature study and case study analysis.

Chapter 5: Design by research: Development of potential energy configurations and their spatial footprint visualisations for three approaches *(Q5.1, Q5.2, Q5.3)*.

Chapter 6: Assessment & evaluation

Figure 1.6: *Overview methodology (by Author)*



1.2.6 Relevance

Societal relevance

- Contribute in the research searching for a smart and innovative renewable energy system, with a specified footprint and spatial visualisations as added value.
- Contribute to the energy transition by exploring the potential energy configurations supplying the heat demand and supplement these configurations with a visualisation of the spatial impact they could have if they are integrated in existing built environment.

Scientific relevance

- Contribute to the smart urban isle project with visually worked out examples of the implementations of a renewable energy system in an existing built environment. Hopefully acting as a next step towards the execution phase of the energy transition of our total energy system in the Netherlands.

1.2.7 Preconditions

The most important precondition of this research if making the new energy systems self-sufficient. No energy originating from outside the neighbourhood will be integrated in the new energy system integrated in the selected area. Secondly the energy will be stored inside the selected area of the neighbourhood. The spatial characteristics of existing neighbourhoods differ, resulting in a different dimensioned renewable energy system that should be integrated. For some neighbourhoods external energy sources are available that could be beneficial for the spatial impact of integration of a renewable energy system. If an external energy source was used in this research the research result would not be applicable on other neighbourhoods without this energy source available. Therefore designing a self-sufficient energy system is an important principle of this research.

This research does not pretend to be complete or fully correct on all aspects of these energy systems, since many simplifications have been assumed. (for example, using the same mean temperature during the entire summer, while in fact the average temperature in the solar thermal panels will be higher near the end of the summer, since then the pit storage will have heated up and the return temperature will not be 10 degrees

Constraints

- This research will only focus on the heat demand of the existing buildings.
- The research will not focus on redesigning buildings in Ramplaankwartier to achieve a reduction of the heat demand. An estimated renovation potential will be used to reduce the heat demand to a future predicted level.
- The gas demand of the buildings in Ramplaankwartier is adapted to the upgraded energy label B & C. The upgrade of the energy label will prevent an unrealistic configuration outcome that is dimensioned for an outdated gas demand. In the coming years it is highly likely that an upgrade of the energy label of Dutch buildings is forced by legislation of the Dutch government.

1.3 Outline

The sub research questions are divided over the following chapters, Figure 1.7.

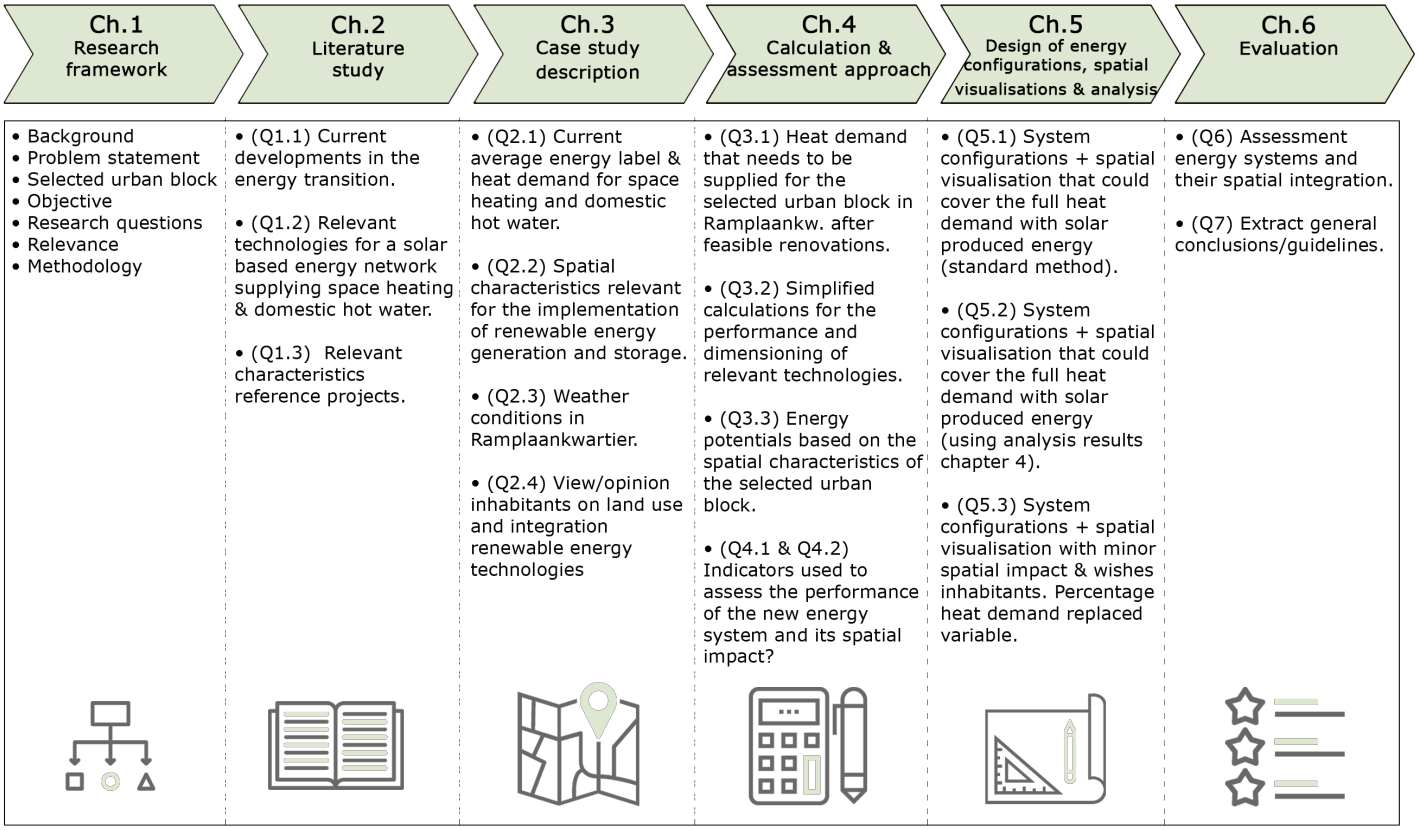


Figure 1.7: *Division research question per chapter (by Author)*

Selected urban blocks
Three different approaches for an energy transition for space heating will be developed as technical configurations and spatial visualisations on an existing selected urban blocks. The configuration and visualisation results will be evaluated using set up indicators enabling the possibility to compare both outcome results.

(Q5.1) Implementation measurems to supply the full heat demand of the buildings using the commonly *applied placement of panels on roofs.*
(All configurations named ***A****.)*

This approach will make use of the technical properties of the available technologies to reach a total reduction of the gas powered heat demand. The necessary area, volume and systems that need to be integrated in the built environment to reach a full gas reduction will be determined during the set-up of the configuration. The spatial visualisation will be a results of this determined set of requirements that needs to be integrated. The placement and integration of renewable technologies will be done using the most commonly used procedures. **Example:** A building will therefore not be refurbished but technologies will be placed on the existing roofs. This approach of the energy transition from a determined gas reduction goal and the spatial and visual interventions to the built environment are subordinate to this.

(Q5.2) *Implementation measures to supply the full heat demand using the energy & spatial analysis of the selected urban blocks (Ch. 4) (All configurations named **B**.)*

This approach will use the results of the analysis done in chapter 4.6. Chapter 4 will provide a comparison of different energy potentials in private and public areas. Several configuration set ups are used for buildings, private areas and public areas. **Example:** For every building typology the following configurations are analysed; minimal visual impact, commonly applied placement of panels on roofs, extension buildings, partly refurbished roof & totally refurbished roof. The comparison of these results will be used to provide the full heat demand of the selected urban blocks.

*(Q5.3)Configurations aiming for minor spatial impact on the selected urban blocks concerning the wishes of inhabitants.(All configurations named **C**.)*

This approach will use the defined energy potentials and heat demand to find matches and opportunities to set-up the configuration. The goal is not to reduce as much gas as possible for space heating but keep negative spatial interventions as minor as possible by using the findings of matching the energy potentials with the demand. Spatial characteristics of the built environment that can be considered added value, are safeguarded or improved. The inhabitants are asked which characteristics of the selected urban blocks they value and what their view on the implementation of renewable technologies is. Based on these results the implementation of more renewable technologies, then the amount causing minor visual impact, could be overruled. The percentage of gas reduction possible is subordinate to this.

2 LITERATURE STUDY

2.1 Current energy transition developments

2.1.1 Overal goal energy transition

In 2015 almost all countries worldwide adopted the first universal & legally binding agreement to reduce climate change and its effects. After the Paris agreements the energy transition process will be accelerated in the coming 35 years. Most countries of the world agreed on limiting climate change and develop sustainable growth. These agreements combined with rising investments and reduced cost in renewable energy technologies, are clear indications that we currently live in the energy transition century (IEA & IRENA, 2017).

The countries bound to the Paris agreement agreed upon a maximum global temperature rise of 2 degrees in 2050 in order to reverse the climate change process. To successfully achieve this goal the international energy agency (IEA) & the international renewable energy agency (IRENA) developed various scenarios to reach 85% reduction of the global carbon-dioxide emissions (IEA & IRENA, 2017). Energy efficiency measurements and renewable energy production might potentially achieve 90% carbon-dioxide reductions. The other estimated 10% could be done by carbon capture and storage (CCS) and fossil fuel switching. This scenario assumes nuclear power is not increased towards 2050, in the following diagram the use of nuclear power is extended in the coming 35 years (Figure 2.1).

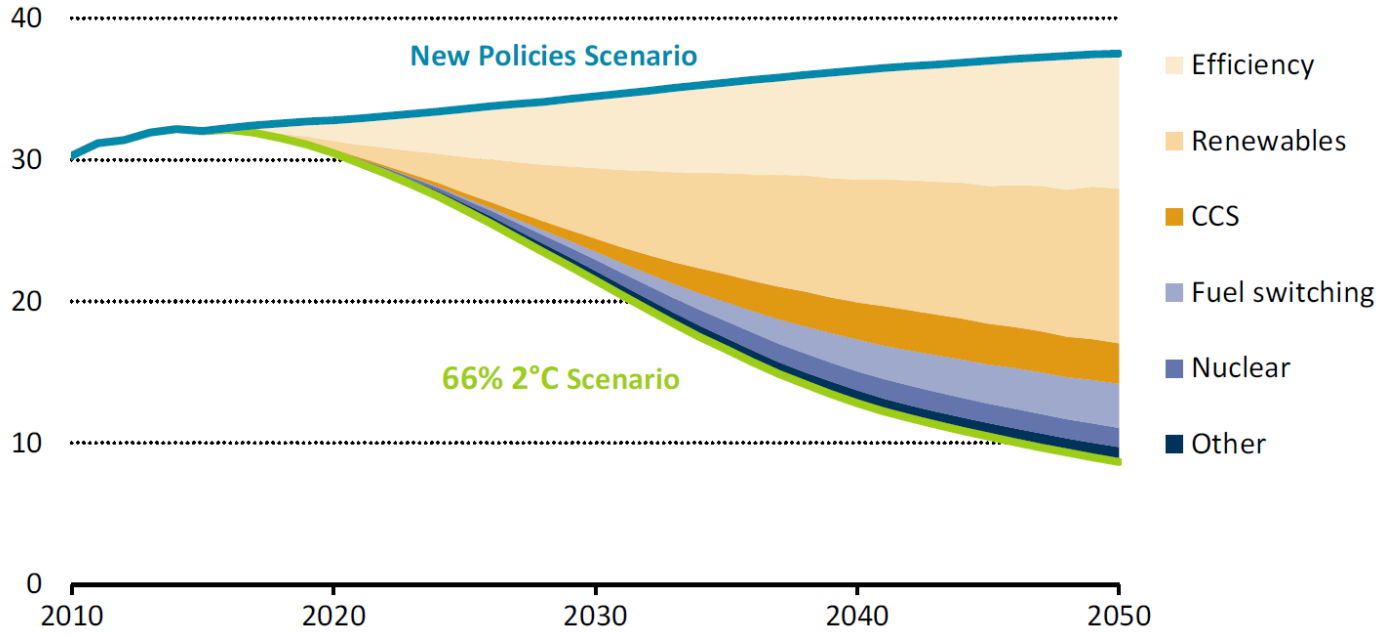


Figure 2.1: *The implications for the energy sector of the NDCs of the Paris Agreement.* (IEA & IRENA, 2017)

In the Netherlands the energy demand can be divided over the following energy industries, Figure 2.2. Every sector causing carbon dioxide emissions will be involved in the energy transition in order to reach the goals of the Paris agreements. For this graduation thesis the main point of interest is the energy usage of residential buildings in the Netherlands.

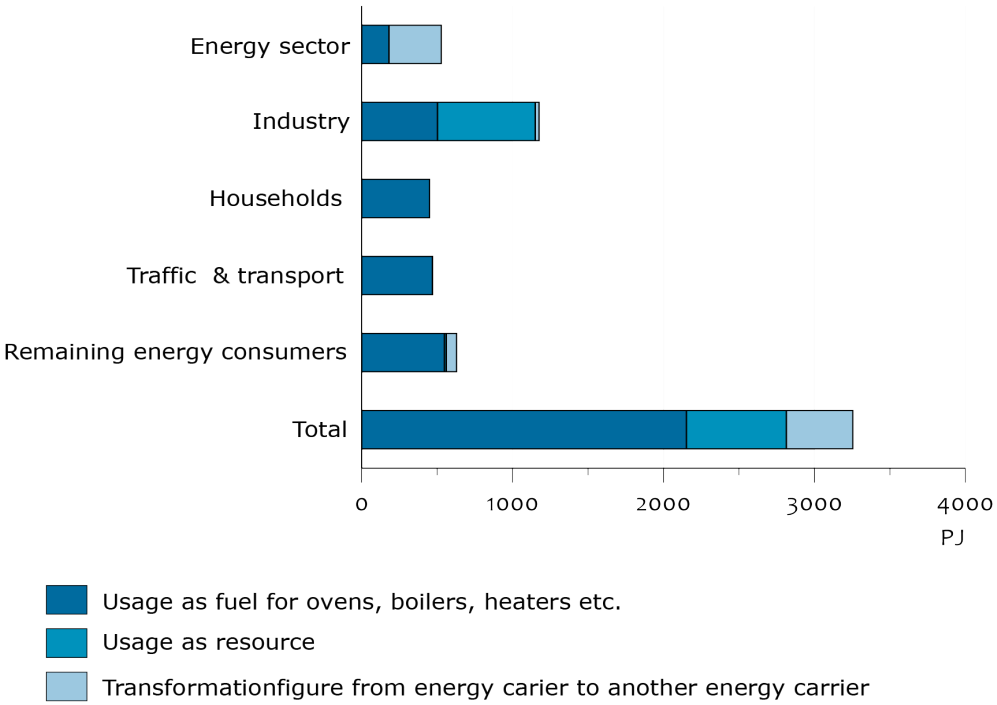


Figure 2.2: *Primary energy use per sector.(Compendium voor de Leefomgeving, 2014)*

Figure 2.2 showed the energy share residential buildings in the Netherlands have compared to the the total primary energy consumption of the country. An estimated 1/6 of the energy usage is caused by residential buildings.

In 2015 only 5,79 percent of the national energy demand was produced using renewable resources. This renewable energy was produced using different methods, see Figure 2.3. In 2020 the share of renewable produced energy should be 16% to achieve the goals from the Paris agreement (CBS, 2015).

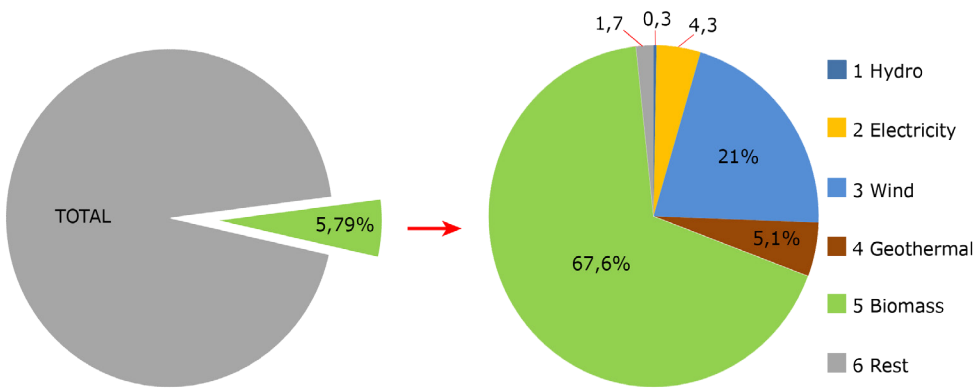


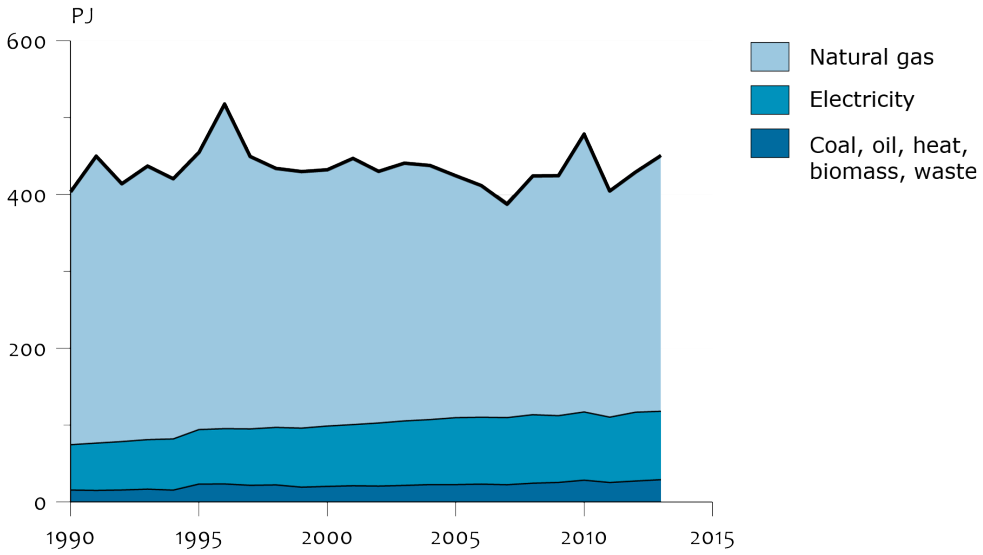
Figure 2.3: *Share renewable produced energy resources. (by Author)*

Share energy use buildings visisble in Fig 2.2.

Energy use of residential buildings
The energy demand for residential buildings located in the Netherlands consists mostly of a large heat demand. The large amount of natural gas usage in Dutch residential buildings indicates the large percentage of energy usage for space heating and domestic hot water. Improving the energy efficiency of residential buildings will reduce the heat demand, but in addition a large share of this heat demand must be supplied by another resource than natural gas Figure 2.4.

Hydro, solar, wind, biomass and geothermal energy sources are quickly developing and they get more exploited every year. On the long run they will have to fully replace the use of natural gas for space heating, if we want to keep our comfort level the same as it is right now, while reducing gas use.

Figure 2.4: *Origen energy demand of the residential buildings in the Netherlands. (Compendium voor de Leefomgeving, 2014)*



2.1.2 Process of the transition towards an energy neutral built environment.
The development of our building sectors aim to make new buildings that are energy neutral. For our existing built environment the aim should be to come as close to energy neutrality as possible with renovating the existing built environment. The idea is to balance the energy demand with a renewable produced energy supply. The overarching goal of this transition is the supply of our energy demand without causing carbon dioxide emissions. The major size of this issue and amount of actors & topics involved in this process is difficult to understand and describe. A document “Energieagenda” was published by the Dutch government with their approach & ambitions for the energy transition. This can be used as support by all actors & industries involved in energy transition projects.

According to research done by N. Soares et al., the research related to the change of the current built environment towards a more sustainable built environment can be sub divided in twelve major topics that will have a significant share in solving this immense issue. The topics are illustrated in Figure 2.5. The diagram shows twelve subjects/research fields that could improve the environmental impact of buildings or developments of new solutions (Soares et al., 2017).

Energieagenda: https://www.rijksoverheid.nl/documenten/rapporten/2016/12/07/ea

This research is related to the following topics performed on the selected urban blocks scale:

- Urban planning
- District scale nearly zero energy buildings (NZEBs)
- Smart grid scenarios
- Thermal storage with phase change materials (PCMs)
- The importance of improving the use of renewables
- The importance of end-users behaviour and the energy saving potential in buildings.

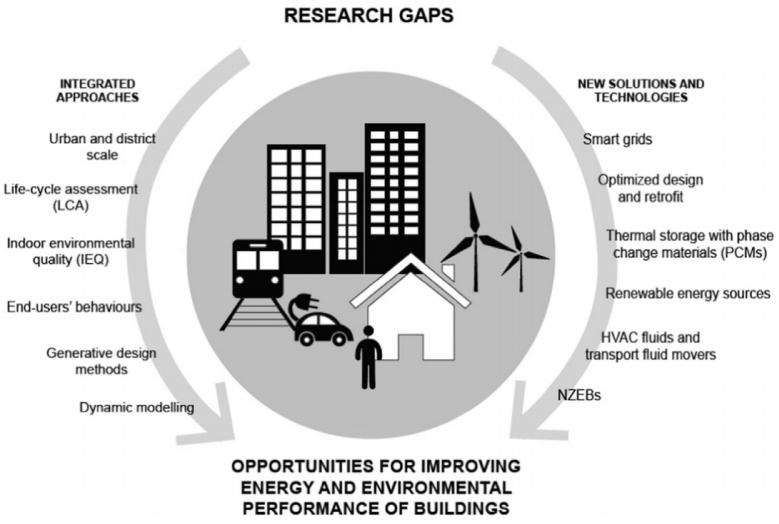


Figure 2.5: *Main research topics energy transitioning built environment. (Soares et al., 2017)*

The most important topic in this thesis is the integration of urban planning in the energy transition. The urban planning research field is the overarching area of research that organises the land use for all possible purposes. The renewable energy systems and their spatial footprint will play a much more important role in urban planning than it did before the energy transition. The energy transition projects are shifting more to the urban scale application, in order to speed up the energy transition of the built environment and apply all developments done on single building on a larger scale. Soares et al. conclude in their paper that further research on design, location and local urban characteristics is necessary to inform decision-making actors in a better way.

The energy transition is not only a challenge for the energy sector and manufactures of renewable energy production methods. Renewable energy production techniques compared to the gas powered energy system, have a spatial footprint and are there for area dependent (Kelly & Gartland, 2016).

This feature stands in total contrast to our current energy system that is mostly invisible for the eye. Dirk Sijmons describes the visibility of our current energy system as a plume of smoke on the horizon combined with electricity pylons (Sijmons, 2014). The origin of our oil, coal or gas that is used in our energy supply, is irrelevant. The energy transition changes this aspect because the distance between energy production and energy consumption is nearly reduced to zero because many renewable resources will be decentralized to prevent large amounts of energy losses. A change of our urban environment is the consequence of these inevitable features leading to an immense challenge for actors involved in urban planning of our existing built environment.

2.2 Reduction of the existing heat demand of residential buildings.

Parallel to the replacement of fossil fuels by renewable resources providing the energy demand of our built environment is the reduction of the energy demand of our buildings. Technical innovations and the implementation of smart systems are important building developments that reduce the energy demand of our buildings. By renovating buildings and improving their insulation, the heat demand of existing buildings is reduced. 40 organisations (public and private) led by the SER (sociaal-economische raad) agreed in an energy agreement on an energy reduction of 100 PJ for the existing buildings . A system currently used in the Netherlands to indicate the energy usage of residential buildings, is the energy label system. (SER, 2013)

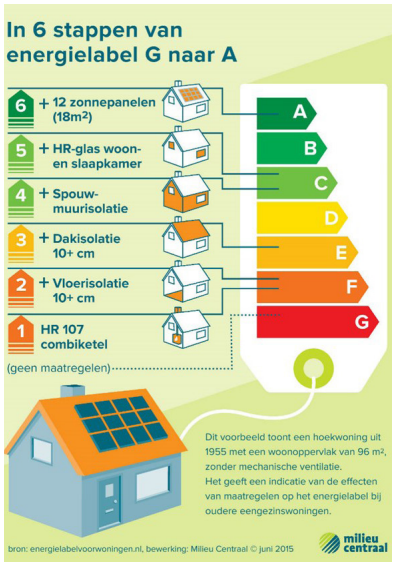


Figure 2.6: *Options to improve the energy label of house build in 1955 (Mileucentraal, 2015)*

Energy label

An estimated amount of 80% of the private rental houses in the Netherlands will have an energy label of C or better in 2020 (Spies, 2012). Secondly the aim in the energy agreement is to renovate 300.000 residential buildings and update them two energy labels. The overarching goal is to upgrade all buildings to energy label A in 2030 (if technically possible). For this case study we are assuming that the private owned buildings, which have a low rated energy label, will be upgraded to a future demanded energy label (Ch. 4.) (SER, 2013). Improving the insulation value of these residential buildings is an obvious intervention that can improve the energy label of outdated building substantially Taking all measurements for residential buildings in Ramplaankwartier will lead to energy label C.

Research about the theoretical and actual gas use of Dutch residential buildings, illustrates the difference in gas use of residential buildings with different energy labels. Figure 2.7 displays an estimated difference of 200 m3 gas usage between energy labels D (1500 m^3) and C (1300 m^3). The graph shows the energy labels plotted against the gas consumption in m3 (Figure 2.7)(Itard, Majcen, & Visscher, 2013).

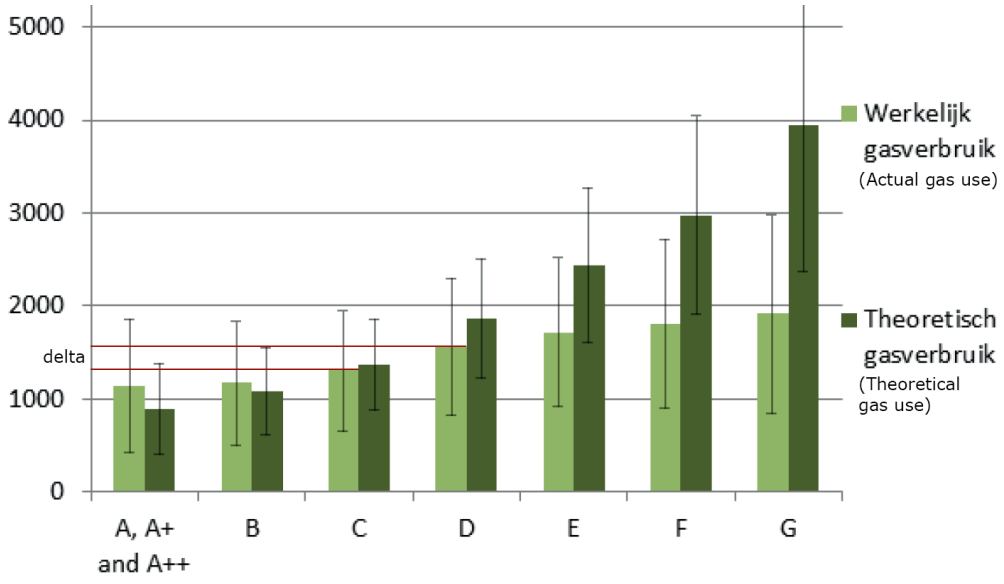


Figure 2.7: *Actual average gas consumption amounts compared with energy labels (Itard et al., 2013)*

2.3 Renewable energy systems introduction & overview.

This paragraph will provide a quick overview of the most commonly known renewable technologies & techniques. Firstly the renewable energy sources will be discussed. Secondly technologies are discussed that could convert electricity into heat. These technologies will play an important role in the configuration designs of chapter 6 because this research only focusses on providing the heat demand, and therefore produced electricity must be converted into heat. Thirdly an overview of the available energy storage technologies/techniques is explained. The last part of this paragraph is used to describe distribution technologies necessary to transport energy to the residential buildings. This paragraph is used to make a first selection of technologies/techniques that will be used in the configuration designs.

2.3.1 Renewable energy sources

Solar energy (focus of this thesis) *(*Figure 2.8*)*
Solar energy is an energy flow coming from the sun transformed into usable energy on earth. *"The total annual solar radiation falling on the earth is more than 7500 times the world's total annual primary energy consumption of 450 EJ"* according to World Energy Council, 2013. In the year 2011 not even 10% of the global energy demand was produced using this technology. Due to the energy transition towards renewable resources, the global solar energy share of the total produced energy on earth is predicted to significantly increase the coming decades. The best known technique to harness the suns power is the solar panel (photovoltaic cells). This technique is used to produce electricity. Secondly the power of the sun can be used to produce energy as thermal heat (National geograpahic, n.d.). Solar energy technologies are further explained in chapter 2.4 .


Figure 2.8: *Solar energy*

Wind energy *(*Figure 2.9*)*
The harvesting of the wind flow on earth into energy is called wind energy or wind power. Heating of the sun, earth's morphology & the spinning of the earth causes a wind flow. Technologies such as wind turbines catch this wind motion, which causes blades to spin, and transform it into mechanical energy. This mechanical energy can be transformed into electricity using a generator. Wind produced energy also has it's downsides, noise and aesthetic impact is a many heard complain from people living close to wind turbines. Wind turbines are therefore mostly placed in open spaces away from dense living environments (Wind Energy Development Programmatic EIS, n.d.).


Figure 2.9: *Wind energy*

Hydropower *(*Figure 2.10*)*
Using the created motion, which gravity of falling water causes, as a source to create electricity is a long existing method to produce energy or motion. In this process the kinetic energy is transformed into electricity. This method is currently used in 159 countries and representing the largest share of produced energy in the total renewable produced energy sector. Hydropower is considered the most reliable renewable energy resource because of the consistent supply. The morphology of the landscape is a crucial factor in the feasibility of hydropower in countries. Disadvantages of hydropower are the high capital costs and the length of the production process of these big technologies (Wagner, Hauer, Schoder, & Habersack, 2017).


Figure 2.10: *Hydropower*

Geothermal energy *(*Figure 2.11*)*
Using the high temperature of the earth crust to produce energy is called geothermal energy. The closer to the earth's core you get the higher the temperature gets. Using a medium that is ideal for energy-bearing, the temperature of the core gets used to transport thermal heat to the surface. This thermal heat can be used directly used or can be used to produce electricity, for example steam generators. This technique is dependent on the presence of geothermal sources close by the surface in order to make it financial feasible. Currently 78 countries in the world are making use of geothermal wells to produce energy (Toth & Bobok, 2016).


Figure 2.11: *Geothermal energy*


Figure 2.12:*Biomass*

Biomass energy *(*Figure 2.12*)*
The burning of organic matter, for example plants, creates energy that can be harvested to produce thermal heat or electricity. The principle is the same as the burning of fossil fuels. Biomass and fossil fuels both emit carbon dioxide during the process. However during the growing process of these plants they absorb carbon dioxide and therefore biomass is considered a much better solution as fossil fuels. The growing process of the plants takes 20-30 years, making the feasibility in the future and the development of this solution unpredictable (Asther, 2018).

2.3.2 Energy storage techniques

Energy storage is responsible for levelling the renewable produced energy for different situations such as day and night or seasonal storage. It can guarantee that the energy system can supply the energy demands of the buildings at all times. There are many different types of energy storage as displaced inFigure 2.13. (TNO, 2013)

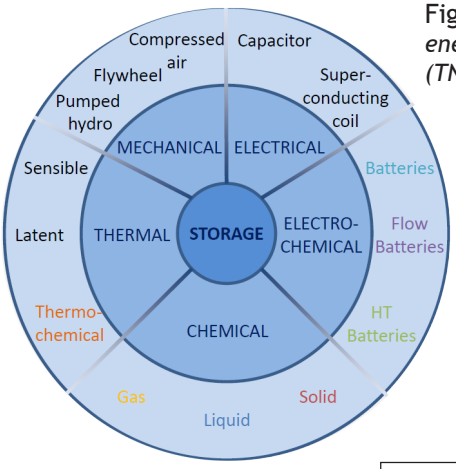
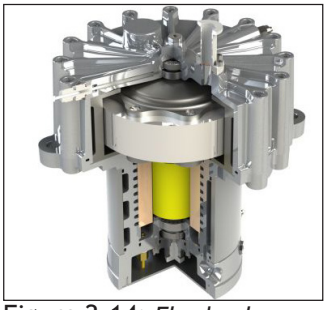


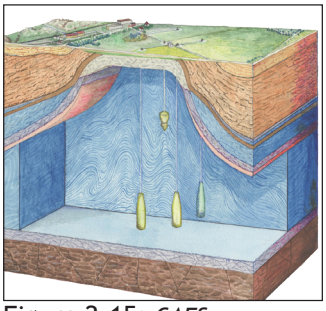
Figure 2.13: *Types of energy storage. (TNO, 2013)*

Mechanical energy storage

Flywheel (Figure 2.14)
The flywheel energy storage method uses torque to rotate a rotor. The rotor will keep spinning in a low resistance environment storing kinetic energy during this process. The stored energy can be regenerated by reducing the speed of the rotor. Using a braking torque the energy can be retrieved. Flywheels have a low energy storage potential which is disadvantageous for large scale energy transition projects. The response time of regenerating energy is short which is beneficial (Bender, 2016).


Figure 2.14: *Flywheel*

Compressed air energy storage *(*Figure 2.15*)*
The compressed air energy storage method uses electricity to compress ambient air in an empty mine or cavern. The energy is regenerated by heating the compressed air in a expansion turbine. The process will regenerate electricity in a generator. CAES has the potential to store large amounts of energy but is dependable on the presence of empty mines and caverns (Garvey & Pimm, 2016).


Figure 2.15: *CAES*

Pumped hydro storage *(*Figure 2.16*)*
The pumped hydro storage method has highest energy storage potential of all known technologies at the current moment. Energy that should be stored is used to pump water to a higher located water basin. During high energy demand periods the water is released and hydro energy is reproduced. The most advanced PHS systems already reach a efficiency of regenerating 80% of the stored energy (Yang, 2016).


Figure 2.16: *PHS*

Electrical energy storage

Super capacitor (Figure 2.17)

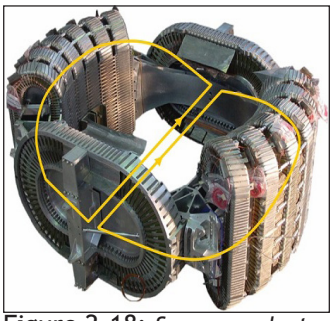
A double layered capacitor is called a super capacitor. Two metal electrodes are coated with a porous material. Both plates are immersed in a electrolyte made out of negative and positive ions in a solvent. The advantage of super capacitors is the long lifetime cycle but the disadvantage is the low energy storage density of this technique (Guerra, 2016).



Figure 2.17: *Super capacitor*

Super conductor *(*Figure 2.18*)*

Superconductors are making use of the effect that a current in the superconductor will keep flowing even after the voltage has been removed from the circuit. This current will create a magnetic field that will store the electrical energy in the coil. This coil can be discharged to regenerate the energy. The biggest advantage of the superconductor is the ability to regenerate high power levels but the capital costs are currently still very high (Barbour, n.d.).


Figure 2.18: *Super conductor*

Chemical(electro) energy storage -Batteries *(*Figure 2.19*)*

Batteries are the most used type of energy storage in the at the current moment. Batteries can be charged and discharged to store or regenerate energy. The negative ions in the electrolyte are moving towards the zinc site of a battery causing a chemical reaction. During this reaction electrical energy is released. The advantage of batteries is the quick response time and the high energy density in a small volume compactness. The disadvantage of batteries are the high costs and the use of toxic materials (Vetter & Lux, 2016).

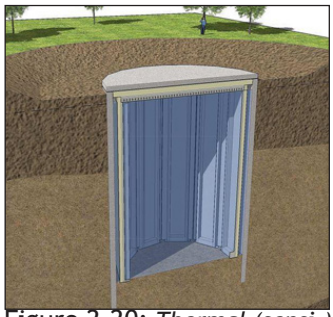


Figure 2.19: *Batteries*

Thermal energy storage (focus of this thesis)

Sensible *(*Figure 2.20*)*

Sensible energy storage is a technique that stores & regenerates energy by raising/ lowering the temperature of a medium. If the temperature of a material rises it is able to store internal energy, if cooled down this energy is released again. The specific heat coefficient and the mass of the storage substance determine the amount of energy that can be stored. The best known substance to store energy with is water. Thermal energy storage is mostly matched with solar energy production. Water filled energy storages consists of a large volume in order to store enough energy. Overtime thermal losses occur with sensible TES (Cruickshank & Baldwin, 2016).


Figure 2.20: *Thermal (sensi.)*

Latent *(*Figure 2.21*)*

Latent thermal energy storage is partly the same as sensible TES. It also relies on a temperature raise of the material in order to store energy. Secondly, during the heating process, the material will undergo a phase change. During this phase change the material is able to store a large amount of energy. The heat of fusion coefficient and the mass determine the amount of energy that can be stored in this process. If the process is reversed and the material changes back to the old phase the energy is released again. The energy density of latent TES is higher compared to sensible TES and therefore the volumetric compactness is smaller (Noel, Kahwaji, Desgrosseilliers, Groulx, & White, 2016).


Figure 2.21: *Thermal(Latent)*

Thermochemical *(*Figure 2.22*)*

This methods is comparable with latent thermal energy storage only the materials do not specifically undergo phase change. A chemical reaction occurs that stores energy in the chemical bonds. Energy is now stored with hardly any thermal losses occurring. If the reaction is reversed the energy is released again. Thermochemical energy storage is able store large amounts of energy and for longer periods of time. This makes thermochemical energy storage one of the most promising future energy storage methods. The technologies and materials used for thermochemical energy storage are still being researched and developed. Currently there are no large scale thermochemical energy storages that can be integrated in an energy system (Kerskes, 2016).

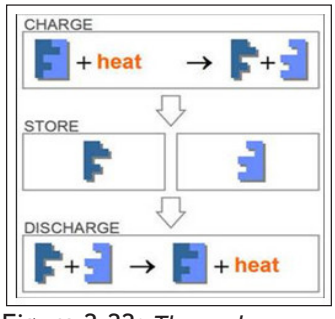


Figure 2.22: *Thermal (thermochemical)*

2.4 Energy from solar radiation

The two best known principles for energy production making use of the sun are solar collectors and photovoltaic systems. Photovoltaic systems (PV) produce electricity and solar collectors produce heat stored in a thermal absorber like water or glycol. A third solar production method is a combination of both methods, the photovoltaic/ thermal systems. To determine which systems will be selected for the integration in the design scenarios, an analysis must be done describing the technical and spatial characteristics of the different technologies. The best known available technologies divided over the three main categories will be discussed in this chapter.

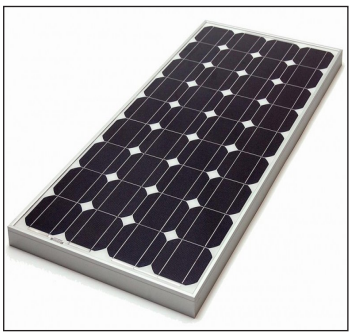


Figure 2.23: *Monocrystalline*

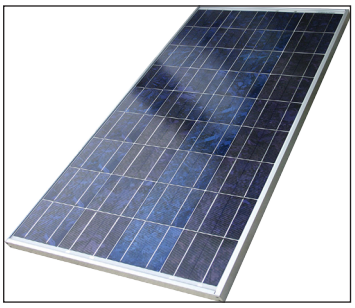


Figure 2.24: *Polycrystalline*



Figure 2.25: *Amorphous*

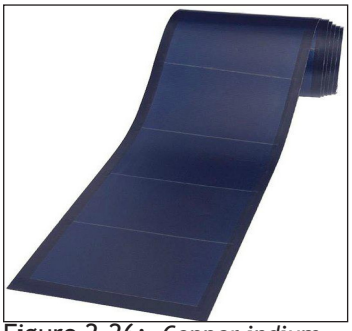


Figure 2.26: *Copper indium gallium*

2.4.1 Solar panels (photovoltaic systems)

Photovoltaic systems use the photovoltaic effect to transform photons coming from the sun into electrical energy. Solar cells are made of different types of materials creating this photovoltaic effect. These solar cells are combined into modules shaping the PV systems (Toothman & Aldous, n.d.). The following types of photovoltaic systems are known:

Monocrystalline silicon solar cells *(*Figure 2.23*)*
Pure silicon is used as the photovoltaic light absorbing material. Manufactory techniques produce small wafers of silicon ingots that will be used to produce the PV module. Monocrystalline silicon solar cells are mostly dark even colored. The efficiency is considered high compared to other solar panels. Mono-Si PV panels are among the most expensive panel types but the life span is longer compared to most panels, up to over 25 years. Making mono-Si panels a long term investment (Maehlum, 2014).

Polycrystalline silicon solar cells *(*Figure 2.24*)*
Polycrystalline PV panels are made of raw silicon with a high purity silicon that is melted in square shaped molts. Compared to the production process of monocrystalline PV panels, less silicon is wasted. Because the purity of the silicon is lower than the of monocrystalline PV panels, the efficiency is a little bit lower. The rest of this polycrystalline PV is comparable to monocrystalline PV, besides the fact that aesthetically the polycrystalline PV panels are evaluated as non-pleasing because they are not looking as uniform collored surface. (Bagher, Vahid, & Mohsen, 2015)

Thin film amorphous silicon *(*Figure 2.25*)*
The best developed thin film solar panel is the Amorphous silicon panel. Thin film solar panels are already existing for over 15 years. They are made by a vapor-depositing of Amorphous silicon creating a thin layer on a glass or metal plate. The potential electrical output of Thin film (a-Si) panels is considered low. Multiple layers of vapor-depositing silicon could increase the efficiency a little but makes the panel more expensive. Another disadvantage of thin film (a-Si) panel is the significant degradation of efficiency that occurs over time. (Bagher et al., 2015)

Thin film copper indium gallium selenide *(*Figure 2.26*)*
Copper Indium Gallium Selenide solar panels are comparable to Amorphous silicon panels. This thin film solar panel is built using thin layer of; copper, indium, gallium and selenide. These are all placed on top of each other on a glass or plastic surface. This thin film panel has a high absorption coefficient that causes that allot of the sunlight is absorbed. The layers together are so thin that they can be placed on curved surfaces, which might in the future be an advantage of this technology compared to the other thin film panels. Secondly the efficiency increased the last years, making it a higher electricity producing panel than the Amorphous silicon panel. The big downside of the copper indium gallium selenide panel is the fact that most of them are still in the developers phase. (Bagher et al., 2015)

Thin film cadmium telluride *(*Figure 2.27*)*
The semiconductor used in the third thin film solar panel is cadmium telluride. The same as in the other two types of thin film panels, a thin layer of cadmium telluride layer is placed on a surface. Cadmium telluride PV panels are the only thin film panels that are cheaper than the crystalline silicon PV panels. The negative environmental impact of these panels is larger compared to other PV panels. Cadmium is a toxic material and a threat for the environment if openly exposed. The recycle process of this panel is therefore more difficult and should be done more careful. On the other hand the panels carbon footprint is lower, the water use in the production phase is lower and the payback time is the shortest of all PV panel technologies available so far. Telluride is a limited available material that might cause future problems for the production of this type PV panel. Currently the CdTe thin film PV panel has a 50% share of electricity production of all thin film PV panels. (Bagher et al., 2015)

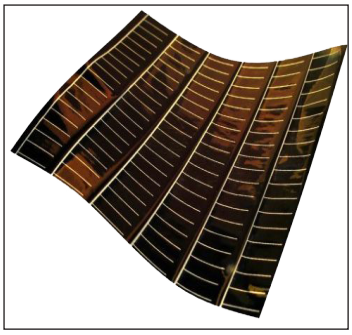


Figure 2.27: *Cadmium telluride*

Future multijunction devices *(*Figure 2.28*)*
Multi junction devices are multiple layers of different semiconductors. The semiconductors are able to catch different wavelengths of the sunlight and converted them into electricity. Multi junction devices are still in the early development phase, making this not an realistic option to be integrated as an energy production method in the selected urban blocks. In laboratories multi junction devices currently reach efficiency levels of 40%, which is more than a duplication of the efficiency levels of the currently existing solar panels. Multi junction devices are therefore the future and worth mentioning because they might provide twice the amount of electricity in the same used space compared to the current PV panels. (Bagher et al., 2015)



Figure 2.28: *Multijunction*

2.4.2 Solar thermal systems (solar collectors)
The second option to produce energy using solar energy, are solar collectors. This technique uses the power of the sun to raise the temperature of a liquid that can be used for spatial heating. An important characteristic of this technique is the demanded output temperature of the liquid. The efficiency of the solar collector fluctuates based on this temperature. The lower the output temperature of the liquid, the better the collectors performs. The output temperature can't be too low because it should be integrated with an energy system with a specific temperature demand. There are two types of solar collectors; flat-plate collector & evacuated tube collector.

Flat-plate collector
Flat-plate collectors use an absorber plate to catch sunlight that is falling through a glass plate that is covering the panel. Solar energy is transformed into heat energy heating up the liquid in the pipes that placed inside the panel. Flat-plate collectors have a lifespan of 20 years and are cheaper compared to evacuated tube collectors. A disadvantage of the flat plate collector is its large weight, which could cause problems if integrated on roofs. (Figure 2.29 & Figure 2.30)

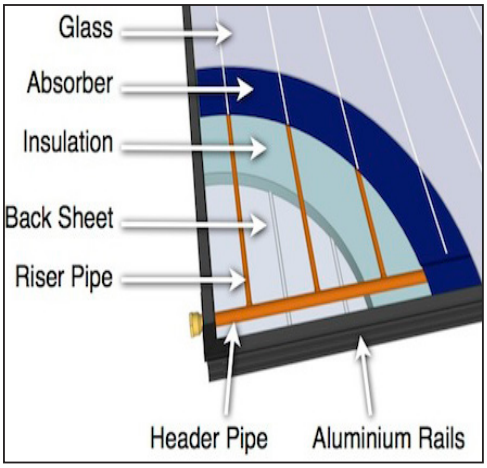


Figure 2.29: *Breakdown flat-plate collector*



Figure 2.30: *Flat-plate collector*

Evacuated tube collector

Evacuated tube collector is built of glass tubes with a vacuum inside. A transfer fluid inside the tube is heated by the sun and heat losses are prevented by the vacuum inside the tubes. The evacuated tube collector can produce higher output temperatures than the flat plate collectors. The performance of evacuated tube collectors is better in cold climates than the flat plate collector because the vacuum causes better insulation. The evacuated tube collector is more expensive and fragile which is disadvantageous (Figure 2.31 & Figure 2.32).

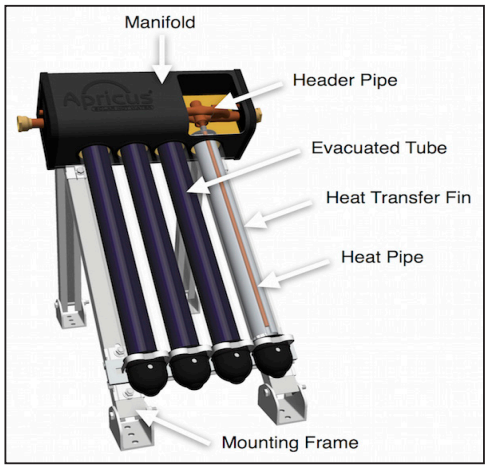


Figure 2.31: *Breakdown evacuated tube collector*

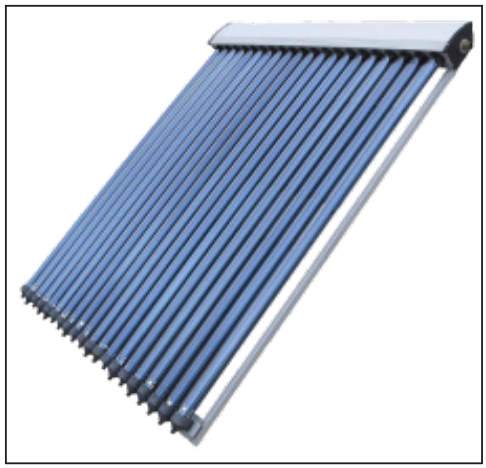


Figure 2.32: *Evacuated tube collector*

2.4.3 Photovoltaic thermal hybrid systems (PVT)

Combing photovoltaic systems with thermal energy production systems results is the third option for solar energy production that is included in this research. These photovoltaic thermal solar panels produce electricity and heat at the same time, ideal if this technology is combined with an heat pump. PVT panels are made of flat plate collectors combined with the PV technologies; Si-monocrystalline, Si-polycrystalline or thin film amorphous silicon. Glazing is placed on the PV module to provide insulation for improving the thermal output of the PV-T panel (Figure 2.33).

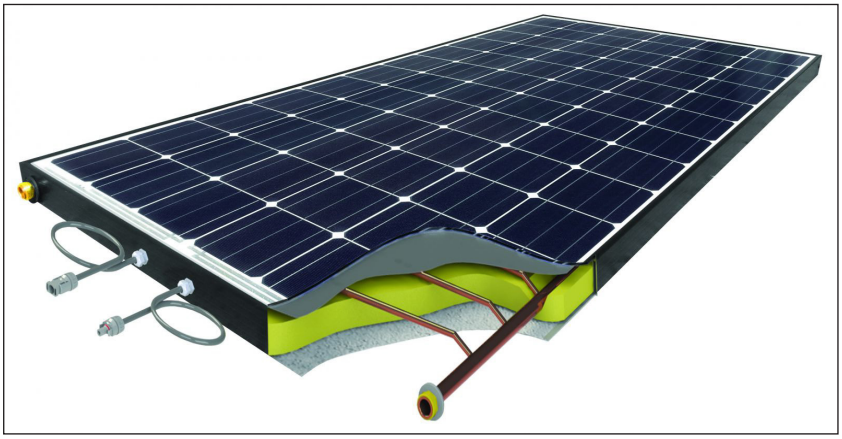


Figure 2.33: *Photovoltaic thermal hybrid solar collector*

Producing electricity with PV cells is also generating heat in the PV module which decreases the efficiency of the PV cells. This decrease in efficiency can be reduced by cooling the PV module. Studies researching the cooling effect of the flat plate collector on the PV module efficiency differ in outcome so far (Leonzio, 2016).
New research assumes that the electrical and thermal output of a PV-T panel is the same as the individual PV module added with the thermal output of a flat-plate collector. (TU Delft, 2017)

Research determining the efficiency improvements of PV modules resulted in 4.74% and 5.44% increase (wind speed 1 m/s) and 3.26% and 3.38% increase (wind speed 4 m/s).(Colangelo, Romano, & Tina, 2015)

Further research about increased efficiency numbers of PV is necessary to make substantiated choices if PV-T panels are better to implement in the built environment compared to solar collectors & pv panels. For this research we assume a PVT panel that is made of monocrystalline pv and a flat-plate solar collector. The thermal and electrical output can, due to the small differences scientific research brought up so far, be equated to the separate PV and solar collector output.

2.4.4 Comparison spatial footprint

Now that all types of solar energy production technologies are discussed, we can make a comparison. The specific characteristic we are interested in for this research is the spatial footprint of all the technologies. Secondly it is important to analyse the energy potential that is matching this spatial footprint. The efficiency values of the different panel technologies, originating from scientific sources, are used to calculate an annual energy output on a flat surface in Haarlem. Because this research is about the energy transition on a urban scale, we are interested in the amount of panels that are needed to provide the energy demand of one buildings located in the selected urban blocks in Ramplaankwartier. The results of the amount of panels necessary are illustrated in m^2, Figure 2.35. The intermediate steps that lead to these results are first discussed.

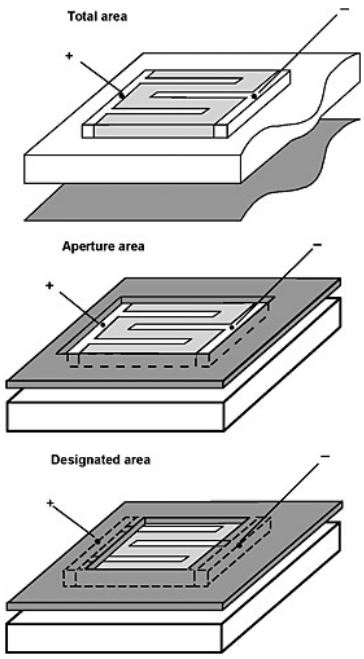


Figure 2.34: *Sizing solar panels. (Honsberg & Bowden)*

Important for the interpretation of the efficiency values, is the corresponding area type used to test the solar panel. If the aperture area is used in documentation, this means that the total module size of the panel is larger. The aperture area is the area covered with PV cells (including busbars, fingers and interconnects) that produce electrical power. Efficiency levels based on the aperture area will result in an increased total modules sizes. Necessary for the calculations about the spatial footprint of solar panels in the built environment is the total area (gross area) of the solar panel, Figure 2.34. Another measuring method is using the designated illumination area, excluding the busbars, fingers and interconnects (Honsberg & Bowden, n.d.).

Based on the literature review we select the following five types of solar panels that will be further investigated and might be used for the creation of a new energy system that will be integrated in the selected urban blocks (configurations in chapter 6). Monocrystalline is selected instead of polycrystalline due to higher valued aesthetics. Thin film – cadmium telluride is the selected thin film PV because it is commercially the most used.

1. *Si-Monocrystalline PV*
2. *Thin film – cadmium telluride*
3. *Evacuated tube collector*
4. *Flat plate collector*
5. *PV-T (flat plate & poly-crystalline PV)*

Solar panel characteristics

Most buildings in the selected urban blocks in Ramplaankwartier are energy label E, this is further explained in paragraph (3.1.4). The average annual gas consumption of one building in the Netherlands with energy label E is 1700 m^3, figure 2.7 (Itard et al., 2013). Gas originating from Groningen equals an energetically value of 33,9 MJ. 3,6 MJ equals 1 kWh.

$$\text{Annual gas demand (kWh):} \quad \frac{(1700*33,9)}{3,6} = 16.008 \text{ kWh}$$

The spatial footprint in m^2, using solar energy production, neccesary to provide the annual heat demand for one building (label E) is made visible in Figure 2.36.

The following efficiency levels and gross areas are determined by product specifications, further explained in chapter (4.2). In paragraph 4.2 the exact calculations providing the energy potentials of solar panels are specified, explained & calculated. Figure 2.34 shows the results on a flat surface.

Figure 2.35: *Energy characteristics solar panels. (by Author)*

Type of panel	Gross area (m^2)	Efficiency (%)	Annual kWh/panel (on a flat surface)	Annual (kWh/m^2)	Amount of panels	Spatial intake (m^2) providing the heat demand of one household
Si-Monocrystalline	1,62	17,9	259	159,6	61,8	100,3
Thin film – cadmium telluride	2,47	17,0	374	151,5	42,8	105,6
Evacuated tube collector	4,2	42-45 (chapter 4.2)	2064 (heated 10-40C°)	469,1	7,8	34,1
Flat plate collector	2,42	54-68 % (chapter 4.2)	1647 (heated 10-40C°)	680,6	9,8	23,5
PV-T (flat plate & poly-crystalline PV)	1,64	24-51 (heat) (chapter 4.2)	768 (heat) (heated 10-40C°)	468,4 (heat)	15,4	25,2
		15,8 (elec)	272 (elec)	165,7 (elec)		
				634,1 (total)		

Comparison spatial footprint

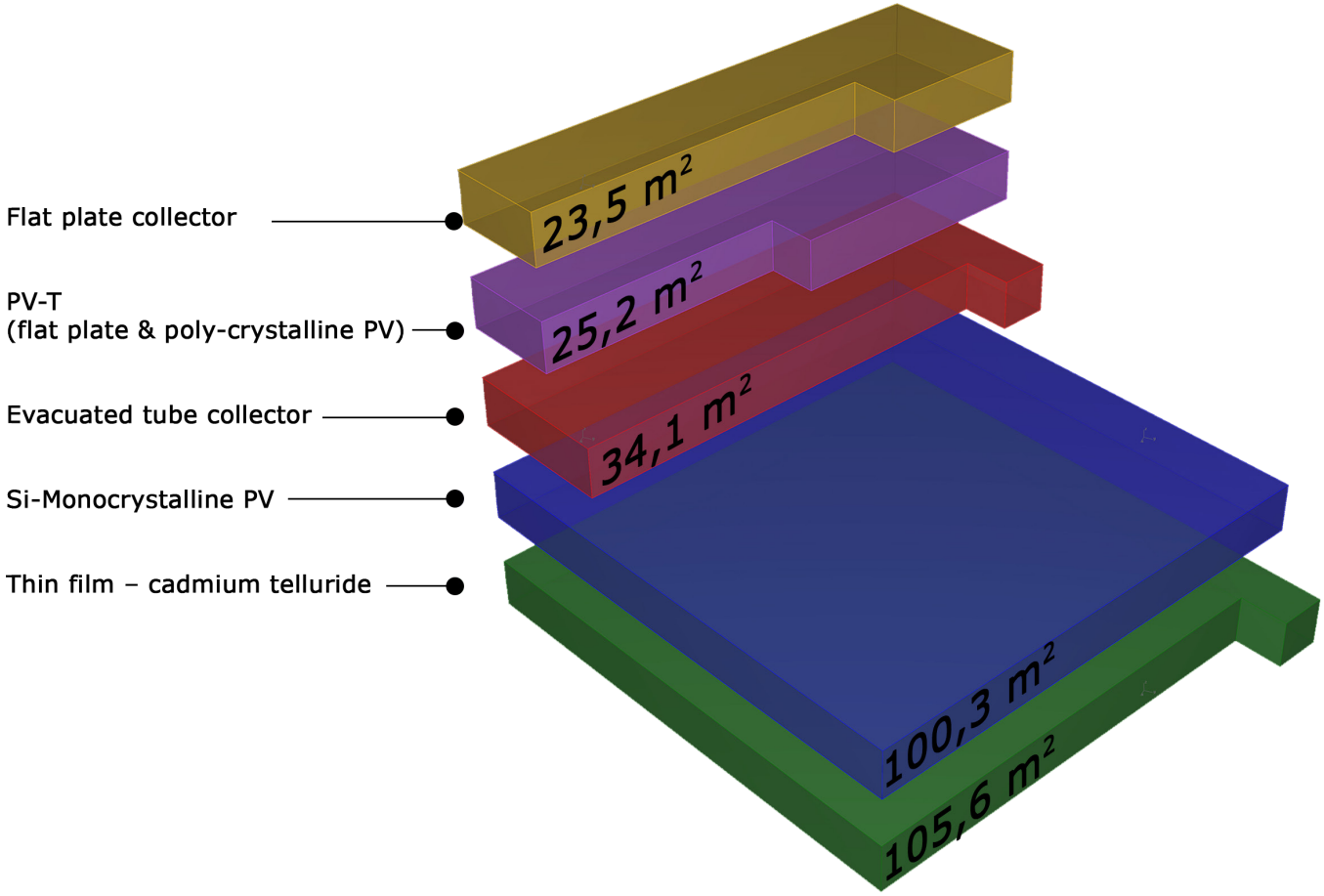


Figure 2.36: *Spatial footprint providing the heat demand of one average building in the Netherlands, based on the previous table. (by Author)*

2.5 Energy conversion technologies:

Heat pumps
The idea of heat pumps is much older than most people think. A reversed heat engine was already proposed in the 1800s but in the twentieth century made for the first time. Refrigerators are in everybody's building and therefore everybody has a heat pump inside his building (Dincer & Rosen, 2015).

The process converting electricity too thermal heat in a heat pumps starts with evaporating a refrigerant, followed by the compression of the refrigerant in order to raise the temperature. This heated refrigerant is transported to a condenser where it exchanges a significant share of its heat with a transport fluid, for example water of a domestic hot water system. The condensated refrigerant is at last transported to an expansion valve where the pressure is lowered. The refrigerant keeps cycling this cycle, extracting heat from an external heat source and heat up the destined transport fluid (Dincer & Rosen, 2015).

Electricity is necessary input for the compressor of the heat pump. The amount produced heat divided by the amount of electricity inserted to the heat pump is the COP value. The higher this value gets the better the heat pump performs. There are three types of heat pumps that extract heat from different sources. Heat sources could be air or water as illustrated in figures 2.37, 2.38 & 2.39. The outside air can be used as a heat source or warmer air from rest heat of nearby industry. An example for water as a heat source is surface water. Warmer water from the ground or rest heat from industry could be more beneficial for the output of the heat pump.

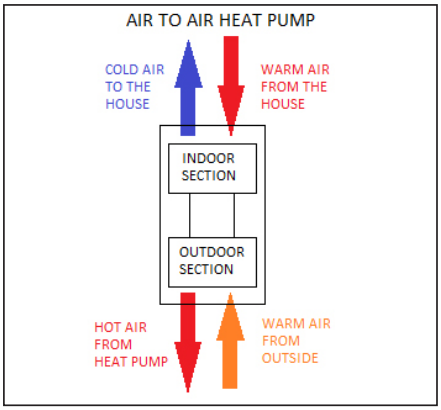


Figure 2.37: *Air to Air*

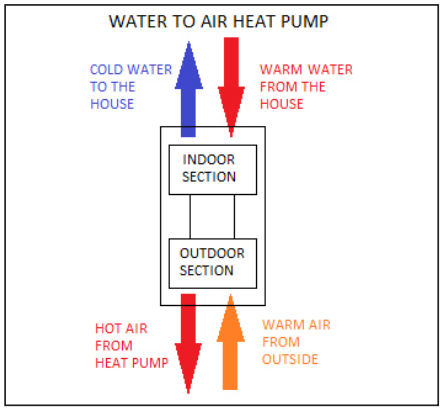


Figure 2.38: *Water to air*

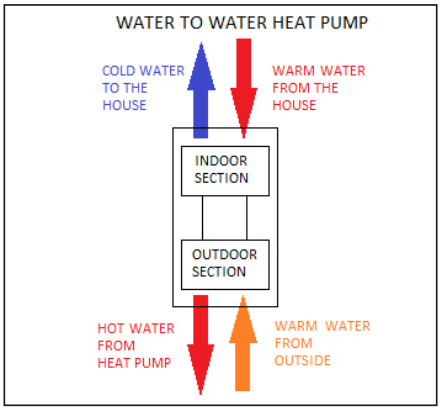
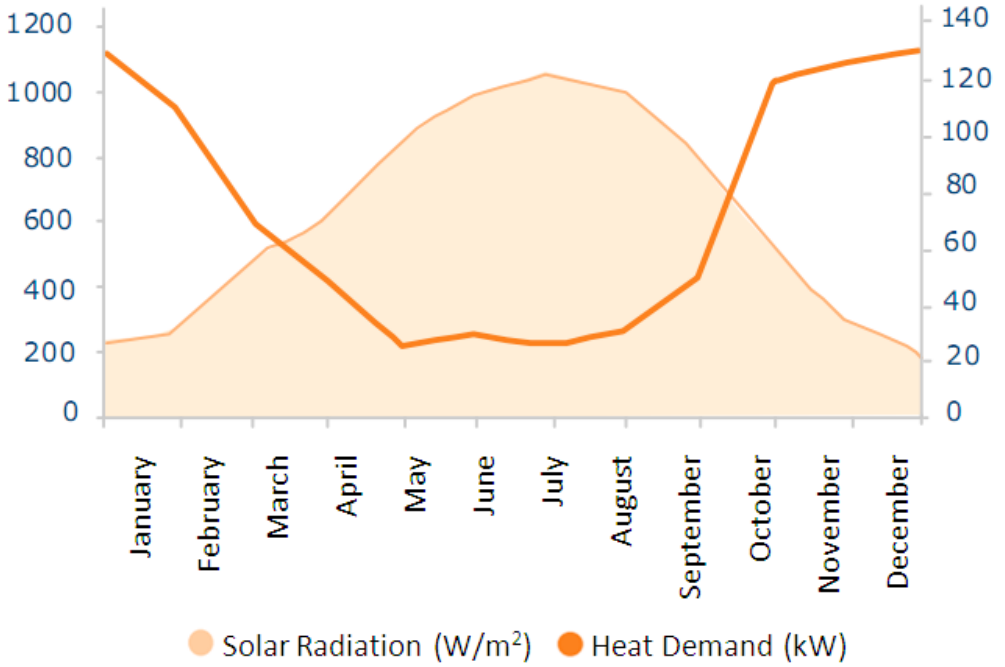


Figure 2.39: *Water to Water*

2.6 Thermal energy storage (TES)

Technical developments in the transition sector are mostly focused on developing renewable energy production methods. These renewable recourses do not provide a consistent output because they are not always available, Figure 2.40. Solar energy production in the Netherlands is simply not equally available in every month of the year. During winter months hardly any solar energy is produced while in summer a surplus of solar energy can be produced. This imbalance is enhanced due to the unequal energy demand during a whole year. The heat demand of Dutch residential buildings is high in winter and low in summer due to seasonal temperature differences. Causing that a renewable energy supply is not always available when there is an energy demand. This mismatch is solved with energy storage technologies. In the current energy system the burning of fossil fuel in power plants does provide a consistent output of energy, independent what the energy demand is (Visscher, Veldhuis, Oonk, Van Ekeren, & Blok, 2004).

Figure 2.40: *Mismatch between solar radiation and annual heat demand. (E-Hub, 2013)*



In an ideal situation all the surplus energy produced in summer months is saved for the high energy demand of the residential buildings during the winter period. The implementation of seasonal energy storage is a solution that can balance the annual output of a solar powered energy network. Using seasonal energy storage for perfect alignment of solar energy production and the energy heat demand of residential buildings, is a solution that can possibly phase-out the use of gas in our current energy network. Seasonal energy storage in residential areas can be done using thermal energy storage (TES) methods. The best know thermal energy storage methods, materials and techniques are discussed in this chapter.

Thermal energy storage can be divided in three main categories; sensible, latent & thermochemical (Figure 2.41). All three types of thermal energy storage rely on a medium that is able to store the solar produced excess heat and can over time be discharged to retrieve the stored energy (Jradi, Veje, & Jorgensen, 2017).

The three main categories of (TES) have a different process/technique of storing energy but also a different set of properties they should be matched with, to fully profit from the technique. Especially interesting for the integration of a storage technique in the living environment, is the dimensioning and capacity of the thermal energy storage types and technologies.

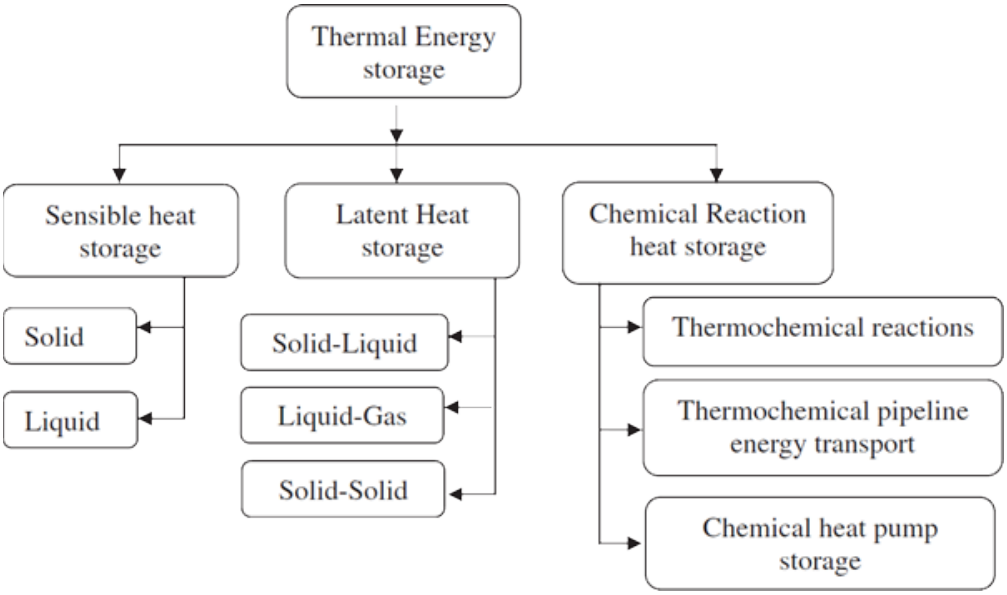


Figure 2.41: *Classification thermal energy storage. (Raam Dheep & Sreekumar, 2014))*

2.6.1 Sensible thermal energy storage (STES)

Sensible energy storage is a technique that is obtained when increasing or decreasing the temperature of a material, with no phase change. Sensible thermal energy storage on a large scale is mostly used as seasonal storage and if integrated in buildings, as small storage vessels, it is used as a short term storage. The specific heat capacity of a material determines the storage capacity of a material. By increasing the temperature of the material heat is stored. The phase of the material won't change with sensible energy storage. Materials suitable for sensible TES can be divided into solid and liquid. (Alva, Liu, Huang, & Fang, 2017). Sensible thermal energy storage is considered one of the best solution so far for seasonal energy storage, both technically and economically. Especially for countries with long winters a long term seasonal energy storage is an solution that could balance energy production and demand, if integrated in the energy network (Jradi et al., 2017).

There are also downsides of sensible energy storage. A relatively large volume of storage medium is needed for storing the energy of one building. The volume used for storing a large amount of water is not always available in the built environment and it is especially difficult for the dense Dutch built environment. The second negative aspect of sensible energy storage is the large amount of insulation material needed to prevent too much heat loss. Overtime the temperature of the storage medium will reduce, which leads to energy losses. Research done by Merosch on different case studies with sensible thermal energy storages, resulted in an estimated efficiency of 50-80% recuperation of the stored energy (Merosch, 2015).

Liquid sensible thermal energy storage

Sensible TES systems are mostly based on the use of water as the storage medium. The heat capacity of water is high: 4.184 kJ/kg*K. The cost of water is low, which makes water based energy storages one of the best solutions of sensible thermal energy storage (Merosch, 2015). Other liquid types usable for energy storage are:

- Molten salts
- Mineral oil
- Liquid metals
- Alcohols
- Water (Alva et al., 2017)

Solid sensible thermal energy storage

- Rocks
- Concrete
- Sand
- Bricks
- Copper

2.6.2 Latent thermal energy storage (LTES)

Latent thermal energy storage systems are systems that will store energy making use of a phase changing transition of materials when a certain temperature level occurs. A substance uses energy to transform into a different phase. Possible phase changes are: Solid-liquid, solid-solid & liquid-gas. The amount of heat needed to let the material change in phase is called latent heat. This phase change happens without a temperature rise and at a fixed temperature (Bakker, Van Helden, & Hauer, 2009). The latent energy storage type most used is the phase change from solid to liquid. This type has the highest absorption value of latent heat but also the biggest change in volume (Alva et al., 2017).

There are two types of materials for latent energy storage; organic and inorganic. Organic materials are applicable with low temperature systems because they have a low thermal conductivity. Organic materials are a eutectic mixture which means; the melting point of the substances shaping the material, are much higher than the melting point of the material itself. Organic materials are capable of congruent melting which means that the composition of the material in the original phase, is the same after the phase change. This property prevents phase separation of the material (Alva et al., 2017).

Organic materials:
- Paraffin
- Fatty acids
- Easters
- Alcohols
- Glycol

Inorganic materials have a high estimated capability to store heat of 350 MJ/m^3. Compared to organic materials their thermal conductivity is higher and they melt incongruent.

Inorganic materials:
- Salt hydrates
- Salts
- Metals/metal alloys

2.6.3 Thermochemical energy storage (TCM)

This method is making use of a reversible chemical process of separating and combining two substances. Heat is used to separate a substance into two components that can be stored without energy loss, Figure 2.42. If the separated substances are brought back together they can regenerate heat. TCM's can have a high output temperature up to 500 °C, they also need a high temperature for the separation process (Bakker et al., 2009). A reactor tank is needed for energy storage in a chemical process. Water is used with most substances to discharge the energy from the system. This method/technology is still in the research and experiment phase and is therefore not applied in the energy transition of the selected urban blocks in Ramplaankwartier.

Best known substances:

- Salt hydrates
- Copper sulphate
- Calcium chloride
- Magnesium sulphate
- Magnesium oxide
- Ammonia

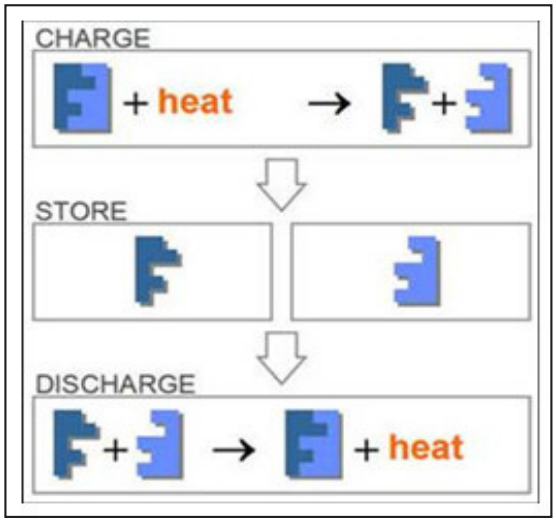


Figure 2.42: *Chemical process (*Bakker et al., 2009.

2.6.4 Comparison of energy storage potential

In a recent study Bakker, Van Helden & Hauer compared the energy storage potential of all three types of thermal energy storage. The results are illustrated in Figure 2.43. For the rest of this research we will only use latent and sensible thermal energy storage because they are already on the market. Latent thermal energy storage has a much higher energy storage potential compared to sensible energy storage but is also much more exspensive per m^3.

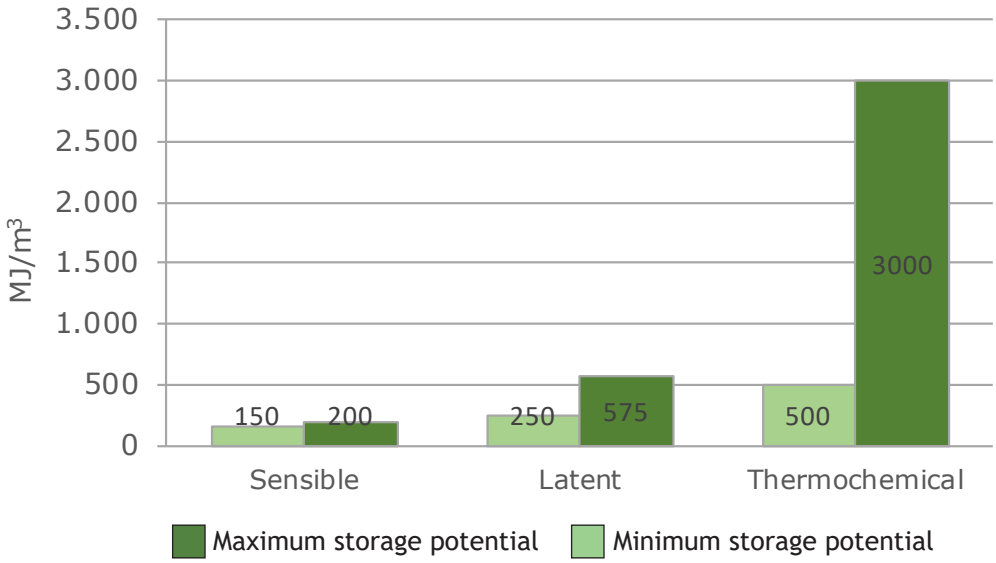


Figure 2.43: *Energy storage potentials.* (Bakker et al., 2009)

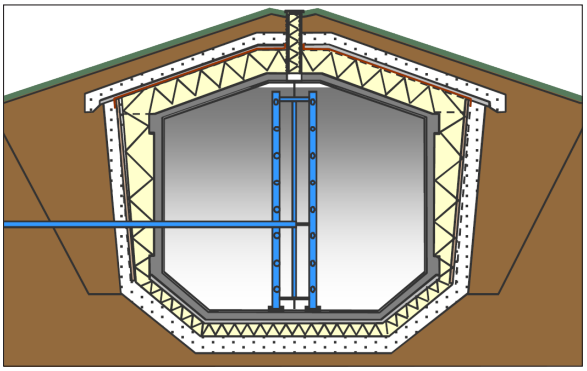


Figure 2.44: *TTES (Schmidt & Miedaner, 2012)*

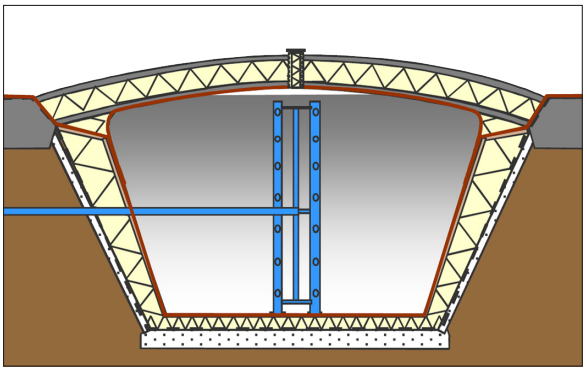


Figure 2.45: *PTES (Schmidt & Miedaner, 2012)*

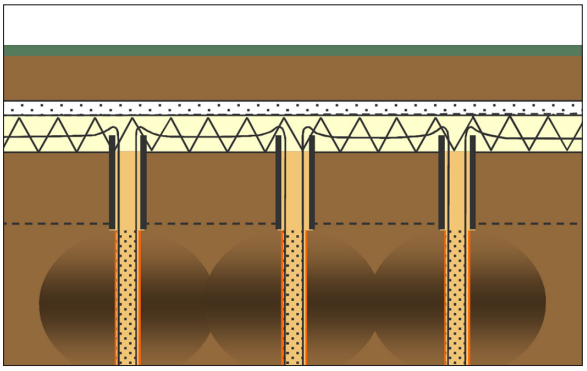


Figure 2.46: *BTES (Schmidt & Miedaner, 2012)*

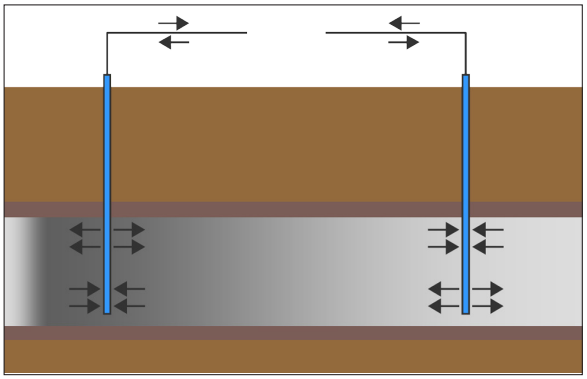


Figure 2.48: *ATES (Schmidt & Miedaner, 2012)*

2.6.5 Energy storage technologies

Tank thermal energy storage (TTES) *(*Figure 2.44*)*
Tanks are filled with a storage medium that is able to absorb energy. Insulation covering the tank will reduce energy losses. The better (insulation value material) and the thicker the insulation the lower the thermal losses, This way most of the stored energy can be used on a later moment. Steel, Aluminium, reinforced concrete and fiberglass are commonly used materials to make the storage tanks used for PTES & TTES. Mineral wool, polyurethane and glass wool are the most used materials to insulate the storage tanks. (Alva et al., 2017).

Storage tanks can be placed underground or above ground. Placing a storage tank underground is beneficial for reduction of thermal losses. The earth around the tank will work as an extra insulating layer. Placing tanks underground is not always beneficial because it causes other problems such as: the pressure on the walls and the influence of the groundwater on the tank.

Pit thermal energy storage (PTES) *(*Figure 2.45*)*
The pit storage is a different version of the tank storage because the pit storage is making use of a construction (mostly concrete) build up against the wall of a hole in the ground. The concrete is covered with a plastic layer and insulation material to separate the basin from the ground. The pit storage is covered with insulating plates preventing large amounts of thermal losses. (Alva et al., 2017)

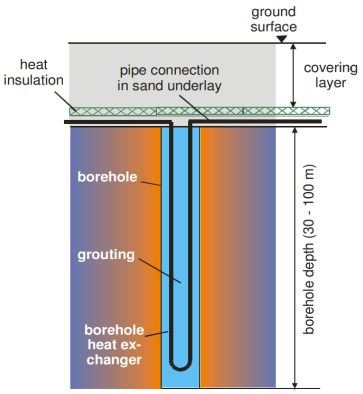


Figure 2.47: *Technical drawing one borehole. (Schmidt & Miedaner, 2012)*

Borehole thermal energy storage (BTES) *(*Figure 2.46*)* *(*Figure 2.47*)*
This technology is storing heat in a solid medium that is poured in the ground. A piping system is used to transport heat with a fluid to this medium. This medium will rise in temperature and is insulated by the surrounding soil. Extracting the energy from the borehole systems reverses this principle. Cold fluid is heated by transporting it through the boreholes. This heated fluid will be used for heating residential buildings (Alva et al., 2017).

Aquifer thermal energy storage (ATES) *(Figure 2.48)*
This storage technology is making use of underground aquifers that are composed of groundwater and surrounding materials like sand and gravel. By using wells and pumps water is injected or extracted from the aquifer. During the charging period cold water is extracted from the cold water basin. This water is heated in a period when there is an excess of energy production. This heated water is injected in the warm water basin and stored for a later moment. This is reversed in a period when this stored heat will be used (Alva et al., 2017).

2.7 Energy distribution

Smart grids (Figure 2.49)
A dynamic energy network that optimizes the distribution of energy in a smart way. The energy production and energy demand are efficiently aligned using an distribution network that is able to quickly respond and transport energy. High peaks of production can be transported to places of high demand and vice versa. Integrating energy storage within these systems optimizes the use of renewable resources even more and might allign the seasonal difference between energy production and energy demand (Zame et al., 2018).

Heat network (Figure 2.50)
Currently the integration of heat networks in the existing built environment is a popular method to provide the heat demand of buildings without burning gas in a building. Water in these networks is mostly heated by the rest heat produced by industries located near the city district. Secondly the heat network principle is easy to combine with renewable energy resources such as the burning of biomass, geothermal power or heat pumps. This creates a much more sustainable energy network exhausting less carbon dioxide. A system of insulated pipes is able to transport warm water (80 °C or higher) to total city districts.

According to the website: (https://www.hierverwarmt.nl/warmtenetten)

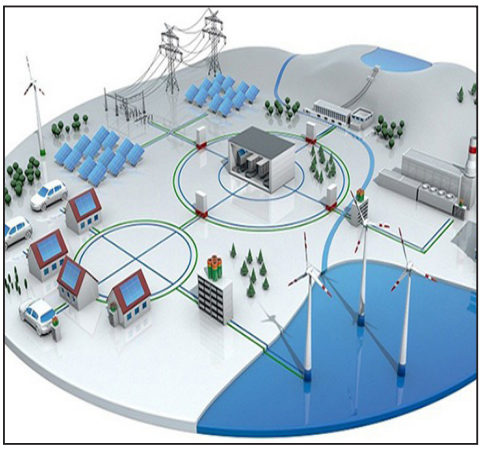


Figure 2.49: *Smartgrid*



Figure 2.50: *Heat network*

2.7 Reference projects



Figure 2.51: *Vojen-Denmark.*

2.6.1 Pit storage & solar collector

Project: Vojen – Denmark, 2012-2014
Main supplier solar collectors: Arcon-Sunmark
Supplier pit storage: Ramboll

Collector area:	70.000 m^2
Annual production:	28.000 MWh
Amount of citizens:	2000
Annual heat demand covered:	45-50%
Type of energy storage:	Water thermal energy storage (pit storage)
Storage capacity volume:	200.000 m^3
In operation:	2015
Life span:	25 years minimum
Investment costs:	16 million euros

(According to the website: http://arcon-sunmark.com/cases/vojens-district-heating)

2.6.2 Tank storage & solar collectors
Project: Munich- Germany, 2007

Collector area:	2.900 m^2
Annual production:	1.080 MWh
Amount of citizens:	300 buildings
Annual heat demand covered:	unknown
Type of energy storage:	Tank thermal energy storage
Storage capacity volume:	5.700 m^3
In operation:	2007
Life span:	unknown
Investment costs:	4,5 million euros

(Mangold & Schmidt, n.d.)



Figure 2.53: *Inside the tank storage Munich*



Figure 2.52: *Construction storage tank in Munich.*

Figure 2.54: *Crailsheim (Lüftenegger & Nigg, 2013)*



2.6.3 Borehole storage & solar collectors
Project: Crailsheim - Germany, 1999
Crailsheim municpality

Collector area:	9.700 m^2
Annual production:	2.050 MWh
Amount of citizens:	260 buildings
Annual heat demand covered:	50%
Type of energy storage:	Borehole thermal energy storage
Storage volume capacity:	75.800 m^3
In operation:	2010 (last phase)
Life span:	unknown
Heat-pump:	350kW (2x) (between buffer tanks)
Investment costs:	7 million euros

(Lüftenegger & Nigg, 2013)



Figure 2.55: *Solar collectors Crailsheim*

2.6.4 Thermochemical & solar collectors
Project: MERTIS project
MERITS project & TNO

Collector area:	12,4 m^2
Annual production:	unknown
Energy output	500W during 7 hours
Type of energy storage:	Thermochemical energy storage
Used material	Salt hydrates
Storage volume capacity:	60 MJ in 326L vessel
In operation:	Set goal 2020
Life span:	unknown
Investment costs:	unknown
Additional advantage:	Applicable for short term storage due to the ability to have more than one energy cycle annually.

According to the website: http://www.merits.eu/)http://www.merits.eu/

Figure 2.56: *Thermochemical energy storage MERITS project*





Figure 2.57: *Storage vessels inside the container*

3 CASE STUDY DESCRIPTION



Figure 3.1: *Haarlem located in the Netherlands (by Author)*

Before the technical configuration options for a new renewable energy systems for space heating are explored, there is a lot of necessary information about the case study that is essential input for the dimensioning and choices of technologies that frame the technical configurations. In this chapter the selected urban blocks for the case study will be described. Section 3.1 presents the main characteristics of the selected urban blocks. Secondly the current heat demand of the buildings located inside the selected urban block are discussed in section 3.2. Thirdly the urban structure of the selected urban blocks are analysed in section 3.3. The goal of this analysis is to determine strengths and limiting factors that are crucial in the dimensioning of a new renewable energy system. In the last section 3.4, the relevant weather data of Haarlem is discussed. The information of this chapter will be used for the development of the new energy plans & energy potentials, in chapters 4 & 5.



Figure 3.2: *Map of Ramplaankwartier, (by Author)*

3.1 Selected urban blocks Ramplaankwartier

The case study neighbourhood Ramplaankwartier is located in Haarlem, which is located in the province North-Holland in the west of the Netherlands. Ramplaankwartier is a neighbourhood located in the west of Haarlem housing 2721 inhabitants divided over 1179 buildings in the year 2009, according to statistics of the Energy transition group (Jansen, 2011). The buildings have a poor energy performance causing a large demand for heating, currently powered with gas.

The largest part of the built environment in Ramplaankwartier is housing. There is not only housing in Ramplaankwartier but there are also small companies located. Buildings and companies combined results in a total amount of 1267 buildings in Ramplaankwartier that have an average annual gas consumption. A map of Ramplaankwartier is displayed in Figure 3.2.

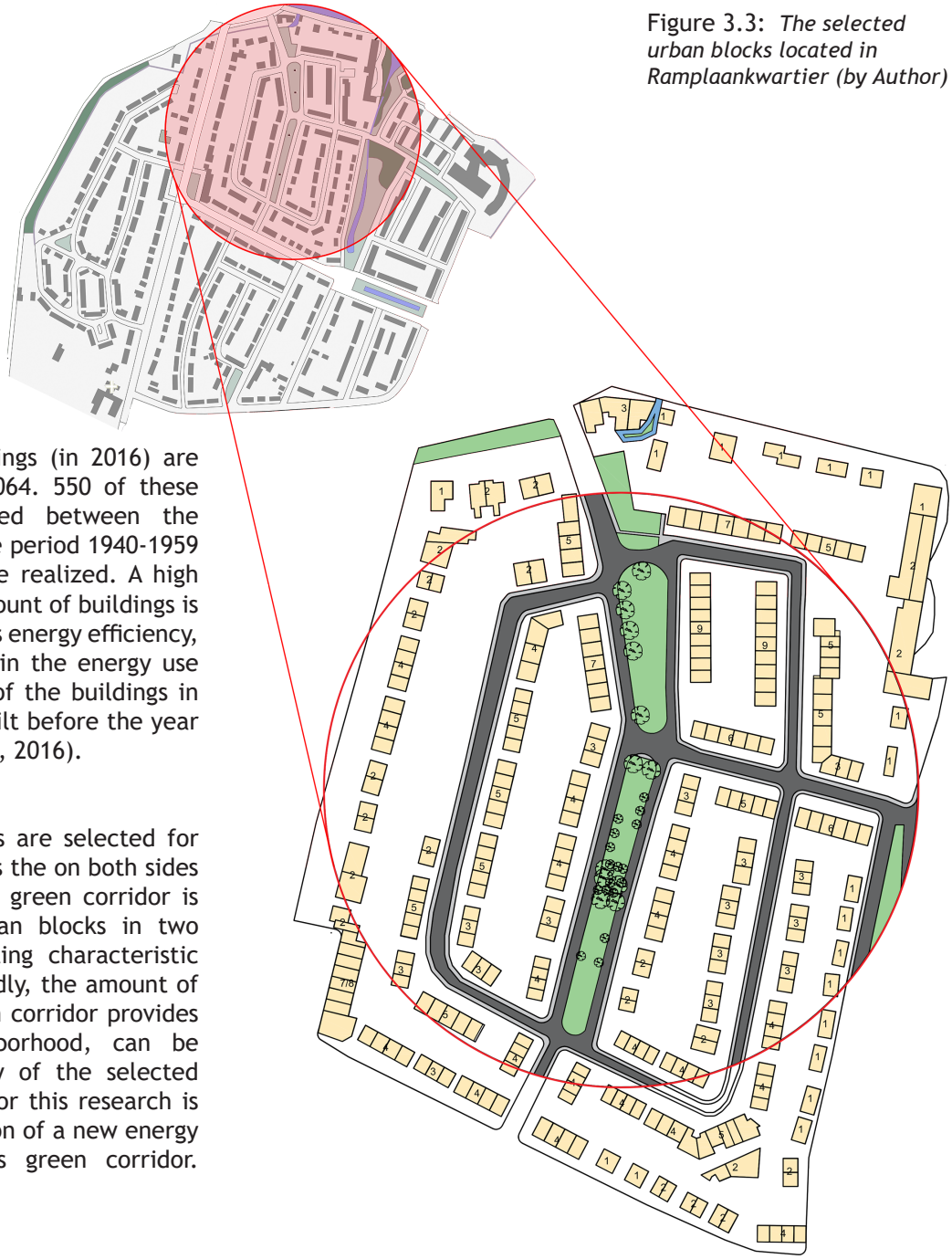


Figure 3.3: *The selected urban blocks located in Ramplaankwartier (by Author)*

The majority of the buildings (in 2016) are single family dwellings, 1064. 550 of these buildings were constructed between the years 1920 and 1939. In the period 1940-1959 another 234 buildings were realized. A high percentage of the total amount of buildings is therefore outdated in terms energy efficiency, which is an import factor in the energy use of buildings. In total 75% of the buildings in Ramplaankwartier were built before the year 1970 (Municipality Haarlem, 2016).

Selected urban blocks
The following urban blocks are selected for this research. Hospeslaan is the on both sides of the green corridor. The green corridor is dividing the selected urban blocks in two parts creating an interesting characteristic to the public space. Secondly, the amount of green space that the green corridor provides in the residential neighborhood, can be characterized as a quality of the selected urban blocks. Interesting for this research is the influence the integration of a new energy system will have on this green corridor. (Figure 3.3).

3.2 Current heat demand

3.2.1 Current gas use buildings Ramplaankwartier

Related to the gas use of the buildings in Ramplaankwartier only the annual gas use is known. There is no information available about the monthly heat demand values for Ramplaankwartier. Therefore the average annual gas use of a building in Ramplaankwartier will be compared to the average annual gas use of a building in the Netherlands, for which monthly demand data are available. The difference between these two categories will be used to make an precise prediction of the monthly average gas use of a building in Ramplaankwartier.

Gas from Groningen has a heating value of 33.9 MJ for 1 m^3 gas. (Jansen, 2011, p. 11).

Commissioned by the Haarlem municipality, an energy analysis was done in 2010 by the network operator Liander. The average gas usage per building in Ramplaankwartier in 2010 is 1.960m^3 which is equal to 66.420 MJ. Detailed analysis of the average annual gas usage per function led to a domestic hot water usage of the main system of 431m^3 (14.622 MJ) (Jansen, 2011).

Annual gas usage for space heating per building: 1960-431 = 1529 m^3
Annual gas usage for domestic hot water per building: 431 m^3

Monthly gas usage for domestic hot water is therefore: 431/12 = 34,42 m^3/month

The average electricity usage is 3.010 kWh per building per year which is equal to 10.845 MJ (Jansen, 2011). The annual average energy use of buildings in Ramplaankwartier is illustrated in Figure 3.4.

The total amount of buildings in Ramplaankwartier that have an average energy consumption is 1179. This brings the annual gas and electricity usage a year to the following total:

Total gas usage Ramplaankwartier:
*1179*1960 = 2.310.840 m^3 = 21.760 mWh*

*Total electricity usage Ramplaankwartier: 1179*3010 = 3549 mWh (annual)*

1 Watt is 1 Joule/second
1 hour is 3600 seconds
1 kWh is 3,6 MJ

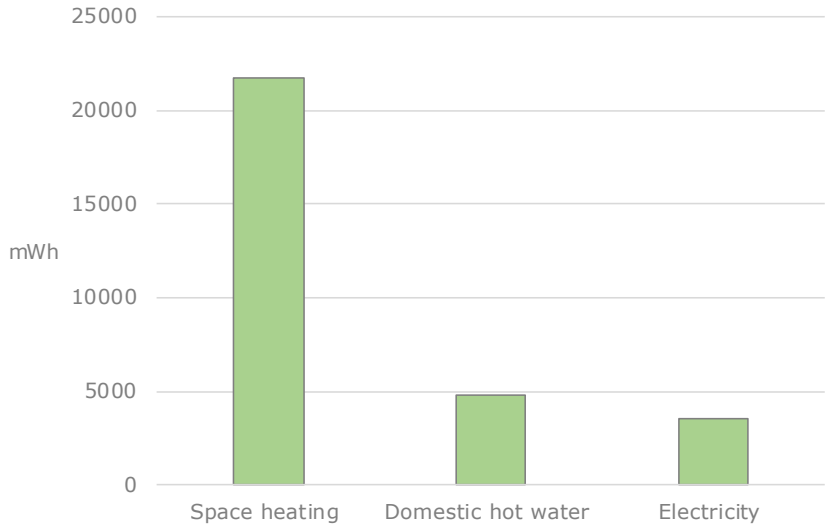


Figure 3.4: *Total energy demand 1179 buildings Ramplaankwartier (by Author).*

3.2.2 National gas use in the Netherlands

The national average annual gas usage for one building in the Netherlands is mapped in the Energie Vademecum. Up to 2007 they analysed the gas use for all different functions within a building. After 2007 they only mapped the total energy use of a building. As visible in the graph the DHW share was around the 400m^3 (Figure 3.5).(Israëls & Stofberg, 2017)

This information about the annual average gas usage for one residential building in the Netherlands, will be combined with another information source that provides the monthly average gas usage numbers for one building in the Netherlands. This will result in a substantiated estimation about the national monthly gas usage numbers for space heating and DHW separately. The energiesite.nl website provides a monthly overview of the national gas consumption per building in the Netherlands (Figure 3.6). This information source does not specify the space heating & DHW share. The total average annual national gas usage per building: 1500 m^3.
According to the website (energiesite.nl)

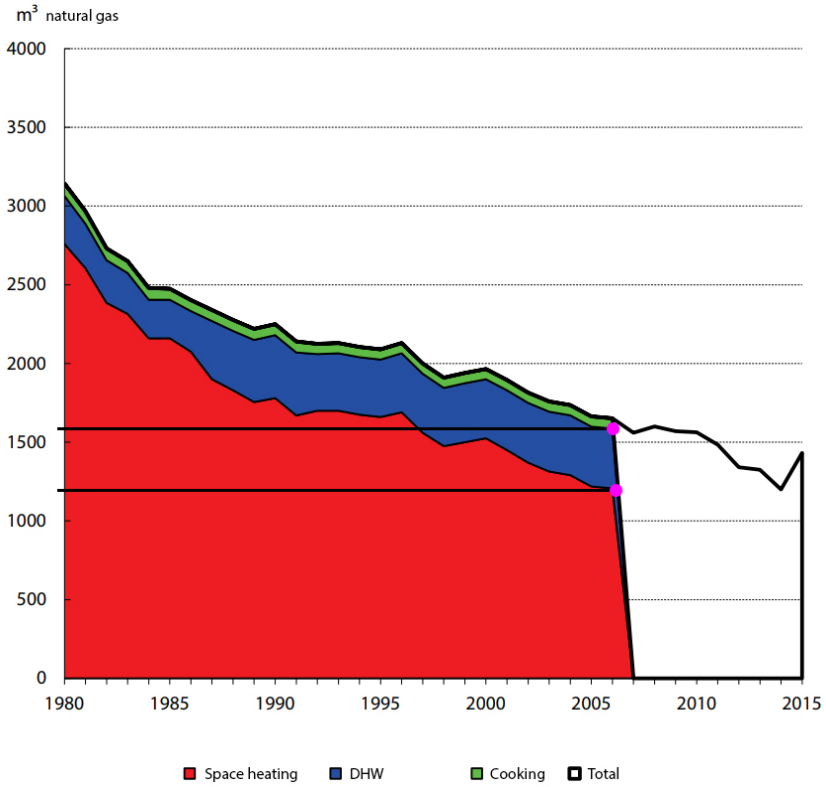


Figure 3.5: *Average natural gas use per residential buildings in the Netherlands. (Israëls & Stofberg, 2017)*

With the information obtained from the Energie Vademecum that the DHW use was 400m^3 in 2007, we assume a DHW use of 350m^3 in 2015 following the declining curve in the graph. The total gas usage for providing the heat demand in 2015 is an estimated 1500m^3. The annual use for space heating is:
1500-350 = 1150m^3

The monthly share of DHW would be: 350/12 = 30 m^3
This 30m^3 will be subtracted from the monthly values of the total national gas usage visible in Figure 3.6. By doing this we get an overview of the monthly national gas usage for space heating and DHW separately.

The heat demand values for the months July and August are below the monthly DHW usage estimations (30 m^3) for those months. Due to people being on vacation in these months this value could be lower than the other months. Therefore we first subtract these two months from the total 350m^3 and divide the result of this equally over the other 10 months.

- *DHW usage in July and August: 20+25 = 45m^3*
- *DHW usage in the other 10 months: (350-45)/10 = 30,5m^3*

Subtracting the above values from the values in Figure 3.6 results in the share gas used for space heating specifically (Figure 3.7).

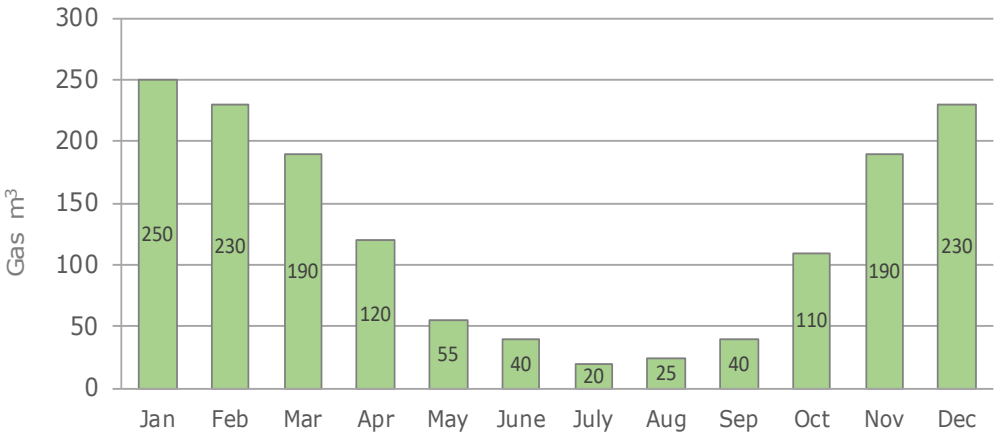
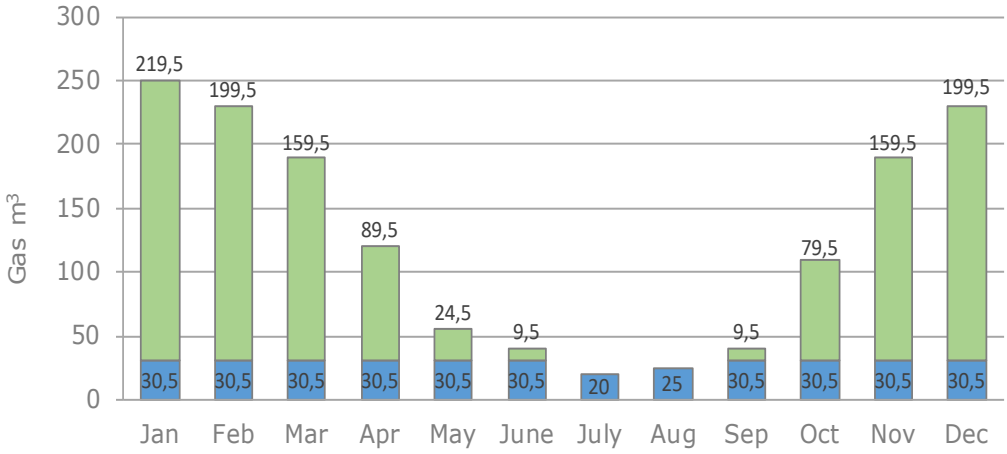


Figure 3.6: *Average monthly gas usage in the Netherlands per building. (energiesite.nl)*

Figure 3.7: *National monthly gas usage per building for space heating and DHW, based on the total monthly values given in Figure 3.6. (by Author)*



3.2.3 Derived monthly gas use values Ramplaankwartier

We now have the annual and monthly values of the national average gas usage per building for the space heating demand.

The annual average national space heating demand is: 1150m³ per building
The annual average Ramplaankwartier space heating demand is: 1529m³ per building

Converting the monthly national space heating values into percentages of the total 1150m³ (Figure 3.7) enables the opportunity to derive the monthly values for space heating in Ramplankwartier by multiplying these percentages with the total 1529m³ (Figure 3.9)

Figure 3.8: *Percentage of the total 1150 m³ gas for space heating (national average per houshold). (by Author)*

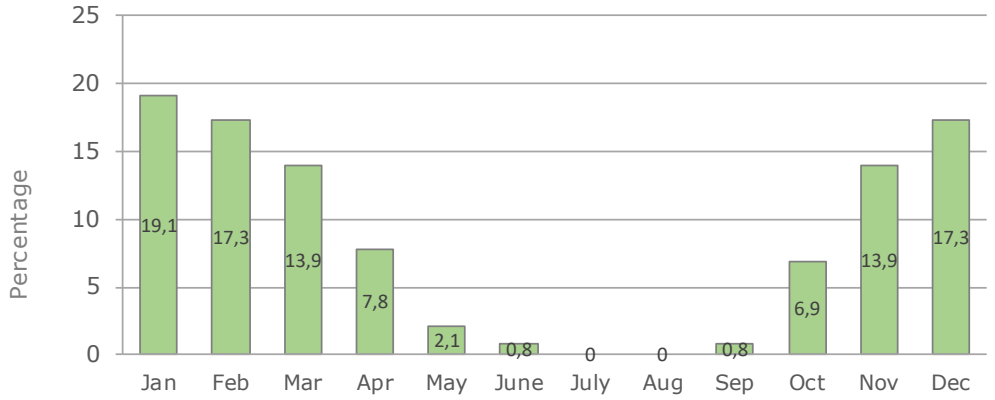
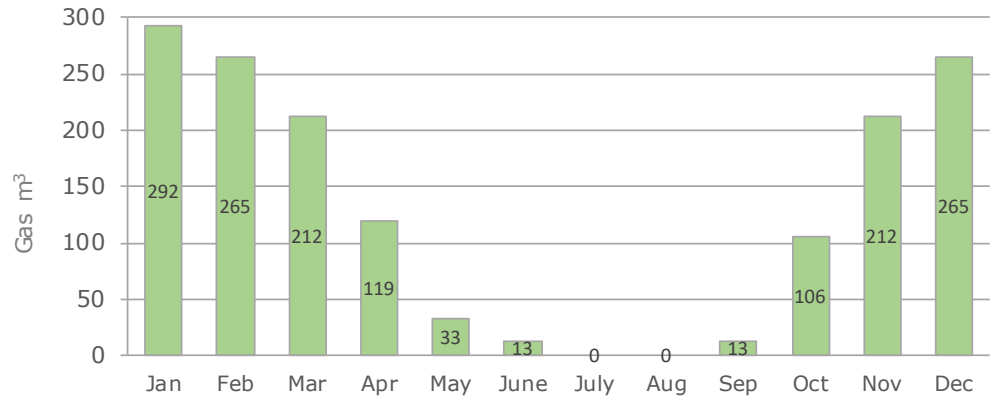


Figure 3.9: *Derived monthly gas use for space heating in Ramplaankwartier per building. (by Author)*



Combining the monthly gas use for DHW (Figure 3.7) and space heating in Ramplaankwartier in one graph results in Figure 3.10. In paragraph 3.2.1 the monthly DHW use of 34,42 m³ was calculated. The total annual heat demand is 1943 m³.

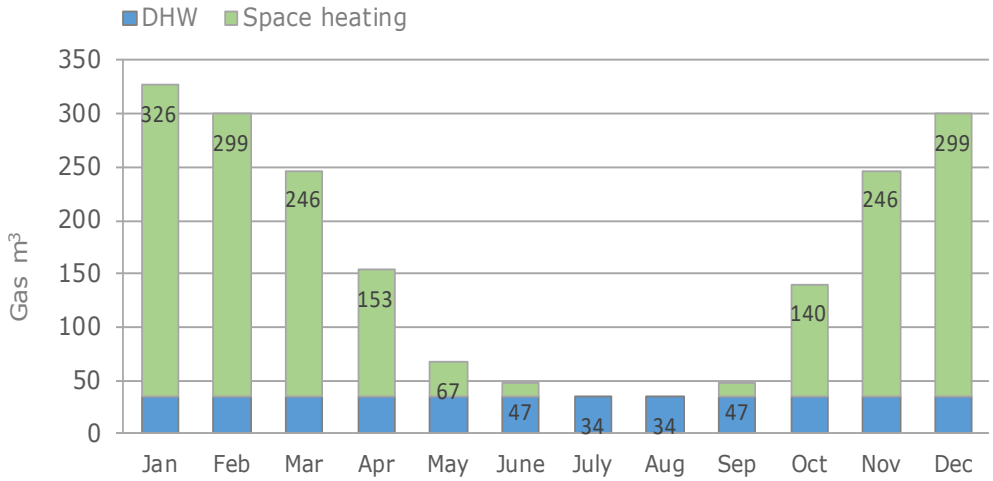


Figure 3.10: *Ramplaankwartier average monthly gas usage per building for space heating and DHW. (by Author)*

3.2.4 Energy labels

A major part of the buildings were constructed between the years 1920 and 1939, causing an outdated energy efficiency of the buildings, resulting in a low rated energy label. Developing a new energy system without considering energy renovations of the buildings is not desired, as this will lead to a very high energy demand. Therefore the energy usage of the buildings will be adapted based no future improvements to the buildings.

The website energielabelatlas.nl provides a more specific overview of the energy labels of the buildings in the selected urban blocks (Figure 3.11).

In chapter 4.1 the heat demand presented in this chapter will be used to calculate a heat demand after feasible renovations. This will be done using the current energy labels as illustrated in the figure and update the residential buildings to energy label C.



Figure 3.11: *Energy labels buildings (by Author based on energielabelatlas.nl)*

3.3 Spatial characteristics

The spatial structure and properties of the selected urban blocks are essential to understand the spatial energy potentials for the employment of the selected technologies. Secondly the spatial analysis can be used for the dimensioning of energy production technologies and energy storage technologies. These technologies are: PV, solar collectors, PVT and thermal energy storage.

The spatial characteristics of the selected urban blocks in the current situation will be compared with the spatial characteristics of the selected urban blocks with the new energy system. These results will be used to make a comparison between all the different configuration outputs and research the impact of the implementation of a new energy system. There are many different spatial characteristics defining the selected urban blocks as described by: Hachem Athienitis & Paul Fazio. The analysis of the characteristics will focus on public and private spaces by using the following characteristics (Figure 3.12). These characteristics cover all the important components of the selected urban blocks that could influence the new renewable energy system and its sizing. Public (A) private (B). (Hachem, Athienitis, & Paul Fazio, 2012)

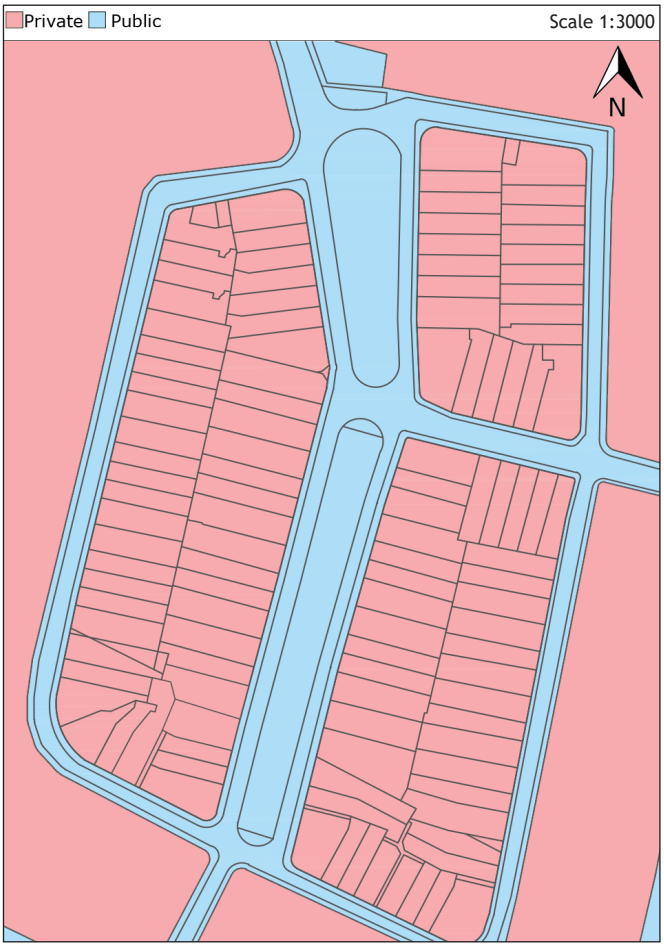
1. Land use
2. Building
3. Orientation
4. Angle/slope
5. Shadows

Figure 3.12: *Analysed urban characteristics. (by Author)*

Type of spatial characteristic		**(A) Public open space**	**(B)Private space**
Land use	Blocks (area and urban structure)	✓	✓
	Buildings (numbers & area)		✓
	Green areas (area)	✓	
	Vegetation type (trees)	✓	✓
	Roads/pavement	✓	
	Parking (street & carports)	✓	✓
Building	Roof area (area)		✓
	Roof interruptions (dormers)		✓
	Form (shape & volume)		✓
	Typology households		✓
	Storage buildings (number & area)		✓
Orientation		✓	✓
Angle/Slope		✓	✓
Shadow	Block form (shadows caused by buildings)	✓	✓
	Vegetation	✓	✓
	Roof interruptions (shadows between dormers)		✓

3.3.1 Private & public space

Figure 3.13: *Private & public owned space. (by Author)*



Defining which areas of the selected urban blocks are privately or publicly owned is important information that should be included in the analysis. Private owned areas have a more complex land use diversity because the owners have a certain authority to arrange their land with their ideal spatial structure and land use, create a micro spatial structure within the whole selected urban blocks. Figure 3.13 shows the private/ public owned spaces in the selected urban blocks. Information is obtained from the Dutch cadastre database.
(Source: https://www.pdok.nl/en)



Figure 3.15: *Photo of cars parked on the side of the road inside the selected urban blocks. (by Author)*

3.3.2 (A) Public - Orientation

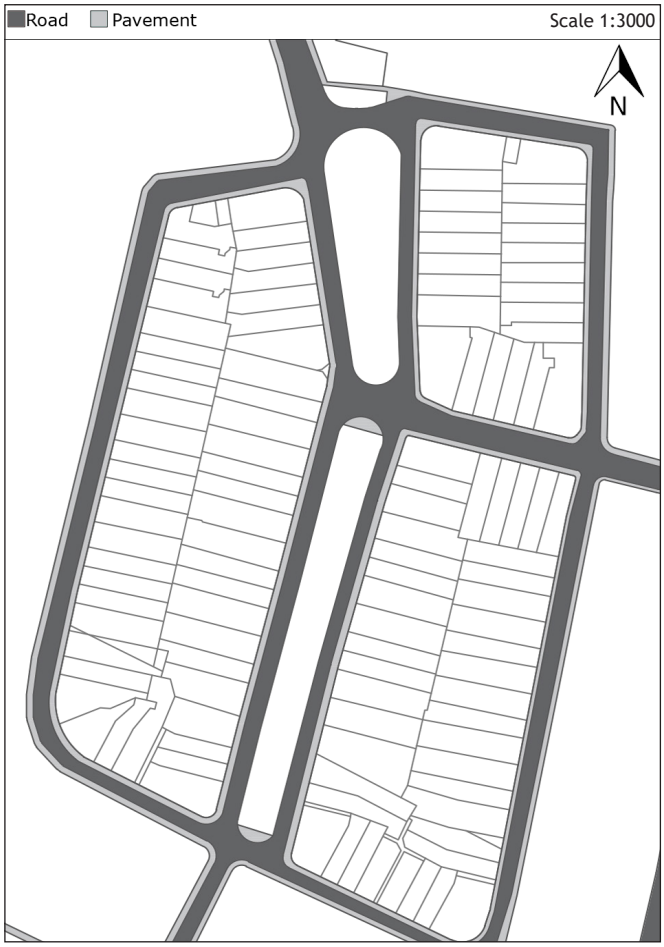
Figure 3.14: *Orientation public space. (by Author)*



Figure 3.14 shows the two orientation directions of the two public grass fields in the centre of the selected urban blocks.

3.3.3 (A) Public - Land use

Figure 3.17: *Roads & pavement. (by Author)*



Road, pavements & parking

The green corridor is surrounded by roads and pavements. Cars are parked on the sides of the roads (pavement side) which is possible due to the width of the roads. Figure 3.16 shows the areas of pavement and roads. The width of the roads variates between 4,5m-6,5m. The width of the pavements variates between 2m-2,5m. Figure 3 shows the parking of cars in the public space.

Vegetation

Figure 3.16: *Green areas (by Author)*



The selected urban blocks is divided by a green space corridor in the middle of the block. The green corridor consists of grass fields, small vegetation and trees. Figure 3.17 shows the dimensions of the vegetation areas and the placement of the trees in the public space.

- Surface 1 is 154m^2.
- Surface 2 is 2134m^2
- Surface 3 is 2403m^2.

(*Numbers are calculated with Autocad)*

3.3.4 (B) Private - Land use

Parcels, buildings & storages

Figure 3.18: *Residential buildings & storages. (by Author)*



Figure 3.18 shows the areas covered by residential buildings and storages. The total surface covered by residential buildings is 11.683 m^2. The total surface covered by storages is 2129 m^2.

Vegetation

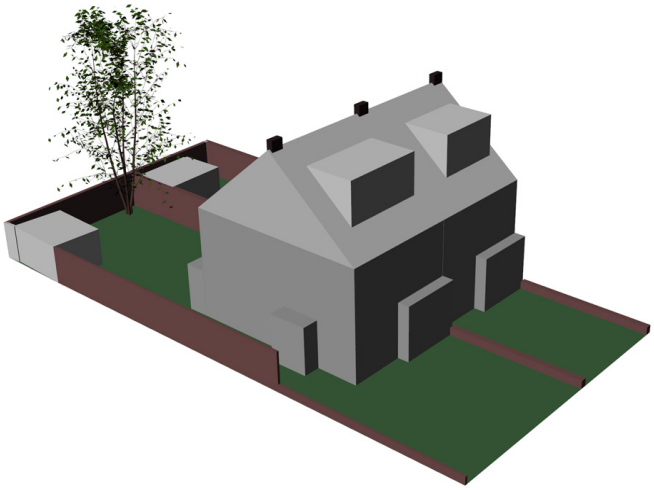
Figure 3.19: *Green in private owned areas. (by Author)*



Figure 3.19 shows the division between the front gardens and the gardens behind the buildings. The gardens are mostly turned inside their block creating more privacy. The trees located on private space are estimated using google maps.

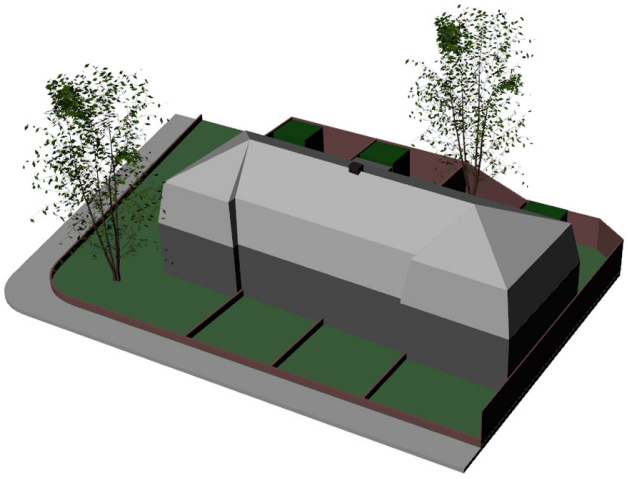
3.3.5 (B) Private - Typology residential buildings

Figure 3.20: *Typology 1 (by Author)*



(Type 1) Most of the buildings in the selected urban blocks are typical row housing. Their geometry is block shaped with a rectangular roof. The roof surface is interrupted by dormers, reducing the amount of roof surface. Their gardens have a storage building in it with sometimes a tree, causing shadows (Figure 3.20).

Figure 3.21: *Typology 2 (by Author)*



(Type 2) In the south of the selected urban blocks there is a different typology row housing. This typology is variating from 2 to 4 connected residential buildings. Their roof shape is more complex for the placement of production panels. (Figure 3.21).

Typology buildings located in the selected urban blocks.

Figure 3.22: *Typology 1 & 2 in the selectec selected urban blocks. (by Author)*



3.3.6 (B) Private - Dimensioning

Roof surface

Figure 3.23: *Roof surfaces of the residential buildings located inside the selected urban blocks. (by Author)*



Figure 3.23 shows the total roof surface. The area of the roof surface is in total 10.570 m^2.

Interruptions

Figure 3.24: *Interruptions in roofs. (by Author)*



Figure 3.24 shows the interruptions in the roof surfaces (dormers and large windows) and the usable roof area for energy production technologies. The total area of the roof interruptions is 1612 m^2. The usable roof surface is therefor: *10570-1612 = 8958 m^2*.

3.3.7 (B) Private - Orientation

Figure 3.25: *Orientation roofs. (by Author)*

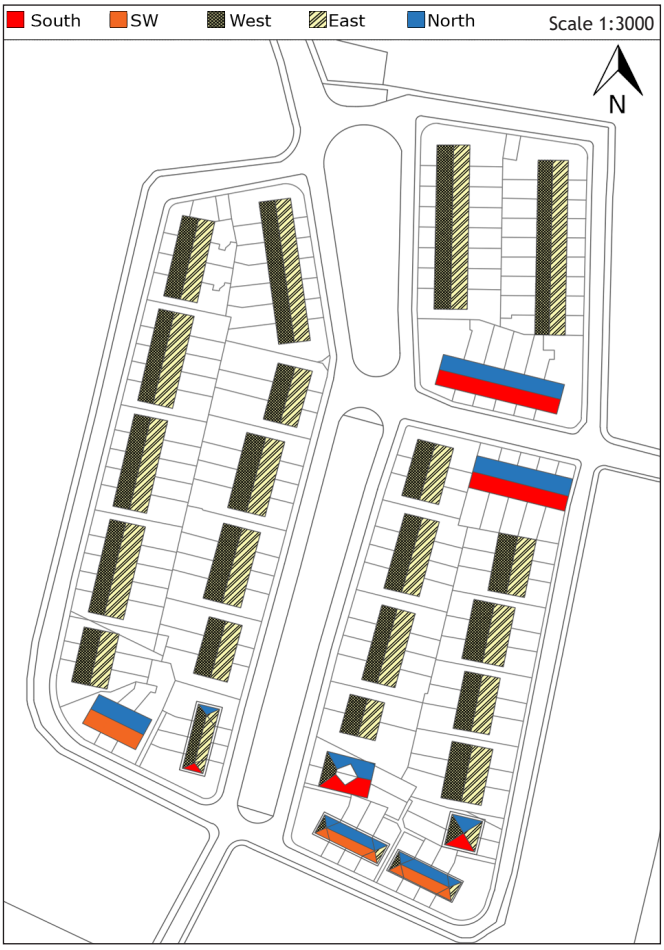


Figure 3.25 shows the orientation of all the roof surfaces in the selected urban blocks. This information is of high value further on in the reseach, due to a higher energy potential ideal situated roofs provide.

3.3.7 (B) Private - Angle/slope

Figure 3.26: *Angles roofs. (by Author)*



Figure 3.26 shows the angle of all the roof surfaces in the selected urban blocks. This information is further on in the reseach of high value due to a higher energy potential of 45 degrees angled roofs.

3.3.8 Shadows (private & public)

Shadow will cause a reduced efficiency of the solar energy production technologies and will therefore be included in the spatial analysis. Areas covered with higher shadow density will not be used for the placement of energy production technologies. A distinction will be made between three types of shadows.

1. Shadow caused by shape and size of the buildings
These shadows are created by the shape and the height of the buildings located in the selected urban blocks. Figures 3.23-3.26 illustrate a merged image of shadows of two time frames on the same date.

2. Shadow caused by vegetation
Shadow caused by vegetation, mostly trees, is important to analyse for both public and private space. In the public space large trees are located, causing shadow in public and private areas. In the private space we are interested in the shadows caused by trees in the gardens, especially on the storage buildings also located in the gardens. This analysis is illustrated in figures 3.27-3.34.

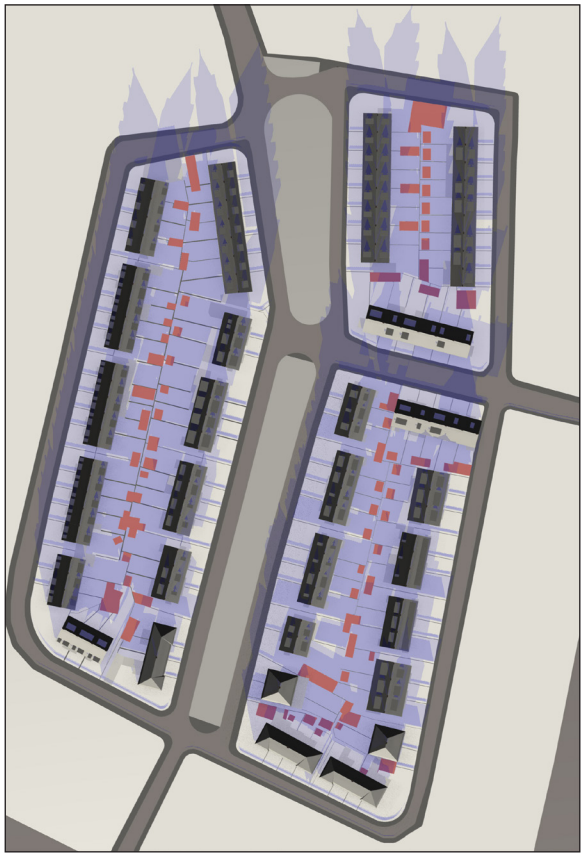
3. Shadow caused by interruptions/dormers on the roofs
Almost all the building have dormers crossing the roof surfaces. They not only reduce the roof surface available for possible energy production but they also cause shadows next to them. Especially the areas between two dormers are interesting to analyse. It will answer the question if placement of solar energy production technologies is feasible between two dormers (in different orientation directions) or is there to much shadow. Figures 3.35-3.42 illustrate the two main orientation directions of the row housing and their shadow at 13:00.

It can be concluded that the dormers on the NE/SW orientated buildings cause too much shadow in the areas between the dormers, which makes the placement of a production technologies unadvisable in these areas.

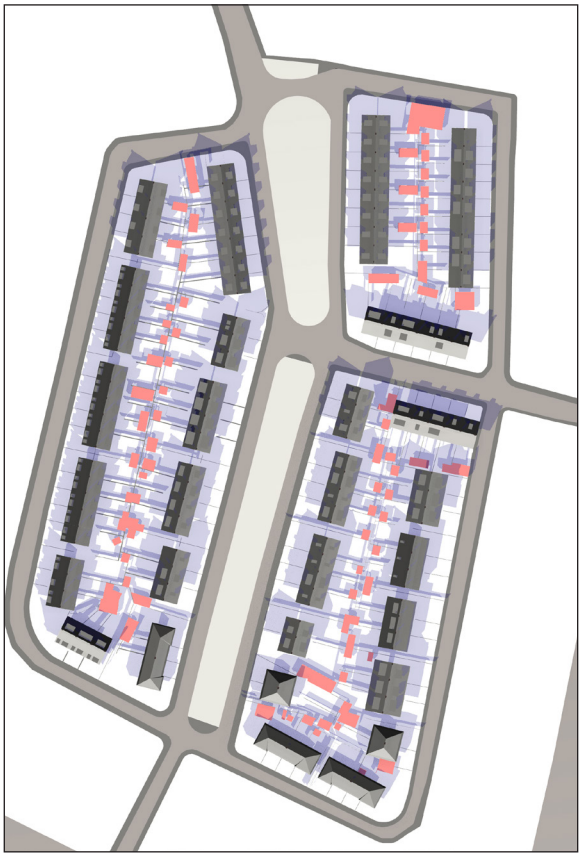
About the West/East orientated buildings could be concluded that placement of production technologies next to the dormer is no problem because hardly any shadows will interrupt the energy production process.

1. Shadow caused by shape and size of the buildings. **Figures 3.27-2.30:**

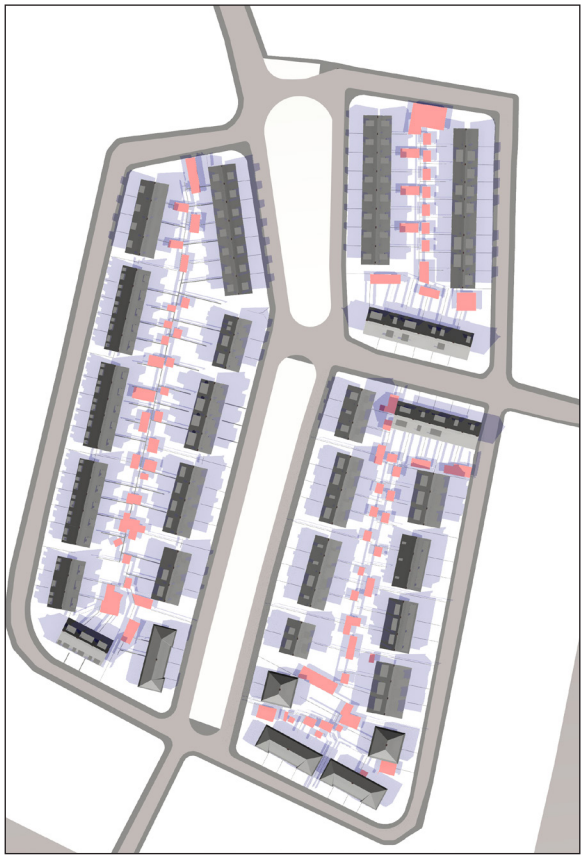
1 January 12:00/14:00



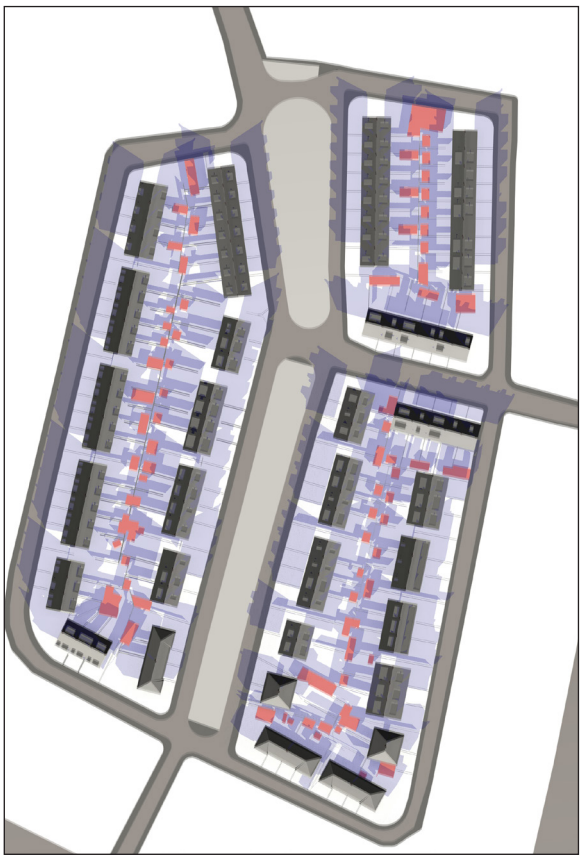
1 April 11:00/15:00



1 July 10:00/16:00



1 October10:00/15:00



2. Shadow caused by vegetation **Figures 3.31-2.34:**

1 January 12:00



1 January 14:00



1 April 11:00



1 April 15:00



Figures 3.35-2.38:

1 July 10:00



1 July 16:00



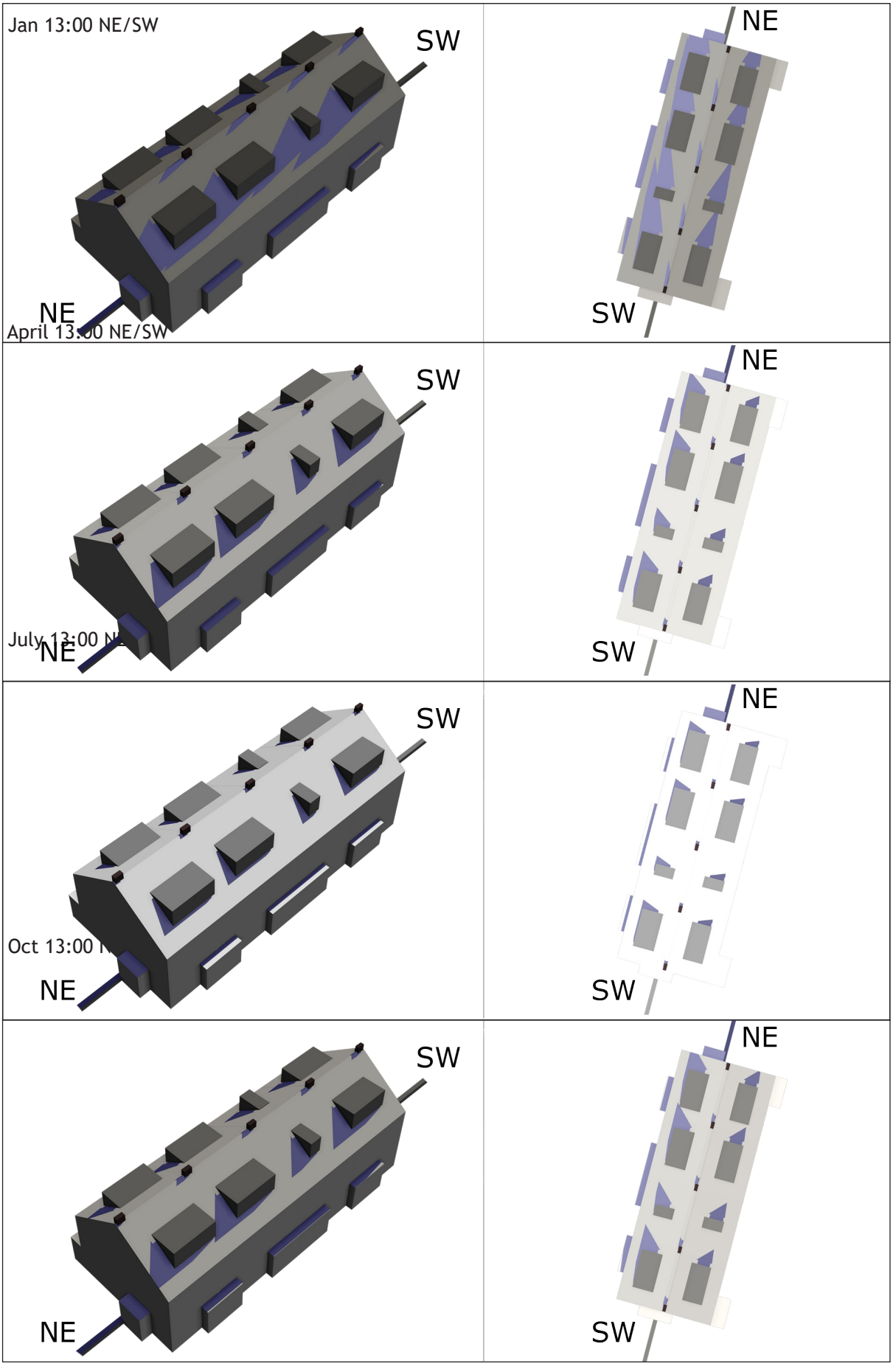
1 October 10:00



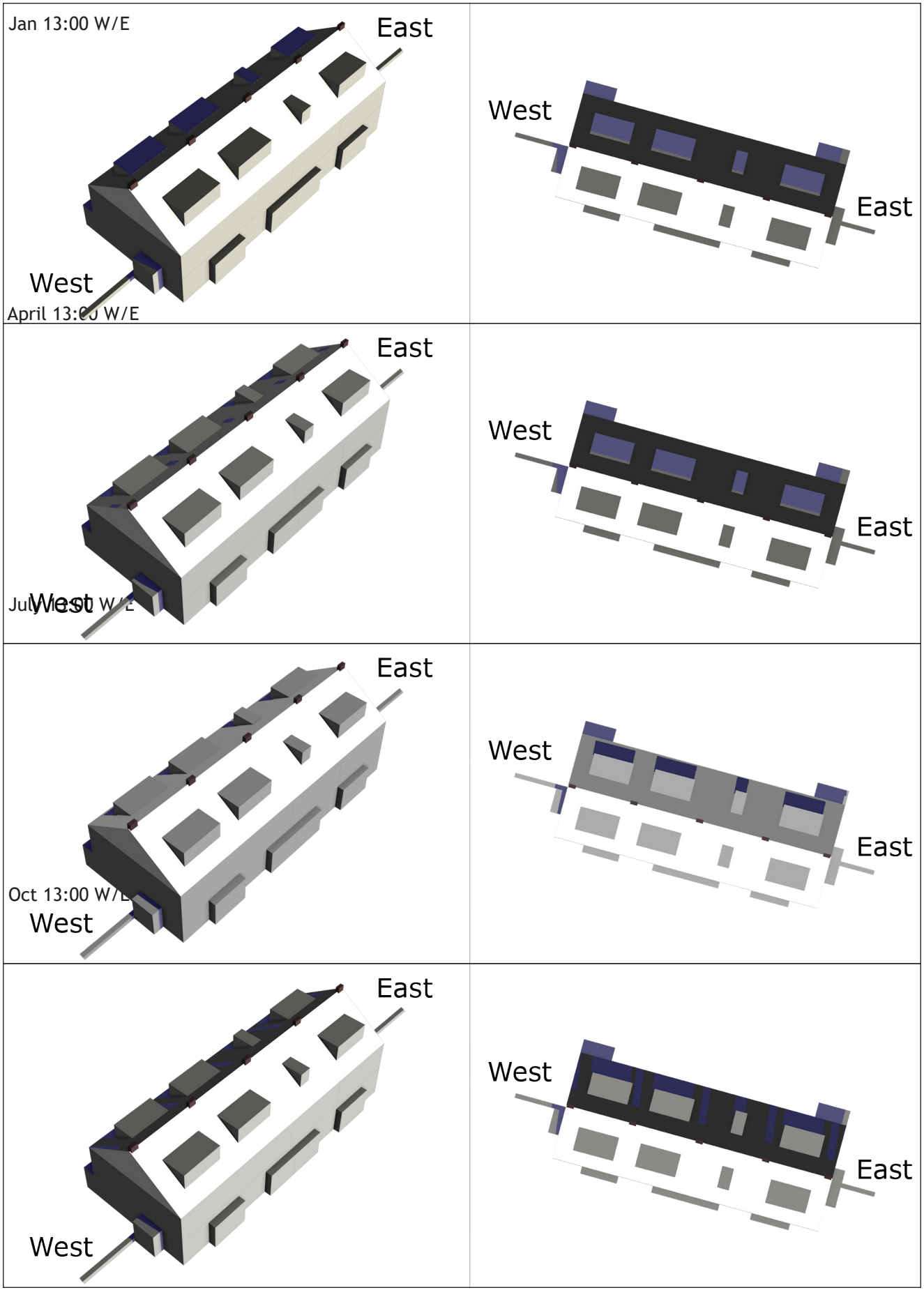
1 October 15:00



3. Shadow caused by interruptions/dormers in the roofs **Figures 3.39-2.42:**

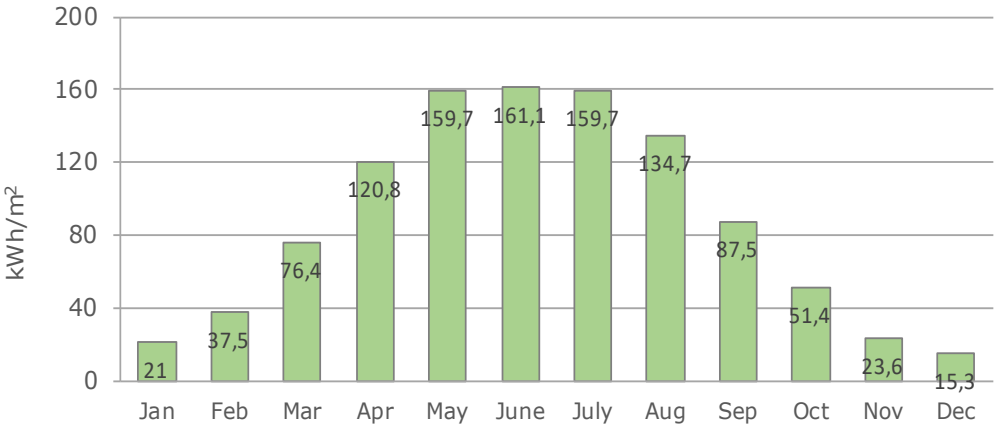


Figures 3.43-2.46:

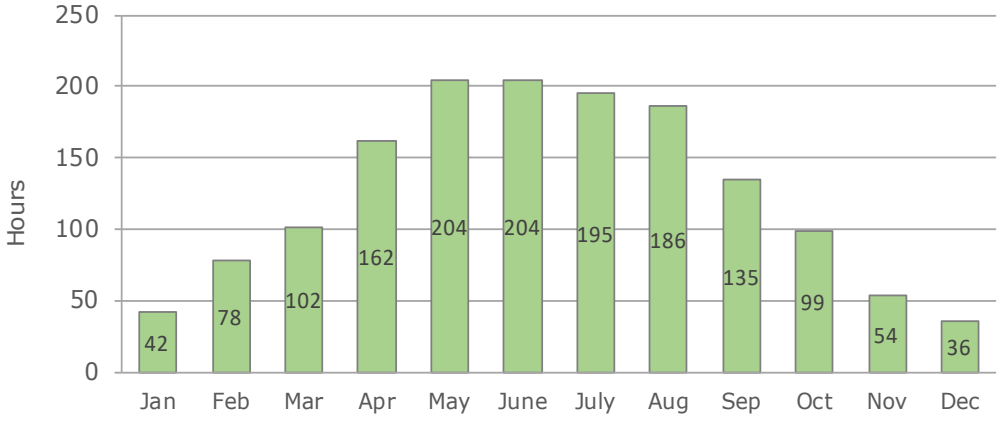


3.4 Solar irradiance

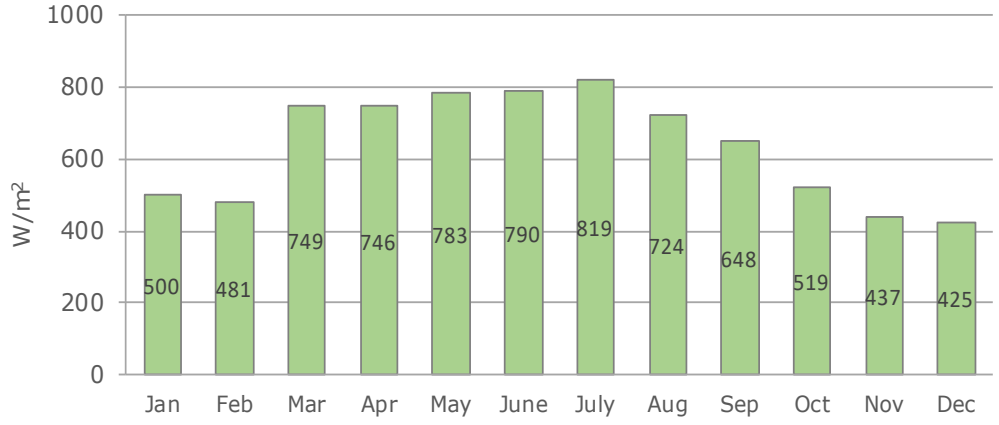
The KNMI measured the monthly total solar irradiance in metrological stations from 1981 until 2010, providing an accurate monthly average solar irradiance number that will be used for the calculations in this master's thesis. KNMI provides maps for each month of the year as illustrated in Figure 3.47. KJ/cm² will be converted to kWh/m² by dividing with 0.36 (Van Sark & Schoen, 2016). All twelve months combined results in the following graph:



The KNMI also measured the monthly solar hours for twenty years, Figure 3.49. Combining all months results in the following graph:



Interesting for the research is the power of the sun on the surface during solar hours. These are the hours in which the energy production panels produce energy. The total solar irradiance in kWh/m² is multiplied by 1000 and divided by the amount of solar hours in that month. This results in the average solar irradiance during solar hours in w/m². The following graph provides the average monthly useful solar irradiance[1]:



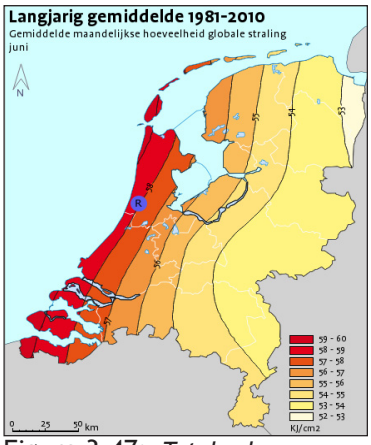


Figure 3.47: *Total solar irradiance in June in the Netherlands. (KNMI)*

Figure 3.48: *Monthly solar irradiance in Ramplaankwartier on flat surface. (Annual 1049 kWh/m²)*

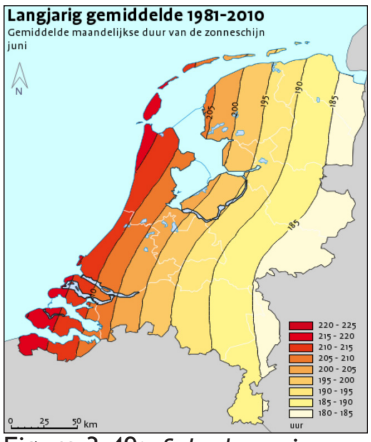


Figure 3.49: *Solar hours in June in the Netherlands. (KNMI)*

Figure 3.50: *Monthly solar hours in Ramplaankwartier. (Annual 1497 hours)*

Figure 3.51: *Average solar irradiance per month during solar hours in Ramplaankwartier[1].*

3.5 Ambient temperature

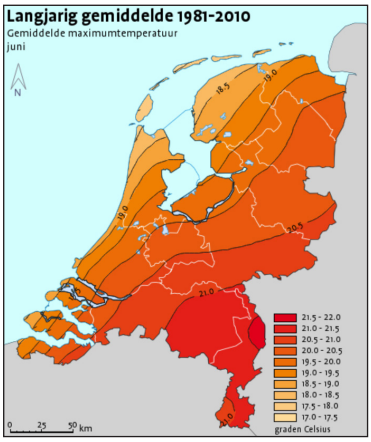


Figure 3.52: *Maximum temp. in June. (KNMI).*

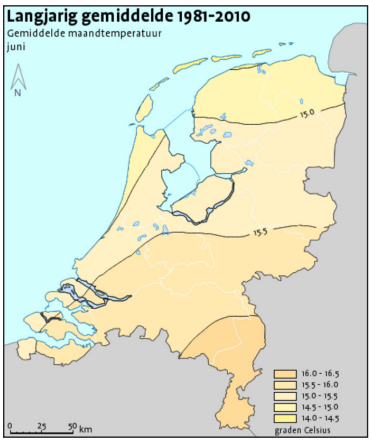


Figure 3.53: *Average temp. in June. (KNMI).*

The average ambient temperature for the specific location Ramplaankwartier is determined by the measurements done by the KNMI. Metrological stations measured temperatures from 1981 until 2010 which provides an accurate estimation to determine the average ambient temperature for Ramplaankwartier. KNMI provides the following maps for each month of the year. One map shows the average temperature and the second maps shows the maximum average temperature. We are interested in the average temperature at day time, because solar energy is produced in those hours and the most energy is used. The average monthly temperature during day time is not publically available in the Netherlands and therefore we derive this monthly temperature as follows: It is derived by taking the mean value of the average temperature and the maximum temperature. The results is illustrated in the following graph:

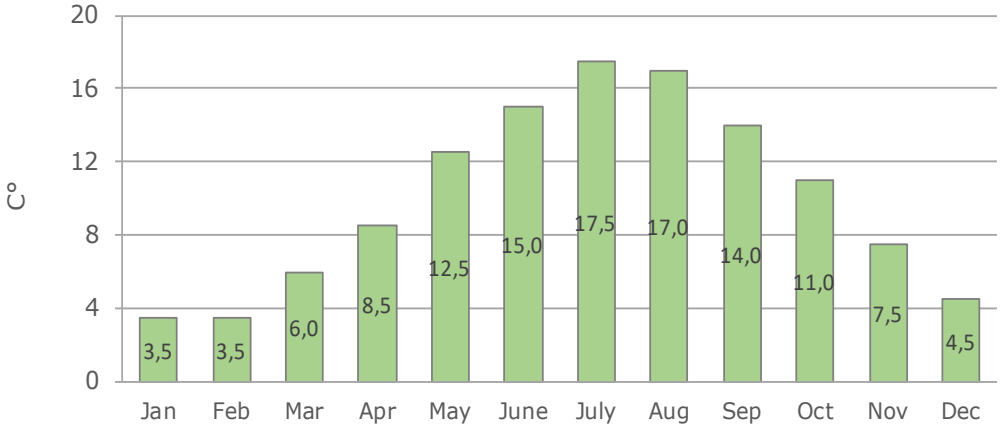


Figure 3.54: *Average Temp. (by Author)*

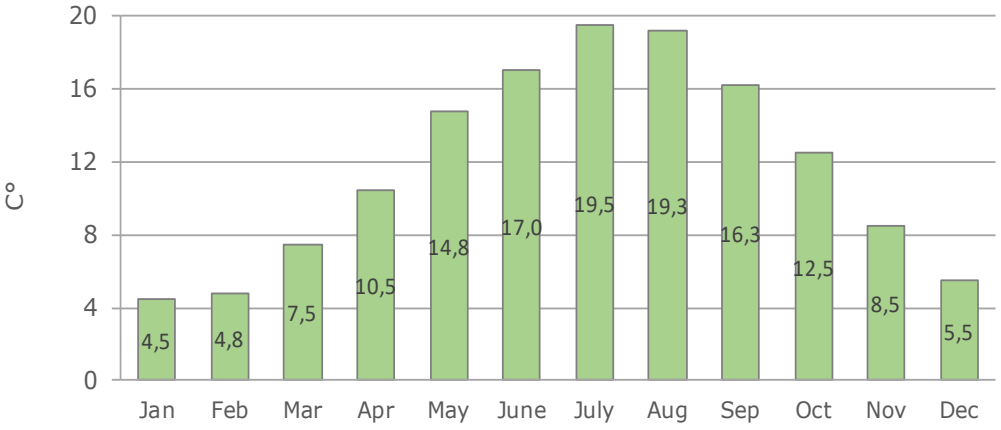


Figure 3.55: *Estimated average day time temp. (by Author)*

(1) In a late stage of the project a calculation mistake was discovered. The solar hours obtained appear to be on the low side in the winter months. The KNMI data calculated full hours where the sun is strong instead of the total monthly solar hours. This resulted in a value for the average solar irradiance per month that is too high. The efficiency percentage of the solar collectors and PVT are therefor too high in winter as well. The total solar irradiance per month obtained from the KNMI is also to low. Because the efficiency is applied with the total monthly solar irradiance on flat surface this calculation mistake is hardly noticeable in the results. The calculation mistake has no further influence on the rest of this research.

3.6 Questionnaire inhabitants

The following questionnaire was filled in by 15 buildings. The results of the questionnaire will be discussed at the end of this paragraph. The conclusions of the questionnaire will be used for the setup of the configurations (**C**).

Configurations **C**: *What are the energy potentials with minor spatial impact & the inhabitants interests and wishes for an energy transition in their neighbourhood. (Q5.3)*



Figure 3.56: *Vegetation selected urban blocks (by Author)*



Figure 3.57: *Parking selected urban blocks (by Author)*



Figure 3.58: *Public space for functional purposes (by Author)*



Figure 3.59: *Example PV roof covering parking space in public space.*



Figure 3.60: *Example commonly applied placement of panels on roofs using PV.*

3.6.1 Questionnaire

(1) *Are you satisfied with the amount of usable public space in your neighborhood?*
- o **More** useful public space may be added.
- o It may **remain** as in the current situation.
- o There may be **less** useful public space

(2) *Are u satisfied with the amount of public vegetation and green in your neighborhood?*
- o **More** vegetation and green may be added to the public space.
- o It may **remain** as in the current situation.
- o There may be **less** green and vegetation in the public space.

(3) *What is your opinion about the amount of trees in your neighborhood?*
- o **More** trees may be added.
- o It may **remain** as in the current situation.
- o There may be **fewer** trees.

(4) *Are you satisfied with the amount of parking space in your neighborhood?*
- o **More** parking spaces may be added.
- o It may **remain** as in the current situation.
- o There may be **fewer** parking spaces.

(5) *Are you satisfied with the amount of public space that can be used for functional purposes? (For example, children's playgrounds, & meeting places)*
- o There may be **more** public space for functional purposes.
- o It may **remain** as in the current situation.
- o There may be **less** public space for functional purposes.

(6) *What is your opinion on the placement of visible technologies for sustainable energy generation in the public space?*
- o I am a **supporter** of this idea.
- o I have **no opinion** about this.
- o I am an **opponent** of this idea.

(7) *What is your opinion about the amount of visible technologies for sustainable energy generation placed on buildings? (For example, solar panels)*
- o **More** visible technologies for sustainable energy generation may be placed on buildings, **including** my own building.
- o **More** visible technologies for sustainable energy generation may be placed on buildings, **not** on my own building.
- o It may **remain** as in the current situation
- o There may be **less** visible technologies for sustainable energy generation placed on buildings.
- o **No** visible technologies for sustainable energy generation may be placed on buildings.

3.6.2 Results questionnaire

The questionnaire was filled in by 15 buildings. The following illustrations (Figures 3.61-3.67, by Author) show the results of the questionnaire. In the legend the amount of buildings that answered the specific answer is included.

(1) Are you satisfied with the amount of usable public space in your neighborhood?

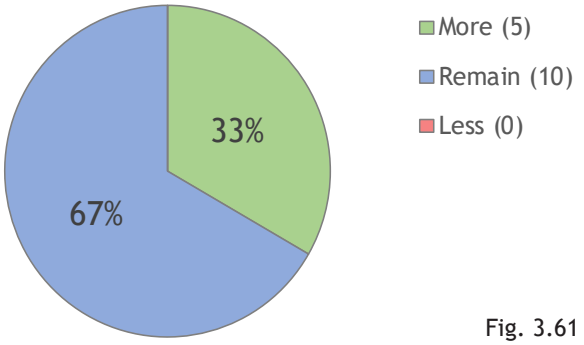


Fig. 3.61

(2) Are u satisfied with the amount of public vegetation and green in your neighborhood?

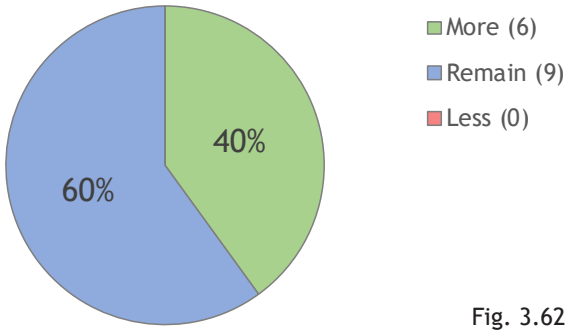


Fig. 3.62

(3) What is your opinion about the amount of trees in your neighborhood?

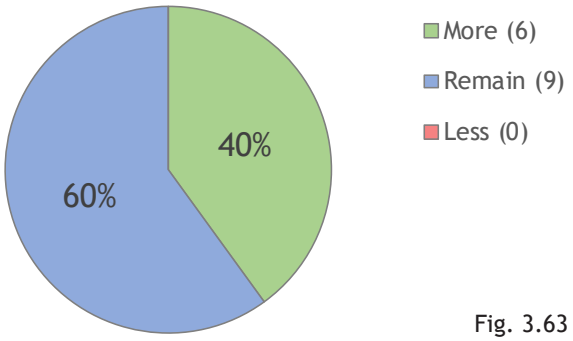


Fig. 3.63

(4) Are you satisfied with the amount of parking space in your neighborhood?

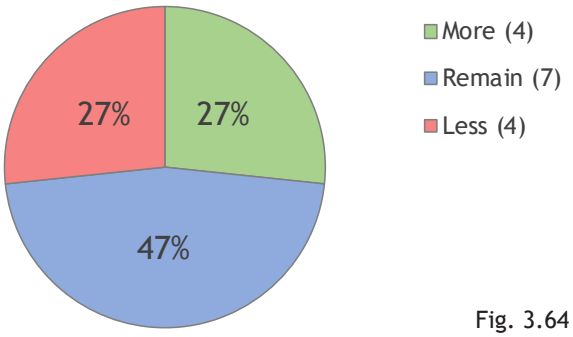


Fig. 3.64

(5) Are you satisfied with the amount of public space that can be used for functional purposes?

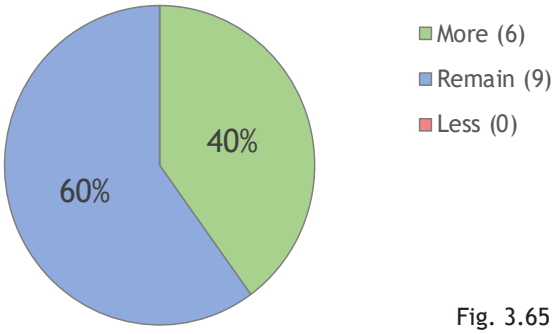


Fig. 3.65

(6) What is your opinion on the placement of visible technologies for sustainable energy generation in the public space?

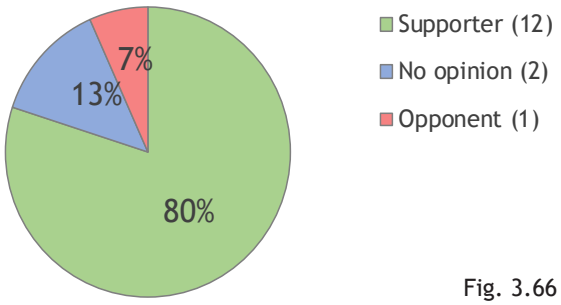


Fig. 3.66

(7) What is your opinion about the amount of visible technologies for sustainable energy generation placed on households?

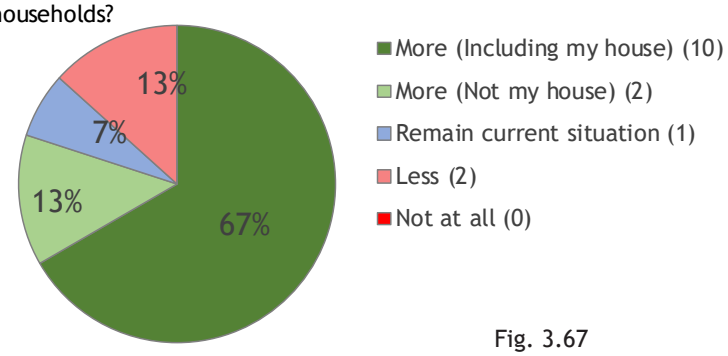


Fig. 3.67

3.6.3 Findings questionnaire

The results of the questionnaire will determine the final choices made in the set-up of the configurations (C). These configurations are aiming for minor visual and spatial impact to the urban bock after the integration of the renewable energy system. The results of the questionnaire make clear that the inhabitants wish to have more/remain as it is: Usable public space, green, trees & areas for public functions. Configurations (C) will aim to integrate these inhabitants wishes.

Secondly the opinions about the amount of parking space in the selected urban blocks differ. 27% wants more parking space, 27% less and 47% wants to remain the amount of parking space in the current situation. Based on these results the configurations (C) will have the same amount of parking space as in the current situation. The answers on the question about the integration of renewable energy technologies in the public space (6) result in the conclusion that 80% of the inhabitants are supporters of this idea. Because the parking spaces need to be integrated in the new urban design we combine this fact with the integration of renewable energy technologies. All the configurations (C) will therefore have covered parking spaces with integrated renewable energy production technologies.

Thirdly approximately 74-80% of the residential buildings in configurations (C) will be used to place renewable energy production technologies on the roof. 67% of the inhabitants are supporters of the integration of renewable technologies on their roof and 13% would agree with more visual renewable technologies on the roofs but not on their own roof. 7% of the inhabitants want the situation to remain as it is. Some buildings in the selected urban blocks already have integrated renewable energy production on their roof, so this group is not against the placement of these technologies on roofs. 13% of the inhabitants answered that they want to see less renewable technologies integrated on roofs. Since only a few buildings in the current situation have renewable technologies on their roof, we can conclude they won't support an increase in placement of these technologies and therefore their buildings won't be used for the placement of these technologies in the (C) configurations.

4 CALCULATION & ASSESSMENT

This chapter will discuss all the energy & spatial characteristics of the technologies necessary for the correct set up of the technical configurations. First the current heat demand of the residential buildings in Ramplaankwartier will be converted to a heat demand after possible feasible renovations. Secondly the solar energy output of the selected technologies are analysed for possible implementation in the selected urban blocks. These results will be compared on their energy potential to determine which technologies are advantageous to be implemented in the selected urban blocks. These potentials are visualized to provide the first insights of the spatial influence they will cause. Thirdly the storage potentials of the selected urban blocks are investigated and visualized in this chapter. A comparison of these results will determine which storage type and technology is best suited to be integrated in the selected urban blocks. These research steps will be followed by an example calculation of a technical configuration. This calculation method will be used for all the 10 configurations integrating a renewable energy system in the selected urban blocks.

This chapter will be concluded with the assessment indicators that will be applied to the results of the 10 configuration designs. These indicators are divided in quantitative indicators that are used to analyze the spatial and energy performance results of the configurations in figures. Secondly an outline is provided for perceptual indicators that will be used during an information evening with the inhabitants. This outline should results in a perceptual analysis of the visual impact that the different configurations could have if they would be implemented in the selected urban blocks.

4.1 Heat demand after feasible renovations

4.1.1 Monthly gas usage for space heating/DHW after feasible renovations.
Chapter 3.2 and Figure 3.11 provided the overview of the energy labels in the selected urban blocks. Energy labels E,F & G are the most common in the selected urban blocks. We assume that all the household will be renovated to energy label C in the future. A higher energy label than C might be too complex to reach with these old households (Itard, Majcen, & Visscher, 2013).

In a recent study (Bourdic, Salat, & Nowacki, 2012), chapter 2.2, the differences in gas usage between energy labels are discussed. That information is used in the following calculation which includes an improvement to a HR-kettle:

Example:
The difference in gas consumption between energy label D and C is 200m^3 as discussed earlier. Energy label improvement from D to energy label C equals a gas usage reduction of 13.33%.

Percentage gas usage reduction: $100 - ((\frac{1300}{1500}) \times 100) = 13{,}33\%$

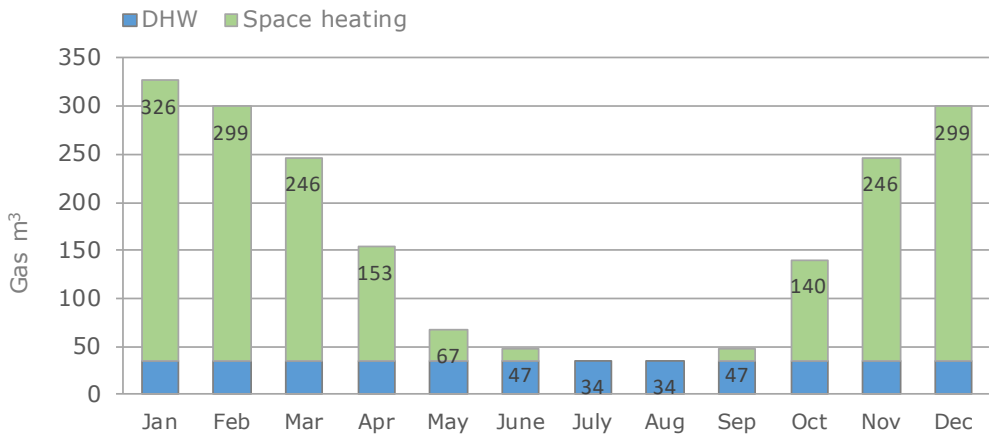
This will be done for the following energy label improvements : F-C, E/F-C & E-C.

Percentage gas usage reduction (F to C): $100 - ((\frac{1300}{1800}) \times 100) = 26{,}78\%$

Percentage gas usage reduction (E/F to C): $100 - ((\frac{1300}{1750}) \times 100) = 25{,}71\%$ kWh

Percentage gas usage reduction (E to C): $100 - ((\frac{1300}{1700}) \times 100) = 23{,}53\%$ kWh

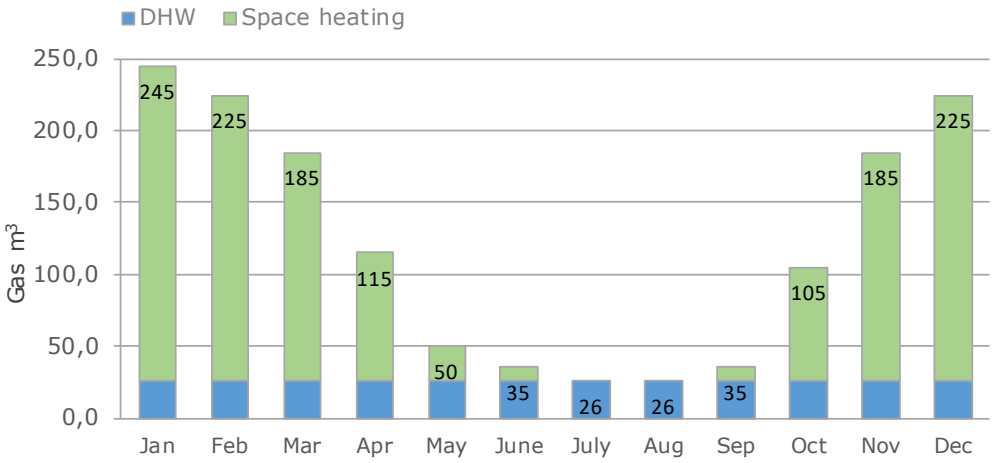
Reducing the total monthly gas values calculated in chapter 3.1 with the above percentages, results in the reduced gas use if all the buildings are upgraded to energy label C. To make the calculation easier we use a recuduction of 25% of the gas use for all buildings, the rounded mean reduction value of the energy label improvement calculations



(Energy label E/F)

Figure 4.1: *Ramplaankwartier average monthly gas usage per building for space heating and DHW. (by Author) (same as fig. 3.10)*

Figure 4.2: *Total average monthly gas use in Ramplaankwartier per building, if improved to energy label C.*



.1.2 Total monthly heat demand for the selected urban blocks.

Gas use to heat demand

The gas usage calculated in the previous paragraphs is not the exact heat demand that must be supplied for the residential buildings There is a difference between the amount of gas that is used by the buildings and the actual heat demand. This is caused by the efficiency of the kettle. It is most likely that an upgrade to energy label C includes an upgrade of the kettle to a HR-kettle. HR-kettles have an estimated efficiency of 90% (Duurzaam thuis, n.d.).

The monthly gas demand in m^3 will be converted to kWh thermal heat demand. First the gas m^3 is multiplied by 33,9 to make MJ (value for gronings gas). Secondly the MJ is divided by 3,6 to make kWh. 90% of the used gas is transformed into thermal heat and therefore 10% losses are reduced from the converted value.

Example:

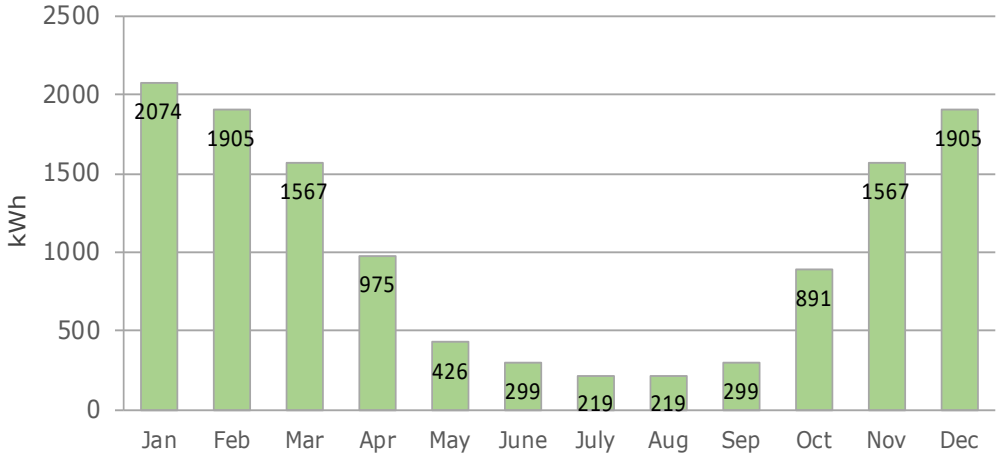
The gas use in the month March for an building that is upgraded from energy label F to C is 185m^3. This equals the following heat demand:

185m^3 gas = (185*33,9)/3,6 = 6272 MJ = 1742 kWh

10% losses due to the kettle efficiency: 1742*0,9 = 1568 kWh net heat demand.

Doing this for all three energy label upgrades results in the following average monthly heat demand, for a building in Ramplaankwartier with a assumed energy label C

Figure 4.3: *Total monthly heat demand in Ramplaankwartier per building, if improved to energy label C.*



The total amount of buildings in the selected urban blocks is 113, Figure 4.4. If we combine the amount of buildings with their estimated energy label and multiply these values, we get the total heat demand of all three sub blocks within the total selected urban blocks, Figure 4.6. Combining all three sub blocks provides us the total monthly heat demand of all 113 buildings in the selected urban blocks. The total annual heat demand of the selected urban blocks is 1,375 x10^6 kWh. The monthly values for all 113 buildings are illustrated in Figure 4.6.

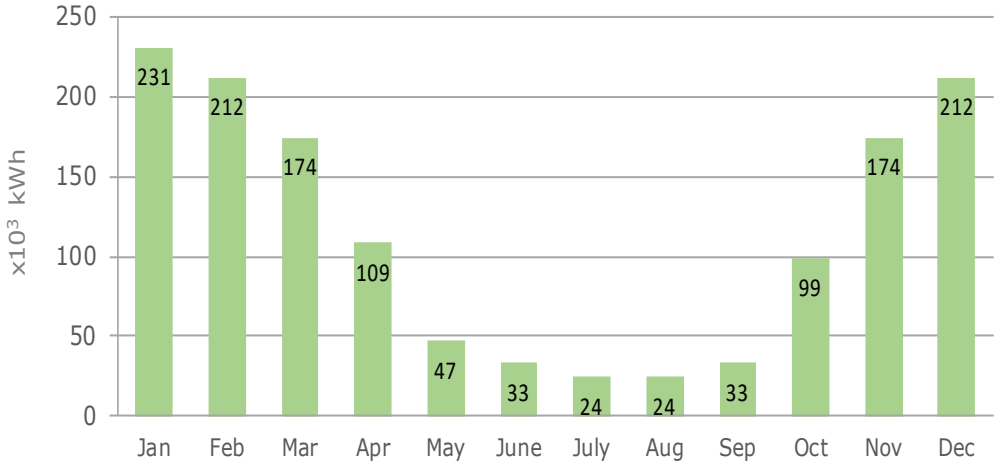


Figure 4.4: *Total monthly heat demand 113 buildings in Ramplaankwartier.*

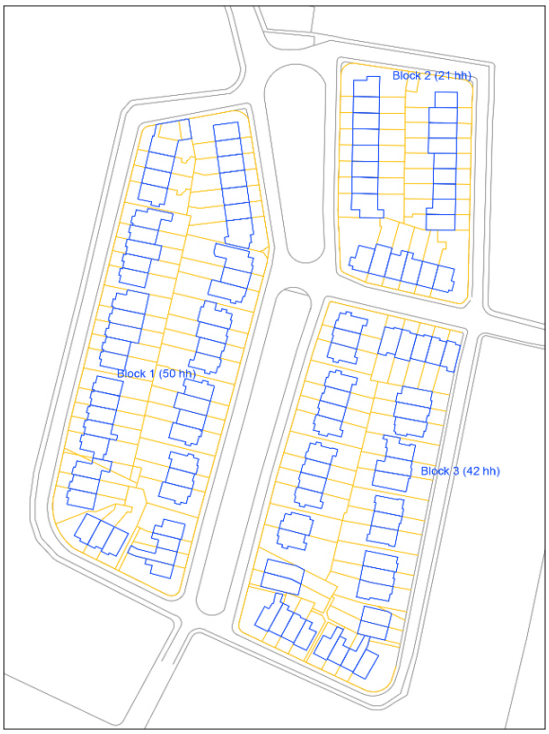
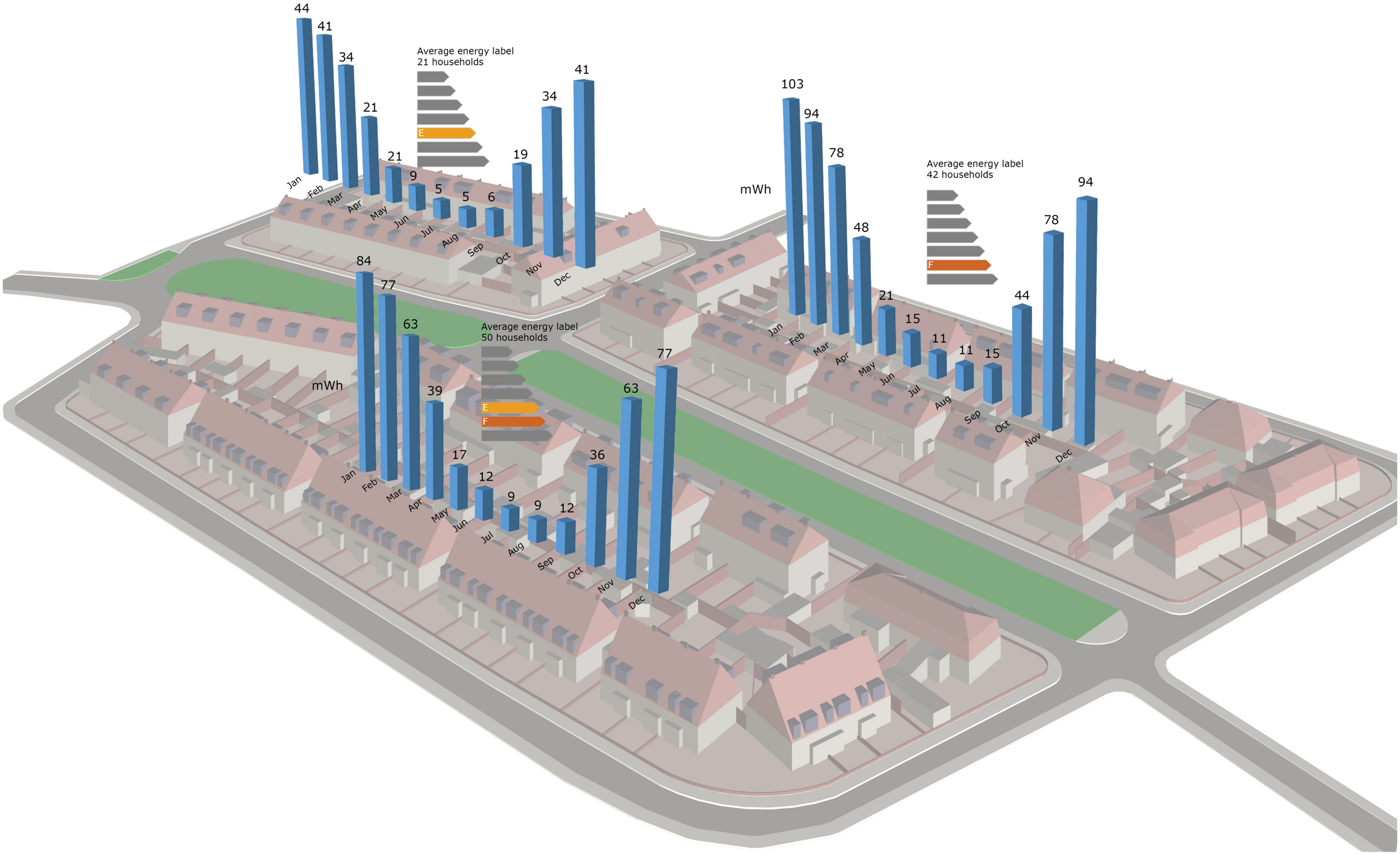


Figure 4.5: *Total amount of buildings in the selected urban block. (by Author)*

Figure 4.6: *Total heat demand divided over the three sub blocks. (by Author)*



4.2 Energy and spatial characteristics

The calculated heat demand of the 113 buildings in the selected urban blocks will be matched with the energy potentials of the selected urban blocks. The spatial characteristics of the selected urban blocks were analysed in chapter 3 and will be combined with the technical and spatial properties off the selected technologies to derive the energy potentials of the selected urban blocks. The sub question answered in this paragraph:

(Q3.2) How can the energy and spatial characteristics of relevant technologies be calculated?

The following technologies will be discussed:

Solar energy production technologies

General characteristics

- (A) Solar irradiance
- (B) Efficiency area
- (C) Panel placement

Photovoltaic systems

- (D) Si-Monocrystalline PV
- (E) Thin film – cadmium telluride

Solar collectors

- (F) Evacuated tube collector
- (G) Flat plate collector

PVT (H)

Thermal energy storage

Sensible thermal energy storage

- (I) Pit storage (water)
- (J) Tank storage (water)

Latent thermal energy storage

- (K) Tank storage (Salt)

Distribution losses

4.2.1 Solar energy production technologies

General characteristics

(A) Solar irradiance

The monthly solar irradiance in Haarlem was analysed in chapter 3.4.
The solar irradiance value is different for different orientation directions of angled roofs compared to the solar irradiance on a flat surface. In a recent study (Allendorf, 2009) the difference in solar irradiance that is absorbed by a surface in different orientations or angles is described. This is illustrated in Figure 4.7. Example: solar irradiance on a flat surface in August 134,7 kWh/m² per month. South 45° is +10%, making it 148 kWh/m² per month.

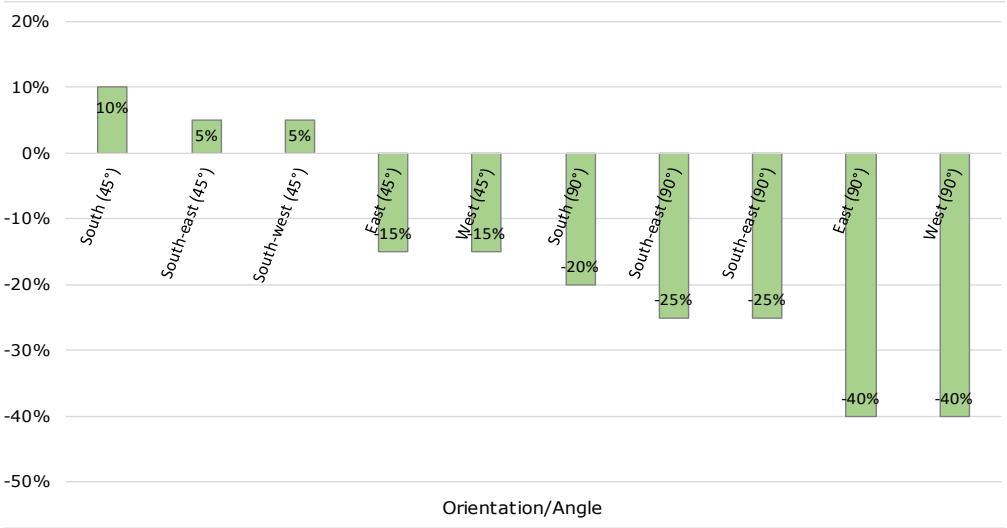


Figure 4.7: *Solar irradiance percentage differences. (Allendorf, 2009)*

(B) Efficiency area

As mentioned in chapter 2.4.4 the spatial properties of the solar energy production technologies are an important aspect of this research. The spatial properties used in this chapter are the total panel sizes also called the gross area. Therefore the efficiency percentage used is lower compared to the product specifications of a solar panel. Companies mostly use the aperture area of a solar panel to describe the efficiency.

We are interested in the gross area efficiency of the solar collectors. Because this is the ratio of the spatial footprint and its matching energy potential. The aperture area is divided by the gross area to calculate the ratio between these two numbers. The maximum efficiency is multiplied with this ratio to calculate the operational efficiency of the solar collector.

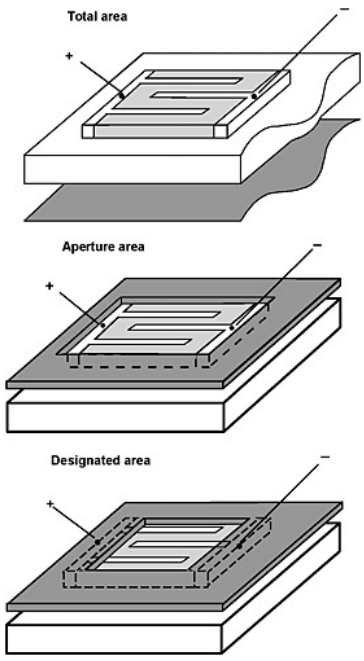


Figure 4.8: *Sizing solar panels. (Honsberg & Bowden)*

(C) Panel placement

The spatial footprint of panel on a flat surface is different compared to a panel that is placed under an angle as visible in Figure 4.9. If placed under a slope, there should be a distance between the rows of solar collectors to prevent shadows from underperforming of the solar collectors. The angle of the slope that is used to place a panel under and the height of the sun combined will determine the distance that should be handled between placing several panels in a row behind each other. As visible in the illustration an angled solar panel has smaller spatial footprint compared to the flat placed solar panel. Another advantage of the angled solar panel is the extra solar irradiance the panel collects and converts into energy.

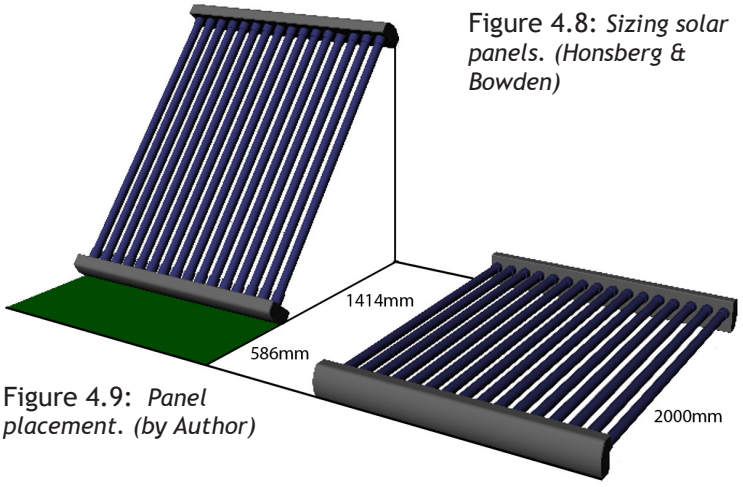


Figure 4.9: *Panel placement. (by Author)*

Photovoltaic systems

The electrical energy production of a PV panel can be calculated with the following formula:

*Energy (kWh): Solar panel Area*Efficiency*Solar radiation (kWh/m²)*PR*
E (kWh) = A*r*H*PR
A = The total collector area in m²
r = Efficiency PV panel in %
H = The monthly solar irradiation on the solar collector in kWh/m²
PR= Performance ratio
According to the website :(http://photovoltaic-software.com/PV-solar-energy-calculation.php)

The PR (performance ratio) is a rating for the quality of the PV system independent of the orientation of the solar panels. Losses included in the PR are: Inverter losses, Temperature losses, DC cables losses, AC cables losses, shading, and losses at weak radiation. Research about the PR in the Netherlands resulted in an average PR of 0,85 (Van Sark & Schoen, 2016).



Figure 4.10: *Si-Monocrystalline solar panel*

(D) Si-Monocrystalline solar panel
The following monocrystalline solar panel is selected for this research: YLM 60 CELL
The panel is produced by Yingli solar and has the following properties:

Length: 1640 mm
Width: 990 mm
Height: 35 mm
Gross Area: 1.624 m²
r = 17,9 % (Gross area efficiency)

Website: http://d9no22y7yqre8.cloudfront.net/assets/uploads/products/downloads/DS_YLM60Cell-30b_35mm_EU_EN_20170615_V04.pdf

Annual energy production 1 panel (South 45°): 285 kWh

Figure 4.11: *Annual energy potential 1 panel, South & 45° angled. Monthly solar irradiance values of chapter 3.3 + 10% due to orientation and angle. (by Author)*

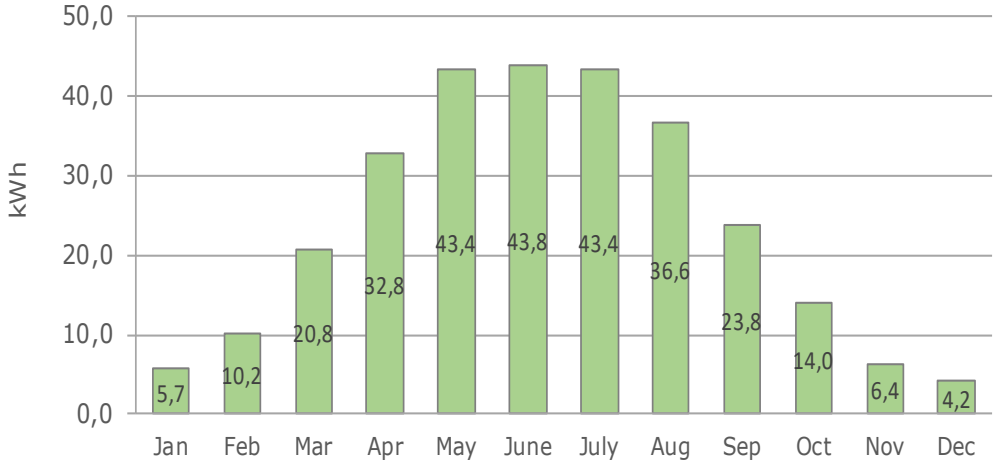


Figure 4.12: *Thin film - cadmium telluride solar panel.*



(E) Thin film - cadmium telluride
The following thin film PV panel is selected for this research: FIRST SOLAR SERIES 6
The panel is produced by First solar and has the following properties: Dimensions:

Length: 2009 mm
Width: 1232 mm
Height: 48,5 mm
Gross Area: 2,47 m²
r = 17,0 % (Gross area efficiency)

Website: http://www.firstsolar.com/en-EMEA/Modules/Series-6

Annual energy production 1 panel (South 45°): 412 kWh

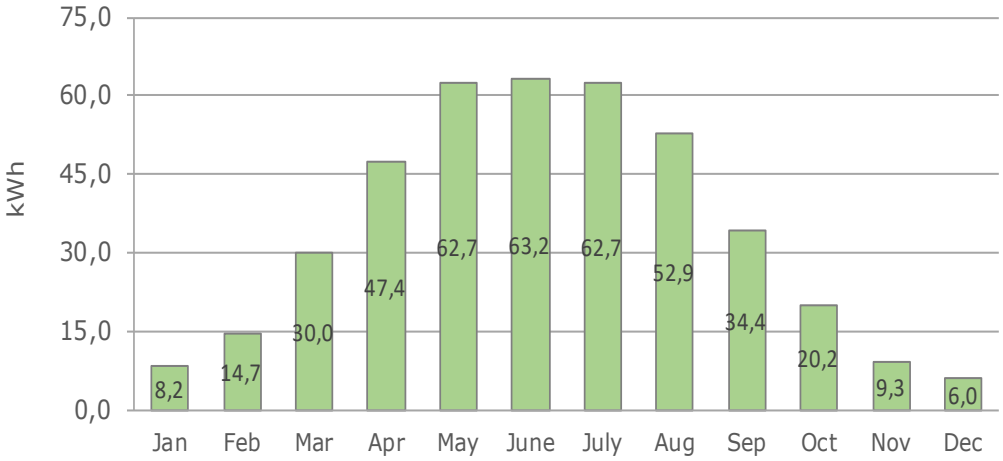


Figure 4.13: *Annual energy potential 1 panel, South & 45° angled. Monthly solar irradiance values of chapter 3.3 + 10% due to orientation and angle. (see fig 4.7)(by Author)*

Solar collectors

The thermal heat output of a solar collector can be calculated with the following formula:

---

*Energy (kWh) = Collector Area*Collector efficiency*Solar radiation*

E (kWh) = A*r*H

A = The total collector area in m^2

r = Monthly efficiency solar collector in %

H = The monthly solar irradiation on the solar collector in kWh/m^2

(Allendorf, 2009)

Efficiency solar collector

The most important value we want to determine is the efficiency of the solar collector. With a low efficiency due to product specifications or external influences such as a cold ambient temperature, the energy potential might be low compared to other solar energy production technologies. The efficiency value will be used to calculate the energy output of the solar collector, monthly and annually.

The following values are necessary to determine the efficiency value of a solar collector:

- Inlet temperature
- Outlet temperature
- Ambient temperature
- Optical efficiency
- Heat loss corrections
- Solar irradiance

The solar irradiance striking the solar collector is reduced by two properties; optical losses & thermal losses.

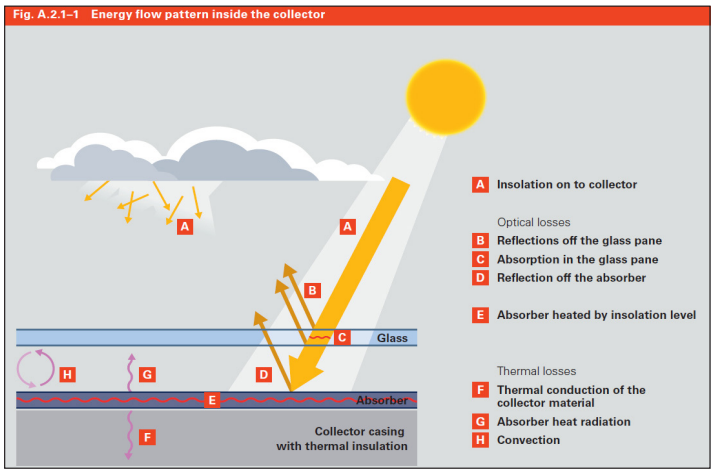


Figure 4.14: *Overview solar irradiance transformed into heat energy and the losses occurring. (Allendorf, 2009)*

The manufactures of solar collectors provide the optical efficiency of their systems. This optical efficiency is determined by the amount of solar irradiance hitting the collector area minus the losses B,C & D. The remaining radiation is transformed into heat energy on the absorber plate.

The rising temperature of the solar collector causes thermal losses F,G & H. These losses are included in the real efficiency calculation of a solar collector by including heat loss correction values. These numbers are provided by the manufactures as well (Allendorf, 2009).

The collector efficiency can be calculated with the following formula:

$$\text{Collector efficiency } (\eta) = \text{Optical efficiency}(\eta 0) - \frac{K1*\Delta T}{Eg} - \frac{K2*\Delta T^2}{Eg}$$

n = Collector efficiency
n_0 = Optical efficiency
*K_1 = Heat loss correction values in W/(m²*K) (Convection losses)*
*K_2 = Heat loss correction values in W/(m²*K²) (Radiation losses)*
E_g = Average monthly radiation power in W/m² (see chapter 3.4)
ΔT = Temperature differential in K
(Allendorf, 2009)
(K_1 and K_2 are values provided by the manufacturer of the solar panel)

The temperature differential used for the efficiency formula is calculated by subtracting the average ambient temperature from the mean collector temperature:

ΔT = Mean collector temperature - Average ambient temperature
ΔT = Tm- Ta

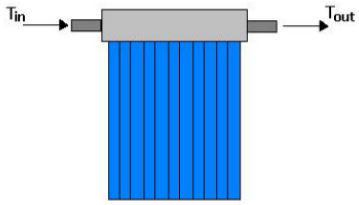


Figure 4.15: *Inlet temperature and outlet temperature solar collector.*

The mean collector temperature can be calculated by determining the input temperature and the output temperature of the solar collector, see Figure 4.15.

$$T_m = \frac{(T_{in} + T_{out})}{2}$$

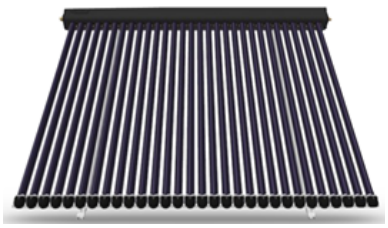
the thermal energy output will be calculated for two mean temperatures: 25 and 45 degrees. With an input temperature of 10 degrees this means an output of 80 °C and 40 °C can be obtained.

$$T_m = \frac{(10+80)}{2} = 45\ C^\circ$$

$$T_m = \frac{(10+40)}{2} = 25\ C^\circ$$

This ΔT is very high which can only be obtained if multiple collectors are placed in series. As a simplifications the average temperatures of all collectors is taken.

(F) Evacuated tube collector
The following evacuated tube collector is selected for this research: ETC-30
ETC-30 evacuated tube collector has the following properties:


Figure 4.16: *Evacuated tube collector*

Length: 2005 mm
Width: 2196 mm
Height: 136 mm
Aperture Area: 2.84 m²
Gross Area: 4.4 m²
n_0 = 0,46 (gross area efficiency)
*K_1 = 0,802 W/(m²*K)*
*K_2 = 0,005 W/(m²*K²)*
E_g = Average monthly radiation power in W/m² (see chapter 3.4)
ΔT= Figure 4.17

Website: http://www.apricus.com/upload/userfiles/downloads/ETC_Collector_Overview_Int.pdf

Temperature differential (Calculated by using chaper 3.5):

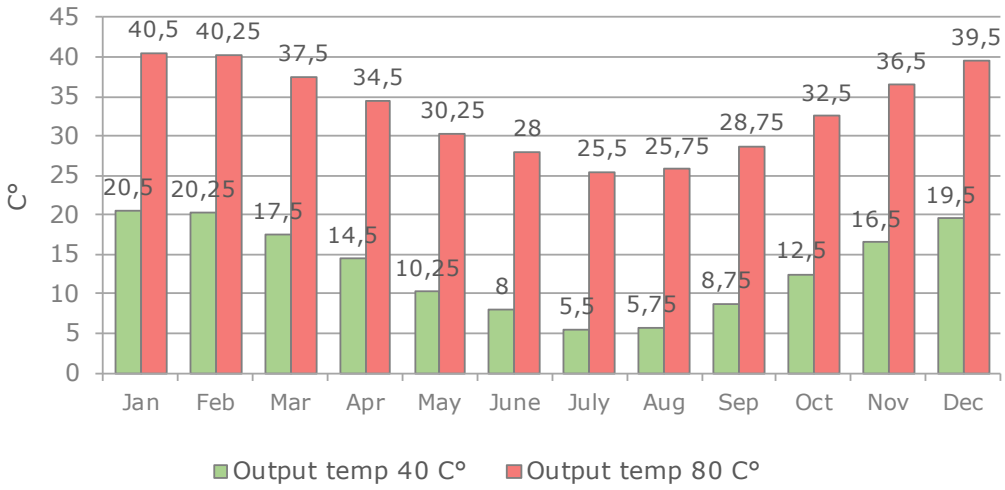


Figure 4.17: *Monthly temperature difference of solar collector output temperature with the ambient temperature in Ramplaankwartier. (by Author)*

Collector efficiency (η) = Optical efficiency(η0) - $\frac{K1*\Delta T}{Eg} - \frac{K2*\Delta T^2}{Eg}$

E_g *(August) = 724 w/m² (chapter 3.4)*

(40 C°) Collector efficiency (August) = 0,46 - $\frac{(0,802*5,75)}{724} - \frac{(0,005*5,75\text{^}2)}{724}$ = 0,45

(80 C°) Collector efficiency (August) = 0,46 - $\frac{(0,802*25,75)}{724} - \frac{(0,005*25,75\text{^}2)}{724}$ = 0,43

Doing this for all months, results in the following collector efficiencies; Figure 4.18.

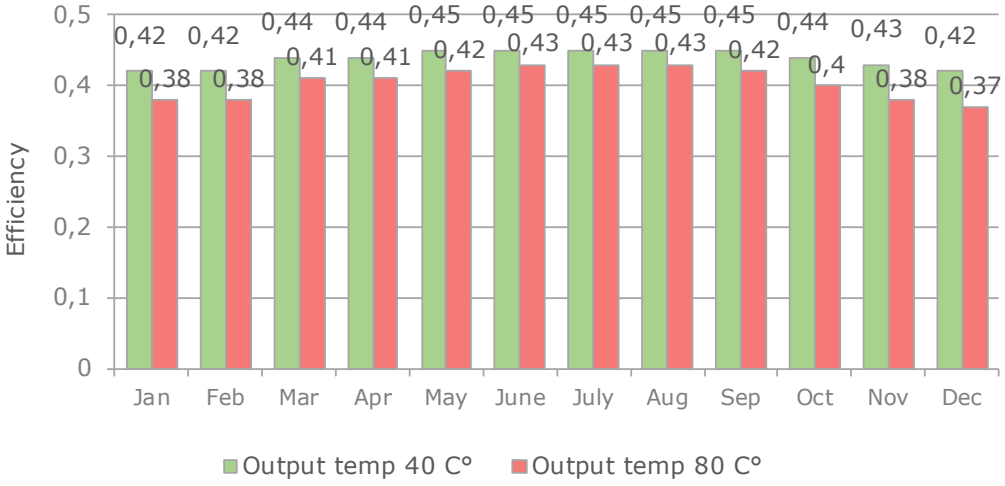


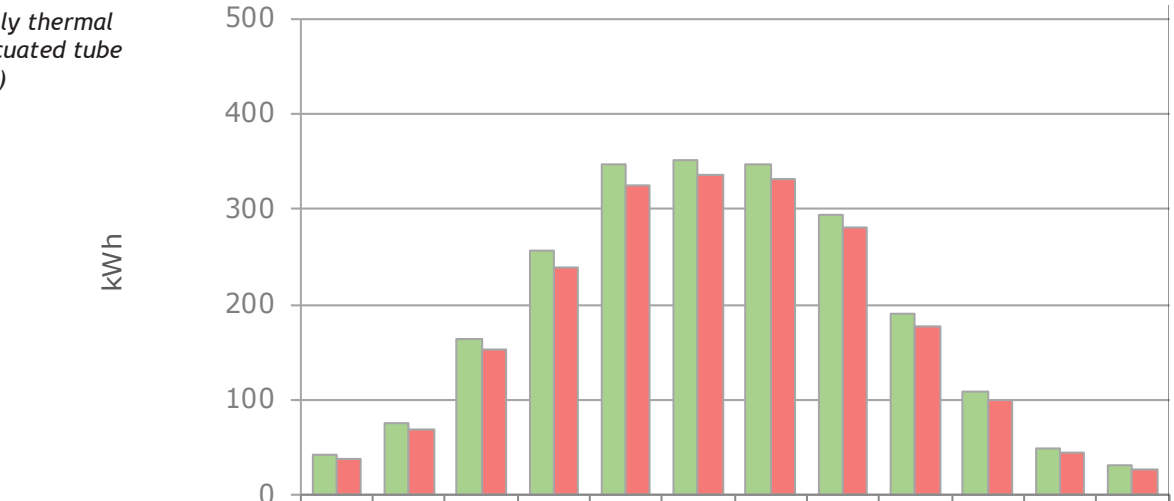
Figure 4.18: *Monthly efficiency values evacuated tube collector (by Author)*

Example (August, South 45, 40 °C): 148 kWh/m²
Energy (kWh) = A*r*H
E (kWh) = 4,4*0,45*148 = 293 kWh

Example (August, South 45, 80 °C): 148 kWh/m²
Energy (kWh) = A*r*H
E (kWh) = 4,4*0,43*148 = 280 kWh

Annual energy production 1 panel (South 45°, 40 °C): 2259 kWh
Annual energy production 1 panel (South 45°, 80 °C): 2120 kWh

Monthly energy production 1 panel (South 45°,40 °C & 80 °C)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Output temp 40 C°	43	76	163	257	348	351	348	293	191	109	49	31
Output temp 80 C°	39	69	152	240	325	335	332	280	178	100	43	27

Figure 4.19: *Monthly thermal heat production evacuated tube collector. (by Author)*



Figure 4.20: *Flat plate collector*

(G) Flat plate collector

The following flat plate collector is selected for this research: FPC-A26
FPC-A26 flat plate collector has the following properties:

Length: 1981 mm
Width: 1222 mm
Height: 80 mm
Aperture Area: 2,26 m²
Gross Area: 2,42 m²
n_0 *= 0,755 (aperture area efficiency)*
K_1 *= 3,738 W/(m²*K)*
K_2 *= 0,007 W/(m²*K²)*
E_g *= Average monthly radiation power in W/m² (see chapter 3.4)*
ΔT= Figure 4.17

Website: http://www.apricus.com/upload/userfiles/downloads/Apricus_FPC-A26_Tech_Info.pdf

Calculating this for all months, results in the following collector efficiencies; Figure 4.21.

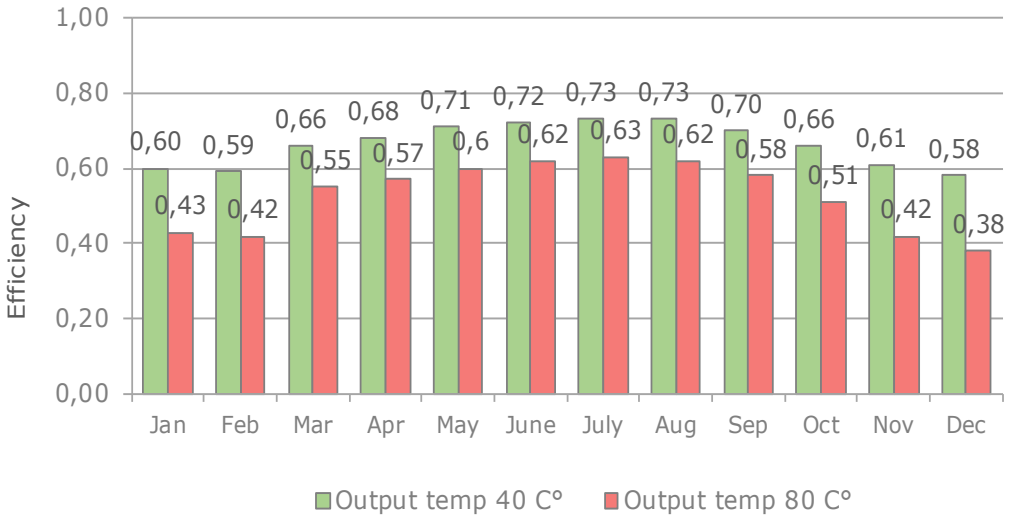


Figure 4.21: *Monthly efficiency values flat plate collector (by Author)*

Efficiency gross area: *(Aperture area/gross area) *Aperture efficiency*
(40 ˚C) (August): 2,26/2,42 * 0,73 = 0,68
(80 ˚C) (August): 2,26/2,42 * 0,62 = 0,57

Monthly efficiency values gross area:

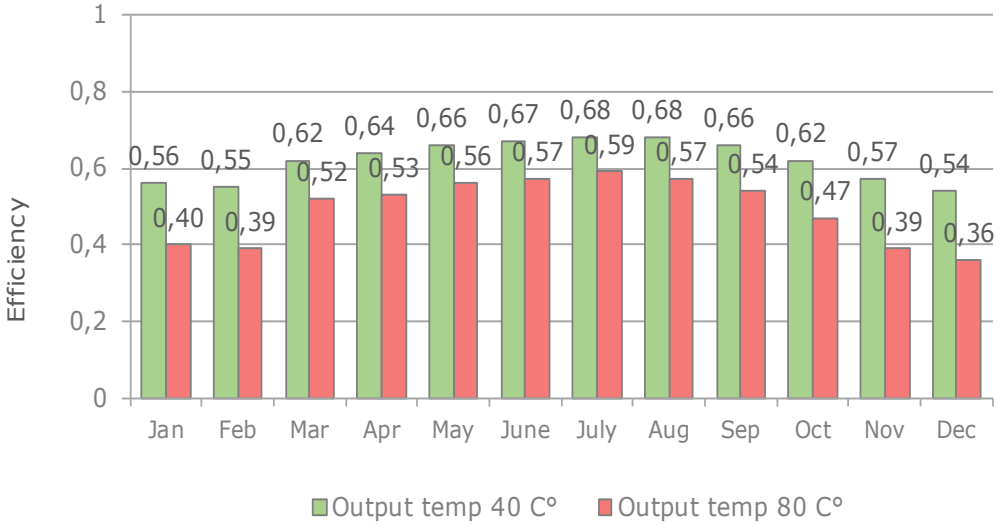
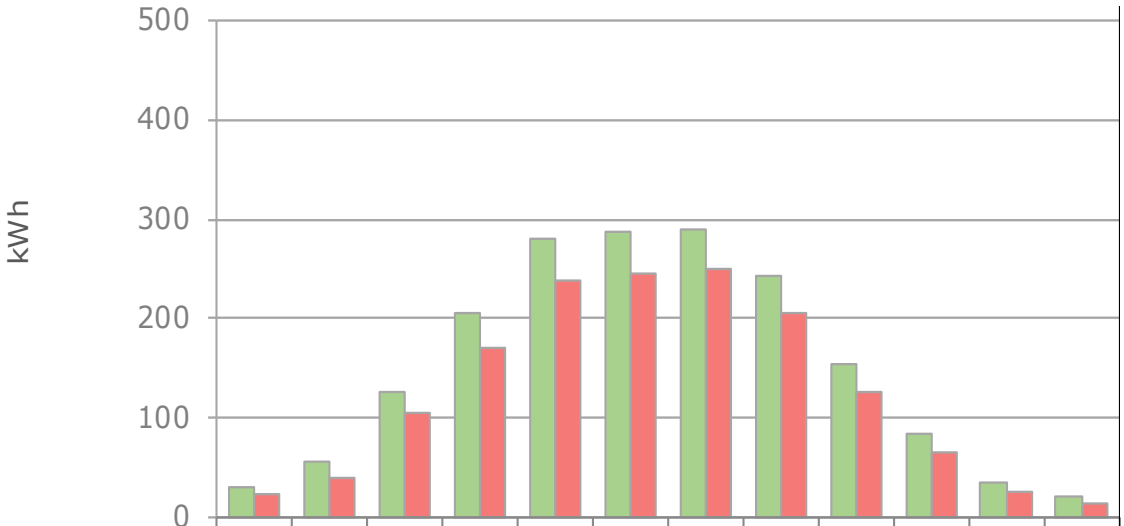


Figure 4.22: *Monthly efficiency values flat plate collector. (by Author)*

Annual thermal energy production 1 panel (South 45˚, 40 ˚C): 1815 kWh
Annual thermal energy production 1 panel (South 45˚, 80 ˚C): 1504 kWh

Monthly energy production 1 panel (South 45˚,40 ˚C & 80 ˚C)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Output temp 40 C°	31	55	126	206	281	287	289	244	154	85	36	22
Output temp 80 C°	22	39	106	170	238	244	251	204	126	64	25	15

Figure 4.23: *Monthly thermal heat production flat plate collector. (by Author)*



Figure 4.24: *PVT panel. (fototherm)*

PVT (H)

Photovoltaic panels combined with thermal heat production panels produce electricity and thermal heat. The thermal heat produced in the panel cause a decrease of the photovoltaic efficiency that should be included in the calculation. The following flat plate collector is selected for this research: Serie-FT260AL. Serie-FT260AL PVT panel has the following properties:

Dimensions:
Length: 1660 mm
Width: 990 mm
Aperture Area: 1,58 m²
Gross Area: 1,64 m²

Website: http://www.fototherm.com/en/fototherm-cs-series.html

Thermal heat production (flat plate collector):
n_0 *= 0,58 (Aperture area efficiency)*
K_1 *= 6,31 W/(m²*K)*
K_2 *= 0,08 W/(m²*K²)*
E_g *= Average monthly radiation power in W/m² (see chapter 3.4)*
ΔT= Figure 4.7

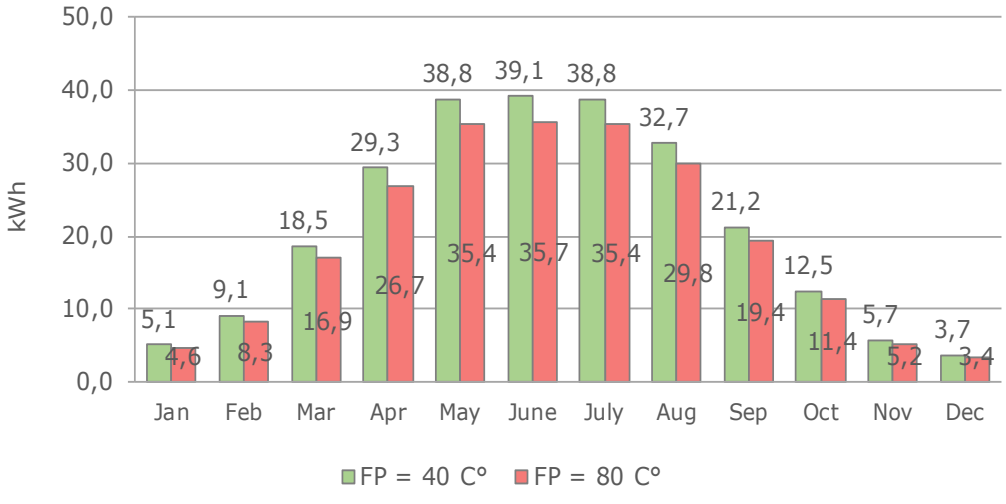
Electricity production (Si-monocrystalline):
r = 15,8 % (Gross area efficiency)
y = -0,44%/ ˚C (Temperature coefficient)
PR value = 0,85

Electricity production
The PV efficiency levels were tested at 25 ˚C. The average temperature in a flat plat collector with output temperature 40 ˚C is 25 ˚C. Output temperature 80 ˚C equals an average temperature of 45 ˚C. Therefore there will be no efficiency decrease of the PV if the output temperature of the flat plate is set on 40 ˚C. If the thermal output is 80 ˚C the PV efficiency will decrease with: (45-25)*0,44 = 8,8%. The PV efficiency will therefore be 15,8*(100-8,8) = 14,4 %

Example (August, South 45˚, 80 ˚C flat plate): 148 kWh/m²
Energy potential: *E (kWh) = A*r*H*PR*
*E (kWh) = 1.68*0.144*148*0.85 = 29,8 kWh*

The monthly electricity output values are displayed in Figure 4.25.

Figure 4.25: *PVT panel. monthly electricity output. (by Author)*



Thermal heat production

Calculating this for all months, results in the following collector efficiencies; Figure 4.26.

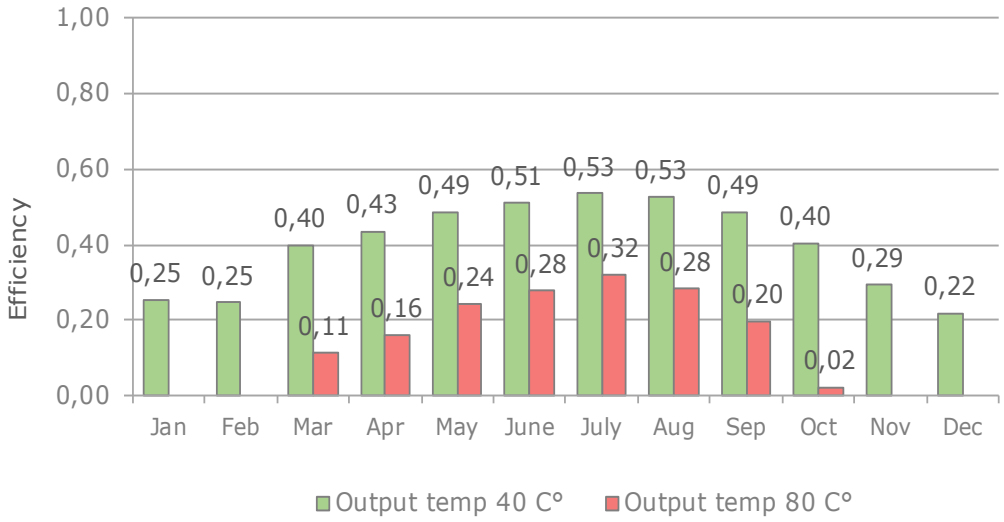


Figure 4.26: *Efficiency thermal output PVT panel (aperture area). (by Author)*

Efficiency gross area: *(Aperture area/gross area) *Aperture efficiency*
(40 °C) (August): 1,58/1,64 * 0,53 = 0,51
(80 °C) (August): 1,58/1,64 * 0,28 = 0,27

Monthly efficiency values gross area:

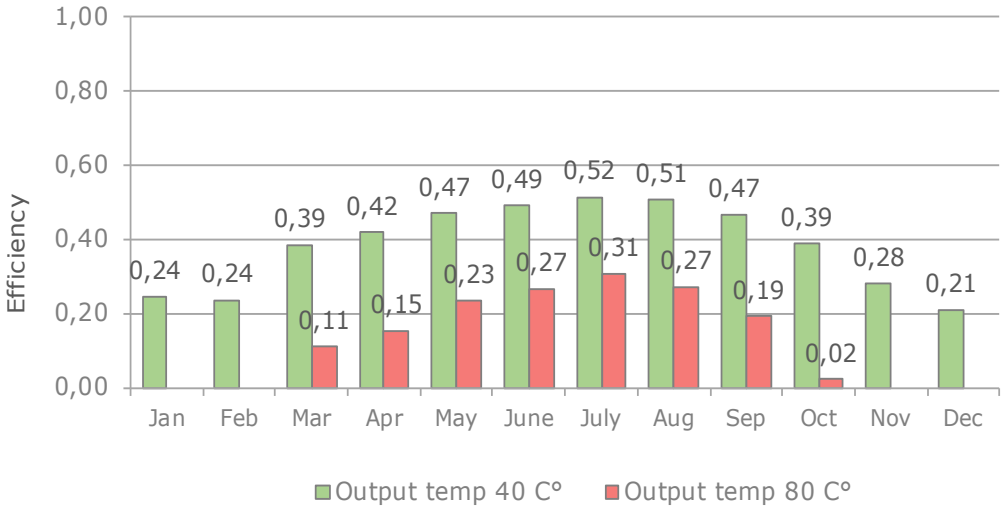
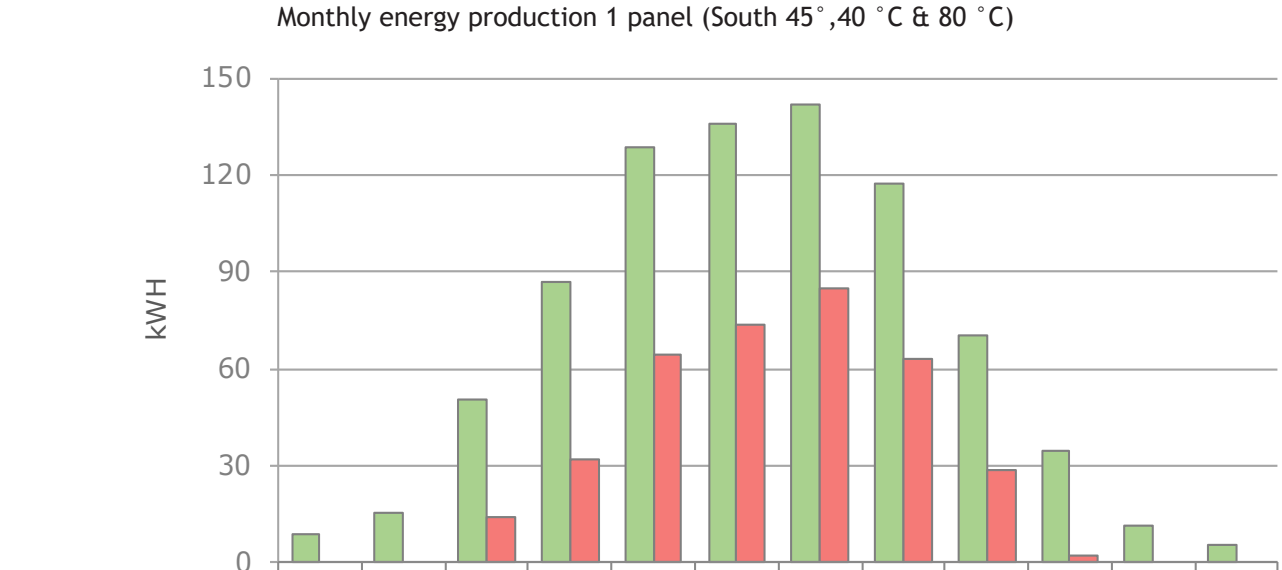


Figure 4.27: *Efficiency thermal output PVT panel (gross area). (by Author)*

Annual energy production 1 panel (South 45°, 40 °C): 1815 kWh
Annual energy production 1 panel (South 45°, 80 °C): 1504 kWh



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Output temp 40 C°	9	15	51	87	129	136	142	118	70	34	11	6
Output temp 80 C°			14	32	64	74	85	63	29	2		

Figure 4.28: *Monthly thermal heat production PVT panel. (by Author)*

4.2.2 Thermal energy storage

The calculations of thermal energy storage consists of two important components. The first component is energy accumulation potential of the thermal energy storage systems and materials. The second component is the energy loss that occurs overtime with thermal energy storage technologies. All the results are displayed in this chapter. The example calculations and their explanation are placed in appendix A.

Sensible thermal energy storage

Energy accumulation

The maximum thermal energy the sensible heat storage can accumulate is calculated with the following formula (De Guadalfajara, Serra, & Lozano, 2014):

$E\ (KJ) = V \cdot \rho \cdot c_p \cdot (T_{max} - T_{min})$

V = volume in m^3
ρ = density storage material in kg/m^3
*c_p = Specific heat in KJ/kg*K (at constant pressure)*
ΔT = temperature change in the storage tank (K)

T_{max} = Before energy loss
T_{min} = After energy loss

Energy losses

Thermal energy storages deal with energy losses over time due to a temperature difference of the storage medium and the ambient temperature around the tank. Thermal energy losses that occur can be calculated with the following formula:

$Q(watt) = U \cdot A \cdot (T - T_{amb})$

U = heat transfer coefficient in W/m^2*K
U = 1/r (r = thermal resistance)
r = d/λ (d = thickness, λ = thermal conductivity)
A = area in m^2
ΔT = Temperature difference between storage tank temperature and ambient temperature in °C or K (De Guadalfajara, 2014)

(I) Pit storage (water)

An example calculation will be made for a thermal pit storage filled with water, to further explain the energy and spatial characteristics of the storage technologies. The following pit storage is placed in the earth, the top surface is not covered with earth.

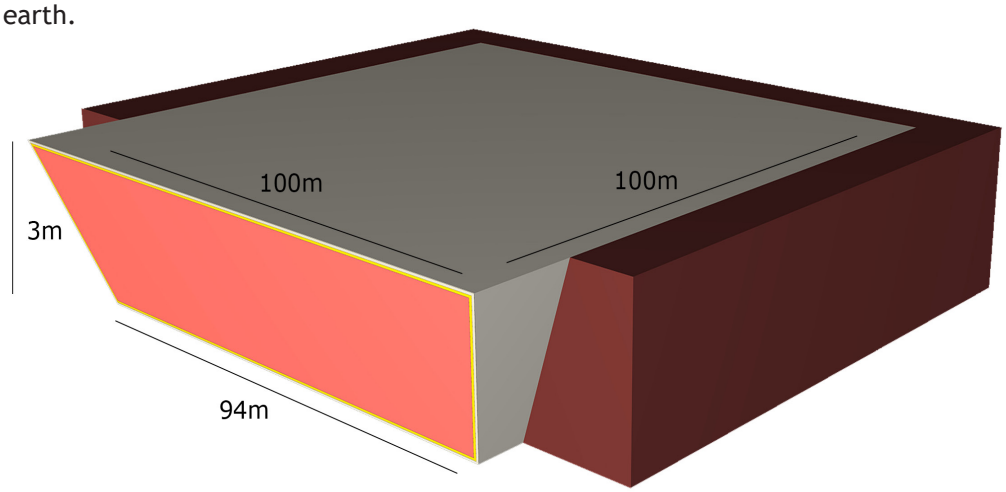


Figure 4.29: *Dimensions pit storage. (by Author)*

Thickness:

Bottom; 600mm concrete + 200mm XPS
Top; 200mm concrete + 500mm XPS
Lateral; 500mm concrete + 500mm XPS

Volume: 28.236 m^3

Properties:

The storage tank is filled with water at 80 °C
Ambient temperature is set at 10 °C
$\lambda_{concrete}$ *= 1,63 (W/m*K)*
λ_{XPS} *= 0,03 (W/m*K)*
λ_{ground} *= 3,00 (W/m*K)*
h_{conv} *= Convective heat transfer coefficient to the air of (10 W/(m²*K))*

If a specific surface of the tank is in close contact with the outside are the convective heat transfer coefficient is included in the calculation. If a thick layer of earth is in contact with the surface of the tank the convective heat transfer coefficient can be neglected (De Guadalfajara et al., 2014).

Energy losses
Q_{tot}= 85.597 W in one month with ambient temperature 10 °C.
85.597 J = 221,9 x 10^6 KJ
(Watt is Joule per second, one month exist of 2.592.000 seconds).

Temperature loss

$$E\ (KJ) = V \cdot \rho \cdot c_p \cdot (T_{max} - T_{min})$$

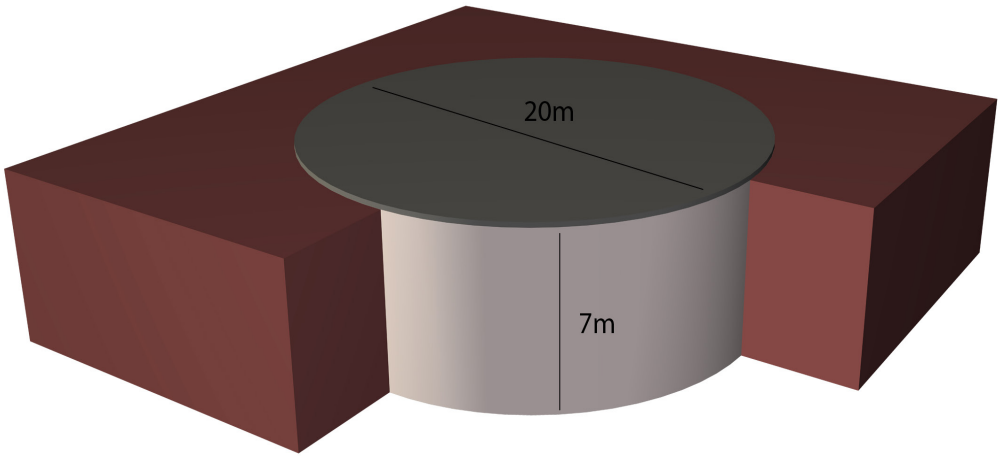
$$221{,}9 \times 10^6 = (28.236 * 999{,}8 * 4{,}192 * (80 - T_{min}))$$

$$1{,}87 = 80 - T_{min}$$

$$T_{min} = 78{,}13\ ^\circ C$$ (temperature one month later)

(J) Tank storage (water)

Figure 4.30: *Dimensions tank storage. (by Author)*



Thickness:

Bottom; 50mm stainless steel + 200mm XPS
Top; 50mm stainless steel + 500mm XPS
Lateral; 50mm stainless steel + 500mm XPS

Volume: 2199,1 m³

Properties:

Storage tank is filled with water at 80 °C
Ambient temperature is set at 10 °C
$\lambda_{stainless\ steel}$ *= 16,0 (W/m*K)*
λ_{XPS} *= 0,03 (W/m*K)*
λ_{ground} *= 3,00 (W/m*K)*
h_{conv} *= Convective heat transfer coefficient to the air of (10 W/(m²*K))*

Energy losses = 5110,7 W = 13,2 x 10^6 KJ in one month.
Temperature loss = 78,56 °C (temperature one month later)

(J) Tank storage (Salt)
The same dimensions and properties as the tank storage filled with water are assumed for the tank storage filled with salt, Figure 4.30.

Storage potential latent thermal energy storage
The maximum thermal energy the latent storage can accumulate is calculated with the following formula and visualised in figure:

$E(KJ) = E_{sensible}(1) + E_{Latent} + E_{Sensible}(2)$

$E_{sensible}(1)\ (KJ) = V \cdot \rho \cdot c_p \cdot (T_{pc} - T_{min})$
$E_{Sensible}(2)\ (KJ) = V \cdot \rho \cdot c_p \cdot (T_{max-} T_{pc})$
$E_{Latent} = V \cdot \rho * L$
V = volume in m^3 (*2199,1 m^3*)
ρ = density storage material in kg/m^3
c_p = Specific heat in kJ/kg*K
T_{pc} = Temperature phase change (K)
L = Latent heat of fusion in kJ/kg
(Dheep & Sreekumar, 2014)

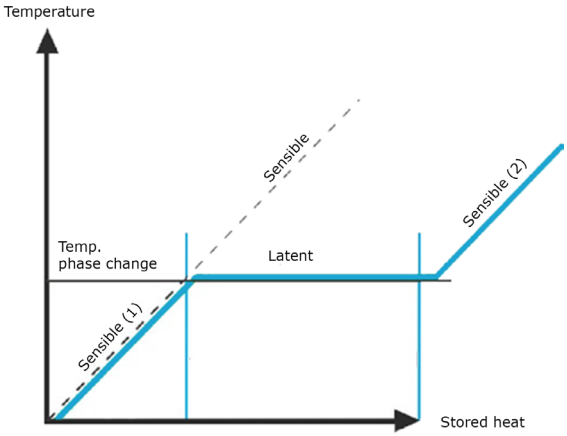


Figure 4.31: *Relation between temperature raise and stored thermal heat of latent thermal energy storage. (by Author)*

Properties salt:
Inorganic salt hydrates: $Na_2S_2O_3 \cdot 5H_2O$
ρ = 1750 kg/m^3
Melting point (T_{pc}) = 48 °C
c_p = 1,5 KJ/kg*K
L = 187-200 kJ/kg (Dheep & Sreekumar, 2014)

Energy accumulation
Example: 2200m^3 storage tank filled with $Na_2S_2O_3 \cdot 5H_2O$ is raised from 10 °C up to 80 °C.
$E_{sensible}(1$ = 2200*1750*1,5 *(48-10) = 219.450.000 KJ = 60.958 kWh
$E_{Sensible}(2)$= 2200*1750*1,5 *(80-48) = 184.800.000 KJ = 51.333 kWh
E_{Latent} = 2200*1750 *187 = 719.950.000 KJ = 199.986 kWh

$E(KJ) = E_{sensible}(1) + E_{Latent} + E_{Sensible}(2)$

E = 219.450.000 + 184.800.000 +719.950.000 = 1,124 $x10^9$ KJ = 312.277 kWh

Energy losses & Temperature loss
The energy losses occurring overtime due to a temperature difference with the ambient temperature can be calculated the same way as the sensible thermal energy storage. If the salt reaches the phase change temperature, the E_{Latent} stored energy is released and can be used to deliver the energy demand of the buildings. Until this energy accumulation is fully used up, the temperature will stay constant around the phase temperature.

4.2.2 Distribution losses

The thermal losses of an insulated piping system can be calculated using the following formula, Figure 4.32:

$$Q = \Delta T / \left(\left(\frac{\ln\left(\frac{R_o}{R_i}\right)}{2\pi * K_p * L}\right) + \left(\frac{\ln\left(\frac{R_s}{R_o}\right)}{2\pi * K_s * L}\right) + \left(\frac{1}{2\pi * h_{conv} * L}\right)\right) \text{ (Watt)}$$

Q = heat transfer out of the pipe (W)
K_p = thermal conductivity pipe (W/m*K)
K_s = thermal conductivity insulation (W/m*K)
L = length pipe (m)
T_o = Temp outside pipe (°C)
T_i = Temp inside pipe (°C)
R_o = outside radius pipe(m)
R_i = inside radius pipe (m)
R_s = outside radius insulation (m)
h_{conv} = convective heat transfer coefficient to the air of (10 W/(m^2*K))
(Crombie, 2016)

Dimensions

For this research we assume two types of piping used to transport heat. The thinner pipes transport the thermal heat from the solar collectors towards the bigger pipes, which transport the thermal heat to the energy storage. The assumed dimensions of the piping system are illustrated in the following figure:

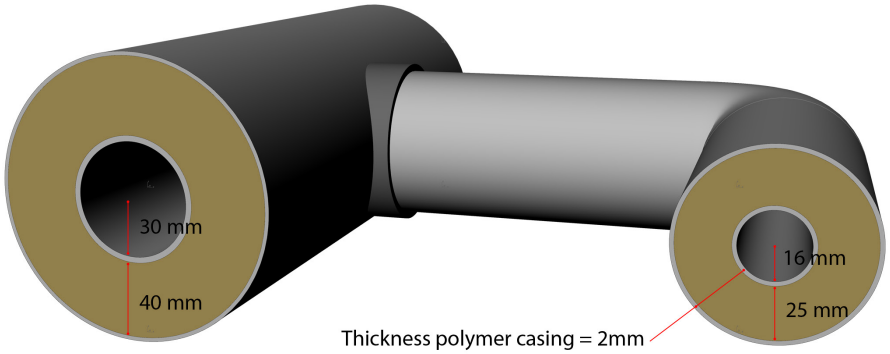


Figure 4.32: *Two types of insulated piping. (by Author)*



Figure 4.33: *Heat piping network. https://www.uponor.com*

The insulation material is XPS, λ = 0,03 W/m*K
The casing material is a polyethylene polymer, λ = 0,045 W/m*K
According to the website: *https://www.uponor.be/nl-be)https://www.uponor.be/nl-be*

Length piping (Figure 4.34)

If all the 133 buildings located in the selected urban blocks are connected to an energy storage system in the centre of the selected urban blocks the following piping necessary to connect all the buildings to the energy storage. The **(blue)** piping is the connection from the solar collectors to the large transport pipes **(yellow)**.

The total length of the blue piping is an estimated 600 meters (AutoCAD calc.). If the vertical transport of the thermal heat on the roof surface is included in the calculation the total piping length is 1100 meters. For 113 residential buildings this means the average pipe length **(blue)** is 10 meters for one building. The total length of the yellow coloured pipes is 1250 meter (AutoCAD calc.) The distribution network exists of 10 main branches. The average travel distance for thermal heat inside the yellow piping is 125 meters. Some residential buildings are connected close to the energy storage while some are connected at the end of the piping system. Therefore we take the mean value of 125 which is 62,5 meters.

The average connection of 1 building in the selected urban blocks to the energy storage is therefore; 10 meters small piping **(blue)** followed by 62,5 meters large piping **(yellow)**.



Figure 4.34: *Estimation on the total length of piping neccesary to connect all 133 buildings to the new energy system. (by Author)*

In the month April there are 162 solar hours, 162*60*60 = 583.200 seconds.

Thermal losses thin pipe (blue):
Energy loss for all 113 buildings: 89.148*113 = 10,1 x10^6 KJ = **2798 kWh**
Energy loss for all 113 buildings: 144.855*113 = 16,4 x10^6 KJ = **4547 kWh**

Thermal losses thick pipe (yellow):
Energy loss for all 10 pipes: 602.620*10 = 6,0 x10^6 KJ = **1674 kWh**
Energy loss for all 10 pipes: 1.011.431*10 = 10,1 x10^6 KJ = **2810 kWh**

Total transport losses in the month April = **12.189 kWh**

4.3 Visualisations energy potentials

Chapter 4 explained how the energy potentials of five types of solar energy production technologies can be calculated for one panel. The dimensioning coherent to the energy potentials of these panels is also included and will now be used in combination with the spatial analysis results (ch. 3.3).
For both identified building typologies the roof potential will be used to create energy potentials with the in chapter 4 selected energy production technologies. The orientation differences of these buildings cause different energy potentials for the roofs because of the difference in solar irradiance. The shadow analysis is used to determine in which orientation directions the space between dormers can be used for energy production or can't be used because of shadows.
Five possibilities to use the roof of the buildings are visualised and their energy potentials are calculated:

1. *Commonly applied placement of panels on roofs*
2. *Minor visual impact*
3. *Building extension*
4. *Partly refurbished roof*
5. *Totally refurbished roof*
6. *Refurbished facade*

Not only the energy potentials of residential buildings are calculated and visualised. The energy potentials of the public areas and the private areas are also determined. The shadow analysis is included in the choices made, in order to prevent energy production technologies that are placed in shadow. The following visualisations and energy potentials are discussed in the order of the selected solar energy production technologies:

4.3.1 Solar collectors

Flat plate collector
Private owned areas
- I. Buildings typology type 1
- II. Buildings typology type 2

Publical areas
- I. Green areas
- II. Parking areas

Evacuated tube collector
Private owned areas
- I. Buildings typology type 1
- II. Buildings typology type 2

Publical areas
- I. Green areas

4.3.2 Photovoltaic panels

Monocrystalline PV panel
Private owned areas
- I. Buildings typology type 1
- II. Buildings typology type 2
- III. Gardens/storages

Publical areas
- I. Green areas
- II. Parking areas

Thin film - cadmium telluride
Private owned areas
- I. Buildings typology type 1
- II. Buildings typology type 2
- III. Gardens/storages

Publical areas
- I. Green areas
- II. Parking areas

4.3.3 PVT

Private owned areas
- I. Buildings typology type 1
- II. Buildings typology type 2

Publical areas
- I. Green areas
- II. Parking areas

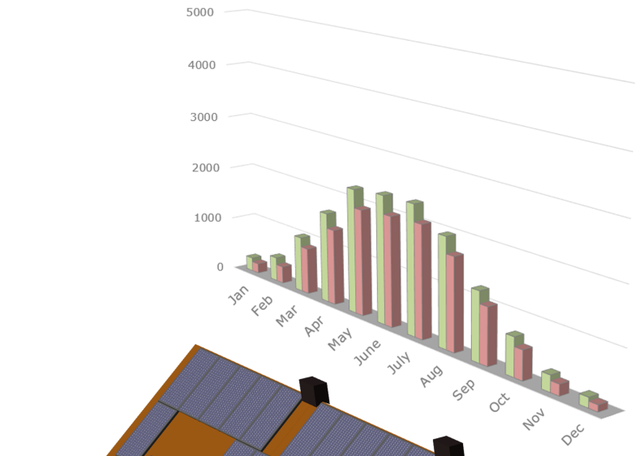
List of side notes:
- Only the flat plate collector for building typology type 1 is shown in this chapter. The rest of the visualisations combined with the energy potentials are placed in appendix B.
- All results are calculated using the calculation methods discussed in 4.2 in combination with the selected urban blocks characteristics described in chapter 3. All energy potentials are calculated in Excel.
- All the thermal energy outputs are calculated for a heating process of water from 10 to 40 °C or 10 to 80 °C.
- Some options for the placement of solar energy production technologies are simply not technically possible and therefore left out, for example: Evacuated tube collectors can't be integrated with the facade & solar collectors can't be placed on the storages because the load would be too heavy.
- Because the solar irradiance for buildings orientated to the west and east is the same, the east orientated buildings are always visualisations of the commonly applied placement of panels on roofs. This provides a comparison option between the different roof set-up possibilities.

Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

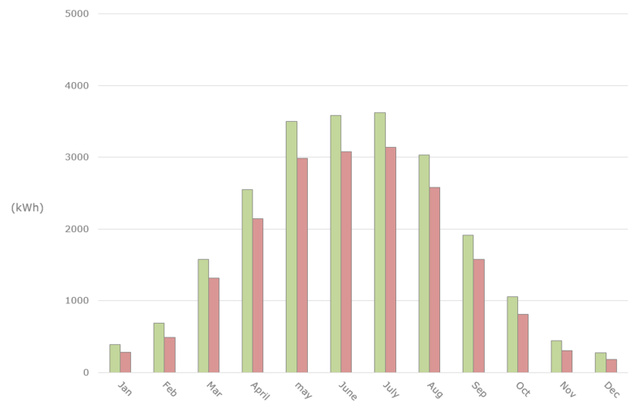
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



Orientation : South
Angle : 45 C°
Panels per household : 12,5
Annual thermal heat production: (40C°) 22.646 kWh
(80C°) 18.895 kWh

Monthy thermal heat production per household in kWh

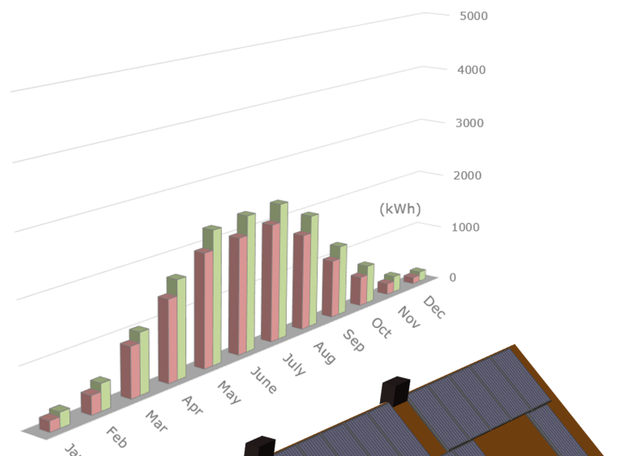
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	389	689	1578	2554	3499	3587	3621	3035	1913	1059	447	274
80 C°	280	488	1317	2143	2989	3081	3142	2577	1578	809	309	182

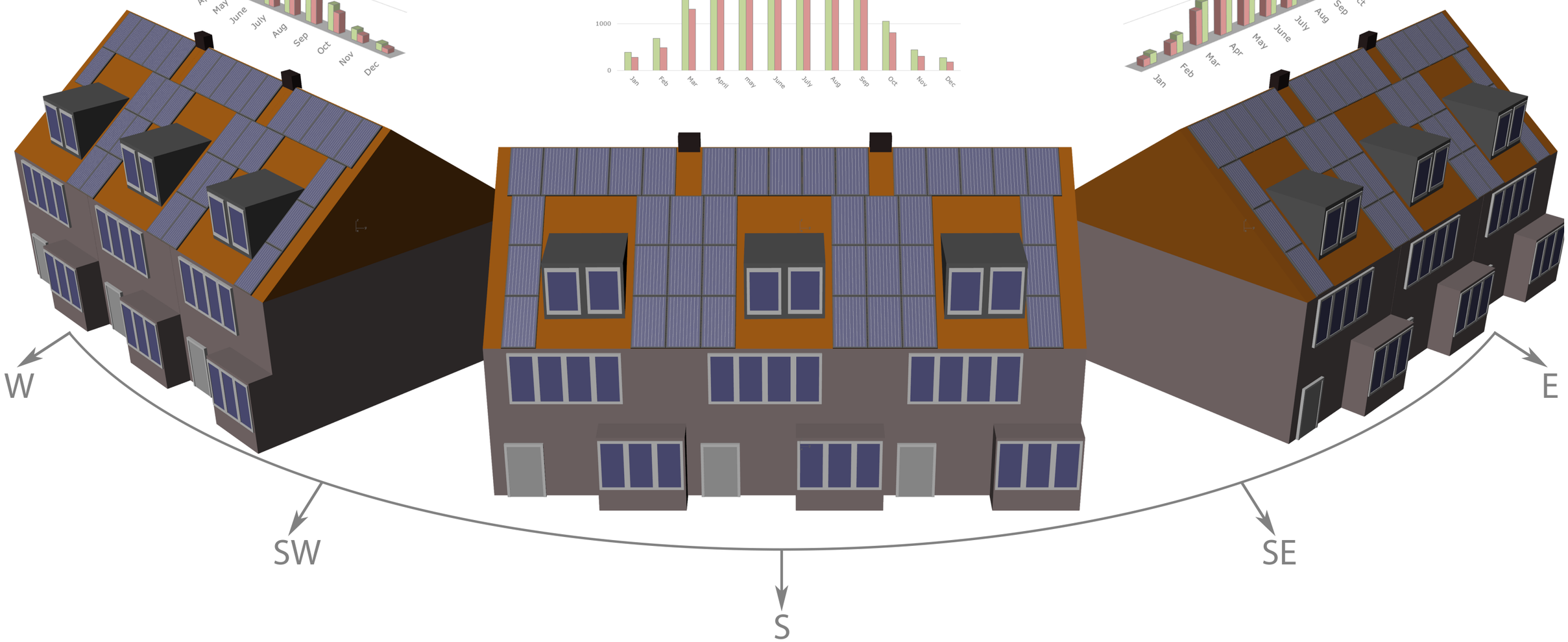


Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



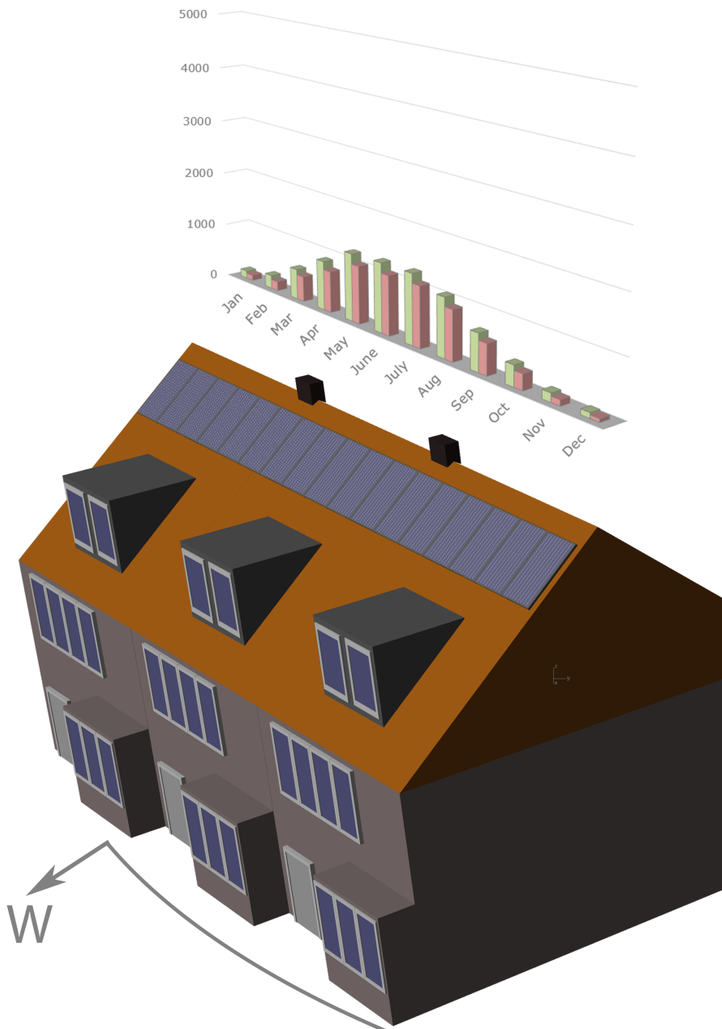


Minor visual impact:

Orientation : West
Angle : 45 C°
Panels per household : 5,66
Annual thermal heat production: (40C°) 7924 kWh
(80C°) 6611 kWh

Monthy thermal heat production per household in kWh

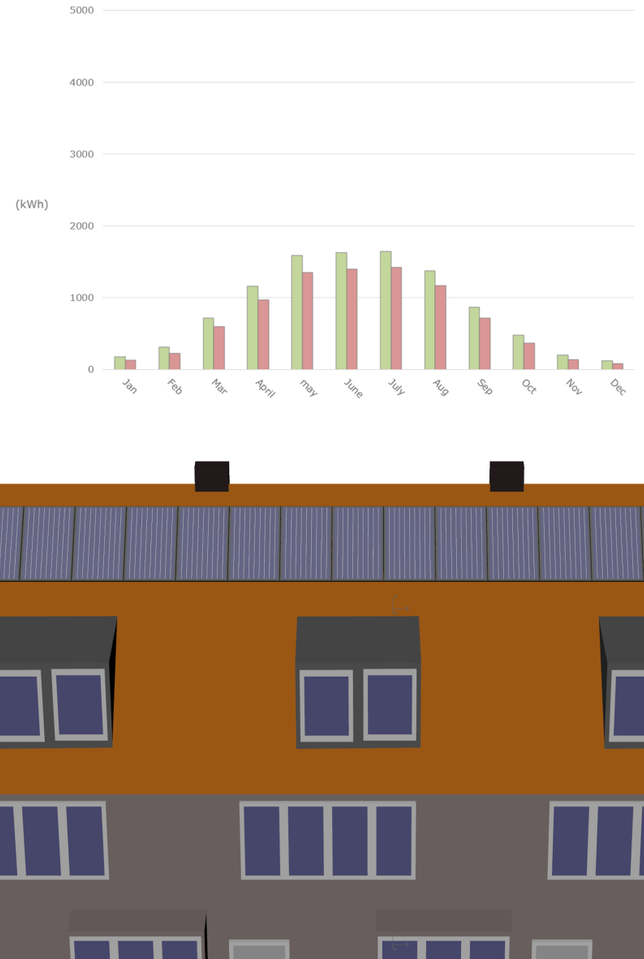
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	136	241	552	894	1224	1255	1267	1062	669	370	156	96
80 C°	98	171	461	750	1046	1078	1099	902	552	283	108	64



Orientation : South
Angle : 45 C°
Panels per household : 5,66
Annual thermal heat production: (40C°) 10.254 kWh
(80C°) 8556 kWh

Monthy thermal heat production per household in kWh

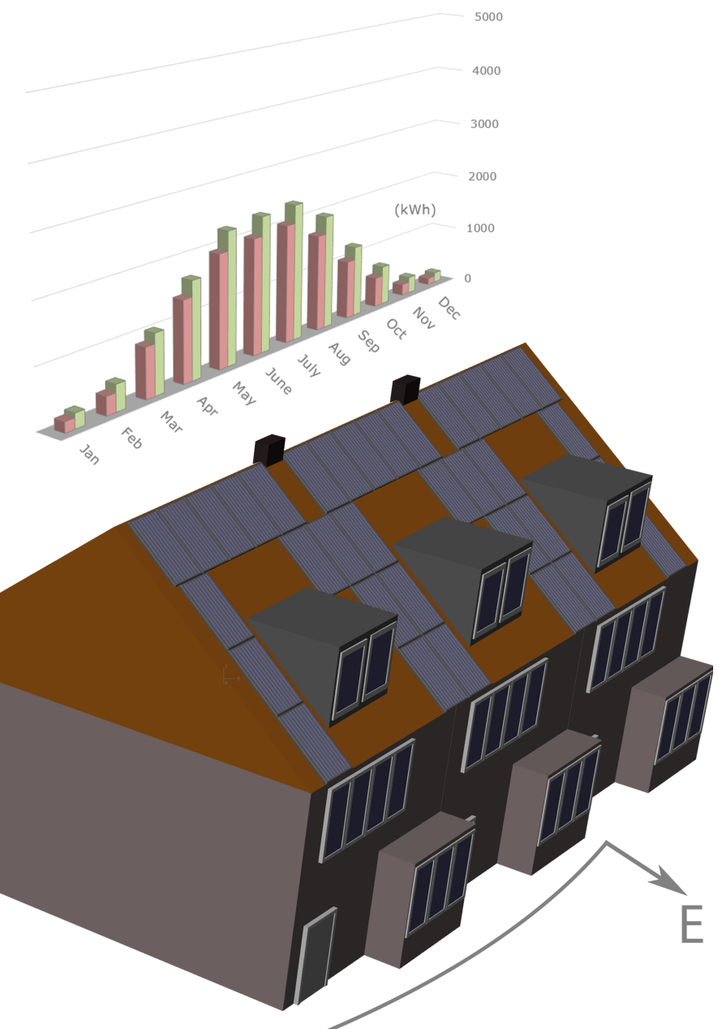
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	176	312	715	1156	1584	1624	1640	1374	866	479	202	124
80 C°	127	221	596	970	1354	1395	1423	1167	714	367	140	82

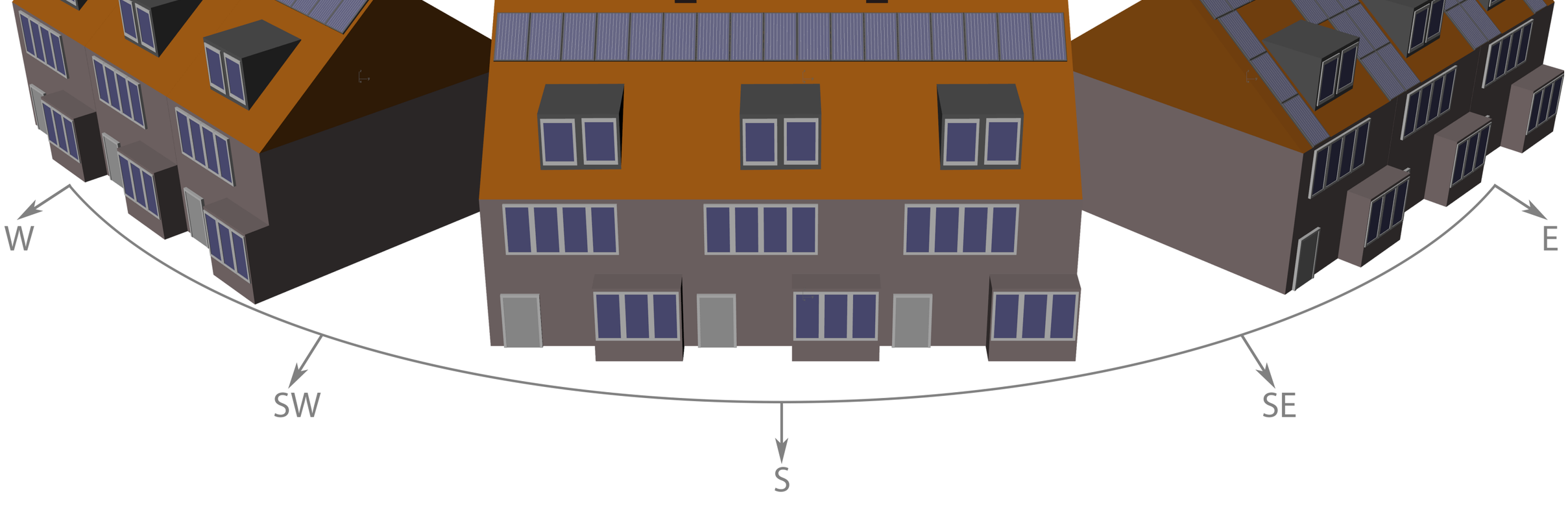


Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



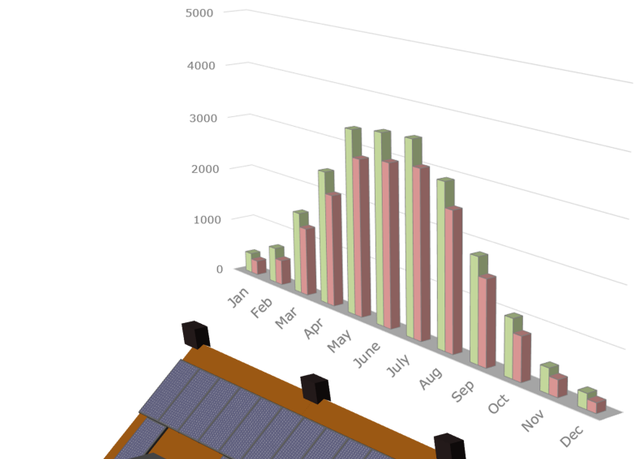


Building extension:

Orientation : West
Angle : 45 C°
Panels per household : 15,5
Annual thermal heat production: (40C°) 21.699 kWh
(80C°) 18.105 kWh

Monthy thermal heat production per household in kWh

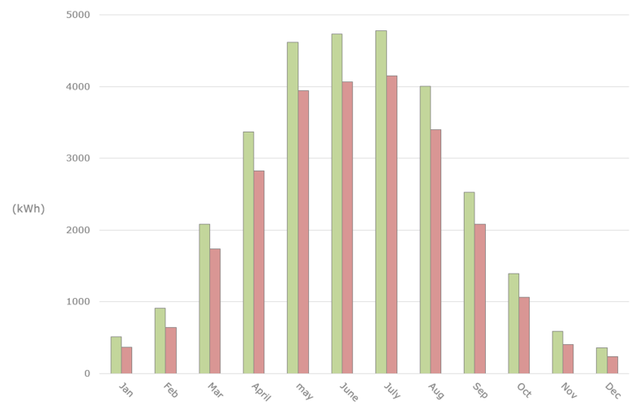
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	373	661	1512	2447	3353	3437	3470	2908	1833	1015	428	263
80 C°	268	467	1262	2053	2864	2953	3010	2469	1512	776	296	174



Orientation : South
Angle : 45 C°
Panels per household : 16,5
Annual thermal heat production: (40C°) 29.893 kWh
(80C°) 24.942 kWh

Monthy thermal heat production per household in kWh

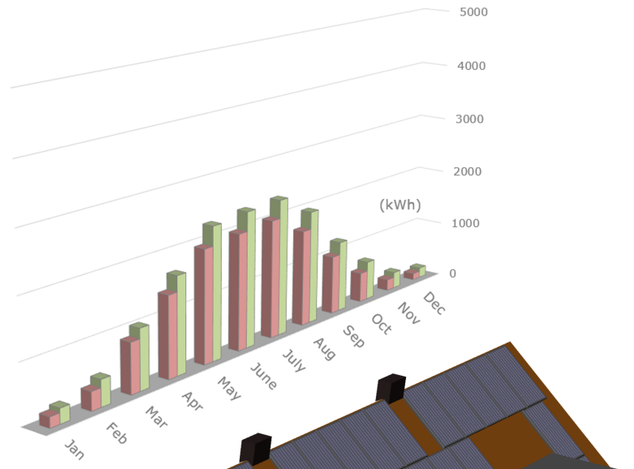
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	513	910	2083	3371	4619	4735	4780	4006	2526	1398	590	362
80 C°	370	644	1738	2829	3946	4067	4147	3402	2083	1068	408	240

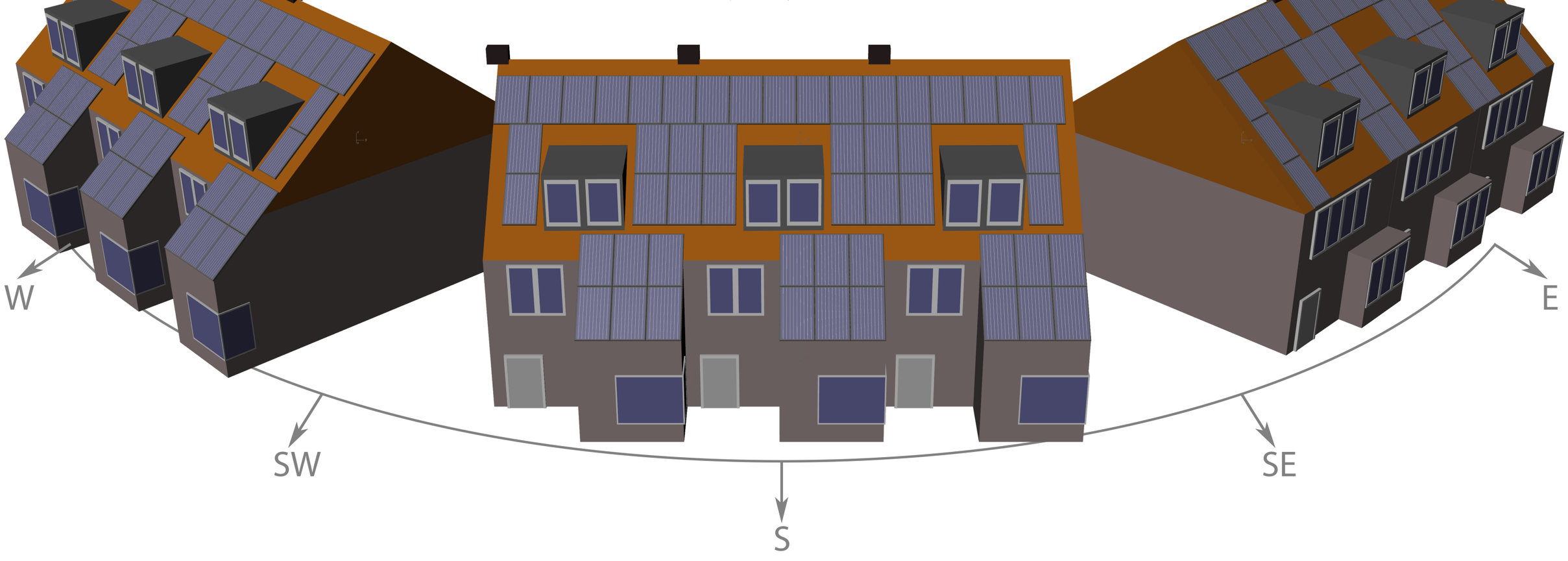


Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



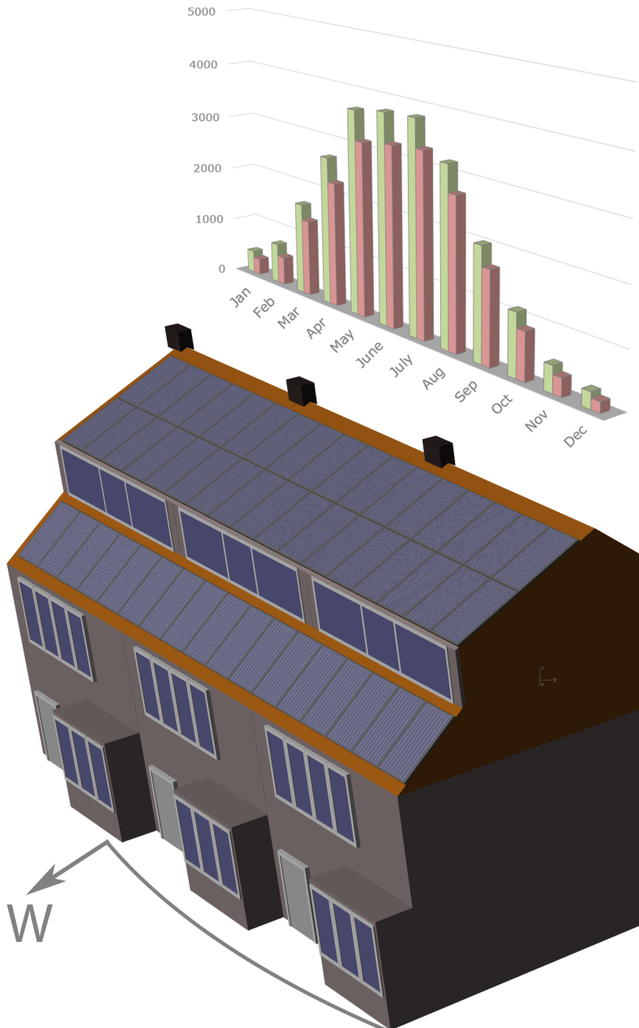


Partly refurbished:

Orientation : West
Angle : 45 C°
Panels per household : 17
Annual thermal heat production: (40C°) 23.799 kWh
(80C°) 19.857 kWh

Monthy thermal heat production per household in kWh

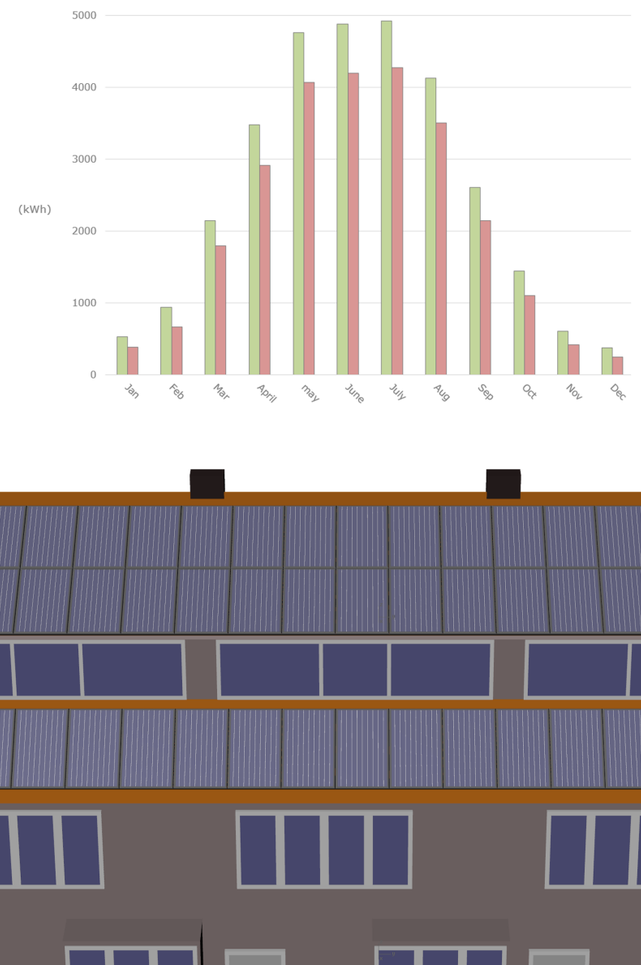
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	409	724	1659	2684	3677	3770	3805	3189	2011	1113	470	288
80 C°	294	512	1384	2252	3142	3238	3302	2708	1658	851	325	191



Orientation : South
Angle : 45 C°
Panels per household : 17
Annual thermal heat production: (40C°) 30.799 kWh
(80C°) 25.697 kWh

Monthy thermal heat production per household in kWh

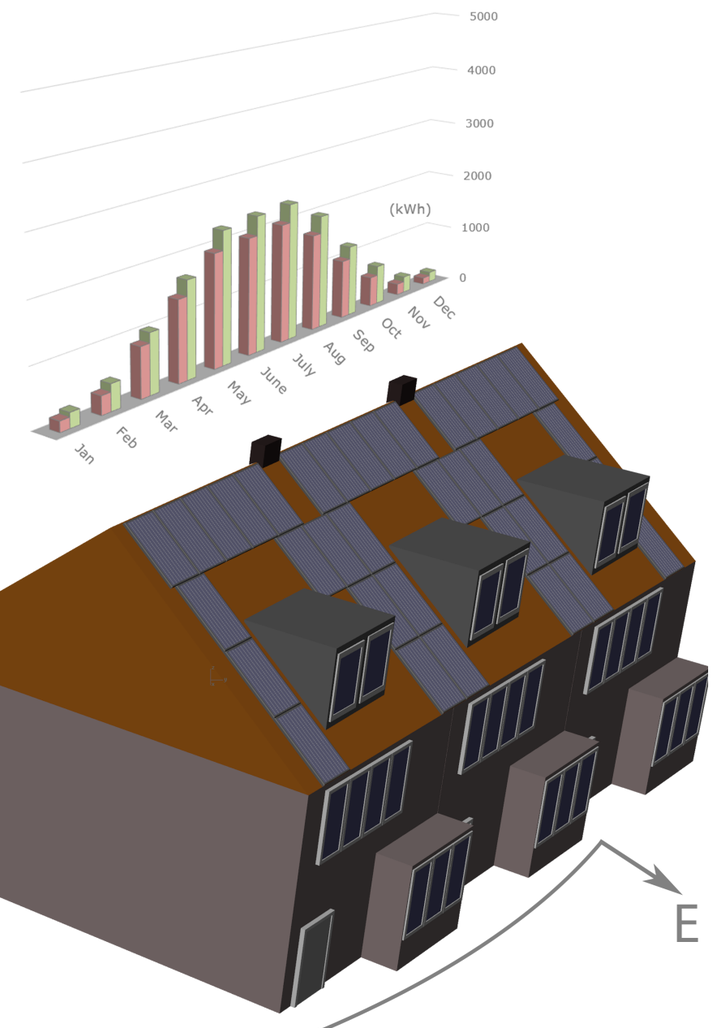
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	529	938	2147	3473	4759	4879	4925	4127	2602	1440	608	373
80 C°	381	663	1791	2914	4066	4191	4273	3505	2146	1101	420	247

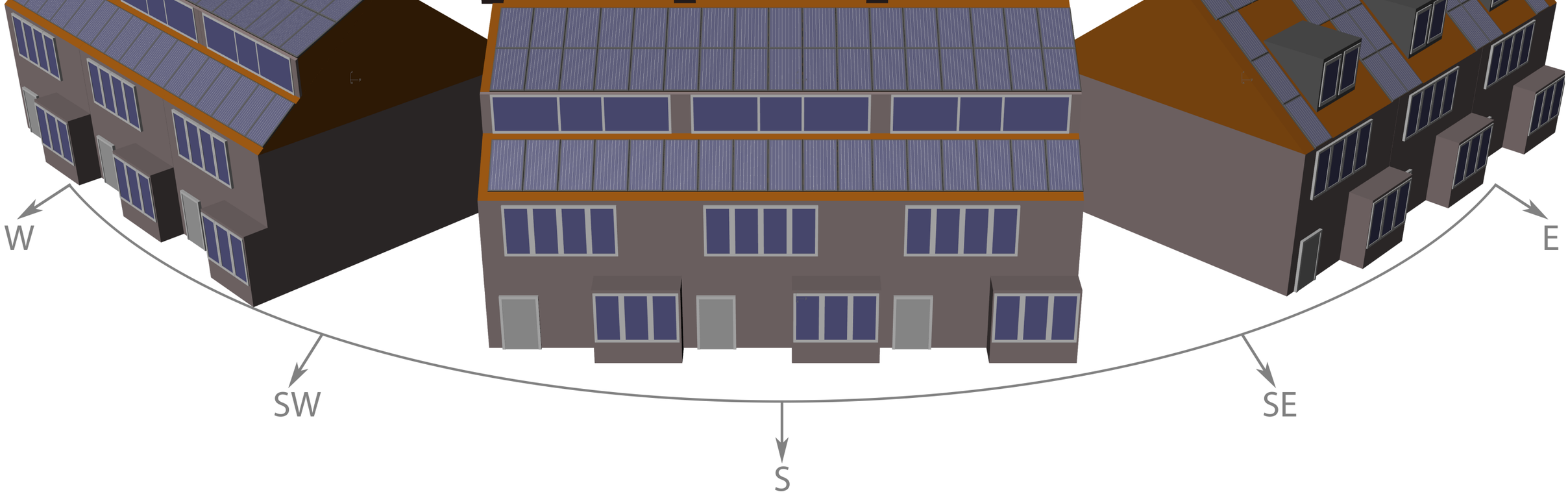


Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



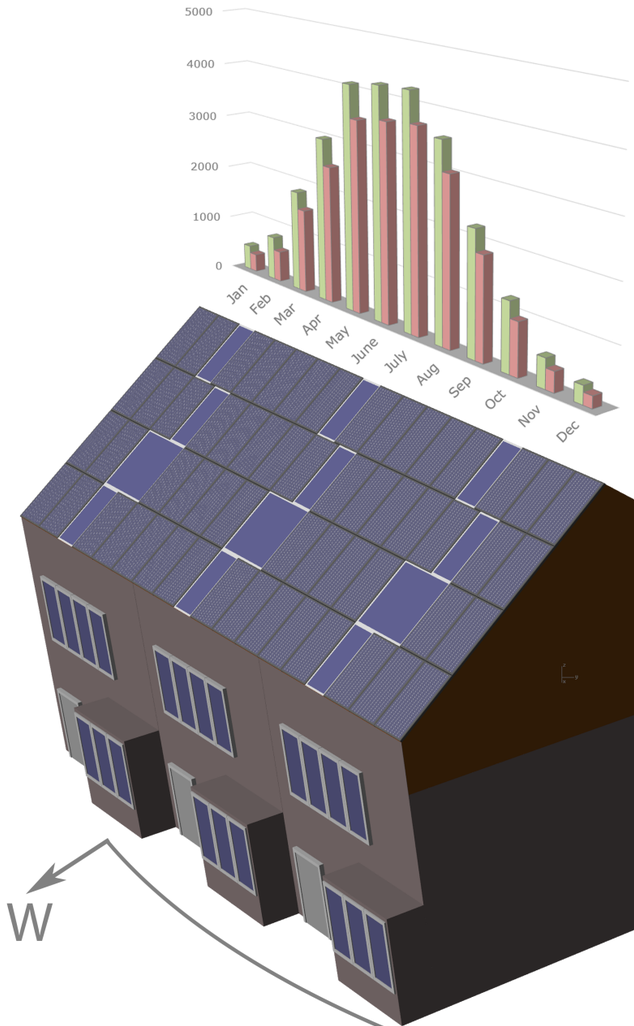


Totally refurbished:

Orientation : West
Angle : 45 C°
Panels per household : 19
Annual thermal heat production: (40C°) 26.599 kWh
(80C°) 22.193 kWh

Monthy thermal heat production per household in kWh

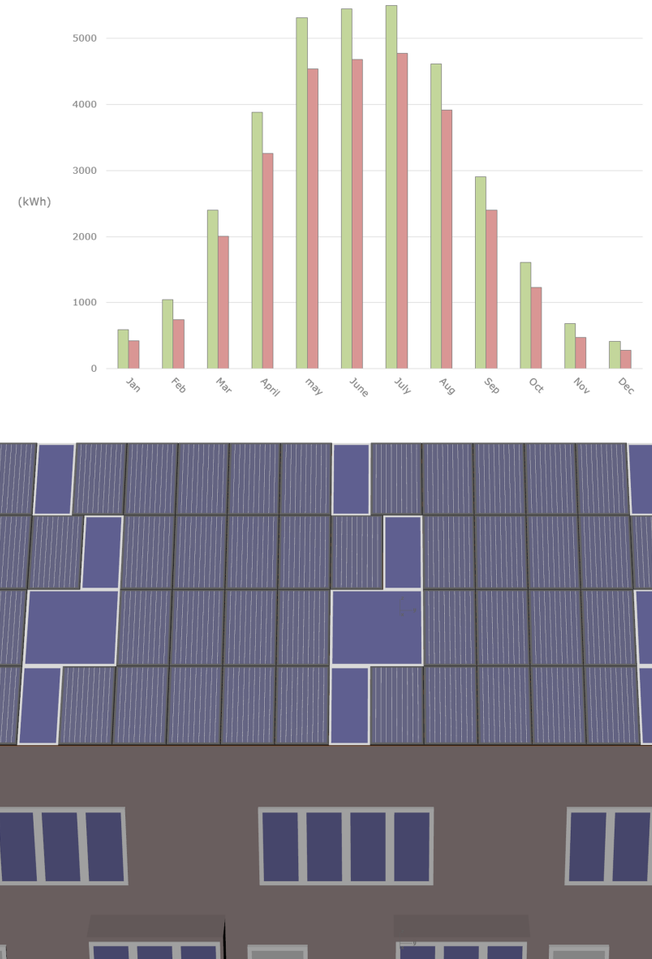
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	457	810	1854	3000	4110	4213	4253	3564	2247	1244	525	322
80 C°	329	573	1547	2517	3511	3619	3690	3027	1853	951	363	213



Orientation : South
Angle : 45 C°
Panels per household : 19
Annual thermal heat production: (40C°) 34.442 kWh
(80C°) 28.721 kWh

Monthy thermal heat production per household in kWh

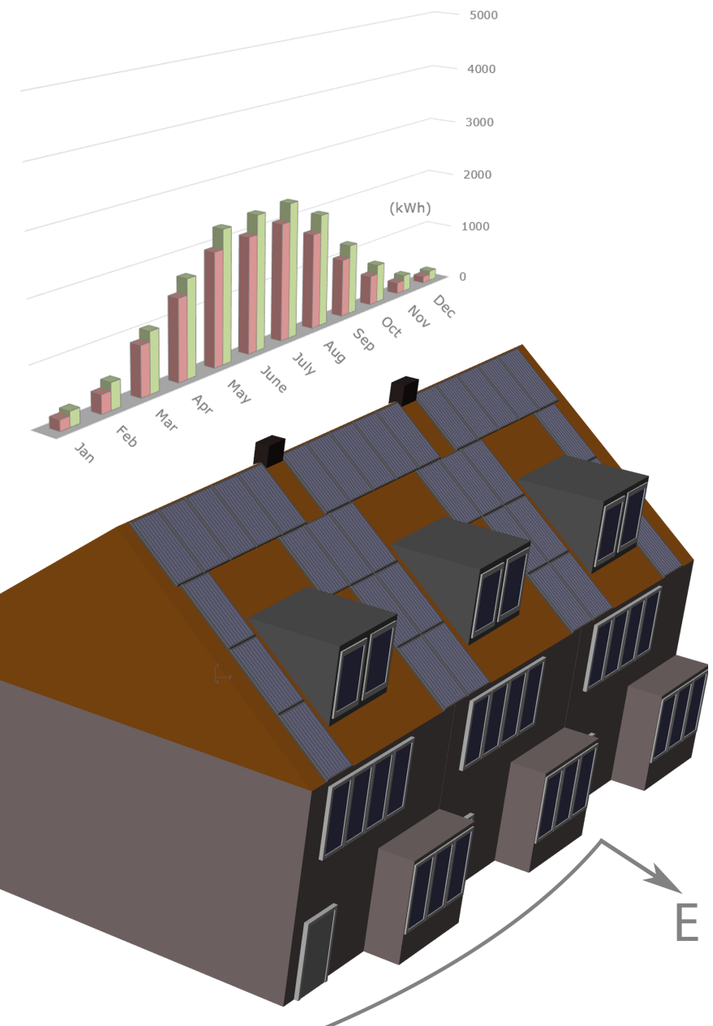
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	591	1048	2399	3882	5319	5453	5504	4613	2908	1609	679	417
80 C°	426	741	2002	3257	4544	4684	4775	3917	2398	1230	470	276



Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118



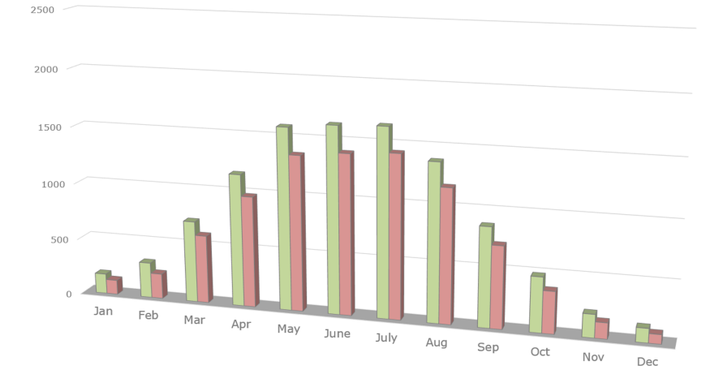
Refurbished facade:

Orientation : West
Angle : 1x 45C° 9x 90C°
Panels per household : 10
Annual thermal heat production: (40C°) 10.294 kWh
(80C°) 8589 kWh

Monthy thermal heat production per household in kWh

**West/east (90C°) is -40% solar irradiance*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	177	313	717	1161	1591	1631	1646	1379	870	481	203	125
80 C°	127	222	599	974	1359	1401	1428	1171	717	368	140	83

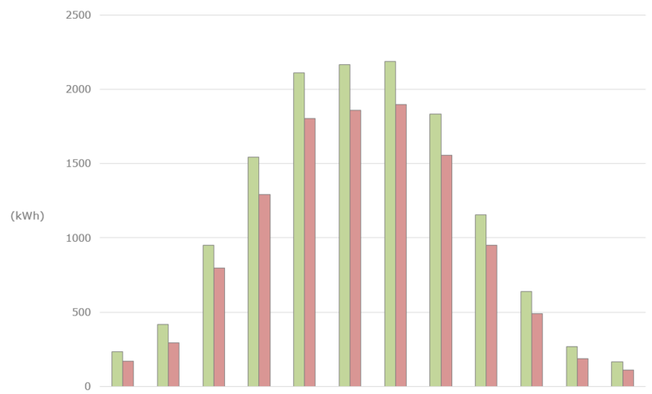


Orientation : South
Angle : 1x 45C° 9x 90C°
Panels per household : 10
Annual thermal heat production: (40C°) 13.670 kWh
(80C°) 11.406 kWh

Monthy thermal heat production per household in kWh

**South (90C°) is -20% solar irradiance*

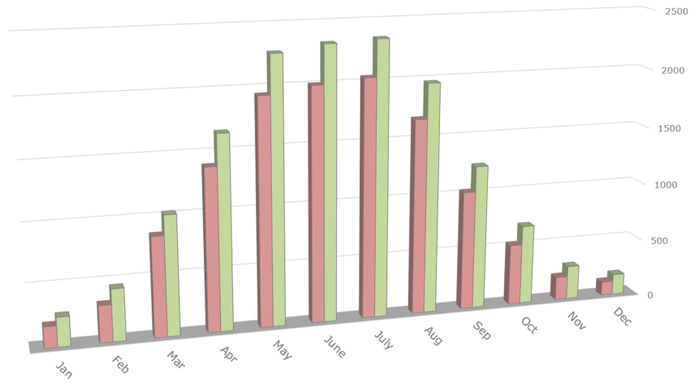
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	235	416	953	1542	2112	2165	2186	1832	1155	639	270	166
80 C°	169	294	795	1294	1805	1860	1896	1556	952	489	187	110

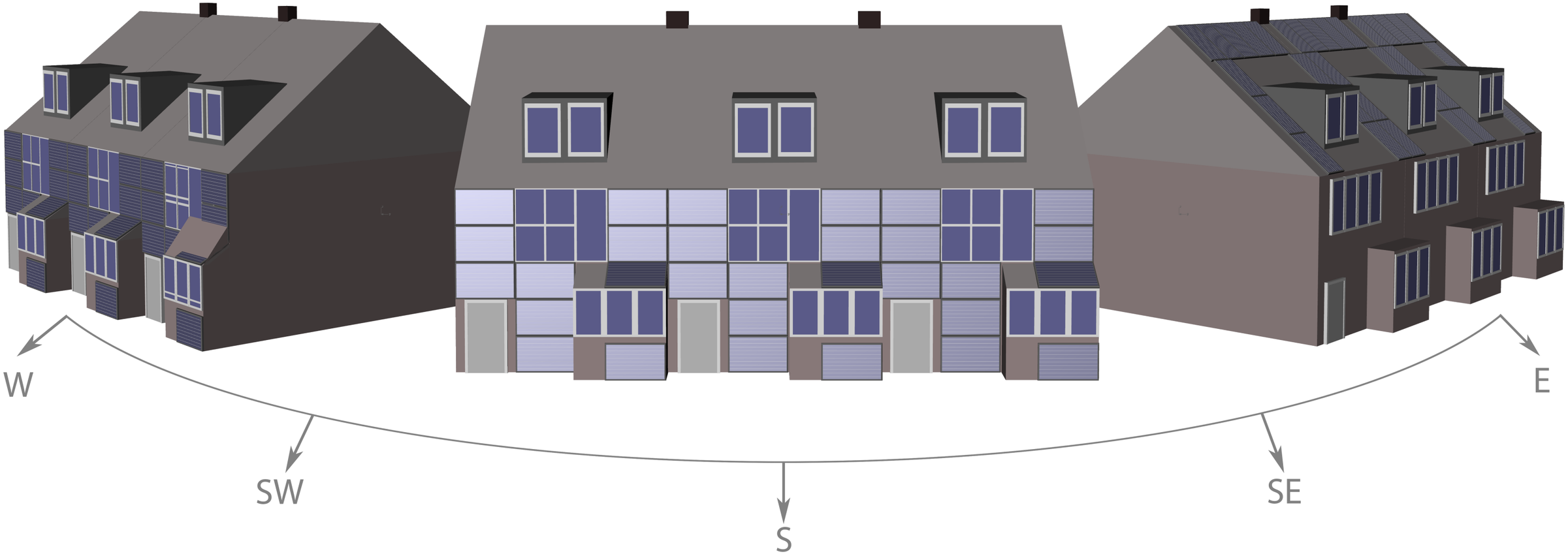


Orientation : East
Angle : 45 C°
Panels per household : 10,5
Annual thermal heat production: (40C°) 14.700 kWh
(80C°) 12.265 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	252	447	1024	1658	2271	2328	2350	1970	1242	687	290	178
80 C°	182	317	855	1391	1940	2000	2039	1673	1024	525	201	118





4.4 Comparison energy potentials

A comparison is made for all five types of solar energy production technologies that are integrated in the roofs or façade for both typology buildings & other public/private areas. The goal of the comparison is making substantiated choices picking the right technologies in the set-up of the configurations in chapter 5. This comparison does not analyse which technologies produces the most energy per m^2. The comparison evaluates which technologies with a selected dimensioning perform best on the buildings typologies of the selected urban blocks. For another case study the results could turn out different due to different typology buildings with a different dimensioning. This could results in placement and integration difficulties/ obstacles of the technologies on the roof or façade. The comparison is illustrated in the following order:

Private

4.4.1 Building typology 1

1. *Commonly applied placement of panels on roofs*
2. *Minor visual impact*
3. *Building extension*
4. *Partly refurbished roof*
5. *Totally refurbished roof*
6. *Refurbished facade*

4.4.2 Building typology 2

1. *Commonly applied placement of panels on roofs*
2. *Minor visual impact*
3. *Building extension*

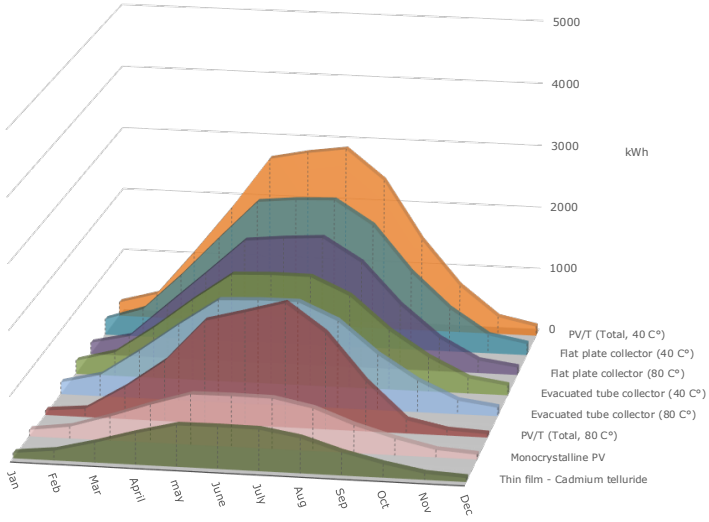
Public

4.4.3 Green areas

1. *Maximum solar field*
2. *Partly solar field*
3. *Covered parking*

4.4.1 Building typology 1

(1) Commonly applied placement of panels on roofs (West)



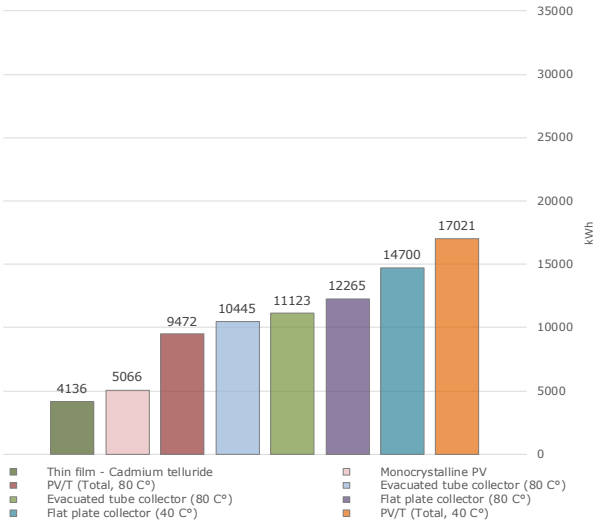
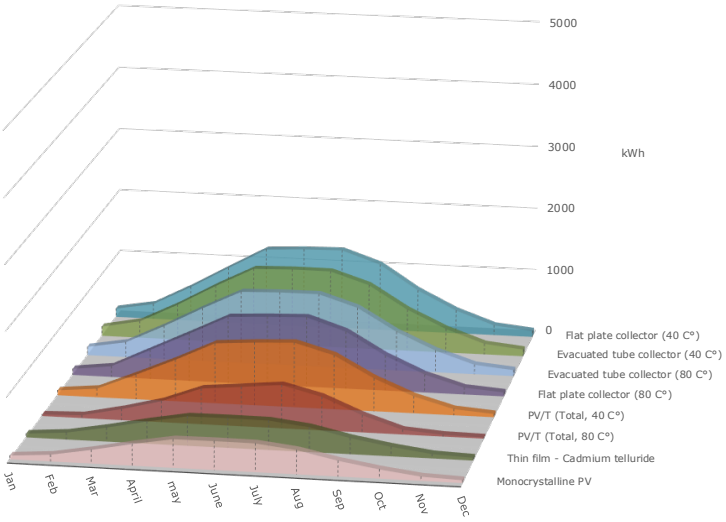


Figure 4.35: *Monthly & annual energy potential.*

(2) Minor visual impact (West)



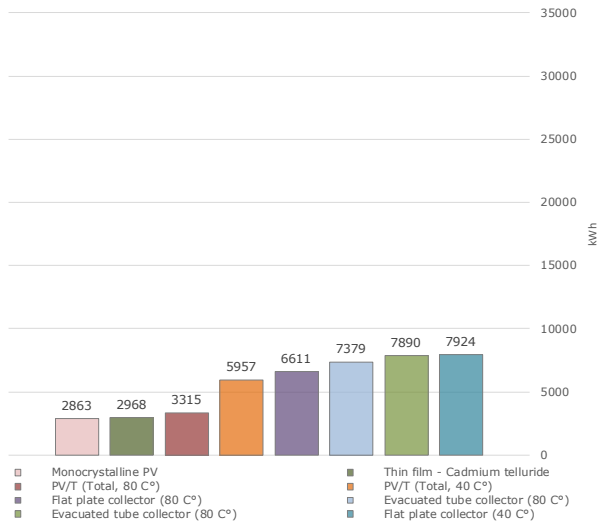
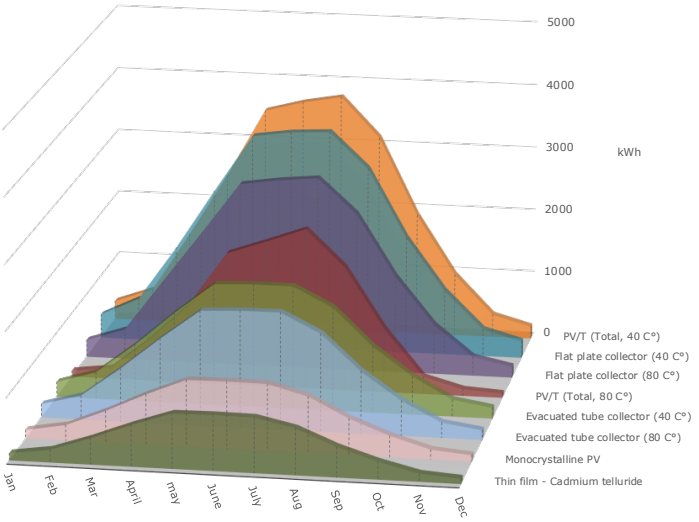


Figure 4.36: *Monthly & annual energy potential.*

(3) Building extention (West)



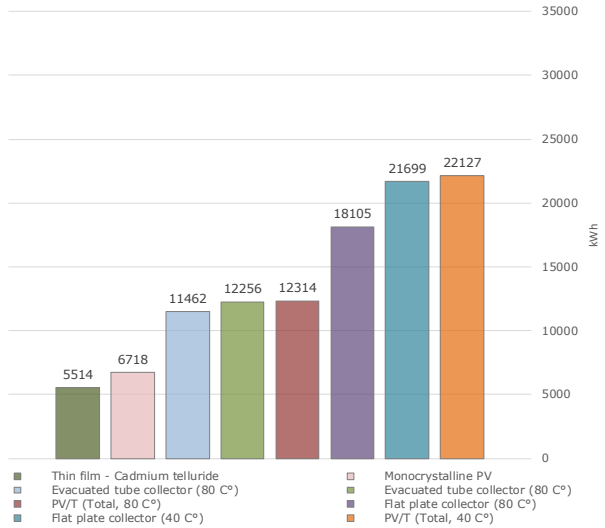
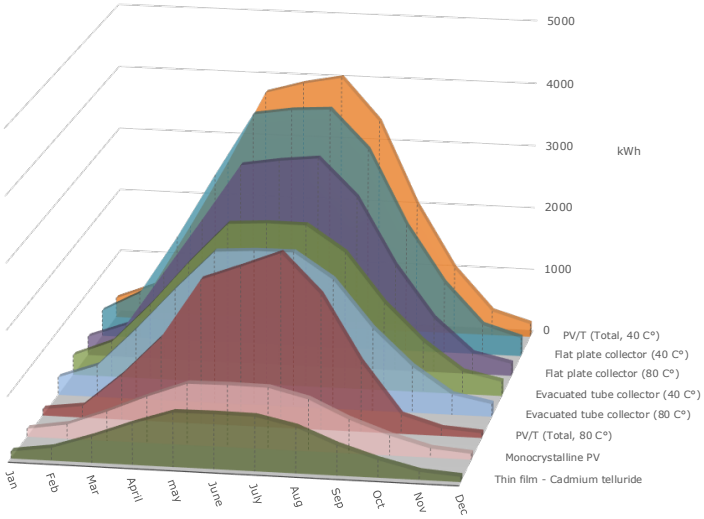


Figure 4.37: *Monthly & annual energy potential.*

(4) Partly refurbished (West)



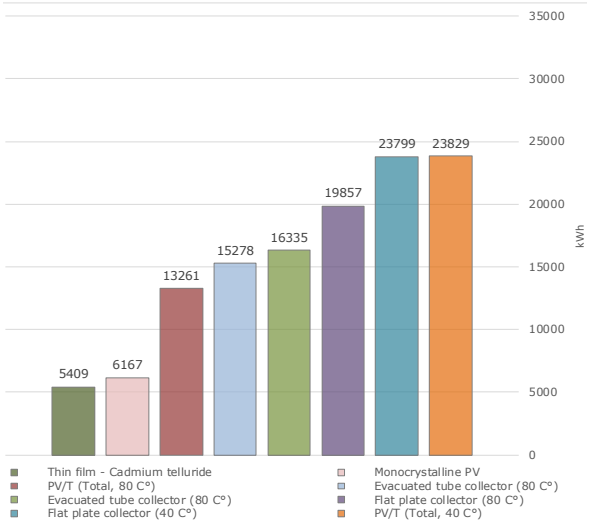
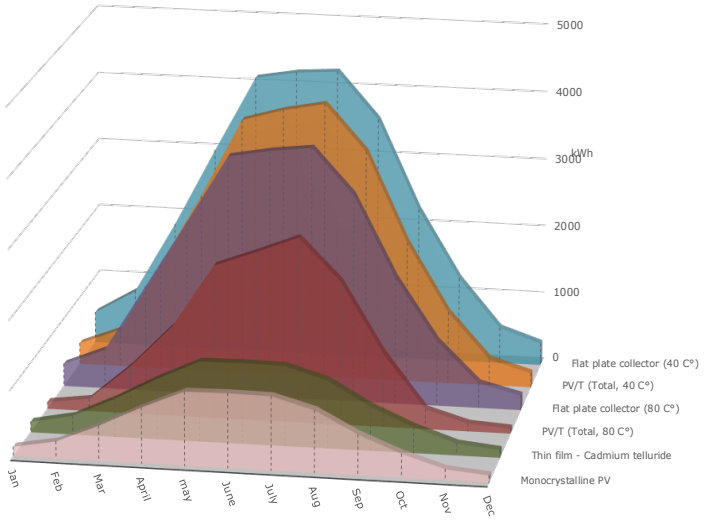


Figure 4.38: *Monthly & annual energy potential.*

(5) Totally refurbished (West)



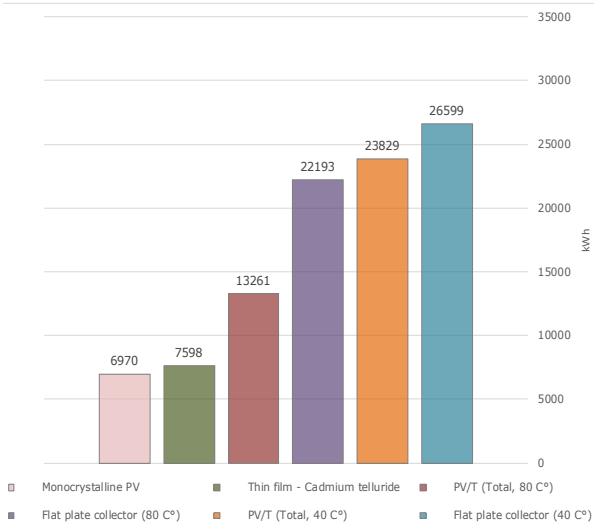
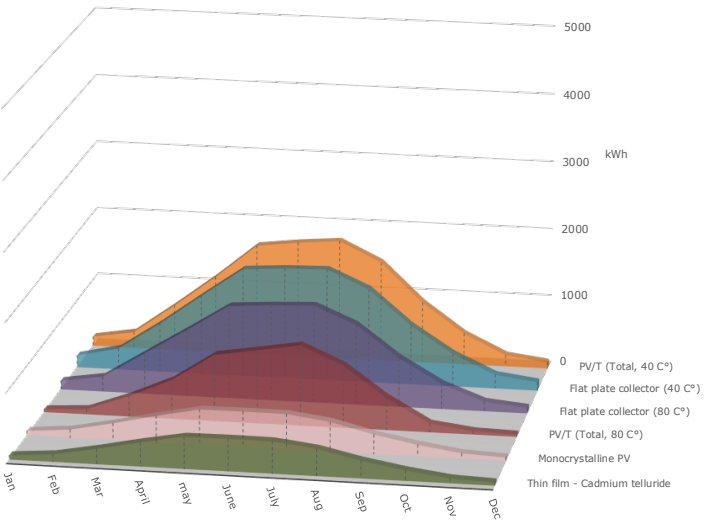


Figure 4.39: *Monthly & annual energy potential.*

(6) Refurbished facade (West)



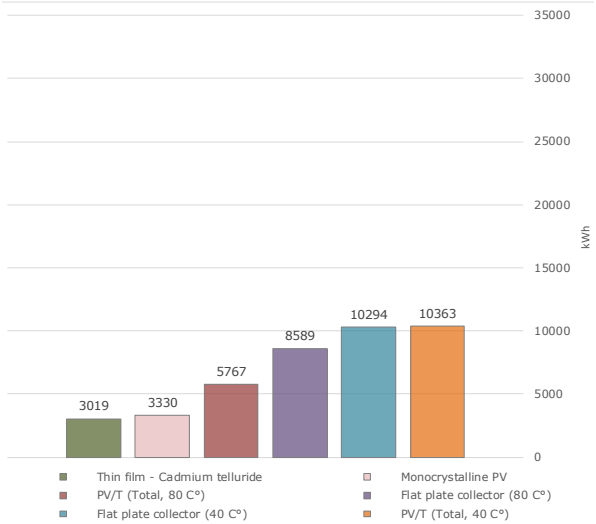
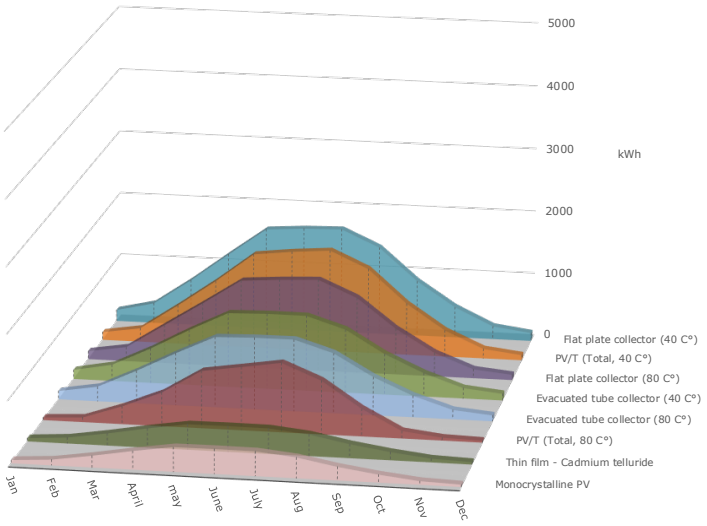


Figure 4.40: *Monthly & annual energy potential.*

4.4.2 Building typology 2

(1) Commonly applied placement of panels on roofs: (South-west)



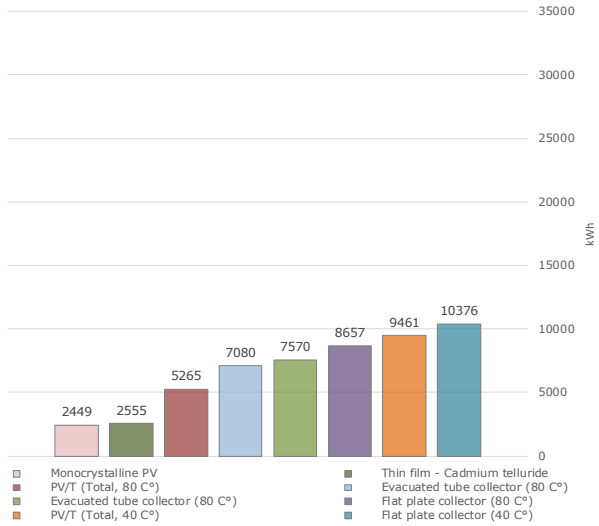
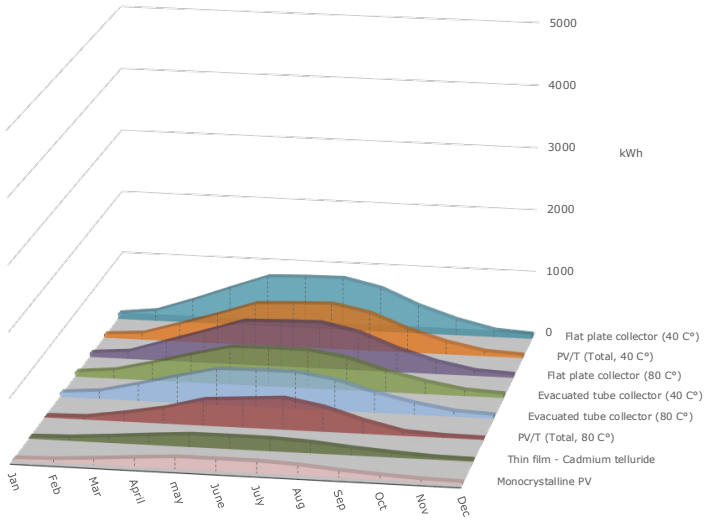


Figure 4.41: *Monthly & annual energy potential.*

(2) Minor visual impact (South-west)



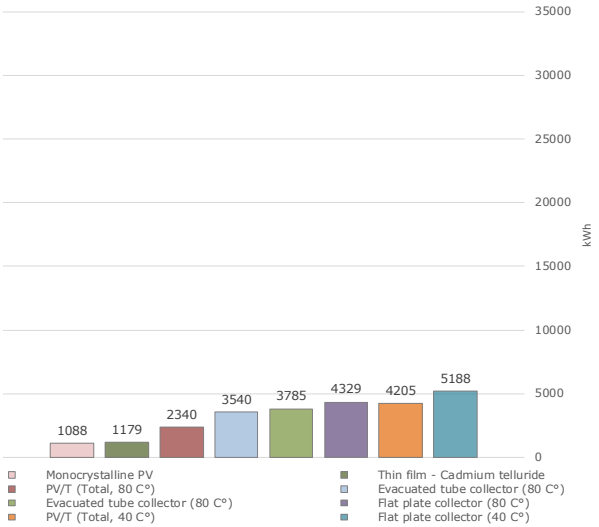
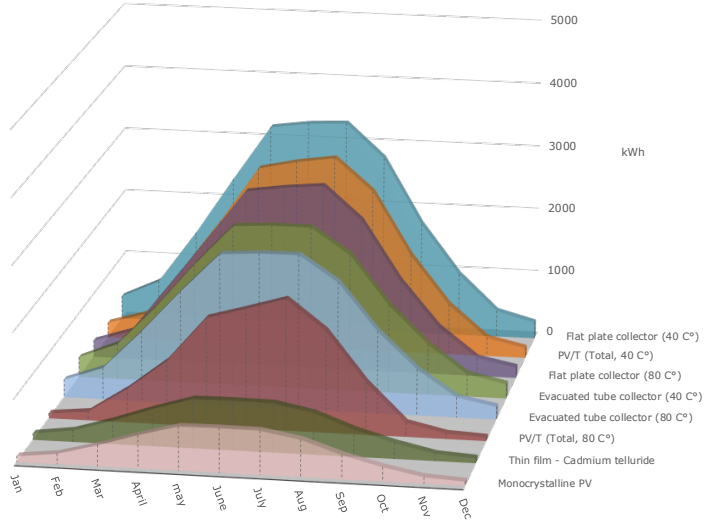


Figure 4.42: *Monthly & annual energy potential.*

(3) Building extention (South-west)



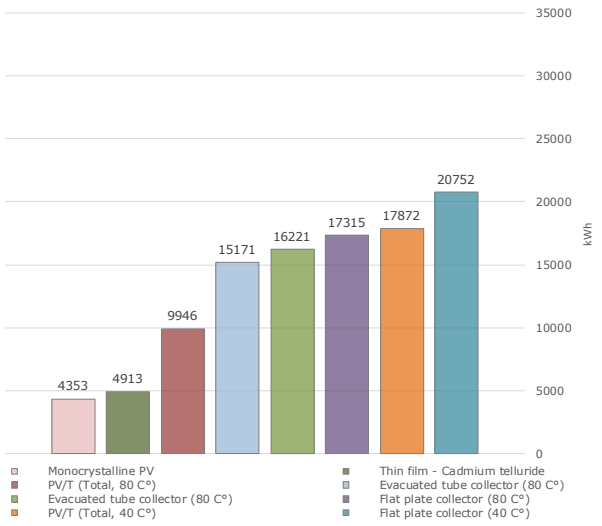
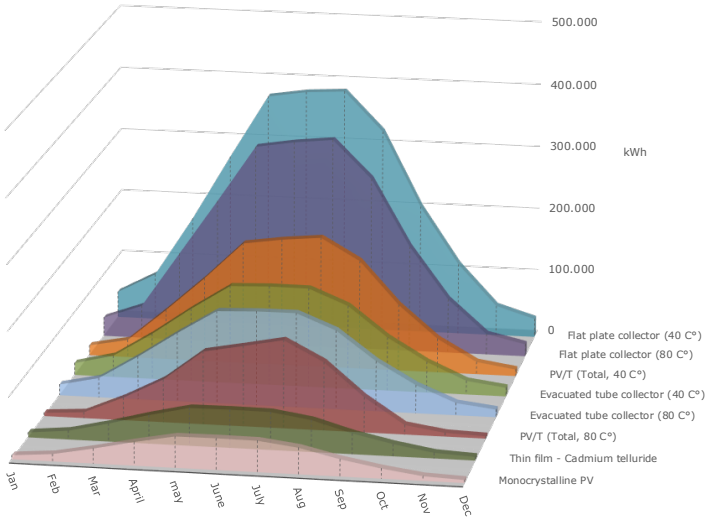


Figure 4.43: *Monthly & annual energy potential.*

4.4.3 Green areas

(1) Maximum potential



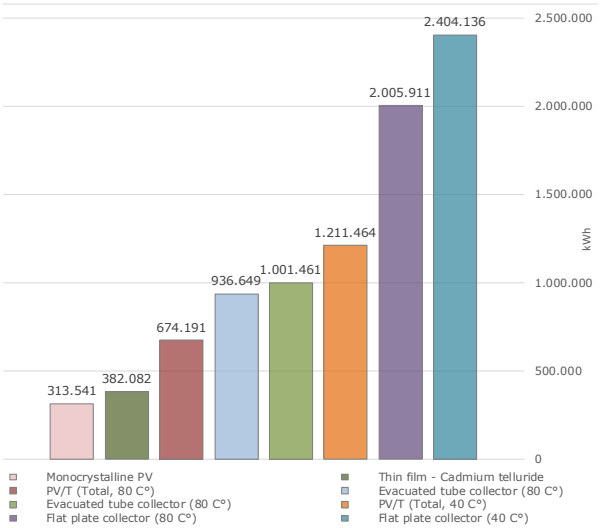
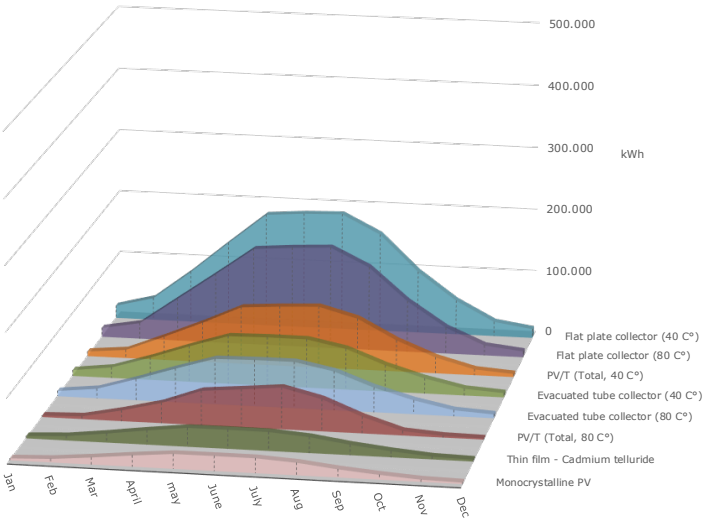


Figure 4.44: *Monthly & annual energy potential.*

(2) Potential considering vegetation



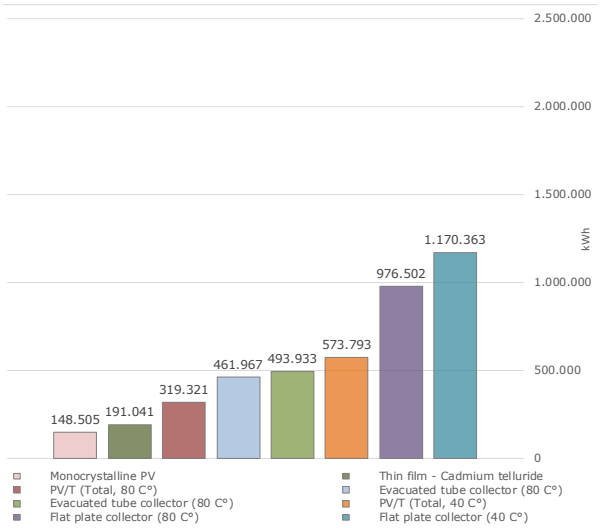
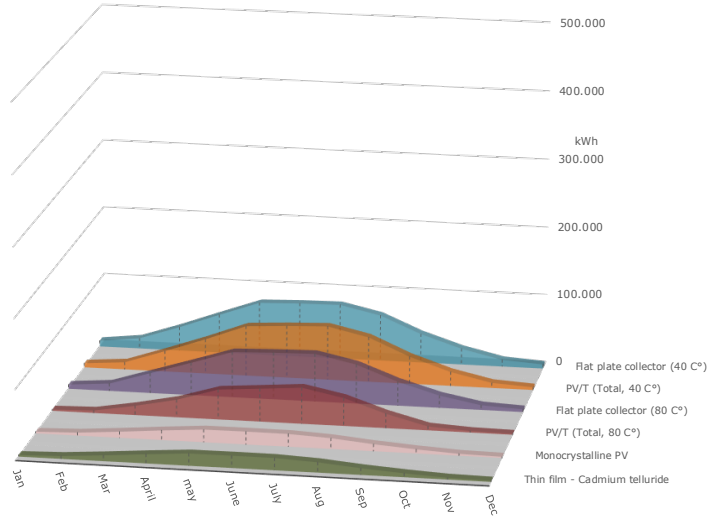


Figure 4.45: *Monthly & annual energy potential.*

(3) Parking areas



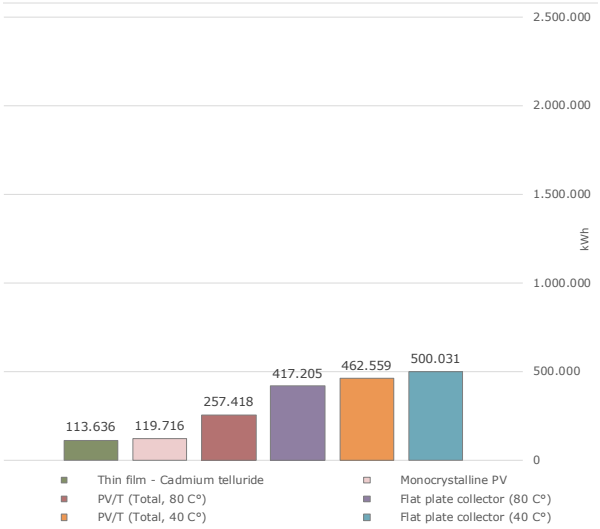


Figure 4.46: *Monthly & annual energy potential.*

4.4.4 Results and conclusions regarding the energy potentials

This comparison will be used to select which photovoltaic system and which solar collector system will be selected for the configurations. The energy potential of only one PVT panel was analysed and will therefore be used in the configurations. Including the PVT in the graphs provides a better overview of the best performing solar energy production technologies.

Choices photovoltaic systems:
As visible in all twelve graphs about the buildings typology 1 there is hardly a difference noticeable between monocrystalline PV and thin film - cadmium telluride PV panels. The result of the commonly applied placement of panels on roofs: , which is an important set-up for the configurations (**A**), is slightly advantageous for monocrystalline PV. Therefore the monocrystalline PV panel will be selected to be integrated in the buildings in the configurations. Secondly there is almost no difference in energy potentials between the photovoltaic systems for buildings typology 2, monocrystalline PV performs slightly better as well.
The only distinctive difference is the energy potential of using the total green area as a solar field. Thin film – cadmium telluride is the more favourable option to choose for energy production in the public space. Secondly these panels are cheaper to produce and therefore a better choice to place in the public areas. Panel placed in the public areas run the risk to be stolen or demolished and therefor the cheaper option is a beneficial option. If configurations choices lead to a solar field in public space this will be designed with thin film PV panels.

Solar collectors
The energy potentials of the flat plate collectors are always higher compared to the results of the evacuated tube collectors (ETC). The higher the temperature output of both types of solar collectors, the worse they perform due to increasing thermal losses. In most results the flat plate collectors with a thermal output of 80 °C (45 °C average) performs even better than the ETC's with an thermal out of 40 °C (25 °C average). Secondly the possibilities of integrating ETC's in for example the covered parking spaces are more complex and sometimes not even possible. Both arguments combined, results in the choice not use the ETC's in the configurations but only use the flat plate collectors.

PVT
The PVT will be used in the set-up of the configurations but this analysis provides an interesting inside. Insights in most energy potential results the PVT panel with a thermal output temperature of 40 °C (25 °C average) performs either the best of all systems or performs second, close to the number one (flat plate c. 40 °C, 25 °C average). The most striking result is the fact that the PVT panel with a thermal output of 80 °C (45 °C average) performs the worst of all systems producing thermal output. The high temperature not only influences the thermal output negatively but also the efficiency for the electrical output is reduced. Secondly the monthly energy potentials values of PVT (80°C) are higher in summer months compared to ETC's in summer months, while the annual production values are lower of ETC's. This means that PVT panels set on a high temperature output have a high peak in energy potential in summer months. Since the heat demand is low in summer, the result is a longer storage period necessary if the PVT (80°C, 45 °C average) system is selected. This will result in a higher necessary storage potential of the energy storages and secondly in more thermal losses that occur overtime in the energy storages.
This analysis results will be taken into account in configuration design making use of PVT panels. The aim will therefore be that the thermal output temperature of PVT panels must be as low as possible.

4.5 Energy storage potentials

In this paragraph we analyse the energy storage potentials of thermal energy storage. The energy storage potentials are calculated using the method earlier discussed in this chapter (4.2). The values presented in this chapter are the maximum energy accumulation values of one cycle without the extraction of energy out of the storage, by for example delivering the heat demand. The analysis results are presented at the end of this paragraph concluding with an explanation which systems will be selected to be integrated in the configurations creating a renewable energy system delivering the heat demand of the building.

The following technologies & types of thermal energy storage are analysed:

4.5.1 Sensible thermal energy storage

Cyclinder tank storage

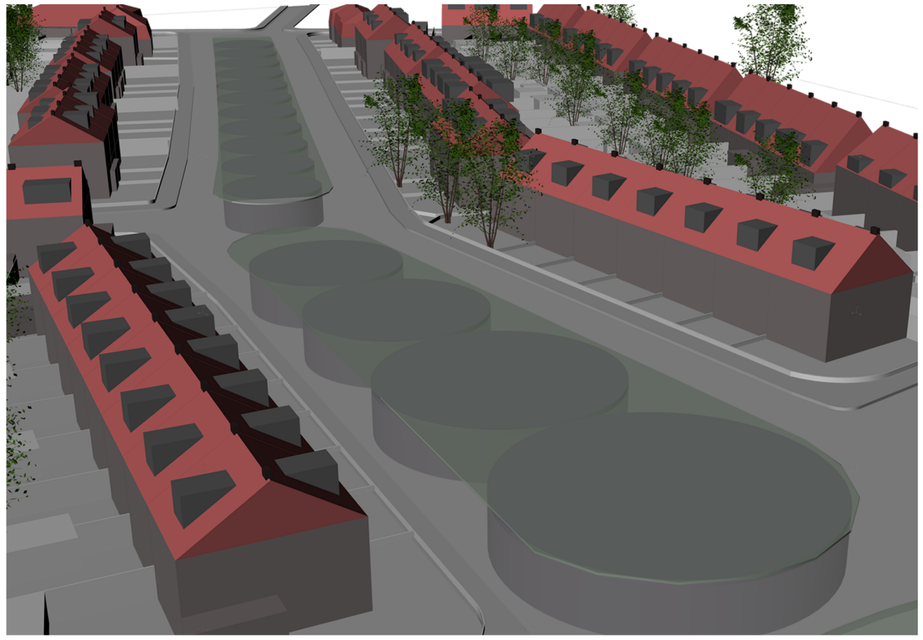
I. Maximum storage potential public area
II. Storage potential maintaining green
III. Increasing height/comparison

Pit storage

I. Maximum storage potential public area
II. Storage potential maintaining green
III. Increasing height/comparison

4.5.2 Latent thermal energy storage - Cylinder tank storage (filled with salt)

Cylinder tank storages filled with water (heigth 5m)





Storage potential:

Volume: 3079 m³
- ***Water: 2059 m³***
- ***XPS insulation: 813 m³***
- ***Steel construction: 207 m³***

Total outside surface: 1671 m²
Volume/surface ratio: 1,84

Storage potential (KJ) = $V \cdot \rho \cdot cp \cdot (T_{max} - T_{min})$
with $(T_{max} - T_{min}) = (80\text{-}40) = 40$

*E (kWh)= (2059*998*4,192*40)/3600*
E (kWh) = ***95.706 kWh***

Volume: 2262 m³
Water: 1466 m³
Total outside surface: 1282 m²
Volume/surface ratio: 1,76
E (kWh)= ***68.134 kWh***

Volume: 1571 m³
Water: 973 m³
Total outside surface: 942 m²
Volume/surface ratio: 1,67
E (kWh)= ***45.236 kWh***

Volume: 1272 m³
Water: 765 m³
Total outside surface: 792 m²
Volume/surface ratio: 1,61
E (kWh)= ***35.539 kWh***

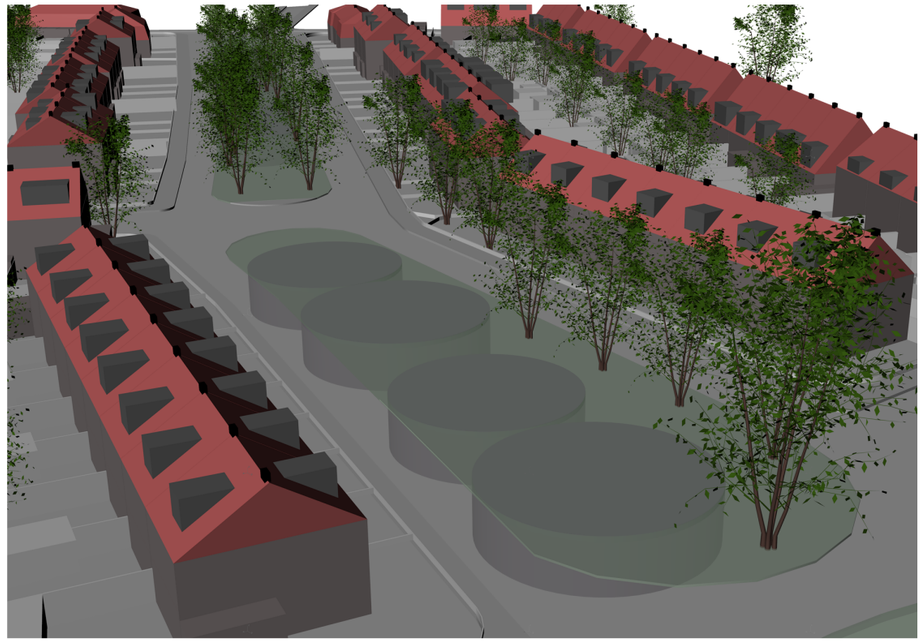
Volume: 884 m³
Water: 499 m³
Total outside surface: 589 m²
Volume/surface ratio: 1,50
E (kWh)= ***23.185 kWh***

11x

Total energy storage potential: ***499.646 kWh***

(1 year cycle)

Cylinder tank storages filled with water (heigth 5m)





Storage potential:

Volume: 1571 m³
- *Water: 973 m³*
- *XPS insulation: 475 m³*
- *Steel construction: 123 m³*

Total outside surface: 942 m²
Volume/surface ratio: 1,67

Storage potential (KJ) = V·ρ·cp·(T_{max}-T_{min})
with (T_{max}-T_{min}) = (80-40) = 40

*E (kWh)= (2059*998*4,192*40)/3600*
*E (kWh) = **45.236 kWh***

2x

Volume: 1272 m³
Water: 765 m³
Total outside surface: 792 m²
Volume/surface ratio: 1,61
*E (kWh)= **35.539 kWh***

2x

Volume: 884 m³
Water: 499 m³
Total outside surface: 589 m²
Volume/surface ratio: 1,50
*E (kWh)= **23.185 kWh***

6x



Total energy storage potential: 300.658 kWh

(1 year cycle)

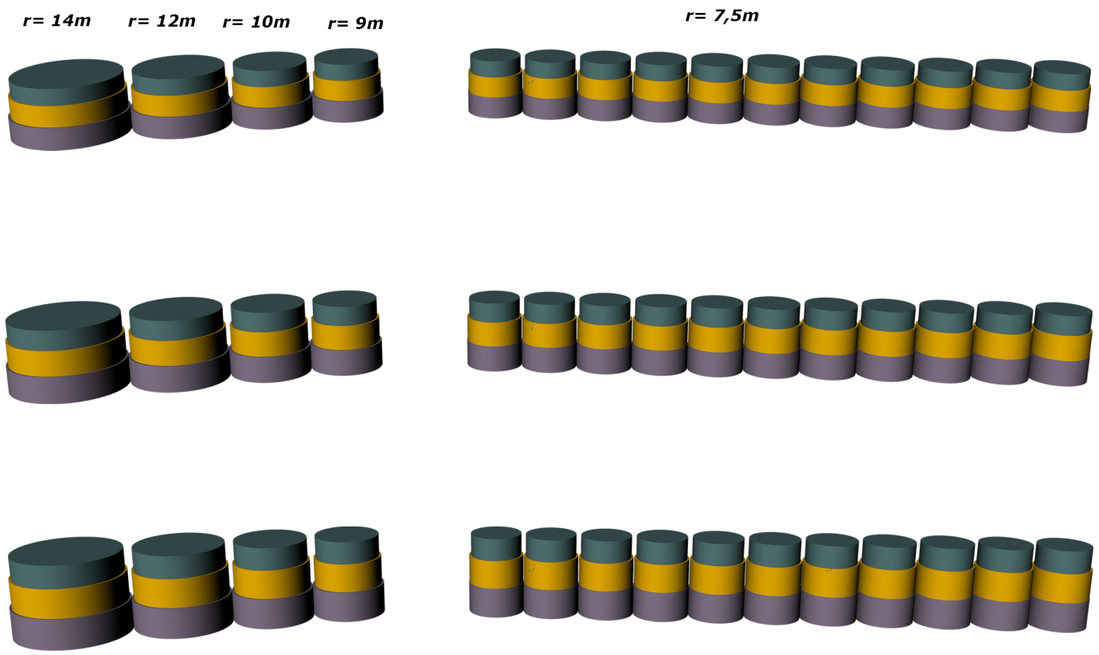
Maximum storage potential public space:

** all tanks added up*

Height storages 5m
- *Volume: 17.903 m³*
- *Water: 10.749 m³*
- *XPS insulation: 5678 m³*
- *Steel construction: 1476 m³*
- *Total outside surface: 11.166 m²*
- *Volume/surface ratio: 1,60*
- *Storage potential (kWh) =* ***499.646 kWh***

Height storages 6m
- *Volume: 21.484 m³*
- *Water: 13.436 m³*
- *XPS insulation: 6413 m³*
- *Steel construction: 1634 m³*
- *Total outside surface: 11.968 m²*
- *Volume/surface ratio: 1,80*
- *Storage potential (kWh) =* ***624.558 kWh***

Height storages 7m
- *Volume: 25.064 m³*
- *Water: 16.123 m³*
- *XPS insulation: 7149 m³*
- *Steel construction: 1793 m³*
- *Total outside surface: 12769 m²*
- *Volume/surface ratio: 1,96*
- *Storage potential (kWh) =* ***749.470 kWh***



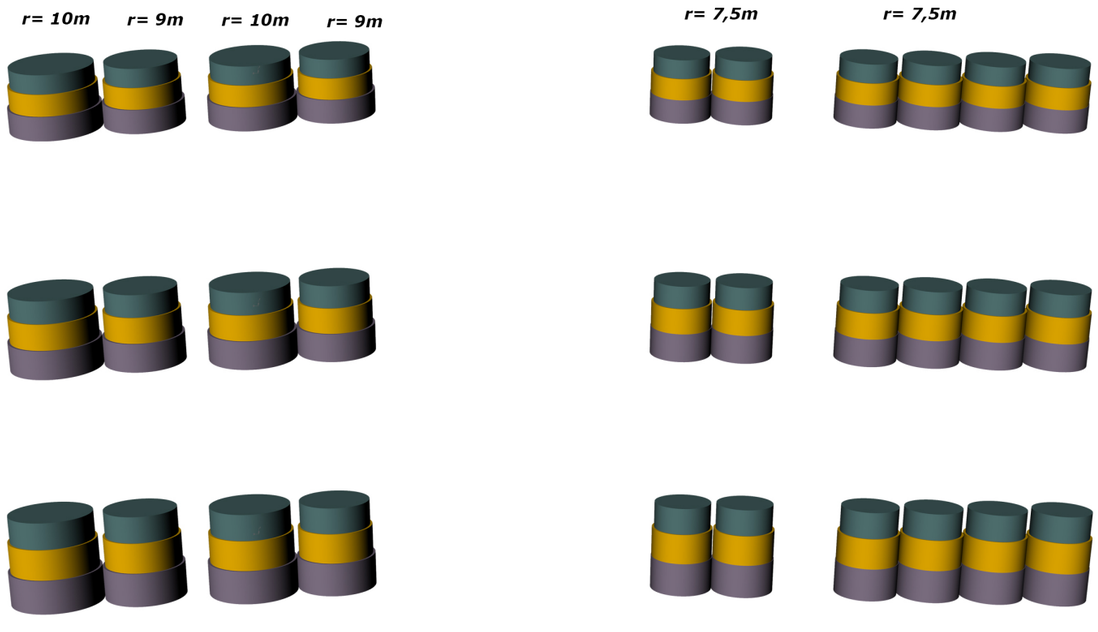
Storage potential maintaining green/public space:

** all tanks added up*

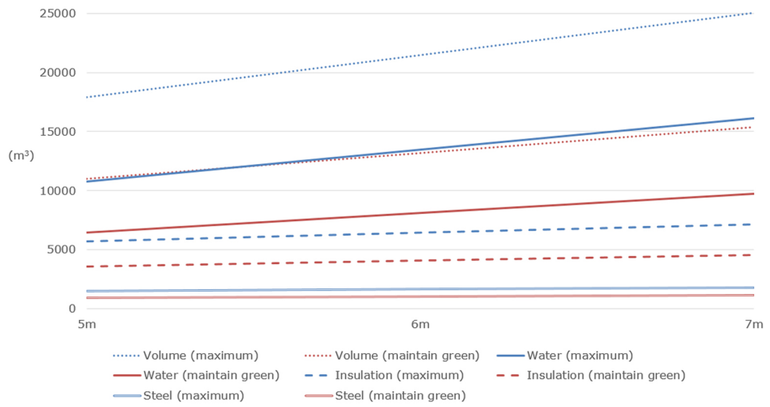
Height storages 5m
- *Volume: 10.988 m³*
- *Water: 6468 m³*
- *XPS insulation: 3586 m³*
- *Steel construction: 934 m³*
- *Total outside surface: 7003 m²*
- *Volume/surface ratio: 1,57*
- *Storage potential (kWh) =* ***300.658 kWh***

Height storages 6m
- *Volume: 13.185 m³*
- *Water: 8085 m³*
- *XPS insulation: 4063 m³*
- *Steel construction: 1037 m³*
- *Total outside surface: 7524 m²*
- *Volume/surface ratio: 1,75*
- *Storage potential (kWh) =* ***375.823 kWh***

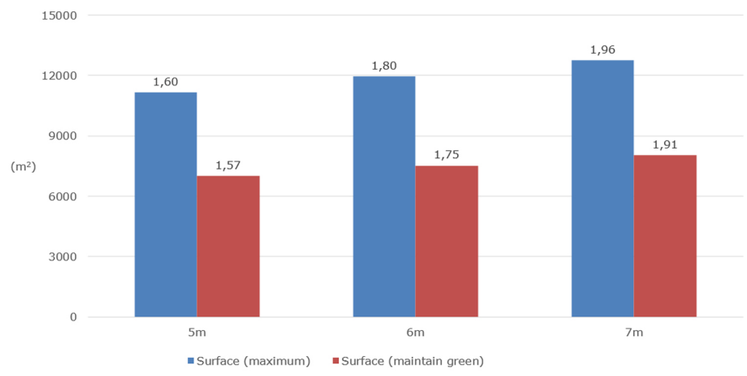
Height storages 7m
- *Volume: 15.383 m³*
- *Water: 9702 m³*
- *XPS insulation: 4541 m³*
- *Steel construction: 1140 m³*
- *Total outside surface: 8046 m²*
- *Volume/surface ratio: 1,91*
- *Storage potential (kWh) =* ***450.988 kWh***



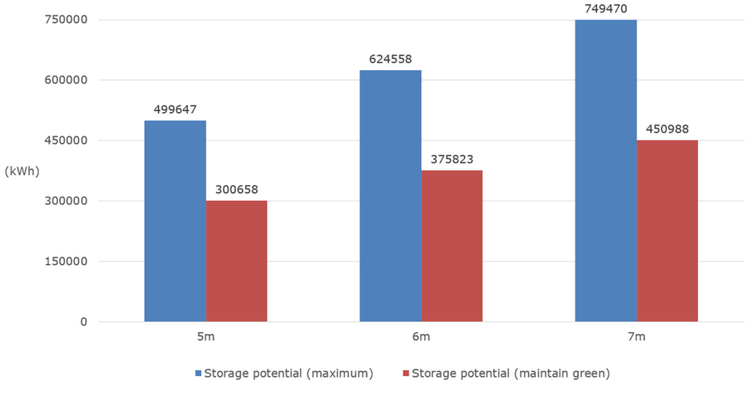
Volumes



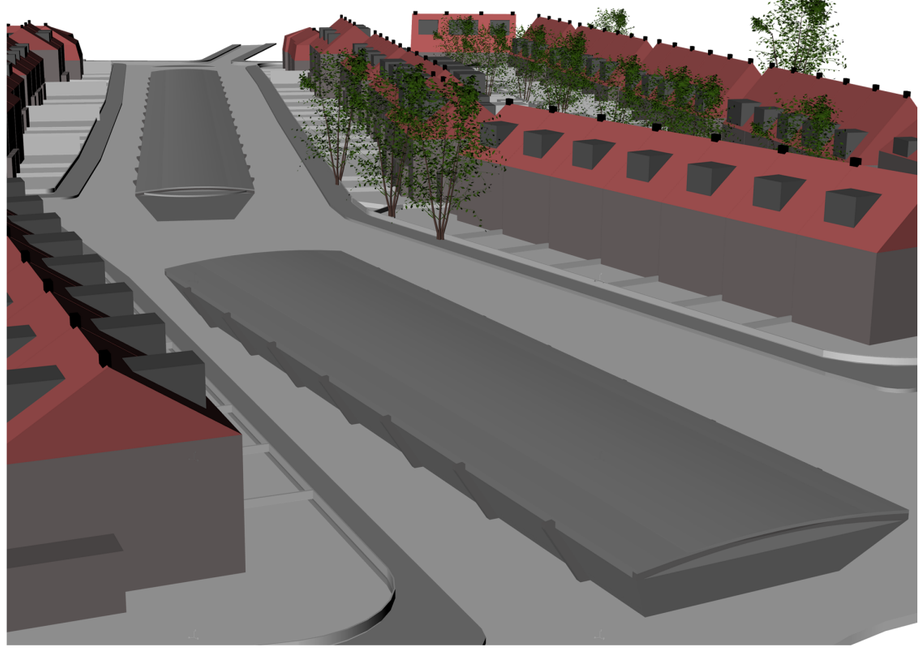
Volume/surface ratio



Storage potential



Pit storages filled with water (heigth 4,5m)





Storage potential:

Height: 4,5m
Volume: 5053 m³

Concrete: *1093m³*
Thickness bottom: 600mm
Lateral: 300mm
Cover: 200mm

XPS insulation: *1025 m³*
Thickness bottom: 200mm
Lateral: 500mm
Cover: 500mm

Water: *2935 m³*

Total outside surface: 3166 m²
Volume/surface ratio: 1,60

Storage potential (KJ) = $V \cdot \rho \cdot cp \cdot (T_{max} - T_{min})$
with $(T_{max} - T_{min}) = (80-40) = 40$

*E (kWh) = (2935*998*4,192*40)/3600*
E (kWh) = ***136.432 kWh***

Height: 4,5m
Volume: 7591 m³
Concrete: *1704 m³*
XPS insulation: *1588 m³*
Water: *4299 m³*

Total outside surface: 5042 m²
Volume/surface ratio: 1,51

*E (kWh) = (4299*998*4,192*40)/3600*
E (kWh) = ***199.837 kWh***



Total energy storage potential: ***336.269 kWh***

(1 year cycle)

Pit storages filled with water (heigth 4,5m)





Storage potential:

Height: 4,5m
Volume: 3740m³

Concrete: *851m³*
Thickness bottom: 600mm
Lateral: 300mm
Cover: 200mm

XPS insulation: *796 m³*
Thickness bottom: 200mm
Lateral: 500mm
Cover: 500mm

Water: *2093m³*

Total outside surface: 2544 m²
Volume/surface ratio: 1,47

Storage potential (KJ) = $V \cdot \rho \cdot cp \cdot (T_{max} - T_{min})$
with $(T_{max} - T_{min}) = (80-40) = 40$

*E (kWh) = (2093*998*4,192*40)/3600*
E (kWh) ***= 97.292 kWh***

Height: 4,5m
Volume: 1171m³
Concrete: *282 m³*
XPS insulation: *256m³*
Water: *633 m³*

Total outside surface: 880 m²
Volume/surface ratio: 1,33

E (kWh)= ***29.425 kWh***

Height: 4,5m
Volume: 2731 m³
Concrete: *642 m³*
XPS insulation: *582m³*
Water: *1507m³*

Total outside surface: 1878 m²
Volume/surface ratio: 1,44

E (kWh)= ***70.052 kWh***

Total energy storage potential: ***196.769 kWh***

(1 year cycle)

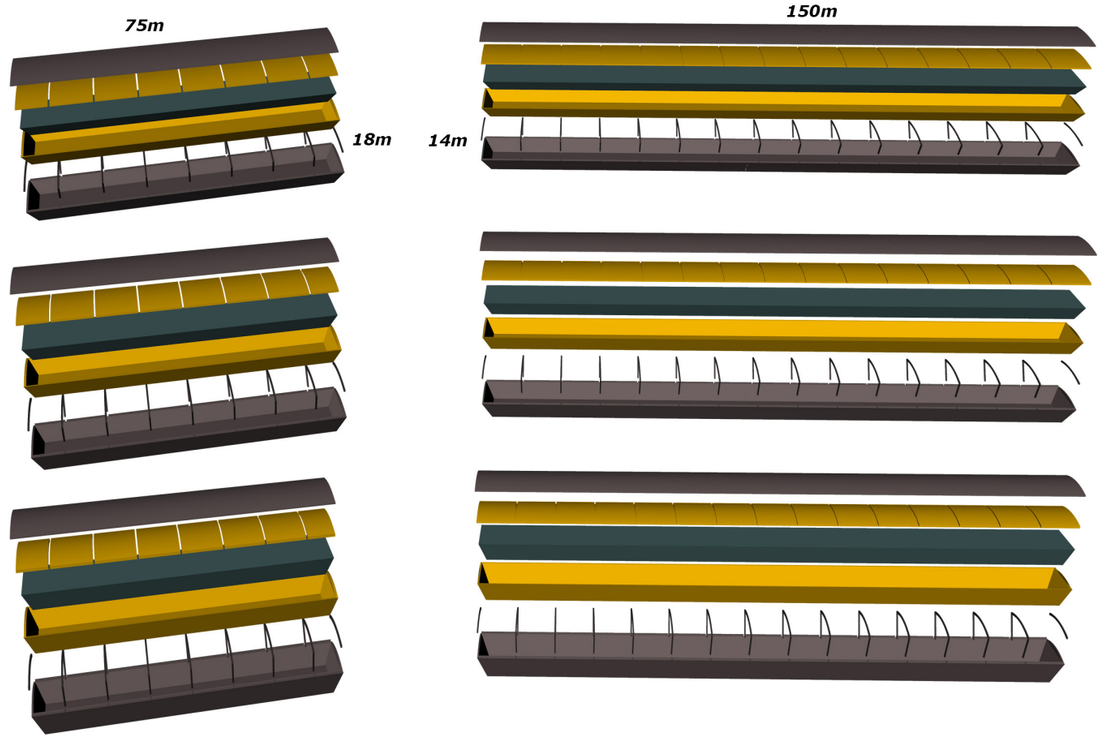
Maximum storage potential public space:

** all pit storages added up*

Height storages 4,5m
- *Volume: 12.644 m³*
- *Water: 7234 m³*
- *XPS insulation: 2613 m³*
- *Concrete: 2797 m³*
- *Total outside surface: 8208 m²*
- *Volume/surface ratio: 1,54*
- *Storage potential (kWh) =* ***336.269 kWh***

Height storages 5,5m
- *Volume: 15.453 m³*
- *Water: 8914 m³*
- *XPS insulation: 3594 m³*
- *Concrete: 2945 m³*
- *Total outside surface: 8650 m²*
- *Volume/surface ratio: 1,79*
- *Storage potential (kWh) =* ***414.346 kWh***

Height storages 6,5m
- *Volume: 18.262 m³*
- *Water: 11.323 m³*
- *XPS insulation: 3847m³*
- *Concrete: 3093 m³*
- *Total outside surface: 9105 m²*
- *Volume/surface ratio: 2,01*
- *Storage potential (kWh) =* ***526.331 kWh***



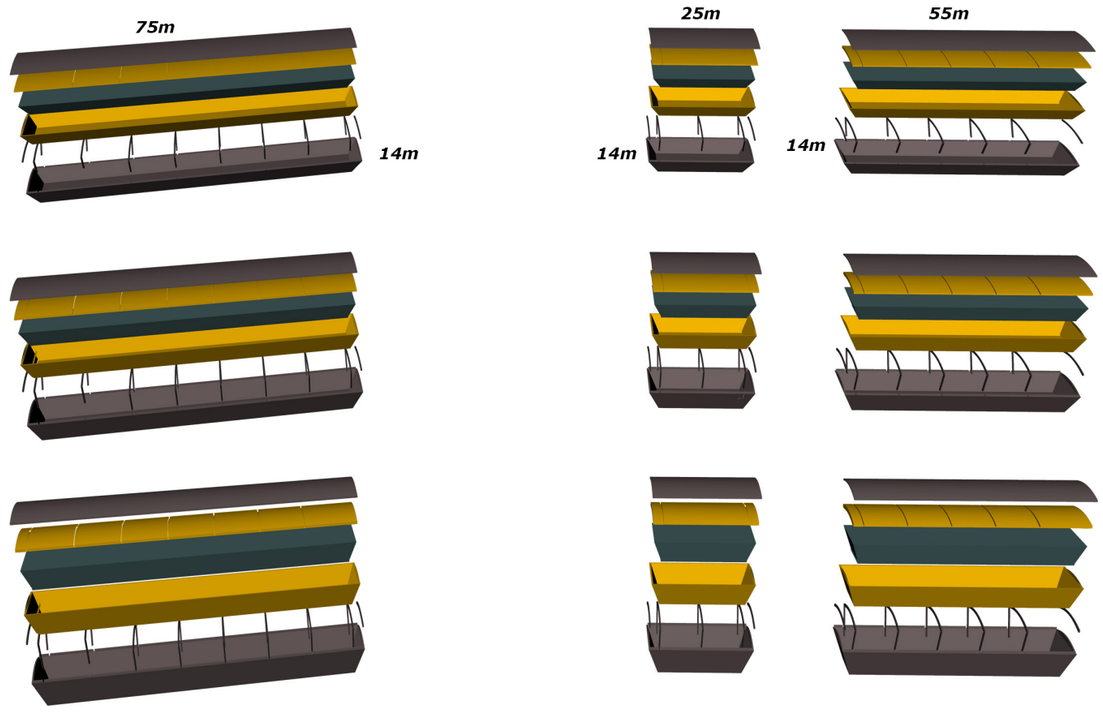
Storage potential maintaining green/public space:

** all pit storages added up*

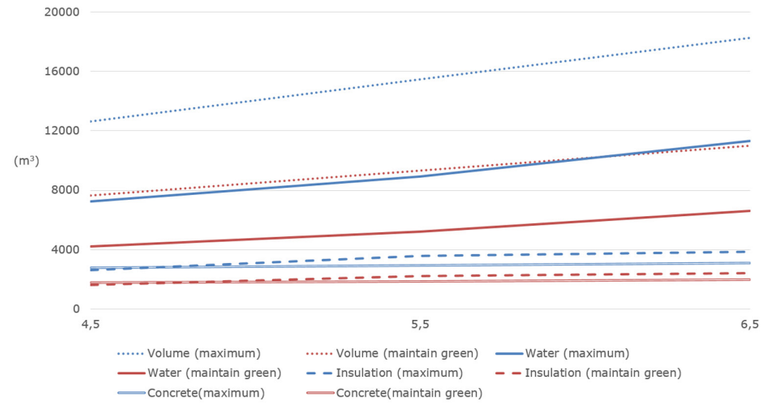
Height storages 4,5m
- *Volume: 7642 m³*
- *Water: 4233 m³*
- *XPS insulation: 1634 m³*
- *Concrete: 1775 m³*
- *Total outside surface: 5302 m²*
- *Volume/surface ratio: 1,44*
- *Storage potential (kWh) =* ***196.769 kWh***

Height storages 5,5m
- *Volume: 9319 m³*
- *Water: 5210 m³*
- *XPS insulation: 2242 m³*
- *Concrete: 1867 m³*
- *Total outside surface: 5629 m²*
- *Volume/surface ratio: 1,66*
- *Storage potential (kWh) =* ***242.171 kWh***

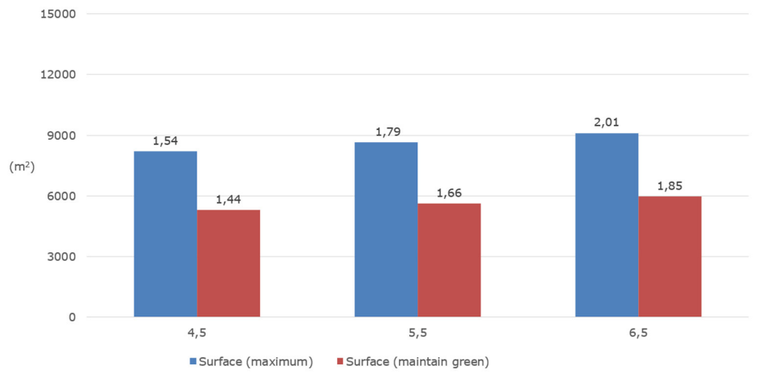
Height storages 6,5m
- *Volume: 11.013 m³*
- *Water: 6618 m³*
- *XPS insulation: 2420 m³*
- *Concrete: 1975 m³*
- *Total outside surface: 5965 m²*
- *Volume/surface ratio: 1,85*
- *Storage potential (kWh) =* ***307.623 kWh***



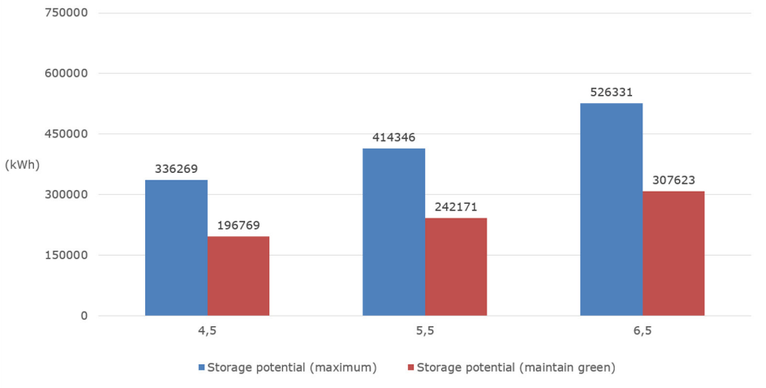
Volumes



Volume/surface ratio



Storage potential



Cylinder tank storages filled with inorganic salt hydrates: Na2S2O3 · 5H2O (heigth 5m)

$E_{Latent} = V \cdot \rho * L$
V = volume in m³
ρ = density storage material, 1750 kg/m³
L = Latent heat of fusion, 187-200 kJ/kg

Other properties Na2S2O3 · 5H2O"
Melting point (Tpc) = 48 C°
c_p = 1,5 KJ/kg*K

Storage potential:

Volume: 3079 m³
Salt: 2059 m³
XPS insulation: 813 m³
Steel construction: 207 m³

Total outside surface: 1671 m²
Volume/surface ratio: 1,84

$E_{sensible}$ (kWh) = (2059*1750*1,5*40)/3600
$E_{sensible}$ (kWh) = **60.054 kWh**

E_{latent} (kWh) = 2059*1750*187/3600
E_{latent} (kWh) = **187.169 kWh**

E_{total} = **247.223 kWh**

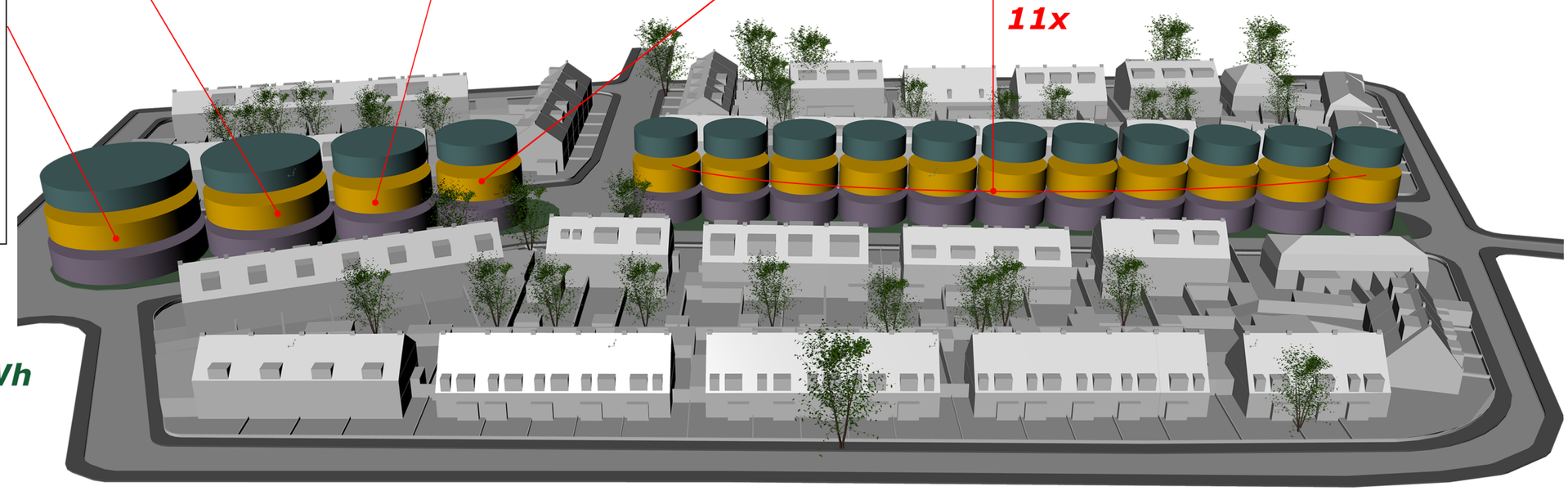
Volume: 2262 m³
Salt: 1466 m³
$E_{sensible}$ = **42.758 kWh**
E_{latent} = **133.263 kWh**
E_{total} = **176.022 kWh**

Volume: 1571 m³
Salt: 973 m³
$E_{sensible}$ = **28.379 kWh**
E_{latent} = **88.448 kWh**
E_{total} = **116.828 kWh**

Volume: 1272 m³
Salt: 765 m³
$E_{sensible}$ = **22.313 kWh**
E_{latent} = **69.541 kWh**
E_{total} = **91.853 kWh**

Volume: 884 m³
Salt: 499 m³
$E_{sensible}$ = **14.554 kWh**
E_{latent} = **45.360 kWh**
E_{total} = **59.915 kWh**

11x



Total energy storage potential: 1.290.991 kWh

(1 year cycle)

Storage potential:

Volume: 1571 m³
Salt: 973 m³
XPS insulation: 475 m³
Steel construction: 123 m³

Total outside surface: 942 m²
Volume/surface ratio: 1,67

$E_{sensible}$ (kWh) = (973*1750*1,5*40)/3600
$E_{sensible}$ (kWh) = **28.379 kWh**

E_{latent} (kWh) = 973*1750*187/3600
E_{latent} (kWh) = **88.448 kWh**

E_{total} = **116.828 kWh**

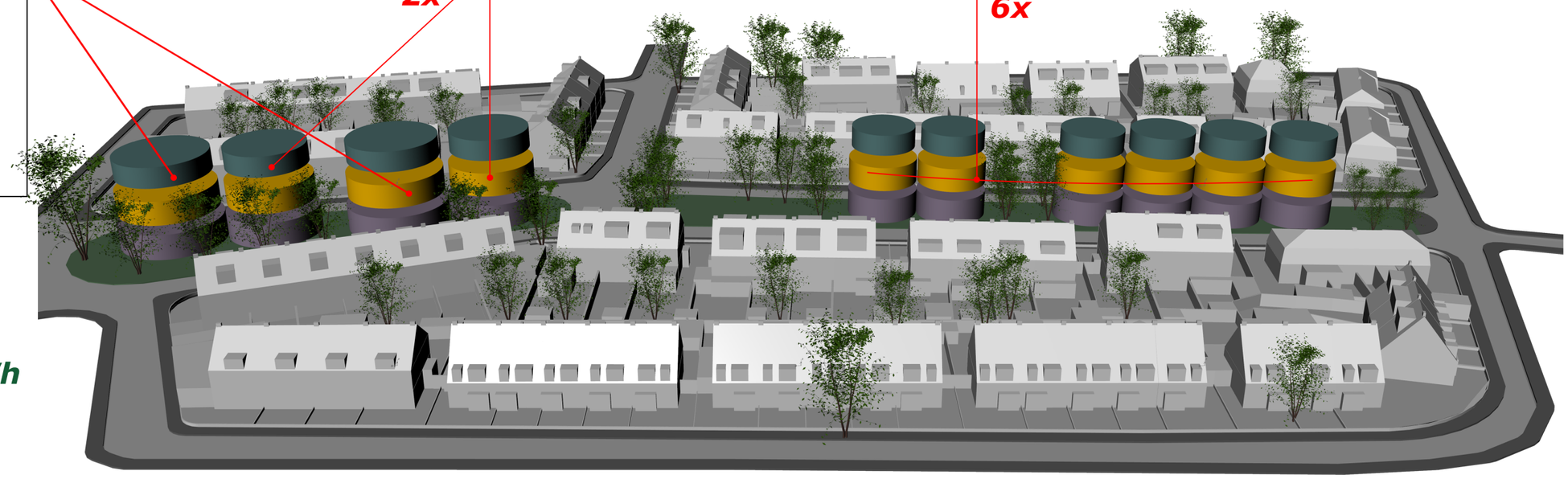
Volume: 1272 m³
Salt: 765 m³
$E_{sensible}$ = **22.313 kWh**
E_{latent} = **69.541 kWh**
E_{total} = **91.853 kWh**

Volume: 884 m³
Salt: 499 m³
$E_{sensible}$ = **14.554 kWh**
E_{latent} = **45.360 kWh**
E_{total} = **59.915 kWh**

2x

2x

6x



Total energy storage potential: 776.852 kWh

(1 year cycle)

4.5.3 Findings energy storage potentials

This analysis will be used to select which energy storage types and technologies are are best for the configurations. The energy storage potential increases linearly with the volume of the storages tanks. Simply meaning the larger the volume of the storage tank the more energy you can store, for both sensible as latent thermal energy storage. Secondly the analysis is used to determine the relative energy losses of the different types of energy storage and technologies.

Sensible thermal energy storage:
If we compare the volume/surface (V/S) ratio of the pit storage with the tank storage we can see that the smaller the height of the tank the more advantageous it is to choose for the pit storage because these volume/surface ratios are higher. The depth of the pit energy storage is 6,5m, which resulted in a V/S ratio of 2,01. The depth of the tank energy storage is between 6m and 7m, which resulted in a V/S ratio between 1,80-1,96. The higher this number is, the more advantageous it is because more volume means more storage potential. Secondly there are fewer thermal losses because the contact surface of the tank with the surrounding is smaller. The tank storages simply have a larger contact surface with the surroundings because of their circular shape. The difference between the maximum storage potential scenario and the scenario aiming to maintain green spaces, have the same problem. If we look at the V/S ratio difference between both scenarios, the pit storages maintaining green space have a lower V/S ratio compared to the maximum potential scenario.

Based on these findings we can conclude it is more optimal to use a pit storage because the higher V/S ratio and therefore the fewer thermal losses and material use. Secondly a pit storage makes more optimal use of the available space because of their adaptable shape and size. This is particularly interesting for dense living environment with limited available space. At last the pit storages used in the configurations will aim to consist out of the largest possible shape instead of several small spitted pit storages. This will results in a higher V/S ratio which is beneficial for the spatial and energy characteristics of the new renewable energy system.

Latent thermal energy storage
As visible in the analysis the storage potential of latent thermal energy storage is much higher than sensible thermal energy storage. This could result in a much smaller use of public space for energy storage because the volume necessary to store a certain amount of energy is more compact. Currently there are no examples of latent thermal energy storage substances applied to pit storage technologies. Tank storages filled with salts are already commercially available making this the second storage option that will be used in the set-up of the configurations in chapter 5.

4.6 Example configuration

The previously discussed components will all be integrated in the calculations of the total energy flow of new energy network proposed in the configuration. For the calculation we are interested in monthly temperature change occurring in the thermal energy storage systems. The following steps will be taken to calculate the monthly temperature change:

I. Determine the monthly heat demand of the buildings (Q_{demand})
II. Determine the monthly energy production potential ($Q_{produced}$)
III. Calculate the thermal losses occurring during transport ($Q_{transportlosses}$)
IV. Calculate the thermal losses of the energy storage ($Q_{transmissionlosses}$)
V. Calculate the net energy value stored/extracted from the energy storage ($Q_{stored/extracted}$)
VI. Calculate the temperature change in the energy storage

$$Q_{stored/extracted}\,(kWh) = Q_{produced} - Q_{demand} - Q_{transmissionlosses} - Q_{transportlosses}$$

Example configuration
25 residentials buildings orientated to the south are connected with a pit thermal energy storage. An extra solar field of 300 evacuated tube collectors is located next to the buildings. They are also oriented to the south and they are sloped under a 45 degrees angle. The energy storage is 50x50 meters for the bottom surface, the top surface is 53x53 meters. The height of the assumed pit storage is 3 meters and filled with water.

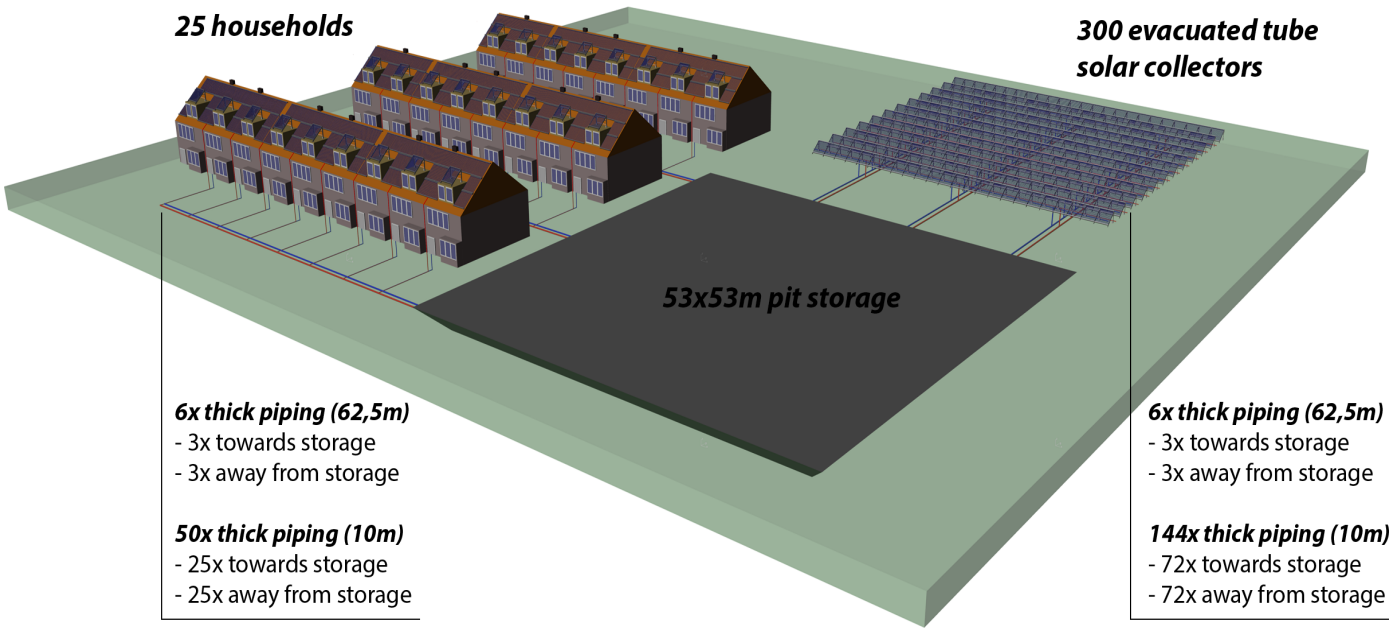


Figure 4.47: *Set-up example configuration. (by Author)*

I. Determine the monthly heat demand of the buildings

Based on chapter 4.1, Figure 4.6, the heat demand of 25 average buildings in Ramplaankartier is:

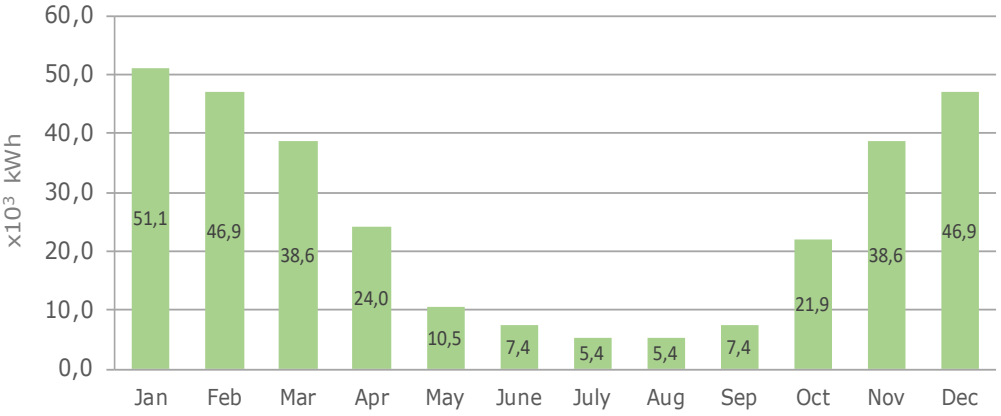


Figure 4.48: *Heat demand 25 average buildings Ramplaankwartier. (by Author)*

II. Determine the monthly energy production potential

The 25 buildings are all oriented with one roof side to the south. There is place for 8 evacuated tube collectors on one roof side of one building (see chapter 4.3), resulting in a toal of 200 ETC's. The evacuated tube collector calculation (4.1.2) is used to calculate the energy output of 25 buildings when the south orientated roofs are filled with evacuated tube collectors. For now we assume that the solar collectors have an output of 80 °C and an input of temperature of 10 °C. The solar collectors will only be used in the months; April, May, June, July, August and September. The energy potential of the solar field with 300 evacuated tube collectors is illustrated in Figure 4.49.

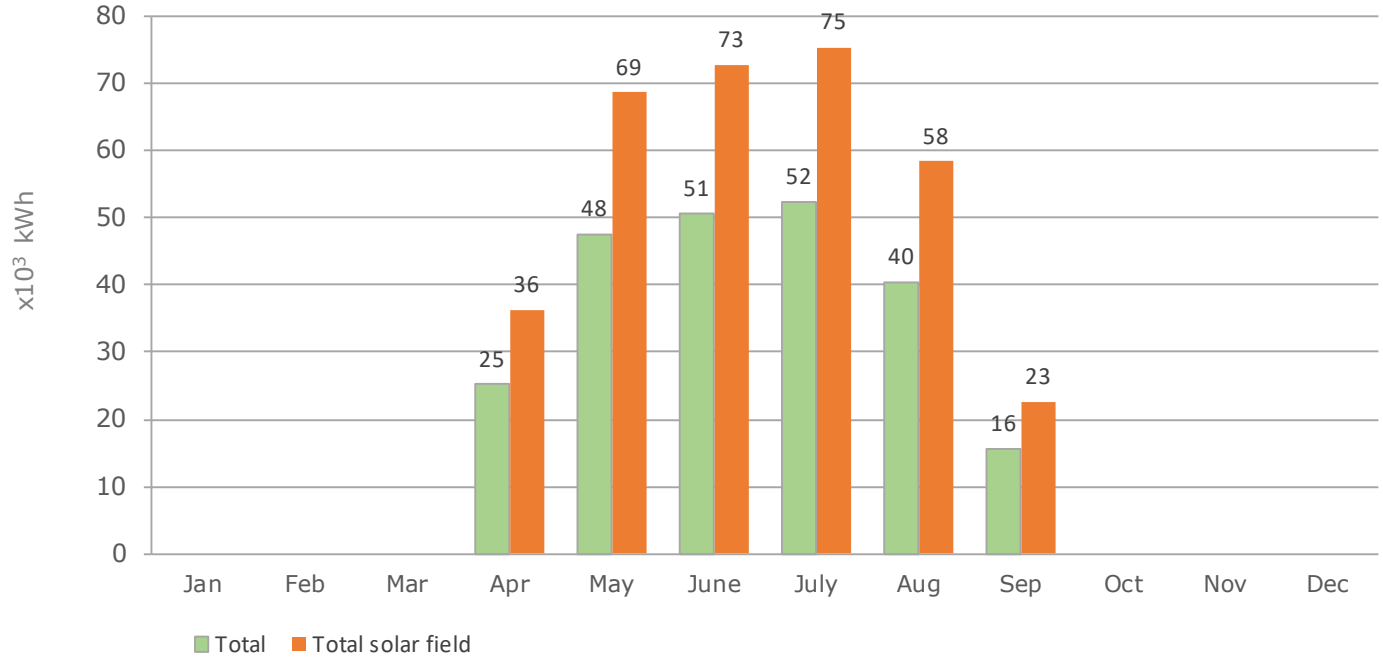
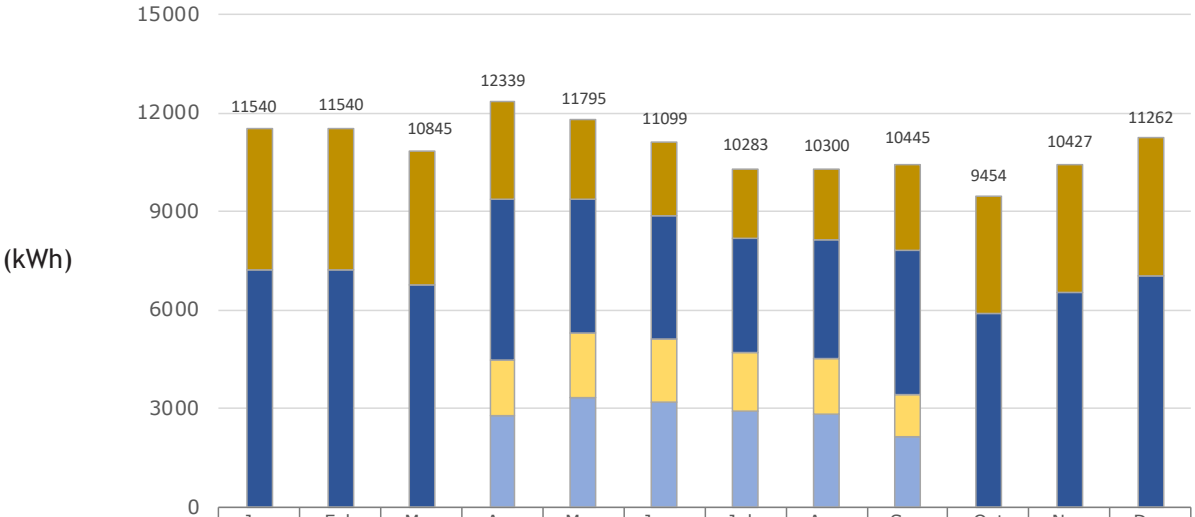


Figure 4.49: *Energy potential roof 25 buildings & solar field Ramplaankwartier. (by Author)*

III. Calculate the thermal losses occurring during transport

In the months: April, May, June, July, August and September the solar hours of these months determine the amount of energy loss that is caused between transport from the solar collectors towards the energy storage. In the other months thermal heat is only transported from the energy storage towards the buildings at 45 °C and here distribution losses are neglected. The monthly overview of the distribution losses is shown in Figure 4.50. The total monthly distribution losses are showed inside the graph. All values are calculated with Excel.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045
Solar collector to storage (thick pipe 80 C°)				1674	1990	1916	1761	1693	1288			
Solar collector to storage (thin pipe 80 C°)				2798	3327	3203	2944	2831	2153			

Figure 4.50: *Monthly and total distribution losses in kWh. (by Author)*

IV. Calculate the thermal losses of the energy storage

For every month we calculate the new temperature in the energy storage. This temperature is used for the next month to calculate the thermal losses of the energy storage. The energy storage is first used in the month April at a starting temperature of 40 °C. That month the thermal losses will be the following:

Energy losses

$Q_{tot} = (U_t*A_t + U_l*A_l + U_b*A_b) * (T_{tank}-T_{ambient})$

*U_t = 0,059 W/m²*K*
*U_l = 0,058 W/m²*K*
*U_b = 0,061 W/m²*K*
A_t = 2809 m²
A_l = 691 m²
U_b = 2500 m²
Volume = 7959 m³ (all calculated the same as in paragraph 4.2.2)

Q_{tot} = (0,059*2809 + 0,058*691+ 0,061*2500) * (40-8,5) = 11.309 Watt
Monthly energy loss:
11.309 Watt = 11.309*(60*60*24*30)/1000 = 29.312.928 KJ = 8142,5 kWh.

Temperature loss

$E (KJ) = V \cdot \rho \cdot c_p \cdot (T_{max}-T_{min})$
$29.312.928 = 7959 * 999,8 * 4,192 * (40 - T_{min})$
$0,88 = 40 - T_{min}$
$T_{min} = 39,12$ °C

V. Calculate the net energy value added/extracted from the energy storage

The net energy added or extracted from the energy storage each month can now be calculated. The delta kWh added/extracted from the energy storages can be used to calculate the temperature change in the storage tank that month, resulting in the new temperature for the next month. The table shows the results of the example configuration in the first 1,5 years (Figure 4.51).

Month	Monthly energy production roofs	Monthly energy solar field (kWh)	Heat demand (25) households (kWh)	Transport losses (kWh)	Thermal losses pit storage (kWh)	Delta (kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	25202	36306	24027	12339	8143	17000	1,8	40
May	47622	68604	10490	11795	7450	86356	9,4	41,8
June	50525	72786	7366	11099	9107	95489	10,3	51,2
July	52326	75380	5388	10283	11022	100652	10,9	61,5
Aug	40493	58333	5388	10300	13857	68806	7,5	72,4
Sep	15655	22552	7366	10445	16446	3363	0,4	79,9
Oct			21944	9454	17187	-49234	-5,3	80
Nov			38604	10427	16929	-66394	-7,2	74,7
Dec			46934	11262	16077	-74475	-8,1	67,5
Jan			51099	11540	14452	-77091	-8,3	59,4
Feb			46934	11540	12294	-70768	-7,7	51,1
Mar			38604	10845	9666	-59115	-6,4	43,4
Apr	25202	36306	24027	12339	7365	17778	1,9	37
May	47622	68604	10490	11795	6829	87112	9,4	38,9
June	50525	72786	7366	11099	8621	96224	10,4	48,4
July	52326	75380	5388	10283	10669	101366	11	58,8
Aug	40493	58333	5388	10300	13637	69501	7,5	69,8
Sep	15655	22552	7366	10445	16358	4037	0,4	77,3
Oct			21944	9454	17246	-48645	-5,3	77,7
Nov			38604	10427	16789	-65821	-7,1	72,5
Dec			46934	11262	15722	-73918	-8	65,3

Figure 4.51: *Net energy added/extracted from the energy storage and the caused temperature change. (by Author)*

The second year visualised in a graph:

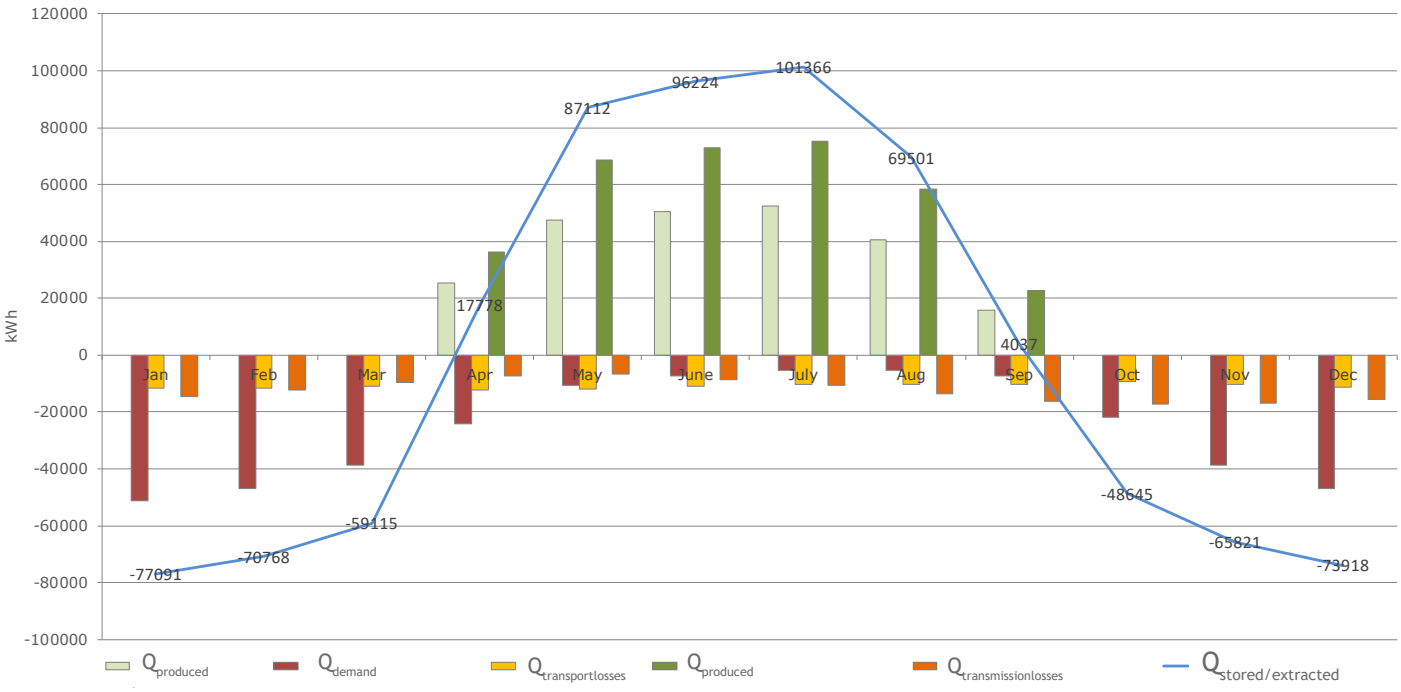


Figure 4.52: *Net energy stored/extracted from the energy storage in the second year. (by Author)*

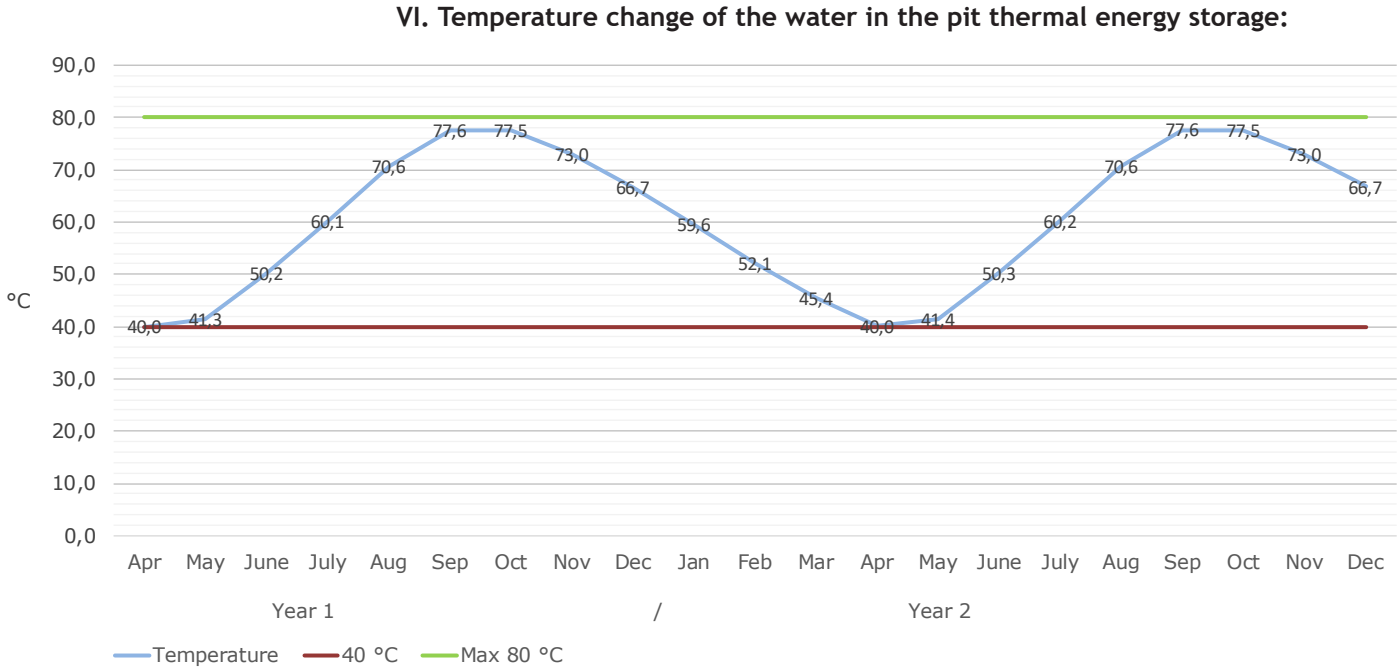


Figure 4.53: *Temperature change energy storage. (by Author)*

4.7 Assessment indicators

4.7.1 Quantitative indicators

The implementation of new energy system in this existing living environment could result in big changes to the spatial organization of the selected urban blocks (UB). Therefore the results of the implementation of a new energy system for all solutions will be assessed and compared. These results will be used to conclude which approach for an energy transitioning, replacing gas for space heating with renewable resources, performs better from an energy and spatial perspective. The assessment indicators will provide results describing the energy performance and the spatial impact of the integration of a new energy system for space heating.

- *Approach 1: Implementation measures to supply the full heat demand of the buildings.*
- *Approach 2: Implementation measures aiming for minor spatial impact.*

The article: "*Assessing cities: A new system of cross-scale spatial indicators*" (Bourdic, Salat, & Nowacki, 2012) describes a set for energy and spatial assessment indicators that can be applied to the selected urban blocks in Ramplaankwartier used in this graduation thesis. Some assessment indicators will be applied without modification and some indicators are modified to make them applicable for this master thesis research. The following part describes selected indicators and their calculation methods, specifying when variations are applied to the original indicators that are obtained from the literature.

Energy assessment indicators

(E1) *Fraction of self-sufficiency:*

Percentage of the total energy demand (after feasible renovations) that is provided with locally produced energy, without exporting and importing energy to/from outside the the selected urban blocks (calc 2). The first calculation provides an analysis about the amount of extra energy that is produced in the energy systems, but is lost before it is used providing the heat demand of the buildings.

Calculation(s):

1. $\frac{\text{Thermal heat produced in UB after energy storage cycle \& distribution}}{\text{Heat demand of the households in UB after feasible renovations}}$ x 100% (annual)
2. $\frac{\text{Thermal heat produced inside the UB}}{\text{Heat demand of the households in the UB after feasible renovations}}$ x 100% (annual)

This indicator is mentioned in the literature. By dividing the indicator in two parts we are able to integrate energy storage and distribution energy losses in the assessment.

A) Heat demand buildings
B) Energy losses storage & distribution
C) Renewable produced heat used by buildings
D) Gas produced heat used by buildings
E) Renewable produced energy

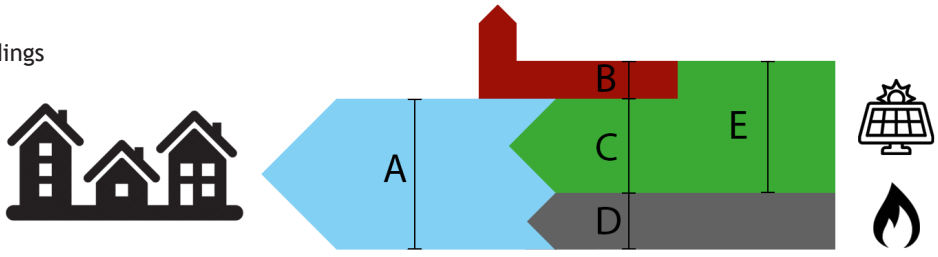


Figure 4.54: *Energy flow diagram (by Author)*

(E2) *Renewable delivered energy/m² of surfaces used for energy production:*

This indicator will calculate the kWh renewable produced energy divided by the used floor & roof areas used to produce this energy. This indicator is calculated for

Important: Energy produced of roof/ground floor, not energy delivered to the buildings. If 188 kWh/m² can be produced this means the building can produce it's own energy demand if it is directly used or there are no energy losses due to storage or distribution.

both public and private used areas. The energy production results of both design approaches can be compared using these indicators. The renewable produced heat is considered at the end of the energy chain, after the losses of the storage cycle and distribution are extracted.

Calculation(s):

1. $\frac{\text{Thermal heat delivered to the buildings}}{\text{Private areas used}}$ kWh/m² (annual)

2. $\frac{\text{Thermal heat delivered to the buildings}}{\text{Public areas used}}$ kWh/m² (annual)

This assessment indicator is a modified indicator obatained from the literature. Private and public areas used for renewable energy production are sub divided in this assessment.

(E3) *Used roof area:*

The use of roof surface for energy production is ideal due to the free slope that is provided causing a higher energy production per square meter. The thermal heat production potential on roofs will be divided by the used roof surface . This will provide information that could be used to analyse how to use the available roof surfaces as optimal as possible.

Calculation:

1. $\frac{\text{Energy production on roofs (UB)(elec or heat)}}{\text{Used roof surfaces (UB)}}$ kWh/m² (annual)

All configurations will be analysed on the ratio effective used roof surface (amount of panels multiplied by their spatial footprint) of the total roof surface of the used buildings in the configuration.

Calculation:

2. $\frac{\text{Used roof surface for energy production (UB)}}{\text{roof surfaces (UB)}}$ x 100%

This assessment indicator is not mentioned in the literature but will be added for this research. The calculation method of indicator E2 is modified for assessment indicator E3.

(E4) *Surface energy intensity production and demand:*

E4.1 This calculation is already predetermined. The current energy consumption after feasible renovations of the residential buildings is divided by their ground floor area in m². An assessment of this energy property of the selected urban blocks will be matched with the energy intensity of energy production on roof & floor areas of the buildings. This will analyse if the heat demand of the buildings can be provided in the private areas (roof & floor) of the buildings. This could provide important information for an energy transition in dense urban areas.

Calculation(s):

1. $\frac{\text{Heat demand households (UB)}}{\text{Total floor area households (UB)}} = \frac{1.374.734}{11.683} = 118$ kWh/m² (annual)

2. $\frac{\text{Energy produced on roof \& floor areas households}}{\text{Roof \& floor areas households used (UB)}}$ x100% -100

118 (D.1)

The first part of indicator E4 is mentioned in the literature and used for this research. The (E4.1) calculation is used as input for a new indicator that compares the energy intensity of production and demand per building.

(E5) *Volumetric compactness:*

The energy storages and additional technologies will have a large volume. This indicator will be employed, providing a comparison of the different techniques for energy storage. Secondly the volume intake of the energy storage tanks will be used, in combination with the contact surfaces to the public space of the storage tanks, to calculate the volumetric compactness of the energy storage and its influence on the public space in the selected urban blocks.

Calculation(s):

1. $\frac{\text{Volume intake of the energy storage \& additional technologies (UB)}}{\text{Provided heat demand to the households (UB)}}$ m^3/kWh (annual)

2. $\frac{\text{Volume intake of the energy storage \& additional technologies (UB)}}{\text{Area intake in the public space (UB)}}$ m^3/m^2

The volumetric compactness indicator is a modified indicator from the literature. We will apply this indicator on the volumetric compactness of the storage tank installations integrated in the selected urban blocks.

Spatial assessment indicators (urban structure)

(S1) *Public areas used:*
This indicator analyses the amount of public space, that is visible to the eye, that is used for the new energy sys-tem.

Calculation(s):

1. $\frac{\text{Visible public areas used for the new energy system}}{\text{Current public areas (UB)}}$ x 100%

This indicator is added to the assessment. The visible public areas used for the implementation of the renewable energy system will be compared to the current amount of public areas of the urban block. This indicator will be used to assess the spatial impact of the renewable energy system on the public space.

(S2) *Land use diversity:*

Based on the spatial analysis of the selected urban blocks all configuration results will be assessed on their diversity in land use. This will be done calculating the used areas for green & parking and compare these with the current land use, previously described in chapter 4. This assessment is used to analyse if configuration results have a negative or positive impact on the land use diversity due to the size and the footprint of the used technologies.

Calculation(s):

1. $\frac{\text{Current green areas (UB)}}{\text{Total area (UB)}}$ x 100 & $\frac{\text{Current parking areas (UB)}}{\text{Total area (UB)}}$ x 100 & $\frac{\text{Current public functions areas (UB)}}{\text{Total area (UB)}}$ x 100

2. $\frac{\text{Configurations green areas (UB)}}{\text{Total area (UB)}}$ x 100 & $\frac{\text{Current parking areas (UB)}}{\text{Total area (UB)}}$ x 100

This indicator will be used to analyse what the influence of the integration of a new energy system is on the land use diversity of the selected urban blocks. This indicators will compare the land use diversity results of the configuration results with the current land diversity of the selected urban blocks.

4.7.2 Perceptual indicators

Only assessing the design results of all energy system solutions in quantifiable numbers is not enough to conclude which result might be called a more positive solution for an energy transitioning of our currently gas powered energy system. A small pilot group of inhabitants will be involved in assessing the results of both approaches.

Firstly it is important to understand which features of the selected urban blocks the inhabitants see as added value or characterize their living environment. Asking them about their view on the land use diversity will provide crucial insight. Secondly the inhabitants will be questioned on their vision of the energy transition. This can provide information about acceptance of technologies that could be implemented in their living environment. These results were discussed in chapter 3.6

The visualization results and the changes to the spatial organization can afterwards be presented in the same way to the pilot group of inhabitants. They can review the changes to their living environment, the integration of a new energy system would cause. The reactions on all design outcomes will be compared to conclude which solution for an energy transition is desirable.

(P1) *Visual impact transformation buildings:*
The results of the proposed integration of energy production and its spatial/visual impact will be analysed with the following approach.

Method: From the configuration results, visualizations that include a proposed integration of energy production technologies will be produced. These visualizations will show the results/influence of this changed appearance for the building typologies. Inhabitants will be asked to evaluate if this different appearance is an improvement or deterioration to the neighbourhood.

Extra sub division: Minor visual impact integrated technologies, commonly applied placement of panels on roofs, party refurbished roof, totally refurbished roof, building extension & technologies integrated in the façade.

(P2) *Visual impact transformation public space:*
The results of the proposed integration of energy production & energy storage in the public space will be analysed with the following approach.

Method: Visualizations of the configuration results, integrated technologies in the public space, that influence the appearance/character of the neighbourhood, will be produced. Visualizations will show the results/influence of this changed appearance to the public space. Inhabitants will be asked to evaluate if this different appearance is an improvement or deterioration to the neighbourhood.

(P3) *Land use diversity:*
The transition of the energy system influences the use of space for different functions in the selected urban blocks. This criteria analyses if inhabitants consider the change in land use as an improvement or deterioration of their neighborhood spatial qualities.

Method: The inhabitants will be asked to evaluate the land use diversity based on the visualizations of the configurations results.

- The green character of the selected urban blocks is improved/deteriorated/no change.
- The value judgement of parking space in selected urban blocks is improved/ deteriorated/no change.

CONFIGURATIONS 5

This chapter will answer the following research question:

(Q5) Which renewable energy based configurations with different ambitions can be developed for the selected urban blocks and what could their energy performance be?

This research question is subdivided into three sub questions. All these sub questions are answered using technical configurations that describe and visualize the spatial and energy characteristics of the integration of a renewable energy system in the selected urban blocks in Ramplaankwartier. The following configuations have been developed:

(A) 100% gas replacement using the commonly applied placement of panels on roofs.

(Q5.1) Implementation measures to supply the full heat demand of the buildings using the commonly applied placement of panels.

- (A.1) Flat plate collectors combined with a water filled pit thermal energy storage.
- (A.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump & aquifer storage.
- (A.2 extra) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycoolers.

(B) 100% gas replacement using the analysis results of chapter 4

(Q5.2) Measures to supply the full heat demand using the energy & spatial analysis of the selected urban blocks (Ch. 4).

- (B.1) Flat plate collectors combined with a water filled pit thermal energy storage.
- (B.2) Flat plate collectors combined with a salt filled latent thermal energy storage.
- (B.3) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants

(Q5.3) Implementation measures aiming for minor spatial impact considering inhabitants interests/wishes.

- (C.1) Flat plate collectors combined with a water filled pit thermal energy storage.
- (C.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycoolers.
- (C.3) Flat plate collectors combined with a salt filled latent tank storage
- (C.4) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

In this chapter the used building typologies and their energy potentials are explained. This is followed by a comparison with the energy demand and the resulting actual heat demand. In the appendix the additional calculations & visualisations are explained.

(A) 100% gas replacement using the commonly applied placement of panels on roofs.

A.1 Flat plate collectors + Pit thermal energy storage (water).
Replaced gas percentage 100%

This configuration will make use of flat plate collectors integrated onto the roofs of the buildings inside the selected urban blocks and this new energy system will replace 100% of the gas use for space heating inside the selected urban blocks. The commonly applied placement of the flat plate collectors on the roofs will be applied to all buildings. The seasonal operational schemes of the flat plate collectors and distribution system are illustrated in the following schemes. These setting were determined using the comparison of the energy potentials and the heat demand of the selected urban blocks (**II**).

Energy flow configuration:

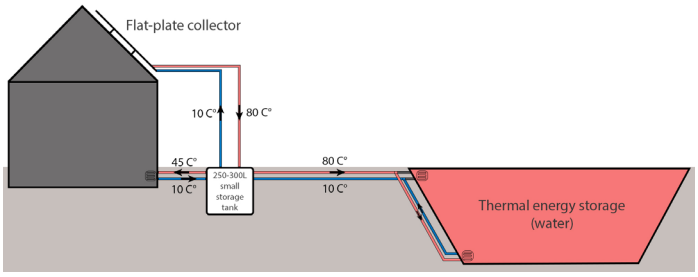


Figure 5.1: *Config. during summer months: Apr, May, June, July, Aug & Sep. (sunny hours)(by Author)*

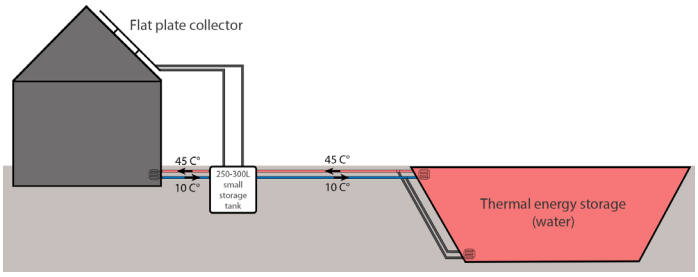


Figure 5.2: *Config. during summer months: Apr, May, June, July, Aug & Sep. (cloudy hours)(by Author)*

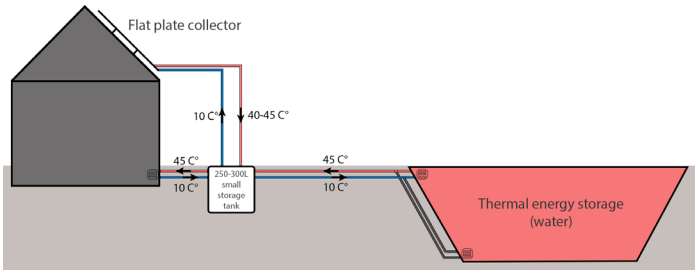


Figure 5.3: *Config. during winter months: Jan, Feb, Nov & Dec. (by Author)*

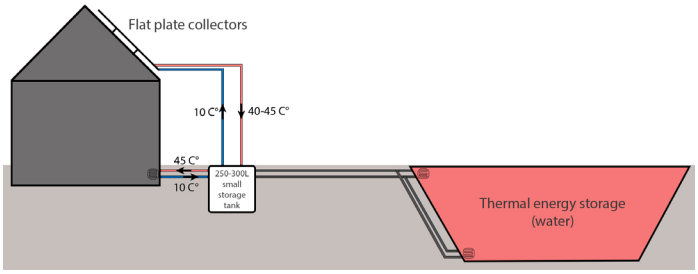
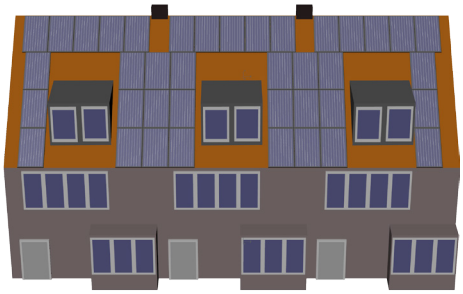


Figure 5.4: *Config. during months that energy potential = heat demand: March & Oct. (by Author)*

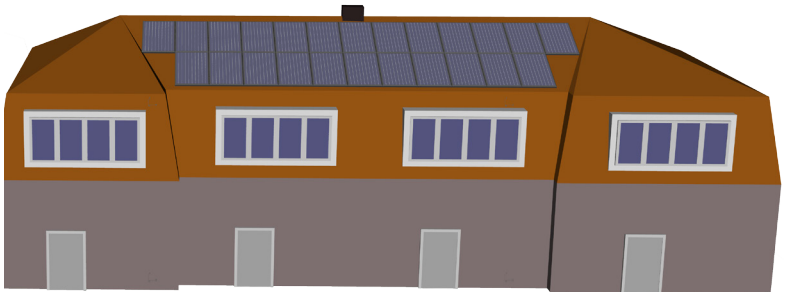
The return temperature of water was assumed at 10 C°. In reality the water return temperature is more likely to be at room temperature.

The storage can be included to balance the energy demand and the energy production, if the small storage tank is not sufficient.

I. Energy production



Typology 1: West/east - 85 buildings
South-west - 3 buildings
South - 11 buildings



Typology 2: South-west - 8 buildings

Both sides of the roofs of the buildings orientated to the west or east can be used for energy production, duplicating their energy potential. Annual energy potentials of all used buildings and the amount of used solar collectors are:

Total energy production of all buildings:
Typology 1 (West/East): 85 dwel. x 2 (roof sides used) x 10,5 panels = 1785 panels.
Annual thermal heat production (40 °C): 2.498.921 kWh
Annual thermal heat production (80 °C): 2.084.996 kWh

Typology 1 (S-W): 3 dwel. x 10,5 panels = 31,5 panels.
Annual heat production (40 °C): 54.475 kWh
Annual heat production (80 °C): 45.451 kWh

Typology 1 (South): 11 dwel. x 12,5 panels = 137,5 panels.
Annual heat production (40 °C): 249.110 kWh
Annual heat production (80 °C): 207.847 kWh

Typology 2 (S-W): 8 dwel. x 6 panels = 48 panels.
Annual heat production (40 °C): 83.009 kWh
Annual heat production (80 °C): 69.259 kWh

Total amount of monocrystalline PV panels: 2002
Annual heat production (40 °C): 2.886 x10^3 kWh
Annual heat production (80 °C): 2.408 x10^3 kWh

Monthly heat production of panels on all 107 buildings:

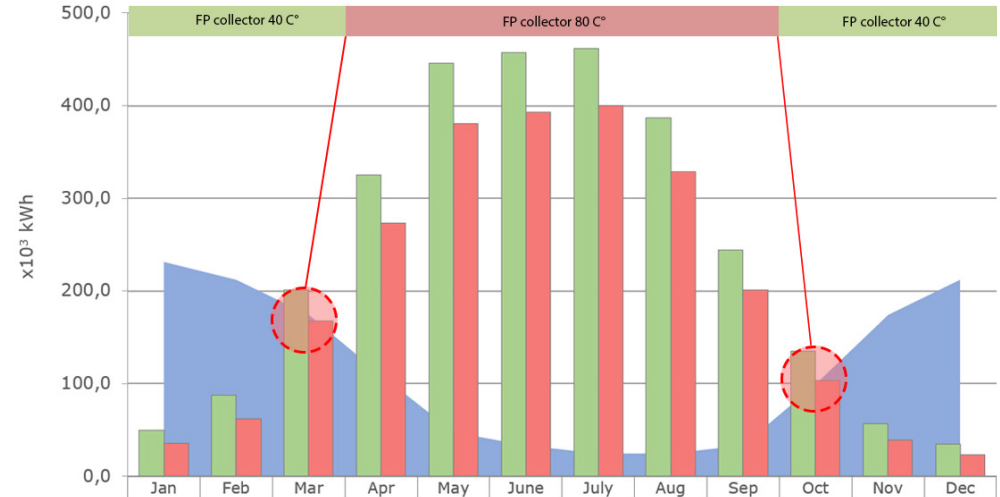


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	49,5	87,8	201,1	325,4	445,9	457,1	461,4	386,7	243,8	134,9	57,0	35,0
80 C°	35,7	62,1	167,8	273,1	380,9	392,6	400,3	328,4	201,0	103,1	39,4	23,1

Figure 5.5: *Energy potential roofs 107 buildings. (by Author)*

II.Comparison heat demand and energy production

Figure 5.6: *Comparison & output temperature settings flat plate collectors. (by Author)*



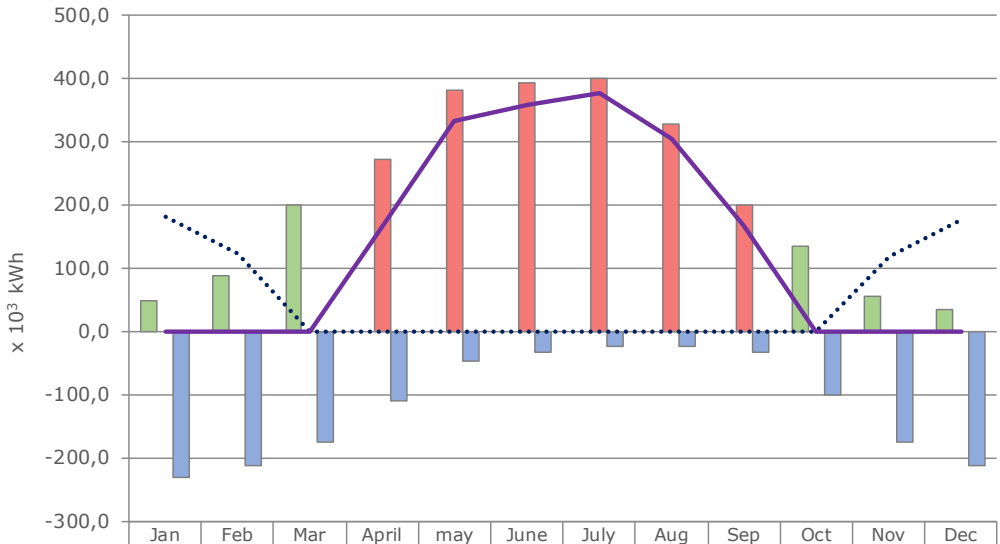
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
40 C°	49,5	87,8	201,1	325,4	445,9	457,1	461,4	386,7	243,8	134,9	57,0	35,0
80 C°	35,7	62,1	167,8	273,1	380,9	392,6	400,3	328,4	201,0	103,1	39,4	23,1

In the months of March and October the thermal heat production of the flat plate collectors is sufficient to provide the heat demand for that month. In the winter (between October & March) the collector output will be provided at 40˚C water, which is assumed to be directly usable for space heating. Tapwater is provided with a booster heat pump, but this is not further investigated in this thesis.. The thermal heat production of these months can be subtracted from the heat demand of the buildings. This will provide the **actual heat demand** of the buildings that should be delivered by the energy storage.

In summer, between March and October, the flat plate collector output temperature can be adjusted to be 80 ˚C. This heat will be used to supply the heat demand of that month directly. Secondly it will be used to heat up the water in the energy storage (thermal input for storage).

III. Actual heat demand & thermal heat delivered to the energy storage:

Figure 5.7: *Net heat demand & Thermal heat for energy storage (by Author)*



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat (40C°)	49,5	87,8	201,1							134,9	57,0	35,0
Thermal heat (80C°)				273,1	380,9	392,6	400,3	328,4	201,0			
Heat demand	-231,0	-212,1	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-174,5	-212,1
Actual heat demand	181,4	124,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	117,5	177,2
Thermal heat input for storage	0,0	0,0	0,0	164,5	333,5	359,3	375,9	304,0	167,7	0,0	0,0	0,0

IV. Properties pit thermal energy storage

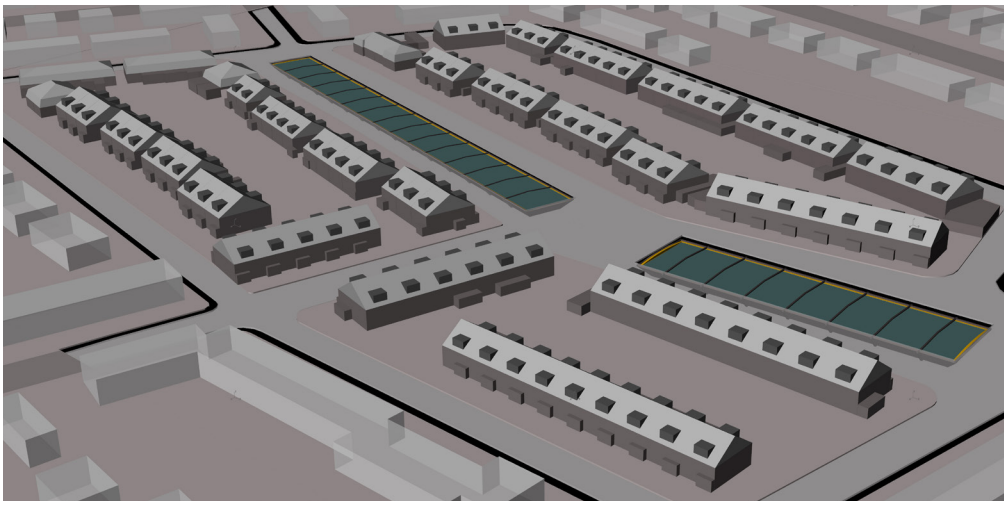


Figure 5.8: *Dimensions energy storage. (by Auhtor)*

Storage 1:
Top surface: 150m x 14m
Bottom surface: 148m x 12m
Height : 6,5m
Volume: 10964 m^3

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m^3

For this configuration the entire open area in the middle of the block is used for storage. The sizes of the storages are calculated in Excel using the energy potential and the delivered energy demand. Fine tuning during the calculation process resulted in the following dimensions:

The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3450 m^2
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 2215 m^2
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3326 m^2
The total volume of both storages combined is : 18.262 m^3



Impression visual/spatial impact A.1 configuration.

(A) 100% gas replacement using the commonly applied placement of panels on roofs.

A.2 PV + large scale heat pump + water pit storage + aquifer heat/cold storage.
Replaced gas percentage 72%

This configuration will make use of monocrystalline PV panels integrated onto the roofs of the buildings inside the selected urban blocks. The goal of this configuration is to replace 100% of the gas use by providing 100% of the heat demand of the buildings. The monocrystalline PV panels will be placed onto the roofs in a standard manner. Because electricity should be transformed into thermal heat to provide the heat demand, a large scale heat pump is integrated in the configuration. The large scale heat pump is combined with a aquifer energy storage, used as a heat source for the heat pump. The monthly settings of the monocrystalline PV, heat pump and distribution system are illustrated in the following schemes. These setting were determined using the comparison of the energy potentials and heat demand of the selected urban blocks.

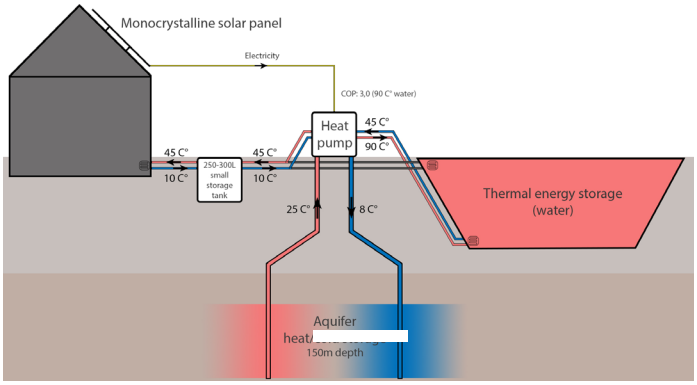


Figure 5.9: *Config. during summer months: Mar, Apr, May, June, July, Aug, Sep & Oct. (sunny hours & charging pit storage)(by Author)*

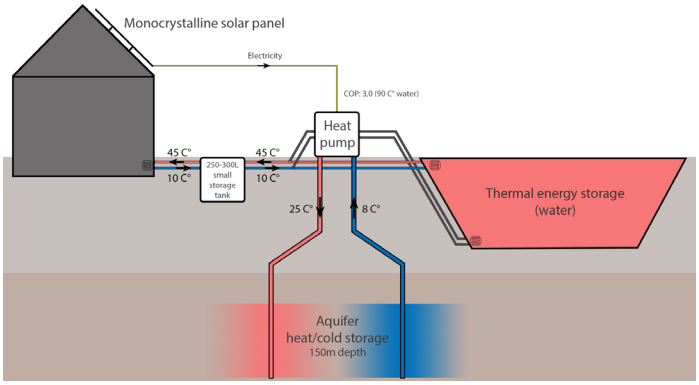


Figure 5.10: *Config. during summer months: Mar, Apr, May, June, July, Aug, Sep & Oct. (sunny hours & charging aquifer) (by Author)*

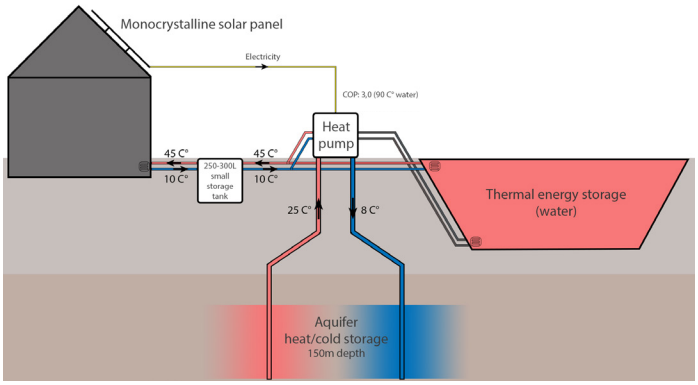


Figure 5.11: *Config. during winter months: Jan Feb, Nov & Dec (Sunny hours)(by Author)*

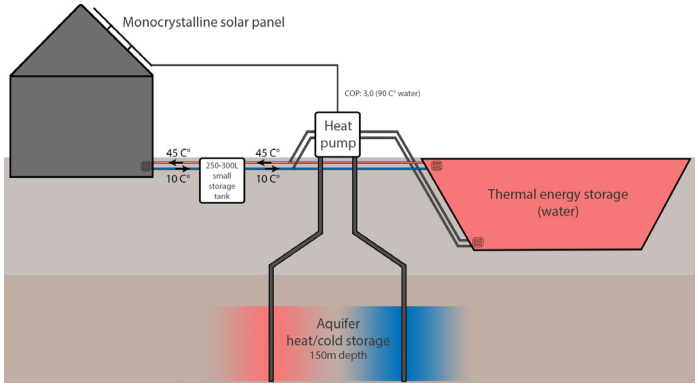


Figure 5.12: *Config. during summer/winter months: (cloudy hours)(by Author)*

The storage can be included to balance the energy demand and the energy production, if the small storage tank is not sufficient.

I. Heat pump + aquifer storage

The Bergheim (Germany) district heating systems uses a heat pump to provide thermal heat for an office of 500 employees. The heat pump is produced by Viessmann. The COP value of this heat pump is 4,4. The heat source used is water of 26 °C from a nearby power plant. The return temperature of the water after extraction of the thermal heat is 10 °C. The output temperature of the water that will be used for space heating reaches a maximum of 73 °C.
(EHPA, 2017)
Based on these properties, this heat pump is selected because it could be combined with an aquifer energy storage. In Ramplaankwartier there is no other heat source available to extract thermal heat from for the total neighbourhood. An air source heat pump would be too noisy for the living environment. The aquifer storage will use water of 25 °C stored at an depth of 150 meters. The return temperature will be 10 °C. Because the aquifer storage is not able to provide a stable output temperature of 26 °C the COP value of the heat pump will be lower. The used COP value will be 3,0.



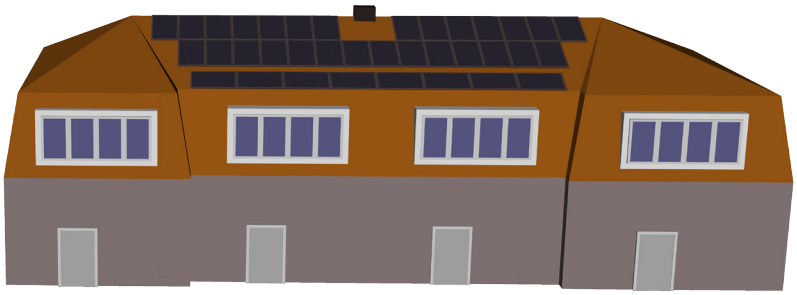
Figure 5.13: *Heat pump Bergheim district.* (EHPA, 2017)

Example: 10 kWh electricity is produced by the monocrystalline PV panels. The heat pump produces 30 kWh thermal heat at a temperature of 73 °C. The 24 kWh extra is extracted from the aquifer storage. In the configuration calculations this extracted energy will be returned to the aquifer storage in the summer periods to prevent environmental impact due to a temperature decrease of the soil.

II. Energy production (buildings)



Typology 1: West/east - 85 buildings
South-west - 3 buildings
South - 11 buildings



Typology 2: South-west - 8 buildings
West/east - 4 buildings

Both sides of the roofs of the buildings orientated to the west or east can be used for energy production, duplicating the energy potential of these buildings. Annual energy potentials of all used buildings and the amount of used PV panels are:

Typology 1 (West/East): 85 x 2 (roof sides used) x 23 panels = 3910 panels.
Annual electricity production: 861.202 kWh

Typology 1 (S-W): 3 x 23 panels = 69 panels.
Annual electricity production: 18.774 kWh

Typology 1 (South): 11 x 25 panels = 275 panels.
Annual electricity production: 78.385 kWh

Typology 2 (S-W): 8 x 9 panels = 72 panels.
Annual electricity production: 15.858 kWh

Typology 2 (West/east): 4 x 2 (roof sides used) x 9 panels = 72 panels.
Annual electricity production: 18.774 kWh

II. Energy production (Solar field + storages)

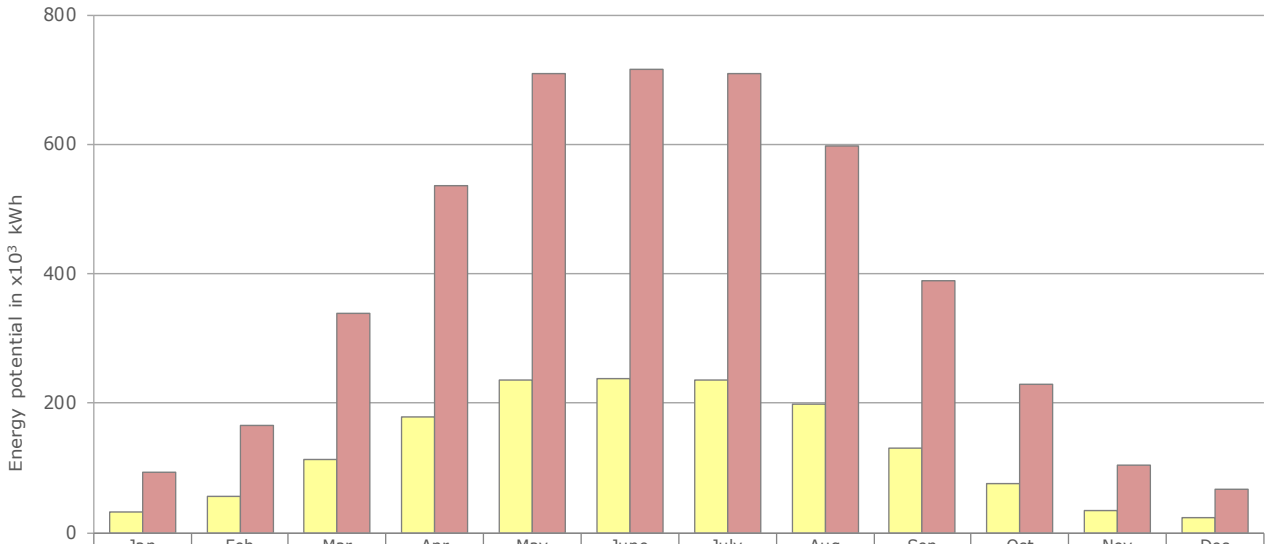
During the making of the calculations for this configuration the amount of energy production on the roofs of the buildings appeared to be insufficient to supply the full heat demand of the selected urban blocks including the energy needed to restore the heat in the ground of the aquifer. Therefore an extra solar field is placed in the public green areas inside the selected urban blocks. The solar field exists of 928 thin film – cadmium telluride panels because they are more suitable to be placed in the public space. Because they are cheaper and therefore cheaper to be replaced if damaged. All panels will be placed with at an angle of 45 °C, orientated south.

Even with an extra solar field the energy production to supply the full heat demand appeared to be insufficient. Therefore the roofs of the storage buildings located in private areas, will need to be used for energy production. 619 extra monocrystalline PV panels will be placed on top of these storages. All panels will be placed with at an angle of 45 °C, orientated south.

Annual electricity production 928 thin film panels: 382.082 kWh
Annual electricity production 619 monocrystalline panel: 176.438 kWh

Total annual electricity production (buildings + solar field + storages): 1552 x10^3 kWh.
Thermal heat energy potential after transformation of electricity into thermal heat: 1552x10^3 x 3,0 = 4657x10^3 kWh

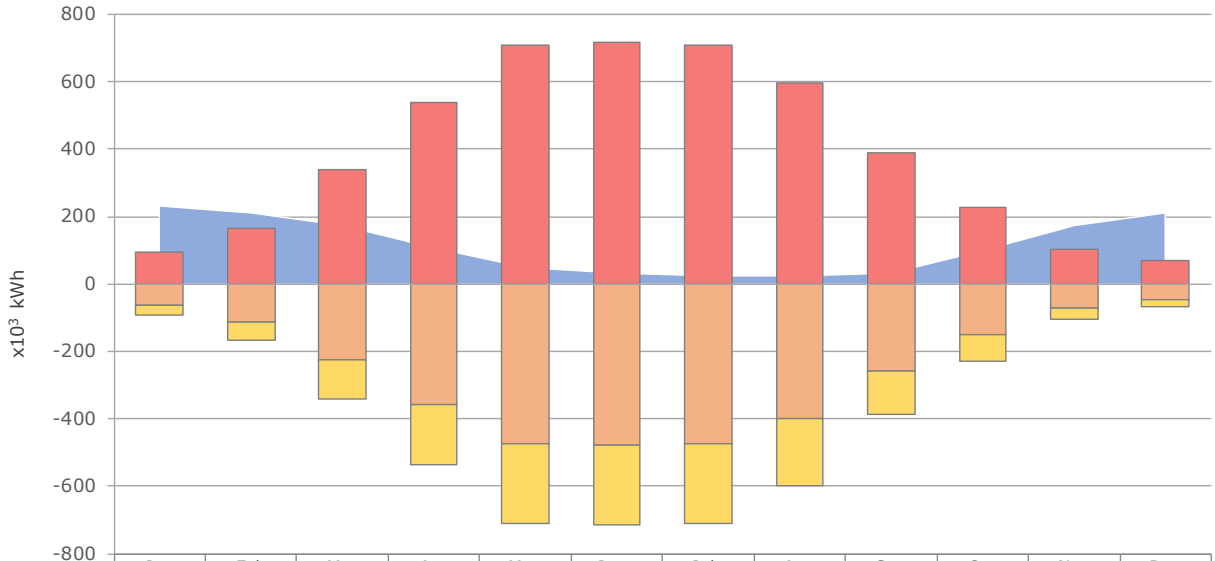
Monthly electricity production & thermal heat potential - heat pump (COP 3,0):



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Electricity	31,1	55,5	113,1	178,8	236,4	238,5	236,4	199,4	129,5	76,1	34,9	22,6
Thermal heat (after heat pump)	93,3	166,5	339,3	536,4	709,2	715,4	709,2	598,2	388,6	228,3	104,8	67,9

Figure 5.14: *Energy potential selected urban blocks (elec & thermal heat)(by Author)*

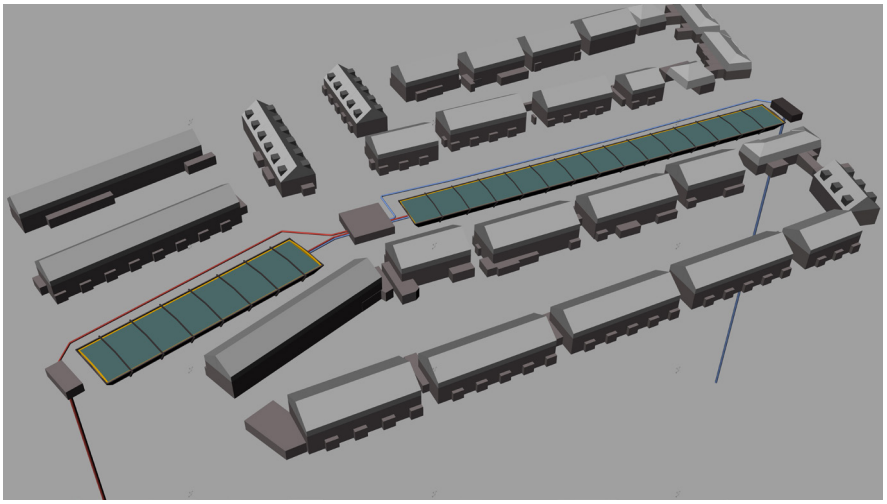
Heat demand and origin energy production:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
Thermal heat (after heat pump)	93,3	166,5	339,3	536,4	709,2	715,4	709,2	598,2	388,6	228,3	104,8	67,9
Electricity	-31,1	-55,5	-113,1	-178,8	-236,4	-238,5	-236,4	-199,4	-129,5	-76,1	-34,9	-22,6
Thermal heat aquifer st.	-62,2	-111,0	-226,2	-357,6	-472,8	-476,9	-472,8	-398,8	-259,0	-152,2	-69,9	-45,3

Figure 5.15: *Comparison heat demand and energy potential. (by Author)*

III. Properties pit thermal energy storage & aquifer storage



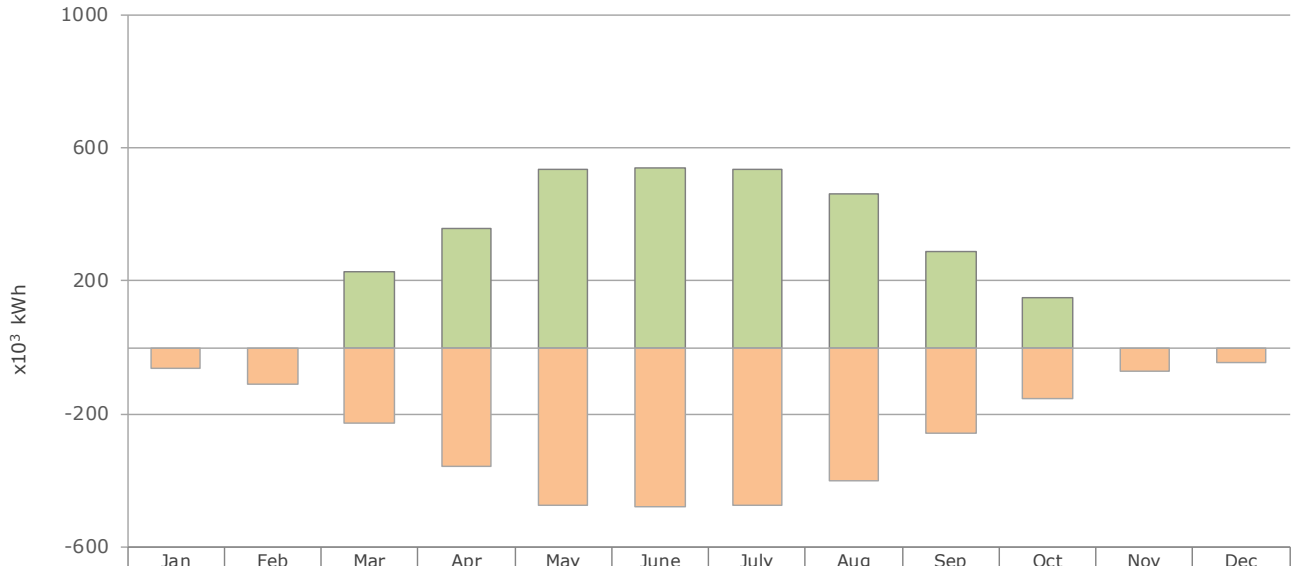
Storage 1:
Top surface: 150m x 14m
Bottom surface: 148m x 12m
Height : 6,5m
Volume: 10964 m^3

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m^3

Figure 5.16: *Aquifer + pit storages (by Author)*

The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3450 m^2
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 2215 m^2
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3326 m^2
The total volume of both storages combined is : 18.262 m^3

The aquifer storage exists of two components: a 150 meter long pipe that transports the heat in and out of the aquifer storage and second a 150 meter deep pipe that transport the cold water in and out the aquifer storage. Figure 5.15 explains the amount of thermal heat that is extracted from the aquifer storage per month. In the summer months a surplus of energy is produced compared to a low heat demand. These months are used to charge the aquifer storage with thermal heat. In this way the aquifer storage can deliver the thermal heat demand necessary for the heat pump without lowering the soil temperature on an annual base. In Figure B.10 the amount of thermal heat that is transported back into the aquifer storage is calculated. The annually extracted and added thermal heat are both 3105 x10^3 kWh.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Extracted thermal heat	-62,2	-111,0	-226,2	-357,6	-472,8	-476,9	-472,8	-398,8	-259,0	-152,2	-69,9	-45,3
Added thermal heat	0,0	0,0	225,6	356,7	535,7	539,8	535,7	461,8	290,4	151,8	0,0	0,0

Figure 5.17: *Thermal heat extracted and added to aquifer (by Author)*



Impression visual/spatial impact A.2 configuration.

This configuration is not a realistic due to the absence of an energy source for the heat pump. In fact most of the heat is supplied by the PV electrical output with the heat produced by the heat pump itself; this results in a very high demand of electricity and this configuration would therefore never be applied or designed in such a way. The next configuration is an adapted version using drycoolers to regenerate the aquifer storage.

A.2 (Extra) PV + large scale heat pump + water pit storage + aquifer heat/cold storage + Drycoolers.
Replaced gas percentage 100%

This configuration is an adaptation to the A.2 configuration. Without an external heat source for the heat pump the PV configuration (A.2) basically works as an electrical heater providing the heat demand of buildings. In this extra configuration drycoolers are integrated in the configuration to regenerate the aquifer storage in the summer months.

I. Heat pump + aquifer storage + drycooler

The heat pump (COP 3,0) & aquifer storage in this configuration are the same as in the A.2 configuration. The drycoolers used in this configuration are the same as in research done by TAUW on the feasibility of sustainable heat supply for the neighbourhood Ramplaankwartier. These drycoolers extract heat from the outside air (as soon as it is above crica 15 °C) to warm up water. The heated water is used to regenerate the aquifer storage, 4 drycooler ventilators are necessary. The (4 ventilators) drycooler extracts 400 kW heat from the air during 4000 hours in summer months. In each month (May, Jun, Jul, Aug, Sep & Oct) 266.667 kWh heat is transported back into the aquifer. Annually this is $1600x10^3$ kWh. (De Brauw & Koezjakov, 2018)

Figure 5.18: *Pictures drycoolers by Sabine Jansen.*



The spatial dimensions of a drycooler unit with 4 ventilators is 15x2 = 30 m^2. These drycoolers will be placed on the heat pump building to prevent more spatial impact.

II. Energy production (buildings)



Typology 1: West/east - 70 buildings
South-west - 3 buildings
South - 11 buildings

In this configuration not all buildings need to be included to reach the 100% replacement of the heat demand. The typology 2 buildings are not even used.

Typology 1 (West/East): 70 x 2 (roof sides used) x 23 panels = 3220 panels.
Annual electricity production: 709.225 kWh

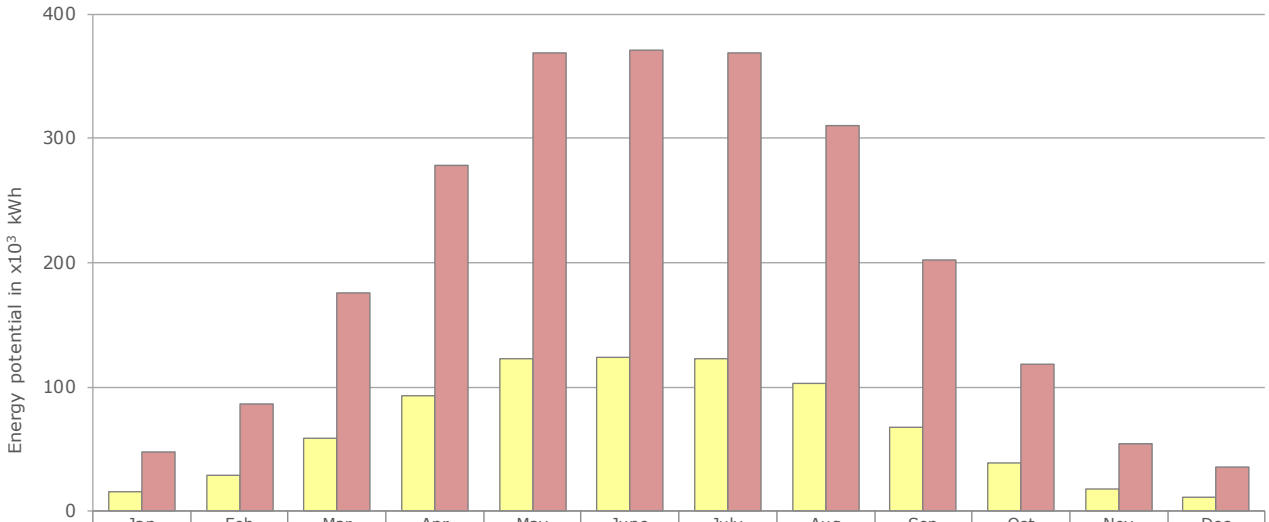
Typology 1 (S-W): 3 x 23 panels = 69 panels.
Annual electricity production: 18.774 kWh

Typology 1 (South): 11 x 25 panels = 275 panels.
Annual electricity production: 78.385 kWh

Total annual electricity production: 806 x10³ kWh.
Thermal heat energy potential after transformation of electricity into thermal heat: 806x10³ x 3,0 = 2419x10³ kWh

Figure 5.19: *Energy potential selected urban blocks (elec & thermal heat)(by Author)*

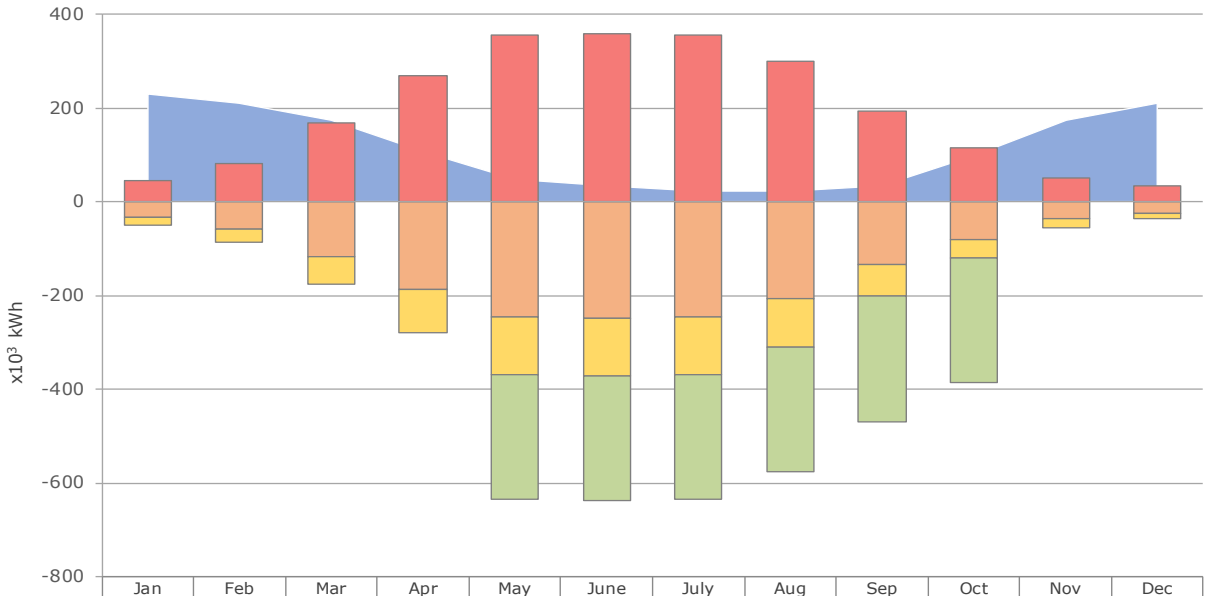
Monthly electricity production & thermal heat potential - heat pump (COP 3,0):



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Electricity	16,1	28,8	58,7	92,9	122,8	123,9	122,8	103,6	67,3	39,5	18,1	11,8
Thermal heat (after heat pump)	48,4	86,5	176,2	278,7	368,4	371,6	368,4	310,7	201,8	118,6	54,4	35,3

Figure 5.20: *Comparison origen heat demand and origen energy potential. (by Author)*

Heat demand and origin energy production:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
Drycoolers					-266,7	-266,7	-266,7	-266,7	-266,7	-266,7		
Thermal heat (after heat pump)	46,7	83,4	169,9	268,6	355,1	358,2	355,1	299,5	194,6	114,3	52,5	34,0
Electricity	-16,1	-28,8	-58,7	-92,9	-122,8	-123,9	-122,8	-103,6	-67,3	-39,5	-18,1	-11,8
Thermal heat aquifer st.	-32,3	-57,7	-117,5	-185,8	-245,6	-247,8	-245,6	-207,2	-134,6	-79,0	-36,3	-23,5

(B) 100% gas replacement using the comparison results of Ch. 4

(B.1) Flat plate collectors combined with a water filled pit thermal energy storage.
Replaced gas percentage 100%

This configuration will make use of flat plate collectors integrated onto & into the roofs of the buildings inside these selected urban blocks and this new energy system will replace 100% of the gas use for space heating. The monthly settings of the flat plate collectors and distribution system are illustrated in the following schemes. These setting were determined using the comparison of the energy potentials and the heat demand of the selected urban blocks.

Energy flow configuration:

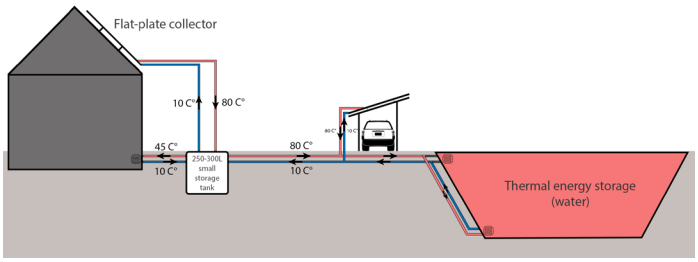


Figure 5.21: *Config. during summer months: Apr, May, June, July, Aug & Sep. (solar hours)(by Author)*

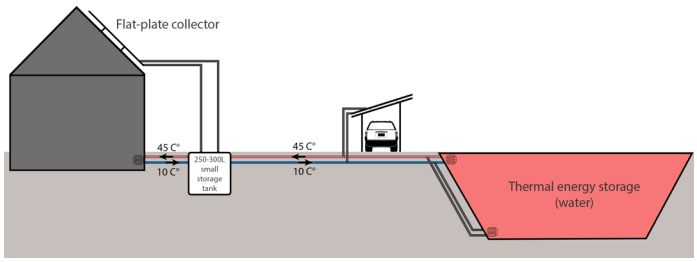


Figure 5.22: *Config. during summer months: Apr, May, June, July, Aug & Sep. (no solar hours)(by Author)*

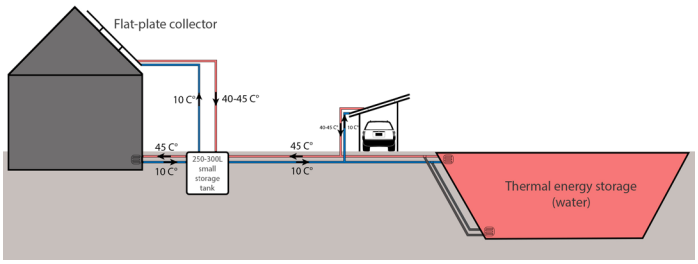


Figure 5.23: *Config. during winter months: Jan, Feb, Nov & Dec. (by Author)*

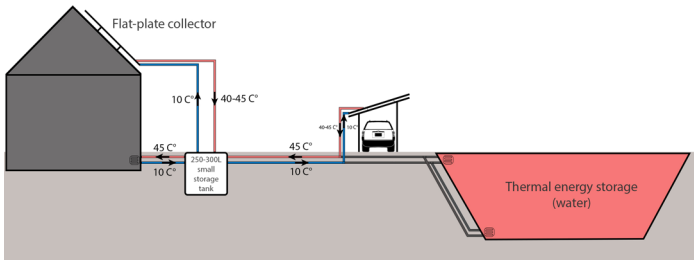
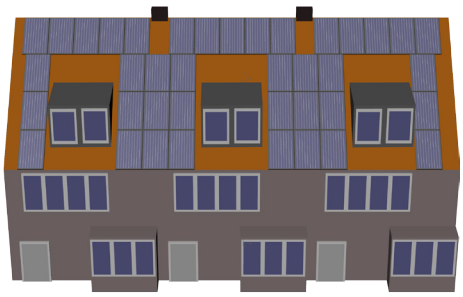
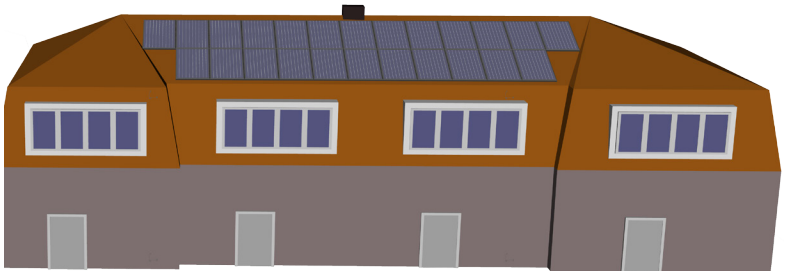


Figure 5.24: *Config. during months that energy potential = heat demand: March & Oct. (by Author)*

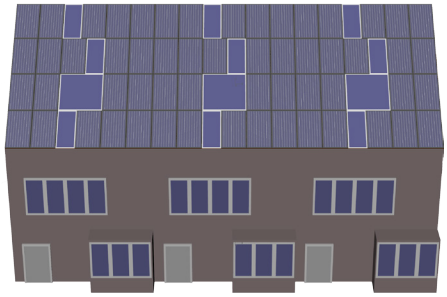
Building configurations resulting from the chapter 4 analysis:



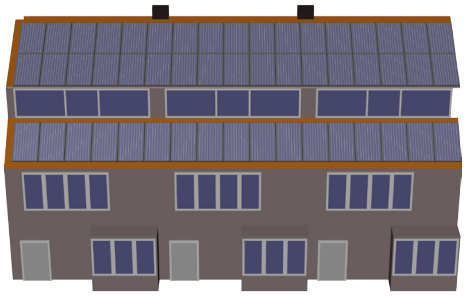
Typology 1: West/east - 61 buildings



Typology 2: South-west - 8 buildings



Typology 1: West/east - 24 buildings



Typology 1: South - 11 buildings & South-west - 3 buildings

I. Energy production

The buildings with a fully refurbished roof will produce energy on both sides of the roof, doubling the energy production of these buildings. In the public space 51 new covered parking spots are created. Flat-plate collectors are integrated on the roofs covering the parking spots. The total amount of flat-plate collectors in the parking roofs is: 96 south & 116 South-west.

Total energy production of all buildings:
Typology 1 (West/East) total refurbished roof:
24 x 2 (roof sides used) x 19 panels = 912 panels.
Annual thermal heat production (40 °C): 1.276.760 kWh
Annual thermal heat production (80 °C): 1.065.275 kWh

Typology 1 (West/East) commonly applied placement of panels on one side:
61 x 10,5 panels = 645 panels.
Annual thermal heat production (40 °C): 896.672kWh
Annual thermal heat production (80 °C): 748.146kWh

Typology 1 (S-W) partly refurbished roof:
3 x 17 panels = 51 panels
Annual thermal heat production (40 °C): 88.197 kWh
Annual thermal heat production (80 °C): 73.588 kWh

Typology 1 (South) partly refurbished roof:
11 x 17 panels = 187 panels.
Annual thermal heat production (40 °C): 338.789 kWh
Annual thermal heat production (80 °C): 282.672 kWh

Typology 2 (S-W) commonly applied placement of panels:
8 x 6 panels = 48 panels.
Annual thermal heat production (40 °C): 83.009 kWh
Annual thermal heat production (80 °C): 69.259 kWh

Parking (S-W): 116 panels.
Annual thermal heat production (40 °C): 200.605 kWh
Annual thermal heat production (80 °C): 167.377 kWh

Parking (South): 96 panels.
Annual thermal heat production (40 °C): 173.924 kWh
Annual thermal heat production (80 °C): 145.115 kWh

Total selected urban blocks:
Total amount of monocrystalline PV panels: 2055
Annual thermal heat production (40 °C): 3.058 $x10^3$ kWh
Annual thermal heat production (80 °C): 2.530 $x10^3$ kWh

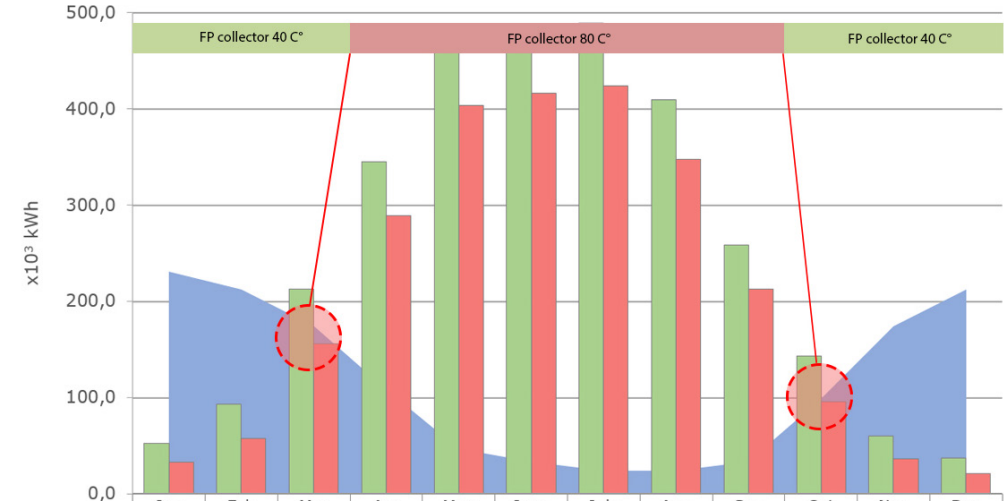
Total monthly energy production potential:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	52,5	93,1	213,1	344,9	472,5	484,4	488,9	409,8	258,4	143,0	60,4	37,1
80 C°	33,2	57,8	156,1	289,4	403,7	416,1	424,2	348,0	213,0	95,9	36,6	21,5

Figure 5.26: *Energy potential roofs all buildings. (by Author)*

Comparison heat demand and energy production:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
40 C°	52,5	93,1	213,1	344,9	472,5	484,4	488,9	409,8	258,4	143,0	60,4	37,1
80 C°	33,2	57,8	156,1	289,4	403,7	416,1	424,2	348,0	213,0	95,9	36,6	21,5

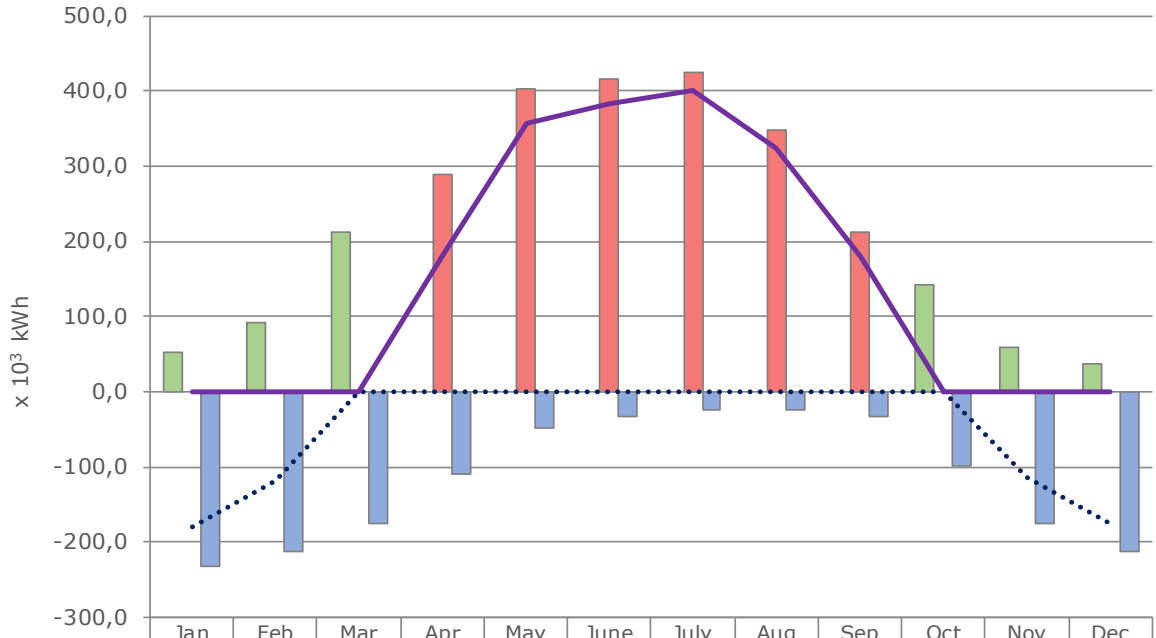
Figure 5.25: *Comparison & output temperature settings flat plate collectors. (by Author)*

In the months March and October the thermal heat production of the flat plate collectors is enough to provide the heat demand for these months. In winter months between October and March the collector output will also be provide water of 40 °C which can directly be used for the buildings. The thermal heat production of these months can be subtracted from the heat demand of the buildings. This will provide the **net heat demand** of the buildings that should be delivered by the energy storage.

In the summer months between March and October the flat plate collector output temperature will be 80 °C. This thermal heat will be used to deliver the heat demand of that month directly and second to heat up the water temperature in the energy storage (thermal input for storage).

In the months March and October the energy production and energy demand is close to equal, therefor the actual heat demand in these two months can be considered 0.

Actual heat demand & thermal heat delivered to the energy storage:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat (40 C°)	52,5	93,1	213,1							143,0	60,4	37,1
Thermal heat (80 C°)				289,4	403,7	416,1	424,2	348,0	213,0			
Heat demand	-231,0	-212,1	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-174,5	-212,1
Actual heat demand	-178,5	-119,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-114,1	-175,1
Thermal heat input for storage	0,0	0,0	0,0	180,8	356,2	382,8	399,9	323,6	179,8	0,0	0,0	0,0

Figure 5.28: *Net heat demand & Thermal heat for energy storage (by Author)*

III. Transport losses

In the months April, May, June, July, August & September water of 80 °C is transported to the energy storage tanks. The return temperature of the water assumed to be 10 °C which is comparable to the ambient temperature in these months resulting in negligible energy losses.

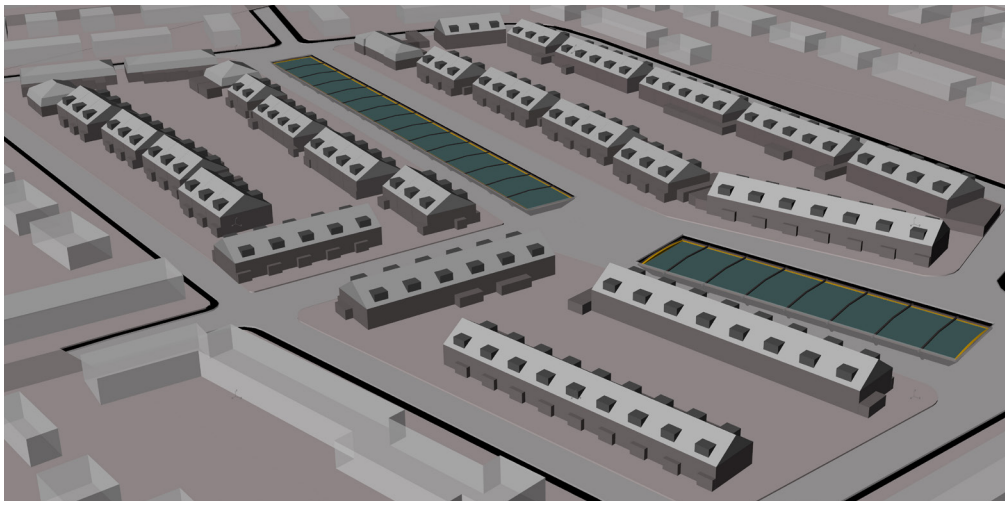
In the months January, February, March, October, November & December water of 45 °C is transported from the energy storage tanks towards the buildings. The return temperature of the water is 10 °C. The distribution losses of this configuration are therefore the same as in the A.1 configuration

IV. Properties pit thermal energy storage

Figure 5.27: *Dimensions energy storage. (by Auhtor)*

Storage 1:
Top surface: 150m x 14m
Bottom surface: 148m x 12m
Height : 6,5m
Volume: 10964 m³

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m³



The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3450 m²
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 2215 m²
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3326 m²
The total volume of both storages combined is : 18.262 m³



Impression visual/spatial impact B.1 configuration.

(B) 100% gas replacement using the comparison results of Ch. 4

(B.2) Flat plate collectors combined with a salt filled latent tank storage.
Replaced gas percentage 100%

This configuration will make use of flat plate collectors integrated onto & into the roofs of the buildings inside the selected urban blocks and this new energy system will replace 100% of the gas use for space heating inside the selected urban blocks. The monthly settings of the flat plate collectors and distribution system are illustrated in the following schemes. These setting were determined using the comparison of the energy potentials and the heat demand of the selected urban blocks.

Energy flow configuration:

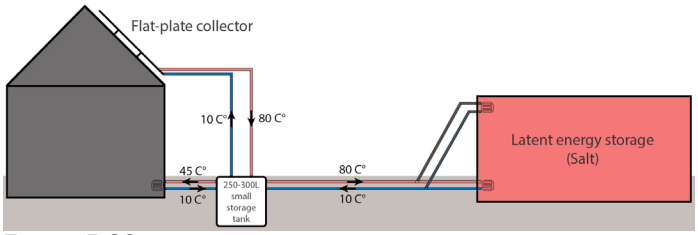


Figure 5.29: *Config. during summer months: Apr, May, June, July, Aug & Sep. (sunny hours)(by Author)*

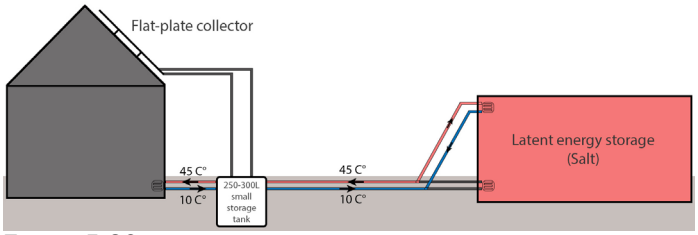


Figure 5.30: *Config. during summer months: Apr, May, June, July, Aug & Sep. (cloudy hours)(by Author)*

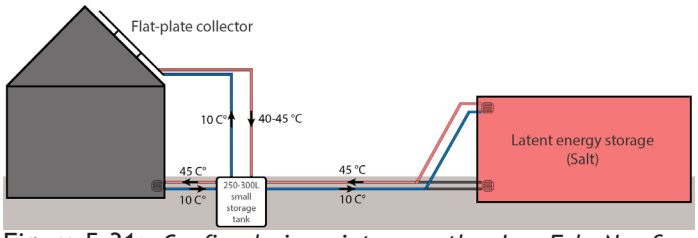


Figure 5.31: *Config. during winter months: Jan, Feb, Nov & Dec. (by Author)*

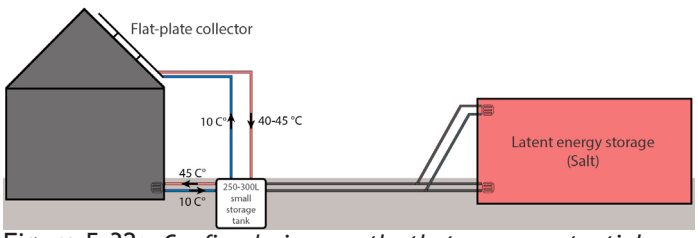
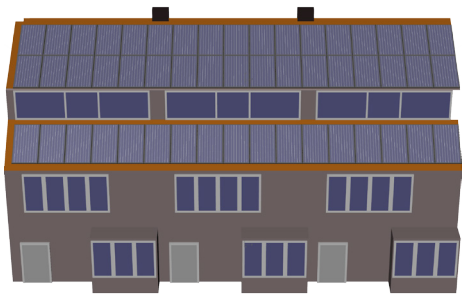


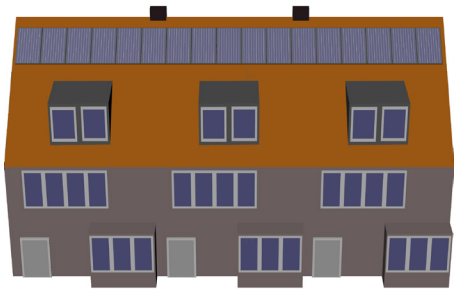
Figure 5.32: *Config. during months that energy potential = heat demand: March & Oct. (by Author)*

The storage can be included to balance the energy demand and the energy production, if the small storage tank is not sufficient.

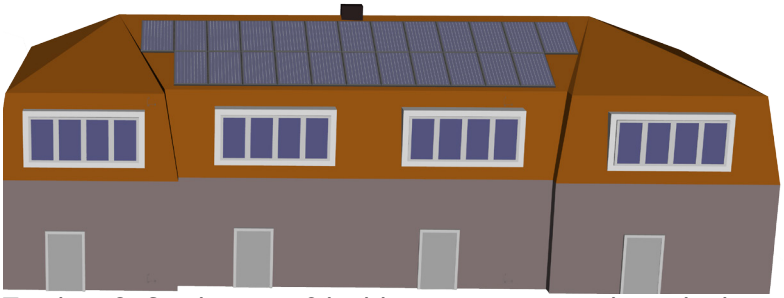
Building configurations resulting from the chapter 4 analysis:



Typology 1: South -11 buildings partly refurbished & South-west 3 buildings partly refurbished



Typology 1: West/east - 85 buildings Minor visual impact



Typology 2: South-west - 8 buildings using commonly applied placement of panels & West - 4 buildings using commonly applied placement of panels

I. Energy production

Both sides of the roofs of the buildings orientated to the west or east can be used for energy production, duplicating the energy potential of these buildings. Annual energy potential of 1 building and the amount of used solar collectors:

Total energy production of all buildings:
Typology 1 (West/East) minor visual impact:
85 x 2 (both sides of the roof) x 5,66 panels = 962 panels.
Annual thermal heat production (40 °C): 1.347.037 kWh
Annual thermal heat production (80 °C): 1.123.912 kWh

Typology 1 (S-W) partly refurbished roof:
3 x 17 panels = 51 panels
Annual thermal heat production (40 °C): 88.197 kWh
Annual thermal heat production (80 °C): 73.588 kWh

Typology 1 (South) partly refurbished roof:
11 x 17 panels = 187 panels.
Annual thermal heat production (40 °C): 338.789 kWh
Annual thermal heat production (80 °C): 282.672 kWh

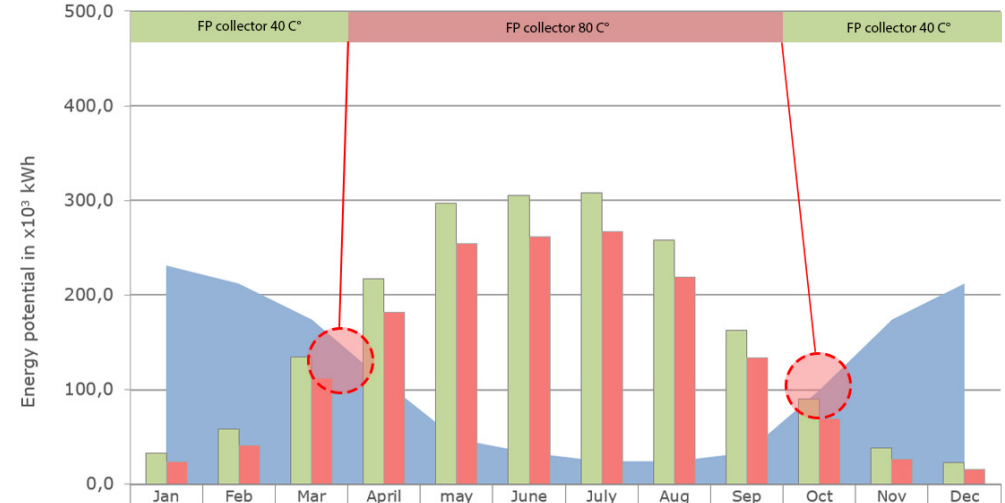
Typology 2 (S-W) commonly applied placement of panels:
8 x 6 panels = 48 panels.
Annual thermal heat production (40 °C): 83.009 kWh
Annual thermal heat production (80 °C): 69.259 kWh

Typology 2 (West) commonly applied placement of panels:
4 x 2 (both sides of the roof) x 6 panels = 48 panels.
Annual thermal heat production (40 °C): 67.198 kWh
Annual thermal heat production (80 °C): 56.067 kWh

Total selected urban blocks:
Total amount of monocrystalline PVT panels: 1296
Annual thermal heat production (40 °C): 1924 $x10^3$ kWh
Annual thermal heat production (80 °C): 1605 $x10^3$ kWh

Comparison heat demand and energy production:

Figure 5.33: *Comparison & output temperature settings flat plate collectors. (by Author)*



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
40 C°	33,0	58,6	134,1	217,0	297,3	304,8	307,7	257,9	162,6	90,0	38,0	23,3
80 C°	23,8	41,4	111,9	182,1	254,0	261,8	266,9	219,0	134,1	68,8	26,3	15,4

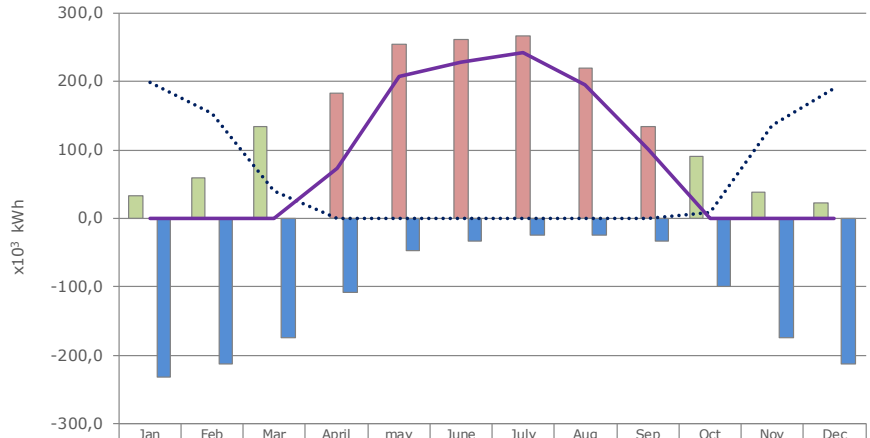
II. Transport losses

In the months April, May, June, July, August & September water of 80 °C is transported to the energy storage tanks. The return temperature of the water is 10 °C which is comparable to the ambient temperature in these months resulting in negligible energy losses.

In the months January, February, March, October, November & December water of 45 °C is transported from the energy storage tanks towards the buildings. The return temperature of the water is 10 °C. The distribution losses of this configuration are therefor the same as in the A.1 configuration

Actual heat demand & thermal heat delivered to the energy storage

Figure 5.34: *Net heat demand & Thermal heat for energy storage (by Author)*



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat (40C°)	33,0	58,6	134,1							90,0	38,0	23,3
Thermal heat (80C°)				182,1	254,0	261,8	266,9	219,0	134,1			
Heat demand	-231,0	-212,1	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-174,5	-212,1
Actual heat demand	197,9	153,6	40,4	0,0	0,0	0,0	0,0	0,0	0,0	9,2	136,5	188,8
Thermal heat input for storage	0,0	0,0	0,0	73,5	206,6	228,5	242,6	194,6	100,8	0,0	0,0	0,0

III. . Properties latent thermal energy storage.

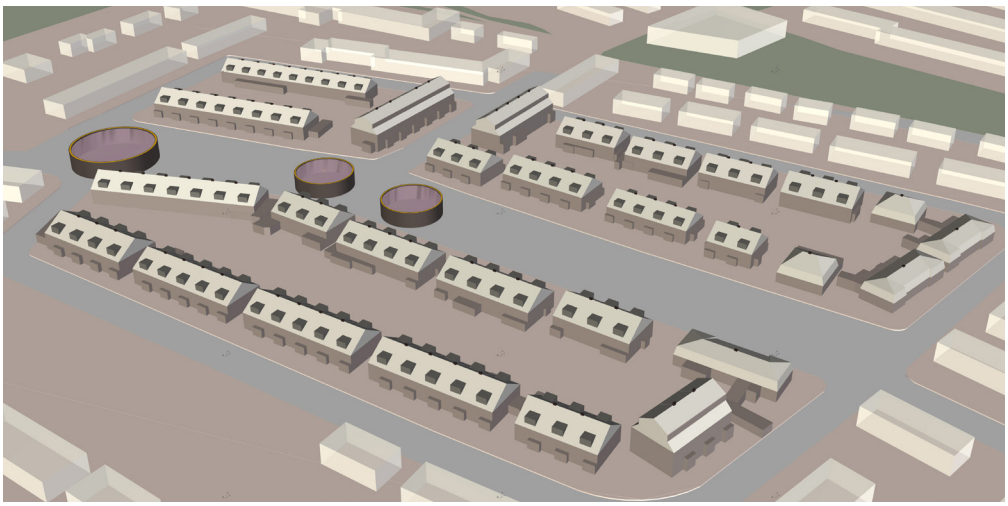


Figure 5.35: *Dimensions energy storage. (by Auhtor)*

Storage 1 (2 times):
Radius: 10 m
Height : 6 m
Volume: 1885 m^3

Storage 2:
Radius: 15 m
Height : 5 m
Volume: 3534 m^3

The total top surfaces (U_t = 0,060 W/m2*K) combined are : 1335 m^2
The total bottom surfaces (U_b = 0,056 W/m2*K) combined are : 1335m^2
The total lateral surfaces (U_l = 0,094 W/m2*K) combined are : 1225 m^2
The total volume of both storages combined is : 7304 m^3

Maximum (latent phase change) energy accumulation($Na_2S_2O_3 \cdot 5H_2O$):
E_{Latent} = 7304*1750 *187 = 2.390.300.405 KJ= 664 $x10^3$ kWh.

(B) 100% gas replacement using the comparison results of Ch. 4

(B.3) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.
Replaced gas percentage 100%

This configuration will make use of PVT panels integrated onto & into the roofs of the buildings inside the selected urban blocks and this new energy system will replace 100% of the gas use for space heating inside the selected urban blocks. The monthly settings of the PVT panels and distribution system are illustrated in the following schemes. These settings are determined using the comparison of the energy potentials and the heat demand of the selected urban blocks, further on explained in this configuration

Energy flow configuration:

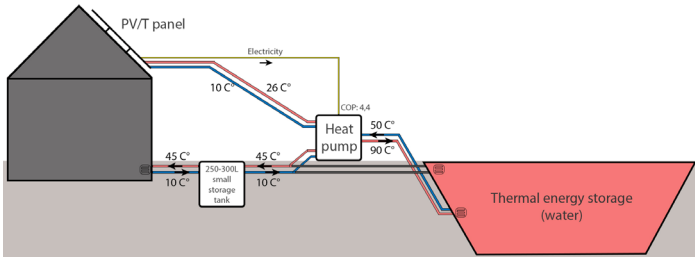


Figure 5.36: *Config. during summer months: Apr, May, June, July, Aug & Sep. (solar hours)(by Author)*

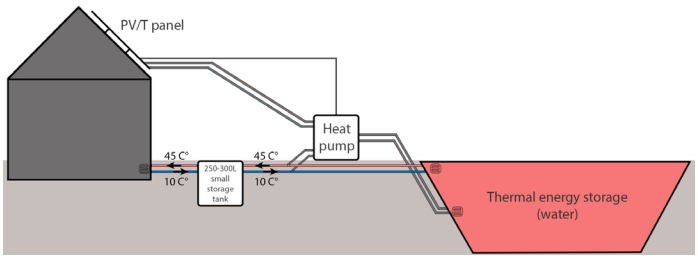


Figure 5.38: *Config. during winter months: Jan, Feb, Nov & Dec. (solar hours)(by Author)*

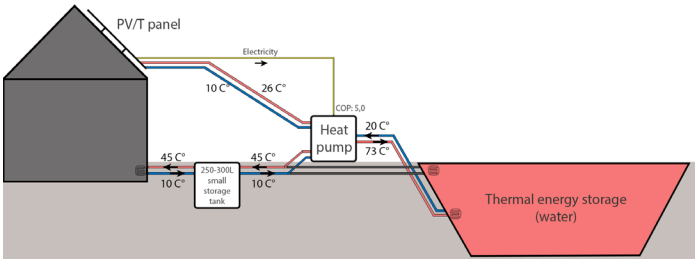
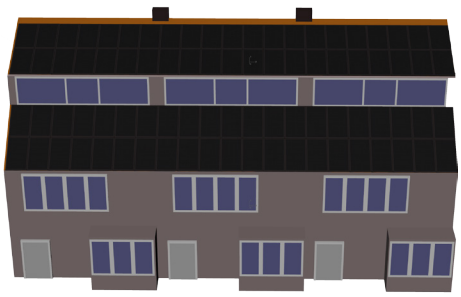
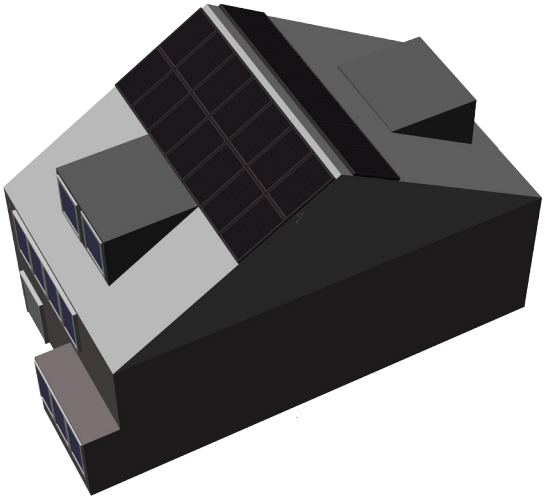


Figure 5.37: *Config. no solar hours, the whole year (by Author)*

Building configurations resulting from the chapter 4 analysis:



Typology 1: South - 11 buildings partly refurbished & South-west - 3 buildings partly refurbished



Typology 1: West/east - 85 buildings
Minor visual impact & double row of PVT panels on one side.



Typology 2: South-west - 8 buildings commonly used placement & West - 4 buildings commonly used placement

I. Energy production

During the process of making the calculations for the B.3 configuration using commonly used placement of PV panels also for the PVT panels, resulted in a surplus of energy potential for the selected urban blocks. The typology 1 buildings orientated south & south-west were given a partial refurbishment, new roof that is more optimal for the placement of PVT panels. This is one of the best options for the buildings resulting from the conclusions of chapter 4. The typology 1 buildings orientated east & west are given the option for minor visual impact with a double row of PVT panels orientated to the street sides. All the energy potentials of the PVT panels are calculated using the method explained in chapter 4. Therefore the thermal output temperature of 26 °C is integrated in the calculation instead of the 40 & 80 °C temperatures used in chapter 4.

Total energy production of all buildings:
Typology 1 (West/East) total refurbished roof:
85 x 3 (rows of 7 panels) x 7 panels = 1785 panels.
Annual thermal heat production (26 °C): 1.356.523 kWh
Annual electricity production : 361.995 kWh

Typology 1 (South) partly refurbished roof:
11 x 28 panels = 308 panels.
Annual thermal heat production (26 °C): 302.910 kWh
Annual electricity production : 80.833 kWh

Typology 1 (S-W) partly refurbished roof:
3 x 28 panels = 84 panels
Annual thermal heat production (26 °C): 78.857 kWh
Annual electricity production : 21.043 kWh

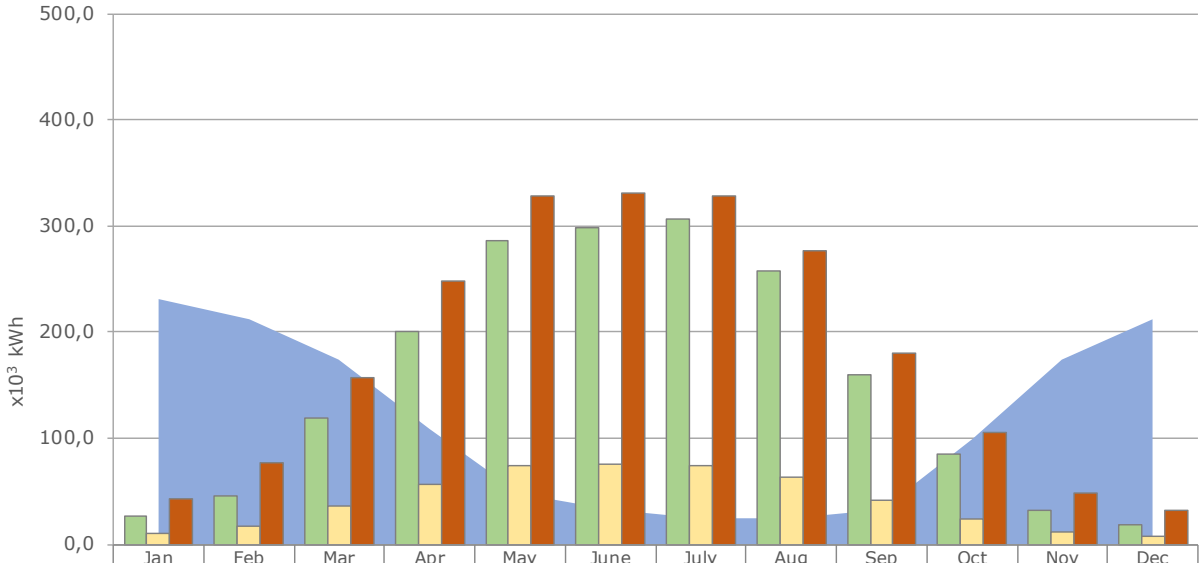
Typology 2 (S-W) commonly used placement:
8 x 9 panels = 72 panels.
Annual thermal heat production (26 °C): 67.591 kWh
Annual electricity production : 18.037 kWh

Typology 2 (West) commonly used placement:
4 x 9 panels = 48 panels.
Annual thermal heat production (26 °C): 27.358 kWh
Annual electricity production : 7301 kWh

Total selected urban blocks:
Total amount of monocrystalline PVT panels: 2285
Annual thermal heat production (26 °C): 1.833 $x10^3$ kWh
Annual electricity production : 489,2 $x10^3$ kWh

Heat pump
The large scale heat pump can heat water only up to 73 °C. Because the thermal output of the PVT panels is 26 °C we the used COP is 4,4.

Total monthly energy production potential:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
Thermal heat (26 C°)	25,9	45,8	118,7	199,8	286,0	298,5	305,9	257,8	159,5	84,7	32,6	18,1
Electricity	9,8	17,5	35,6	56,4	74,5	75,2	74,5	62,8	40,8	24,0	11,0	7,1
Thermal heat after HP (COP 4,4)	43,1	77,0	156,8	247,9	327,8	330,7	327,8	276,5	179,6	105,5	48,4	31,4

Figure 5.39: *Energy potential roofs all buildings & heat demand. (by Author)*

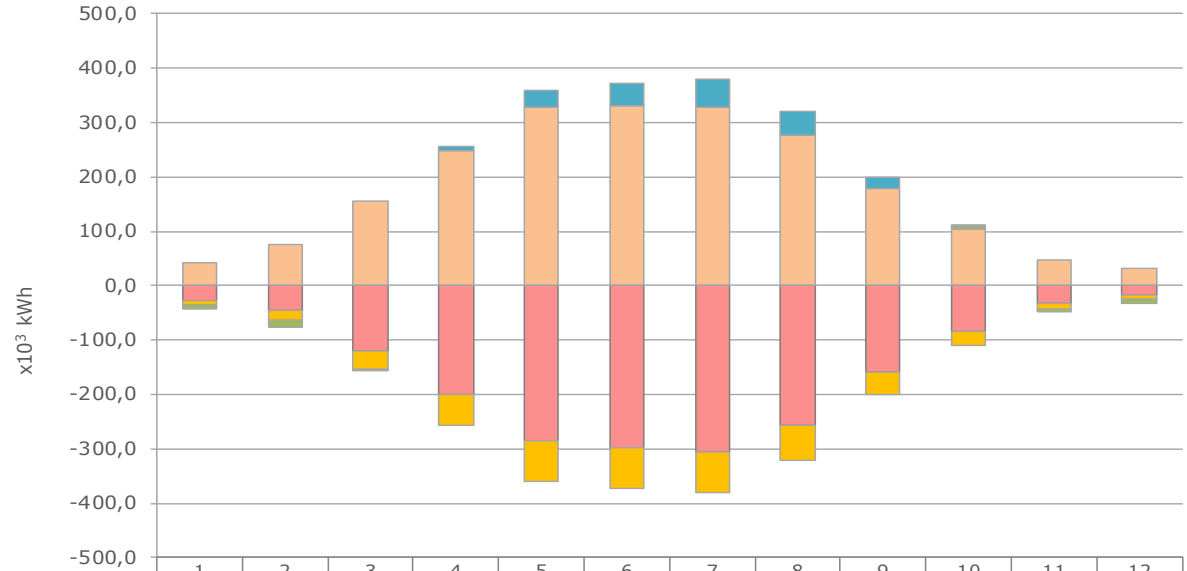
(Thermal heat after heat pump = electricity x 4,4, sometimes heat from the pit storage is used if not enough thermal heat is produced.)

Throughout the whole year the settings of the PVT panel will be set on a thermal output temperature of 26 °C. The lower the temperature the more advantageous it is for the thermal & electricity output.

Thermal output after heat pump

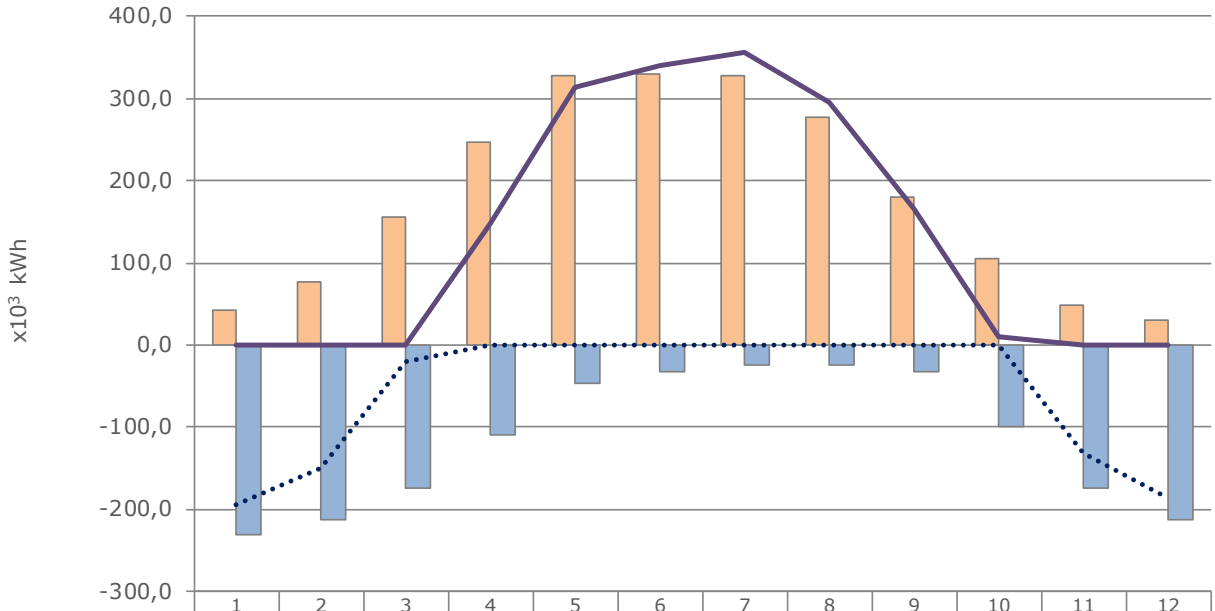
In the winter months the thermal output is to low compared to the electricity output for the heat pump to use all the electricity and use it to produce thermal heat. Therefor a little heat is extracted from the pit storage (26 °C) to use all the electricity. In the summer months to much thermal heat is produced that will be placed added to the pit storage.

Figure 5.40: *Extra thermal heat added/extracted from storage. (by Author)*



	1	2	3	4	5	6	7	8	9	10	11	12
Thermal heat added to storage				8,2	32,7	43,0	52,7	44,1	20,7	3,2		
Thermal heat extracted from storage	-7,4	-13,7	-2,4							3,2	-4,8	-6,2
Thermal heat after HP (COP 4,4)	43,1	77,0	156,8	247,9	327,8	330,7	327,8	276,5	179,6	105,5	48,4	31,4
Electricity	-9,8	-17,5	-35,6	-56,4	-74,5	-75,2	-74,5	-62,8	-40,8	-24,0	-11,0	-7,1
Thermal heat (26 C°)	-25,9	-45,8	-118,7	-199,8	-286,0	-298,5	-305,9	-257,8	-159,5	-84,7	-32,6	-18,1

III. Actual heat demand & thermal heat extracted and added to pit storage.



	1	2	3	4	5	6	7	8	9	10	11	12
Thermal heat after HP (COP 4,4)	43,1	77,0	156,8	247,9	327,8	330,7	327,8	276,5	179,6	105,5	48,4	31,4
Heat demand	-231,0	-212,1	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-174,5	-212,1
Actual heat demand	-195,3	-148,9	-20,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-130,9	-186,9
Thermal heat input for storage	0,0	0,0	0,0	147,5	313,1	340,3	356,1	296,3	167,0	9,5	0,0	0,0

The added and extracted thermal heat is included in the calculation.

Figure 5.41: *Net heat demand & Thermal heat for energy storage (by Author)*

IV. Properties pit thermal energy storage



Figure 5.42: *Dimensions energy storage. (by Auhtor)*

Storage 1:
Top surface: 150m x 14m
Bottom surface: 148m x 12m
Height : 6,5m
Volume: 10964 m^3

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m^3

The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3450 m^2
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 2215 m^2
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3326 m^2
The total volume of both storages combined is : 18.262 m^3

(C) Configurations aiming for minor spatial impact on the selected urban blocks combined with participation of the inhabitants.

(C.1) Flat plate collectors combined with a water filled pit thermal energy storage.
Replaced gas percentage 62%

This configuration will make use of flat plate collectors integrated onto & into the roofs of the buildings inside the selected urban blocks. The questionnaire held under some of the inhabitants resulted in a 74-80% unusable buildings for energy production due to predicted opposition against this. Therefore only 68 out of the 85 buildings typology 1 will be covered with flat plate collectors with minimal visual impact. The 11 buildings typology 1 orientated south will be partly refurbished for energy production due to their ideal situation. The building blocks next to these buildings will not be covered with flat plate collectors to limit the visual impact of this part of the selected urban blocks. Covered parking with integrated flat plate collectors is integrated in the public space as resulted from the questionnaire.
The monthly settings of the flat plate collectors and distribution system are illustrated in the following schemes. These setting were determined using the comparison of the energy potentials and the heat demand of the selected urban blocks.

Energy flow configuration:

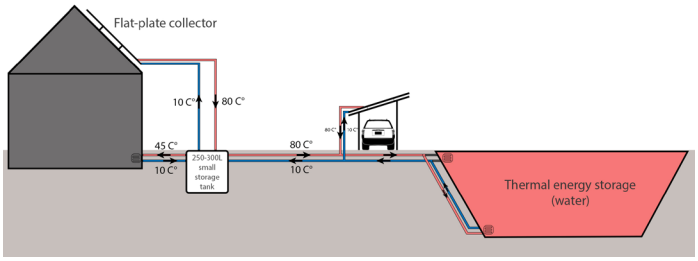


Figure 5.43: *Config. during summer months: Apr, May, June, July, Aug & Sep. (solar hours)(by Author)*

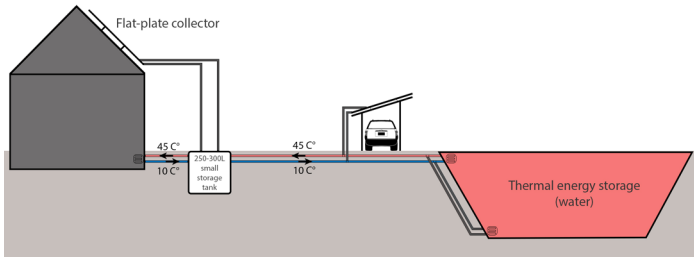


Figure 5.44: *Config. during summer months: Apr, May, June, July, Aug & Sep. (no solar hours)(by Author)*

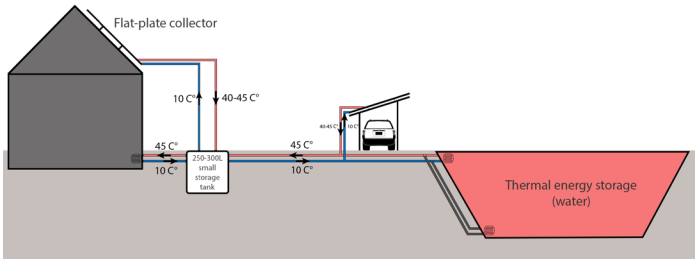


Figure 5.45: *Config. during winter months: Jan, Feb, Nov & Dec. (by Author)*

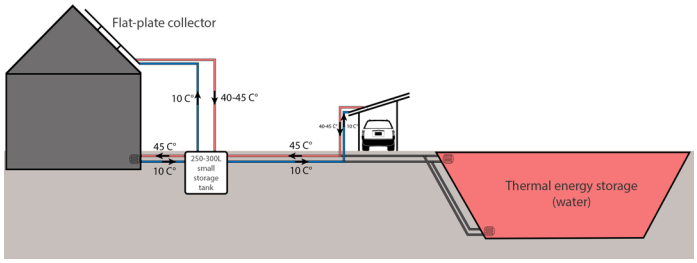
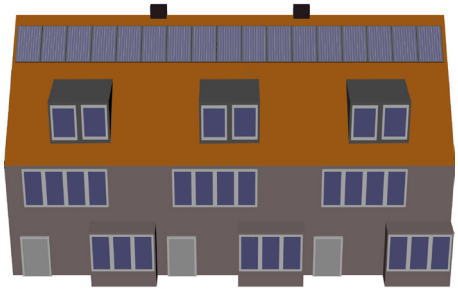


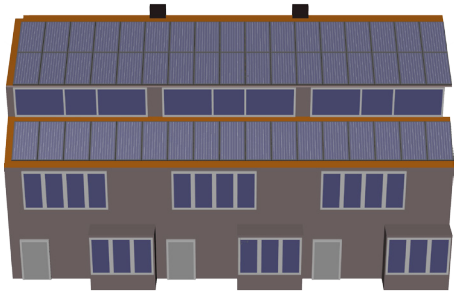
Figure 5.46: *Config. during months that energy potential = heat demand: March & Oct. (by Author)*

The storage can be included to balance the energy demand and the energy production, if the small storage tank is not sufficient.

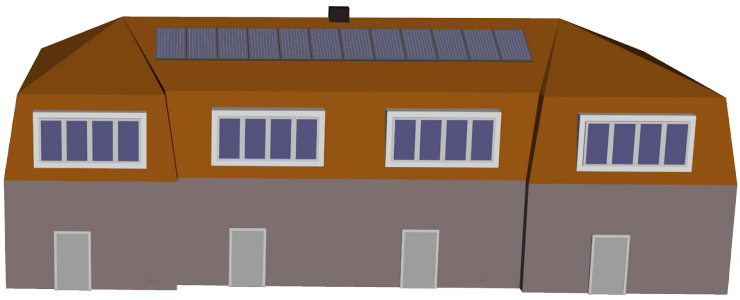
Building configurations resulting from the chapter 4 analysis:



Typology 1: West/east - 68 buildings
Minor visual impact



Typology 1: South - 11 buildings
partly refurbished



Typology 2: South-west - 8 buildings minor visual impact

I. Energy production

The buildings typology 1 with minor visual impactwill produce energy on both sides of the roof, doubling the energy production of these buildings. In the public space 48 new covered parking spots are created. Integrated in the roof covering the parking spots are flat-plate collectors. The total amount of flat-plate collectors in the parking roofs is: 48 x 6 all south orientated.

Typology 1 (West/East) minor visual impact:
68 x 2 (roof sides used) x 5,66 panels = 770 panels.
Annual thermal heat production (40 °C): 1.077.630 kWh
Annual thermal heat production (80 °C): 899.130 kWh

Typology 1 (South) Partly refurbished:
11 x 17panels = 187 panels.
Annual thermal heat production (40 °C): 338.789 kWh
Annual thermal heat production (80 °C): 282.672 kWh

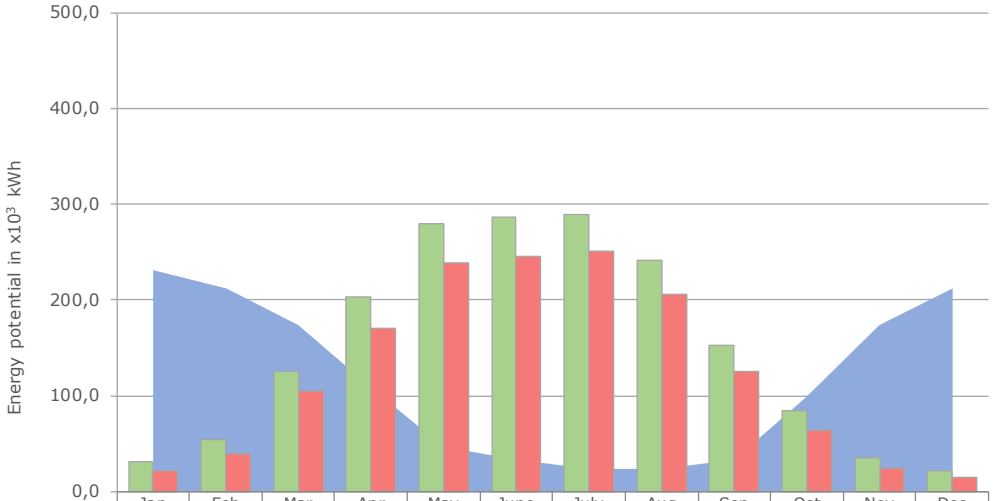
Typology 2 (S-W) minor visual impact:
8 x 3 panels = 24 panels.
Annual thermal heat production (40 °C): 41.505 kWh
Annual thermal heat production (80 °C): 34.630 kWh

Parking (South): 48 x 6 = 288 panels.
Annual thermal heat production (40 °C): 347.848 kWh
Annual thermal heat production (80 °C): 290.230 kWh

Total selected urban blocks:
Total amount of monocrystalline PV panels: 1269
Annual thermal heat production (40 °C): 1806 $x10^3$ kWh
Annual thermal heat production (80 °C): 1507 $x10^3$ kWh

Comparison heat demand and energy production:

Figure 5.47: *Energy potential & heat demand roofs 107 buildings. (by Author)*

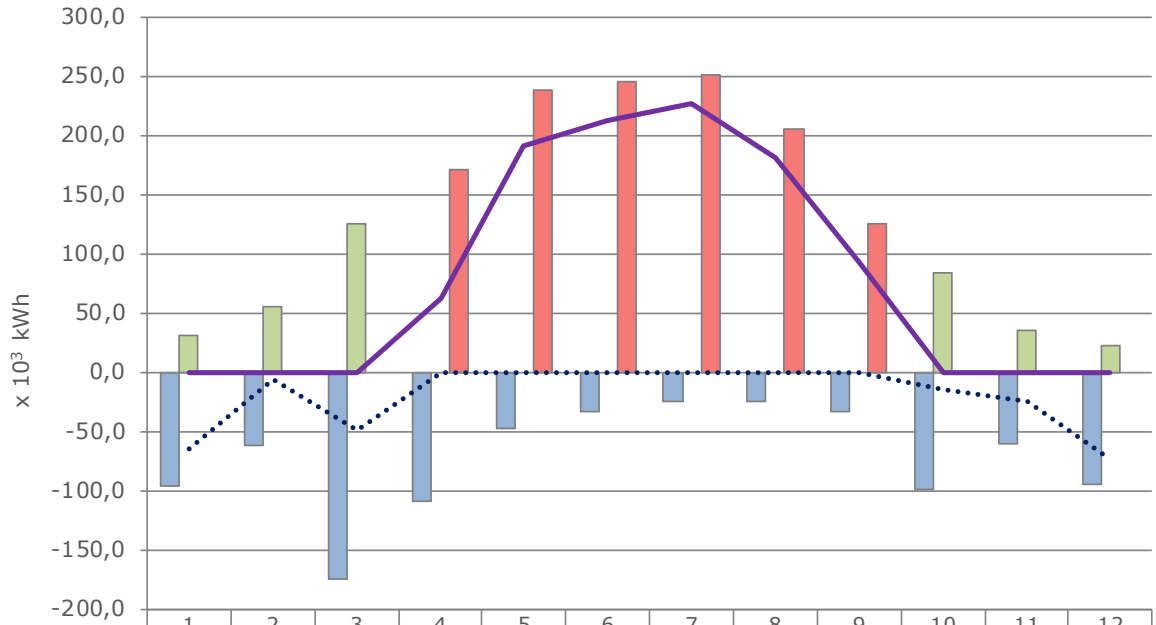


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
40 C°	31,0	55,0	125,9	203,6	279,0	286,0	288,7	242,0	152,6	84,4	35,6	21,9
80 C°	22,3	38,9	105,0	170,9	238,4	245,7	250,5	205,5	125,8	64,5	24,6	14,5

As visible in the graph, the energy potential of the selected urban blocks is lower compared to the A.1 configuration in chapter 5. The percentage of gas replaced in this scenario will therefor not be 100%. In the months were the energy potential is lower than the heat demand a reducted delivered heat demand will be calculated. We use the same settings for the flat plate collectors as in the A.1 configuration:
In the months March and October the thermal heat production of the flat plate collectors is enough to provide the heat demand for that month. In the winter months between March and October the collector output will also be provided in 40 °C and is assumed to be directly used for the buildings. The thermal heat production of these months can be subtracted from the heat demand of the buildings.

In the summer months between March and October the flat plate collector output temperature will be 80 °C. This thermal heat will be used to directly deliver the heat demand of that month and secondly heat up the water temperature in the energy storage (thermal input for storage).

Actual heat demand & thermal heat delivered to the energy storage



	1	2	3	4	5	6	7	8	9	10	11	12
Heat demand	-96,0	-61,7	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-60,3	-94,8
Thermal heat (40 C°)	31,0	55,0	125,9							84,4	35,6	21,9
Thermal heat (80 C°)				170,9	238,4	245,7	250,5	205,5	125,8			
Actual heat demand	-65,0	-6,7	-48,6	0,0	0,0	0,0	0,0	0,0	0,0	-14,8	-24,7	-72,9
Thermal heat input for storage	0	0	0	62,3	191,0	212,4	226,2	181,1	92,5	0	0	0

Figure 5.49: *Net heat demand & Thermal heat for energy storage (by Author)*

IV. Properties pit thermal energy storage

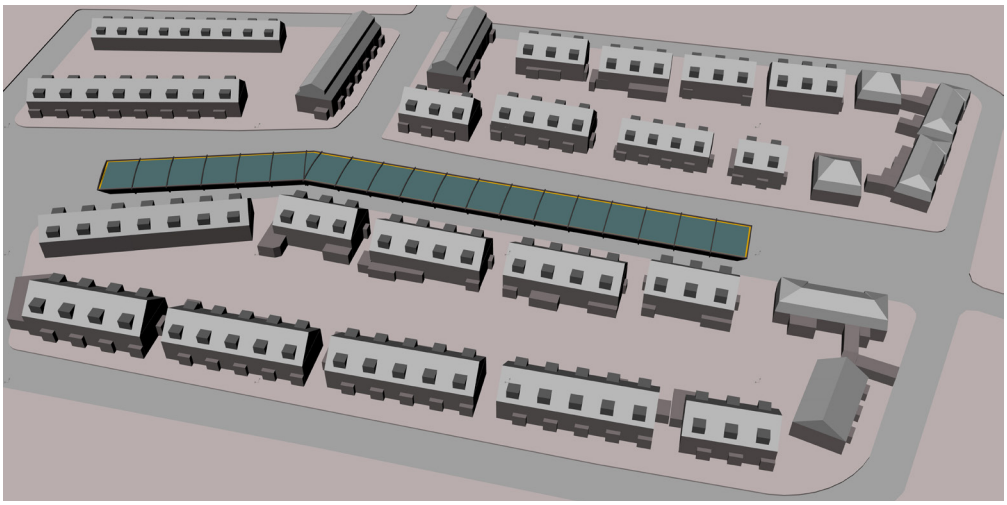


Figure 5.48: *Dimensions energy storage. (by Auhtor)*

Storage :
Top surface: 220m x 12m
Bottom surface: 216m x 8m
Height: 6,5m
Volume: 14.092 m^3

The total top surface (U_t = 0,059 W/m2*K) : 3450 m^2
The total bottom surface (U_b = 0,061 W/m2*K) : 2640 m^2
The total lateral surfaces (U_l = 0,058 W/m2*K) : 3101 m^2
The total volume is : 14.092 m^3

(C) Configurations aiming for minor spatial impact on the selected urban blocks combined with participation of the inhabitants.

(C.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycoolers.
Replaced gas percentage 87%

The aquifer storage and heat pump are the same as in configuration (A.2).

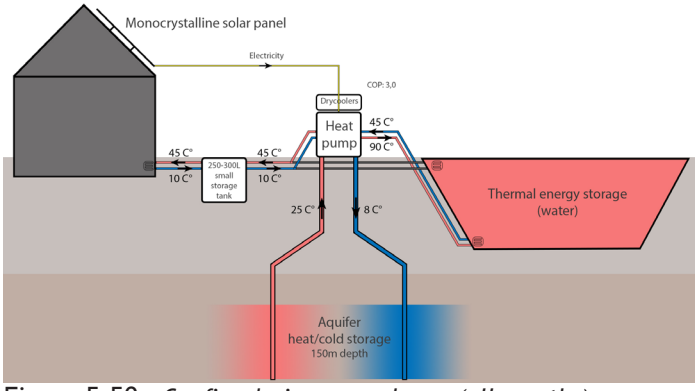


Figure 5.50: *Config. during sunny hours (all months) (by Author)*

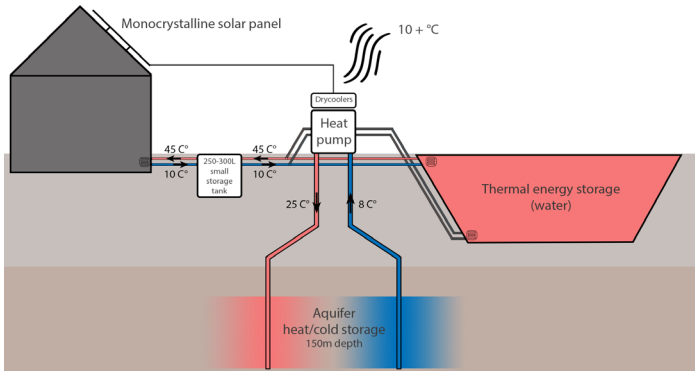


Figure 5.51: *Config. during summer months on cloudy days. (by Author)*

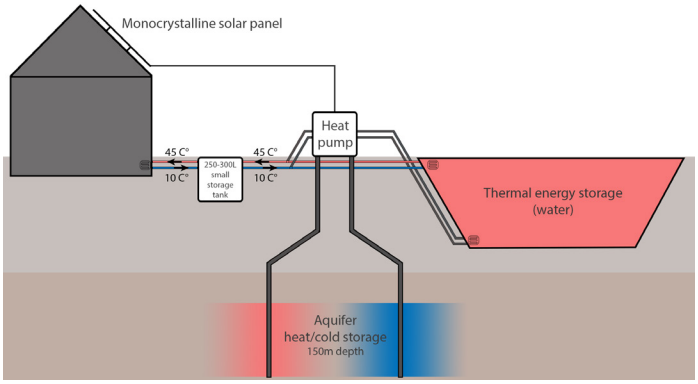
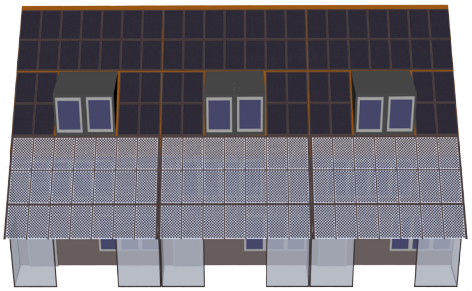
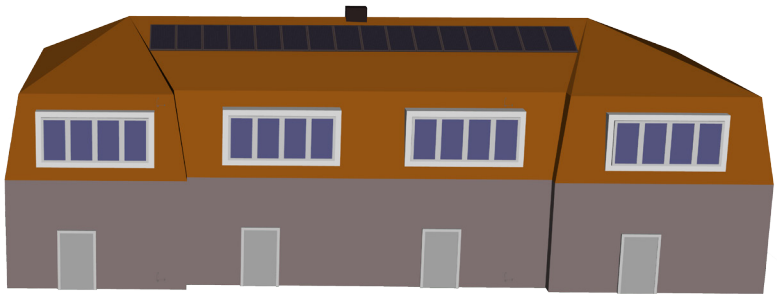


Figure 5.52: *Config. during winter months on cloudy days.(by Author)*

I. Energy production (buildings)







Typology 1 (minor viusal impact):
West/east - 68 buildings
Typology 1 (building extention): South - 11 buildings
Typology 2 (minor viusal impact): South-west - 8 buildings

Both sides of the roofs of the buildings orientated to the west or east can be used for energy production, duplicating the energy potential of these buildings. Annual energy potential of 1 building and the amount of used PV panels:

Typology 1 (West/East): 68 x 2 (roof sides used) x 14 panels = 1904 panels.
Annual electricity production: 419.368 kWh

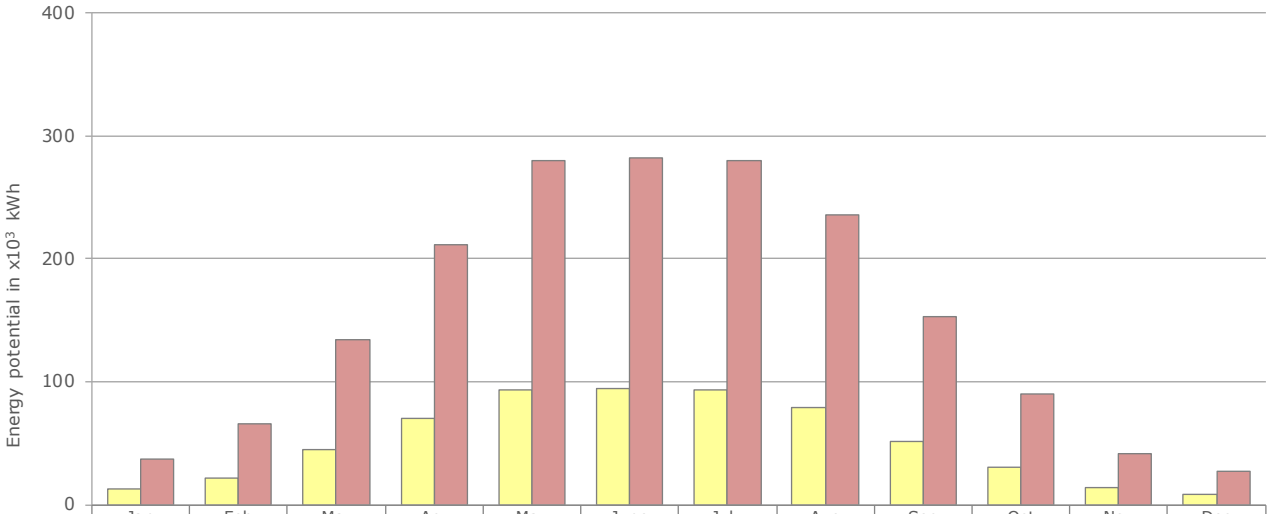
Typology 1 (South): 11 x (10,5 glass & 22 roof) panels = 357,5 panels.
Annual electricity production: 101.901 kWh

Typology 2 (S-W): 8 x 4 panels = 32 panels.
Annual electricity production: 8707 kWh

Parking (South): 48 x 6 = 288 panels.
Annual electricity production: 82.091 kWh

Total annual electricity production: 612 x10³ kWh.
Thermal heat energy potential after transformation of electricity into thermal heat:
612x10³ x 3,0 = 1836x10³ kWh.

Monthly electricity production & thermal heat potential - heat pump (COP 3,0):

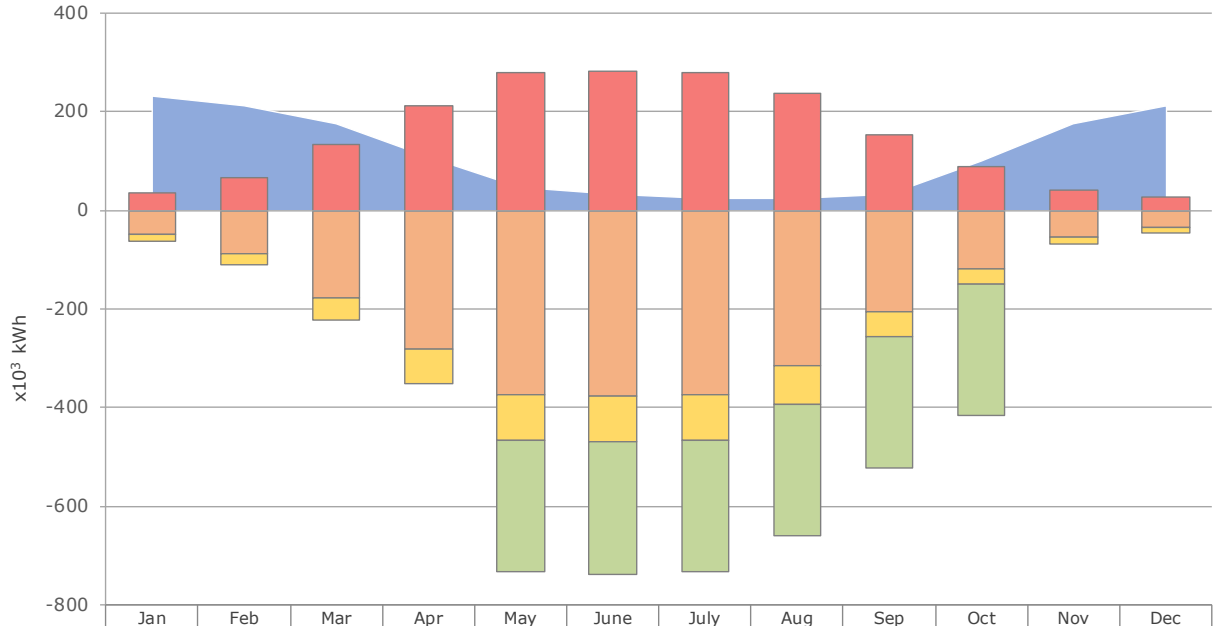


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Electricity	12,3	21,9	44,6	70,5	93,2	94,0	93,2	78,6	51,1	30,0	13,8	8,9
Thermal heat (after heat pump)	36,8	65,7	133,8	211,5	279,6	282,1	279,6	235,9	153,2	90,0	41,3	26,8

Figure 5.53: *Energy potential selected urban blocks (elec & thermal heat)(by Author)*

II. Drycoolers
Annual external heat neccesary from the aquifer storage is:
1836x10³ - 612 x10³ = 1224x10³ kWh.

This heated water is used to regenerate the aquifer storage, 4 drycooler ventilators are necessary. The (4 ventilators) drycooler extracts 400 kW heat from the air during 4000 hours in summer months. In each month (May, Jun, Jul, Aug, Sep & Oct) 266.667 kWh heat is transported back into the aquifer. Annual this is 1600x10³ kWh. (De Brauw, Koezjakov, & TAUW, 2018)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
Drycoolers					-266,7	-266,7	-266,7	-266,7	-266,7	-266,7		
Thermal heat (after heat pump)	36,8	65,7	133,8	211,5	279,6	282,1	279,6	235,9	153,2	90,0	41,3	26,8
Electricity	-12,3	-21,9	-44,6	-70,5	-93,2	-94,0	-93,2	-78,6	-51,1	-30,0	-13,8	-8,9
Thermal heat aquifer st.	-49,0	-87,5	-178,4	-282,0	-372,8	-376,1	-372,8	-314,5	-204,3	-120,0	-55,1	-35,7

Figure 5.54: *Comparison origen heat demand and origen energy potential. (by Author)*

III. Properties pit thermal energy storage & aquifer storage

Storage 1:
Top surface: 150m x 14m
Bottom surface: 148m x 12m
Height : 6,5m
Volume: 10964 m³

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m³

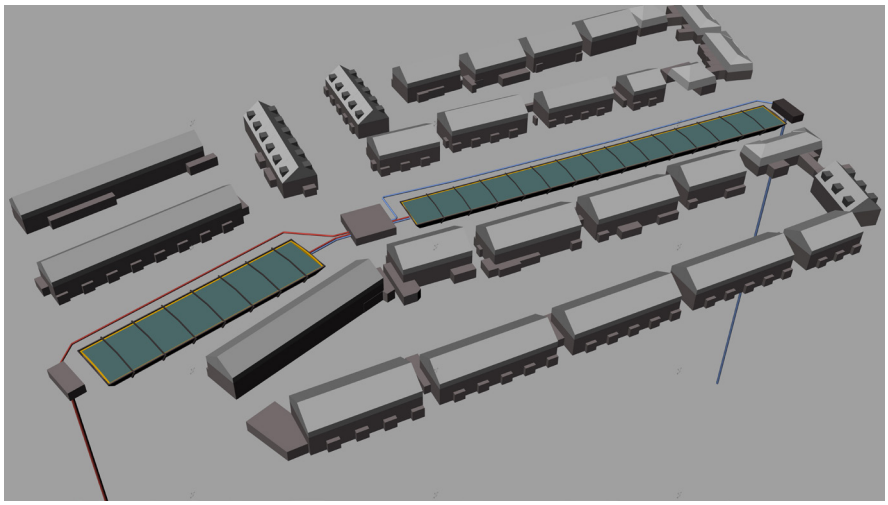


Figure 5.55: *Aquifer + pit storages (by Author)*

The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3450 m²
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 2215 m²
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3326 m²
The total volume of both storages combined is : 18.262 m³

(C) Configurations aiming for minor spatial impact on the selected urban blocks combined with participation of the inhabitants.

(C.3) Flat plate collectors combined with a salt filled latent tank storage

Replaced gas percentage 94%

Energy flow configuration:

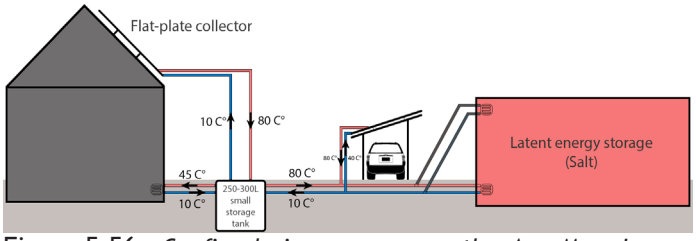


Figure 5.56: *Config. during summer months: Apr, May, June, July, Aug & Sep. (sunny hours)(by Author)*

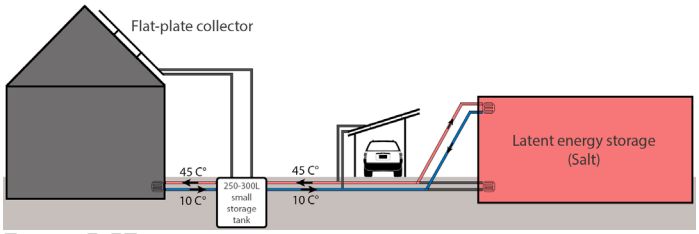


Figure 5.57: *Config. during summer months: Apr, May, June, July, Aug & Sep. (cloudy hours)(by Author)*

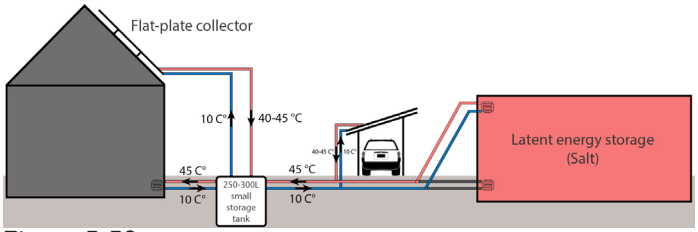
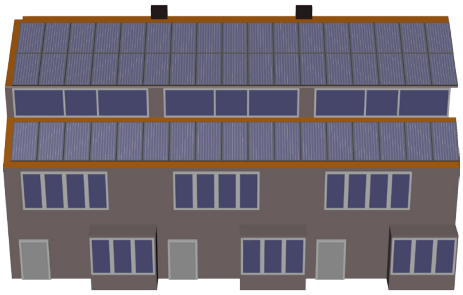


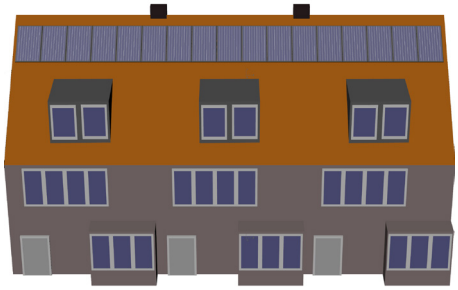
Figure 5.58: *Config. during winter months: Jan, Feb, Nov & Dec. (by Author)*

The storage can be included to balance the energy demand and the energy production, if the small storage tank is not sufficient.

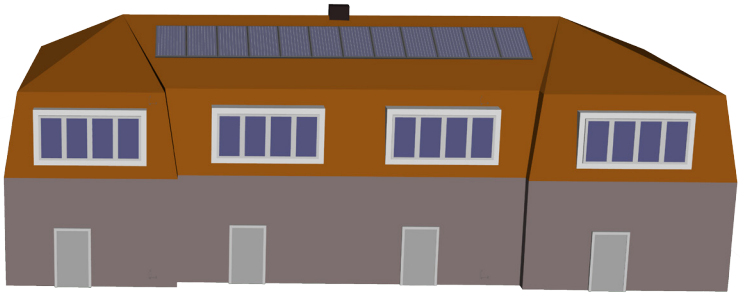
Building configurations resulting from the chapter 4 analysis:



Typology 1: South -11 buildings partly refurbished



Typology 1: West/east -68 buildings Minor visual impact



Typology 2: South-west - 8 buildings minor visual impact

I. Energy production

The buildings typology 1 with minor visual impact will produce energy on both sides of the roof, doubling the energy production of these buildings. In the public space 48 new covered parking spots are created. Integrated in the roof covering the parking spots are flat-plate collectors. The total amount of flat-plate collectors in the parking roofs is: 48 x 6 all south orientated.

Typology 1 (West/East) minor visual impact:
68 x 2 (roof sides used) x 5,66 panels = 770 panels.
Annual thermal heat production (40 °C): 1.077.630 kWh
Annual thermal heat production (80 °C): 899.130 kWh

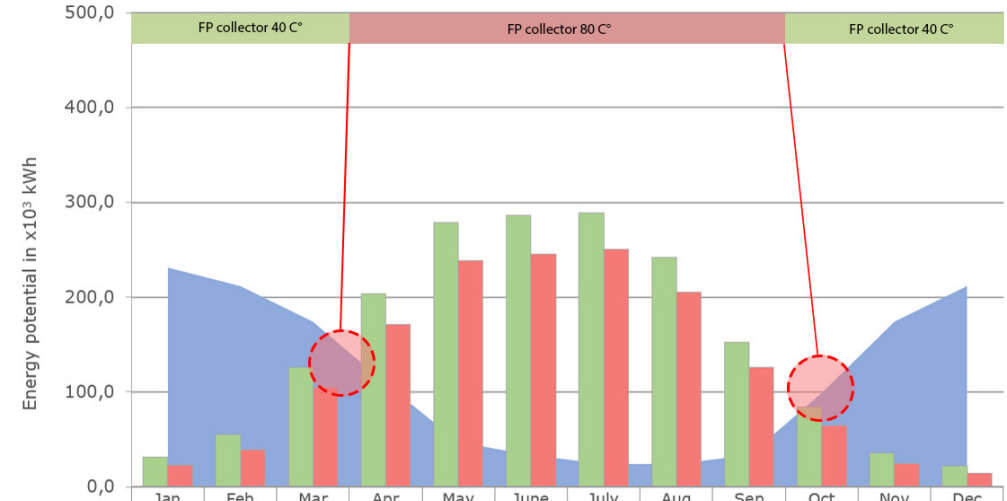
Typology 1 (South) Partly refurbished:
11 x 17panels = 187 panels.
Annual thermal heat production (40 °C): 338.789 kWh
Annual thermal heat production (80 °C): 282.672 kWh

Typology 2 (S-W) minor visual impact:
8 x 3 panels = 24 panels.
Annual thermal heat production (40 °C): 41.505 kWh
Annual thermal heat production (80 °C): 34.630 kWh

Parking (South): 48 x 6 = 288 panels.
Annual thermal heat production (40 °C): 347.848 kWh
Annual thermal heat production (80 °C): 290.230 kWh

Total selected urban blocks:
Total amount of monocrystalline PV panels: 1269
Annual thermal heat production (40 °C): 1806 x10^3 kWh
Annual thermal heat production (80 °C): 1507 x10^3 kWh

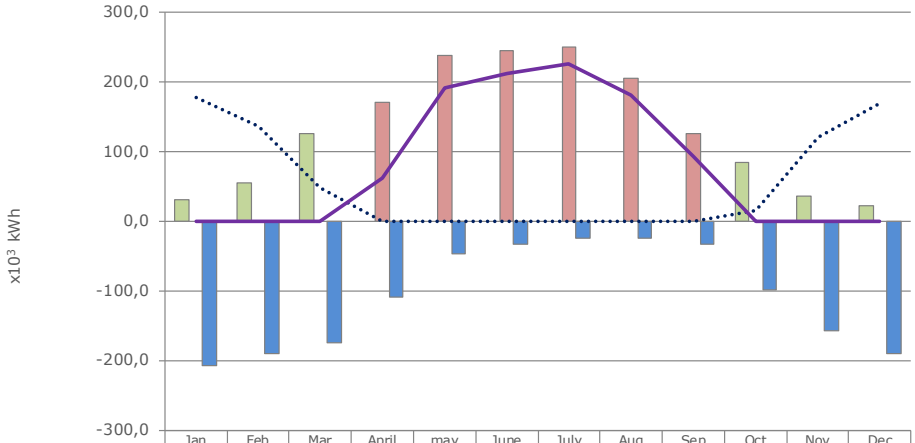
Comparison heat demand and energy production:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
40 C°	31,0	55,0	125,9	203,6	279,0	286,0	288,7	242,0	152,6	84,4	35,6	21,9
80 C°	22,3	38,9	105,0	170,9	238,4	245,7	250,5	205,5	125,8	64,5	24,6	14,5

Figure 5.59: *Comparison & output temperature settings flat plate collectors. (by Author)*

Actual heat demand & thermal heat delivered to the energy storage



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat (40 °C)	31,0	55,0	125,9							84,4	35,6	21,9
Thermal heat (80 °C)				170,9	238,4	245,7	250,5	205,5	125,8			
Provided heat demand	-207,9	-190,9	-174,5	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-157,0	-190,9
Actual heat demand	176,9	136,0	48,6	0,0	0,0	0,0	0,0	0,0	0,0	14,8	121,4	169,0
Thermal heat input for storage	0,0	0,0	0,0	62,3	191,0	212,4	226,2	181,1	92,5	0,0	0,0	0,0

Figure 5.61: *Actual heat demand & Thermal heat for energy storage (by Author)*

II. Transport losses

The transport losses are the same as in the A.1 & B.2 configuration.

III. . Properties latent thermal energy storage.

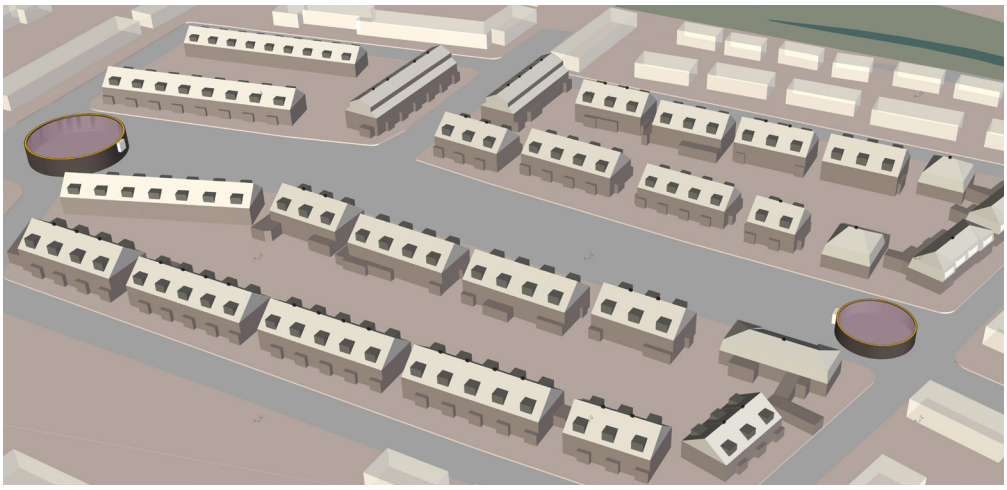


Figure 5.60: *Dimensions energy storage. (by Auhtor)*

Storage 1:
Radius: 10 m
Height : 6 m
Volume: 1885 m^3

Storage 2:
Radius: 16 m
Height : 6 m
Volume: 4825 m^3

The total top surfaces (U_t = 0,060 W/m2*K) combined are : 1118 m^2
The total bottom surfaces (U_b = 0,056 W/m2*K) combined are : 1118 m^2
The total lateral surfaces (U_l = 0,094 W/m2*K) combined are : 980 m^2
The total volume of both storages combined is : 6710 m^3

Maximum (latent phase change) energy accumulation($Na_2S_2O_3 \cdot 5H_2O$):
E_{Latent} = 6710*1750 *187 = 2.195.992.114 KJ= 610 $x10^3$ kWh.



Impression visual/spatial impact C.3 configuration.

(C) Configurations aiming for minor spatial impact on the selected urban blocks combined with participation of the inhabitants.

(C.4) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

Replaced gas percentage 75%

This configuration will make use of PVT panels integrated onto & into the roofs of the buildings inside the selected urban blocks. The seasonal operational schemes of the PVT panels and distribution system are illustrated in the following schemes. These settings are determined using the comparison of the energy potentials and the heat demand of the selected urban blocks, further on explained in this configuration.

Energy flow configuration:

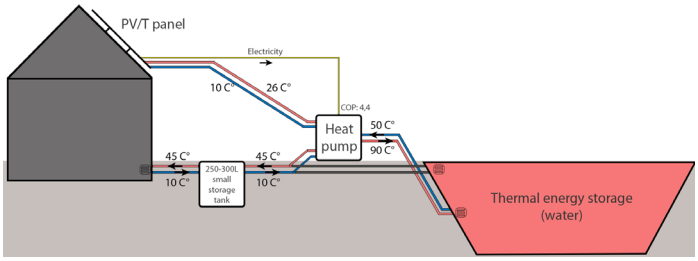


Figure 5.62: *Config. during summer months: Apr, May, June, July, Aug & Sep. (solar hours)(by Author)*

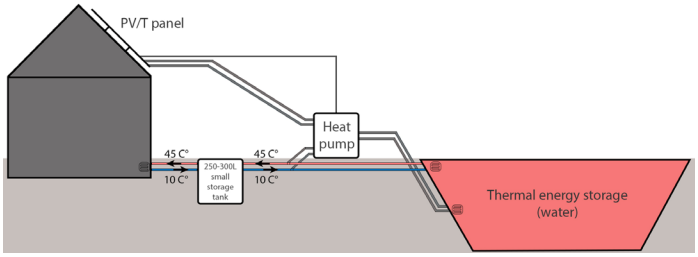


Figure 5.64: *Config. during winter months: Jan, Feb, Nov & Dec. (solar hours)(by Author)*

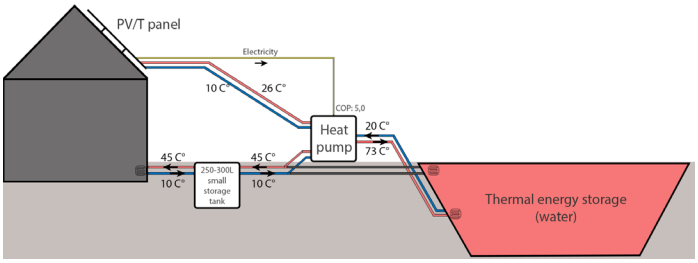
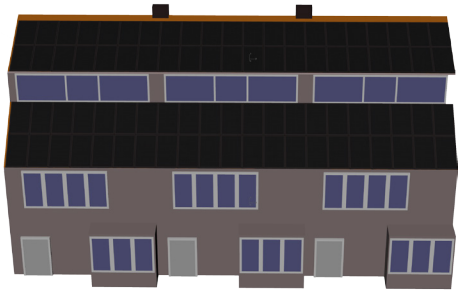


Figure 5.63: *Config. no solar hours, the whole year (by Author)*

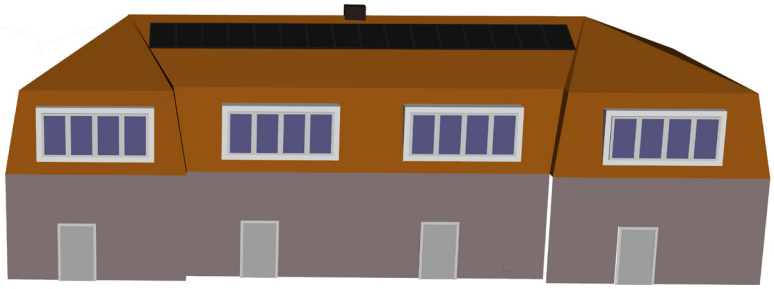
Building configurations resulting from the chapter 4 analysis:



Typology 1: South -11 buildings partly refurbished



Typology 1: West/east - 85 buildings
Minor visual impact



Typology 2: South-west - 8 buildings
commonly used placement

I. Energy production

All the energy potentials of the PVT panels were calculated using the method explained in chapter 4. Therefor the thermal output temperature of 26˚C is used in the calculation instead of the 40 & 80 ˚C temperatures used in chapter 4. Resulting from the questionnaire, 48 covered parking spaces (orientated south) with integrated PVT are assumed to be acceptable in the public space. The same heat pump as in the B.3 configuration is used in this configuration.

Total energy production of all buildings:
Typology 1 (West/East) minor visual impact:
68 x 2 (both sides of the roof) x 7 panels = 952 panels.
Annual thermal heat production (26 ˚C) : 723.479 kWh
Annual electricity production : 193.064 kWh

Typology 1 (South) partly refurbished roof:
11 x 28 panels = 308 panels.
Annual thermal heat production (26 ˚C) : 302.910 kWh
Annual electricity production : 80.833 kWh

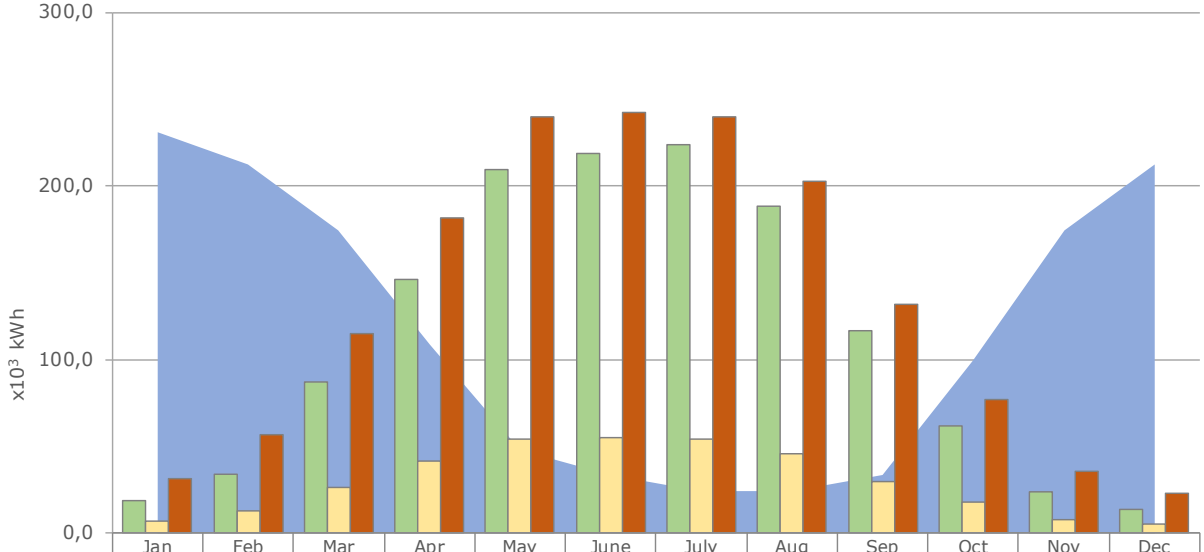
Typology 2 (S-W) commonly used placement:
8 x 4 panels = 32 panels.
Annual thermal heat production (26 ˚C) : 31.471 kWh
Annual electricity production : 8398 kWh

Covered parking spaces:
48 x 6 panels = 288 panels.
Annual thermal heat production (26 ˚C) : 283.240 kWh
Annual electricity production : 75.584 kWh

Total selected urban blocks:
Total amount of monocrystalline PVT panels: 1580
Annual thermal heat production (26 ˚C) : 1.341 x10^3 kWh
Annual electricity production : 357,9 x10^3 kWh

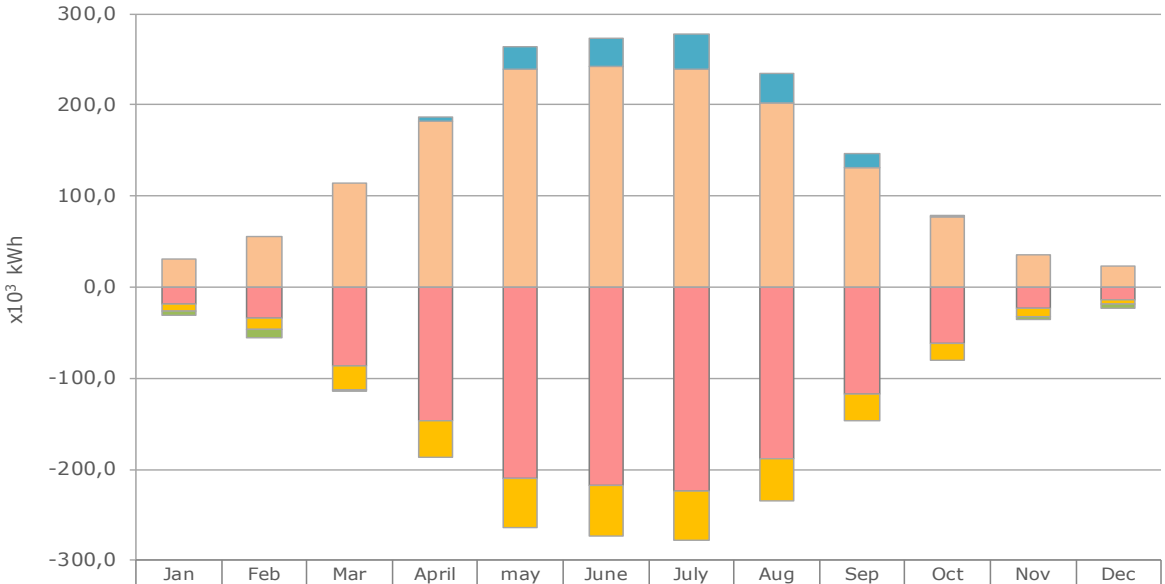
Figure 5.65: *Energy potential roofs all buildings & heat demand. (by Author)*

Total monthly energy production potential:
(Thermal heat after heat pump = electricity x 4,4, sometimes heat from the pit storage is used if not enough thermal heat is produced.)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Heat demand	231,0	212,1	174,5	108,6	47,4	33,3	24,4	24,4	33,3	99,2	174,5	212,1
Thermal heat (26 C°)	18,9	33,5	86,9	146,2	209,2	218,4	223,8	188,6	116,7	61,9	23,8	13,2
Electricity	7,2	12,8	26,1	41,2	54,5	55,0	54,5	46,0	29,9	17,5	8,1	5,2
Thermal heat after HP (COP 4,4)	31,5	56,3	114,7	181,4	239,8	241,9	239,8	202,3	131,4	77,2	35,4	23,0

hroughout the whole year the settings of the PVT panel will be set on a thermal output temperature of 26 °C. The lower the temperature the more advantageous it is for the thermal & electrical output.



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat added to storage				6,0	23,9	31,4	38,5	32,3	15,1	2,3		
Thermal heat extracted from storage	-5,4	-10,0	-1,8								-3,5	-4,5
Thermal heat after HP (COP 4,4)	31,5	56,3	114,7	181,4	239,8	241,9	239,8	202,3	131,4	77,2	35,4	23,0
Electricity	-7,2	-12,8	-26,1	-41,2	-54,5	-55,0	-54,5	-46,0	-29,9	-17,5	-8,1	-5,2
Thermal heat (26 C°)	-18,9	-33,5	-86,9	-146,2	-209,2	-218,4	-223,8	-188,6	-116,7	-61,9	-23,8	-13,2

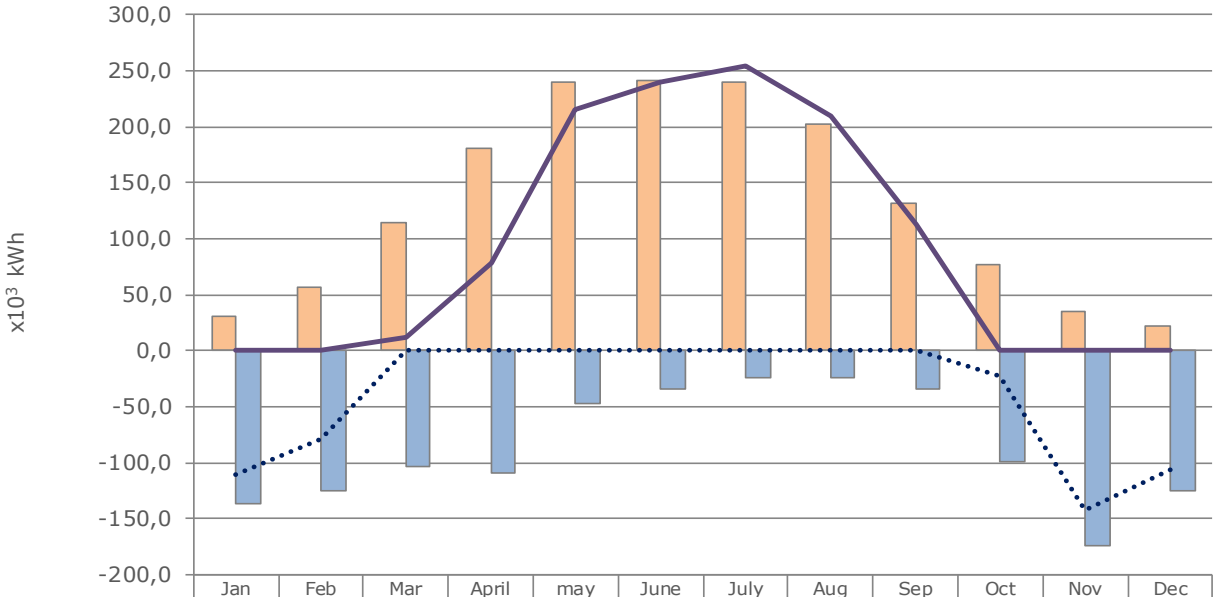
Figure 5.66: *Extra thermal heat added/extracted from storage. (by Author)*

Thermal output after heat pump

In the winter months the thermal output is to low compared to the electricity output for the heat pump to use all the electricity and use it to produce thermal heat. Therefor a little heat is extracted from the pit storage (26 °C) to use all the electricity. In the summer months to much thermal heat is produced that will be added to the pit storage.

Figure 5.67: *Actual heat demand & Thermal heat for energy storage (by Author)*

III. Actual heat demand & thermal heat extracted and added to pit storage.



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
Thermal heat after HP (COP 4,4)	31,5	56,3	114,7	181,4	239,8	241,9	239,8	202,3	131,4	77,2	35,4	23,0
Heat demand	-136,3	-125,2	-102,9	-108,6	-47,4	-33,3	-24,4	-24,4	-33,3	-99,2	-174,5	-125,2
Actual heat demand	-110,2	-78,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-22,0	-142,6	-106,7
Thermal heat input for storage	0,0	0,0	11,8	78,8	216,3	240,0	254,0	210,2	113,2	0,0	0,0	0,0

The added and extracted thermal heat is included in the calculation.

As visible in the previous graph the heat demand that is delivered to the buildings is lower in the months December, January, February & March. In these months 59% of the heat demand is delivered to the buildings. These values are calculated using excel and are based on temperature change in the pit storage aiming to keep a stable (low as possible but above 45 °C) temperature of the water. This prevents extra thermal losses due the high temperature.

IV. Properties pit thermal energy storage



Figure B.1: *Dimensions energy storage. (by Auhtor)*

Storage 1:
Top surface: 120m x 14m
Bottom surface: 115m x 9m
Height : 6,5m
Volume: 8740m^3

Storage 2:
Top surface: 75m x 70m
Bottom surface: 18m x 13m
Height: 6,5m
Volume: 7298 m^3

The total top surfaces (U_t = 0,059 W/m2*K) combined are : 3030 m^2
The total bottom surfaces (U_b = 0,061 W/m2*K) combined are : 1945 m^2
The total lateral surfaces (U_l = 0,058 W/m2*K) combined are : 3022 m^2
The total volume of both storages combined is : 16.038 m^3



Impression visual/spatial impact C.4 configuration.

ASSESSMENT 6

The following categories of quantitative indicators are assessed:

Energy assessment indicators:

(E1) Fraction of self-sufficiency:
Percentage of the heat demand after feasible renovations, that was produced inside the selected urban blocks. Secondly it provides an analysis of the energy losses of the energy system.

(E2) Renewable produced energy/m^2 of surfaces used for energy production
kWh renewable produced energy divided by the used ground floor & roof surfaces. This indicator is further specified for private areas and public areas. The renewable produced heat will include all systems for energy production, storage & distribution.

(E3) Used roof area
The thermal heat production potential on roofs will be divided by the used roof surface. This will provide information that could be used to analyse how to use the roof surfaces available as optimal as possible.

(E4) Surface energy intensity production and demand:
This indicator will analyse if the heat demand of the buildings can be produced in the private areas (ground floor & roof) of the buildings, that cause the the heat demand.

(E5) Volumetric compactness
The energy storage tanks and additional technologies will have a large volume intake. This will be assessed and provide comparisons of the different techniques for energy storage. Secondly the volume intake of the energy storage tanks will be used, in combination with the contact surfaces to the public space of the storage tanks, to calculate the volumetric compactness of the energy storage and its influence on the public space in the selected urban blocks.

Spatial assessment indicators:

(S1) Public areas use ratio
This assessment indicator will analyse the percentage of the available public space used for the integration of a renewable energy system that are visible to the eye.

(S2) Land use diversity
This indicators will compare the land use diversity of the configurations with the current land use diversity in the selected urban blocks.

6.1 Quantitative assessment results

All the results are calculated with Excel or Autocad based on the 10 configurations.

Energy assessment indicators		***Configurations***											
E1.1 Energy losses caused by the energy system	*Units*	**A.1**	**Result**	**A.2**	**Result**	**A.2 EXTRA**	**Result**	**B.1**	**Result**	**B.2**	**Result**	**B.3**	**Result**
			%		%		%		%		%		%
Thermal heat produced inside the UB	kWh	2541592	185	4656988	339	2419152	176	2693481	196	1694883	123	2152518	157
Heat demand of the buildings after feasible renovations	kWh	1374734		1374734		1374734		1374734		1374734		1374734	
E1.2 Fraction of self-sufficiency:	*Units*		%		%		%		%		%		%
Thermal heat provided to the buildings	kWh	1374734	100	988538	72	1374734	100	1374734	100	1374734	100	1374734	100
Heat demand of the buildings	kWh	1374734		1374734		1374734		1374734		1374734		1374734	
E2.1 Renewable produced energy/m² used private areas	*Units*												
Thermal heat provided to the buildings	kWh	1374734	156	988538	90	1374734	183	1374734	206	1374734	135	1374734	142
Privately owned areas used	m²	8824		10953		7511		6664		10202		9651	
E2.2 Renewable produced energy/m² used public areas	*Units*												
Thermal heat provided to the buildings	kWh	1374734	398	988538	192	1374734	365	1374734	330	1374734	1030	1374734	377
Publically owned areas used	m²	3450		5157		3766		4172		1335		3646	
E3.1 Renewable produced energy on roof/Used roof area	*Units*												
Energy production on roofs (elec/heat)	kWh	2541592	288	993809	113	806384	107	2363591	355	1694883	166	2152518	223
Used roof surfaces	m²	8824		8824		7511		6664		10202		9651	
E3.2 Effective used roof area	*Units*		%		%		%		%		%		%
Effective used roof surface for energy production	m²	4845	55	7201	82	5788	77	4462	67	3139	31	3747	39
Used roof surface	m²	8824		8824		7511		6664		10202		9651	
E4.1 Surface energy intensity production and demand:	*Units*			Elec roofs: 993.809 COP: 3,0		Elec: 806.384 COP: 3,0						COP 4,4 (PV/T)	
Energy produced on floor & roof areas households (Elec x COP 3,0 (PV) or 4,4 (PVT))	kWh	2541592	288	2981427	338	2419152	322	2363591	355	1694883	166	2152518	223
Total floor area buildings inside the UB	m²	8824		8824		7511		6664		10202		9651	
E4.2 Surface energy intensity production and demand:	*Units*		% extra		% extra		% extra		% extra		% extra		% extra
Thermal heat provided	kWh/m²	288	144	338	186	322	173	355	201	166	41	223	89
Private areas used	kWh/m²	118		118		118		118		118		118	
E5.1 Volumetric compactnes of the storage	*Units*												
Provided heat demand to the buildings	kWh	1374734	75	988538	51	1374734	72	1374734	75	1374734	195	1374734	73
Volume intake of the energy storage & additional technologies	m³	18262		19210		19210		18262		7034		18850	
E5.2 Volumetric footprint	*Units*												
Volume intake of the energy storage & additional technologies	m³	18262	1826	19210	59	19210	59	18262	1826	7034	5	18850	96
Used area in the public space (no covered parking)	m²	10		324		324		10		1335		196	

Spatial assessment indicators													
S1.1 Public areas used	*Units*	**A.1**	**Result**	**A.2**	**Result**	**A.2 EXTRA**	**Result**	**B.1**	**Result**	**B.2**	**Result**	**B.3**	**Result**
			%		%		%		%		%		%
Public areas used visible integration of a renewable energy system.	m²	10	0,1	3838	37,6	326	3,2	772	7,6	1335	13,1	206	2,0
Public areas in the urban block (currently)	m²	10206		10206		10206		10206		10206		10206	
S2.1 Land use diversity	*Units*		% extra		% extra		% extra		% extra		% extra		% extra
Green areas after implementation new energy network	m²	5648	20	250	-95	5620	20	5648	20	4313	-8	5004	7
Green areas urban block (currently)	m²	4691		4691		4691		4691		4691		4691	
S2.2 Land use diversity	*Units*		% extra		% extra		% extra		% extra		% extra		% extra
Amount of parking spots after new energy network	m²	606	4	534	-8	534	-8	366	-37	388	-33	454	-22
Amount of parking spots in current urban block	m²	582		582		582		582		582		582	

All the results are calculated with Excel or Autocad based on the 10 configuration.

Energy assessment indicators

E1.1 Energy losses caused by the energy system	*Units*	C.1	Result	C.2	Result	C.3	Result	C.4	Result
			%		%		%		%
Thermal heat produced inside the UB	kWh	1590543	116	1836198	134	1590543	116	1574668	115
Heat demand of the buildings after feasible renovations	kWh	1374734		1374734		1374734		1374734	
E1.2 Fraction of self-sufficiency:	*Units*		%		%		%		%
Thermal heat provided to the buildings	kWh	857849	62	1193184	87	1291760	94	1034540	75
Heat demand of the buildings	kWh	1374734		1374734		1374734		1374734	
E2.1 Renewable produced energy/m² used private areas	*Units*								
Thermal heat provided to the buildings	kWh	857849	95	1193184	172	1291760	186	1034540	149
Privately owned areas used	m²	9057		6928		6928		6928	
E2.2 Renewable produced energy/m² used public areas	*Units*								
Thermal heat provided to the buildings	kWh	857849	297	1193184	274	1291760	806	1034540	272
Publically owned areas used	m²	2891		4348		1603		3798	
E3.1 Renewable produced energy on roof/Used roof area	*Units*								
Energy production on roofs (elec/heat)	kWh	1284155	185	529975	76	1284155	185	1340155	193
Used roof surfaces	m²	6928		6928		6928		6928	
E3.2 Effective used roof area	*Units*		%		%		%		%
Effective used roof surface for energy production	m²	2374	34	3644	53	2374	34	2119	31
Used roof surface	m²	6928		6928		6928		6928	
E4.1 Surface energy intensity production and demand:	*Units*			Elec: 529.975 COP: 3,0				COP 4,4 (PV/T)	
Energy produced on floor & roof areas households (Elec x COP 3,0 (PV) or 4,4 (PVT))	kWh	1284155	185	1589925	229	1284155	185	1340155	193
Total floor area buildings inside the UB	m²	6928		6928		6928		6928	
E4.2 Surface energy intensity production and demand:	*Units*		% extra		% extra		% extra		% extra
Thermal heat provided	kWh/m²	185	57	229	94	185	57	193	64
Private areas used	kWh/m²	118		118		118		118	
E5.1 Volumetric compactnes of the storage	*Units*								
Provided heat demand to the buildings	kWh	857849	61	1193184	62	1291760	193	1034540	62
Volume intake of the energy storage & additional technologies	m³	14091		19210		6710		16626	
E5.2 Volumetric footprint	*Units*								
Volume intake of the energy storage & additional technologies	m³	14091	1409	19210	59	19210	17	19210	98
Used area in the public space (no covered parking)	m²	10		324		1118		196	

Spatial assessment indicators

S1.1 Public areas used	*Units*	C.1	Result	C.2	Result	C.3	Result	C.4	Result
			%		%		%		%
Public areas used visible integration of a renewable energy system.	m²	583	5,7	898	8,8	1603	15,7	768	7,5
Public areas in the urban block (currently)	m²	10206		10206		10206		10206	
S2.1 Land use diversity	*Units*		% extra		% extra		% extra		% extra
Green areas after implementation new energy network	m²	5731	22	5620	20	4960	6	5726	22
Green areas urban block (currently)	m²	4691		4691		4691		4691	
S2.2 Land use diversity	*Units*		% extra		% extra		% extra		% extra
Amount of parking spots after new energy network	m²	582	0	582	0	582	0	582	0
Amount of parking spots in current urban block	m²	582		582		582		582	

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler

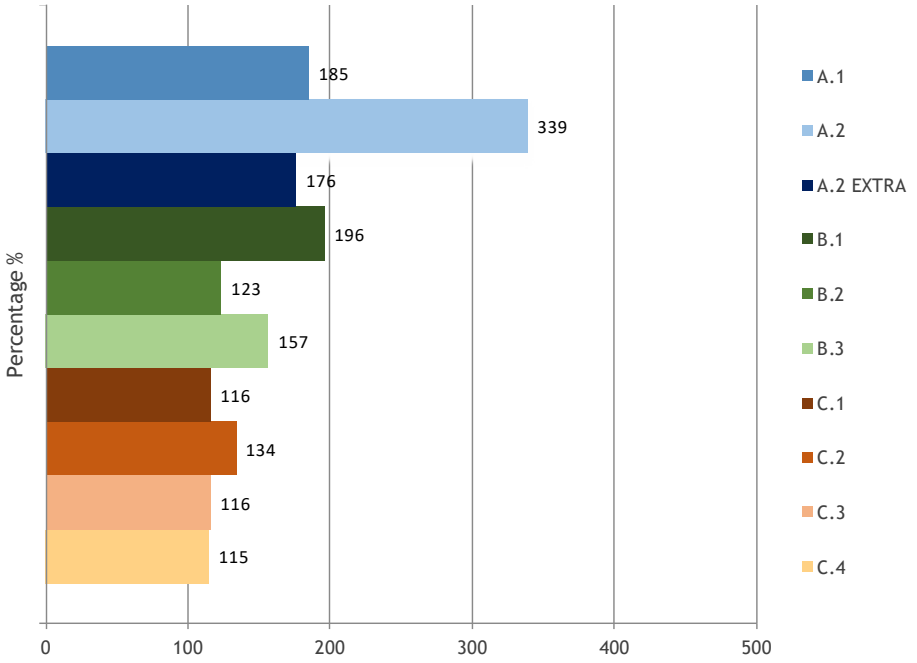
6.2 Comparison & findings

Sub research question: (Q6) How do the energy systems, including spatial integration, perform on the defined indicators?

6.2.1 Results energy assessment indicators:

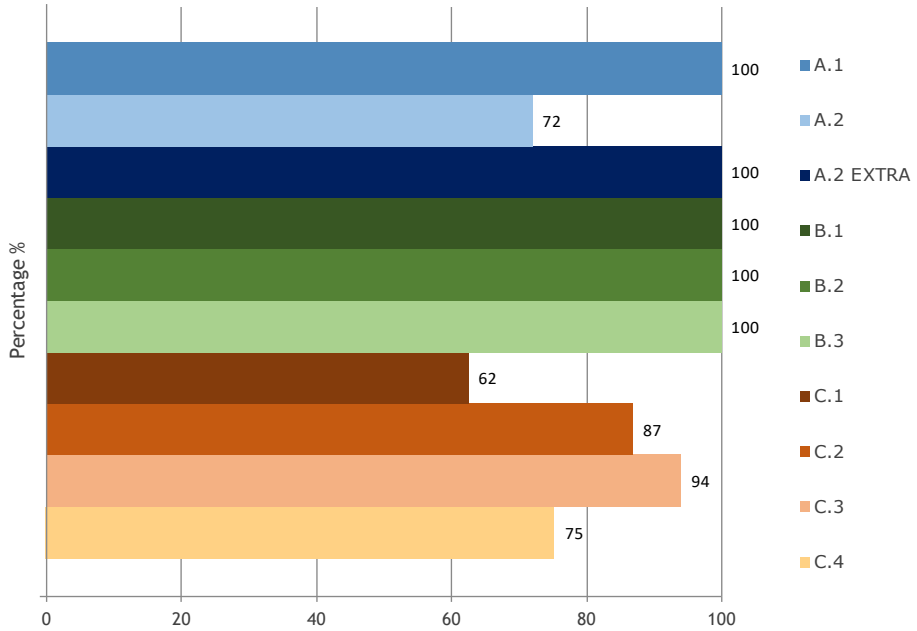
E1.2. Energy losses caused by the energy system

$$\frac{\text{Thermal heat produced inside the UB}}{\text{Heat demand of the households in the UB after feasible renovations}} \times 100\%$$



E1.2 Fraction of self-sufficiency:

$$\frac{\text{Thermal heat produced in UB after energy storage cycle \& distribution}}{\text{Heat demand of the households in UB after feasible renovations}} \times 100\%$$



Comparing the amount of produced thermal heat with the thermal heat demand of the 10 configuration results, there is one result that clearly stands out in a negative way. The configuration (A.2) making use of PV panels, heat pump & aquifer storage produces much more thermal heat inside the selected urban blocks compared to the other configurations which is lost in the systems. The reason for this is the necessary surplus of extra produced thermal heat that needs to be added to the aquifer storage to prevent cooling down the aquifer over the years. In this configuration heat is extracted from the aquifer storage but the aquifer must be regenerated in the summer period. This configuration basically works as an electrical heater. The A.2 (extra) configuration (with the integrated drycoolers to regenerate the aquifer) already performs much better and produces 50% of the A.2 configurations heat. If the annually provided heat demand is included in the assessment the A.2 configuration also stand out negatively. This configuration was also (as in the case of A.1, B.1, B.2 & B.3) supposed to provide 100% of the heat demand but simply does not reach that number.

The C.2 configuration also making use of PV panels and drycoolers provides 87% of the heat demand. An external heat source providing the thermal heat for the heat pump is a necessity to make energy systems using PV panels a successful option. Drycoolers are a technology example that could provide energy generation using an external heat source, in this case the outside air.

There are three specific configuration results that stand out positively. Firstly the B.2 configuration provides 100% of the annual heat demand to the buildings and only produces a surplus of 23,3 % (123,3-100) extra thermal heat inside the selected urban blocks. This means the latent thermal energy storage prevents large amounts of thermal energy loss. This resulted in a lower amount of m^2 area energy production technologies that needs to be integrated in the selected urban blocks. This is financially and spatially beneficial for integration of a new energy system.

The results of configuration C.4 making use of PVT panels and a large scale heat pump are positive. This configuration has the lowest thermal losses over the year compared, visisble in the 15% extra (15-100). Combining the PVT output (electricity & thermal) with a heat pump is a super effective way of producing thermal heat for buildings without losing to much energy during the process and overproducing too much energy.

Of the four configurations (C) aiming for minor visual & spatial impact C.4 provides the largest amount of thermal heat (94 %). Latent thermal energy storage prevents large amounts of thermal losses resulting in a super effective way of using a large share of the produced energy after a seasonal storage cycle.

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

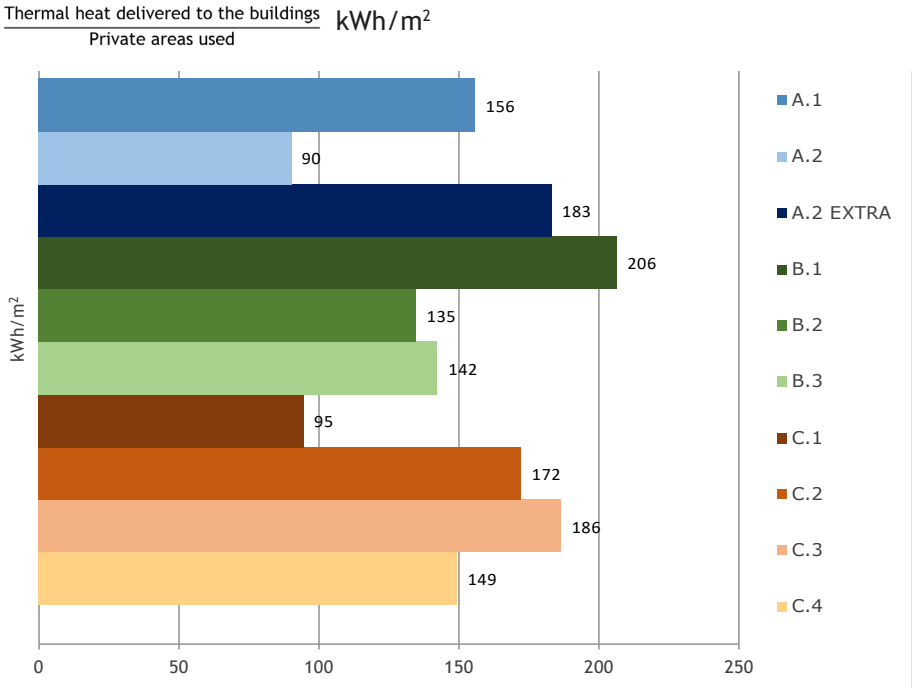
FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler

(E2) Renewable produced energy/m² of surfaces used for energy production: This indicator analyses 'spatial efficiency' of the total system. How much heat is actually delivered for divided by the m² used private or public areas. The higher this value the better because the areas are used more optimal.

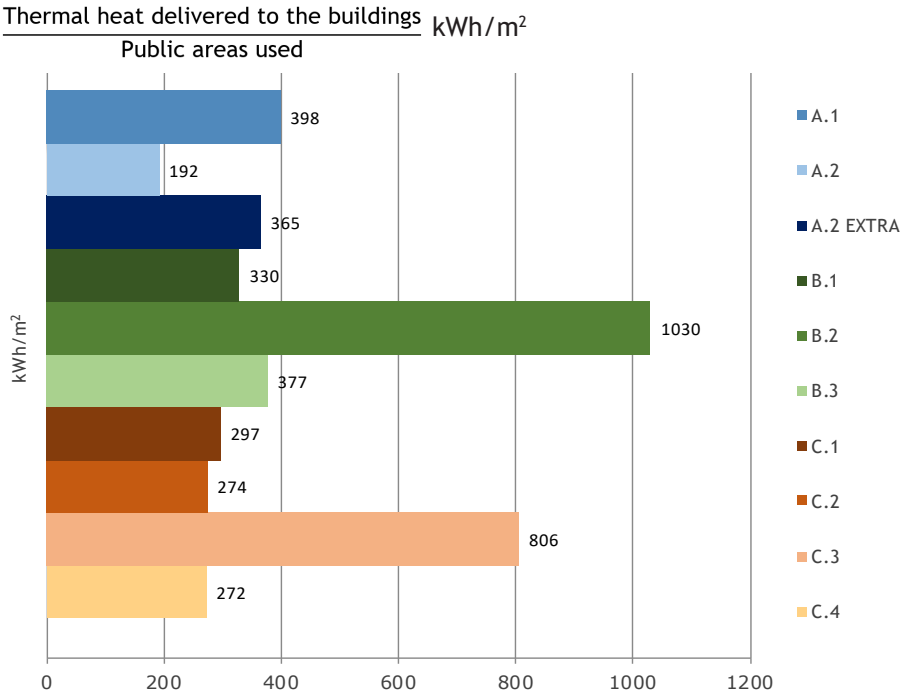
E2.1 Renewable delivered energy/ m² private used areas

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler



E2.2 Renewable produced & delivered energy/ m² public used areas



Analysing the results about the amount of provided heat demand divided by the used m² private areas for the new energy systems, the B.1 configuration stands out the most. This configuration provides the highest heat demand per square meter private area used (206 kWh/m²). The A.2 configuration making use of PV is scoring the lowest due to the fact that it only produces electricity (which is much less than thermal heat) on the private space, which is mostly used roof potential.

The configurations (A.1 & B.1) producing heat with solar collectors and use a pit storage, need to produce more heat to supply the same heat demand, and thus use more m^2 of private area to provide 100% of the heat demand. This is caused by the larger thermal losses that occur in systems that only use and produce thermal heat and don't include a heat pump.

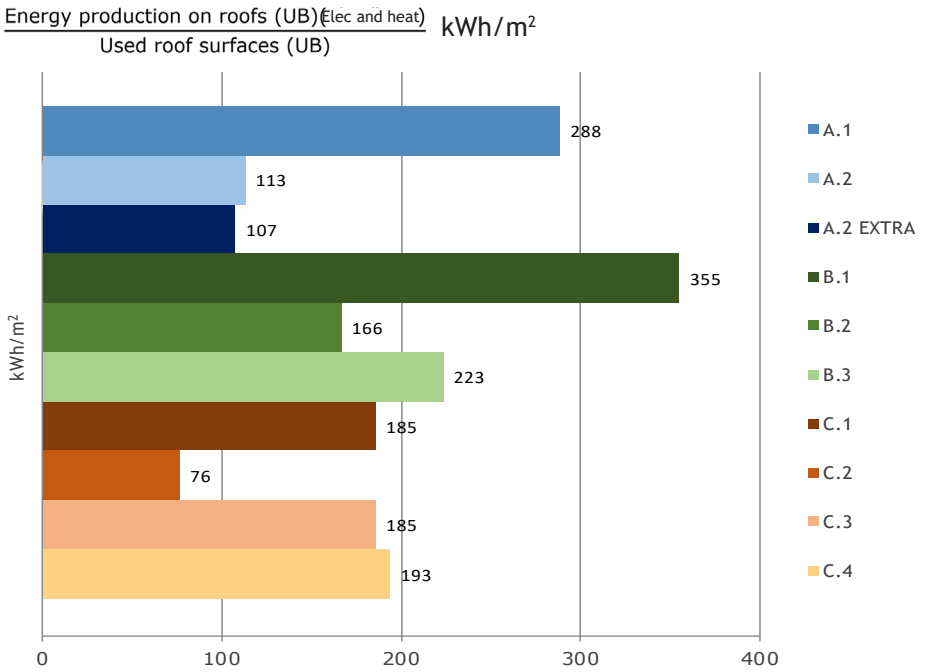
The C.4 configuration using PVT collectors is scoring higher (149 kWh/m^2) compared to the C.1 configuration using flat plate collectors (95 kWh/m^2), while they both aim for minor spatial impact and don't use 25% of the buildings for energy production. This could be caused by the fact PVT produces thermal heat & electricity and the heat pump combines both making the energy output larger than the output of solar collectors.

The effective method of latent thermal energy storage reducing the thermal losses, causes that the C.3 configuration performs best if it comes to provided heat demand per square meter used private space (188 kWh/m^2).

The assessment results about the amount of provided thermal heat to the buildings is divided by the used m^2 public area. Visible is the B.2 configuration scoring much higher compared to the other configuration results (1030 kWh/m^2). The C.3 configuration is scoring the best of the configurations aiming for minor visual impact (806 kWh/m^2). Based on these two results, we can conclude the latent thermal energy storage is advantageous in compact areas and provides a large heat demand.

(E3) Used roof area:

E3.1 Renewable produced energy on roof/Used roof area



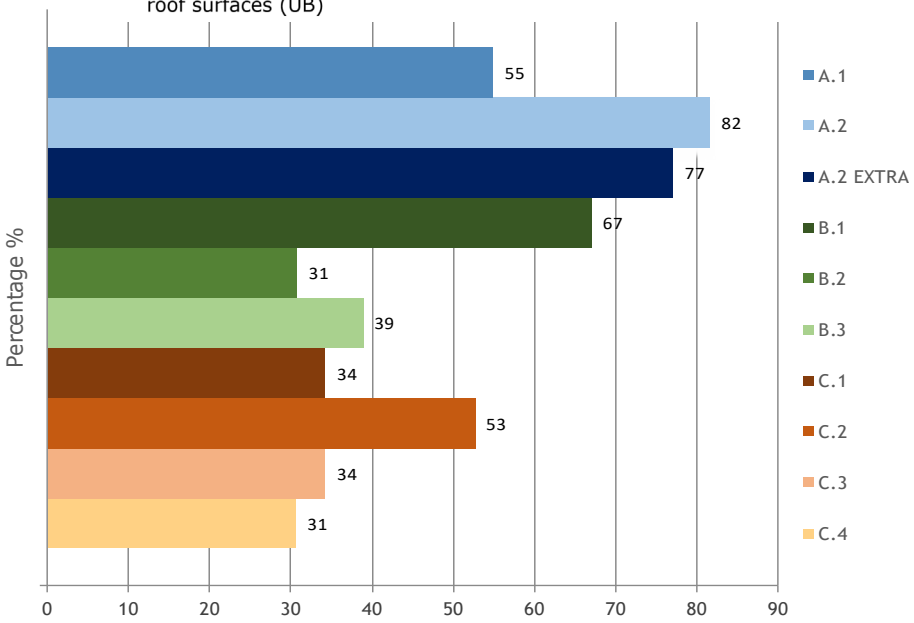
The amount of energy produced on the roof per square meter is calculated by dividing the amount of kWh produced by the used roof surfaces of the buildings on which technologies are placed. The A.1 & B.1 configuration aiming for 100% gas replacement and making use of flat plate collectors score the highest results. The commonly used placement of energy production technologies using the maximum available roof surface for energy production in these configuration, leads to a high amount of produced kWh/m2 used roof surface. These configurations are making use of much more placed panels on the used roofs causing this result. The configurations making use of PV (A.2, A.2 extra & C.2) produce electricity on the roofs which is transformed, in a heat pump placed in public space, to thermal heat.

E3.2 Percentage of roof area used for renewable energy production

$$\frac{\text{Used roof surface for energy production (UB)}}{\text{roof surfaces (UB)}} \times 100\%$$

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler



The effective used roof (amount of panels multiplied with the size of the panels) divided by the total amount of roof surface results in the interesting fact that PV panels are making more effective use of the roof due to their smaller size (A.2, A.2 extra & C.2 score highest in the configuration class A & C).

Because the C configurations are making use of the roof set up aiming for minor visual impact, they are not making optimal use of the roof surface for energy production. This might seem a bad characteristic but the visual impact of these configurations is much lower compared to the A & B configurations. In the C configurations one row of panels placed on one side of the roof is mostly used.

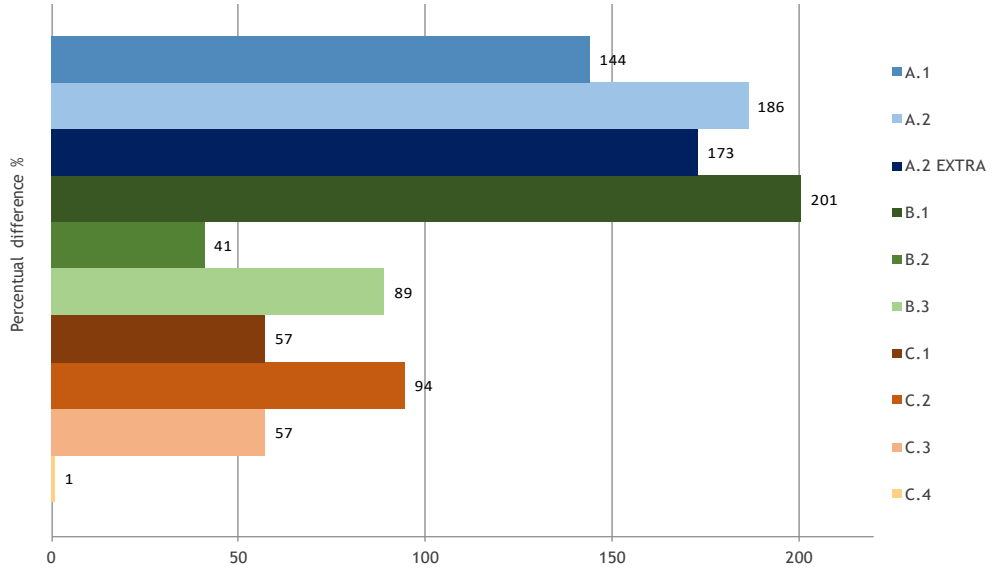
Interesting is the higher effective use of the roof surface of the B.1 configuration compared to the A.1 configuration. Both configurations replace 100% gas and use flat plate collectors. The A.1 configuration uses commonly used placement of the flat plate collectors on the roof while the B.1 configuration is making use of roof refurbishments, resulting in a more effective use of the available roof surface. This proves that optimization of the roof form for energy production, is beneficial for the energy characteristics of a new energy system.

(E4) Surface energy intensity production and demand:
The percentage of difference energy produced per square meter private space in percentages deflecting from the 118 kWh/m^2 yearly average heat demand per square meter of building. Central axis is 118 kWh/m^2.

$$\frac{\text{Energy produced on roof \& floor areas households}}{\text{Roof \& floor areas households used (UB)}} \times 100 - 100$$

118 (D.1)

The heat demand per square meter ground floor of the buildings is annually 118 kWh/m^2. Interesting is if this spatial dimensions of the buildings can effectively be used to produce this heat demand itself. The amount of provided heat demand divided by the used private space is compared to the 118 kwh/m^2 demand of the buildings.
Important: Energy produced of roof/ground floor, not energy delivered to the buildings. If 188 kWh/m^2 can be produced this means the building can produce it's own energy demand if it is directly used or there are no energy losses due to storage or distribution.



The configurations making use of PV panels produce 96% extra thermal heat after the electricity has been converted into thermal heat in a heat pump. This indicates that PV panels integrated on roofs are able to provide more heat per square meter than the heat demand per square meter ground floor caused by the buildings. This is only the case if a heat pump is integrated in the configuration that there is an external heat source.

The B.1 configuration, optimizing roof surface for energy production, produces 201% extra (on top of the 118 kWh/m^2) heat in the used private space and scores the highest. All the other configurations also score higher than the 118 kWh/m^2 and the buildings are therefore able to produce their own thermal heat demand if the new energy systems are integrated in the selected urban blocks. If the produced energy could be stored without any energy losses all configurations would be able to produce and provide the heat demand in the same space that causes the heat demand.

The B.2 configuration using latent thermal energy storage provides 100% of the heat demand and only produces 41% extra heat per square meter used private area. This illustrates the effectiveness of latent thermal energy storage. This is also visible in the result of the C.3 configuration, producing 57% extra heat, providing 94% of the total heat demand of the buildings. The C configurations only make use of 75% of the buildings and therefor don't replace 100% of the heat demand.

(E5) Volumetric compactness of storage

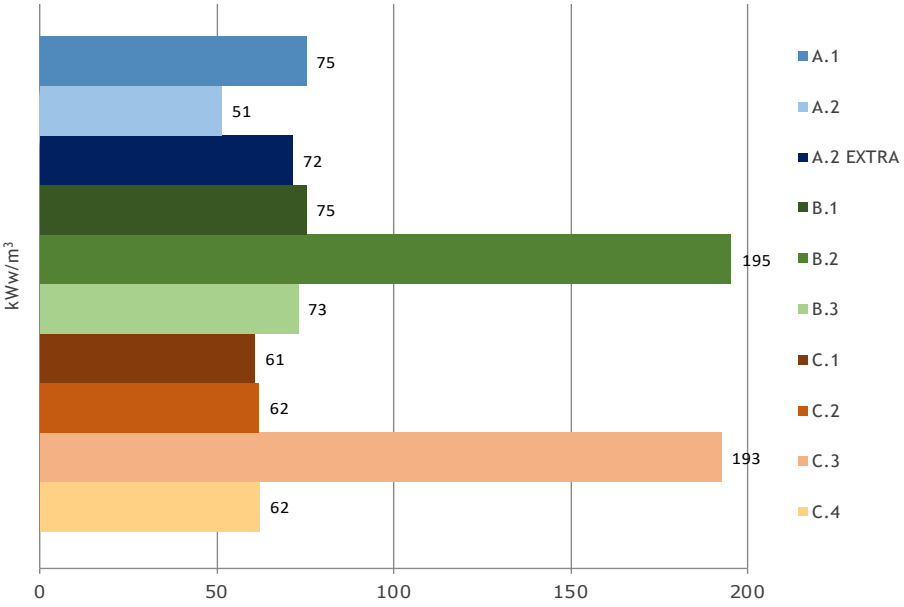
As expected, the latent thermal energy storages (B.2 & C.3) have the highest storage densities because they deliver the highest heat demand per cubical meter used volume for energy storage, as visible in figure E5.1 The larger the sensible pit storages (A.1 & B.1) the higher the delivered heat demand per m^3 used storage. As discussed earlier, this is caused by the lower amount of thermal losses/m^3 because the surface/volume ratio is more positive for large storage systems.

E5.1 Provided heat demand/volume intake energy storage & additional technologies

$$\frac{\text{Provided heat demand to the households (UB)}}{\text{Volume intake of the energy storage \& additional technologies (UB)}} \quad \text{kWh/m}^3$$

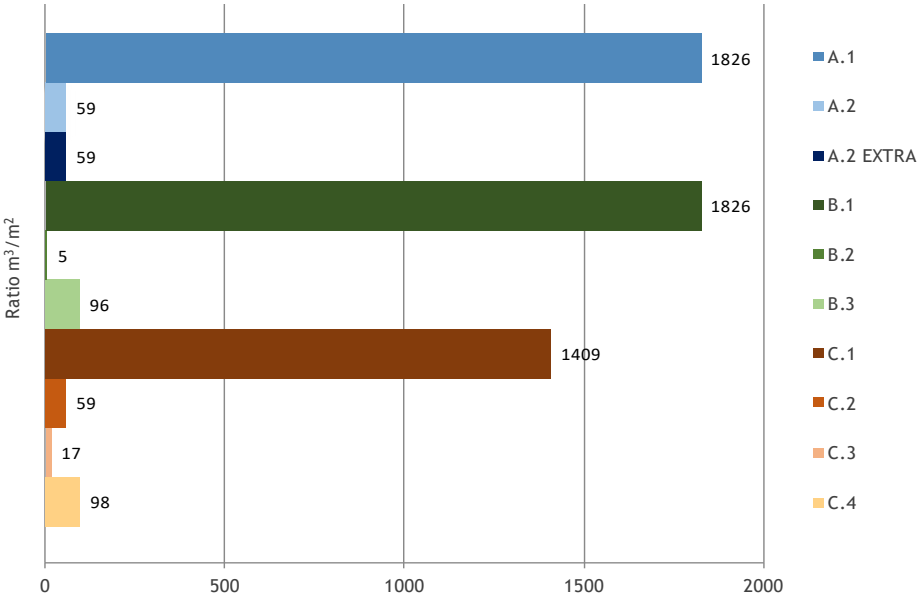
(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler



E5.2 Volume intake/used area in the public space
(Technologies placed underground are not included)

$$\frac{\text{Volume intake of the energy storage \& additional technologies (UB)}}{\text{Area intake in the public space (UB)}} \quad m^3/m^2$$



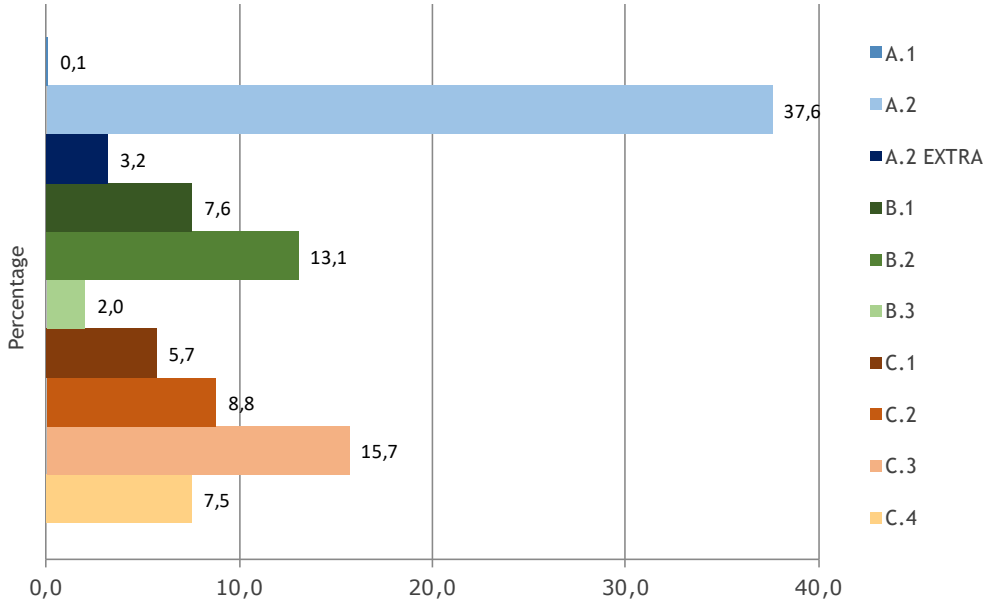
If the spatial footprints on the public space of the energy storages are included, it becomes clear that the configurations that only use pit thermal energy storages (A.1, B.1 & C.1) improved the performance. This is due to the fact that the pit thermal energy storages can be fully placed underground (besides their technical rooms). This is beneficial for the public space because the ground above can be used for other purposes. A small spatial footprint is assumed for the technical rooms. For the aquifer storage the estimated volume of the technical rooms is also included in the calculation.

The latent thermal energy storage systems will be placed partly above ground. The technology of this storage method is much more complex and engineers should be able to reach all parts of the storage volume in case of a failure. Secondly the environment impact of latent thermal energy storage substances is much higher compared to water and therefor advised to not be fully placed underground to prevent leakage of hazardous substances in the environment.

6.2.2 Results spatial assessment indicators:

(S1) Percentage of the available public space used for visible integration of a renewable energy system.

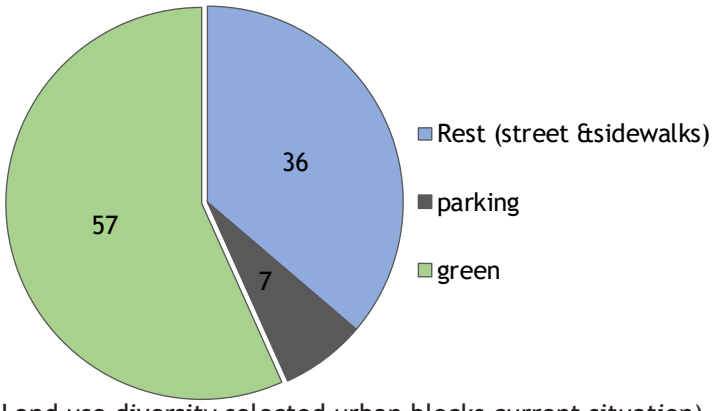
Public area in the urban block (currently): 10.206 m^2.



The B.2 & C.3 configurations stand out negatively because the percentage of public used areas is higher in comparison to the other configuration results. This is caused by the fact that the latent thermal energy storages have a small spatial footprint on the public space compared to the sensible thermal pit storages, that are placed underground. The A.2 configuration resulted in the highest percentage public areas used because a solar field is placed in the public space. The C configurations and B.1 are making use of energy production integrated in the covered parking, resulting in extra used public areas for the new energy system.

(S2) Land use diversity

The current diversity in land use of the central corridor of the selected urban blocks in percentages is as follows. The integration of a new energy system results in rearranging the spatial land division of the selected urban blocks.



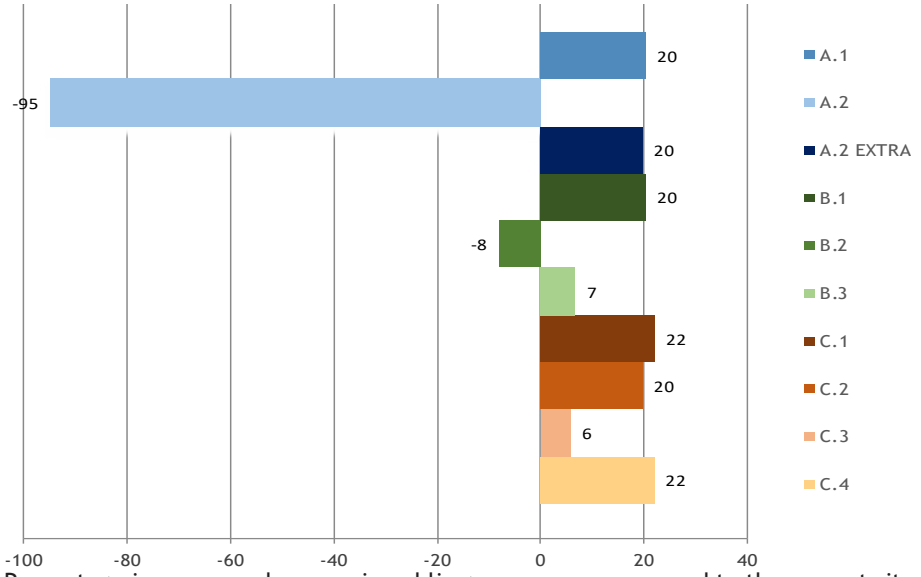
(Land use diversity selected urban blocks current situation)

Especially the green corridor in the center of the public space of the selected urban blocks is influenced by the developed new energy system. Most configuration proposals result in a small increase of the green space of 20%. This is caused by the rearranging of the public space if a new energy system is integrated. The configurations making use of heat pumps and aquifer storages, lose a small amount of extra space for these building volumes.

The configurations using latent thermal energy storage score negatively due to the placement of these tanks above ground. As visible in S.2.1 the B.2 & C.3 configurations score lower compared to the configurations with exception from A.2. Only the A.2 configuration that uses the public space as a solar field has a negative performance because the green space is reduced with 95%. The placement of a solar field in the total area of the public space causes this result. As earlier discussed the heat must be powered with an external heat source otherwise the PV scenarios will be over dimensioned.

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

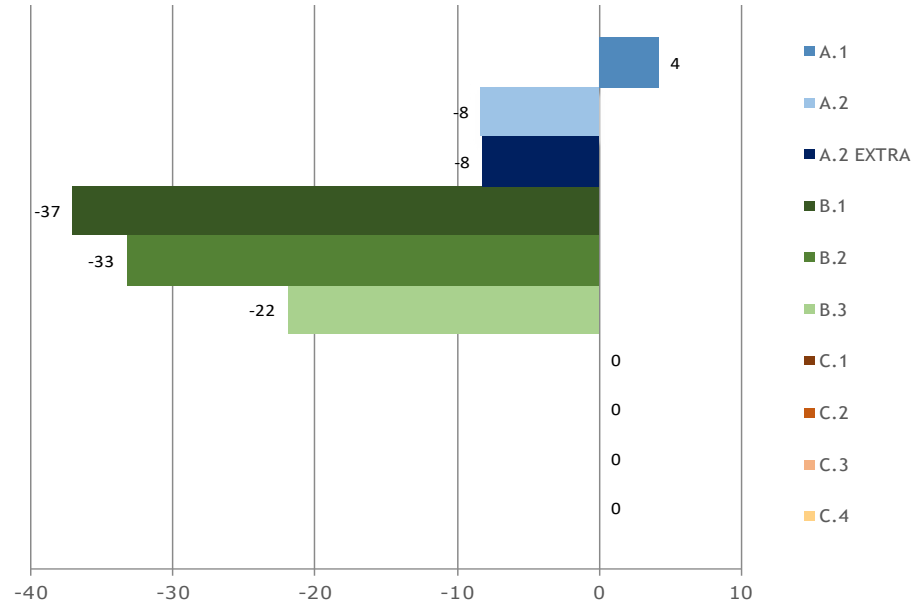
FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler



Percentage increase or decrease in public green areas, compared to the current situation

S2.1 Green areas

Currently cars are parked next to the road in the selected urban blocks. Making roads smaller and integrate parking in the central corridor is a more efficient way to use the availble public areas. According to a small pilot group of inhabitants, the amount of parking spaces must stay the same. Combining these parking spaces with covered roofs integrated with energy producing technologies, as done in configurations C, seems beneficial for the new energy systems and possibly also for the demands of the inhabitants although this must be tested.



Percentage increase or decrease in public parking areas, compared to the current situation

S2.2 Parking areas

6.2.3 Findings

The best performing energy system, providing 100% of the heat demand, that could be integrated in the selected area of urban blocks in Ramplaankwartier, is the B.1 configuration. Based on only the results of the quantifiable indicators. This configuration uses the optimal spatial properties of the selected urban blocks & buildings to produce thermal heat using flat plate collectors. Energy is stored in a pit thermal energy storage that has minimal influences on the visual impact & usability of the public space because it may be placed underground entirely. The A.1 and B.1 configuration are comparable, but the B.1 configuration makes more optimal use of the available roof surface, resulting in the highest energy production per square meter used private space.

The configuration A.2, not using drycoolers, appears to perform the lowest according to the spatial assessment indicators. Hardly any public space would be left if a solar field is placed in the public space and this energy solution not even reaches 100% gas replacement. This is an unrealistic solution not foun anywhere in the world. The A.2 extra configuration, using integrated drycoolers, performs much better because the solar field in the public space is not necessary anymore. This configuration produces the second highest amount of kwh/m^2 used private area (B.1 is the highest). Integration of a heat pump + drycoolers + aquifer storage is necessary to reach self sufficiency with this system. On the other hand, this configuration only uses 70 out of 85 of the typology 1 buildings for energy production with the integration of all these additional technologies.

The B.2 configuration, using latent thermal energy storage, performs better on the energy indicators about storage compactness. of the new energy systems. However, the spatial impact of this system is higher compared to the energy solutions using pit energy storages.

The B.3 configuration using PVT panels to produce energy, scores similar on the energy indicators compared to the B.1 configuration. The necessary large scale heat pump that needs to be integrated in this configuration is a big disadvantage. These systems can't be placed underground and will have a negative influence on the visual appearance of the public space and will spatially divide the green corridor in two parts.

Of the C configurations aiming for minor spatial/visual impact, the C.3 configuration performs the most positive on the used indicators, immediately followed by the C.2 configuration. The C.3 configuration uses latent thermal energy storage which hardly causes thermal losses and drastically reduces the area necessary for energy production. This is beneficial for energy systems aiming for minor spatial/visual impact. Due to the size of the monocrystalline PV panels, the C.2 configuration is able to place a double row of panels above the dormers of the buildings. This resulted in extra energy production panels, which results in 87% gas replacement while using 3644 m^2 of placed panels.

The C.4 configuration scores best on the energy production characteristics because of its efficiency of produced heat that is actually delivered to the buildings. This is due to the production of electricity and thermal heat in PVT panels at the same time. The electricity and thermal heat are combined using a heat pump, this create a high heat output provided to the buildings. C.4 delivers 75% of the heat demand while 2119 m^2 of PVT panels is used to produce this energy. A large scale heat pump will be integrated in this configuration, which has more negative spatial impact, compared to the C.1 configuration, due to the higher percentage used public area. Due to this large scale heat pump the volume & size of the pit thermal energy is reduced significantly which is really beneficial for the environmental impact, due to a smaller volume of storage that is placed underground.

6.3 Perceptual assessment results

(drycooler were not included in the configurations during the assessment by the small group of inhabitants. The spatial impact of C.2 stayed almost the same, only the placement of drycoolers on top of the heat pump was not visible.)

The possible perceptual assessment of the spatial/visual impact of the integration of a new energy system might have on the selected urban blocks, was performed during an information meeting organised for a small pilot group of inhabitants living in Ramplaankwartier. The visualisation results of the 9 configurations (appendix C) were presented to the inhabitants and they were asked to fill in a questionnaire to collect their opinion about the spatial/visual impact. The following three categories were integrated in the visualisations:

(P1) Visual impact of the integration on buildings:
(P2) Visual impact of the transformation of public areas:
(P3) Land use diversity:

		Calculation factor
0-20	Negative	0
20-40	Moderately negative	1
40-60	Neutral	2
60-80	Moderately positive	3
80-100	Positive	4

Figure 6.1: *Scaling & calculation factor.*

The inhabitants were asked to assess the results using the following scale:
- o Negative
- o Moderately negative
- o No opinion
- o Moderately positive
- o Positive

The results are applied in a calculation factor to determine the average result of each configuration. 25 inhabitants filled in the questionnaire resulting in the following results:

	Negative	Moderately negative	Neutral	Moderately positive	Positive	Total score	Result
A.1		1		6	18	91	Positive
A.2	22	3				3	Negative
B.1	2	4	2	15	2	61	Moderately positive
B.2	6	9	3	5	2	38	Moderately negative
B.3	1	1	4	7	12	78	Moderately positive
C.1		2	1	14	8	78	Moderately positive
C.2	3	5	5	10	2	53	Neutral
C.3	5	9	5	6		37	Moderately negative
C.4	3	6	3	11	2	53	Neutral

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler

6.3.1 Outcomes

- The most notable result is the highest rated configuration A.1. The commonly used placement of flat plate collectors on both sides of the roofs is not valued as visually disturbing. The B.1 configuration, using the same technologies, scored lower. B.1 uses covered parking and optimized roofs (buildings orientated south) which is assessed lower compared to the A.1 configuration.

- The A.2 configuration is assessed most negative of all 9 configurations. The energy solution uses almost all of the public space for energy production which is not appreciated by the inhabitants.

- The configurations using latent thermal energy storages (B.2 & C.3) both scored moderately negative. The visibility of these tanks, placed above ground, is a negative characteristic of these energy systems.

- The best assessed configuration aiming for minor spatial impact (C) is the C.1 configuration. The pit storages are placed underground and in the public space only covered parking is used for the new energy system. Because flat plate collectors are used, no additional technologies are placed in the public space as thermal heat is directly produced.

6.4 Summary & Sub conclusion

The relation between energy characteristics and the spatial footprint of a renewable energy system is the focus of this research. A quantitative and a qualitative assessment are used in this research. The perceptual assessment focusses on the spatial impact of integration of a new energy system. The quantifiable assessment mainly focusses on the energy characteristics and partly on the spatial impact. The indicators shown in figure 6.2, are considered the most important indicators that summarizes the important aspects of theenergy systems. The final percentage replaced heat demand and the m^2 production panels used, provides an overview on the energy characteristics of the energy system. The percentage visible public space used and the perceptual analysis of the inhabitants, provides an overview on the spatial impact the integration of this energy system causes.

Figure 6.2: *Assessment results.*

Config.	Quantifiable assessment			Perceptual assessment (inhabitants)
	Percentage delivered heat demand buildings	m^2 of solar panels used	Percentage public areas used	
A.1	100	4845	0,1	Positive
A.2	72	7201	37,6	Negative
A.2 extra	100	5788	3,2	-
B.1	100	4462	7,6	Moderately positive
B.2	100	3139	13,1	Moderately negative
B.3	100	3747	2,0	Moderately positive
C.1	62	2374	5,7	Moderately positive
C.2	87	3644	8,8	Neutral
C.3	94	2374	15,7	Moderately negative
C.4	75	2119	7,5	Neutral

(A) 100% gas replacement using the commonly used placement of panels on roofs.

(B) 100% gas replacement using the analysis results of chapter 4.

(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

(A.1) FP + PTES(water)
(A.2) MPV + PTES(water) + HP
(A.2E) MPV + PTES(water) + HP + DC
(B.1) FP + PTES(water)
(B.2) FP + LTES(salt)
(B.3) PVT + PTES(water) + HP
(C.1) FP + PTES(water)
(C.2) MPV + PTES(water) + HP +DC
(C.3) FP + LTES(salt)
(C.4) PVT + PTES(water) + HP

FP = flat plate collector
MPV = monocrystalline PV
PVT = photovoltaic + solar collector
PTES= pit thermal energy storage
LTES = latent therma energy storage
HP = heat pump
DC = drycooler

The best solution is not determined by the energy system with the best energy characteristics or the best spatial properties separately. Integration of both research fields is necessary to provide insights in the energetic performance of energy systems, wheter these systems are accepted by inhabitants, if integrated in their living environment.

6.4.1 Solutions that are 100% self-sufficient for heating

Based on the opinion of the inhabitants the A.1 configuration is the most desirable option for an energy transition in the selected urban blocks. The public space used for the integration of the new energy systems is only 0,1% because all systems are placed underground (not the technical room). All 4845 of m^2 energy production panels are integrated on the roofs of the buildings. Compared to configurations B & C much more panels are used to produce energy. The C.1 config. replaces 62 % of the heat demand and only uses 2374 m^2 panels (49% of the 4845 m^2). The A.1 configuration uses the production panels and the available spatial characteristics to produce energy suboptimally, which is a negative aspect of this configuration.

Occupation of public space with additional built volumes (for technical systems such as heat pumps) or energy production technologies (solar field), resulted in a negative assessment. This is visible in the results of B.2 & C.3 results using latent thermal energy storage tanks. Although this technology improves the efficiency of the energy system, due to a more efficient energy storage cycle (C.3 uses 2374 m^2 panels and replaces 94% of the heat demand), the opposition against these tanks is likely to be large because their amount of used public space is high.

Configuration A.2 using PV panels, including a solar field in public space, is assessed the most negative by the inhabitants. Integration of drycoolers resolves this problem but these drycoolers will cause a noise pollution of 45-48 dB. Besides drycoolers, the integration of an aquifer storage and a large scale heat pump is required, leading to extra buildings placed in public space.

Most positive solution
Configuration B.3 is the best option if 100% of the heat demand will be delivered to the selected urban blocks. First of all, the inhabitants reacted moderately positive on the spatial impact that this energy system would have. With the use of a heat pump, configuration B.3 uses only 2% of the public space. This configuration uses 3747 m^2 PVT panels in combination with a heat pump. PVT en and a heat pump combined, energetically optimizes the energy system resulting in lower amount of m^2 used production panels.

6.4.2 Minor visual/spatial impact
The C.2 & C.3 configurations deliver the highest amounts of the heat demand out of the four C configurations. As earlier discussed the latent thermal energy storage in C.3, was not appreciated by the inhabitants although only two latent thermal energy storage tanks are used in this energy solution. C.2 is appreciated equally compared to C.4 by the inhabitants and replaces an additional 8% of the heat demand (fig 6.2: 87-75).

In config C.2 all the additional technologies necessary, aquifer storage, drycoolers and 1525 m^2 (3644-2119) of extra m^2 production panels, make the energy characteristics of this configuration disadvantageous. These technologies are necessary because the focus of this research is a self-sufficient energy system. The aquifer storage is necessary to provide the thermal input for the heat pump. The drycoolers are needed to regenerate this aquifer storage in the summer periods.

Most positive solution
The possible options are therefore either C.1 or C.4. The energy characteristics are more advantageous in the C.4 configuration because of the higher percentage delivered heat demand in combination with a lower used m^2 area of production panels. On the other hand, the C.1 configuration does not include a large scale heat pump and is therefore spatially assessed as a better option by the inhabitants. Based on the differences between the results of both configurations, there is no decisive conclusion which of the two is more optimal. External criteria, not involved in this research, will have a determining role in deciding which energy systems is best.

7 CONCLUSION

7.1 Research result

The goal of this research was to investigate the relation between the integration of a renewable self-sufficient energy system for space heating and its related spatial impact after integration in selected urban blocks in Ramplaankwartier. Due to the ambition of energy self-sufficiency, the investigated solutions not only consider solar energy production but also thermal energy storage. It does not pretend to be complete or fully correct on all aspects of these energy systems, since many simplifications have been assumed. (for example, using the same mean temperature during the entire summer, while in fact the average temperature in the solar thermal panels will be higher near the end of the summer, since then the pit storage will have heated up and the return temperature will not be 10 degrees.

Energy solutions can be chosen according to the goals of an energy transition project, set by actors involved in these projects. This conclusion is subdivided in three answers, providing solutions for projects with different set goals concerning the amount of gas replacement and the spatial impact. Considering the following arguments: Energy potential, spatial impact, inhabitants acceptance, amount of m^2 used energy production panels & necessary additional technologies, configuration C.4 seems the optimal solution of the investigated solutions.

C.4: PVT + large scale heat pump + pit thermal energy storage.

The C.4 configuration, placing a large scale heat pump in the public space in combination with a underground pit thermal energy storage and PVT panels to produce the thermal heat and electricity, is the best technical solution for a renewable self-sufficient energy system reducing the gas use for space heating. C.4 uses the beneficial spatial characteristic of the selected urban blocks with optimal placement of the PVT panels (south 45 °C), increasing the energy output of these panels. The C.4 configuration has small spatial/visual impact but has a large energy potential resulting in high amount of gas use reduction. A small pilot group of inhabitants also evaluated this integration of a heat pump + PVT as acceptable.

Adaptations for energy transition projects with specific goals:

Purely based on the energy characteristics replacing 100% of the gas use,
the best option would be (combination of configurations C.3 & C.4):

PVT + large scale heat pump + latent thermal energy storage.

Latent thermal energy storage options compared to sensible energy storage options, perform better energetically. This energy storage type reduces thermal losses significantly compared to sensible thermal energy storage. A more efficient storage cycle will result in less amount of m^2 energy production panels placed, which will result in a lower spatial/visual impact. The spatial impact of these latent thermal energy storage tanks, if placed above ground in public space, is significantly more negatively. These tanks use public space which is negative assessed by the pilot group of inhabitants.

If spatial/visual impact in the public space of an energy transition project is not accepted or there is an aim for zero spatial/visual impact of stakeholders, then the B.1 or C.1 configurations (without covered parking) are the best solutions:

Flat-plate collectors + pit thermal energy storage (underground)

In these solutions there is no negative impact on the public space because the pit thermal energy storages are placed underground. Based on the desired spatial/visual impact of energy production panels integrated on roofs (private space), a choice

can be made between the B.1 or C.1 configuration. B.1 aims for optimizing roofs for energy production while C.1 aims for minor visual impact of energy production panels integrated on roofs.

This research aimed for supplying a self-sufficient energy system. Self-sufficiency is a solution for neighbourhoods that can't rely on the connection to an external energy grid. Such a connection would reduce the dimensioning of the energy systems because energetically the energy systems would be supported by external energy resources, energy storage solutions (reducing energy losses) and smart grids optimizing energy potential and energy demand.

Side notes:
The configurations making use of PV panels came out most negative in this research as a result of aiming for self-sufficiency. The absence of an available heat source that can be used without regeneration, causes this problem. The drycoolers integrated in these configuration provides a more realistic option but causes noise pollution. The PV configuration may become a more realistic option if the noise pollution is reduced or causing no bother to local resident. Using the aquifer storage in combination with the heat pump to deliver the heat demand to the buildings directly, is a better solution. The aquifer storage can be regenerated by the return temperature of the water used for space heating. This prevents the use of drycoolers and thermal energy storage in the energy system. This option is not included in the research because it is not self-sufficient. If in periods without sunshine heat is stored in an aquifer storage, no electricity is produced to power the heat pump. A thermal energy storage is necessary to provide the heat demand in these periods without sunshine, to guarantee self-sufficiency.

The latent thermal energy storage is scoring much higher, compared to sensible energy storage, on the energy assessment indicators used in this research because of its high storage capacity. These systems are currently being developed and brought to the market, making this a possible choice for projects executed in the coming years. Secondly the storage materials have a large negative influence on the environment in case of a failure. Future development and options for placement underground might in the future lead to the choice that latent thermal energy storage is a decisive better option compared to sensible thermal energy storage

Future developments of energy production and storage technologies may lead to more efficient energy production and storage cycle. If these technologies improve, the current aim to replace 100% of the gas is not even necessary. Technical updates of the energy systems overtime may increase the energy output of the energy system. Replacing solar panels after their life span with improved solar panels could improve the energy potential of the energy system. Aiming for a smaller sized energy systems, not replacing 100% the gas use, could in the future reach the 100% gas replacement with the same dimensioning.

Not aiming for self-sufficiency but partly using external energy could be beneficial for the energy performance and dimensioning of the energy system. This external energy could be more constantly available and not be seasonally depending, resulting in smaller energy storage volumes necessary for the energy system.

Additional conclusions on the used technologies:
A large selection of the available technologies for energy production, energy storage and distribution are summarized in the literature study of this report. It indicates a large number of technology options that are available for energy transition projects. Quickly scanning the technologies on their usability demands, resulted in the demarcation of the research by only using solar energy production technologies and thermal energy storage. After spatially analysing the selected urban blocks, the selected technologies were analysed further by integrating the spatial analysis with the properties of the selected technologies. Based on the dimensions of the

buildings, energy potentials were calculated for different orientation directions and roof angles. Resulting in the following conclusions:

- Monocrystalline PV makes the most effective use of the roof surface due the low difference between the gross and aperture area of these panels. This may result in an extra row of panels that can be placed on a roof. Furthermore the weight of PV panels is lower compared to solar collectors. This may be a decisive factor, if the roof construction is not strong enough to carry the solar collectors.
- Flat plate collectors are the best solar collector type to be integrated in the neighbourhood because they have a higher energy output. This is due to the more advantageous gross/aperture area ratio of flat plate panels. Secondly, these systems are also cheaper and less vulnerable compared to evacuated tube collectors.
- PVT panels are a better option than the photovoltaic & solar collector technologies because of a higher energy potential, especially if combined with a (large scale) heat pump.
- Sensible thermal energy storage can best be executed in the shape of a pit thermal energy storage. The shape of the pit can be adjusted to the shaping of the public space, leading to less spatial impact and a maximal use of the underground volume.
- The storage density of latent thermal energy storage is advantageous compared to sensible thermal energy storage.

Integration of spatial planning
The best energy system for space heating to be spatially integrated in the neighbourhood Ramplaankwartier can't be expressed in only a technical solution. The governance and project management approach used during energy transition projects, is at least as important as the chosen technical solution.

If the only goal of an energy transition project is self-sufficiency and replacement of 100% of the gas use in the neighbourhood, the process approach focusses mostly on the available space and the performance of technologies in the existing spatial context. Spatial characteristics that could be beneficial for the performance & dimensioning of a new energy system are often overlooked and left unused. Coordination of energy-spatial planning is complex in energy transition projects concerning dense builing environments. However, if integrated early in the process, the available spatial characteristics could be turned into an advantageous energy performance of the energy system. An example of this phenomenon is the B.1 configuration, using the roofs orientated South in a more optimal way for energy production, resulting in a lower amount of necessary m^2 of production panels to provide 100% of the heat demand. A spatial analysis of the neighbourhood characteristics can support the identification and understanding of constrains and opportunities, resulting in an integrated and successful transition towards an urban environment not dependable on gas.

The limiting factors are:
- Shadows that negatively influence the energy production potentials of areas.
- Shape and size of buildings & public space that influence the usability of areas/roofs

The advantageous factors are:
- Use of optimal orientated roofs & areas.
- Use the available slopes of roofs.
- Testing different set ups for roofs, researching their spatial impact and energy potential.
- Selecting the best type of energy storage & its storage potential fitting in the available space.

7.2 General guidelines

This research focused on creating a self-sufficient energy system for heating a group of building blocks in a Dutch neighbourhood. Solar energy was used because no external energy source is currently available that can be integrated. Other neighbourhoods in the Netherlands may have an available external energy source that can be integrated in a new energy network. If only a part of the energy demand needs to be produced and stored inside the urban structure of the neighbourhoods, the size of the energy system can be reduced. A smaller size will automatically result in a reduction of the spatial and visual impact of a new energy systems. Therefore the approach used in this research, can be seen as a study for neighbourhoods that have no available energy potential and storage potentials, outside of the neighbourhood.

The following process steps in the process of energy transition are identified in this research:

(1.) A spatial analysis of the selected urban blocks led to defined areas & characteristics inside the selected urban blocks that are advantageous and could be optimized for energy production.
(2.) Analysing which technologies are suitable/usable to be applied in inside the selected urban blocks.
(3.) Calculate & visualize energy (storage) potentials with different spatial impacts by combining the characteristics of the spatial analysis & the properties of the selected technologies.
(4.) Involve inhabitants and analyse their wishes for a new energy systems and its spatial impact
(5.) Formulate goals for the design of the configuration with different levels of spatial/ visual impact and different levels of replaced gas percentages.
(6.) Quantitative & perceptual analysis (with inhabitants) to conclude which technologies should be integrated in which areas of the selected urban blocks.

This approach may be transferable and applied to other energy transition projects in the Netherlands. The spatial characteristics will be different, leading to different results. Other technologies could be more ideal to be integrated. Inhabitants may react different to the spatial impact of proposed energy systems.

The process steps can be used for neighbourhoods that will be partly provided with energy originating from outside. If 50% of the heat demand for a neighbourhood is provided using rest heat from nearby industry, the process steps can be used to provide the other 50%. Solar energy is heavily dependent on energy storage to balance the seasonal differences. An external energy source might have lower seasonal differences, further reducing the size of the new energy system.

7.3 Recommendations future research

- The costs of a new energy system is the most important missing factor in this research. Especially for policy makers, costs are an important characteristic deciding if projects succeed or fail. Therefore the costs of proposed energy solutions must be analysed.
- If in the coming years thermochemical energy storage is developed further and becomes available, this option should be included in feasibility studies researching energy transition projects. With an even higher storage density compared to latent thermal energy storage, this option might be the future solution for dense built environments.
- Research about circular material use for all technologies included in renewable energy systems, should be a future objective that is included in feasibility studies. This will make renewable energy systems replicable for production and create a sustainable solution without being dependent of the availability and scarcity of materials and fossil fuels on Earth.

8 REFLECTION

1. The relationship between research and design.

In this research ten technical configuration are designed for a renewable energy grid providing the heat demand of the buildings for selected urban blocks in the Netherlands. All the ten configurations are set up with different purposes/goals and are making use of different combinations of solar energy production and sensible thermal energy storage. The idea behind this research was not to only investigate what the best performing energy system is based on energy characteristics, but also to include the spatial influence on the existing built environment, the integration of such energy systems would have.

The early integration of spatial planning in energy transition projects was an already identified factor that is important to integrate early on in the process of such projects. But what the exact influence is on the energy characteristics & spatial impact of these energy systems was unknown territory for me. Using “design” as the tool to visualize the research results of different energy solutions, provided visualisations that could be compared to research the difference in spatial impact. This comparison added an extra dimension to the research that enables the possibility to perform an perceptual analysis. This perceptual analysis provides a different view on energy transition projects and their spatial integration in existing urban structures because it is based on the opinion of inhabitants. Personally I consider “design” the important method that integrates perception and numerical characteristics of energy solutions, resulting in a more in-depth analysis of the consequences the integration of energy solutions would have. I personally think these types of research, in the long term, could improve the project & process management of energy transition projects.

2. The relationship between the theme of the graduation lab and the subject/ case study.

Sustainable design is the theme of the Building technology graduation lab. Throughout the master programme sustainability played an important role in constructive, façade & climatological design projects. In almost all projects the scale of the design had the size of a single building. Using an urban scale for an energy transition projectm, I personally consider more interesting for research. Removing large quantities of fossil fuel in a short period of time, will mostly happen by worldwide transitioning large scale urban structures at once. Establishing a bridge of knowledge between urban design and the technical side of an energy transition is for me the most learning full method, providing the best starting position for a career in energy transition projects meeting my ambitions and goals. The used case study Ramplaankwartier in Haarlem provided the chance to integrate an energy transition project in an existing urban structure, that characterizes the typical urban structure of Dutch neighbourhoods.

3. The relationship between the methodical line of approach of the graduation lab and the method.

During the setup of the research outline & planning, the first concrete shaping of the research and the necessary products were documented. This step in the graduation process was the most difficult part in the whole graduation process and took a large share of the total used time for the project. Due to the urban scale, which is partly unknown territory in the BT master program, this inexperience let too a research outline that had to be adapted throughout the research. The demarcation of the research and the set-up of the assessment was different from the methodical approach of the BT master programme. In the BT master programme most research results & demarcations are assessed/set-up using a numerical outline. In this graduation research a numerical method would have been insufficient because a perceptual analysis on the spatial/impact of the urban design is least as important as a numerical analysis. If going back in time was an option, this knowledge at the beginning of the graduation trajectory would have led to a more efficient use of

time. Secondly the quality of the research framework could have been higher, using a more specific demarcation of the project, resulting in a more compact and efficient research. Learning from this process is the most valuable learning experience I could take away from this research.

4. The relationship between the project and the wider social context.

During my graduation project, earthquakes in the province Groningen massively increased the wishes from society, for a reduction in gas use for space heating and the large scale industry using gas. Climate change is worldwide the most heard argument for an energy transition but these concerns of Dutch inhabitants will accelerate the transition from gas to renewables even more in the Netherlands. The Netherlands are already struggling transitioning their energy supply to more sustainable solutions in the short time period that is agreed upon in the Paris agreement. Besides the costs & interest of actors, these transition projects are complex due to the urban structure with limited public areas. This research aimed to reduce the complexity of these projects, by providing new insights about the unavoidable spatial impact of energy solutions, the energy transition will cause.

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Figure 4.8
Sizing solar panels. (Honsberg & Bowden)

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Figure 4.14
Overview solar irradiance transformed into heat energy and the losses occurring. (Allendorf, 2009)

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Heat piping network. Retrieved January 05, 2017, from https://www.uponor.com

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Figure 5.13
Heat pump Bergheim district. (EHPA, 2017)

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Figure 5.13
Pictures drycoolers by Sabine Jansen.

APPENDIX A

Sensible thermal energy storage:

Energy accumulation
The maximum thermal energy the sensible heat storage can accumulate is calculated with the following formula:
$E\ (KJ) = V \cdot \rho \cdot c_p \cdot (T_{max} - T_{min})$
V = volume in m^3
ρ = density storage material in kg/m^3
*c_p = Specific heat in KJ/kg*K (at constant pressure)*
ΔT = temperature change in the storage tank (K) (Gabriela, 2011)

Example: 1000m^3 storage tank filled with water is raised from 10 °C up to 80 °C.

*E (KJ) = 1000*998*4,192*(80-10) = 292.853.120 KJ = 81.348 kWh (kWh = KJ/3600)*
V = 1000 m^3
ρ = 998 Kg/m^3 (10 °C)
cp = 4,192 KJ/kg°C*
ΔT = 80-10 = 70 °C

Energy losses
Thermal energy storages deal with energy losses overtime due to a temperature difference of the storage medium and the ambient temperature around the tank. Thermal energy losses that occur can be calculated with the following formula:
$Q(watt) = U \cdot A \cdot (T - T_{amb})$
U = heat transfer coefficient in W/m^2*K
U = 1/r (r = thermal resistance)
r = d/λ (d = thickness, λ = thermal conductivity)
A = area in m^2
ΔT = Temperature difference between storage tank temperature and ambient temperature in °C or K (De Guadalfajara, Serra, & Lozano, 2014)

Example: 10x10m wall filled with 80 °C water.
500 mm concrete (λ = 1.63)
500 mm XPS insulation (λ = 0.03)
Ambient temp. 10 °C

$$U = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right) + \left(\frac{d_{ins}}{\lambda_{ins}}\right)} \ (W/m^2*K)$$

$$U = \frac{1}{\left(\frac{0,5}{1,63}\right) + \left(\frac{0,5}{0,03}\right)} = 0,059 \ (W/m^2*K)$$

$Q(watt) = U \cdot A \cdot (T - T_{amb})$
Q = 0.059*(10*10)*(80-10) = 413 Watt

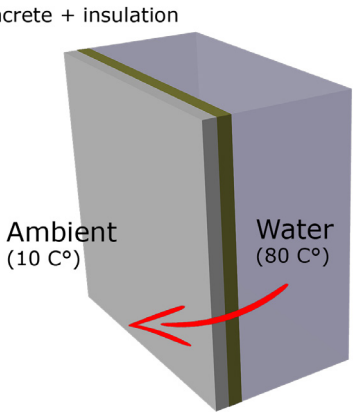


Figure 4.55: *Section of the wall of a storage. (by Author)*

(I) Pit storage (water)
An example calculation will be made for a thermal pit storage filled with water to further explain the energy and spatial characteristics of the storage technologies. The following pit storage is placed in the earth, the top surface is not covered with earth.

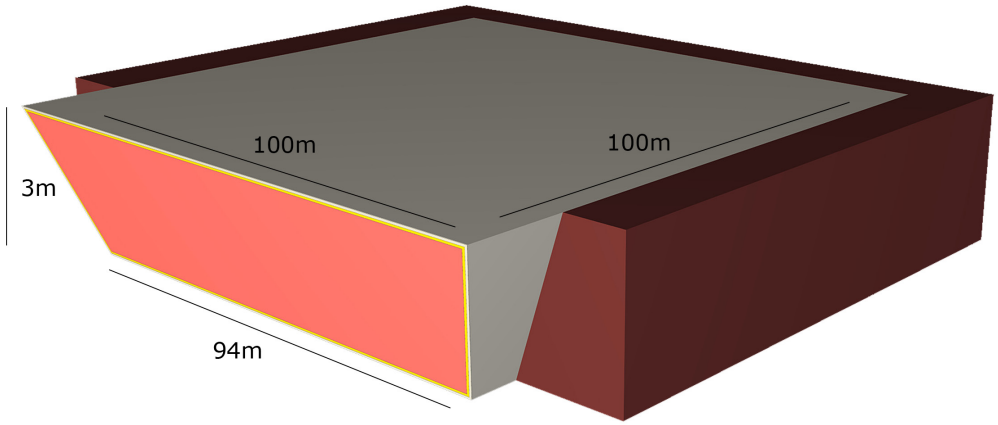


Figure 4.56: *Dimensions pit storage. (by Author)*

Thickness:
Bottom; 600mm concrete + 200mm XPS
Top; 200mm concrete + 500mm XPS
Lateral; 500mm concrete + 500mm XPS

Areas:
*The bottom area of the pit storage is: 94*94 = 8836 m²*
*The top area is : 100*100 = 10.000 m²*
*Total lateral areas (4 sides) : 4*411,5 = 1646 m²*
The lateral areas can be calculated using the following method.
The length difference between top and bottom on each side is:
(100-94)/2 = 3m
The height is also 3m
Diagonal length: √((32)+(32)) = 4,243 m
*Lateral area: 4,243 * (((100-94)/2) + 94) = 411,5 m²*

Volume:
To calculate the volume of the pit storage we need to know either the bottom surface or the top surface of the pit storage. The secondary component we need to know is the slope of the sides.
The following formula will be used:
Volume (m^3) = (height/3)*(A_{top} + A_{bot} +(√ (A_{top}* A_{bot})))
(adapted formula for truncated pyramid volume)
Volume = (3/3)*(10.000 + 8836 + (√(10.000*8836))) = 28.236 m^3

Properties:
Storage tank is filled with water at 80 °C
Ambient temperature is set at 10 °C
$\lambda_{concrete}$ = 1,63 (W/m*K)
λ_{XPS} = 0,03 (W/m*K)
λ_{ground} = 3,00 (W/m*K)
h_{conv} = Convective heat transfer coefficient to the air of (10 W/(m^2*K))
If a specific surface of the tank is in close contact with the outside are the convective heat transfer coefficient is included in the calculation. If a thick layer of earth is in contact with the surface of the tank the convective heat transfer coefficient can be neglected (De Guadalfajara et al., 2014).

Placement
The storage tank surfaces can be in contact with the outside air or earth, if they are buried, dependable on the placement of the tank thermal energy storage. Most of the times tank thermal energy storages are placed underground. To make a more accurate calculation about the thermal energy losses the surfaces of the tank storages can be divided in; Top area, lateral area and ground area.

The total thermal energy loss is: $Q_{tot} = Q_{top} + Q_{lateral} + Q_{bottom}$
The result of splitting the surfaces of the tank is a more accurate calculation of the thermal energy losses resulting in the following formula:
$Q_{tot} = (U_t*A_t + U_l*A_l + U_b*A_b)*(T_{tank}-T_{ambient})$

$$U_{top} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{1}{H_{conv}}\right)} \quad (W/m^2*K)$$

$$U_{top} = \frac{1}{\left(\frac{0,2}{1,63}\right)+\left(\frac{0,5}{0,03}\right)+\left(\frac{1}{10}\right)} = 0,059\ W/m^2*K$$

Calculating the heat transfer coefficient for the lateral surfaces of the tank is complex due to the increasing thickness of the ground layer over the height of the lateral surface. We simplify this calculation by taking the mean value of the ground thickness of the top of the lateral surface and the bottom of the lateral surface. In the case of the example; (0+3)/2 = 1,5m

$$U_{lateral} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{d_{ground}}{\lambda_{ground}}\right)} \quad (W/m^2*K)$$

$$U_{lateral} = \frac{1}{\left(\frac{0,5}{1,63}\right)+\left(\frac{0,5}{0,03}\right)+\left(\frac{1,5}{3}\right)} = 0,057\ W/m^2*K$$

Simplifying the thickness of the earth layer that functions as insulation for the bottom, we take the mean distance of the middle of the bottom area and the outside of the bottom area. The middle is half of the total length, in this case 50 meters. The mean distance is therefore (0+50)/2 = 25 meters. The height of the storage tank is added to this value, 25+3 = 28 meters.

$$U_{bottem} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{d_{ground}}{\lambda_{ground}}\right)} \quad (W/m^2*K)$$

$$U_{bottem} = \frac{1}{\left(\frac{0,6}{1,63}\right)+\left(\frac{0,2}{0,03}\right)+\left(\frac{28}{3}\right)} = 0,061\ W/m^2*K$$

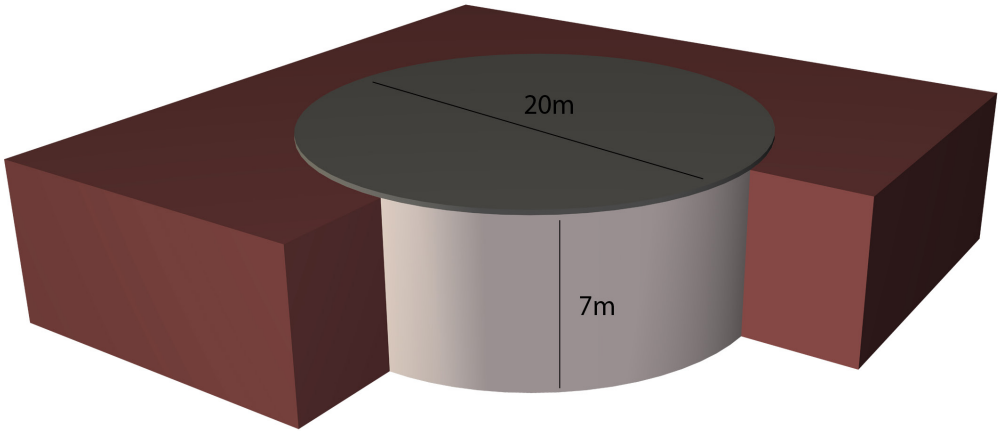
Energy losses
$Q_{tot} = (U_t*A_t + U_l*A_l + U_b*A_b) * (T_{tank}-T_{ambient})$
$Q_{tot} = ((0,059*10.000) + (0,057*1646) + (0,061*8836))*(80-10) = 85.597\ W$

Example temperature drop in one month. Assumed ambient temperature of 10 degrees stays constant. Watt is Joule per second. One month exist of 2.592.000 seconds
85.597 J/s = 85.597*(60*60*24*30)/1000 = 221,9 x 10^6 KJ in one month.

Temperature loss
$E\ (KJ) = V\cdot\rho\cdot c_p\cdot(T_{max}-T_{min})$
$221,9 \times 10^6 = (28.236*999,8*4,192*(80 - T_{min}))$
$1,87 = 80 - T_{min}$
$T_{min} = 78,13\ ^\circ C$ (temperature one month later)

Figure 4.57: *Dimensions tank storage. (by Author)*

(J) Tank storage (water)



Thickness:

Bottom; 50mm stainless steel + 200mm XPS
Top; 50mm stainless steel + 500mm XPS
Lateral; 50mm stainless steel + 500mm XPS

Areas:

The bottom area of the pit storage is: $\pi r^2 = \pi*10^2 = 314,2\ m^2$
The top area is : $\pi r^2 = \pi*10^2 = 314,2\ m^2$
Total lateral area is : $2*\pi*r*H = 2\pi*10*7 = 439,8\ m^2$

Volume:

Volume (m^3) = $\pi*r^2*H$
V = $\pi*10^2*7 = 2199,1\ m^3$

Properties:

Storage tank is filled with water at 80 °C
Ambient temperature is set at 10 °C
$\lambda_{stainless\ steel}$ = 16,0 (W/m*K)
λ_{XPS} = 0,03 (W/m*K)
λ_{ground} = 3,00 (W/m*K)
h_{conv} = Convective heat transfer coefficient to the air of (10 W/(m^2*K))

Placement

The total thermal energy loss is: $Q_{tot} = Q_{top} + Q_{lateral} + Q_{bottom}$

$$Q_{tot} = (U_t*A_t + U_l*A_l + U_b*A_b)*(T_{tank}-T_{ambient})$$

$$U_{top} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{1}{H_{conv}}\right)}\ (W/m^2*K)$$

$$U_{top} = \frac{1}{\left(\frac{0,05}{16}\right)+\left(\frac{0,05}{0,03}\right)+\left(\frac{1}{10}\right)} = 0,06\ W/m^2*K$$

The mean distance covered through ground as insulation: (0+7)/2 = 3,5m

$$U_{lateral} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{d_{ground}}{\lambda_{ground}}\right)}\ (W/m^2*K)$$

$$U_{lateral} = \frac{1}{\left(\frac{0,05}{16}\right)+\left(\frac{0,05}{0,03}\right)+\left(\frac{3,5}{3}\right)} = 0,056\ W/m^2*K$$

The mean distance is therefore (0+10)/2 = 5 meters. The height of the storage tank is added to this value, 5+7 = 12 meters.

$$U_{bottem} = \frac{1}{\left(\frac{d_{constr}}{\lambda_{constr}}\right)+\left(\frac{d_{ins}}{\lambda_{ins}}\right)+\left(\frac{d_{ground}}{\lambda_{ground}}\right)} \ (W/m^2*K)$$

$$U_{bottem} = \frac{1}{\left(\frac{0,05}{16}\right)+\left(\frac{0,02}{0,03}\right)+\left(\frac{12}{3}\right)} = 0,094 \ W/m^2*K$$

Energy losses

$Q_{tot} = (U_t*A_t + U_l*A_l + U_b*A_b) * (T_{tank}-T_{ambient})$
$Q_{tot} = ((0,060*314,16) + (0,056*439,82) + (0,094*314,16))*(80-10) = 5110,7 \ W$

Example temperature drop in one month:

5110,7 J/s = 5110,7 *(60*60*24*30)/1000 = 13,2 x 10^6 KJ in one month.

Temperature loss

$E \ (kWh) = V \cdot \rho \cdot c_p \cdot (T_{max}-T_{min})$
$13,2 \times 10^6 = (2199,1 * 999,8 * 4,192 * (80 - T_{min}))$
$1,44 = 80 - T_{min}$
$T_{min} = 78,56 \ ^\circ C$ (temperature one month later)

Total monthly transport energy loss:

There are two types of energy loss in the distribution network. Firstly if thermal heat is transported through the distribution system, from the solar panels towards the energy storage system (mostly summer). Secondly thermal losses occur if thermal heat is transported from the energy storage system towards the buildings. We assume there are no thermal losses if produced thermal heat is directly used by a building. The distance the thermal heat will cover is so small that the thermal losses can be neglected.

$$Q = \Delta T / \left(\left(\frac{\ln\left(\frac{R_o}{R_i}\right)}{2\pi * K_p * L}\right) + \left(\frac{\ln\left(\frac{R_s}{R_o}\right)}{2\pi * K_s * L}\right) + \left(\frac{1}{2\pi * h_{conv} * L}\right)\right) \text{ (Watt)}$$

Thermal losses thin pipe (blue):

Energy loss caused by transport between solar collector (output 80 °C) and energy storage. Energy loss thin pipe in April (average ambient temp 8,5 °C, chapter 3.5):

Properties & dimensions:

K_p = *0,45 W/m*K, polymer*
K_s = *0,03 W/m*K, XPS*
L = *10 m*
T_o = *8,5 °C*
T_i = *80 °C*
R_o = *0,018 m*
R_i = *0,016 m*
R_s = *0,043 m*
h_{conv} = *10 W/(m²*K)*

$$Q = 71{,}5 / \left(\left(\frac{\ln\left(\frac{0{,}018}{0{,}016}\right)}{2\pi * 0{,}04 * 10}\right) + \left(\frac{\ln\left(\frac{0{,}043}{0{,}018}\right)}{2\pi * 0{,}03 * 10}\right) + \left(\frac{1}{2\pi * 10 * 10}\right)\right) = 152{,}86 \text{ W}$$

In the month April there are 162 solar hours, 162*60*60 = 583.200 seconds.

Monthly energy loss for distribution from solar collectors towards the energy storage: (152,86*583.200)/1000 = 89.148 KJ per pipe.
Energy loss for all 113 buildings: 89.148*113 = 10,1 x10^6 KJ = **2798 kWh**

Energy loss caused by transport between energy storage (output 45 °C) and the buildings. In the month April there are: 30*24*60*60 = 2.592.000 seconds. During the solar hours thermal is directly used in the buildings or thermal heat is transported towards the energy storage. The amount of seconds thermal heat is transported from the storage towards the buildings is: 2.592.000 - 583.200 = 2.008.800 sec.

$$Q = 36{,}5 / \left(\left(\frac{\ln\left(\frac{0{,}018}{0{,}016}\right)}{2\pi * 0{,}04 * 10}\right) + \left(\frac{\ln\left(\frac{0{,}043}{0{,}018}\right)}{2\pi * 0{,}03 * 10}\right) + \left(\frac{1}{2\pi * 10 * 10}\right)\right) = 72{,}11 \text{ W}$$

Monthly energy loss for distribution energy storage towards the buildings: (72,11*2.008.800)/1000 = 144.855 KJ per pipe.
Energy loss for all 113 buildings: 144.855*113 = 16,4 x10^6 KJ = **4547 kWh**

Total energy loss thin pipe in the month April: 2798 + 4547 = **7345 kWh**

Thermal losses thick pipe (yellow):
Energy loss caused by transport between solar collector (output 80 °C) and energy storage. Energy loss thin pipe in April (average ambient temp 8,5 °C, chapter 3.5):

Properties & dimensions:

K_p = *0,45 W/m*K, polymer*
K_s = *0,03 W/m*K, XPS*
L = *62,5 m*
T_o = *8,5 °C*
T_i = *80 °C*
R_o = *0,032 m*
R_i = *0,03 m*
R_s = *0,072 m*
h_{conv} = *not relevant because the piping is buried underground*

$$Q = 71{,}5 / \left(\left(\frac{\ln\left(\frac{0{,}032}{0{,}030}\right)}{2\pi * 0{,}045 * 62{,}5}\right) + \left(\frac{\ln\left(\frac{0{,}072}{0{,}032}\right)}{2\pi * 0{,}03 * 62{,}5}\right)\right) = 1033{,}3 \text{ W}$$

Monthly energy loss for distribution from solar collectors towards the energy storage:
(1033,3*583.200)/1000 = 602.620 KJ per pipe.
Energy loss for all 10 pipes: 602.620*10 = 6,0 x10^6 KJ = **1674 kWh**

Energy loss caused by transport between energy storage (output 45 °C) and the buildings:

$$Q = 36{,}5 / \left(\left(\frac{\ln\left(\frac{0{,}032}{0{,}030}\right)}{2\pi * 0{,}045 * 62{,}5}\right) + \left(\frac{\ln\left(\frac{0{,}072}{0{,}032}\right)}{2\pi * 0{,}03 * 62{,}5}\right)\right) = 503{,}5 \text{ W}$$

Monthly energy loss for distribution energy storage towards the buildings:
(503,5 *2.008.800)/1000 = 1.011.431 KJ per pipe.
Energy loss for all 10 pipes: 1.011.431*10 = 10,1 x10^6 KJ = **2810 kWh**

Total energy loss thick pipe in the month April: 1674 + 2810 = **4844 kWh**

The total distribution losses in the month april: 4844 + 7345 = **12.189 kWh***

**This value is slightly different from the actual value because the the numbers were rounded up in the intermediate steps.*

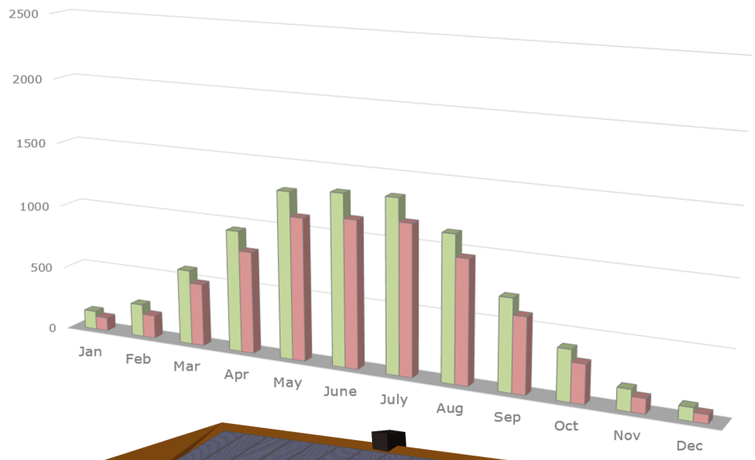
APPENDIX B

Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 6
Annual thermal heat production: (40C°) 8.400 kWh
(80C°) 7.006 kWh

Monthy thermal heat production per household in kWh

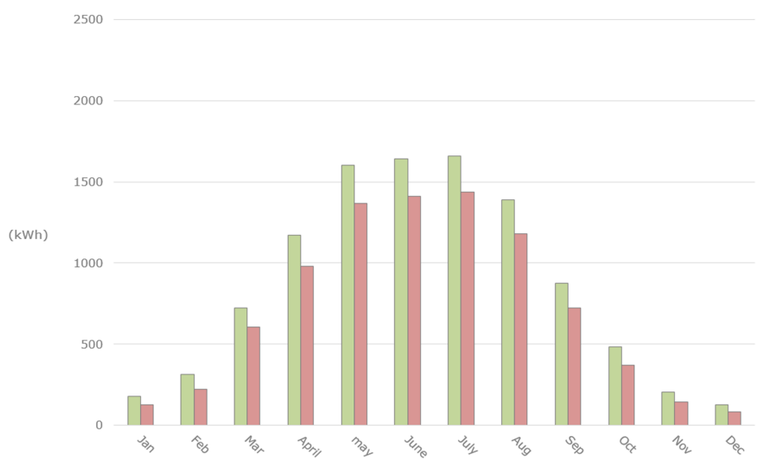
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	144	256	585	947	1298	1331	1343	1126	710	393	166	102
80 C°	104	181	488	795	1109	1143	1165	956	585	300	115	67

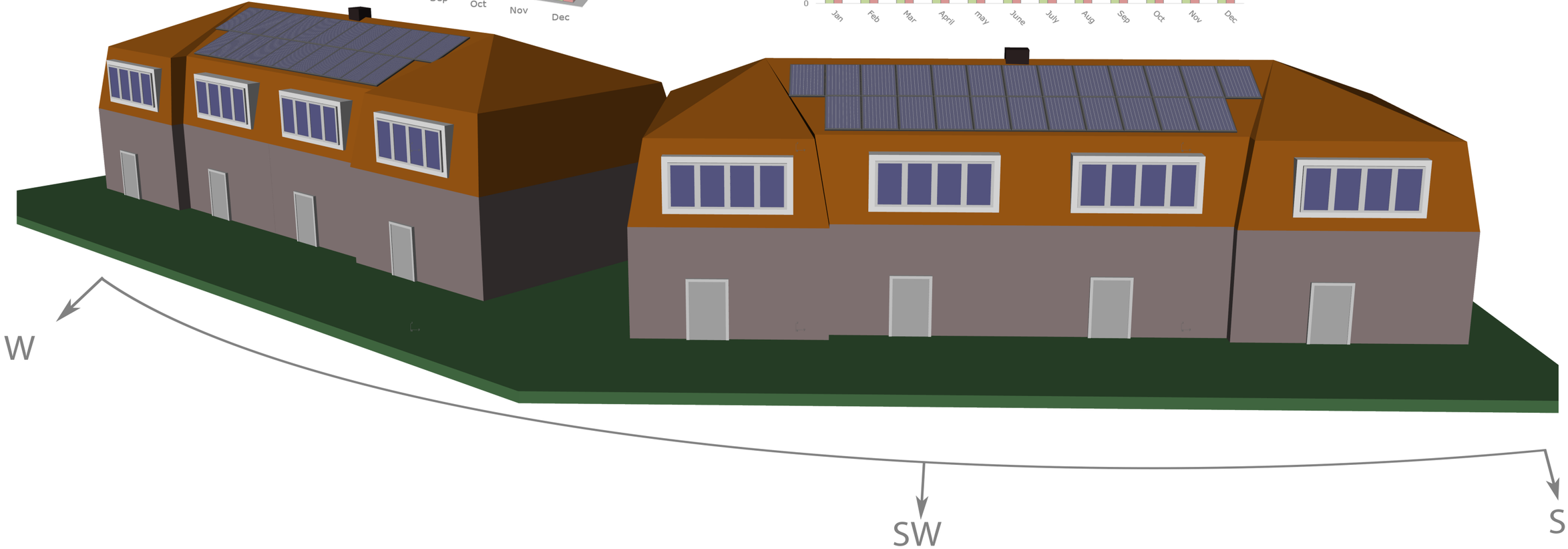


Orientation : South-west
Angle : 45 C°
Panels per household : 6
Annual thermal heat production: (40C°) 10.376 kWh
(80C°) 8.657 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	178	316	723	1170	1603	1644	1659	1390	877	485	205	126
80 C°	128	223	603	982	1370	1412	1439	1181	723	371	142	83



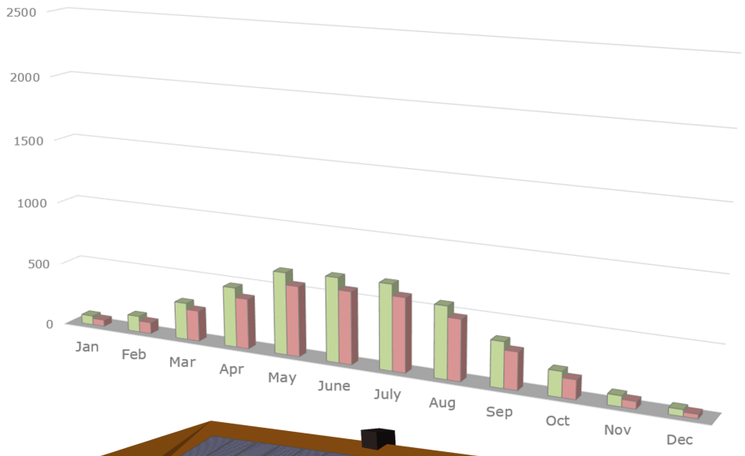


Minor visual impact:

Orientation : West
Angle : 45 C°
Panels per household : 3
Annual thermal heat production: (40C°) 4.200 kWh
(80C°) 3.502 kWh

Monthy thermal heat production per household in kWh

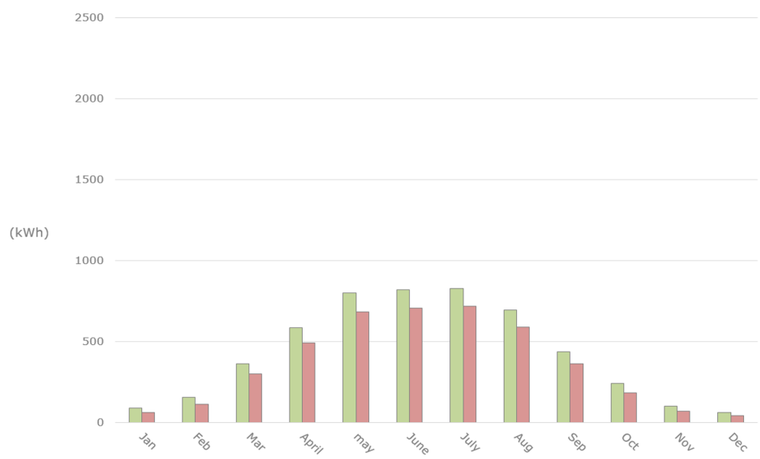
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	72	128	293	474	649	665	672	563	355	196	83	51
80 C°	52	90	244	397	554	571	583	478	293	150	57	34

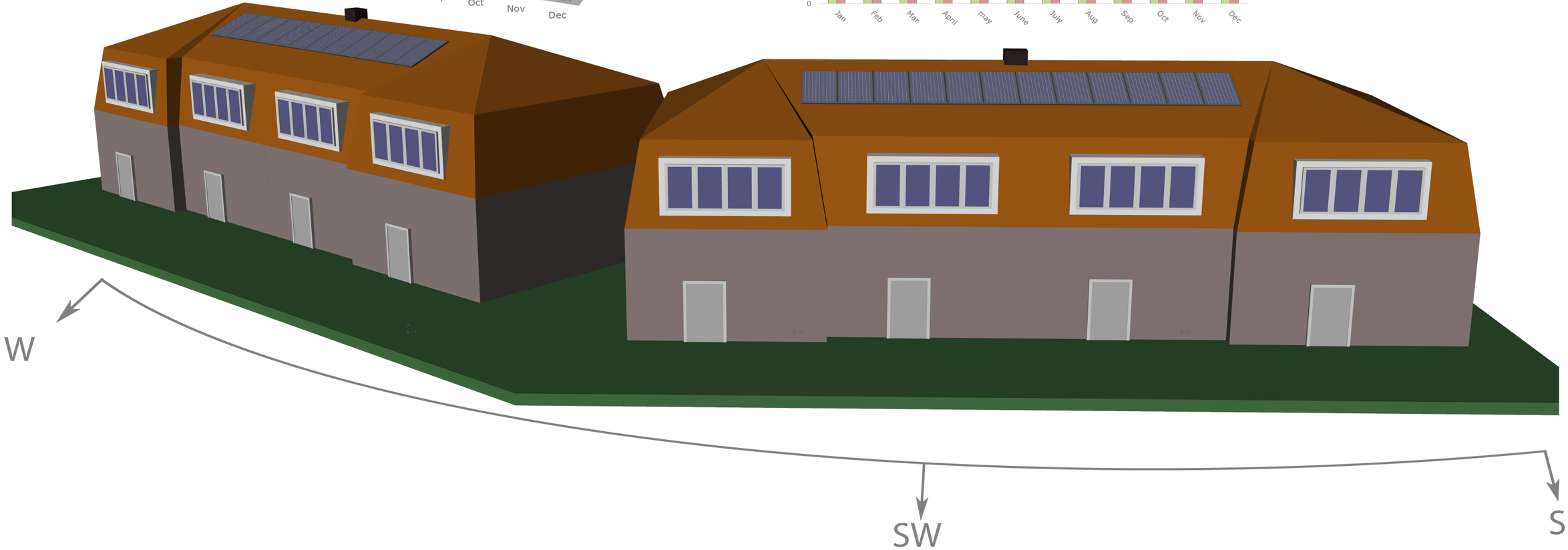


Orientation : South-west
Angle : 45 C°
Panels per household : 3
Annual thermal heat production: (40C°) 5.188 kWh
(80C°) 4.329 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	89	158	362	585	802	822	830	695	438	243	102	63
80 C°	64	112	302	491	685	706	720	590	361	185	71	42



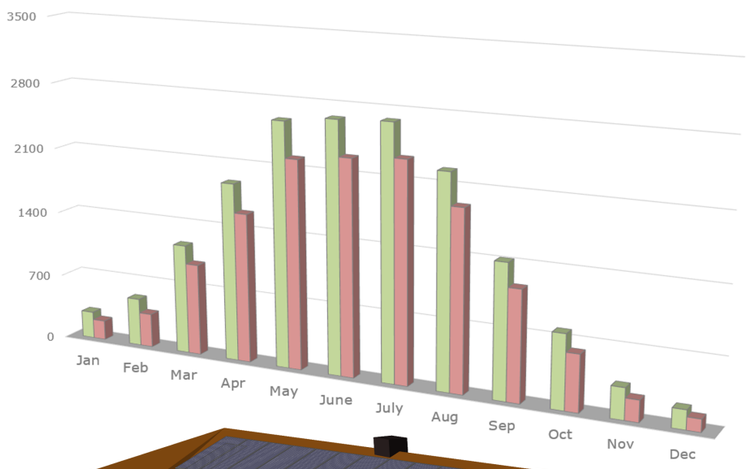


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 12
Annual thermal heat production: (40C°) 16.799 kWh
(80C°) 14.017 kWh

Monthy thermal heat production per household in kWh

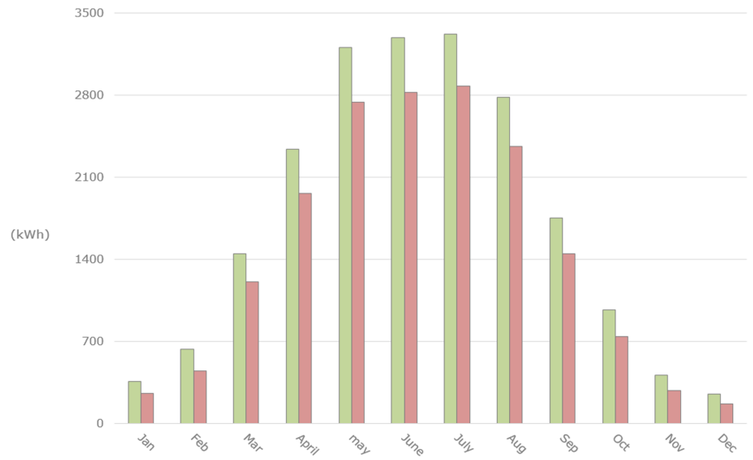
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	288	511	1171	1895	2596	2661	2686	2251	1419	785	332	204
80 C°	208	362	977	1590	2218	2286	2331	1912	1170	600	229	135

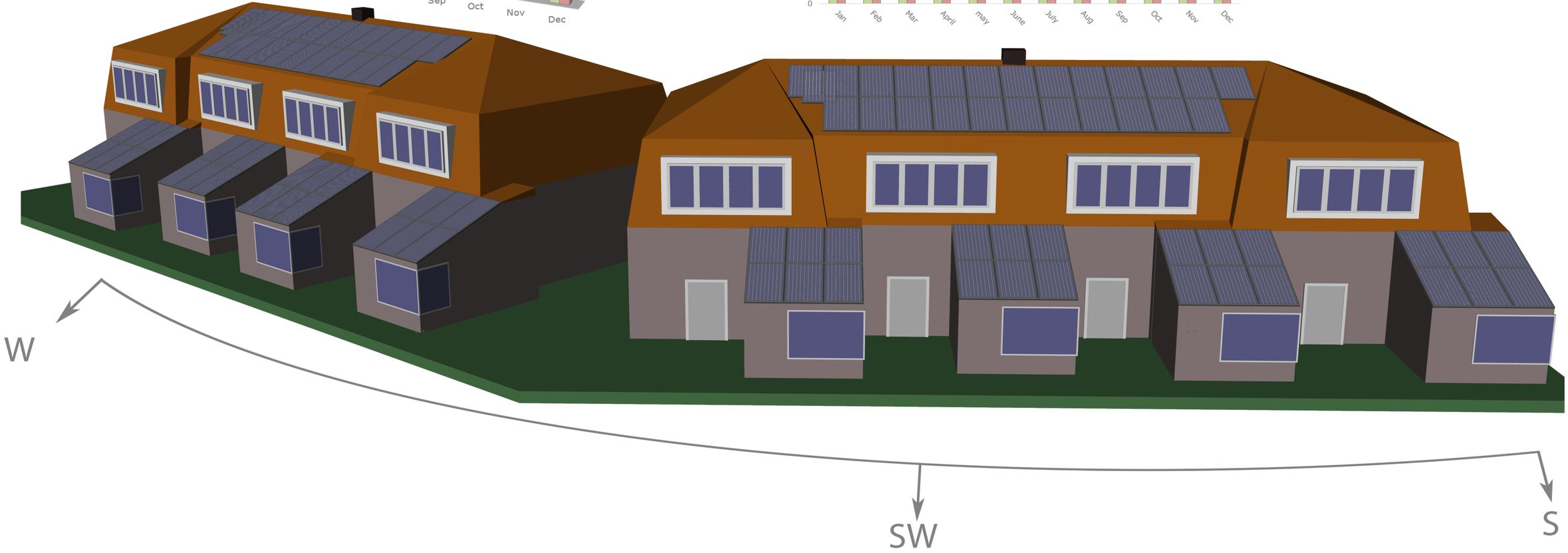


Orientation : South-west
Angle : 45 C°
Panels per household : 12
Annual thermal heat production: (40C°) 20.752 kWh
(80C°) 17.315 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	356	632	1446	2340	3207	3287	3318	2781	1753	970	410	251
80 C°	257	447	1207	1964	2739	2824	2879	2362	1446	742	283	166





Maximum potential

Flat plate collector



Energy potential 1327 panels (south)
Annual prod: 2.404.136 kWh (40 C°)
Annual prod: 2.005.911 kWh (80 C°)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	41280	73185	167556	271122	371483	380823	384401	322165	203130	112404	47453	29135
80 C°	29738	51768	139809	227502	317355	327119	333517	273586	167497	85930	32814	19275

Potential considering vegetation:

Flat plate collector



Energy potential 646 panels (south)
Annual prod: 1.170.363 kWh (40 C°)
Annual prod: 976.502 kWh (80 C°)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	20095	35627	81568	131986	180842	185389	187131	156834	98886	54720	23101	14183
80 C°	14477	25201	68061	110751	154492	159246	162360	133185	81540	41832	15974	9383

Flat plate collector



Energy potential 276 panels (south)
Annual prod: 500.031 kWh (40 C°)
Annual prod: 417.205 kWh (80 C°)

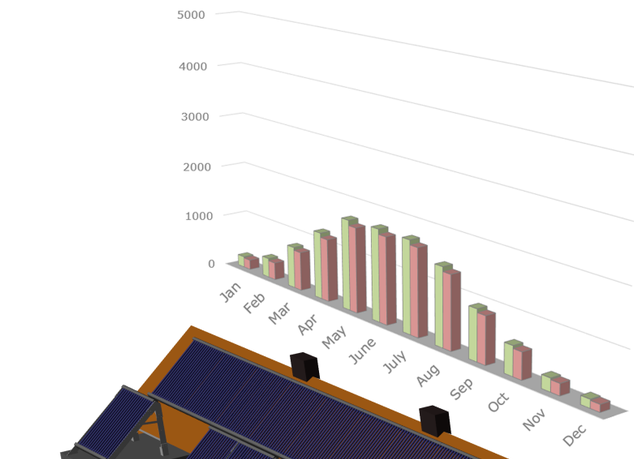
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	8586	15222	34850	56390	77264	79207	79951	67006	42249	23379	9870	6060
80 C°	6185	10767	29079	47318	66006	68037	69367	56903	34837	17872	6825	4009

Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 6,33
Annual thermal heat production: (40C°) 11.123 kWh
(80C°) 10.445 kWh

Monthy thermal heat production per household in kWh

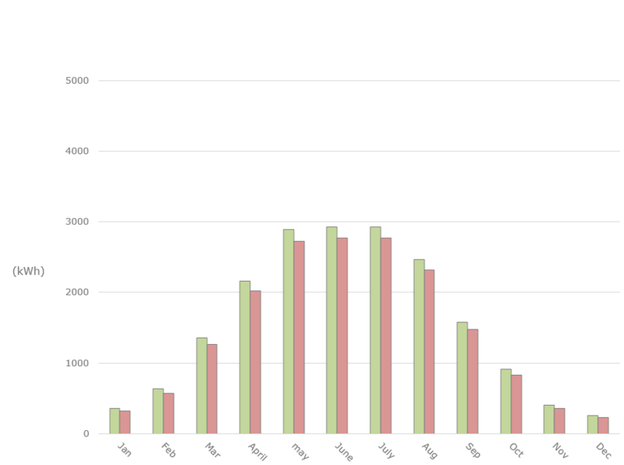
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	210	375	794	1267	1697	1722	1718	1446	929	534	238	152
80 C°	188	334	742	1187	1600	1627	1630	1361	866	486	211	133



Orientation : South
Angle : 45 C°
Panels per household : 8,33
Annual thermal heat production: (40C°) 18.874 kWh
(80C°) 17.652 kWh

Monthy thermal heat production per household in kWh

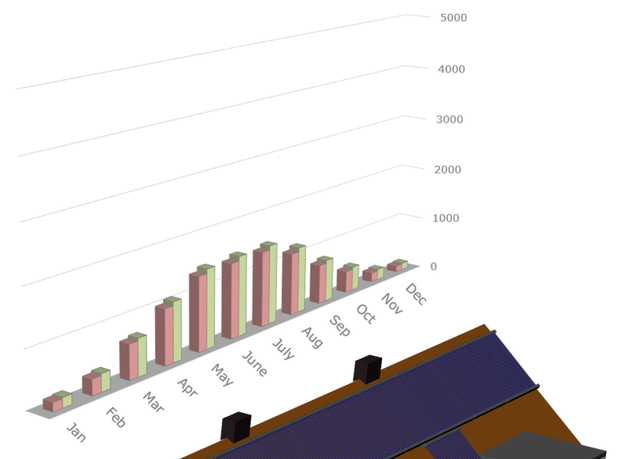
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	358	638	1353	2158	2890	2932	2926	2462	1582	910	406	258
80 C°	321	568	1264	2021	2725	2771	2775	2318	1475	828	359	226

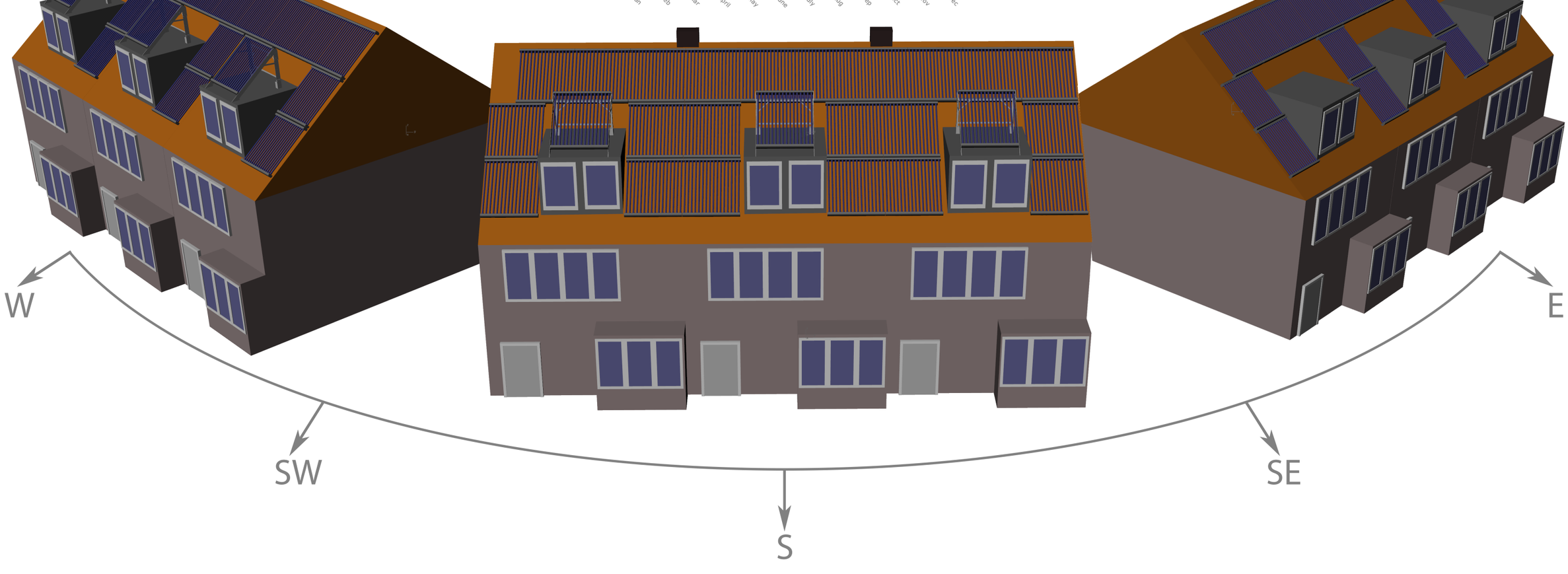


Orientation : East
Angle : 45 C°
Panels per household : 5,33
Annual thermal heat production: (40C°) 9.332 kWh
(80C°) 8.728 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	177	315	669	1067	1429	1450	1447	1217	782	450	201	128
80 C°	159	281	625	999	1347	1370	1372	1146	729	409	178	112



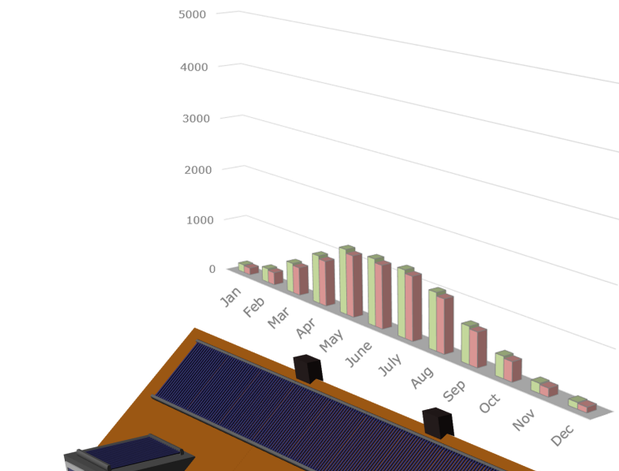


Minor visual impact:

Orientation : West
Angle : (3) 45 C° / (1) 0 C°
Panels per household : 4,33
Annual thermal heat production: (40C°) 7.890 kWh
(80C°) 7.379 kWh

Monthy thermal heat production per household in kWh

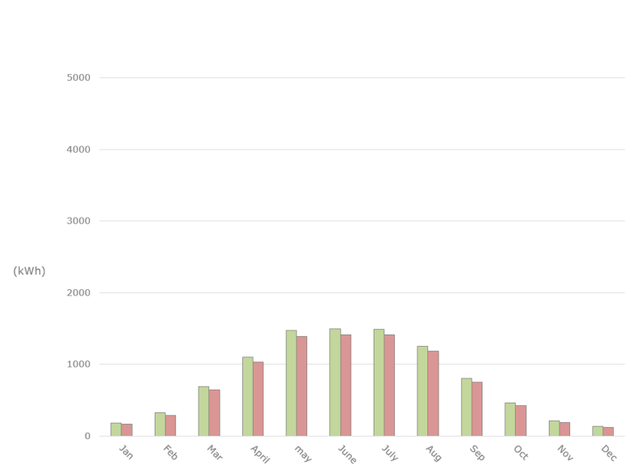
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	150	267	566	902	1208	1226	1223	1029	662	380	170	108
80 C°	134	238	529	845	1139	1158	1160	969	617	346	150	95



Orientation : South
Angle : (3) 45 C° / (1) 0 C°
Panels per household : 4,33
Annual thermal heat production: (40C°) 9.605 kWh
(80C°) 8.983 kWh

Monthy thermal heat production per household in kWh

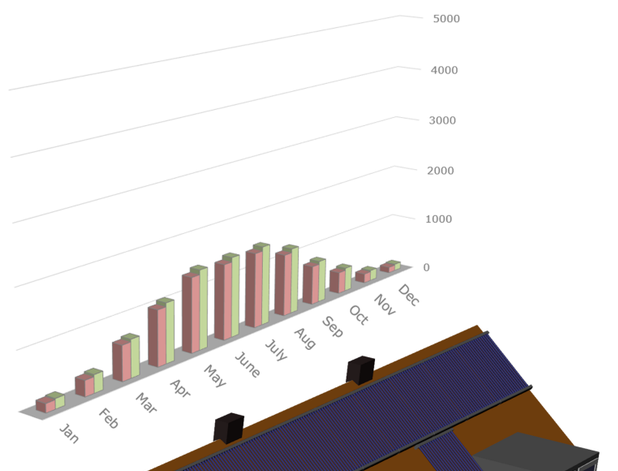
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	182	325	688	1098	1471	1492	1489	1253	805	463	207	131
80 C°	163	289	643	1028	1387	1410	1412	1180	751	421	183	115

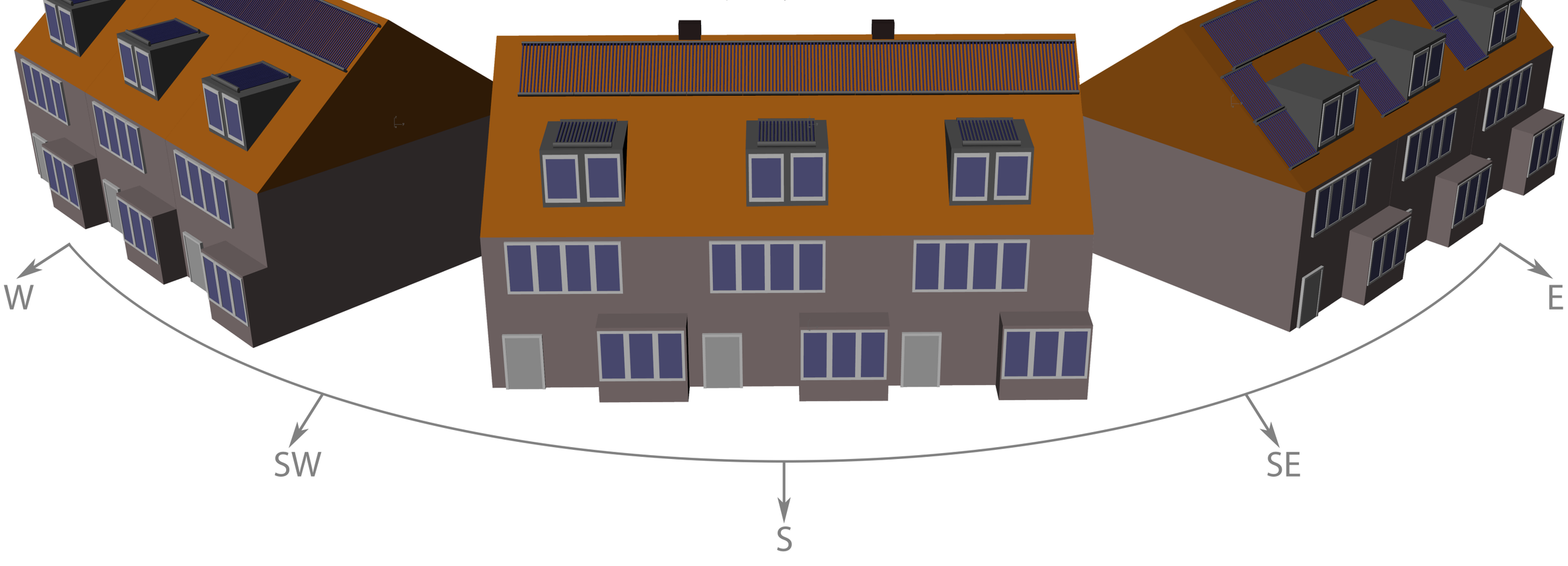


Orientation : East
Angle : 45 C°
Panels per household : 5,33
Annual thermal heat production: (40C°) 9.332 kWh
(80C°) 8.728 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	177	315	669	1067	1429	1450	1447	1217	782	450	201	128
80 C°	159	281	625	999	1347	1370	1372	1146	729	409	178	112



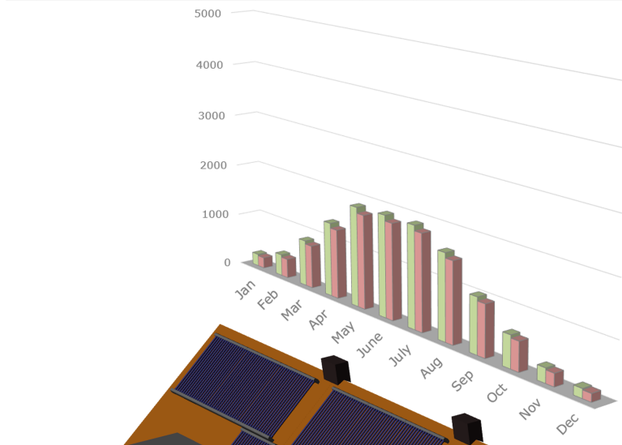


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 7
Annual thermal heat production: (40C°) 12.256 kWh
(80C°) 11.462 kWh

Monthy thermal heat production per household in kWh

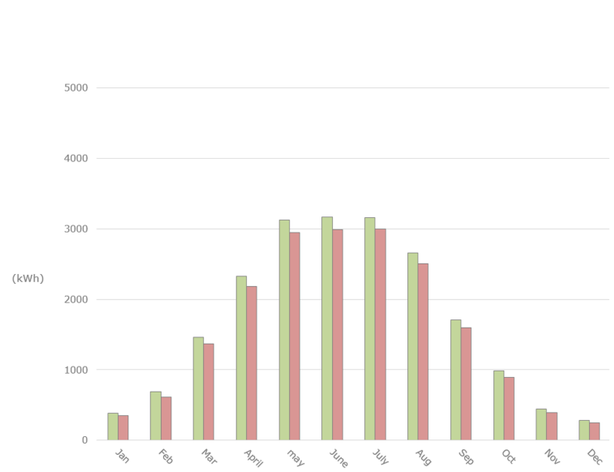
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	233	414	879	1401	1877	1904	1900	1599	1028	591	264	168
80 C°	208	369	821	1312	1769	1799	1802	1505	958	538	233	147



Orientation : South
Angle : 45 C°
Panels per household : 9
Annual thermal heat production: (40C°) 20.392 kWh
(80C°) 19.072 kWh

Monthy thermal heat production per household in kWh

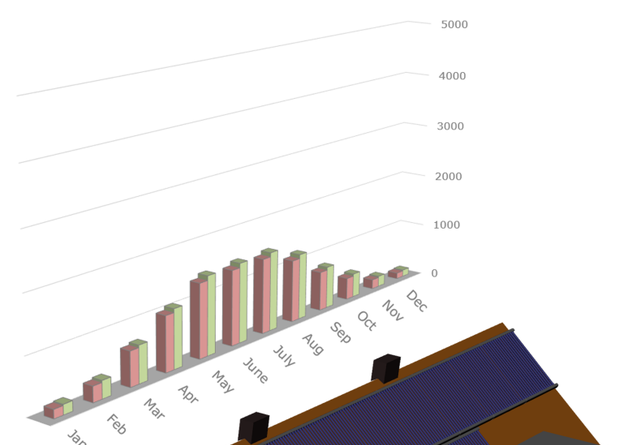
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	387	689	1462	2331	3122	3168	3161	2660	1710	983	439	279
80 C°	346	614	1366	2183	2944	2994	2999	2505	1593	895	388	245

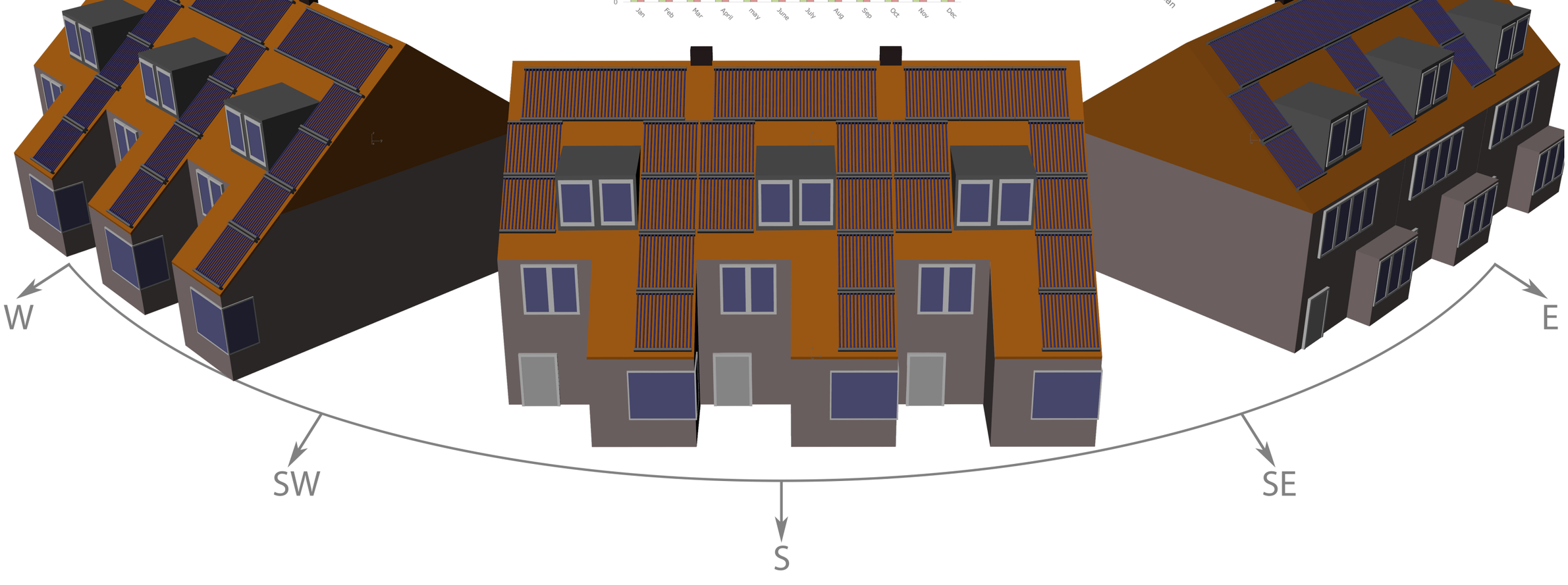


Orientation : East
Angle : 45 C°
Panels per household : 5,33
Annual thermal heat production: (40C°) 9.332 kWh
(80C°) 8.728 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	177	315	669	1067	1429	1450	1447	1217	782	450	201	128
80 C°	159	281	625	999	1347	1370	1372	1146	729	409	178	112



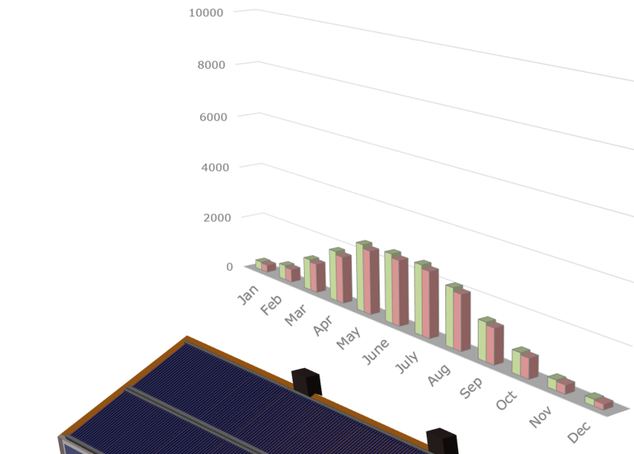


Partly refurbished:

Orientation : West
Angle : 45 C°
Panels per household : 9,33
Annual thermal heat production: (40C°) 16.335 kWh
(80C°) 15.278 kWh

Monthy thermal heat production per household in kWh

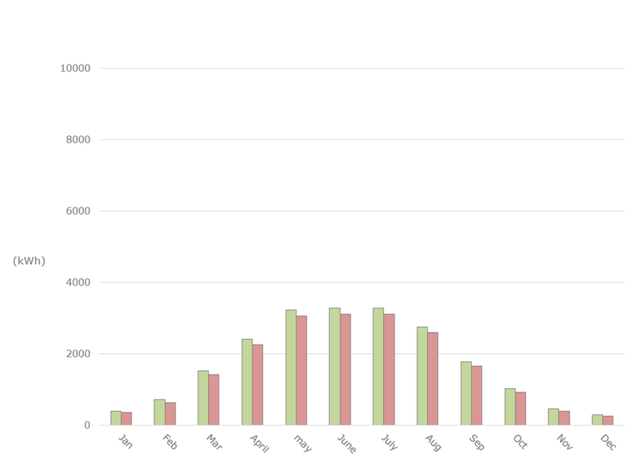
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	310	552	1171	1867	2501	2538	2532	2131	1370	788	351	224
80 C°	277	492	1094	1749	2358	2398	2402	2007	1276	717	311	196



Orientation : South
Angle : 45 C°
Panels per household : 9,33
Annual thermal heat production: (40C°) 21.139 kWh
(80C°) 19.771 kWh

Monthy thermal heat production per household in kWh

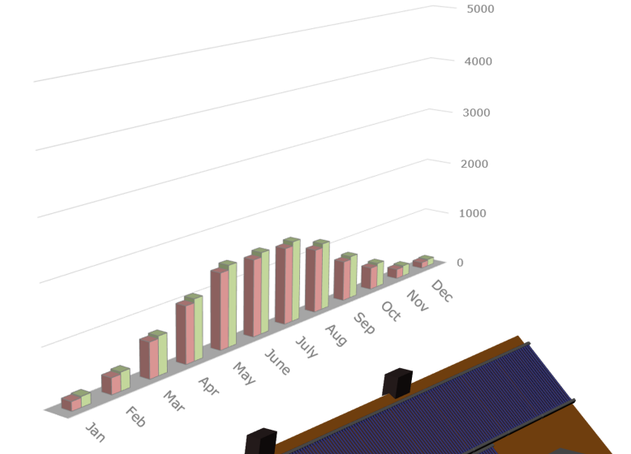
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	401	715	1515	2417	3237	3284	3277	2758	1772	1019	455	289
80 C°	359	637	1416	2263	3052	3103	3109	2597	1652	928	403	254

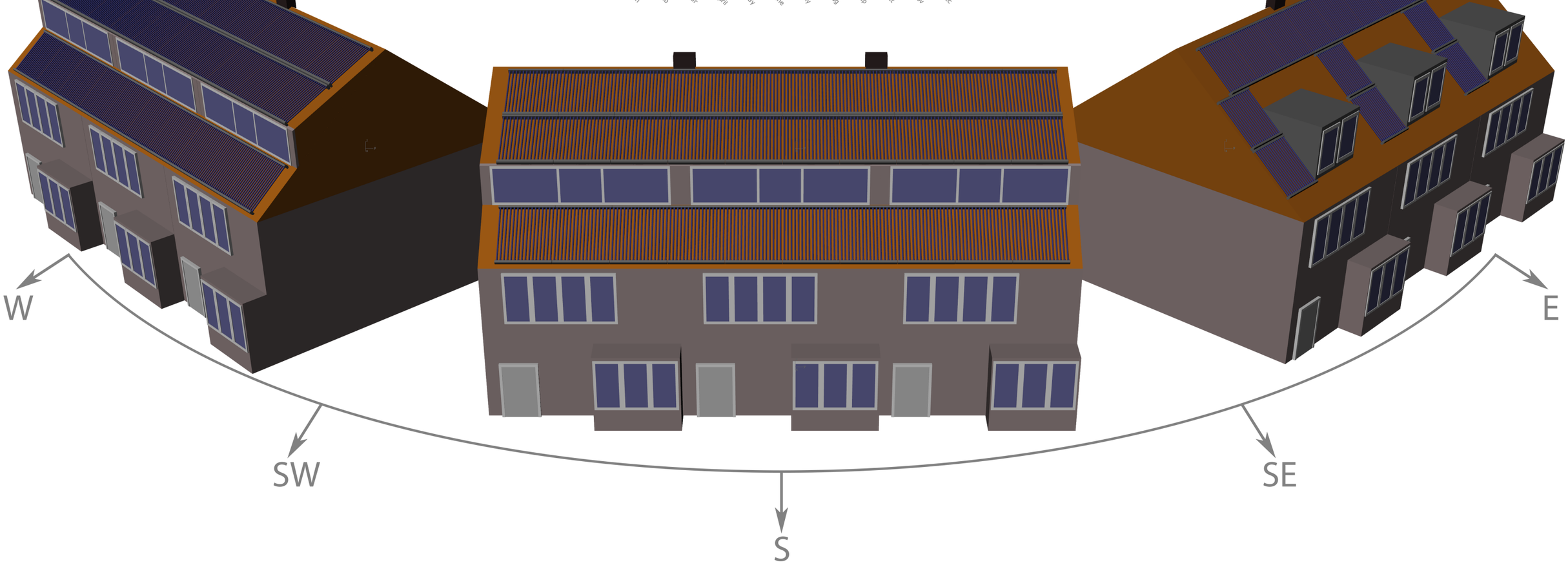


Orientation : East
Angle : 45 C°
Panels per household : 5,33
Annual thermal heat production: (40C°) 9.332 kWh
(80C°) 8.728 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	177	315	669	1067	1429	1450	1447	1217	782	450	201	128
80 C°	159	281	625	999	1347	1370	1372	1146	729	409	178	112



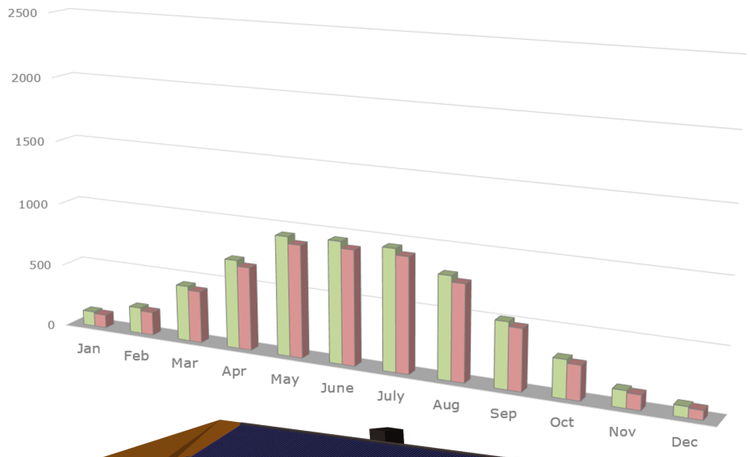


Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 3,5
Annual thermal heat production: (40C°) 6.128 kWh
(80C°) 5.731 kWh

Monthy thermal heat production per household in kWh

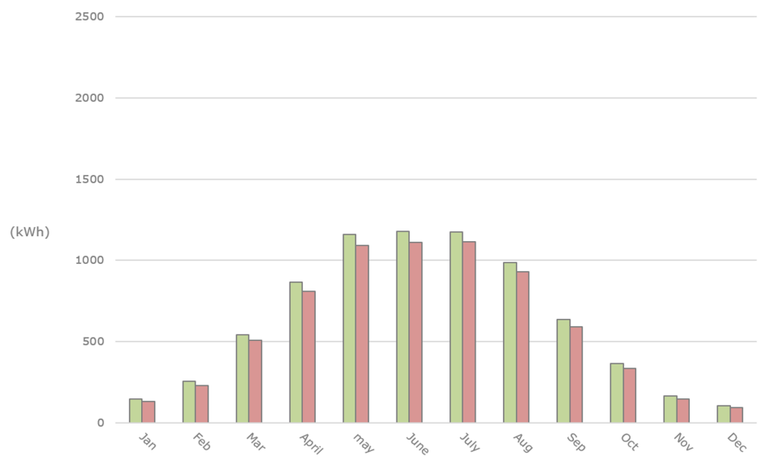
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	116	207	439	700	938	952	950	799	514	295	132	84
80 C°	104	185	410	656	885	900	901	753	479	269	117	74

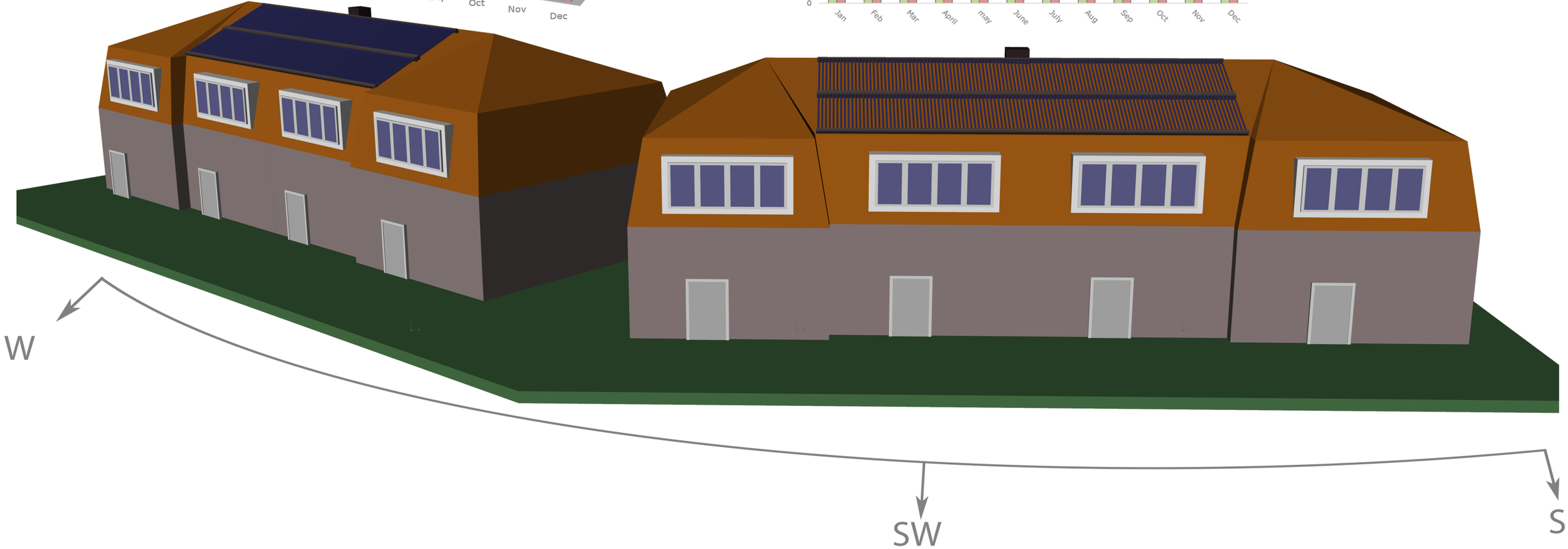


Orientation : South-west
Angle : 45 C°
Panels per household : 3,5
Annual thermal heat production: (40C°) 7.570 kWh
(80C°) 7.080 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	144	256	543	865	1159	1176	1173	988	635	365	163	104
80 C°	129	228	507	810	1093	1111	1113	930	591	332	144	91



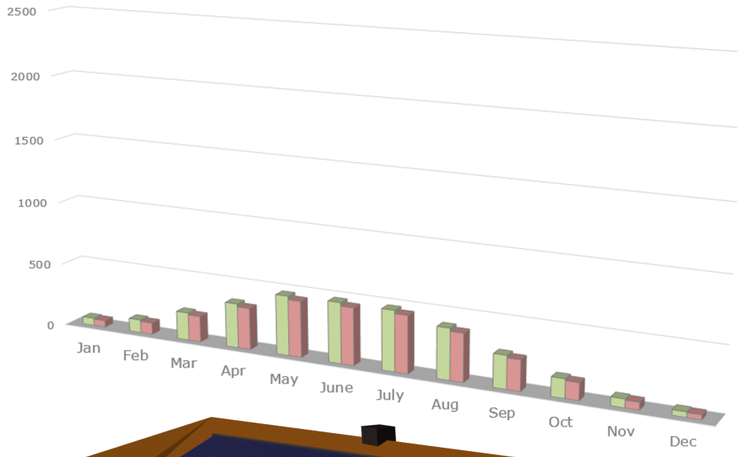


Minor visual impact:

Orientation : West
Angle : 45 C°
Panels per household : 1,75
Annual thermal heat production: (40C°) 3.064 kWh
(80C°) 2.866 kWh

Monthy thermal heat production per household in kWh

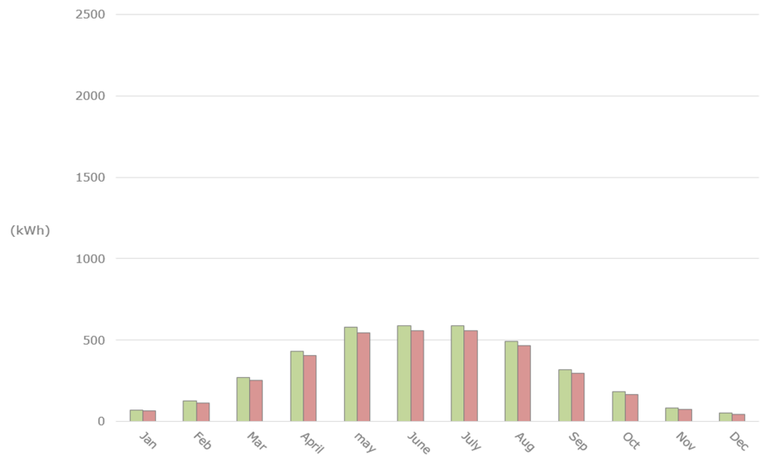
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	58	104	220	350	469	476	475	400	257	148	66	42
80 C°	52	92	205	328	442	450	451	376	239	134	58	37

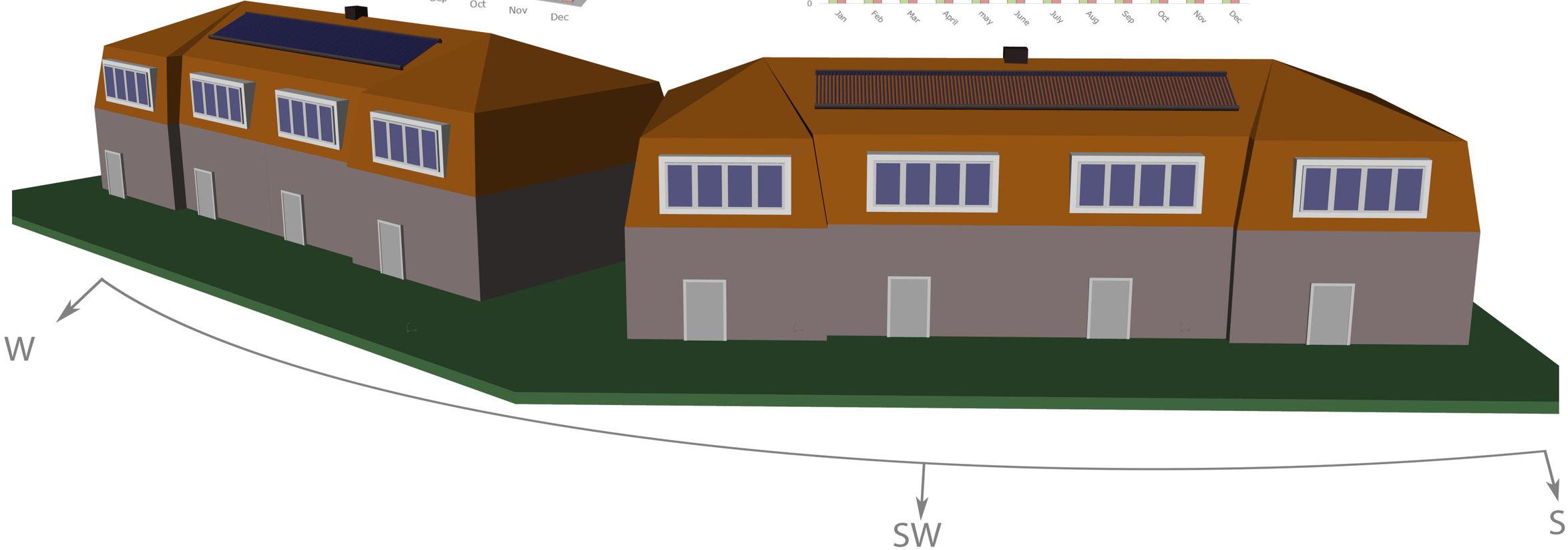


Orientation : South-west
Angle : 45 C°
Panels per household : 1,75
Annual thermal heat production: (40C°) 3.785 kWh
(80C°) 3.540 kWh

Monthy thermal heat production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	72	128	271	433	580	588	587	494	317	183	81	52
80 C°	64	114	254	405	546	556	557	465	296	166	72	45



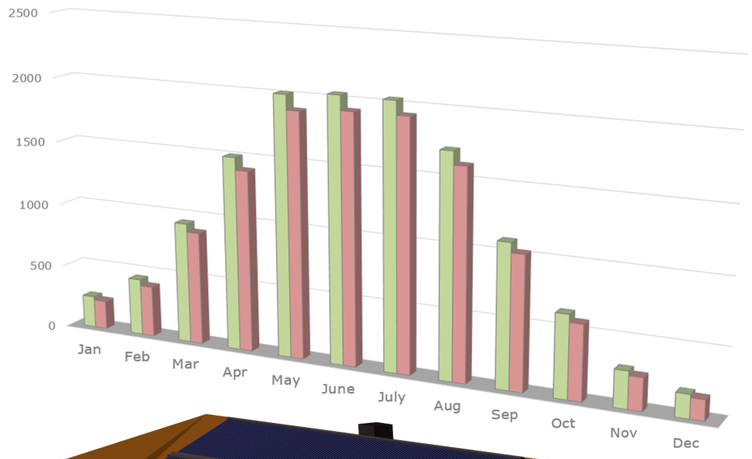


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 7,5
Annual thermal heat production: (40C°) 13.131 kWh
(80C°) 12.281 kWh

Monthy thermal heat production per household in kWh

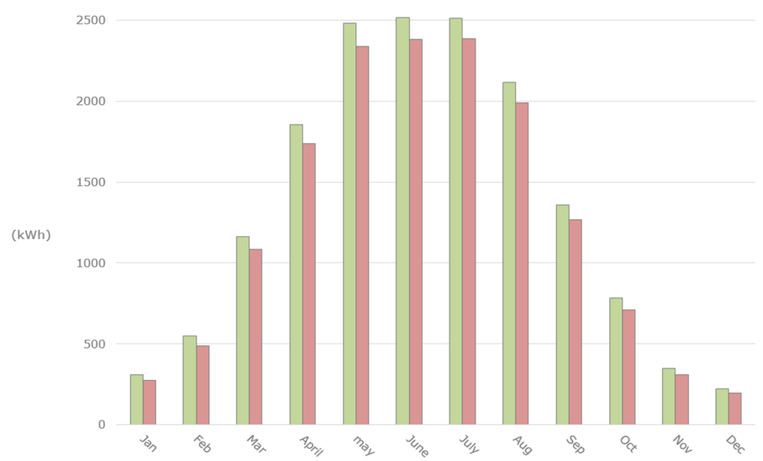
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	249	444	941	1501	2011	2040	2036	1713	1101	633	282	180
80 C°	223	396	880	1406	1896	1928	1931	1613	1026	576	250	158

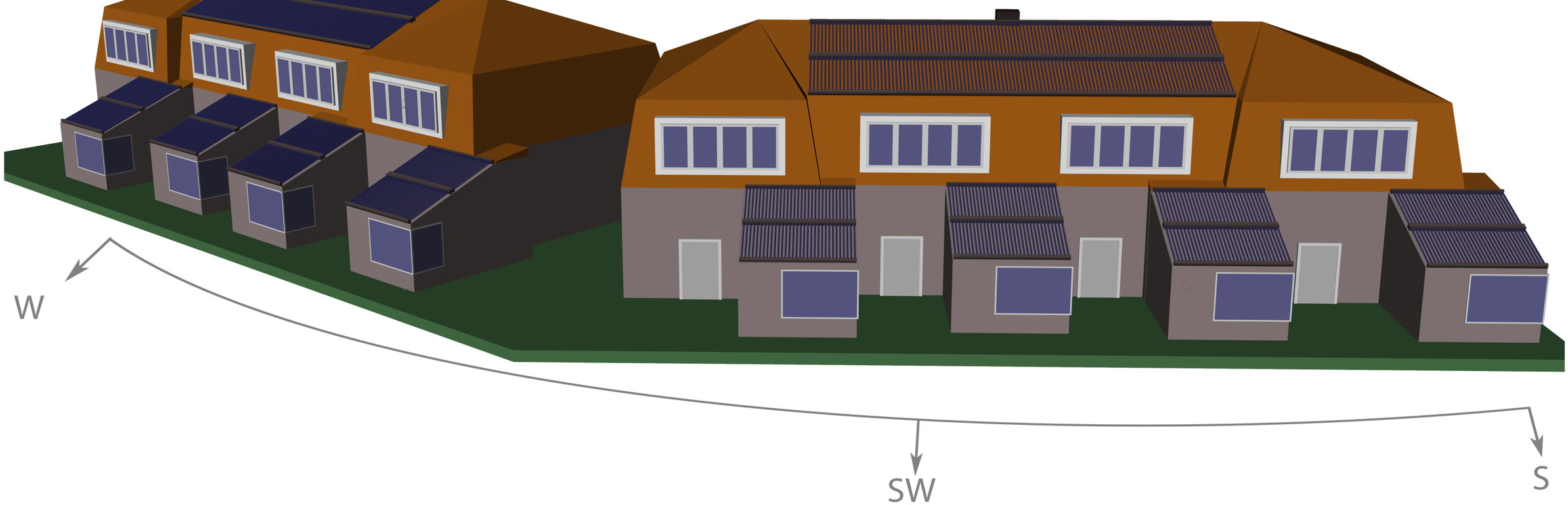


Orientation : South-west
Angle : 45 C°
Panels per household : 7,5
Annual thermal heat production: (40C°) 16.221 kWh
(80C°) 15.171 kWh

Monthy thermal heat production per household in kWh

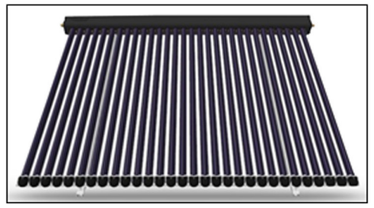
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	308	548	1163	1854	2484	2520	2515	2116	1360	782	349	222
80 C°	276	489	1087	1737	2342	2381	2385	1993	1267	712	309	195





Maximum potential

Evacuated tube collector

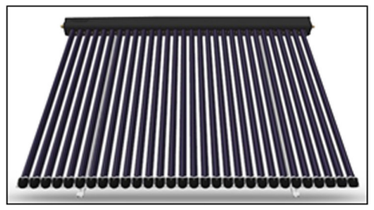


Energy potential 442 panels (south)
Annual prod: 1.001.461 kWh (40 C°)
Annual prod: 936.649 kWh (80 C°)

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	18999	33851	71786	114481	153339	155594	155253	130653	83969	48292	21538	13705
80 C°	17010	30164	67086	107224	144571	147023	147268	123018	78253	43942	19073	12016

Potential considering vegetation:

Evacuated tube collector



Energy potential 218 panels (south)
Annual prod: 493.933 kWh (40 C°)
Annual prod: 461.967 kWh (80 C°)

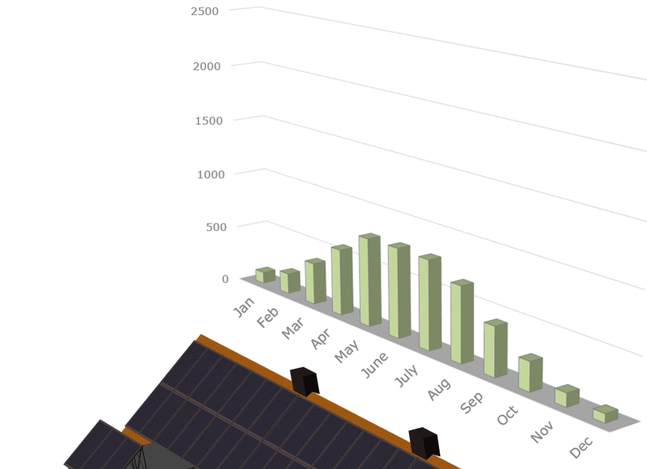
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	9371	16695	35406	56463	75629	76741	76573	64440	41414	23818	10623	6760
80 C°	8390	14878	33088	52884	71304	72513	72635	60674	38596	21673	9407	5926

Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

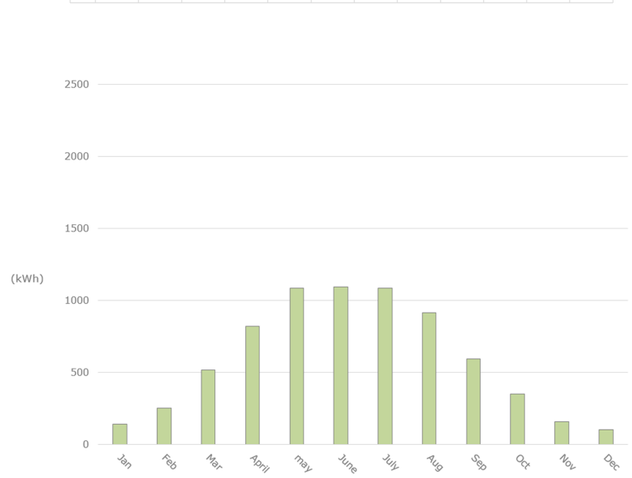
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74



Orientation : South
Angle : 45 C°
Panels per household : 25
Annual electricity production : 7.126 kWh

Monthy electricity production per household in kWh

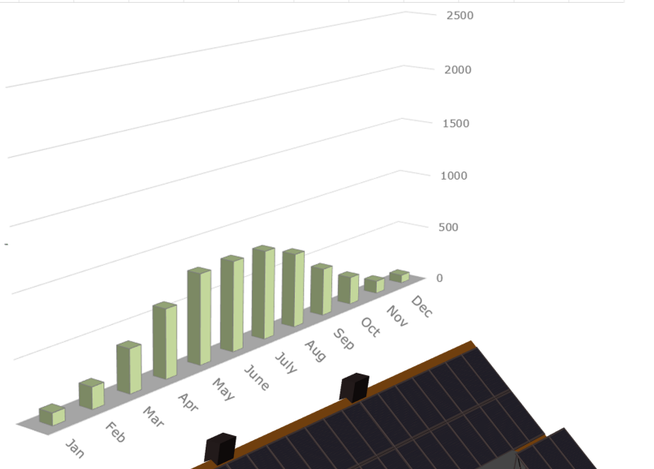
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	143	255	519	821	1085	1095	1085	915	595	349	160	104

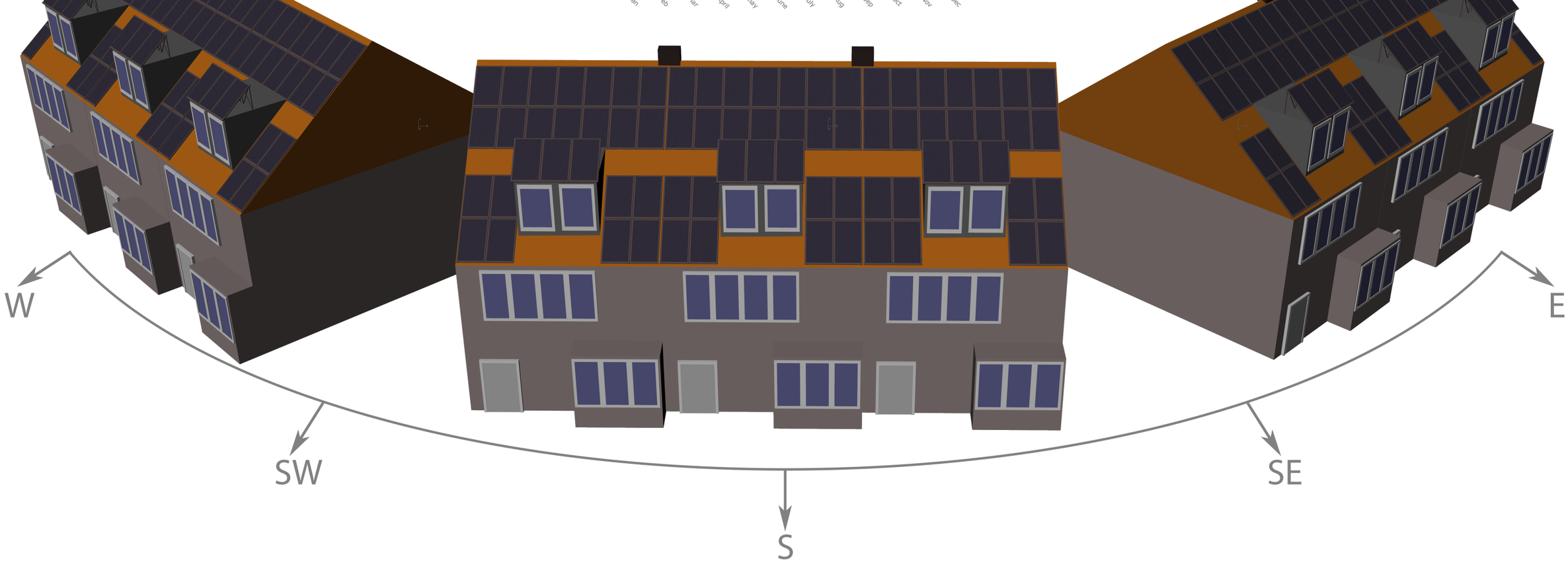


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74



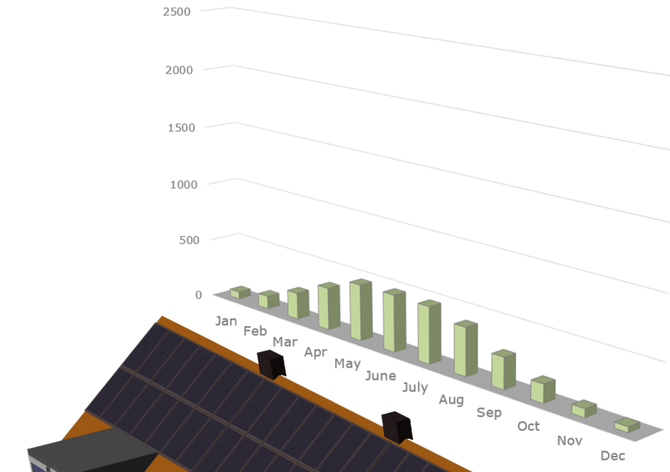


Minor visual impact:

Orientation : West
Angle : 45 C°
Panels per household : 14
Annual electricity production : 3.084 kWh

Monthy electricity production per household in kWh

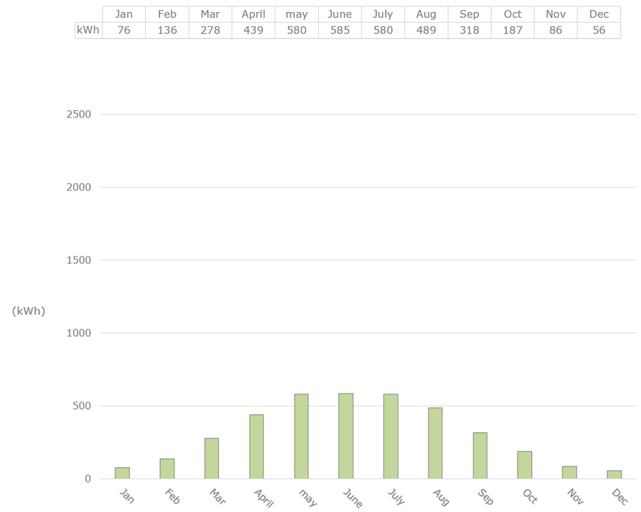
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	62	110	225	355	470	474	470	396	257	151	69	45



Orientation : South
Angle : 45 C°
Panels per household : 14
Annual electricity production : 3.809 kWh

Monthy electricity production per household in kWh

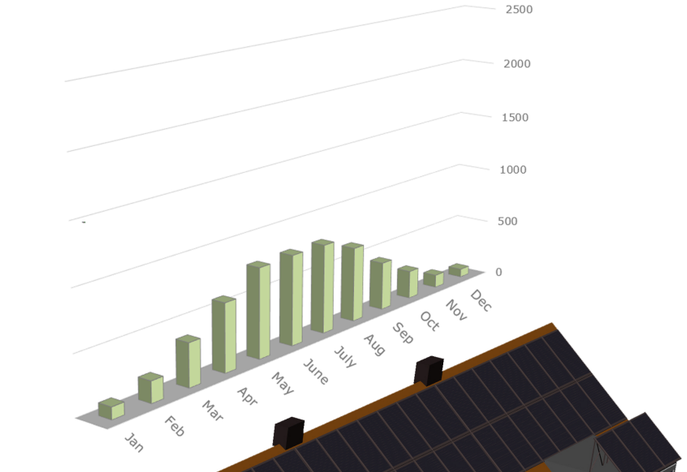
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	76	136	278	439	580	585	580	489	318	187	86	56

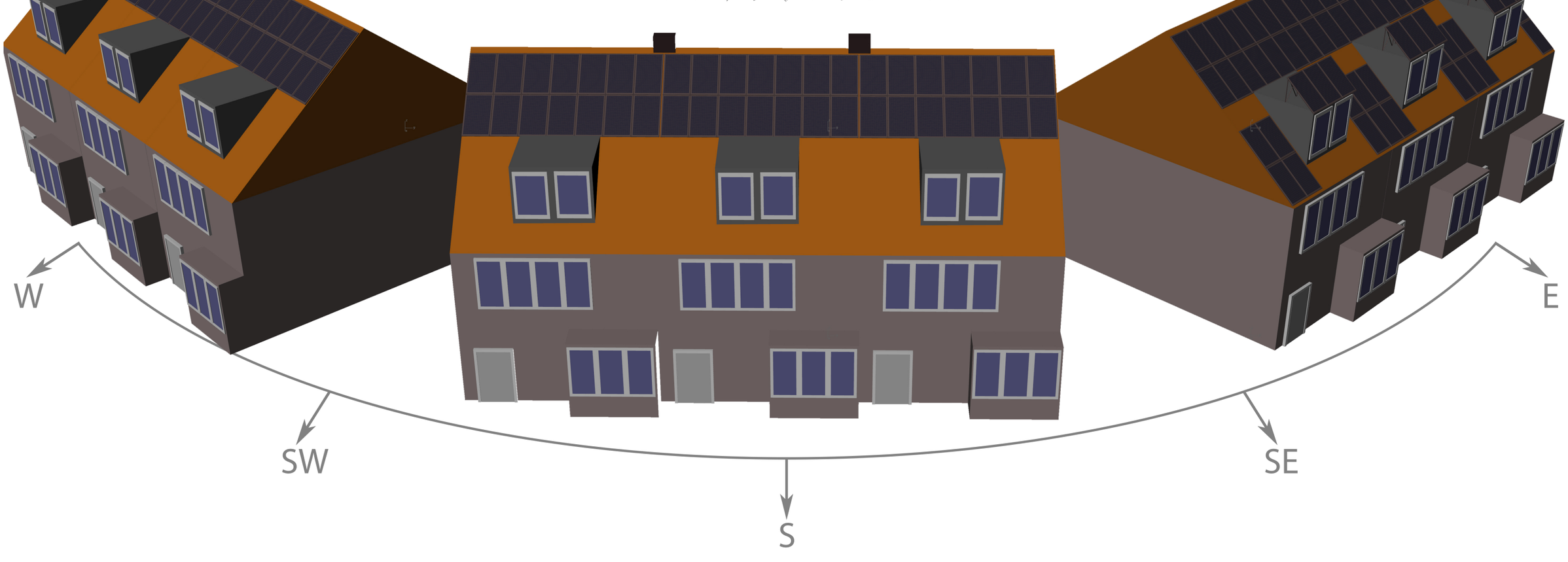


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74



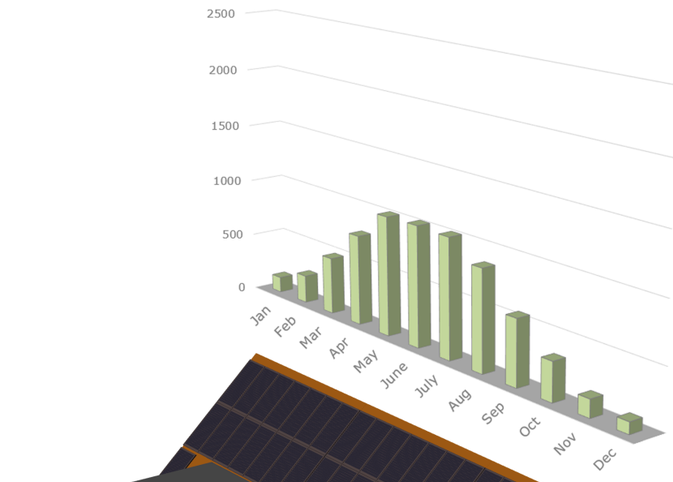


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 30,5 (10,5 glass + 20 roof)
Annual electricity production : 6.718 kWh

Monthy electricity production per household in kWh

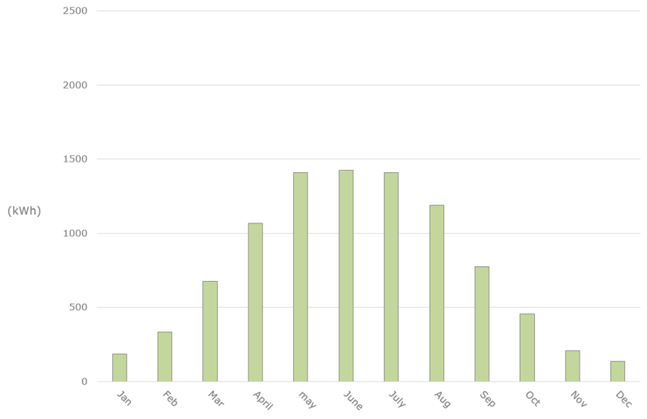
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	135	240	489	774	1023	1032	1023	863	561	329	151	98



Orientation : South
Angle : 45 C°
Panels per household : 32,5 (10,5 glass + 22 roof)
Annual electricity production : 9.264 kWh

Monthy electricity production per household in kWh

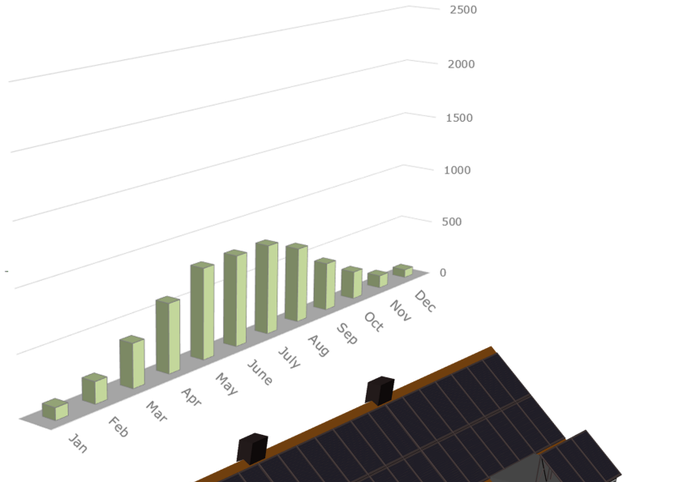
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	186	331	675	1067	1411	1423	1411	1190	773	454	208	135

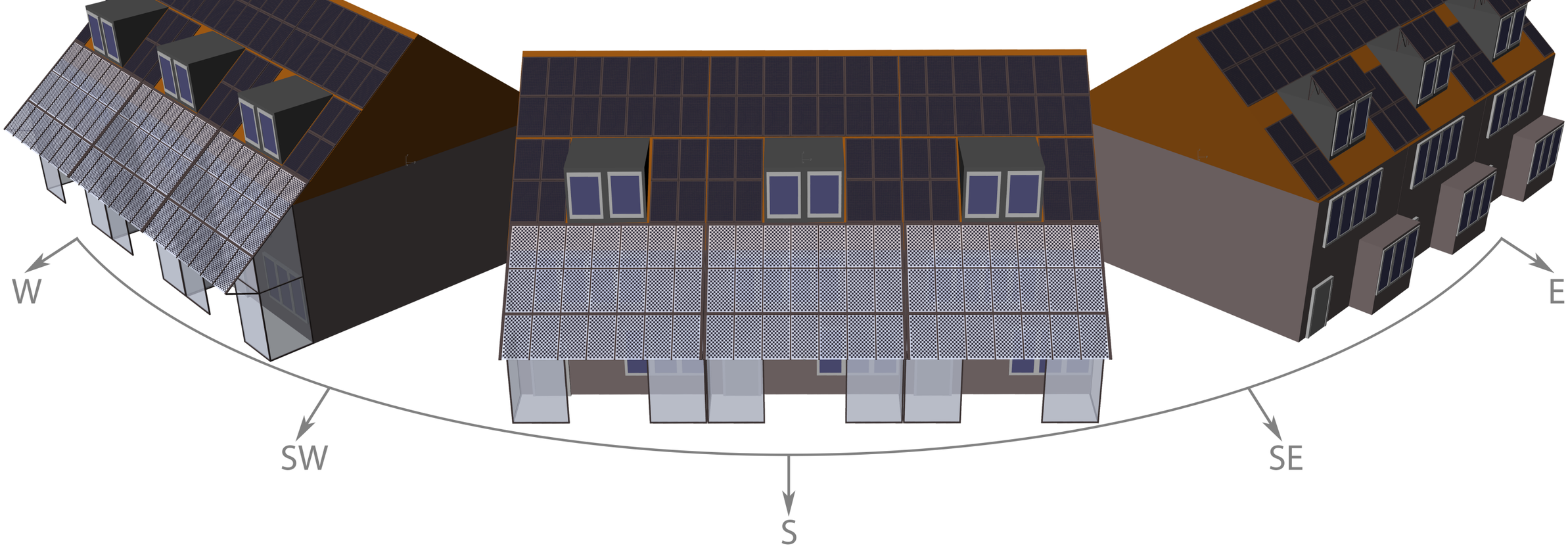


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74



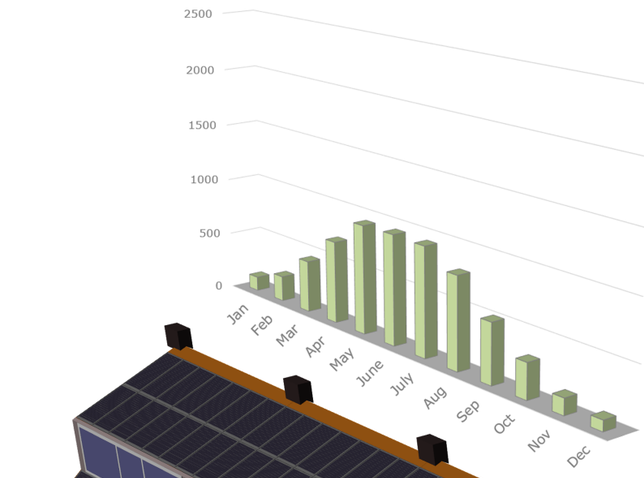


Partly refurbished

Orientation : West
Angle : 45 C°
Panels per household : 28
Annual electricity production : 6.167 kWh

Monthy electricity production per household in kWh

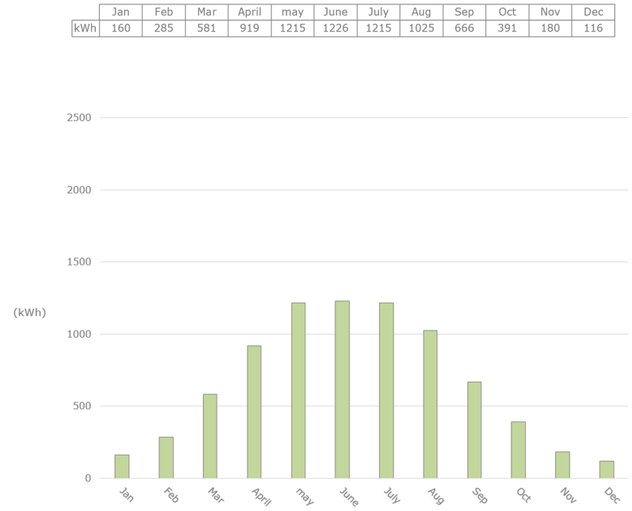
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	123	221	449	710	939	947	939	792	515	302	139	90



Orientation : South
Angle : 45 C°
Panels per household : 28
Annual electricity production : 7.981 kWh

Monthy electricity production per household in kWh

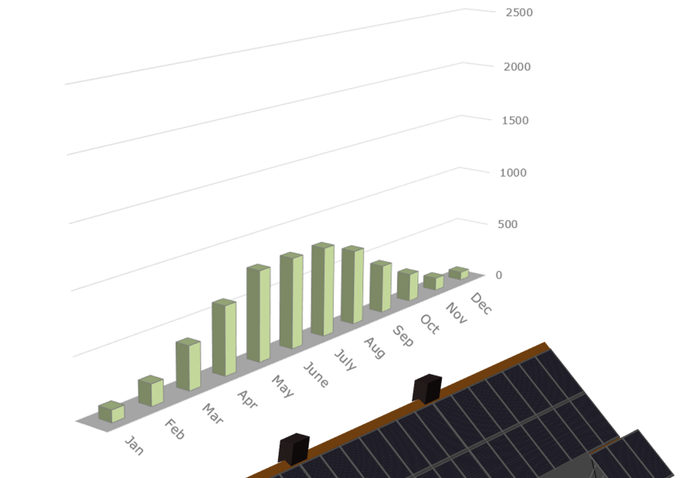
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	160	285	581	919	1215	1226	1215	1025	666	391	180	116

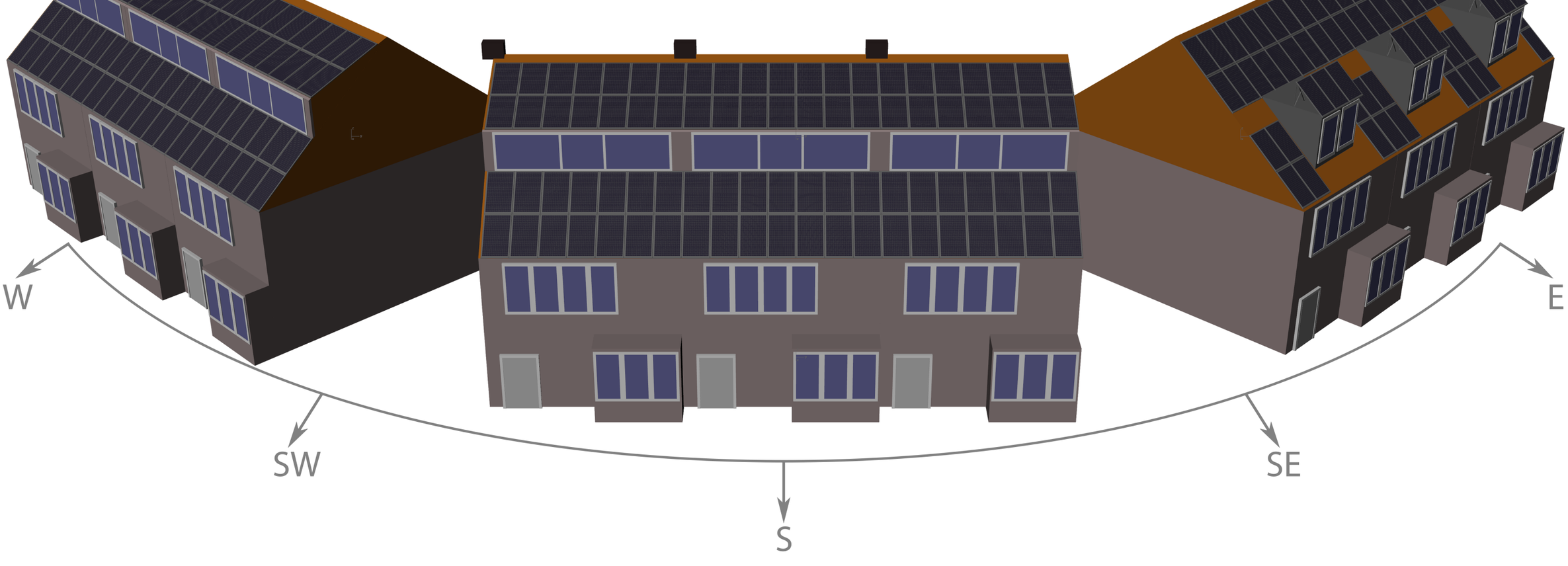


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74





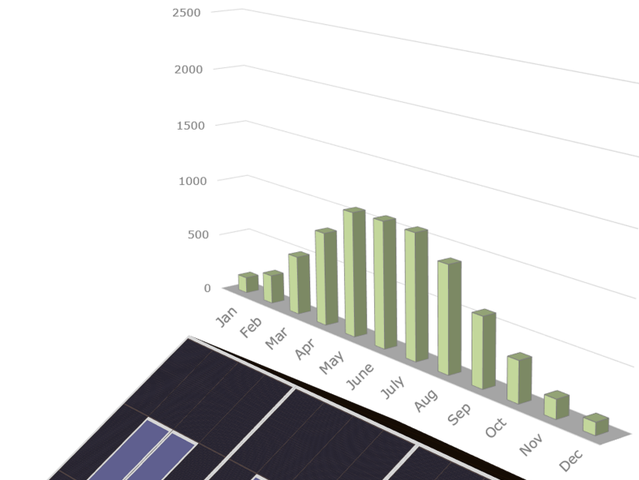
Totally refurbished:

Orientation : West
Angle : (26 x 45C°) + (8 x 90C°)
Panels per household : 34
Annual electricity production : 6.970 kWh

Monthy electricity production per household in kWh

**Solar irradiance west/east 90° = -40%*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	140	249	508	803	1061	1071	1061	895	582	342	157	102

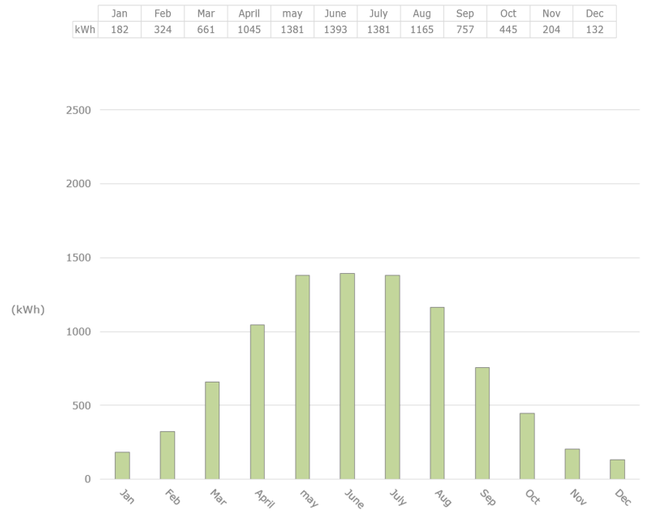


Orientation : South
Angle : (26 x 45C°) + (8 x 90C°)
Panels per household : 34
Annual electricity production : 9.069 kWh

Monthy electricity production per household in kWh

**Solar irradiance south 90° = -20%*

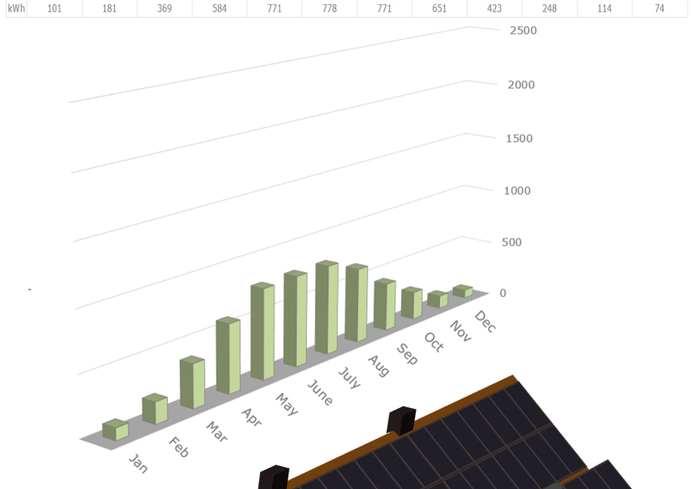
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	182	324	661	1045	1381	1393	1381	1165	757	445	204	132

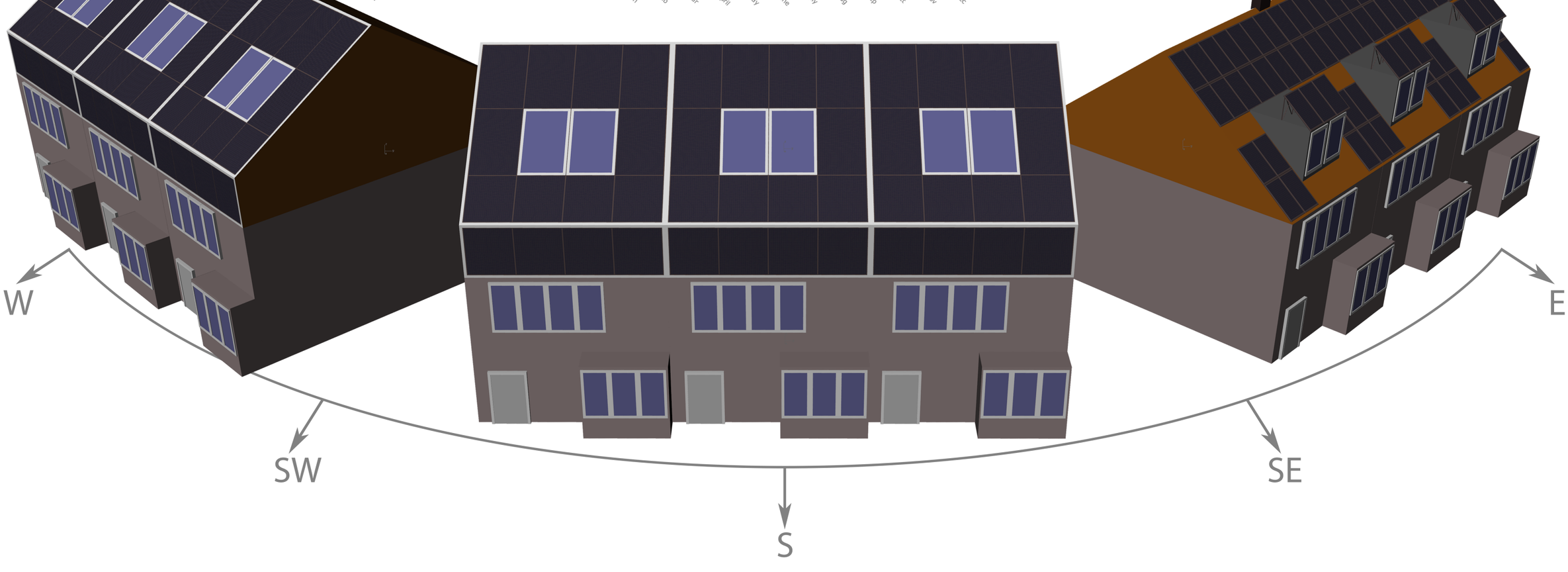


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74





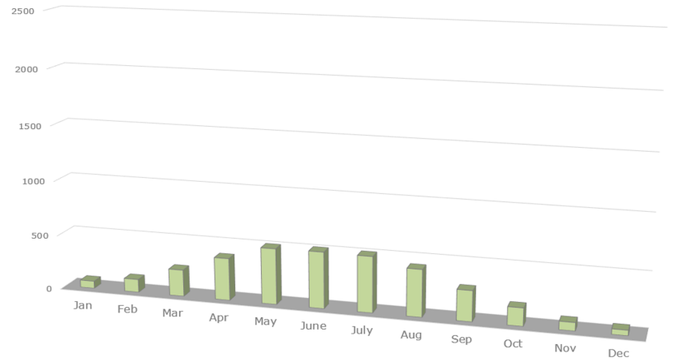
Refurbished facade:

Orientation : West
Angle : 3x 45C° 13x 90C°
Panels per household : 16
Annual electricity production : 3330 kWh

Monthy electricity production per household in kWh

**West/east (90C°) is -40% solar irradiance*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	67	119	243	384	507	512	507	428	278	163	75	49

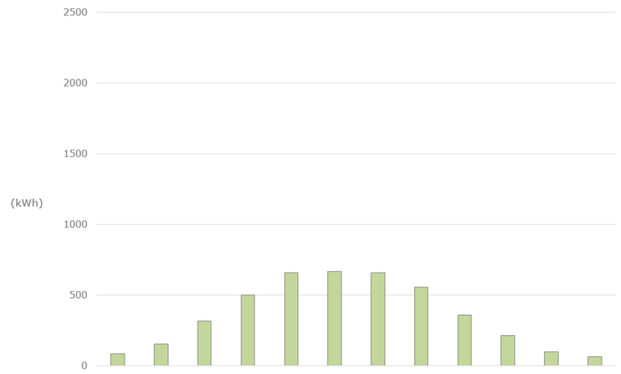


Orientation : South
Angle : 3x 45C° 13x 90C°
Panels per household : 16
Annual electricity production : 4327 kWh

Monthy electricity production per household in kWh

**South (90C°) is -20% solar irradiance*

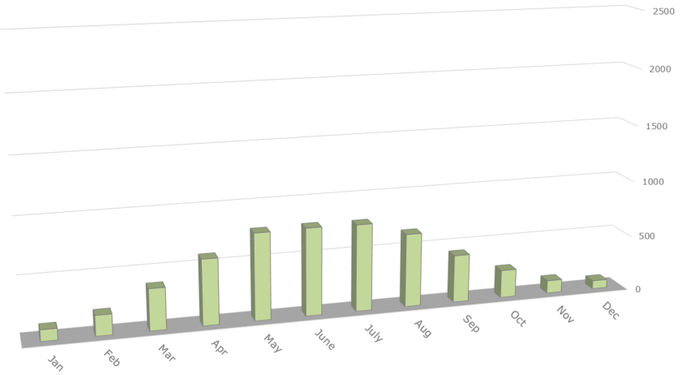
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	87	155	315	498	659	665	659	556	361	212	97	63

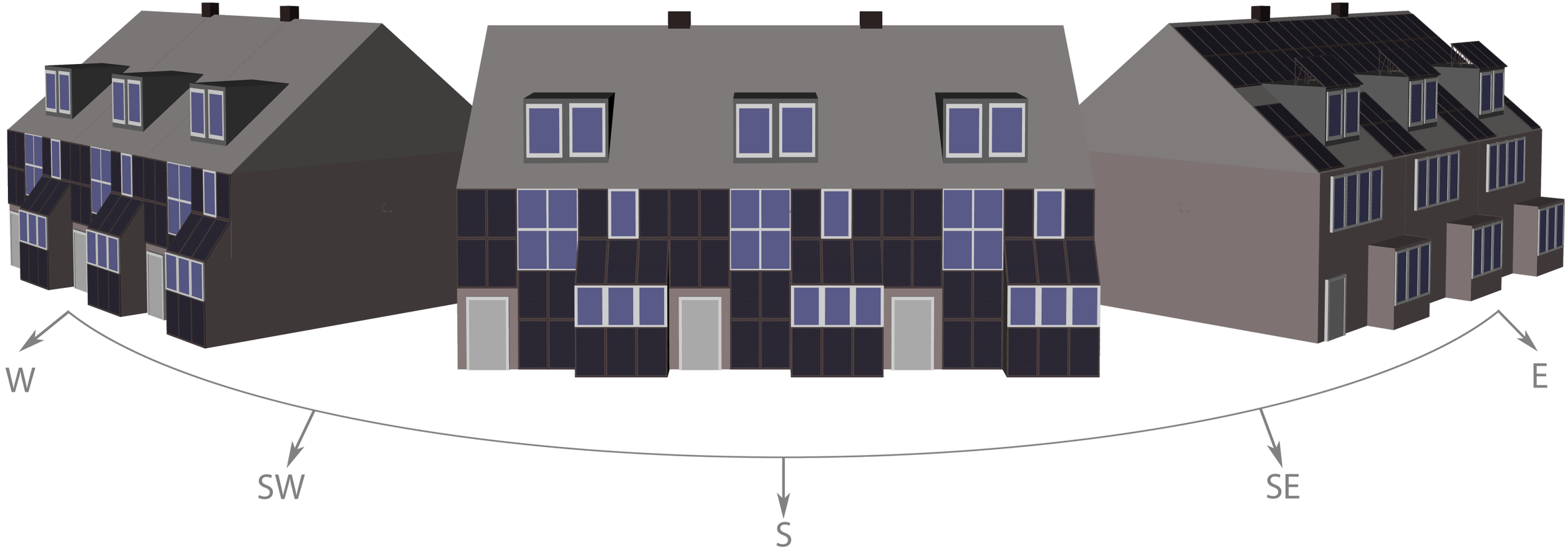


Orientation : East
Angle : 45 C°
Panels per household : 23
Annual electricity production : 5.066 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	101	181	369	584	771	778	771	651	423	248	114	74



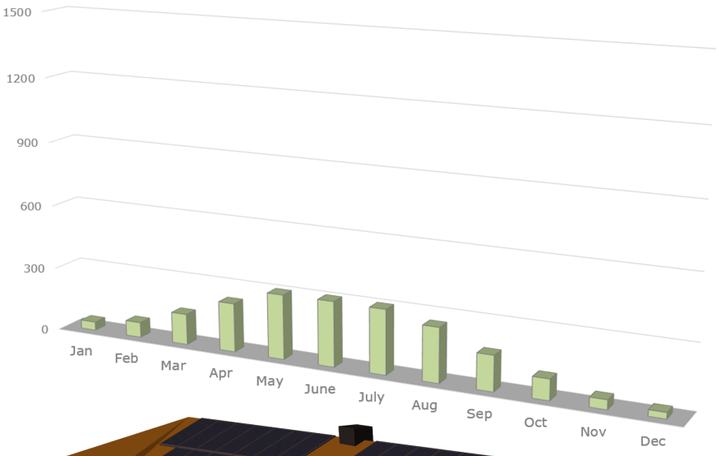


Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 9
Annual electricity production : 1.982 kWh

Monthy electricity production per household in kWh

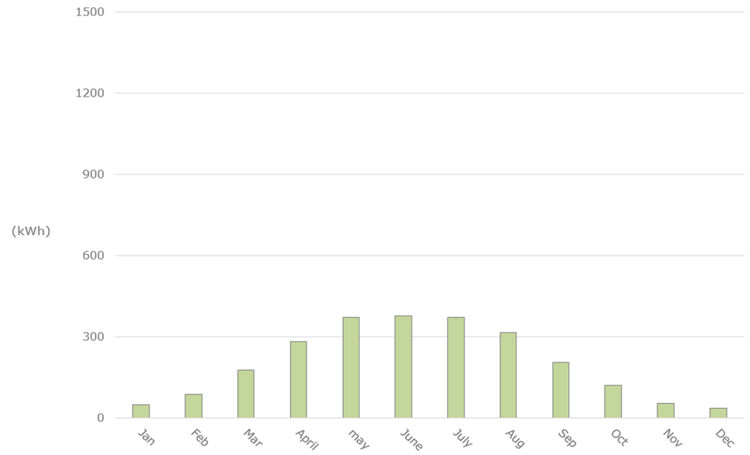
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	40	71	144	228	302	305	302	255	165	97	45	29

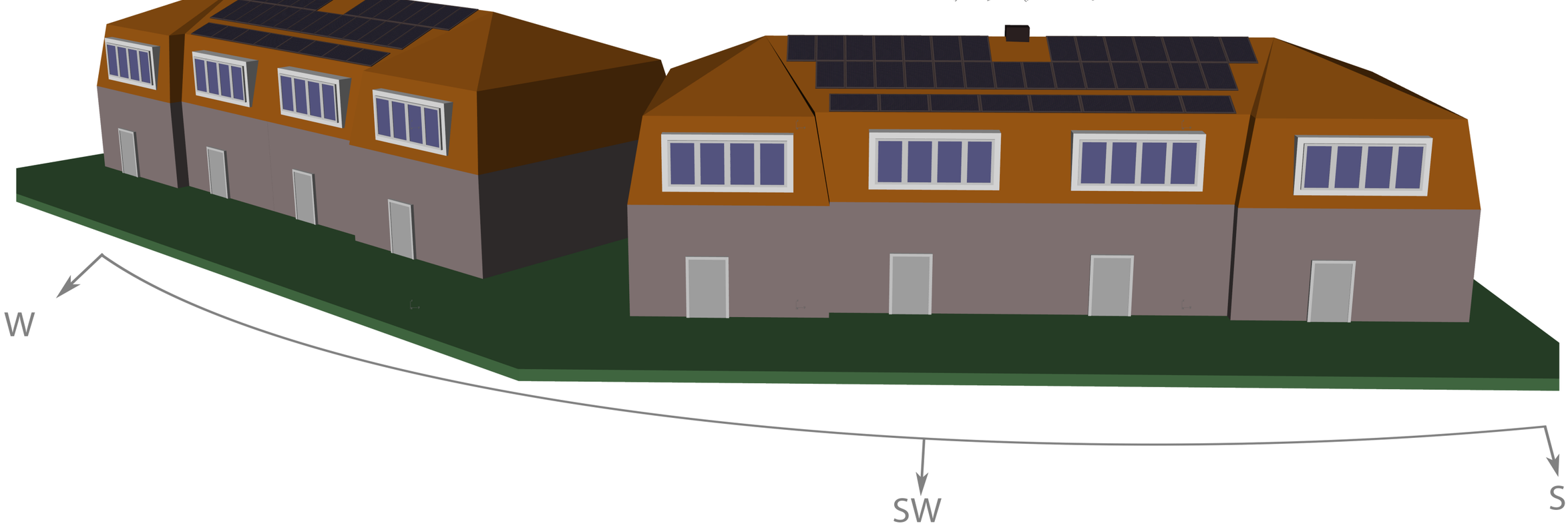


Orientation : South-west
Angle : 45 C°
Panels per household : 9
Annual electricity production : 2.449 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	49	88	178	282	373	376	373	315	204	120	55	36



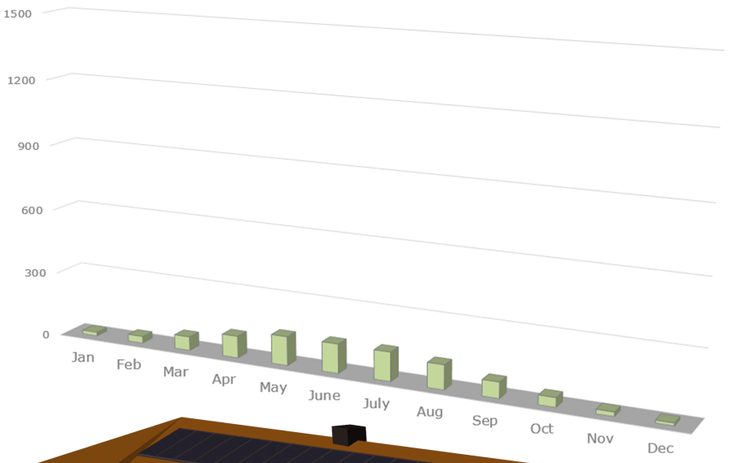


Minor visual impact:

Orientation ***: West***
Angle ***: 45 C°***
Panels per household ***: 4***
Annual electricity production ***: 881 kWh***

Monthy electricity production per household in kWh

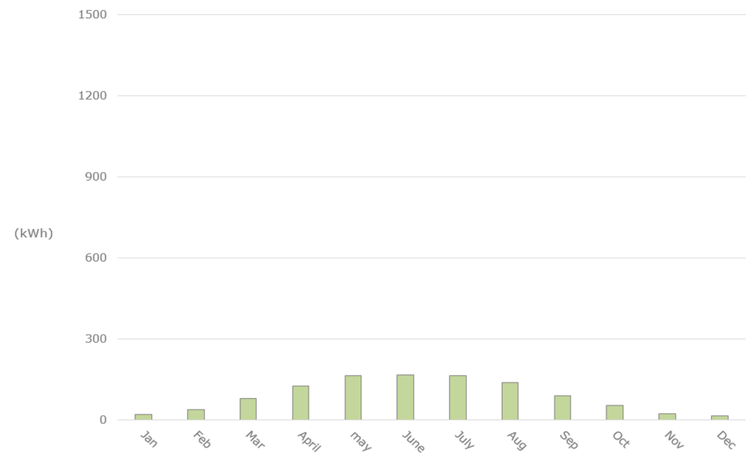
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	18	32	64	101	134	135	134	113	74	43	20	13

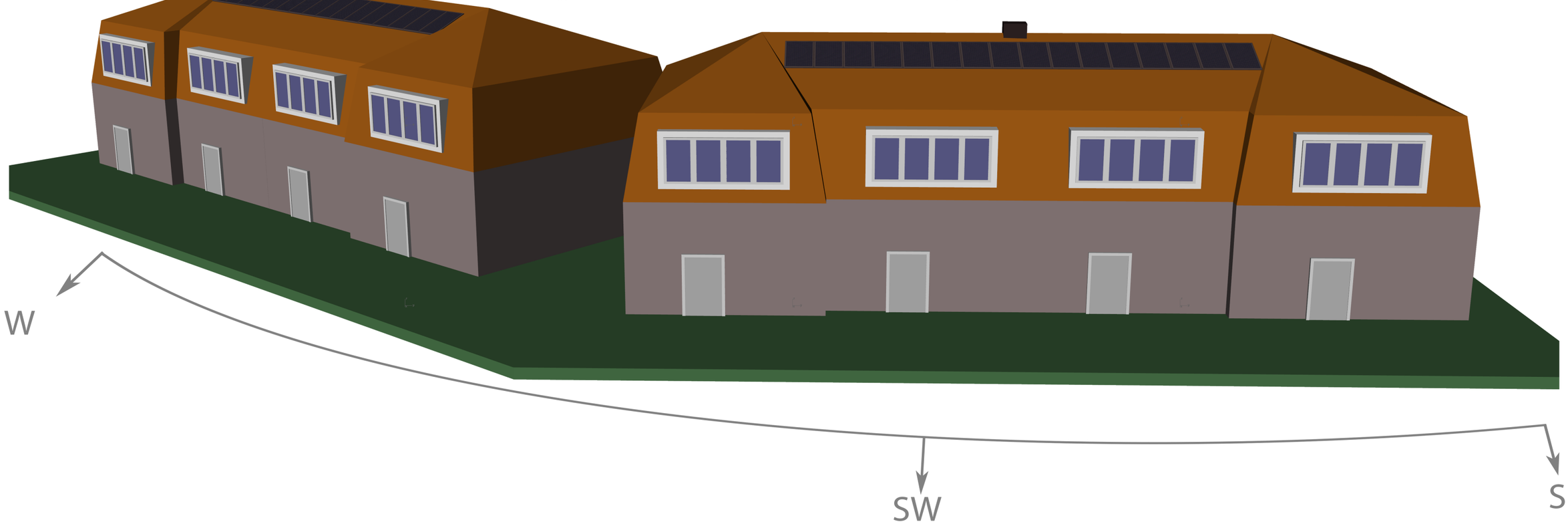


Orientation ***: South-west***
Angle ***: 45 C°***
Panels per household ***: 4***
Annual electricity production ***: 1.088 kWh***

Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	22	39	79	125	166	167	166	140	91	53	24	16



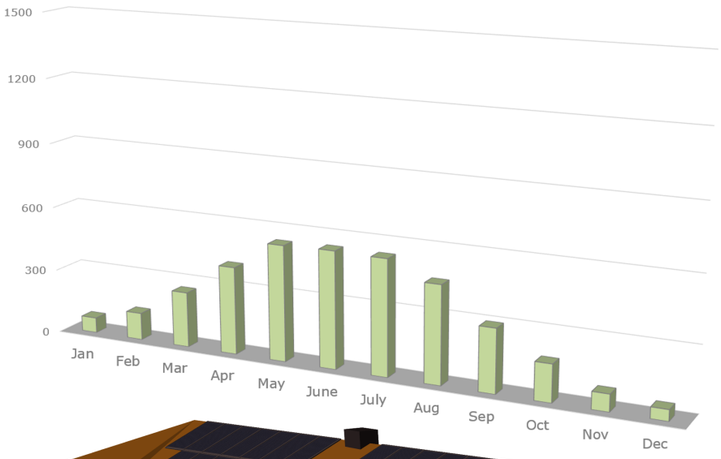


Building extention:

Orientation	*: West*
Angle	*: 45 C°*
Panels per household	*: 7 (glass) + 9 (roof)*
Annual electricity production	*: 3.524 kWh*

Monthy electricity production per household in kWh

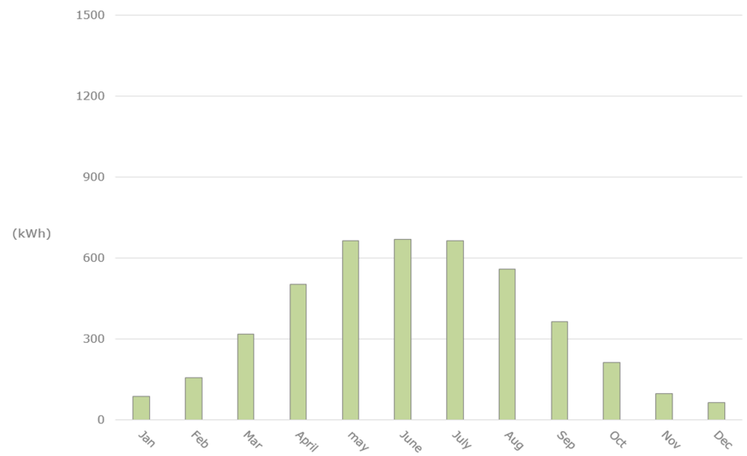
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	71	126	257	406	537	541	537	453	294	173	79	51

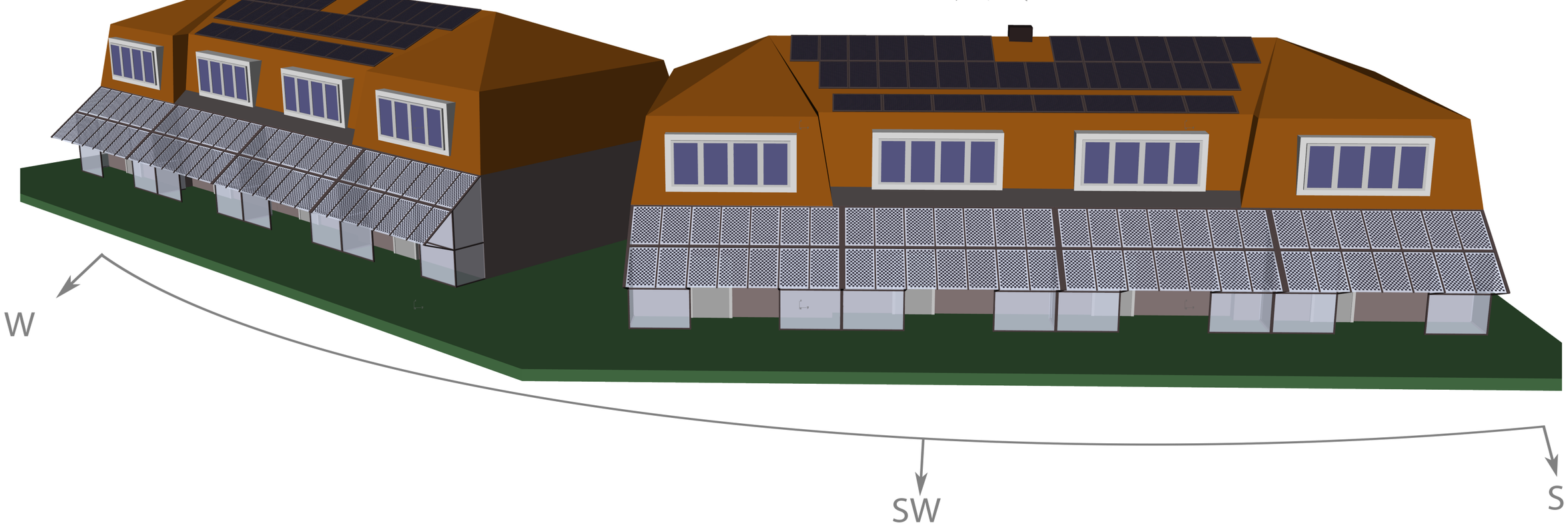


Orientation	*: South-west*
Angle	*: 45 C°*
Panels per household	*: 7 (glass) + 9 (roof)*
Annual electricity production	*: 4.353 kWh*

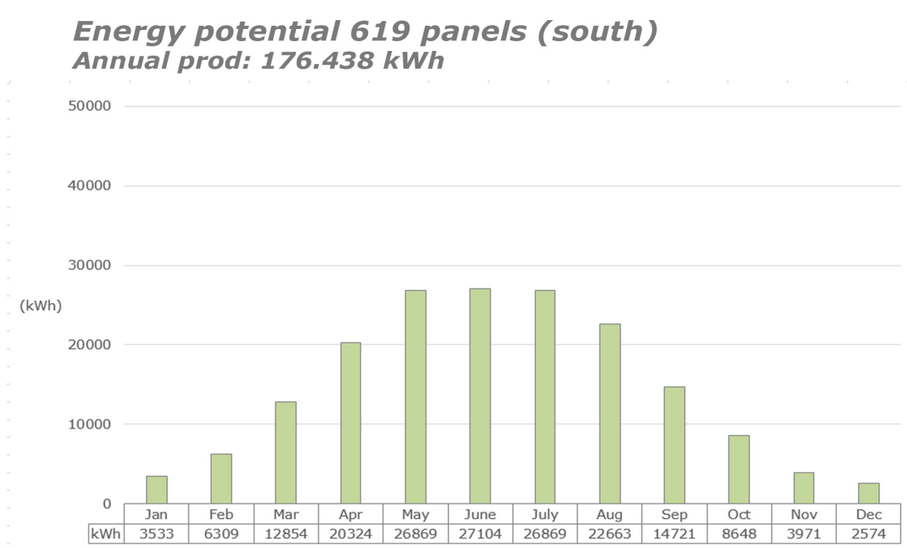
Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	87	156	317	501	663	669	663	559	363	213	98	64





Maximum potential:

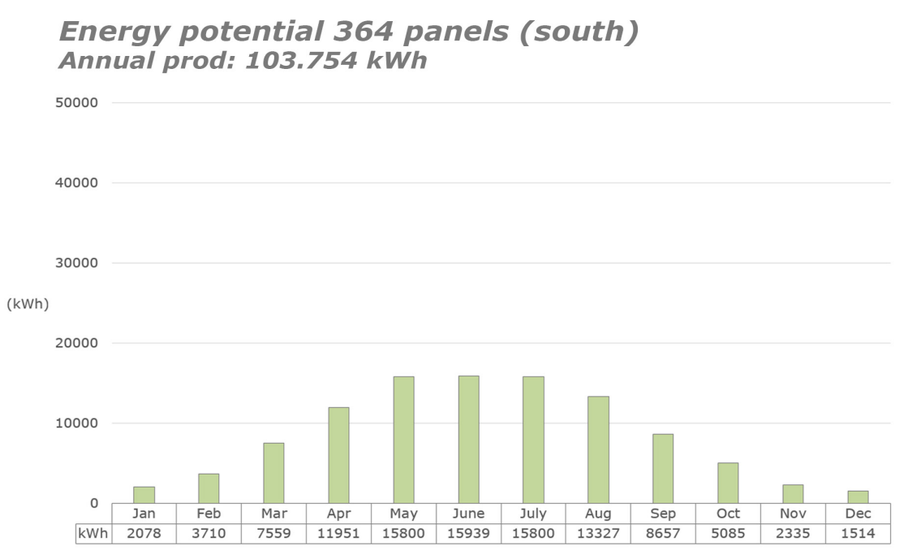






Si-Monocrystalline solar panel

Potential considering vegetation:



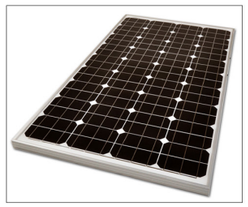




Si-Monocrystalline solar panel

Maximum potential:

Si-Monocrystalline solar panel

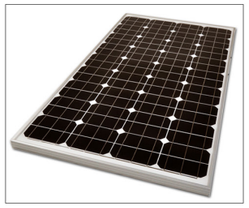


Energy potential 1100 panels (south)
Annual prod: 313.541 kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	4852	8664	17651	27909	36896	37219	36896	31120	20215	11875	5452	3535

Potential considering vegetation:

Si-Monocrystalline solar panel

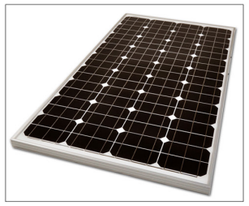


Energy potential 521 panels (south)
Annual prod: 148.505 kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	2298	4103	8360	13218	17475	17628	17475	14739	9575	5624	2582	1674

Maximum potential:

Si-Monocrystalline solar panel



Energy potential 420 panels (south)
Annual prod: 119.716 kWh

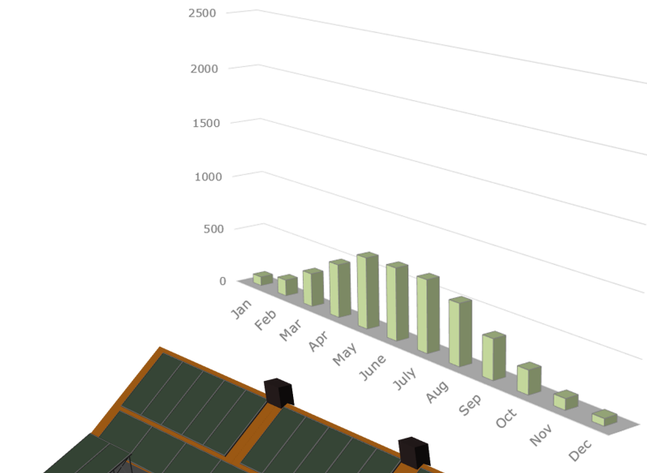
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	2298	4103	8360	13218	17475	17628	17475	14739	9575	5624	2582	1674

Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4.136 kWh

Monthy electricity production per household in kWh

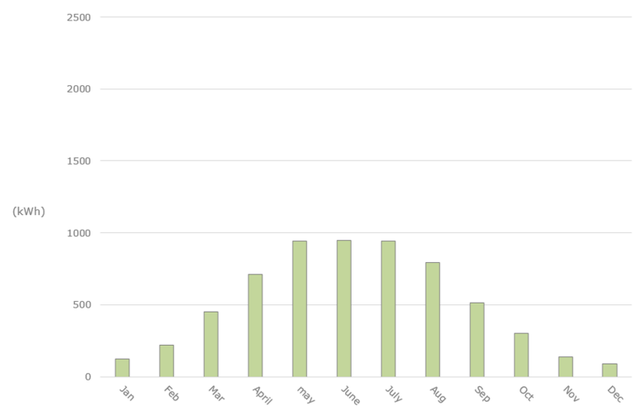
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60



Orientation : South
Angle : 45 C°
Panels per household : 15
Annual electricity production : 6.176 kWh

Monthy electricity production per household in kWh

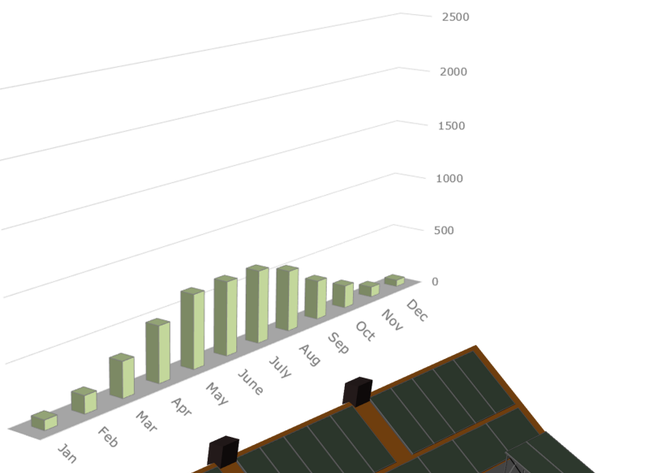
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	124	221	450	711	940	949	940	793	515	303	139	90

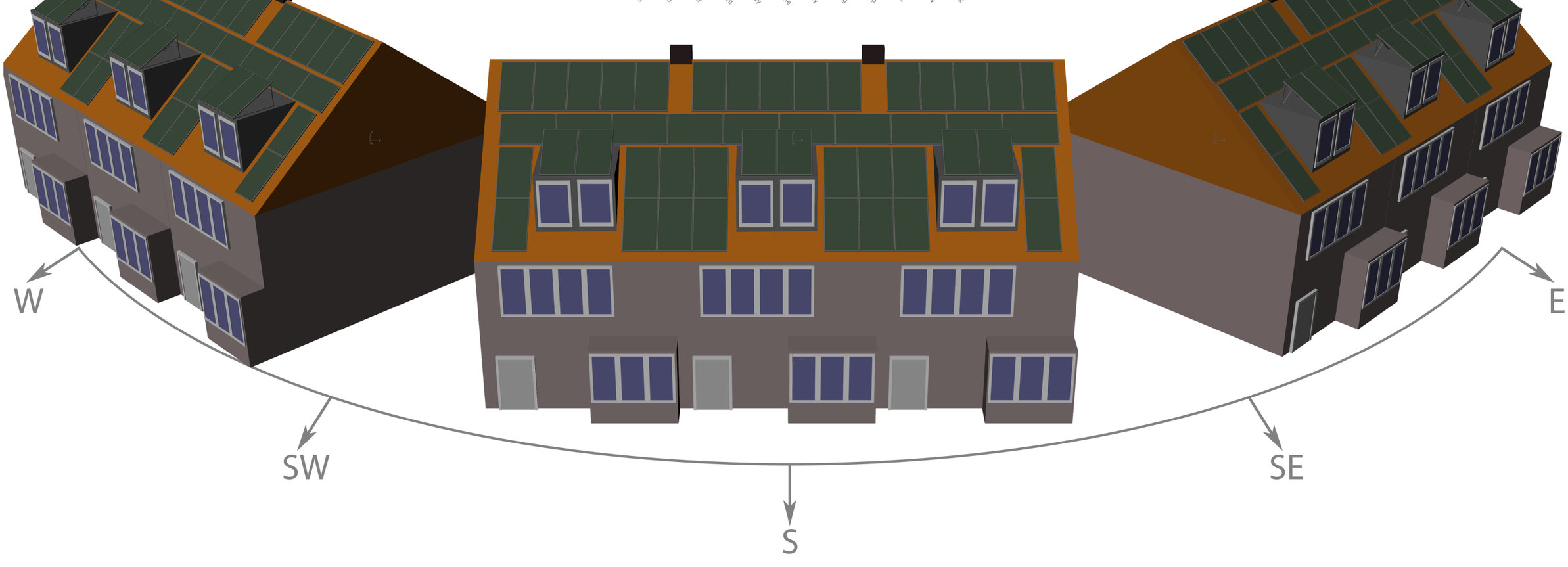


Orientation : East
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4.136 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60



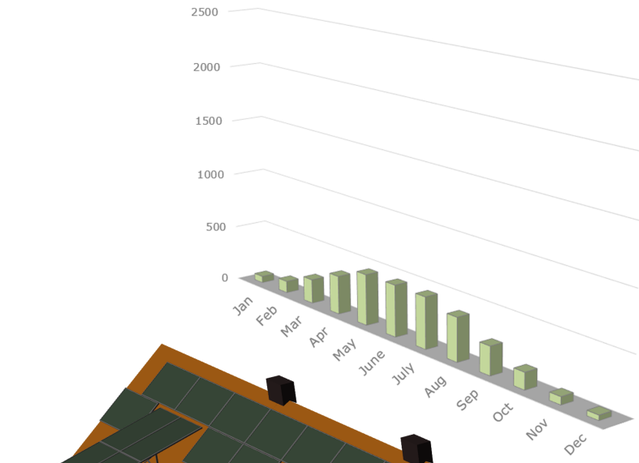


Minor visual impact:

Orientation : West
Angle : 45 C°
Panels per household : 9,33
Annual electricity production : 2.968 kWh

Monthy electricity production per household in kWh

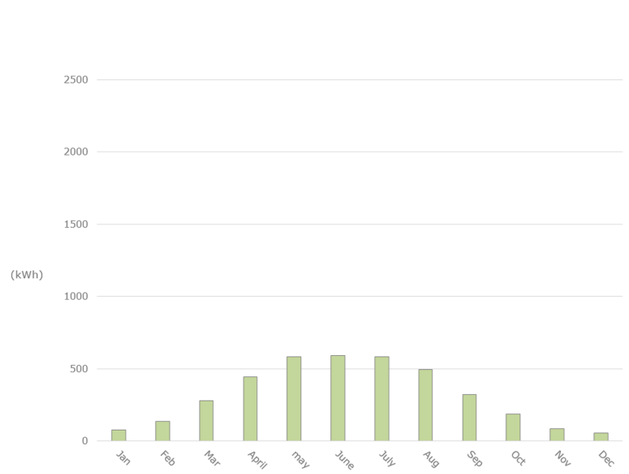
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	59	106	216	342	452	456	452	381	248	145	67	43



Orientation : South
Angle : 45 C°
Panels per household : 9,33
Annual electricity production : 3.841 kWh

Monthy electricity production per household in kWh

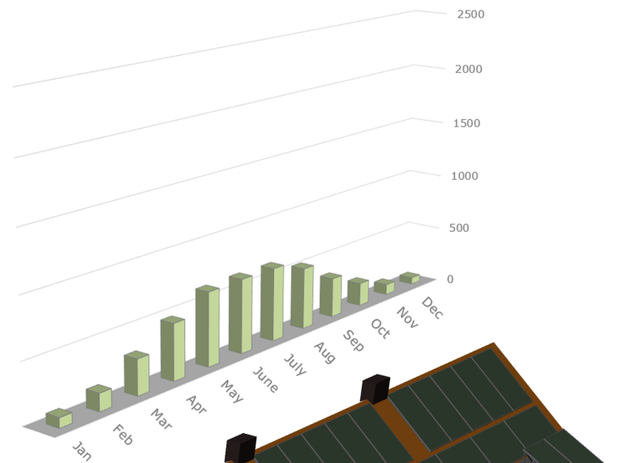
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	77	137	280	442	585	590	585	493	321	188	86	56

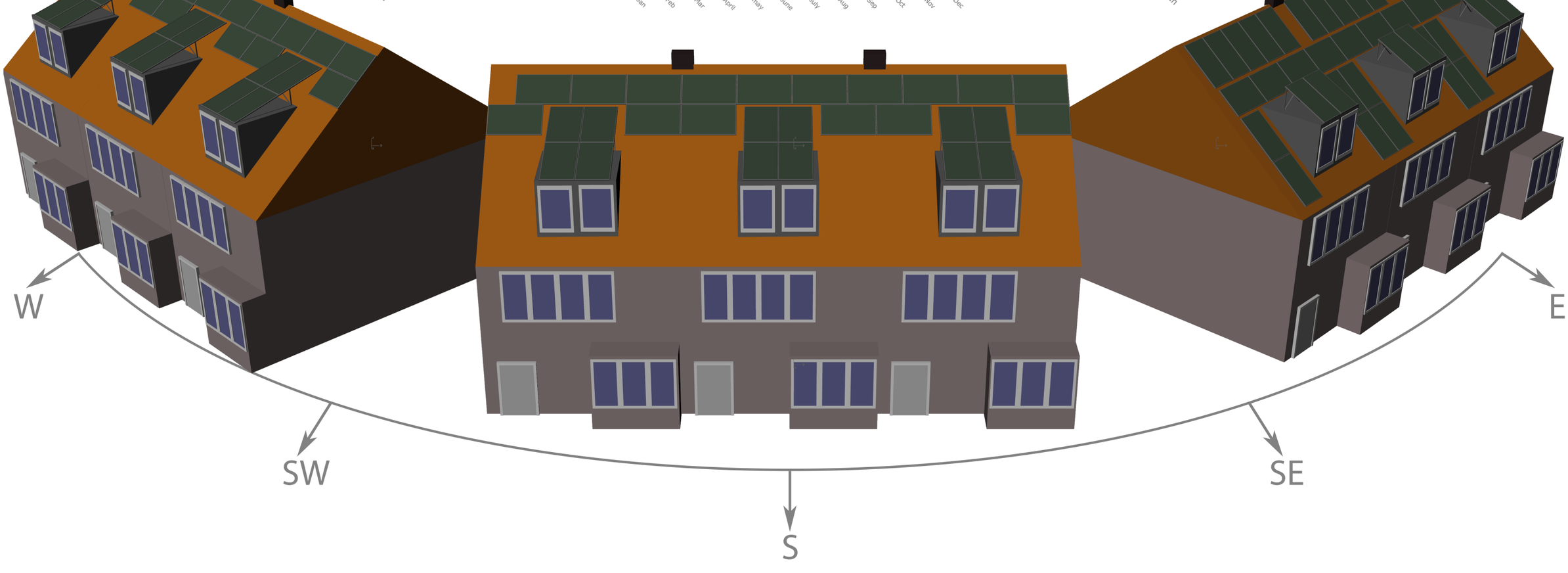


Orientation : East
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4.136 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60



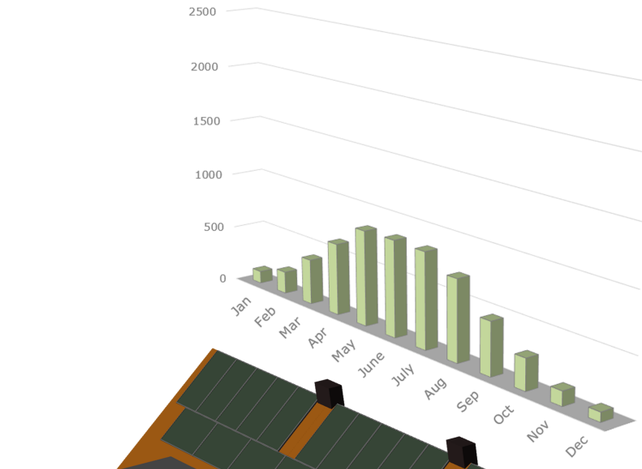


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 17,33
Annual electricity production : 5.514 kWh

Monthy electricity production per household in kWh

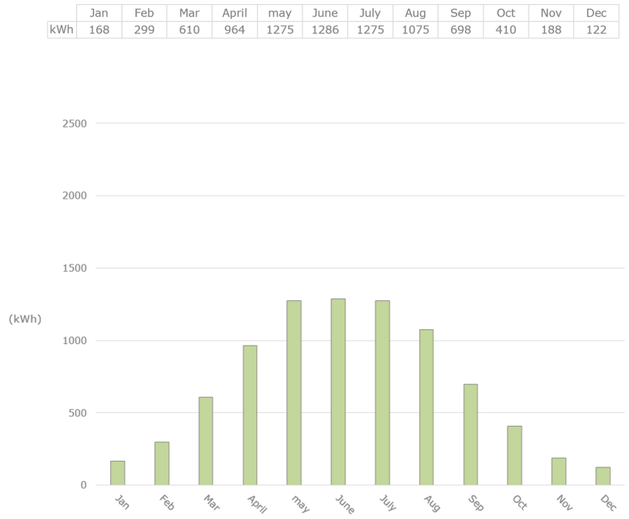
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	110	197	402	635	840	847	840	708	460	270	124	80



Orientation : South
Angle : 45 C°
Panels per household : 20,33
Annual electricity production : 8.370 kWh

Monthy electricity production per household in kWh

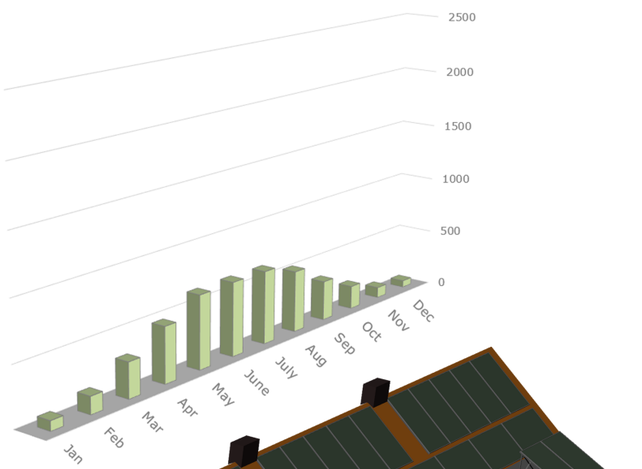
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	168	299	610	964	1275	1286	1275	1075	698	410	188	122

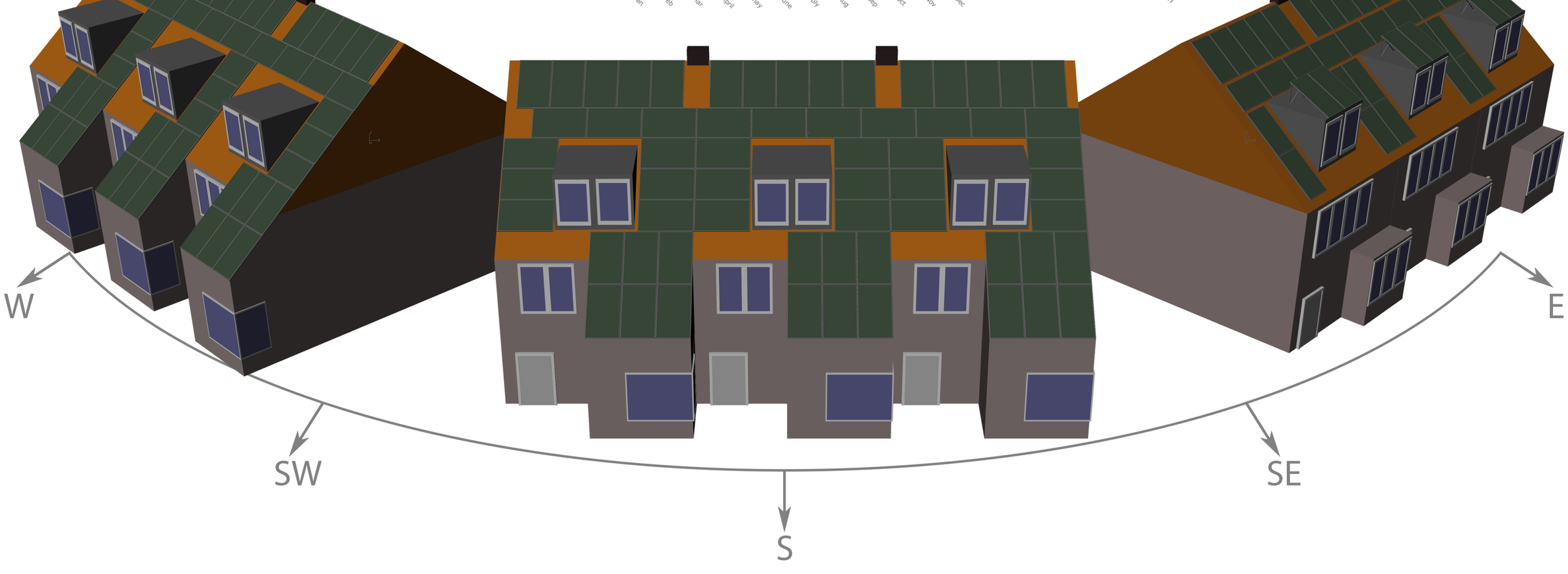


Orientation : East
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4.136 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60



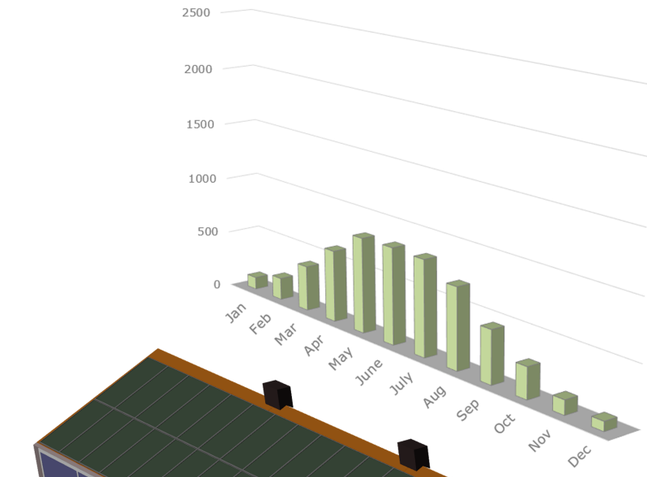


Partly refurbished:

Orientation : West
Angle : 45 C°
Panels per household : 17
Annual electricity production : 5.409 kWh

Monthy electricity production per household in kWh

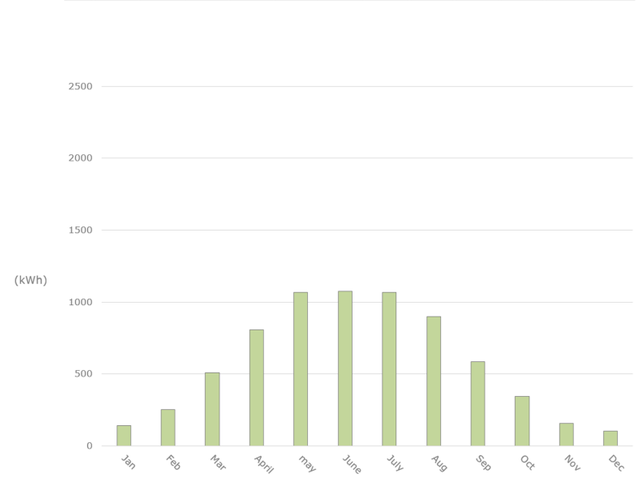
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	108	193	394	623	824	831	824	695	451	265	122	79



Orientation : South
Angle : 45 C°
Panels per household : 17
Annual electricity production : 6.999 kWh

Monthy electricity production per household in kWh

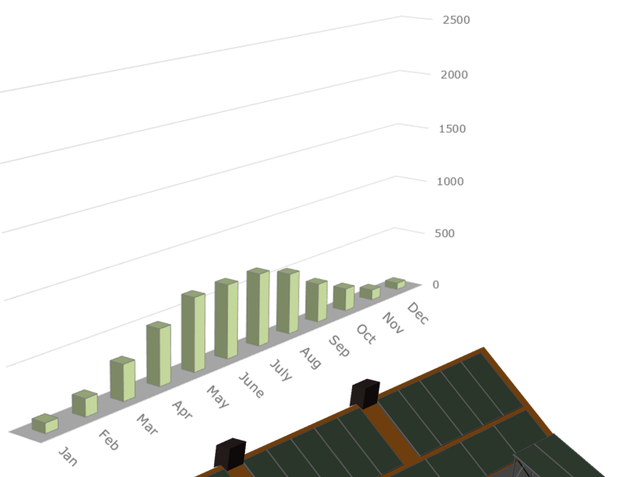
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	140	250	510	806	1066	1075	1066	899	584	343	158	102

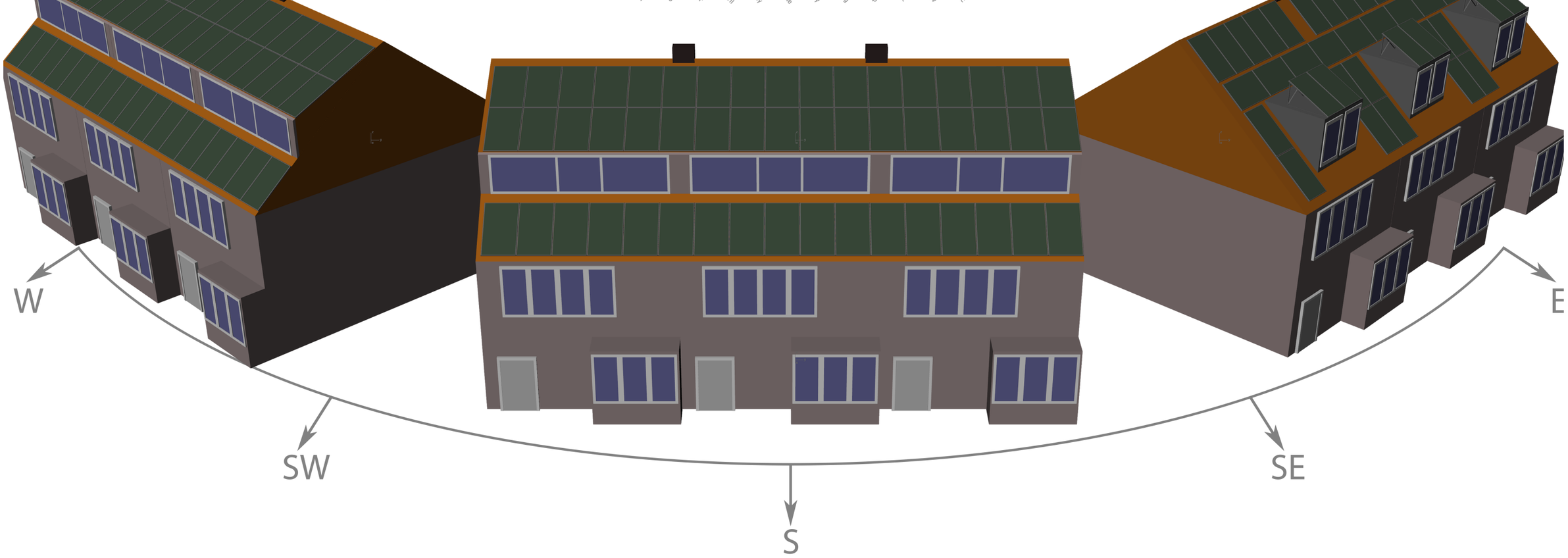


Orientation : East
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4.136 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60





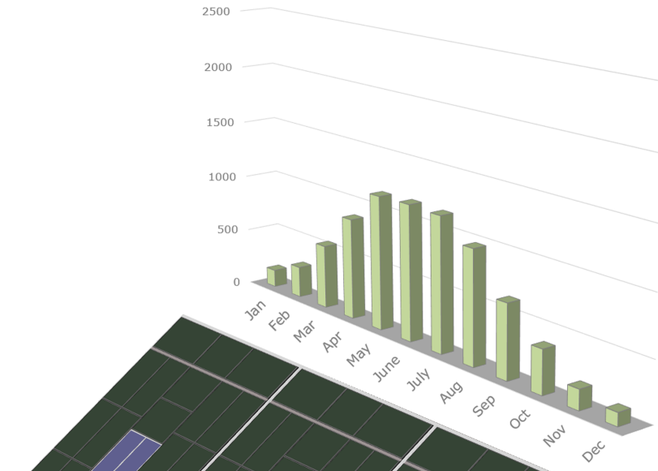
Totally refurbished:

Orientation ***: West***
Angle ***: (20 x 45C°) + (5,5 x 90C°)***
Panels per household ***: 25,5***
Annual electricity production ***: 7.598 kWh***

Monthy electricity production per household in kWh

****Solar irradiance west/east 90° = -40%***

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	152	272	554	875	1157	1167	1157	976	634	372	171	111

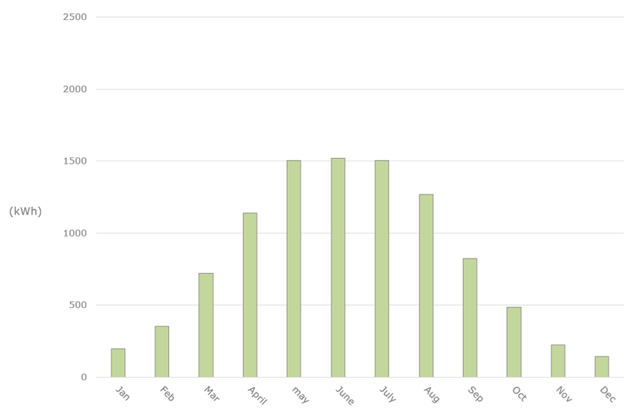


Orientation ***: South***
Angle ***: (20 x 45C°) + (5,5 x 90C°)***
Panels per household ***: 25,5***
Annual electricity production ***: 9.881 kWh***

Monthy electricity production per household in kWh

****Solar irradiance south 90° = -20%***

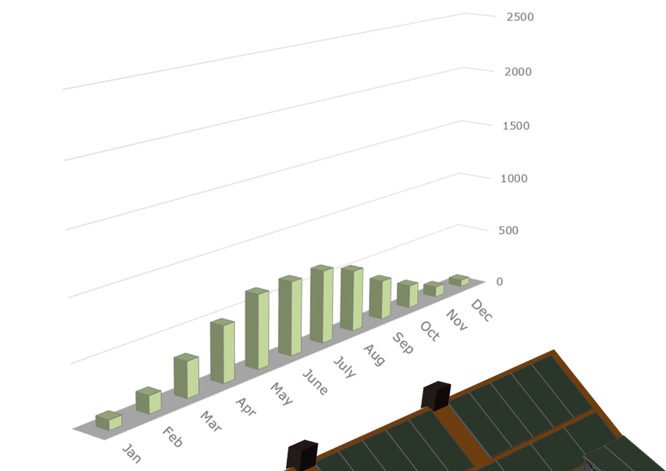
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	198	353	720	1138	1505	1518	1505	1269	824	484	222	144

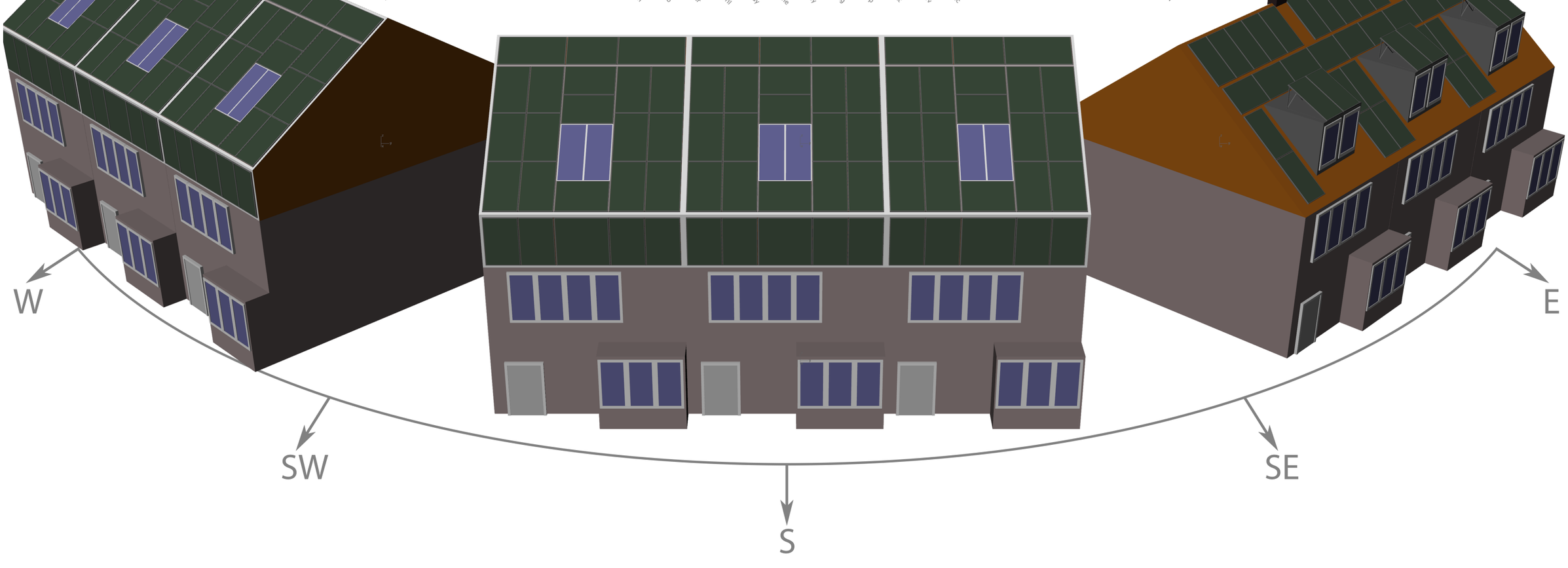


Orientation ***: East***
Angle ***:45 C°***
Panels per household ***: 13***
Annual electricity production ***: 4.136 kWh***

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60





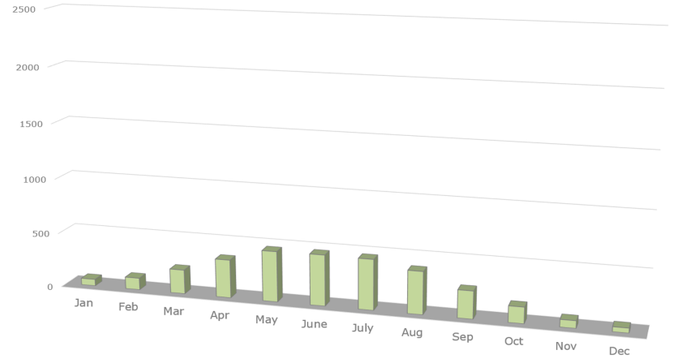
Refurbished roof:

Orientation : West
Angle : 1x 45C° 9x 90C°
Panels per household : 10
Annual electricity production : 3019 kWh

Monthy electricity production per household in kWh

**West/east (90C°) is -40% solar irradiance*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	60	108	220	348	460	464	460	388	252	148	68	44

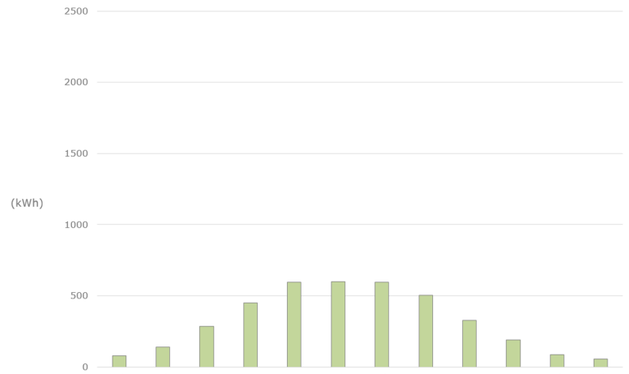


Orientation :South
Angle : 1x 45C° 9x 90C°
Panels per household : 10
Annual electricity production : 3913 kWh

Monthy electricity production per household in kWh

**South (90C°) is -20% solar irradiance*

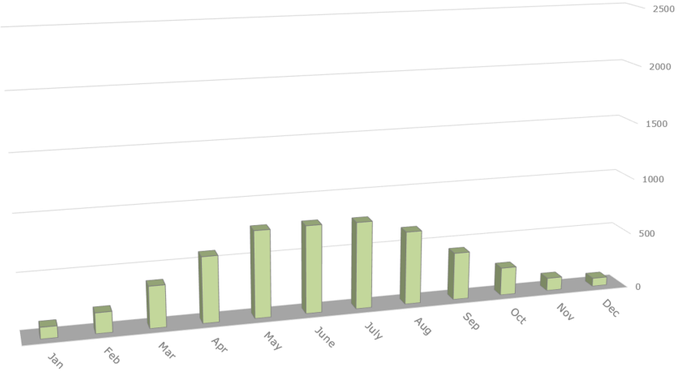
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	78	140	285	451	596	601	596	503	326	192	88	57

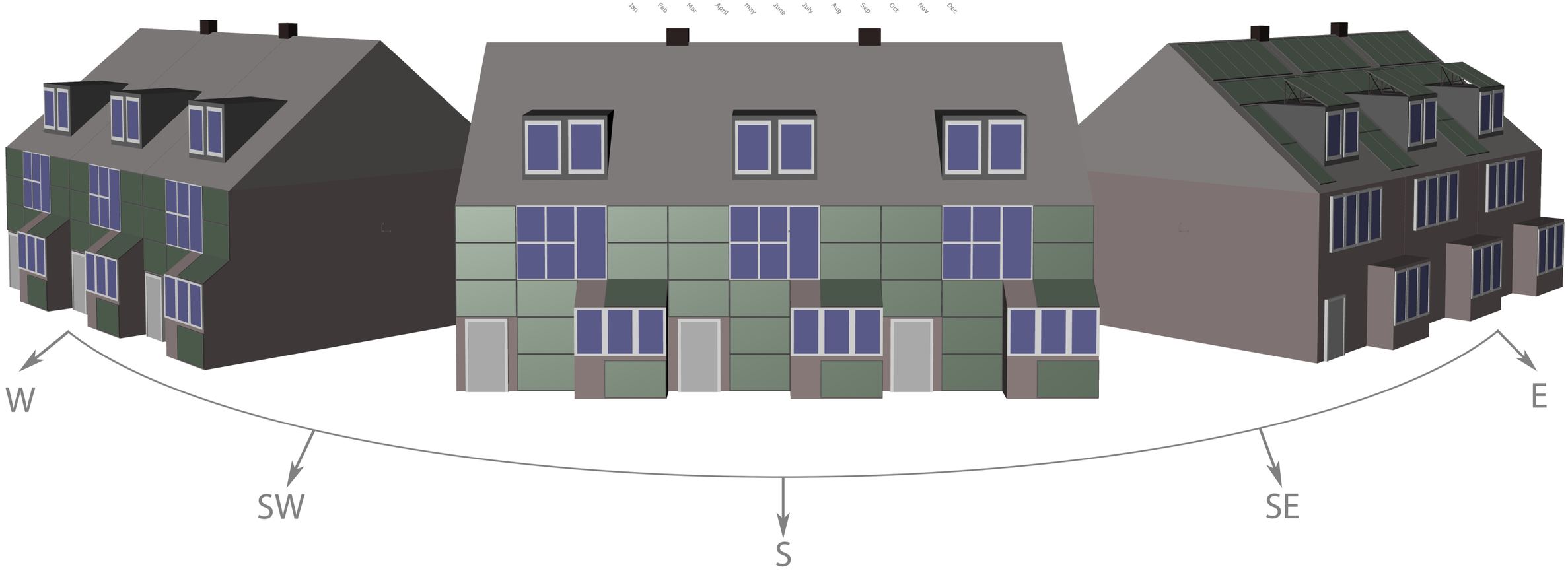


Orientation : East
Angle : 45 C°
Panels per household : 13
Annual electricity production : 4136 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	83	148	301	476	630	635	630	531	345	203	93	60



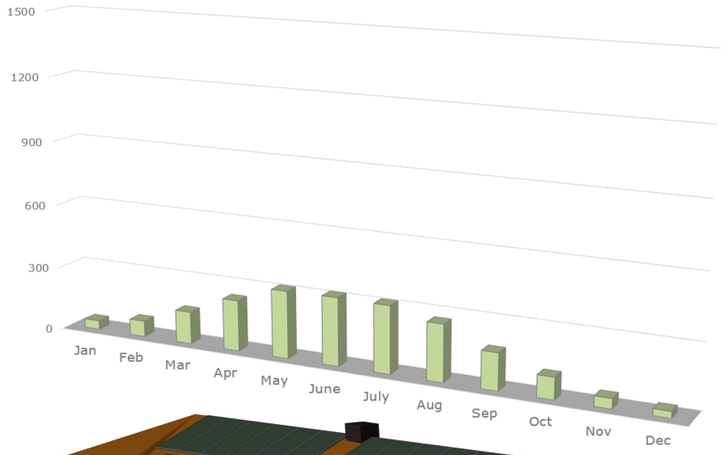


Commonly applied placement of panels on roofs:

Orientation : West
Angle : 45 C°
Panels per household : 6,5
Annual electricity production : 2.068 kWh

Monthy electricity production per household in kWh

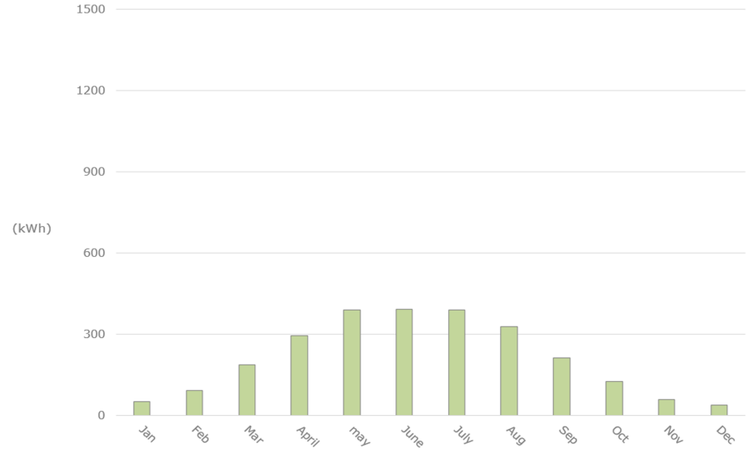
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	41	74	151	238	315	318	315	266	173	101	47	30

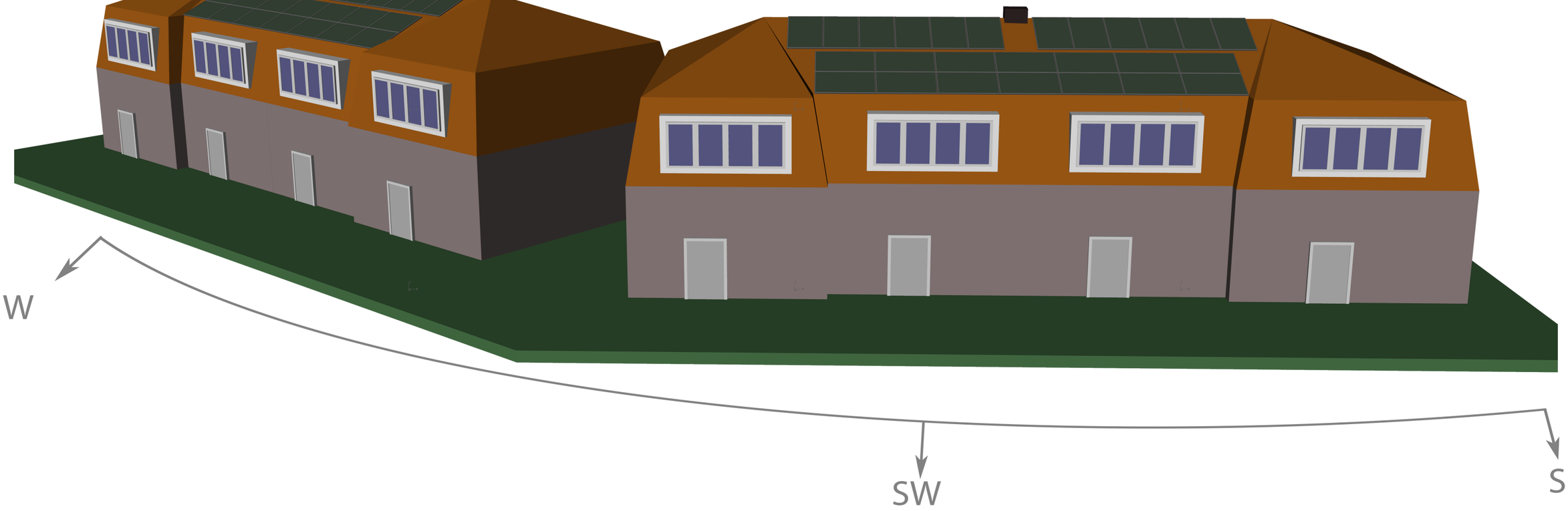


Orientation : South-west
Angle : 45 C°
Panels per household : 6,5
Annual electricity production : 2.555 kWh

Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	51	91	186	294	389	392	389	328	213	125	57	37



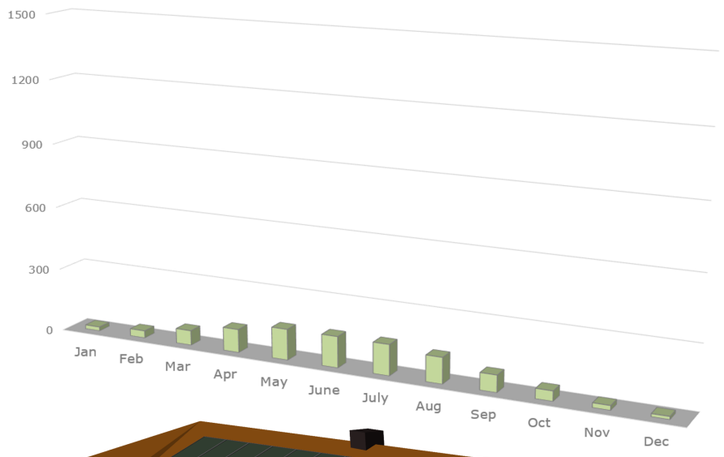


Minor visual impact:

Orientation	***: West***
Angle	***: 45 C°***
Panels per household	***: 3***
Annual electricity production	***: 954 kWh***

Monthy electricity production per household in kWh

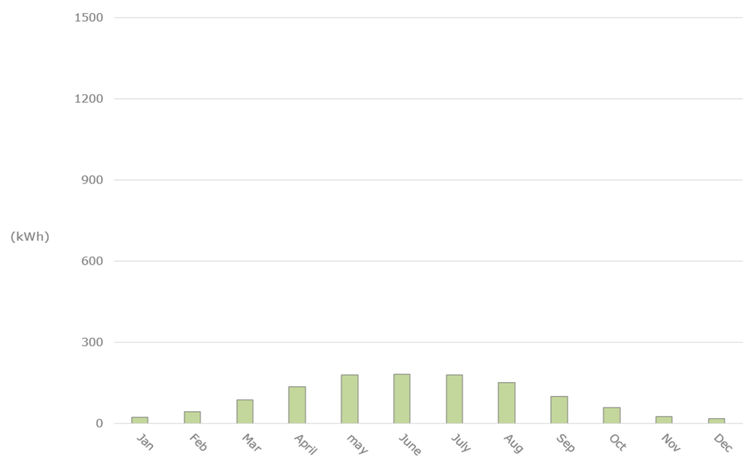
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	19	34	70	110	145	147	145	123	80	47	21	14

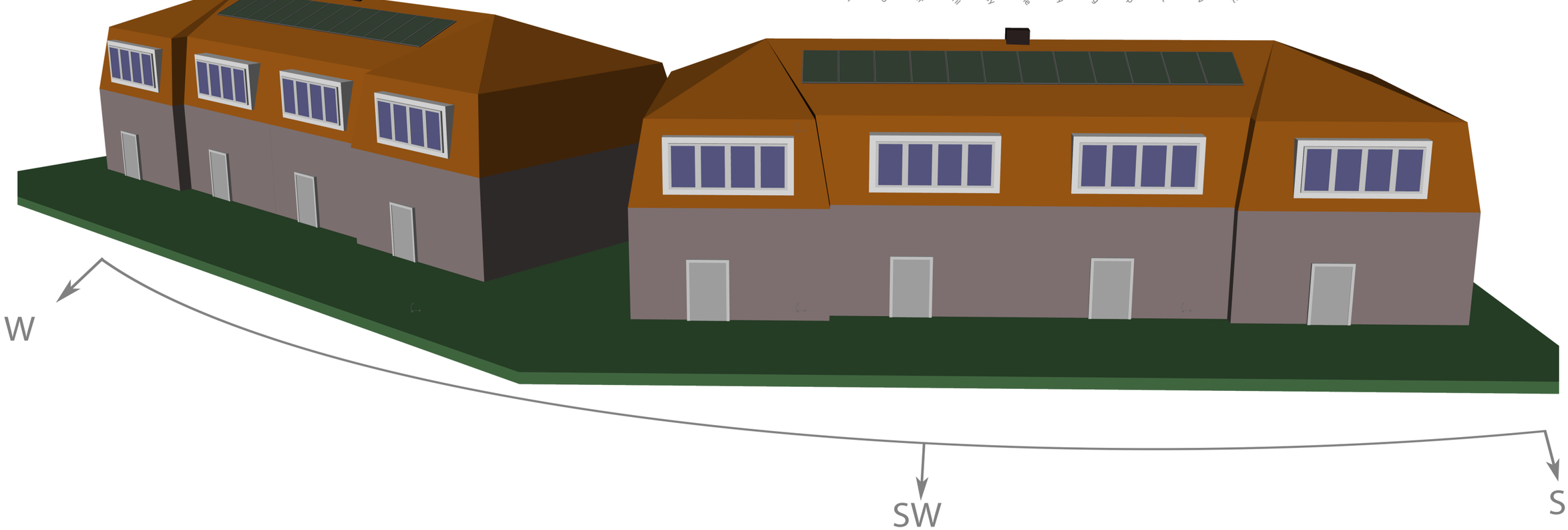


Orientation	***: South-west***
Angle	***: 45 C°***
Panels per household	***: 3***
Annual electricity production	***: 1.179 kWh***

Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	24	42	86	136	180	181	180	151	98	58	27	17



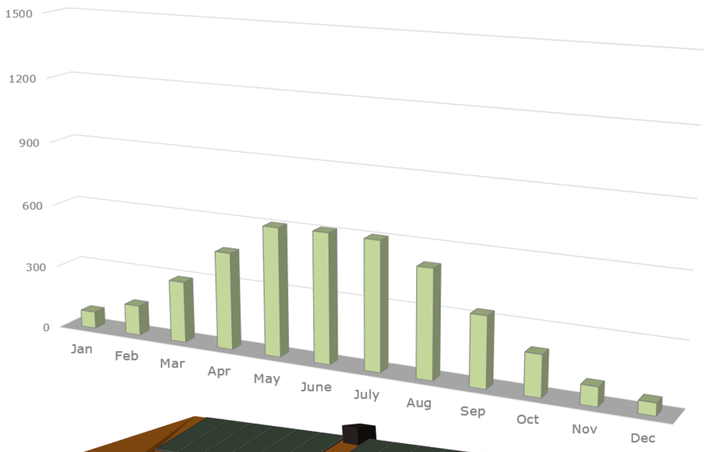


Building extention:

Orientation : West
Angle : 45 C°
Panels per household : 12,5
Annual electricity production : 3.977 kWh

Monthy electricity production per household in kWh

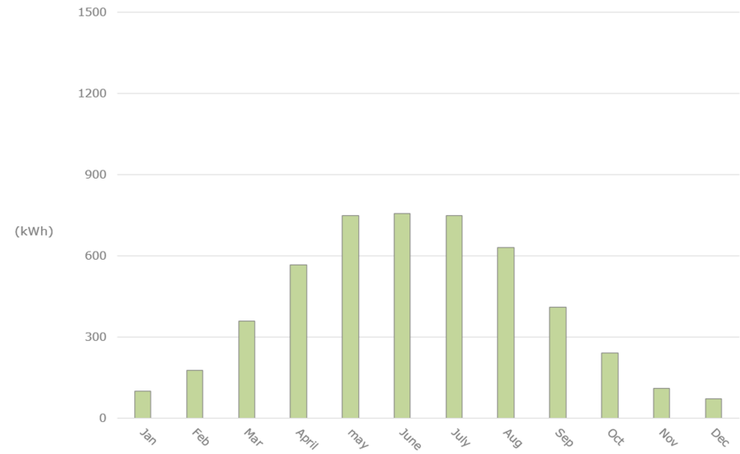
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	80	142	290	458	606	611	606	511	332	195	89	58

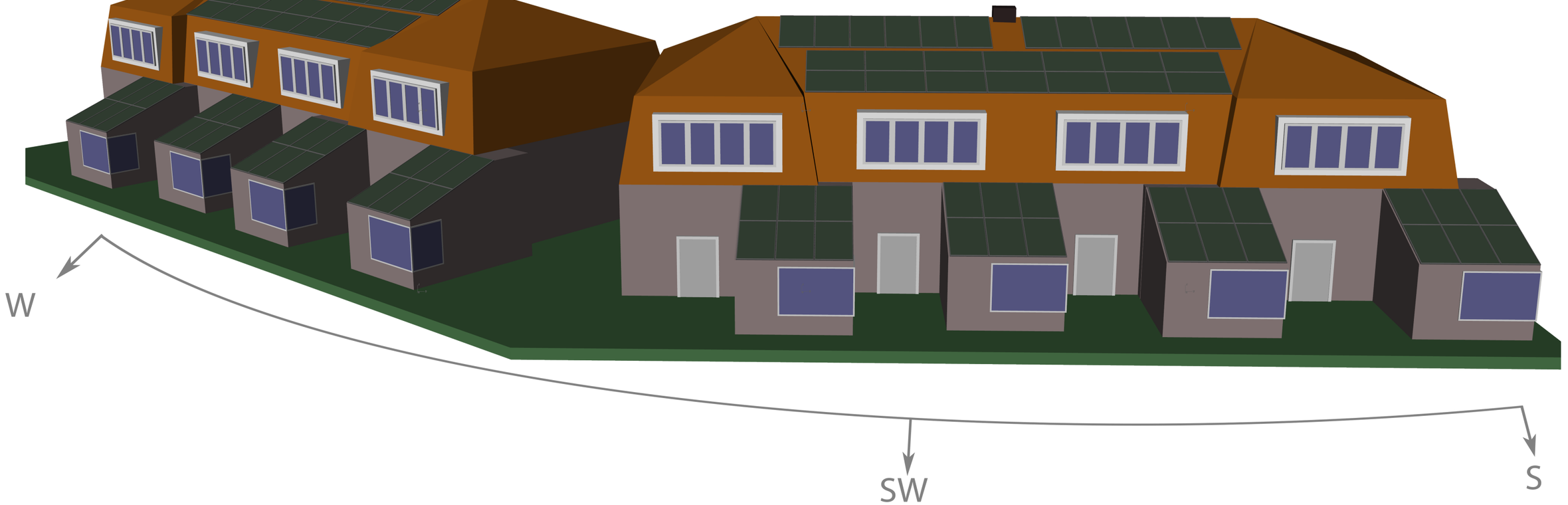


Orientation : South-west
Angle : 45 C°
Panels per household : 12,5
Annual electricity production : 4.913 kWh

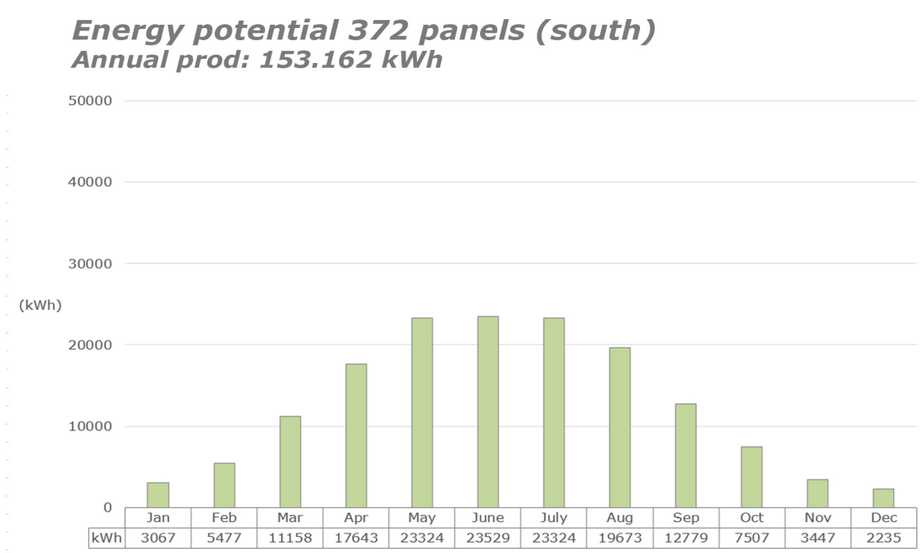
Monthy electricity production per household in kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
kWh	98	176	358	566	748	755	748	631	410	241	111	72





Maximum potential:

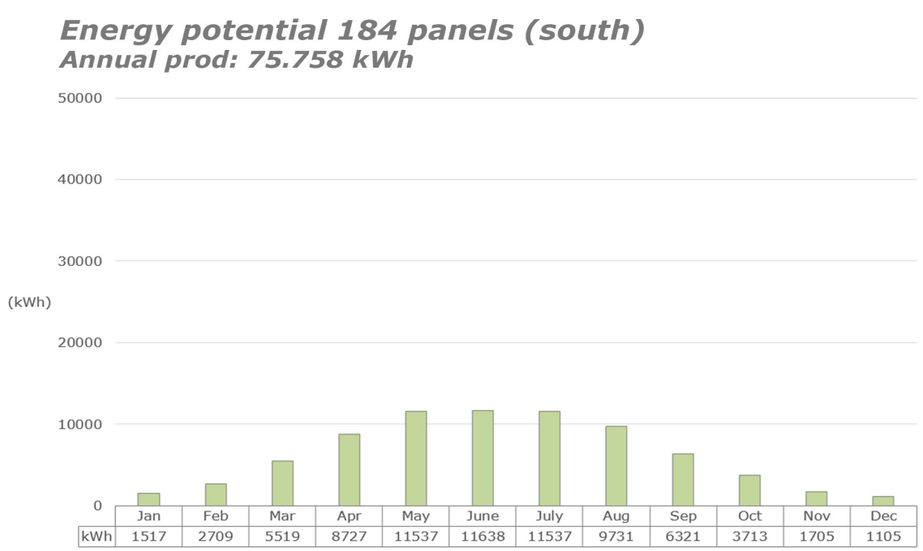






Thin film – cadmium telluride

Potential considering vegetation:







Thin film – cadmium telluride

Maximum potential:

Thin film – cadmium telluride



Energy potential 1327 panels (south)
Annual prod: 382.C [illegible] Vh
927

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	7651	13663	27835	44012	58185	58695	58185	49076	31880	18727	8598	5574

Potential considering vegetation:

Thin film – cadmium telluride



Energy potential 464 panels (south)
Annual prod: 191.041 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	3826	6831	13918	22006	29092	29347	29092	24538	15940	9364	4299	2787

Maximum potential:

Thin film – cadmium telluride



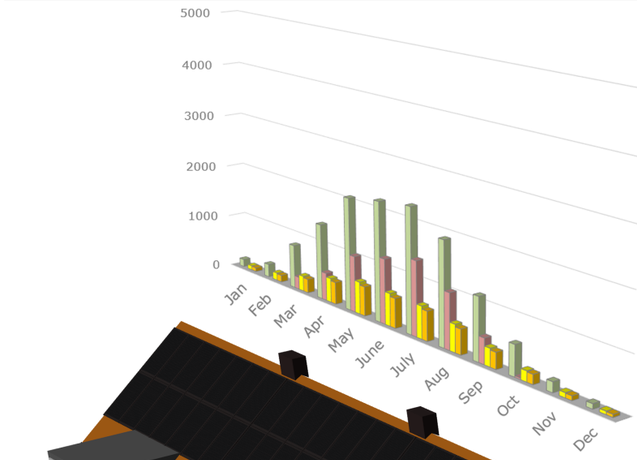
Energy potential 276 panels (south)
Annual prod: 113.636 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kWh	2276	4063	8279	13090	17305	17457	17305	14596	9481	5570	2557	1658

Commonly applied placement of panels on roofs:

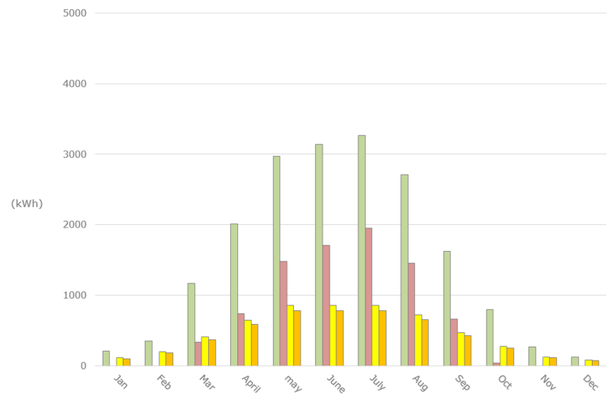
Orientation : West
Angle : 45 C°
Panels per household : 20
Annual thermal heat production: (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52



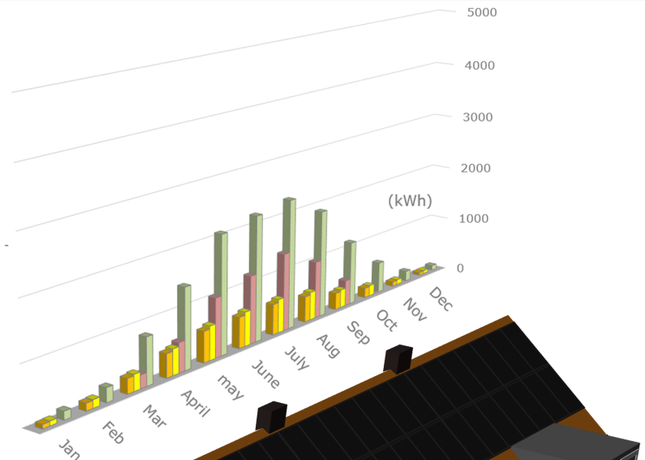
Orientation : South
Angle : 45 C°
Panels per household : 22
Annual thermal heat production: (40C°) 18.628 kWh
(80C°) 8375 kWh
Annual electricity production : (40C°) 5601 kWh
(80C°) 5108 kWh

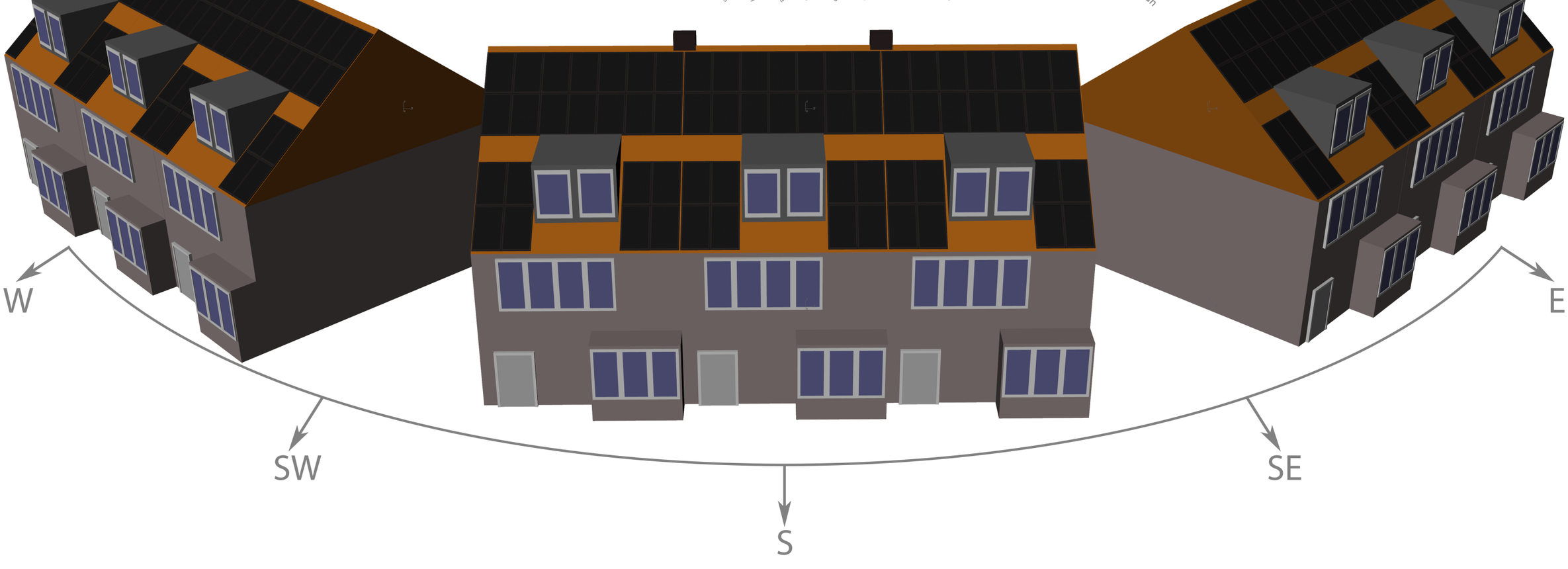
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	204	353	1168	2008	2972	3139	3265	2710	1624	794	263	128
80 C°			333	741	1482	1705	1954	1454	663	44		
Elec (40C°)	112	200	408	645	853	860	853	719	467	275	126	82
Elec (80C°)	102	183	372	588	778	785	778	656	426	250	115	75



Orientation : East
Angle : 45 C°
Panels per household : 20
Annual thermal heat production: (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52

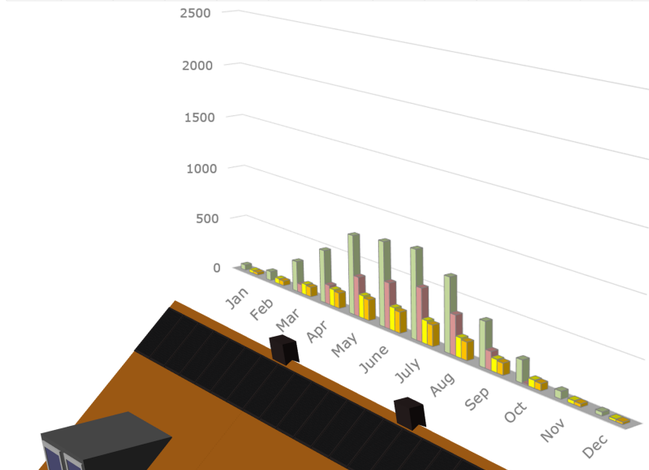




Minor visual impact:

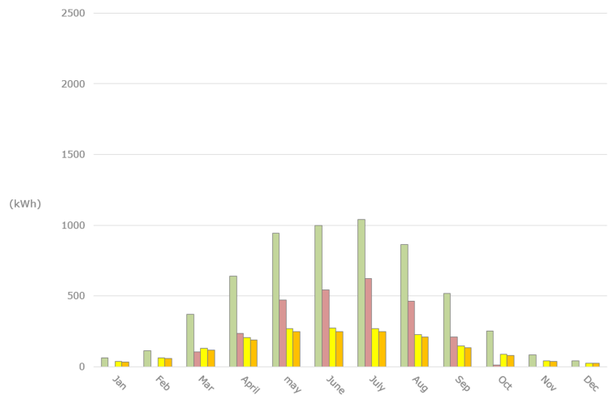
Orientation : West
Angle : 45 C°
Panels per household : 7
Annual thermal heat production : (40C°) 4580 kWh
(80C°) 2059 kWh
Annual electricity production : (40C°) 1377 kWh
(80C°) 1256 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	50	87	287	494	731	772	803	666	399	195	65	31
80 C°			82	182	364	419	480	358	163	11		
Elec (40C°)	28	49	100	159	218	212	210	177	115	67	31	20
Elec (80C°)	25	45	92	145	191	193	191	161	105	62	28	18



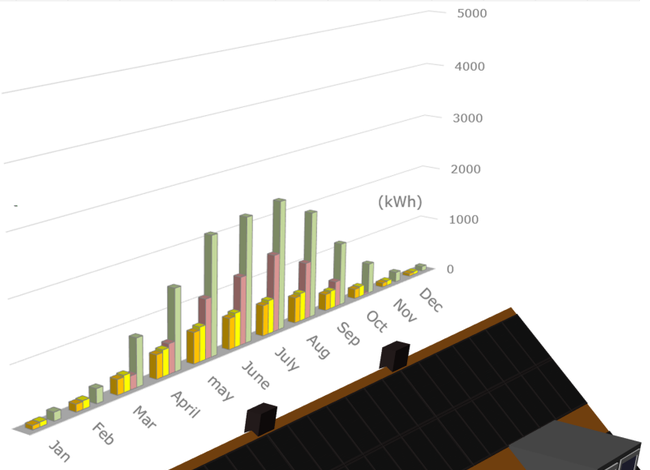
Orientation : South
Angle : 45 C°
Panels per household : 7
Annual thermal heat production : (40C°) 5927 kWh
(80C°) 2265 kWh
Annual electricity production : (40C°) 1782 kWh
(80C°) 1625 kWh

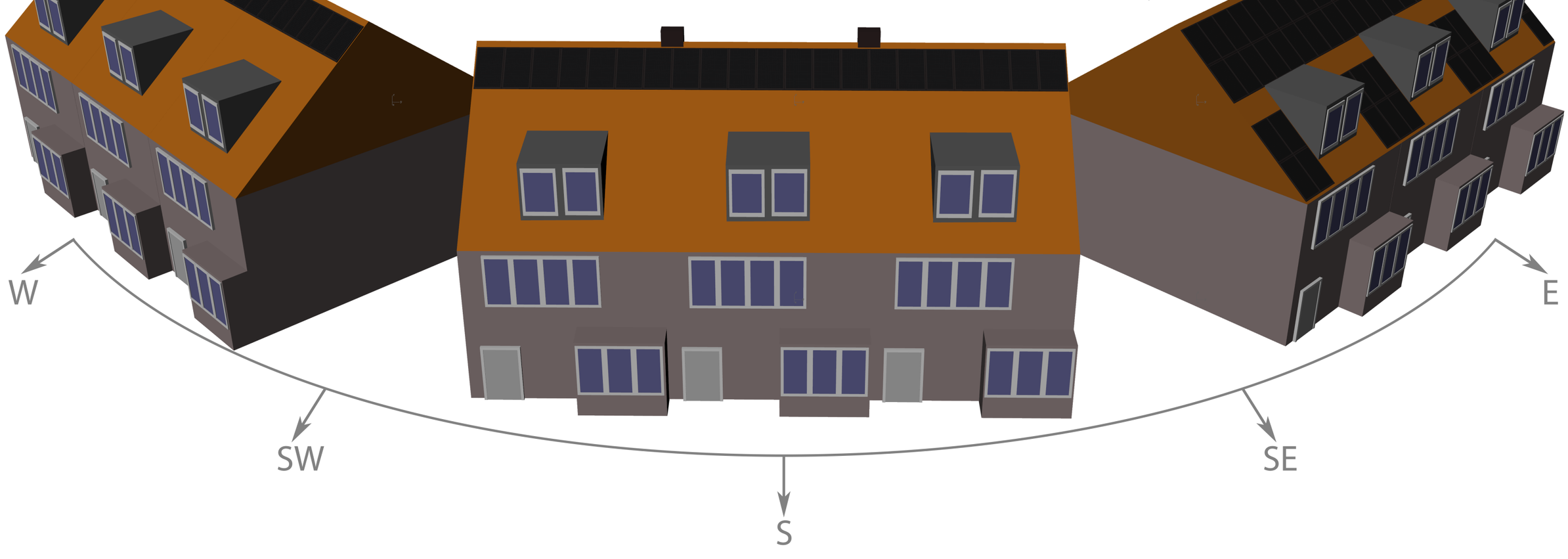
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	65	112	372	639	946	999	1039	862	517	253	84	41
80 C°			106	236	471	543	622	463	211	14		
Elec (40C°)	36	64	130	205	271	274	271	229	149	87	40	26
Elec (80C°)	33	58	118	187	248	250	248	209	136	80	37	24



Orientation : East
Angle : 45 C°
Panels per household : 20
Annual thermal heat production : (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52

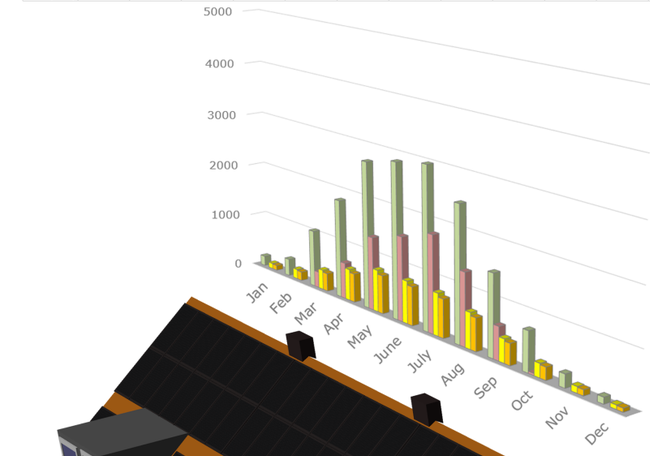




Building extention:

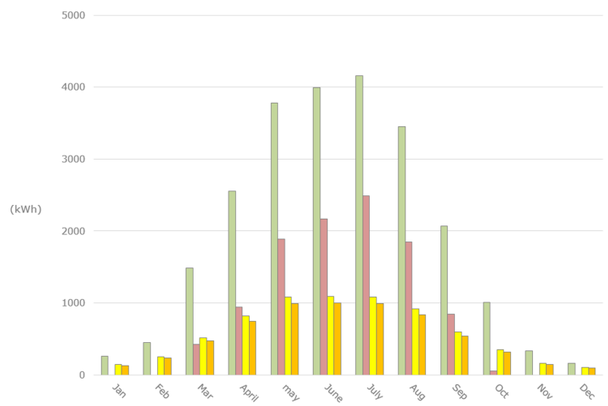
Orientation : West
Angle : 45 C°
Panels per household : 26
Annual thermal heat production : (40C°) 17.012 kWh
(80C°) 7649 kWh
Annual electricity production : (40C°) 5115 kWh
(80C°) 4665 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	186	322	1067	1834	2714	2867	2982	2475	1483	725	241	117
80 C°			304	676	1353	1557	1785	1328	605	40		
Elec (40C°)	102	183	373	589	779	786	779	657	427	251	115	75
Elec (80C°)	93	167	340	537	710	717	710	599	389	229	105	68



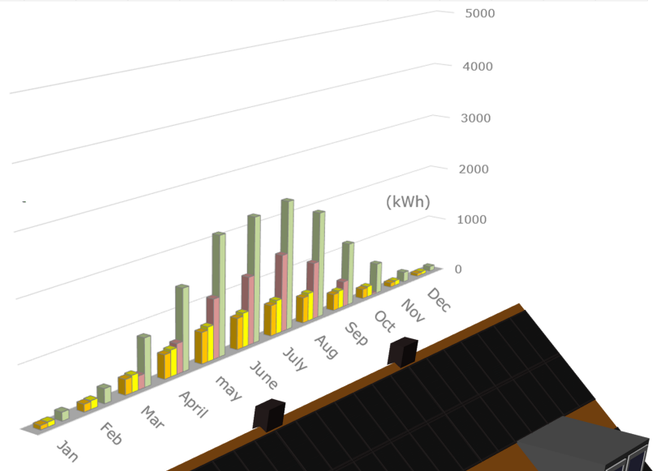
Orientation : South
Angle : 45 C°
Panels per household : 28
Annual thermal heat production : (40C°) 23.708 kWh
(80C°) 10.660 kWh
Annual electricity production : (40C°) 7129 kWh
(80C°) 6502 kWh

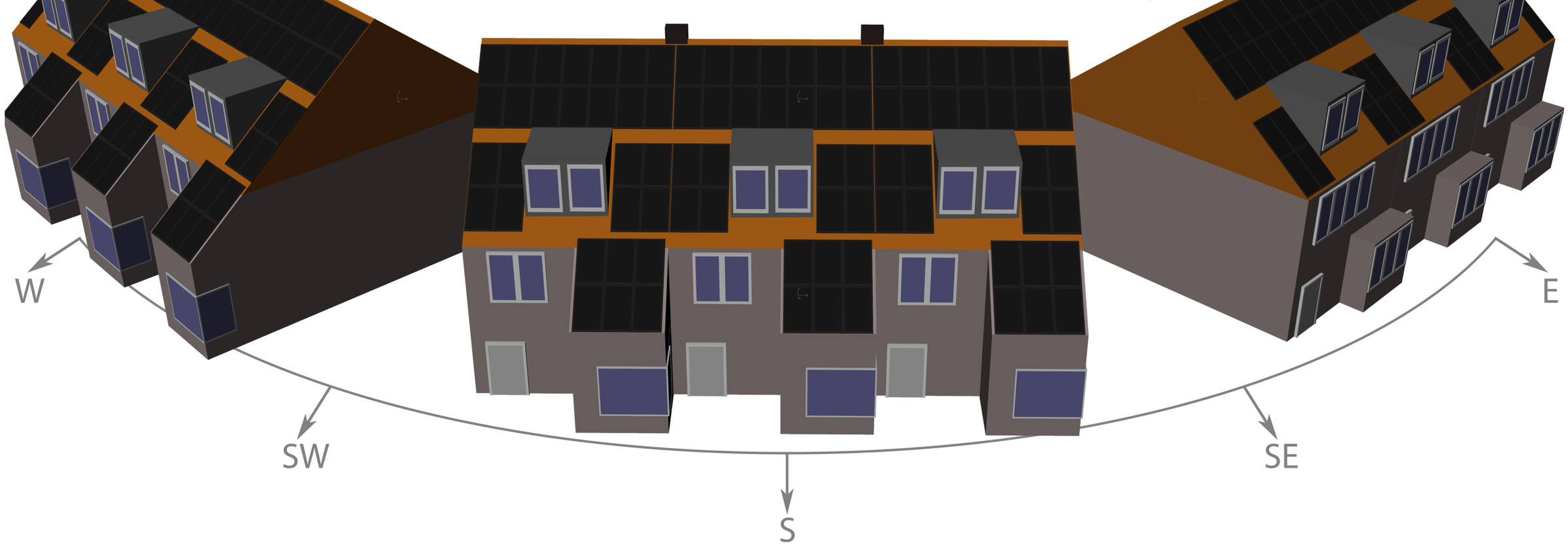
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	260	449	1487	2556	3782	3995	4155	3450	2067	1011	335	163
80 C°			423	943	1886	2170	2487	1851	843	56		
Elec (40C°)	143	255	519	821	1086	1095	1086	916	595	349	160	104
Elec (80C°)	130	232	474	749	990	999	990	835	542	319	146	95



Orientation : East
Angle : 45 C°
Panels per household : 20
Annual thermal heat production : (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52

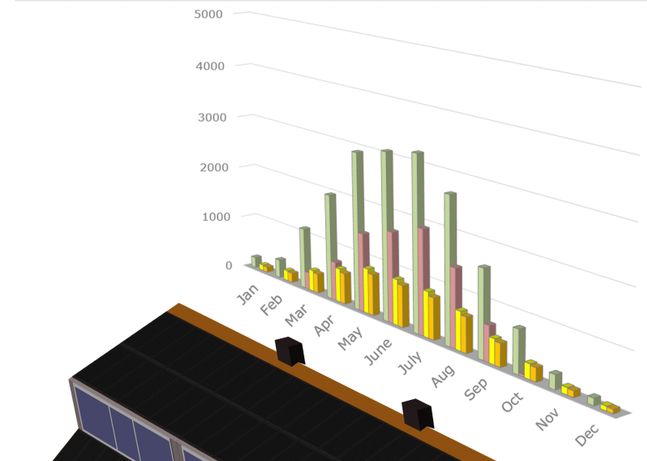




Partly refurbished:

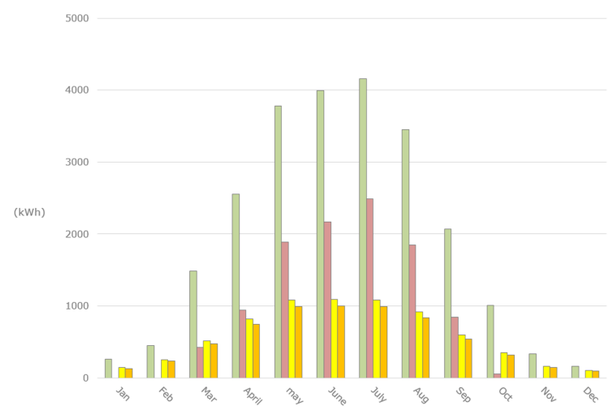
Orientation : West
Angle : 45 C°
Panels per household : 28
Annual thermal heat production: (40C°) 18.320 kWh
(80C°) 8237 kWh
Annual electricity production : (40C°) 5509 kWh
(80C°) 5024 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	201	347	1149	1975	2922	3087	3211	2666	1597	781	259	126
80 C°			327	728	1457	1677	1922	1430	652	43		
Elec (40C°)	110	197	401	635	839	846	839	708	460	270	124	80
Elec (80C°)	101	180	366	579	765	772	765	645	419	246	113	73



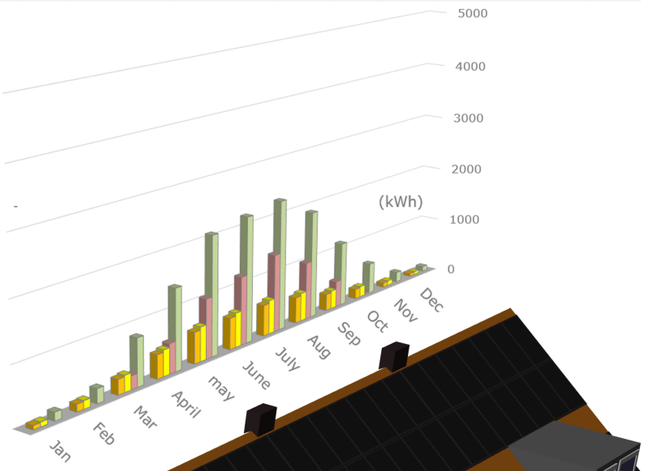
Orientation : South
Angle : 45 C°
Panels per household : 28
Annual thermal heat production: (40C°) 23.708 kWh
(80C°) 10.660 kWh
Annual electricity production : (40C°) 7129 kWh
(80C°) 6502 kWh

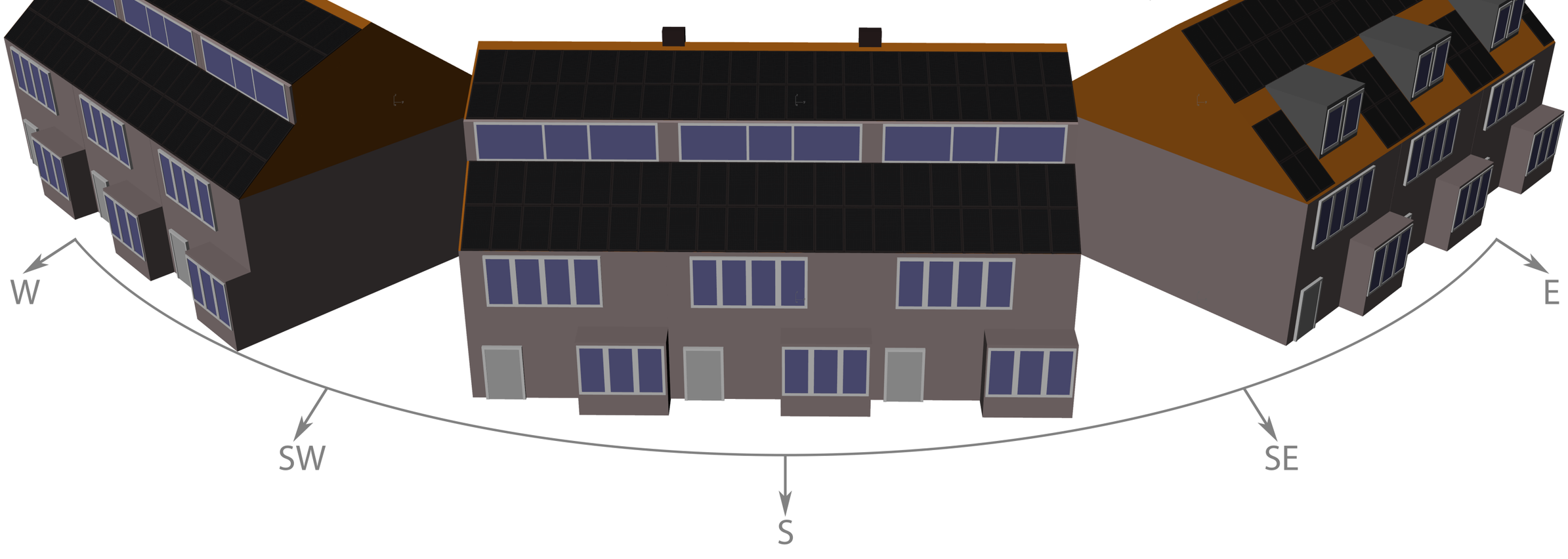
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	260	449	1487	2556	3782	3995	4155	3450	2067	1011	335	163
80 C°			423	943	1886	2170	2487	1851	843	56		
Elec (40C°)	143	255	519	821	1086	1095	1086	916	595	349	160	104
Elec (80C°)	130	232	474	749	990	999	990	835	542	319	146	95



Orientation : East
Angle : 45 C°
Panels per household : 20
Annual thermal heat production: (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52

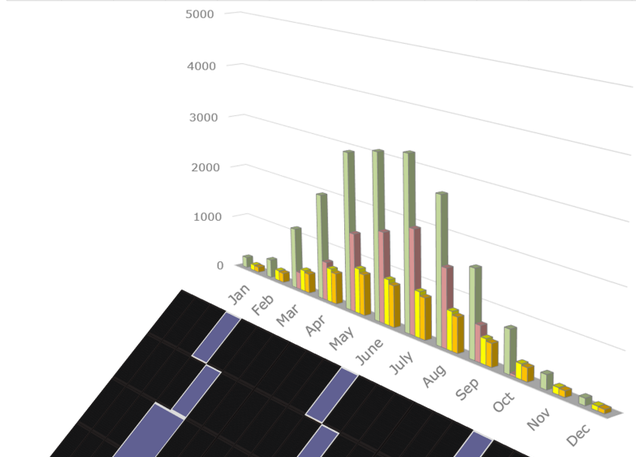




Totally refurbished:

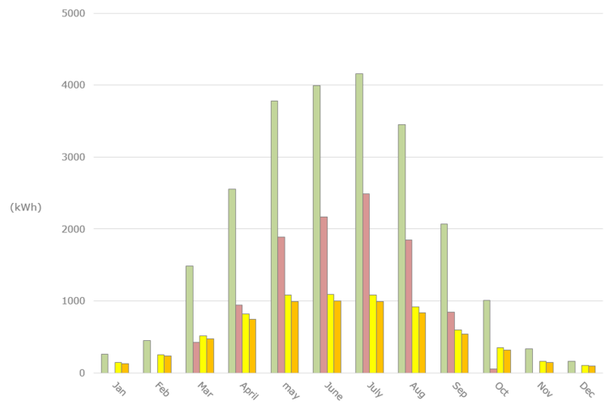
Orientation : West
Angle : 45 C°
Panels per household : 28
Annual thermal heat production : (40C°) 18.320 kWh
(80C°) 8237 kWh
Annual electricity production : (40C°) 5509 kWh
(80C°) 5024 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	201	347	1149	1975	2922	3087	3211	2666	1597	781	259	126
80 C°			327	728	1457	1677	1922	1430	652	43		
Elec (40C°)	110	197	401	635	839	846	839	708	460	270	124	80
Elec (80C°)	101	180	366	579	765	772	765	645	419	246	113	73



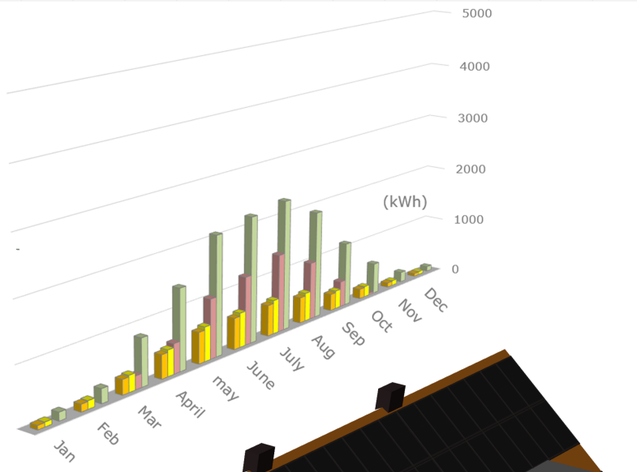
Orientation : South
Angle : 45 C°
Panels per household : 28
Annual thermal heat production : (40C°) 23.708 kWh
(80C°) 10.660 kWh
Annual electricity production : (40C°) 7129 kWh
(80C°) 6502 kWh

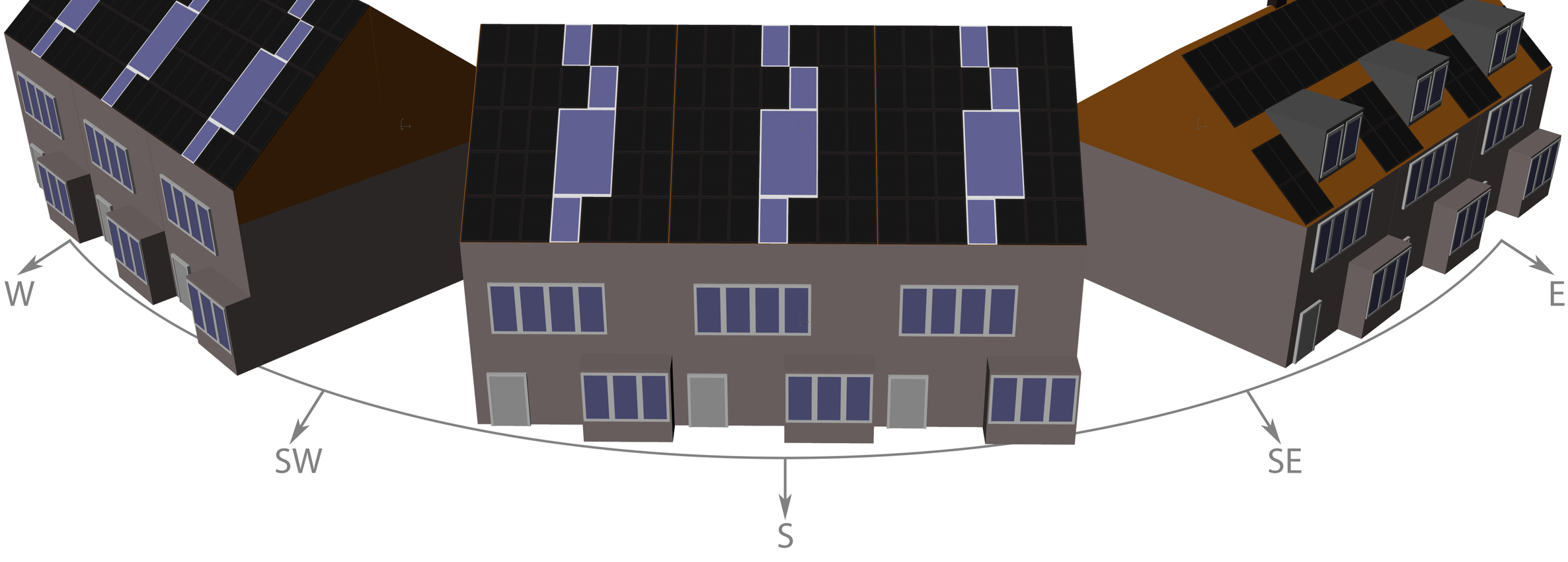
	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	260	449	1487	2556	3782	3995	4155	3450	2067	1011	335	163
80 C°			423	943	1886	2170	2487	1851	843	56		
Elec (40C°)	143	255	519	821	1086	1095	1086	916	595	349	160	104
Elec (80C°)	130	232	474	749	990	999	990	835	542	319	146	95



Orientation : East
Angle : 45 C°
Panels per household : 20
Annual thermal heat production : (40C°) 13.086 kWh
(80C°) 5884 kWh
Annual electricity production : (40C°) 3935 kWh
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52



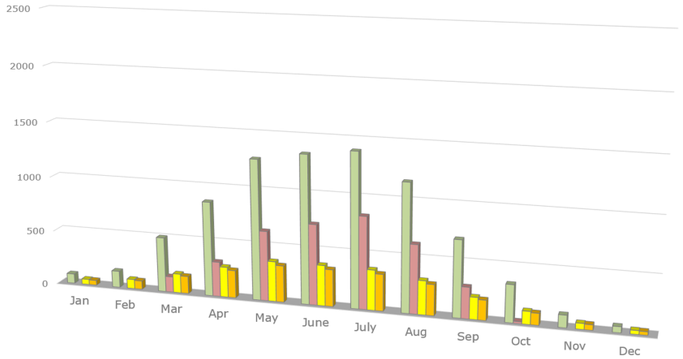


Refurbished roof:

***Orientation* : West**
***Angle* : 3x 45C° 13x 90C°**
***Panels per household* : 16**
***Annual thermal heat production*: (40C°) 7967 kWh**
(80C°) 3582 kWh
***Annual electricity production* : (40C°) 2396 kWh**
(80C°) 2185 kWh

**West/East (90C°) is -40% solar irradiance*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	87	151	500	859	1271	1343	1396	1159	695	340	113	55
80 C°			142	317	634	729	836	622	283	19		
Elec (40C°)	48	86	175	276	365	368	365	308	200	117	54	35
Elec (80C°)	44	78	159	252	333	336	333	281	182	107	49	32



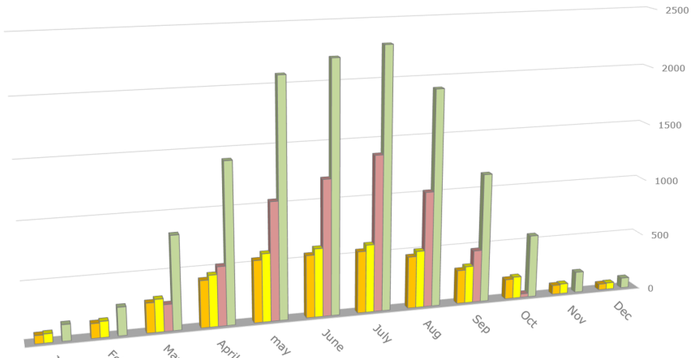
***Orientation* : South**
***Angle* : 3x 45C° 13x 90C°**
***Panels per household* : 16**
***Annual thermal heat production*: (40C°) 10.546 kWh**
(80C°) 3332 kWh
***Annual electricity production* : (40C°) 3171 kWh**
(80C°) 2892 kWh

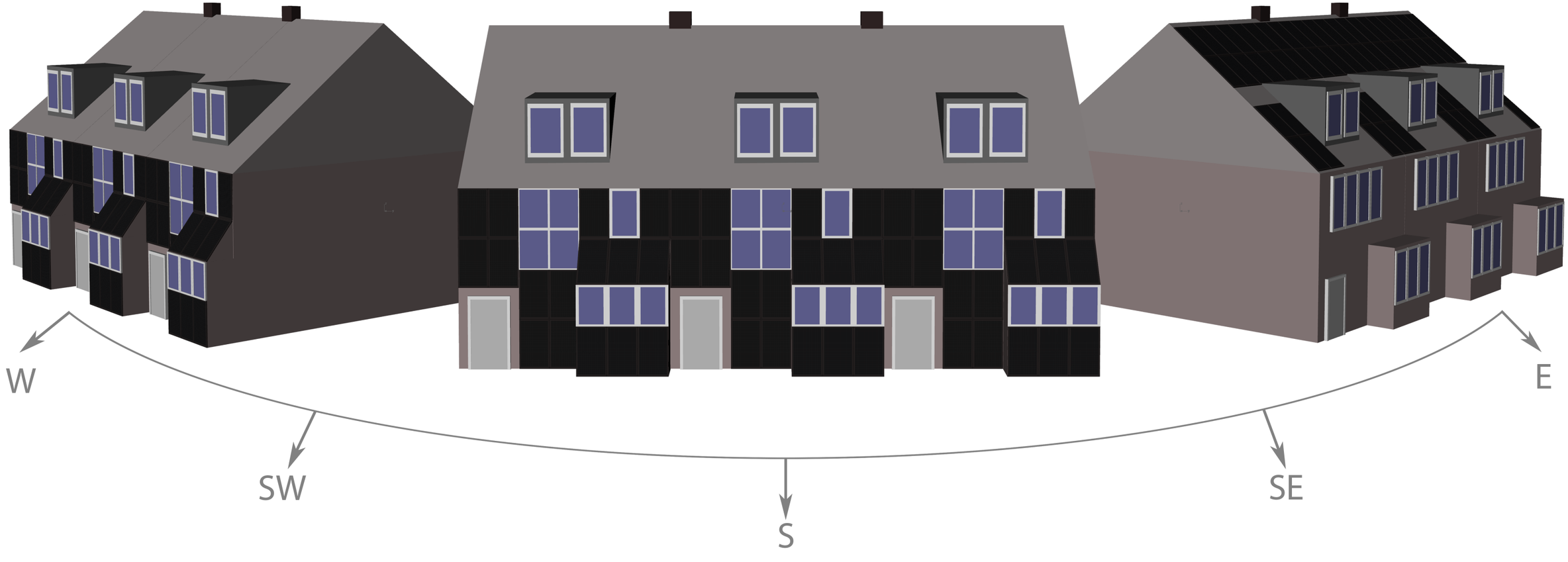
**South (90C°) is -20% solar irradiance*

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	115	200	661	1137	1682	1777	1848	1534	919	449	149	72
80 C°			132	295	590	678	777	579	264	17		
Elec (40C°)	63	113	231	365	483	487	483	407	265	155	71	46
Elec (80C°)	58	103	211	333	440	444	440	371	241	142	65	42

***Orientation* : East**
***Angle* : 45 C°**
***Panels per household* : 20**
***Annual thermal heat production*: (40C°) 13.086 kWh**
(80C°) 5884 kWh
***Annual electricity production* : (40C°) 3935 kWh**
(80C°) 3589 kWh

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	143	248	821	1411	2087	2205	2293	1904	1141	558	185	90
80 C°			234	520	1041	1198	1373	1022	466	31		
Elec (40C°)	79	141	287	453	599	604	599	505	328	193	89	57
Elec (80C°)	72	128	261	413	546	551	546	461	299	176	81	52

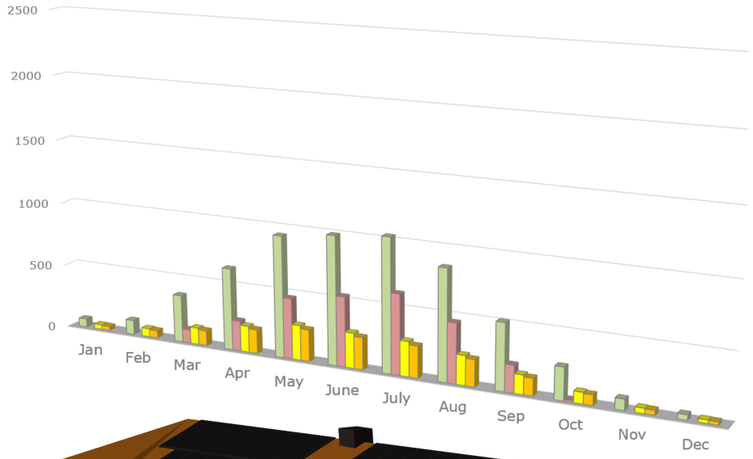




Commonly applied placement of panels on roofs:

Orientation ***: West***
Angle ***: 45 C°***
Panels per household ***: 9***
Annual thermal heat production: (40C°) 5889 kWh
(80C°) 2648 kWh
Annual electricity production : (40C°) 1771 kWh
(80C°) 1615 kWh

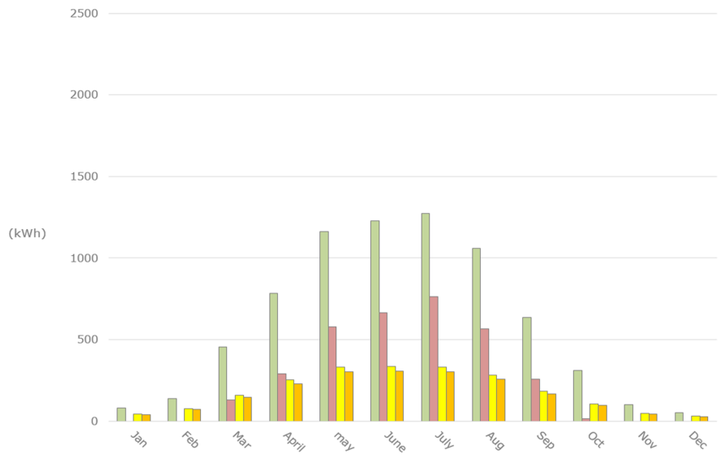
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	64	111	369	635	939	992	1032	857	513	251	83	40
80 C°			105	234	468	539	618	460	209	14		
Elec (40C°)	35	63	129	204	270	272	270	227	148	87	40	26
Elec (80C°)	32	58	118	186	246	248	246	207	135	79	36	24

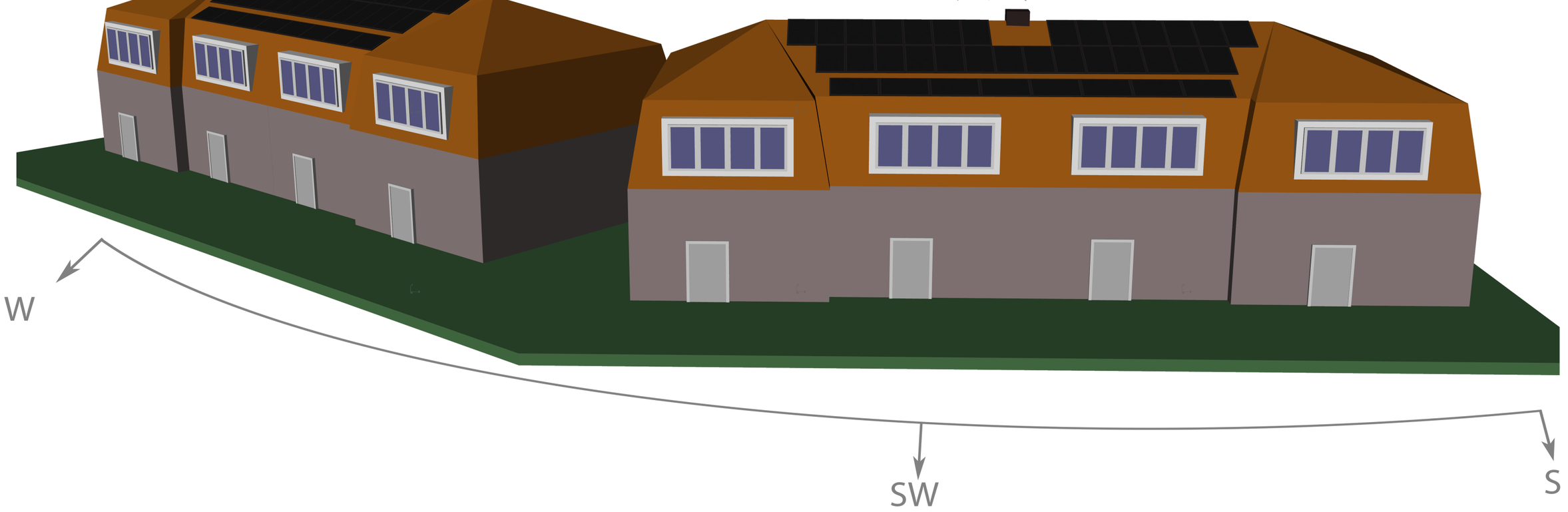


Orientation ***: South-west***
Angle ***: 45 C°***
Panels per household ***: 9***
Annual thermal heat production: (40C°) 7274 kWh
(80C°) 3271 kWh
Annual electricity production : (40C°) 2187 kWh
(80C°) 1995 kWh

**South-west is 105% solar irradiance*

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	80	138	456	784	1160	1226	1275	1058	634	310	103	50
80 C°			130	289	579	666	763	568	259	17		
Elec (40C°)	44	78	159	252	333	336	333	281	182	107	49	32
Elec (80C°)	40	71	145	230	304	306	304	256	166	98	45	29

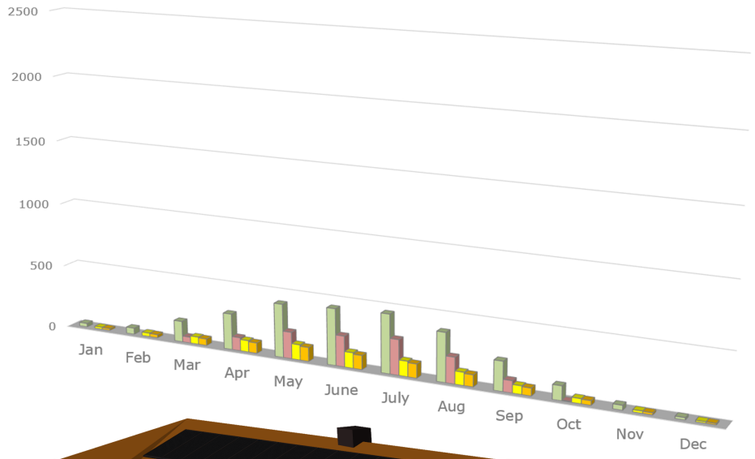




Minor visual impact:

***Orientation* : West**
***Angle* : 45 C°**
***Panels per household* : 4**
***Annual thermal heat production*: (40C°) 2617 kWh**
(80C°) 1177 kWh
***Annual electricity production* : (40C°) 787 kWh**
(80C°) 718 kWh

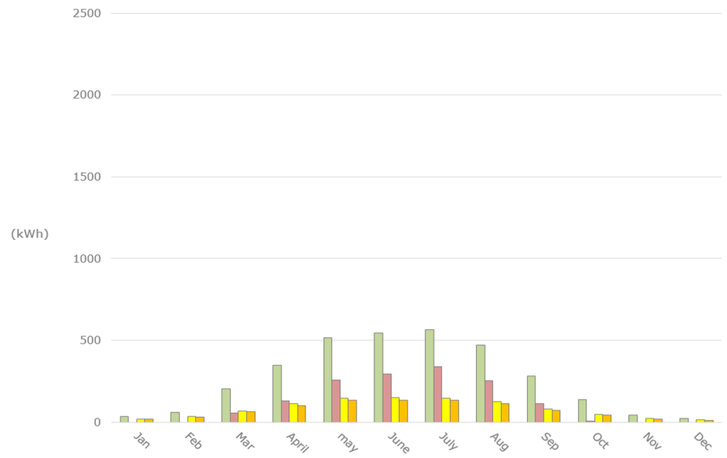
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	29	50	164	282	417	441	459	381	228	112	37	18
80 C°			47	104	208	240	275	204	93	6		
Elec (40C°)	16	28	57	91	120	121	120	101	66	39	18	11
Elec (80C°)	14	26	52	83	109	110	109	92	60	35	16	10

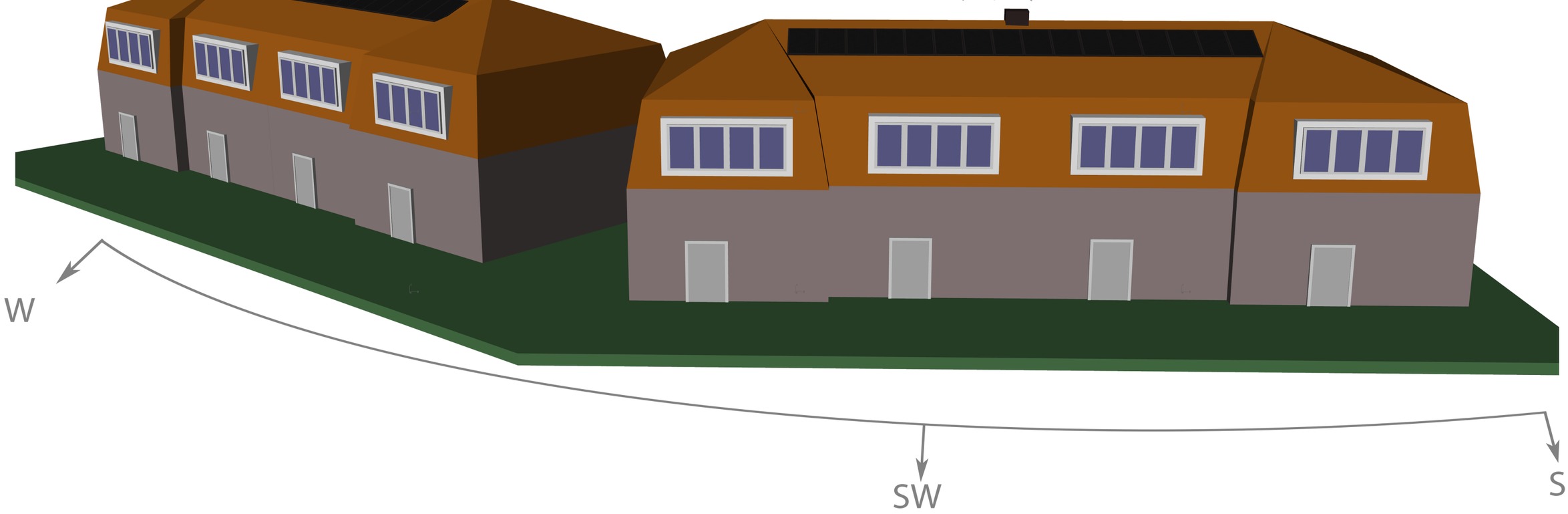


***Orientation* : South-west**
***Angle* : 45 C°**
***Panels per household* : 4**
***Annual thermal heat production*: (40C°) 3233 kWh**
(80C°) 1454 kWh
***Annual electricity production* : (40C°) 972 kWh**
(80C°) 887 kWh

**South-west is 105% solar irradiance*

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	35	61	203	349	516	545	567	470	282	138	46	22
80 C°			58	129	257	296	339	252	115	8		
Elec (40C°)	19	35	71	112	148	149	148	125	81	48	22	14
Elec (80C°)	18	32	65	102	135	136	135	114	74	43	20	13

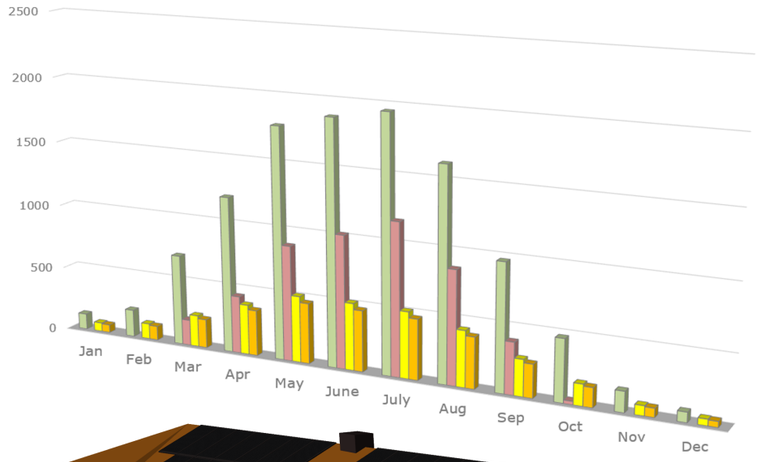




Building extention:

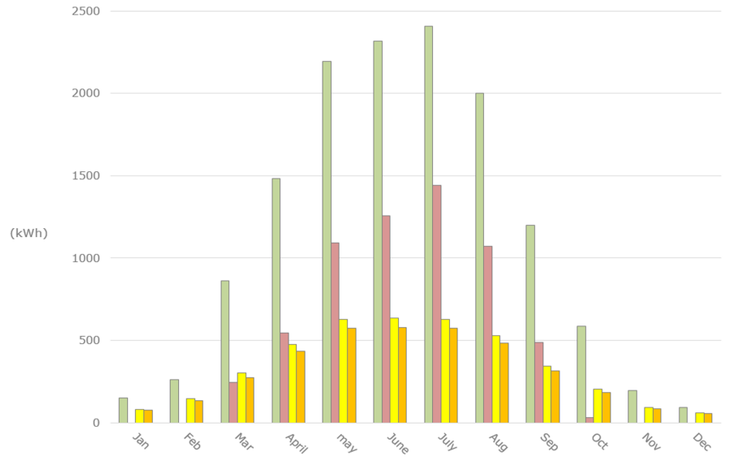
Orientation : West
Angle : 45 C°
Panels per household : 17
Annual thermal heat production: (40C°) 11.123 kWh
(80C°) 5001 kWh
Annual electricity production : (40C°) 3345 kWh
(80C°) 3050 kWh

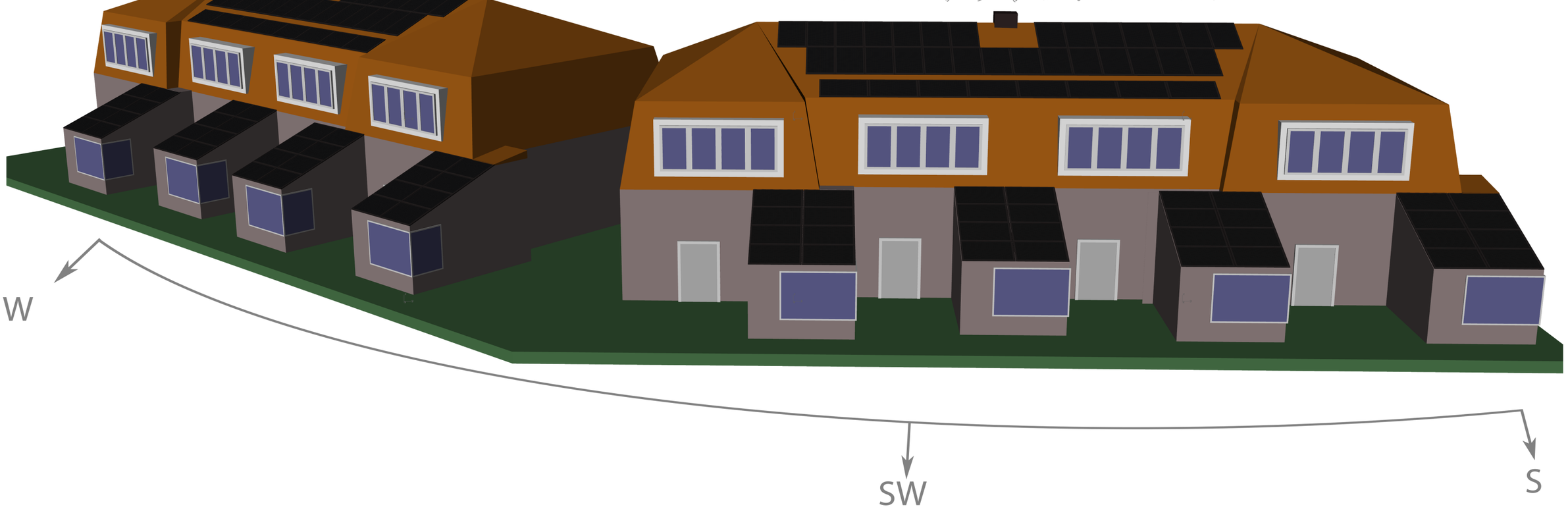
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	122	211	697	1199	1774	1874	1949	1618	970	474	157	76
80 C°			199	442	885	1018	1167	868	396	26		
Elec (40C°)	67	120	244	385	509	514	509	430	279	164	75	49
Elec (80C°)	61	109	222	351	465	469	465	392	255	150	69	45



Orientation : South-west
Angle : 45 C°
Panels per household : 17
Annual thermal heat production: (40C°) 13.740 kWh
(80C°) 6178 kWh
Annual electricity production : (40C°) 4132 kWh
(80C°) 3768 kWh
**South-west is 105% solar irradiance*

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	150	260	862	1481	2192	2315	2408	1999	1198	586	194	94
80 C°			245	546	1093	1258	1441	1073	489	32		
Elec (40C°)	83	148	301	476	629	635	629	531	345	202	93	60
Elec (80C°)	75	135	275	434	574	579	574	484	314	185	85	55



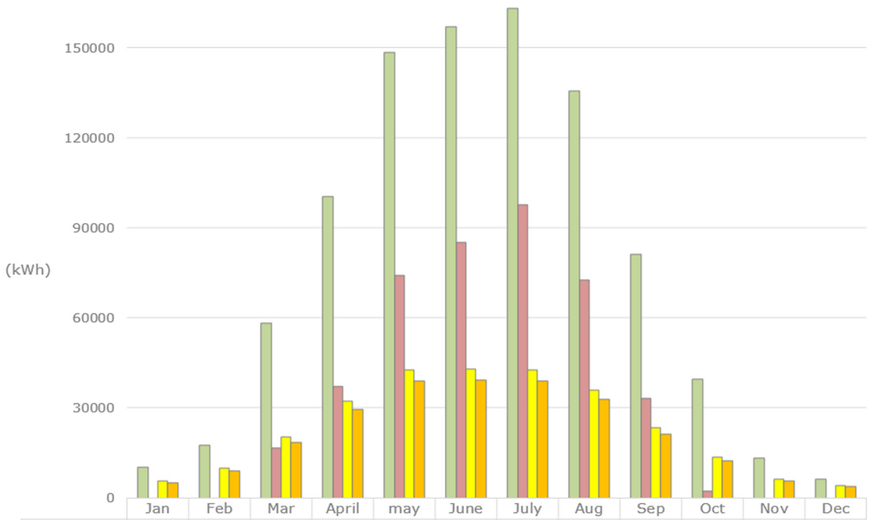


Maximum potential:

PV/T - Monocrystaline/flat-plate collector



Energy potential 1100 panels (south)
Annual thermal heat production :(40C°) 931.401 kWh
(80C°) 418.773 kWh
Annual electricity production :(40C°) 280.063 kWh
(80C°) 255.418 kWh



	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	10200	17636	58405	100402	148580	156950	163242	135519	81193	39700	13172	6403
80 C°			16635	37035	74088	85267	97704	72721	33136	2187		
Elec (40C°)	5608	10015	20403	32261	42649	43023	42649	35973	23368	13727	6303	4086
Elec (80C°)	5115	9133	18608	29422	38896	39237	38896	32807	21311	12519	5748	3726

Potential considering vegetation:

PV/T - Monocrystaline/flat-plate collector



Energy potential 521 panels (south)
Annual thermal heat production :(40C°) 441.145 kWh
(80C°) 198.346 kWh
Annual electricity production :(40C°) 132.648 kWh
(80C°) 120.975 kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	4831	8353	27663	47554	70373	74337	77317	64187	38456	18803	6239	3033
80 C°			7879	17541	35091	40386	46276	34443	15694	1036		
Elec (40C°)	2656	4743	9664	15280	20200	20377	20200	17038	11068	6501	2985	1935
Elec (80C°)	2423	4326	8813	13935	18423	18584	18423	15539	10094	5929	2722	1765

Maximum potential:

PV/T - Monocrystaline/flat-plate collector



Energy potential 420 panels (south)
Annual thermal heat production :(40C°) 355.626 kWh
(80C°) 159.895 kWh
Annual electricity production :(40C°) 106.933 kWh
(80C°) 97.523 kWh

	Jan	Feb	Mar	April	may	June	July	Aug	Sep	Oct	Nov	Dec
40 C°	3894	6734	22300	38335	56730	59927	62329	51744	31001	15158	5029	2445
80 C°			6352	14141	28288	32557	37305	27766	12652	835		
Elec (40C°)	2141	3824	7790	12318	16284	16427	16284	13735	8922	5241	2406	1560
Elec (80C°)	1953	3487	7105	11234	14851	14981	14851	12526	8137	4780	2195	1423

APPENDIX C

(A) 100% gas replacement traditional placement method

P. (A.1) Flat plate collectors + pit thermal energy storage.
(A.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump & aquifer storage.
(A.2 extra) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycooler.

(B) 100% gas replacement using the analysis results of chapter 4

P. (B.1) Flat plate collectors combined with a water filled pit thermal energy storage.
P. (B.2) Flat plate collectors combined with a salt filled latent tank storage.
P. (B.3) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants

P. (C.1) Flat plate collectors combined with a water filled pit thermal energy storage.
P. (C.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycooler.
P. (C.3) Flat plate collectors combined with a salt filled latent tank storage
P. (C.4) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

Heat demand (the heat demand is the same for every configuration)

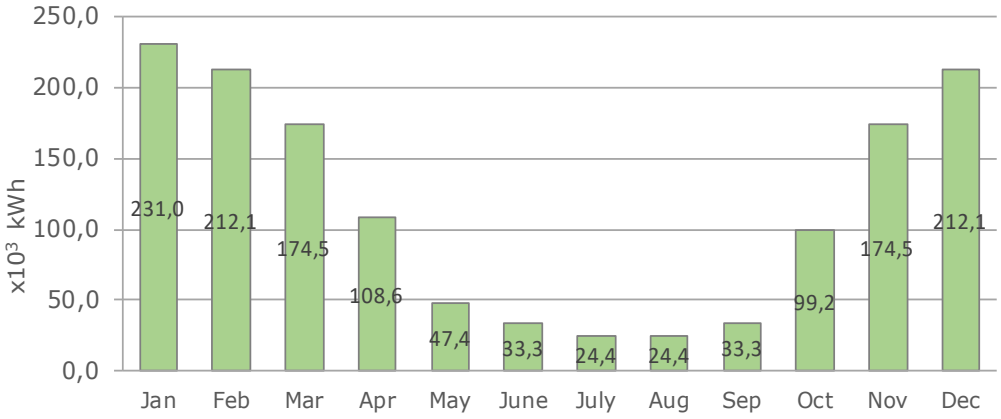


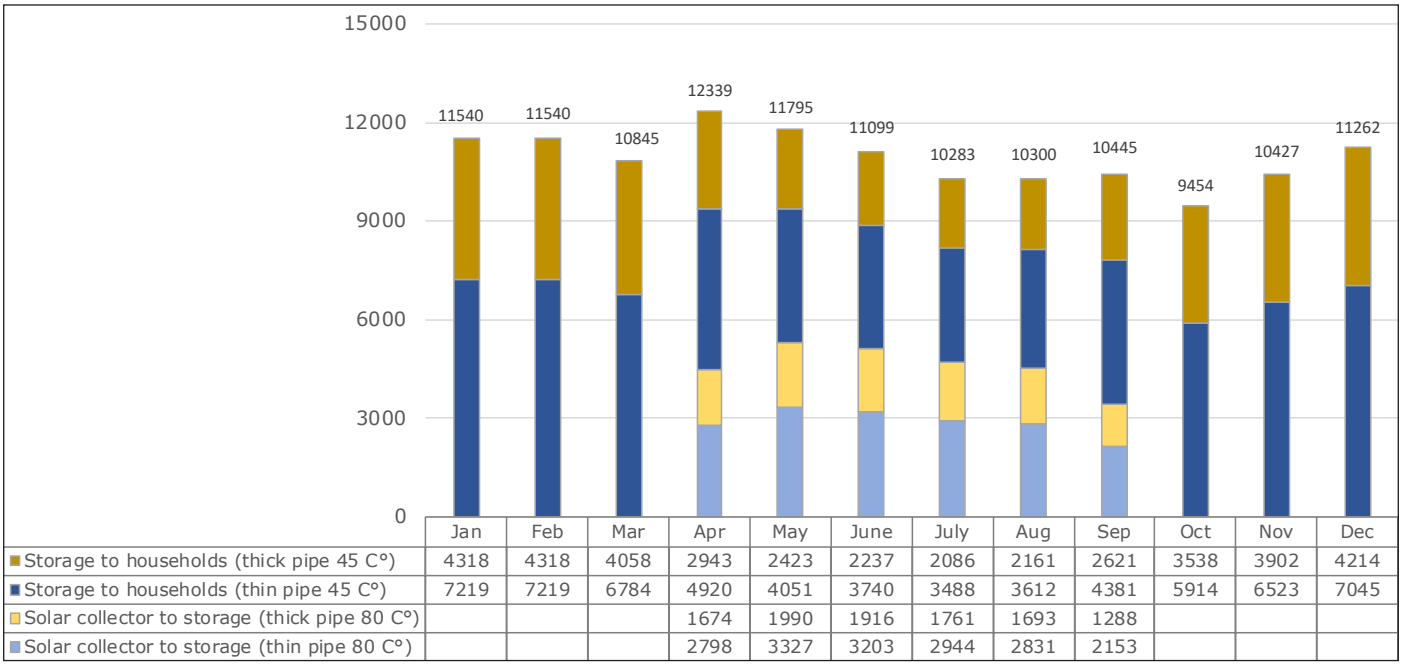
Figure B.2: *Total monthly heat demand 113 buildings in Ramplaankwartier. (Ch. 4.1)*

(A) 100% gas replacement using the commonly applied placement of panels on roofs.

A.1 Flat plate collectors + pit thermal energy storage.

I. Transport losses

In the months April, May, June, July, August & September water of 80 °C is transported to the energy storage tanks. The return temperature of the water is 10 °C which is comparable to the ambient temperature in these months resulting in negligible energy losses.
In the months January, February, March, October, November & December water of 45 °C is transported from the energy storage tanks towards the buildings. The return temperature of the water is 10 °C. Because most of the piping is underground and the ambient temperature in the winter months is only a few degrees lower than the return temperature, the energy losses caused in this part of the distribution system can be neglected.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045
Solar collector to storage (thick pipe 80 C°)				1674	1990	1916	1761	1693	1288			
Solar collector to storage (thin pipe 80 C°)				2798	3327	3203	2944	2831	2153			

Figure B.3: *Transport losses*

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production (x10^3 kWh)	Heat demand households (x10^3 kWh)	Transport losses (x10^3 kWh)	Thermal losses pit storage (x10^3 kWh)	Delta (x10^3 kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	273	109	12	5	147	6,9	15,0
May	381	47	12	7	315	14,8	21,9
June	393	33	11	16	332	15,7	36,8
July	400	24	10	26	339	16,0	52,5
Aug	328	24	10	39	255	12,0	68,5
Sep	201	33	10	50	107	5,1	80,0
Oct	135	99	9	52	-26	-1,2	80,0
Nov	57	174	10	54	-182	-8,6	78,8
Dec	35	212	11	50	-238	-11,2	70,2
Jan	50	231	12	42	-235	-11,1	59,0
Feb	88	212	12	34	-169	-8,0	47,9
Mar	201	174	11	26	-10	-0,5	39,9
Apr	273	109	12	23	129	6,1	39,4
May	381	47	12	25	297	14,0	45,5
June	393	33	11	34	315	14,9	59,5
July	400	24	10	43	323	15,2	74,4
Aug	328	24	10	48	246	11,6	80,0
Sep	201	33	10	50	107	5,1	80,0
Oct	135	99	9	52	-26	-1,2	80,0
Nov	57	174	10	54	-182	-8,6	78,8
Dec	35	212	11	50	-238	-11,2	70,2

Figure B.4: *Delta kWH added/ extracted energy storage.*

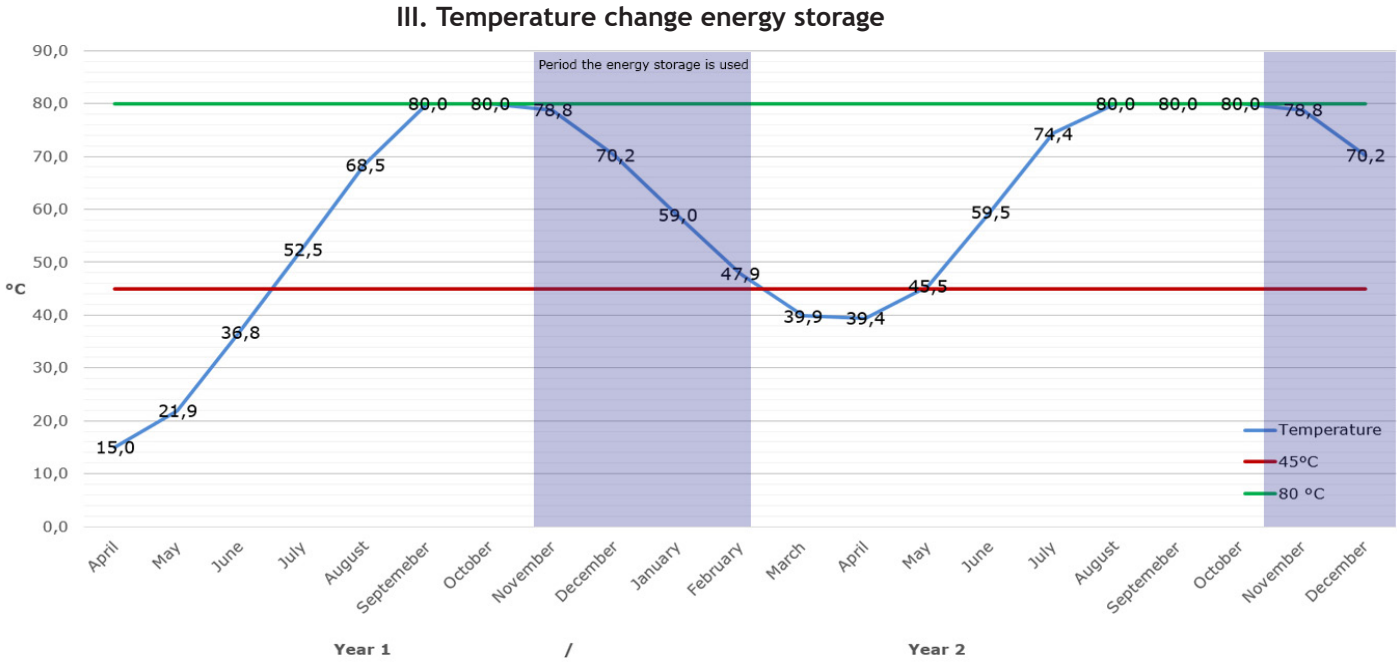
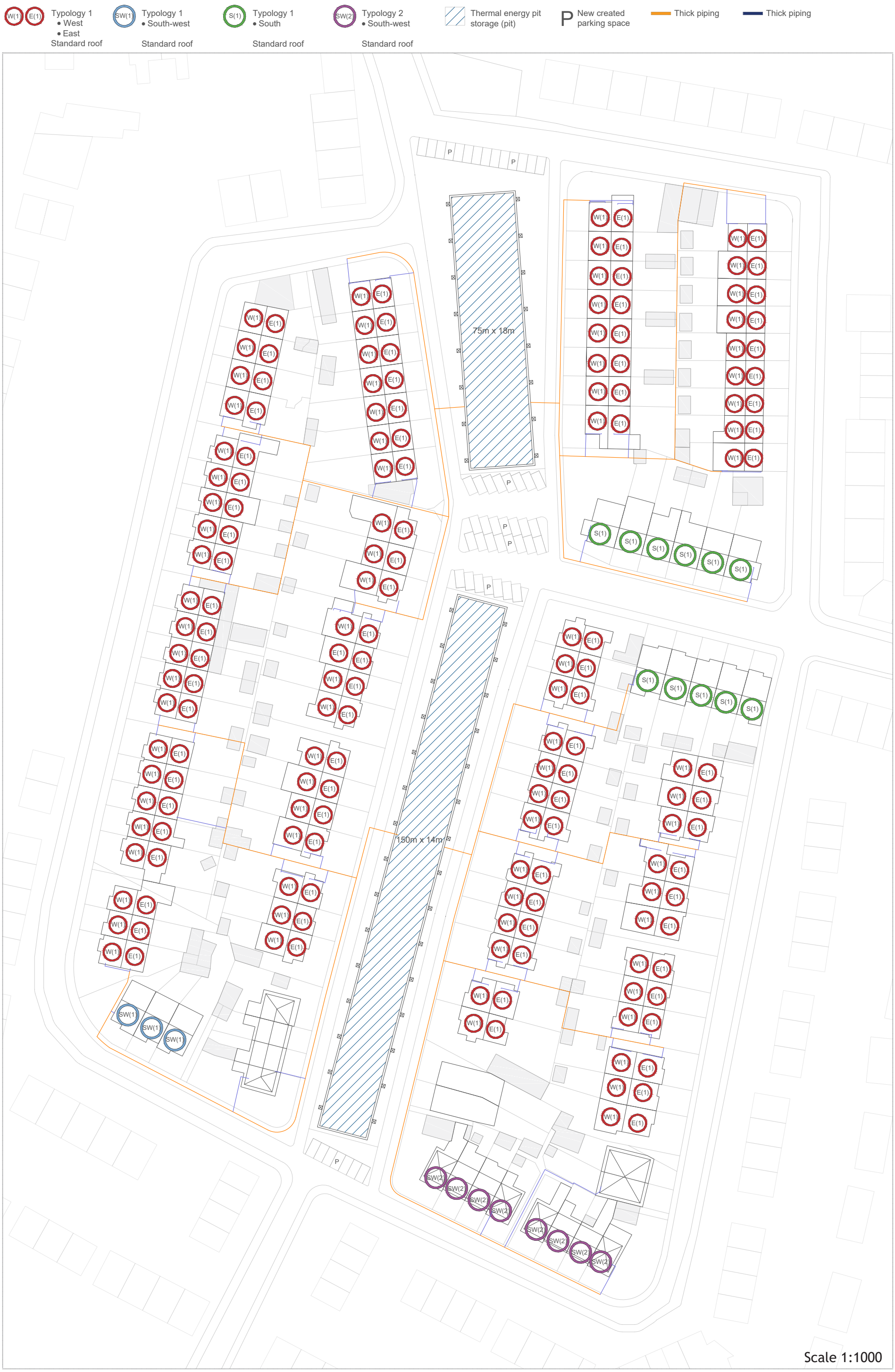


Figure B.5: *Temperature change energy storage. (by Author)*

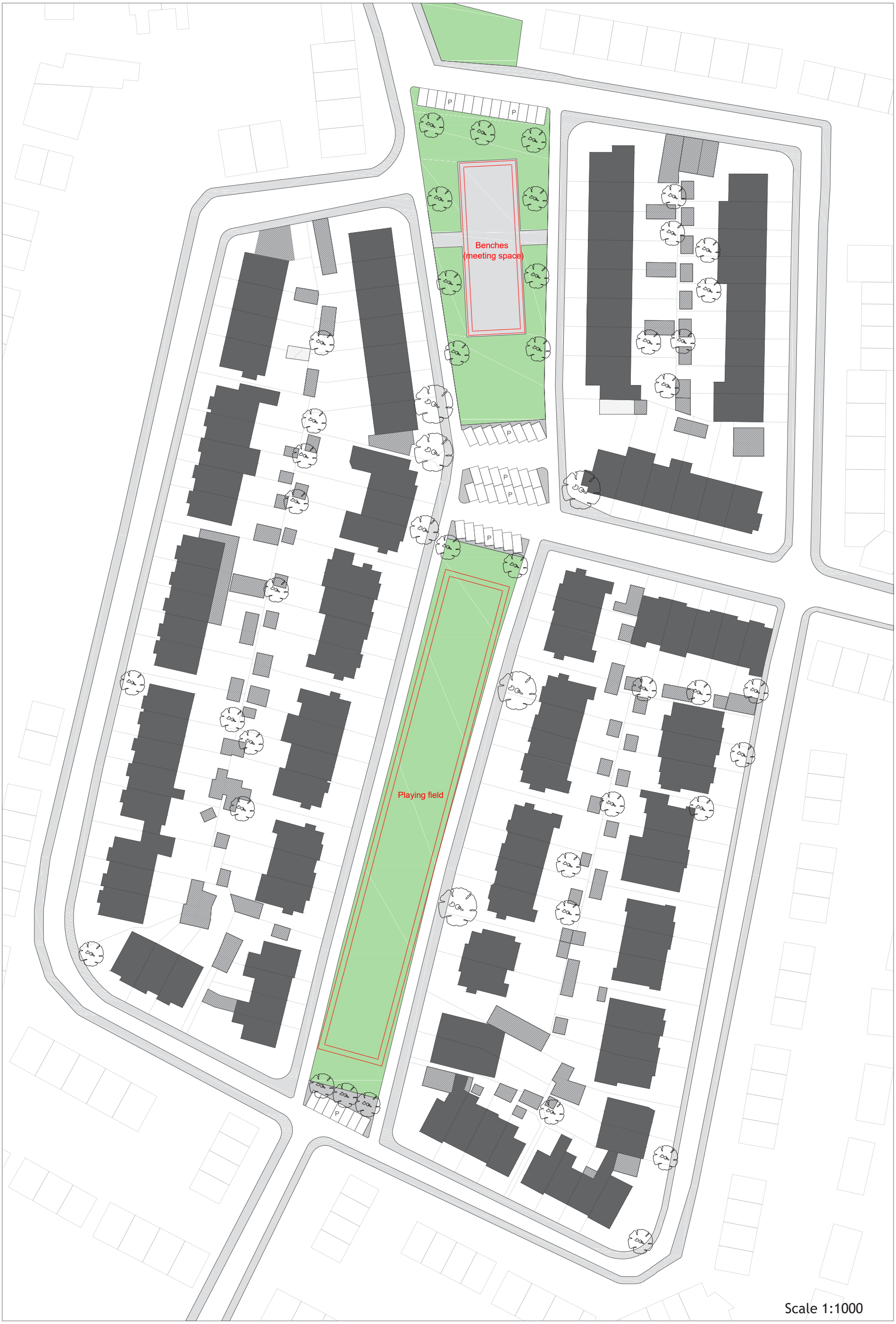
The blue areas are the periods that the buildings use thermal heat from the energy storage. In these months the water in the storage tank should atleast be 45 ˚C.

IV. Technical floor plan



V. Visual floor plan

Grass · Households · Storages · Public functions · P New created parking space · Trees









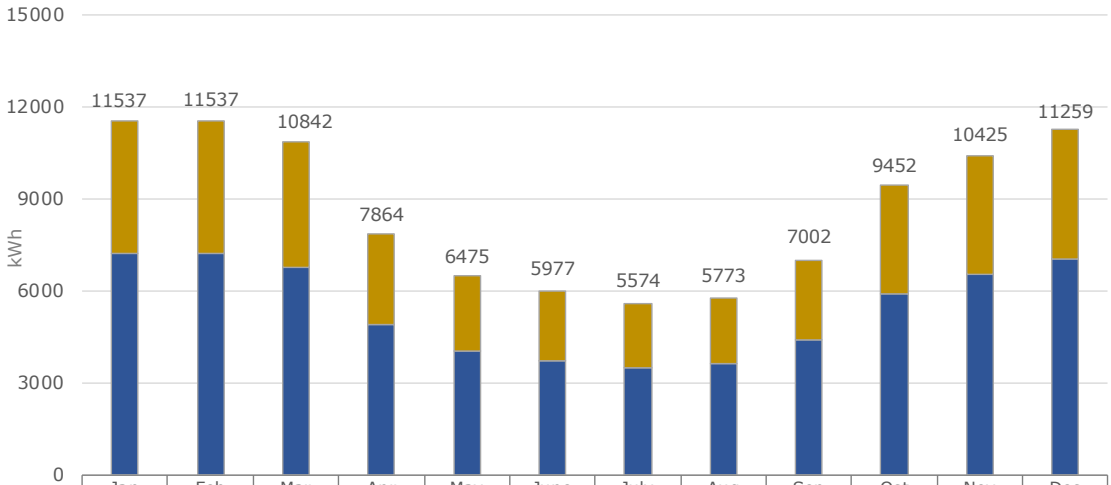


(A) 100% gas replacement traditional method

A.2 PV + large scale heat pump + water pit storage + aquifer heat/cold storage.

I. Transport losses

The energy losses of electricity transport are so small that they can be neglected in the calculation. The rest of the year thermal heat is transported towards the buildings at a temperature of 45 °C resulting in the following distribution losses:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045

Figure B.6: *Monthly net energy value & temperature difference (by Auhtor)*

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production (elec) (x10³ kWh)	Monthly energy production (T. heat) (3,0COP)(x10³ kWh)	Deliverd heat demand households (x10³ kWh)	Heat added to aquifer storage (x10³ kWh)	Transport losses (x10³ kWh)	Thermal losses pit storage (x10³ kWh)	Delta (x10³ kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	178,8	536,4	108,6	356,7	7,9	27,6	35,7	1,7	45,0
May	236,4	709,2	47,4	535,7	6,5	25,8	93,8	4,4	46,7
June	238,5	715,4	33,3	539,8	6,0	27,3	109,1	5,1	51,1
July	236,4	709,2	24,4	535,7	5,6	29,3	114,3	5,4	56,3
Aug	199,4	598,2	24,4	461,8	5,8	33,7	72,5	3,4	61,7
Sep	129,5	388,6	33,3	290,4	7,0	37,0	20,8	1,0	63,0
Oct	76,1	228,3	64,5	151,8	9,5	39,3	-36,7	-1,7	63,0
Nov	34,9	104,8	113,4	0,0	10,4	40,6	-59,6	-2,8	61,3
Dec	22,6	67,9	137,9	0,0	11,3	40,7	-122,0	-5,8	58,5
Jan	31,1	93,3	150,1	0,0	11,5	37,2	-105,6	-5,0	52,7
Feb	55,5	166,5	137,9	0,0	11,5	33,4	-16,3	-0,8	47,7
Mar	113,1	339,3	113,4	225,6	10,8	30,9	-41,5	-2,0	46,9
Apr	178,8	536,4	108,6	356,7	7,9	27,6	35,7	1,7	45,0
May	236,4	709,2	47,4	535,7	6,5	25,8	93,8	4,4	46,7
June	238,5	715,4	33,3	539,8	6,0	27,3	109,1	5,1	51,1
July	236,4	709,2	24,4	535,7	5,6	29,3	114,3	5,4	56,2
Aug	199,4	598,2	24,4	461,8	5,8	33,7	72,5	3,4	61,6
Sep	129,5	388,6	33,3	290,4	7,0	37,0	20,8	1,0	63,0
Oct	76,1	228,3	64,5	151,8	9,5	39,3	-36,7	-1,7	63,0
Nov	34,9	104,8	113,4	0,0	10,4	40,6	-59,6	-2,8	61,3
Dec	22,6	67,9	137,9	0,0	11,3	40,7	-122,0	-5,8	58,5
Jan	31,1	93,3	150,1	0,0	11,5	37,2	-105,6	-5,0	52,7
Feb	55,5	166,5	137,9	0,0	11,5	33,4	-16,3	-0,8	47,7
Mar	113,1	339,3	113,4	225,6	10,8	30,9	-41,5	-2,0	46,9
Apr	178,8	536,4	108,6	356,7	7,9	27,6	35,7	1,7	45,0
May	236,4	709,2	47,4	535,7	6,5	25,8	93,8	4,4	46,7
June	238,5	715,4	33,3	539,8	6,0	27,3	109,1	5,1	51,1
July	236,4	709,2	24,4	535,7	5,6	29,3	114,3	5,4	56,2
Aug	199,4	598,2	24,4	461,8	5,8	33,7	72,5	3,4	61,6
Sep	129,5	388,6	33,3	290,4	7,0	37,0	20,8	1,0	63,0
Oct	76,1	228,3	64,5	151,8	9,5	39,3	-36,7	-1,7	63,0
Nov	34,9	104,8	113,4	0,0	10,4	40,6	-59,6	-2,8	61,3
Dec	22,6	67,9	137,9	0,0	11,3	40,7	-122,0	-5,8	58,5

III. Temperature change energy storage

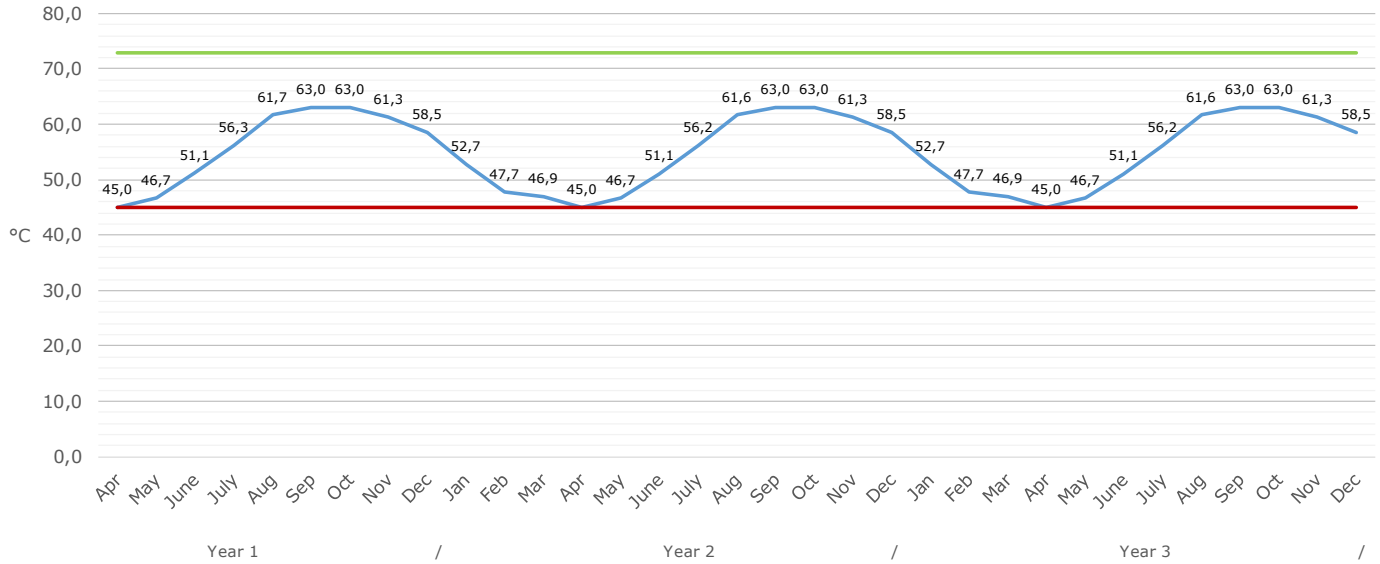
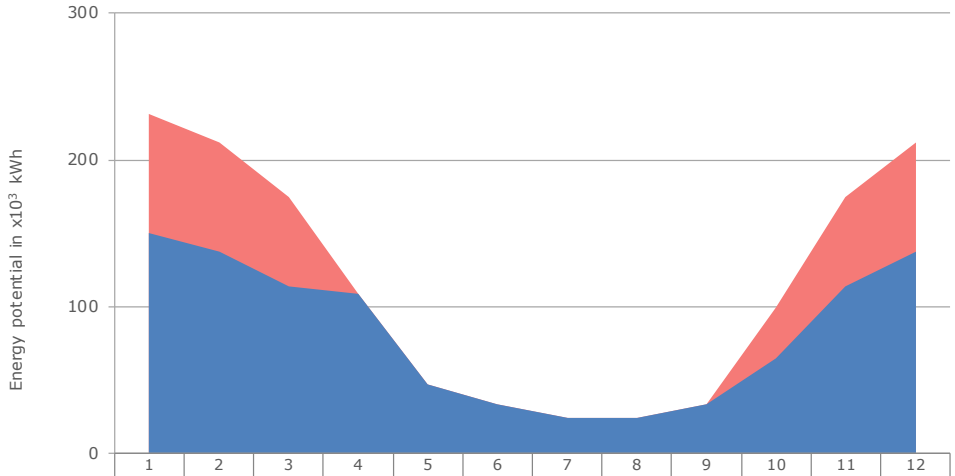


Figure B.7: *Temperature change energy storage. (by*

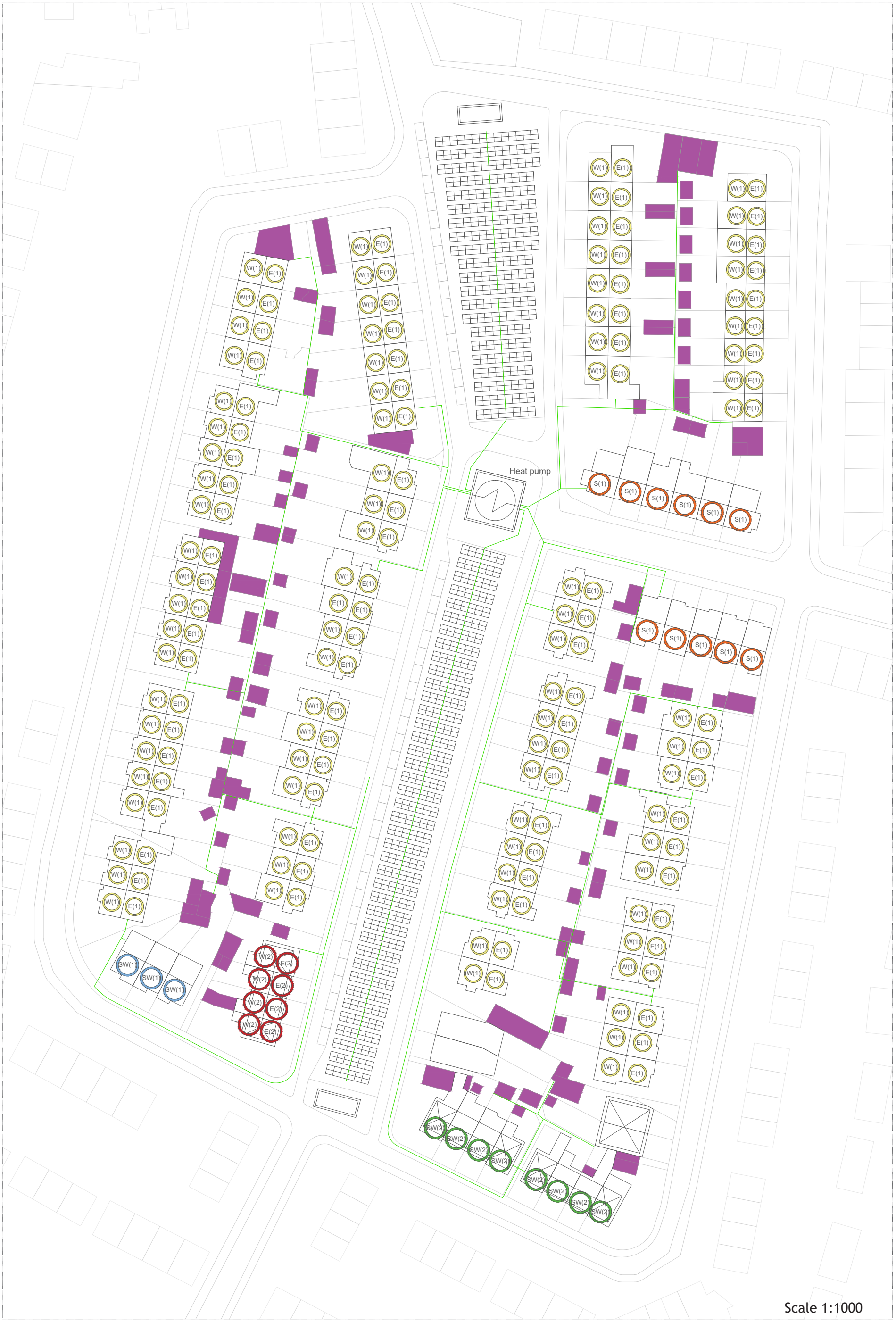


	1	2	3	4	5	6	7	8	9	10	11	12
Total heat demand	231	212	174	109	47	33	24	24	33	99	174	212
Provided heat demand	150	138	113	109	47	33	24	24	33	64	113	138

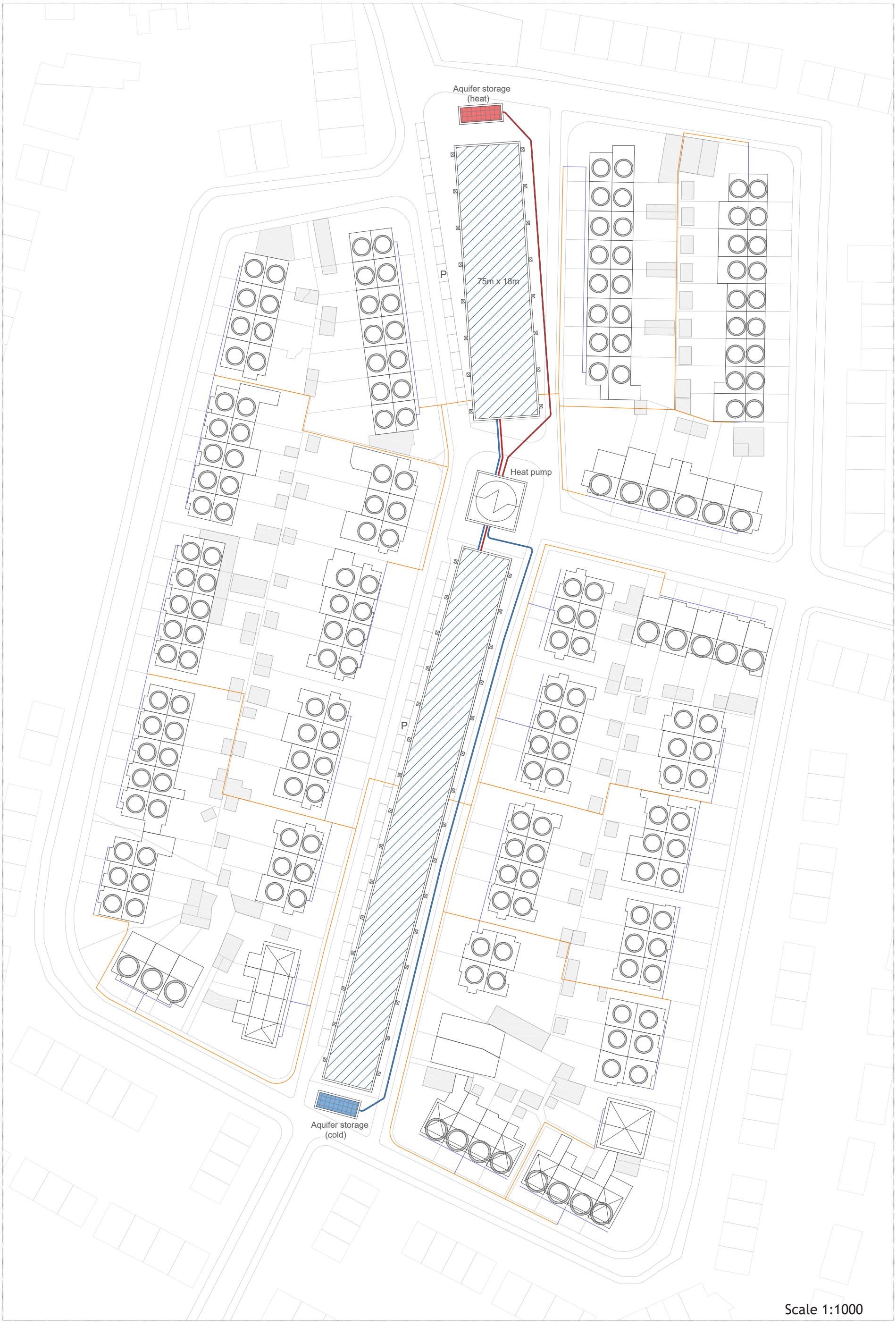
Figure 5.68: *Actual provided heat demand. (by Author)*

As visible in the table the heat demand that is supplied to the buildings is lower than the actual heat demand of the buildings. This configuration with the commonly applied placement of panels on roofs is simply not able to replace 100% of the gas use in the selected urban blocks. In the following months the new energy systems provides 65% of the heat demand: Jan, Feb, Mar, Oct, Nov & Dec. In the summer months the new energy systems does provide 100% of the heat demand. The total annual provided heat demand by the new energy systems is 989 x 10^3 kWh. The total heat demand of the selected urban blocks is 1375 x10^3 kWh. On annual base this configuration can therefor only provide 71,9% of the total annual heat demand.

IV. Technical floor plan



IV. Technical floor plan (2)



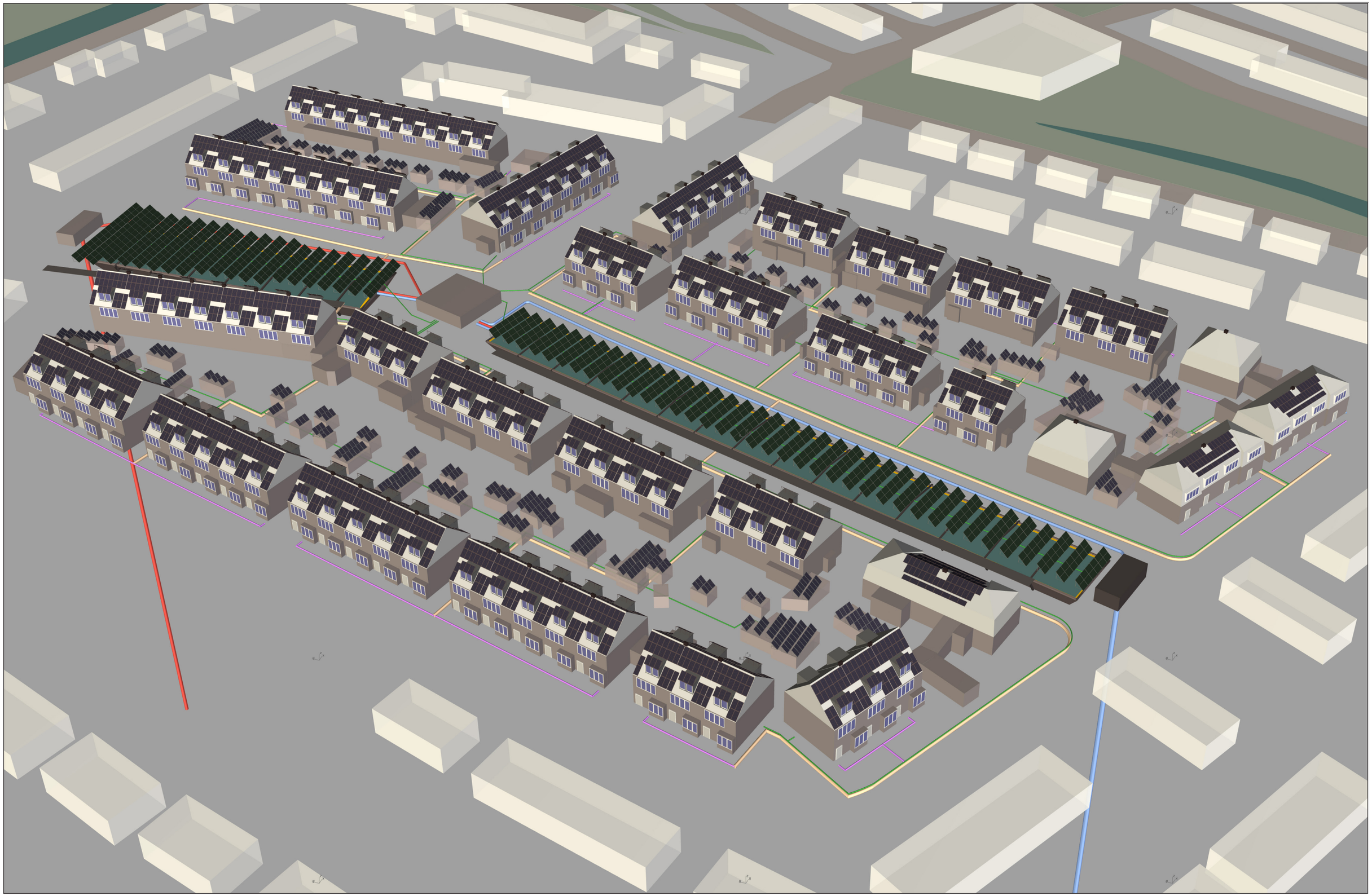
V. Visual floor plan

Grass
Households
Storages
P New created parking space
Trees
Solar field









(A.2 extra) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycooler.

I. Transport losses (same as A.1)

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production (elec) (x10^3 kWh)	Monthly energy production (T. heat) (3,0COP)(x10^3 kWh)	Deliverd heat demand households (x10^3 kWh)	Heat added to aquifer storage (x10^3 kWh)	Transport losses (x10^3 kWh)	Thermal losses pit storage (x10^3 kWh)	Delta (x10^3 kWh) (No inc. heat added Afuifer)	Delta temp.(C°)	Temp. tank (C°)
Apr	92,9	278,7	108,6	0,0	7,9	27,6	134,6	6,2	45,0
May	122,8	368,4	47,4	266,7	6,5	29,3	285,2	13,3	51,2
June	123,9	371,6	33,3	266,7	6,0	37,5	294,9	13,8	64,6
July	122,8	368,4	24,4	266,7	5,6	46,0	292,5	13,7	78,4
Aug	103,6	310,7	24,4	266,7	5,8	55,1	225,5	10,5	90,0
Sep	67,3	201,8	33,3	266,7	7,0	57,4	104,2	4,8	90,0
Oct	39,5	118,6	99,2	266,7	9,5	59,7	-49,7	-2,3	90,0
Nov	18,1	54,4	174,5	0,0	10,4	60,5	-191,0	-9,0	87,7
Dec	11,8	35,3	212,1	0,0	11,3	56,0	-244,1	-11,5	78,6
Jan	16,1	48,4	231,0	0,0	11,5	48,0	-242,1	-11,4	67,1
Feb	28,8	86,5	212,1	0,0	11,5	39,4	-176,6	-8,3	55,7
Mar	58,7	176,2	174,5	0,0	10,8	31,2	-40,3	-1,9	47,4
Apr	92,9	278,7	108,6	0,0	7,9	27,9	134,3	6,2	45,4
May	122,8	368,4	47,4	266,7	6,5	29,6	284,9	13,3	51,7
June	123,9	371,6	33,3	266,7	6,0	37,8	294,6	13,8	65,0
July	122,8	368,4	24,4	266,7	5,6	46,3	292,2	13,7	78,8
Aug	103,6	310,7	24,4	266,7	5,8	55,1	225,5	10,5	90,0
Sep	67,3	201,8	33,3	266,7	7,0	57,4	104,2	4,8	90,0
Oct	39,5	118,6	99,2	266,7	9,5	59,7	-49,7	-2,3	90,0
Nov	18,1	54,4	174,5	0,0	10,4	60,5	-191,0	-9,0	87,7
Dec	11,8	35,3	212,1	0,0	11,3	56,0	-244,1	-11,5	78,6

Figure 5.69: *Monthly net energy value & temperature difference (by Auhtor)*

III. Temperature change energy storage

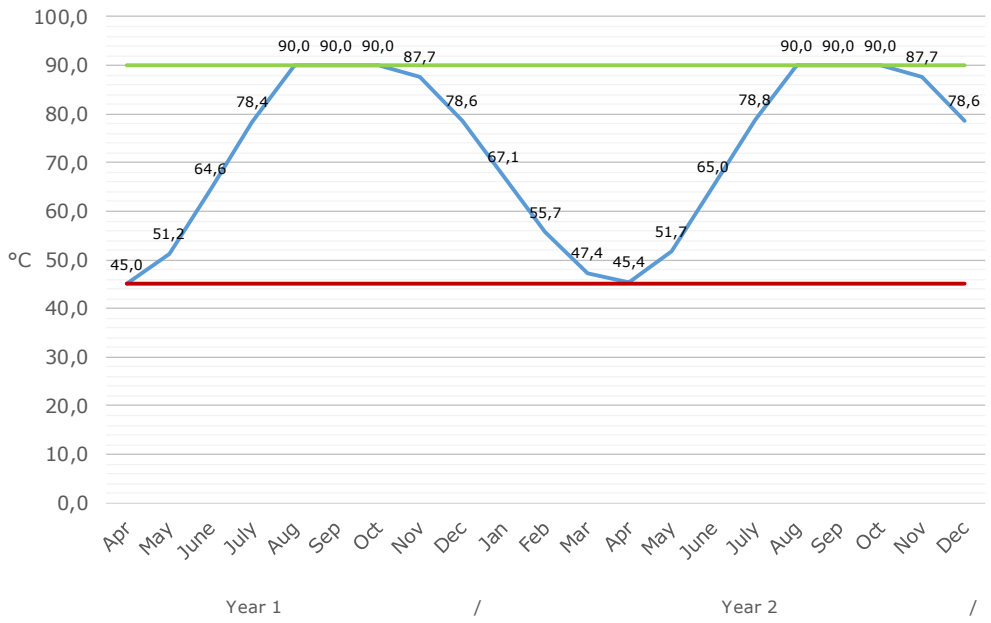
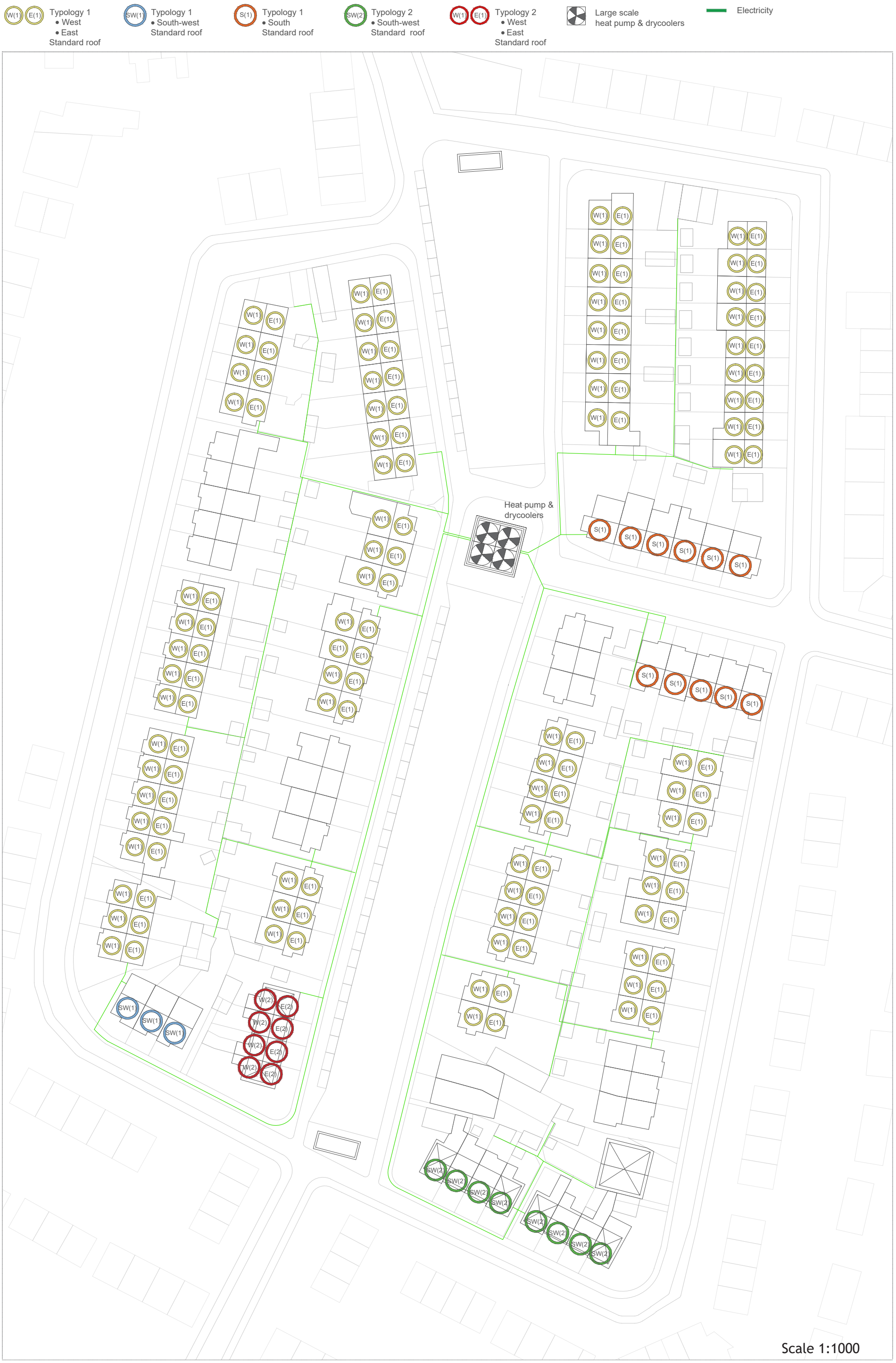


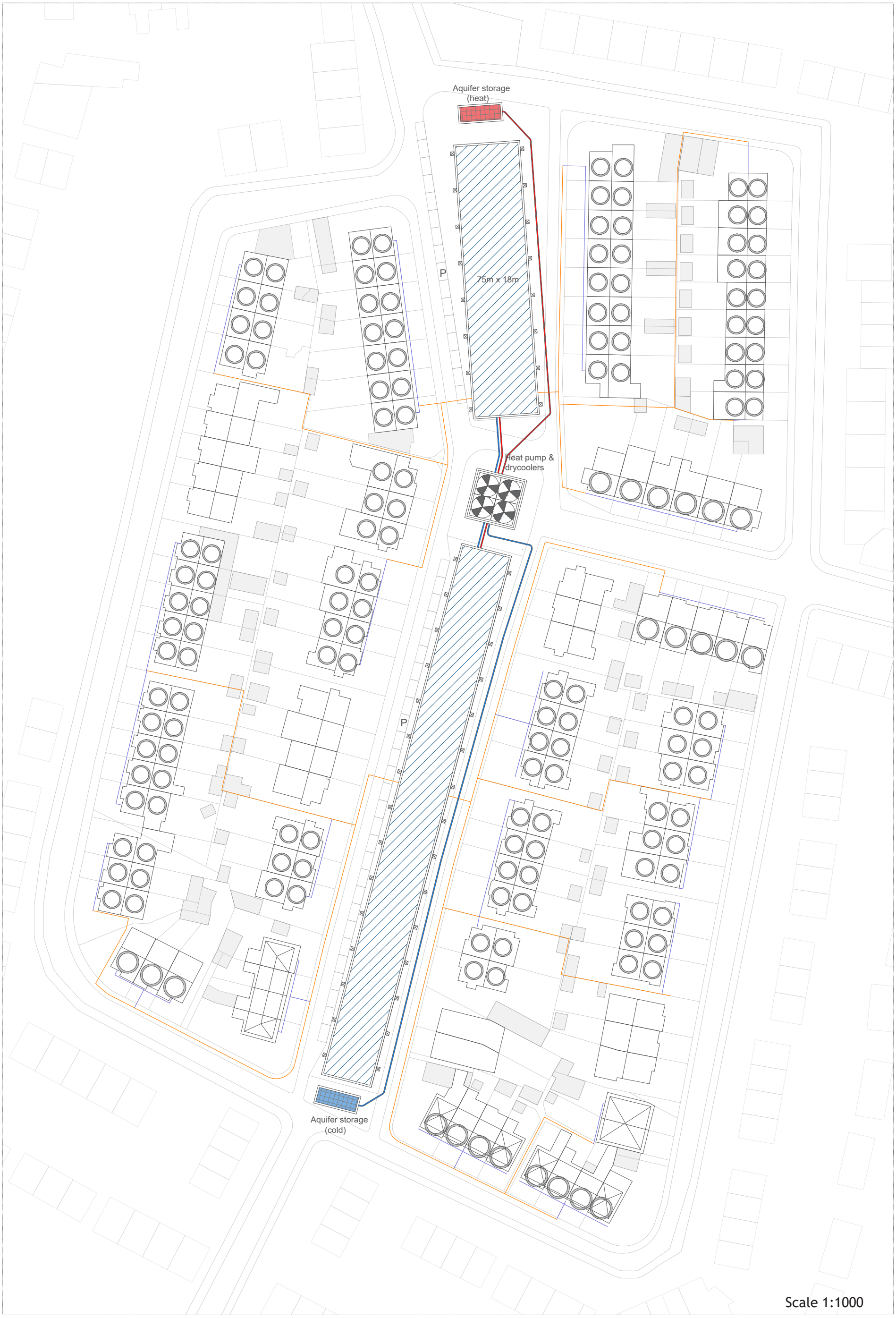
Figure 5.70: *Temperature change energy storage. (by Author)*

This configuration is able to provide 100% of the heat demand. The regeneration of the aquifer storage by drycoolers, provides the neccesary heat for the heat pump to use all the electricity to produce the full heat demand of the buildings.

IV. Technical floor plan



IV. Technical floor plan (2)



V. Visual floor plan

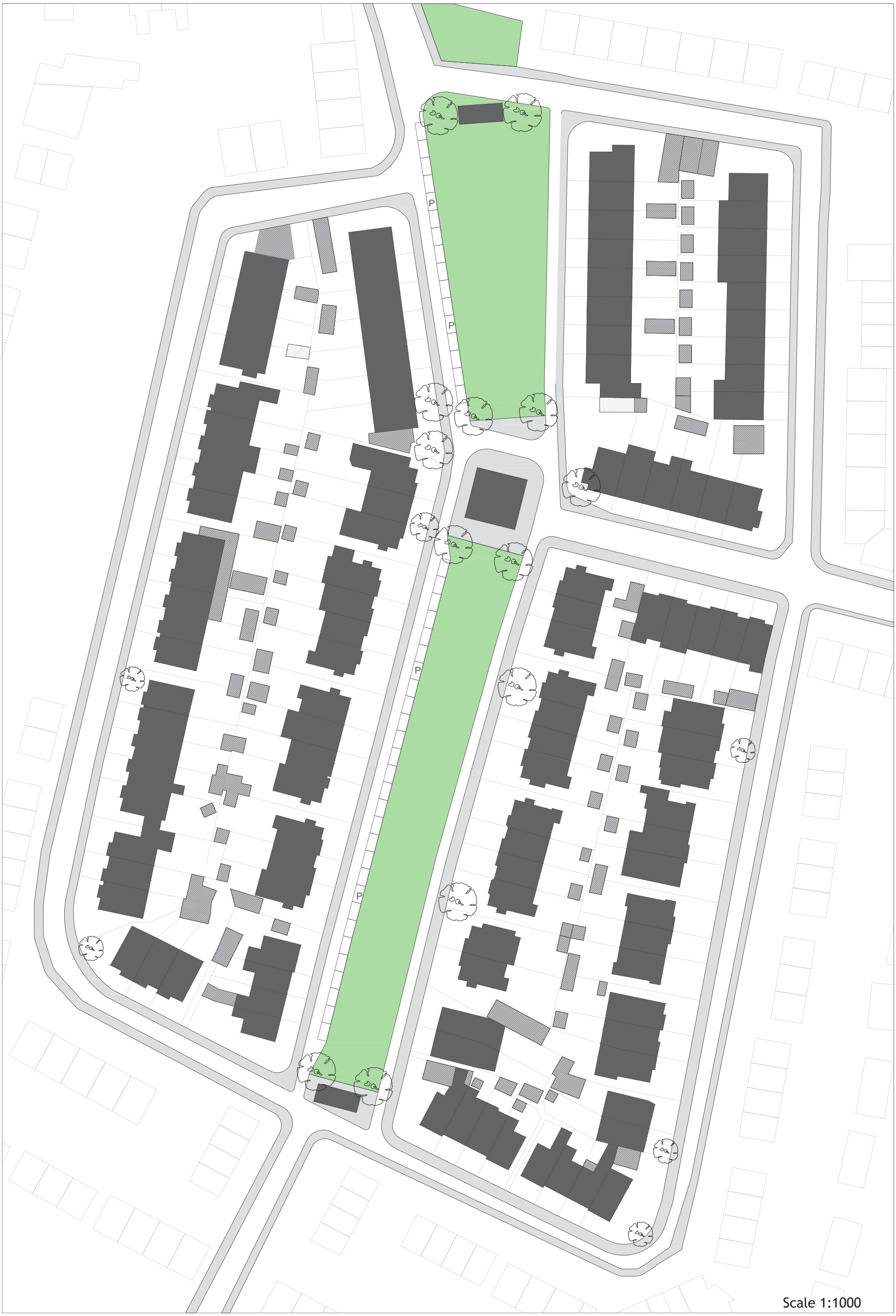
Grass

Households

Storages

P New created parking space

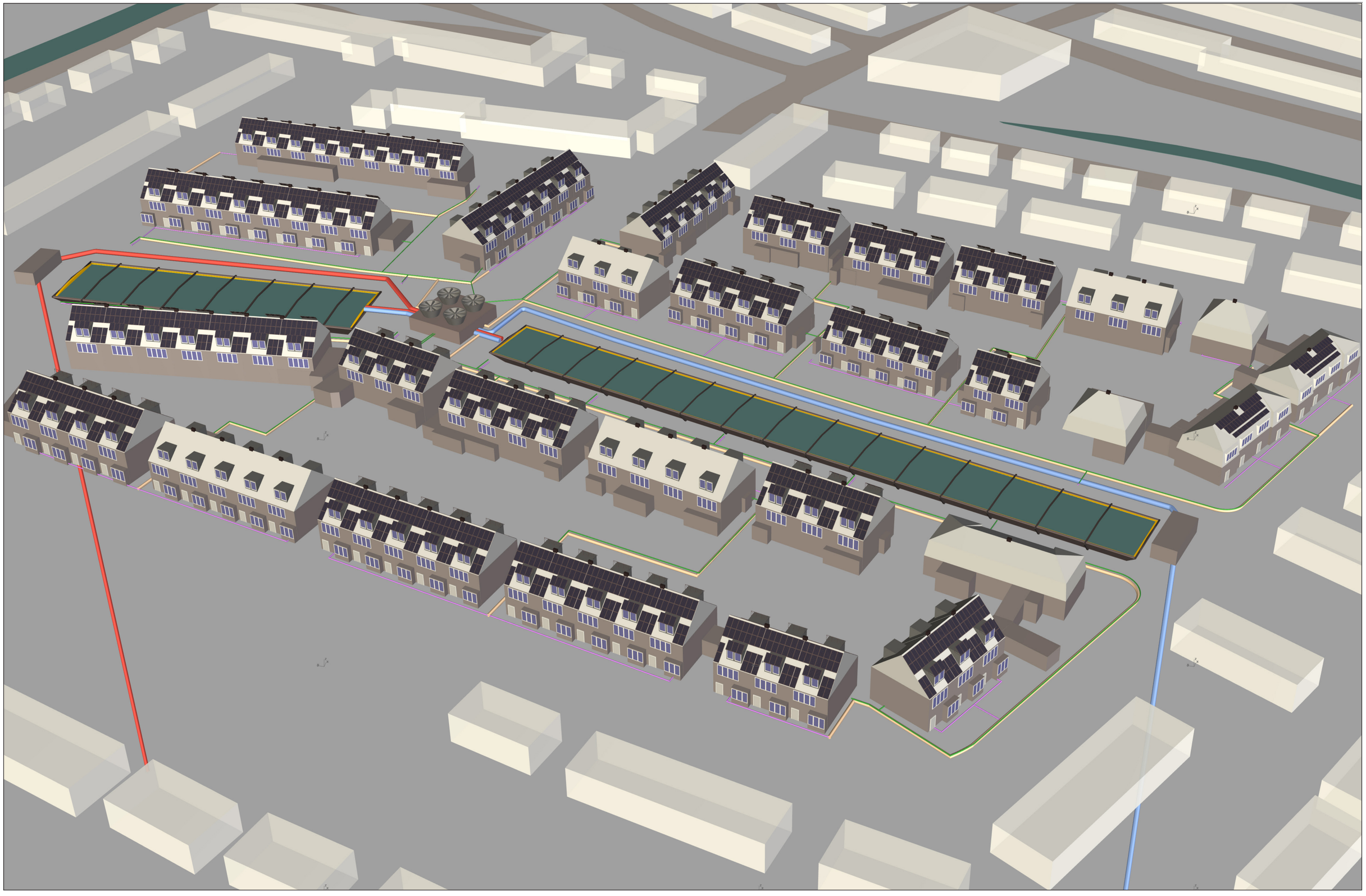
Trees



Scale 1:1000







(B) 100% gas replacement using the comparison results of Ch. 4

(B.1) Flat plate collectors combined with a water filled pit thermal energy storage.

I. Transport losses

In the months April, May, June, July, August & September water of 80 °C is transported to the energy storage tanks. The return temperature of the water is 10 °C which is comparable to the ambient temperature in these months resulting in negligible energy losses.
In the months January, February, March, October, November & December water of 45 °C is transported from the energy storage tanks towards the buildings. The return temperature of the water is 10 °C. The distribution losses of this configuration are therefor the same as in the A.1 configuration

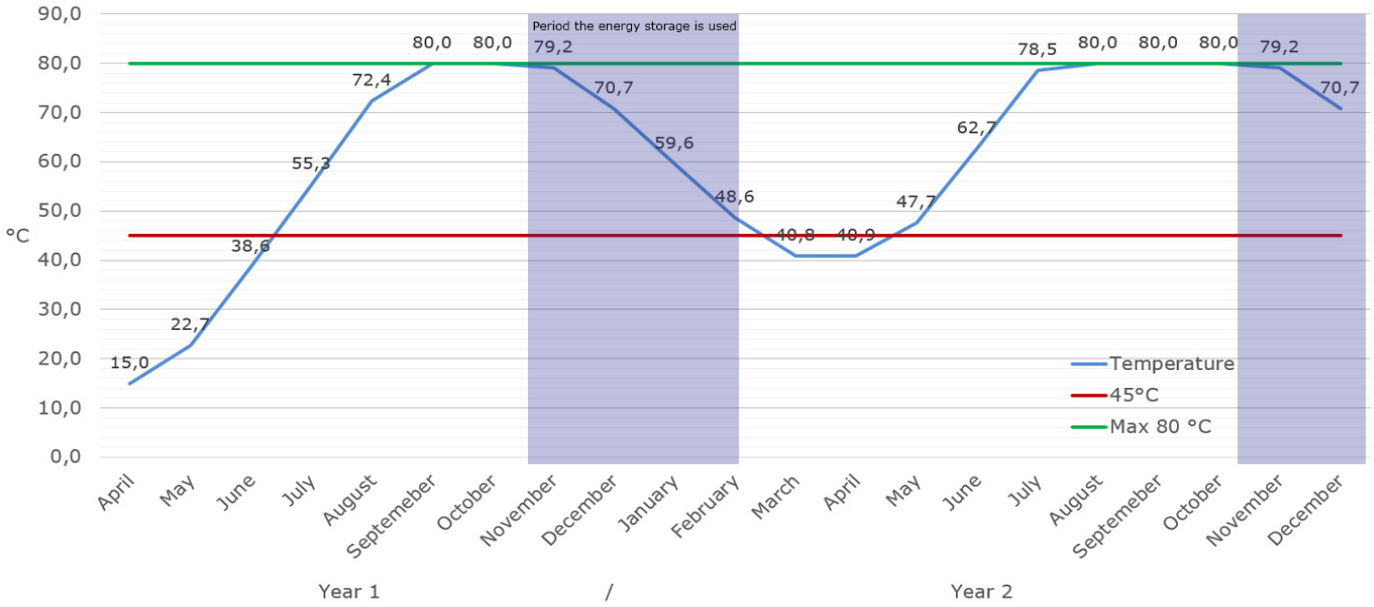
II. Net energy value added/extracted from the energy storage

Figure 5.71: *Monthly net energy value & temperature difference (by Auhtor)*

Month	Monthly energy production (x10³ kWh)	Heat demand households (x10³ kWh)	Transport losses (x10³ kWh)	Thermal losses pit storage (x10³ kWh)	Delta (x10³ kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	289,4	108,6	12,3	4,9	163,5	7,7	15,0
May	403,7	47,4	11,8	7,7	336,7	15,9	22,7
June	416,1	33,3	11,1	17,8	353,9	16,7	38,6
July	424,2	24,4	10,3	28,6	361,0	17,0	55,3
Aug	348,0	24,4	10,3	41,8	271,5	12,8	72,4
Sep	213,0	33,3	10,4	49,8	119,5	5,6	80,0
Oct	143,0	99,2	9,5	52,1	-17,8	-0,8	80,0
Nov	60,4	174,5	10,4	54,1	-178,7	-8,4	79,2
Dec	37,1	212,1	11,3	50,0	-236,4	-11,2	70,7
Jan	52,5	231,0	11,5	42,3	-232,3	-11,0	59,6
Feb	93,1	212,1	11,5	34,1	-164,7	-7,8	48,6
Mar	213,1	174,5	10,8	26,3	1,5	0,1	40,8
Apr	289,4	108,6	12,3	24,5	144,0	6,8	40,9
May	403,7	47,4	11,8	26,6	317,9	15,0	47,7
June	416,1	33,3	11,1	36,0	335,7	15,8	62,7
July	424,2	24,4	10,3	46,1	343,5	16,2	78,5
Aug	348,0	24,4	10,3	47,6	265,8	12,5	80,0
Sep	213,0	33,3	10,4	49,8	119,5	5,6	80,0
Oct	143,0	99,2	9,5	52,1	-17,8	-0,8	80,0
Nov	60,4	174,5	10,4	54,1	-178,7	-8,4	79,2
Dec	37,1	212,1	11,3	50,0	-236,4	-11,2	70,7

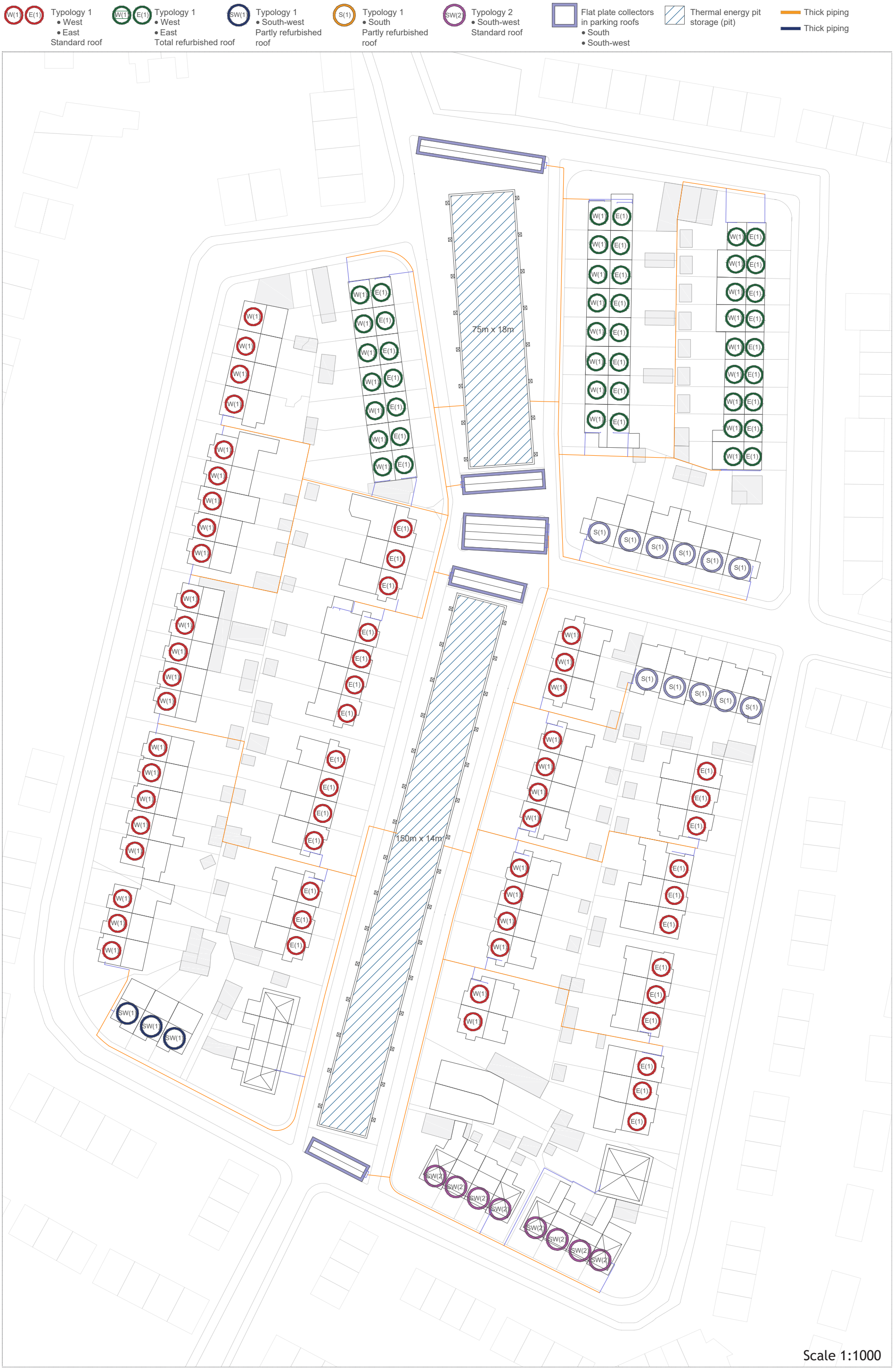
Figure 5.72: *Temperature change energy storage. (by Author)*

III. Temperature change energy storage



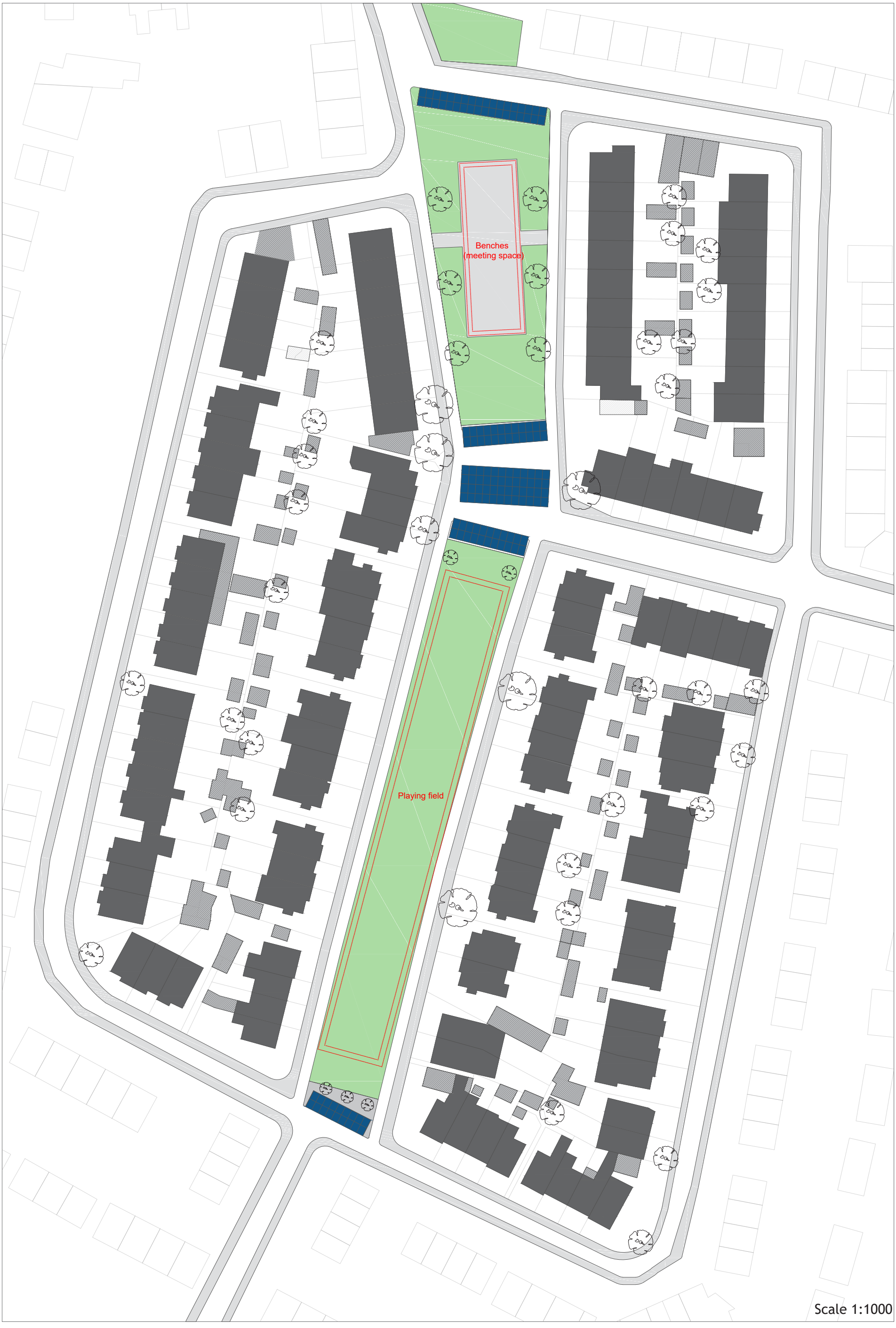
The blue areas are the periods that the buildings use thermal heat from the energy storage. In these months the water in the storage tank should atleast be 45 °C.

IV. Technical floor plan



V. Visual floor plan

Grass · Households · Storages · Public functions · P New created parking space · Trees · Covered parking space









Total(B) 100% gas replacement using the comparison results of Ch. 4

(B.2) Flat plate collectors combined with a salt filled latent tank storage.

I. Transport losses: The same as in configuration A.1

II. Net energy value added/extracted from the energy storage

Month	Energy input for storage x10^3 kWh)	Actual heat demand households (x10^3 kWh)	Transport losses (x10^3 kWh)	Thermal losses tank storage (x10^3 kWh)	Delta (x10^3 kWh)	Possible sensible temp. swing(C°)	Temp. tank (C°)	Delta temp.(C°) not stored sensible	Latent stored energy (x10^3 kWh)	Latent storage potential left (x10^3 kWh) Total 1 cycle: 664 x10^3 kWh	Sensible stored energy after phase change at 48 °C. (x10^3 kWh)	Delta temp.(C°) Sensible	Latent regenerated stored energy (x10^3 kWh)	Laten stored regenerated energy (x10^3 kWh) Total 1 cycle: 664 x10^3 kWh	Sensible stored regenerated energy after phase change at 48 °C. (x10^3 kWh)	Delta temp.(C°) Sensible
April	73,5	0,0	19,9	1,3	52,3	9,8	**15,0**									
May	206,6	0,0	18,8	2,4	185,4	34,8	**24,8**	11,6	62,0	602,0						
June	228,5	0,0	18,1	6,5	203,9	38,3	**48,0**	38,3	203,9	398,1						
July	242,6	0,0	17,4	6,0	219,2	41,2	**48,0**	41,2	219,2	178,9						
August	194,6	0,0	17,5	6,1	171,0	32,1	**48,0**	32,1	171,0	7,9						
September	100,8	0,0	18,3	6,7	75,7	14,2	**48,0**	14,2	75,7	-67,8	67,8	12,7				
October	0,0	9,2	9,5	9,8	-28,5	-5,3	**60,7**									
November	0,0	136,5	10,4	9,5	-156,4	-29,4	**55,4**	22,0					117,1	546,9		
December	0,0	188,8	11,3	8,6	-208,7	-39,2	**48,0**	39,2					208,7	338,2		
January	0,0	197,9	11,5	8,8	-218,3	-41,0	**48,0**	41,0					218,3	120,0		
February	0,0	153,6	11,5	8,8	-173,9	-32,6	**48,0**	32,6					173,9	-53,9	53,9	10,1
March	0,0	40,4	10,8	6,3	-57,5	-10,8	**37,9**	10,8								
April	73,5	0,0	19,9	3,7	49,9	9,4	**27,1**									
May	206,6	0,0	18,8	4,7	183,1	34,4	**36,5**	22,8	121,6	542,4						
June	228,5	0,0	18,1	6,5	203,9	38,3	**48,0**	38,3	203,9	338,4						
July	242,6	0,0	17,4	6,0	219,2	41,2	**48,0**	41,2	219,2	119,2						
August	194,6	0,0	17,5	6,1	171,0	32,1	**48,0**	32,1	171,0	-51,8	51,8	9,7				
September	100,8	0,0	18,3	8,6	73,8	13,9	**57,7**									
October	0,0	9,2	9,5	12,0	-30,6	-5,8	**71,6**									
November	0,0	136,5	10,4	11,5	-158,4	-29,8	**65,8**	11,9					63,5	600,4		
December	0,0	188,8	11,3	8,6	-208,7	-39,2	**48,0**	39,2					208,7	391,8		
January	0,0	197,9	11,5	8,8	-218,3	-41,0	**48,0**	41,0					218,3	173,5		
February	0,0	153,6	11,5	8,8	-173,9	-32,6	**48,0**	32,6					173,9	-0,4		
March	0,0	40,4	10,8	8,3	-59,5	-11,2	**48,0**	11,2					59,5	-59,9	59,9	11,2
April	73,5	0,0	19,9	5,6	48,0	9,0	**36,8**	-2,2	-11,8	675,8						
May	206,6	0,0	18,8	7,0	180,8	33,9	**48,0**	33,9	180,8	495,0						
June	228,5	0,0	18,1	6,5	203,9	38,3	**48,0**	38,3	203,9	291,1						
July	242,6	0,0	17,4	6,0	219,2	41,2	**48,0**	41,2	219,2	71,9						
August	194,6	0,0	17,5	6,1	171,0	32,1	**48,0**	32,1	171,0	-99,1	99,1	18,6				
September	100,8	0,0	18,3	10,4	72,0	13,5	**66,6**									
October	0,0	9,2	9,5	13,6	-32,3	-6,1	**80,0**									
November	0,0	136,5	10,4	13,1	-160,1	-30,1	**73,9**	4,1					21,9	642,1		
December	0,0	188,8	11,3	8,6	-208,7	-39,2	**48,0**	39,2					208,7	433,4		
January	0,0	197,9	11,5	8,8	-218,3	-41,0	**48,0**	41,0					218,3	215,1		
February	0,0	153,6	11,5	8,8	-173,9	-32,6	**48,0**	32,6					173,9	41,2		
March	0,0	40,4	10,8	8,3	-59,5	-11,2	**48,0**	11,2					59,5	-18,3	18,3	3,4
April	73,5	0,0	19,9	7,1	46,5	8,7	**44,6**	5,3	28,2	635,7						
May	206,6	0,0	18,8	7,0	180,8	33,9	**48,0**	33,9	180,8	454,9						
June	228,5	0,0	18,1	6,5	203,9	38,3	**48,0**	38,3	203,9	251,0						
July	242,6	0,0	17,4	6,0	219,2	41,2	**48,0**	41,2	219,2	31,8						
August	194,6	0,0	17,5	6,1	171,0	32,1	**48,0**	32,1	171,0	-139,2	139,2	26,1				
September	100,8	0,0	18,3	11,9	70,5	13,2	**74,1**									
October	0,0	9,2	9,5	13,6	-32,3	-6,1	**80,0**									
November	0,0	136,5	10,4	13,1	-160,1	-30,1	**73,9**	4,1					21,9	642,1		
December	0,0	188,8	11,3	8,6	-208,7	-39,2	**48,0**	39,2					208,7	433,4		

Figure 5.73: *Monthly net energy value & temperature difference (by Auhtor)*

III. Temperature change energy storage

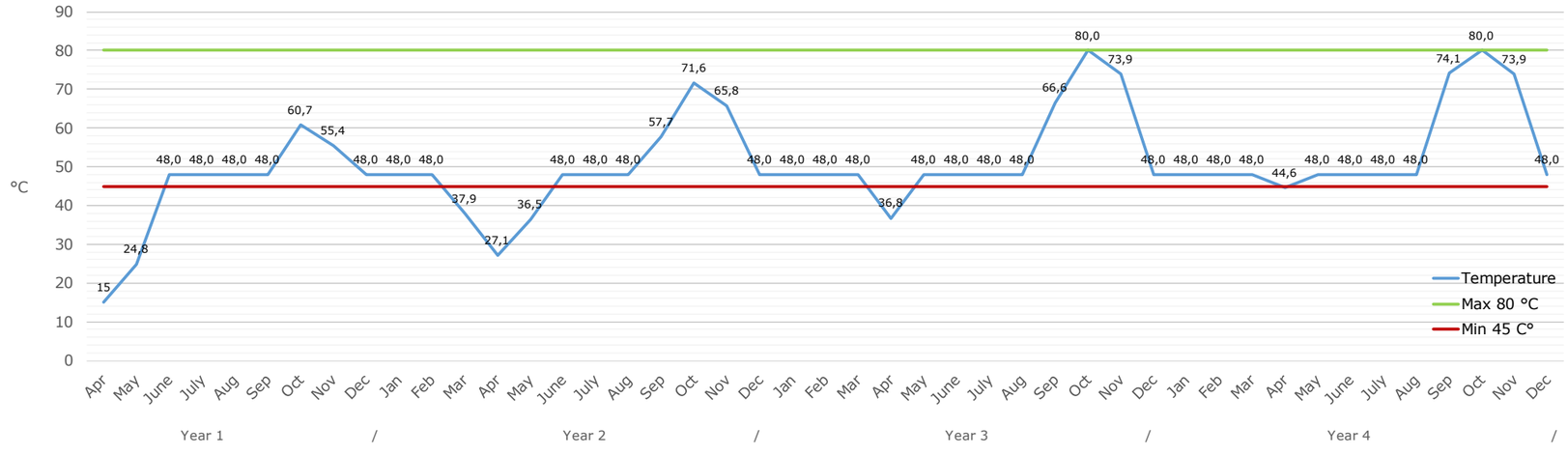
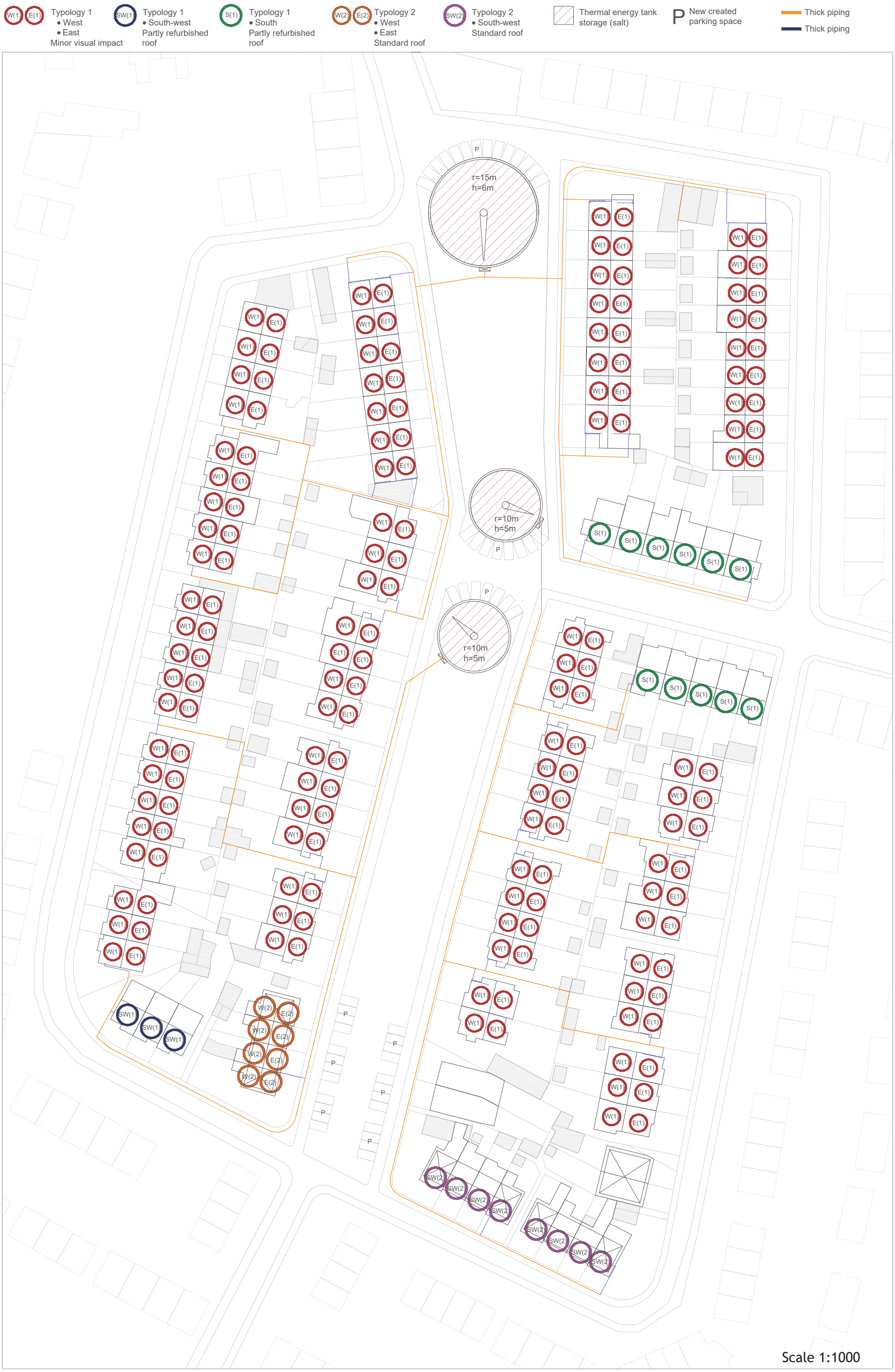


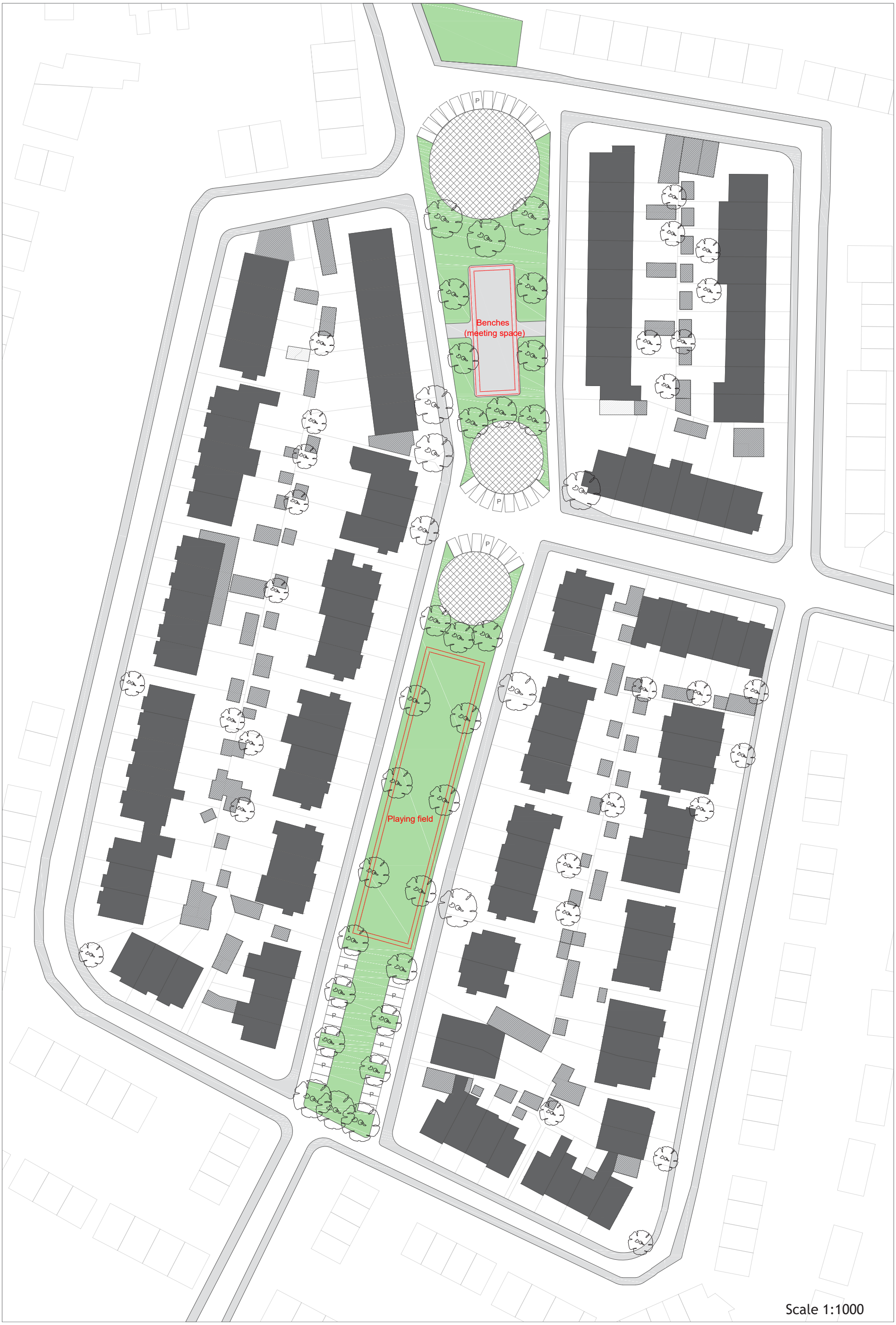
Figure 5.74: *Temperature change energy storage. (by Author)*

IV. Technical floor plan



V. Visual floor plan

Grass · Households · Storages · Public functions · P New created parking space · Trees







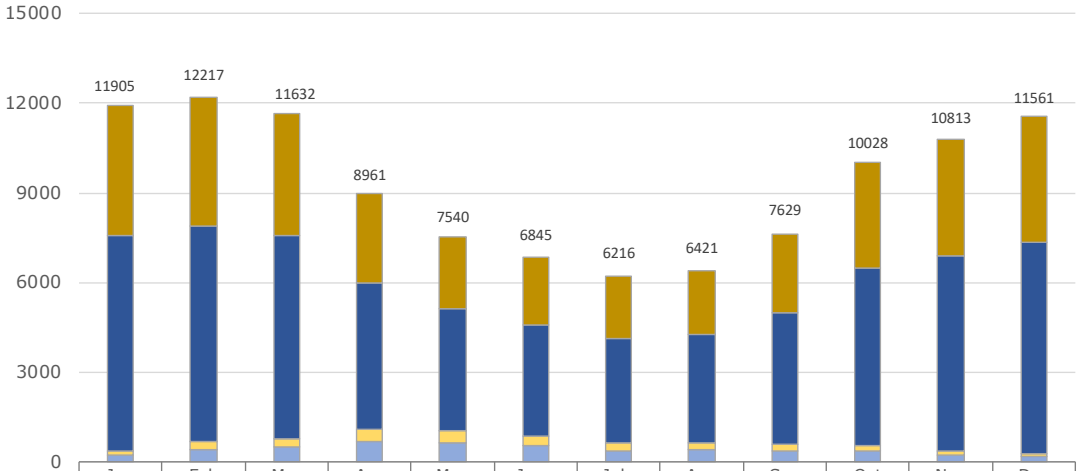


(B) 100% gas replacement using the comparison results of Ch. 4

(B.3) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

I. Transport losses

Transport thermal energy losses occur during the transport of thermal heat (26 °C) from the PVT panels towards the heat pump every month of the year. Secondly there are monthly thermal losses if thermal heat is transported from the heat pump/pit storage towards the buildings at a temperature of 45 °C.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage/HP to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage/HP to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045
PV/T panel to storage & HP (thick pipe 26 C°)	137	254	295	410	398	324	240	242	234	215	144	112
PV/T panel to storage & HP (thin pipe 26 C°)	228	424	493	685	665	542	400	404	391	359	241	187

Figure B.8: *Transport energy losses. (by Author)*

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production	Heat demand households	Transport losses (x10^3 kWh)	Thermal losses pit storage	Delta (x10^3 kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	247,9	108,6	9,0	5,0	125,4	5,9	15,0
May	327,8	47,4	7,5	6,4	266,4	12,6	20,9
June	330,7	33,3	6,8	14,2	276,4	13,0	33,5
July	327,8	24,4	6,2	22,2	275,0	13,0	46,5
Aug	276,5	24,4	6,4	32,5	213,2	10,1	59,5
Sep	179,6	33,3	7,6	42,5	96,1	4,5	69,6
Oct	105,5	99,2	10,0	48,3	-52,0	-2,5	74,1
Nov	48,4	174,5	10,8	49,1	-186,0	-8,8	71,7
Dec	31,4	212,1	11,6	44,7	-237,0	-11,2	62,9
Jan	43,1	231,0	11,9	36,9	-236,7	-11,2	51,7
Feb	77,0	212,1	12,2	28,3	-175,7	-8,3	40,5
Mar	156,8	174,5	11,6	20,1	-49,4	-2,3	32,2
Apr	247,9	108,6	9,0	16,4	114,0	5,4	29,9
May	327,8	47,4	7,5	17,4	255,4	12,1	35,3
June	330,7	33,3	6,8	24,8	265,8	12,5	47,3
July	327,8	24,4	6,2	32,4	264,8	12,5	59,9
Aug	276,5	24,4	6,4	42,4	203,3	9,6	72,4
Sep	179,6	33,3	7,6	52,0	86,6	4,1	82,0
Oct	105,5	99,2	10,0	57,5	-61,2	-2,9	86,1
Nov	48,4	174,5	10,8	57,9	-194,8	-9,2	83,2
Dec	31,4	212,1	11,6	53,2	-245,5	-11,6	74,0
Jan	43,1	231,0	11,9	45,1	-244,9	-11,6	62,4
Feb	77,0	212,1	12,2	36,2	-183,6	-8,7	50,8
Mar	156,8	174,5	11,6	27,7	-57,0	-2,7	42,2
Apr	247,9	108,6	9,0	23,7	106,7	5,0	39,5
May	327,8	47,4	7,5	24,5	248,3	11,7	44,5
June	330,7	33,3	6,8	31,6	259,0	12,2	56,2
July	327,8	24,4	6,2	39,0	258,2	12,2	68,5
Aug	276,5	24,4	6,4	48,7	197,0	9,3	80,7
Sep	179,6	33,3	7,6	58,1	80,5	3,8	90,0
Oct	105,5	99,2	10,0	60,5	-64,2	-3,0	90,0
Nov	48,4	174,5	10,8	60,8	-197,7	-9,3	87,0

Nov	48,4	174,5	10,8	60,8	-197,7	-9,3	87,0
Dec	31,4	212,1	11,6	56,0	-248,3	-11,7	77,6
Jan	43,1	231,0	11,9	47,8	-247,5	-11,7	65,9
Feb	77,0	212,1	12,2	38,8	-186,2	-8,8	54,2
Mar	156,8	174,5	11,6	30,2	-59,5	-2,8	45,4
Apr	247,9	108,6	9,0	26,1	104,3	4,9	42,6
May	327,8	47,4	7,5	26,8	246,0	11,6	47,6
June	330,7	33,3	6,8	33,8	256,7	12,1	59,2
July	327,8	24,4	6,2	41,2	256,1	12,1	71,3
Aug	276,5	24,4	6,4	50,8	194,9	9,2	83,4
Sep	179,6	33,3	7,6	58,2	80,5	3,8	90,0
Oct	105,5	99,2	10,0	60,5	-64,2	-3,0	90,0
Nov	48,4	174,5	10,8	60,8	-197,7	-9,3	87,0
Dec	31,4	212,1	11,6	56,0	-248,3	-11,7	77,6

Figure 5.75: *Monthly net energy value & temperature difference (by Auhtor)*
Calculated with excel using the method explained in chapter 4.6.

III. Temperature change energy storage

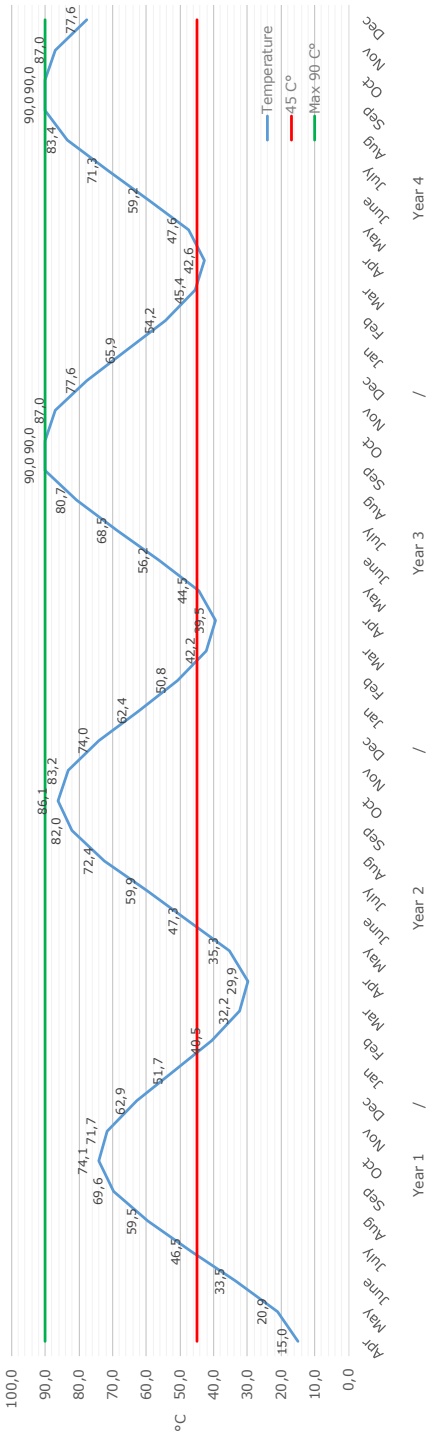
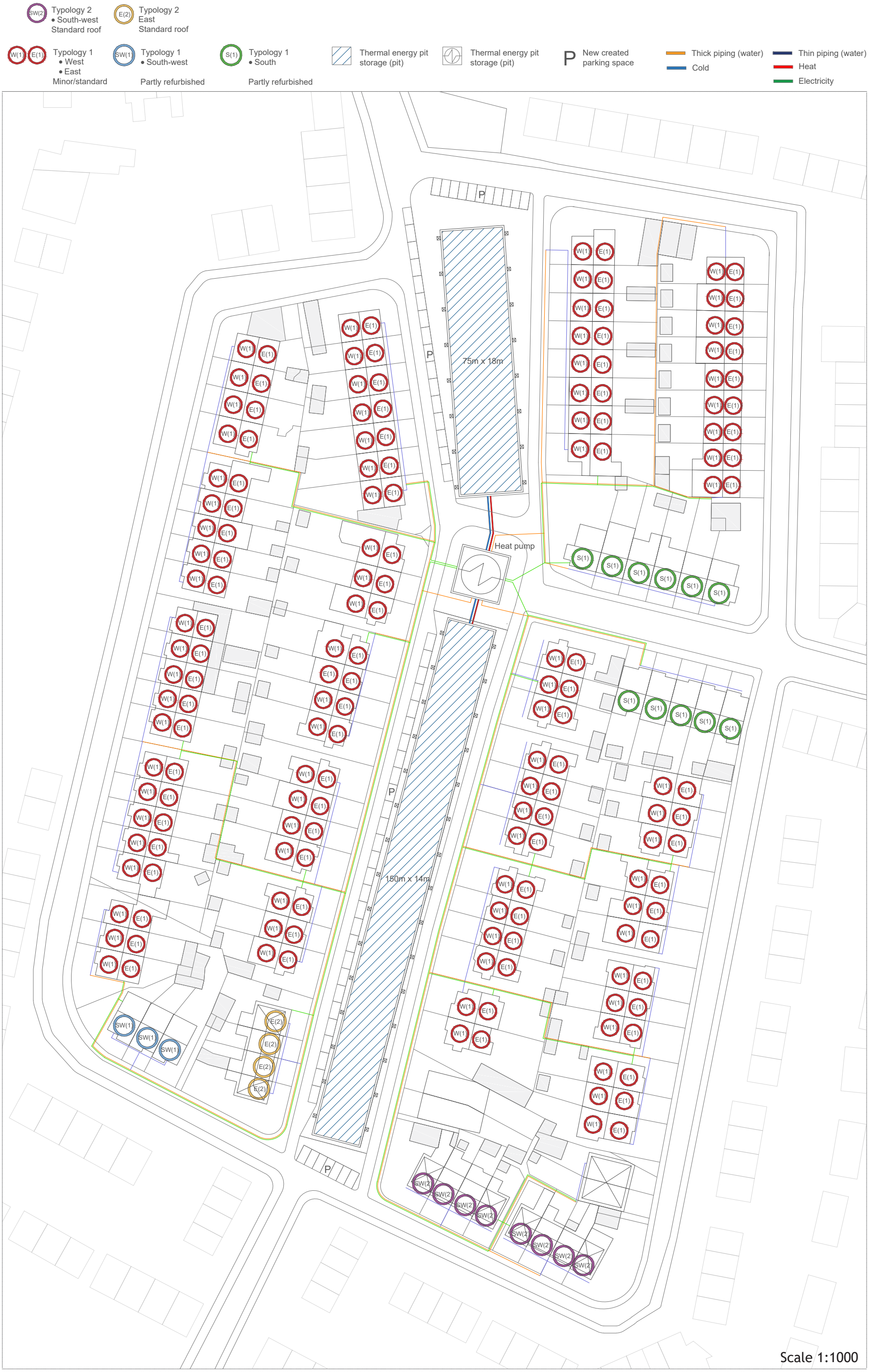
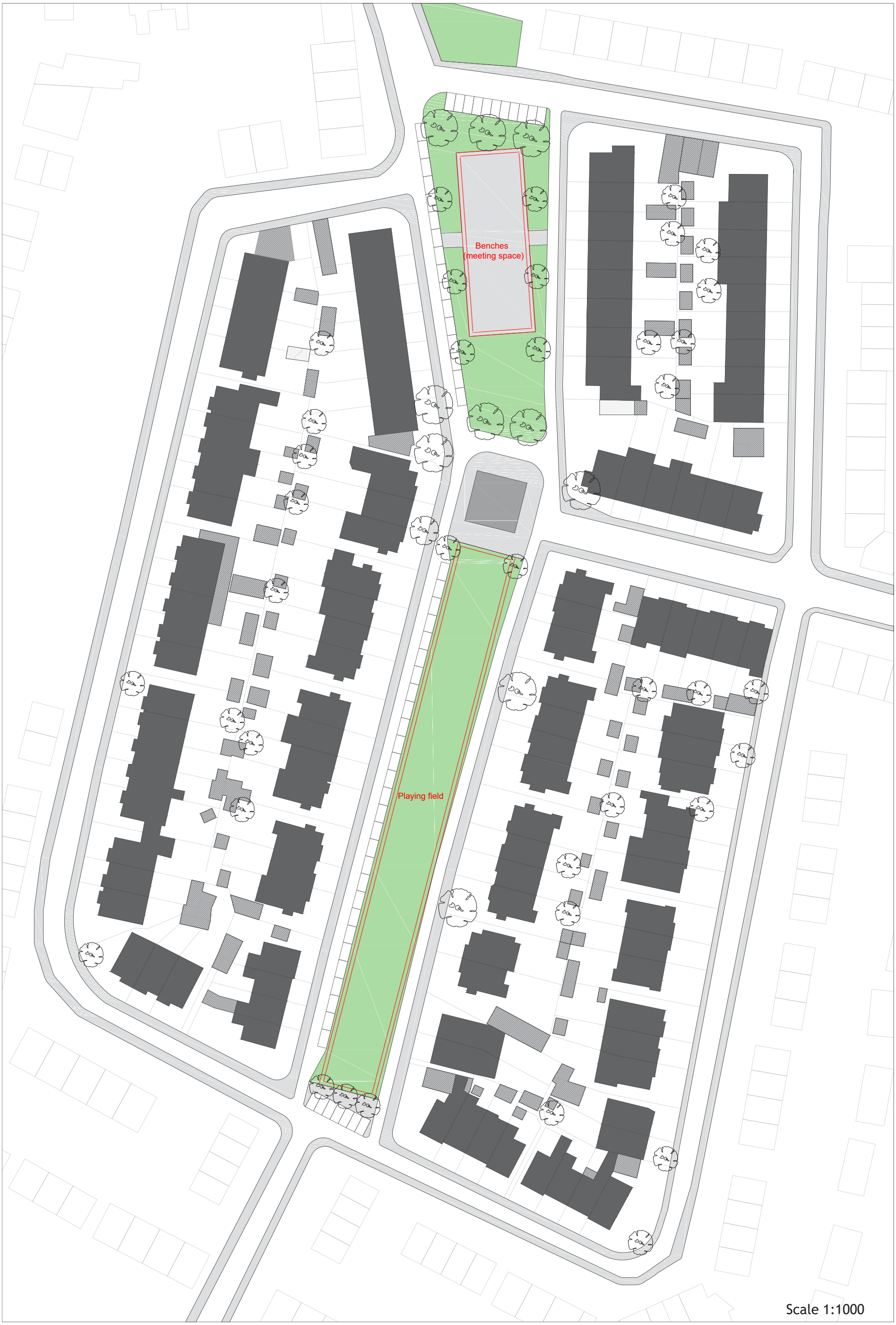


Figure 5.76: *Temperature change energy storage. (by Author)*

IV. Technical floor plan

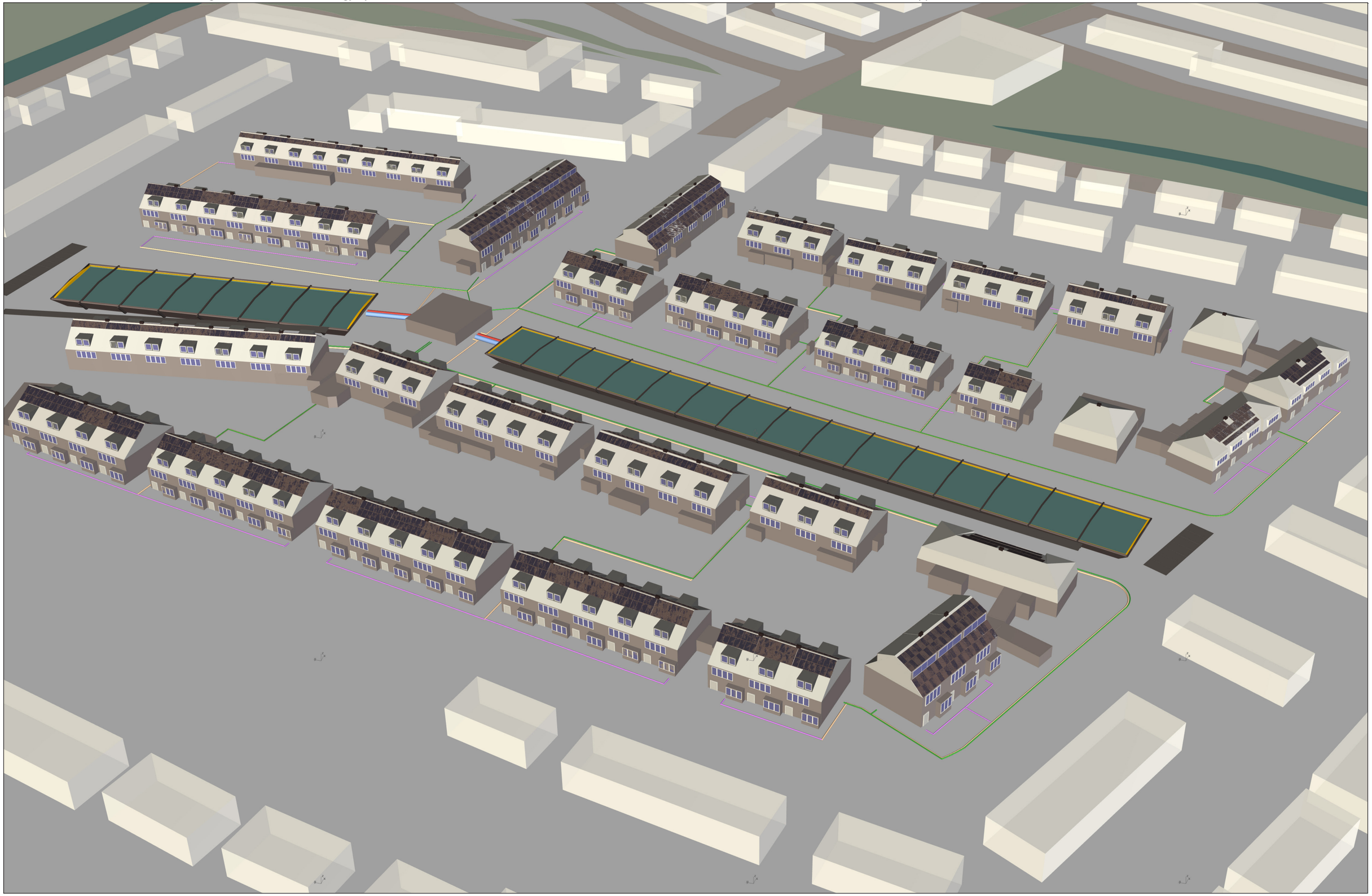


V. Visual floor plan









(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

(C.1) Flat plate collectors combined with a water filled pit thermal energy storage.

I. Transport losses

In the months April, May, June, July, August & September water of 80 °C is transported to the energy storage tanks. The return temperature of the water is 10 °C which is comparable to the ambient temperature in these months resulting in negligible energy losses.
In the months January, February, March, October, November & December water of 45 °C is transported from the energy storage tanks towards the buildings. The return temperature of the water is 10 °C. The distribution losses of this configuration are therefor the same as in the A.1 configuration

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production	Heat demand households	Transport losses (x10^3 kWh)	Thermal losses pit storage	Delta (x10^3 kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	170,9	108,6	12,3	4,1	45,9	2,8	15,0
May	238,4	47,4	11,8	3,3	175,8	10,8	17,8
June	245,7	33,3	11,1	8,5	192,8	11,8	28,6
July	250,5	24,4	10,3	14,4	201,5	12,3	40,4
Aug	205,5	24,4	10,3	22,4	148,4	9,1	52,7
Sep	125,8	33,3	10,4	30,0	52,0	3,2	61,8
Oct	84,4	99,2	9,5	33,9	-58,1	-3,6	64,9
Nov	35,6	60,3	10,4	33,9	-69,0	-4,2	61,4
Dec	21,9	94,8	11,3	33,1	-117,3	-7,2	57,2
Jan	31,0	96,0	11,5	29,2	-105,8	-6,5	50,0
Feb	55,0	61,7	11,5	25,2	-43,4	-2,7	43,5
Mar	125,9	174,5	10,8	21,9	-81,4	-5,0	40,9
Apr	170,9	108,6	12,3	17,2	32,7	2,0	35,9
May	238,4	47,4	11,8	16,0	163,2	10,0	37,9
June	245,7	33,3	11,1	20,7	180,6	11,1	47,9
July	250,5	24,4	10,3	26,1	189,8	11,6	58,9
Aug	205,5	24,4	10,3	33,7	137,2	8,4	70,5
Sep	125,8	33,3	10,4	40,8	41,2	2,5	78,9
Oct	84,4	99,2	9,5	43,4	-67,6	-4,1	80,0
Nov	35,6	60,3	10,4	43,0	-78,1	-4,8	75,9
Dec	21,9	94,8	11,3	41,9	-126,1	-7,7	71,1
Jan	31,0	96,0	11,5	37,7	-114,2	-7,0	63,4
Feb	55,0	61,7	11,5	33,3	-51,5	-3,2	56,4
Mar	125,9	174,5	10,8	29,7	-89,2	-5,5	53,2
Apr	170,9	108,6	12,3	24,7	25,2	1,5	47,8
May	238,4	47,4	11,8	23,2	156,0	9,5	49,3
June	245,7	33,3	11,1	27,6	173,7	10,6	58,9
July	250,5	24,4	10,3	32,7	183,2	11,2	69,5
Aug	205,5	24,4	10,3	39,6	131,2	8,0	80,0
Sep	125,8	33,3	10,4	41,5	40,6	2,5	80,0
Oct	84,4	99,2	9,5	43,4	-67,6	-4,1	80,0
Nov	35,6	60,3	10,4	43,0	-78,1	-4,8	75,9
Dec	21,9	94,8	11,3	41,9	-126,1	-7,7	71,1

Figure 5.77: *Monthly net energy value & temperature difference (by Auhtor)*

Calculated with excel using the method explained in chapter 4.6.

III. Temperature change energy storage

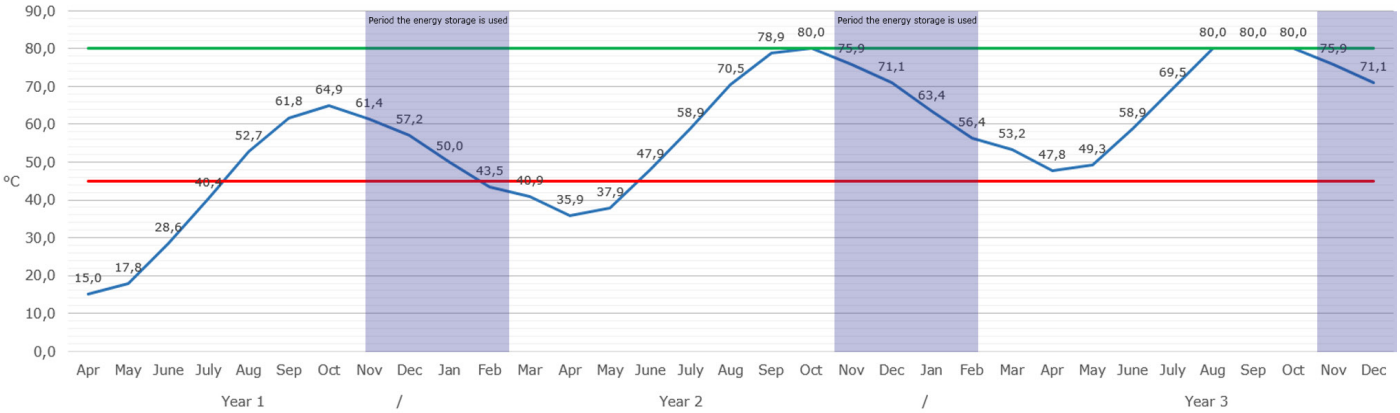
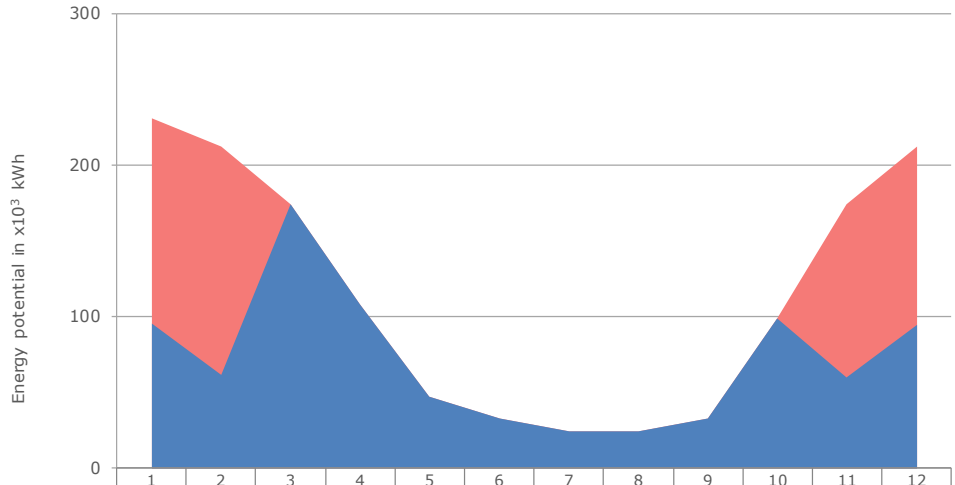


Figure 5.78: *Temperature change energy storage. (by Author)*

The blue areas are the periods that the buildings use thermal heat from the energy storage. In these months the water in the storage tank should atleast be 45 °C.

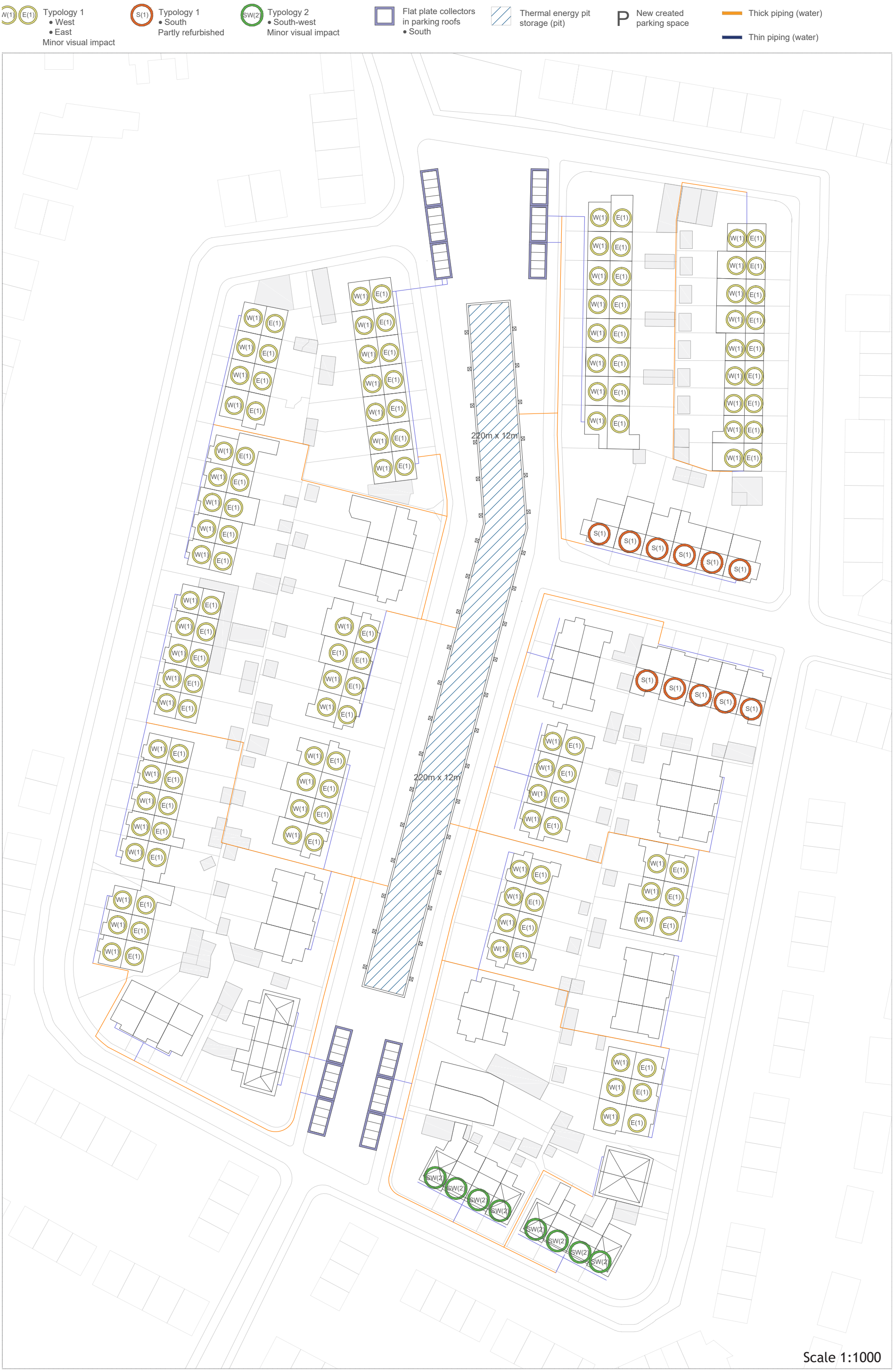


	1	2	3	4	5	6	7	8	9	10	11	12
Total heat demand	231	212	174	109	47	33	24	24	33	99	174	212
Provided heat demand	96	62	174	109	47	33	24	24	33	99	60	95

Figure 5.79: *Actual provided heat demand. (by Author)*

As visible in the table the heat demand that is supplied to the buildings is lower than the actual heat demand of the buildings. This configuration is simply not able to replace 100% of the gas use in the selected urban blocks. In Jan & Dec the provided heat demand is 42%. In Feb & Nov the provided heat demand is 32%. In the months in between the new energy systems does provide 100% of the heat demand. The total annual provided heat demand by the new energy systems is 858 x10^3 kWh. The total heat demand of the selected urban blocks is 1375 x10^3 kWh. On annual base this configuration can therefor provide 62,4 % of the total annual heat demand.

IV. Technical floor plan



V. Visual floor plan

Grass
Households
Storages
P New created parking space
Trees







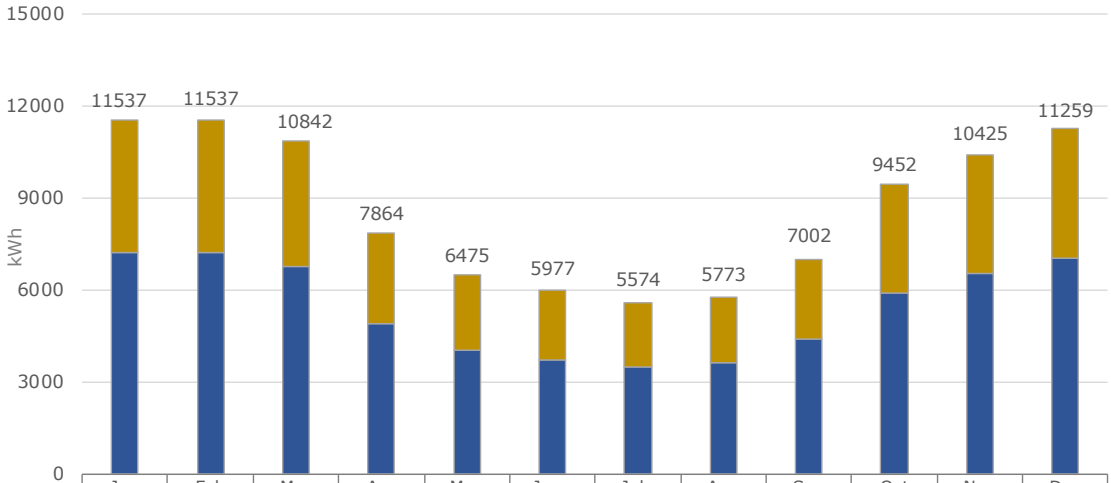


(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

(C.2) Monocrystalline PV panels combined with water filled pit thermal energy storage, large scale heat pump, aquifer storage & drycoolers.

I. Transport losses

The energy losses of electricity transport are so small that they can be neglected in the calculation. The rest of the year thermal heat is transported towards the buildings at a temperature of 45 °C resulting in the following distribution losses:



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045

Figure 5.80: *Distribution losses (by Author)*

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production (elec) (x10^3 kWh)	Monthly energy production (T. heat) (3,0COP)(x10^3 kWh)	Deliverd heat demand households (x10^3 kWh)	Heat added to aquifer storage (x10^3 kWh)	Transport losses (x10^3 kWh)	Thermal losses pit storage (x10^3 kWh)	Delta (x10^3 kWh) (No inc. heat added Afuifer)	Delta temp.(C°)	Temp. tank (C°)
Apr	70,5	211,5	81,5	0,0	7,9	27,9	94,3	4,3	45,0
May	93,2	279,6	47,4	266,7	6,5	28,2	197,5	9,2	49,3
June	94,0	282,1	33,3	266,7	6,0	33,3	209,5	9,8	58,5
July	93,2	279,6	24,4	266,7	5,6	38,9	210,8	9,9	68,3
Aug	78,6	235,9	24,4	266,7	5,8	46,8	158,9	7,4	78,2
Sep	51,1	153,2	33,3	266,7	7,0	54,8	58,1	2,7	85,6
Oct	30,0	90,0	99,2	266,7	9,5	59,1	-77,8	-3,7	88,2
Nov	13,8	41,3	174,5	0,0	10,4	59,0	-202,6	-9,6	84,6
Dec	8,9	26,8	212,1	0,0	11,3	54,0	-250,6	-11,8	75,0
Jan	12,3	36,8	173,2	0,0	11,5	45,7	-193,7	-9,1	63,2
Feb	21,9	65,7	159,1	0,0	11,5	38,7	-143,7	-6,8	54,0
Mar	44,6	133,8	130,9	0,0	10,8	31,6	-39,5	-1,9	47,3
Apr	70,5	211,5	81,5	0,0	7,9	28,2	94,0	4,3	45,4
May	93,2	279,6	47,4	266,7	6,5	28,5	197,2	9,2	49,7
June	94,0	282,1	33,3	266,7	6,0	33,6	209,2	9,8	58,9
July	93,2	279,6	24,4	266,7	5,6	39,2	210,5	9,8	68,7
Aug	78,6	235,9	24,4	266,7	5,8	47,1	158,6	7,4	78,5
Sep	51,1	153,2	33,3	266,7	7,0	55,0	57,9	2,7	85,9
Oct	30,0	90,0	99,2	266,7	9,5	59,4	-78,0	-3,7	88,6
Nov	13,8	41,3	174,5	0,0	10,4	59,2	-202,8	-9,6	84,9
Dec	8,9	26,8	212,1	0,0	11,3	54,2	-250,8	-11,8	75,3

Figure 5.81: *Monthly net energy value & temperature difference (by Auhtor)*

Calculated with excel using the method explained in chapter 4.6.

III. Temperature change energy storage

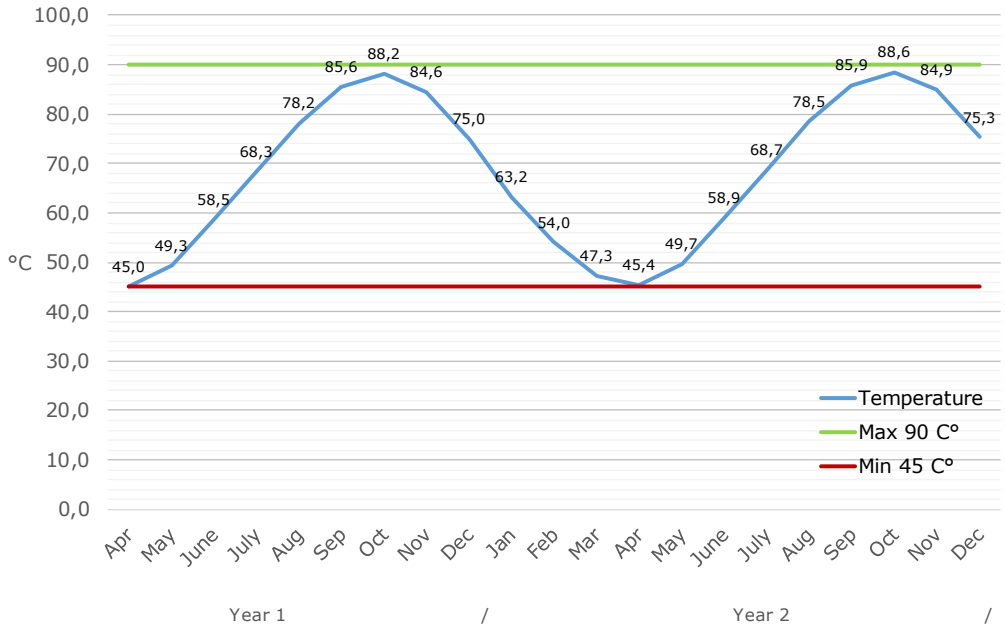
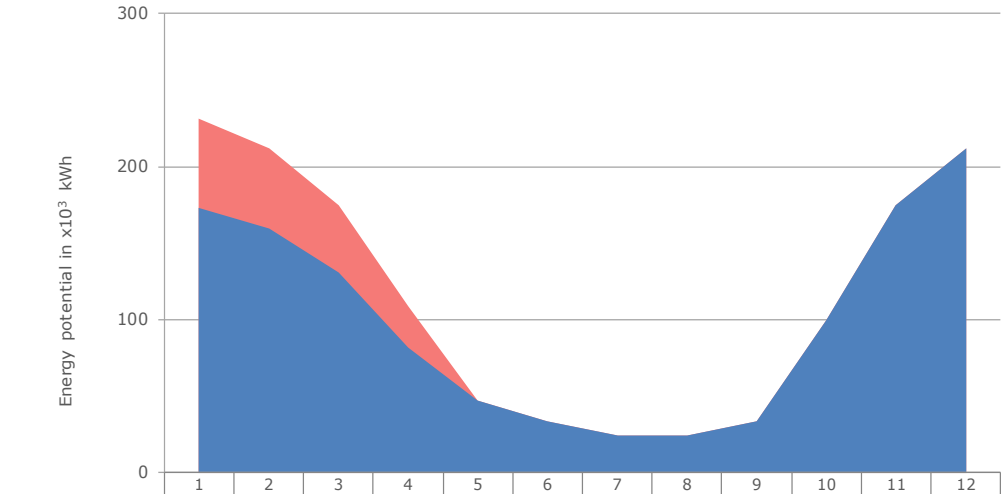


Figure 5.82: *Temperature change energy storage. (by Author)*



	1	2	3	4	5	6	7	8	9	10	11	12
Total heat demand	231	212	174	109	47	33	24	24	33	99	174	212
Provided heat demand	173	159	131	81	47	33	24	24	33	99	174	212

Figure 5.83: *Actual provided heat demand. (by Author)*

This configuration provides 75% of the heat demand in the months: Jan, Feb, March & April. In the months in between the new energy systems does provide 100% of the heat demand. The total annual provided heat demand by the new energy systems is 1193 x10^3 kWh. The total heat demand of the selected urban blocks is 1375 x10^3 kWh. On annual base this configuration can therefor provide 86,8 % of the total annual heat demand.

IV. Technical floor plan

W(1) E(1) Typology 1
- West
- East

Minor visual impact

S(1) Typology 1
- South

Partly refurbished

SW(2) Typology 2
- South-west

Minor visual impact

PV/T in parking roofs
- South

Thermal energy pit storage (pit)

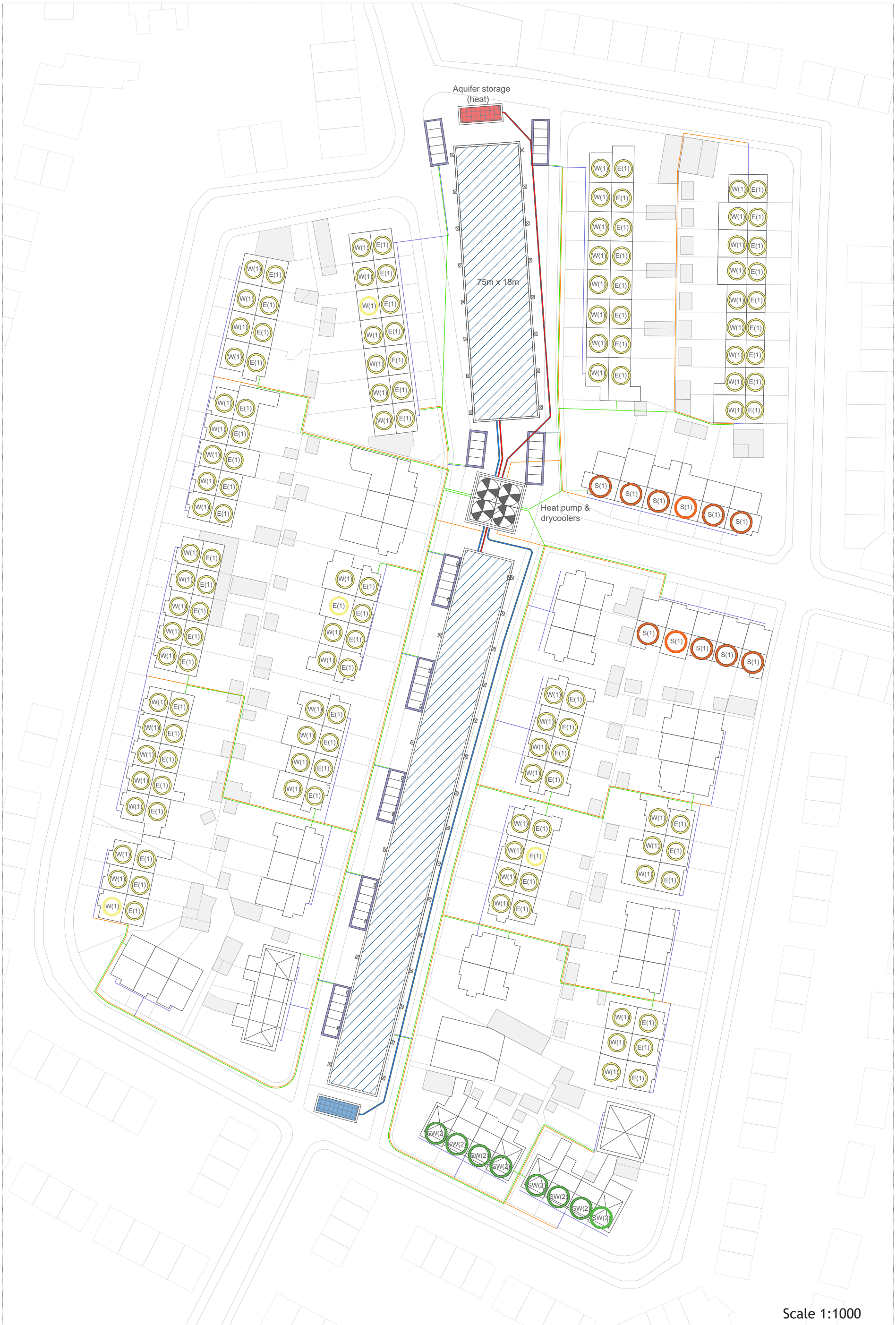
Large scale heat pump & drycoolers

Thick piping (water)

Thin piping (water)

Cold

Heat



Scale 1:1000

V. Visual floor plan

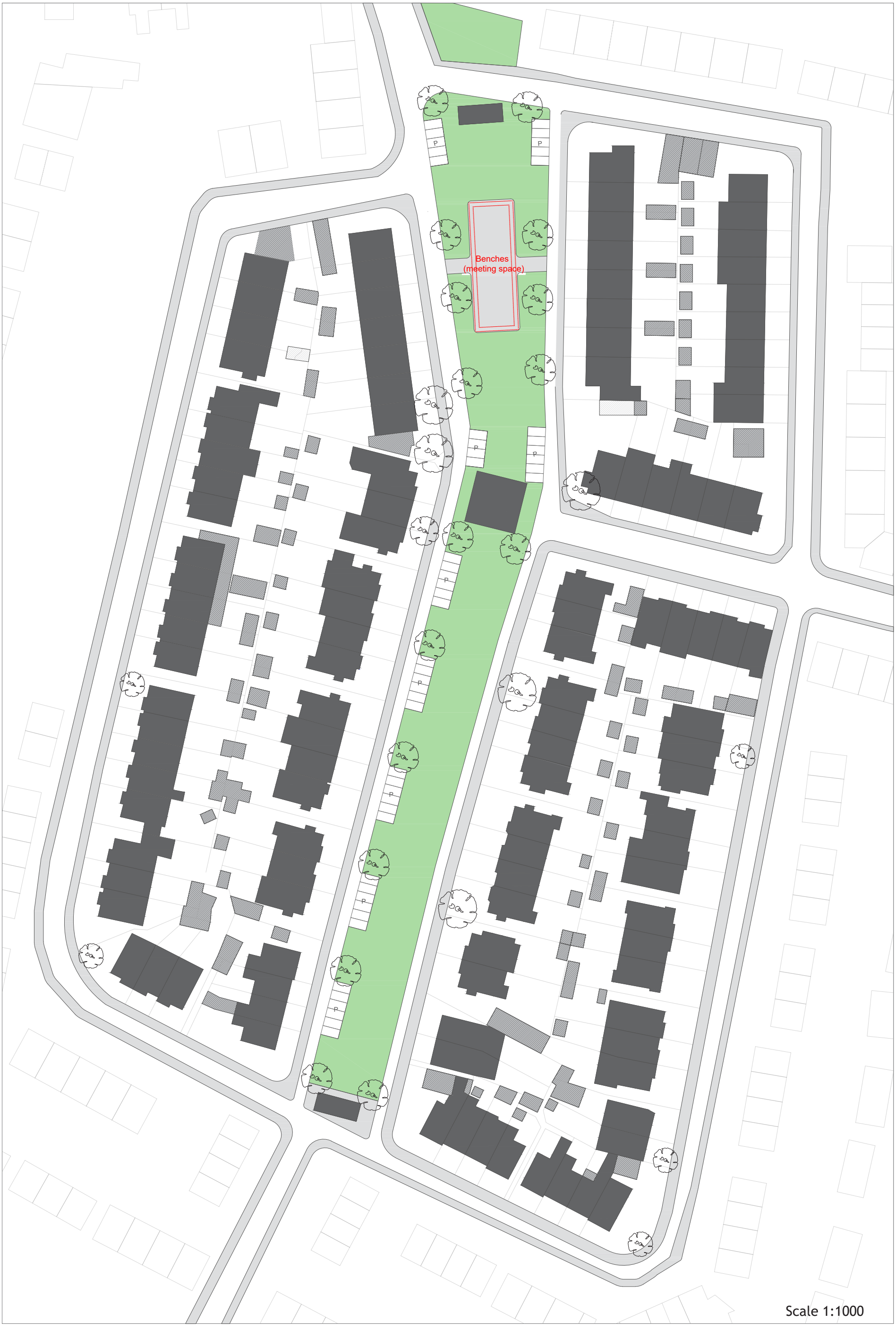
Grass

Households

Storages

P New created parking space

Trees









(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

(C.3) Flat plate collectors combined with a salt filled latent tank storage.

I. Transport losses: The same as in configuration A.1

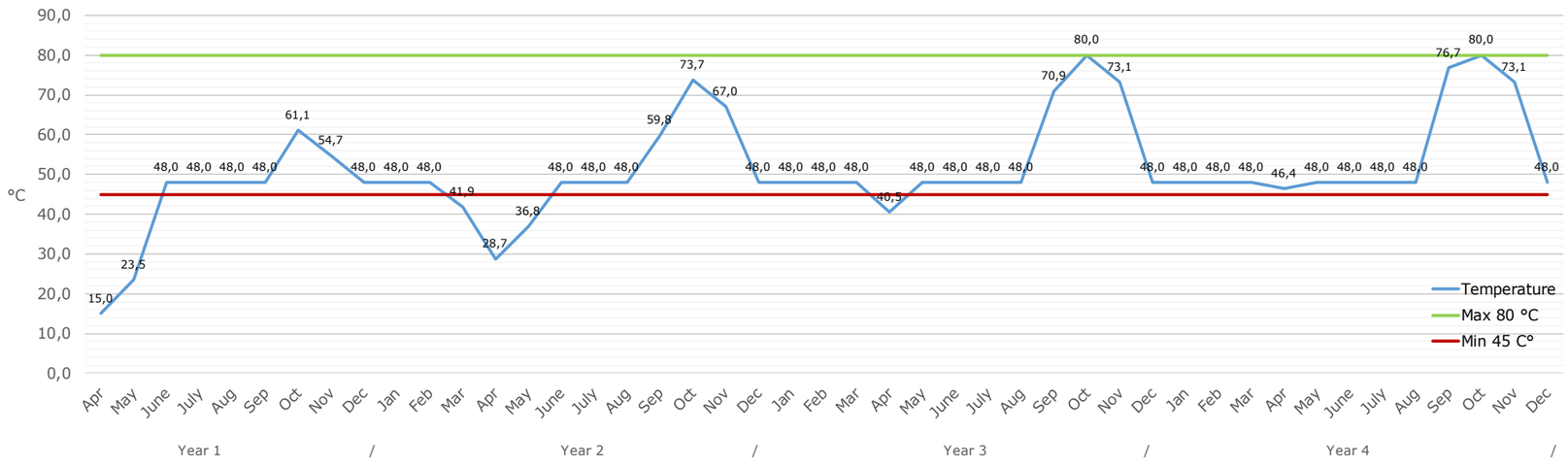
II. Net energy value added/extracted from the energy storage

Figure 5.84: *Monthly net energy value & temperature difference (by Auhtor)*

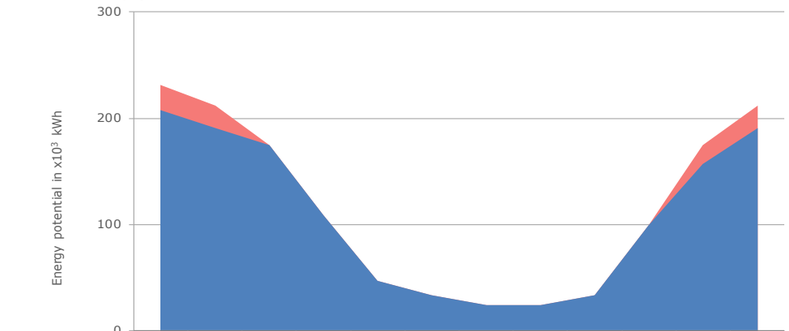
Month	Energy input for storage x10³ kWh)	Actual heat demand households (x10³ kWh)	Transport losses (x10³ kWh)	Thermal losses tank storage (x10³ kWh)	Delta (x10³ kWh)	Possible sensible temp. swing(C°)	Temp. tank (C°)	Delta temp.(C°) not stored sensible	Latent stored energy (x10³ kWh)	Latent storage potential left (x10³ kWh) Total 1 cycle: 664 x10³ kWh	Sensible stored energy after phase change at 48 °C. (x10³ kWh)	Delta temp.(C°) Sensible	Latent regenerated stored energy (x10³ kWh)	Laten stored regenerated energy (x10³ kWh) Total 1 cycle: 664 x10³ kWh	Sensible stored regenerated energy after phase change at 48 °C. (x10³ kWh)	Delta temp.(C°) Sensible
April	62,3	0,0	19,9	0,9	41,5	8,5	**15,0**									
May	191,0	0,0	18,8	1,5	170,7	34,9	**23,5**	10,4	50,7	559,3						
June	212,4	0,0	18,1	4,5	189,8	38,8	**48,0**	38,8	189,8	369,5						
July	226,2	0,0	17,4	4,2	204,6	41,8	**48,0**	41,8	204,6	164,9						
August	181,1	0,0	17,5	4,3	159,4	32,6	**48,0**	32,6	159,4	5,6						
September	92,5	0,0	18,3	4,7	69,5	14,2	**48,0**	14,2	69,5	-63,9	63,9	13,1				
October	0,0	14,8	9,5	6,9	-31,1	-6,4	**61,1**									
November	0,0	121,4	10,4	6,5	-138,3	-28,3	**54,7**	21,6					105,5	504,5		
December	0,0	169,0	11,3	6,0	-186,3	-38,1	**48,0**	38,1					186,3	318,2		
January	0,0	176,9	11,5	6,1	-194,5	-39,8	**48,0**	39,8					194,5	123,7		
February	0,0	136,0	11,5	6,1	-153,6	-31,4	**48,0**	31,4					153,6	-29,9	29,9	6,1
March	0,0	48,6	10,8	4,9	-64,4	-13,2	**41,9**	13,2								
April	62,3	0,0	19,9	2,8	39,6	8,1	**28,7**	-8,1								
May	191,0	0,0	18,8	3,3	168,8	34,5	**36,8**	23,3	114,1	495,9						
June	212,4	0,0	18,1	4,5	189,8	38,8	**48,0**	38,8	189,8	306,1						
July	226,2	0,0	17,4	4,2	204,6	41,8	**48,0**	41,8	204,6	101,5						
August	181,1	0,0	17,5	4,3	159,4	32,6	**48,0**	32,6	159,4	-57,8	57,8	11,8				
September	92,5	0,0	18,3	6,3	67,9	13,9	**59,8**									
October	0,0	14,8	9,5	8,6	-32,8	-6,7	**73,7**									
November	0,0	121,4	10,4	8,2	-140,0	-28,6	**67,0**	9,6					47,2	562,8		
December	0,0	169,0	11,3	6,0	-186,3	-38,1	**48,0**	38,1					186,3	376,5		
January	0,0	176,9	11,5	6,1	-194,5	-39,8	**48,0**	39,8					194,5	182,0		
February	0,0	136,0	11,5	6,1	-153,6	-31,4	**48,0**	31,4					153,6	28,4		
March	0,0	48,6	10,8	5,8	-65,3	-13,3	**48,0**	13,3					65,3	-36,9	36,9	7,5
April	62,3	0,0	19,9	4,4	38,0	7,8	**40,5**	0,2	1,1	608,9						
May	191,0	0,0	18,8	4,9	167,3	34,2	**48,0**	34,2	167,3	441,6						
June	212,4	0,0	18,1	4,5	189,8	38,8	**48,0**	38,8	189,8	251,8						
July	226,2	0,0	17,4	4,2	204,6	41,8	**48,0**	41,8	204,6	47,2						
August	181,1	0,0	17,5	4,3	159,4	32,6	**48,0**	32,6	159,4	-112,2	112,2	22,9				
September	92,5	0,0	18,3	7,8	66,3	13,6	**70,9**									
October	0,0	14,8	9,5	9,5	-33,7	-6,9	**80,0**									
November	0,0	121,4	10,4	9,0	-140,9	-28,8	**73,1**	3,7					18,0	592,0		
December	0,0	169,0	11,3	6,0	-186,3	-38,1	**48,0**	38,1					186,3	405,7		
January	0,0	176,9	11,5	6,1	-194,5	-39,8	**48,0**	39,8					194,5	211,2		
February	0,0	136,0	11,5	6,1	-153,6	-31,4	**48,0**	31,4					153,6	57,6		
March	0,0	48,6	10,8	5,8	-65,3	-13,3	**48,0**	13,3					65,3	-7,7	7,7	1,6
April	62,3	0,0	19,9	5,2	37,2	7,6	**46,4**	6,0	29,5	580,5						
May	191,0	0,0	18,8	4,9	167,3	34,2	**48,0**	34,2	167,3	413,2						
June	212,4	0,0	18,1	4,5	189,8	38,8	**48,0**	38,8	189,8	223,4						
July	226,2	0,0	17,4	4,2	204,6	41,8	**48,0**	41,8	204,6	18,8						
August	181,1	0,0	17,5	4,3	159,4	32,6	**48,0**	32,6	159,4	-140,5	140,5	28,7				
September	92,5	0,0	18,3	8,6	65,5	13,4	**76,7**									
October	0,0	14,8	9,5	9,5	-33,7	-6,9	**80,0**									
November	0,0	121,4	10,4	9,0	-140,9	-28,8	**73,1**	3,7					18,0	592,0		
December	0,0	169,0	11,3	6,0	-186,3	-38,1	**48,0**	38,1					186,3	405,7		

III. Temperature change energy storage

Figure 5.85: *Temperature change energy storage. (by Author)*

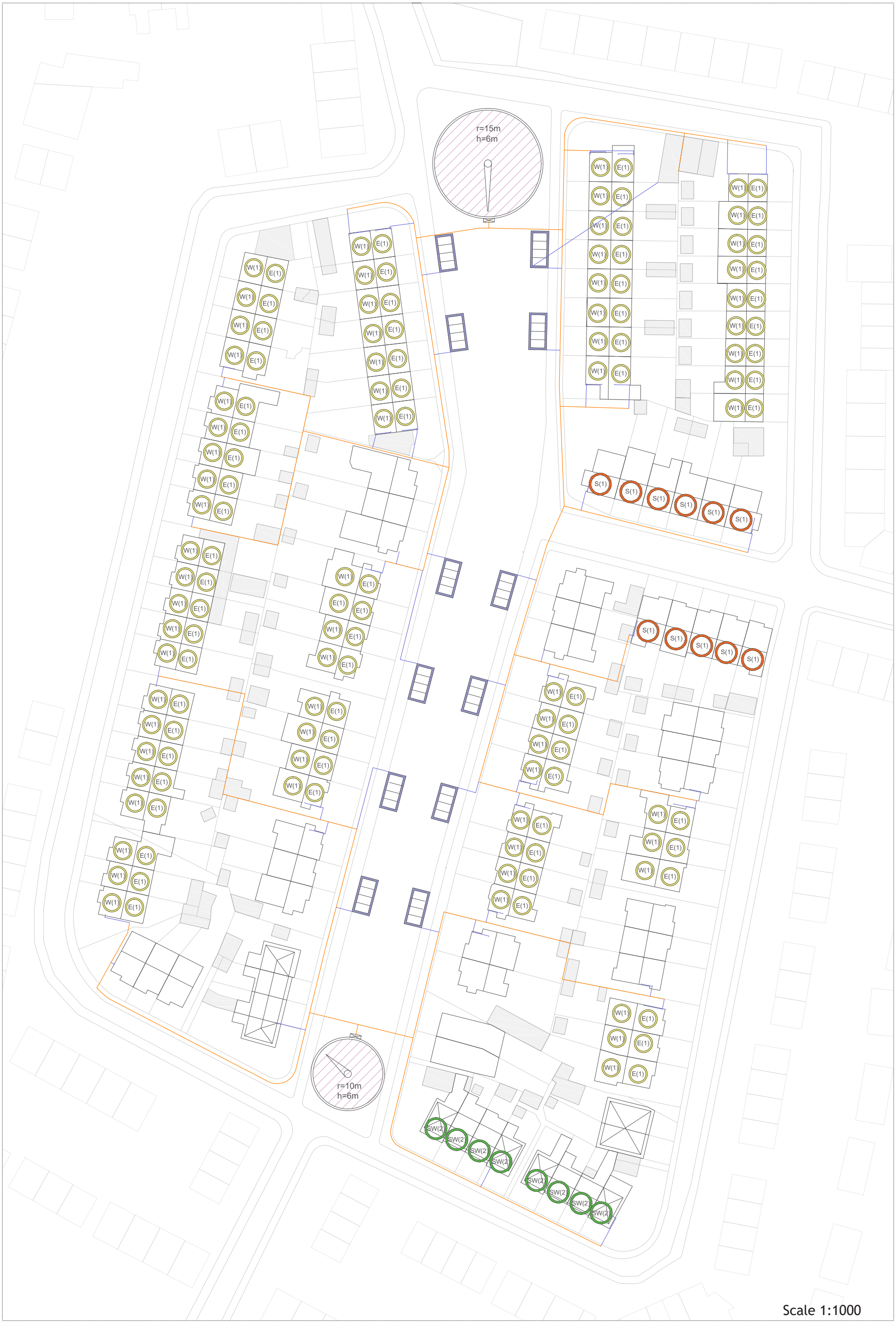


In the following months the new energy systems provides 90% of the heat demand: Jan, Feb, Nov Dec. In the summer months the new energy systems does provide 100% of the heat demand. The total annual provided heat demand by the new energy systems is 1291,8x 10^3 kWh. The total heat demand of the selected urban blocks is 1375 x10^3 kWh. On annual base this configuration can therefor only provide 94,0% of the total annual heat demand.



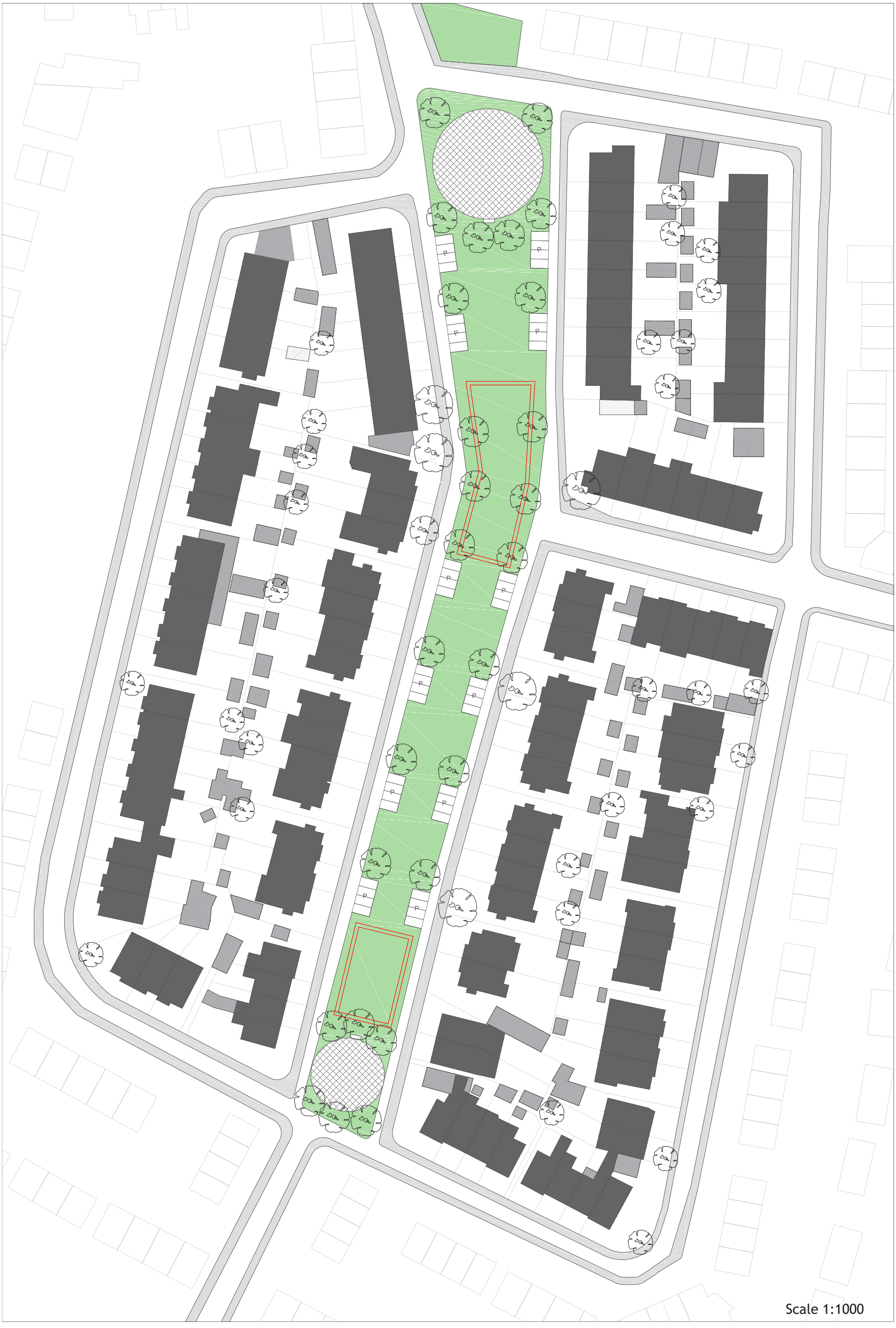
	1	2	3	4	5	6	7	8	9	10	11	12
Total heat demand	231	212	174	109	47	33	24	24	33	99	174	212
Provided heat demand	208	191	174	109	47	33	24	24	33	99	157	191

IV. Technical floor plan



V. Visual floor plan

Grass
Households
Storages
Latent thermal energy storage
Public functions
P New created parking space
Trees



Scale 1:1000





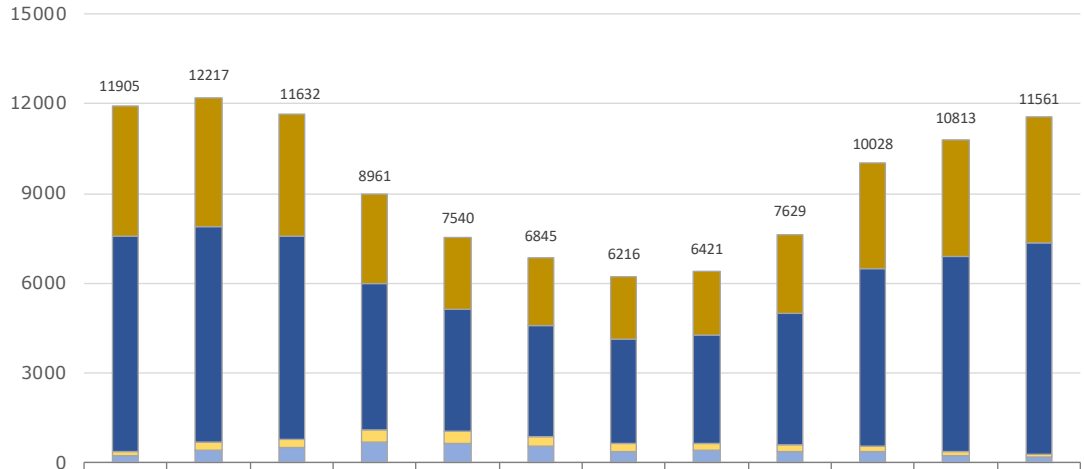


(C) Configurations aiming for minor spatial impact on the selected urban blocks taking into account the wishes of inhabitants.

(C.4) PVT panels combined with water filled pit thermal energy storage and a large scale heat pump.

I. Transport losses

Transport thermal energy losses occur during the transport of thermal heat (26 °C) from the PVT panels towards the heat pump every month of the year. Secondly there are monthly thermal losses if thermal heat is transported from the heat pump/pit storage towards the buildings at a temperature of 45 °C.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Storage/HP to households (thick pipe 45 C°)	4318	4318	4058	2943	2423	2237	2086	2161	2621	3538	3902	4214
Storage/HP to households (thin pipe 45 C°)	7219	7219	6784	4920	4051	3740	3488	3612	4381	5914	6523	7045
PV/T panel to storage & HP (thick pipe 26 C°)	137	254	295	410	398	324	240	242	234	215	144	112
PV/T panel to storage & HP (thin pipe 26 C°)	228	424	493	685	665	542	400	404	391	359	241	187

Figure B.10: *Transport energy losses. (by Author)*

II. Net energy value added/extracted from the energy storage

Month	Monthly energy production	Heat demand households	Transport losses (x10^3 kWh)	Thermal losses pit storage	Delta (x10^3 kWh)	Delta temp.(C°)	Temp. tank (C°)
Apr	181,4	108,6	9,0	24,5	39,3	2,1	45,0
May	239,8	47,4	7,5	23,3	161,6	8,7	47,1
June	241,9	33,3	6,8	27,4	174,3	9,4	55,8
July	239,8	24,4	6,2	32,0	177,2	9,5	65,2
Aug	202,3	24,4	6,4	38,8	132,7	7,1	74,7
Sep	131,4	33,3	7,6	45,6	44,9	2,4	81,8
Oct	77,2	99,2	10,0	49,2	-81,3	-4,4	84,2
Nov	35,4	174,5	10,8	48,7	-198,5	-10,7	79,9
Dec	23,0	125,2	11,6	43,5	-157,2	-8,5	69,2
Jan	31,5	136,3	11,9	38,5	-155,1	-8,3	60,7
Feb	56,3	125,2	12,2	32,9	-114,0	-6,1	52,4
Mar	114,7	102,9	11,6	27,1	-26,9	-1,4	46,3
Apr	181,4	108,6	9,0	24,4	39,4	2,1	44,8
May	239,8	47,4	7,5	23,2	161,7	8,7	46,9
June	241,9	33,3	6,8	27,3	174,4	9,4	55,6
July	239,8	24,4	6,2	31,9	177,3	9,5	65,0
Aug	202,3	24,4	6,4	38,7	132,8	7,1	74,5
Sep	131,4	33,3	7,6	45,5	45,0	2,4	81,7
Oct	77,2	99,2	10,0	49,1	-81,2	-4,4	84,1
Nov	35,4	174,5	10,8	48,6	-198,4	-10,7	79,7
Dec	23,0	125,2	11,6	43,4	-157,2	-8,4	69,1
Jan	31,5	136,3	11,9	38,4	-155,0	-8,3	60,6
Feb	56,3	125,2	12,2	32,8	-113,9	-6,1	52,3
Mar	114,7	102,9	11,6	27,0	-26,9	-1,4	46,2
Apr	181,4	108,6	9,0	24,4	39,5	2,1	44,7
May	239,8	47,4	7,5	23,1	161,7	8,7	46,8
June	241,9	33,3	6,8	27,3	174,5	9,4	55,5

Figure B.9: *Monthly net energy value & temperature difference (by Auhtor)*

Calculated with excel using the method explained in chapter 4.6.

July	239,8	24,4	6,2	31,9	177,3	9,5	64,9
Aug	202,3	24,4	6,4	38,6	132,9	7,1	74,5
Sep	131,4	33,3	7,6	45,4	45,0	2,4	81,6
Oct	77,2	99,2	10,0	49,1	-81,1	-4,4	84,0
Nov	35,4	174,5	10,8	48,5	-198,4	-10,7	79,7
Dec	23,0	125,2	11,6	43,4	-157,1	-8,4	69,0

III. Temperature change energy storage

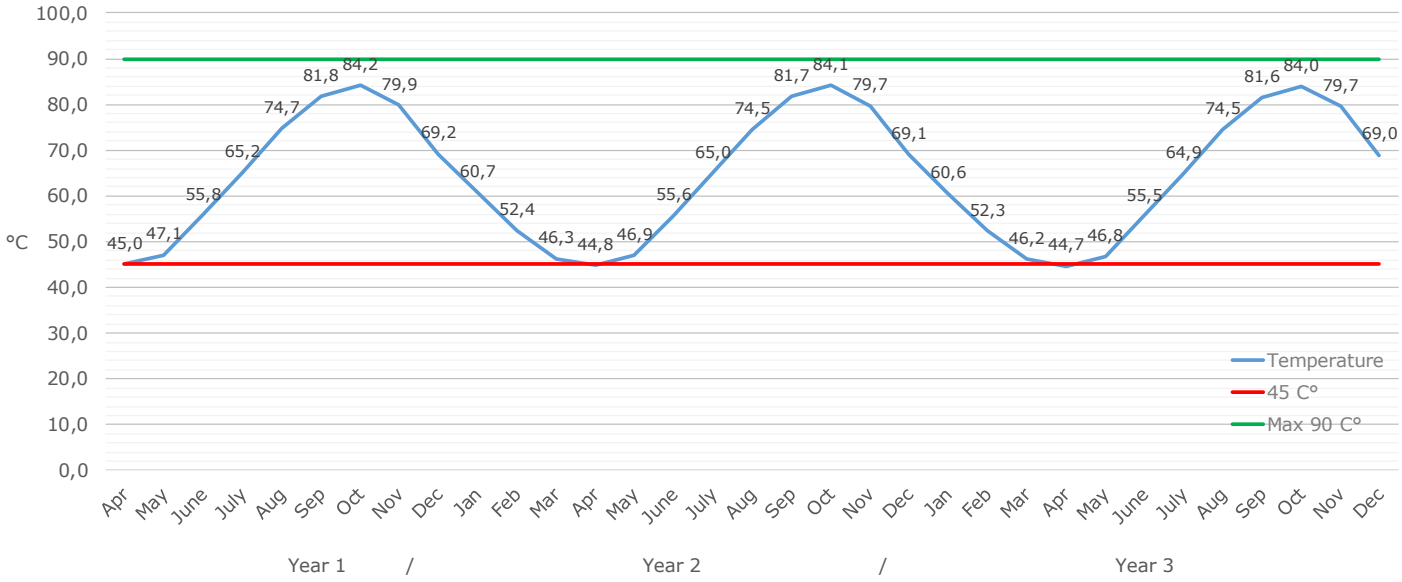
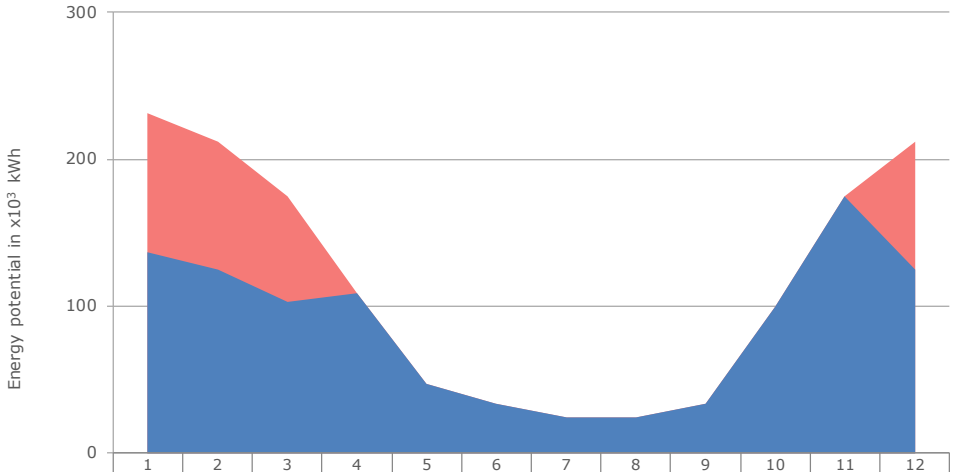


Figure B.11: *Temperature change energy storage. (by Author)*

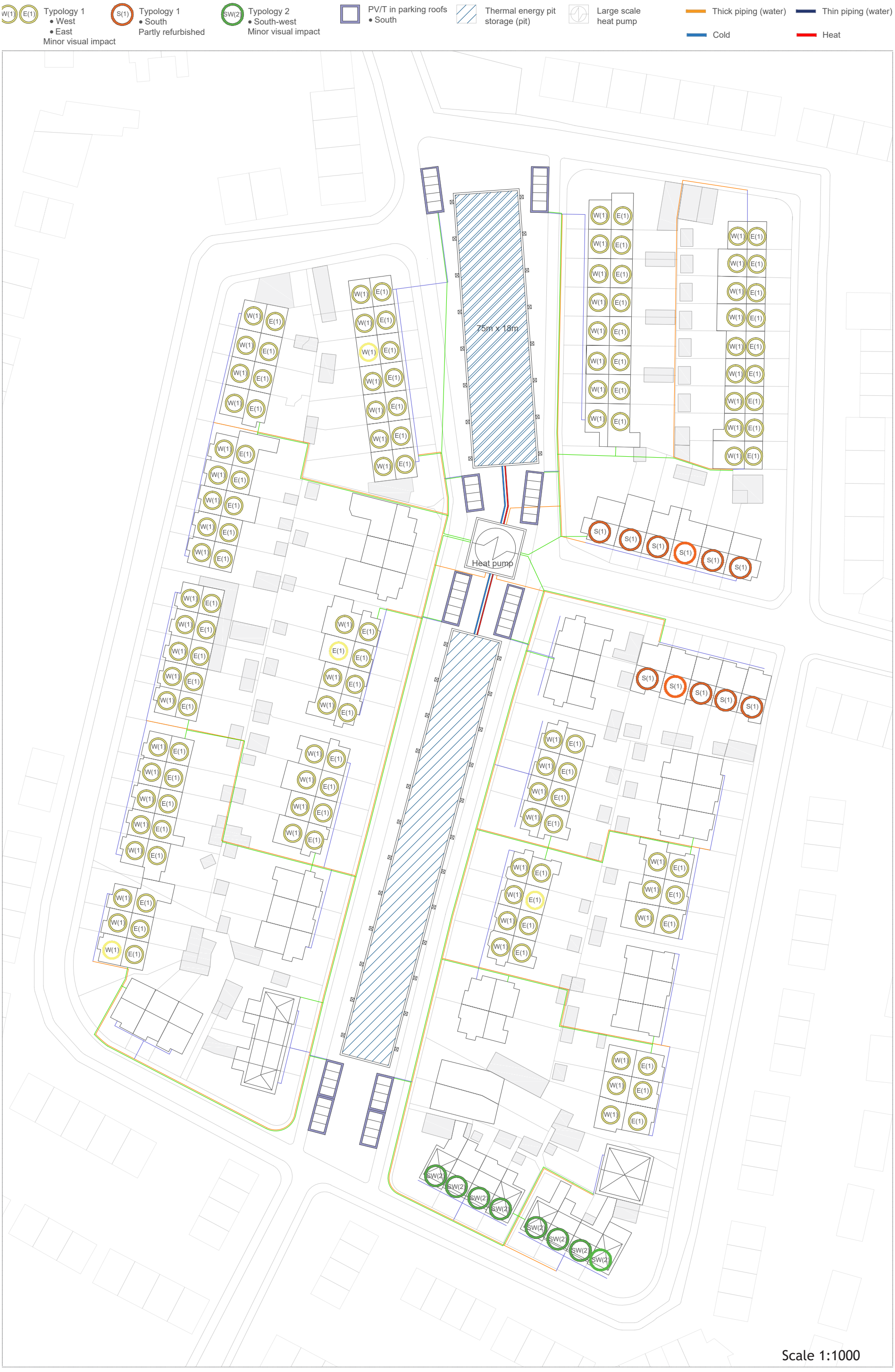


	1	2	3	4	5	6	7	8	9	10	11	12
Total heat demand	231	212	174	109	47	33	24	24	33	99	174	212
Provided heat demand	136	125	103	109	47	33	24	24	33	99	174	125

Figure 5.86: *Actual provided heat demand. (by Author)*

In the following months the new energy systems provides 59% of the heat demand: Jan, Feb, Mar, Dec. In the summer months the new energy systems does provide 100% of the heat demand. The total annual provided heat demand by the new energy systems is 1034,5 x 10^3 kWh. The total heat demand of the selected urban blocks is 1375 x10^3 kWh. On annual base this configuration can therefor only provide 75,3% of the total annual heat demand.

IV. Technical floor plan



V. Visual floor plan

Grass
Households
Storages
P New created parking space
Trees
Solar field







