ENERGY FLAT BUIKSLOTERHAM

On how to design energy flat multifunctional urban blocks

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DELFT UNIVERSITY OF TECHNOLOGY

TUDelft

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MSc thesis Building technology track of the master of science in Architecture, Urbanism and Building sciences

Delft University of Technology

Date: July 4th, 2019

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Acknowledgements

In front of you lies the thesis written by Kjell-Erik Prins in order to complete the master track Building technology of the master of science in Architecture, Urbanism and Building sciences at the Delft University of Technology. This thesis covers the research and design process of an energy flat urban block. The main objective of this research is to provide the reader with a guideline on how to design an energy flat multifunctional urban block, including governance components.

I would like to take this opportunity to thank some people that supported me during my thesis. First of all, I would like to thank my mentors, Sabine and Thomas, for all their time, feedback, knowledge and suggestions. Your mentoring helped me to look critical at my own work and to stay focused on the end goal. A special thanks goes to the KoWaNet project partners whom I had the opportunity with to validate/discuss my research findings.

I also want to thank my family, friends and fellow students who were always interested in my research and supported me with suggestions, information and foremost the positive energy to enjoy the last few months.

I hope you enjoy reading this thesis.

Kjell-Erik Prins
Woudrichem, June 2019

Content

Abstract

Due to the increasing amount of intermittent supply (renewable resources) the energetic mismatch between supply and demand increases. Current possibilities to balance this mismatch mainly focus on single functional (residential) buildings and/or adding extra services. On first sight, multi functionality can play an important role in balancing the mismatch on an urban block level. However, too little is known on how these different functions can collaborate on energetic level and what this implies for governance to create an energy flat urban block in which energy supply and demand are equal on an hourly basis. Therefore, this research focusses on providing guidelines on how energy flat multifunctional urban blocks can be designed, including governance components.

First of all, architectural design can play a significant role in reducing the mismatch over time. With architectural design the space heating demand can be reduced and the cooling demand can be increased. Additionally, for well-insulated buildings the energy system that is most suited largely depends on the functional program of the area. When the area has a lot of functional area with a high heat-cold ratio, i.e. more cooling demand than heating demand, energy exchange can increase its autonomy. With the introduction of continuous cooling even more energy can be exchanged between functions and the energy system is less dependent on other technologies to supply heat other than subtracting heat from the building itself and use it as heat source.

For energy flat multifunctional urban blocks optimization of the overall energy system through stakeholder collaboration and integral technological approach is a key component. Hence, these energy systems are becoming quite complex. In order for the concept of energy flatness to be taken up the supply, payment regulations and distribution of energy within an urban block should be financed, maintained and operated by a third party, an Energy service contracting company (ESCO).

1. Research framework

1.1 Background

In 2016 the Dutch built environment used 37% of all energy used in the country, of which the majority, around 50%, of the energy is used for heating appliances (Ministerie van Economische zaken en Klimaat, 2016 and Van Bueren, Van Bohemen, Itard, & Visscher, 2011). According to Gales et al. (2007) energy usage, economic growth and human welfare are linked to each other, whereas economic growth goes parallel with proportionate increase of energy usage. Thus, with a yearly increase of the Dutch population and wealth, the energy demand will proportionately increase in the future as well.

The current energy system of the Netherlands is largely dependent on fossil fuels. In 2017, this amount was 92% of all energy production (CBS, 2018). Due to the environmental impact, possibilities for cost savings and security of supply there is an urgent call for reducing the amount of fossil fuel dependency of our energy systems worldwide. These are as well some of the main reasons to place the transition towards the use of renewable resources high on political and scientific agendas all over the world including the Netherlands (Van Bueren et al., 2011).

In 2017, only 6.6% of the Dutch energy production was from renewable resources, whereas this should increase to 14% in 2020 and 16% in 2023 according to the Paris energy agreement (CBS, 2018 & ECN, 2016). Due to the geolocation of the Netherlands, the majority of these resources are from wind and solar.

However, production of energy from renewable resources strongly depends on its climatic context. For these renewable resources this results in intermittency in nature, they do not provide us with a constant supply of energy. In addition to that, the energy demand also depends on several fluctuating factors like user adaptation and climatic context. As can be seen in Figure 1 having both intermittent supply and demand resources results in an increasing mismatch between demand and supply (Höfte, 2018). For a well working energy system the supply and demand should be in balance (Kothari & Nagrath, 2009).

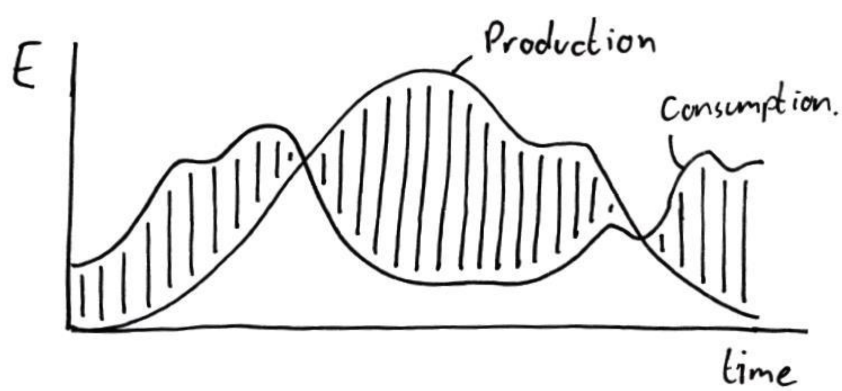


Figure 1: Demand and supply mismatch, source: V. Höfte (2018)

This phenomena to balance demand and supply is not a new concept. According to Knight (2016), historically, with a fossil fuel based system, the supply that is needed is matched with the demand that is estimated. In this way, energy generation could be scheduled a day ahead, fine-tuned during the day and the supply and demand were almost even. With the intermittencies in nature of the renewable energies this approach cannot be used anymore. Thus, since the increase of local/regional renewable energy usage as supply a lot of research is conducted on using energy storage, smart grids/appliances, flexible generation and adapting user behavior to reduce the mismatch (Stadler, 2009 and Stluka, Godole & Samad, 2011, Lund et al. 2015, Gelazanskas & Gamage 2014). In addition to that research, in 2018, Vincent Höfte wrote his master thesis about energy flat housing, in which he flattened out peaks in demand and supply through architectural design of one residential household. In *chapter 3; Approach* the literature on ways to balance the mismatch will be elaborated on. However, the majority of the research mentioned above has a limited scope of one single function (residential or commercial) at a time and do not combine several ways of balancing the mismatch.

1.2 Scope/Boundary conditions

This thesis focuses on the design of a sustainable energy system for a newly build/to be build building block in the Netherlands, precisely Buiksloterham in Amsterdam, the Netherlands. This area is picked because it is part of the KoWaNet research project to be conducted by the department climate design of the Faculty of Architecture and Built Environment of the TU Delft. In addition to that, this particular area is a multifunctional area ranging from residential to cafés. This location is in state of development, which causes the fact that there are preliminary designs for all the buildings and the whole neighborhood.

During the design of a sustainable energy system various different aspects can be elaborated on extensively. Therefore, it is important to define a clear scope and limitations for this thesis. The most important aspect for this research is the multi functionality of the area. This multi functionality has two main implementations on the focus points of this research first [1] on balancing the mismatch and second [2] on the possibility to add governance to the research.

[1] Previous research is all conducted for one single function and therefore multi functionality can address a different way of balancing the mismatch, direct heat exchange. Although direct heat exchange will be used, first the architectural design parameters found by Vincent Höfte (2018) will be used to reduce the demand of the buildings. However, due to the fact that the location is in state of development, preliminary designs will be used as guidance for the architectural design and no major impactful interventions like changing the building shape will be done in this research, however interventions like window type, insulation and function distribution/adding will be done.

[2] Multi functionality cannot only be useful for the balancing of the energetic mismatch in one building and/or urban block. By implementing existing solar and wind energy possibilities (Multifunctional roof edge systems) as main supply source and energy storage as extra way to balance the mismatch if needed, it indicates the need for a lot of collaboration between different

functions. Therefore, this research not only exists of energetic collaboration between functions but also in an institutional energy flow diagram way. Different institutional energy flow diagrams will be analyzed and implementations for all stakeholders are explained.

1.3 Problem statement

Following from the background and the scope of this thesis the problem statement is as follows:

Due to the increasing amount of intermittent supply (renewable resources) the energetic mismatch between supply and demand increases. Current possibilities to balance this mismatch mainly focus on single functional (residential) buildings and/or adding extra services. On first sight, multi functionality can play an important role in balancing the mismatch on a urban block level. However, too little is known on how these different functions can collaborate on energetic level and what this implies for governance to create an energy flat urban block

1.4 Research questions

The main research question in this thesis is:

How can you design an energy flat multifunctional urban block in the Netherlands and what does this imply for governance [Case study Buiksloterham, Amsterdam]?

To be able to answer the above stated research question the following sub questions have to be answered in the next chapters:

- What parameters influence energy profiles of demand and supply and how can these be adapted?
- To what extent can different functions exchange energy?
- In what way does [thermal] energy storage influence energy flatness?
- How can the energy flatness of a multifunctional urban block be evaluated?
- What stakeholders play a role in the energy system of an urban block and how do they play a role?
- What are barriers and opportunities [laws & regulations, subsidies and socio-economic] for governance aspects in the current (governmental/society) system?
- Under what governance conditions could the energy flat concept work?

1.5 Objectives

The main objective of this research is to provide a guideline on how to design an energy flat multifunctional urban block, including governance components.

To be able to provide the reader with this guideline several final products/sub objectives need to be made:

- An overview of existing parameters that influence energy profiles of different functions.
- An overview of energetic and governance collaboration possibilities between different functions.
- An [excel] tool that can evaluate/design the energy flatness of a multifunctional urban block and can help analyzing the current energetic mismatch between functions.
- An overview of different stakeholders that play a role in energy systems in an urban block.
- An overview of different barriers and opportunities [Laws & regulations, subsidies and socio-economic] that governance is facing in the current society.
- A design of a case study example of a working energy flat energy system that also takes governance implications into account.

1.6 Hypothesis

It is expected that multi functionality is a strong asset in creating an energy flat urban block. However, it largely depends on how diverse the different functions are in both user schedules as well as average energy consumption. For example, a residential building and a hotel building are not expected to help each other that significantly to become energy flat, this is mainly due to the fact that the user schedules are kind of similar to each other as well as the average energy consumption of both functions. However, areas with functions that have completely different schedules and average energy consumption, for example, a swimming pool or supermarket and an office building can significantly collaborate through the possibility of direct energy exchange. Although a wide diversity of functions can be really beneficial for the energetic balance in a neighborhood, it will also make the feasibility or a working governance model for the energy system more complex. With more diverse functions, more stakeholders with their own agenda come into play.

1.7 Methodology

The two main types of research that are used in this thesis are literature study and research by design. The first type of research is mainly to extract different ways of balancing the mismatch according to existing literature and to get a good understanding how the different functions can collaborate with each other on an energetic level. Another literature study will be conducted focusing on the governance of multifunctional energy systems. An overview of the different stakeholders will be analyzed using literature and possible business model concepts are researched as well. In the meantime the research by design also started. Research by design is an iterative process which is based on trial and error, analyzing/evaluating and adjusting. During this part a sustainable energy system is designed for the case study of Buiksloterham, Amsterdam using the Smart Urban Isle method. First the area is analyzed according to its current usage and the potentials for the area are evaluated. In combination with the energetic mismatch balance parameters found in literature these potentials are placed into an excel tool (combination and modification of two already existing tools) which can be used to evaluate the energetic mismatch between the different functions and in general. Additionally, a conceptual energy business model is researched in literature and modified that it suits the particular context of the case study. At the end, the energy flatness of the overall design will be validated using the energy flatness key performance indicators (which are also used during the design) and the design will be evaluated on feasibility. Through the research by design phase the overview of parameters, collaboration possibilities, overview of stakeholders and energy governance models can be tested in a real case study and the excel tool can be modified to its desired use. In the end this whole research will translate into an overview or a guideline on how to design an energy flat multifunctional urban block and how you can evaluate its energy flatness per year, per month, per week and even per day.

METHODOLOGY

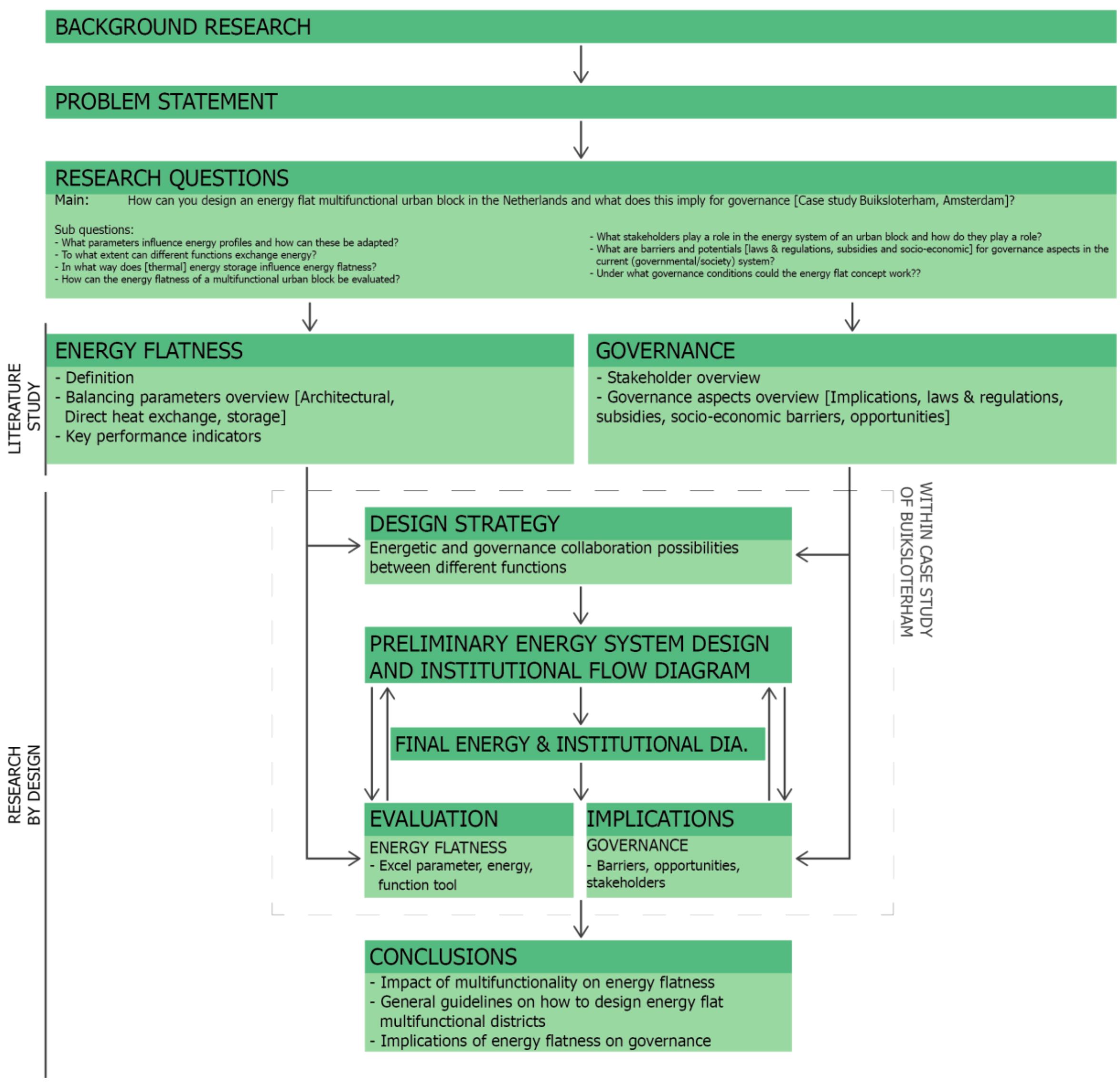


Figure 2: Methodology used for this research

1.8 Planning and organization

Figure 3 shows an overview of the planning for this thesis.

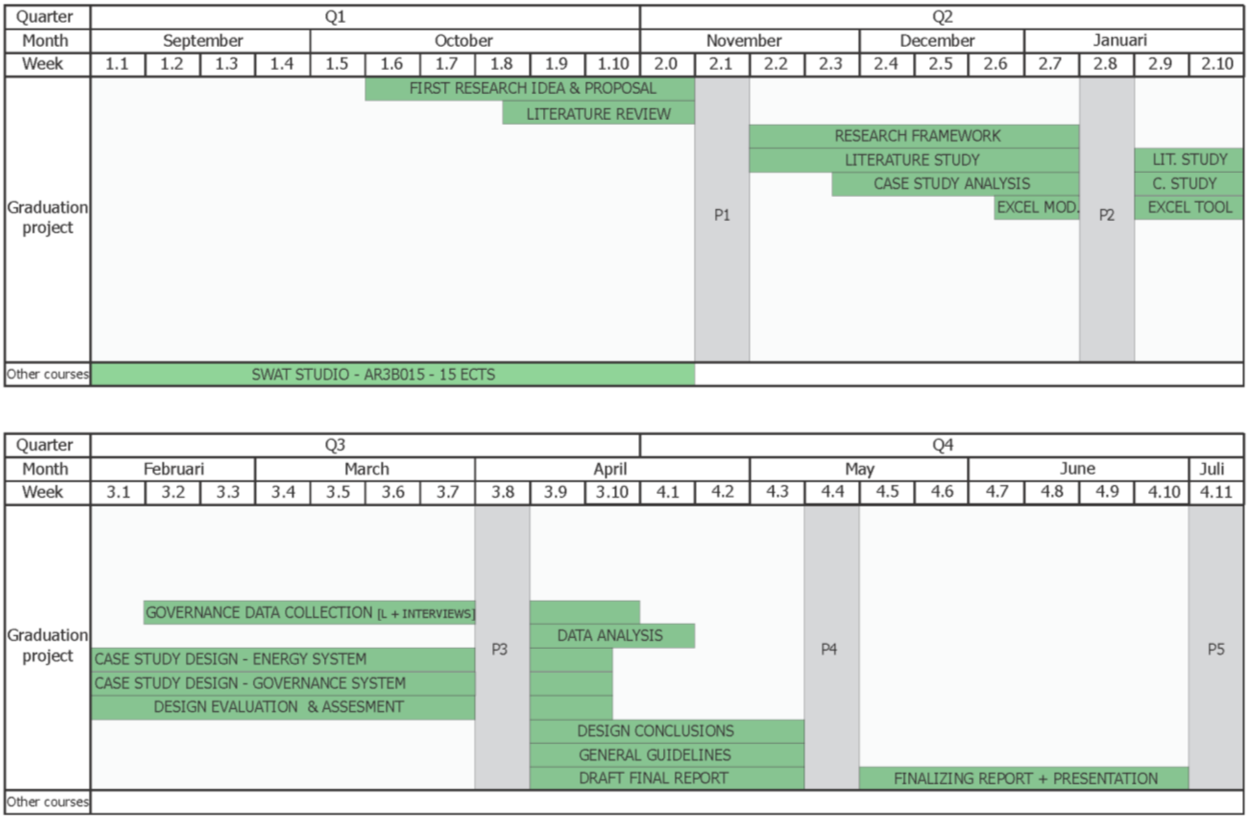


Figure 3: Overview of the planning for this thesis.

1.9 Relevance

Societal relevance:

In the last years people tend to prefer to move away from the fossil fuel based energy system, it is harmful for the environment, in some cases our energy supply depends on foreign countries so the security of supply is low in case of conflicts and people want to become independent. An energy flat urban block means that the neighborhood depends on a decentralized local renewable energy supply. Thus, with the collaboration between local supply, reducing demand and energy exchange between functions it causes a cost effective alternative to the fossil fuel based system. Additionally, the increase of supply by intermittent in nature renewable resources results in peak loads in the national energy system that cannot be used immediately. With energy flat urban blocks these peaks are dealt with on a local scale, which results in (almost) no peak loads in the current national energy system that could cause failure of the current system.

Scientific relevance:

The case study area of the particular location in Buiksloterham, Amsterdam is part of the KoWaNet research project of the TU Delft. For that project a sustainable energy system is going to be designed for the neighborhood. However, this thesis is going one step further than that research project. In this case an energy flat urban block is going to be designed, so for the whole energy system everything will be dealt with locally and the mismatch between supply and demand will be balanced out per year, month and day. At the end of the project it could be possible to compare two kind of similar areas for which the TU Delft has designed a sustainable energy system on both the theoretical energy used in the area and what design has a better institutional flow diagram. Additionally to that, the excel tool that will be made during this research can be used by other researchers or students to evaluate the energy flatness of their design.

2. Literature review

In chapter one; research framework the term energy flatness is first touched upon. In 2018 Vincent Höfte came up with this term in his master thesis Energy flat housing - towards continuous balance in the residential energy system. To be able to understand the term energy flatness in the case of this research, first, the difference between primary energy, final energy and demand is explained. Secondly, the basis of energy demand calculations is talked about. Then, several energy systems and the underlying institutional energy flow diagrams are described. Next, the scope of energy flatness is introduced. Followed by the key performance indicators that are used to evaluate the overall energy flatness of a design. Lastly, the method that is used for the case study design, i.e. the Smart Urban Isle method, is explained.

2.1 Primary energy, final energy and energy demand

Figure 4 shows the three general characteristics of the energy supply chain, energy demand, final energy and primary energy. Energy calculations start from the building perspective and therefore, the chain starts with the energy demand. Energy demand represents all heating, cooling and electrical energy needs that are used to keep the indoor climate at a pleasant level for the users of a building. These demands are produced by the building energy system, which uses final energy as an input. The final energy is the energy that is consumed by the end-user to fulfill all energy demand including the energy losses of the building services and distribution throughout the building. The final energy is also known as the energy that end-users buy at the meter in the form of an energy carrier like heating, cooling or electricity. Final energy is made through the conversion of primary energy. Primary energy is the energy that is not yet been subjected to conversion or transformation processes which can either be carried out on a local, regional or national level with for example coal power plants or photovoltaic panels (Jansen, Mohammadi & Bokel, 2019).

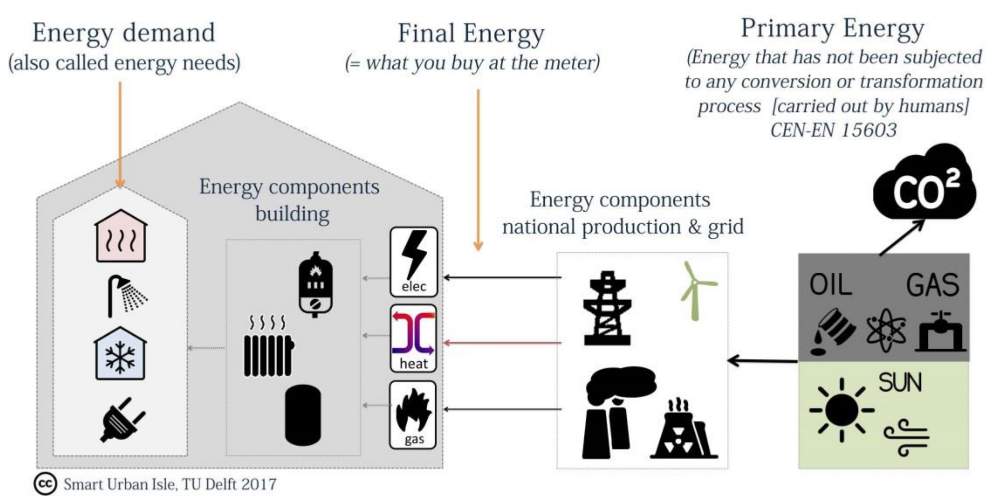


Figure 4; Primary energy, final energy and energy demand in the energy supply chain, source: Jansen Mohammadi & Bokel (2019)

2.2 Energy balance

The energy balance, also known as heat balance, forms the basis for all energy performance calculations. Using the energy balance the total energy demand of a building/zone can be calculated through steady state calculations of one hour at a time. The energy balance provides an overview of all incoming and outgoing energy flows within a building/zone, resulting in the heating or cooling demand to keep the indoor climate at a certain temperature. The following energy flows can be determined in one zone/building: transmission, infiltration, ventilation, solar gains, internal heat gains and energy demand (see Figure 5). Table 1 provides the exact definitions and equations needed to calculate the energy flow (Jansen & van den Ham, 2016).

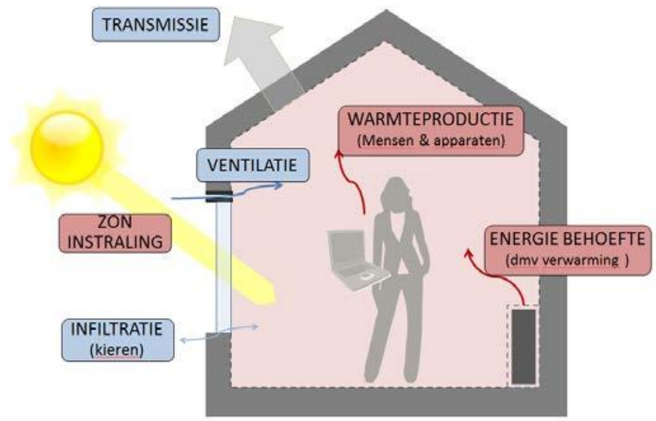


Figure 5: Visualization of incoming and outgoing energy flows in a zone, source: Jansen & van den Ham (2016)

Energy flow	*Abbreviation*	*Description*	*Equation*
Transmission	Q_{trans}	Heat transfer through façade	$Q_{trans} = U * A * (T_e - T_i)$ [W]
Infiltration	Q_{inf}	Heat transfer through gaps in façade	$Q_{inf} = V_{inf} * \rho * c_p * (T_e - T_i)$ [W]
Ventilation	Q_{vent}	Heat transfer through ventilation	$Q_{vent} = V_{vent} * \rho * c_p * (T_e - T_i)$ [W]
Solar gains	Q_{solar}	Passive heat gains through solar radiation	$Q_{sol} = A_{glass} * q_{sun} * g$
Internal heat gains	Q_{int}	Passive heat gains by people, appliances and lights	$Q_{int} = Q_{people} + Q_{appliances} + Q_{light}$

Table 1: Overview of energy flows with corresponding equation to calculate them, source: Jansen & van den Ham (0016) (edited by author)

In these formulas:

U	Thermal transmittance of a dividing surface	[W/m^{2}k]
A	Surface area of a dividing surface	[m^2]
T_e	Outdoor temperature	[^{o}C]
T_i	Indoor temperature	[^{o}C]
V_{inf}	Volume of infiltration flow	[m^3/s]
V_{vent}	Volume of ventilation flow	[m^3/s]
ρ	Density of air ≈ 1.2	[kg/m^3]
c_p	Specific heat capacity air ≈ 1000	[J/kg.K]
g	Solar energy transmittance of glass surface	[-]

The energy balance is a steady state situation and therefore, the result of the combination of all heat flows is 0, which leads to the following energy balance:

$Q_{trans} + Q_{inf} + Q_{vent} + Q_{solar} + Q_{int} – Q_{demand} = 0$

Thus, the energy demand can be determined as follows:

$Q_{demand} = Q_{trans} + Q_{inf} + Q_{vent} + Q_{solar} + Q_{int}$

2.3 Energy systems

In the last few decades the resource we use as primary energy for our energy systems to be able to fulfill all energy demands is shifting from a fuel based system to a highly/total renewable resource energy system. This section has the aim to provide an overview of the ups and downs of both systems.

Conventional energy system:

The current national energy system is a conventional energy system. The conventional energy system (Figure 6) is based on the use of fossil fuels as main resource and has a small penetration of renewable resources. This system uses nonrenewable resources like oil and gas as primary energy, which goes to factories that turn the primary energy into electricity that can then be transported via our national electricity net towards the building site. Due to all of these different steps from primary energy towards usable energy there are a lot of energy transformation losses within this system. However, one of the main benefits of this system is that over the years it became relatively easy to predict the energy demand and match the supply in the factories with this demand and thus, be able to reduce the mismatch between supply and demand to almost zero.

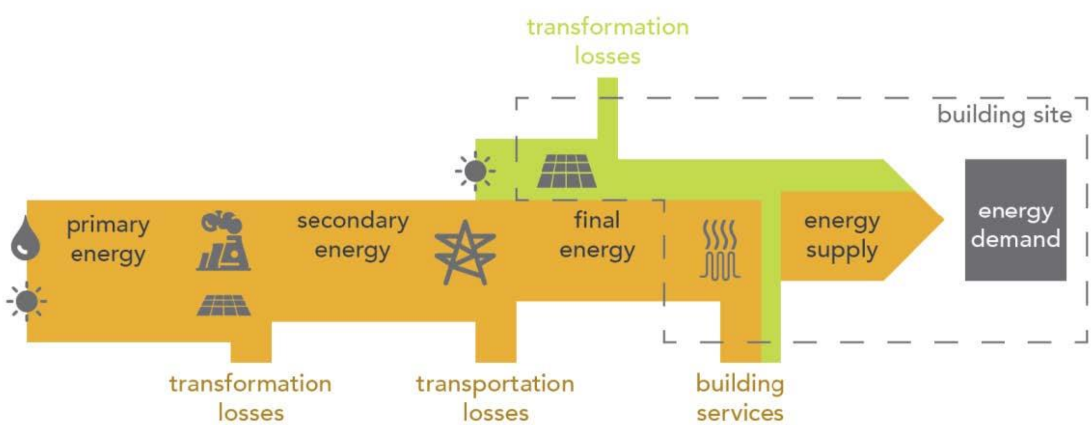


Figure 6: Conventional energy system, source: Höfte (2018)

Institutional energy flow diagram conventional energy system:

According to Koirala et al. (2016) the underlying principle for a conventional energy system is centralization. This means that several big parties are responsible for a constant production of energy on a national/regional scale. While another big party arranges the distribution of energy over the national and regional grids. The end-user can buy energy carriers from licensed energy suppliers or intermediary companies. The whole system is regulated and the companies involved in this energy system have a monopoly status (Koirala et al., 2016 & Sorgdrager, 1996). The overall flow diagram can be seen in Figure 7.

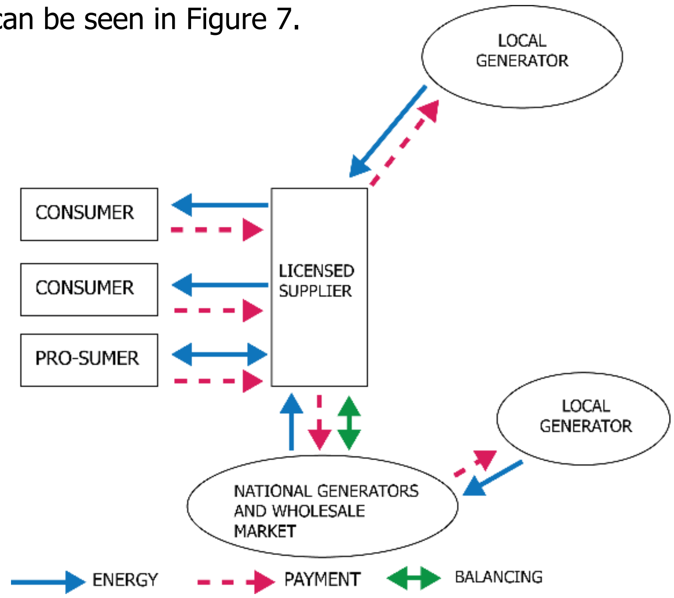


Figure 7: Institutional energy flow diagram conventional energy system (by author)

Sustainable energy system:

All over the world in local, small scale projects the conventional energy system is substituted for a renewable supply based system (Figure 8). In this system the primary energy does not consist of fossil fuel based resources anymore, it is solely dependent on renewable resources like the sun and wind. Within this system the primary energy can most of the time be transformed into electricity by one single step (for example photovoltaics). By reducing the amount of steps for primary energy to turn into usable energy the transformation losses are minimized as well. However, contrary to the conventional this system relies on resources that are intermittent in nature. Therefore, balancing the supply and demand to reduce the mismatch becomes more complex than turning on/off a factory.

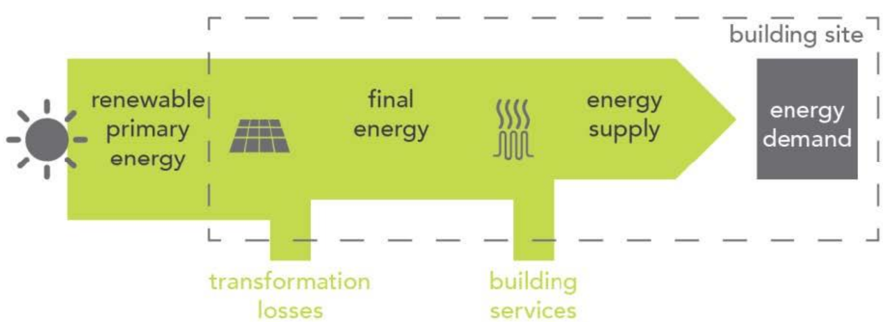


Figure 8: Renewable supply based system, source: Höfte (2018)

Institutional energy flow diagram sustainable energy system:

In contrast to the conventional energy system the sustainable energy system does not use fossil fuels as primary energy anymore, it uses renewable primary energy like wind and solar. Hence, the ability to supply the energy demand with local resources increases, while the subjection to the monopolistic energy companies could be lower. As can be seen in Figure 9 there are two ways the institutional energy flows can be arranged. The left Figure shows that there can still be an underlying centralized principle. Throughout the world this centralization of all local production and supply is often arranged by third parties, also known as ESCOs (energy service companies) (Koirala et al., 2016 and Vine, 2005). However, as of writing these companies are not yet common in the Netherlands. Another possibility would be the introduction of decentralized supply and consumer hubs (Figure 9; right). Within this concept all end-users act as both producer as well as consumer. The precise configuration and underlying potentials and barriers about these institutional energy flow diagrams can be found in chapter 5.

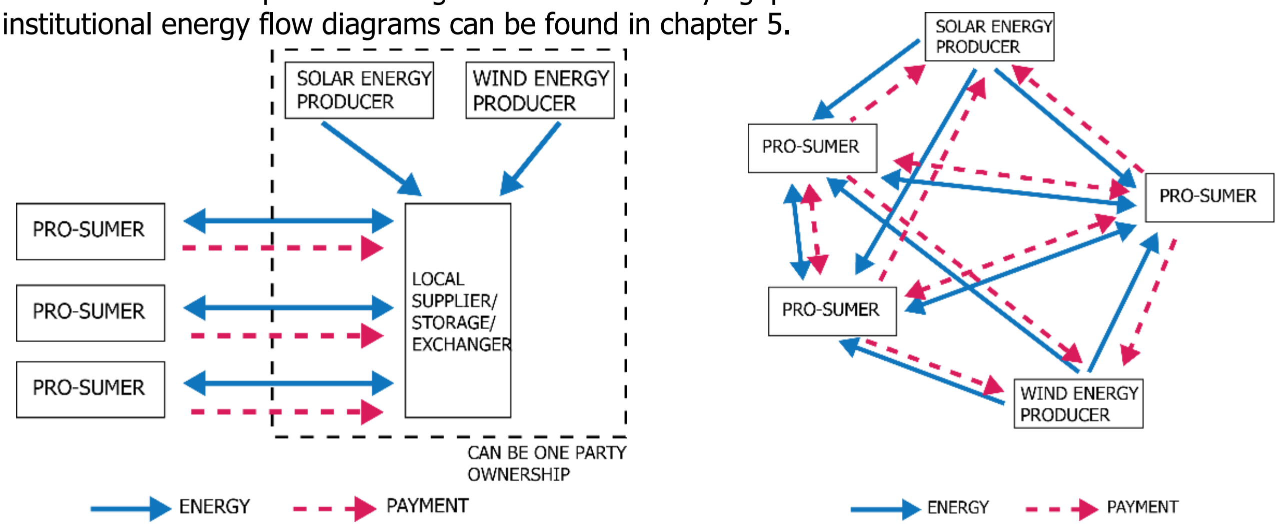


Figure 9: Institutional energy flow diagram sustainable energy system; centralization (left) + decentral supply and consumer hubs (right) (by author)

2.4 Scope of energy flatness

The in paragraph 2.1 renewable supply based system forms the basis for both zero energy urban blocks and energy flat urban blocks. Of these two zero energy urban blocks are the best known to the general public. According to Marszal and Heiselberg (2009) there is no clear, general definition for zero energy buildings/urban blocks. However, the main objective of zero energy urban blocks is the fact that the needed energy for a whole year is reduced through gains in efficiency in such a way that the majority of the energy needed can be supplied from renewable resources. In his master thesis Höfte (2018) came up with the term energy flatness. Although there are a lot of similarities between zero energy urban blocks and energy flat urban blocks, they are not completely the same, which will be explained in this paragraph.

Because of these similarities we are able to use some parts of the framework set up by Sartori, Napolitano and Voss in 2012 to define the scope for energy flatness in the case of this research. This is mainly due to the fact that this makes us able to define clear key performance indicators for evaluation of the energy flatness and to direct us towards ways of reducing the energetic mismatch. For this research the following criteria are discussed upon: balance boundary and balancing period.

Balance boundary:

In an energy system as described in paragraph 2.1 there are multiple energy flows that go through a system. As can be seen in Figure 10 the different energy flows that can be balanced are the electricity and heat balance. According to Höfte (2018) the most straightforward energy flow to balance is the heat balance, within this energy flow the only aspect that has to be considered is matching supply and demand. Contrary to that, when you want to create electricity flatness as well, other aspects like building services efficiency has to be taken into account as well. This research focusses on how multi functionality can be used to become an energy flat urban block and thus, the overall building energy system has to be designed, which includes building service efficiencies and distribution losses, therefore the main focus of this research is reducing the mismatch within the electrical energy balance.

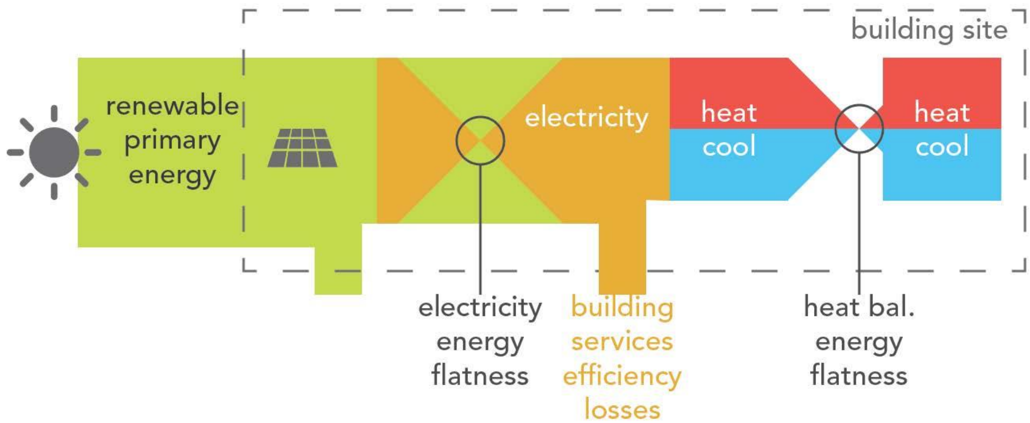


Figure 10: Different energy flows that can be balanced, source: Höfte (2018)

Balancing period:

The biggest difference between zero energy urban blocks, energy neutral urban blocks and energy flat urban blocks is the balancing period. For an energy flat urban block the difference between supply and demand is zero at any time of the year (Höfte, 2018). For the evaluation of energy flatness throughout the year however, different intervals should be taken into account. This is mainly due to the climatic context this research is placed into. The case study area is in Amsterdam, the Netherlands. Therefore, three intervals should at least be taken into account, yearly, monthly and weekly/daily. A yearly energy flat urban blocks is also called energy neutral. The Netherlands has four different seasons in a year, every season has its own properties considering solar and wind potentials and temperature differences. Therefore, with the interval of monthly energy flatness seasonal differences can be looked into. Lastly, with an interval of weekly/daily the difference between day and night can be looked into.

APPROACH

Approach

3 Approach

3.1 Smart Urban Isle method [SUI]

The previous sections explained the energy supply chain, introduced a method to calculate the energy demand for a building, talked about different energy systems, described how this translated into the scope of energy flatness and how the energetic performance of a certain urban block/building can be evaluated. To find out the role multi functionality has on energy flatness and to what extend an urban block can be made energy flat, in this research a case study design is carried out. As basis for this design the smart urban isle method, also known as SUI, is used. This approach has the aim to develop innovative energy concepts focused on a local scale in order to create a 'smart urban isle'. According to Jansen, Mohammadi & Bokel (2019) a smart urban isle can be defined as "an area around a (public) building that locally balances the energy as much as possible, resulting in minimized import and export of energy from outside this area". Although the SUI approach consists of general guidelines for each case study, the outcome is rather case study specific. There are five general guidelines within the SUI approach: Case study description, energy status quo, energy concept potentials, concept development and evaluation & selection (Table 2, from Jansen, Mohammadi & Bokel, 2019).

Steps	**Goal**	**Results**
1. **Case study description** a) Site description b) Buildings c) Context d) KPI's	to define the project area, site characteristics, describe buildings and infrastructure and select Key Performance Indicators (KPI's).	1.1 Site characteristics 1.2 Overview of existing and planned buildings & infrastructure 1.3 Context and boundaries 1.4 Selected KPI's
2. **Energy status quo:** a) Existing energy infrastructure b) Energy demand c) Current energy supply	to provide an overview of the status quo of the current energy system. For new buildings a reference situation based on requirements can be defined.	2.1 Existing energy infrastructure 2.2 Current energy demand 2.3 Current local renewable energy supply
3. **Energy concept potentials** a) SUI Bioclimatic improvement potential b) SUI energy exchange c) SUI renewables potential	to determine all energy potentials: potential reduction of the demand, exchange between different functions and renewable supply using different technologies.	3.1 Quantified demand for various building solutions 3.2 Potential energy exchange 3.3 Energy potential of local resources
4. **Conceptual network development** a) Connecting demand and supply potentials b) Heating and cooling options c) Electricity supply options	to develop energy configurations that meet the demand with maximized use of local energy potential, in order to evaluate the preferred option in step 5.	4.1 Schemes of the different energy configurations that can meet the demand 4.2 Energy balances of the configurations
5. **Evaluation & selection**	To quantify the performance and evaluate the KPI's for the different solutions developed in step 4	5.1 KPI's of each concept 5.2 Selection of 1 or 2 promising SUI solutions for further development

Table 2: Smart urban isle guidelines to develop locally balanced energy concepts for urban areas, Directly derived from source: Jansen, Mohammadi & Bokel, 2019)

In the next chapters the steps from the SUI approach are used to define the different sections of each chapter in order to provide the reader with a clear overview of measures or literature representing the different steps.

3.2 Evaluation of energy performance

To evaluate the energy flatness of an urban block the energy performance has to be evaluated. The main objective for energy flatness is to reduce the mismatch between supply and demand at any given time in a year. To be able to quantitatively describe the energy flatness of a building/urban block key performance indicators (KPI) can be used. As base for these key performance indicators the scheme shown in figure 11 (Jansen, Mohammadi & Bokel, 2019) and the key performance indicators came up by Höfte (2018) have been used. The first key performance indicator (KPI 1) describes the total energy neutrality of a system and the second, third and fourth KPI provide us with characteristics about the aspects that are not yet energy flat. Additionally, to evaluate the influence of multi functionality, i.e. reusing waste energy streams between functions a new key performance indicator is introduced (KPI 5).

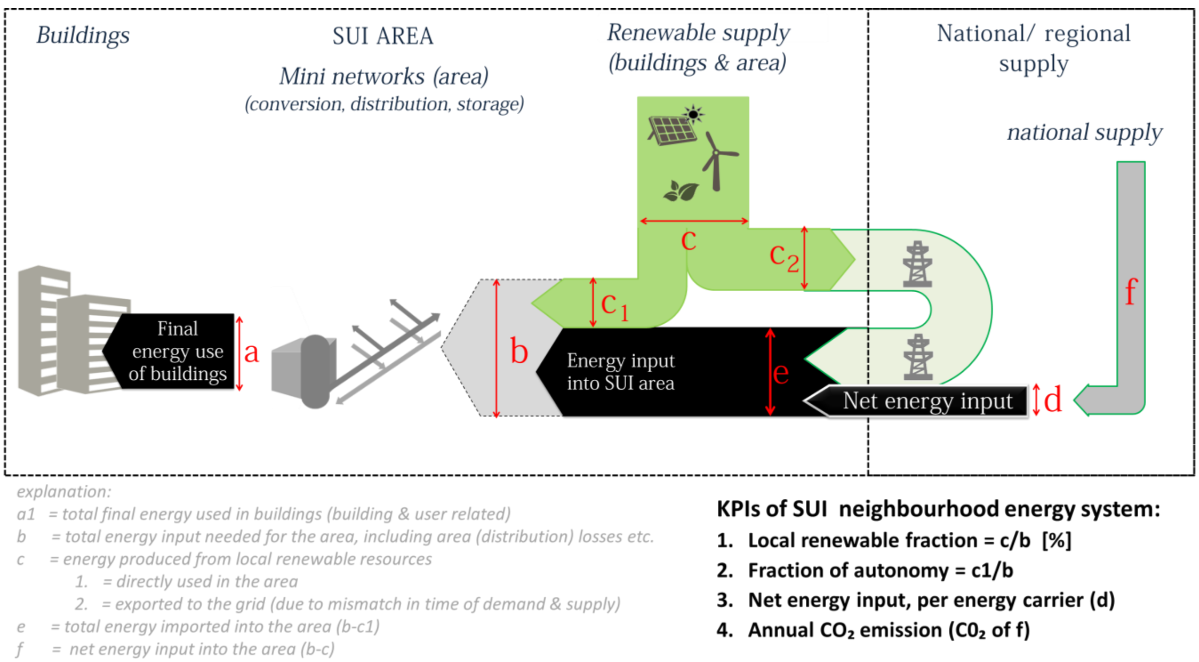


Figure 11: Base scheme of used key performance indicators (Jansen, Mohammadi & Bokel, 2019)

KPI 1; Energy neutrality/Local renewable fraction:

The first key performance indicator evaluates the total energy neutrality of the overall system. This KPI is defined as the total difference between energy supply and demand over a certain set time interval, i.e. in figure 11 this gives C minus B to get the exact value and C divided by B to get the overall renewable percentage. Hence, it shows whether energy needs to be imported from the grid on a yearly basis. This key performance indicator does not show the amount of energy that needs to be stored for later use. This KPI can both be described as kWh or MWh per certain time interval and/or can also be described as a percentage [%].

This KPI can also be described as the following mathematical equations:

$$KPI1.A = C - B \ = \sum_{t=0}^{t=8760} E_{On-site_{supply(t)}} - \sum_{t=0}^{t=8760} E_{final_{used(t)}} \ [kWh/yr]$$

$$KPI1.B = C/B \ = \frac{\sum_{t=0}^{t=8760} E_{On-site_{supply(t)}}}{\sum_{t=0}^{t=8760} E_{final_{used(t)}}} \qquad [\%]$$

In these equations $E_{on\text{-}site\_supply\ (t)}$ is the amount of energy that is supplied at time t and $E_{final\_used\ (t)}$ is the energetic demand at a certain time t. An outcome of the equation closer to zero means that the building or urban block is more energy flat. This KPI can be used to determine the total energy flow through the system over a certain time in a year (Höfte, 2018).

KPI 2; Fraction of autonomy:

The second key performance indicator determines the fraction of autonomy of the energy system. To be able to determine the autonomy of an energy system hourly calculations have to be made to differentiate C1 and C2 from C in figure 11. According to figure 9 this autonomy is the fraction of locally produced energy (C1) that can directly be used to supply the local final demand (B) on an hourly basis. This KPI can both be described as kWh or MWh per certain time interval and/or can also be described as a percentage[%]. Therefore, this KPI can be described as the following mathematical equations:

$$KPI2.A = C1 = \sum_{t=0}^{t=8760} E_{Directly\ used_{supply(t)}} \qquad [kWh/yr]$$

$$KPI2.B = C1/B \ = \frac{\sum_{t=0}^{t=8760} E_{Directly\ used_{supply(t)}}}{\sum_{t=0}^{t=8760} E_{final_{used(t)}}} \qquad [\%]$$

In these equations $E_{Directly\ used\_supply\ (t)}$ is the amount of renewable energy that is directly used to supply the demand at time t and $E_{final\_used\ (t)}$ is the energetic demand at a certain time t. To understand the maximum autonomy of the energy system over time a surplus of energy should not be taken into account, i.e. The $E_{Directly\ used\_supply\ (t)}$ has a maximum value of $E_{final\_used\ (t)}$. This means that on an hourly basis the $E_{Directly\ used\_supply\ (t)}$ can be determined as follows:

IF C > B: C1 = B -> $E_{Directly\ used\_supply\ (t)} > E_{final\_used\ (t)}$: $E_{Directly\ used\_supply\ (t)} = E_{final\_used\ (t)}$

OTHERWISE C1 = C -> $E_{Directly\ used\_supply\ (t)} = E_{on\text{-}site\_supply(t)}$

KPI 3; Maximum power mismatch:

The third key performance indicator defines the biggest mismatch between supply and demand over a certain time in a year (Figure 12).

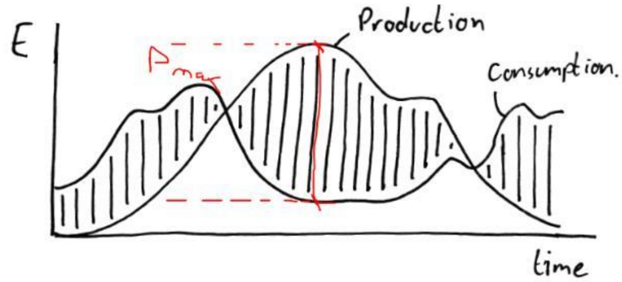


Figure 12: Maximum difference between supply and demand at a certain time, source: Höfte (2018)

It can be divided into a maximum positive mismatch (supply > demand) or a minimum negative mismatch (supply < demand). This KPI can also be described as the following mathematical equations:

$$KPI3.A = \max(C - B) = \max_{0 \leq t \geq 8760} (E_{On-site_{supply(t)}} - E_{final_{used(t)}})\ [W]$$

$$KPI3.B = \min(C - B) = \min_{0 \leq t \geq 8760} (E_{On-site_{supply(t)}} - E_{final_{used(t)}})\ [W]$$

In these equations $E_{on\text{-}site\_supply(t)}$ is the supplied energy at time t and $E_{final\_used(t)}$ is the energetic demand at certain time t. Because this KPI is time dependent it relates to power [W] instead of the value of energy [J or kWh] like KPI 1. With these mathematical equations both the negative and positive maximum power mismatch can be determined.

KPI 4; Maximum cumulative mismatch:

Key performance indicator three determines the maximum cumulative mismatch of the entire system. As can be seen in Figure 13 this KPI uses the biggest difference between maximum overproduction and maximum shortage in the whole system. Thus, theoretically, this KPI can be used to determine the size of the energy storage method to be used to shift energy for later use.

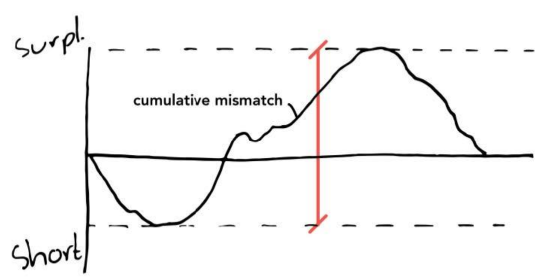


Figure 13: Maximum difference between oversupply and shortage in demand, source: Höfte (2018)

With an energy neutral building/urban block as boundary condition, this KPI can also be described as the following equation:

$$KPI4 = \max_{0<t<8760}\left(CEM_{(t)}\right) - \min_{0<t<8760}\left(CEM_{(t)}\right) \qquad [KWh]$$

In this equation $CEM_{(t)}$ is the cumulative energetic mismatch at time t, i.e. hourly supply minus the hourly demand. This is calculated by adding the mismatch from every time interval to the $CEM_{(t)}$ of the previous time interval.

KPI 5; Inter-exchange of reusable energy flow fraction:

This key performance indicator is developed by the author. With this KPI the influence of multi functionality on energy flatness can be evaluated. With the aspect of multi functionality the possibility to reuse waste energy flows for other functions is introduced, i.e. different functions have different user- and energy profiles over time. By dividing the amount of reused energy between different functions through the total demand of energy in an urban block and multiply this value with 100, the inter-exchange of reusable energy fraction can be defined.

This KPI can be described as the following equation:

$$KPI5 = \frac{\sum_{t=0}^{t=8760} E_{reused\,(t)}}{\sum_{t=0}^{t=8760} E_{final_{used(t)}}} \qquad [\%]$$

In this equation $E_{reused(t)}$ is the amount of energy that is inter-exchanged between different functions at time t and $E_{final\_used(t)}$ is the total energy demand of a certain energy type at time t.

3.3 Reducing the mismatch between supply and demand

To have a properly working energy system all energy flows need to be in balance. Hence, the energy system needs flexibility to have the ability to cope with fluctuations of demand over time (Lund, Lindgren, Mikkola, & Salpakari, 2015). However, the phenomena to balance the supply and demand in order to reduce the mismatch is not a new concept. Research into balancing the energetic mismatch is widely conducted in both the built environment as in other disciplines. According to Stadler (2009) and Stluka, Godole & Samad (2011)), Lund et al. (2015), Gelazanskas & Gamage (2014) and Höfte (2018) the mismatch can be reduced by using energy storage, smart grids, flexible generation, adapting user behavior and through architectural design. The aim of this paragraph is to provide the reader with an overview of state of the art ways to reduce the mismatch on both demand and supply sides.

3.3.1 Adapting demand

According to Gelazanskas and Gamage (2014) one of the ways the mismatch could be reduced is through adapting the energy demand, also known as demand side management (DSM). Demand side management is the planning, implementation and monitoring of aspects that have a big influence on customer use of energy. Basically, it encourages the end-user to use less power when there is peak production and/or to flatten the demand curve through shifting the energy use to off-peak hours.

Demand side management can be categorized in reducing, increasing and rescheduling of the energy demand over time (Lund et al., 2015). In 1989 Gellings and Smith came up with different load shaping objectives to reduce, increase and reschedule energy over time. Reducing the energy demand can be done through peak shaving and conservation of energy, increasing the energy demand can be done through valley filling and load growth and lastly load shifting can be used to reschedule the energy demand. Figure 14 shows a graphical overview of these different load shaping objectives.

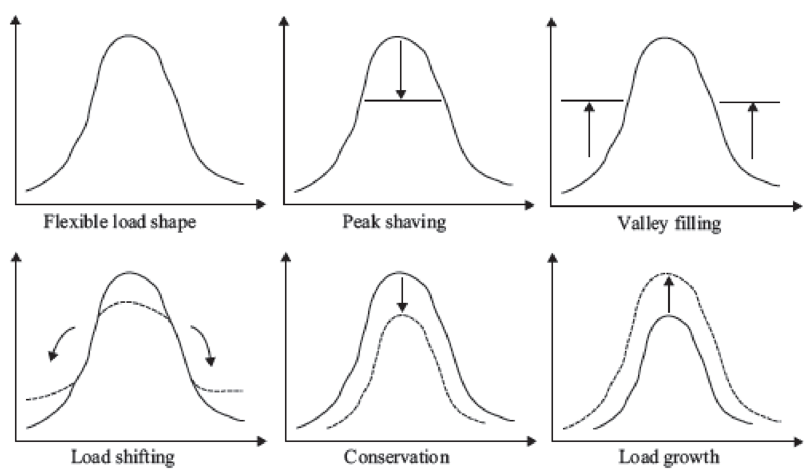


Figure 14: Load shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Within a conventional energy system the different load shaping objectives made it the energy production company able to shape the energy system in such a way that the energy supply would follow the energy demand pattern (Lund et al., 2015). However, within an energy system that totally relies on renewable generation it is different. Due to its climatic context fluctuations in energy production of renewable generation are very high. Therefore, according to Strbac (2008) it is not desired or easy to control the amount of renewable energy production in order to follow the energy demand pattern.

Where the original idea of the load shaping objectives was mainly to use them to reshape the energy supply generation, in a sustainable energy system the load shaping objectives become more important for the energy demand side. According to Stadler (2009) and Stluka, Godole & Samad (2011), Lund et al. (2015), Gelazanskas & Gamage (2014) and Höfte (2018) user engagement, storage, smart appliances in a smart grid and architectural design are important aspects to reshape the energy demand curve. In the next paragraphs these different aspects will be further explained as well as the different load shaping objectives these aspects achieve.

3.3.1.1 Architectural design

Architectural design is one of the objects that can change both the energy demand and supply for an entire building. Although buildings can be designed in endless different ways according to different aspects like aesthetics, functionality, energy performance, etcetera, Vincent Höfte (2018) found nine principles that has a big impact on the energy flatness of a building. One principle affects the energy supply of a building (Supply; share of production), one other principle affects both demand and supply for a building (Geometry; energy surface) and the rest of the principles (Surface; insulation, Surface; thermal mass, Windows; share per orientation, Windows; g-value, Comfort; ventilation rate, Comfort; temperature range and Geometry; orientation) all affect the energy demand of the building. In this paragraph all the different architectural design parameters that influence energy flatness will be described, all findings are from the master thesis of Vincent Höfte (2018) unless stated otherwise.

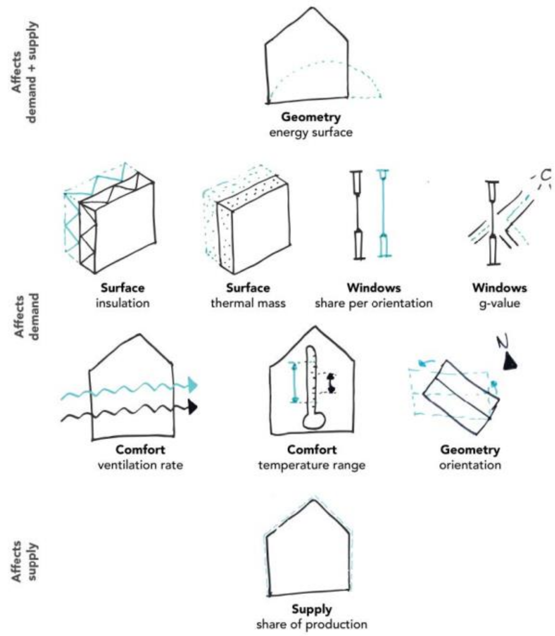


Figure 15: Nine architectural design parameters that influence energy flatness, source: Höfte (2018)

Geometry; energy surface

The parameter geometry; energy surface investigates the change in energy performance while changing the energy losing surface, in other words, changing the building shape. It is commonly known that the smaller the surface area is the smaller the amount of energy that can transfer through will be. Therefore, it can be concluded that with the aim for energy flatness the energy losing surface should be decreased to its minimum. However, decreasing the energy losing surface also implicates the fact that the potential for supply surface decreases and that there will be a lower capacity for heat disposal in summer (Höfte, 2018).

Additionally, this parameter is not only subject to the energy performance of a building. Changing the building shape has also a big impact on the comfort, functionality and aesthetics of a building. Moreover, this parameter can only be changed in an early design stage, because changing the building shape of an existing building is rather hard. For the case study design research preliminary drawing are already provided and therefore this parameter will not be changed in the case study design research of this thesis and thus, this parameter is out of scope for this research.

Effect on energy profile:

Changing the energy losing surface leads to a reduction of losing heat in winter time. This means the main load shaping objective for this parameter is energy conservation (Figure 16).

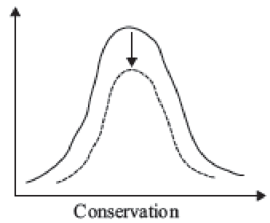


Figure 16: Energy conservation shaping objective, source: Lund et al. (2015) and Gellings & Smith (1989)

Surface; insulation

With the parameter surface; insulation the energy performance of a building is investigated through the change of insulation values/thickness of the insulation layers. Heating energy flows through surfaces between the inside of a building and the outside air. The speed that this flow occurs depends on the amount of thermal insulation a surface has. Due to climatic context, especially temperature differences between inside and outside air, this flow can be either desired or unwanted. It can be concluded that for the energy flatness of a building an increase of insulation value is preferred. In summer time however, the increase of insulation value implicates the increase in cooling loads as well, which should be kept at a reasonable level that can be dealt with locally (Höfte, 2018).

For the architectural design of a building increasing the insulation value often implies an increase in building construction thickness and the possibilities for cold bridges to occur. However, for the case study design research in this thesis the building construction is out of scope and therefore, just the impact of insulation value of commonly used properties will be used.

Effect on energy profile:

Increasing the amount of insulation reduces the amount of heat that is lost throughout the winter. In summer time however, because of the higher insulation value more cooling is needed. Thus, the main load shaping objectives for this parameter are energy conservation and load growth (Figure 17).

Figure 17: Energy conservation and Load growth shaping objectives, , source: Lund et al. (2015) and Gellings & Smith (1989)

Surface; thermal mass

The parameter surface; thermal mass explored the influence of thermal mass changes on the energy performance of a building. Thermal mass can be used for temporal storing of heat. Thermal mass has the ability to slowly extract heat from its environment over time and slowly release it when its surrounding are cooler than the thermal mass itself. It can be concluded that for the energy flatness of a building an increase in the amount of thermal mass is beneficial for decreasing the energetic mismatch, especially during the inter-seasonal months when indoor temperature and outdoor temperature are relatively close to each other (Höfte, 2018).

For the architectural design of a building thermal mass will always be present. Every material has its specific thermal mass and specific heat coefficient. However, for a big impact of thermal mass on the energy flatness of a building, specific materials have to be handpicked, most often heavy materials. For the case study design research in this thesis selecting specific construction materials are out of scope and therefore, this parameter is not included in the research by design part of this thesis.

Effect on energy profile:

By using more thermal mass the a building has the ability to have a more constant temperature and thus reduces the peak needed for heating. The thermal mass heats up over a period of time and releases it slowly again as well. Therefore, the main load shaping objectives for this parameter are load shifting and peak shaving (Figure 18).

Figure 18: Load shifting and peak shaving energy shape objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Windows; share per orientation

With the parameter windows; share per orientation the influence of the amount of window surface per orientation on the overall energy performance of a building. Windows have an enormous impact on the overall architectural design of a building. It not only influences the overall composition/aesthetics, it also influences the indoor comfort and energy performance of a building. It can be concluded that for the energy flatness of a building a seasonal and orientation approach is beneficial. With bigger window areas the amount of energy that goes in and out of the building increases. Therefore, in winter a big window area on the south façade is desired, for the other façades the amount of window area should be kept to its minimum and should have a high insulation value. Due to the indoor comfort during summer days it is not advisable to have large window areas on all façades of a building, although it could be positive during summer nights to lose heat (Höfte, 2018).

Thus, for the architectural design of a building a balance should be found between aesthetics, indoor comfort and energy performance. The most desired solution would be a dynamic solution, where insulation value and transparency changes over time. Because of its impact, changing the amount of glazing per orientation surface will be a big element in the research by design case study. While the aesthetics and indoor comfort of the building are out of scope for this research, they will not be completely neglected due to the realism and stakeholders of this project.

Effect on energy profile:

Changing the amount of glazing area per façade orientation has a few impacts on the energy profiles. By minimizing the amount of glazing the transmission losses will be minimized as well which also means a reduced heating necessity. However, lower amount of glazing area also indicates less surface area to release heat through during summer night and thus an increase in needed cooling loads are expected. Therefore, the main load shaping objectives of this parameter are peak shaving, energy conservation and load growth (Figure 19)

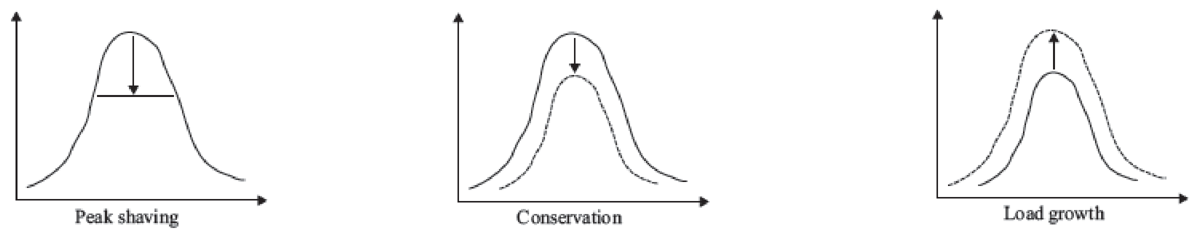


Figure 19: Peak shaving, energy conservation and load growth shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Windows; g-value

The parameter windows; g-value investigates the impact of changing the g-value of a window has on the energy performance. The g-value is the property of a window that indicates how much solar energy is transmitted through a window. This property is expected to differ per situation, for example when passive heat gain is desired a high g-value should be used. It can be concluded that in the Dutch climate changing the g-value of windows on the south façade has the biggest impact on the heating and cooling loads that are needed, but again a seasonal approach would be the best (Höfte, 2018).

For the architectural design of a building this is quite a challenging element. Historically, the g-value of a window is a fixed property, but with state of the art technology like electronic pulses this g-value can even be changed inside a window plane according to the climate. Another aspect that can be used to change the g-value of a window is adding sun shading to the building. Because of the common use of sun shading in the built environment, this is the most logical way to change the g-value in the case study design.

Effect on energy profile:

By increasing the g-value of windows its insulation properties and passive heating properties are improved, which reduces the overall heating of a building in winter. Additionally, adding sun shading to a building completely removes the solar radiation that can go through a building and thus reduces the peak in heating that is needed in summer. Therefore, the main load shaping objective of this parameter is energy conservation and peak shaving (Figure 20).

Figure 20: Energy conservation and peak shaving shaping objective, source: Lund et al. (2015) and Gellings & Smith (1989)

Comfort; ventilation rate

With the parameter comfort; ventilation rate reducing the energetic mismatch by changing the ventilation rate is investigated. Ventilate rate is the amount of fresh outside air that enters/leaves a building hourly according to the desired user comfort. This air that enters or leaves a building/room has its own specific heat and thus, carries energy in or out of the building which can result in energy loss or gaining. Ventilation can both be manually or mechanically controllable, this depends on function and desired comfort of the users. It can be concluded for the energy flatness of a building that a seasonal approach for the ventilation system can have a positive impact, whereas in winter the ventilation rate should be low, the rest of the year a daily changing approach should be chosen. When a seasonal approach is not reachable, it is advised to keep the ventilation rate low all year long, this will result in a lower mismatch between supply and demand (Höfte, 2018).

Although different ventilation approaches has an impact on the architecture of a building like amount of service space needed for mechanical installations or the ability to have openable windows, the indoor comfort is out of scope for the research of the case study design in this thesis and however, because of the large impact of ventilation on heating and cooling loads, the ventilation rate is set to the minimum limit according to the Dutch Building Decree and therefore depends on the amount of people, function of the building and user schedule.

Effect on energy profile:

Ventilation can have a big impact on the energy profile of a building. By choosing for a completely naturally ventilated approach the electricity demand can be reduced significantly. Night ventilation can also be used during summer time, whereas cooling loads will be reduced by optimal use of cooler air from outside during the night to pre cool the building. Another approach is adaptive ventilation rate, where the airflow rate depends on the time of the day. With this approach a reduced heating load can be achieved by moving the biggest amount of air when the temperature difference between inside and outside are minimal. Therefore, the main load shaping objectives for this parameter are energy conservation, peak shaving and load shifting (Figure 21).

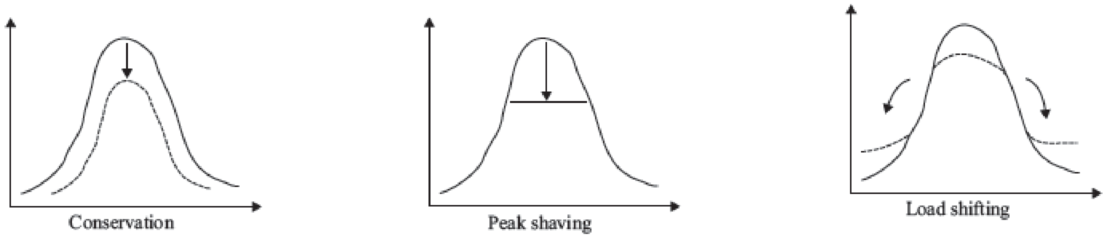


Figure 21: Energy conservation, peak shaving and load shifting shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Comfort; temperature range

The parameter comfort; temperature range is meant to explore the effect of comfort temperature range setting points on the overall energy performance of a building. These comfort temperature setting points are meant for both heating and cooling appliances in order to start working when desired. By shifting these comfort temperature setting points towards a temperature that is closer to the outdoor temperature, the temperature difference between indoors and outdoors will be reduced. This is done to reduce the amount of heating and cooling needed in a building. It is concluded that for the energy flatness of a building a seasonal approach for the temperature setting points has a positive impact. In winter, the heating temperature set point should be lower, while in the rest of the year a lower cooling set point is desired, except for the months of July and August, then the cooling set point should be close to the outdoor temperature which is relatively high. Although the seasonal approach is advised for reducing the mismatch, whenever this approach is not possible the widest range of temperatures all year long is best to lower the mismatch (Höfte, 2018).

There are no huge implementations for the architectural design caused by changing the temperature setting points. This range mainly depends on the comfortability level the user wants in a building. The case study design includes a lot of different functions, which all have different temperature ranges for heating and cooling. This multi functionality can have a big impact on the way the temperature range has on reducing the mismatch. In the research by design part it has to be investigated whether the temperature set points for different functions should be set close to each other or the ranges should be set individual with a bigger difference. This also has to do with the inter-exchange of energy between functions. For example, it might be beneficial for the overall energy system to keep one function at a constant temperature of 22 degrees Celsius all day/yearlong whereas another function can have big temperature differences to provide other functions with energy/heating.

Effect on energy profile:

By using an adaptive indoor comfort approach the difference between outdoor temperature and indoor temperature is kept at its minimum. In addition to that, a small increase in load flexibility can be found due to the fact that there is less electricity needed for the heating demand. Therefore, the main load shaping objectives for this parameter are energy conservation and flexible load shape (Figure 22).

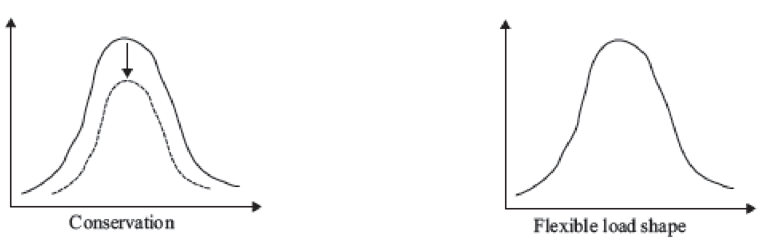


Figure 22: Energy conservation and flexible load shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Geometry; orientation

With the parameter geometry; orientation the influence of changing the original orientation of a building on the overall energy performance. By changing the orientation of the building different façades get different properties for solar radiation, shading needed and wind loads working on the façade. From the studied designs it can be concluded that for energy flatness changing the orientation of a whole building is not necessarily beneficial. Though, orienting the whole building towards the south gives a small decrease in the energetic mismatch. In this study however, the parameters of window (sizes and types) and supply areas are not included and thus, the orientation of a building can have a big impact on reducing the overall mismatch of a building (Höfte, 2018).

For the architectural design of a building the orientation often depends on the urban context. This induces that it can be rather difficult to optimally position the whole building for the desired orientation. Therefore, for each different building element the desired orientation should be investigated. The same thing goes for the case study design. Hence, for all building elements the desired orientation will be investigated.

Effect on energy profile:

By using the optimal orientation for a building a maximum of passive solar gain can be achieved in winter time. In summer the optimal orientation can achieve a lower cooling load when a lot of façade surfaces are turned away from the sun. Moreover, with the best orientation for a building the passive solar gains can be used to its optimum which reduces the energy valleys it could have. Therefore, the main load shaping objectives of this parameter are energy conservation, peak shaving and valley filling (Figure 23).

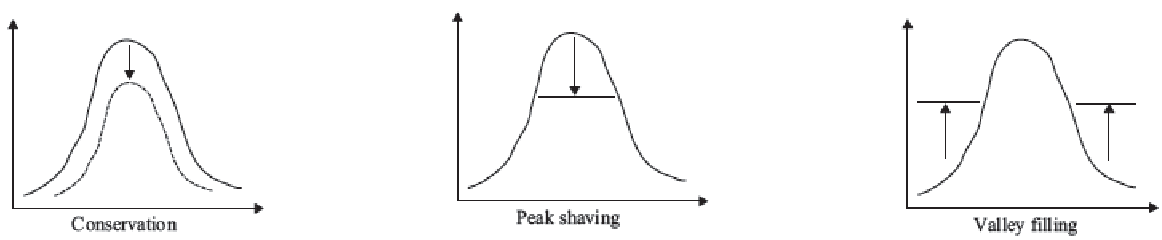


Figure 23: Energy conservation, peak shaving and valley filling shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

Supply; share of production

The parameter supply; share of production explores the effect of the amount of supply area on reducing the mismatch. For this exploration Höfte (2018) solely used solar potential as main supply source. The sun can be passively used as heat energy through windows, direct electricity usage through photovoltaics and actively used as heat energy through solar collectors. Solar potential depends largely on orientation and the amount of surface area it can use depends on the architecture. It can be concluded that for the energy flatness of a building increasing the supply surface are can both be beneficial in winter due to passive heating gains, but it can also increase the mismatch through increasing oversupply in summer. However, in all cases to decrease the overall energetic mismatch the supply should be increased in winter (Höfte, 2018).

For the architectural design of a building the amount of supply area has a big impact on the aesthetics of a building. In addition to that, the supply area on a façade is limited, a fully covered façade with photovoltaics is undesired. Therefore, in the case study design not only the optimal photovoltaics supply area will be investigated but also other resources like wind energy will be used, more information about adapting supply in chapter 3.4.

Effect on energy profile:

For the supply the amount of supply area does not reduce the mismatch on itself. However, the orientation of photovoltaics (horizontal and vertical orientation has less peaks and a more constant supply) and using other renewable energies like wind energy could balance out the mismatch on the supply side of the problem. Therefore, the main load shaping objectives for this parameter are valley filling and peak shaving (Figure 24).

Figure 24: Valley filling and peak shaving shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

3.3.1.2 User behavior

Another way to reduce the mismatch between supply and demand is influencing the behavior of users. According to Delzendeh, Wu, Lee and Zhou (2017) user behavior can be defined as the interaction between the user and building systems in order to have control over the indoor environment to feel healthy and comfortable in case of thermal, visual and acoustical aspects. Not only does the user desires to have absolute control over the indoor environment, which influences the energy usage of a building, more (seven) different parameters influences the energy use behavior of occupants. As can be seen in Figure 18 these parameters these parameters are climatic, building type (function) state of occupants, socio-personal, architecture, economic and regulations & policies.

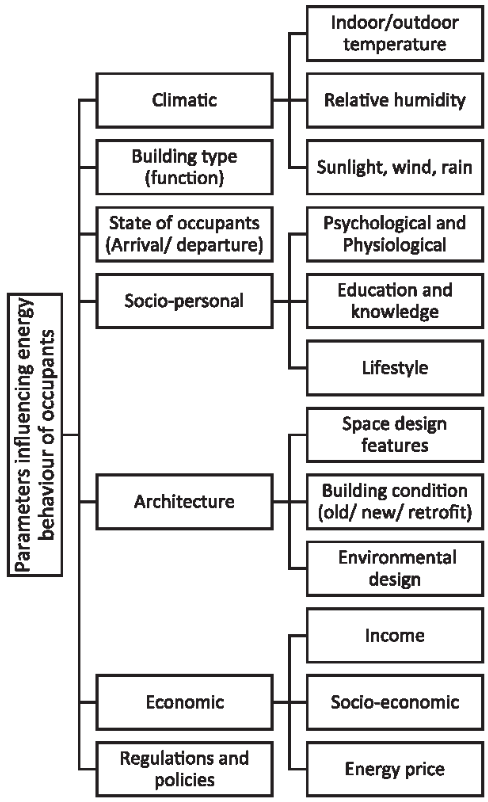


Figure 25: Parameter overview of aspect that influence energy behavior of occupants, source: Delzendeh, Wu, Lee and Zhou (2017)

According to Stadler (2009) the desired shift in user behavior would be to change their user pattern. Users should use appliances like dish washers and washing machines during the day when there is peak production rather than during off peak hours like they do currently. However, as can be seen in Figure 25 there are so many different parameters that influence the energy behavior of users and thus, the change of user behavior is rather complex due to psychological and socio-personal aspects. Therefore, for the case study design in this research influencing user behavior is out of scope.

Effect on energy profile:

When changing the user pattern is achieved by influencing the occupants behavior the demand of electricity usage will be more distributed over the day. Therefore, the main load shaping objective user behavior has is load shifting (Figure 26).

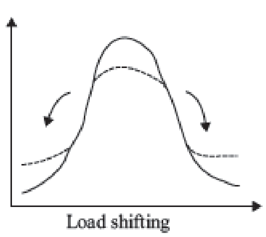


Figure 26: Load shifting shaping objective, source: Lund et al. (2015) and Gellings & Smith (1989)

3.3.1.3 Smart grids

Another method that can be used to reduce the mismatch between demand and supply is the concept of smart grids. A smart grid is basically a power grid with intelligent connection between all different stakeholders like energy producers, energy wholesaler and consumers (Lund et al., 2015). The main objective of a smart grid is both the two way flow of information and electricity. Within this system technologies like storage, advanced metering, inter-exchange between functions and automation of appliances can be included, which makes the system able to deliver the energy in a more efficient way and reply rapidly to changing conditions or events. In other words, smart grids basically consists of three main subjects; smart infrastructure system, smart management system and smart protection system (Fang, Misra, Xue and Yang, 2012).

With multi functionality as a key factor in the research and design part of this thesis introducing a smart grid based energy system is a logical step to integrate different aspects like advanced metering, storage and inter-exchange between functions in the overall energy system design. Moreover, the introduction of a smart grid makes it able to have a two way flow of information between the stakeholders that will be discussed in chapter 5.

Effects on energy profile:

By introducing a smart grid as basis for the energy system a two way flow of information and electricity appears. Energy producers get the information of demand through advanced metering, forecasting, user behavior and they can activate smart appliances remotely, while consumers get the desired electricity demand. Thus, smart grids create more flexibility in the energy system, can shift loads throughout the day and also reduce the peaks by forecasting management. Therefore, the main load shaping objective that can be achieved with a smart grid is load shifting, flexible load shape and peak shaving (Figure 27).

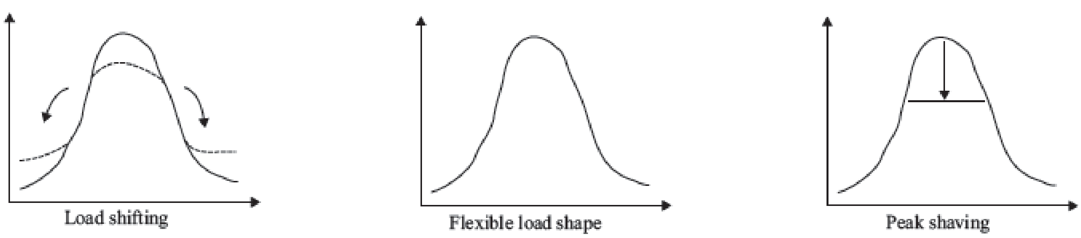


Figure 27: Load shifting, flexible load shape and peak shaving shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

3.3.2 Adapting supply

Another method to reduce the mismatch between supply and demand is supply side management. Supply side management is basically flexible generation of energy. According to Lund et al. (2015) originally energy generation flexibility are the measures that has to be taken for modification of the output of power generation units to attain a constant power in the energy grid. In case of renewable energy constant power could be achieved with a method called curtailment, which limits the power output. Within photovoltaic based energy systems inverters could be used as on/off control or as droop-control which gradually reduces the power output over time. In wind energy based systems network congestion is often used as a form of curtailment that implicates turning off the wind energy system (Lund et al., 2015). Hence, the method of curtailment is used in systems that are only partly dependent on renewable energy resources, when the production of these resources are in peak times their production will be limited to not overpower the current energy infrastructure.

However, with a sustainable energy system that is solely based on renewable energy usage, curtailment does not seems to be the best solution for reducing the mismatch between supply and demand. It reduces the production of renewable energy in peak times, but it still does not fix the mismatch between supply and demand during times where supply is limited and demand is high. A better way to reduce the supply peak seems like to be using several different renewable energy sources.

The most commonly used renewable energy resource is solar. Photovoltaics have large peaks throughout the year. However, another approach to reduce this peak is by orienting the photovoltaic panels in horizontal, vertical and/or on the east and west façade. This will reduce the maximum output of energy, but will produce a more constant production rate of solar energy. Another option is the introduction of wind energy. According to historical weather data wind energy has a larger production rate throughout winter and night time, with that given using wind as an energy resource could help to reduce difference between day and night production of energy supply. A way that both solar energy and wind energy can be combined in one single building appliance is the multifunctional roof edge technology made by Anerdgy (2018). Within this research only solar and wind energy are considered. Therefore, for ways to calculate the hourly and yearly supply of PV, PVT, PT and MRE (wind + solar) modules see appendix A.7.

Effects on energy profile:

Supply flexibility seems not to be the solution for reshaping the supply curve in an energy profile. A better way is to combine several different renewable resources with all different intermittencies in nature that can provide a more constant supply throughout the year. Therefore, the main load shaping objective that can be achieved with supply side management is load shifting and valley filling (Figure 28).

Figure 28: Load shifting and valley filling shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

3.3.2.1 Storage

Another approach to reduce the mismatch between supply and demand is energy storage. According to Lund et al. (2015), Gelazanskas & Gamage (2014) and Hadjipaschalis, Poullikas & Efthimiou (2009) energy storage is one of the crucial factors for renewable energy to become completely reliable as a primary source of energy. The main purpose of energy storage is to time shift the delivery of energy, which makes it a valuable tool to reduce the mismatch between supply and demand (Lund et al., 2015). The basic characteristics of different energy storage systems are the energy storage capacity and the power capacity. The bigger the storage capacity the longer the storage can respond to longer mismatches in the system, while power capacity allows to release more energy faster which makes them able to respond to mismatches of higher magnitude (Lund et al., 2015).

Storage of energy can both be done through electrical energy storage in for example lead-acid of lithium batteries and in thermal energy storage facilities. The choice of storage depends on the amount of energy that needs to be stored and on the discharge time of the energy that is desired (Hadjipaschalis et al., 2009).

Storage technologies:

As mentioned above multiple different systems can be used to store energy. The two main ways of storing energy are thermal energy storage and electrical energy storage. In this section both systems are shortly introduced. Additionally, an overview (Figure 29) of current state of the art storage systems and their technological, economic and environmental properties (Hadjipaschalis et al., 2009)

Thermal energy storage (TES):

Within a thermal energy storage system thermal energy can be stored on both high and low temperatures. Since a few decades the concept of thermal energy has proven to be capable of shifting electrical loads form high peak times to off peak times. The basic principle a thermal energy storage works on is the same as the majority of other storage systems. It charges up through supply of energy, energy is now stored and when needed the energy is released (discharged) from the system. Thermal energy storage systems is a system that ensures energy security, energy efficiency and low environmental impact. For exergy purposes the best solution of thermal energy storage is the low temperature thermal energy storage. As can be seen in Figure 16 the thermal energy storage system overall has a big energy capacity, is quite low cost and has a long lifetime expectancy (Hadjipaschalis et al., 2009)

Electrical energy storage:

An electrical energy storage system is capable of storing energy to produce electricity when it is needed. Within this system electrical energy can be stored directly or indirectly depending on different methods of storing energy. It can either be done mechanically, chemically or by modifying electrical/magnetic fields. Although the most logical methods would to use in current society are either mechanically through flywheels due to its high efficiency, very fast response time and small size of the method, or another method would be chemically through the use of lead-acid batteries which are commonly used and are relatively cheap compared to other batteries, electrical energy storage is out of scope for this research (Hadjipaschalis et al., 2009).

	Efficiency (%)	Capacity (MW)	Energy density (Wh/kg)	Capital ($/kW)	Capital ($/kWh)	Response time	Lifetime (years)	Maturity	Environmental impact	References
TES	30–60	0–300	80–250	200–300	3–50	–	5–40	Developed	Small	[29,156]
PHS	75–85	100–5000	0.5–1.5	600–2000	5–100	Fast (ms)	40–60	Mature	Negative	[154,156,158]
CAES	50–89	3–400	30–60	400–2000	2–100	Fast	20–60	Developed	Negative	[149,156,161]
Flywheel	93–95	0.25	10–30	350	5000	Very fast (<ms)	~15	Demonstration	Almost	[156,165,171]
Pb–acid battery	70–90	0–40	30–50	300	400	Fast	5–15	Mature	Negative	[9,156,184,185]
Ni–Cd battery	60–65	0–40	50–75	500–1500	800–1500	Fast	10–20	Commercial	Negative	[187–193]
Na–S battery	80–90	0.05–8	150–240	1000–3000	300–500	Fast	10–15	Commercial	Negative	[156,171,187,195,196]
Li-ion battery	85–90	0.1	75–200	4000	2500	Fast	5–15	Demonstration	Negative	[156,197]
Fuel cells	20–50	0–50	800–10,000	500–1500	10–20	Good (<1 s)	5–15	Developing	Small	[156,210]
Flow battery	75–85	0.3–15	10–50	600–1500	150–1000	Very fast	5–15	Developing	Negative	[156,213]
Capacitors	60–65	0.05	0.05–5	400	1000	Very fast	~5	Developed	Small	[156]
Supercapacitors	90–95	0.3	2.5–15	300	2000	Very fast	20+	Developed	Small	[156,220,221]
SMES	95–98	0.1–10	0.5–5	300	10,000	Very fast	20+	Demonstration	Benign	[156,223–225]

Figure 29: Overview of different energy storing methods, source: Kousksou, Bruel, Jamil, El Rhafiki, & Zheraouli (2014)

Effect on energy profile:

With the ability to store energy in one of the described methods stated above the energy system has the ability to store energy during production peak hours for later use in off peak hours. Therefore, the main load shaping objective energy storage has is load shifting (Figure 30)

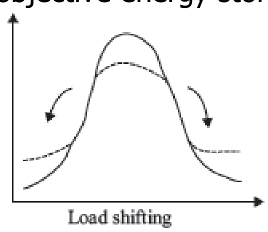


Figure 30: Load shifting shaping objective, source: Lund et al. (2015) and Gellings & Smith (1989)

3.3.3 Inter-exchange of energy

Another method to decrease the mismatch between supply and demand is the inter-exchange of energy. Within the concept of the Rotterdam Energy Approach and Planning Tillie et al. (2009) came up with this phenomena to reuse waste streams of one function to provide another function with parts of this waste stream. It is part of the new stepped strategy for a building. First the energy consumption should be reduced. Then all waste streams of one individual building should be recycled, but to solve the rest of the demand waste streams from surrounding buildings with different usage patterns and energy requirements should be analyzed and reused in order to fulfil the demand and lastly the rest of the demand can be fulfilled with renewable resources. An example can be found in modern office buildings. Due to the internal heating loads of the people in an office, an office building starts cooling while outdoor temperatures just reach over 12 degrees Celsius, whereas regular homes still need heating at those ranges of temperature (Tillie et al., 2009).

In current research the inter-exchange of energy between functions is mainly conducted for a whole year round. Therefore, for the case study design in the research by design part of this thesis the main focus area of the inter-exchange of energy will lay on how this inter-exchange can help an urban block to become energy flat at any hour of the year. This will implicate a lot of collaboration between different functional stakeholders and thus, in chapter 5 the governance for energy flatness is described.

Effect on energy profile:

With the possibility to reuse waste streams between functions the needed supply of energy will be reduced in its whole. Moreover, to match the desired demand the system does not solely depend on renewable energy anymore therefore, by reusing the waste streams you can achieve a more flexible load shape. Hence, the main load shaping objectives that can be achieved through inter-exchange of energy are energy conservation and flexible load shape (Figure 31).

Figure 31: Energy conservation and flexible load shaping objectives, source: Lund et al. (2015) and Gellings & Smith (1989)

3.4 Sustainable energy system development

The section above describe the way the energetic mismatch between supply and demand can be reduced. However, these measures on itself cannot create an energy flat urban block, they represent the energy demand to keep an comfortable indoor climate and the final energy that can be supplied to match this demand. However, these two types of energy still need to be matched with each other in order to create a working energy system. This is done through the energy components [building services]. Within the SUI approach this can be both be done on a building scale [individual system] or on a urban area scale [collective system]. Therefore, the SUI method uses 5 types of different energy system concepts. One on the individual scale; all-electric and four on the collective scale with different operating temperatures, 1; Ultra low temperature (10-20 ^{o}C), 2; low temperature (25-40 ^{o}C), 3; medium temperature (35-50 ^{o}C) and 4; high temperature (> 65 ^{o}C) (Jansen, Mohammadi and Bokel, 2019). Table 3 shows the characteristics of each conceptual energy system. These concepts can be used as a starting point from where the energy system can be optimized based on different available supply technologies, energy exchange and stakeholder collaboration.

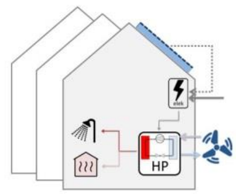
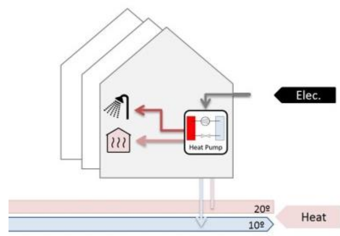
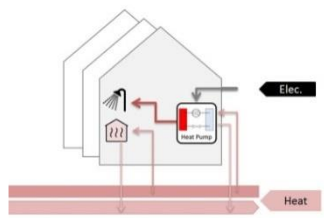
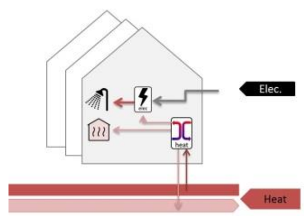
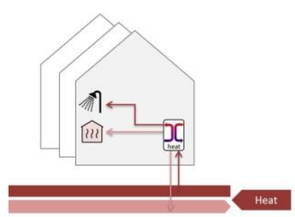
All-electric: Individual air source heat pump		- Cooling mode: no passive cooling - Heating mode: space heating and hot water must be produced with a heat pump - Can still be connected to an electricity or gas grid, but is not connected to a heat grid. - Can be preferred when only a small amount of buildings are present in the urban area.
Heat & Cold Thermal Grid (Ultra-low temperature)		- Cooling mode: passive cooling - Heating mode: space heating and hot water must be produced with a heat pump - This temperature level can be preferred if there is also much cooling demand, and in case the temperature of local sources is below 25 degrees.
Low temperature Thermal Grid		- Temperatures: warm ca. 30-40°C, return ca 20-25°C - Cooling mode: no passive cooling possible, must be with heat pump - Heating mode: space heating directly; hot water with a heat pump - This temperature level can be preferred if there is negligible cooling demand, and in case the temperature of local sources is between 30-40 degrees.
Medium temperature Thermal Grid		- Temperatures: warm ca. ca 55°C, return ca 35°C - Cooling mode: no passive cooling possible, additional cooling equipment needed - Heating mode: SH directly; DHW can be upgraded with an electric boiler - Preferred if there is negligible cooling demand, if buildings need a higher supply temperature than 40°C, and in case local heat is available at ca 55°C
High temperature Thermal Grid		- Temperatures: warm > 65°C, return ca 45°C - Cooling mode: no passive cooling possible, additional cooling equipment needed - Heating mode: SH directly; DHW directly - Preferred only in case local heat is available at temperatures > 65°C, since a lot of distribution losses are introduced at high temperature levels.

Table 3: Characteristics of 5 different energy system concepts used in the SUI approach, source: Jansen, Mohammadi and Bokel (2019)

3.5 Conclusion

Chapter three provides an answer to the following sub-questions: "*What parameters influence energy profiles of demand and supply and how can these be adapted?"* and "*How can the energy flatness of a multifunctional urban block be evaluated?"* These answers are given by performing a literature study based on the five steps of the Smart Urban Isle approach. First, the SUI method is shortly described. Then, the key performance indicators that can be used for the evaluation are explained. After that, ways to reduce the energetic mismatch of supply and demand are talked about and lastly, different concepts for energy system network development are provided.

In this thesis the Smart urban isle method is used as base for the case study design. This approach has the goal to develop locally balanced energy systems and contains five different steps: case study description, energy status quo, energy concept potentials, concept development and evaluation & selection. This approach is also used as guideline for the literature study. The literature study of this chapter focused on the evaluation of energy flatness, reducing the mismatch between supply and demand and energy network development.

The energy flatness of an urban block can be evaluated based on the six key performance indicators as stated in chapter 3.2, which are: absolute energy flatness, maximum absolute mismatch, maximum cumulative mismatch, inter-exchange of reusable energy flow fraction, yearly renewable supply fraction and direct use of energy supply for demand fraction. These KPIs describe the absolute mismatch between supply and demand on a yearly basis, the amount of time energy flatness can be achieved on an hourly basis, the autonomy of the overall energy system and the possible impact of multi functionality on the energy flatness of an urban block. In order to be able to evaluate the energy flatness of an urban block both the hourly supply and demand has to be calculated. In this research the demand is calculated through steady state energy balance calculations performed in excel, while the supply is also calculated on an hourly basis in excel by using the formulas as stated in appendix A.7.

Besides the calculation of the energy status quo, energy concept potentials, i.e. reducing the mismatch between supply and demand, are also part of the SUI approach. Reducing the mismatch between supply and demand can be carried out in three ways: Adapting demand, adapting supply and inter-exchange of energy. Adapting demand can be done through architectural design optimization, changing user behavior and by introducing smart grids. Within an energy system with renewables as primary energy, adapting the supply can be done through the introduction of multiple renewable sources like solar and wind or by the introduction of temporal energy storage. Another option to reduce the mismatch is by exchanging energy between functions over time. When adaptation of either the supply or demand curve is desired, the load shape objective of each parameter can be used to find out what parameter is best to change in order to reduce the mismatch.

However, these measures on itself cannot create an energy flat urban block, they represent the energy demand to keep an comfortable indoor climate and the final energy that can be supplied to match this demand. However, these two types of energy still need to be matched with each other in order to create a working energy system. This is done through the energy components [building services]. Within the SUI approach this can be both be done on a building scale [individual system] or on a urban area scale [collective system]. Therefore, the SUI method uses 5 types of different energy system concepts. One on the individual scale; all-electric and four on the collective scale with different operating temperatures, 1; Ultra low temperature (10-20 ^{o}C), 2; low temperature (25-40 ^{o}C), 3; medium temperature (35-50 ^{o}C) and 4; high temperature (> 65 ^{o}C).

Research by design

RESEARCH BY DESIGN

4 Buiksloterham, Amsterdam [Case study design]

From this chapter onwards the research by design part of the thesis starts. For this part a particular case study area in Buiksloterham a neighborhood in Amsterdam the Netherlands is designed. As mentioned earlier as base for the energetic part of this research the Smart Urban Isle approach is used. This method consist of five [5] different steps. First the general case study characteristics are described. Secondly, the energy status quo is analyzed. The third step is analyzing the energy potentials for the location. Fourth, a conceptual mini energy network is designed. And lastly, the overall design is evaluated and the outcomes are discussed.

4.1 Project description

The case study is located in Buiksloterham, Amsterdam in the Netherlands on a total surface area of 6370 m^2 and is situated on the North-west (Figure 32) . Building block 14 is used in the analysis.

Building block 14 is designed by Marc Koehler architects in collaboration with Superlofts. These architects got the assignment from Vinkbouw, who is both developer and contractor of the whole building block. Figure 33 shows an illustration of building block 14 conceived from the preliminary design.

Figure 32: Aerial picture of the location, source: Marc Koehler architects (2017)

Figure 33: 3D visualization of building block 14, source: Marc Koehler architects (2017)

As can be seen in Figure 33 in the case study area you can find six different buildings. Each building with a different total area, different function and different building heights. For the case study design the building shapes will be kept the same. The current energy status quo will be analyzed for the current preliminary design of the building block. Next to the building shape, orientation and location of the building it also means the current distribution of functions will be kept the same for the analysis of the current energy status quo. An overview of the different function can be found in Table 4 and Figure 34.

Function	Area [m^2]	Color in Figure 34
Café [commercial]	304	
Hotel	5 380	
Residential (buy) **Residential (rent)**	6 777	
Shops/sport [commercial]	1150	
Offices	304	
Leisure [commercial]	265	
Warehouse [commercial]	530	
Total area	14 710	

Table 4: Different functions and their space area (by author)

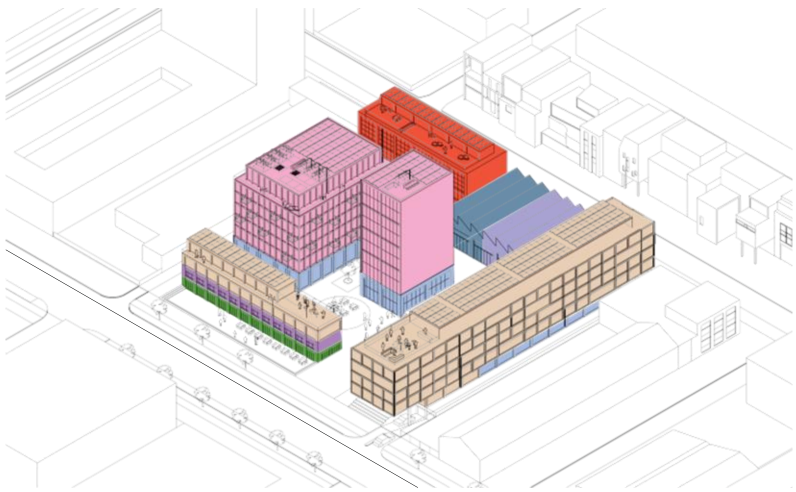


Figure 34: 3D visualization of functions building block 14, source: Marc Koehler architects (2017)

As can be seen in Table 4 there are eight different functions ranging from a hotel to a warehouse. For the analysis of the case study however, the functions are divided into six different groups; residential (buy), residential (rent), commercial (non-hotel), commercial (hotel), hotel and office. The functions are divided into these groups based on the possible implications for governance, i.e. these functions all have different stakeholders. Additionally, the shops, sport facilities, café and warehouse are combined into one group based on the fact that in the current stage [preliminary design] it is not yet determined what exactly is there and to make it less complex for the energy calculations.

4.2 Energy status quo

In this paragraph the energy status quo is analyzed. The energy status quo consists of the space heating, cooling, domestic hot water and electricity demand. Space heating and cooling can be calculated using the thermal energy balance described in chapter 2.2. A detailed description of calculating domestic hot water and electricity demands can be found in appendix A.2. Considering the overall energy demand of an urban block both building design and non-building design parameters have an impact. Non-building design parameters are parameters like amount of people, amount of appliances in a building, the amount of electrical lighting within a building and the building function. Building design parameters include insulation value, window percentage, type of glazing, infiltration rate, heat recovery efficiency and blind control.

To calculate the current energy demand in the case study area the certain above described parameters have to be determined. As mentioned earlier the case study area is in stage of development. Therefore, the exact building design parameters are not yet known. To be able to calculate the overall energy demand per function the minimum requirements as stated in the Dutch building decree 2012 are used as parameter inputs. When there are no minimum requirements set for a certain parameter by the Dutch building decree an educated guess is done by the author. These used building parameters for the energy status quo can be seen in Table 5 [next page]. For a more detailed overview of the parameters see appendix A.1.

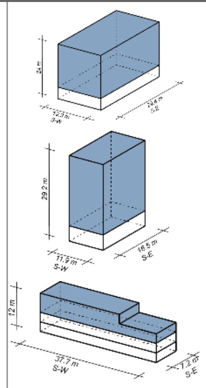
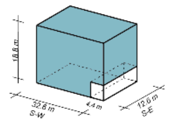
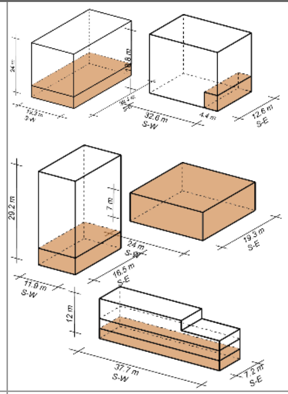
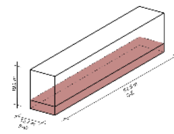
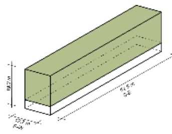
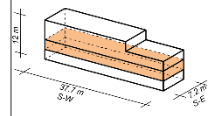
		Residential (Buy)	Residential (Rent)	Commercial (Non-hotel)	Commercial (Hotel)	Hotel	Office	Based on
Buildings								
		4696 m^2	1700 m^2	1909 m^2	820 m^2	5079 m^2	300 m^2	
User schedule		From 17:00-10:00 h	From 17:00-10:00 h	From 8:00-22:00 h	24-hour schedule	24-hour schedule	From 8:00-20:00 h	Itard, 2018 & common opening hours in Amsterdam
Amount of people in function type		83 people [2.2 per unit of 125 m^2]	30 people [2.2 per unit of 125 m^2]	215 people [0.125 p. per m^2]	103 people [0.125 p. per m^2]	178 people [0.05 p. per m^2 with 70 % occupied all the time]	64 people [0.05 p. per m^2]	NTA 8800 maximum requirements & average household size per building type
Light & appliances schedule		23:00-7:00 h: 20 % 7:00-10:00 h: 100 % 10:00-17:00 h: 20 % 17:00-23:00 h: 100 %	3:00-7:00 h: 20% 7:00-10:00 h: 100% 10:00-17:00 h: 20% 17:00-23:00 h: 100 %	8:00-22:00 h: 100 % 22:01-7:59 h: 20 %	24-hours: 100 %	24-hours: 100 %	8:00-20:00 h: 100 % 20:01-7:59: 0 %	Itard, 2018
Indoor temperature heating mode [°C]	Spring Summer Autumn Winter	20 °C 20 °C 20 °C 20 °C		21 °C 21 °C 21 °C 21 °C				Dutch building decree 2012 [minimum]
Indoor temperature Cooling mode [°C]	Spring Summer Autumn Winter	24 °C 24 °C 24 °C 24 °C						Dutch building decree 2012 [minimum]
Window percentage [%]	N (NE + NW) S (SE + SW)	30 30						
Insulation [m^{2}K/W]	Wall Roof Floor	4.5 m^{2}K/W 6.0 m^{2}K/W 4.5 m^{2}K/W						Dutch building decree 2012 [minimum]
U-value windows [W/m^{2}K]	N (NE + NW) S (SE + SW)	1.65 W/m^{2}K 1.65 W/m^{2}K						Dutch building decree 2012 [minimum]
Solar heat factor glass	N (NE + NW) S (SE + SW)	0.6 0.6						Corresponding to type of glass
Solar heat factor blinds	N (NE + NW) S (SE + SW)	1 1						All sun goes through
Solar blinds go down	Spring Summer Autumn Winter	Never						No solar blinds
Air change rate		0.15						Dutch building decree 2012
Heat recovery efficiency		0						No heat recovery
Ventilation flow rate per person [m^3/h]	Spring Summer Autumn Winter	25.0 m^3/h 25.0 m^3/h 25.0 m^3/h 25.0 m^3/h		14.4 m^3/h 14.4 m^3/h 14.4 m^3/h 14.4 m^3/h		25.0 m^3/h 25.0 m^3/h 25.0 m^3/h 25.0 m^3/h	23.4 m^3/h 23.4 m^3/h 23.4 m^3/h 23.4 m^3/h	Dutch building decree 2012

Table 5: Input building parameters for energy status quo [base design] (by author)

Excel model:

The case study area is modeled in excel, which is based on a previous excel made by Laure Itard. This excel performs steady state calculations for 8760 hours [one year]. With real weather data from De Bilt, the Netherlands, in the year 1965 it calculates the amount of heating and cooling is needed in one year. Heating and cooling only occurs when people are in the building. Additionally, it also calculates the hourly energy demand for domestic hot water and electricity for lights and appliances. A more detailed description of the excel model and the formulas used to determine all energy demands are described in appendix A.1. The expected energy demand per demand type and function can be seen in the following Figures. These Figures contain the overall yearly energy demand, energy demand per month and energy demand for one week in a particular season.

Yearly demand:

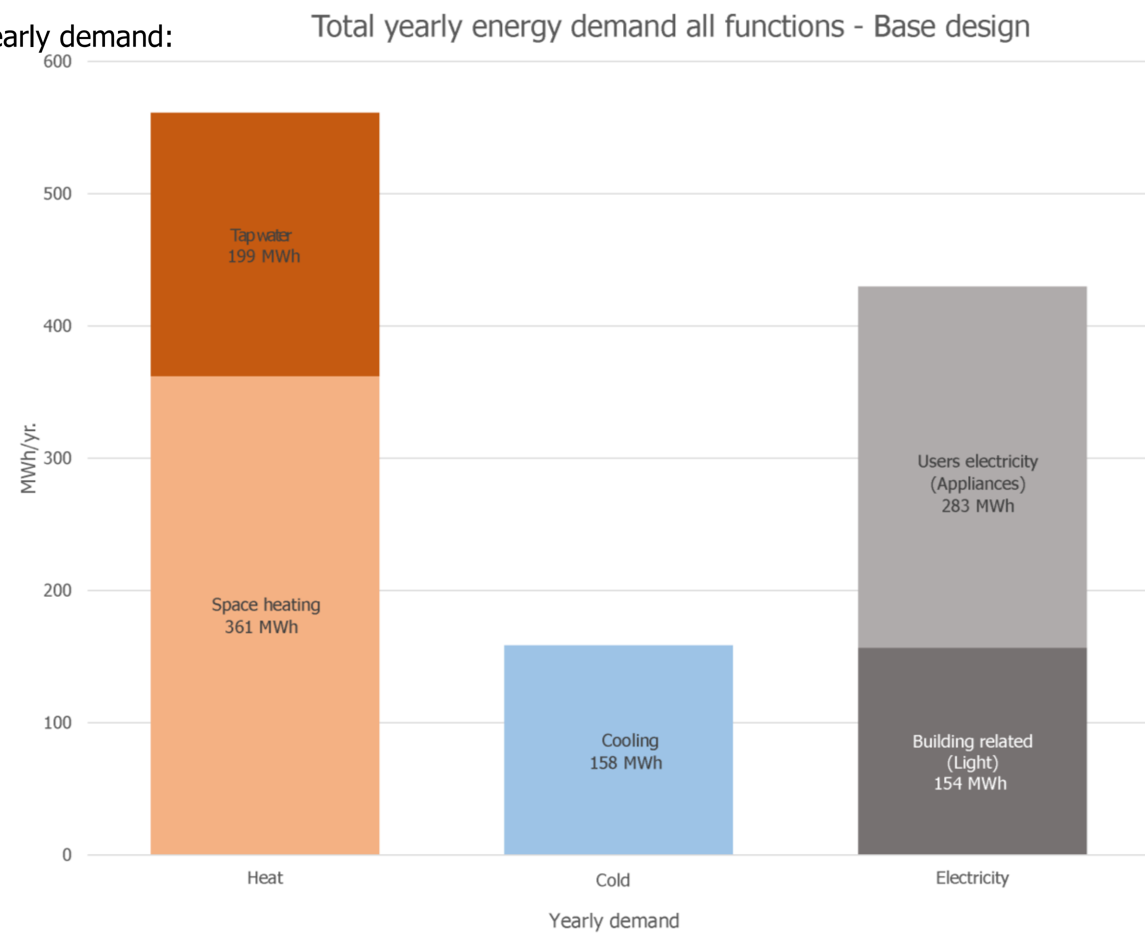


Figure 35: Overall yearly expected energy demand per energy type (by author)

Figure 35 shows the overall yearly expected energy demand per energy type. The heating demand consists of space heating and tap water, the cold demand consists of cooling and electricity consists of users electricity (appliances) and building related electricity (lights). As can be seen the energy type with the biggest demand is heating, of which space heating is the biggest contributor. Moreover, space heating is almost 2.5 times bigger than the cooling demand and users electricity (appliances) contributes for the majority of the electrical demand.

Monthly demand:

In Figure 36 the monthly energy demand values per demand type are shown. As can be seen domestic hot water and electrical energy demand are less dependent on the ambient outdoor temperature than space heating and cooling and thus have a more constant value throughout the year. Also Figure 36 shows that during winter the largest contributor to the energy demand is space heating while during summer cooling becomes the biggest energy demand per month. According to Figure 37 these large space heating peaks during winter are mainly formed by two different functions, respectively residential (buy) and hotel. Although these peaks seem rather high compared to the other functions, it can be explained by looking at the total area of each function, residential (buy) and hotel are with floor areas of almost 7000 m^2 and 5500 m^2 by far the largest function in the case study area. Another aspect that can be seen in Figure 36 is the fact that both space heating and cooling occurs in spring, summer and autumn, whereas space heating and cooling is mostly in balance during spring and autumn.

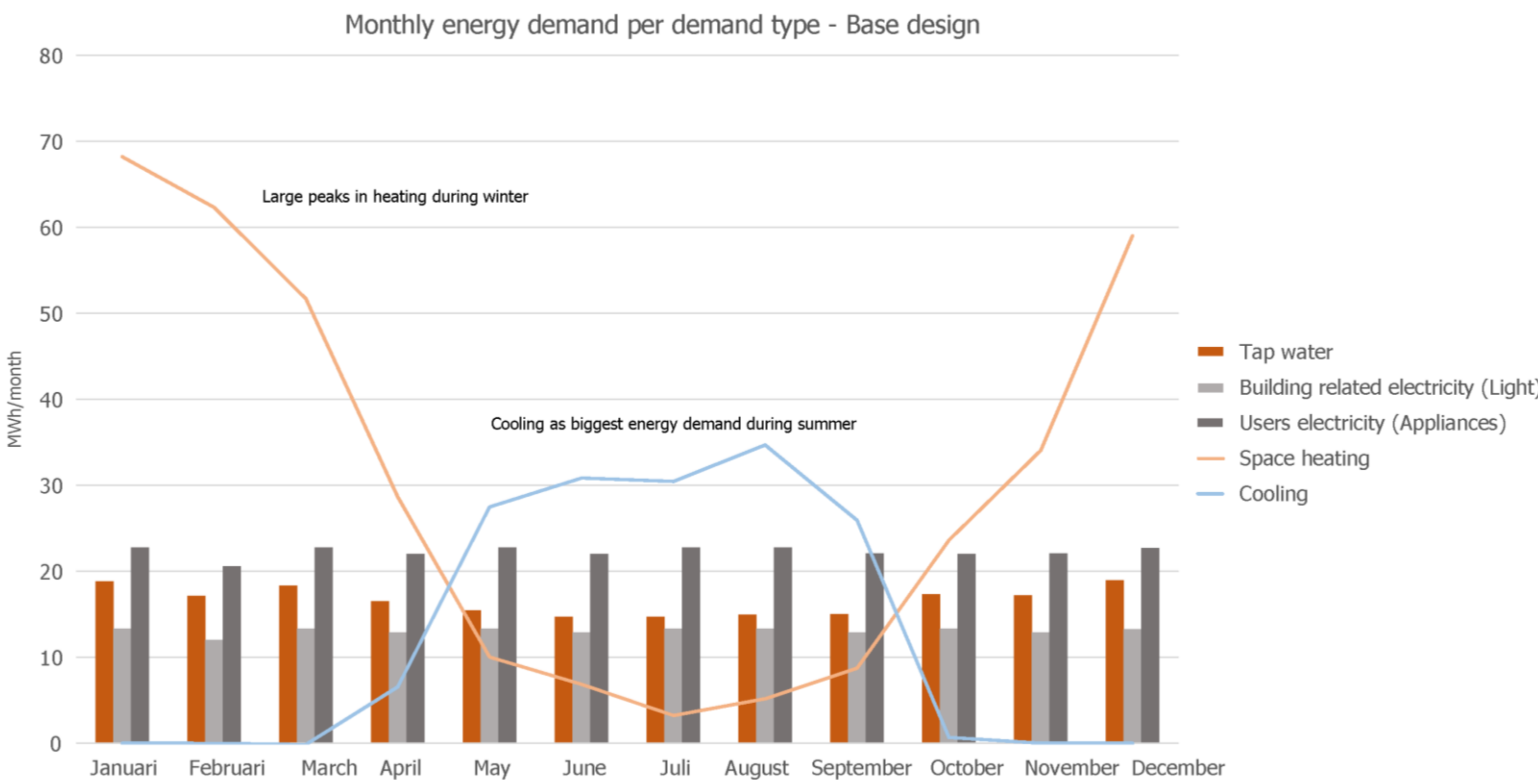


Figure 36: Monthly energy demand per demand type [base design] (by author)

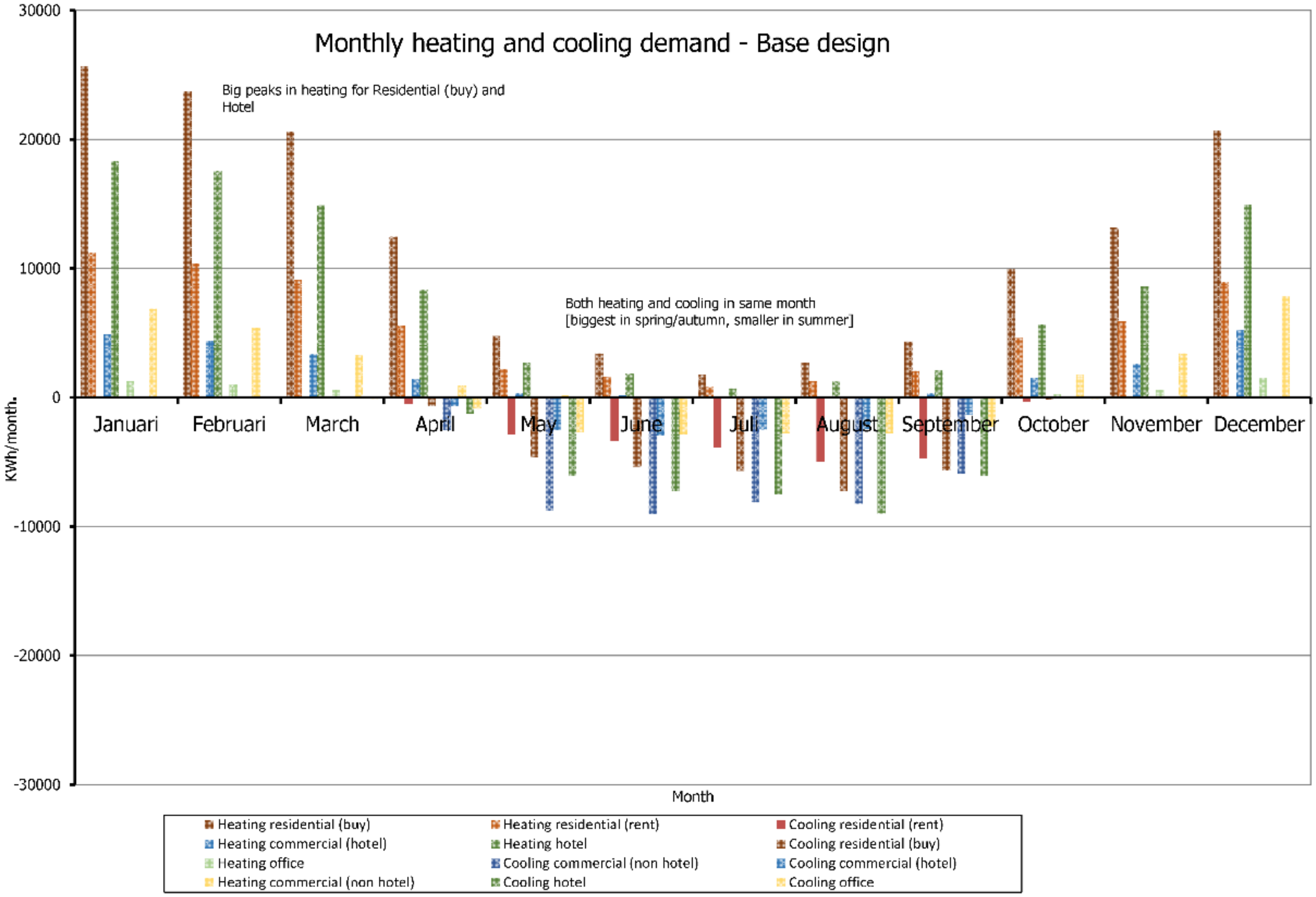


Figure 37: Monthly energy demand per function [base design] (by author)

Weekly/hourly demand:

Figures 38 and 39 show weekly/hourly heating and cooling demands per function of respectively a spring week and autumn week. For weekly/hourly graphs of the winter and summer situation see appendix A.3. In this paragraph the spring and autumn weeks are shown because these are the most interesting seasons. Winter and summer are rather 'extreme', i.e. the majority of the demand is either heating or cooling, whereas in spring and autumn both heating and cooling can occur in the same day [depends on the parameters] and create a balance between heating and cooling.

As can be seen in Figure 38 in spring only heating occurs, of which residential (buy) and hotel are the largest contributors. Almost all heating take place at the same time, however, every functions has its own amount of heating per hour. Figure 39 represents the energy profile of all functions during a week in autumn. The two main differences between spring and autumn are firstly, the time shift in energy demand, in spring the energy demand falls in the early morning whereas in autumn the demand shifts to morning and afternoon. And, secondly, in autumn both heating and cooling occurs in one day. In both diagrams the difference in outdoor temperature over several days can be seen, especially in autumn in which there is a large cooling peak on Sunday compared to a smaller peak on Saturday.

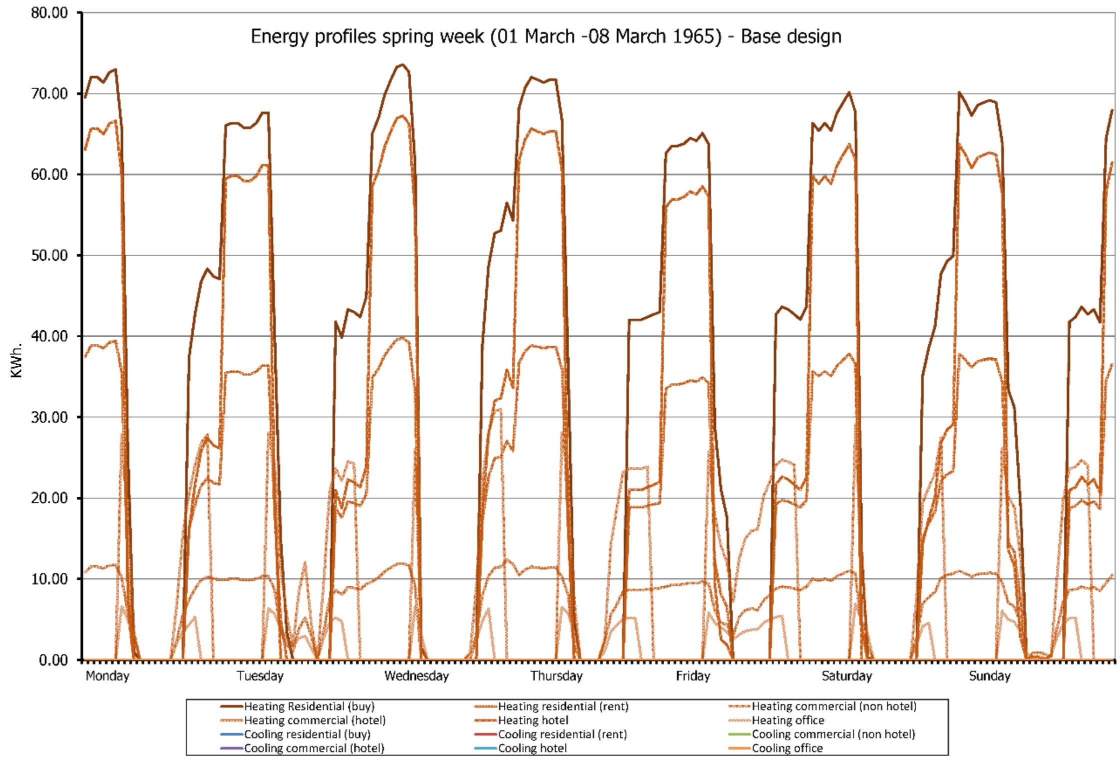


Figure 38: Weekly/hourly demand spring week (by author)

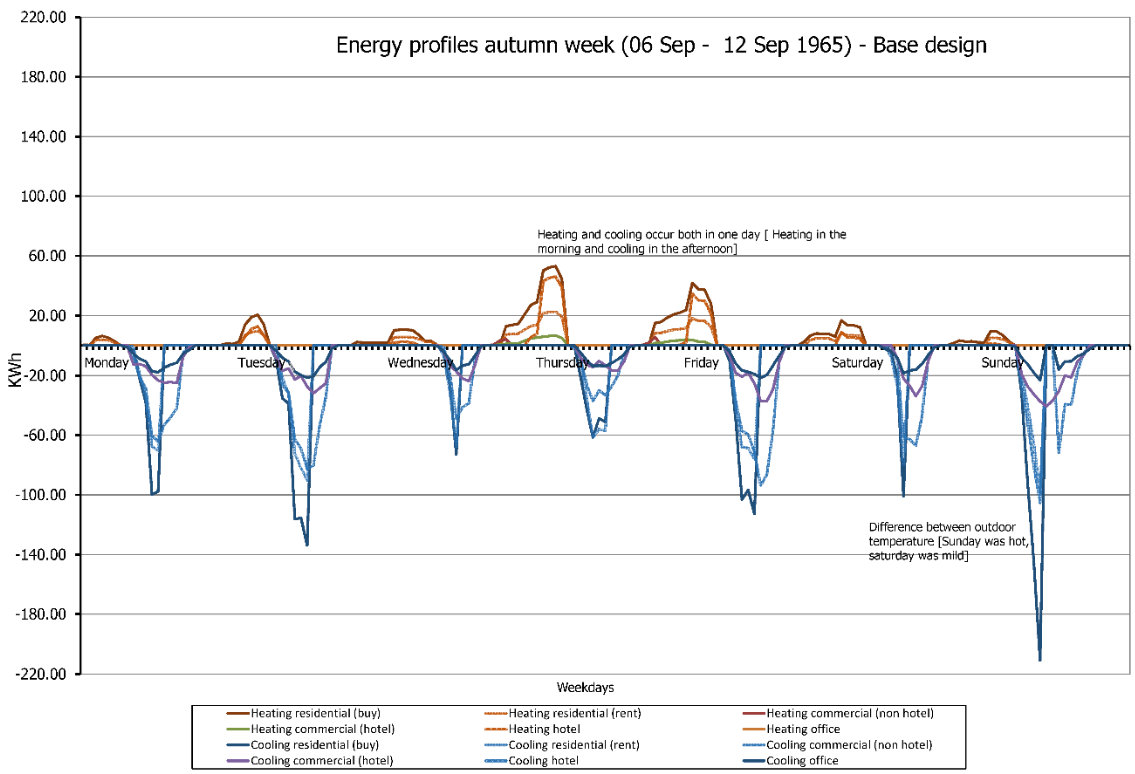


Figure 39: Weekly/hourly demand autumn week (by author)

Energy demands per m² and validation:

In order to be able to compare different design options and to reference buildings with the same functions Table 6 provides the yearly energy demand per m² for each demand type. Additionally, Table 7 shows an overview of energy demand per m² of reference buildings according to BENG kentallen Uniforme maatlat gebouwde omgeving (Agentschap NL, 2018)

Energy demand per function for BASE DESIGN					
	Space heating	**Cooling**	**Tap water**	**Electricity lighting**	**Electricity not building related [appliances]**
	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]
Residential (buy) [Apartment]	30.4	6.3	11.7	4.6	17.5
Residential (rent) [Apartment]	37.3	12.1	11.7	4.6	17.5
Shop [commercial non hotel]	15.4	23.2	2.1	10.4	26.4
Shop [commercial hotel]	29.3	15.2	2.1	12.3	26.3
Hotel	19.0	7.3	23.2	18.4	17.5
Office	16.8	48.6	1.8	13.3	33.2

Table 6: Yearly energy demand per m² for each demand type (by author)

Energy demand per function according to BENG kentallen Uniforme Maatlat Gebouwde Omgeving (Agentschap NL, 2018)					
	Space heating [kWh/m²/jr]	**Cooling [[kWh/m²/jr]**	**Tap water [kWh/m²/jr]**	**Electricity lighting [kWh/m²/jr]**	**Electricity not building related [appliances]**
	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]	[kWh/m²/jr]
Apartment	9.5	8	12.3	5.0	19.9
Office	14.5	6.6	1.4	13.9	35
Shop [commercial]	34.5	3.9	1.4	11.6	26.3

Table 7: Yearly energy demand per m² according to Beng kentallen uniforme maatlat gebouwde omgeving (by author)

Hotel: For the hotel no reference numbers were to be found. Therefore, for the calculation of DHW and electricity lighting and not building related the given outcomes per m² are based on the residential function, but will be higher because of the schedule of the hotel compared to residential.

By comparing the calculated energy demand per m² with the energy demand as stated for a reference building it can be seen that the heating demand of the residential function is much higher than the residential function in the reference design. Also, the cooling demand of residential (rent), commercial (non-hotel), commercial (hotel) and office is much higher than in the reference building. A possible explanation for this difference is the fact that the thermal mass of a building is out of scope for this research and therefore, not included in this research. Moreover, the energy demand of tap water, electricity for lighting and appliances all fall in the same range.

4.3 Energy potentials

The third step in the Smart Urban Isle method is energy potentials. In this chapter architectural design, energy exchange and local energy supply opportunities are talked about. For the section architectural design a parameter study is carried out and the results are highlighted, compared to the energy status quo design [base design] and implemented in an 'improved' design. In the section energy exchange three designs are analyzed based on the balance between space heating and cooling, i.e. the possibility to exchange heat over time, and the role of each function in this balance is described. After that, the paragraph local energy supply opportunities provides an overview of possible local energy supply for this particular case study based on its context and the described energy supply options as stated in chapter 3.3.

4.3.1 Architectural design

Within the architectural design potential the bioclimatic context of the case study area is used to improve the overall energy demand. As mentioned in chapter 4.2 the space heating and cooling demand of most functions is rather high compared to reference buildings. Space heating and cooling largely depends on the outdoor climate and the used building design parameters. Tap water is also dependent on the outdoor climate, whereas the outdoor climate does not influence the electricity demands. Additionally, tap water and the electricity demands are not influenced by building design parameters at all. Thus, to understand what the impact of each building design parameter is on the space heating and cooling demand a parameter study is performed. As base design the same parameters are used as for the energy status quo design. For the parameter study every time one of the following parameters is changed:

- Indoor temperature heating mode setting point
- Indoor temperature cooling mode setting point
- Window percentage
- Insulation value
- Heat recovery efficiency
- Blind control

Or the following parameters are combined:

- Window percentage + blind control
- Window percentage + insulation value windows.

The value these parameters are changed to are based on state of the art products/technologies or based on radical situation changes. For each parameter study the impact of changing the parameters of one function on the overall space heating and cooling demand and the impact of changing the parameters of all functions at the same time on the overall space heating and cooling demand are studied and compared to the energetic demand values of the base design. Table 8 shows the impact of changing the parameters for all functions on the energetic demand. For an overview of the impact of parameter changes on each separate function see appendix A.3.

		Influence per parameter change for all functions on yearly heating and cooling demand compared to base design			
Parameter group	Parameter	Old	New	Heating [%]	Cooling [%]
Indoor temperature heating and cooling mode setting points	Cooling mode set-point (summer and autumn)	20-21 ºC	28 ºC	0 %	-44 %
	Cooling mode set-point (winter and spring)	20-21 ºC	28 ºC	0 %	-10 %
	Heating mode set-point (summer and autumn)	24 ºC	18 ºC	-9 %	0 %
	Heating mode set-point (winter and spring)	24 ºC	18 ºC	-22 %	0 %
Window percentage	North (NE + NW) façade	30 %	80 %	+ 53 %	+ 90 %
	South (SE + SW) façade	30 %	80 %	+ 49 %	+ 202 %
Insulation value	Wall: R_c value	4.5 m^2K/W	10 m^2K/W	-13 %	+ 2 %
	Roof: R_c value	6 m^2K/W	10 m^2K/W	-3 %	+ 1 %
	Floor: R_c value	4.5 m^2K/W	10 m^2K/W	-3 %	+ 4 %
	Window North (NE + NW) façade: U-value & solar heat factor	U-value: 1.65 W/m^2K SHF: 0.6	U-value: 0.7 W/m^2K SHF: 0.5	-22 %	-5 %
	Window South (SE + SW) façade: U-value & solar heat factor	U-value: 1.65 W/m^2K SHF: 0.6	U-value: 0.7 W/m^2K SHF: 0.5	-21 %	-13 %
	Insulation value wall, roof, floor, windows: Rc value, U-value and solar heat factor	Rc = 4.5-6 m^2K/W U-value: 1.65 W/m^2K SHF: 0.6	Rc = 10 m^2K/W U-value: 0.7 W/m^2K SHF: 0.5	-57 %	-14 %
Heat recovery efficiency	Heat recovery	0	0.9 for residential (small) and the rest 0.7	-40 %	0 %
Blind control with maximum solar heat factor blinds	Blind control during hot season (summer + autumn)	No blind control	Blind control above 150 W. Solar heat factor blinds on all façades for residential, hotel and office: 0.15 & commercial: 0.5	0 %	-51 %
	Blind control during cold season (winter + spring)	No blind control	Blind control above 150 W. Solar heat factor blinds on all façades for residential, hotel and office: 0.15 & commercial: 0.5	0 %	-14 %
Window percentage + blind control	Glazing percentage north (NE + NW) façade + blind control during hot season (summer + autumn)	Glazing: 30 % No blind control	Glazing: 80 % Blind control above 150 W. Solar heat factor blinds on all façades for residential, hotel and office: 0.15 & commercial: 0.5	+ 52 %	-12 %
	Glazing percentage south (SE + SW) façade + blind control during hot season (summer + autumn)	Glazing: 30 % No blind control	Glazing: 80 % Blind control above 150 W. Solar heat factor blinds on all façades for residential, hotel and office: 0.15 & commercial: 0.5	+ 49 %	+ 6 %
Window percentage + insulation value windows	Glazing percentage north (NE + NW) façade + U-value & solar heat factor windows	Glazing: 30 % U-value: 1.65 W/m^2K SHF: 0.6	Glazing: 80 % U-value: 0.7 W/m^2K SHF: 0.5	-7 %	+ 71 %
	Glazing percentage south (NE + NW) façade + U-value & solar heat factor windows	Glazing: 30 % U-value: 1.65 W/m^2K SHF: 0.6	Glazing: 80 % U-value: 0.7 W/m^2K SHF: 0.5	-8 %	+ 151 %

Table 8: Influence per parameter change for all functions on yearly heating and cooling demand compared to base design (by author)

As can be seen in Table 8 some parameter changes increase both the heating and cooling load, other changes decrease both heating and cooling demand, while others increase one demand and decreasing or not changing the other demand. Most parameter changes have the expected outcome, however some changes have to be more elaborated on. For example, changing the window percentage to 80 %, the cooling demand is expected to increase, however, the heating demand increases as well. This is mainly due to the fact that with only changing the window percentage parameter the insulation value of the windows stays the same as in the base design; U-value = 1.65 W/m^{2}K. Therefore, the heat loss through transmission during the night and early morning is larger than the solar heat gains during the day. This transmission loss during the night could be reduced by introducing a lower U-value for all windows. With a U-value of 0.7 W/m^{2}K the biggest effect in overall heating demand reduction could be found by keeping the window percentage low. However, with a window percentage of 80 % and a U-value of 0.7 W/m^{2}K there is still a significant decrease in heating demand. Although the heating demand decreases, the cooling demand increases, but this demand could be reduced by introducing mechanical outdoor solar blinds. Another parameter change that needs to be more elaborated on are the indoor temperature heating and cooling mode setting points. These setting points have the potential to decrease both heating and cooling significantly throughout the year. However, most heating and cooling systems work with a desired indoor temperature rather than rigid setting points at what temperature heating and cooling occurs. Hence, this parameter change is interesting to see the theoretical impact, but is not that practical to implement.

To provide a visual overview of the impact of building design parameters on the space heating and cooling demand compared to the base design the following parameters are shown in Figures 40 and 41: insulation value, heat recovery efficiency, window percentage + blind control and window percentage + insulation value windows.

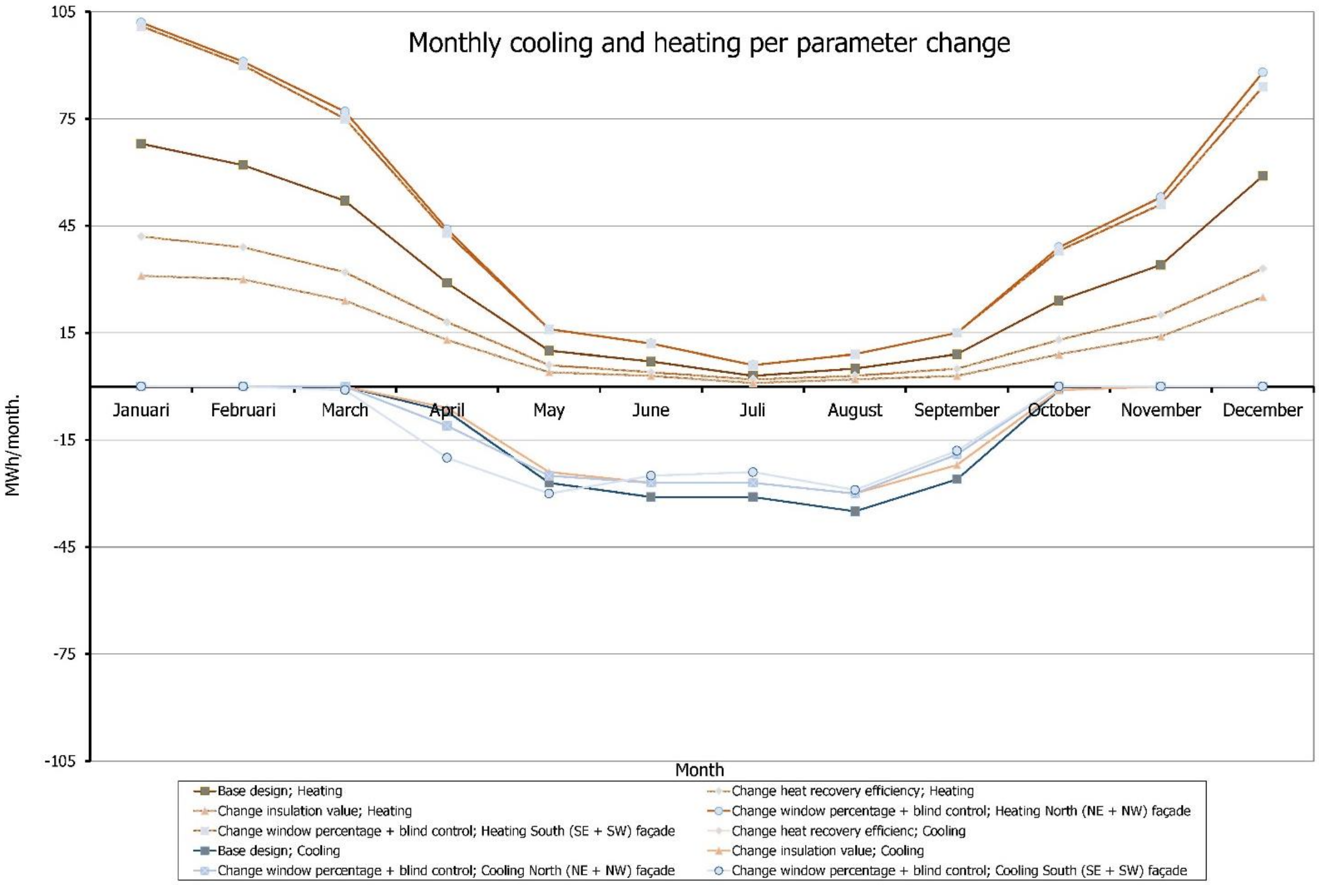


Figure 40: Monthly impact of parameter change on energy demand compared to base design (by author)

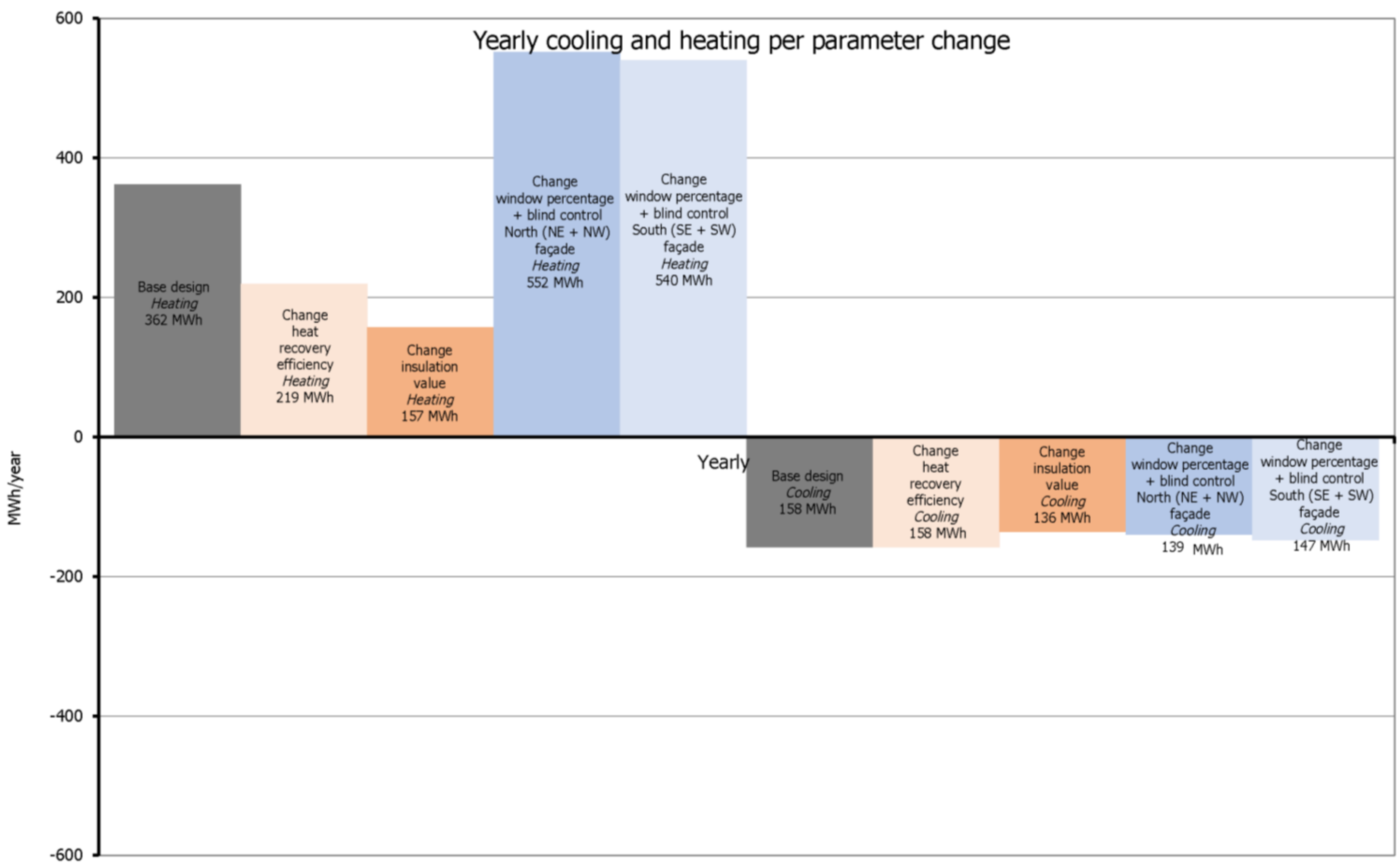


Figure 41: Yearly impact of parameter change on energy demand compared to base design (by author)

Improved base design:

The above described parameter study can be used to improve the base design in order to reduce the overall heating demand and simultaneously increase the cooling demand. For this improvement only the building design parameters are changed. Therefore, the improved base design still has the same parameters for amount of people, floor areas, user schedules and light + appliances schedule. Thus, within this improved base design the demands for tap water, electricity light and electricity appliances are same as for the base design. By changing all parameters to its maximum values as stated in the paragraph above the overall energy reduction could be 85 % of the total energy needed for heating and cooling. However, to improve the base design in a more realistic way the parameters are changed to the values stated in Table 9. With these parameters the space heating demand is reduced by 67 % to 119 MWh/year and the cooling demand is reduced by 28 % to 114 MWh/year. These demands can also be seen in the following Figures which contain the overall yearly energy demand, energy demand per month and energy demand for one week in a particular season. Moreover, the difference between base design and improved base design is explained.

		Residential (Buy)	**Residential (Rent)**	**Commercial (Non-hotel)**	**Commercial (Hotel)**	**Hotel**	**Office**	**Based on**
Indoor temperature heating mode [°C]	Spring Summer Autumn Winter	20 °C 20 °C 20 °C 20 °C		21 °C 21 °C 21 °C 21 °C				Dutch building decree 2012 [minimum]
Indoor temperature Cooling mode [°C]	Spring Summer Autumn Winter	24 °C 24 °C 24 °C 24 °C						Dutch building decree 2012 [minimum]
Window percentage [%]	N (NE + NW) S (SE + SW)	50 50						
Insulation [m²K/W]	Wall Roof Floor	6.0 m²K/W 8.0 m²K/W 8.0 m²K/W						
U-value windows [W/m²K]	N (NE + NW) S (SE + SW)	0.7 W/m²K 0.7 W/m²K						Maximum U-value [state of the art]
Solar heat factor glass	N (NE + NW) S (SE + SW)	0.5 0.5						Corresponds with U value window
Solar heat factor blinds	N (NE + NW) S (SE + SW)	0.15 0.15		1 0.5		0.15 0.15		Dutch building decree 2012 [maximum]
Solar blinds go down with incoming solar radiation of	Spring Summer Autumn Winter	150 W 150 W 150 W 150 W						
Infiltration rate [ACH]		0.15						Dutch building decree 2012
Heat recovery efficiency		0.9		0.7				Maximum heat recovery [state of the art]
Ventilation flow rate per person [m³/h]		25.0 m³/h		14.4 m³/h		25.0 m³/h	23.4 m³/h	Dutch building decree 2012 [minimum]

Table 9: Input building parameters for energy potentials [improved base design] (by author)

Yearly demand:

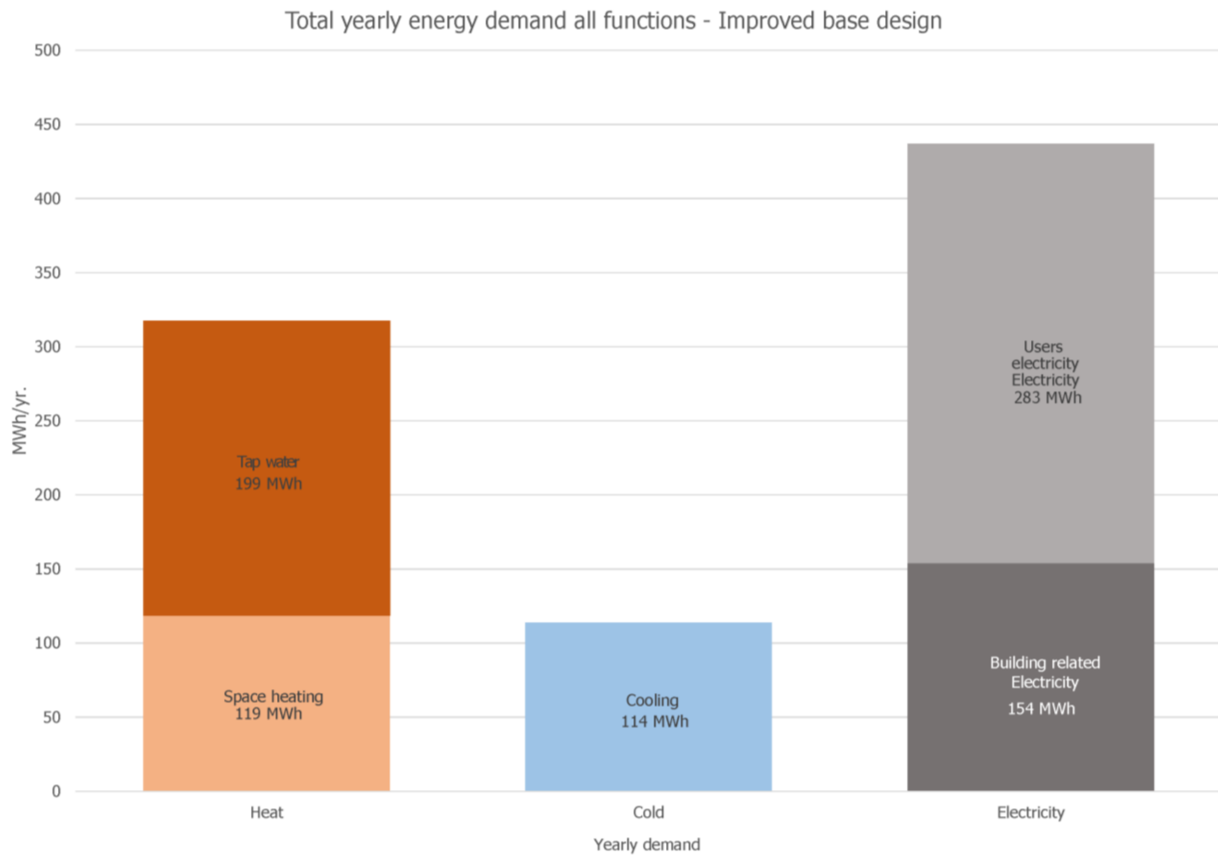


Figure 42: Overall yearly expected energy demand per energy type (by author)

Figure 42 shows the yearly expected energy demand per energy type. Again the heating demand consists of space heating and tap water, the cooling demand consists of cold and electricity consists of users electricity (appliances) and building related electricity (lights). As can be seen in Figure 42 the energy type with the biggest demand is electricity, whereas in the base design the biggest demand was heating. Additionally, within the improved design space heating and cooling are almost in balance, while in the base design space heating was almost 2.5 times bigger than the cooling demand.

Monthly demand:

In Figure 43 the monthly energy demand values per demand type are shown. Compared to the overall demands in the base design all energy demands are more leveled out to each other than before. Now almost all year round electricity (appliances) is the biggest energy demand per month. Only in summer cooling becomes slightly larger than electricity (appliances). However, according to Figure 44 there are still large peaks in both heating and cooling throughout the year. In winter there is a heating peak caused by the function residential (buy), but, it has to be noted that this peak is around 50 % less than the peak caused by the same function in the base design, the heating peaks by the function hotel in the base design are completely leveled out to other function in the improved design and functions like commercial and office do not have a heating demand at all anymore. In summer there are still cooling peaks caused by the function commercial (non-hotel), but again, it has to be noted that this demand is slightly larger than the cooling demand for the same function in the base design, only in the improved design the cooling demand for all other functions decreased more significantly. Another aspect that can be seen in Figure 43 is the fact that both space heating and cooling occurs in spring, summer and autumn, however, in contrary to the base design these demands are more imbalanced in one month than in the base design. For the whole year the cooling and space heating demand are more in balance.

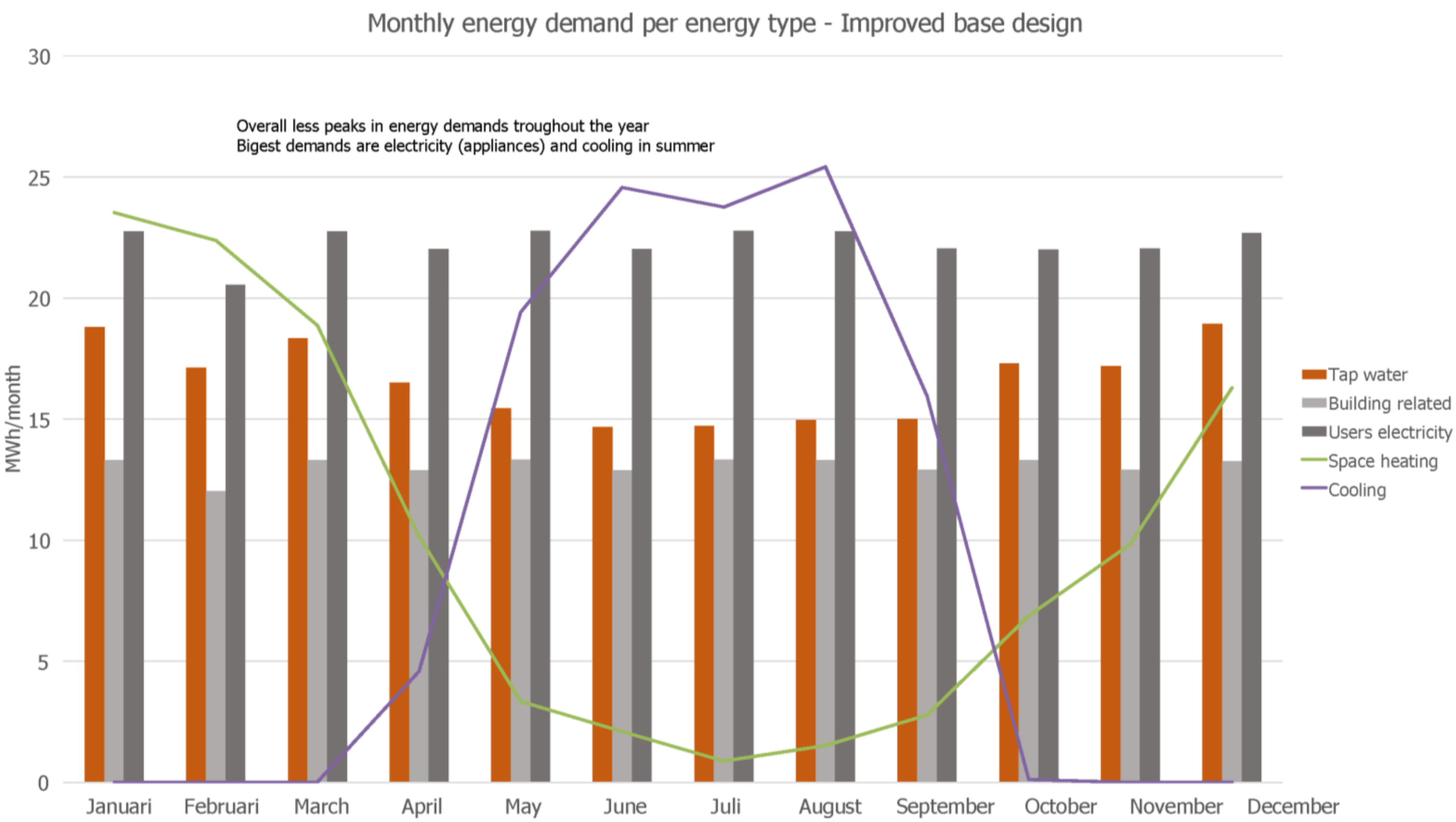


Figure 43: Monthly energy demand per demand type [Improved base design] (by author)

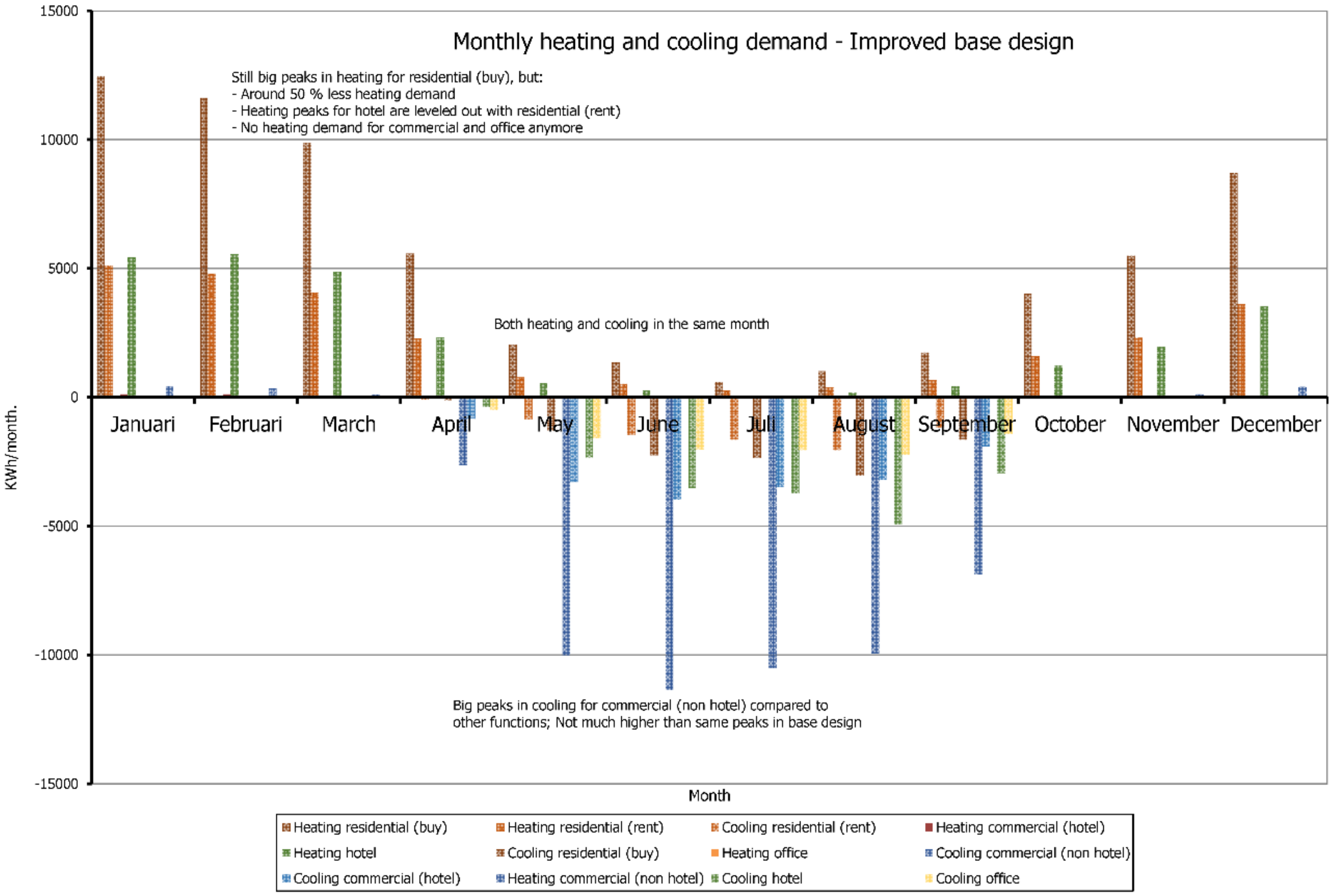


Figure 44: Monthly energy demand per function [Improved base design] (by author)

Weekly/hourly demand:

Figures 45 and 46 show weekly/hourly heating and cooling demands per function of respectively a spring week and autumn week. For weekly/hourly graphs of the winter and summer situation see appendix A.4. Again in this paragraph the spring and autumn weeks are shown because these are the most interesting seasons. Winter and summer are rather 'extreme', i.e. the majority of the demand is either heating or cooling, whereas in spring and autumn both heating and cooling can occur in the same day [depends on the parameters] and create a balance between heating and cooling. As can be seen in Figure 45 in spring only heating occurs, of which residential (buy) is the largest contributor. Almost all heating take place during the night/early morning. In contrary to the base design only residential (buy), residential (rent), hotel and commercial (non- hotel) have their own amount of heating per hour, however, compared to the base design the peaks are shaped off by almost 45 %. Figure 46 represents the energy profile of all functions during a week in autumn. The two main differences between spring and autumn are firstly, the time shift in energy demand, in spring the energy demand falls in the early morning whereas in autumn the demand shifts to morning and afternoon. Additionally, both heating and cooling peaks in autumn are shaped off by almost 25 %. And, lastly, in autumn both heating and cooling occurs in one day. In both diagrams the difference in outdoor temperature over several days can be seen, especially in autumn in which there is a large cooling peak on Sunday compared to a smaller peak on Thursday.

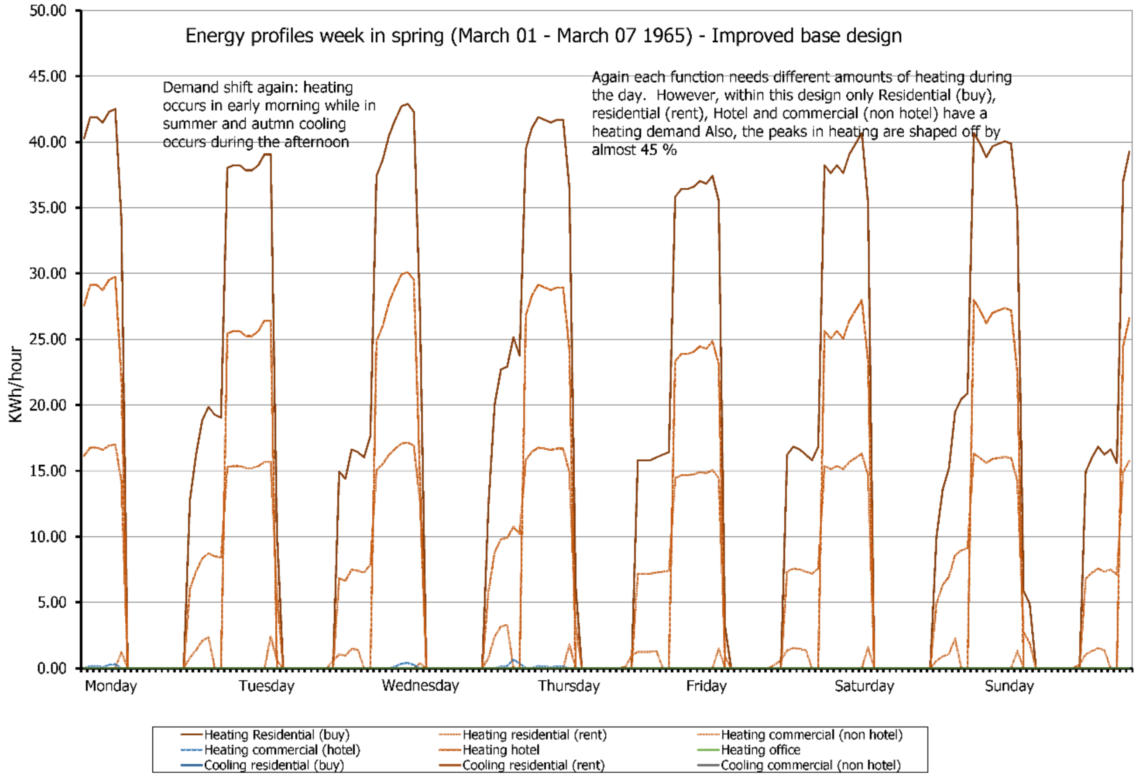


Figure 45: Weekly/hourly energy demand spring week per function (by author)

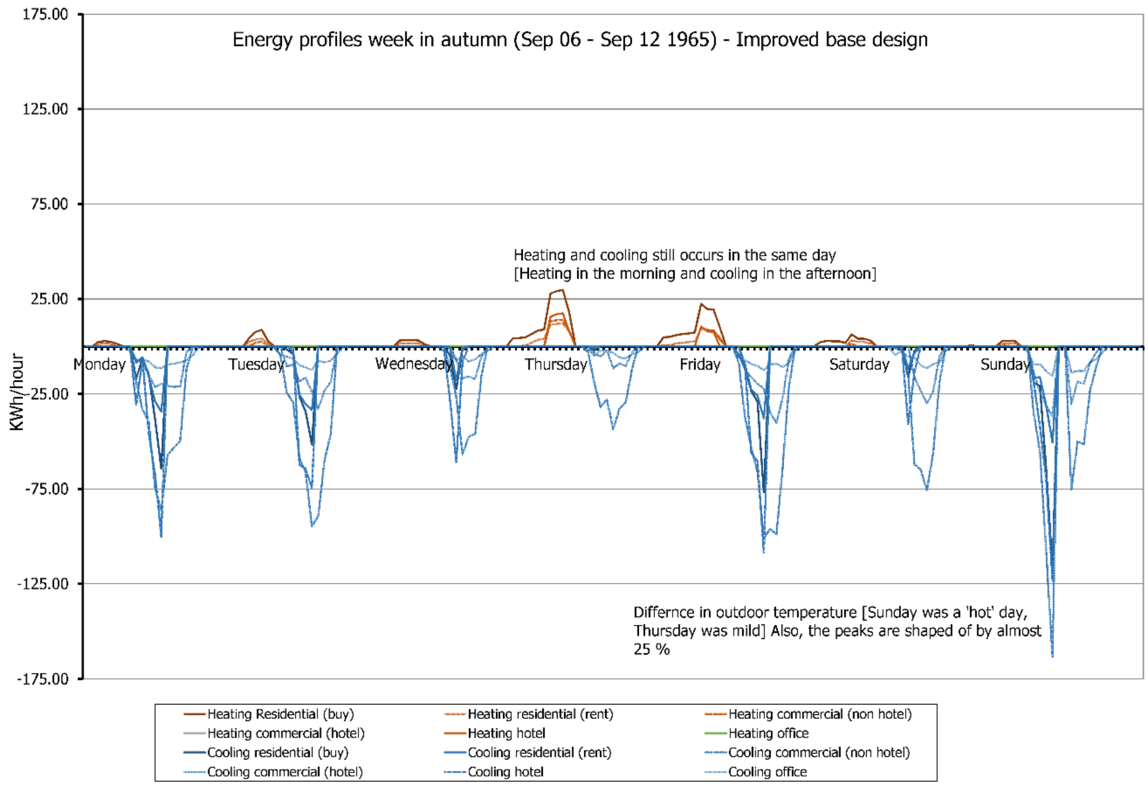


Figure 46: Weekly/hourly energy demand autumn week per function (by author)

Energy demand per m^2:

Table 10 shows the yearly energy demand per demand type per m^2 for each function. As can be seen residential and hotel functions need more heating over the year than cooling. For commercial and office functions this is the other way around. Compared to the base design the overall energy demand is decreased significantly. Compared to the reference building however, space heating for residential functions are still much higher and for commercial and office functions the same goes for the cooling demand. Again, a possible explanation is the thermal mass that is not included in this research.

Energy demand per function for IMPROVED BASE DESIGN					
	Space heating [kWh/m^2/jr]	**Cooling [kWh/m^2/jr]**	**Tap water [kWh/m^2/jr]**	**Electricity lighting [kWh/m^2/jr]**	**Electricity not building related [appliances]**
	[kWh/m^2/jr]	[kWh/m^2/jr]	[kWh/m^2/jr]	[kWh/m^2/jr]	[kWh/m^2/jr]
Residential (buy) [Apartment]	13.7	2.3	11.7	4.6	17.5
Residential (rent) [Apartment]	15.5	4.3	11.7	4.6	17.5
Shop [commercial non hotel]	0.7	26.9	2.1	10.4	26.4
Shop [commercial hotel]	0.4	20.4	2.1	12.3	26.3
Hotel	5.2	3.5	23.2	18.4	17.5
Office	0	32.8	1.8	13.3	33.2

Table 10: Yearly energy demand per m^2 for each demand type (by author)

4.3.2 Energy exchange

Within the case study there are five different types of energy: Space heating, Cooling, Tap water, Electricity (lighting) and Electricity (appliances). These can be divided into three categories; Heating, Cooling and Electricity. Space heating and tap water together are the heating category, cooling is a category on its own, electricity (light) and electricity (appliances) both fall in the electricity category. Additionally, each function has its own user profile, hence, each function has a slightly different overall energy demand profile. When the time and amount of energy differs per function over a week/month there is a possibility to exchange energy over time. As mentioned earlier electricity and tap water are more constant values throughout the year, because they are less dependent on the climatic context of the case study area. Although tap water is more constant throughout the year there can also exist exchange between tap water and cooling. Thus, the energy types that has to be considered for energy exchange are tap water, space heating and cooling. Therefore, in this paragraph the possibilities to exchange heat-cold between different functions throughout the year are analyzed and a comparison between different designs is made.

Heat-cold ratio:

To be able to compare different designs with each other the energy exchange possibility should be expressed quantitatively. This can be done through defining the heating and cooling demand per x amount of time as a heat-cold ratio. This ratio explains the amount of cooling that is equivalent to 1 kWh of heating per x amount of time, i.e. it can be expressed as the following equation:

$$Heat - cold\ ratio = \frac{Amount\ of\ cooling\ over\ time\ x}{Amount\ of\ space\ heating + tap\ water\ over\ time\ x} \quad [-]$$

An outcome closer to 1 means that the amount of cooling and heating is in balance over x amount of time. An outcome closer to 0 indicates that there is more heating needed than cooling and an outcome bigger than 1 points out that there is a larger cooling demand over time x.

Case study analysis:

For this case study the heat-cold ratio is expressed on a yearly, monthly basis and per function type. Per function type is added in order to be able to evaluate the influence of multi functionality on the energy balance. This evaluation is done for the base design, improved base design and an extra design; improved base design with continuous cooling. The extra design provides knowledge about the impact of focusing on overall system optimization rather than every function focusses on its own.

Base design:

For the base design the overall space heating demand is 362 MWh/year, heating demand for tap water is 199 MWh/year (total heating demand is 561 MWh/year) and the overall cooling load is 158 MWh/year. On a yearly basis this means that 28 % of the heating demand can be provided by extracting heat from different functions. However, as you can see in Table 11 cooling demand only occurs from April to September, which indicates that when energy exchange is wanted thermal energy storage has to be included in the energy system design. Additionally, as can be seen in Table 12, within this design the functions commercial (non-hotel) and office need more cooling in a year while all other functions need significantly more heating per year.

Month	Heating [kWh]	Cooling [kWh]
January	1	0
February	1	0
March	1	0
April	1	0.1
May	1	1.1
June	1	1.4
July	1	1.7
August	1	1.7
September	1	1.1
October	1	0
November	1	0
December	1	0
Yearly	1	0.28

Table 11: Heat-cold ratio base design: Monthly and yearly (by author)

Function	Heating [kWh]	Cooling [kWh]
Residential (buy)	1	0.2
Residential (rent)	1	0.3
Commercial (non-hotel)	1	1.3
Commercial (hotel)	1	0.5
Hotel	1	0.17
Office	1	2.6

Table 12: Heat-cold ratio base design per function: Yearly (by author)

Improved base design:

The overall space heating for the improved base design is 119 MWh/year, heating demand for tap water is 199 MWh/year (total heating demand is 318 MWh/year) and the overall cooling load is 114 MWh/year. On a yearly basis this means that 36 % of the heating can be provided through cooling. However, as you can see in Table 13, again, cooling demand only occurs from April through September. Thus, when energy exchange is wanted again a thermal energy storage has to be included in the energy system design. In contrast to the base design, the cooling demand of the functions commercial (non-hotel), commercial (hotel) and office increased significantly, the office function does not need heating at all anymore. This is mainly due to the fact that the insulation value of the buildings is increased significantly, which leads to less heat flowing out of the building. Thus, when more heat is needed in a year one of these three functions can be added in order to compel to this heat increase.

Month	Heating [kWh]	Cooling [kWh]
January	1	0
February	1	0
March	1	0
April	1	0.2
May	1	1.0
June	1	1.5
July	1	1.5
August	1	1.5
September	1	0.9
October	1	0
November	1	0
December	1	0
Yearly	1	0.36

Table 13: *Heat-cold ratio improved base design: Monthly and yearly (by author)*

Function	Heating [kWh]	Cooling [kWh]
Residential (buy)	1	0.1
Residential (rent)	1	0.2
Commercial (non-hotel)	1	9.7
Commercial (hotel)	1	8.3
Hotel	1	0.12
Office	0	18.5

Table 14: Heat-cold ratio improved base design per function: Yearly (by author)

Extra design; Improved base design with continuous cooling:

In order to gain knowledge about the impact of focusing on overall system optimization rather than every function focusses on its own an extra design is created; Improved base design with continuous cooling. This design is a design with the same design parameters as the improved base design, but with continuous cooling throughout the year. This means that the functions are also cooled when no one is present. Within this design the total heating demand (space heating and tap water) is 318 MWh/year and the cooling demand increases up to 281 MWh/year. This means that 88 % of the heating demand can be fulfilled with subtracting heat from buildings, i.e. cooling. In contrast to both other designs, it can be seen in Table 15 that within the extra design cooling occurs from January to October. In winter buildings with the function residential are passively heated up through the sun when no one is present in the afternoon. Again, the heat-cold ratio of commercial and office functions is higher than the other functions, but, the heat-cold ratio for residential is closer to 1, which means that the residential function is more in balance as well.

Month	Heating [kWh]	Cooling [kWh]
January	1	0.1
February	1	0.2
March	1	0.3
April	1	0.8
May	1	2.6
June	1	3.2
July	1	3.7
August	1	2.9
September	1	1.7
October	1	0.1
November	1	0
December	1	0
Yearly	1	0.88

Table 15: Heat-cold ratio extra design: Monthly and yearly (by author)

Function	Heating [kWh]	Cooling [kWh]
Residential (buy)	1	0.7
Residential (rent)	1	0.9
Commercial (non-hotel)	1	14.6
Commercial (hotel)	1	13.8
Hotel	1	0.3
Office	1	22.1

Table 16: Heat-cold ratio extra design per function: Yearly (by author)

Impact of continuous cooling:

The impact of continuous cooling can best be explained using the weekly heating and cooling profiles. Figure 47 and 48 show the weekly energy profiles of a week in spring and autumn. For the weekly profiles in winter and summer see appendix A.4. As can be seen in Figure 46 in contrast to the previous designs cooling is introduced in spring, in previous designs cooling mostly occurred in summer. This means that with continuous cooling the time in which energy can be exchanged throughout the year is shorter than compared to the other designs, i.e. less need for seasonal thermal energy storage. Additionally, as can be seen in Figure 47 in autumn now heating and cooling take place at the same time. This means that within a design with continuous cooling and without changing the functions in the area, direct heat exchange between functions take place instead of exchange through temporal thermal storage. However, the impact of continuous cooling also largely depends on the energy system configuration that is chosen. When energy exchange between functions over time is not possible continuous cooling only increases both heating and cooling demand. Contrary, in the case of this research where energy exchange is possible continuous cooling allows to provide 86 % of the total heating demand (Space heating, Tap water and distribution losses) by subtracting heat from the buildings through cooling.

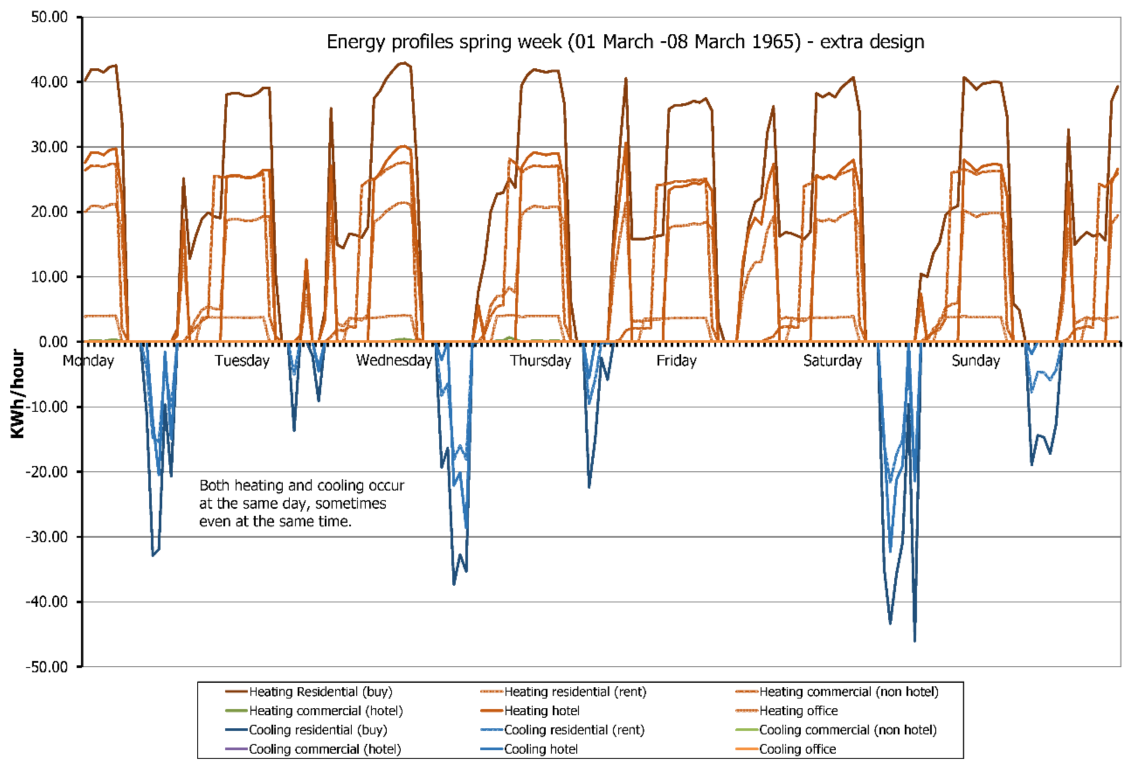


Figure 47: Weekly energy profile spring – continuous cooling (by author)

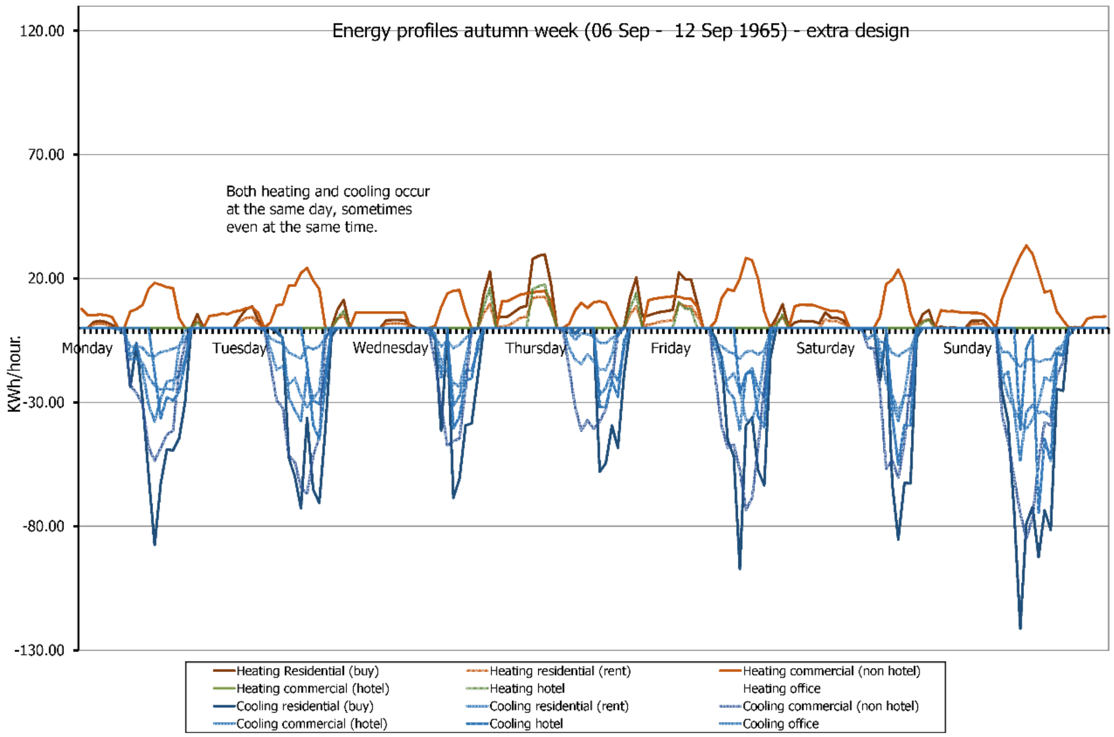


Figure 48: Weekly energy profile autumn – continuous cooling (by author)

Impact of multi functionality on the heat-cold balance:

As is analyzed in the above paragraph the impact of multi functionality on the heat-cold balance largely depends on the design parameters the building has. For a design with the minimal requirements according to the Dutch building decree [base design] the difference of heat-ratio between the functions is rather minimal, only the function office needs some more cooling than the other functions. This is due to the fact that the buildings are not that well insulated, which leads to a lot of heat transfer through the façade. When a design is optimized using the bioclimatic context [improved base design] however, the difference between the several functions increases, i.e. commercial (hotel) has now a heat-cold ratio of 1:9,7. This is mainly due to the fact that within in optimized bioclimatic design the insulation value significantly increases and it optimally uses passive heat/cooling of its bioclimatic context (window percentage and orientation). Which indicates that the cooling demand could significantly be increased or decreased by adding/removing these functions. When continuous cooling is introduced into the design the impact of multi functionality slightly increases more. With continuous cooling the yearly overall heat-cold ratio for commercial and office increases while the heat-cold ratio of residential comes closer to 1, which means that the residential function on its own becomes more in balance. Thus, multi functionality could potentially have a big impact on the overall energy balance within all bioclimatic based improved designs. However, for each separate design the best way to increase the cooling demand should be chosen, i.e. introducing continuous cooling or increasing the amount of functions with a higher heat-cold ratio in the design.

4.3.3 Local renewable supply potentials

To design an energy system for the case study area not only the energy demand needs to be known, local energy supply potentials have to be analyzed as well. The technologies suited for the case study area and how they can be calculated can be found in chapter 3.3. These technologies make optimal use of solar and wind energy. Some technologies can only supply one energy type; electricity, whereas some technologies can supply both heating and electrical energy. The following technologies are used in this research [in brackets energy type they provide]:

- Photovoltaic panels (PV) [Electricity)
- Photovoltaic thermal panels (PVT) [Electricity + Heat]
- Multifunctional roof edge (MRE-hybrid; wind and solar energy) [Electricity]
- Multifunctional roof edge (MRE-light; solar energy) [Electricity]

As can be seen in Figure 48 the biggest potential considering electrical energy supply is the MRE-hybrid, which makes use of solar and wind energy. Considering heating PVT could potentially provide almost 2700 MWh of thermal energy each year, which can be stored in the ground. However, it is expected that only 50 % of roof of one building is enough to compel to all heating demands. Other 'heating supply' sources can be energy exchange which is not included in Figure 49, but talked about extensively in chapter 4.3.2. For more detailed description of the calculations see appendix A.7.

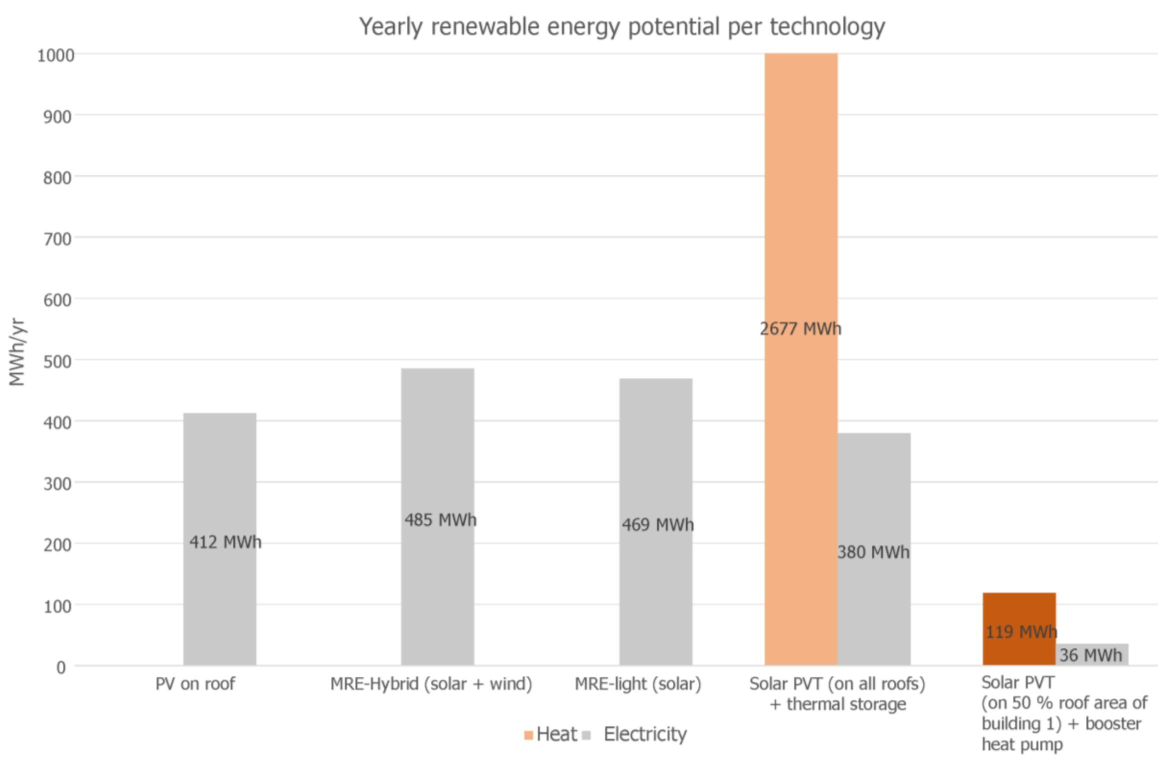


Figure 49: Yearly renewable energy potential per technology (by author)

4.4 Energy system development

The fourth step in the Smart Urban Isle method is network development. In this chapter the calculated expected energy demands, energy exchange potentials and local renewable energy potentials are used to design several energy configurations that can be quantitatively be assed in order to pick the best suited option for the case study area in order to design an energy flat urban block as possible. For the energy demand the calculated energy demands for the improved base design WITHOUT continuous cooling are used. Within this design it means that all of the cooling demand could potentially be used for heating purposes of space heating. Additionally, the yearly renewable energy potentials per technology are repeated in order to get a clear overview of demand, possible exchange and energy supply potentials within the design of the improved base design.

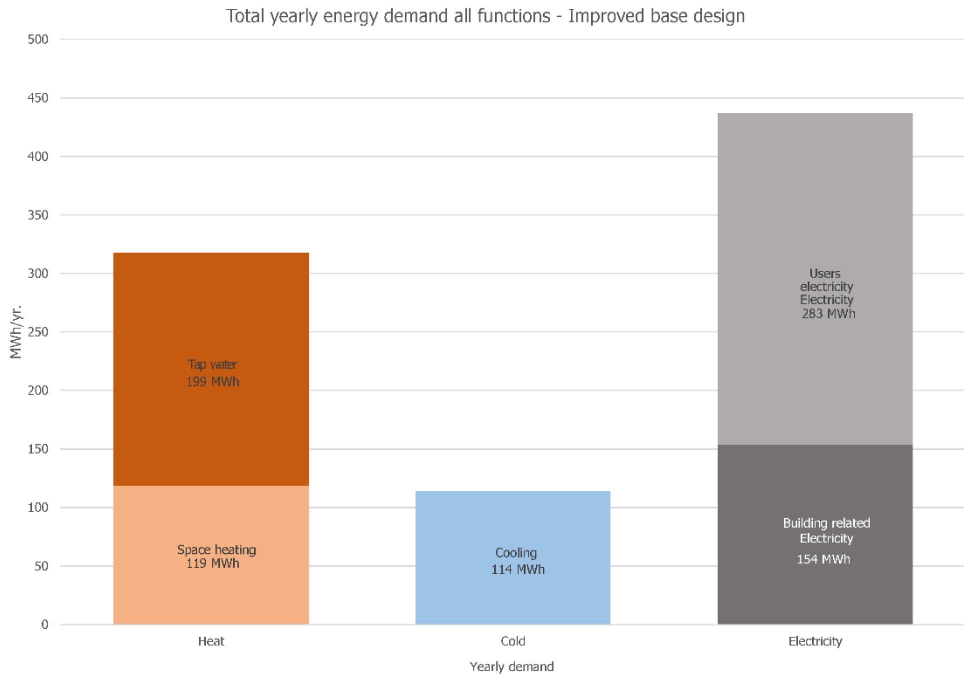


Figure 50: Yearly energy demand per demand type – Improved base design (by author)

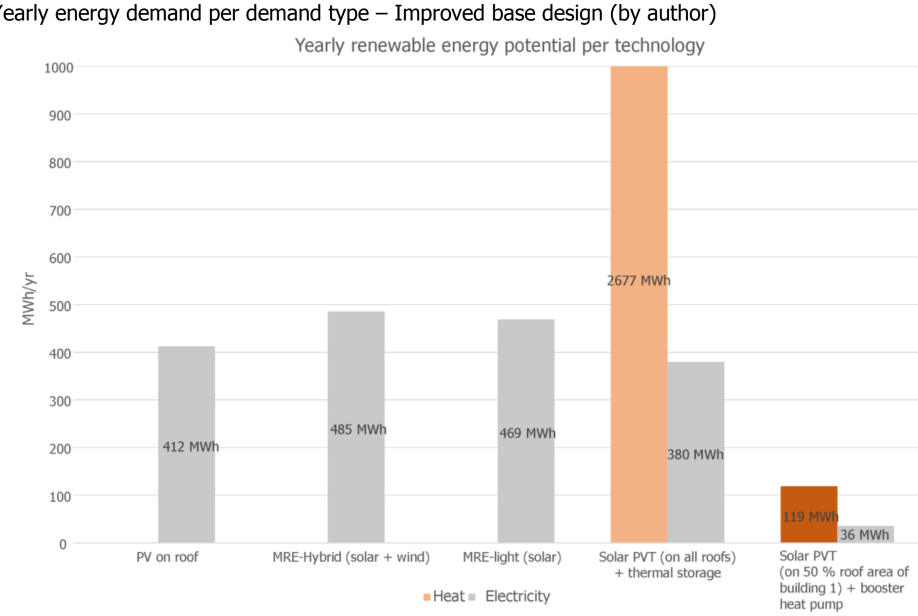


Figure 51: Yearly renewable energy potential per technology (by author)

System design

The energy demands stated in Figure 50 can be fulfilled with different supply technologies from Figure 51. As mentioned earlier some technologies can only supply one energy type, while other technologies can supply multiple energy types. This means that multiple energy configurations can be made to supply all the energy demand within the case study area. For this research three different configurations are designed and evaluated: All-electric, medium temperature thermal grid + separate cooling grid and low temperature thermal grid. These configurations are used to provide information about the impact of collaboration between different functions and to provide more information about the influence of grid temperature on multifunctional urban blocks. Therefore, each configuration is introduced with the basic principle it uses. Then, if applicable, the conceptual spatial implementation of the configuration is shown and the distribution losses are talked about. After that, the local supply and demand are connected to each other and an energy flow diagram is provided. Moreover, the impact of program change, design parameter variation, continuous cooling and possible scalability of the configuration are discussed.

4.4.1 Option 1: All electric [individual heat pump per building/unit]:

Figure 52 shows the energetic principle of option 1; all electric. This option makes use of electrical energy and converts this electricity into heating and cooling. A heat pump with the outdoor air as source is used for this conversion. The results of this option provide information whether it is possible to create a locally balanced energy system with only local supplied electricity and whether it is useful for different functions within a case study area like this to collaborate with each other or not, and exchange energy.

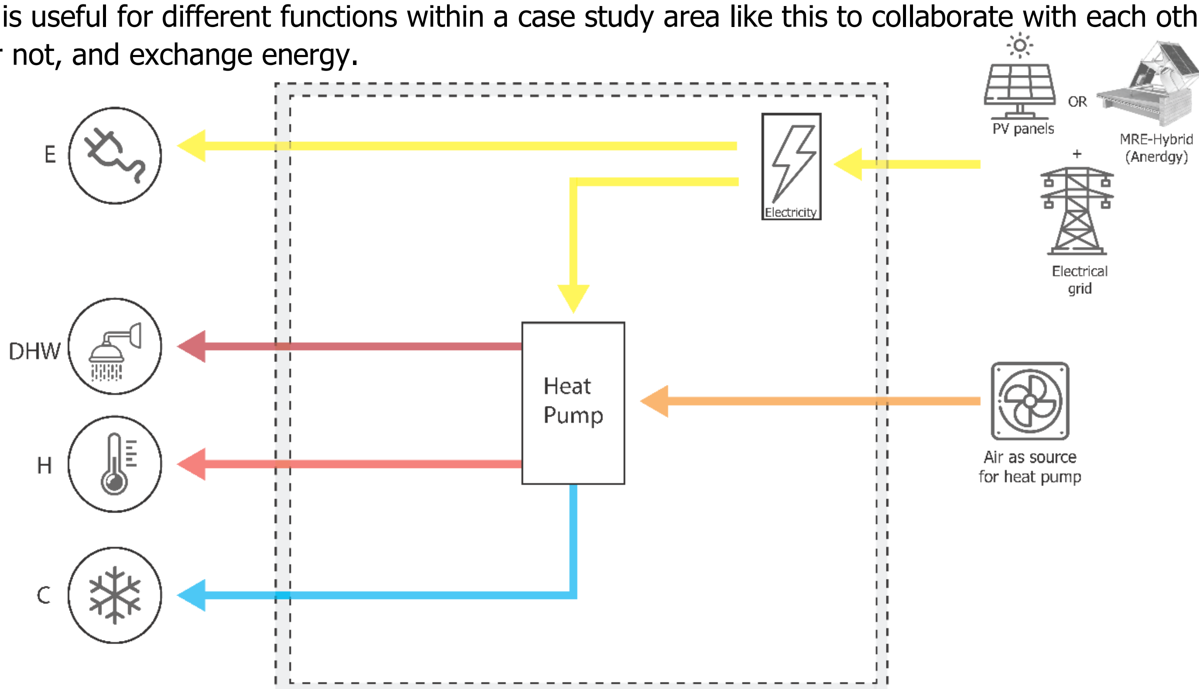


Figure 52: Energy principle option 1: all electric (by author)

In this energy principle all energy services take place within the building boundary. Heat pumps can be used on both the whole building scale and the individual unit/function scale. Although both options have its benefits and disadvantages, for the sake of this research only heat pumps on the building scale are considered. With the outdoor air as source for the heat pump can achieve a COP of 3.9 for space heating, a COP of 4.0 for cooling and a COP of 2.6 for domestic hot water. Additionally, in this research only grid distribution losses on the urban block level are considered, therefore, distribution losses within the building itself are out of scope, therefore, there are no heat losses within this option. Thus, the overall local energy demand and supply can be seen in Figure 53.

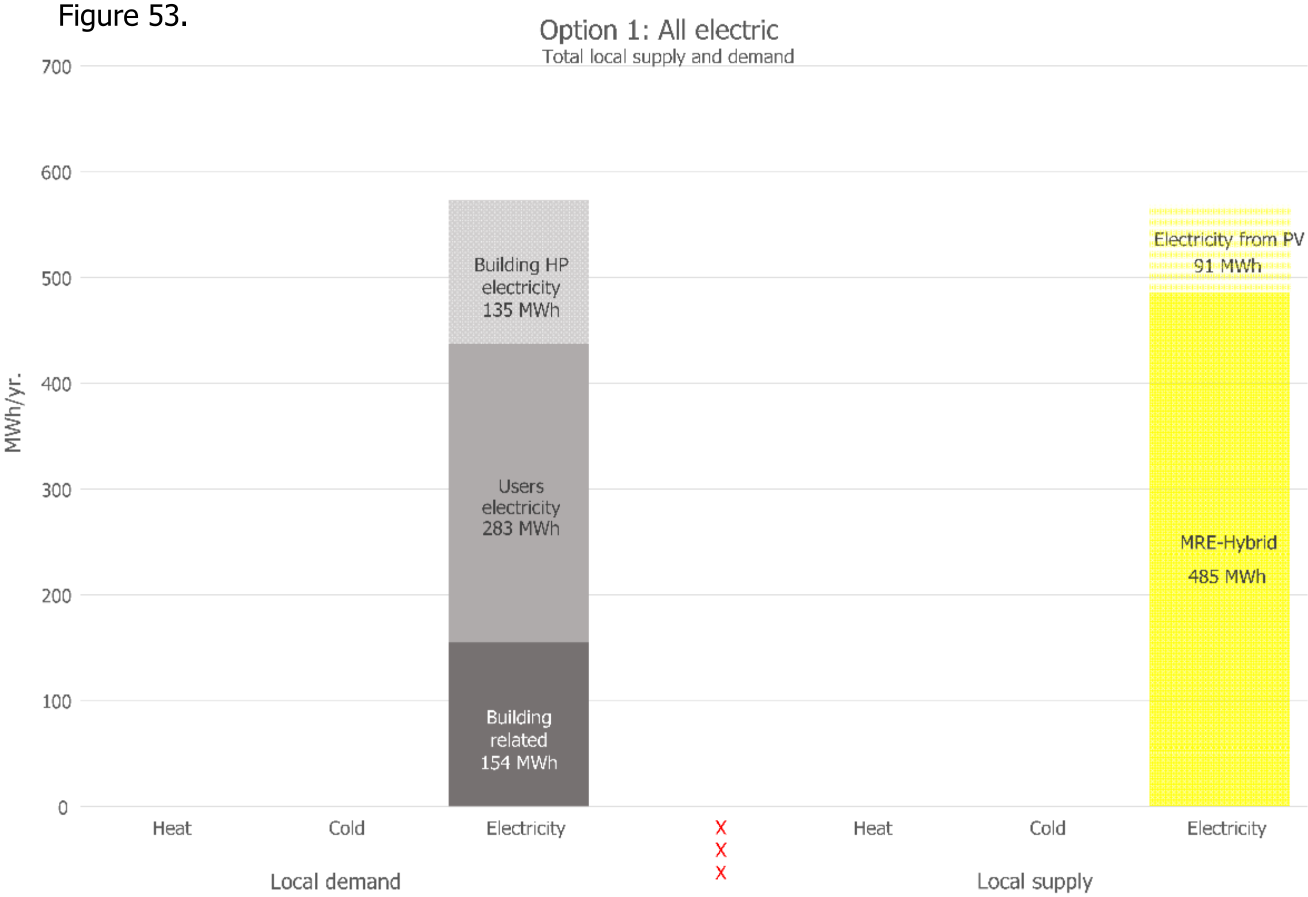


Figure 53: Yearly local energy demand and supply per energy type – option 1 (by author)

As can be seen in Figure 53 all energy demands are turned into electrical energy demand, i.e. the total demand for electricity is now 572 MWh. However, the maximum yearly local electricity supply caused by the MRE-Hybrid technology is only 485 MWh. This means that additionally to that on around 22 % of all roofs PV panels have to be installed to supply the rest, which is 91 MWh.

Energy flow diagram:

Figure 54 presents all energy flows within the energy system configuration. As can be seen in figure 54 with the use of the MRE-hybrid and PV technologies all energy can be locally produced within the urban block boundary. 39 % of the locally by these technologies produced electricity are either directly used for the base load (light + appliances) or for the heat pumps used for space heating, domestic hot water and cooling demands. These heat pumps use the outdoor air as heat source. The rest of the electricity is temporarily stored in a battery with the size of 145 MWh for later use.

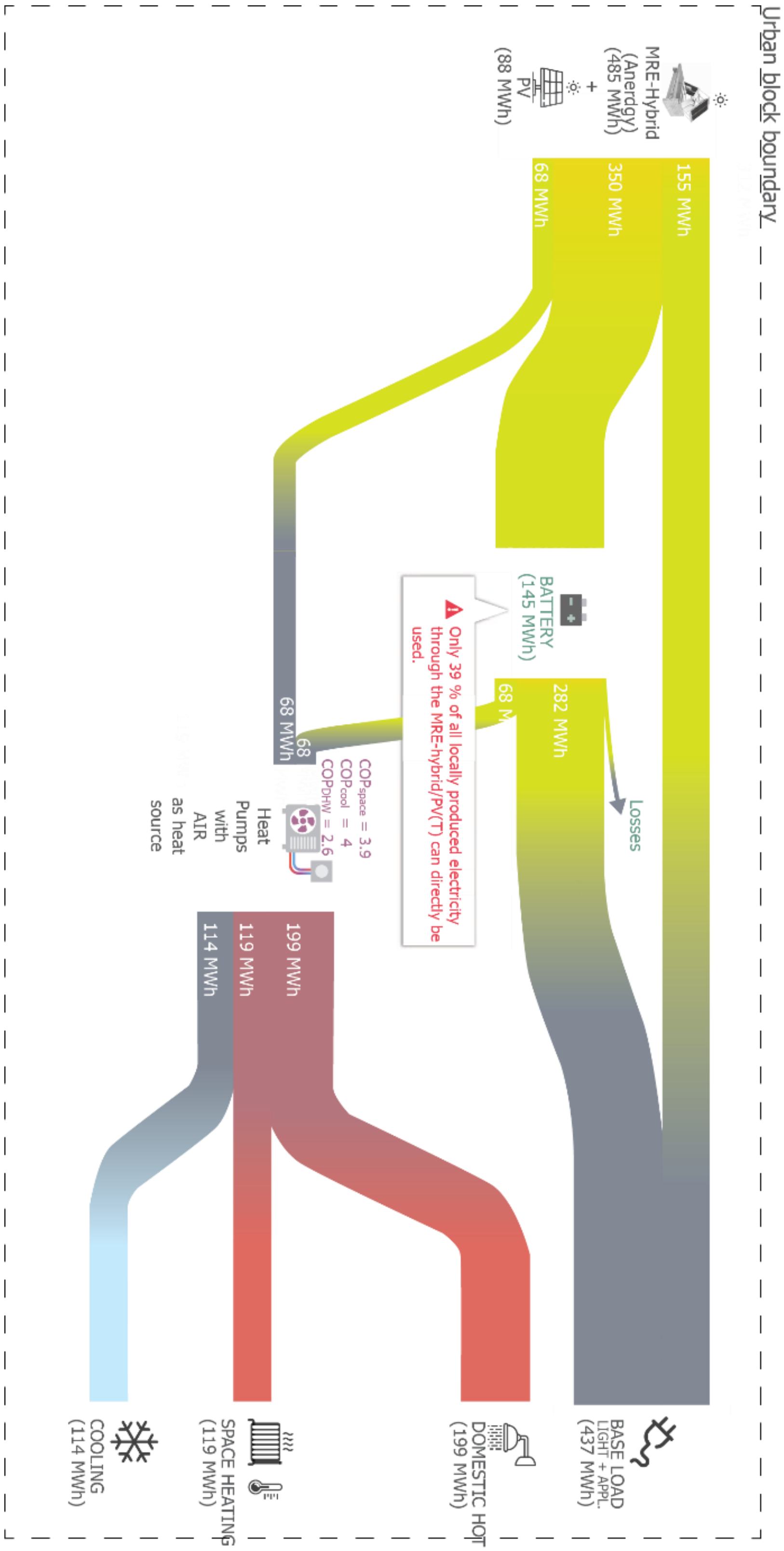


Figure 54: Energy flow diagram – option 1 (by author)

Impact of design changes:

The design can be changed in several ways. Because of the fact that all energy demand is electrical demand, changing the program of the area is only beneficial for this option when the total amount of functions is reduced or when functions with high heating, cooling and electrical demand are replaced by functions with lower heating, cooling and electrical demand. In that case the overall energy demand per function reduces and the total electrical demand reduces as well. The current design is optimized according its bioclimatic context, by changing the design parameters it is expected that the space heating demand will increase, which leads to an overall increase in electrical energy demand. Also, continuous cooling is not beneficial for this option. With continuous cooling the cooling demand increases while no energy exchange is used, this leads to an overall increase in electrical energy demand. Option 1 is also not scalable. The current yearly energy demand cannot be balanced with the local energy supply, therefore, scaling up the amount of program in this area only growths the imbalance between demand and supply.

4.4.2 Option 2: Medium temperature thermal grid + separate cooling grid

The energetic principle for option 2 (2a & 2b) is showed in Figure 55. For this option a collective heating and cooling system is introduced. There is a separate heating and cooling grid. The heating grid has a medium inlet temperature [40 ºC] and a return temperature of around 25-30 ºC. This temperature can directly be used as space heating and for domestic hot water this temperature is upgraded to around 60 ºC. The cooling grid has a low inlet temperature [10 ºC] and a return temperature of around 20 ºC. This option provides information on the impact of energy exchange on the local demand and supply balance and on what temperatures are most suited to use in this research. There are two sub-designs within option 2, 2a and 2b. Option 2a is a medium temperature thermal grid + separate cooling grid WITHOUT continuous cooling, whereas option 2b is a medium temperature thermal grid + separate cooling grid WITH continuous cooling.

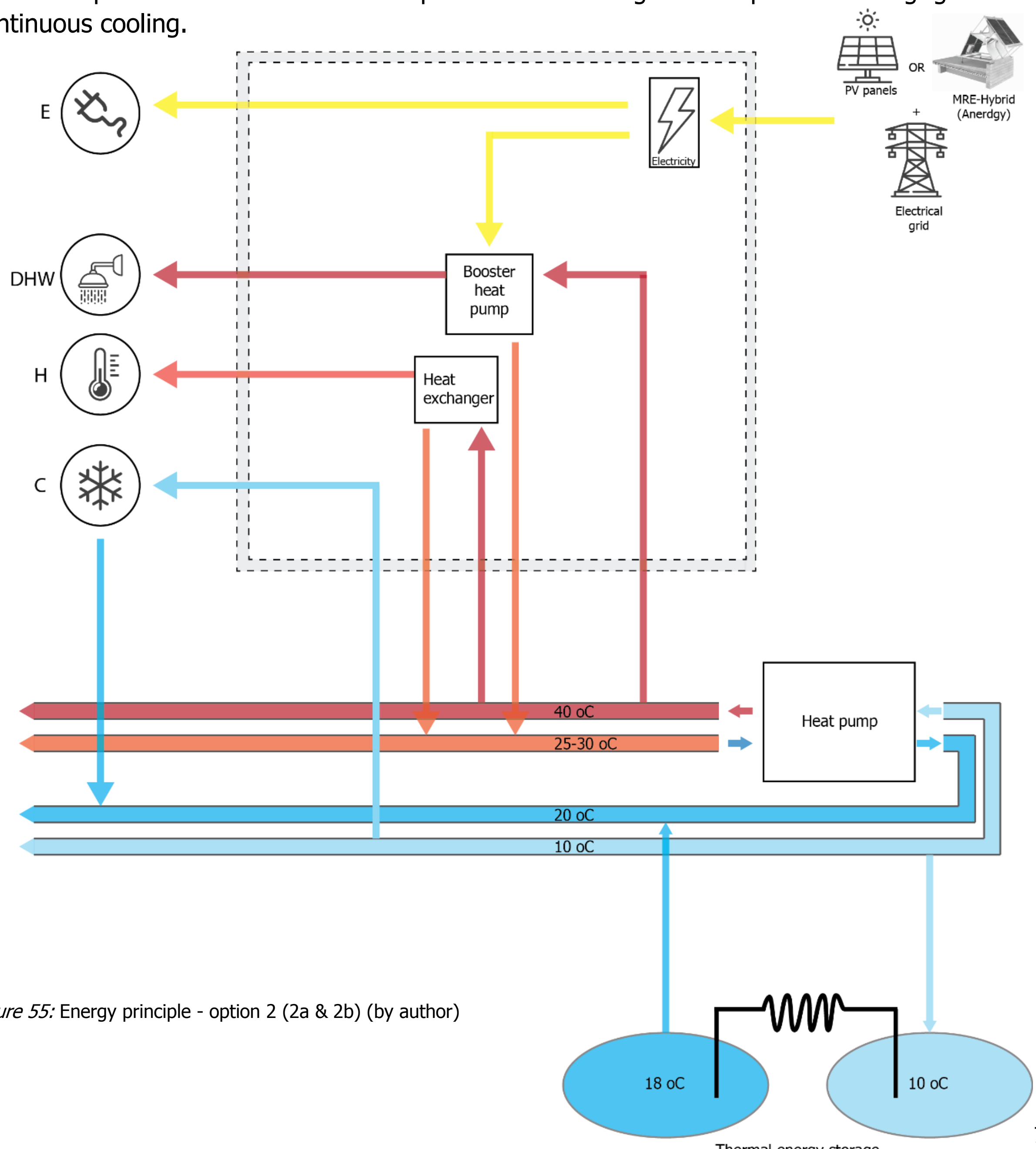


Figure 55: Energy principle - option 2 (2a & 2b) (by author)

In this energy principle the building services are both on a building scale as well as on the urban block scale. As can be seen in Figure 56 on the urban block scale a heat pump with a COP of 7 is placed. This heat pump ensures that each pipe has the correct temperature. Additionally, the urban block has thermal energy storage, this storage is only being used when there is an imbalance between the heating and cooling pipes. The temperature produced by the collective heat pump can be used directly for space heating purposes. For domestic hot water however, A booster heat pump is used to upgrade the inlet heating temperature to 60 °C. With the heating grid as source the booster heat pump can achieve a COP of 4.2. This heat pump can again be placed on a building or a unit/function scale. For this research only heat pumps on the building scale are considered. The main advantage of this whole system is the fact that heating and cooling of different functions can occur at the same time, which creates a better balance in the overall system. Also, for this option grid distribution losses have to be taken into account, i.e. 13 MWh of heat is lost over a year. For more detailed calculation of the distribution grid losses see appendix A.7.

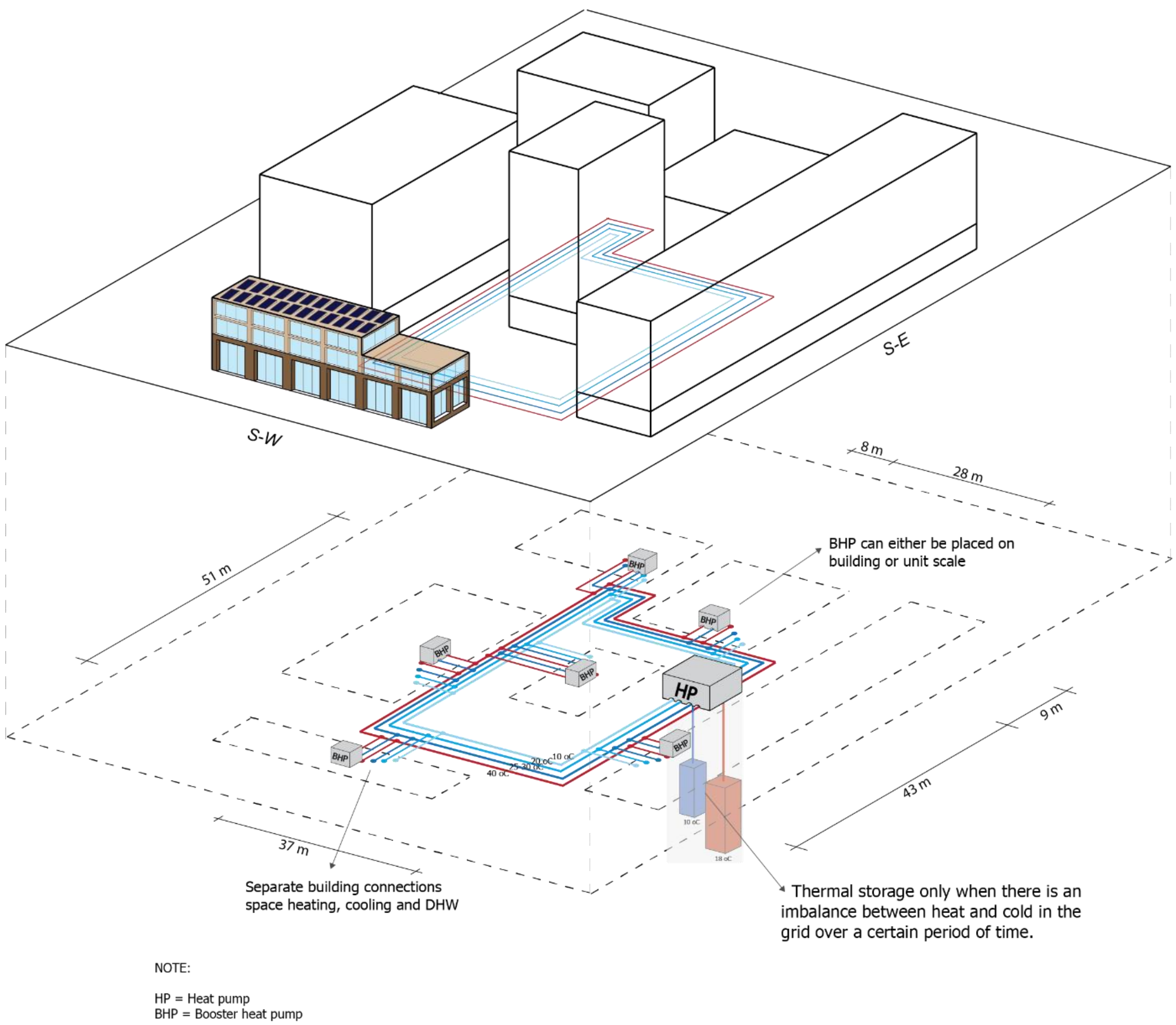


Figure 56: Conceptual spatial implementation of heating and cooling grid – option 2a & 2b (by author)

4.4.2.A Option 2a: Medium temperature thermal grid + separate cooling grid [NO continuous cooling]

As mentioned earlier option 2a is a sub-design of option 2. Option 2a follows the same energy principle as option 2, i.e. medium temperature thermal grid + separate cooling grid WITHOUT continuous cooling.

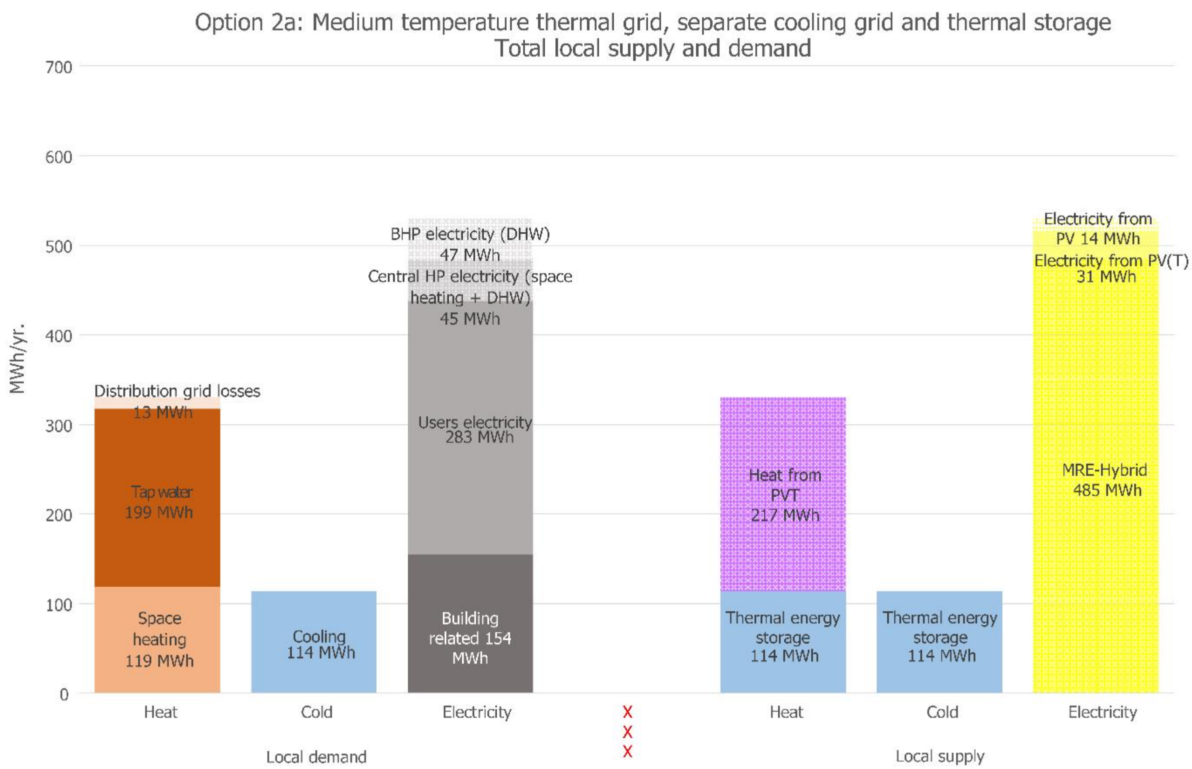


Figure 57: Yearly local energy demand and supply per energy type – option 2a (by author)

As can be seen in Figure 57 within the energy system of option 2 there is a demand for heating, cooling and electricity. Heating can be partly supplied by energy exchange from cooling to heating and storing this thermal energy within the pipes/ground, around 114 MWh/yr. The additional heating needed can be provided by using PVT panels to supply extra thermal energy [217 MWh/yr.]. Cooling can use the phenomena of energy exchange as well. The electricity demand can be partly supplied through the usage of the MRE-hybrid system. Additionally, the rest of the electricity demand can be supplied through the PVT panels (31 MWh/yr.) and PV panels on around 8 % of the roof area of the urban block. With these technologies there is only a surplus of energy of 1 MWh over a year.

Energy flow diagram:

Figure 58 presents all energy flows within the energy system configuration of option 2a. As can be seen in figure 58 with the use of the MRE-hybrid, PVT and PV technologies all energy can be locally produced within the urban block boundary. 36 % of the locally by these technologies produced electricity are either directly used for the base load (light + appliances), for the collective heat pump used for space heating or booster heat pumps used for domestic hot water. The rest of the electricity is temporarily stored in a battery with the size of 128 MWh for later use. The collective heat pump uses the thermal storage and/or PVT (30 MWh directly usable [15% of the total PVT production]) as heat source, whereas the booster heat pump uses heat from the collective heat pump as heat source. Cooling can directly be used from the collective thermal storage.

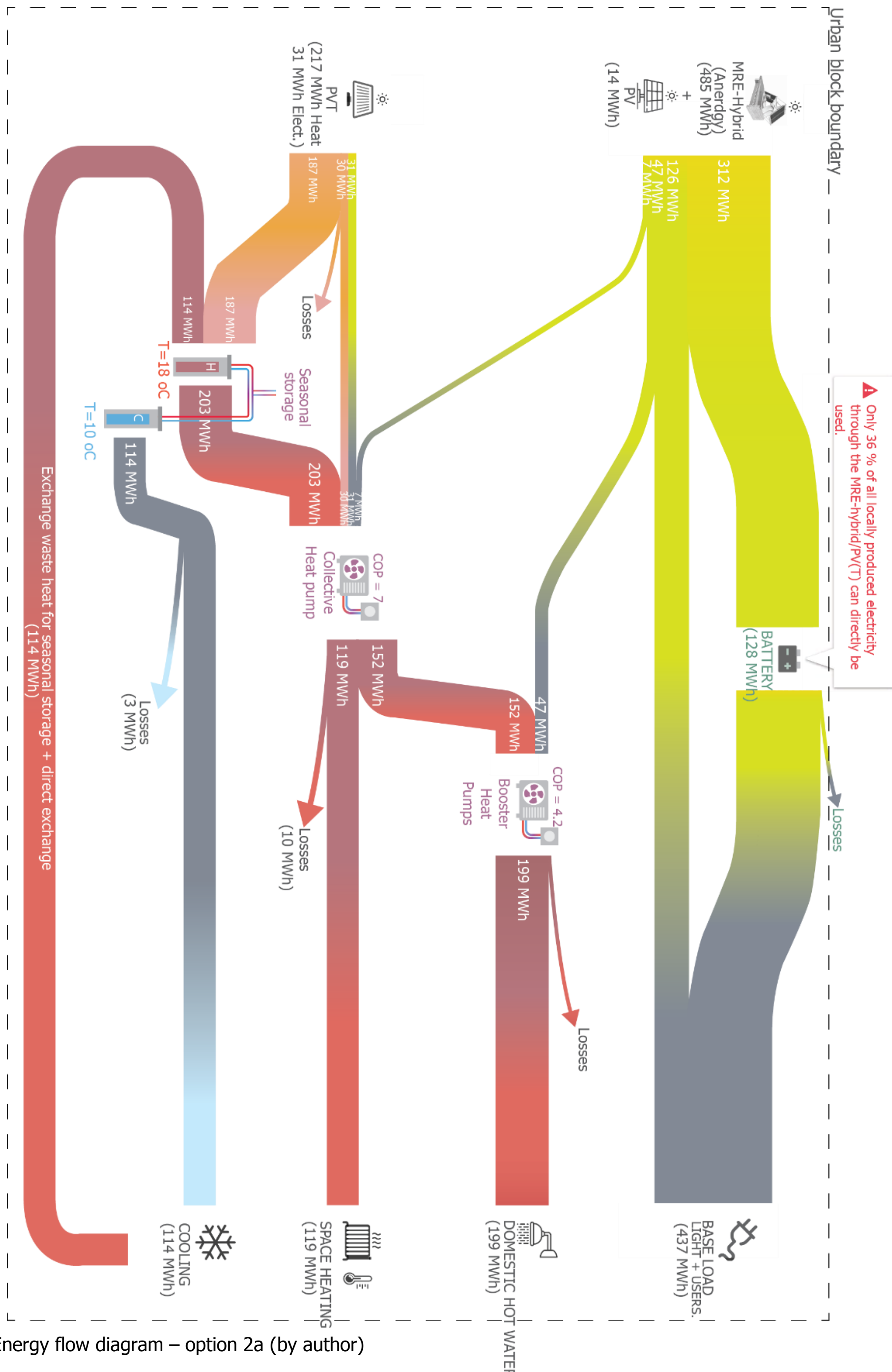


Figure 58: Energy flow diagram – option 2a (by author)

Impact of design changes:

For option 2a changing the design can have both a positive and negative impact. Considering changing the program of the case study, it has the biggest impact on the amount of energy that can be exchanged between functions over time. As mentioned in chapter 4.3.2 each function has its own heat-cold ratio. By adding a function with a higher heat-cold ratio, the total cooling demand is increased, which means that more thermal energy can be exchanged. In that case not only the space heating can be supplied with exchanged thermal energy but also an x amount of tap water. Changing the program can also have a negative impact when functions with a high heat-cold ratio are eliminated, i.e. less energy can be exchanged. Changing the design parameters can also have an impact on the amount of energy that can be exchanged. In case of the current design the buildings are well insulated, i.e. the heat loss through transmission is limited. This means that when, for example, the façades get a higher window percentage the solar heat gains are higher than the total transmission losses, this leads to an increase in overall cooling demand while keeping the heating demand low, more energy can be exchanged. As mentioned in chapter 4.3.2 introducing continuous cooling has an impact on energy exchange as well. In the current design the introduction of continuous cooling leads to an overall increase in cooling demand, while the overall heat-cold ratio increases as well. Therefore, another sub-design of option 2 is introduced, option 2b: Medium temperature thermal grid + separate cooling grid WITH continuous cooling. Moreover, for both option 2a as well as for option 2b it means that when retaining the balance in the overall energy system this configuration can be scaled up easily and connected to other urban blocks in order to increase the overall balance between the different energy types.

4.4.2.B Option 2b: Medium temperature thermal grid + separate cooling grid [WITH continuous cooling]

Within the sub-design option 2b continuous cooling is introduced. This means that buildings also cool when no one is present inside of the building. As can be seen in figure 59 the cooling demand in option 2b is increased to 281 MWh/yr., i.e. besides providing all space heating demand it can also supply partly the domestic hot water and distribution losses energy demand. Although cooling a building when no one is present does not sound logical at all, within an energy system in which all heating and cooling is locally balanced it means that there is less dependency on extra technologies like PVT to provide the heating demand needed. According to figure 59 the PVT needed to supply heat is now 50 MWh/yr. in contrast to 207 MWh/yr. in option 2a. Additionally, both heating and cooling occur in a smaller time interval, which increases the balance between heat and cold over a shorter period of time. In that case option 2b has a better balance between the temperatures in both heating and cooling pipes and thus, are less dependent on thermal storage facilities over time.

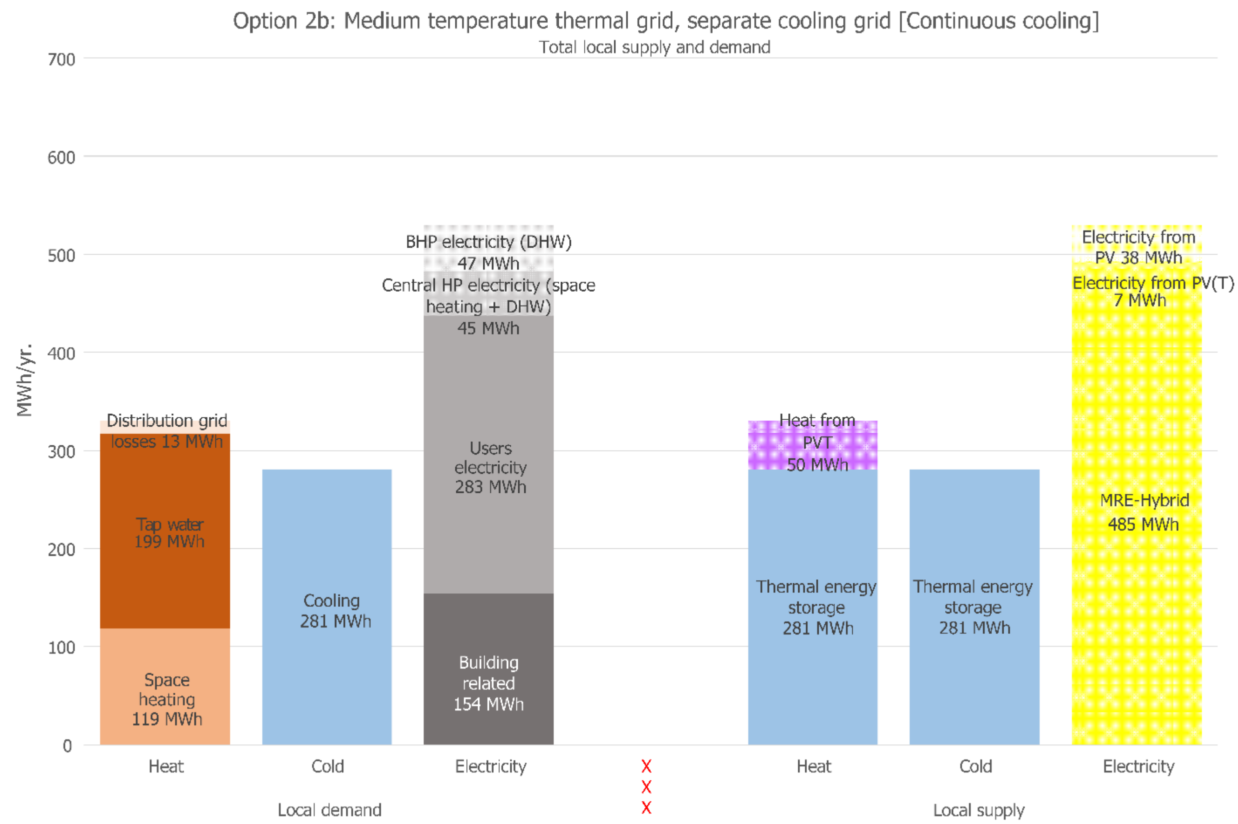


Figure 59: Yearly local energy demand and supply per energy type – option 2b (by author)

Energy flow diagram:

Figure 60 presents all energy flows within the energy system configuration of option 2b. As can be seen in figure 60 with the use of the MRE-hybrid, PVT and PV technologies all energy can be locally produced within the urban block boundary. 37 % of the locally by these technologies produced electricity are either directly used for the base load (light + appliances), for the collective heat pump used for space heating or booster heat pumps used for domestic hot water. The rest of the electricity is temporarily stored in a battery with the size of 139 MWh for later use. The collective heat pump uses the thermal storage and/or PVT (30 MWh directly usable [60 % of total PVT production]) as heat source, whereas the booster heat pump uses heat from the collective heat pump as heat source. Cooling can directly be used from the collective thermal storage. With subtracting heat out of the building through cooling 281 MWh/yr. can be reused, which means that the system is less dependent on PVT as a heat source than option 2a.

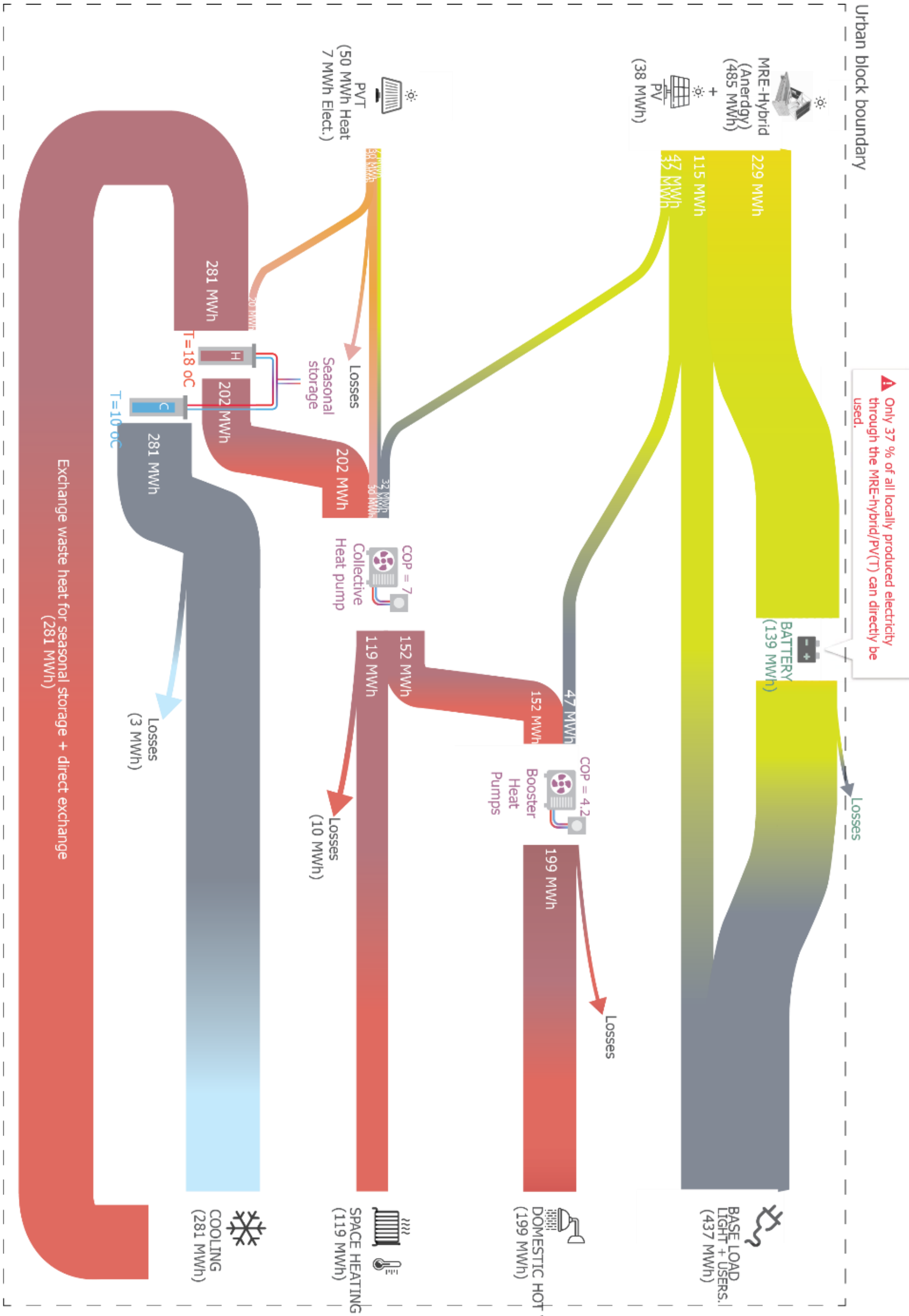


Figure 60: Energy flow diagram – option 2b (by author)

4.4.3 Option 3: Low temperature thermal grid + thermal storage

Figure 61 shows the energy principle used for option 3. This option makes use of a collective low temperature thermal grid in combination with thermal energy storage. The thermal grid has one pipe with a temperature of 20 °C which has to be upgraded to a higher temperature in order to be useful for space heating and domestic hot water purposes. The second pipe has a temperature of around 10 °C, this can directly be used for cooling purposes. Therefore, this option is mostly suited for urban blocks with a high overall cooling demand. This option provides information about the impact of energy exchange for a configuration like this and what low temperature use means for a multifunctional urban block.

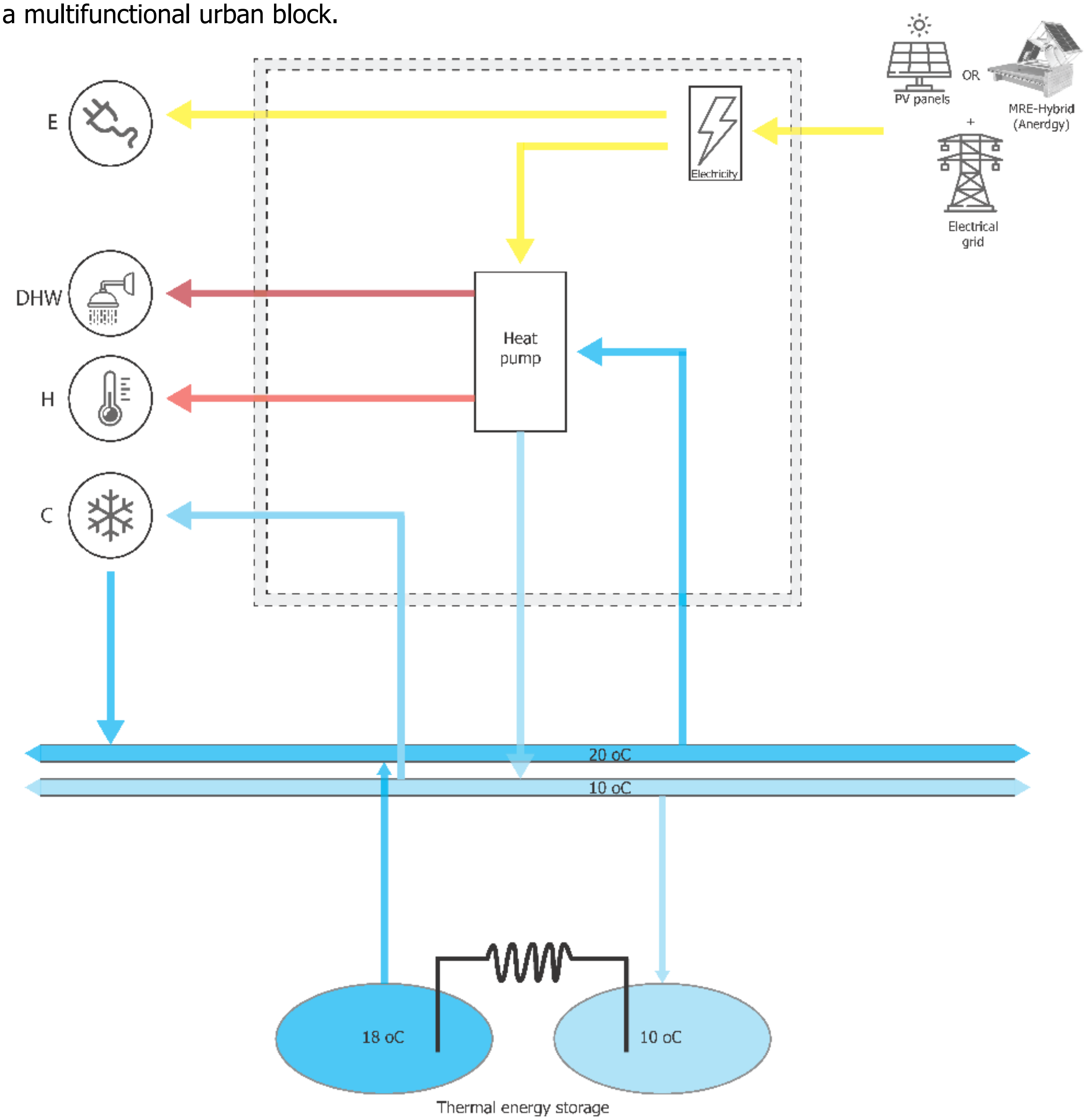


Figure 61: Energy principle – option 3 (by author)

In this energy system configuration the building services are placed on both the building/unit and urban block scale again. A heat pump is used to upgrade the low temperature from the thermal grid to be useful for space heating and domestic hot water purposes. With the thermal grid as source for the heat pump it can achieve a COP of 6.3 for space heating and a COP of 3.7 for domestic hot water. Again, this heat pump can either be used on a building or a unit/function scale, but for this research only a heat pump on building scale is considered. As can be seen in Figure 62 on the urban block scale there is a thermal grid with thermal energy storage integrated. In the current design all functions have similar profiles for heating and cooling demand or have zero demand while other functions still have an energy demand. Hence, the thermal grid is arranged in such a way that it can either be used for cooling or heating, i.e. no cooling and heating at the same time is possible. During the distribution of this low temperature through the grid only a small part of the heat is lost, 3 MWh/yr. The overall local energy demand and supply for option 3 can be found in Figure 63.

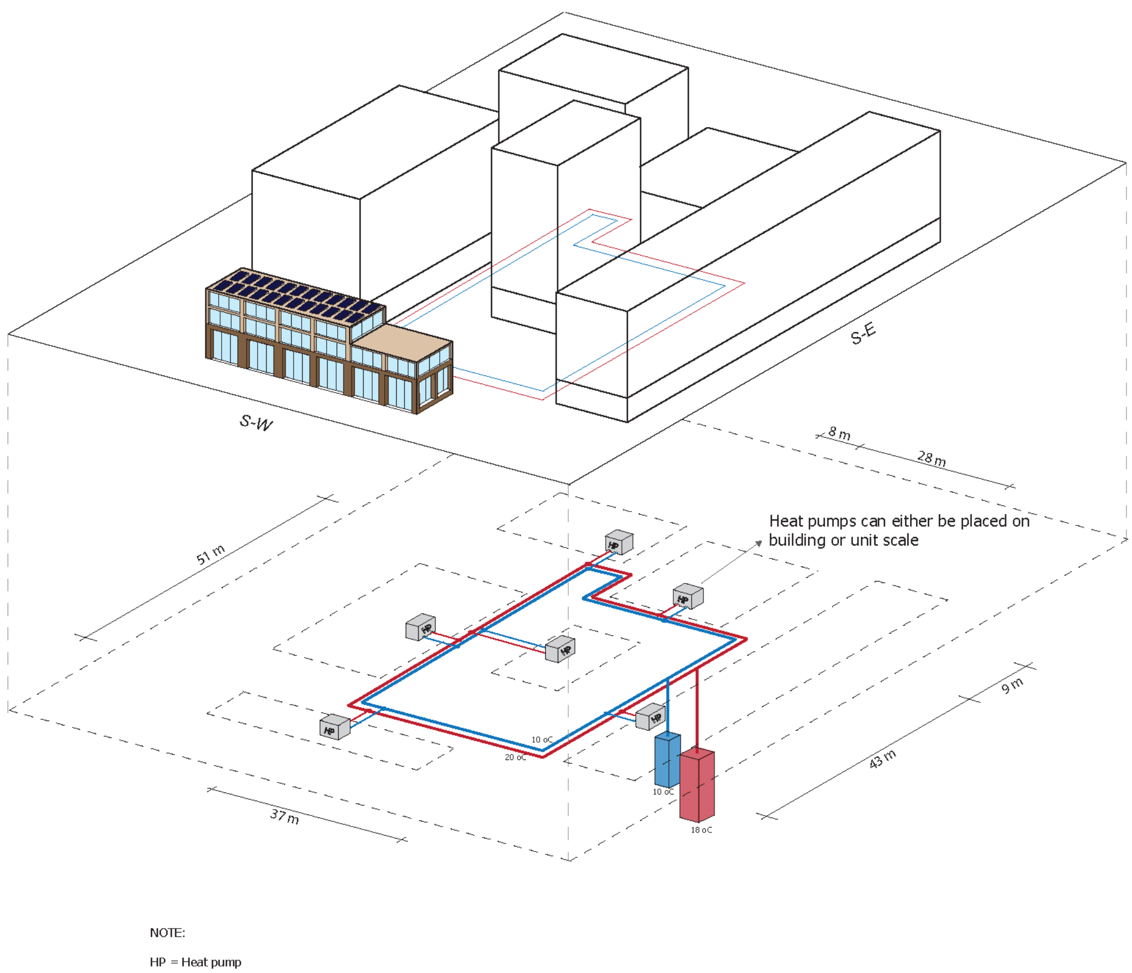


Figure 62: Conceptual spatial implementation of heating and cooling grid – option 3 (by author)

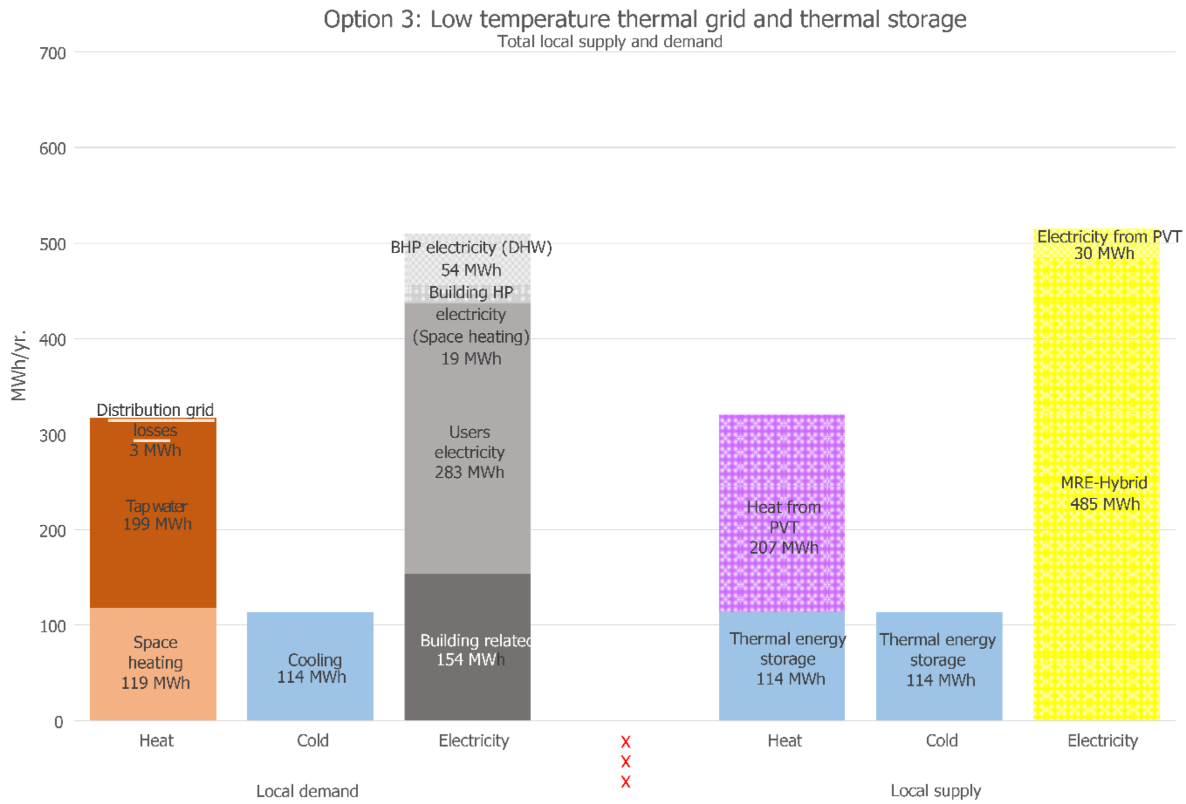


Figure 63: Yearly local energy demand and supply per energy type – option 3 (by author)

As can be seen in Figure 63 there is a demand for heat, cold and electricity. Again, same as in option 2 with temporal thermal energy storage all of the cooling demand and part of the heating demand can be fulfilled. Additionally, out of the three options option 3 has the lowest overall electricity demand. This is due to the fact that one heat pump can be used for both space heating and domestic hot water, i.e. water is not heated up through a collective heat pump first and then upgraded with a booster heat pump. Because PVT is used to supply the retaining heating demand, more electricity can be produced on the roofs than solely with the MRE-hybrid system. Thus, on a yearly basis all energy demand can be produced on a local scale. Moreover, the grid distribution losses reduced significantly compared to option 2, from 13 MWh/yr. to 3 MWh/yr., however, the distribution losses within the building are out of scope in this research.

Energy flow diagram:

Figure 64 presents all energy flows within the energy system configuration of option 3. As can be seen in figure 64 with the use of the MRE-hybrid and PVT technologies all energy can be locally produced within the urban block boundary. 37 % of the locally by these technologies produced electricity are either directly used for the base load (light + appliances) or for the heat pumps used for space heating and domestic hot water purposes. The rest of the electricity is temporarily stored in a battery with the size of 138 MWh for later use. The collective heat pump uses the thermal storage and/or PVT (30 MWh directly usable [15 % of total PVT production]) as heat source. Cooling can directly be used from the collective thermal storage. With subtracting heat out of the building through cooling 114 MWh/yr. can be reused.

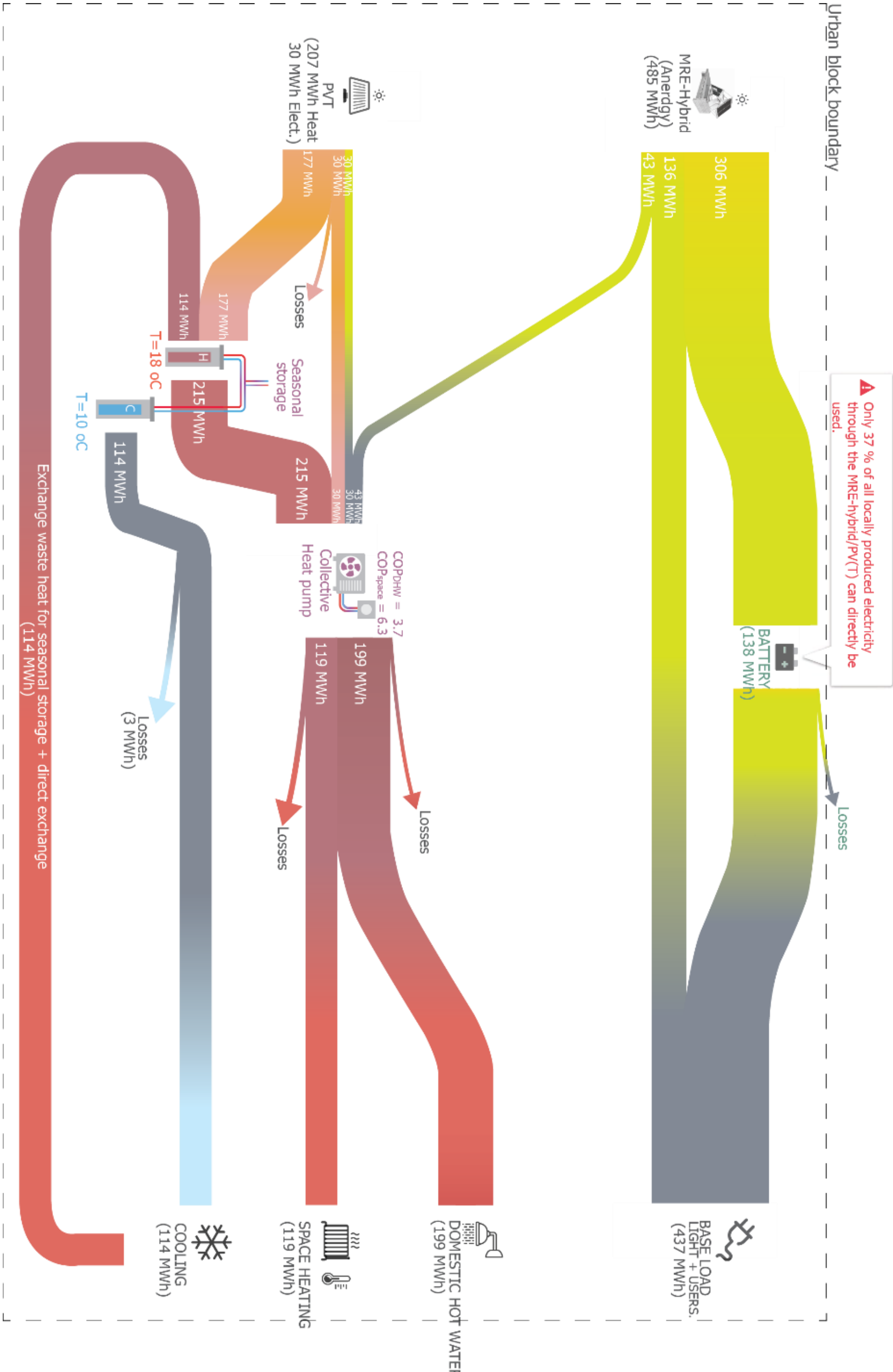


Figure 64: Energy flow diagram – option 3 (by author)

Impact of design changes:

Changing the design has several impacts on the energy system of option 3, both negative and positive. First of all, changing the program has the same impact as for option 2. When the amount of functions with a high heat-cold ratio are increased in the case study the overall cooling demand increases as well, therefore, this also increases the possibility to exchange energy. However, changing the program can also have a negative impact when functions with a high heat-cold ratio are eliminated, i.e. less energy can be exchanged. The impact of changing the design parameters has again the same impact as for option 2. When more cooling is wanted, a higher window percentage can be used. When more heating is needed, the overall insulation has to be lowered. In contrast to option 2 continuous cooling has a negative impact on the energy system of option 3. As mentioned earlier with continuous cooling almost every day of the year there is a heating demand during the night/early morning and a cooling demand during the afternoon, heating and cooling even occurs sometimes at the same time. In option 3 the thermal grid can only either heat or cool, heating and cooling cannot take place at the same time. Therefore, almost every day the heat pump needs to switch between heating and cooling several times a day. A heat pump works best when it can work on a regular basis. Every time a heat pump has to switch or start-up it loses a bit of efficiency (Greenhome, 2016). Also, the system cannot heat and cool at the same time, which indicates that a buffer tank has to be installed for each building/unit. Thus, continuous cooling has a negative impact on the energy system of option 3. Scalability of the energy system is also limited for option 3. For the exchange of energy the thermal energy storage is a key component for the system. However, this thermal storage is dimensioned based on the calculated energy demand and supply and when these are increased the dimensions of the thermal storage should increase as well, but this is not always possible.

4.5 Evaluation

The last step in the Smart Urban Isle method is evaluation and selection of the different configuration options. In this paragraph the energy system options are evaluated using the key performance indicators as stated in chapter 3.2. With these key performance indicators different designs can quantitatively be evaluated based on the energy neutrality/fraction of local renewable supply, fraction of autonomy, maximum power mismatch, maximum cumulative mismatch and the fraction of inter-exchange of energy. In Table 17 the evaluation of all different energy system configuration options can be seen.

Network configurations	Options			
	All-electric	Medium temperature thermal grid + separate cooling grid		Low temperature thermal grid + thermal storage
	1	2a: Heating/cooling when people present	2b: With continuous cooling	3
KPI 1: Energy neutrality (MWh/yr.)/fraction of local renewable supply per year (%)				
Heating (MWh/yr.) [%]	n.a.	0 [100 %]	0 [100 %]	0 [100 %]
Electricity (MWh/yr.) [%]	4 [101 %]	1 [100 %]	1 [100 %]	5 [101 %]
KPI 2: Fraction of autonomy; Direct energy supply use (MWh/yr.) [%]				
Heating (MWh/yr.) [%]	63 [11 %] *	30 [9 %] **	30 [9 %] **	30 [9 %] **
Electricity (MWh/yr.) [%]	226 [39 %]	193 [36 %]	194 [37 %]	188 [37 %]
KPI 3: Maximum power mismatch (kW) [positive and negative]				
Electricity (kW)	388 -188	382 -178	386 -178	381 -158
KPI 4: Maximum cumulative mismatch (MWh)				
Electricity (MWh)	145	128	139	138
KPI 5: Fraction of inter-exchange of energy (%)	n.a	34	85	36

Table 17: Final evaluation of all energy system configuration options (by author)

* Value represent electric supply that can directly be used for heating, cooling and domestic hot water purposes only, so just HP electricity. This is to be able to compare the different supply technologies that are used for heating purposes only.

**Values represent direct use of available heating supplied through the amount of added PVT panels in order to match total demand (Space heating + DHW + losses) and supply on yearly basis. Exchange of energy and temporal storage are not taken into account for this KPI.

As can be seen in Table 17 all options can match the energy demand for heating and electricity for 100 % or more with local renewable supply on a yearly basis. Considering the fraction of autonomy/direct energy supply use only supply technologies that can directly turn solar energy into electricity or thermal energy needed for heating are evaluated. For thermal grids this value shows the amount of PVT supply that can directly be used to supply the total heating demand. It also shows the percentage of total demand that can directly be supplied with thermal energy from PVT panels. Together these values present the value when direct use of PVT technology should be preferred over stored thermal energy in order to provide the smallest temperature difference as input for the heat pumps. However, for option 2a, 2b and 3 thermal energy that can be used for heating is also stored within the case study area and therefore, the fraction of heating demand can be supplied at any given time of the year, while the fraction of electricity to turn into heating that can directly be used in the all-electric option is lower due to the fact that electricity also is used for all other energy demands. Additionally, considering the fraction of autonomy for the overall electricity demand, option 1 has the largest amount that can be used directly for electrical purposes, 226 MWh/yr. This is caused by the fact that this option has the largest amount of PV panel area which means that the local electricity production is higher during the day. However, when we look at the overall fraction of autonomy of the different options, i.e. combining the heating and electricity fractions of autonomy, we see that option 1 still has the highest amount of energy that directly can be used, 226 MWh/yr. (39 %), but, option 2b has the highest percentage of local supply that can directly be used, namely 46 % or 224 MWh/yr. This is mainly due to the fact that for options 2a, 2b and 3 both the fractions of autonomy of heating and electricity can be added up because these energy types are separated, while for option 1 only the electricity fraction of autonomy can be considered.

Although the maximum power mismatch can be found in option 1, there is only a little difference between the 4 options, of these options option 3 has the lowest maximum power mismatch. Option 1 has the biggest share of PV panels, which leads to the fact that option 1 has the biggest maximum cumulative mismatch within one year, i.e. 145 MWh while for option 2a, 2b and 3 these values are respectively 128 MWh, 139 MWh and 138 MWh. When introducing electrical energy storage the battery would be smallest for option 2a, the biggest for option 1 and about the same size for options 2b and 3. It is expected that these little differences are caused by the fact that the users electricity (appliances) and building related electricity (lights) are by far the largest contributors to the electrical energy demand in comparison to the electricity that is needed for the heat pumps. This leads to minimal differences between the different options over a total year. Considering the amount of electricity needed for the heat pumps, option 1 requires 135 MWh/yr., option 2a & 2b require 92 MWh/yr. and option 3 requires 73 MWh/yr..

When looking at the fraction of energy that can be exchanged we see the highest amount for option 2b: continuous cooling, it is almost 2 times higher than for option 2a and 3. This means that the energy system proposed in option 2b is less dependent on other supply technologies rather than the building and functional program itself. Furthermore, on a yearly basis the heating and cooling provided by ground energy thermal storage technologies always need to be in balance. When the exchange of energy fraction is closer to 100 % it means that this balance is achieved by the energy demands within the building itself. When this balance is not met by the building itself, other technologies like regeneration of the thermal source by surface water or PVT can be used to create a balance.

Therefore, according to the KPIs there is little difference between all options. All options are almost equally energy neutral on a yearly basis, they have almost the same maximum power and cumulative mismatch and the amount of produced energy that can directly be used is roughly the same as well. However, considering the percentage of the total demand that can directly be supplied on a yearly basis is slightly bigger for options 2b and 3. Option 2b however, has another main advantage. The main advantage of option 2b over option 2a and 3 is the fact that less low temperature heating for the regeneration of the thermal storage is required, i.e. more energy can be exchanged between functions.

In short:

For the current configuration within the case study area it is best to separate the heating, cooling and the electricity demand into the three energy types of heat, cold and electricity. In that case more locally produced energy can directly be used to supply the energy demand on an hourly basis. With the current functional program of the case study area option 2b has a slight advantage compared to the other options. Option 2b introduces continuous cooling which improves the amount of energy that can be exchanged. However, when the functional program changes in favor of functions with a high heat-cold ratio, for example, twice as much office space, both options 2a and 3 might be favorable to use.

4.6 Conclusion

This chapter describes the case study design for an urban block located in Buiksloterham, Amsterdam. The already explained SUI method is used as an approach. With this research by design part of the thesis the following sub-questions are answered: "*To what extent can different functions exchange energy?" and "In what way does [thermal] energy storage influence energy flatness?".* This chapter also provides an overview of the energy status quo of the case study, an overview of the influence of design parameters in order to reduce the mismatch, the impact multi functionality has on energy flatness and variations on the conceptual energy systems networks as described in chapter 3.4.

The case study area is located in Buiksloterham, Amsterdam and consist of 6 different functions, respectively residential (buy), residential (rent), commercial (non-hotel), commercial (hotel), hotel and office. For the calculation of the energy status quo the minimal requirements as stated in the Dutch building decree are used. This gives the overall energy demands 361 MWh/yr for space heating, 199 MWh/yr for domestic hot water, 158 MWh/yr for cooling, 154 MWh/yr building related (lights) electricity demand and 283 MWh/yr for non-building related (appliances) electrical demand. Space heating and cooling demands are largely dependent on the building design parameters. Thus, by changing the architectural design to its maximum values based on the bioclimatic context the space heating and cooling demand can be reduced by 85%. However, for the sake of this research a more 'realistic' design is made for the development of the case study area. Although this design is more realistic the space heating and cooling demand are still reduced by 67% for space heating and 28% for cooling, which gives them values of 119 MWh/yr. for space heating and 114 MWh/yr. for cooling. In this design the most peaks of heating and cooling throughout the year are reduced by the principles found in chapter 3.3.

This architectural design optimization can also be used to increase the amount of energy that can be exchanged. Together with multi functionality the building design parameters increase the possibility to exchange energy. Functions like commercial space and office have a higher heat-cold ratio than residential and hotel. The difference between the heat-cold ratio of these functions increases when buildings are better insulated than the minimal requirements as stated in the

Dutch building decree. The way heating and cooling is arranged also influences the possibilities of energy exchange. When heating and cooling only occur when people are present in a building, all functions have similar energy profiles, i.e. heating in winter and cooling in summer and thermal energy storage is needed to exchange energy. When continuous cooling throughout the year is introduced, the difference between the energy profiles of the functions increases, i.e. heating and cooling all year long, and energy can directly be exchanged between functions throughout the year.

Furthermore, with the introduction of energy exchange and the optimization of the architectural design based on the bioclimatic context the overall demand is decreased. To find out to what extent the case study design can be made energy flat the local renewable supply options are calculated. In this research only solar and wind energy are used, because these are both suited for the case study area. PV and Multifunctional roof edge technology [MRE] are used to provide electrical energy, while PVT and PT are considered for regeneration of possible thermal energy storage.

This thermal energy storage is introduced to find out to what extent it influences the possibility to create an energy flat urban block. Energy can be defined in three types, respectively electricity, heating and cooling. When heating and cooling are not stored in thermal storage all three types of energy have to be supplied by building energy components like an electrical heat pump or have to be imported from the national grid. With the introduction of thermal energy storage both the heating and cooling type can be (partly) passively gained within a building, i.e. the rest can be supplied with other local renewable resources, and temporarily stored for later use. In that case the heating and cooling energy types are in balance throughout the year within the urban block itself. Whereas in the all-electric version both electrical, heating and cooling demand have to be supplied by local renewable electricity resources, in options with thermal energy storage only the electrical demand has to be supplied with electricity. This means that not only the yearly directly usable fraction of renewable supply increases, but also the urban block becomes less dependent on other technologies that can be used as heat source.

The fourth step in the SUI approach is the energy concept. Within this research 4 types of energy systems are designed; 1) All-electric, 2a) Medium temperature thermal grid + separate (two pipes) cooling grid with heating and cooling when people are present, 2b) Medium temperature thermal grid + separate (two pipes) cooling grid with continuous cooling, 3) Low temperature thermal grid + thermal energy storage. The exact configurations and matching energy demand and supply can be found in chapter 4.4.

Lastly, the KPIs introduced in chapter 3.2 are used to evaluate the energetic performance of the overall energy system. according to the KPIs there is little difference between all options. All options are almost equally energy neutral on a yearly basis, they have almost the same maximum power and cumulative mismatch and the amount of produced energy that can directly be used is roughly the same as well. However, considering the percentage of the total demand that can directly be supplied on a yearly basis is slightly bigger for options 2b and 3. Option 2b however, has another main advantage. The main advantage of option 2b over option 2a and 3 is the fact that less low temperature heating for the regeneration of the thermal storage is required, i.e. more energy can be exchanged between functions. Thus, for the current configuration within the case study area it is best to separate all energy types, i.e. the heating, cooling and the electricity demand and to fulfill them with local supply. In that case the amount of energy that can directly be supplied is the largest. With the current functional program of the case study area option 2b has a slight advantage compared to the other options. Option 2b introduces continuous cooling which improves the amount of energy that can be exchanged. However, when the functional program changes in favor of functions with a high heat-cold ratio, for example, twice as much office space, both options 2a and 3 are favorable to use.

GOVERNANCE

5. Governance

Within the concept of energy flatness all energy that is used in an urban block is either passively gained, reused from different functions and/or locally produced. Energy flatness aims to optimize the overall energy system in order to reduce the mismatch between local supply and local demand. Introducing renewability as sole dependency for the energy system, i.e. the national energy grid should not be used in case of demand/supply peaks, implicates that for a working energy system collaboration and arrangements between stakeholders is key. These findings are supported by the designed case study area in Buiksloterham in chapter 4. The results from the research by design part show that in order to create an energy flat urban block a collective energy system is a key component. For the designed case study the conceptual energy network with the highest potential on an energetic level even requires continuous cooling throughout the year, i.e. for an optimized local energy system the collaboration between all functions is more important than the individual functions. Therefore, it is expected that the concept of energy flatness has big implications on all governance aspects involved in energy systems. Thus, this chapter describes the governance of energy flatness. Due to the interest of the implications on a system level and because the energy flatness concept is innovation in technological change, the sectoral innovation systems framework is used as an analytical framework to get a general idea of the different aspects found in literature that are key for energy flatness to succeed (Siva, Hoppe & Jain, 2017).

5.1 Institutional energy flow diagrams for energy systems

Chapter two describes the difference between a conventional energy system and a sustainable energy system that only depends on renewable energy and a first introduction to the institutional energy flows is given. By looking at the underlying commonly used institutional energy flow diagrams between the two systems two main different aspects can be found. One for the conventional system and one for the sustainable system. The underlying principle for the conventional energy system is centralization. This means that several big parties are responsible for a constant production of energy on a national/regional scale. While another big party arranges the distribution of energy over the national and regional grids. The end-user can buy energy carriers from licensed energy suppliers or intermediary companies. The whole system is regulated and the companies involved in this energy system have a monopoly status (Koirala et al., 2016 & Sorgdrager, 1996). The sustainable system is mostly used on a local scale. On this local scale the developing, monitoring, maintaining, financing and distribution of the overall energy system can be done through third parties (Figure 65). In countries like the United Kingdom these companies are also known as energy service company (ESCO) (Koirala et al., 2016 and Vine, 2005). However, currently only limited ESCOs are to be found in the Netherlands, in which the sustainable energy system is still in early stages of development.

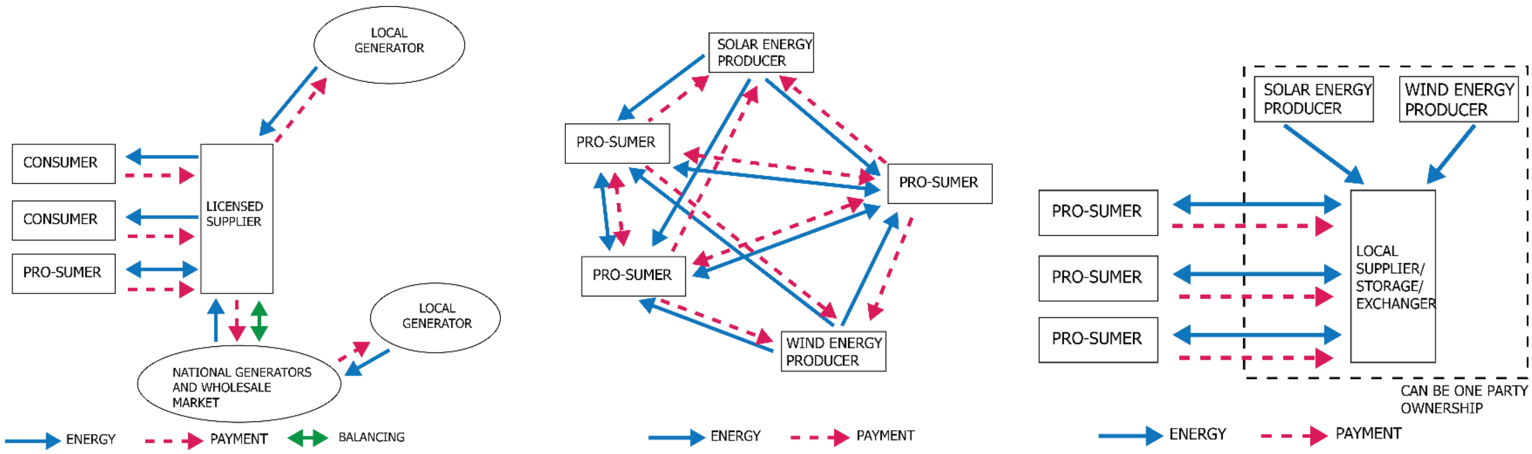


Figure 65: Conventional energy system (left), Sustainable energy systems; Decentral supply hubs (middle), Third party involvement (right) (by author)

As mentioned before, a multifunctional energy flat urban block uses all of the energy that is either passively gained, reused from different functions and/or locally produced energy inside the urban block itself. This system is based on the sustainable system described in chapter two, however, within this system multi functionality is a key asset to become energy flat. Multi functionality is used to provide residual energy of one function to another function. However, this reuse can be done in two different ways, direct reuse of energy or indirect reuse of energy, i.e. transporting residual energy to one central storage and then distribute it over functions that need energy. Although the second way of reusing energy enables the opportunity to use energy service companies as main organizer for the energy system, it also implies energy transmission and transformation losses due to the use of storage facilities. Therefore, the ideal way of reusing residual energy is through direct reuse between functions. In other words, having decentralized distribution hubs to supply energy, either newly produced or reused, within one urban block. These hubs would differ from renewable production from wind and solar, towards waste energy flows for each different function. However, with an increase in different functions that can provide energy to each other, there is an increase in different stakeholders as well. Furthermore, other aspects like laws and legislation, policies, financing, maintaining different building services and monitoring all energy can have an impact on changing the governance system as well. Therefore, in the next paragraph the existing barriers and challenges concerning energy flat urban block market development are explained and after that, an analytical framework is used to investigate different aspects that play a role in the feasibility of the implementation of energy flatness on an urban block level.

5.2 Sectoral innovation systems framework

As explained in chapter 5.1 it could be beneficial for multifunctional energy flat urban blocks to have decentralized energy supply hubs. In this research we are most interested to find out how this actually could be arranged on the governance system level of an energy system. The sectoral innovation systems framework (Figure 66) can be used to analytically analyze the different aspects whether a project is feasible or not. The sectoral innovation framework is based on four key aspects, respectively agents, interactions and networks, technological regime, institutional framing and market demand, that can be used to analyze the current state of these aspects regarding energy flatness (Siva, Hoppe & Jain, 2017). In the next paragraph;5.3 this framework is used to reflect on the currents state of the art of these aspects considering the case study location of Buiksloterham, Amsterdam.

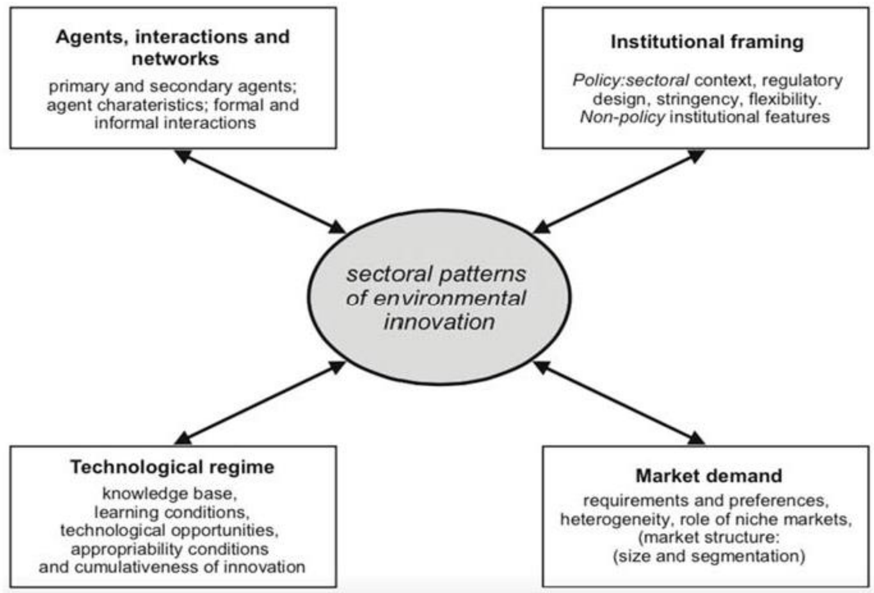


Figure 66: Graphical representation of the sectoral innovation systems framework, source: (Siva, Hoppe & Jain, 2017)

But, first a short introduction is made into the different elements of the sectoral innovation systems framework and eventual obstacles that can play a role in the case study design will be further explained.

Agents, interactions and networks

The aspect agents, interactions and networks describe all the different stakeholders that are part of incorporating an innovative idea in a system. According to Faber and Hoppe (2013) these agents are organizations or individual people that use several different processes to communicate, cooperate, exchange, competition and commanding to interact with each other. Examples of primary agents in the built environment are contractors, users, developers, installers, etcetera (Faber and Hoppe, 2013). This is the aspect where actual people are involved and by pursuing to implement an innovative idea into a system this is where you have to be persuasive to convince all people to follow you.

Obstacles regarding the uptake of energy innovation:

The main objective of the aspect agents, interactions and networks are the different stakeholders that can collaborate and communicate with each other in order to implement innovative ideas into a system. One of the main obstacles would be the fact that every stakeholder has its own view on a certain topic which increases the complexity in collaboration possibilities. Thus, the main advantages for all stakeholders have to be investigated and the importance of their role in the system should be emphasized.

Institutions

Within the dimension of institutions all possible rules that can have an influence have to be addressed. These rules differ from formal to informal. According to Siva, Hoppe and Jain (2018) formal rules are rules came up by government in forms of legislation, policies, regulation and initiatives. Informal rules are rules people use unconsciousness like common habits, routines and standards.

Obstacles regarding the uptake of energy innovation:

The main objective for the dimension institutional framing is to provide the legal context in which a new technology would be implemented. One of the main obstacles of this dimension is the slow pace at which legislation and policies are changed. Innovation is often hindered by these legislation and therefore, often experimental status to devise from current legislation is needed in order to implement innovation. In the Netherlands, this experimental status can be given by the ministry of economic affairs and climate, but this is only limited to a certain amount of projects each year.

Technological regime

The dimension of technological regime consist basically of four main aspects, respectively technology, complementarities and interdependencies, knowledge base and learning conditions. In other words, the technological regime describes the influence a new technology can have on a system. It describes the way society can extend their knowledge through both internal and external learning processes and whether the new technology eliminates existing technologies or whether it is complementary or dependent on other technologies (Siva, Hoppe and Jain, 2018)

Obstacles regarding the uptake of energy innovation:

The main objective of the dimension technological regime is to find out what the impact of a new technology can have on current systems. Because of the fact that within this research framework the mentioned technologies often consist of innovative/new products, the impact these products could have can only to a certain amount be quantitatively explained.

Market demand

According to Faber and Hoppe (2013) the dimension market demand represents the preference of the end-user to use the new technology, i.e. whether the demand is high enough to bring the innovative technology/product onto the market. By consulting potential end-users throughout the design of a new technology people can help you with information on how they would use that technology.

Obstacles regarding the uptake of energy innovation:

Although the dimension market demand should lead to end-user participating in the design process, it also brings certain obstacles. It could have a negative impact to solely design a new technology in order to fulfil the current end-user preference. People tend to stick to their standards/regular habits rather, which can lead to a less innovative end product.

5.3 Case study analysis

In this section the sectoral innovation systems framework is used to analyze the case study area for the research by design part carried out in chapter 4 of this thesis. As mentioned in chapter 4.1 the case study is located in Buiksloterham, Amsterdam in the Netherlands and it is a multifunctional urban block within the jurisdictional area of the municipality of Amsterdam, which indicates a certain type of stakeholders and regulations that are specific for this case study area. The technological regime and market demand also depend on the geolocation of a urban block, however, these aspects depend less on locality and more on regional and/or national scale.

5.3.1 Stakeholder analysis

In this section all stakeholders that play a role in the design and using phase of an energy system are discussed, the precise stakeholders for the case study area are used to create a generic overview of stakeholders within an energy system. In order to get a clear overview of the different roles stakeholders have in an energy system, the stakeholders are divided into three groups: Stakeholders active in distributing energy, stakeholders active in design, development and construction of urban block, stakeholders active in user stage of the urban block. For each stakeholder its general function/role is described, interrelation with other stakeholders is mentioned, implementations of the energy flat concept on the particular stakeholder is explained and their expected opinion towards energy flatness is talked about. All these aspects can be found in Table 18.

5.3.2 Institutions

As mentioned above the section; Institutions consists of the rules that apply to the specific case study area. These rules can be either formal, i.e. formed by the government, or they can be informal, i.e. the unconsciousness used common habits, standards and routines of people. However, these formal and informal rules do not only implicate barriers for innovation, they also create opportunities that can trigger innovation. Therefore, this section is divided into two parts, namely barriers and opportunities of which all of them apply to the case study area of Buiksloterham, Amsterdam.

Barriers:

Formal and informal rules tell us how society should function in order to be a well-functioning country. The government comes up with formal rules, i.e. laws and regulations, to what everyone has an obligation to obey. These formal rules are all written down and people can read them online. Informal rules, however, are more complex to define. People use informal rules unconsciousness through common habits, standards and routines. Therefore, these informal rules have to be conceived through interviews or literature study. Both formal and informal rules can be found in Table 19. The Table consists of six aspects; 1) Type of barrier (formal/informal), 2) Name, 3) Starting year of the barrier, 4) Short description, 5) Influence on energy flatness and 6) Influence on stakeholders.

Opportunities:

By thinking about the word rules, people immediately think of different aspects they are not allowed to do anymore. However, these rules also initiate the urge of people that want to deviate from these rules and create opportunities for innovation in energy systems to happen. The government, for example, has initiated different laws and regulations to differ and/or experiment within the above described laws and regulations. They also provide subsidies to people or businesses that want to improve the level of sustainability they currently have. Another way that rules create opportunities falls within socio-economic aspects of society. These three opportunity creating aspects are explained in Table 20. The Table consists of six aspects; 1) Type of barrier (formal/informal), 2) Name, 3) Starting year of the opportunity, 4) Short description, 5) Influence on energy flatness and 6) Influence on stakeholders.

Table 18: Stakeholder analysis (by author)

Stakeholder group	**Stakeholder** (Derived from Jansen et al., 2016 & Marc Koehler architects, 2017)	**Position and function** (by author)	**Interrelation with other stakeholders** (by author)	**Expected opinion towards uptake of energy flatness** (by author)	**Expected benefits** (by author, unless stated otherwise)	**Expected barriers** (by author, unless stated otherwise)
Active in energy services	Network operator electricity and gas	Distribute/supply electricity and gas from a production company to the end-user and operates the national grid	Supplies energy to the end-user. Regulated by the government.	Positive to a certain extent	Energy flatness reduces peaks in the national grid because areas with high renewability percentage are left out of the national grid.	Obligated to provide a physical connection with the national grid to all end-users that want and/or need that connection
	Heating network operator	Distribute/supply heat from a production company to the end-user, operates the grid and determines the payment rate for consumers.	Supplies heat to the end-user. Maximum payment regulated by the government.	Negative	-	With heating arranged per urban block heating network operators are no longer needed.
	Electricity and gas production companies (All regional/national operating energy production companies)	Produce electricity or gas and sell their electricity or gas to the end-user at a competitive level.	Sell electricity and gas to the end-user.	Negative	Less dependency on big (foreign) production companies	In the Netherlands the end-user is free by law to choose the electricity and gas supplier that they want.
	Third party as local network operator (Owners association or Energy service contracting company)	Operate, distribute and even produce energy on a local scale, i.e. building/urban block. Currently only energy service contractors can do this. With upcoming changes in laws also owners associations can act as a local network operator.	Supply and sell energy to the end-user.	Positive	All people living in an urban block can create, operate and collaborate in their own energy system. This provides everyone with the cheapest energy possible.	Currently owners associations are not allowed by law to operate a local network and for other local network operator a lot of extra duties like financing, distributing and maintaining a grid have to be done. They also do not commit to operate it for longer than 15 years just yet. Also is difficult to get an unanimous vote for uptake while each member has veto rights.
Active in design, development and construction	Real estate developer	Initiating, financing and conceptually designing the overall project. Can either develop to sell or to rent, but almost always tries to maximize their profit.	Providing all design and construction companies with a general concept and money. Permits obtained by local government and contracts with end-users.	Positive to a certain extent (depends on initial purpose)	When the initial purpose is develop to rent: The overall performance of the urban block will be higher (optimized).	When the initial purpose is develop to sell: Often they only want to meet the minimal requirements. Also, with insecurities about the working of the technology for the future a longer return on investment period is expected
	Contractor	Realizing a project. A contractor can have multiple different contracts during the lifespan of a building which differ from a traditional building contract all the way to a design, build, finance, maintain and operate contract (DBFMO).	In order to be able to realize a project a contractor should have a close connection with the rest of the design team. Contract with real estate developer and end-user (depends on contract type)	Positive to a certain extent (depends on the contract)	When maintenance is part of their contract: The overall performance of the urban block will be higher (optimized)	Working with an (new) integral technology: Leads to lack of end-user participation, lack of skilled workers, financial short coming, lack of knowledge about benefits.
	Architect	Design the overall looks and functionality of an urban block. The architect also integrates all different aspects like building physics requirements, mechanical systems and fire safety requirements into one design.	Working closely with all the technical engineers in order to be able to integrate those aspects. Contract with real estate developer and/or architect.	Slightly negative	It can create better indoor climates and when embracing the concept it can be used as sustainable marketing (expert interview)	Gets less creative freedom because certain design parameters influence energy flatness a lot.
	Building physics, structural and fire safety engineer	Design the overall building technology that is needed for a building or urban block to be build. They create a pleasant and comfortable indoor climate, ensure the building does not collapse and that everyone is safe inside of a building.	Provide the architect with information to integrate into the design and provide information to the contractor on how the urban block should be built.	No opinion for structural and fire engineer Positive for building physics consultant	An optimized energy system that also benefits the building physics of a building.	More collaboration between building physics engineer and energy systems engineer. Possible lack of information.
	Mechanical, electrical and plumbing engineer	Design mechanical, electrical and plumbing systems to ensure that all flows of energy and waste products are distributed throughout the urban block.	Provide the architect with information to integrate into the design and provide information to the contractor on how the urban block should be built.	Positive	They can innovate and optimize their energy system design.	Has to work closely with other stakeholder like the architect, building physics consultant, contractor and developer.
	Local government	Run local initiatives to set higher sustainability standards. Grant and regulates energy system design permits and building design permits.	She serves the common interest of its inhabitants.	Positive	Provide all inhabitants with a sustainable, steady secure and cheap energy system as possible.	Different views on sustainability when political landscape changes. Also, lack of knowledge in ensuring stable connections and overall benefits.
Active in the usage phase	Owners association	An association in which all owners of real estate in one urban block/building are represented. They come up with rules everyone has to follow and are responsible for the public areas within the building block. All occupants have to pay a yearly fee to this association for this responsibility.	Representing all occupants of the urban block	Positive to a certain extent	Create and operate their own energy system with the lowest pricing.	Operating an energy system takes more responsibility than a regular owners association. It also requires a higher initial investment of all owners, which leads to higher overall service costs. Owners associations will become VAT liable in the near future (expert interview)
	Private home and commercial unit ownership	Everyone who owns a unit or building in the urban block	Buys the units/buildings from the real estate developer and is represented in the owners association	Positive	It will provide all owners with secure, steady and cheap energy supply.	They cannot choose the energy production company that they want anymore, they have to be part of the system.
	Housing association, commercial rent corporation and hotel	All people that rent out units/houses in the urban block are represented.	Are represented in the owners association and rent out units to tenants. Contract with the owners association to fulfill all requirements.	Positive	It will provide everyone with secure, steady and cheap energy supply.	They also have to be part of the system when units are not rented out.
	Tenants [residential] and tenants [commercial]	People who rent a unit/house from a housing corporation or a commercial rent corporation for a certain amount of time.	Contract with housing corporations, commercial rent corporation and hotels to rent a unit.	Positive	It will provide everyone with secure, steady and cheap energy supply.	They probably do not want to commit to very long contracts regarding operating the energy system.

Table 19: Institutions - Barriers

Type of barrier	**Name** *[Dutch name]*	**Starting year**	**General short description**	**Influence on energy flatness** (by author)	**Influence on stakeholders** (by author, unless stated otherwise)
Laws and regulations	Electricity law *[Elektriciteitswet]*	1998	This law describes the rights and duties the end-user has considering electricity: The end-user has the right to have the closest usable connection with the electricity grid as possible. For the installation, maintenance and security of this physical connection the end-user has to pay. They also have to pay for the distribution of electricity over the grid, both incoming and outgoing electricity. The end-user also has the right to choose the electricity supplier of their choice (Sorgdrager, 1998).	A network operator is not allowed to both produce and distribute electricity by itself. Ideally, the urban block wants to have its own electricity grid, without a connection with the national grid, on which electricity is distributed by the producers/users itself. Within this law this not allowed yet.	Through this law the electricity & gas network operator and electricity & gas production companies have a monopolist status and certain rights are given to the end-user. It also implies a lot of restrictions like people cannot share electricity with each other.
	Heating law *[Warmte wet]*	2013	In the heating law heat is defined as heat or warm tap water that is used for heating up a room, sanitary purposes and household usage. This means that cold and/or low temperature heating is not included in this law. Everyone that has something to do with the supply of heat is a supplier. These suppliers have the legal obligation to provide a user with reliable supply of heat and they have to provide the user with adequate information about the supply of heat and the amount the user has to pay for the heat. Currently this payment is based on the gas price the user otherwise would use to heat up a building (Kamp, 2013a).	From July 2019 the revised heating law is binding. In this review several aspects could have an influence on energy flat urban blocks. First of all, the law does not apply to suppliers that are owners associations or similar legal forms. Also, low temperature heating is part of the review and for this kind of heating the same payment rate as 'normal' heat will be used. Additionally, there is room for experiments and the obligation to connect to the national gas network will be broadened.	Through this law the heating network operator can only operate a heating network within an urban block, i.e. they have a monopolist status. The end-user pays the same amount as they would pay when using gas as heating source, thus in that case changing to a more sustainable heating source does not make that much sense moneywise. With the revised heating law the above stated barriers are eliminated.
	Ground source energy systems law *[Wijzigingsbesluit bodemenergiesystemen]*	2013	This law has both implications for users of open/closed ground source energy systems as well as the authorized supervision. For open systems the province of North-Holland has the authorized supervision, whereas for closed systems the municipality has the authorized supervision. In general for both cases the ground source energy systems law has implications for the following aspects: Energy balance, return temperature, energy efficiency, interference, leakage, decommissioning, monitoring, registration, quality assurance, discharges and supervision (Kamp, 2013b).	Balancing (hourly) energy flows is one of the main aspects within the energy flat concept. To have a well working ground source energy supply, heating and cooling needs to be balanced throughout the year. Thus, when using the ground as energy source, not only the heating demand should be reduced but the cooling demand should also be increased.	This law gives the local government the rights to set standards and requirements for certain areas. However, as stated in the general short description it depends on the type of system who gives out the permit.
	Water law *[Water wet]*	2009	An open ground source energy system needs to fulfill the requirements stated in the water law. According to this law you need a permit for water discharge in both constructing as in usage phase, which is the case for an open ground source energy system. Five ways of discharging large amounts of used ground water are stated in the water law. From preferred to last option these options are 1; In the ground, 2; Surface water, 3; Clean water sewer, 4; Black water sewer, 5; Third party. Moreover, without a permit you cannot drain groundwater or infiltrate water for the purpose of industrial applications (Heringa, 2009).	The concept of energy flat urban blocks are scalable, they could be connected to other urban blocks in order to increase the efficiency. This means that the open ground source energy system should be scalable as well, i.e. the ability to discharge more water should be considered.	The constructor and operator of the energy system has to compel with this law considering discharging water. Therefore, they have to receive a permit from the authorized party.
	Ground source energy plan Buiksloterham *[Bodemenergieplan Buiksloterham*]	2014	Buiksloterham is listed as an interference area for both open and closed ground source energy systems. An interference area means that the municipality has more rights about the design of the ground usage in this area. Both the municipality of Amsterdam and the province of North-Holland want to create an as sustainable as possible area in the North of Amsterdam, therefore they want to use multiple ground source energy systems. With the title of an interference area the authorized supervisors have the ability to supervise the design of the ground in a better way, i.e. they appoint places on a map where warm and cold sources can be located. Additionally they added extra regulations for both closed and open ground source energy systems to which developing companies have to compel (Floris, 2014).	When using ground source energy in the case study area of Buiksloterham to become an energy flat urban block, you have to compel to the requirements stated in the ground source energy plan Buiksloterham document.	This document gives the local authority (municipality) the right to increase the sustainable requirements of the area to which people have to compel.
Socio-economic barriers	Information	-	For occupants it is common to have a lack of information in the benefits of more sustainable/optimized energy systems in contrast to more conventional energy systems. There is also a lack of knowledge in aspects they can do themselves in order to increase the efficiency of an energy system. Considering the building industry itself, the most common barrier is the lack of knowledge and unfamiliarity among craftsman on how to implement innovations into their building process (Palm and Reindl, 2018, Lindkvist et al., 2014 and Mlecnik, 2016)	Within the concept of energy flatness an urban block is designed using existing techniques in a smarter way to become energy flat. This means that the knowledge how to implement these techniques is already there, but the outcome of this optimization can only be calculated/simulated based on theory.	A lack of knowledge about energy flatness influences all stakeholders and therefore the benefits and differences to a traditional energy system should be elaborated on from the start.
	Social behavior	-	The building industry is from its nature rather conservative and therefore quite often not willing to change their way of working. Moreover, the building industry needs to earn money, therefore they often go for the minimal requirements stated in the Dutch building decree, which means they rather do not like to set higher goals than necessary (Palm and Reindl, 2018).	Conservatism could hinder the implementation of the energy flat concept into any design. It is not set in laws and regulations yet that an urban block should be energy flat and therefore this barrier could be have a big impact in its implementation just now.	This barrier has an influence on all stakeholders in the designing phase of a project. When energy flatness is wanted, only parties that are willing to implement this concept should be considered for collaborations. Also, the end-user has to agree with all the plans in order to increase the end-user involvement. It also largely depends when the end-user comes into play, often this is only at the end and thus, more collaboration between professional stakeholders is key (expert interview)
	Financial	-	When introducing innovations quite often the precise outcomes and improvements to the current situation are vague and the investment costs are quite often higher. For the companies in the building industry this means that they have to invest more in a product or process they do not know whether it will improves the situation, i.e. the risk of losing money at the end is higher. Occupants are concerned that these higher investment costs of innovations are calculated in their rental price, i.e. they are afraid that they have to pay a higher monthly fee than is 'necessary' (Palm and Reindl, 2018).	The energy flat concept is based on reducing the overall demand and using existing techniques to supply this demand. Therefore, the initial investment costs should be higher than traditional energy systems, but overall costs of energy will be reduced and overtime the system should pay itself pay.	Developers/contractors and end-users are most concerned about the financial aspects of energy flatness. Therefore the increase the possible implementation of energy flatness the developing party should have contract in which maintenance is included. Moreover, for the end-users there should be experimented with flexible payments for their energy.

Table 20: Institutions - Opportunities

Type of opportunity	**Name** *[Dutch name]*	**Starting year**	**General short description**	**Influence on energy flatness** (by author)	**Influence on stakeholders** (by author, unless stated otherwise)
Laws and regulations + policy and planning	Crisis and restore law *[Crisis en herstel wet]*	2010	During the crisis that started in 2008 the government came up with the crisis and restore law. At that time the building industry was not performing well and with this law the government tried to create a positive impulse to the building industry. This law consists of two categories: 1; Several measures for certain projects (project list) to stimulate faster production, 2; Changes in several other laws. With these two changes in above state categories there is more room for sustainability, energy and innovations within building and infrastructural projects. The crisis and restore law is going to be replaced/taken up into the Environmental and planning act (Hirsch Ballin, 2010).	In case of the concept of energy flat urban blocks the crisis and restore law could potentially be used based on energy and sustainability innovation. In that case the law could be used in order to deviate from the electricity law and the heat law as described in the section above. However, this law is mainly used by very big projects and there might be more applicable laws to use for the case study in this thesis.	With this law it is possible for developers that want to experiment (introduce energy flatness into their design/developments) and therefore deviate from other laws, to get a permit.
	Continuous energy transition law *[Voortgang energietransitie]*	2018	This law allows people to deviate from the electricity law [1998] with the possibility to perform experiments. These experiments are focused on local sustainable production, higher efficiency of electricity infrastructure and more involvement of end-users with decisions of energy productions. On behalf of the minister of economic affairs the governmental service for entrepreneurs (RVO) gives exemption permits based on the electricity law [1998] and the Authority consumer & market assesses the payment rate of your system (Wiebes, 2018).	With this law it is possible to create a local project network with the owners association as the network operator, in which they are both distributor and producer of local electricity. Additionally, the payment rate for the electricity supply can diverge from the legally binding amount published each year.	Through this law the owners association can act as an electrical grid operator and electricity producer. For the best energy flatness result all stakeholders should be involved in one system and therefore, the end-user does not have the right to choose the energy supply that they want. Additionally, the with this law the owners association becomes VAT liable (expert interview)
	Revised heating law *[Herziene warmtewet]*	Expected July 2019-2021	This law will replace the heating law stated in the barriers table. This reviewed law does not apply to suppliers that are owners associations or similar legal forms. Also, low temperature heating is part of the review and for this kind of heating the same payment rate as 'normal' heat will be used. Moreover, the obligation to be connected to the national gas network will be broadened and there will be room for experiments. The minister of economic affairs can grant permission to differ from the existing heat law when the experiment is focusing on the implementation of renewable energy resources, energy demand reduction, CO2 emission reduction and/or efficient use of a heat network. Experiments can also be used to test or optimize innovative business models (Woonbond, 2018).	In case of the concept of an energy flat urban block it implies that when the produces/distributor of heat (both high temperature as low/ultra-low heating) is not the owners association or similar legal form, the price users have to pay for their heating is the same price as they would need for heating with conventional gas.	Through this law the owners association can act as a heating network operator and heating producer. For the best energy flatness result all stakeholders should be involved in one system and therefore, the end-user does not have the right to choose the energy supply that they want.
	Environmental and planning act *[Omgevingswet]*	Expected 2021	To provide people with a more coherent, easy to read overview of all the laws concerning the environment and planning of the living environment, the government combines all these laws in one law; the environmental and planning act. Within this law aspects like participation, healthy living environment, air, water, extern safety, smell, heritage, wind hindrance, social issues and monitoring. This law will also replace the crisis and restore law [2010], thus for more room for sustainability, energy and innovations in different projects this law could be used to get an exemption for certain legally binding aspects in the three named components. Besides that, this new formed law will also provide people with information on general permits and/or reports that need to be carried out while designing a new energy system (Ministerie van infrastructuur en veiligheid, 2014).	From 2021 and onwards the environmental and planning act could potentially be used for the concept of energy flat urban blocks based on energy and sustainability innovation. In that case the law could be used in order to deviate from the electricity law and the heat law as described in the section above.	With this law it is possible for developers that want to experiment (introduce energy flatness into their design/developments) and therefore deviate from other laws, to get a permit.
	Circular Buiksloterham *[Circulair Buiksloterham]*	2015	The manifesto Circular Buiksloterham states that Buiksloterham will become a circular neighborhood on the aspects of energy, biodiversity, all material/product loops and a livability that is an example for other districts. It wants to become a neighborhood that depends on the local circular economy in which experimenting and innovations are part of the daily routine. To be able to stimulate this ambition, the municipality gave Buiksloterham the status of Living lab (Gemeente Amsterdam et al., 2015). Although this is not a legally binding document this report can be used to persuade hesitant stakeholders to implement more sustainable aspects into their projects.	The Living lab status means to a certain extend that in collaboration with the municipality experiments can be carried out. Although current laws and regulations prohibit new materials and clean technologies to be used, this experimental status gives people the opportunity to experiment with these technologies.	Through the living lab status developers, contractors and end-users are able to perform experiments. However, it is not a legally document on its own, thus still permission needs to be granted by the local authority.
Subsidies	Demonstration energy- and climate innovations, DEI+ *[Demonstratie energie innovatie]*	End-date 2020	This subsidy is based on five themes: Energy innovation, CO2 emissions reduction, flexible electricity networks, innovations gas free house, neighborhoods & buildings and spatial impact of large scale sustainable energy production. All five of these themes have their own budget and starting/end time to apply for the subsidy. One condition for all subsidies in this category is that there must be at least one entrepreneur in the project group (RVO, 2019b).	Because the case study is a newly build urban block two themes might be eligible for this case study: Energy innovation and flexible electricity networks. Within the subject energy innovation both pilot- and demonstration projects can be carried out and a project must have a focus on energy efficiency, using renewable energy sources or have a focus on infrastructure. For the theme flexible electricity networks only pilot projects are eligible and the focus has to lay on stimulation of storing and conversion of renewable electricity production, stimulation of demand side response, stimulation of CO2 free adjustable voltage level or flexible use of electricity networks (RVO, 2019).	The developer could reduce their financial worries by applying for this subsidy. When this subsidy is granted the high initial investment costs will be partly supplied by the government.
	Stimulating sustainable energy production, SDE +(+) [Stimulering duurzame energieproductie]	End-date 2019, from 2020 its SDE ++	This subsidy is based on six themes: Biomass, Geothermal, Water, Wind (land & Sea) and Solar. These themes together have a budget of 5 billion euros. SDE + pays for the difference between cost price of the produced energy and the market price, i.e. the unprofitable top. The main objective for solar projects is that it needs a big users connection and has more power than 15 KWp. This subsidy can also be used for heat pumps. (RVO, 2019c)	This subsidy can be used to reduce the financial barrier developers and end-users have for the concept of energy flatness. Experiments can be carried out in order to find out whether energy flatness really create a cheaper option for an energy system.	The developer could reduce their financial worries by applying for this subsidy. When this subsidy is granted the high initial investment costs will be partly supplied by the government.
	Renewable energy *[Hernieuwbare energie]*	End-date 2020	The main purpose of this subsidy is to use innovations in order to produce more renewable energy while the cost of it goes down. Therefore, these projects needs to have a focus on one of the following aspects: Creating cheaper renewable energy production with existing techniques, creating cheaper wind energy in the sea, combining production and storing of energy, combining production and smart distribution (smart grids) on a decentralized scale or other renewable energy options that are not part of the SDE+ subsidy and which can produce more energy with innovations (techniques like; Solar heat, non-grid connected PV systems, shallow ground source energy systems). All these options need to produce cheaper renewable energy production than current state of the art techniques at least before the year 2030 (RVO, 2019b).	This subsidy can be used to reduce the financial barrier developers and end-users have for the concept of energy flatness. Experiments can be carried out in order to find out whether energy flatness really create a cheaper option for an energy system.	The developer could reduce their financial worries by applying for this subsidy. When this subsidy is granted the high initial investment costs will be partly supplied by the government.
	Urban Energy *[Innovatieprogramma Urban energy]*	End-date 2019	Subsidy on the grounds of urban energy can be based on five themes: 1; Solar energy, 2; Sustainable installations for heat/cold and pleasant indoor climate, 3; Physical integration, 4; Flexible energy infrastructure, 5; Energy monitoring and services for and of players from the energy market. All themes have their own closing date and their own yearly budget (RVO, 2019c).	In the case of the usage of the concept of an energy flat multifunctional urban block as described in this thesis a project could be eligible for the urban energy subsidy on the grounds of theme five; Energy monitoring and services for and of players from the energy market.	The developer could reduce their financial worries by applying for this subsidy. When this subsidy is granted the high initial investment costs will be partly supplied by the government.
Socio-economic factors	Information	-	Lack of knowledge about energy innovations is commonly found by end-users and building industry professionals. For both the benefits of optimizing an energy system are not yet clear enough to get them started to implement these concepts.	Informational barriers can hold back the implementation of energy flatness in designs. Therefore, they should be limited by introducing open communication between project developers and end-users of the project.	By having open communication between all stakeholders, information can be shared in order to reduce the lack of knowledge for all stakeholders.
	Social behavior	-	Social behavioral barriers are often caused by the non-existing willingness of people to change their behavior concerning setting higher goals and implementing innovation in their process.	To overcome this barrier the municipality of Amsterdam can be used as an example. Before construction of buildings took place in the district, the municipality set in collaboration with different stakeholders a higher standard in building/district requirements than the law and regulations. By writing this down and publishing this document before construction took place, everyone that is a potential construction partner knows what it gets itself into.	When there is a clear legally binding document at the start of a project in which high sustainable goals are defined, conservative parties that do not want to include innovation can be informed from the start and left out when wanted. This enables the technology to be used by people that want it in order to gain information on scalability of the technology. Which at the end could benefit also the conservative people.
	Financial	-	Both end-users and project partners are concerned of financial aspects and see them as a barrier for innovation to happen. They are afraid to have a higher investment cost (developer) or that they have to pay more on a monthly basis.	By pointing out the possible subsidies a project can apply to energy flatness can become more viable.	With subsidies the financial worries of both the developer and the end-users can be reduced. Also, other financing options like crowdfunding, sustainability funds of banks, private investors, etcetera.

5.3.3 Technological regime

In paragraph 5.1; Institutional energy flow diagrams for energy systems three possible flow diagrams are explained. One for a conventional energy system and two for a sustainable energy system on which an energy flat energy system is based upon. The conventional system is based on central production and supply of energy, whereas the sustainable systems can be either consist of decentral supply hubs or one party that arranges the whole energy system. Table 21 shows the differences for all three different energy flow diagrams. These types are analyzed on the following aspects: Usability for energy flatness, Complexity of the system (Supply connections & payment flows), Stakeholder who finances, operates and maintains the overall system and whether the arranged system is juridical feasible or not.

Type of institutional energy flows	**Usable for energy flat concept**	**Amount of supply connections between end-user and other stakeholders**	**End-user pays for energy**	**Financing, operating and maintaining the energy infrastructure is done by**	**Juridical feasibility as of July 2019**
Conventional	No	1	One way	Network operator	Yes
Decentral supply hubs	Yes	5	Two ways	Multiple possibilities	No
Third party	Yes	1	One way/two ways	Third party	With permission

Table 21: Overview differences between energy system arrangements (by author)

As can be seen in Table 21 only two system arrangements are suited for the energy flat concept, i.e. decentral supply hubs and third party ownership. The overall performance of the energy system is a key component to succeed within an energy flat urban block. In order to optimally use the overall system there should be a lot of connections between all different stakeholders to exchange energy at different times of the day/year. Because of all the stakeholders that can exchange energy the system of decentral supply hubs becomes a very complex system with endless connection between the different stakeholders. Although, the technologies used to create an energy flat urban block are existing technologies, the key component to energy flatness is the integral approach to combine all techniques. The combination of all the connections between stakeholders and the integral approach even increase the complexity of the design and operating of the energy system. Therefore, to limit the overall complexity of the energy system third party involvement seems like an essential aspect to create an energy flat urban block. In that system the third party finances, maintains and operates the supply, payment regulations and distribution of energy within an urban block. Ideally, this third party would be the owners association of the urban block. However, during the workshop session with experts it became clear that the owners association is (often) not capable of handling complex energy systems. Thus, when an energy system is complex a professional energy service company (ESCO) should come into play.

Figure 67 shows two possible arrangements of the third party involvement system. In both systems the residents of the urban block provide heat to the heating grid for later use, heating energy flows both in and out, and they receive electricity from the electricity supply owned by the third party. With current regulations a price is tagged on every energy flow that occurs, i.e. for both incoming and outgoing energy (heat) a price needs to be paid by the receiver.

By incorporating the requirements of energy flow payments into an institutional energy flow diagram design we get the diagram showed in Figure 67 (left). Within this diagram the residents/tenants maintain the right to choose when they want to be part of the overall energy system. They still own extra services needed that are in their unit/building and thus maintain freedom to use them when wanted. However, for a well working energy flat system it is expected that the overall performance reduces when not all stakeholders are involved all the time. Therefore, Figure 67 (right) shows an optimized institutional energy flow diagram. In this diagram the third party also owns and operates all energy services within all buildings. In that case the third party can operate the system also when no one is in the building, which can lead to an overall increase in performance of the system.

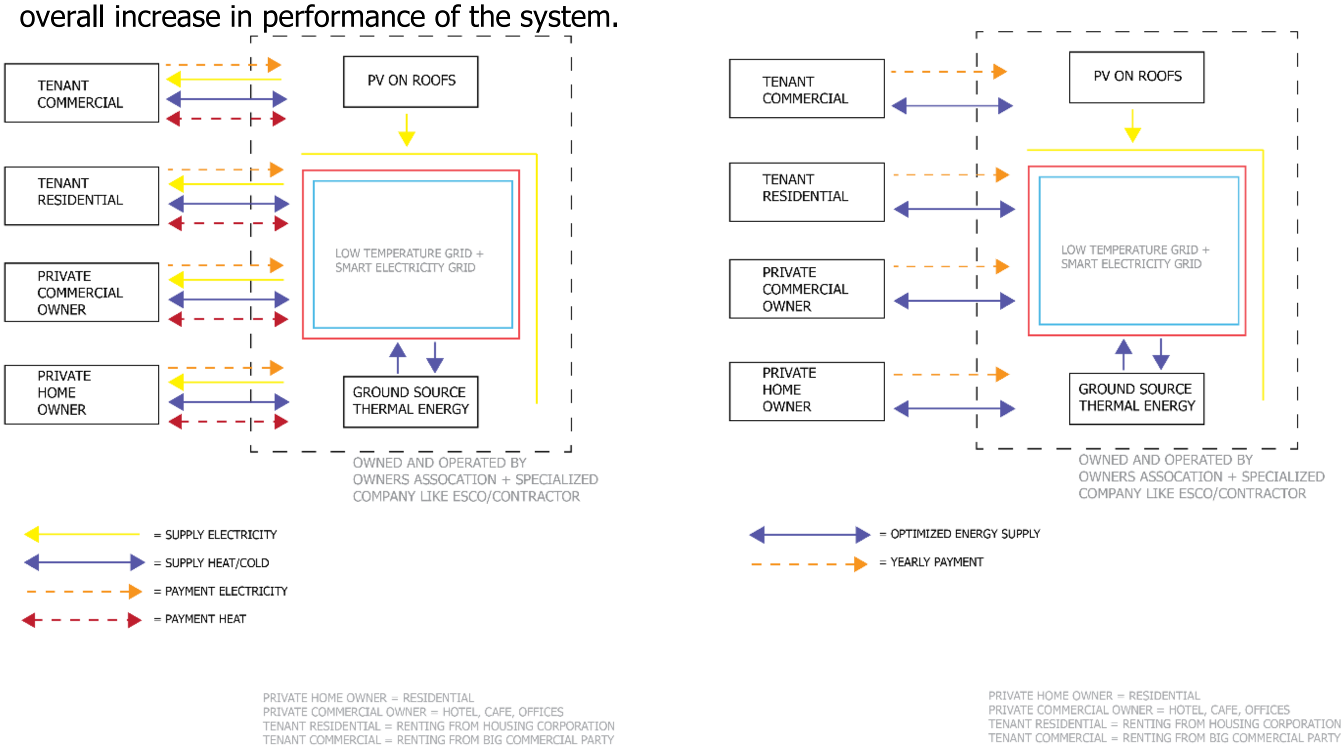


Figure 67: Third party involvement diagram: Two way payment (left), One way payment (right) (by author)

5.3.4 Market demand

In paragraph 5.3.3 two possible flow diagrams that can be used to arrange an energy flat urban block are described. To get an understanding what diagram is preferred by its users the market demand has to be analyzed. In both systems the same stakeholders have different roles, responsibility and relationships with other stakeholders. Table 22 provides an overview of the benefits and the disadvantages for the stakeholders that are involved. It explains what stakeholders are involved, the role they have, interrelation with other stakeholders, benefits and disadvantages of each stakeholder. In order to get an understanding what changes for all stakeholders compared to mostly used energy system in current society, a comparison with a conventional energy system is made.

Table 22: Stakeholders and energy system

	Conventional system				Sustainable system: Two way payment				Sustainable system: One way payment			
Stakeholder	**Position and function**	**Interrelation with other stakeholders**	**Expected benefits**	**Expected disadvantages**	**Position and function**	**Interrelation with other stakeholders**	**Expected benefits**	**Expected disadvantages**	**Position and function**	**Interrelation with other stakeholders**	**Expected benefits**	**Expected disadvantages**
Network operator electricity and gas (NUON & Liander)	Finance, maintain and operate the electricity/gas grid	Gets a yearly payment from end-users for maintenance. Ensure the energy production companies that they can distribute energy to the end-user.	Have a monopolist status.	With increasing renewability fraction the grid cannot handle it anymore.	-	-	-	-	-	-	-	-
Heating network operator (NUON warmte, Westpoort warmte and Alliander DGO)	Finance, maintain and operate the heating grid	Provide end-users with heat. Gets a yearly payment from end-users for maintenance.	Have a monopolist status.	-	-	-	-	-	-	-	-	-
Electricity and gas production companies (All regional/national operating energy production companies)	Produce electricity or gas and sell their electricity or gas to the end-user at a competitive level.	Sell electricity and gas to the end-user.	Can produce energy on a large scale away from cities.	When grid cannot handle the amount anymore, they cannot sell energy to the end-users.	-	-	-	-	-	-	-	-
Third party as local network operator (Possible owners association together with Energy service contracting company)	-	-	-	-	Finance, maintains and operate the electricity & heating distribution grid and production of energy on urban block scale. They deliver energy to a building where it is scaled up for final use.	Provide end-users with energy they need. Receive payments for heating and electricity. Have to pay for heating they receive from the end-users.	Their responsibility is limited to the urban block, not into the buildings. Possibility to experiment with flexible payments.	No optimizing for the whole system is possible. Experimenting with flexible payments is limited.	Finance, maintains and operate the electricity & heating distribution grid and production of energy for the total urban block including inside the buildings.	Provide end-users with energy they need. Receive payments for heating and electricity.	Possibility to optimize the overall energy system without dependency of other stakeholders.	Possibility to experiment with flexible payments is limited.
Private home and commercial unit ownership	Everyone who owns a unit or building in the urban block. These are the end-users of the energy.	Buys energy from licensed suppliers. Has to pay for maintenance of the grids.	Are free to choose the energy supplier that they want.	Has to pay for delivering energy back to the grid.	Everyone who owns a unit or building in the urban block. These are the end-users of the energy. They own the building services within their building.	Buys electricity and heat from a third party. Is able to sell heat to the third party. Has to pay a yearly fee to the owners association for maintenance.	Has the freedom to choose whenever they want to be part of the energy system.	There is a chance that the balance between buying and selling heat is not the same, i.e. no balanced payment.	Everyone who owns a unit or building in the urban block. These are the end-users of the energy.	Buys all energy from the third party. Has to pay a yearly fee to the owners association for maintenance.	Does not have to act as an energy supplier at all. Only has to pay a yearly amount for the energy needed.	Their building maybe uses the building services when there is no one. Their payment for energy could be higher than needed.
Tenants [residential] and tenants [commercial]	People who rent a unit/house from a housing corporation or a commercial rent corporation for a certain amount of time. These are the end-users of the energy.	Buys energy from licensed suppliers. Has to pay for maintenance of the grids.	Are free to choose the energy supplier that they want.	Has to pay for delivering energy back to the grid.	People who rent a unit/house from a housing corporation or a commercial rent corporation for a certain amount of time. These are the end-users of the energy. Their renter owns the building services within their building.	Buys electricity and heat from a third party. Is able to sell heat to the third party. Has to pay a yearly fee to the owners association for maintenance.	Has the freedom to choose whenever they want to be part of the energy system.	There is a chance that the balance between buying and selling heat is not the same, i.e. no balanced payment.	People who rent a unit/house from a housing corporation or a commercial rent corporation for a certain amount of time. These are the end-users of the energy.	Buys all energy from the third party. Has to pay a yearly fee to the owners association for maintenance.	Does not have to act as an energy supplier at all. Only has to pay a yearly amount for the energy needed.	Their building maybe uses the building services when there is no one. Their payment for energy could be higher than needed.

- = No role in the described energy system.

5.4 Conclusion

This chapter answers the following sub-questions: 1) *What stakeholders play a role in the energy system of an urban block and how do they play a role?, 2) What are barriers and opportunities [laws & regulations, subsidies and socio-economic] for governance aspects in the current (governmental/society) system?, 3) Under what governance conditions could the energy flat concept work?* These questions are answered by analyzing the case study area in Buiksloterham using the sectoral innovation systems framework. The case study is analyzed on agents, interactions & networks, institutions, technological regime and market demand.

Concerning the agents, interactions and networks three groups of stakeholders active in energy systems can be found: 1) stakeholders active in distributing energy, 2) stakeholders active in design, development and construction of an urban block, 3) stakeholders active in user stage of the urban block. These stakeholders all have their own function/role within an energy system, ranging from energy distribution to granting permits to design/construct an energy system. Because of the different functions the stakeholders have, different stakeholders largely depend on each other to fulfill their role. For some stakeholder energy flatness means that the role they have within the energy system changes. Therefore, for each individual stakeholder the energy flat concept has different implementations, both positive and negative, and thus, they have different opinions towards the energy flat concept.

However, these stakeholders not only have different opinions towards the energy flat concept, they also have to obey to certain rules that apply to the specific case study area. These rules are described under the section Institutions and can be either formal, i.e. formed by the government, or they can be informal, i.e. the unconsciousness used common habits, standards and routines of people. However, these formal and informal rules do not only implicate barriers for innovation, they also create opportunities that can trigger innovation to happen. Considering the barriers within the specific case study area the laws and regulations that have to be compel to are the Electricity law, Heating law, Ground source energy systems law, Water law and Ground source energy plan Buiksloterham. Of these formal rules the Electricity and Heating laws have the biggest impact on the uptake of the energy flat concept. According to both laws it is not allowed to directly exchange energy between functions and have one party that arranges the production, distribution and arranging payments in one area. To be able to introduce an energy flat optimized energy system an experimental status has to be granted by the Ministry of economic and climate affairs. However, from July 2019 and onwards the revised Heating law is in place which gives third parties in local energy systems more freedom to own, operate and maintain a local energy system. Other barriers can also be found in socio-economic factors like informational, social behavior and financial aspects. However, laws and regulations + policy and planning also introduce opportunities for the uptake of energy flatness. The Crisis and restore law, Continuous energy transition law, Revised Heating law, Environmental and planning act and Circular Buiksloterham provide possibilities to deviate from earlier mentioned barriers, i.e. permission from the ministry of economic and climate affairs and/or local authorities has to be granted. Also, innovative energy projects can apply for four different subsidies; 1) Demonstration pilot- and climate innovations, DEI+, 2) Stimulating sustainable energy production, 3) Renewable energy and 4) Urban energy, which can reduce existing financial barriers. Additionally, socio-economic factors like information, financial and social behavior can be used as opportunities as well.

With the knowledge about the barriers and opportunities the energy flat concept and its stakeholders are facing, the technological regime and market demand are analyzed. Within these sections possible institutional energy flow diagram arrangements are investigated. Although, both decentral supply hubs and third party involvement can be used to arrange energy flatness in an urban block, to decrease the overall complexity of the energy system third party involvement seems like an essential aspect to create an energy flat urban block. In that system the third party finances, maintains and operates the supply, payment regulations and distribution of energy within an urban block. Ideally, this third party would be the owners association of the urban block. However, during the workshop session with experts it became clear that the owners association is (often) not capable of handling complex energy systems. Thus, when an energy system is complex a professional Energy service company (ESCO) should come into play.

Additionally, the third party involvement option can be arranged in two ways. In both arrangements the residents/tenants of the urban block provide heat to the heating grid for later use, heating energy flows both in and out, and they receive electricity from the electricity supply owned by the third party. Within the first arrangement a price needs to be paid by the receiver both incoming and outgoing energy (heat). Within the first arrangement the residents/tenants maintain the right to choose when they want to be part of the overall energy system. They still own the extra services needed that are in their unit/building and thus maintain freedom to use them when wanted. However, for a well working energy flat system it is expected that the overall performance reduces when not all stakeholders are involved all the time. In the second arrangement the third party also owns and operates all energy services within all buildings. In that case the third party can operate the system also when no one is in the building, which can lead to an overall increase in performance of the system. End-users only pay a yearly fee for the operation and maintenance of the energy system instead of per incoming/outgoing energy flow.

GENERAL CONCLUSION

6. General conclusion

This research focused on the impact multi functionality has on both energetic and governance level in order to create an energy flat urban block. This is done through literature research and by making an example design of an energy flat urban block. Therefore, the research question that is answered in this research is:

How can you design an energy flat multifunctional urban block in the Netherlands and what does this imply for governance [Case study Buiksloterham, Amsterdam]?

In order to be able to answer this question, seven sub-questions are answered. In the next section a short summary per sub-question is given.

6.1 Summary of research results

What parameters influence energy profiles of demand and supply and how can these be adapted?

Reducing the mismatch between supply and demand can be carried out in three ways: Adapting demand, adapting supply and inter-exchange of energy. Adapting demand can be done through architectural design optimization, changing user behavior and by introducing smart grids. Within an energy system with renewables as primary energy, adapting the supply can be done through the introduction of multiple renewable sources like solar and wind or by the introduction of temporal energy storage. Another option to reduce the mismatch is by exchanging energy between functions over time. When adaptation of either the supply or demand curve is desired, the load shape objective of each parameter can be used to find out what parameter is best to change in order to reduce the mismatch.

To what extent can different functions exchange energy?

The inter-exchange of energy can be used to reduce the mismatch between supply and demand. Although the amount of energy that can be exchanged largely depends on the building design parameters, multi functionality increases the possibility to exchange energy. Functions like commercial space and office have a higher heat-cold ratio than residential and hotel. The difference between the heat-cold ratio of these functions increases when buildings are better insulated than the minimal requirements as stated in the Dutch building decree. The way heating and cooling is arranged also influences the possibilities of energy exchange. When heating and cooling only occur when people are present in a building, all functions have similar energy profiles, i.e. heating in winter and cooling in summer and thermal energy storage is needed to exchange energy. When continuous cooling throughout the year is introduced, the difference between the energy profiles of the functions increases, i.e. heating and cooling all year long, and energy can directly be exchanged between functions throughout the year.

In what way does [thermal] energy storage influence energy flatness?

Energy can be defined in three types, respectively electricity, heating and cooling. When heating and cooling are not stored in thermal storage all three types of energy have to be supplied by building energy components like an electrical heat pump or have to be imported from the national grid. With the introduction of thermal energy storage both the heating and cooling type can be (partly) passively gained within a building, i.e. the rest can be supplied with other local renewable resources, and temporarily stored for later use. In that case the heating and cooling energy types are in balance throughout the year within the urban block itself. Whereas in the all-electric version both electrical, heating and cooling demand have to be supplied by local renewable electricity resources, in options with thermal energy storage only the electrical demand has to be supplied with electricity. This means that not only the overall fraction of autonomy increases, but also residual energy can be exchanged between different functions over time.

How can the energy flatness of a multifunctional urban block be evaluated?

Within the energy flat concept supply and demand are equal at any given time of the year. Hence, the required energy supply and demand calculations have to be carried out per hour. In this research hourly steady state energy balance calculations are performed using excel; 8760 hours are calculated per building function. The supply of different renewable technologies is also calculated on an hourly basis. By combining the information of both supply and demand the energy flatness of an urban block can be evaluated based on the five key performance indicators as stated in chapter 3.2, which are: energy neutrality/fraction of renewable supply per year, fraction of autonomy; direct energy supply use, maximum power mismatch, maximum cumulative mismatch, inter-exchange of reusable energy flow fraction. These KPIs describe the mismatch between supply and demand on a yearly basis, the amount of energy that can directly be used, the power of the energy system, the size of needed storage facilities and the possible impact of multi functionality on the energy flatness of an urban block.

What stakeholders play a role in the energy system of an urban block and how do they play a role?

There are three groups of stakeholders active in energy systems: 1) stakeholders active in distributing energy, 2) stakeholders active in design, development and construction of an urban block, 3) stakeholders active in user stage of the urban block. These stakeholders all have their own function/role within an energy system, ranging from energy distribution to granting permits to design/construct an energy system. Because of the different functions the stakeholders have, different stakeholders largely depend on each other to fulfill their role. For some stakeholder energy flatness means that the role they have within the energy system changes. Therefore, for each individual stakeholder the energy flat concept has different implementations, both positive and negative, and thus, they have different opinions towards the energy flat concept.

What are barriers and opportunities [laws & regulations, subsidies and socio-economic] for governance aspects in the current (governmental/society) system?

Within the concept of energy flatness the overall energy system is optimized rather than the energetic performance of each individual function. Theoretically, with the use of existing techniques it is possible to implement this concept to improve the overall energetic performance of an urban block. However, for the maximum uptake of this concept it should not only be viable on an energetic level, it also has to obey to certain rules that apply to this specific case study area. These rules can be either formal, i.e. formed by the government, or they can be informal, i.e. the unconsciousness used common habits, standards and routines of people. However, these formal and informal rules do not only implicate barriers for innovation, they also create opportunities that can trigger innovation to happen. Considering the barriers within the specific case study area the laws and regulations that have to be compel to are the Electricity law, Heating law, Ground source energy systems law, Water law and Ground source energy plan Buiksloterham. Of these formal rules the Electricity law and Heating law have the biggest impact on the uptake of the energy flat concept. According to both laws it is not allowed to directly exchange energy between functions and have one party that arranges the production, distribution and payments in one area. To be able to introduce an energy flat optimized energy system an experimental status has to be granted by the Ministry of economic and climate affairs. However, from July 2019 and onwards the Revised Heating law is in place which gives third parties in local energy systems more freedom. Other barriers can also be found in socio-economic factors like informational, social behavior and financial aspects. However, laws and regulations + policy and planning also introduce opportunities for the uptake of energy flatness. The Crisis and restore law, Continuous energy transition law, Revised Heating law, Environmental and planning act provide possibilities to deviate from earlier mentioned barriers, i.e. permission from the ministry of economic and climate affairs has to be granted. Also, innovative energy projects can apply for four different subsidies; 1) Demonstration pilot- and climate innovations, DEI+, 2) Stimulating sustainable energy production 3) Renewable energy and 4) Urban energy, which can reduce existing financial barriers. Additionally, socio-economic factors like information, financial and social behavior can be used as opportunities as well.

Under what governance conditions could the energy flat concept work?

To implement the energy flat concept successfully into an energy system design the overall performance of the energy system is a key component. In order to optimally use the energy system there should be a lot of connections between all different stakeholders to exchange energy at different times of the day/year. Additionally, the technologies used to create an energy flat urban block are existing technologies, another key component to energy flatness is the integral approach to combine all techniques. With the combination of all the connections between stakeholders and the integral approach increases the complexity of the design and operating of the energy system. In order to be able to limit the complexity for all parties involved a third party should be involved. In that system the third party finances, maintains and operates the supply, payment regulations and distribution of energy within an urban block. Due to the complexity this third party should be an Energy service company (ESCO).

This third party involvement option can be arranged in two ways. In both arrangements the residents of the urban block provide heat to the heating grid for later use, heating energy flows both in and out, and they receive electricity from the electricity supply owned by the third party. Within the first arrangement a price needs to be paid by the receiver both incoming and outgoing energy (heat). Within the first arrangement the residents/tenants maintain the right to choose when they want to be part of the overall energy system. They still own the extra services needed that are in their unit/building and thus maintain freedom to use them when wanted. However, for a well working energy flat system it is expected that the overall performance reduces when not all stakeholders are involved all the time. In the second arrangement the third party also owns and operates all energy services within all buildings. In that case the third party can operate the system also when no one is in the building, which can lead to an overall increase in performance of the system. End-users only pay a yearly fee for the operation and maintenance of the energy system instead of per incoming/outgoing energy flow.

6.2 Limitations of this research

While carrying out this research some limitations were noticed that have to be addressed.

The most important limitation of a research by design are the assumptions that you have to make in order to be able to calculate things quantitatively. Within this research the case study that is used is not yet build or designed in detail. Therefore, real life data cannot be used and theoretical assumptions have to be made. Additionally, the case study area is located in the Netherlands, this means that the guidelines of the energy flat concept on energetic level only can be applied to areas with the same bioclimatic context. Also, the implications concerning governance components only include the Netherlands, other regions are out of scope.

Concerning the energy calculations two main limitations can be found due to the need for simplification of the calculations. Steady state calculations are used to calculate both the supply and demand. This means that thermal mass is out of scope for this research. Also, a limited amount of different technologies are considered for supply purposes.

Moreover, as expressed by the experts during the workshop session money is probably the main driver whether sustainable energy concepts are implemented or not. The cost analysis of the overall energy system and how energy flatness influences this is out of scope in this research. Also, there are possible benefits in low and flexible payments as proposed within section 4.3 of this research. However, to what extent energy flatness influences the amount end-users have to pay for their energy is out of scope for this research.

6.3 Recommendations for future research

This research focused on creating guidelines on how energy flat multifunctional urban blocks can be designed, including governance components. Throughout this study multiple potential research topics emerged. Hence, this study could serve as a starting point for further research and topics that still need more in depth research can be found in the following areas;

- It is expected that the indoor climate could benefit from the introduction of energy flatness as described in this research. However, these benefits are not yet quantitatively described.
- Creating a constantly optimizing energy system cannot take place without the introduction of IT components in order to create a 'smart and dynamic' energy system that can monitor, predict and respond quickly. Thus, still more technical research in the fields of electrical engineering and mechanical engineering has to be done.
- In this research the calculations were made through steady state calculations, which has the disadvantage that thermal mass is not included in the research. It is expected that it has a

big influence in reducing the peaks throughout the year. Therefore, in future research thermal mass should be included.

- Within this research it is the first time governance components and the energy flat concept are linked to each other. Hence, this research consisted of creating an overview of all governance components influencing the uptake of the energy flat concept. Therefore, still more in depth research into stakeholder participation and the risks they are facing when energy flatness is introduced. Potentially, this could be done to extensive qualitative research.
- Additionally, as proposed in this research the institutional energy flow diagrams change the way energy is produced, distributed and sold to the end-user. In order to create clearness of potential benefits concerning money, experiments with the proposed diagrams should be carried out. In that way both the governance components and energetic performance can be analyzed. The best way to do this is the implementation of energy flatness in a real life project. However, there might be a way to simulate it.

6.4 Recommendations for policy makers

For energy flat multifunctional urban blocks optimization of the overall energy system through stakeholder collaboration and integral technological approach is a key component. Within chapter 4.3 it is explained that these energy systems are becoming quite complex and that third party involvement is rather important for the concept of energy flatness to be taken up. However, currently laws like the Electricity law forms the biggest hindrance for the uptake of the energy flat concept. In order to increase the uptake of energy flatness it is advised that the Electricity law will be changed in the same way as the Revised Heating law, i.e. creating more freedom for third parties like the owners association to deviate from the existing law and experiment with innovative solutions like flexible payments.

Reflection

7. Reflection

My thesis is part of the sustainable design graduation studio of the master track building technology. This studio focusses on sustainability related topics in the built environment like structural design, façade design and climate design. For my thesis the main topic is energy flat multifunctional urban blocks with a second emphasis on governance implementations. Currently, when intermittent resources are used in an energy system and there is too much production than can be used, the system delivers energy back to the national energy grid. Within energy flat urban blocks all energy is produced using intermittent techniques like solar/wind and directly used within the same urban block as well without delivering back to the national grid. This research in particular investigated how multi functionality could be used to balance out the peaks in both supply and demand of energy to increase the effectiveness of renewable energy production/usage within one urban block. Initially, the aim was to investigate whether multi functionality can be used to provide an energy system with different user profiles and direct energy exchange between functions. With the focus on multi functionality the second emphasis of this research come into play, namely governance. With this focus we can come up with solutions to create an energy flat energy system and to gain knowledge what this implies for governance. Hence, the focus area of my research lies within the climate design emphasis of the sustainable design graduation studio.

At the beginning of my research I immediately decided to use a case study area which is part of the KoWaNet research program of the climate design department. With an actual case study area I was able to use the SUI method as a start for the energy analysis of the area. Moreover, extensive research is previously done on ways to reduce the energy demand within a building. For the balancing I could use a lot of this literature. As mentioned before multi functionality is a key component in my research. However, not much is known in literature about ways to use multi functionality in order to directly reuse energy of these functions and ways they could influence a demand shift. Therefore, I had to perform a lot of calculations/simulations with excel to find out what the impact is of multi functionality for energy flatness, by looking back this part actually took me too long. Moreover, because of the fact that I wanted to focus the governance components on my findings of multi functionality, I started rather late with this research. But by looking back, these calculations where an important aspect of my research.

In the design part of this research an energy system is designed and is based on already existing techniques to produce, store and consume thermal and electrical energy in an urban block. The design within this research is thus rather conceptual/abstract. The research behind this design is of more significant innovation. This research includes and described how the existing techniques could be used more effectively in order to create a more energy flat urban block.

This research does not only create an overview of ways existing techniques could be used more effectively, it also provides an overview of implications energy flatness has on the governance of an urban block. Thus, by reading this research the reader can learn about the technological aspects that they can implement in their own projects and provide the reader with knowledge about what energy innovation implies for governance.

Currently in society there is a problem with delivering back of intermittent renewable energy to the nation grid. The grid cannot handle the large peaks the intermittent resources create in the grid. With implementing the concept of energy flatness in more projects these peaks on the national grids will be reduced and therefore, this research can help society to become more future proof.

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APPENDICES

9. Appendices

A. Case study energy calculation characteristics

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B. Description of governance components

B.1: Description of expert interviews

A. Case study energy calculation characteristics

A.1: Detailed building parameters and excel model input

A1.1: Amount of people:

- Amount of people for hotel and office space are based on the values found in figure below. These values are based on the minimal requirements form the Dutch building decree (BRIS, 2012). For office the value is 0.05 people per m^2 and hotel [logiesfunctie] is 0.05 people per m^2. For commercial the value of celfunctie.b: andere celfunctie is used, which is 0.05 people per m^2.
- For residential amount of people are calculated based on the average unit size in the case study area (125 m^2) and the average size of household in the Netherlands which is 2.2 (CBS, 2018b).

Tabel 9 Minimaal aantal personen volgens artikel 1.2 van het Bouwbesluit 2012

Gebruiksfunctie	Ten minste aan te houden aantal personen per m² verblijfsgebied
Bijeenkomstfunctie a. voor het aanschouwen van sport b. andere gebruiksfunctie (lees: bijeenkomstfunctie)	 0,3 0,125
Celfunctie a. voor bezoekers b. andere celfunctie	 0,125 0,05
Gezondheidszorgfunctie a. met bedgebied b. andere gezondheidszorgfunctie	 0,125 0,05
Industriefunctie	n.v.t.
Kantoorfunctie	0,05
Logiesfunctie	0,05
Onderwijsfunctie	0,125
Sportfunctie	n.v.t.
Winkelfunctie	n.v.t.
Overige gebruiksfunctie	n.v.t.
Bouwwerk geen gebouw zijnde	n.v.t.

Figure: Amount of people per m2 user area, source: BRIS, 2012.

A1.2: Set-point temperatures

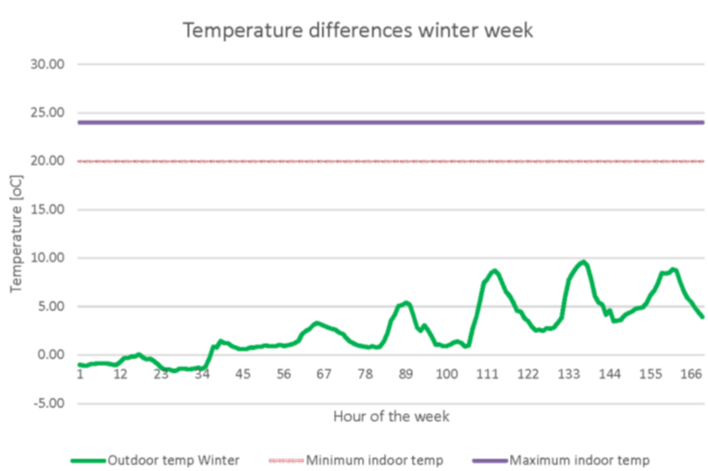
- The used set-point temperatures for all functions are based on the minimal requirements according to the Dutch building decree (BRIS, 2012). Table below provides an overview of these values. Additionally, the difference between indoor and outdoor temperatures for one week in all seasons is shown. These weeks corresponds with the weeks used for energy profile analysis.

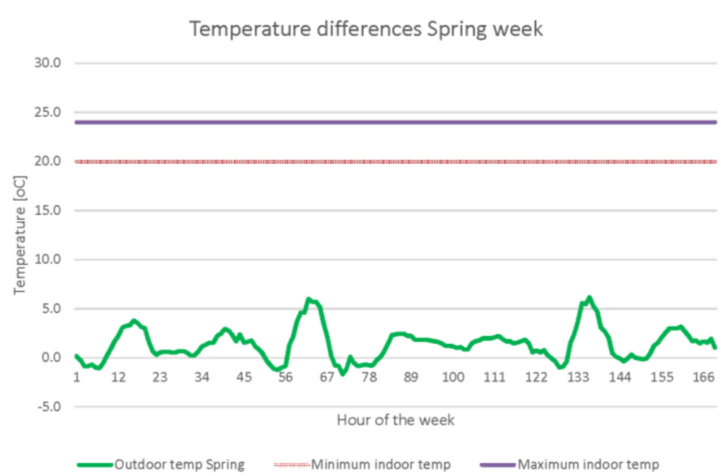
Tabel 7.11— Setpointtemperatuur voor thermisch geconditioneerde zones

Gebruiksfunctie van een gebouw of van een gedeelte van een gebouw	$\theta_{int;set;H;stc;zi}$ °C	$\theta_{int;set;C;stc;zi}$ °C
Bijeenkomstfunctie voor kinderopvang	21	
Bijeenkomstfunctie overig	21	
Celfunctie	21	
Gezondheidszorgfunctie met bedgebied	22	
Gezondheidszorgfunctie overig	21	
Kantoorfunctie	21	24
Logiesfunctie	21	
Onderwijsfunctie	21	
Sportfunctie	16	
Winkelfunctie	21	
Woonfunctie	20	

OPMERKING Voor de maandelijkse berekeningsmethoden kan bij verwarming de werkelijke gemiddelde interne temperatuur hoger zijn door onmiddellijke oververhitting. Echter, met dit effect wordt rekening gehouden door middel van de benuttingsfactor voor de warmtewinst. Vergelijkbaar kan voor koeling de werkelijke gemiddelde interne temperatuur lager zijn door onmiddellijke verliezen die groter zijn dan de winst.

Figure; Set-point temperature for heating and cooling for all functions, source: BRIS, 2012.





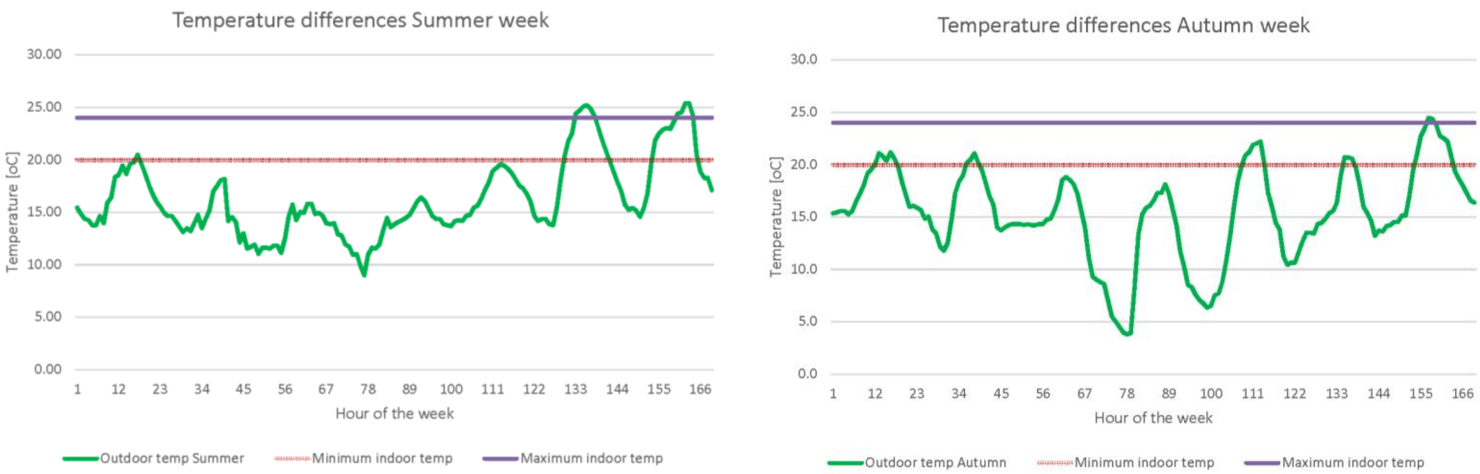


Figure: Difference between indoor and outdoor temperature throughout the year (by author)

A1.3: Transmission rate

- The heating loss through the façade; Transmission rate is defined by the insulation value of the façade. For the energy status quo calculations again the minimal requirements are used.
- Formula used to calculate transmission loss (Jansen and van den Ham, 2016):

$$Qtrans = U * A * (Te - Ti)\ [W]$$

In this formula:

U	Thermal transmittance of a dividing surface	[W/m^{2}k]
A	Surface area of a dividing surface	[m^2]
T_e	Outdoor temperature	[^{o}C]
T_i	Indoor temperature	[^{o}C]

According to Nicolai (2017) insulation is only beneficial to a certain extent. From a Rc value for the insulation of walls, roofs and floors around 8 W/m^{2}K is not reducing that much transmission loss anymore. Therefore, for the improvement of the base study no values bigger than an Rc of 8 W/m^{2}K are used.

A1.4: Ventilation rates

- The ventilation rates per function are based on the minimal requirements according to the Dutch building decree (BRIS, 20112), which are:
  - Residential = 25 m^3/h per person
  - Office = 23.4 m^3/h per person
  - Commercial = 14.4 m^3/h per person
  - For hotel the same value as residential is used.
- The following formulas are used, ventilation only occurs when people are present:

When $T_{outside} - T_{inside} < -5$:

Q_{vent} = (1 – heat recovery) * V_{vent} * ρ * c_p * (T_e – T_i) [W]

In this formula:

V_{vent}	Volume of ventilation flow	[m^3/s]
ρ	Density of air ≈ 1.2	[kg/m^3]
c_p	Specific heat capacity air ≈ 1000	[J/kg.K]

When the temperature difference is smaller than -5, i.e. it becomes a positive value. Additional natural ventilation (2/h) is added to the ventilation of the building.

A1.5: Internal gains

Internal gains consist of amount of heat produced by people, lights and appliances. The following formulas are used:

Q_{people} = amount of people * heat gain per person [100 W/person] * presence of people [Wh]

Q_{lights} = Surface area floor * light power per m^2 * thermally released fraction [1] * lighten floor percentage [0.7] * presence of people [Wh]

$Q_{appliances}$ = Surface area floor * appliances power per m^2 * presence of people [Wh]

Both light power per m^2 and appliances power per m^2 are based on the values reference buildings with the same function in BENG uniforme maatlat kengetallen have.

A.2: Domestic hot water (DHW) and electricity demands

A2.1: Domestic hot water (DHW)

- The assumed domestic hot water demand is based on the amount of hot water each person uses per day for each different function. Additionally, the input temperature of the water is assumed at 13 ^oC and the required temperature of hot water is 60 ^oC (Jansen, 2013). It is assumed that of the total hot water needed 30 % is heated up to 60 ^oC while 70 % is heated up to 45 ^oC.

- Per function the amount of water per day is used from the Table below (KvINL, 2016), it is assumed that 1/3 of the water is used for hot water (Nibud, n.d.):

Specifieke tapwaterverbruiken (warm en koud)

GEBOUW	EENHEID	VERBRUIK (L/DAG)
WONING MET DOUCHE*		
1 en 2 kamers	Per woning	100 - 150
3 kamers	Per woning	150 - 200
4 kamers	Per woning	225 - 300
5 kamers	Per woning	300 - 350
UTILITEITSBOUW		
Verzorgingshuis	Per bed	100 - 150
Verpleeghuis	Per bed	250 - 300
Ziekenhuis	Per bed	300 - 700
Hotel	Per bed	300 - 600
Kantoor	Per werknemer	20
Werkplaats	Per werknemer	25 - 35
Fabriek	Per werknemer	25 - 35
Restaurant	Per bezoeker	20
School l.o.	Per leerling	5 - 10
School m.o.	Per leerling	10 - 20
School huis	Per leerling	20 - 30
Kleine ziekenhuizen	Per dag per bed	100 - 200
Grote ziekenhuizen	Per dag per bed	200 - 250
Kazerne	Per dag per persoon	30 - 40
Zwembad, douche	Per bezoeker	60 - 80
Zwembad, badverversing	Per bezoeker	30 - 75
Medische baden	Per bezoeker	200 - 400
Kantoren	Per dag per persoon	20 - 30
Kindertehuizen	Per dag per plaats	30 - 40
Verzorgingshuizen	Per dag per plaats	30 - 50
Restaurants	Per dag per plaats	40 - 60
Hotels	Per dag per gast	100 - 200

**Indien met bad, 50 liter extra.*

Bron: Handboek Installatietechniek (TVVL, ISSO, Novem), Recknagel, Heizung und Klimatechnik, 1990, 1991 (bewerkt).

*For the hotel function the same values as for residential are used, only the user schedule differs.

- Inlet temperature of water depends on the ambient outdoor temperature and fluctuates throughout the year: Average supply temperature DHW =

$$\frac{(outside\ temperature + outside\ temperature + normalized\ supply\ temperature)}{3}$$

- Daily amount of hot water is calculated with the following formula: Daily amount of DHW=

$$\frac{(Amount\ pppd * average\ supply\ temp. * specific\ heat\ water * amount\ of\ people\ )}{3600}$$

A2.2: Electricity demands

Electrical energy demand consist of both lighting and appliances together. The electricity needed for lights and appliances are calculated with the same formulas as in 1.5; internal gains.

A.3: Detailed description/calculation of parameter study

As mentioned in chapter 4 case study design there are a lot of architectural design parameters that can be changed in order to come to a more energy flat overall design. These parameters are Indoor temperature heating and cooling mode setting points, window percentage, Rc value façade, air change rate infiltration, heat recovery efficiency, ventilation flow rate per person, solar heat factor glass and solar heat factor blinds. In appendix A.3 for all of these parameters the individual changes are looked into. For the cause of comparison between different designs a base design is constructed. The parameters used in this base design are the minimal requirements according to the Dutch building decree and/or chosen to provide the ability to see differences between functions. The used parameters can be found in Table 23. These parameters only influence the heating/cooling demand of a building and therefore only these two aspects are looked into in this parameter study.

		Residential (Buy)	Residential (Rent)	Commercial (Non-hotel)	Commercial (Hotel)	Hotel	Office	Based on
Indoor temperature heating mode [°C]	Spring Summer Autumn Winter	20 °C 20 °C 20 °C 20 °C		21 °C 21 °C 21 °C 21 °C				Dutch building decree 2012 [minimum]
Indoor temperature Cooling mode [°C]	Spring Summer Autumn Winter	24 °C 24 °C 24 °C 24 °C						Dutch building decree 2012 [minimum]
Window percentage [%]	N (NE + NW) S (SE + SW)	30 30						
Insulation [m^2K/W]	Wall Roof Floor	4.5 m^2K/W 6.0 m^2K/W 4.5 m^2K/W						Dutch building decree 2012 [minimum]
U-value windows [W/m^2K]	N (NE + NW) S (SE + SW)	1.65 W/m^2K 1.65 W/m^2K						Dutch building decree 2012 [minimum]
Solar heat factor glass	N (NE + NW) S (SE + SW)	0.6 0.6						Corresponds with U value window
Solar heat factor blinds	N (NE + NW) S (SE + SW)	1 1						All sun goes through
Solar blinds go down with voltage of	Spring Summer Autumn Winter	Never						No outdoor solar blinds
Infiltration rate [ACH]		0.15						Dutch building decree 2012
Heat recovery efficiency		0						No heat recovery in base design
Ventilation flow rate per person [m^3/h]		25.0 m^3/h		14.4 m^3/h		25.0 m^3/h	23.4 m^3/h	Dutch building decree 2012 [minimum]

Table 23: Parameters used for base design parameter study (Made by author)

A3.1: Indoor temperature heating and cooling mode setting points

Indoor temperature cooling mode hot seasons (summer and autumn) to 28 oC														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Residential (rent)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (non-hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Hotel	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
All functions	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	28	28	31	23	1	0	0	145	-8 %
Residential (rent)	0	0	0	7	27	30	30	34	24	0	0	0	151	-4 %
Commercial (non-hotel)	0	0	0	7	27	26	26	30	22	1	0	0	138	-13 %
Commercial (hotel)	0	0	0	7	27	30	30	33	25	1	0	0	152	-4 %
Hotel	0	0	0	7	27	27	27	30	22	1	0	0	140	-11 %
Office	0	0	0	7	27	30	30	34	25	1	0	0	154	-3 %
All functions	0	0	0	7	27	14	16	15	10	0	0	0	88	-44 %

Indoor temperature cooling mode cold seasons (winter and spring) to 28 oC

Change to function	Monthly heating [MWh]												Yearly heating [MWh]	Difference to base design
	January	February	March	April	May	June	July	August	September	October	November	December		
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	7	3	5	9	24	34	5	362	0 %
Residential (rent)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (non-hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Hotel	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
All functions	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %

Change to function	Monthly cooling [MWh]												Yearly cooling [MWh]	Difference to base design
	January	February	March	April	May	June	July	August	September	October	November	December		
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	6	24	31	31	35	26	1	0	0	155	-2 %
Residential (rent)	0	0	0	3	26	31	31	35	26	1	0	0	157	-1 %
Commercial (non-hotel)	0	0	0	5	23	31	31	35	26	1	0	0	153	-3 %
Commercial (hotel)	0	0	0	6	25	31	31	35	26	1	0	0	156	-1 %
Hotel	0	0	0	3	24	31	31	35	26	1	0	0	154	-3 %
Office	0	0	0	6	26	31	31	35	26	1	0	0	157	-1 %
All functions	0	0	0	2	15	31	31	35	26	1	0	0	142	-10 %

Indoor temperature heating mode hot seasons (summer and autumn) to 18 oC														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	5	2	4	7	21	31	59	350	-3 %
Residential (rent)	68	62	52	29	10	6	3	5	8	22	32	59	356	-1 %
Commercial (non-hotel)	68	62	52	29	10	7	3	5	8	22	32	59	357	-1 %
Commercial (hotel)	68	62	52	29	10	7	3	5	8	22	32	59	358	-1 %
Hotel	68	62	52	29	10	6	3	4	7	21	30	59	351	-3 %
Office	68	62	52	29	10	7	3	5	9	23	33	59	360	0 %
All functions	68	62	52	29	10	4	1	3	5	14	22	59	329	-9 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Residential (rent)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (non-hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Hotel	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Office	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
All functions	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %

Indoor temperature heating mode cold seasons (winter and spring) to 18 oC														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	64	58	48	25	8	7	3	5	9	24	34	54	339	-6 %
Residential (rent)	67	60	50	27	9	7	3	5	9	24	34	57	350	-3 %
Commercial (non-hotel)	65	59	49	28	10	7	3	5	9	4	34	55	347	-3 %
Commercial (hotel)	66	60	49	27	10	7	3	5	9	24	34	56	349	-3 %
Hotel	63	67	46	25	8	7	3	5	9	24	34	53	333	-7 %
Office	68	61	51	28	10	7	3	5	9	24	34	58	356	-1 %
All functions	50	46	37	19	6	7	3	5	9	24	34	40	281	-22 %

	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Residential (rent)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (non-hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Hotel	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Office	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
All functions	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %

A3.2: Window percentage North and South façade

Due to the fact that the calculation performed in excel are static calculations and therefore, the calculations are done for each building separately instead of as one big urban block the parameters can be changed per function instead of per building. For simplicity reasons the South-west and South-east façades are combined as South façade, same goes for the North-west and North-east façades which are combined into the North façade. In this parameter study all parameters are kept the same as in the base design except for the window percentage per façade which is changed to 80 % for the North or South façade.

North (NE + NW) façade 80 % glazing														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	81	74	62	34	13	9	4	7	11	30	41	69	434	+ 20 %
Residential (rent)	74	68	57	31	11	8	4	6	20	27	38	64	395	+ 9 %
Commercial (non-hotel)	72	65	54	29	10	7	3	5	9	26	37	63	379	+ 4 %
Commercial (hotel)	71	65	54	29	10	7	3	5	9	46	36	62	377	+ 4 %
Hotel	78	71	60	33	12	8	4	6	10	28	40	67	415	+ 15 %
Office	69	63	52	28	10	7	3	5	9	24	35	60	364	0 %
All functions	102	92	77	44	16	11	6	9	15	39	54	88	552	+ 53 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	31	37	37	41	32	1	0	0	187	+ 18 %
Residential (rent)	0	0	0	7	30	35	35	39	30	1	0	0	177	+ 12 %
Commercial (non-hotel)	0	0	0	8	35	41	40	42	32	1	0	0	199	+ 26 %
Commercial (hotel)	0	0	0	7	30	35	35	38	29	1	0	0	175	+ 10 %
Hotel	0	0	0	7	31	37	37	41	32	1	0	0	185	+ 17 %
Office	0	0	0	7	28	33	32	36	27	1	0	0	165	+ 4 %
All functions	0	0	1	11	52	60	61	60	49	3	0	0	297	+ 90 %

South (SE + SW) façade 80 % glazing														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	80	73	61	34	13	9	4	7	11	29	40	67	430	+ 19 %
Residential (rent)	74	67	56	31	11	8	4	6	10	26	37	63	393	+ 8 %
Commercial (non-hotel)	72	65	54	29	10	7	3	5	9	26	37	63	378	+ 4 %
Commercial (hotel)	71	65	54	29	10	7	3	5	9	26	36	62	376	+ 4 %
Hotel	78	71	59	33	12	8	4	6	10	28	39	66	412	+ 14 %
Office	69	63	52	28	10	7	3	5	9	24	35	60	364	0 %
All functions	101	90	76	43	16	11	6	9	15	38	51	84	538	+ 49 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	1	10	38	44	45	53	42	4	0	0	238	+ 50 %
Residential (rent)	0	0	1	9	32	38	38	44	36	5	0	0	202	+ 28 %
Commercial (non-hotel)	0	1	2	13	42	46	45	49	40	2	0	0	239	+ 51 %
Commercial (hotel)	0	0	0	8	31	36	35	40	30	1	0	0	180	+ 15 %
Hotel	0	0	1	11	40	45	45	51	40	2	0	0	235	+ 50 %
Office	0	1	1	8	30	34	34	38	29	2	0	0	176	+ 11 %
All functions	0	1	5	26	79	85	86	99	85	12	0	0	479	+ 202 %

A3.3: Insulation value façade

Wall:

Insulation value wall to 10 m²K/W														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	66	60	49	27	9	6	3	5	8	22	32	57	343	-5 %
Residential (rent)	67	62	50	28	10	7	3	5	8	23	33	58	352	-2 %
Commercial (non-hotel)	68	62	51	28	10	7	3	5	9	23	33	58	355	-1 %
Commercial (hotel)	68	62	51	28	10	7	3	5	8	23	33	59	356	-1 %
Hotel	66	61	49	27	9	6	3	5	8	22	32	57	348	-3 %
Office	68	63	51	28	10	7	3	5	9	23	34	59	359	0 %
All functions	61	56	45	25	8	6	3	4	7	20	29	52	314	-13 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	32	31	35	27	1	0	0	159	+ 1 %
Residential (rent)	0	0	0	7	27	32	31	35	27	1	0	0	159	+ 1 %
Commercial (non-hotel)	0	0	0	7	27	32	31	36	27	1	0	0	159	+ 1 %
Commercial (hotel)	0	0	0	7	27	32	31	35	26	1	0	0	158	0 %
Hotel	0	0	0	7	27	32	31	36	27	1	0	0	159	+ 1 %
Office	0	0	0	7	27	32	31	35	26	1	0	0	158	0 %
All functions	0	0	0	7	27	32	32	36	27	1	0	0	161	+ 2 %

Insulation value roof to 10 m²K/W														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	61	52	28	10	7	3	5	8	23	34	59	357	-1 %
Residential (rent)	68	62	52	28	10	7	3	5	8	23	34	59	359	-1 %
Commercial (non-hotel)	68	62	52	28	10	7	3	5	9	23	34	59	360	0 %
Commercial (hotel)	68	62	52	28	10	7	3	5	9	24	34	59	361	0 %
Hotel	68	61	52	28	10	7	3	5	8	23	34	59	357	-1 %
Office	68	62	51	28	10	7	3	5	9	24	34	59	361	0 %
All functions	67	60	51	27	10	7	3	5	8	22	33	59	351	-3 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Residential (rent)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (non-hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Hotel	0	0	0	7	27	32	31	35	26	1	0	0	158	0 %
Office	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
All functions	0	0	0	7	27	32	31	35	27	1	0	0	159	+ 1 %

Insulation value floor to 10 m²K/W														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Residential (rent)	68	62	52	29	10	7	3	5	8	24	33	59	360	-1 %
Commercial (non-hotel)	68	62	52	28	10	7	3	5	9	24	34	58	357	-1 %
Commercial (hotel)	68	62	52	28	10	7	3	5	8	24	33	58	357	-1 %
Hotel	67	62	52	29	10	7	3	5	9	24	34	59	361	0 %
Office	67	62	52	29	10	7	3	5	9	23	34	59	361	0 %
All functions	66	62	52	29	10	7	3	5	8	23	32	56	348	-3 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Residential (rent)	0	0	0	7	27	32	31	35	26	1	0	0	159	+ 1 %
Commercial (non-hotel)	0	0	0	7	27	32	32	36	27	1	0	0	161	+ 2 %
Commercial (hotel)	0	0	0	7	27	32	31	36	27	1	0	0	159	+ 1 %
Hotel	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Office	0	0	0	7	27	32	31	36	27	1	0	0	159	+ 1 %
All functions	0	0	0	7	28	33	32	37	27	1	0	0	164	+ 4 %

U-value window North (NE + NW) façade to 0.7 W/m²K with a solar heat factor of 0.5														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	64	58	48	26	9	6	3	4	7	21	32	55	332	-8 %
Residential (rent)	65	61	50	28	9	6	3	5	8	22	34	57	348	-4 %
Commercial (non-hotel)	67	62	51	28	10	7	3	5	9	24	33	58	354	-2 %
Commercial (hotel)	67	61	51	29	10	7	3	5	8	24	33	58	356	-2 %
Hotel	65	59	49	27	9	6	3	5	8	22	33	56	341	-6 %
Office	68	63	51	28	10	7	3	5	9	24	34	59	361	0 %
All functions	55	51	42	22	7	5	2	4	6	18	27	46	284	-22 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
Residential (rent)	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
Commercial (non-hotel)	0	0	0	7	26	31	30	35	26	1	0	0	156	-1 %
Commercial (hotel)	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
Hotel	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
Office	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
All functions	0	0	0	6	25	30	29	34	25	1	0	0	150	-5 %

U-value window South (SE + SW) façade to 0.7 W/m²K with a solar heat factor of 0.5														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	64	58	48	26	9	6	3	4	8	21	34	55	334	-8 %
Residential (rent)	66	64	49	27	9	6	3	5	8	23	33	58	349	-4 %
Commercial (non-hotel)	67	62	51	28	10	7	3	5	9	23	34	58	354	-2 %
Commercial (hotel)	67	62	51	28	10	7	3	5	8	24	33	58	356	-2 %
Hotel	65	59	48	27	9	6	3	5	8	23	33	56	342	-6 %
Office	68	63	52	28	10	7	3	5	9	24	33	59	361	0 %
All functions	56	51	41	22	7	5	2	4	6	18	26	47	286	-21 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	6	26	31	30	34	25	1	0	0	153	-3 %
Residential (rent)	0	0	0	7	26	31	31	35	26	1	0	0	155	-2 %
Commercial (non-hotel)	0	0	0	6	26	30	30	34	25	1	0	0	153	-3 %
Commercial (hotel)	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
Hotel	0	0	0	6	26	31	30	34	25	1	0	0	153	-3 %
Office	0	0	0	7	26	31	31	35	26	1	0	0	157	-1 %
All functions	0	0	0	6	25	28	27	31	22	0	0	0	137	-13 %

Insulation value wall, roof, floor: Rc = 10 m²K/W + insulation value windows all façades: U-value: 0.7 W/m²K & solar heat factor: 0.5														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	55	51	41	22	7	5	2	4	6	18	27	48	285	-21 %
Residential (rent)	62	57	47	25	9	6	3	4	7	21	31	54	325	-10 %
Commercial (non-hotel)	63	59	49	28	10	7	3	5	9	22	31	54	340	-6 %
Commercial (hotel)	65	60	49	27	10	7	3	5	9	22	32	55	344	-5 %
Hotel	59	54	45	25	9	6	3	4	8	21	29	51	311	-14 %
Office	68	62	51	29	10	7	3	5	9	23	34	58	359	-1 %
All functions	31	30	24	13	4	3	1	2	3	9	14	25	157	-57 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	6	27	30	29	33	25	1	0	0	151	-4 %
Residential (rent)	0	0	0	7	27	30	30	34	25	1	0	0	154	-3 %
Commercial (non-hotel)	0	0	0	6	27	30	30	34	25	1	0	0	153	-3 %
Commercial (hotel)	0	0	0	7	27	31	30	35	26	1	0	0	156	-1 %
Hotel	0	0	0	6	27	30	29	33	25	1	0	0	151	-4 %
Office	0	0	0	7	27	31	30	35	26	1	0	0	156	-1 %
All functions	0	0	0	6	24	27	27	30	22	1	0	0	136	-14 %

A3.5: Heat recovery efficiency

Heat recovery efficiency to its maximum [0.9 for residential (small) and the rest 0.7]														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	63	58	46	25	9	6	3	4	7	21	31	54	327	-10 %
Residential (rent)	66	61	49	27	9	6	3	5	8	22	33	57	348	-4 %
Commercial (non-hotel)	64	59	49	28	10	7	3	5	8	22	32	54	339	-6 %
Commercial (hotel)	65	59	48	27	10	7	3	5	8	22	32	55	341	-6 %
Hotel	60	54	44	24	8	6	3	4	7	20	30	51	312	-14 %
Office	67	62	51	28	10	7	3	5	9	23	34	58	356	-1 %
All functions	42	39	32	18	6	4	2	3	5	13	20	33	219	-40 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Residential (rent)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (non-hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Commercial (hotel)	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Hotel	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
Office	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %
All functions	0	0	0	7	27	31	31	35	26	1	0	0	158	0 %

A3.8: Blind control above 150 W with solar heat factor blinds of 0.15 for residential, hotel & office and 0.5 for commercial

Blind control above 150 W with solar heat factor blinds of residential: 0.15, other functions: 0.5 for hot season (summer + autumn) on all façades														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Residential (rent)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (non-hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Hotel	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
All functions	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	27	28	26	30	21	1	0	0	138	-13 %
Residential (rent)	0	0	0	7	27	29	28	31	22	0	0	0	144	-9 %
Commercial (non-hotel)	0	0	0	7	27	27	27	31	23	1	0	0	141	-11 %
Commercial (hotel)	0	0	0	7	27	30	29	34	25	1	0	0	152	-4 %
Hotel	0	0	0	7	27	26	25	29	22	1	0	0	136	-14 %
Office	0	0	0	7	27	30	29	34	25	1	0	0	151	-4 %
All functions	0	0	0	7	27	12	11	13	7	0	0	0	77	-51 %

Blind control above 150 W with solar heat factor blinds of residential: 0.15, other functions: 0.5 for cold season (winter + spring) on all façades

	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Residential (rent)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (non-hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Commercial (hotel)	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Hotel	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %
All functions	68	62	52	29	10	7	3	5	9	24	34	59	362	0 %

	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	6	22	31	31	35	26	1	0	0	153	-3 %
Residential (rent)	0	0	0	6	24	31	31	35	26	1	0	0	155	-2 %
Commercial (non-hotel)	0	0	0	6	22	31	31	35	26	1	0	0	152	-4 %
Commercial (hotel)	0	0	0	6	25	31	31	35	26	1	0	0	156	-1 %
Hotel	0	0	0	6	22	31	31	35	26	1	0	0	152	-4 %
Office	0	0	0	6	25	31	31	35	26	1	0	0	155	-2 %
All functions	0	0	0	3	8	31	31	35	26	1	0	0	136	-14 %

A3.9: Window percentage and blind control above 150 W with solar heat factor blinds of 0.15 for residential, hotel & office and 0.5 for commercial

North (NE + NW) façade 80 % glazing + Hot season (summer + autumn) blind control above 150 W: Solar heat factor blinds 0.15 for residential, hotel and office. Commercial; 0.5 on all façades														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	80	73	61	45	13	9	5	7	12	29	41	69	433	+ 20 %
Residential (rent)	74	67	56	31	11	8	4	6	10	26	37	63	395	+ 9 %
Commercial (non-hotel)	72	65	53	29	10	7	3	5	9	25	36	63	378	+ 4 %
Commercial (hotel)	71	64	54	30	10	7	3	5	9	25	36	62	376	+ 4 %
Hotel	78	71	59	33	12	8	4	6	10	28	39	67	415	+ 15 %
Office	69	63	52	29	10	7	3	5	9	24	34	60	363	0 %
All functions	102	91	77	44	16	12	6	9	15	39	53	88	552	+ 52 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	9	23	29	29	32	23	1	0	0	146	-8 %
Residential (rent)	0	0	0	7	22	30	30	33	34	0	0	0	156	-1 %
Commercial (non-hotel)	0	0	0	8	26	32	31	36	26	1	0	0	160	+ 1 %
Commercial (hotel)	0	0	0	8	25	31	31	35	26	1	0	0	157	-1 %
Hotel	0	0	0	7	24	28	28	32	24	1	0	0	144	-9 %
Office	0	0	0	7	24	30	30	34	25	1	0	0	151	-4 %
All functions	0	0	0	11	25	27	27	30	19	0	0	0	139	-12 %

South (SE + SW) façade 80 % glazing + blind control above 150 W: Solar heat factor blinds 0.15 for residential, hotel and office. Commercial; 0.5 on all façades throughout the year														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	80	73	61	35	13	9	5	7	12	29	40	67	429	+ 19 %
Residential (rent)	73	67	56	31	11	8	4	6	10	26	37	63	392	+ 8 %
Commercial (non-hotel)	71	64	53	29	10	7	3	5	9	25	36	63	377	+ 4 %
Commercial (hotel)	71	64	53	30	10	7	3	5	9	25	36	61	375	+ 4 %
Hotel	78	71	59	33	12	8	4	6	10	27	38	66	411	+ 14 %
Office	69	63	52	29	10	7	3	5	9	24	34	59	363	0 %
All functions	101	90	75	43	16	12	6	9	15	38	51	84	540	+ 49 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	10	31	28	27	31	22	1	0	0	150	-5 %
Residential (rent)	0	0	0	9	30	29	29	32	23	0	0	0	152	-4 %
Commercial (non-hotel)	0	0	1	16	27	33	33	38	28	1	0	0	177	+ 12 %
Commercial (hotel)	0	0	0	13	32	31	31	36	27	1	0	0	171	+ 8 %
Hotel	0	0	0	15	38	27	27	31	23	1	0	0	162	+ 3 %
Office	0	0	1	6	26	30	30	34	25	1	0	0	153	-3 %
All functions	0	0	1	20	30	25	24	29	18	0	0	0	147	-6 %

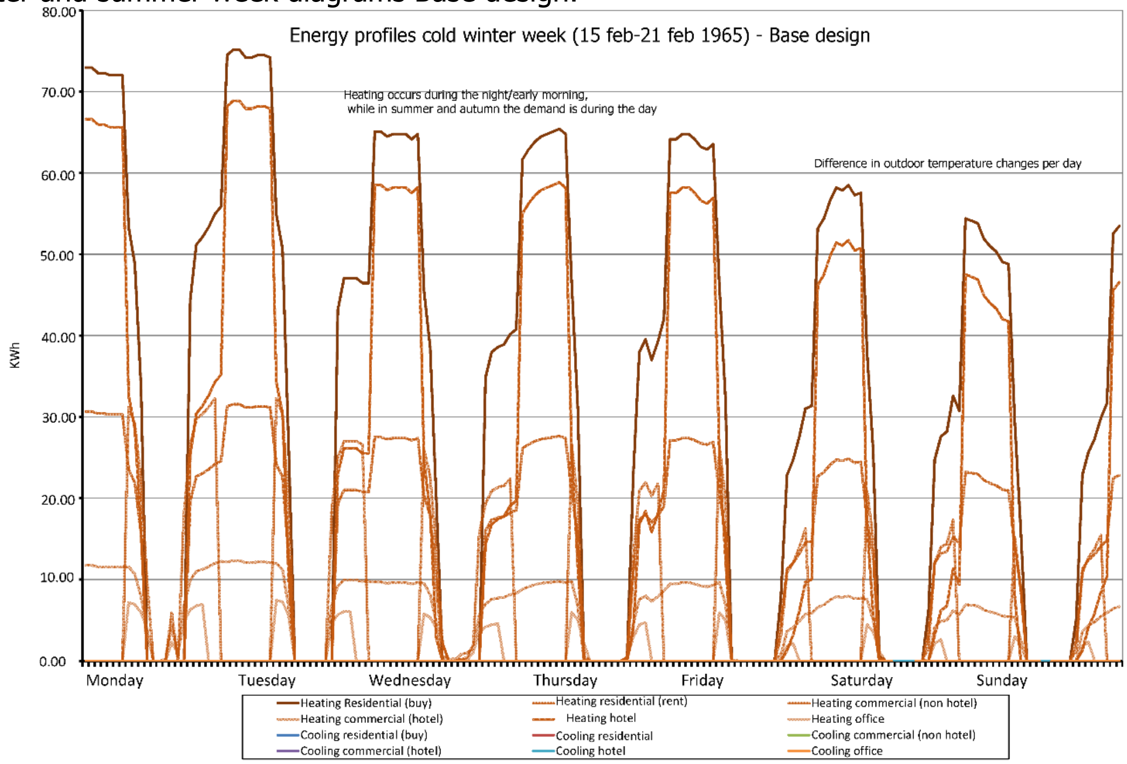
A3.10: Window percentage and insulation value window

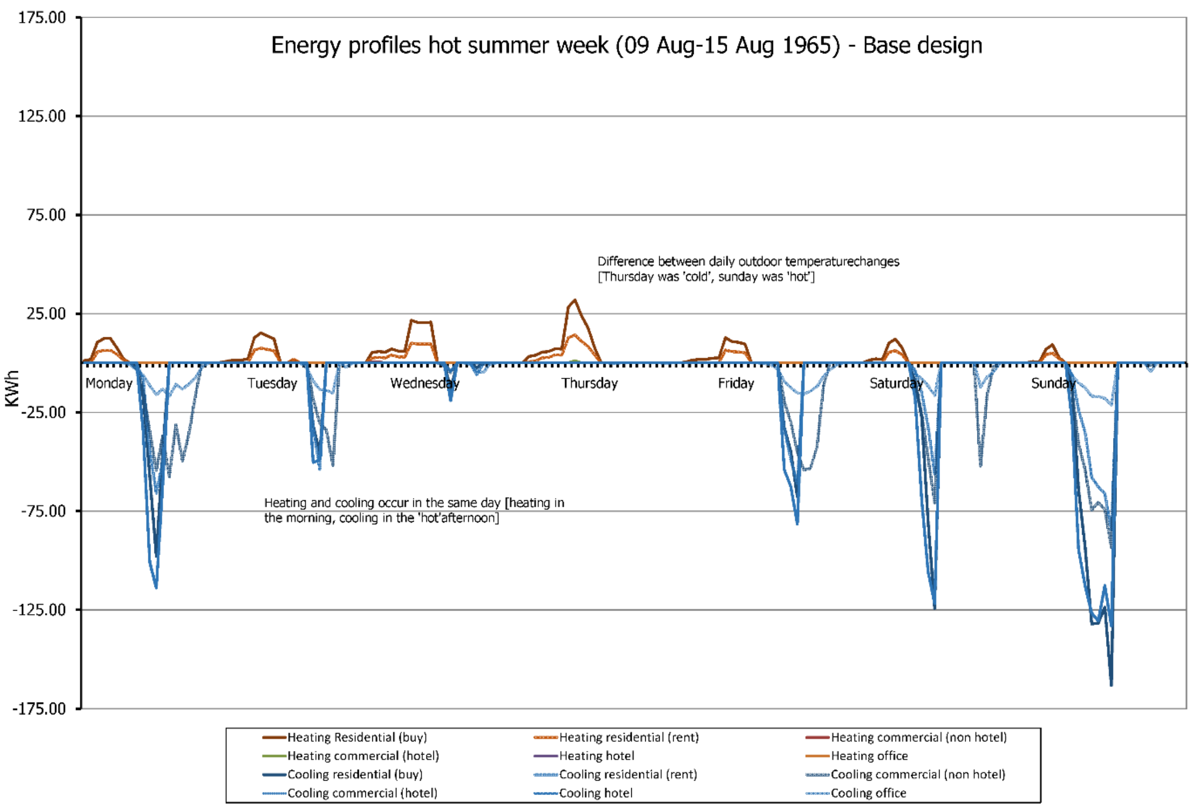
North (NE + NW) façade 80 % glazing + insulation value window North (NE + NW) façade to 0.7 W/m²K with a solar heat factor of 0.5														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	67	61	51	28	10	7	31	35	9	23	33	57	353	-2 %
Residential (rent)	68	62	51	28	10	7	3	5	9	23	34	58	358	-1 %
Commercial (non-hotel)	67	62	51	29	10	7	3	5	9	23	34	58	358	-1 %
Commercial (hotel)	68	62	52	29	10	7	3	5	9	24	34	59	360	-1 %
Hotel	68	62	51	28	10	7	3	5	9	23	33	58	356	-2 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	361	0 %
All functions	65	59	49	27	9	6	3	5	8	22	31	54	338	-7 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	0	7	31	35	36	40	30	1	0	0	181	+ 15 %
Residential (rent)	0	0	0	7	30	34	34	37	29	2	0	0	173	+ 9 %
Commercial (non-hotel)	0	0	0	8	34	38	37	40	31	1	0	0	188	+ 19 %
Commercial (hotel)	0	0	0	7	30	34	33	37	28	1	0	0	169	+ 6 %
Hotel	0	0	0	7	31	35	36	39	31	1	0	0	180	+ 14 %
Office	0	0	0	7	29	32	32	36	27	1	0	0	163	+ 3 %
All functions	0	0	1	11	48	54	55	55	45	3	0	0	270	+ 71 %

South (SE + SW) façade 80 % glazing + insulation value window South (SE + SW) façade to 0.7 W/m²K with a solar heat factor of 0.5														
	Monthly heating [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly heating [MWh]	Difference to base design
Base design	*68*	*62*	*52*	*29*	*10*	*7*	*3*	*5*	*9*	*24*	*34*	*59*	*362*	-
Residential (buy)	67	61	51	28	10	7	3	5	9	23	33	57	351	-3 %
Residential (rent)	68	62	51	28	10	7	3	5	9	23	34	58	357	-1 %
Commercial (non-hotel)	67	62	51	29	10	7	3	5	9	23	34	58	357	-1 %
Commercial (hotel)	68	62	51	29	10	7	3	5	9	24	34	59	359	-1 %
Hotel	68	62	51	28	10	7	3	5	9	23	33	57	354	-2 %
Office	68	62	52	29	10	7	3	5	9	24	34	59	361	0 %
All functions	65	59	48	26	9	6	3	5	8	21	30	52	333	-8 %
	Monthly cooling [MWh]													
Change to function	January	February	March	April	May	June	July	August	September	October	November	December	Yearly cooling [MWh]	Difference to base design
Base design	*0*	*0*	*0*	*7*	*27*	*31*	*31*	*35*	*26*	*1*	*0*	*0*	*158*	-
Residential (buy)	0	0	1	9	36	40	41	48	38	4	0	0	217	+ 37 %
Residential (rent)	0	0	1	8	32	36	36	41	33	4	0	0	191	+ 21 %
Commercial (non-hotel)	0	0	1	11	39	41	40	44	35	2	0	0	214	+ 35 %
Commercial (hotel)	0	0	0	7	31	34	34	38	29	1	0	0	173	+ 10 %
Hotel	0	0	1	10	38	41	41	47	36	2	0	0	216	+ 37 %
Office	0	0	1	8	30	33	32	37	28	1	0	0	171	+ 8 %
All functions	0	1	4	21	68	71	72	82	70	10	0	0	397	+ 151 %

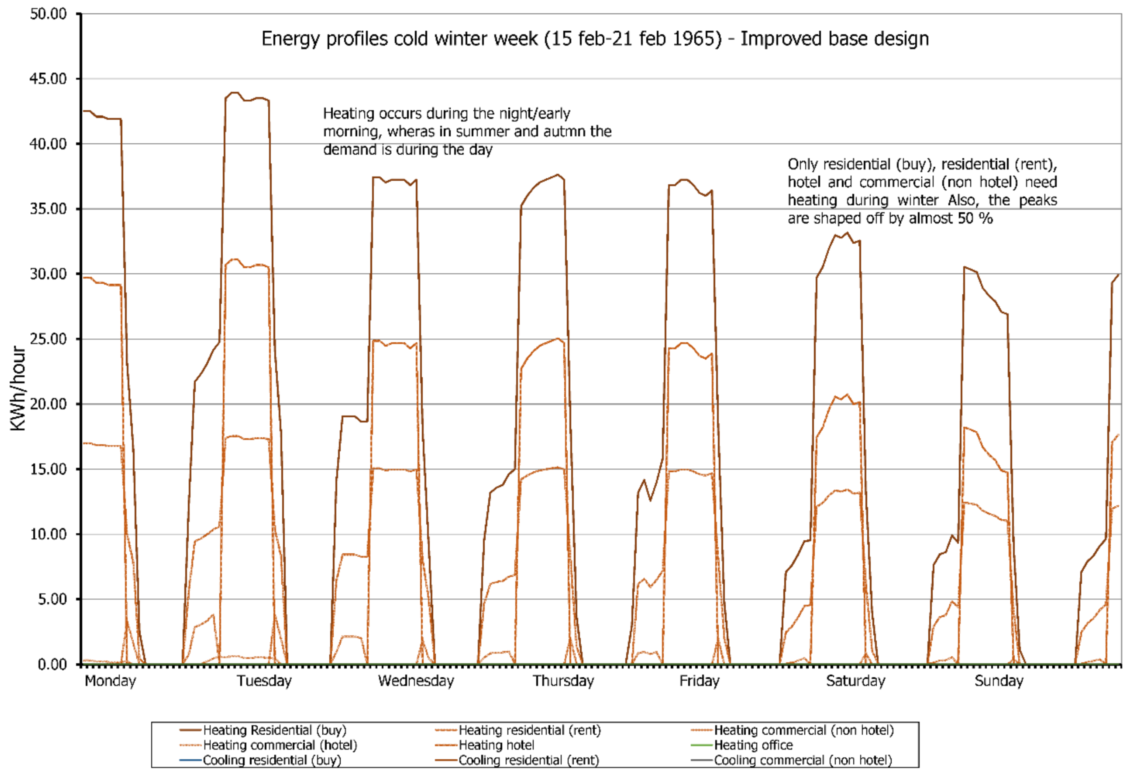
A.4: Winter and summer space heating and cooling demand profiles [all designs]

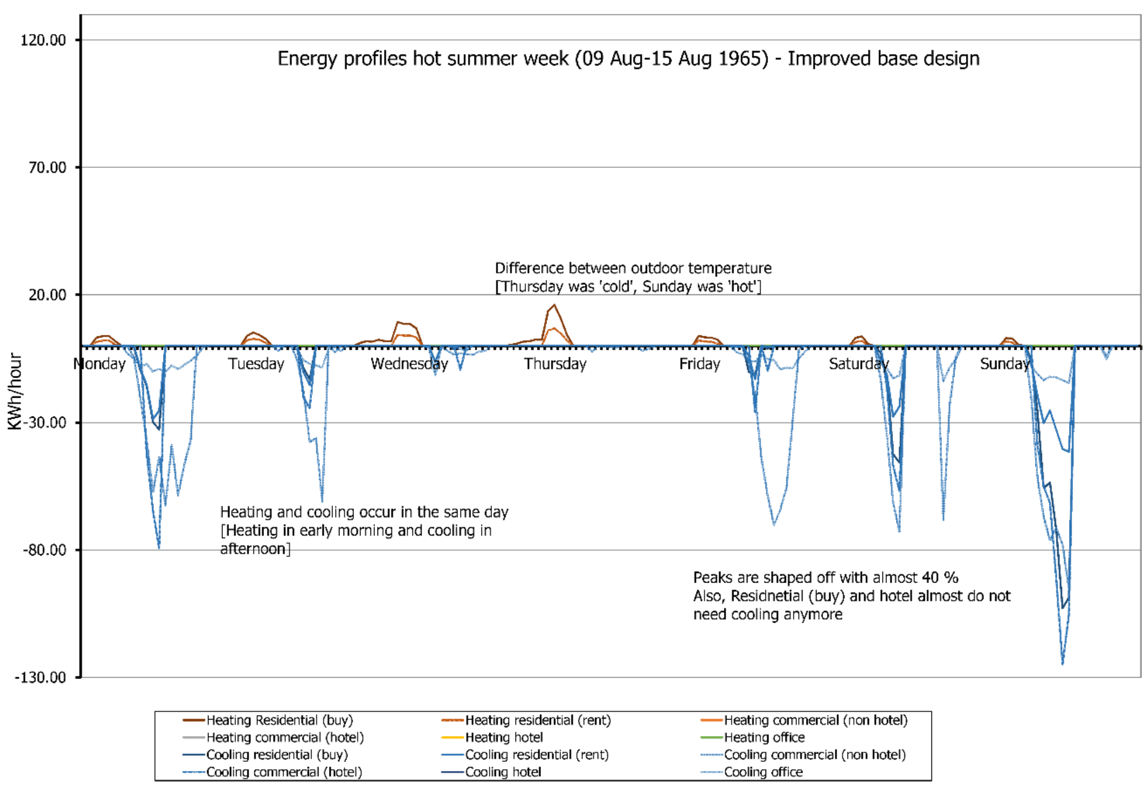
Winter and summer week diagrams Base design:



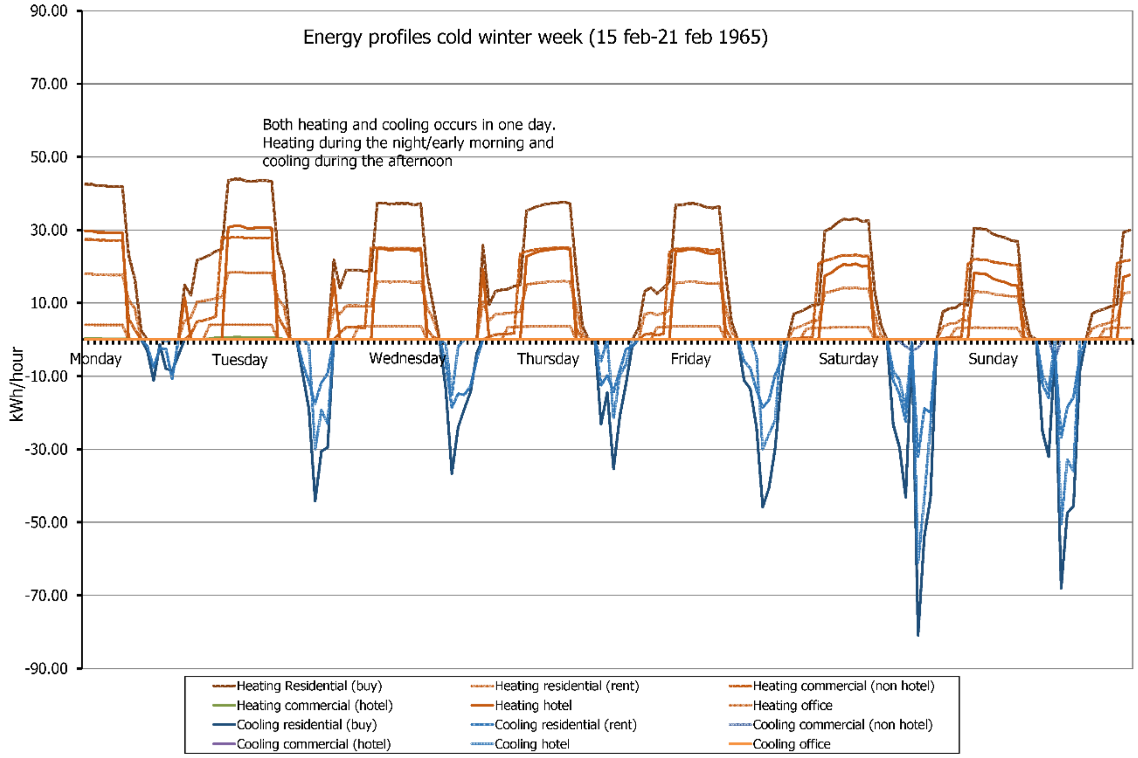


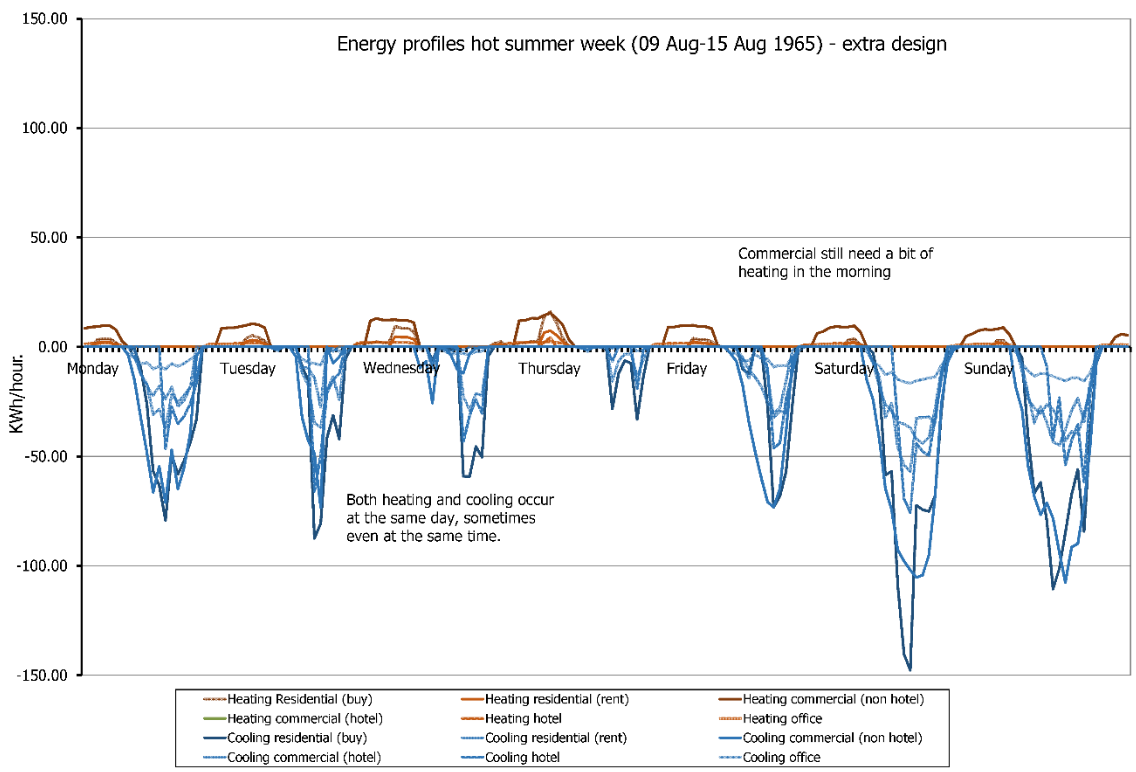
Winter and summer week diagrams improved base design:





Winter and summer week diagrams Improved base design with continuous cooling:





A.5: Detailed description distribution grid losses

Distribution heat losses for each option:

General:

The yearly distribution heat losses can be calculated using the following formula (KoWaNet, 2019):

$$Q_{distr.loss} = L \cdot U \cdot \left(\frac{T_{supply}+T_{return}}{2} - T_{surroundings}\right) \cdot n\ hour(s)/1000$$

In this formula L is the total length of a pipe, U is the heat loss coefficient of the pipe in W/(m¹K, T_{supply} and T_{return} are the temperatures of the grid and $T_{surroundings}$ is the temperature of its surroundings [for pipes in below surface a value of 12 °C can be taken or the ambient outdoor temperature can be used]. N is the amount of hours the distribution losses are calculated for, i.e. yearly losses n= 8760 hours and hourly losses are n = 1.

Furthermore, the heat loss coefficient of the pipe largely depends on the diameter of the pipe, which can be calculated using the following formula (KoWaNet, 2019):

$$\text{Required pipe diameter} = \sqrt{\frac{flow\ rate}{speed} \cdot \frac{4}{\pi}}$$

The flow rate depends on the maximum thermal power and the temperature difference between supply and return. The speed depends on the type of pipe, i.e. secondary pipes have a maximum speed of 2 m/s and for building connecting pipes the maximum is 1 m/s.

The flow rate can be calculated with the following formula (KoWaNet, 2019):

$$Flow\ rate\ \left(\frac{m^3}{s}\right) = \frac{\dot{Q}}{\rho c \cdot (T_{supply} - T_{return})}$$

In this formula Q is the maximum thermal power, ρ is the density (kg/m^3); for water it is 1000 kg/m^3 and c is the specific heat (kJ/(kgK)); for water this is 4.2 kJ/(kgK).

Lastly, with the calculated required pipe diameter the U*C [heat loss coefficient of the pipe] can be found in the Table below.

Table 4-1: pipe diameters and corresponding heat transfer coefficients (ISSO, 2012)

DN	d_i [m]	d_o [m]	U*C [$Wm^{-1}K^{-1}$]
20	0.0217	0.090	0.136
25	0.0285	0.090	0.165
32	0.0372	0.110	0.160
40	0.0431	0.110	0.194
50	0.0545	0.125	0.215
65	0.0703	0.140	0.253
80	0.0825	0.160	0.261
100	0.1071	0.200	0.276
125	0.1325	0.200	0.318
150	0.1603	0.250	0.375
200	0.2101	0.315	0.401
250	0.2630	0.400	0.357

Figure: Pipe diameters and corresponding transfer coefficiencies, source: Kowanet, 2019

By using the above described method and the conceptual spatial arrangements of the pipes within the urban block the distribution heat losses can be calculated for each energy system option separately.

Option 1: Individual heat pump (all electric)

All needed energy is upgraded within the building itself. In this chapter only the distribution heat losses on the urban block scale, i.e. not within the building itself, are calculated. Therefore, for this option it is assumed that no heat is lost.

Option 2a & 2b: Medium temperature thermal grid + separate cooling grid

For both option 2a and 2b there is a medium temperature thermal grid with a separate cooling grid. Therefore, the distribution losses for both heating and cooling grid have to be calculated. Although the yearly amount of heating/cooling flowing through the pipes differs per option 2a and 2b, both have the same maximum power, i.e. they have the same amount of distribution losses. For heating this means there is a supply pipe and a return pipe (double pipe). The total length of one pipe is 177 meters, i.e. total length of pipes is 354 meters. Water from the ground is pumped up and upgraded to 40 °C with a heat pump. This heat is directly used for space heating or upgraded to 60 °C using a small heat pump on building scale. The temperature at which the water returns to the local grid is around 20 °C. All buildings have two connections with the grid (supply and return) these pipes have a total length of 48 meters. For option two the maximum peak thermal heating power is around 135 kW in a whole year [maximum power needed for heating functions for all buildings in one hour]. With a supply temperature of 40 °C and a return temperature of 20 °C [ΔT is 20 °C], this gives us a flow rate of 0.0016 m^3/s. Thus, with a maximum speed of 2 m/s for a secondary pipe, therefore, the required diameter is 0.031 m; from the Table it is 32 mm. According to the Table above the corresponding UC is 0.160 W/(m^1K).

The maximum thermal power peak from to grid to a building that determines the pipe diameter of the building connection occurs within the residential (buy) function [heating load] which is 54 kW. Thus, the flow rate is 0.0006 m^3/s. With the maximum speed of 1 m/s for a building connection this gives us a pipe diameter of 0.03 m; 32 mm. According to the Table above the corresponding UC is 0.160 W/(m^1K).

Note that for the yearly distribution heat loss the $T_{surroundings}$ for pipes in the ground is used; 12 °C.

Type	Length	T_{supply}	T_{ret}	DN	U*C	Heat loss	Heat loss
	m	°C	°C	mm	W/(mK)	kWh/year	MWh/year
Primary	-	40	20	-	-	-	-
Secondary	354	40	20	32	0.160	8930	8.9
Building connection	48	40	20	30	0.160	1210	1.2

However, the cooling grid also has a supply and return pipe. Thus, besides the heating grid the cooling grid has a supply temperature that flows through the grid is around 10 °C, whereas the return temperature is around 20 °C. Again all buildings have two connections with the grid (supply and return). For option 2 the maximum peak thermal power is around 470 kW in a whole year [maximum power needed for cooling for all buildings in one hour]. With a supply temperature of 20 °C and a return temperature of 10 °C [ΔT is 10 °C], this gives us a flow rate of 0.011 m^3/s. Thus, with a maximum speed of 2 m/s for a secondary pipe, therefore, the required diameter is 0.084 m; 84 mm or from the Table it is 100 mm. According to the Table above the corresponding UC is 0.276 W/(m¹K).

The maximum thermal power peak from to grid to a building that determines the pipe diameter of the building connection occurs within the hotel function [cooling load] which is 142 kW. Thus, the flow rate is 0.003 m^3/s. With the maximum speed of 1 m/s for a building connection this gives us a pipe diameter of 0.062 m; 62 mm or from the Table 65 mm. According to the Table above the corresponding UC is 0.253 W/(m¹K).

Type	Length	T_{supply}	T_{ret}	DN	U*C	Heat loss	Heat loss
	m	°C	°C	mm	W/(mK)	kWh/year	MWh/year
Primary	-	20	10	-	-	-	-
Secondary	354	20	10	100	0.276	2568	2.7
Building connection	48	20	10	65	0.253	319	0.3

Note that for the yearly distribution heat loss the $T_{surroundings}$ for pipes in the ground is used; 12 °C.

Option 3: Low temperature heat grid

The energy system of option 3 consists of a low temperature heat grid with seasonal thermal storage. For both heating and cooling this means there is a supply pipe and a return pipe (double pipe). Again the total length of one pipe is 177 meters, i.e. total length of pipes is 354 meters. Water from the ground is pumped up and upgraded to 40 °C with a small heat pump within a building. Thus, the supply temperature that flows through the grid is around 20 °C, whereas the return temperature is around 10 °C. The water that returns can also be used for cooling purposes. All buildings have two connections with the grid (supply and return) these pipes have a total length of 48 meters. For option three the maximum peak thermal power is around 470 kW in a whole year. With a supply temperature of 20 °C and a return temperature of 10 °C [ΔT is 10 °C], this gives us a flow rate of 0.011 m^3/s. Thus, with a maximum speed of 2 m/s for a secondary pipe, therefore, the required diameter is 0.084 m; 84 mm or from the Table it is 100 mm. According to the Table above the corresponding UC is 0.276 W/(m¹K).

The maximum thermal power peak from to grid to a building that determines the pipe diameter of the building connection occurs within the hotel function [cooling load] which is 142 kW. Thus, the flow rate is 0.003 m^3/s. With the maximum speed of 1 m/s for a building connection this gives us a pipe diameter of 0.062 m; 62 mm or from the Table 65 mm. According to the Table above the corresponding UC is 0.253 W/(m¹K).

Note that for the yearly distribution heat loss the $T_{surroundings}$ for pipes in the ground is used; 12 °C.

Type	Length	T_{supply}	T_{ret}	DN	U*C	Heat loss	Heat loss
	m	°C	°C	mm	W/(mK)	kWh/year	MWh/year
Primary	-	20	10	-	-	-	-
Secondary	354	20	10	100	0.276	2568	2.7
Building connection	48	20	10	65	0.253	319	0.3

Hourly calculation of distribution heat losses:

For the hourly calculation of the heat losses through distribution can be calculated using the formula as stated in x. With the knowledge of required pipe diameter, U*C, thermal peak and flow rate as calculated above, there is one parameter that could be changed; $T_{surroundings}$. Instead of the above used ground temperature as the $T_{surroundings}$ now the ambient outdoor temperature can be used, i.e. the outdoor temperature from weather data as used in the excel calculation sheets. However, when choosing the ambient outdoor temperature as $T_{surroundings}$ an extra high insulation should be calculated in [pipes are often placed in the ground which has its own insulation value. Therefore, for this case study the ground temperature of 12 °C is used.

A.6: Steady state hand calculations for validation

For validation reasons the excel outcome of one hour in a whole year for the function residential in building 1 are calculated using the following formulas as stated in chapter 2.3; energy balance. First each energy flow has to be calculated separate and then the demand for heating or cooling can be calculated.

Energy flow	*Abbreviation*	*Description*	*Equation*
Transmission	Q_{trans}	Heat transfer through façade	$Q_{trans} = U * A * (T_e - T_i)$ [W]
Infiltration	Q_{inf}	Heat transfer through gaps in façade	$Q_{inf} = V_{inf} * \rho * c_p * (T_e - T_i)$ [W]
Ventilation	Q_{vent}	Heat transfer through ventilation	$Q_{vent} = V_{vent} * \rho * c_p * (T_e - T_i)$ [W]
Solar gains	Q_{solar}	Passive heat gains through solar radiation	$Q_{sol} = A_{glass} * q_{sun} * g$
Internal heat gains	Q_{int}	Passive heat gains by people, appliances and lights	$Q_{int} = Q_{people} + Q_{appliances} + Q_{light}$

Table: Overview of energy flows with corresponding equation to calculate them, source: Jansen & van den Ham (0016) (edited by author)

Hour 660 of the year is chosen to be calculated, this hour has the following characteristics:

T_e	-5.13 °C	
T_i	20 °C	
$Q_{sun;\ North-East}$	1.4 W/m²	
$Q_{sun;\ South-East}$	3.87 W/m²	
$Q_{sun;\ South-West}$	1.4 W/m²	
$Q_{sun;\ North-West}$	1.4 W/m²	
$A_{facade;closed}$	181.4 m²	(North-East and South-West façade)
$A_{facade;closed}$	276.4 m²	(North-East and South-West façade)
A_{window}	181.4 m²	(North-East and South-West façade)
A_{window}	276.4 m²	(South-East and Norht-West façade)
A_{roof}	567.4 m²	
$A_{ground\ floor}$	0 m²	
$A_{total\ floor\ area}$	3405 m²	
U_{window}	0.7 W/m²K	(all facades)
g_{window}	0.5	
$R_{c;\ wall}$	6 m²K/W	- > U = 0.16 W.m²K
$R_{c;\ floor}$	8 m²K/W	- > U = 0.12 W.m²K
$R_{c;\ roof}$	8 m²K/W	- > U = 0.12 W.m²K
ACH_{inf}	0.15/h	
$V_{Building}$	10894 m³	
ρ_{air}	1.2 kg/m³	
$c_{p;air}$	1000 J/kgK	
Amount of people	60	
$V_{vent;\ per\ person}$	25 m³/h	
$\eta_{heat\ recovery\ vent}$	0.9	

<u>Transmission losses:</u>

$Q_{trans;total} = Q_{trans;window} + Q_{trans;wall} + Q_{trans;roof} + Q_{trans;floor}$ in which, $Q_{trans} = U * A * (T_e - T_i)$ [W]

$Q_{trans;window} = 0.7 * (A_{all\ windows}$ [915.6 m²] * ($T_e - T_i$ [-25.13] = -16106,32 Wh

$Q_{trans;wall}$ = 0.16 * 915.6 * -25.13 = -3681.45 Wh

$Q_{trans;roof}$= 0.12 *567.4 * -25.13 = -1711.05 Wh

$Q_{trans;floor}$ = 0

Thus, $Q_{trans;total}$ = -21498,82 Wh

Infiltration losses:

$Q_{inf} = V_{inf} * \rho * c_p * (T_e – T_i)$ [W]

$V_{inf} = V_{building}$ * ACH = 10894 *0.15 =1634 m^3/h ->

Q_{inf} = (1634 * 1.2)/3600 * 1000 * -25.13 = -13687.47 Wh

Ventilation losses:

$Q_{vent} = V_{vent} * \rho * c_p * (T_e – T_i)$ [W]

V_{vent} = Amount of people * $V_{vent;\ per\ person}$ = 1500 m^3/h

Q_{vent} = (1500 * 1.2)/3600 * 1000 * -25.13 = -12567 Wh

With a heat recovery of 0.9 -> Q_{vent} = (1-0.9) * -12567 = -1257 Wh

Solar heat gains:

$Q_{sol} = A_{glass} * q_{sun} * g$

$Q_{sol;North-East}$ = 181.4 * 1.4 * 0.5 = 127 Wh

$Q_{sol;South-East}$ = 276.4 * 3.87 * 0.5 = 534.8 Wh

$Q_{sol;South-West}$ = 181.4 * 1.4 * 0.5 = 127 Wh

$Q_{sol;North-West}$ = 276.4 * 1.4 * 0.5 = 193.5 Wh

$Q_{sol;\ total}$ = 982.3 Wh

Internal heat gains:

$Q_{int} = Q_{people} + Q_{appliances} + Q_{light}$

Q_{people} = Amount of people * heat gain per person [100 W/person] -> Q_{people} = 6000 Wh

$Q_{appliances} = A_{floor\ area}$ * appliance power per m^2 [1.5 W/m^2]* percentage lighten up floor [0.7]

$Q_{appliances}$ = 3405 * 1.5 * 0.7 = 3575 Wh

$Q_{light} = A_{floor\ area}$ * light power per m^2 [4 W/m^2]* schedule [1 when people are present]

Q_{light} = 3405 * 4 * 1 = 13620 Wh

Q_{int} = 6000 + 3575 + 13620 = 23195 Wh

Heating or cooling demand:

$Q_{demand} = Q_{int} + Q_{sol} – Q_{trans} - Q_{inf} - Q_{vent}$

Q_{demand} = 23195 + 982.3 - 21498,82 - 13687.47 – 1257 = -12265.99 Wh

= -12.27 kWh

A negative value means that heating is needed. Thus, for hour 660 in a year 12.27 kWh of heating is needed.

According to the excel there is 12.35 kWh of heating needed. This value might be slightly higher due to rounding up some values. However, it indicates that the excel is working properly.

A.7: Local renewable supply characteristics and calculations

As mentioned in chapter 3.3 the mismatch between supply and demand can be reduced by supply side management. For an energy system that is solely dependent on renewable energy it is expected that a diverse selection of renewable resources helps in order to create a more constant supply. For this research solar and wind energy are used to find out whether this diversification is helpful. In this section each technology is explained further and ways to calculate the hourly energy supply are explained.

PV and PVT electrical output:

PV panels are widely used as main source of renewable energy. They transform the primary energy of solar energy into a usable energy carrier: final energy. This technology is solely dependent on solar energy and thus, it has high peaks when the solar radiation is high, i.e. in summer and during the day. For function that have high demands during the day it is a very useful technology to increase energy flatness. However, during the night there is no production.

The supply of electricity by PV panels [and PVT electricity output] can be calculated on an hourly basis with the following formula (Huitema, 2018):

$$E = A * r * qsun * PR \ [kWh]$$

In this formula:

E	Electricity output	[kWh]
A	Surface area pv panel	[m^2]
r	Efficiency of PV panel	[-]
qsun	Hourly solar irradiation	[W/m^2]
PR	Performance ratio	[-]

The efficiency used in this research is 0.17, whereas the performance ratio used is 0.812 for PV panels and for PVT electricity output the efficiency used is 0.16 and performance ratio is 0.75.

PT and PVT thermal output:

For the regeneration of thermal energy storage PVT panels are used. When no extra electricity is needed PT panels can also be used. PV(T) panels use solar energy to heat up a liquid inside the panel which than can be used as thermal energy, i.e. this liquid is often water. Because of the dependency on solar energy, the maximum output can be achieved in summer. However, the heating demand often is larger in winter and thus the produced thermal energy has to be stored in a thermal energy storage.

The supply of thermal energy by PV[T] panels can be calculated on an hourly basis with the following formula (Huitema, 2018):

$$Q_{collector} = Q_{sun} - Q_{transmission} \ [W]$$

For this research unglazed solar collectors are used based on the findings of Huitema (2018) that with low temperature differences unglazed solar collectors have the highest output potential. Thus for this research the following formulas are used (Derived from Huitema (2018) and edited by author):

$$Q_{sun} = A * a * qsun\ [W]$$

$$Q_{transmission} = \frac{T_m - T_e}{R_e} + \frac{T_m - T_e}{R_e}\ [\text{W}]$$

In these formulas:

A	Absorber area of collector	[m^2]
a	Absorption coefficient	[-]
qsun	Hourly solar irradiation	[W/m^2]
T_m	Ambient temperature liquid inside collector	[^oC]
T_e	Ambient outdoor temperature	[^oC]
R_e	Resistance to the outside (for air 0.004 W/m^2K)	[W/m^2K]

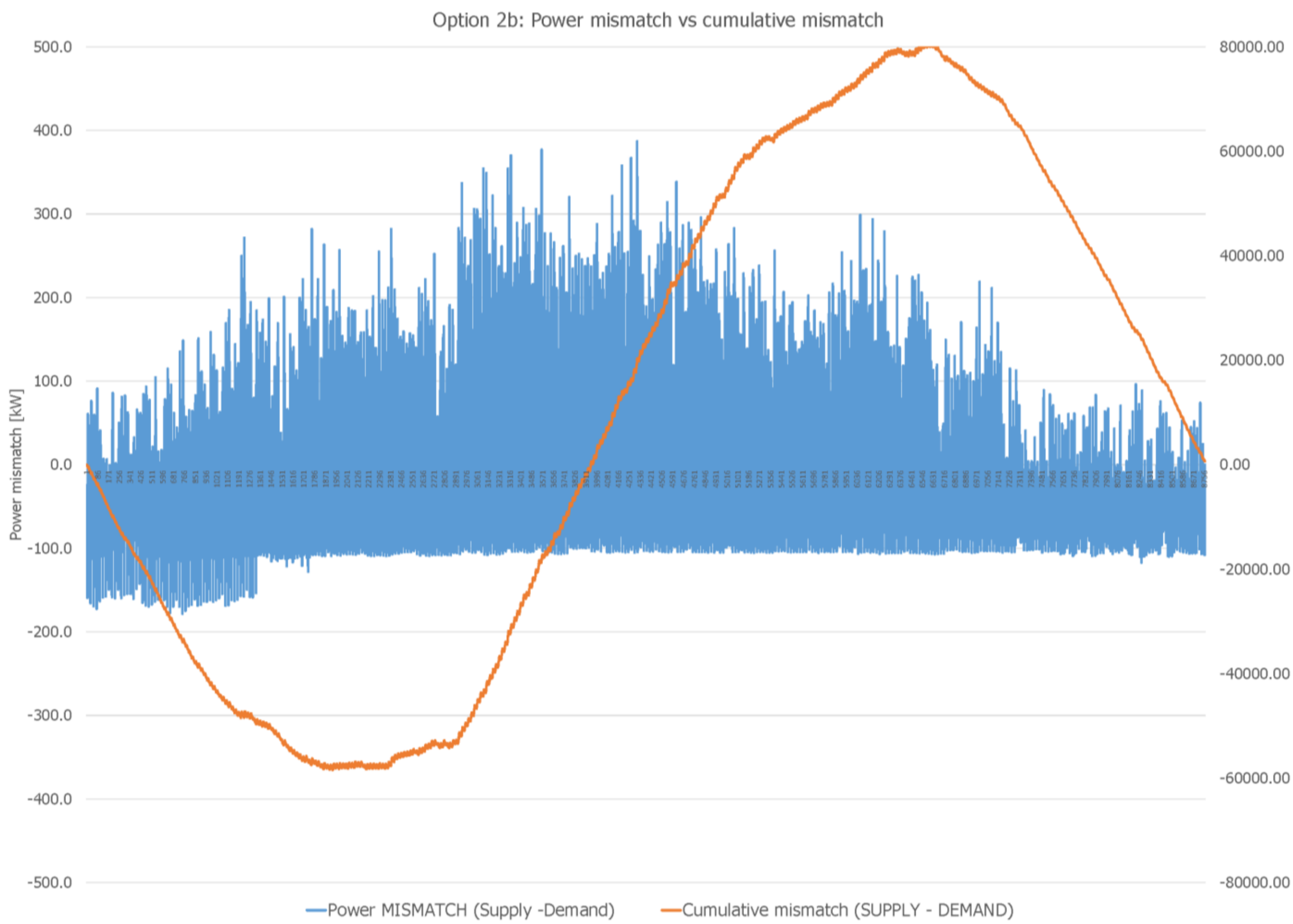
<u>MRE-hybrid:</u>

The MRE-hybrid, short for Multifunctional roof edge technology, is a product made by the company Anerdgy. It combines both solar and wind energy to produce electricity. Additionally, other aspects like PVT panels, storage and building service units can be placed within one module. These modules are placed on the sides of a roof which means that the rest of the roof can still be used for other purposes. For this research this module is used on every roof of the buildings. However, the modules with integrated small wind turbines can only be placed on the correct façade, i.e. the façade with the highest annual wind speed, in the Netherlands this is the case for the South-West façade. Calculations of the maximum output of this technology for the case study from this research is carried out by the company itself. Due to the small areas on which the MRE-hybrid could be placed the electricity production by wind energy is only 9000 kWh per year for this case study, whereas the PV panels in the same module produce up to almost 475 MWh per year. Therefore, for this case study the wind energy is almost neglect able. However, with the optimization of the orientation of the PV panels it can still produce more electricity than when all roofs are completely covered by solar panels. Additionally, analysis of the hourly electrical supply by wind energy showed that the output is higher during the night than it is during the day. Thus, when a design is perfectly located for the usage of these modules it could be beneficial to create an energy flat urban block.

Figure: MRE-hybrid module
source: Anerdgy (2018)

A.8 Graph power mismatch VS cumulative mismatch for option 2b

In the graph below the power mismatch vs the cumulative mismatch is shown for option 2b. The other options have similar profiles and thus, this option is respresentative for all other options as well. As can be seen during the colder seasons (winter + spring) the cumulative mismatch is negative, which is shown by the bigger negative peaks in the power mismatch. During the beginning of summer the power mismatch turns into higher positive values. Hence, the cumulative mismatch becomes positive. During the end of autumn, begin of winter the power mismatch becomes negative again and the cumulative mismatch reduces to 0 again. This means that over a year this system is almost energy neutral.



B. Description of governance components

B.1: Description of workshop session with experts

For validation reasons of the findings regarding governance components a workshop session with experts was held on June 12th of 2019. These experts are part of the KoWaNet research project of which the case study area is also part of. The following experts (name and institution) were present during the workshop session:

- Saskia Müller — Stadslab Buiksloterham
- Marcel Elswijk — EnergyGo
- Herman Eijdems — MijnWater B.V.
- Sabine Jansen — TU Delft

Due to the fact that all participants and the author are Dutch, the workshop session was held in Dutch, the questions and answers are translated by the author. The plan for the workshop session was to first give a presentation (15 minutes) about my thesis. This presentation contained the following information: Concept of energy flat urban blocks, Case study description, Detailed stakeholders description, Description of barriers in current society, Description of opportunities in current society, Short elaboration on implementation of energy flatness in the case study area and A detailed overview of different Institutional energy flow diagrams.

Beforehand, it was planned to first give the presentation and afterwards discuss the questions as stated below with all participants together.

- *Hoe ziet een energy flat gebouwblok er volgens u idealiter uit (conceptuele methode en energy flow diagrams)?*
- *Bent u betrokken (geweest) bij een project waarin energy flat onderdelen aanbod komen? Zo ja, hoe bent u betrokken?*
- *Welke ervaringen heeft u bij deze projecten opgedaan en wat heeft u ervan geleerd?*
- *Wat zijn volgens u de belangrijkste barrières voor het energy flat concept? Zelf opgedaan of verwachting.*
- *Hoe verwacht u deze barrières op te lossen?*
- *Wat zijn volgens u de belangrijkste stakeholders om het energy flat concept te implementeren?*
- *Wat zijn de grootste uitdagingen om het energy flat concept marktrijp te maken?*
- *Welke kansen ziet u, en op welk vlak liggen die (technisch, economisch, sociaal, dan wel wet- en regelgeving)?*
- *Wat zou een doorbraak zijn om innovatie-diffusie van energy flat buildings (gebouwblokken) te versnellen en op te schalen?*

Or for the Non-Dutch speaking readers of this thesis, a translation into English is given:

- *How do you think an energy flat urban block ideally looks like (conceptual and energy flow diagrams)?*

- *Have you ever been involved in a project with energy flat components? If so, how are you involved?*
- *What experiences have you gained from these projects and what have you learned from them?*
- *What do you think are the most important barriers for the energy flat concept? Experienced yourself or expectations.*
- *How do you expect to overcome these barriers?*
- *What do you think are the most important stakeholders to implement the energy flat concept on a large scale?*
- *What are the biggest challenges to get the energy flat concept ready for the market?*
- *What opportunities do you see, and in what area do you see them (technical, economic, social or laws and regulations)?*
- *What would be a breakthrough to accelerate and scale up the innovation diffusion of energy flat buildings?*

However, the experts already gave feedback and started discussions during the presentation, and therefore, afterwards there was limited time and thus not all of these questions were answered by the experts. Nonetheless, the some of the bigger questions were answered during these discussions and feedback and therefore, the questions that are answered are talked about in the section below. Note that due to privacy reasons of the participants of the workshop session statements are not attached to one of the names of the experts. The author interpreted the answers of the participants in such a way that the questions are answered based on the opinions of the experts. For coherence in the overall thesis the questions and answers are only provided in English. Additionally, questions are sometimes answered together because the answer would be almost the same or these questions strengthen the overall answer.

- *How do you think an energy flat urban block ideally looks like (conceptual and energy flow diagrams)?*
- *What would be a breakthrough to accelerate and scale up the innovation diffusion of energy flat buildings?*

Within the presentation the author proposed an energy system that is arranged by a third party, ideally the owners association. However, the experts experienced during several projects that in general owners associations are not suitable to operate complex energy systems like that. The majority of the time owners associations have only a few (2 or 3) people that are really involved in the owners association, the rest that is part of the owners association only want to occasionally do something. Nevertheless, the experts agree that the only way to arrange energy systems on a local scale are with third party involvement. According to them Energy service companies would be the best option to arrange the energy system. Ideally, the tenants/residents would have a leasing contract with the ESCO, they have a monthly/yearly subscription with the company and the company arranges all energy related aspects. This would be a simple solution and when this is possible it is expected that a lot of people would be interested.

- *Have you ever been involved in a project with energy flat components? If so, how are you involved?*
- *What experiences have you gained from these projects and what have you learned from them?*

The experts have not yet been involved in projects with direct technical aspects of energy flatness. However, another key component of energy flatness is the collaboration between all stakeholders and the open and transparent communication between them. All stakeholders should be involved from early design stages in order to make the uptake of energy flatness successful. According to the experts currently the demand for housing, especially in Amsterdam, is just too high. This means that people only get involved in newly build urban blocks in the last few weeks of the construction. They do not have anything to say during the design process. Therefore, currently the users of the area are left out of the discussion about type of energy systems at all which makes it very difficult to implement innovations that could be beneficial for the end-users but requires more initial investments.

- *What do you think are the most important barriers for the energy flat concept? Experienced yourself or expectations.*
- *How do you expect to overcome these barriers?*
- *What are the biggest challenges to get the energy flat concept ready for the market?*
- *What would be a breakthrough to accelerate and scale up the innovation diffusion of energy flat buildings?*

According to the experts there are two main barriers for the uptake of the energy flat concept. Firstly, the risks every stakeholder is facing is not included in research yet. When the risks or non-risks are not yet known, a lot of people do not want to take the risk of implementing new concepts. Moreover, money is the another big barrier for the energy flat concept. When bigger commercial parties are involved the first question that is often asked before all benefits and disadvantage of something are explained is what is the cheapest option? There are still a lot of companies that want to continue working the way they did for the last decades. Secondly, without knowing the benefits for the end-users regarding their energy bill, the majority of people is not willing to implement unknowing innovations. The best way to overcome these barriers is to do more research on the money aspects of the energy flat concept. How is the energy bill of the end-user influenced by energy flatness? What are the initial investment cost of energy flatness and what is the return on investment period? Before these aspects are known a lot of parties/stakeholders would not be interested in implementing the energy flat concept.

- *What opportunities do you see, and in what area do you see them (technical, economic, social or laws and regulations)?*

The experts agree with each other that this is the time for energy innovations to take place. With the social pressure of current society regarding climate action it would be easier to implement innovative energy concepts. For example, within the Netherlands on the 28th of July the final Climate agreement was presented. Within this document harsh goals considering climate action are explained. Hence, in order to be able to meet these goals we have to experiment/implement innovations. Therefore, currently the biggest opportunities for the uptake of energy innovations lies within the social area.