UNCLOGGING THE GRID – A STUDY ON HOW DEEP ENERGY RENOVATIONS CAN REDUCE THE LOAD ON THE ELECTRICAL ENERGY GRID AND CREATE A SELF-SUFFICIENT BUILDING.

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ABSTRACT

With the rise of all-electric buildings the load on the electrical grid grows. This could slow down the energy transition and densification of existing neighbourhoods as the current grid is not capable to withstand a higher load. This research gathers literature on different peak shaving techniques to create a clear overview and investigates the impact on the load profile when techniques are combined. This new insight in combined techniques will provide a solid basis to develop a more detailed modelling tool to simulate the actual energy use and generation on a daily and annual basis. The load profiles of these techniques are combined with the existing energy demand curve to see how these techniques reduce peak loads that occur during the day. To asses the influence on the annual load curve the ZED-tool was used to simulate peak shaving techniques on a case-study building. The results show that a combination of outside insulation, sun shading and a heat pump flatten the daily and annual load profile significantly. However the implementation of east and west facing façade PV in combination with wind energy decreases the peak loads the most. Finally when all techniques are combined with a battery a building block can become not only energy neutral but almost self sufficient.

KEYWORDS

Energy transition, Deep energy renovations, Energy systems, Energy storage, Energy generation, grid congestion, self-sufficient buildings, Zero Energy Buildings, Load shifting, Peak Shaving, Load matching, Self-consumption.

I. INTRODUCTION

By now it is common knowledge that humans are responsible for the global warming due to the large amount of greenhouse gasses (GHG) that humans emit. These emissions are mostly emitted while burning fossil fuels for our energy consumption (IPCC, 2013). Existing houses are accountable for 36% of the final energy consumption in the EU (Filippidou et al., 2017). Especially the energy consumption for space heating is high as can be seen in figure 1. Therefore, a huge reduction in GHG emissions can be realized if the energy performance of these buildings is updated, as most existing buildings were built in the previous century when the energy efficiency requirements were non existing. The problem with updating the energy performance of existing houses is bifold; First there is the financial aspect as renovating a house is very expensive on short term. Secondly due to the long payback period (PBP) of such an investment often only cost effective measurements like PV-panels and Heat Pumps (HP) are installed. A heat pump runs on electricity and replaces the CV-installation that runs on natural gas, thus lowering the GHG emissions of a dwelling however the electricity demand rises. To lower the GHG emissions even further, PV-panels are often installed to generate electricity to cover the increase in demand in a renewable way. Because the most cost-effective orientation of PV-panels is south the duck-curve phenomena occurs.

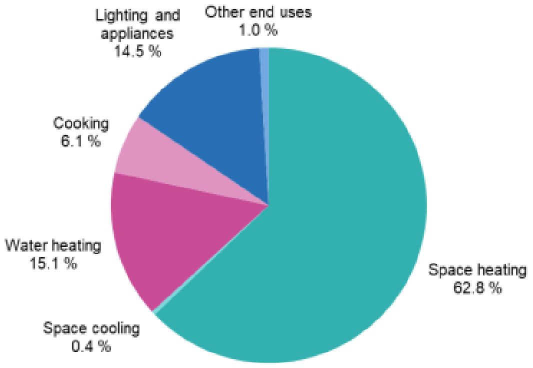

Figure 1. Residential energy consumption by use (Eurostat, 2020)

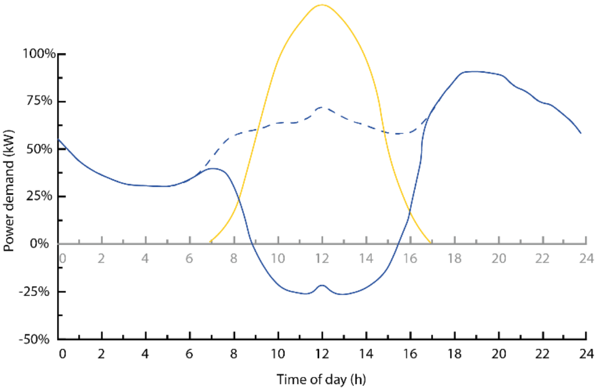

Figure 2. Duck curve phenomena

Figure 2 shows a graph shaped like a duck caused by the large amount of energy generated during noon by the south facing PV-panels and the steep increase in demand during 5 pm. This phenomena creates the second problem; the current Dutch electrical energy grid is not capable to withstand the vast increase of electrical load (Nortier et al., in press; Schermeyer et al., 2017). This slows down the energy transition as the load on the grid will only grow the coming years (Mutani & Todeschi, 2021) and we cannot just upgrade the energy grid due to the lack of skilled workers (Mertens, 2022; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022). Thus, the implementation of Renewable Energy Sources (RES) might slow down due to the current limited grid capacity and lack of time and resources to upgrade this.

The aim of this paper is to gain more insight on how to improve the energy performance of a building without increasing the load on the electrical energy grid. This should lead to a program of demands on renovating existing houses that is not slowing down due to limited grid capacity. Furthermore this paper will provide a basis for a tool to simulate the electrical load of buildings and how specific measures like insulation, thermal mass and battery systems influence this.

In order to reach this goal the following question is posed: *How can a typical existing building block, such as at Boerhaave, be made energy neutral and advance towards more self-sufficiency without increasing the peak load on the (local) electricity grid by optimizing energy reduction, local renewable energy generation, distribution and energy storage with the use of saltwater battery systems?*

II. METHODS

To answer this question a literature study is conducted to get more grip on ways to reduce the peak demand of households. The literature will also provide daily and annual load graphs which are compared to see how interventions will influence the load of a building. Also the Zero Energy Design tool (ZED-tool) provided by dr. ir. Leo Gommans is used to model the annual load graph of a case study building. This tool is also used to model the impact of different interventions on the annual load graph. The case-study building is an apartment building build in the 1960s and situated in Haarlem, more information about this building can be found in Appendix 1. With the graphs found in the literature and the ZED-tool new graphs are made. These graphs visualize how different interventions will influence the load on the grid. Therefore they provide more insight in the influence of an intervention on the daily and annual load profile. Thus, the interventions are assessed by means of this visual validation.

III. LITERATURE REVIEW

3.1. Current demand

The energy demand of a household is very unpredictable because it is strongly related to the users (Azarova et al., 2018, pp. 319-323). According to Newing et al. the daily demand differs between high and low income households but also household composition (2015, p. 857-859). Staats et al. also points out that there is a difference in demand during the weekend compared with a week day (2017, p. 83). For instance someone working from home has a higher demand during the day than someone that works at the office. This can be seen in figure 3 where the demand is different during the week but also per season. Another important factor is thermal comfort. When someone is thermally uncomfortable and the space heating runs on electrical appliances the energy use of that person is higher. Thus the energy demand of a building is complex to calculate due to the large amount of factors that influence each other. Therefor we aim to use the average Dutch energy demand of a household as given by (Staats et al., 2017, p. 83).

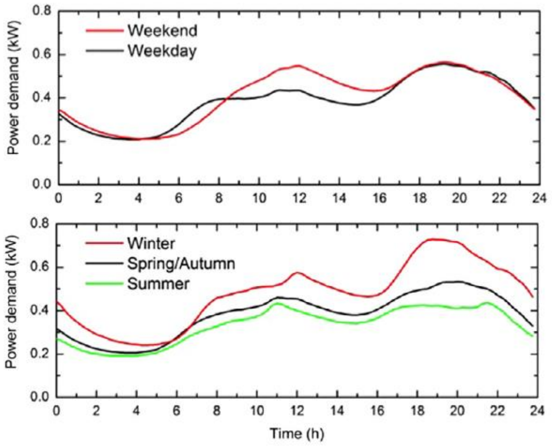

Figure 3. Daily load profile of an average household in the Netherlands (Staats et al., 2017, p. 83).

According to Brouwer et al. this demand profile is going to stay roughly the same until 2030 (2013 p. 38-39)**.** The only significant differences between their graph and the one of Staats et al. is the amount of power used and the height of the evening peak which can be seen in figure 4.

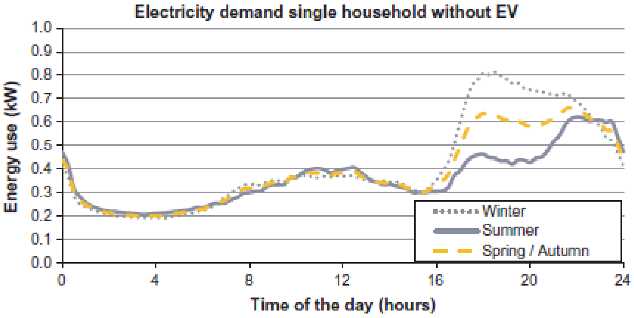

Figure 4. Prediction of the average electricity demand pattern of a single household for different seasons in 2030 based on SEPATH simulations of the patterns of 2000 households in 2003.

If we look at figure 3&4 we can see the daily energy demand of an average Dutch household. The peaks in demand occur during the morning and evening. Therefore if we want to lower the peaks during these times without burdening the grid or apply large amounts of storage, the production of energy is needed during these moments of the day.

Now that we got more grip on the daily energy use we need to look at the annual load profile. This is done to get more insight in the annual energy demand. Average annual energy use of an apartment building: 850m3 gas (approx. 8500 kWh-primary) and 2040 kWh electricity (CBS, 2022). Thus, a household needs roughly 8500+2040= 10540 kWh of energy per year. Figure 5 shows the annual energy demand of an average Dutch household for a day and throughout the year. Here it is visible that there is significantly more energy demand in the winter months during the evening.

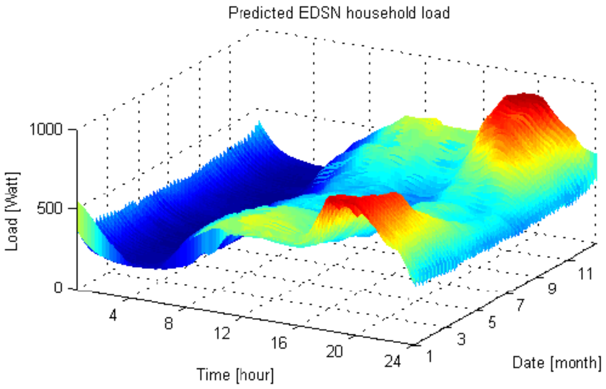

Figure 5. Standard load profile for an average household in the Netherlands (Klaasen et al. 2015)

Fattahi et al. visualized the yearly energy demand of several European countries and can be seen in figure 6 (p. 6, 2021). The Dutch annual load profile is shown in purple. Further this figure shows the increase in electricity demand during the winter months compared with the summer months. This has probably to do with the increase in heat demand due to lower outside temperatures. As figure 1 demonstrates the majority of energy use is caused by space heating, thus when its cold outside there is more demand for space heating compared with other appliances. But also with the increase in use of lighting due to the shorter days during the winter could lead to a higher energy demand.

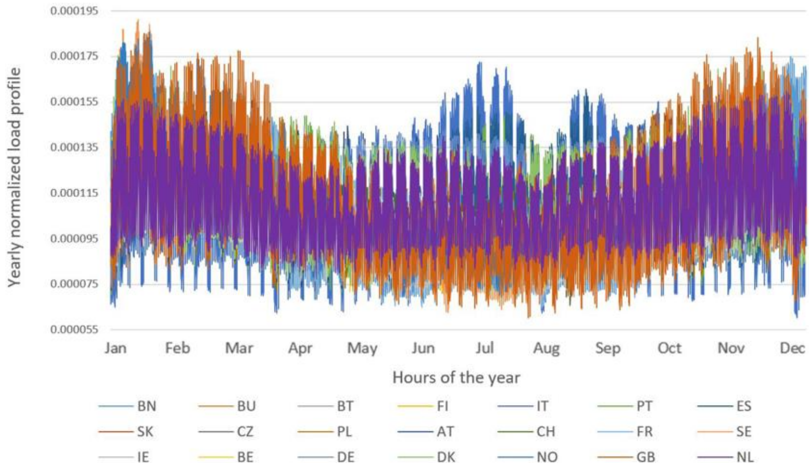

Figure 6. EU countries' yearly electricity load profiles. IESA-Opt assumes a high seasonal variability of load profile for northern countries. In addition, a weekly variation can be observed for all countries (Fattahi et al., p. 6, 2021).

After reviewing the literature on the daily and annual energy demand of a household we can conclude the following: The average Dutch household has daily peaks during the morning and evening. Moreover the evening peaks are higher in winter than during the other seasons. Further the annual demand is higher during winter due to the cold weather and shorter days.

3.2. Peak shaving techniques

Now that it is known when the peak demand of a household occurs we need to look at ways to reduce this in order to lower the load on the electrical energy grid. Reducing these peaks is called “peak shaving” and can be done by looking at different ways to produce energy or reduce demand during moments of peak demand. Peak shaving can be done in several ways. One is to change the time of demand with home automation, for example to run the dryer when there is energy production. Another solution is hybrid production of RES-E which means producing wind and solar (Mertens, 2022; Heide et al., 2010; Mulder, 2019). Furthermore a different orientation and slope of solar panels (façade 90° and E-W orientation) can help with peak shaving (Freitas et al., 2018; Hartner et al., 2015; Khatib & Deria, 2022; Mosalam, 2018; Zappa & van den Broek, 2018). And finally energy storage can provide peak shaving by storing overproduced energy and providing the stored energy during peak demand hours. All these techniques are described in the coming paragraphs.

3.2.1. Passive demand reduction

To lower the load on the grid the energy use needs to be lowered. Sousa et al. states that improving the energy efficiency of buildings helps changing the load profile (2021). Therefore we need to look at ways to improve this. In 1996, Trias Energetica was introduced by Lysen (1996) based on the work of Kees Duijvenstein. This theory explained the approach to make a building more energy-efficient with three steps; 1. reduce the demand, 2. use renewable energy sources, 3. Use fossil fuels as efficient as possible (see figure 1). Later Dobbelsteen (2008) improved this theory by adding an extra step called: the New Stepped Strategy (NSS)(see figure 7). Since 2008, this strategy is used to improve energy-efficiency of buildings by lowering the energy demand first, then use residual streams as much as possible, solve the remaining demand with renewable energy and finally reuse the created waste as food for other purposes like compost.

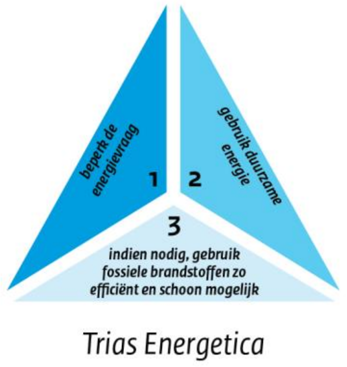

Figure 7. Trias Energetica (Rijksdienst Voor Ondernemend Nederland, 2013)

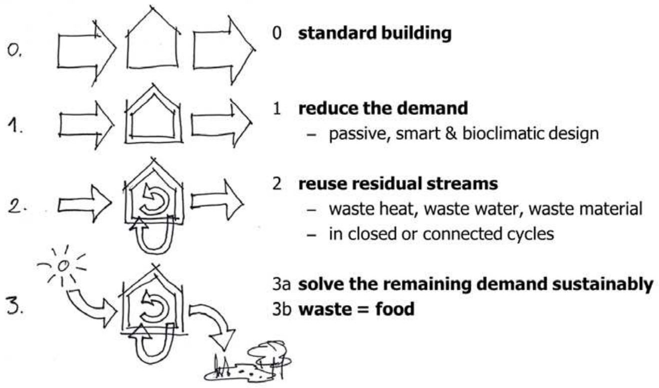

Figure 8. New Stepped Strategy (Dobbelsteen, 2008)

So the first step to improve the energy-efficiency of a building is implementing techniques that lower the energy demand like: passive, smart and bioclimatic design solutions. In order to arrive at an appropriate strategy to reduce the energy demand the local climate needs to be analysed. This is done in order to exploit the environment as much as possible. After thorough analysis of the local context passive design strategies can be implemented in order to reduce the energy demand. Knaack et al. states that there needs to be an energy balance in order to achieve comfort levels that satisfy the dwellers. This balance is as following: *Heat loss + ventilation heat loss= solar heat gain+ casual heat gain+ energy for heating or cooling* (2012 p. 24). These factors can be manipulated with architectural elements to reduce the energy needed for heating or cooling and thus the energy demand of a building. By manipulating the building form we try to improve the following aspects:

Thermal performance (heat loss and gain due to radiation), airtightness (heat loss due to infiltration and convection), thermal bridges (heat loss due to conduction) and out- dated installations (high energy demand).

Manipulating form to change the energy demand is called passive design and can be done in a variety of ways. Knaack et al. provides the following general functions of passive design: Heat protection by improving air tightness and heat transmission. This can be done by adding insulation, updating windows or prevent air leakage by filling gaps and cracks. Passive solar heating in winter by adding glazed area at strategic points in the façade can also reduce the energy demand during winter. However this radiation should be blocked during summer to prevent overheating by installing shading devices (2012 p.24-30). Yanovshtchinsky et al. adds to these strategies by providing urban design principals as well.

Urban design:

- Orientation of the building;
- Obstructions of surrounding buildings;
- Other obstructions.

Architectural design:

- Zoning of spaces;
- Façade versus floor ratio
- Open versus closed façade ratio;
- Façade construction (insulation value, thermal mass, thermal bridges etc.);
- Amount of daylight in building to reduce lighting costs;
- Application of sun shading.

Building engineering:

- Thermal mass
- Insulation value closed façade
- Insulation value open façade;
- G-value of glazing;
- F-value of thermal bridges;
- Qv-value of infiltration. (2012 p. 66-86).

All these factors need to be taken into account in order to reduce the energy demand of a building, as these factors are all linked it is a complex task to simulate the change of a single factor.

3.2.2. Peak shaving with automation of appliances

The energy demand of a building can also be lowered through change the times we need energy. For instance we use the dishwasher, dryer or washing machine only during the day when the most energy is being produced (Staats et al., 2017, p.81). Even more energy can be saved if automated systems could pre heat the space or DHW into a buffer vat. To achieve this a complex tool is needed that is linked to the weather forecast to predict if there is a rise in energy demand due to cold weather. There are already some charging docks of electrical cars that only charge when there is an overproduction of energy. Gao et al. states that delayed charging of Electrical Vehicles (EV) curtails the peak load in the evening (2014, p. 3021).

3.2.3. Peak shaving by changing heat source

Houses in the Netherlands are mostly heated via installations that run on natural gas. So in order to reduce the GHG emissions of buildings it is crucial to replace this installation with a different source of energy. One solution is changing the energy source from natural gas to hydrogen gas because it does not use electricity thus not increasing the load on the grid. However the technology needs new infrastructure, is still in development and does not provide cooling. Therefor a heating system powered with hydrogen is not preferred for quick renovations.

A more suitable option is then a HP system that runs on electricity. This installation subtracts heat or cold form a source. This source can be outside air, the ground or surface water. There are multiple ways of programming the heating system as can be seen in figure 9. This figure shows a bi-modal and continuous heating pattern. A bi-modal pattern means that the system turns on in the morning and evening creating demand peaks around those times. A continuous pattern has almost no peaks and runs consistently throughout the day.

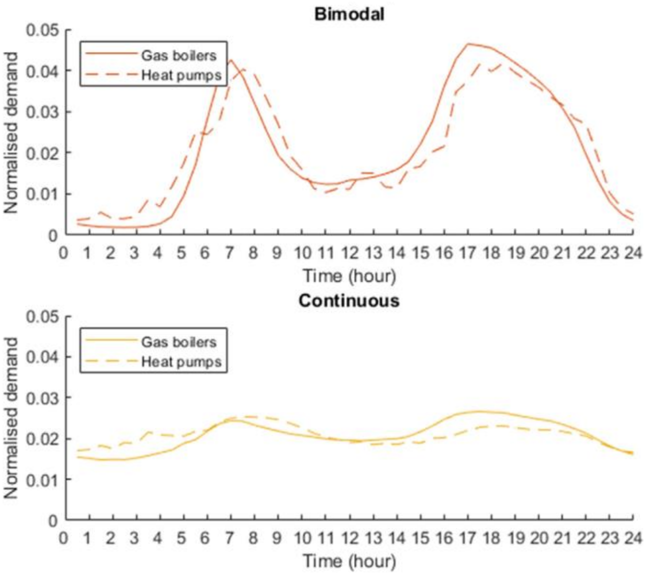

Figure 9. Load profile of different heating patterns (Watson et al. 2021, p. 6).

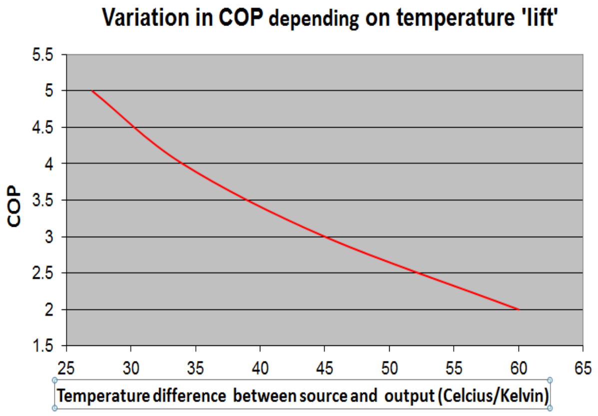

Figure 10. COP of heat pumps (Cantor, n.d.)

So when installing a HP system the electrical demand will increase. Regardless Watson et al. states that HP systems predominantly use a continuous heating pattern (2021, p. 6-7). This means changing the heating system will increase the electricity use but its contribution to steeper peaks in the load profile is not significant. Kemmler & Thomas also points out that buildings with floor heating and low supply temperatures have a higher level of self consumption (2020). Therefor a system with these characteristics will decrease the demand from the grid, thus lowering the load on the grid. The amount of energy is then dependent on the thermal efficiency of the building and the efficiency of the heating source. Meaning that if these elements are improved the normalised demand is lower. Previous paragraph describes how the thermal efficiency can be improved. The efficiency of the HP system is expressed in Coefficient Of Performance (COP) and is influenced by the difference in temperature between the source and the preferred temperature. Figure 10 shows the graph where this correlation can be seen. Thus a higher COP of a HP system means less energy from the grid or a RES is needed to heat or cool a building revealing that the peaks are also lower.

3.2.4. Peak shaving by changing RES production

As stated before the production of electrical renewable energy sources (RES-E) can be spread more evenly throughout the day and year lowering the peak load on the energy grid. A common problem with the production of renewable energy is the irregularity of the production. Figure 11 shows the production of solar power during the day versus the demand.

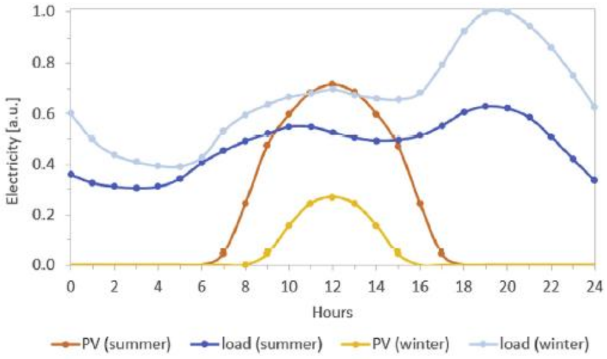

Figure 11. Example of equator-facing PV production (orange and yellow solid lines) and aggregated demand (blue solid lines) for a Mediterranean city (Freitas & Brito, 2019, p. 272)

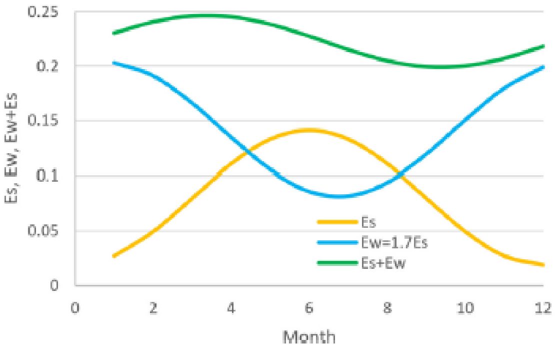

Figure 12. Illustration of the resulting Dutch profiles for solar PV: Es , wind: Ew = 1.7Es and the total energy Ew + Es. (Mertens, 2022)

The first solution is to combine different RES-Es together in one system. According to Mertens the energy yield of solar PV during the summer months is the highest, while during the winter months the energy yield of wind turbines is the highest (2022). Therefor a hybrid mix of wind and solar power creates a steady production of RES-E during the long-term (seasonally) (figure 12) . Mertens is also arguing that this hybrid mix is ideal for the short-term because the generation of wind and solar add up to a total that has less flaws in energy supply and less peaks than when energy sources are installed individually (2022). Couto & Estanqueiro shares the same conclusion and adds that the bulk of daily wind energy generation occurs in the evening, when less solar energy is generated as can be seen in figure 13 (2020, p. 7-9). Thus, combining wind and solar energy will provide a steady energy production throughout the day and year with less peaks. This will also reduce the storage capacity needed to be self-sufficient. The potential of wind energy and its use to lower the inconsistency of RES-E production is also described by (Agrawal et al., 2016; de Chassy et al., 2019; Heide et al., 2010; Mulder, 2014; Rezaeiha et al., 2018; Zappa & van den Broek, 2018).

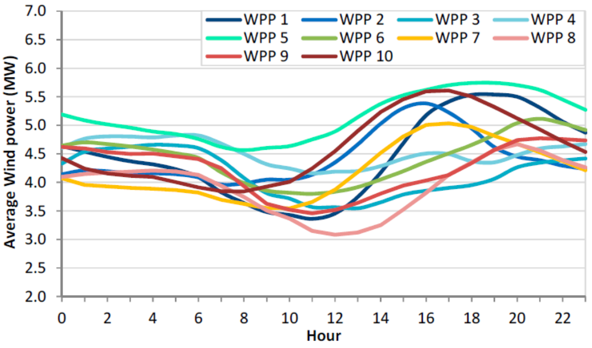

Figure 13. Average daily wind power profiles for all ten WPPs identified with the clustering approach. (Couto & Estanquerio, 2020)

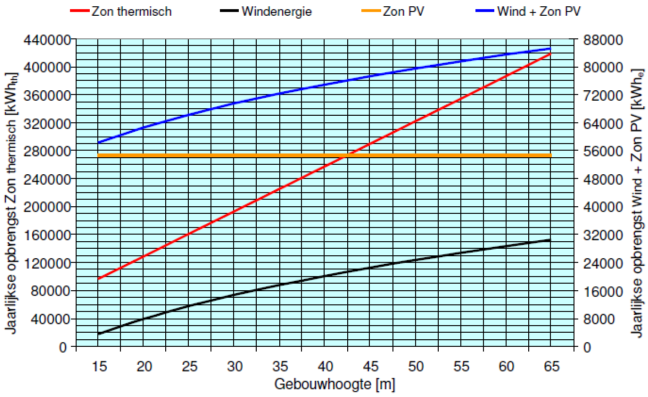

Figure 14. Total energy performance solar and wind as a function of building height. (Bronsema, 2013, p. 313)

The energy production of wind energy on buildings increases as the building height increases as can be seen in figure 14 (Bronsema, 2013, p. 313). This adds an argument for topping up existing buildings not only improving the energy performance but also the density of a neighbourhood.

The second solution is the optimal orientation and slope of PV panels that matches the energy demand. When you compare the solar generation graphs of the different solar set ups a difference in peak load can be seen (figure 15) . The generation peaks of east and west oriented façade PV creates peaks during the morning and evening. During these times the demand load curve also shows an increasing demand. Thus combining the right solar set-up that matches the demand curve can lower the peaks because they cancel each other out. (Brito et al., 2017; Freitas et al., 2018; Freitas & Brito, 2019; Jouttijärvi et al., 2022; Thebault & Gaillard, 2021).

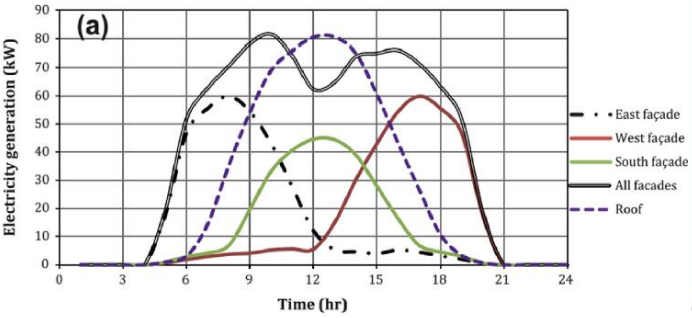

Figure 15. Electricity generation of different BIPV components covering different areas of east, south and west facades, and south facing roof of a 12-storey building, on a summer design day. (Freitas & Brito, p. 278, 2019)

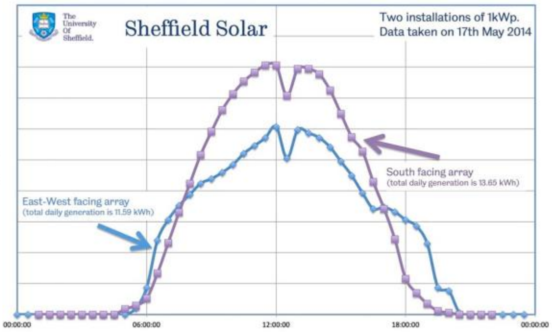

Figure 16. Comparison between east–west oriented PV system and south oriented PV system (Khatib & Deria, p. 2, 2022).

Not only façade PV can reduce the peaks several studies state that the optimal orientation or slope of PV-panels on buildings can increase the self-consumption thus reducing the need for energy storage (Khatib & Deria, 2022; Litjens et al., 2017; Mosalam, 2018; Mutani & Todeschi, 2021; Sousa et al., 2021; Awad & Gül, 2018; Hartner et al., 2015). Even PV-panels placed on a roof with a east-west orientation lowers the peak generation and spreads the generation time more towards the morning and evening compared with a south oriented roof PV system as can be seen in figure 16 (Khatib & Deria, 2022). The annual production of façade PV and roof PV are compared in figure 17. In the graph made with the ZED-tool we can see that façade PV generates significantly less energy during the summer and a bit more during the winter compared with roof PV set-ups. Thus, façade PV provides a more stable energy generation throughout the year. Although the implementation of façade PV reduces the peak loads, more PV panels are needed in order to fulfill the energy demand of a building due to the reduced generation at these slopes and orientations. This creates an other argument to lower the energy use and combine façade PV with wind energy as this can provide extra generation.

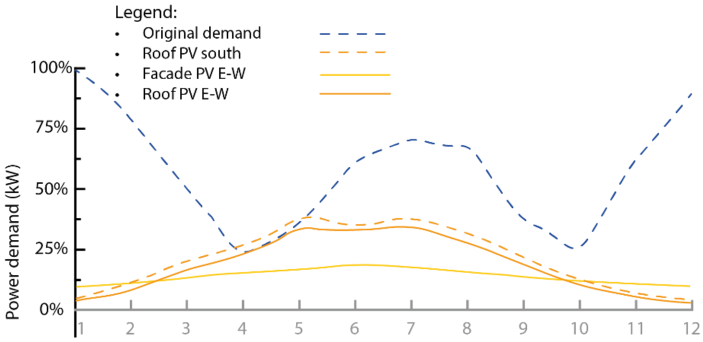

Figure 17. Annual generation of different PV set-ups on the case study building simulated by the ZED-tool

3.2.5. Energy storage

As mentioned earlier, battery systems are also a strategy of peak shaving. The generated energy that is not immediately needed can be stored in a battery for later use (Hernández et al., 2019; Jankowiak et al., 2020; Koirala et al., 2018; Kovač et al., 2019; Schram et al., 2018). Kovač et al. conducted a case study to determine the size of energy storage needed for an all electric household in Ljubljana, Slovenia (2019, p. 1187). Figure 18 shows the yearly storage level of a battery system of 60 kWh that is loaded with a south facing PV array. It can be seen that the battery mostly discharges and charges between 60 and 30 kWh during the whole year. Only 3 times a year the battery is completely discharged. Because the battery is charged by a south facing solar array there is a great uncertainty in energy generation. Therefor the capacity of a battery can be lower when there is a mix of RES like façade PV, wind energy etc.

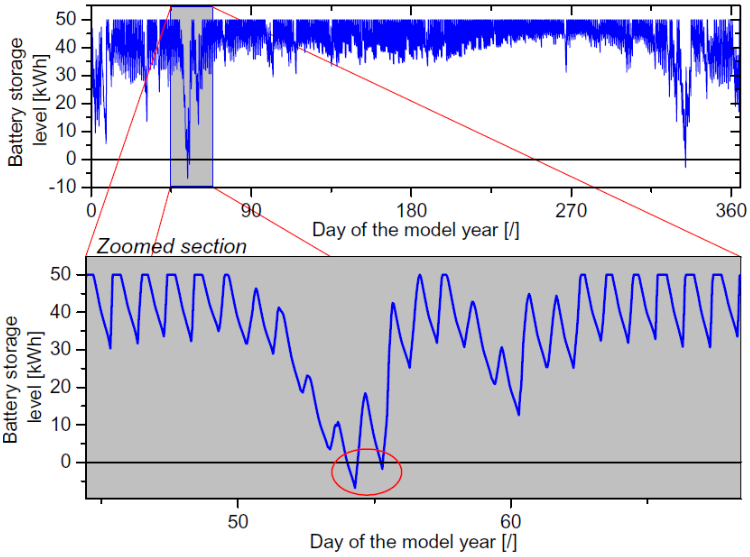

Figure 18. The result of the model shows the battery storage level over the model year (top). The greyed section is zoomed at the bottom, where battery storage level dips under 0 kWh. (Kovač et al. 2019, p. 1187).

Lowering the storage capacity is essential because most batteries are made of scarce materials that are being mined in harsh conditions. Even though the efficiency of these batteries are higher it is not preferred to contribute to other problems. There are battery systems made with non-scares materials like salt water batteries (SWB). These batteries are made with natural salts and water in stead of scarce and toxic materials. Another added benefit is that these batteries are non-flammable and thus safer to use in buildings. However the problem with these batteries is that their energy density (kg/ kWh) is lower than the ones made from scarce materials. This means that they take up more space to reach the same capacity of storage. Therefor it is crucial for the implementation of SWBs to lower the needed storage capacity. In addition the increase of self-consumption elongates the lifetime of the battery systems. Hernández et al. states that the more charge and discharge cycles occur the shorter the lifetime of a battery. Because self-consumption decreases the amount and depth of charge and discharge cycles the lifetime is elongated (2019).

IV. RESULTS

4.1. Daily load graph

Like stated in the method the results are gathered by means of a literature study. Graphs found in the literature are then scaled in order to compare the graphs on the same scale. These graphs are then traced and combined to see how a certain intervention will influence the load graph.

If we combine the findings of the literature research and visualize them we get the following daily load graphs: The first graph (figure 19) shows the average energy demand of a Dutch household with the blue dotted line. These houses are usually heated by natural gas boilers and are poorly insulated (Staats et al., 2017). Figure 20 shows the energy load of an average household with continuous heat pump heating in solid yellow (Love et al., 2017). When we combine the original demand graph and the HP load graph we get the new load graph in solid orange. The new graph is higher because the two loads are added. There is a load increase in the morning and evening peaks due to the small peaks of the HP load graph.

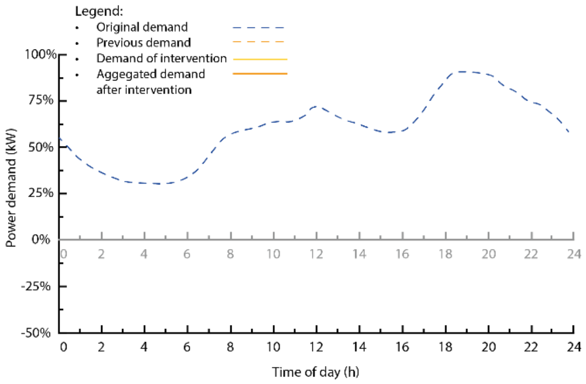

Figure 19. Daily load profile average Dutch household

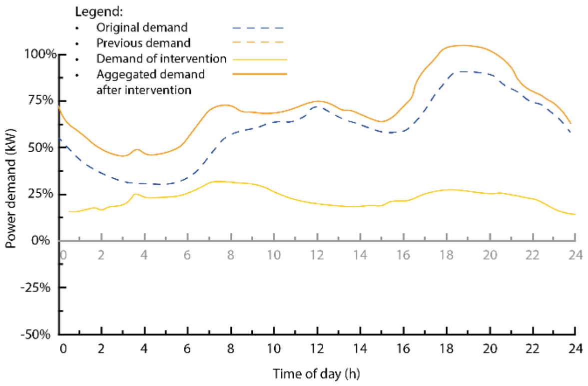

Figure 20. Daily load profile after implementation of a heat pump

In figure 21 we can see the load profile of a household with improved insulation properties lowering the energy demand and thus the load graph. The peaks also flatten as insulation prevents heat loss, especially when applied on the outside activating the thermal mass of the building and reducing thermal bridges (Knaack et al., 2012, p. 24-30; Knaack & Konstantinou, 2012, p. 38; Yanovshtchinsky et al., 2012, p. 72-79; Lundström & Wallin, 2016, p. 290). Figure 22 shows the load profile of PV panels on the east and west façade. If the loads are combined the total graph gets lowered during 8:00 and 18:00 (Brito et al., 2017; Freitas et al., 2018; Freitas & Brito, 2019; Jouttijärvi et al., 2022; Thebault & Gaillard, 2021).

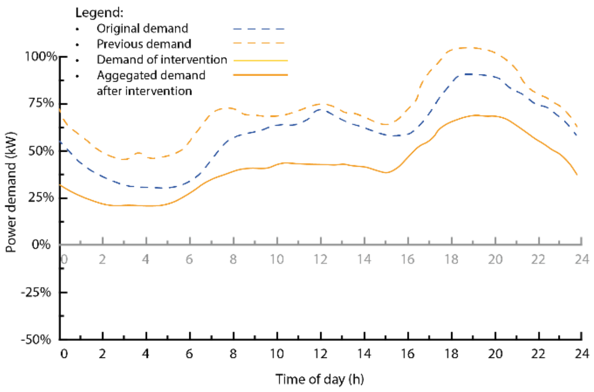

Figure 21. Load graph after insulation improvements

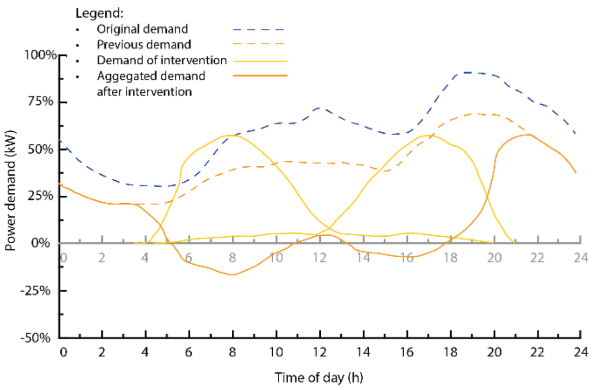

Figure 22. Load graph with E-W façade PV

Figure 23 introduces the average daily production graph of wind turbines reproduced from Couto & Estanqueiro (2020). Due to the peak generation during the evening and night the demand peaks during these times gets lowered as well. The final graph in figure 24 gives the load graph of all the measures together. In this particular case there is a surplus of energy during 5-10am and from 12-20 pm. This surplus can be stored in a battery system to buffer the energy during the night when there is less energy production. If there is no surplus of energy to fulfil the demand more PV-panels or wind turbines can be added to become more self-sufficient.

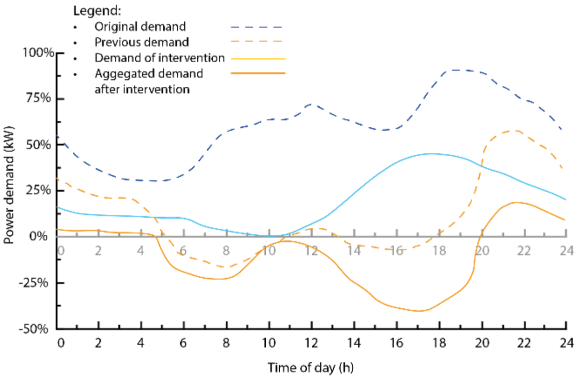

Figure 23. Daily load curve with wind production

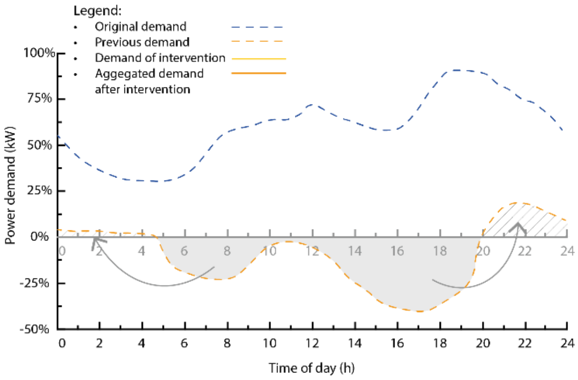

Figure 24. Daily load curve with energy storage

When comparing the final graph (orange dotted line) with the original graph (blue dotted line) we can clearly see that the energy demand is reduced significantly. Furthermore the bandwidth of the load graph in figure 24 is smaller then the bandwidth in figure 2 thus, less pressure on the grid. This shows that it is possible to reduce the energy demand of a household while not burdening the electrical grid. The capacity that is still available in the current grid can then be used to add more dwellings or other functions to densify an existing neighbourhood.

Thus, by implementing all these systems together a household can be made self-sufficient on a daily base. However there is one side note: due to different circumstances that influence the energy demand and production the amount of self-sufficiency varies per specific building. Some buildings do not have a large façade area facing east and west and there for a limited amount of PV-panels can be placed on the façade. If so, a different strategy needs to be implemented and the exact same result will not be achieved.

4.2. Annual load graph

If we look at the annual load graphs provided by the ZED-tool we can see that the graph has similarities with the graphs found in the literature. Figure 25 shows a high load during the winter a low load during spring and autumn and a small increase during summer due to cooling demand. This annual load graph was simulated by the ZED-tool by importing the properties of the case study building given in appendix I. A side note is that this tool cannot calculate the demand where the house is heated with natural gas. Therefore this graph has a higher electrical load that the average Dutch household as the gas use is converted to electrical use. Furthermore the average Dutch house has no cooling device thus the summer peak should also be lower in reality. This can be seen if we compare the graph produced by the ZED-tool and the graphs found in the literature (figure 5&6).

If we take this graph as a starting point we can make changes in the ZED-tool to simulate the implications of an intervention. The exact figures that were put into the ZED-tool to simulate the annual load graph after different interventions can be found in appendix II. When we change the heat source to a HP with a ground source the demand gets lowered due to the higher COP of the HP system. This can be seen in figure 26 where the aggregated load is represented by the solid orange line and the load of the HP system is shown with the yellow line. The dotted blue line shows the current demand of the building.

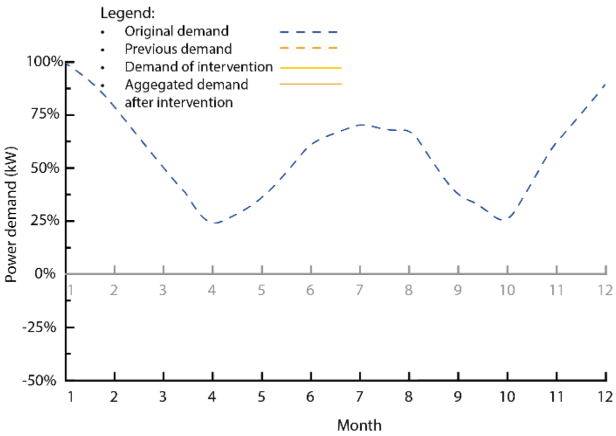

Figure 25. Annual load curve of the case-study building simulated by the ZED-tool

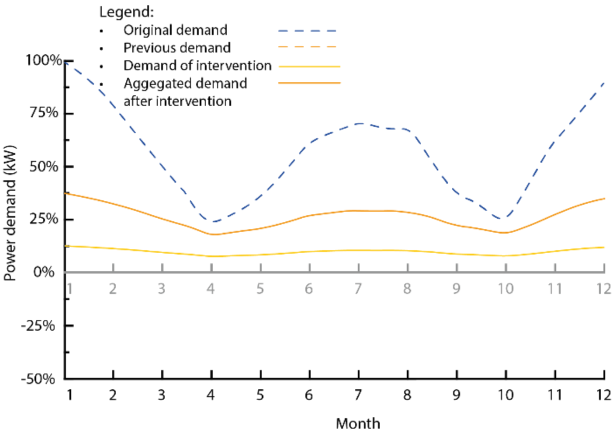

Figure 26. Annual load curve after HP implementation

Figure 27 shows the influence of thermal insulation on the energy load of the building. The new R-values that were used can be found in appendix II. It demonstrates that the load curve gets lowered and flattened that results in a smaller and more steady load profile. Especially during the winter months the load is lowered making the “gap” between the energy production and demand smaller. This line can be even flatter and lower if the ZED-tool could also simulate the influence of thermal mass and solar shading during summer. The buffering capability of thermal mass provides an argument to insulate on the exterior of a building rather than insulating the interior. As research has shown that more thermal mass helps to hold heat or cold for a longer period of time, thus lowering the energy demand (Knaack et al., 2012; Knaack & Konstantinou, 2012; Yanovshtchinsky et al., 2012). Finally Reynders et al. states that floor heating as a heat emission system helps activate the thermal mass of a building more than radiators (2013, p. 194). Thus, by implementing floor heating the graph can be flatter and lower in theory. Figure 28 introduces the production graph of façade PV on the east and west side of the building in solid yellow. In the case study the available façade surface on east was 656m^2 and west was 569m^2. Because the production is quite consistent throughout the year the aggregated load profile gets lowered.

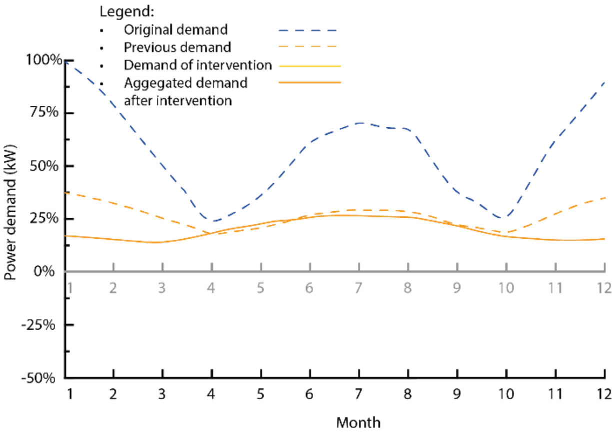

Figure 27. Load curve after implementation of insulation

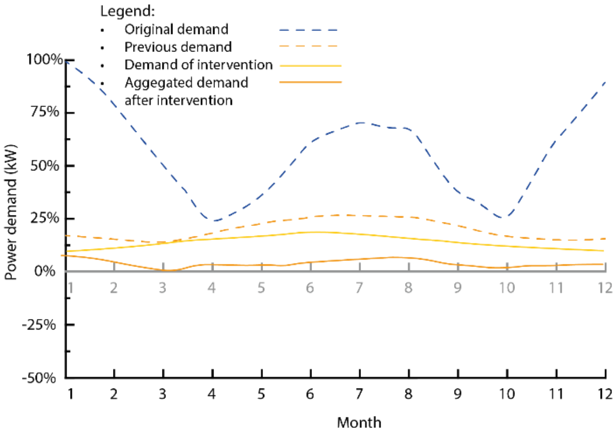

Figure 28. Load curve with façade PV production

In figure 29 the load graph of a EAZ wind turbine is added with wind production data from Marksson (2021). Like Mertens stated more wind energy is produced during the winter months “filling the gap” that solar energy leaves (2022). Therefor the aggregated load curve is mostly lowered during the winter months flattening the curve completely and even overproducing a bit during spring and autumn. This overproduction can be stored like figure 30 suggests, however storing energy for a long period of time in a battery needs a lot of capacity. A smaller capacity like suggested earlier could also help but this could not be simulated by the ZED-tool so more research has to be done on this topic.

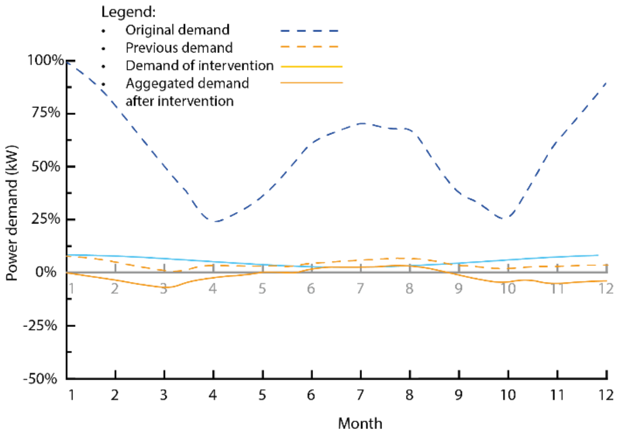

Figure 29. Load curve after implementation of wind energy

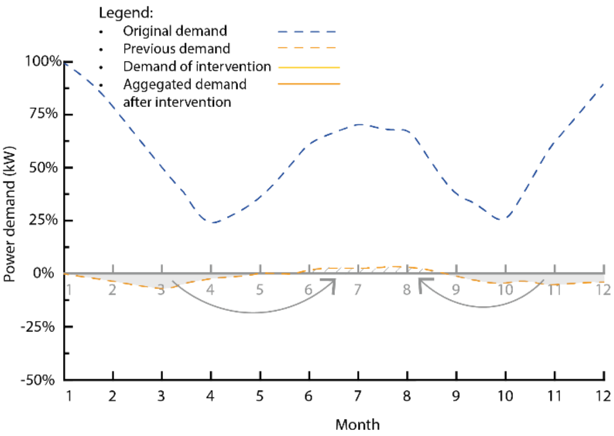

Figure 30. Load curve after implementation of a battery system

4.3. Energy program of requirements

By now this paper has given a number of possibilities on how the load on the energy grid can be lowered while also improving the energy performance of a building. To apply these interventions in a building this paper provides a program of requirements. If we combine our findings from the literature and the ZED-Tool a list of demands can be formulated as the following: The specific values used in the ZED-tool can be found in Appendix II.

a) Change heat (and cooling) source to a Heat Pump with a high COP to minimize the demand for heating and cooling. Preferably with floor heating as delivery system to increase the buffer capacity of the thermal mass. This will eliminate the GHG emissions of the building lowering its contribution to global warming.

    i) In the ZED-tool a COP of 4 was used as a heat pump with ground source was installed.

b) Insulate the building on the outside to minimize heat loss, thermal bridges and maximize the buffering effect of the thermal mass.

    i) The values used in the ZED-tool are: roof $R_c > 7{,}5$ m^{2}K/W, walls $R_c > 6{,}0$ m^{2}K/W, floor $R_c > 5{,}0$ m^{2}K/W, windows $U < 1{,}2$ W/m^{2}K. These values were assumed form the common values to make homes more sustainable. The optimal insulation values are depending per situation and how optimal is valued. A optimal insulation value with the lowest cost or environmental impact can be reached. This requires more research and a tool to calculate this.

    ii) Preferably also apply adaptive insulating screens to minimize heat loss during the night. Furthermore apply adaptive sun shading to block the sun during the summer and let the sun in during winter minimizing cooling and heating demand.

c) Install the maximum amount of façade PV on the east and west façade in order to lower the morning and evening demand peaks.

    i) In the case study building there was an available façade space of 405m^2 on the east and 326m^2 on the west façade. This means an energy generation of approximately 109650 kWh per year if we assume a yield of 150 kWh per m^2 of vertical solar panel.

d) Install wind turbines to have more RES generation during the winter months like a ventecroof designed by Bronsema (2013) (See appendix III for an overview and more information on RES). Given the fact that there are now 48 apartments in the building that approximately use 3000 kWh a year a total energy generation of 144000 kWh is needed. The solar panels already generate 109650 kWh so 34350 kWh needs to be generated by wind energy. One EAZ wind turbine could cover this. However small vertical wind turbines can also be used but then 35 are needed. It is up to the designer to make a decision what to use as long as enough energy is generated.

    i) The results of (Marksson, 2021) were used in the ZED-tool. However the theoretical values found by Bronsema can also be used to estimate the amount of wind energy generation (2013, p. 313). To maximize the wind generation it is preferred to place the wind turbines 20m or higher (Bronsema, 2013, p. 312). This adds an argument for topping up existing buildings as this will not only increase density but also energy generation. Thus, the optimal wind energy production depends on a optimal technology, size and height and has yet to be determined.

e) Install E-W oriented roof PV when demand is still positive during the day. The size is dependent on the missing demand and available roof space.

f) Use salt water batteries with a capacity of 30 kWh of electrical energy storage to become fully self sufficient. This will take up approximately 12 battery packs per apartment. Thus the space needed for the battery system will be roughly 1350*900*1920mm (l*w*h).

V. CONCLUSION

The rise of heat pumps, electric cars and south facing solar arrays to provide buildings with sustainable energy is slowing down the energy transition in the Netherlands, because the Dutch energy grid is not capable to withstand large peaks in energy use and production. Furthermore the Dutch government is abolishing the net metering fee which gives owners less financial incentive to generate their own renewable energy. This research focused on the possibility to lower the peak loads on the grid while making a residential building more energy efficient and self-sufficient.

The aim of the present research is to gain more insight in ways to improve the energy performance of a building without increasing the load on the electrical energy grid. This will provide a solution to speed up the energy transition. The current daily and annual demand of average Dutch households were analysed to create a base load profile. A literature study on peak shaving was conducted to identify techniques that lower the demand and production peaks and enhance the amount of self consumption of RES-E. Hourly load profiles found in the literature were then scaled in order to combine existing profiles and create new load profiles after peak shaving techniques were applied. This way more insight on how these techniques influence the daily load profiles was created. The ZED-tool was used to create more insight in the annual load profile after implementation of certain peak shaving techniques.

The results show that passive techniques like insulation and sun shading lowers and flattens the daily and annual demand. Moreover changing the heat source to a HP system increases the energy demand, however this increase is limited when a continuous heating pattern is used. Furthermore the results show that the application of east and west façade PV provides the biggest peak reduction on a daily base because they generate energy during the morning and evening when the peak demand is also high. If there is not enough production capacity on the façade due to a small east or west facing façade, roof PV with an east-west orientation can be added to still have daytime energy production. Additionally the application of wind energy provides more energy generation when solar generation is low. This happens mostly during the night and during the winter months filling the generation “gaps” solar energy leaves. Also the daily generation curve of wind energy significantly decreases the evening peak. All this in combination with a 30 kWh SWB will flatten the load curve in such a way that the building could become fully self-sufficient. In that case no grid connection is needed eliminating the load on the grid. The findings in this study provide new understanding of how to implement RESs in such a way that they reduce the peak loads on the electrical energy grid providing more capacity to densify existing areas and buildings can become self-sufficient in energy use.

There were several challenges when trying to calculate the exact load profiles and influences of certain systems. Existing calculation tools like ZED-tool are to limited but gave some insight. The ZED-tool was limited due to the shear complexity of parameters that are needed to calculate the energy demand of a house hold. Further the ZED-tool was only designed to calculate the annual demand while the daily demand was also relevant for this study. Therefor a literature study is conducted in this research to estimate the implications on the daily energy demand. This meant that the data and graphs are not exact. However they give an insight in how load curves can be manipulated with certain systems, architectural elements and building installations.

In future research these outcomes can be used as a basis to develop a complex calculation/ simulation tool to predict the energy demand and calculate implications more precise. This tool has to connect multiple calculations like; solar gains, insulation thickness, thermal mass, user profiles, PV production and wind production. The tool can then be used to calculate the optimal insulation values, amount PV panels and wind turbines and give a detailed program of requirements. Furthermore the outcome can de validated via a test setup / case study and measure the influences of different interventions like adding façade PV. Both studies can then be used to optimize battery size, insulation etc.

During this research discussions in the Dutch politics started on the abolishment of the Net-metering rule (salderen in Dutch) that change the impact of this research. The abolishment of the net-metering rule and the threat of some energy providers implementing demand driven(dynamic) pricing when this rule is abolished, makes a stronger financial case to renovate existing buildings with above stated method. Two scenarios can be explained as following: First the abolishment of the net-metering rule means that overproduction of energy is not valued the same as energy demand. This results in a longer PBP thus, it is financially less attractive to overproduce and more attractive to have a high self-consumption of self produced energy. The second scenario of the implementation of flexible means a household would get paid to use energy during the day due to the large amount of energy overproduction. This also means that the prices in the night are higher thus, when producing energy during this time with wind energy or façade PV a household will save more money, thus the PBP of the investment will be shorter. So this design will make the deep energy renovation of existing buildings more financial attractive and hopefully speed up the energy transition.

A final critical note can be added about the use of critical materials needed to implement so much RES. When implementing façade PV there is more surface of PV panels needed to reach the same energy yield. Thus, more critical materials are needed making it a more viable solution to just upgrade the existing energy grid as less critical materials are needed. However like stated earlier this is not feasible on short term due to the lack of skilled workers.

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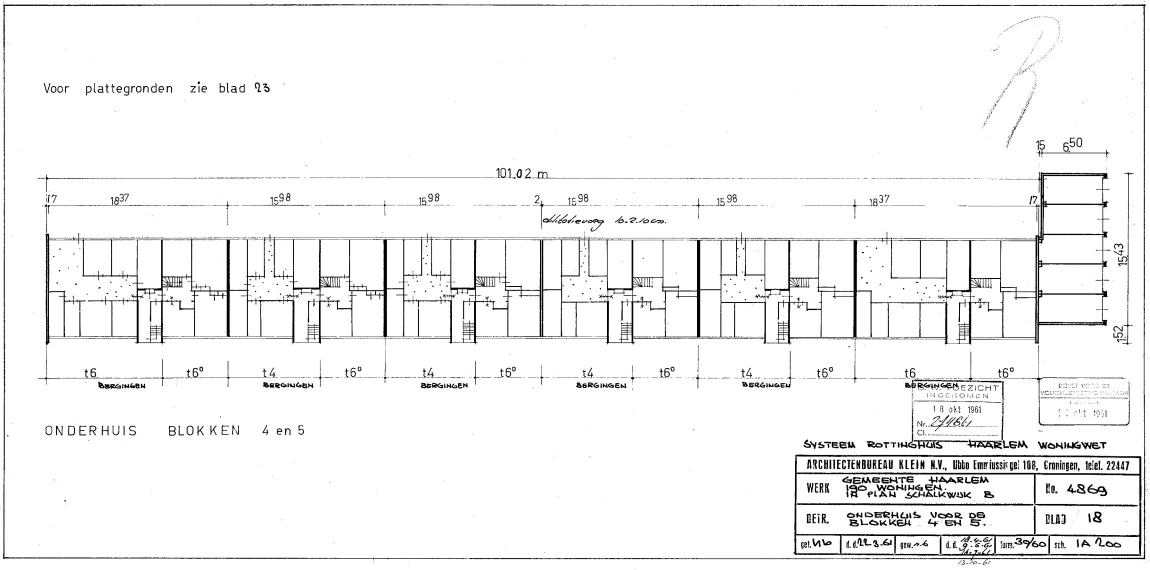
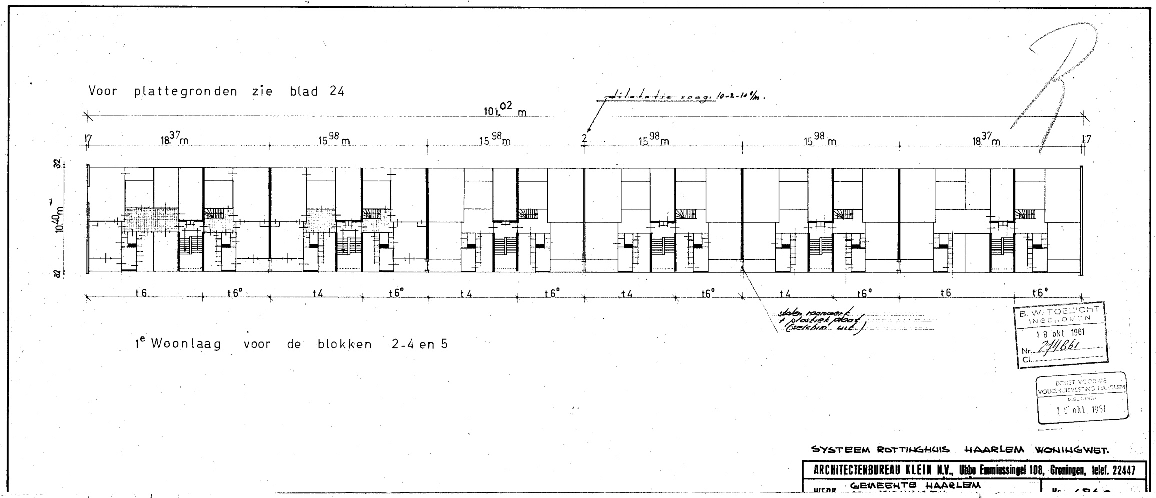
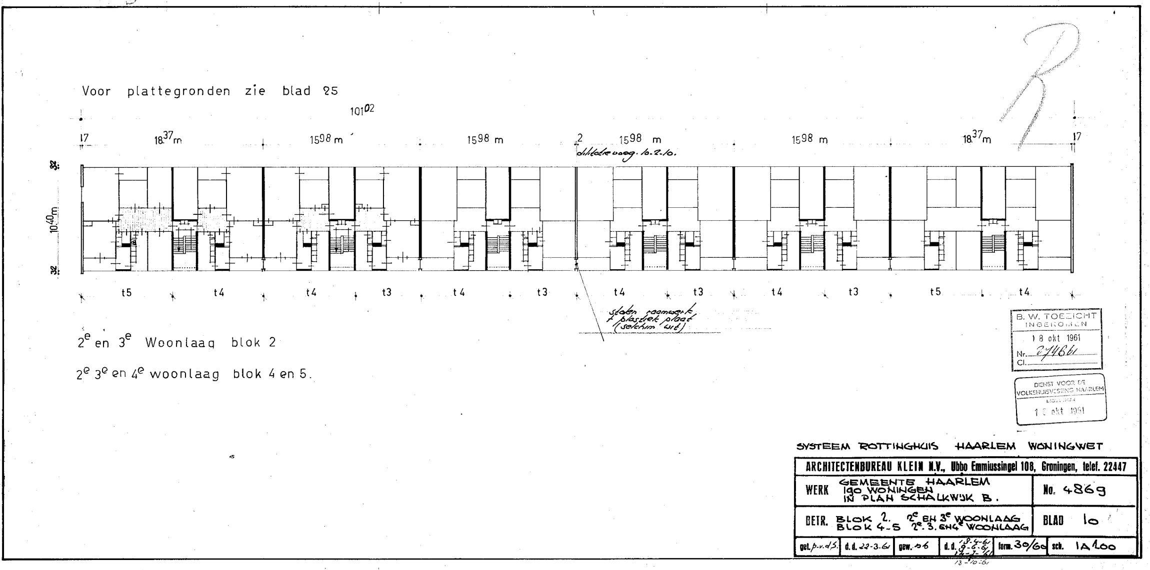
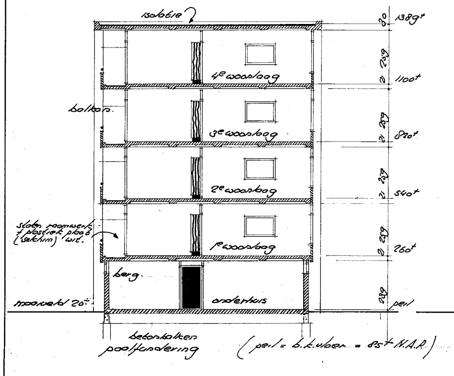
APPENDIX I

Drawings of the case study building in Haarlem: It houses 48 dwellings is 13,9m high, 101m long and 10,4m wide.

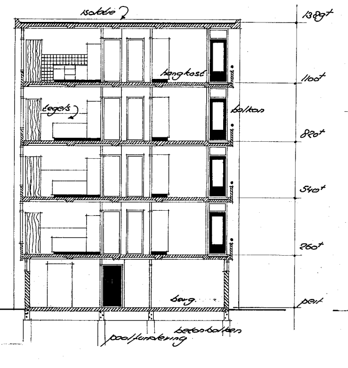




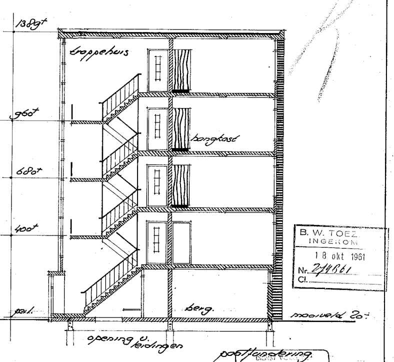




DOORSHEDE a-a.



DOORSHEDE b-b.



B.W. TOEZ.
INGEKOM.
18 okt 1961
Nr. 274861
Cl.

DIENST VOOR DE
VOLKSHUISVESTING HAARLEM
18 okt 1961

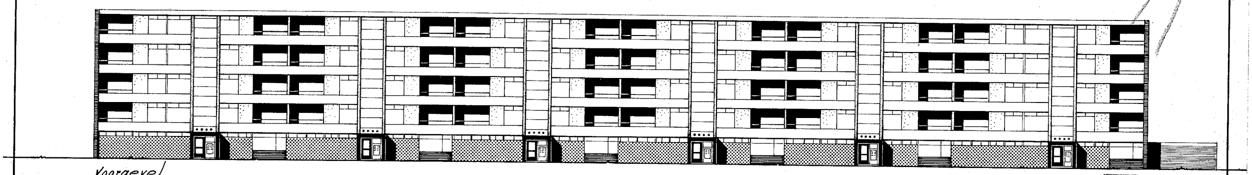
DOORSNEDE C-C.

SYSTEEM ROTTINGHUIS HAARLEM WONINGWET

ARCHITECTENBUREAU KLEIN N.V., Ubbo Emmiussingel 100, Groningen, telef. 22447

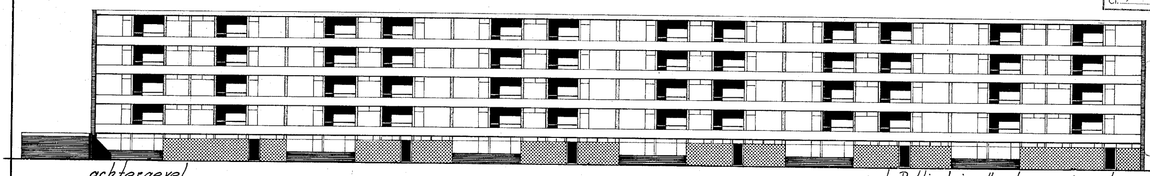
WERK	GEMEENTE HAARLEM 190 WONINGEN IN PLAN SCHALKWIJK B	No.	4869
BETR.	DWARSDOORSN: a.a b.b. c.c. VOOR 4 WOONLAGEN	BLAD	29

get. hb | d.d. 22.3.61 | gew. n.b | d.d. 18-4-61 9-6-61 14-7-61. 13-10-61 | form. 30/60 | sch. 1A100.



Voorgevel.

B.W. TOEZICHT
INGEKOMEN
18 okt 1961
Nr. 274861
Cl.



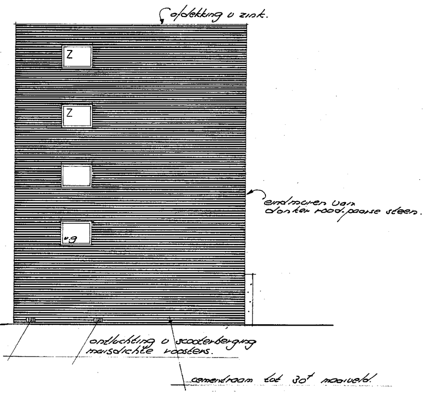
DIENST VOOR DE
VOLKSHUISVESTING HAARLEM
18 okt 1961

achtergevel.

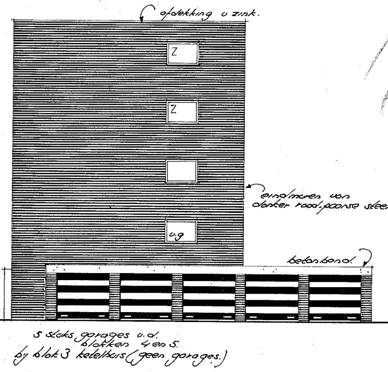
syst. Rottinghuis. Haarlem-woningwet.

ARCHITECTENBUREAU KLEIN N.V., Ubbo Emmiussingel 100, Groningen, telef. 22447

WERK	Gemeente Haarlem. 190 woningen in plan Schalkwijk B.	No.	4869.
BETR.	gevelschema's blokken 4 en 5	BLAD	19.



LINKERZIJGEVEL.



RECHTER ZIJGEVEL.

B.W. TOEZICHT
INGEKOMEN
18 okt 1961
Nr. 274861
Cl.

DIENST VOOR DE
VOLKSHUISVESTING HAARLEM
18 okt 1961

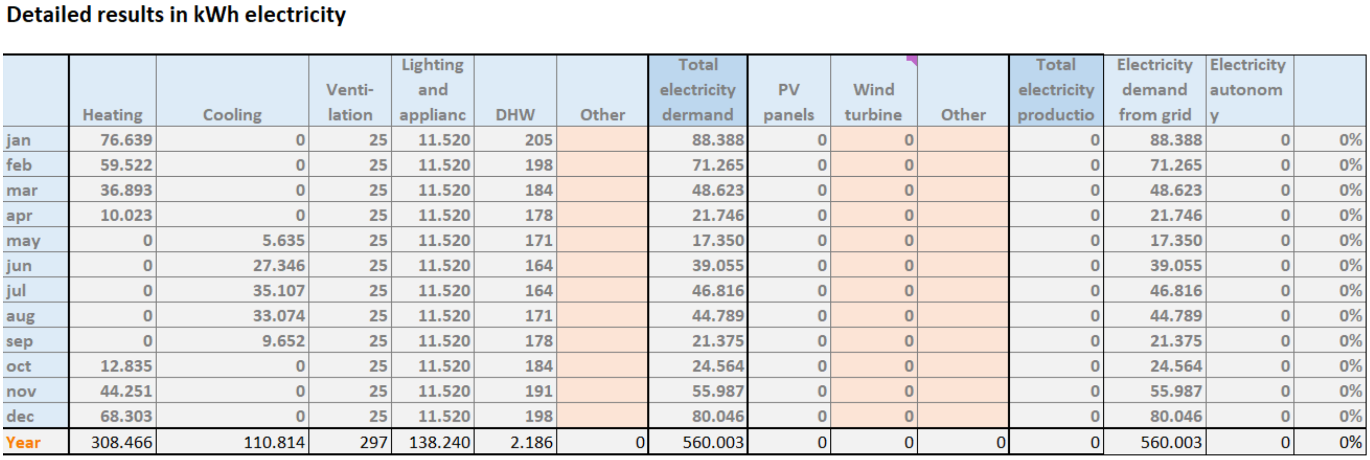
SYSTEEM ROTTINGHUIS HAARLEM WONINGWET

ARCHITECTENBUREAU KLEIN N.V., Ubbo Emmiussingel 100, Groningen, telef. 22447

WERK	GEMEENTE HAARLEM 190 WONINGEN IN PLAN SCHALKWIJK B	No.	4869
BETR.	EINDGEVELS VOOR 4 WOONLAGEN	BLAD	34

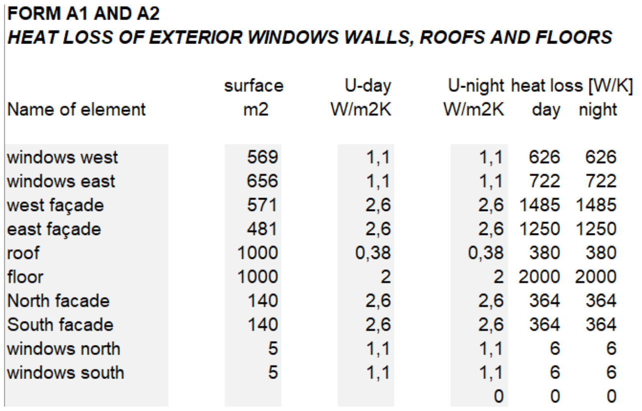
get. hb | d.d. 22-3-61 | gew. p/h.s. n.b | d.d. 18-1-61. 9-6-61 14-7-61. 13-10-61 | form. 30/60 | sch. 1A100

Entered ZED-tool values of the existing case study building:
These were used to simulate the current annual energy demand of figure 24.



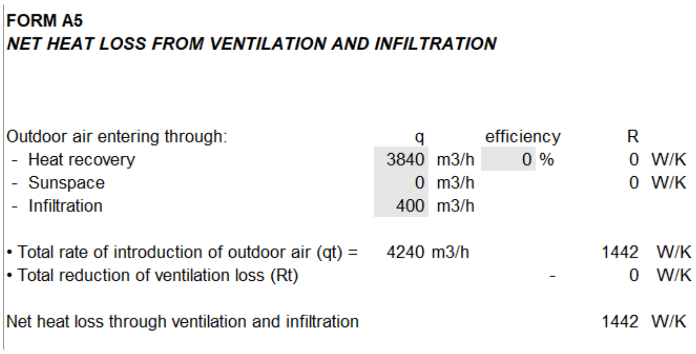
Detailed results in kWh electricity

	Heating	Cooling	Venti-lation	Lighting and applianc	DHW	Other	Total electricity dermand	PV panels	Wind turbine	Other	Total electricity productio	Electricity demand from grid	Electricity autonom y	
jan	76.639	0	25	11.520	205		88.388	0	0		0	88.388	0	0%
feb	59.522	0	25	11.520	198		71.265	0	0		0	71.265	0	0%
mar	36.893	0	25	11.520	184		48.623	0	0		0	48.623	0	0%
apr	10.023	0	25	11.520	178		21.746	0	0		0	21.746	0	0%
may	0	5.635	25	11.520	171		17.350	0	0		0	17.350	0	0%
jun	0	27.346	25	11.520	164		39.055	0	0		0	39.055	0	0%
jul	0	35.107	25	11.520	164		46.816	0	0		0	46.816	0	0%
aug	0	33.074	25	11.520	171		44.789	0	0		0	44.789	0	0%
sep	0	9.652	25	11.520	178		21.375	0	0		0	21.375	0	0%
oct	12.835	0	25	11.520	184		24.564	0	0		0	24.564	0	0%
nov	44.251	0	25	11.520	191		55.987	0	0		0	55.987	0	0%
dec	68.303	0	25	11.520	198		80.046	0	0		0	80.046	0	0%
Year	308.466	110.814	297	138.240	2.186	0	560.003	0	0	0	0	560.003	0	0%



FORM A1 AND A2
HEAT LOSS OF EXTERIOR WINDOWS WALLS, ROOFS AND FLOORS

Name of element	surface m2	U-day W/m2K	U-night W/m2K	heat loss [W/K] day	night
windows west	569	1,1	1,1	626	626
windows east	656	1,1	1,1	722	722
west façade	571	2,6	2,6	1485	1485
east façade	481	2,6	2,6	1250	1250
roof	1000	0,38	0,38	380	380
floor	1000	2	2	2000	2000
North facade	140	2,6	2,6	364	364
South facade	140	2,6	2,6	364	364
windows north	5	1,1	1,1	6	6
windows south	5	1,1	1,1	6	6
			0	0	0

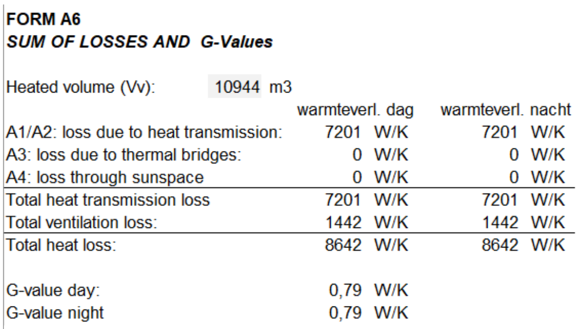


FORM A5
NET HEAT LOSS FROM VENTILATION AND INFILTRATION

Outdoor air entering through:	q		efficiency	R	
- Heat recovery	3840	m3/h	0 %	0	W/K
- Sunspace	0	m3/h		0	W/K
- Infiltration	400	m3/h			

• Total rate of introduction of outdoor air (qt) = 4240 m3/h 1442 W/K
• Total reduction of ventilation loss (Rt) - 0 W/K

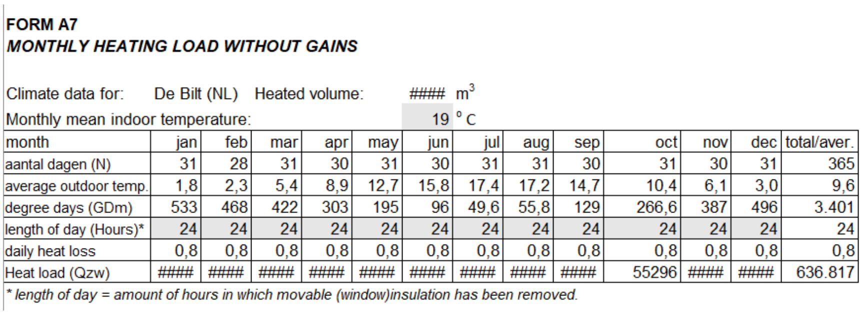
Net heat loss through ventilation and infiltration 1442 W/K



FORM A6
SUM OF LOSSES AND G-Values

Heated volume (Vv): 10944 m3

	warmteverl. dag		warmteverl. nacht	
A1/A2: loss due to heat transmission:	7201	W/K	7201	W/K
A3: loss due to thermal bridges:	0	W/K	0	W/K
A4: loss through sunspace	0	W/K	0	W/K
Total heat transmission loss	7201	W/K	7201	W/K
Total ventilation loss:	1442	W/K	1442	W/K
Total heat loss:	8642	W/K	8642	W/K
G-value day:	0,79	W/K		
G-value night	0,79	W/K		

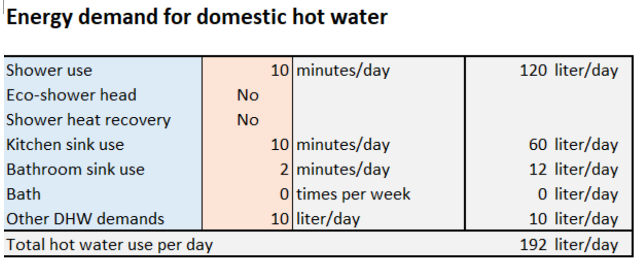


FORM A7
MONTHLY HEATING LOAD WITHOUT GAINS

Climate data for: De Bilt (NL) Heated volume: #### m^3
Monthly mean indoor temperature: 19 °C

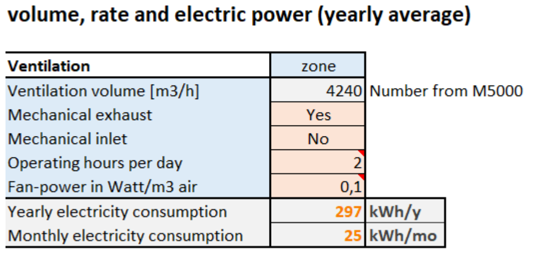
month	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	total/aver.
aantal dagen (N)	31	28	31	30	31	30	31	31	30	31	30	31	365
average outdoor temp.	1,8	2,3	5,4	8,9	12,7	15,8	17,4	17,2	14,7	10,4	6,1	3,0	9,6
degree days (GDm)	533	468	422	303	195	96	49,6	55,8	129	266,6	387	496	3.401
length of day (Hours)*	24	24	24	24	24	24	24	24	24	24	24	24	24
daily heat loss	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Heat load (Qzw)	####	####	####	####	####	####	####	####	####	55296	####	####	636.817

** length of day = amount of hours in which movable (window)insulation has been removed.*



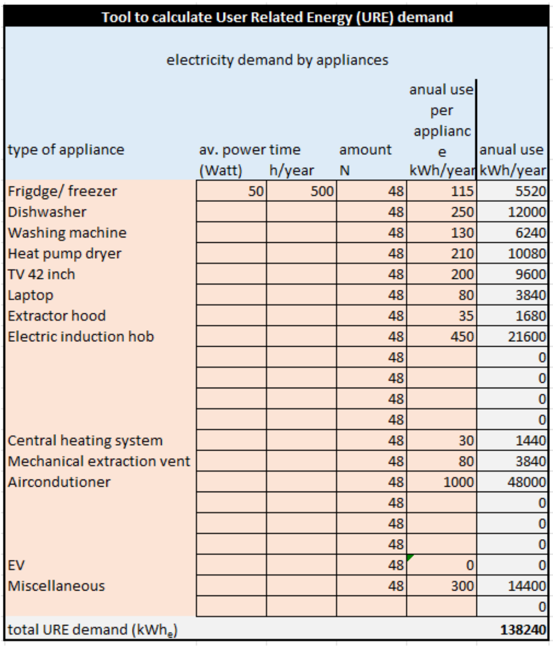
Energy demand for domestic hot water

Shower use	10	minutes/day	120 liter/day
Eco-shower head	No		
Shower heat recovery	No		
Kitchen sink use	10	minutes/day	60 liter/day
Bathroom sink use	2	minutes/day	12 liter/day
Bath	0	times per week	0 liter/day
Other DHW demands	10	liter/day	10 liter/day
Total hot water use per day			192 liter/day



volume, rate and electric power (yearly average)

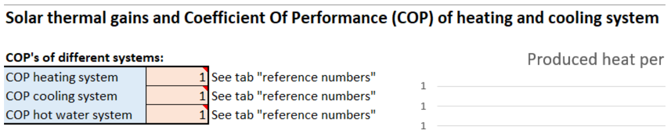
Ventilation	zone	
Ventilation volume [m3/h]	4240	Number from M5000
Mechanical exhaust	Yes	
Mechanical inlet	No	
Operating hours per day	2	
Fan-power in Watt/m3 air	0,1	
Yearly electricity consumption	297	kWh/y
Monthly electricity consumption	25	kWh/mo



Tool to calculate User Related Energy (URE) demand

electricity demand by appliances

type of appliance	av. power (Watt)	time h/year	amount N	anual use per appliance kWh/year	anual use kWh/year
Frigdge/ freezer	50	500	48	115	5520
Dishwasher			48	250	12000
Washing machine			48	130	6240
Heat pump dryer			48	210	10080
TV 42 inch			48	200	9600
Laptop			48	80	3840
Extractor hood			48	35	1680
Electric induction hob			48	450	21600
			48		0
			48		0
			48		0
			48		0
Central heating system			48	30	1440
Mechanical extraction vent			48	80	3840
Aircondutioner			48	1000	48000
			48		0
			48		0
			48		0
EV			48	0	0
Miscellaneous			48	300	14400
					0
total URE demand (kWh_e)					**138240**



Solar thermal gains and Coefficient Of Performance (COP) of heating and cooling system

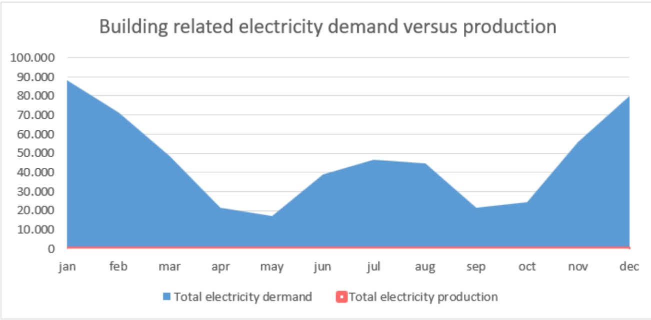
COP's of different systems:

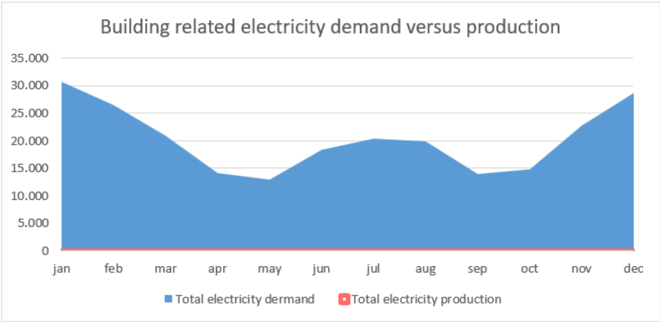
COP heating system	1	See tab "reference numbers"
COP cooling system	1	See tab "reference numbers"
COP hot water system	1	See tab "reference numbers"

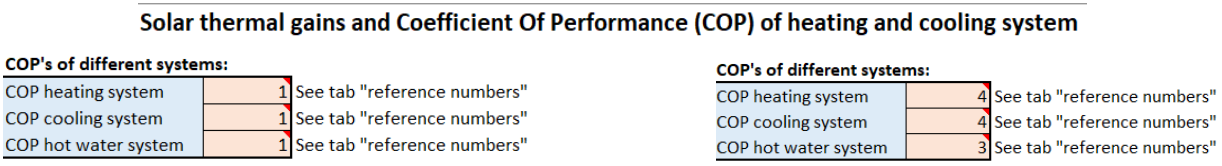
APPENDIX II

This appendix shows all the input values that were changed per intervention and its corresponding load profile form the ZED-tool.

Basis for figure 24 (left) and 25 (right) change of heat source COP (left is the current situation and right the changed with new COP values):







Solar thermal gains and Coefficient Of Performance (COP) of heating and cooling system

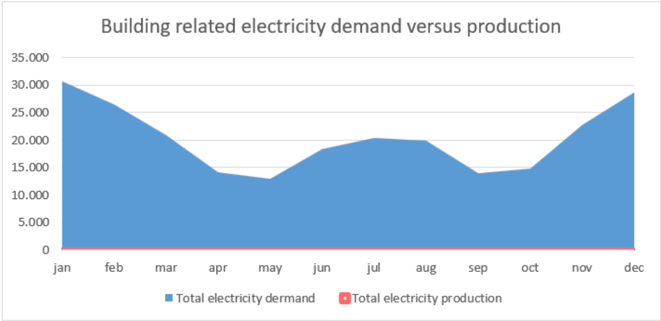
COP's of different systems:

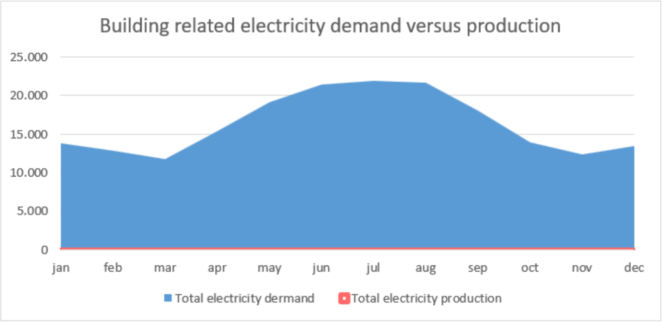
COP heating system	1	See tab "reference numbers"
COP cooling system	1	See tab "reference numbers"
COP hot water system	1	See tab "reference numbers"

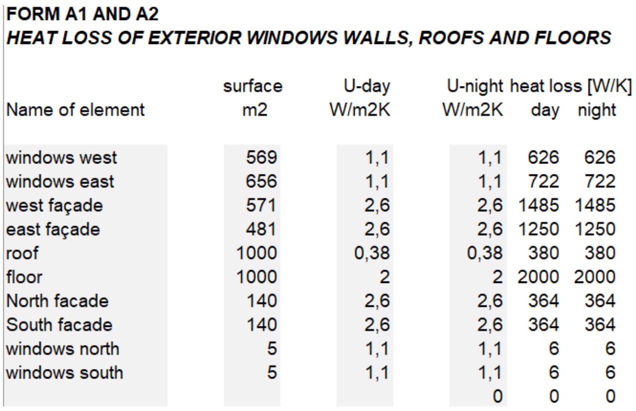
COP's of different systems:

COP heating system	4	See tab "reference numbers"
COP cooling system	4	See tab "reference numbers"
COP hot water system	3	See tab "reference numbers"

Figure 26 change of insulation values (left current values and right the new U-values):



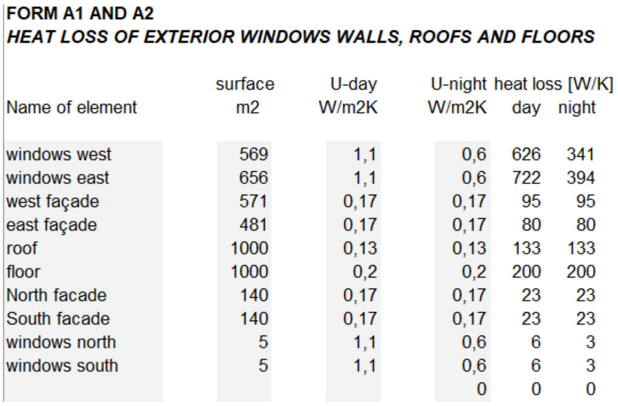




FORM A1 AND A2

HEAT LOSS OF EXTERIOR WINDOWS WALLS, ROOFS AND FLOORS

Name of element	surface m2	U-day W/m2K	U-night W/m2K	heat loss [W/K] day	night
windows west	569	1,1	1,1	626	626
windows east	656	1,1	1,1	722	722
west façade	571	2,6	2,6	1485	1485
east façade	481	2,6	2,6	1250	1250
roof	1000	0,38	0,38	380	380
floor	1000	2	2	2000	2000
North facade	140	2,6	2,6	364	364
South facade	140	2,6	2,6	364	364
windows north	5	1,1	1,1	6	6
windows south	5	1,1	1,1	6	6
			0	0	0

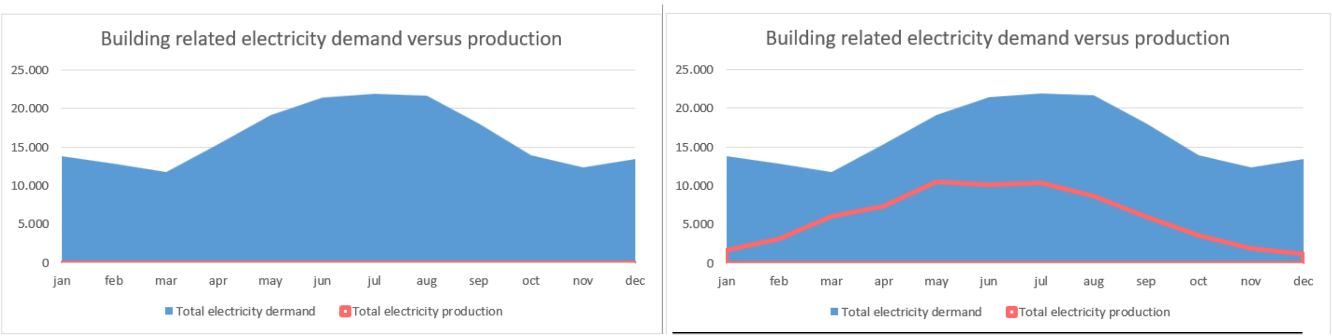


FORM A1 AND A2

HEAT LOSS OF EXTERIOR WINDOWS WALLS, ROOFS AND FLOORS

Name of element	surface m2	U-day W/m2K	U-night W/m2K	heat loss [W/K] day	night
windows west	569	1,1	0,6	626	341
windows east	656	1,1	0,6	722	394
west façade	571	0,17	0,17	95	95
east façade	481	0,17	0,17	80	80
roof	1000	0,13	0,13	133	133
floor	1000	0,2	0,2	200	200
North facade	140	0,17	0,17	23	23
South facade	140	0,17	0,17	23	23
windows north	5	1,1	0,6	6	3
windows south	5	1,1	0,6	6	3
			0	0	0

Basis for figure 27 (right) addition of PV panels of façade (red line):



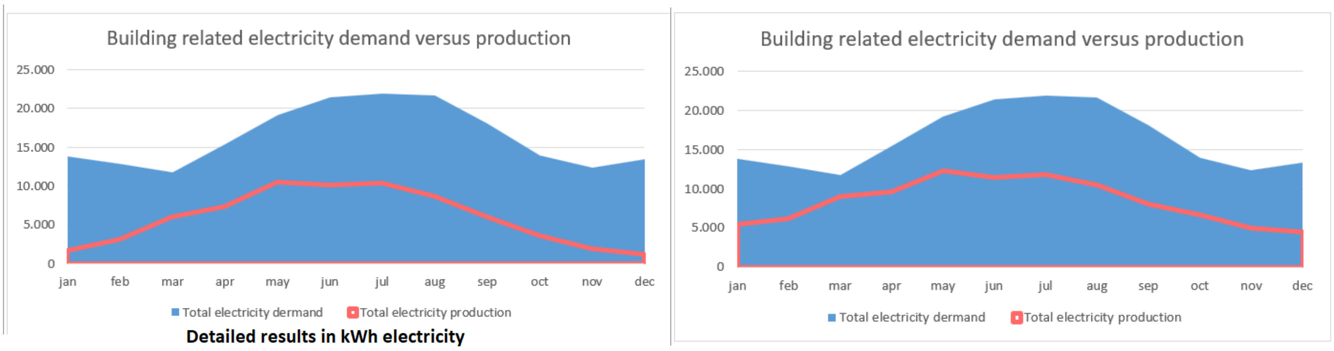
Electricity production by Photo Voltaic (PV) panels

PV-systems	Orientation	Tilt angle	Area [m2]	PV-efficiency
PV-system 1	E	10	0	15%
PV-system 2	E	0	0	15%
PV-system 3	W	0	0	15%
PV-system 4	E	90	0	15%
PV-system 5	W	90	0	15%
PV-system 6	S	90	0	15%

Electricity production by Photo Voltaic (PV) panels

PV-systems	Orientation	Tilt angle	Area [m2]	PV-efficiency
PV-system 1	E	10	0	15%
PV-system 2	E	0	0	15%
PV-system 3	W	0	0	15%
PV-system 4	E	90	400	15%
PV-system 5	W	90	400	15%
PV-system 6	S	10	0	15%

Basis for figure 28 (right) addition of wind energy:



Detailed results in kWh electricity

	Heating	Cooling	Venti-lation	Lighting and appliances	DHW	Other	Total electricity dermand	PV panels	Wind turbine	Other	Total electricity production	Electricity demand from grid	Electricity autonomy	
jan	2.244	0	25	11.520	68		13.857	1.714	0		1.714	12.143	1.714	12%
feb	1.269	0	25	11.520	66		12.880	3.156	0		3.156	9.724	3.156	25%
mar	131	0	25	11.520	61		11.737	6.020	0		6.020	5.717	6.020	51%
apr	0	3.796	25	11.520	59		15.400	7.390	0		7.390	8.010	7.390	48%
may	0	7.603	25	11.520	57		19.204	10.539	0		10.539	8.666	10.539	55%
jun	0	9.881	25	11.520	55		21.481	10.214	0		10.214	11.266	10.214	48%
jul	0	10.350	25	11.520	55		21.949	10.342	0		10.342	11.607	10.342	47%
aug	0	10.038	25	11.520	57		21.640	8.735	0		8.735	12.905	8.735	40%
sep	0	6.504	25	11.520	59		18.108	5.997	0		5.997	12.111	5.997	33%
oct	0	2.318	25	11.520	61		13.924	3.640	0		3.640	10.284	3.640	26%
nov	830	0	25	11.520	64		12.439	1.990	0		1.990	10.448	1.990	16%
dec	1.807	0	25	11.520	66		13.418	1.194	0		1.194	12.223	1.194	9%
Year	6.282	50.489	297	138.240	729	0	196.037	70.933	0	0	70.933	125.104	70.933	36%

Detailed results in kWh electricity

	Heating	Cooling	Venti-lation	Lighting and appliances	DHW	Other	Total electricity dermand	PV panels	Wind turbine	Other	Total electricity production	Electricity demand from grid	Electricity autonomy	
jan	2.244	0	25	11.520	68		13.857	1.714	3.750		5.464	8.393	5.464	39%
feb	1.269	0	25	11.520	66		12.880	3.156	3.000		6.156	6.724	6.156	48%
mar	131	0	25	11.520	61		11.737	6.020	3.000		9.020	2.717	9.020	77%
apr	0	3.796	25	11.520	59		15.400	7.390	2.250		9.640	5.760	9.640	63%
may	0	7.603	25	11.520	57		19.204	10.539	1.750		12.289	6.916	12.289	64%
jun	0	9.881	25	11.520	55		21.481	10.214	1.250		11.464	10.016	11.464	53%
jul	0	10.350	25	11.520	55		21.949	10.342	1.500		11.842	10.107	11.842	54%
aug	0	10.038	25	11.520	57		21.640	8.735	1.750		10.485	11.155	10.485	48%
sep	0	6.504	25	11.520	59		18.108	5.997	2.000		7.997	10.111	7.997	44%
oct	0	2.318	25	11.520	61		13.924	3.640	3.000		6.640	7.284	6.640	48%
nov	830	0	25	11.520	64		12.439	1.990	3.000		4.990	7.448	4.990	40%
dec	1.807	0	25	11.520	66		13.418	1.194	3.250		4.444	8.973	4.444	33%
Year	6.282	50.489	297	138.240	729	0	196.037	70.933	29.500	0	100.433	95.604	100.433	51%

APPENDIX III

This appendix shows all the possible RESs and their energy yield.

(Postma, 2022)

eaz-wind

Circulair windmill
+/- 20m high (depending on local rules)
+/- 38000 kWh per year per windmill

(Bouman, 2019)

powernest

Prefab roof based wind and solar generation system
7.2*7.2*4.8m (w*l*h)
E-W oriented PV-panels + Wind turbine
+/- 12000 kWh per year per module (9000 kWh solar + 3000 kWh wind)

(RTL Nieuws, 2020)

airturb

Vertical axis windmill
+/- 1.5m high
+/- 1000 kWh per year per windmill

(Duurzaam gebouwd, 2018)

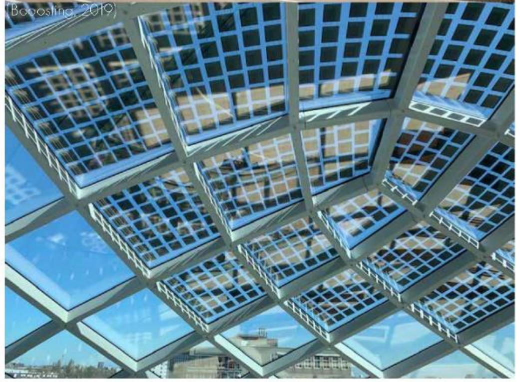
mecanoo

De Spakler
Facade PV slope 90°
+/- 150 kWh per year per panel

(MEDIASHOTS, 2020)

jessenvollenweider architektur

Amt für Umwelt und Energie
Facade PV 90°
+/- 150 kWh per year per panel



(Booosting, 2019)

ZJA

Diamond exchange amsterdam
Roof PV semi- transparent
+/- ? kWh per year