research plan | aE studio

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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studio
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Argumentations of choice of the studio

This studio really focuses on the current problems we face and its possible solutions while others did not have this focus. Furthersmore, there is more attention on the technical side of architecture in this studio, especially on the integation of asthetics and technology. In my opinion this aspect is often overlooked by architects and they only look at aesthetics and space. This way there is little incorporation of technology in the architecture that will become a problem in the end phase of a design. So to gain more knowledge on the technical side of architecture and to incorporate technology early on in the design phase I choose this graduation studio.

Title

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.

Keywords

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

Contents

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 lower. Most of the low hanging fruit, like installing double glazing, has already been updated but this is not really improving the energy performance. This can only be done by conducting deep energy renovations but the rate in which these deep energy renovations are being conducted is not fast enough to meet the sustainability goals of the EU (Filippidou et al., 2017; Ebrahimigharehbaghi, et al., 2019; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022).

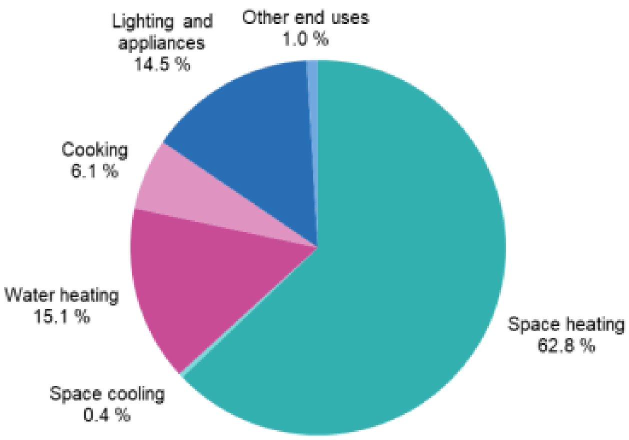

Figure 1: Final energy consumption in the residential sector by use (Eurostat, 2020)

Furthermore, recent events in Ukraine have shown that we need to speed up the energy transition. A lot of European countries import Russian fossil fuels like natural gas. After sanctions that limit the amount of imported gas from Russia, the Netherlands has become more aware of the dependency of the Dutch energy system. This dependency creates other problems like high energy bills that we would not have if we redefined our energy system. However, this redefinition of our electricity grid is only possible on short term if it happens in such a way that there is no extra load on the grid. Meaning that if the electricity demand per dwelling becomes higher it needs to generate and buffer its own electricity.
A lot of studies pose that there are several barriers that slow down the energy transition. Most of them state that the main barriers are not technical related but rather a lack of knowledge by owners and designers, a lack of financial incentives, slow permit procedures and above all a lack of a clear policy (Broers et al., 2022; D'Oca et al., 2018; Ebrahimigharehbaghi, Qian, et al., 2019; Fořt & Černý, 2022; Gram-Hanssen, 2014; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022).

Because every renovation project is unique, the approach is also different. Several social housing cooperations have knowledge and experience on how to approach this but do not share their knowledge with other cooperations which slow down the project (M. Dieters & S. Verweij, 2014; S. Blom & M. Dieters, 2014). At the end of the day these companies are financial driven and therefore need a strong business case (through subsidies) or mandatory regulations in order to encourage them to renovate their housing stock.

A big threat for the implementation of Electrical Renewable Energy Sources (RES-E) is that the Dutch government is planning to stop the so called "Salderingsregeling" from 2030. This means that people who produce energy and return it into the grid will no longer get paid the same amount as it would cost to withdraw electric energy. This creates even less financial incentive because it takes longer to earn back the investment of PV panels decreasing the incentive to invest in the generation of your own renewable energy. This could lead to an environmental problem because this reduces the already slow rate of the energy transition even more. The new incentive when the "salderingregeling" stops, would be to become self-sufficient in energy use. This way home owners do not buy electricity from the grid but "save" energy by producing their own demand when needed. These savings are then used to earn back your investment in RESs.

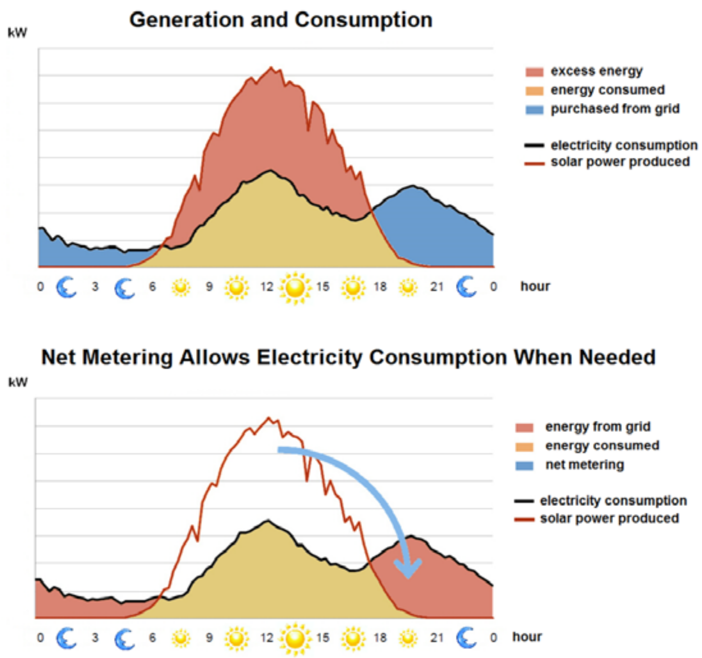

Figure 2: Example of net metering, use of excess energy during the night (Delphi234, n.d.)

Another reason why the energy transition is moving slow is the lack of infrastructure needed to generate and use more renewable energy creating grid congestion (Nortier et al., in press; Schermeyer et al., 2017). With the current rise of Electrical Vehicles (EV), the use of electrical appliances like heat pumps and PV panels, the load on the electrical grid will only grow (Mutani & Todeschi, 2021). When the load on the electrical grid becomes so high that the cables cannot manage the amount of electricity any more it is called grid congestion.

Grid congestion is caused because the Dutch infrastructure is not designed to put a large amount of generated energy back in the grid (Nortier et al., 2022). We cannot just upgrade the electricity grid because changing the current electrical grid will take a long time and skilled workers which we do not have (Mertens, 2022; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022). If we look deeper in the difference between energy demand and energy production due to the mass implementation of south-oriented PV panels, we can conclude that there is an imbalance between production and demand. Figure 2 shows that there is excess energy production during the day and no production during the night. Additionally, figure 3 shows a similar imbalance over the course of a year with an underproduction of energy during the winter and overproduction during the summer months.

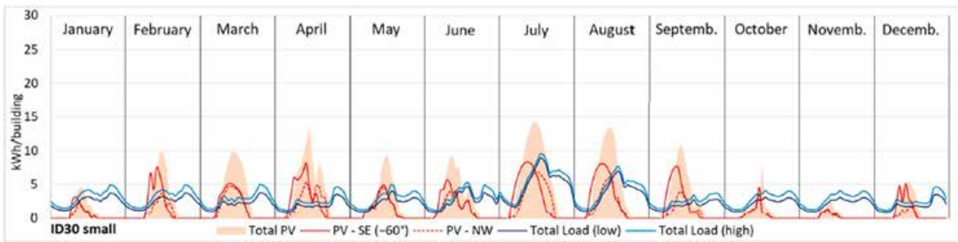

Figure 3: Hourly profils of total load and the total PV production per month (Mutani & Todeschi, 2021)

This means that we need to look at alternative ways to distribute the energy production evenly throughout the day and year (Filippidou et al., 2017). If energy demand and renewable production are locally in balance, the existing building stock will have a better energy performance while not putting more load on the power grid. Thus we have to reduce the peak moments of production and demand in order to facilitate a fast energy transition which is also known as peak-shaving or load matching.

If we look at the Boerhaave neighbourhood in Haarlem we can see the poor energy performance of the buildings. Figure 4 shows the energy labels within the neighbourhood proving the fact that existing houses have a high energy consumption. The Boerhaave neighbourhood was designed in the 1960s as post-war expansion plan. In the Netherlands there are a lot of these neighbourhoods with similar building typologies and urban plans. Therefore, defining a strategy to reduce the energy demand of these building blocks without increasing the peak loads on the grid could also be used in other neighbourhoods. If this strategy gets implemented it will have a large impact on the GHG emissions of existing buildings.

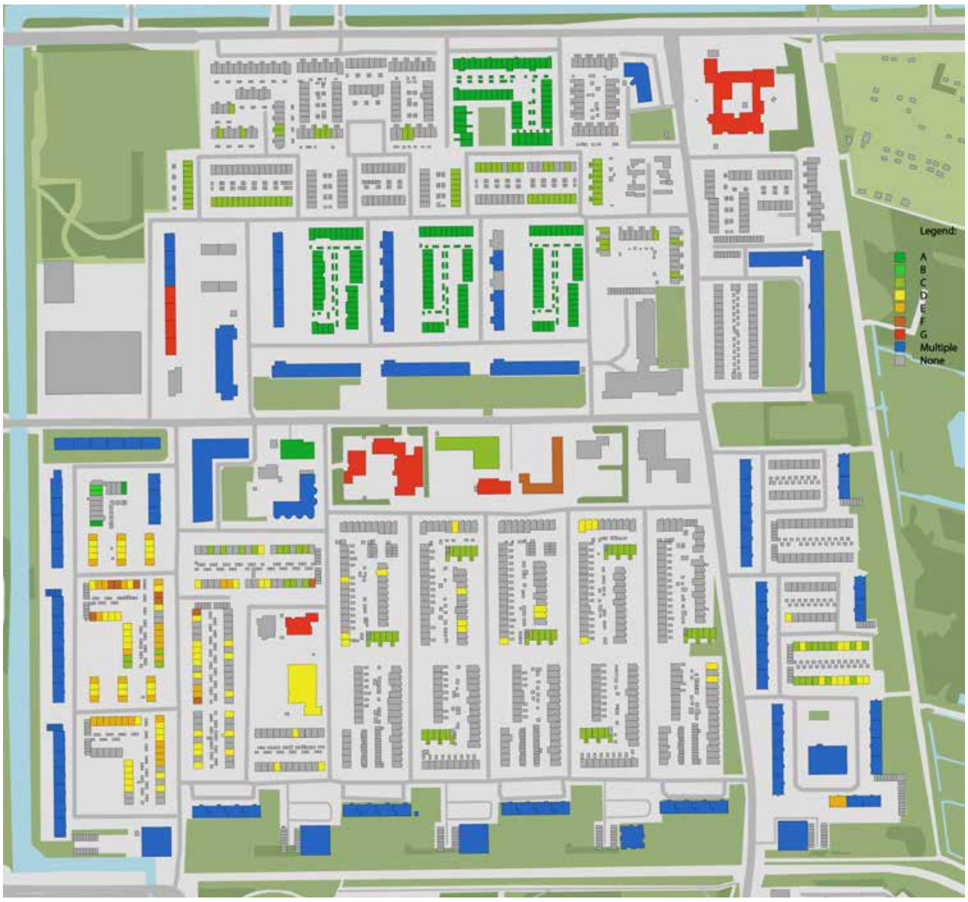

Figure 4: Map of energy labels in the Boerhaave neighbourhood, own image

A solution to this problem could be to store electrical energy in battery systems (Brinkel et al., 2022; van Westering & Hellendoorn, 2020). This will buffer the self-generated energy over a certain period in which we cannot generate energy achieving self-sufficiency. Added benefits of this are no dependency on other countries and weather conditions. However, battery systems are hard to implement because they are often made form scarce materials making them not available for everyone. Furthermore, batteries are expensive to install, again not speeding up the transition because it is hard to earn back the investment. There are alternatives made with natural salts but these batteries take up a large amount of space because their energy density is lower than Li-ion batteries, meaning they need more space to store the same amount of energy.

Thus, in order to speed up the energy transition and reduce the Dutch' energy dependency on other countries, we need to look at ways of buffering the generated renewable energy of a neighbourhood. This way the generated renewable energy will not burden the (electric) energy grid and will divide the energy evenly throughout the day, creating a steady supply of renewable energy. Hence making the neighbourhood more sustainable and less dependent.

I. Problem Statement

Considering the information stated above, figure 5 gives an overview of the problem analysis from a broad perspective to a more focused one. The biggest problem is global warming due to human GHG emissions. On a smaller scale we see that existing houses are accountable for 36% of the energy use. Another problem is the energy dependency of some EU member states. If we zoom in to the Dutch context we can conclude that the deep energy renovation of these houses lag behind due to several reasons. One of the reasons for this is grid congestion caused by the large implementation of south facing roof PV and electrical heat pumps. This shows that the Dutch infrastructure is not capable to fit the energy transition with the current energy concepts that are being implemented. This leads to the following problem statement: Due to the increasing amount of local energy production and electrification (use of heat pumps and EV charging) in the build environment energy demand and production are out of balance, creating grid congestion which might slow down the energy transition.

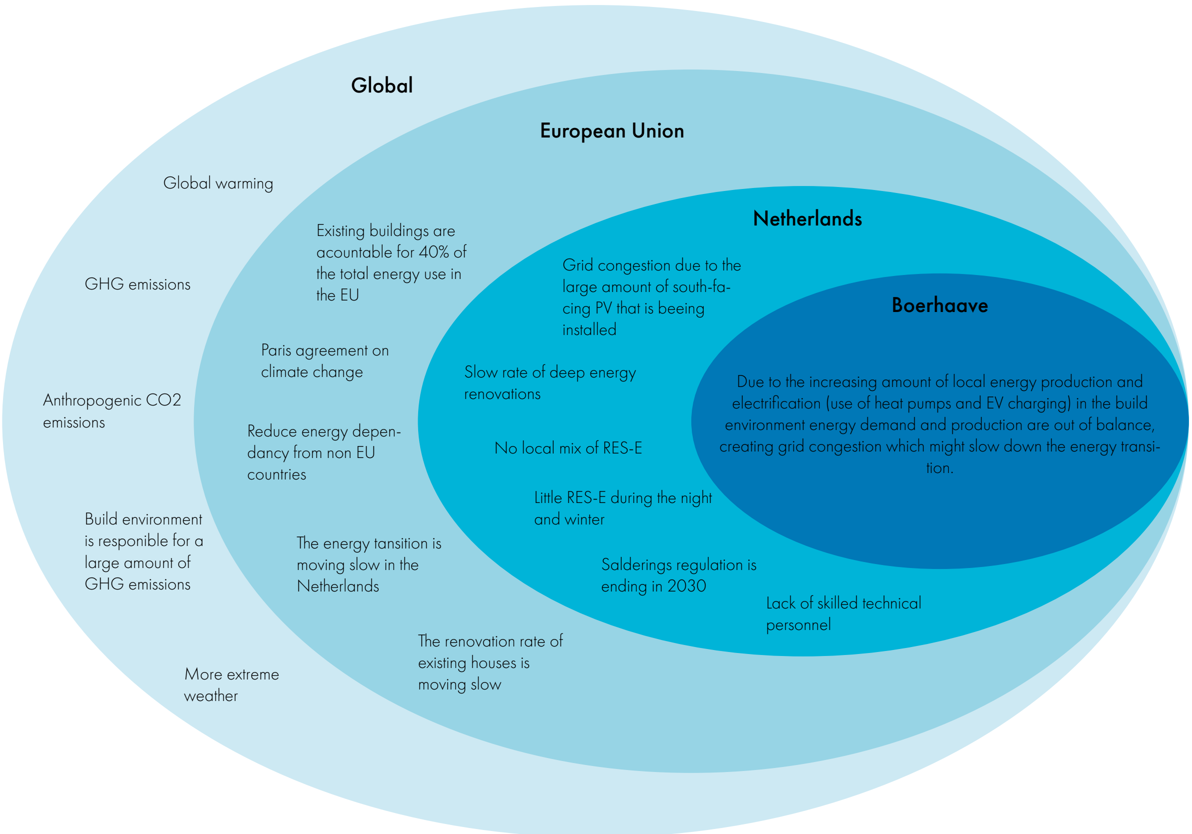

Figure 5: Problem Statement Diagram, own image

II. Objective

The aim of this research is to find ways to make existing homes more energy efficient without creating new problems that slow down the speed of deep energy renovations. By achieving this, we lower the GHG emissions, energy bills and enhance thermal comfort of existing houses. This goal is reached by deep renovation of an existing building with a minimum energy demand and an energy concept that generates the energy demand in a renewable way. The generated energy is stored or managed in such a way that demand and generation are in balance reducing the peak loads and need of energy storage. This could be achieved by optimizing the mix of RES on different scale levels (neighbourhood, building block or apartment) creating a better match between energy demand and generation as shown in figure 6.

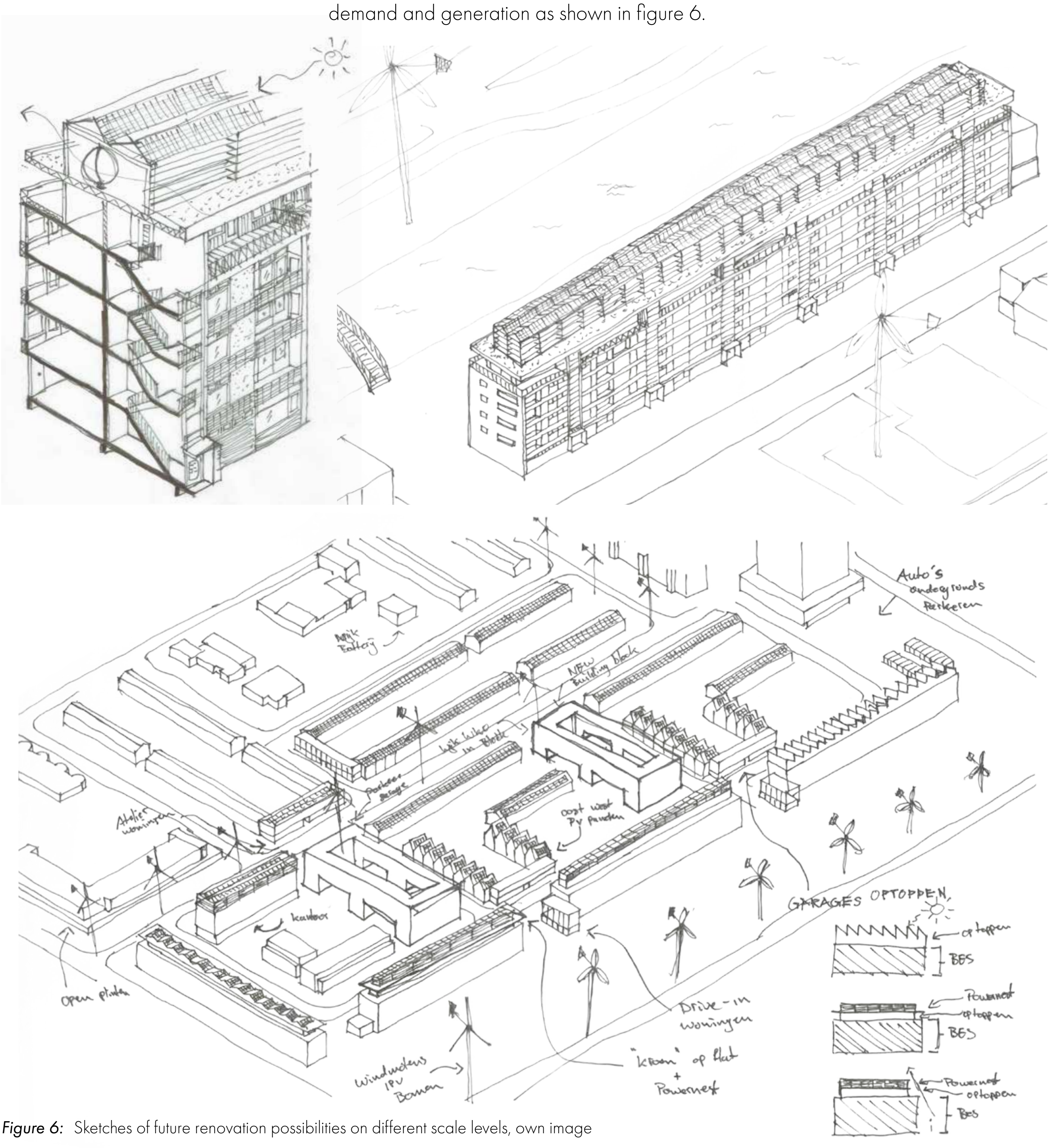

Figure 6: Sketches of future renovation possibilities on different scale levels, own image

III. Overall Design Question

In order to reach the stated objective for this graduation year a design question and research question are stated. This division between design and research is to provide focus points. The answer to the research question will inform the design later on in the process. The overall design question is:
How can existing post-war modernist building blocks be improved while updating the energy performance?

IV. Thematic Research Question

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 storage with the use of saltwater battery systems?

IV.i Sub Questions

How can we reduce the energy demand of existing building block?

- *What is the current energy demand and peak load of the building block?*
- *What passive ways are there to reduce the energy demand of an existing building block?*
- *What all electric energy concepts are there to eliminate the fossil energy demand of an existing building block?*
- *What is the energy demand graph of a renovated building block?*
    - *What does the daily graph look like?*
    - *What does the seasonal graph look like?*

How can we generate renewable energy while avoiding peak loads by changing the RES-E techniques?

- *How can we lower peak generation by changing the slope of PV panels (60° or façade PV)?*
- *How can we lower peak generation by changing the azimuth of PV panels (E-W orientation)?*
- *How can hybrid energy generation (wind+ solar) lower the peak generation?*
- *How can implementation of PVT panels reduce the peak load?*

What techniques are there to store energy on a building block scale?

- *How can thermal energy be stored?*
- *How can electric energy be stored?*

What combination of renewable energy generation and energy storage creates a self-sufficient building block?

- *What combination of energy generation techniques will provide a load match?*
- *How much salt water batteries are needed to create a self-sufficient building block?*

V. Hypothesis

We suspect that the building block's energy demand in winter and summer can be lowered by insulation, sun shading and a heat pump system. This heat pump system will increase the electrical energy demand so a steady amount of RES-E needs to be realized. This can be done by installing solar panels on different orientations and slopes generating energy on different times. Wind energy also needs to be installed generating energy in winter when solar generation is lower. Finally, a small battery system is installed to make sure there is always enough energy. All these techniques combined will give a different load profile with different implications. Below are some load graphs of different scenarios that show the connection between generation and demand curve (figure 7-9).

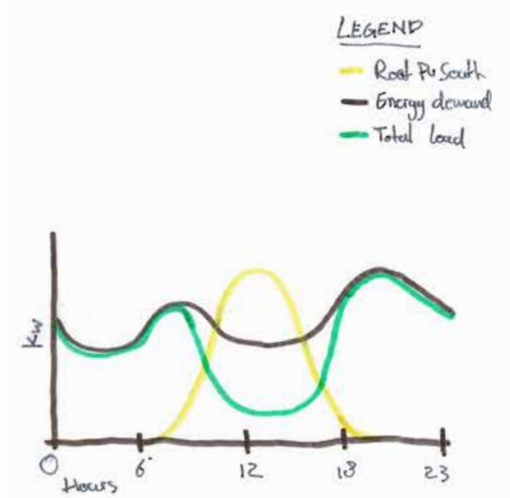

Figure 7: Current energy demand curve with south facing roof PV production, own image

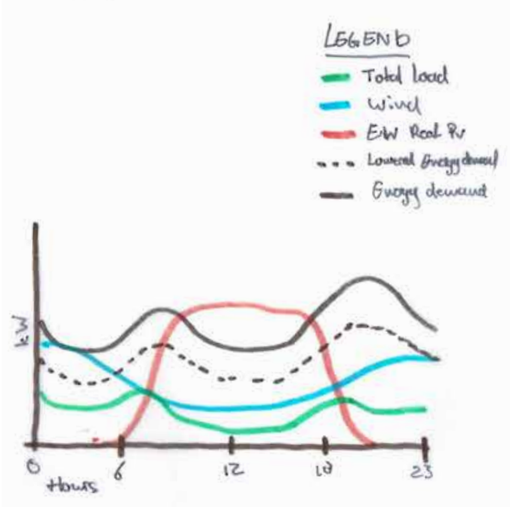

Figure 8: Possible future energy curve with E-W roof PV, wind energy and lowered demand, own image

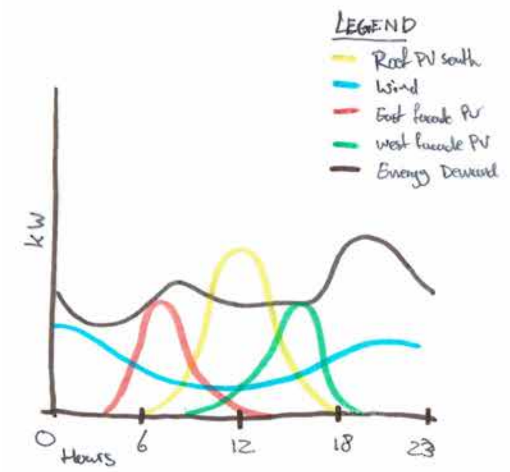

Figure 9: Possible future energy curve with E-W facade PV, south facing roof PV and wind energy, own image

VI. Research Methodologies

Research question: *How can an existing building block at Boerhaave be made energy self-sufficient with local renewable energy systems without increasing the peak load on the electricity grid and using a large amount of battery systems?*

Subquestion		Why is this relevant?	What data do I need?	How can this data be collected?	How will the data be analysed?	What will be the expected result?
How can we reduce the energy demand of an existing building block?	What is the current energy demand and peak load of the building block?	To know the load capacity of the grid and thus how much load can be increased before creating grid congestion	Info of the neighbourhoods energy use	Literature study/ simulation	Estimate/ calculation of energy demand	A graph of the daily and seasonal energy demand and max. grid load
	What passive ways are there to reduce the energy demand of an existing building block?	Researches ways to reduce energy demand that do not use energy to acheive this	Qualitative data on ways to reduce energy demand	Literature + simulation (ZED-tool)	Comparative overview	A list of techniques and amount of energy reduction
	What all electric energy concepts are there to eliminate the fossil energy demand of an existing building?	Get insight in installation systems that could be used to renovate the building block	Quantitative data on techniques to heat and cool a building block in a sustainable way	Literature study + simulation (ZED-tool)	Comparative overview	A list of energy systems (with their energy use) that do not depend on fossil fuels
	What is the daily and seasonal energy demand graph of a renovated building block?	Know the load demand of a building in order to see when generation is needed	Qualitative data about the energy demand of a building	Case study + simulation (ZED-tool)	Estimate/ calculation of energy demand	A graph of the daily and seasonal energy demand
How can we generate renewable energy while avoiding peak loads by changing the RES-E technoques?	How can we lower peak generation by changing the slope of PV panels (60° or facade PV)?	Get insight in ways to reduce the production peaks of RES-E techniques	Load profiles of different RES-E techniques	Simulation (ZED-tool)	Comparative overview	A selection of different RES-Es load profiles that match the demand
	How can we lower peak generation by changing the azimuth of PV panels (E-W orientation)?	Get insight in ways to reduce the production peaks of RES-E techniques	Load profiles of different RES-E techniques	Simulation (ZED-tool)	Comparative overview	A selection of different RES-Es load profiles that match the demand
	How can hybrid energy generation (wind+solar) lower the peak generation?	Get insight in ways to reduce the production peaks of RES-E techniques	Load profiles of different RES-E techniques	Simulation (ZED-tool)	Comparative overview	A selection of different RES-Es load profiles that match the demand
	How can implementation of PVT panels reduce the peak loads?	Get insight in ways to reduce the production peaks of RES-E techniques	Load profiles of different RES-E techniques	Simulation (ZED-tool)	Comparative overview	A selection of different RES-Es load profiles that match the demand
What techniques are there to store energy on a building block scale?	How can thermal energy be stored?	Creates grip on the ways to store energy	Quantitative data on ways to store energy	Literature study	Comparative overview	A list of techniques with specifications
	How can electrical energy be stored?	Creates grip on the ways to store energy	Quantitative data on ways to store energy	Literature study	Comparative overview	A list of techniques with specifications
What combination of renewable energy generation and energy storage creates a self sufficient building block?	What combination of energy generation techniques will provide a load match?	Gives insight in what combination of RES can accomodate the energy demand throughout the year	Quantitative and qualitative data on ways to generate energy thourgout the year	Simulation (ZED-tool)	Comparison simulations of different renovation scenarios	Different energy concepts with corresponding load graph
	How much salt water batteries are needed to create a self-sufficient building block?	Get insight in ways to reduce the production peaks with energy storage	Load profiles of different RES-E techniques	Simulation (ZED-tool)	Comparison simulations of different renovation scenarios	A selection of different energy concepts that match the demand 100%

VII. Demarcation

This research focuses on electrical energy storage through peak shaving and load matching fitting the typical 60s apartment blocks of the Boerhaave neighbourhood in Haarlem. There are multiple ways to store energy, such as like producing hydrogen with the redundant power. This research will not focus on energy storage that converts electrical energy into another energy form as part of the energy is lost during this conversion process. However, this research will look at heat generation through electrical appliances like a heat pump, but only at building based sources not in a large heat network of some sort. Furthermore, to prevent the fuellingfueling of future problems this research will not consider batteries made with scarce materials like Li-ion batteries, but only salt-water batteries made out of non-scarce materials. Because the energy density of these batteries isare lower, the goal is to reduce the need for energy storage in order to save space.

VIII. Relevance

The relevance of this study is mostly practical as this study tries to solve the problem of grid congestion caused by the one-sided implementation of RES-Es that do not match the demand of a building. Moreover, the outcome of this research will provide an energy concept that improves the energy performance of existing post-war buildings lowering the GHG emissions.

This study contributes to the existing knowledge by combining the knowledge of different studies into practice. Most studies only look at one RES-E but this study tries to combine multiple RES-Es to see what the effect is on the peak-load of a building.

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X. Planning

	MSc. 3																		
Week	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4
	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1	2.2	2.3	2.4	2.5	2.6	-	-	2.7	2.8	2.9
Month			Oktober				November				December					Januari			
Dates	19/9/22 - 25/10/22	26/9/22 - 2/10/22	3/10/22 - 9/10/22	10/10/22- 16/10/22	17/10/22- 23/10/22	24/10/22- 30/10/22	31/10/22 - 6/11/22	7/11/22 - 13/11/22	14/11/22- 20/11/22	21/11/22- 27/11/22	28/11/22- 4/12/22	5/12/22- 11/12/22	12/12/22- 18/21/22	19/12/22- 25/12/22	26/12/22- 1/1/23	1/1/23- 8/1/23	9/1/23- 15/1/23	16/1/23- 22/1/23	23/1/23- 29/1/23
Deadlines								P1	No edu.						No edu.	No edu.			P2
Research plan	Facination development		Research Plan Development																
							Prepare P1 Presentation												
Research paper					Literature study				SQ 1										
											SQ2								
												SQ3							
													SQ4: Scenario simulations						
														Conclusions					
														Finish Draft paper			Finalize Research paper	Prepare P2 Presentation	
Context analys	Problem, location, objective				Site Visit					Site Visit									
		Site analysis			Collecting Info&Data					Case study analysis									
Design project												Concept development							

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Figure 10: Perspective sketch of a future renovation possibility, own image

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

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Research Plan
November, 2022