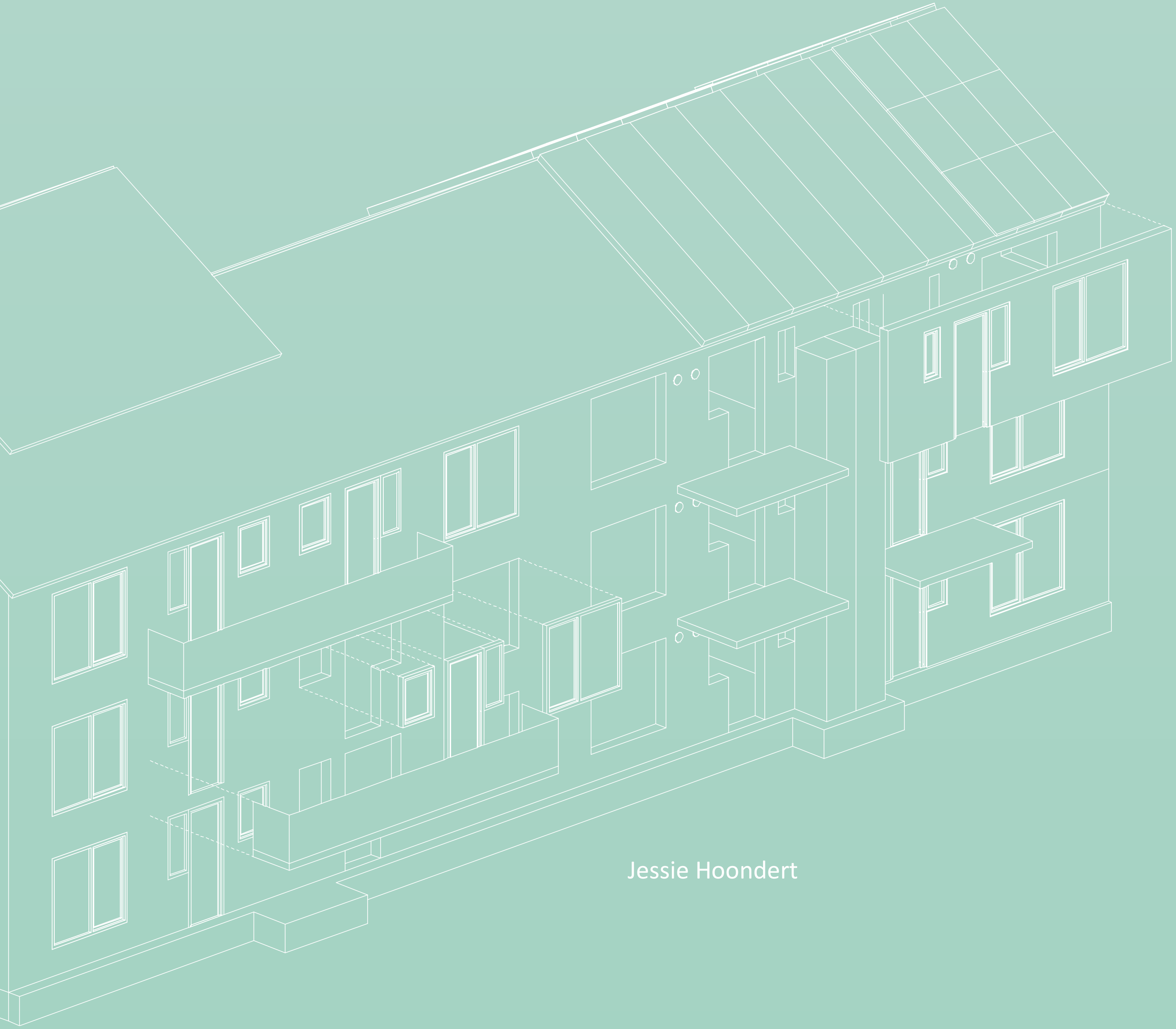
RENOVATION FOR DIFFERENT ENERGY SYSTEMS

Prefabricated renovation approach for post-war walk-up apartments that is applicable to different energy systems



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Glossary

ATES – Aquifer Thermal Energy Storage

BENG – Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]

BIPV – Building Integrated Photovoltaic

Bouwbesluit – Dutch building regulations

Building services – Equipment needed to provide heating, DHW and ventilation

DHW – Domestic hot water

Energy demand – Energy that is needed to provide heating, DHW and ventilation

Energy neutral – Building related energy is annual zero. Excluding user related energy

EPC – Energie Prestatie Coëfficiënt [Energy Performance Coefficient]

EPV – Energie Prestatie Vergoeding [Energy Performance Compensation]

NoM – Nul op de Meter [zero-on-the-meter]: building related and user related energy is annual zero

PEF – Primary Energy Factor

PV panels – Photovoltaic panels

PVT panels – Photovoltaic thermal panels

RES – Renewable energy sources

Abstract

The post-war building stock represents 33% of all residential buildings. A common characteristic is that they are poorly insulated compared to the current Dutch building regulations. This research will focus on post-war walk-up apartments, they account for approximately 8% of the total residential building stock. 70% out of this 8% is social housing. All housing corporations agreed that in 2020 the residential portfolio should have an energy label which is at least B. The refurbishment of post-war walk-up apartments is really needed to achieve this energy label. The 2ndSKIN approach is a prefabricated system for the renovation of walk-up apartments. This approach contains a zero-on-the-meter concept, where building services are integrated into the façade. The 2ndSKIN approach is still too costly and the zero-energy target is only met in specific conditions. To optimize the retrofit of residential buildings different energy systems should be applied. The approach can then be used in different urban contexts, which will result in upscaling the refurbishment of walk-up apartments.

Literature research on several existing renovation approaches and different energy systems has been conducted. Together with the analysis of post-war walk-up apartments, it resulted in four main energy systems. These concepts have been simulated with the software Uniec[2.2]. The goal of the simulation was to achieve the BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]). In order to achieve the BENG regulations, a low and high impact variant have been designed. These variants differ in insulation value and how ventilation is provided. The conclusion of the simulation provided direct input for the design phase. A case-study is used to apply the outcomes of the simulations in detail and to design an approach where it is possible to accommodate different energy systems.

The outcome of this research is a prefabricated renovation approach for post-war walk-up apartments that is applicable to accommodate energy saving measures with different energy systems. Building services are integrated into the façade and different building services units can be placed in the backyard to have different energy systems in the building. With the new building services and the increased insulation value of the building envelope, it is possible to fulfil the BENG regulations with a post-war walk-up apartment building. Except for one concept, all other concepts are even zero-energy.

The different energy concepts and variants for the building envelope have been included in a decision-making diagram. With this diagram, housing corporations or homeowners associations can choose between the different concepts, based on three different goals. Also, some considerations concerning the choice between the low and high impact for the building envelope are made.

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INTRODUCTION

Introduction

1. Background

Over the last century the burning of fossil fuels, like coal and oil, has increased the concentration of CO_2. This certain gas blocks the heat from escaping the atmosphere, which results in a higher global temperature. A higher temperature will lead to more evaporation and rainfall overall. A stronger greenhouse effect will warm the oceans and melt glaciers and other ice, which will increase sea level (NASA, n.d.).

The current building stock is responsible for nearly 40% of energy-related CO_2-emissions. This consists of 28% global energy-related CO_2-emissions for the building sector and another 11% for the construction of buildings. Therefore, they are responsible for a big part in the greenhouse effect (UN Environment and International Energy Agency, 2017).

During the 2015 climate conference in Paris, a climate agreement with 195 countries is signed, to reduce the greenhouse gases and to lower global warming. It consists of different agreements, regarding lowering CO_2 emission by 2050. This includes the 20-20-20 target, which ensures that CO_2 emissions in 2020 are reduced by 20 per cent (UN, 2015).
The targets for 2020 are:

1. 20% less CO_2 emissions than in 1990;
2. 20% less energy consumption;
3. 20% of total energy consumption must come from renewable energy.

The residential building stock needs to be upgraded to reach the energy and CO_2-emissions targets of 2020. They require an eventual reduction of up to 90% for the building sector (European Commission, 2011). New buildings only add 1% to the existing building stock, the remaining 99% of buildings are already built and are one of the biggest energy users. So, refurbishment of the existing building stock is the solution to improve the environmental performance of the building sector (Konstantinou & Knaack, 2013).

The Dutch government has the ambition to improve the Dutch building stock to energy neutral (SER, 2013). To achieve this goal, it is necessary to develop products and processes for renovating residential buildings. The role of the occupants becomes more important in the post-refurbishment phase, but also in the design and planning phase. For example, minimum disturbance during the renovation, so that occupants can stay in their dwellings and do not have to be relocated. This can be achieved by prefabrication of the retrofitting components. They are the potential to achieve high-performance solutions while minimizing on-site construction (Konstantinou, Klein, Guerra-Santin, Boess, & Silvester, 2015).

The post-war building stock, which represents 33% of all residential buildings, is particularly relevant to refurbishment (CBS Statline, 2018). It has the common characteristic that they are poorly insulated compared to the current building regulations so there is a need for refurbishment (Silvester et al., 2016). Since the entire post-war building stock is too extensive for the scope of this research, it was decided to focus on the post-war walk-up apartments. Walk-up apartments of the post-war period account for approximately 8% of the total residential building stock, 70% of which are social housing (Agentschap NL, 2011). The social sector is mostly in the possession of a housing corporation. All housing corporations agreed that in 2020 the residential portfolio should have an energy label which is at least B. The refurbishment of post-war walk-up apartments is really needed to achieve this target (Ministerie van Algemene Zaken, 2012).

Silvester et al. (2016) designed the 2ndSKIN approach. It consists of a prefabricated system for the building renovation of walk-up apartments. It is translated into a zero-on-the-meter concept, where building services are integrated into the façade of the building. Therefore, they are more accessible in the future for maintenance and replacement. The conclusion of the 2ndSKIN approach is that the zero-energy target can be met under specific conditions. These specific conditions are the number of apartments (therefore the energy demand), the orientation of the roof and the change in behaviour of the occupants. If there are too many apartments in the building or if the PV panels are not placed with an attic structure in South facing direction or if the occupants are not changing their behaviour, then the zero-energy target will not be met. On top of that, a cost assessment performed during the project showed that costs are still 160% of the targeted cost. Maybe a zero-energy concept is not the most cost and energy efficient system for walk-up apartments.

Research of Panteli (2017) and Jablonska et al. (2011) show that different energy systems can be applied in a neighbourhood. Which energy systems should be applied is dependent on different factors, since not every building typology is suitable with a specific energy system. For example: if district heating is present in the neighbourhood, then it will be suitable for some building typologies to connect to this grid. By connecting to district heating costs will be saved.

The aim of this research is to design a prefabricated system for the building renovation of post-war walk-up apartments, where different energy concepts can be applied. By doing this, the renovation approach will be more specific to the context and will help in upscaling the refurbishment of post-war walk-up apartments.

2. Research framework

2.1 Problem statement

The 2ndSKIN approach is still too costly and the zero-energy target is only met in specific conditions. To optimize the retrofit of residential buildings different energy systems should be applied. The approach can then be used in different urban contexts.

Until today, most of the refurbishment projects result in individual building measures. Panteli (2017) showed in her research that the optimal energy performance results can be achieved if the building is connected to district heating. The solution for optimizing the retrofit of residential buildings must be made on different energy scales. If the building can be connected to district heating, then it will be the most time and cost efficient to do so.

The 2ndSKIN approach can be used to renovate dwellings in the neighbourhood with a zero-on-the-meter energy system. The conclusion of the 2ndSKIN approach is that the zero-energy target can be met under specific conditions. These specific conditions are the number of apartments (therefore the energy demand), the orientation of the roof and the change in behaviour of the occupants. These requirements are so specific, that in most of the analysed possibilities the zero-energy target will not be met. Cost assessment of the 2ndSKIN concept performed during the project showed that costs are still 160% of the targeted per dwelling (Silvester et al., 2016).

By making the approach suitable for different renewable energy systems it is possible to take less energy saving measures. This can save costs and time. In this research, the prefabricated system for building renovation from the 2ndSKIN approach will be used to design an approach with the possibility to apply different energy systems.

2.2 Objective

The main objective is the development of a prefabricated system for building renovation of post-war walk-up apartments, that is applicable for different energy systems.

Phase 1: Inventory

1. Prefabricated renovation approaches
    a. Define parameters for a renovation approach
    b. Define the different energy systems used in the renovation approaches
2. Walk-up apartments
    a. Define the building characteristics of a walk-up apartment
    b. Define the energy system and building services that are used in a walk-up apartment
3. Energy systems
    a. Define different energy systems
    b. Define building services that are related to the energy systems
    c. Define the requirements for the different energy systems/ building services

Phase 2: Context

1. Existing building
    a. Define the building characteristics
    b. Define the construction type of the building
    c. Define the lay-out of the building
2. Indoor climate
    a. Define the building services
    b. Define the energy demand of the building

Phase 3: Simulation

1. Existing building
    a. Validate the energy demand of the existing building
2. Energy systems
    a. Define the different energy systems
    b. Define the parameters for simulation
    c. Simulate the energy demand for the different energy systems
    d. Define the building services for each energy system

Phase 4: Design

1. Template design
    a. Define sub construction, fixed window openings and cladding material
2. Energy systems
    a. Define if the prefabricated element is applicable for different energy systems

2.3 Research questions

Main question:

What prefabricated renovation approach for post-war walk-up apartments is applicable to accommodate energy saving measures, depending on different energy systems?

Phase 1: Inventory

1. Prefabricated renovation approaches
    a. What are the parameters for a renovation approach?
    b. What are the differences between the renovation approaches?
    c. What are the different energy supply systems?
        i. Which building services are used in the renovation approaches?
2. Walk-up apartments
    a. What are possible construction types of a walk-up apartment?
    b. What is the typical layout of a walk-up apartment building?
    c. What is the energy supply system?
        i. Which building services are used in a walk-up apartment building?
3. Energy systems
    a. Which different energy suppliers are there?
    b. Which energy systems are there?
        i. What building services are related to that specific energy system?
        ii. What are the requirements for the different energy systems?

Phase 2: Context

1. Existing building
    a. What are the building characteristics?
    b. What is the construction type of the building?
2. Indoor climate
    c. Which building services are there in the building?
    d. What is the current energy demand?

Phase 3: Simulation

1. Energy systems
    a. Which energy system can be applied in the prefabricated element?
    b. What is the energy demand with the new energy systems?
    c. What are the requirements for the building services?

Phase 4: Design

1. Template design
    a. Which template design is applicable to different energy systems?
2. Energy systems
    a. Which building services are needed to implement in the design?
    b. Is the prefabricated element applicable to different energy systems?

2.4 Approach and methodology

The main objective is the development of a prefabricated system for building renovation, where different energy systems can be applied. To make the system more suitable for different residential typologies in neighbourhoods. The general research framework used, follows a combination of the approaches of design by research and research by design.

The research is divided into four different phases: phase 1 is an inventory phase, phase 2 is the context phase, phase 3 is the simulation phase and phase 4 is the design phase. In Figure 1 an overview is given of the different phases of the research and which topics are integrated.

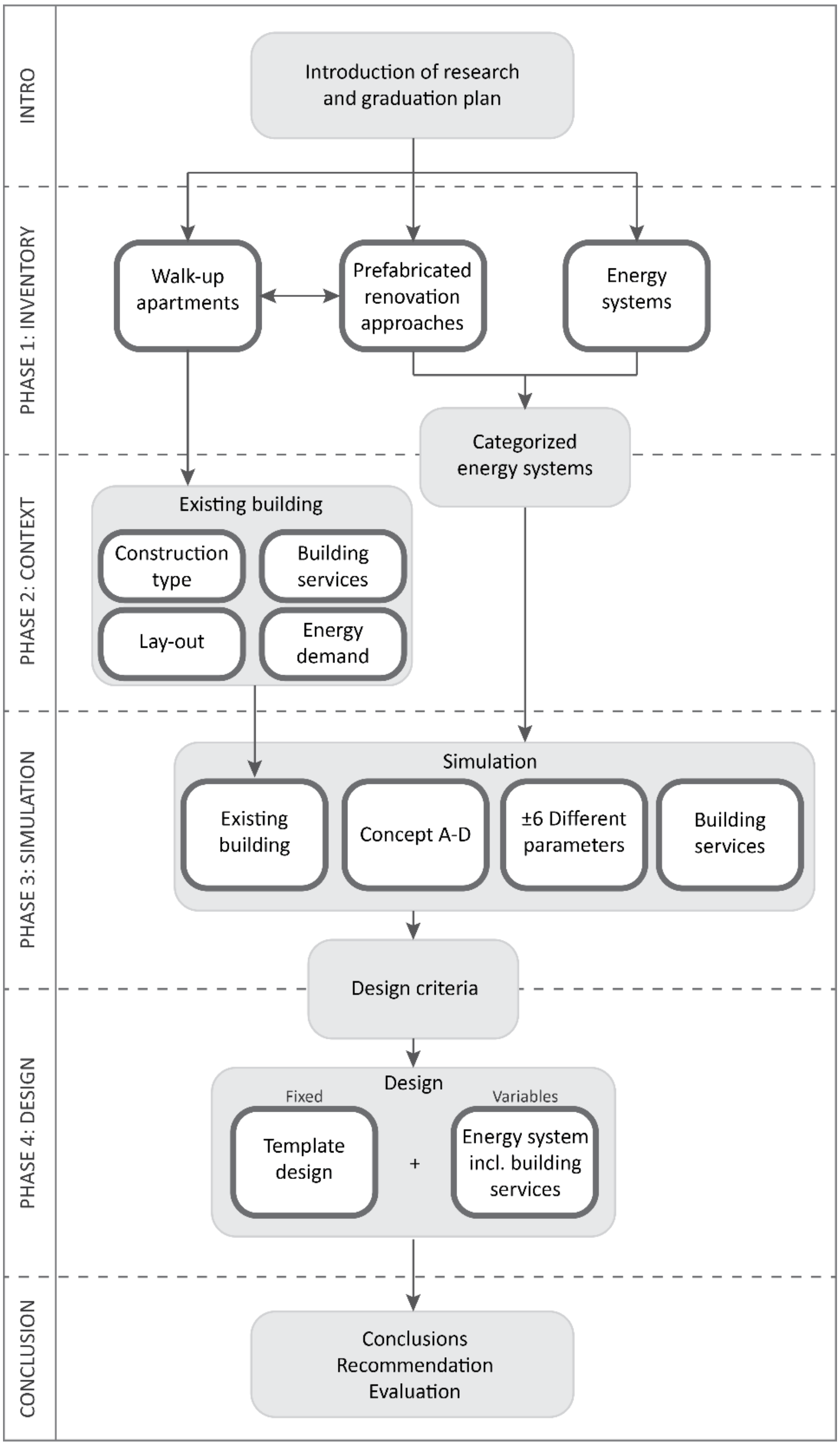


Figure 1: Research structure

Phase 1: Inventory
The aim of phase 1 is to gain more insight into the different renovation approaches that have been designed and are currently available on the market. In this phase, information will also be gathered on walk-up apartments and different energy systems on district and building level. Based on these results and insights all the limitations and possibilities will be listed and integrated into categorized energy systems. Those energy systems will be input for the simulation phase.

Phase 2: Context
Phase 2 is used to analyse a case-study building. This building will be selected based on the number of this type of walk-up apartment buildings in the Netherlands. This building will be used to elaborate more on the design in detail. The literature study on walk-up apartments is used as basic knowledge to understand the existing buildings better. For the design and the simulation of the existing building some parameters are needed, they will be collected in this phase. The parameters are: the construction type, the lay-out, the building services and the current energy demand. The construction type and the lay-out are needed as input for the design phase. The building services and the energy demand constitute the input for the simulation phase. As a validation of the simulated model, the existing building will also be simulated.

Phase 3: Simulation
The model in the software Uniec[2.2] will be validated by the references of the energy demand of the existing building. The categorized energy systems are input for the simulation of the different concepts. The goal of the simulation is to reach the BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]). A result of the simulation is the primary energy consumption and the produced electricity. Those results will be design criteria which consist of the different energy concepts with the related building services and can be directly used in Phase 4: Design.

Phase 4: Design
In the design phase, the existing building will be used as a case-study. All energy systems will be applied in one building. The context will be seen as something that can change since some energy systems are dependent on other factors, like the presence of district heating. In this phase, a distinction will be made between the building envelope and the building services. For the building envelope, two variants will be designed which can have different building services which will lead to different energy systems.

Conclusion & recommendations
After completing the four research phases conclusions can be drawn about the applicability of the prefabricated renovation approach to post-war walk-up apartments with different energy systems. Recommendations will be given on approach improvements and any possible future research.

2.5 Planning

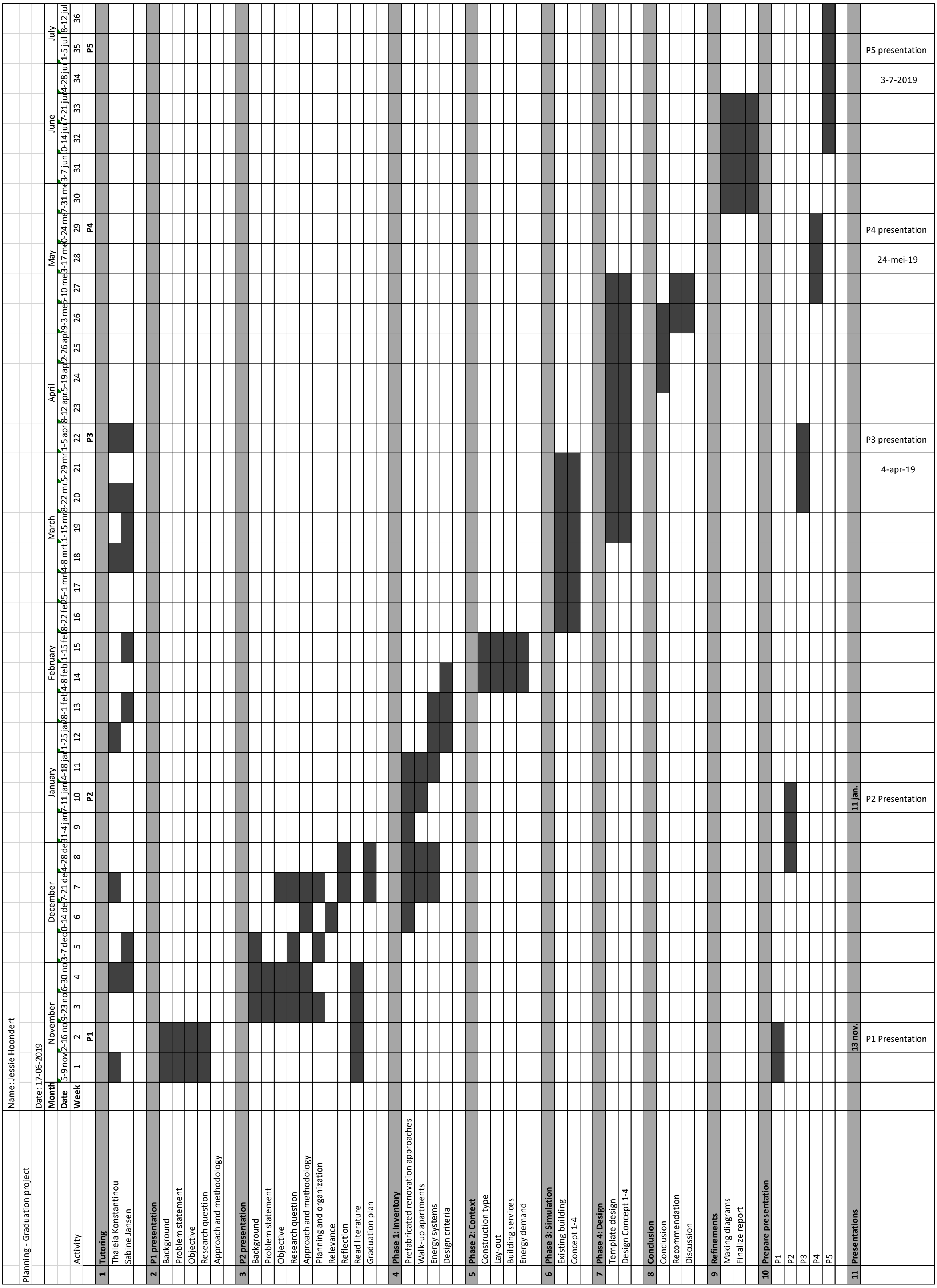


Figure 2: Graduation planning

2.6 Relevance

Scientific relevance
The project is directly related to the 2ndSKIN approach that provides a prefabricated and integrated façade module that gives the possibility to improve the energy performance up to zero energy (Silvester et al., 2016). By creating a prefabricated façade module that is suitable for different energy systems, it can be applied in different residential building typologies. This can reduce the energy demand for the entire neighbourhood. The renovation approach will contribute to a more self-sustaining energy system for the Netherlands. Therefore the Netherlands will be more independent from the fossil energy supplies of other countries.

Societal relevance
Many people can benefit from reducing buildings energy demands. Residents of buildings that will be refurbished will benefit from the energy retrofit of the building, which will result in a better quality of living. It will result in energy savings, and therefore reduction of the energy bill, as well. Engineers and architects also benefit, since there are a lot of residential buildings that need to be refurbished. Generally, this project contributes to the reduction of CO_2-emissions and therefore helps to achieve the climate targets of 2020.

PHASE 1: INVENTORY

Phase 1: Inventory

3. Prefabricated renovation approaches

The aim of the first research part is to obtain more knowledge about the different parameters of the main research question. In this chapter different renovation approaches will be analysed to gather more background information on renovation approaches. The approaches are based on their energy concept, type of dwelling or the use of prefabricated elements. Most of them have a zero-on-the-meter concept, just one of the approaches had the goal to achieve an energy label of A. Each renovation approach will give some general information and more detailed information about the prefabrication and building services that are used. The differences and comparisons between them will be given in the conclusion of this chapter.

3.1 2ndSKIN approach

The 2ndSKIN approach consists of a prefabricated system for the building renovation of post-war walk-up apartments. It is translated into a zero-on-the-meter concept where the building services will be integrated into the façade of the building. The innovative part of the 2ndSKIN approach is that all building services are integrated into one prefabricated element. The element is lightweight and can therefore be applied without adapting the existing structure of the wall or the foundation. Since the building services are accessible from the outside, they can be easily maintained or replaced. By doing this it also gives the opportunity to contract providers which can provide no 'energy' but rather the agreed thermal comfort and air quality and which will own and maintain the equipment needed (Silvester et al., 2016).

The following measures are taken to meet the zero-energy consumption requirement and to satisfy the occupants' comfort (Silvester et al., 2016):

1. A modular façade system, which could be adjusted to the existing structure without any major construction adjustments to the existing building;
2. Minimum disturbance for the occupants;
3. All the building services needed are to be situated in a unit outside the existing building in order to separate the structure of the building and the installations and to make a division in property possible. This also makes it possible to start with a short-term strategy at low costs and to change in the long term to a more efficient system;
4. Increase the thermal insulation value of the building envelope;
5. Install a heat recovery ventilation system to reduce the energy demand for heating while providing adequate indoor air quality;
6. Use PV-panels to generate energy.

Prefabrication

To ensure minimum disturbance for the occupants, the approach was to start with a prefabricated façade element. Figure 3 shows the building sequence of the 2ndSKIN concept where the numbers correspond with the numbers in the text. Firstly, a substructure that consists of wooden posts is connected to the existing structure (1). Ventilation ducts are integrated into an insulation board that covers the opaque part of the façade. This panel is installed first and arrive at the building site in one piece, in order to minimize the connection between the ducts (2). The prefabricated, floor-height, sandwich panels, with new windows, are attached to the substructure (3). Sealings are placed (4). Finally, the cladding material is attached (5). To achieve the zero energy targets, it can be necessary to integrate PV panels into the façade. PV panels and ventilation units are placed on the roof, this is not visible in the figure (Silvester et al., 2016).

Building services unit
The new more energy efficient building services for heating and ventilation are integrated into the façade. They are therefore accessible from the outside of the building and can be easily maintained. Heat recovery ventilation units are placed on the roof, while the ventilation ducts are integrated into an insulation board that covers the opaque part of the existing façade. Room heating and domestic hot water are covered by an all-electric decentral heat pump, with a 200-litre buffer tank for each apartment. The flexibility of the system and the accessibility from the outside allows for the maintenance and upgrading of the building services in further phases of the development during the building's lifetime (Silvester et al., 2016). Table 1 shows an overview of all measures with the corresponding values used in the 2ndSKIN approach.

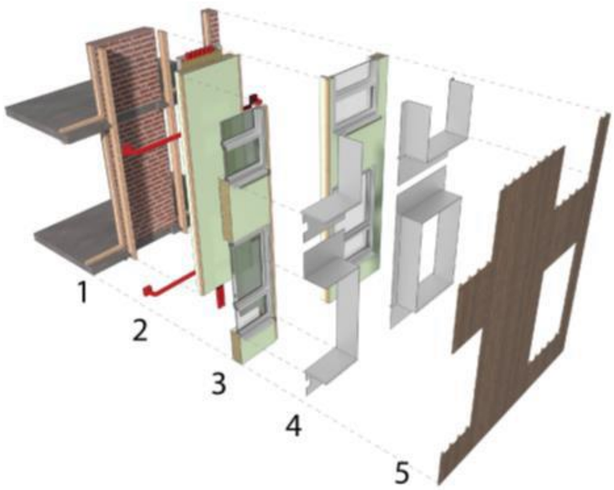


Figure 3: Detailed assembly sequence of the 2ndSKIN concept on an existing building (Silvester et al., 2016)

Parameters	Criteria	Value
Energy		
Energy performance	Energy consumption	0 kWh/dwel/yr
Energy supply	PV panels	CSun255-60P
Renovation from the outside as much as possible		
Inhabitants' disturbance	Building duration max.	10 days
Façade		
Façade construction	Roof	5 m^2K/W
	Façade elements	5 m^2K/W
	Window frames	0,8 W/m^2K
	Double glazing	0,8 W/m^2K
	Airtightness	0,4 $dm^3/s{\cdot}m^2$
Indoor comfort		
Ventilation	Heat recovery & ventilation unit on roof, inlet in	Efficiency 0,75

	façade, extraction through renovated shunt duct	
Room heating and DHW	Individual air-water heat pump with buffer for domestic hot water	Heating boiler 200-litre, 2kW
Heat emission system	Use existing radiators	

Table 1: List of parameters, requirements and quantified criteria of the 2ndSKIN refurbishment concept (Silvester et al., 2016)

3.2 BAM Heerhugowaard

BAM group, together with housing corporation Woonwaard, have renovated 55 terraced dwellings to a zero-on-the-meter dwelling. The aim of the project was to develop an industrial approach to net-zero fitting. By prefabrication of different elements and some other innovative strategies, it was possible to renovate the dwellings in ten days. A building services unit of 3m^3 will be attached to the dwelling in the backyard. The building services unit consists of all equipment that is needed to provide heating, DHW and ventilation. Roof and façade elements are all prefabricated and arrive at the building site in one piece. While renovating the building envelope they also renovated the bathroom, toilet and kitchen. To insulate the entire building envelope, the crawl space is filled with Dowa chips to reach a higher insulation value (RVO, 2014).

Figure 4: Prefabricated element on the building site (Akkerman, n.d.)

Prefabrication

To ensure minimum disturbance for the occupants, the roof and façade elements are prefabricated. The roof elements are insulated and have integrated PV panels. Before installing the new roof elements, roof tiles are taking off. The prefabricated façade element is made of wooden posts and consists of new windows with triple glazing, new doors, insulation and cladding material (Stroomversnelling, 2018).

Building services unit

The more efficient building services are placed in a building services unit of 3m^3, that will be attached to the dwelling in the backyard. Therefore, it can be easily accessible from the outside of the building, accordingly facilitating the maintenance. In the building services unit, the following equipment is placed: a heat recovery ventilation unit and an air-water heat pump for providing room heating and DHW. By placing the building services in a separate unit, it provides easy maintenance and upgrading the building services in further phases of the development during the building's lifetime. PV panels are placed on both sides of the roof in the NW and SE direction (RVO, 2014).

Table 2 shows an overview of all measures with the corresponding values used in the BAM Heerhugowaard project.

Parameters	Criteria	Value
Energy		
Energy performance	Energy consumption	0 kWh/dwel/yr
Energy supply	PV panels	327 Wp/panel
Renovation from the outside as much as possible		
Inhabitants' disturbance	Building duration max.	10 days
Façade		
Façade construction	Roof	5 m^2K/W
	Façade elements	5 m^2K/W
	Ground floor	4 m^2K/W
	Triple glazing	0,7 W/m^2K
Indoor comfort		
Ventilation	Balanced ventilation system with heat recovery	
Room heating and DHW	Individual air-water heat pump with buffer for domestic hot water	
Heat emission system	Existing radiators	

Table 2: List of parameters, requirements and quantified criteria of BAM Heerhugowaard (TNO, RIGO, Van Beek, BAM, & Vereniging Stroomversnelling, 2016)

3.3 Dura Vermeer Groningen

Dura Vermeer and housing corporation Lefier have renovated a walk-up apartment building in Groningen to a zero-on-the-meter concept. The type of building that they renovated is typical for the Netherlands. So far, the zero-energy approach was limited to terraced dwellings. This project is used as a pilot, to see if this approach will be used for the renovation of other walk-up apartments. To ensure minimum disturbance for the occupants, the goal was to renovate the apartments in ten days. The façade elements are prefabricated to minimize the construction time on site. In the new situation, the resident can close their balcony with sliding glass panels in winter. Building services are centralized in the central staircase of the building. The roof is insulated with prefabricated panels and PV panels are placed on top (Dura Vermeer, 2015).

Figure 5: Prefabricated element (Dura Vermeer, 2015)

Prefabrication
The façade elements are prefabricated in the factory and arrive at the building site in one piece. New windows with triple glazing are included in the elements. Since the new façade elements needed a new foundation, the construction time on the building site increased.

Building services
In this project, one collective location in the central staircase is used instead of separate building services per apartment. The collective building services are: a ventilation system with heat recovery and preheated air and a boiler to store heat from the solar collectors on the roof. Since the installation space is placed in the central staircase it is easily accessible for maintenance. The solar collectors in combination with a heat pump provide heat for room heating and for DHW. The fresh air is preheated before it enters the apartments. 1100 PV panels are placed on the roof of the building to provide electricity (Dura Vermeer, 2016).

Table 3 shows an overview of all measures with the corresponding values used in the Dura Vermeer project.

Parameters	**Criteria**	**Value**
Energy		
Energy performance	Energy consumption	0 kWh/dwel/yr
Energy supply	PV panels	1100 PV panels (total building)
Renovation from the outside as much as possible		
Inhabitants' disturbance	Building duration max.	10 days
Façade		
Façade construction	Roof	-
	Façade elements	-
	Ground floor	-
	Triple glazing	0,7 W/m^{2}K

Indoor comfort		
Ventilation	Balanced ventilation system with heat recovery with preheated air	
Room heating and DHW	Solar collector in combination with a heat pump	
Heat emission system	Preheated fresh air and existing radiators	

Table 3: List of parameters, requirements and quantified criteria of the Dura Vermeer project (RVO, 2015a)

3.4 SWZ Zwolle

126 Walk-up apartments on the Pieter Steijnstraat in Zwolle are renovated to sustainable and more liveable dwellings with an energy label of A. The construction year of the apartments is 1955. Via a selection procedure, the residents have chosen the winning plan for renovation. They needed 30% support, but in the end, 60% of the residents selected this plan. This selected plan was the basis of the renovation of the apartments. Measures that are taken to renovate the apartments are: insulating façade elements, new window frames with HR++ glazing, floor- and roof insulation. Except that, a new HR-condensing boiler is placed and the ventilation system is CO_2 regulated. All apartments are renovated, and the original state has been retained (Raadgevende Ingenieurs Nieman, 2015).

Figure 6: Renovated walk-up apartments in Zwolle (Stichting WE Adviseurs, n.d.)

Building services

Different from the other projects is that the goal of this project is not a zero-energy consumption. The goal in this project was to achieve an energy label of A. The building is still connected to the city grid for electricity and gas. The insulation value of the building envelope is increased and the façade elements, including window frames and glazing, are replaced. Ventilation is provided by a mechanical exhaust that is CO_2 regulated. Room heating and DHW is provided by an HR-condensing boiler and the heat is distributed via the existing radiators (Raadgevende Ingenieurs Nieman, 2015).

Table 4 shows an overview of all measures with the corresponding values used in the SWZ Zwolle project.

Parameters	Criteria	Value
Energy		
Energy performance	Energy consumption	Energy label A
Energy supply	Gas/electricity	City grid
Renovation from the outside as much as possible		
Inhabitants' disturbance	Building duration max.	-
Façade		
Façade construction	Roof	2,86 m^2K/W
	Façade elements	1,86 m^2K/W
	Ground floor	0,12 m^2K/W
	Floor storage space	3,36 m^2K/W
	Window frames + double glazing	1,8 W/m^2K
	Double glazing	HR ++ - glazing
Indoor comfort		
Ventilation	Mechanical exhaust ventilation based on CO_2-regulation	
Room heating and DHW	HR-condensing boiler	Intergas Kombi Kompakt HRE 24/18 – CW3
Heat emission system	Existing radiators	

Table 4: List of parameters, requirements and quantified criteria of the SWZ project (Raadgevende Ingenieurs Nieman, 2015)

3.5 Conclusion

After analysing different renovation approaches, it is possible to say something about them together. Table 5 shows an overview of the approaches with all the different measures. The location of the new more efficient building services is different in all approaches. In the 2ndSKIN approach, the building services are integrated into the façade element, in the BAM approach a separate building services unit is placed in the backyard, in the Dura Vermeer project the building services are placed in the central staircase and in the SWZ project each apartment has its' own building services. The location of the building services is dependent on how they are supplied (collective or individual). In each approach the accessibility of the building services is important. If they are easily accessible, they can also be easily maintained. To provide ventilation, heat recovery is used in 3/4 approaches. The SWZ project is the only one using ventilation based on CO_2-regulation. To provide room heating and DHW 3/4 approaches uses a heat pump. All approaches use existing radiators to distribute the heat. Notable is that the SWZ project, with goal energy label of A, is the one that uses different systems for ventilation, room heating and DHW. The other approaches with a zero-energy concept use more or less the same building services.

	2nSKIN	**BAM**	**Dura Vermeer**	**SWZ**
Goal	Zero energy	Zero energy	Zero energy	Energy label A
Type dwelling	Walk-up apartments	Terraced dwellings	Walk-up apartments	Walk-up apartments
Prefabrication	Facade, building services	Roof, facade, building services unit	Facade	Unknown
Building services	Integrated into facade	Building services unit in backyard	Central staircase	Per apartment
Ventilation	Heat recovery & ventilation unit on roof, inlet in façade, extraction thru renovated shunt duct	Balanced ventilation system with heat recovery	Balanced ventilation system with heat recovery with preheated air	Mechanical exhaust ventilation based on CO_2-regulation
Room heating + DHW	Individual air-water heat pump with buffer for domestic hot water	Individual air-water heat pump with buffer for domestic hot water	Solar collector in combination with a heat pump	HR-condensing boiler
Heat emission system	Existing radiators	Existing radiators	Preheated fresh air and existing radiators	Existing radiators

Table 5: Overview of renovation approaches

4. Walk-up apartments

This research part fully focusses on walk-up apartment buildings. Firstly, an explanation will be given why it was decided to only focus on post-war walk-up apartments. Secondly, the characteristics of walk-up apartments will be categorized. Different 'non-traditional' building methods will be analysed and compared to each other. Finally, the energy systems used in walk-up apartments will be listed.

4.1 Necessity for refurbishment

The target group for this research is the post-war walk-up apartment buildings in the Netherlands. It is a difficult type of building, because of their difference in shape, design and quality (Silvester et al., 2016). To understand why this building type should particularly be chosen, some data on the building stock is represented. The Dutch residential stock accounts for 7,6 million dwellings (CBS Statline, 2018). Around 847.000, approximately 11% of the Dutch housing stock, are walk-up apartments. Walk-up apartments of the post-war period account for approximately 8% of the total residential building stock, 70% of which are social housing (Agentschap NL, 2011). Housing corporations are important stakeholders for post-war walk-up apartments. All housing corporations agreed that in 2020 the residential portfolio should have an energy label of at least B. So, refurbishment of post-war walk-up apartments is really needed to achieve this target (Ministerie van Algemene Zaken, 2012).

4.2 Typical lay-out and appearance

The typical characteristics of a walk-up apartment are the following:

- Mid-rise apartment block;
- Mostly consists of 6-8 apartments, two apartments per floor;
- Central staircase, accessible in the front façade;
- Massive wall with reinforced concrete slabs;
- Brick cladding with cavity and no insulation;
- Large windows;
- Continuous floor slabs in the balconies;
- 'Non-traditional' building method.

Figure 7: Walk-up apartment building in Amsterdam (Gemeente Amsterdam, n.d.)

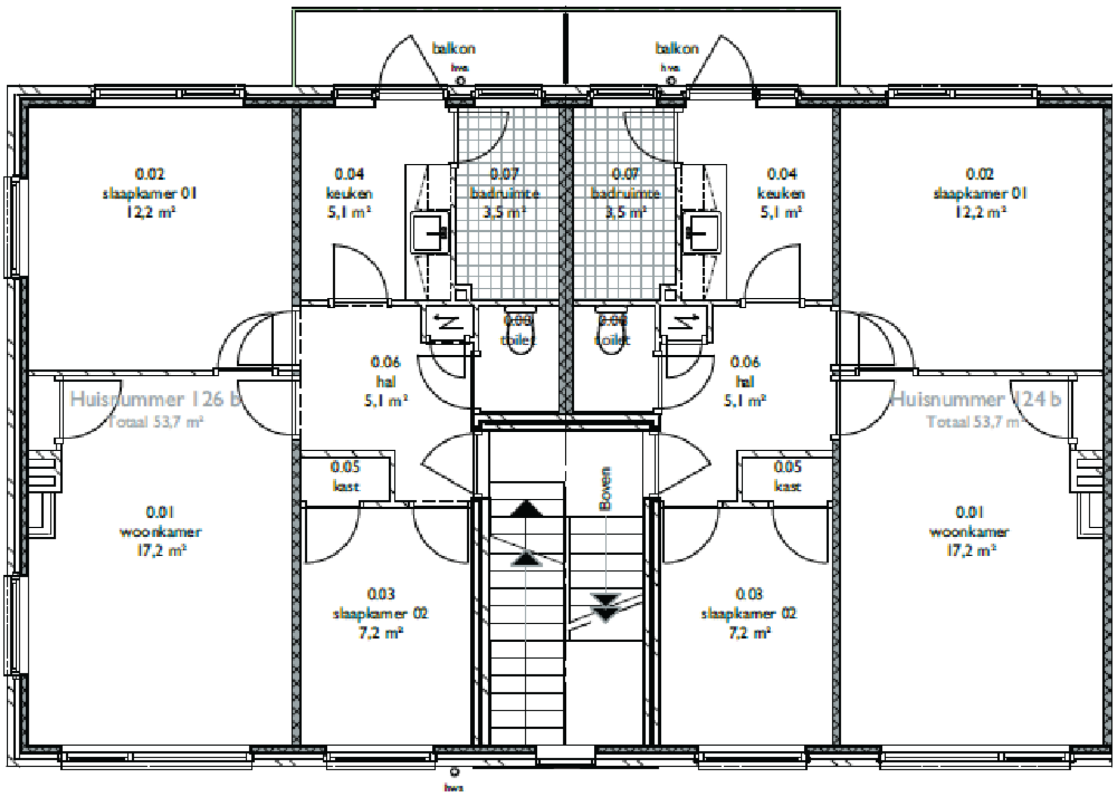


Figure 8: Typical lay-out of two post-war walk-up apartments. Adapted from (KAW, 2017, DO-02_b)

Figure 8 shows a typical lay-out of a post-war walk-up apartment building. The apartments are accessible via a central staircase. The living room of the apartment is situated at the front façade, together with the second bedroom. The master bedroom is located at the back façade. The kitchen gives access to the bathroom and to the balcony. There is a separate toilet. In this building, all apartments have the same lay-out, but they are mirrored over an axis.

4.3 Construction types

After World War II there was a turning point in the development of the residential building stock. There was a housing shortage, due to demolition, population increase and economic growth. There was a shift away from traditional construction methods to the production of large numbers of dwellings, to be built as quickly and economically possible. The focus was on quantity rather than on quality. Therefore, the dwellings were lacking in technical and functional performance. Such buildings were poorly insulated compared to the current Dutch building regulations. The building envelope of post-war buildings reached their end of life. So together with the lack of insulation, there is a need for refurbishment (Silvester et al., 2016).

The new construction techniques were aimed at achieving quicker and cheaper housing production. The new systems were characterized as 'non-traditional' and they were dominated by industrialization in the construction. There was a shortage of skilled construction workers and therefore more labour-saving methods were sought. This resulted in element building methods or cast-in-situ methods. Element building means that large concrete elements are prefabricated in the factory, transported to the building site, and assembled with the help of a crane. Prefabrication leads to more homogenous elements of higher quality and with less construction time on the building site. In cast-in-situ methods, a framework is used in which the concrete is poured on the building site. This is the most common method since it saves time on the building site. If the series are large ones, they cost less than traditional building methods (Van Elk & Priemus, 1971).

The ‘non-traditional’ building methods are developed and named after the construction companies that invented and applied them. The six most popular building systems will be analysed, which represent approximately half of the stock built using ‘non-traditional’ methods (Silvester et al., 2016). These building methods are also analysed for the 2ndSKIN project. This analysis is used and extended for the purposes of this research. Table 6 shows an overview of the construction characteristics of the six most popular ‘non-traditional’ systems depending on the type of construction.

The prefabricated renovation approach needs to be applicable to a large number of buildings. Therefore, it is necessary to analyse the characteristics of the construction and the lay-out that may influence the design. The overview of construction characteristics can be used for the context and design phase of this research. The construction type of the case-study can be compared with this overview. It gives for example information of the façade. Can it be demolished or is it a load-bearing construction?

	Stack construction		**Poured construction**		**Assembly construction**	
	MUWI	*Pronto*	*R.B.M.*	*E.B.A.-gietbouw*	*B.M.B.*	*Coignet-groep*
Nr. of dwellings	37.831	17.836	32.292	19.291	29.369	31.378
Percentage of post-war systems	11%	5%	9%	6%	9%	9%
Utility rooms position/ distance from façade	Kitchen on façade, Bathroom adjacent (appx. 1-2m from façade).	Kitchen on façade. Bathroom adjacent (appx. 1m from façade).	In the middle of apartment (appx. 2m from the façade).	In the middle of apartment (appx. 3-4m from the façade).	Kitchen on façade. Bathroom adjacent (appx. 1-2m from façade).	In the middle of the apartment (appx. 3-4m from the façade).
Load-bearing construction	Cavity wall: stacked concrete blocks with poured in-situ concrete	Cavity wall: stacked concrete blocks with poured in-situ concrete	Cavity wall: poured lightweight concrete	Poured lightweight concrete	Cavity wall: prefab floor height concrete elements	Prefab sandwich concrete panels with 2,5cm polystyrene
Non-load bearing construction	Floor height panels	No specific information	Plaster blocks	Panels of aerated concrete	Trade products	No specific information
Floor type	Concrete floor system	Concrete floor system	In-situ poured reinforced lightweight concrete	In-situ poured reinforced lightweight concrete	Prefab reinforced concrete slab	Prefab reinforced concrete slab
Balcony type	Half-loggia	Mostly cantilever	Cantilever	Cantilever	Loggias and cantilever	Loggia
Slab extension	No, prefab concrete slab	No, prefab concrete slab	Yes, prefab concrete slab	No, prefab or poured concrete slab	No, prefab concrete slab	No, prefab concrete slab
Percentage of openings	60%	60%	30-60% (varies significantly between walk-up and gallery flats).	-	30%	30%

Table 6: Overview of construction characteristics of the six most popular non-traditional systems. Adapted from (Silvester et al., 2016, p. 29) (Van Elk & Priemus, 1971)

4.4 Commonly used building services

Post-war walk-up apartments can be categorized into different years as shown in Table 7. The labels for those different years are as follow:

- Until 1945: Pre-war dwellings;
- 1946 – 1964: Early post-war dwellings;
- 1965 – 1974: Housing shortage dwellings;
- 1975 – 1991: Energy crisis dwellings;
- 1992 – 2005: Building code dwellings.

Table 7 shows building services that are used for room heating, DHW and ventilation in walk-up apartments in different periods of time. It also shows the insulation values for the building envelope and the corresponding energy labels. This research focusses on the post-war walk-up apartments since it is interesting to see the transition of the building services more time categories are shown.

		Until 1945	1946-1964	1965-1974	1975-1991	1992-2005
Building stock						
	Dwellings	256.000	267.000	112.000	142.000	70.000
	Dwelling stock	3,8%	3,9%	1,7%	2,1%	1,0%
Room heating						
	Collective	2%	13%	44%	12%	11%
	Individual	61%	78%	56%	88%	89%
	VR condensing boiler	27%	27%	14%	31%	20%
	HR condensing boiler	23%	25%	22%	41%	64%
	CR boiler	6%	7%	6%	2%	-
DHW						
	Collective	-	-	39%	8%	-
	VR + HR	50%	48%	37%	76%	60%
	Kitchen geyser	36%	34%	24%	5%	-
	Kitchen boiler	3%	2%	5%	2%	1%
	Electrical boiler	-	8%	14%	4%	-
Ventilation						
	Natural ventilation	82%	74%	70%	41%	6%
	Mechanical exhaust	16%	26%	30%	58%	84%
	Heat recovery	1%	-	-	1%	9%
Building envelope						
	Double glazing	50%	60%	70%	80%	47%
	HR glazing	4%	11%	5%	11%	52%
	Single glazing	47%	29%	-	9%	1%
	Closed façade elements insulated	3%	13%	13%	100% (no high R_c value)	100% (R_c: 2,5)
Certification						
	Energy label	F	E	D	C	B
	EPC	2,90	2,06	1,72	1,31	1,24

Table 7: Walk-up apartments in Dutch building stock (Agentschap NL, 2011)

There are several things that are noticeable from this table. The percentage of collective room heating in the 1965-1974 period is quite high compared to the other periods. In the period from 1945-2005 more HR-condensing boilers were used than VR-condensing boilers, probably due to the higher efficiency of the HR-condensing boiler. This was the same for providing DHW. To provide ventilation at that period more mechanical exhaust was used. Until 2005 heat recovery on ventilation air was still barely used. In the building envelope, double glazing was most common. It is clearly shown that in 1975 regulation for the insulation of the closed façade elements started. The information about roofs and floors was not available for all periods. All housing corporations agreed that by 2020 the residential portfolio should have an energy label of at least B. As shown in Table 7, the average energy label of the walk-up apartments is not B. So, it is really necessary to refurbish the post-war walk-up apartments to achieve this target (Ministerie van Algemene Zaken, 2012).

5. Energy systems

As already stated in the research framework, the aim of this study is to design a prefabricated renovation approach for post-war walk-up apartments that is applicable to different energy systems. It is necessary to have more background knowledge about the different existing energy systems. It is necessary to know, before the design phase can start, what are the characteristics and requirements of the different systems. In this chapter firstly the principles of energy systems will be explained. Secondly, the different energy systems will be clarified and finally building services related to the energy systems will be analysed.

5.1 Principles of energy systems

Energy can be generated from a large number of sources. These sources can be separated into renewable sources and fossil sources. Fossil sources are finite sources and CO_2 will be released while burning. Since the fossil sources are finite and the world is producing too much CO_2, an energy transition towards renewable sources is necessary. Renewable sources are for example: sun, wind, water and biomass. The 'Trias Energetica', changed in Nieuwe Stappenstrategie [New steps strategy] is a strategy to deal with this problem. It has the following four steps:

1. Reduce the energy demand;
2. Reuse sources;
3. Use renewable sources to fulfil the energy demand;
4. Waste = food.

The first step requires a smart design. It starts with the urbanism plan, the orientation of the building and the surrounding of the building. To optimize the design of the building important factors are: the orientation of the facades, glass surfaces and the insulation value of the building envelope. When renovating, not all factors can be changed. The second step involves reusing sources. One might think of residual heat from a factory that is reused to heat residential buildings. Step three involves producing renewable energy to fulfil the energy demand. The fourth step involves seeing waste not as a finite source, but as something to use again (Yanovshtchinsky, Huijbers, & Van den Dobbelsteen, 2012).

The energy use of a building consists of two parameters: building-related energy (heating, cooling, ventilation, lighting and DHW) and user-related energy (appliances such as computers and dishwashers). Since it is not possible to influence the residents' behaviour, the building related energy is the most important parameter for refurbishment. But in practice, the resident can have a big influence on the total energy consumption.

Building related energy depends on the following technical aspects:

1. The quality of the building: building envelope (U and R-values) and use of passive solar gains;
2. The quality of the energy components: efficiencies of the building services and distribution;
3. Renewable energy production on site: PV, solar collectors, PVT;
4. The national primary energy factor (PEF) of the energy delivered to the 'meter' of a dwelling: the PEF is determined by national calculations, based on the national average primary energy used to produce and transport electricity and gas to the consumer.

It is possible to measure energy consumption at different points, this is illustrated in Figure 9. Since in this research different energy systems will be simulated and compared, it is necessary to look at the same point of energy consumption. The primary energy consumption is based on the energy demand, the efficiency of the energy system in the building (adding the losses of the building services) and the primary energy factor (Jansen & Tenpierik, 2015).

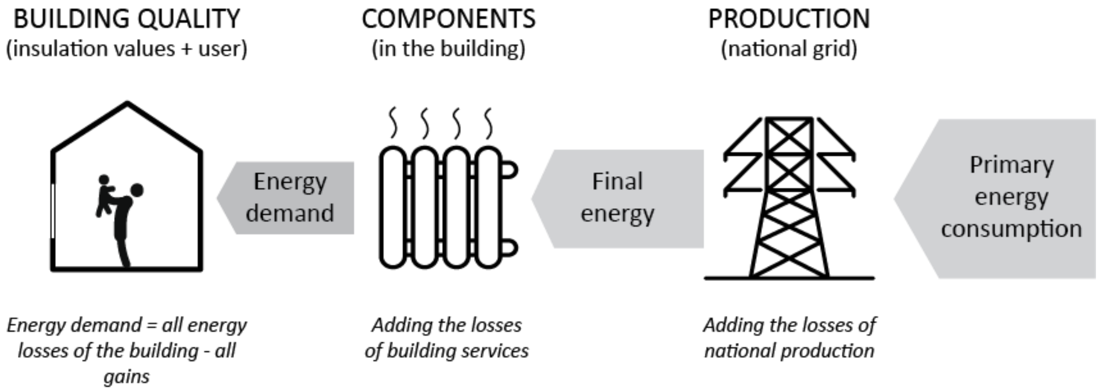


Figure 9: Scheme of built-up of energy use for heating and cooling. Adapted from (Jansen & Tenpierik, 2015, p.3)

5.2 Energy systems

Energy systems can be divided into collective and individual systems. A collective system can be used in case of a high heating demand, if there is a large potential of energy exchange between buildings or if there are high heat sources that can be used by a large number of buildings. Thermal grids can be designed at different temperature levels. The temperature usually relates to the available renewable sources. Individual systems can run on different types of heat sources like outdoor air, solar thermal energy or a ground source storage. In this chapter different collective and individual heat sources and systems will be listed and explained. The collective systems are dependent on the different temperature levels of the heat sources.

5.2.1 Collective systems

District heating network

The heat that is produced during industrial production processes can be used for the heating of buildings. The re-use of this residual heat will increase the efficiency of the used energy. A district network is required for the transportation of the heat from the source to the neighbourhood (City-zen, 2018). This is a closed system, the heat will be transferred to the building via a heat exchanger. The heat from the source is around 120˚C and the heat is delivered to dwellings at a temperature of around 90˚C. Heat losses, due to long transportation pipes, are not a problem since the start temperature is so high. Newer networks can work at lower temperatures, but in order to supply DHW, a delivery temperature of at least 70˚C is required (RVO, 2015b).

Rest heat from a factory or power plant (1) is collected in a heat transfer station (2) and transferred to the dwellings (3), as shown in Figure 10.

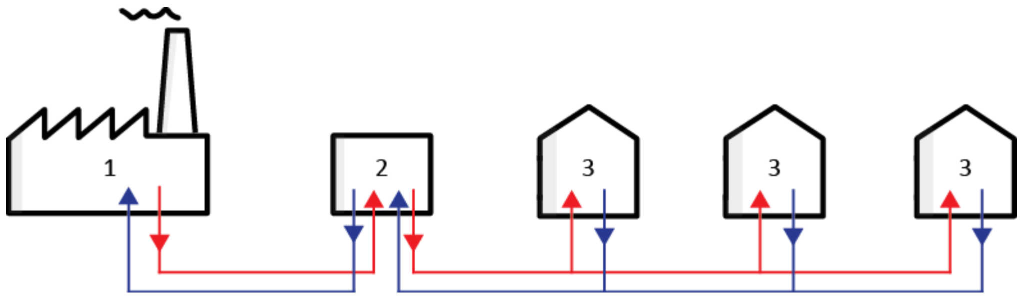


Figure 10: District heating network. Adapted from (Yanovshtchinsky et al., 2013, p.121)

There are 13 large district heat networks in the Netherlands. Approximately 5% of the total housing stock is connected to a district heating network. The largest network is in Rotterdam followed by Almere, Amsterdam Zuid-Oost, Utrecht, Amsterdam West North and Purmerend. The primary energy source for district heating is natural gas. Around 69% is provided by power plants. One exception is the network in Tilburg and Breda, which is supplied by a coal-fired plant (co-fired with biomass). Another 7% of the heat comes from waste incinerators. Biomass and biogas provide 6% of the total heat supply to district heat networks (ECN, Niessink, & Rösler, 2015).

Every district heating network has its own heating efficiency for the primary or secondary grid. This heating efficiency influences the energy demand of the building. The heating efficiency for the largest district heating networks in the Netherlands is shown in Table 8.

District heating network	**Equivalent heating efficiency ηHD;gen;equiv;tot**	
	Primary grid	*Secondary grid*
Rotterdam	2,3	2,0
Almere (Amsterdam Zuid-Oost)	2,0	1,6
Utrecht	1,6	1,3
Amsterdam West Noord	2,2	2,1
Purmerend	2,5	1,9

Table 8: Equivalent heating efficiency largest heat distribution networks in the Netherlands (Bureau CRG, 2015)

Deep geothermal system

A deep geothermal system subtracts heat from the deep earth layers (0,5 - 4km depth). There is the ground temperature around 40 – 130˚C. In the Netherlands, the temperature extracted from the ground is around 60-70˚C. The heat can directly be used for room heating and DHW. The heat in this layer can be extracted with a doublet system: consisting of a production and an injection pipe. The production pipe pulls warm water up that will be injected back in the earth layer after usage by the building. Advantages of geothermal energy are the constant availability and independency from the weather and climate circumstances (City-zen, 2018).

The deep geothermal system is suitable for neighbourhoods from 1.500 dwellings. It is less suitable for refurbishment projects since the pipes and probably the entire building services needs to be replaced. The deep geothermal system can be used for refurbishment if district heating is present (Yanovshtchinsky et al., 2013).

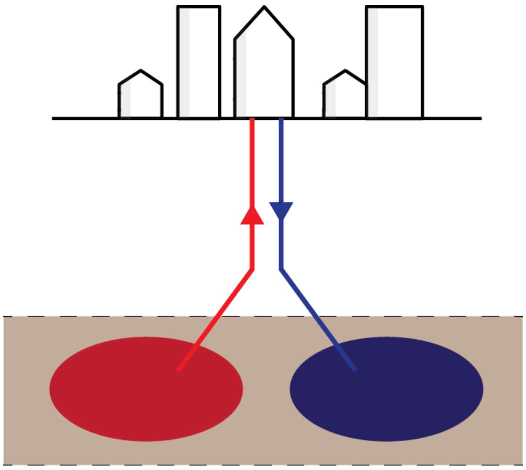


Figure 11: Deep geothermal system. Adapted from (Yanovshtchinsky et al., 2013, p.98)

Aquifer Thermal Energy Storage (ATES)
Thermal energy storage systems make use of the insulating character of the top earth layers and take place at a depth of 50-250m. At this depth, the water-bearing layers (aquifers) of the earth are found. In these aquifers, thermal energy can be stored seasonally with the use of a doublet system: called Aquifer Thermal Energy Storage (ATES). A doublet system consists of two open sources in the aquifer: the heat and cold source. These sources are connected by means of transport pipes and pass through a heat exchanger that transfers the heat or cold to the building (City-zen, 2018). This ATES system is suitable for neighbourhoods from 50 dwellings. Because it is necessary to have a balance between the heat and cold storage, mixing of functions is desirable. The maximum ground temperature that is allowed to be extracted from the ground is between the 25 and 30˚C (Yanovshtchinsky et al., 2012).

During the summer cold water is pumped up from the cold source, heated with heat from the building by going through the heat exchanger and pumped towards the heat source. While at the same time the cold is transferred towards the building by the heat exchanger. In the winter this principle works the other way around: warm water is pumped up to heat the building and the cold from the building is pumped back into the cold source (City-zen, 2018).

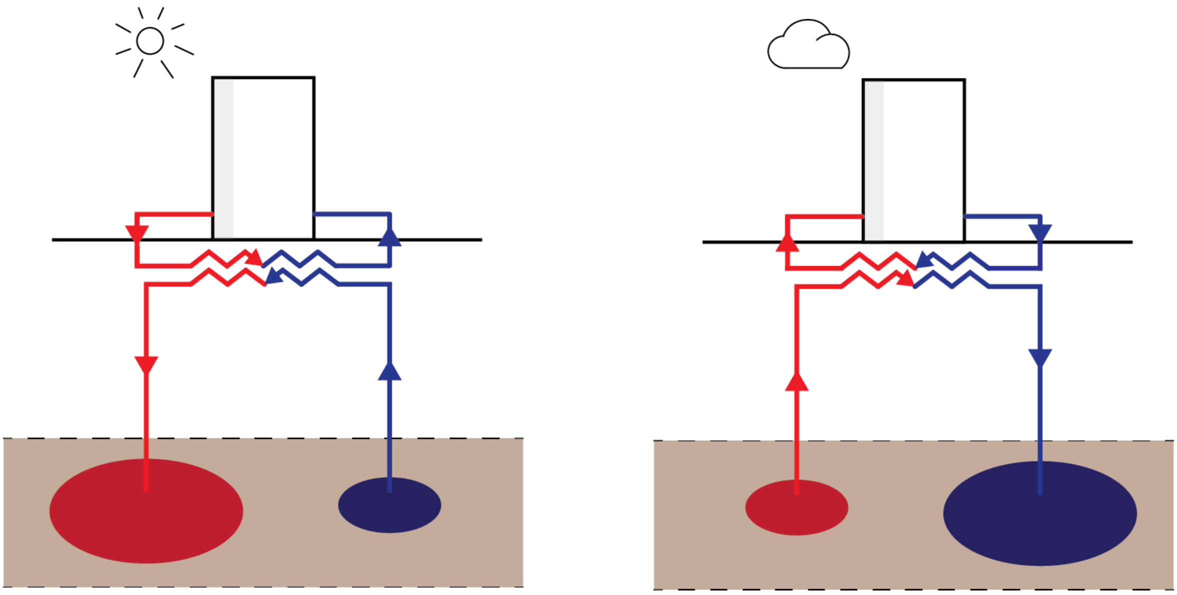


Figure 12: ATES system in summer (left) and winter (right). Adapted from (Yanovshtchinsky et al., 2013, p.100)

Biogas
Biogas is generated with the fermentation of biomass in an anaerobic digester. This can, for example, be food waste. When biogas is upgraded to the same quality as natural gas, it can be used in the existing gas network. In the building, biogas will be converted into high temperature heating by the existing boiler. This means that the building services can remain the same. Another option to use biogas is to convert biogas into both electricity and heat with a combined heat power (CHP) installation. This principle is also called co-generation and does not only generate electricity but also uses the heat that is released during this process.

When biogas is upgraded to the same quality as natural gas it can be used in the existing gas network. This will directly increase the share of renewable energy. With the limited potential to replace about 5 – 10% of the current natural gas supplies, this energy should only be used for locations where heat supply by other sustainable energy sources is not possible. As for example to supply high temperature heating to monumental buildings, since they lack the potential of energy retrofitting due to the protected status. By simply replacing the natural gas supply by biogas the building services and the building envelope can remain the same (City-zen, 2018).

Since biogas should only be used for locations where heat supply by other sustainable energy sources is not possible, this energy system will not be further simulated in this research. The most post-war walk-up apartments have no monumental status, so an energy system on biogas is not suitable.

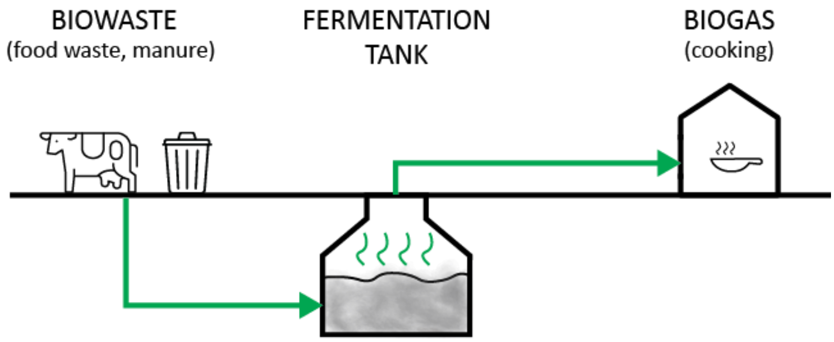


Figure 13: Production method of biogas

5.2.2 Individual systems

Zero-on-the-meter concept

The zero-on-the-meter concept results in an energy concept in which the energy demand for heating, ventilation, DHW and user-related energy over the year are in balance with the amount of energy generated. This means that annually the energy demands are zero, resulting in no energy bill. Every building needs a specific approach to make it zero energy, but the first step is always lowering the energy demand and avoiding heat losses as much as possible. In the next step, the energy demand will be reduced by the re-use of energy streams in the building: for example by the use of heat recovery in the ventilation system. The final step is to fulfil the remaining energy demand by adding principles that produce energy. The critical point in becoming zero-energy is the area of the roof since this is the most suitable place to put PV panels for electricity production.

The final payback time of the renovation towards zero-on-the-meter depends on the energy costs before the renovation and the specific building characteristics. When the building is owned by a housing corporation the tenant pays a certain amount each year for the energy supply, the so-called EPV (Energie Prestatie Vergoeding [Energy Performance Compensation]). In this way, not only the tenant benefits from the refurbishment with higher comfort levels for the same or even lower monthly expenses as before refurbishment but also the investment by the housing corporations will (partly) be paid back with the income of the EPV (City-zen, 2018).

All-electric

The all-electric concept results in an energy concept in which the energy demand of the building is supplied by electricity. This includes energy for heating, cooling and domestic hot water. To do so heating is provided with a heat pump. To increase the efficiency of the heat pump the temperature for heating should be low and the temperature for cooling high. Thereby a high energetic performance of the building is required. This is done by increasing the insulation values by adding insulation to the ground floor, façade and roof. Also, the heating system needs to be replaced: for example floor heating to supply low temperature heating. In most cases, even more energy savings are achieved by replacing the natural ventilation system for a balanced system with heat recovery.

The difference between the all-electric concept and the zero-on-the-meter concept is that not all of the electricity needs to be generated at the building plot; the electricity can also be supplied by the electricity grid. However all-electric buildings are still often combined with PV panels to decrease the electricity demands from the grid. It is possible that a building with an all-electric concept is not annually zero-energy.

The disadvantage of the all-electric concept is that it increases peak demands for the electricity grid by the use of the heat pump. This peak demands mainly cause a problem when multiple buildings in a certain district use all-electric heating. Since these peak demands determine the capacity of the network and power plant. An advantage is that only a connection to the electricity grid is needed. No infrastructure for heating has to be constructed and maintained (City-zen, 2018).

5.3 Explanation of different building services

In the previous chapter, the energy systems on building or neighbourhood scale are explained. An overview is given of all related building services. This chapter will be used to explain the different building services. Important are the requirements of the building services and how much they produce.

Heat pump

A heat pump can upgrade the temperature of a heat source to a higher temperature to fulfil the energy demand. A heat pump extracts heat from a fluid that is undergoing phase transitions from liquid to gas and gas to liquid. This gas will become hot, due to high pressure. When the gas is releasing its heat, it is exchanged with the building. The heat source for the heat pump variates per application and can be the ventilation exhaust, the ground, the outside air, a heat network, the heat of a PVT panel, surface water and so on. An air source heat pump and a hybrid heat pump will be explained in the next paragraphs (City-zen, 2018).

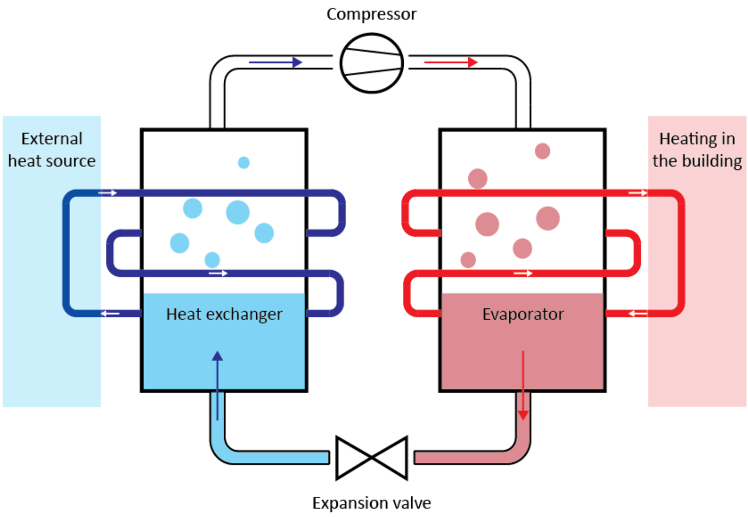


Figure 14: Process of a heat pump

Air source heat pump

The air source heat pump extracts the heat from the outside air by blowing this air across the heat exchanger. The heat pump upgrades this heat until the required temperature for room heating is reached. The heat pump works the most efficient when the source temperature and heating temperature are close to each other, therefore low temperature heating is necessary. The efficiency of the heat pump is in winter lower, since there is a bigger difference in temperature between inside and outside. Another disadvantage is the noise that is generated by the van (City-zen, 2018).

Hybrid heat pump

A hybrid heat pump is in principle a combination of a boiler and an air-source heat pump. They can provide heating between 25˚C and 80˚C. With these temperatures, they can be used with each heating system. So the existing pipes and radiators can still be used by refurbishment. The hybrid heat pump can provide high temperature heat. There are three operation modes: heat pump only, hybrid mode or boiler only. Which operation mode is active is dependent on the outdoor temperature. About 70-80% of the energy for room heating is provided by the air source of the heat pump. The DHW supplies are provided by the boiler, however preheating with the heat pump is possible in combination with a water storage tank to increase the efficiency (City-zen, 2018).

PV panel

Photovoltaic panels convert solar radiation into electricity. In the Netherlands it is possible to deliver to the public network when more energy is generated by the PV panels then demanded. PV panels can be placed on the roof or the façade. The final output is dependent on the placement of the panel, location, orientation, angle and how the panel is ventilated (City-zen, 2018).

1. Frame
2. Glass
3. EVA-encapsulant
4. Solar PV cells
5. EVA-encapsulant
6. Back sheet

Figure 15: Schematic structure of a PV panel. Reprinted from (Svarc, 2018)

Solar collector

A solar collector absorbs solar radiation and converts this into heat. This heat is absorbed by a fluid that is running through the pipes of the solar collector. The heated fluid can be used to supply the DHW and can also give a contribution to room heating. The solar collector will be placed on the roof of the building to getter the most solar radiation as possible. The amount of heat produced will not be sufficient to supply the full DHW demand of a building. Therefore, an extra system is needed to fulfil this demand like an electric boiler, biogas boiler or a heat pump (City-zen, 2018).

Figure 16: Tube solar collector. Reprinted from (The renewable energy hub UK, n.d.)

PVT panel

A PVT panel is a combination of a PV panel with a solar collector into one system. The solar collector is located on the back of the PV panel. The efficiency compared to the ‘normal’ PV panel increases because the water of the solar collector will cool down the panel. The heat generated with a PVT panel will have a lower temperature (about 35˚C) than the output of a ‘normal’ solar collector but can still provide low temperature heating for the building. If this heat will be used for DHW an electric boiler or heat pump is needed to head up the temperature (City-zen, 2018).

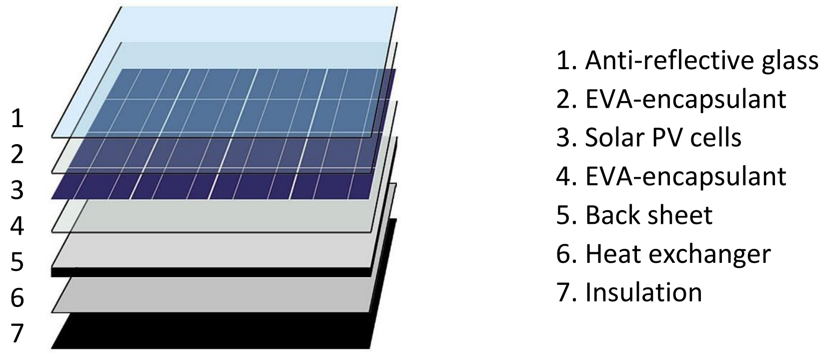


Figure 17: Schematic structure of a PVT panel. Reprinted from (Castelnuovo, 2010)

Heat exchanger

A heat exchanger uses two fluids or gasses to transfer heat. When a warm fluid is guided next to a cold fluid, the heat is transferred to the cold fluid. For example: when heated ventilation air is guided next to the cold fresh air, the fresh air will be preheated by the exhausted air. The heat exchanger makes use of two closed loops. The exhaust air and the fresh air is not mixed, only the heat is transferred (Yanovshtchinsky et al., 2012).

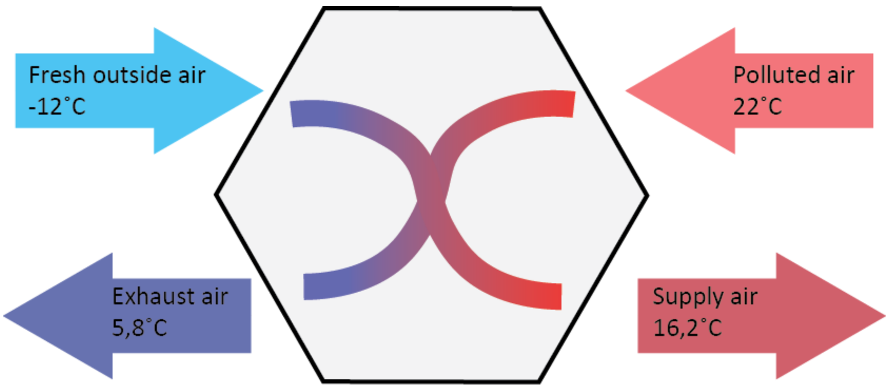


Figure 18: Heat exchanger. Adapted from (Gasservice Brabant, n.d.)

Ventilation types

For providing fresh air in a dwelling, different ventilation systems can be used. Ventilation can be provided with natural ventilation (1). Fresh air will enter the dwelling via openings in the façade. By different air pressures, the exhaust of air will be provided. Ventilation can also be provided with all mechanical (4). This means that the inlet and exhaust of air are controlled. This requires also building services that can provide mechanical ventilation. A combination of natural and mechanical ventilation is also possible (2,3). The inlet or exhaust of air can be mechanical or natural. A common type used in refurbishment projects is a natural inlet and mechanical exhaust that is CO_2-regulated. If CO_2-levels are too high, the mechanical exhaust will start working. By pressure differences, fresh air will be sucked in from the natural inlets.

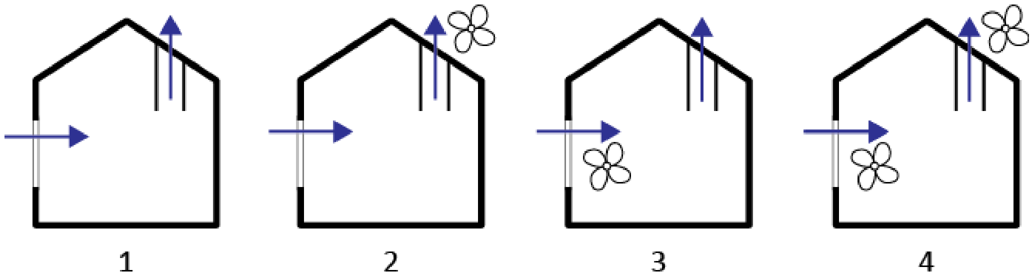


Figure 19: Different types of ventilation

CATEGORIZED ENERGY SYSTEMS

Energy systems for simulation

6. Input for the simulation phase

6.1 Building envelope

The building envelope of the refurbished post-war walk-up apartment building should meet the Dutch building regulations ‘Bouwbesluit 2012’. The regulations for refurbishment are lower than the regulations for new buildings. An exception of the regulations is the legally obtained level (rechtens verkregen niveau). Which means that after refurbishment the level should not be lower than the level before the refurbishment, but the level can never be lower than 1,3 $m^2 \cdot K/W$. In Table 9 the required R_c-values and U-value for new buildings and refurbishment are shown. In the simulation phase, both cases will be simulated. These values will be elaborated more in 8. Simulation in Uniec[2.2].

	Floor	Façade	Roof	Façade openings
New buildings	3,5 $m^2 \cdot K/W$	4,5 $m^2 \cdot K/W$	6,0 $m^2 \cdot K/W$	1,65 $W/m^2 \cdot K$
Refurbishment	2,5 $m^2 \cdot K/W$	1,3 $m^2 \cdot K/W$	2,0 $m^2 \cdot K/W$	2,2 $W/m^2 \cdot K$

Table 9: Requirements from Dutch building regulations 'Bouwbesluit 2012'

6.1.1 Prefabrication

The role of the occupants becomes more important during the refurbishment of their apartments. It is necessary that at least 70% of all occupants agree with the refurbishment of the building before it can take place. Otherwise, the housing corporation needs to ask the court to judge the renovation proposal (Rijksoverheid, 2018). The reasons for the occupants to agree with the refurbishment are dependent on different factors. Occupants want to stay in their dwellings during the renovation and do not want to be relocated. This can be achieved by the prefabrication of components. The on-site construction time can be minimized and high-performance solutions can be achieved (Konstantinou et al., 2015). When using prefabricated elements, it is also possible to inform the occupants more accurate when which building activities will take place.

6.2 Four energy systems for simulation

After analysing different energy systems in Chapter 5.2 Energy systems, it is possible to choose a system for the simulation. This energy system should be applicable for the refurbishment of the post-war walk-up apartments. Different energy systems are presented, which can be applied on a building or a neighbourhood scale. These energy systems will have an influence on the building services in the building.

Jansen et al. (2018) made a distinction between four main types of collective heat grids dependent on their temperature. The district heating network and deep geothermal systems can be simulated as one concept since they both provide external heat at a temperature of 70˚C. The other extreme is a collective heat grid of a temperature around 20˚C. In this concept, it is necessary to boost the temperature with a separate building service system like a heat pump. An example of a collective heat grid around a temperature of 20˚C is an aquifer thermal energy storage (ATES). Those collective grids will lead to concept A and B. The third and fourth concept are individual concepts. What a zero-on-the-meter concept and an all-electric concept have in common is that heat is provided by a heat pump. Therefore, is chosen to simulate two concepts with a heat pump with different heat sources. The outdoor air will be used as a heat source in concept C and PVT panels in concept D.

Figure 20, Figure 21, Figure 22, Figure 23 and Table 10 show a schematic overview of the concepts that will be simulated.

		Heating	DHW	Produce electricity	Heat source
Collective systems					
A. (>70˚C)	External heat supply >70˚C	Extern	Extern	PV panels	District heat network, deep geothermal system
B. (≈20˚C)	External heat supply ≈20˚C	Extern	Heat pump	PV panels	Heat and cold storage, ATES
Individual systems					
C.	Outdoor air	Heat pump + outdoor air	Heat pump	PV panels	Outdoor air
D. PVT	PVT panels	Heat pump + PVT panels	Heat pump	PVT panels	PVT panels

Table 10: Concepts A-D for simulation

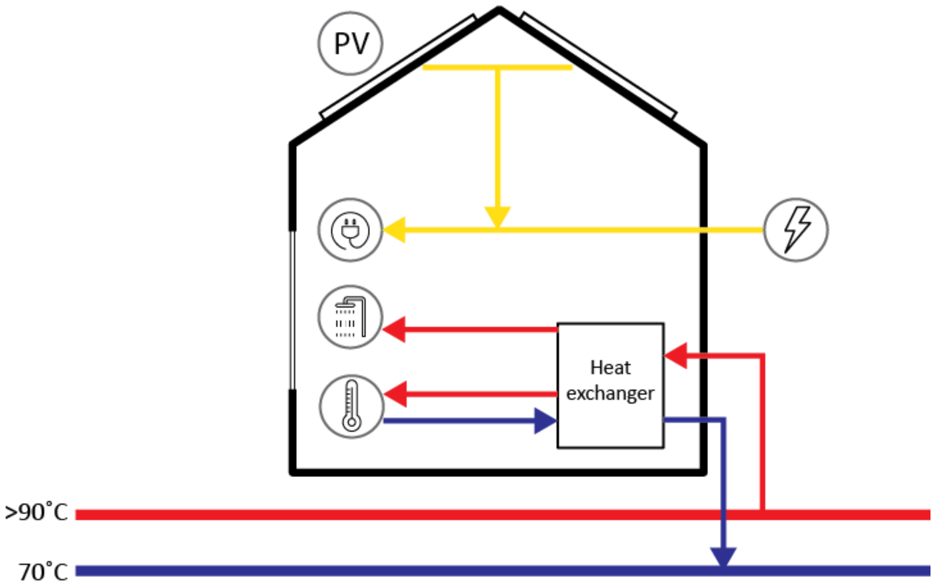


Figure 20: Scheme of concept A with an external heat supply >70˚C

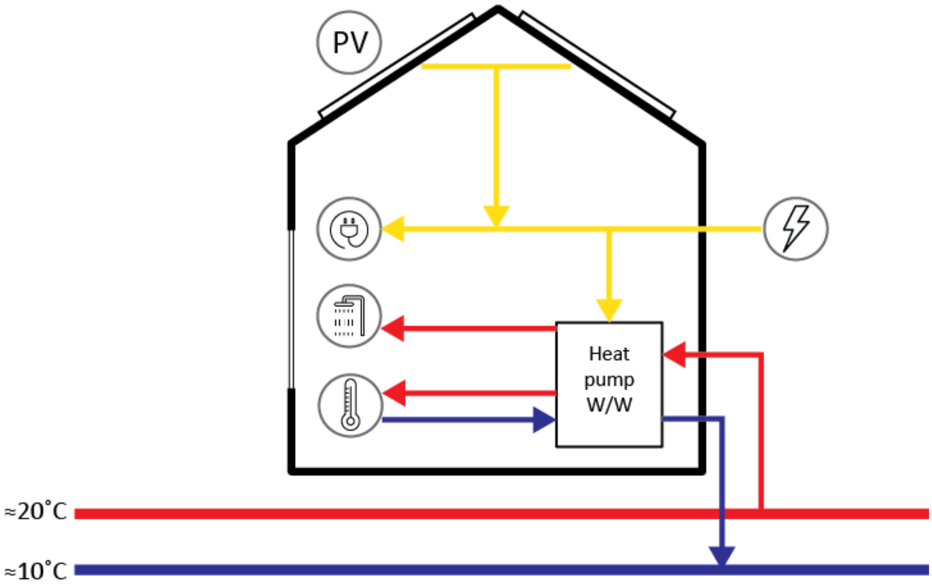


Figure 21: Scheme of concept B with an external heat supply ≈20˚C

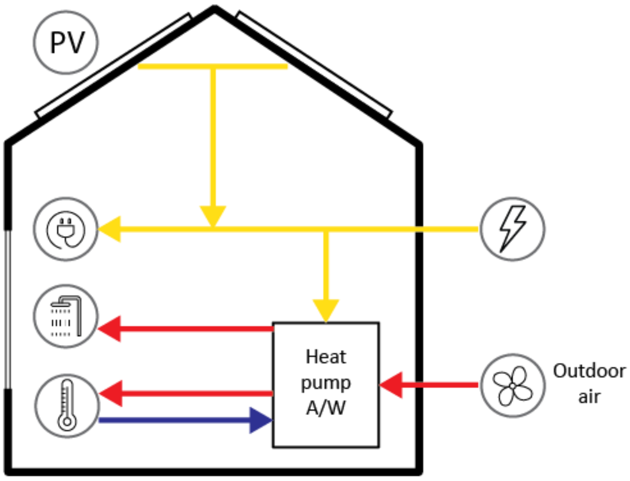


Figure 22: Scheme of concept C with a heat pump with outdoor air as heat source

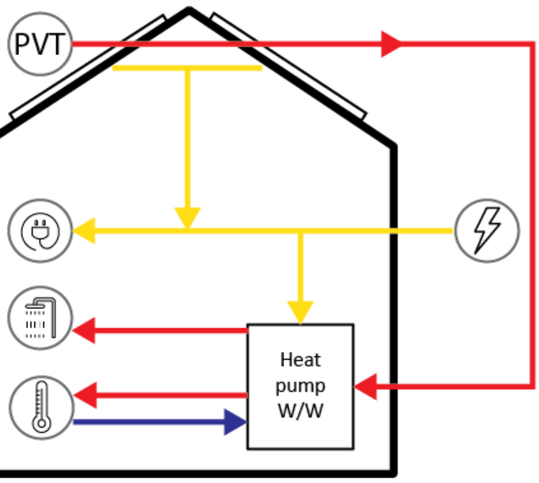


Figure 23: Scheme of concept D with a heat pump with PVT panels as heat source

6.2.1 Providing ventilation

Four different ventilation types can be used for providing fresh air. It can be provided with natural ventilation where the inlet and exhaust are naturally controlled by pressure differences. However, this type of ventilation is not suitable for the refurbishment of the post-war walk-up apartments. The CO_2-levels cannot be controlled, which can lead to an unhealthy indoor environment. A combination of natural and mechanical ventilation is also possible. The inlet can be natural and the exhaust can be mechanical controlled. With a CO_2-regulated exhaust, it is possible to control the CO_2-level inside the apartment. If the CO_2-levels are too high, the exhaust will start working. Due to pressure differences, fresh air will be sucked in from the natural inlets. The fourth option is a full mechanical controlled system. With this system, the inlet and exhaust will be mechanical controlled. Therefore, it is possible to use a heat exchanger. The outlet air will heat up the inlet air, for this, an extra building service is needed which will use extra electricity.

In Phase 3: Simulation different energy systems will be simulated. Two types of ventilation systems will be simulated for each above mentioned energy concepts: natural inlet and mechanical exhaust CO_2-regulated, all mechanical with a heat exchanger. With these systems, it is possible to control the CO_2-levels in the apartment and therefore creating a healthy indoor environment.

PHASE 2: CONTEXT

Phase 2: Context

7. Existing building

For Phase 3: Simulation and Phase 4: Design a case-study will be used to continue the research. Since the 2ndSKIN project is the foundation for this research the same case-study will be used. This is the post-war walk-up apartment building at the Soendalaan in Vlaardingen. Drawings and other information are already available and can be used as input for the different phases. The existing situation of the building will be analysed and simulated, so not the situation after the refurbishment of the 2ndSKIN project. This specific building will be used as case-study, but the aim of this research is upscaling the approach. The lay-out of this building will be used but to implement the energy systems from the last chapter the context will be abstract. For example: there is no district heating in Vlaardingen, but this is one of the energy systems that will be simulated. So it is assumed that there is district heating in the neighbourhood.

The building is constructed in 1952. It is located at the Soendalaan in Vlaardingen. The apartment building is North-South orientated. The roof has an inclination of 29˚. The apartment block consists of 12 apartments and is three stories high. There are two central staircases that serve on each floor two apartments. The apartments are around 54m^2. In Figure 24 the post-war walk-up apartment block is shown by the dark grey colour.

Figure 24: Situation post-war walk-up apartment block at the Soendalaan in Vlaardingen. Reprinted from (KAW, 2017, DO-00)

Figure 25: Post-war walk-up apartments at the Soendalaan in Vlaardingen. Reprinted from (personal communication, February 6, 2019)

Figure 26: South orientation on the balcony side. Reprinted from (Climate-KIC, n.d.)

7.1 Construction type: Simplex

In Chapter 4.3 Construction types different common construction types of the post-war building stock are summarized. The construction type of the case-study in Vlaardingen is not included in this chapter since it is not one of the most used construction types. In this chapter, the principles of the simplex building system will be explained and influences for the design phase will be determined.

7.1.1 Characteristics of the Simplex system

The post-war walk-up apartments at the Soendalaan in Vlaardingen are built with a Simplex system. This is an assembly construction type. Characteristic of this construction type is the prefabricated floor height concrete elements. They are placed on site by the use of a crane. The load-bearing construction elements have a width of 50cm and the non-load bearing construction elements have a width of 15cm. On the building site, a masonry façade construction will be stacked. The floor is not included in the system.

The vertical cavities between the prefabricated concrete elements are filled with concrete on site. Reinforcement will be placed in the cavities to connect different floor elements with each other. Window frames are connected with anchors to the concrete elements or are connected to the brick masonry. A continuous concrete ring beam is poured to connect all wall elements and window openings together. By doing this the floor forms a whole with the concrete ring beam. The height and the width of this concrete ring beam are related to the ones from the floor. The balconies are cantilevering and are cold connected to the floor system.

Table 11 shows an overview of the construction characteristics of the Simplex system. Figure 27 and Figure 28 show pictures of the prefabricated concrete elements.

	Assembly construction
	Simplex
Nr. of dwellings	3.800
Percentage of post-war systems	1%
Utility rooms position/ distance from façade	Kitchen on façade. Bathroom adjacent (appx. 1-2m from façade).
Load-bearing construction	Prefab floor height concrete elements, width 50cm
Non-load bearing construction	Prefab floor height concrete elements, width 15cm
Floor type	Not included in the system. In-situ poured reinforced concrete
Balcony type	Cantilever, cold connected
Slab extension	-
Percentage of openings	40%

Table 11: Overview of construction characteristics of the Simplex system. Adapted from (Van Elk & Priemus, 1971)

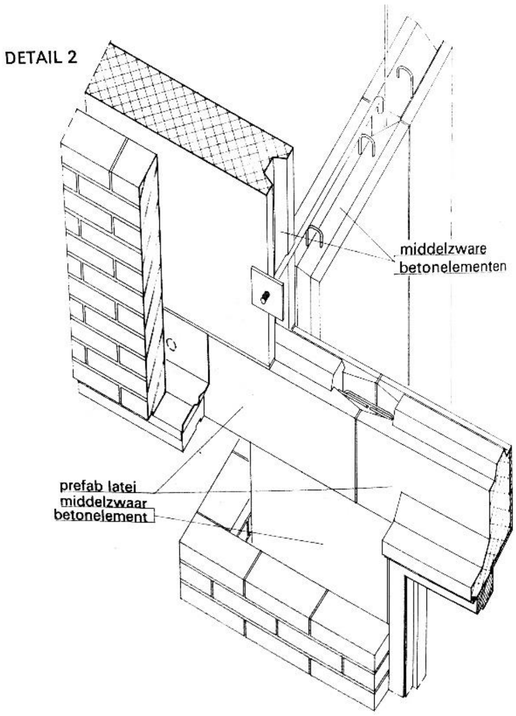


Figure 27: Detail floor connection. Reprinted from (Van Elk & Priemus, 1971)

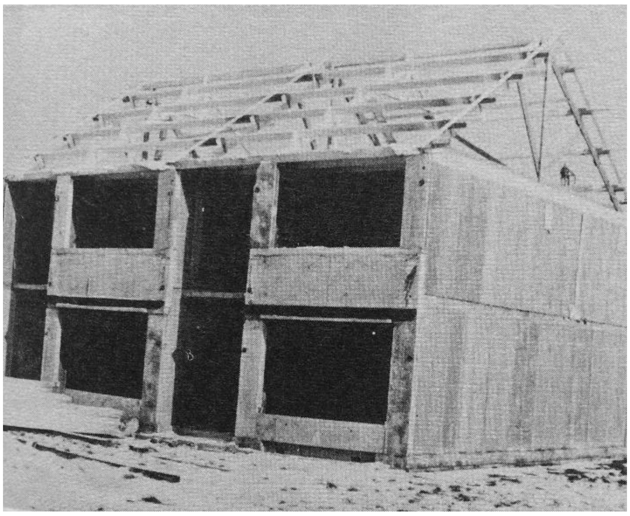


Figure 28: Simplex system. Reprinted from (Van Elk & Priemus, 1971)

7.1.2. Consequences due to the construction type

As explained in the previous paragraph, the construction type could have an influence on the refurbishment of the building. The Simplex system results in three main consequences for the design phase. Since the window frames are connected with anchors to the concrete elements or the masonry, it is not that easy to replace the window frames. Secondly, due to the continuous concrete ring beam that is connected with the wall elements, it is not possible to remove the entire front façade. So the window openings cannot be made bigger. Finally, the balconies are cold connected to the floor system and therefore they form a thermal bridge. In the refurbishment phase, this needs to be solved. A solution can be a replacement or by wrapping up the balcony.

7.2 Lay-out apartments

The lay-out of the apartments are an important factor in the refurbishment of the building. Especially the location of the delivery equipment (sink, shower, radiators) is important since the distance to the building services has to be as small as possible. In Figure 29 location of different living, functions are highlighted on the left. The functions that require building services are all located at the back of the building on the North side. The living room is situated at the front of the building and is orientated to the South. There are two bedrooms in each apartment. The main bedroom is situated on the North façade.

Figure 29: Floor plan Soendalaan with the location of delivery equipment. Adapted from (KAW, 2017, DO-02_b)

7.3 Building services

The current building services that are used in the building influence the energy demand. The location of the building services is important since the distance between the delivery device and the building services needs to be as short as possible to prevent pipe losses. Figure 29 shows the different functions in the apartment that require building services.

Heating and DHW is provided by a combi boiler. It is located in the bathroom. The heat for room heating is distributed by radiators. Those are placed near the façade underneath the windows. The resident can adjust the temperature by the thermostat that is placed in the living room.

Ventilation is provided by natural air via ventilation grids in the façade openings. A mechanical exhaust is used to remove the old air. Due to pressure differences, new air will be sucked in when the air will be removed by the mechanical exhaust.

The apartment block is connected to the electricity grid to provide electricity for the apartments. There are no PV panels on the roof or on the façade.

7.4 Final energy consumption

It is important to know the current final energy consumption since the new energy concepts can be compared to this value. The current final energy consumption of the building is the starting point for Phase 3: Simulation. The existing situation can be simulated and the outcome can be compared to the reference value, as validation of the model.

In the report of the 2ndSKIN, reference dwellings of WoON statistical information from 2012-2013 are used to calculate the final energy consumption. This value is including building related energy (heating, ventilation, lighting) and user-related energy (DHW, appliances). All numbers are given in kWh/dwelling/year (Silvester et al., 2016, p. 14).

In the 2ndSKIN project, a Chi-square test was used to determine the prevalence of specific types of households in the reference building. The WoON dataset was split into a sub-dataset containing only the cases of building similar to the reference building: low rise (three to five levels) rental apartments built between 1946 and 1975. The sub-dataset contains 2.194 cases. The final energy consumption is including gas, electricity and water consumption. Gas usage is given in m^3/year and the electricity value in kWh/year (Silvester et al., 2016, p. 22).

Klimaatmonitor gives gas and electricity usages on neighbourhood level. A distinction can be made between different types of dwellings. In this case, the neighbourhood 'Indische buurt' and as housing type apartments are chosen. The final energy consumption contains gas and electricity. Gas usage is given in m^3/year and electricity in kWh/year (Rijkswaterstaat, 2017).

The values of the three references mentioned above are shown in Table 12. Note that the gas usage is in m^3, but converted to kWh to compare the references with each other. In Phase 3: Simulation these values can be compared to the simulated final energy consumption to validate the model.

2ndSKIN based on WoOn (Silvester et al., 2016, p. 14)		**2ndSKIN (Silvester et al., 2016, p. 22)**		**Klimaatmonitor (Rijkswaterstaat, 2017)**	
Heating [kWh]	11.671	Gas [m^3]	1.231,8 m^3 12.033 kWh	Gas [m^3]	900 m^3 8.792 kWh
DHW [kWh]	1.333	Electricity [kWh]	2.306	Electricity [kWh]	1.800
Appliances [kWh]	2.306				
Total	**15.310 kWh/dwel/yr**	**Total**	**14.339 kWh/dwel/yr**	**Total**	**10.592 kWh/dwel/yr**

Table 12: Final energy consumption existing building per apartment

PHASE 3: SIMULATION

Phase 3: Simulation

In the third phase of this research, simulations will be carried out from the different energy concepts derived from chapter Categorized energy systems. Information from the existing building and the literature research is used to decide which energy concepts will be simulated. First, the strategy of the simulation is explained. Secondly, the input measures for the simulations will be defined. Results will be analysed and a conclusion of the simulations will be made. This phase will end with design criteria that can directly be used as input for Phase 4: Design.

8. Simulation in Uniec$^{2.2}$

8.1 Strategy

This paragraph will explain the strategy and the goal of the simulation. The simulation will have the outline showed in Figure 30. The input is the post-war walk-up apartment building at Soendalaan in Vlaardingen (including orientation, number of apartments, construction material). This information is derived from Phase 2: Context. The specific input measures can be found in appendix A. Input areas in Uniec$^{2.2}$. For every concept, a low and high impact simulation will be made and simulated with the software Uniec$^{2.2}$. The difference between the low and high impact variant are the R_c-values, U-values and how ventilation is provided. From Uniec$^{2.2}$ different results can be derived: the primary energy consumption, final energy consumption and the energy production. The goal of the simulation is to meet the BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]), those will be explained in the next paragraph. The low impact variant should meet BENG 2 and 3 and the high impact variant should meet all BENG regulations. The conclusion will be an input for the design criteria.

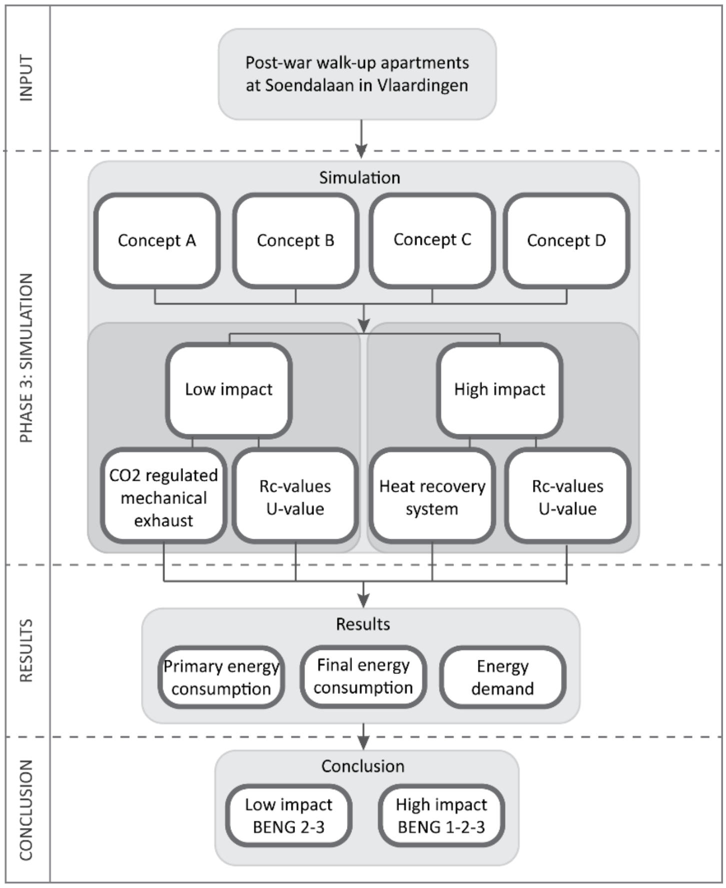


Figure 30: Strategy simulation in Uniec$^{2.2}$

8.1.1 Goal simulation

There are different ways to measure the result of the simulation. For example, look at the energy label, EPC (Energie Prestatie Coëfficiënt [Energy Performance Coefficient]), is the building energy neutral or does the building meet the BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings. Since the main objective of this research is not to have a renovation approach that is energy neutral, this possible goal can be dismissed. The energy label is not a result of Uniec[2.2]. Since the EPC will be replaced by the BENG regulations in 2020 (RVO, 2015c), the goal of this simulation is to meet the BENG regulations.

The BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]) consists of three parameters which new buildings should meet. A distinction is made between residential buildings and utility buildings. In this research the focus is on residential buildings which should meet the following requirements:

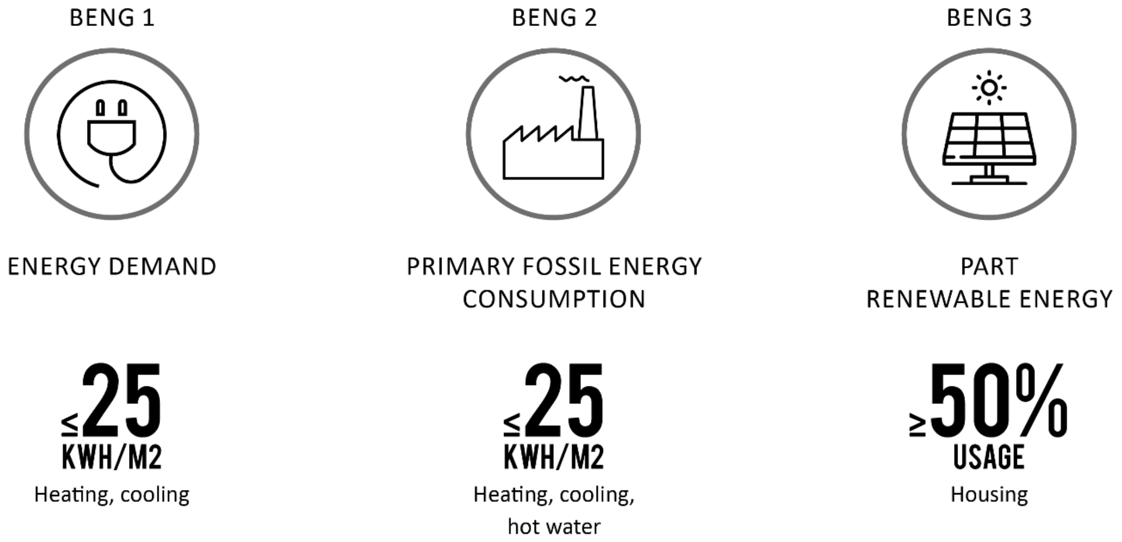


Figure 31: BENG regulations 2015

In 2020 the BENG regulations will change, since this is not in the timespan of this research, the regulations from 2015 will be used (RVO, 2018).

In the approach of the simulation, a distinction is made between a low impact variant and a high impact variant. The low impact should meet BENG 2 and 3 and the high impact variant should meet all BENG regulations. The next chapter will explain the difference between the low and high impact variant.

8.2 Low impact vs. high impact

For each concept, two variants will be simulated. A variant with low impact and one with a high impact for the building. The impact level can be dependent for example on the impact on the building, labour time or costs. In this paragraph, the low and high impact variant will be explained by looking at different building components by using the existing apartment block at Soendalaan in Vlaardingen. For each component, an R_c-value or U-value will be used as an outline to start the simulations. In Phase 4: Design, the final R_c-values and U-values will be set, dependent on the design decisions that are made.

Floor

It is possible to insulate the crawl space in two ways. This can be done by insulating the floor or by insulating the ground. In the existing building, the crawl space has a height of 300-400 mm, so it is not possible to enter the crawl space. Therefore, it is not possible to insulate the floor. The ground can be insulated by insulating chips made out of polystyrene. These are injected into the crawl space via a hose in the crawl hatch. The thickness of the insulating chips can be varied.

For the low and high impact variant, two different R_c-values will be used. Since the material lends itself to varying in thickness, the R_c-values of the Dutch building regulations 'Bouwbesluit 2012' will be seen as a requirement mentioned in Table 9 on page 50. The low impact variant will maintain the R_c-value of renovated buildings and the high impact variant will maintain the R_c-value that is needed to meet the BENG regulations.

Façade

For the façade, two possibilities can be devised for a low impact and a high impact solution. One option is to only fill the cavity of the façade with insulation material. This can be done by insulation chips made out of polystyrene. They can fill the cavity with insulating material by making a small opening in the façade. Since the façade will not be enlarged, this will be the low impact variant. The high impact variant consists of filling the cavity with insulating material plus insulation material on the outside of the façade. As a result, the R_c-value of the façade is increased even more, but a new façade finish is necessary.

Roof

For the roof, no difference will be made in a low impact and a high impact variant. Since in any case PV panels have to be installed for the production of electricity. Since the R_c-value in the existing situation is low, a low impact variant with only PV panels is not desirable. It is more sensible to bring the entire roof to the right R_c-value at once and then place the PV panels. Since it is not desirable to higher the insulation values of the roof after placing the PV panels, only one variant will be simulated.

Glazing

For the low and high impact variant, two types of glazing will be used. The low impact variant will consist of the existing window frame with new glazing. The glazing will be replaced for double glazing with an argon filling. The high impact variant consists of new highly insulated window frames with thermal breaks. The glazing will be replaced for triple glazing with an argon filling.

Ventilation

As mentioned in Chapter 6.2.1 Providing ventilation two types of ventilation will be simulated. The low impact variant will have a mechanical exhaust that is CO_2-regulated. The high impact variant will be mechanical ventilation with a heat recovery system.

An overview of all values related to the low and high impact variant are shown in Table 13.

	Floor	**Façade**	**Roof**	**Façade openings**	**Ventilation type**
Low impact	2,6 $m^2 \cdot K/W$	2,1 $m^2 \cdot K/W$	6,1 $m^2 \cdot K/W$	1,38 $W/m^2 \cdot K$	Mechanical exhaust CO_2-regulated
High impact	4,3 $m^2 \cdot K/W$	4,6 $m^2 \cdot K/W$	6,1 $m^2 \cdot K/W$	0,93 $W/m^2 \cdot K$	Mechanical with heat recovery

Table 13: Values for simulation for low impact and high impact variant

8.3 Validating model of Uniec$^{2.2}$

In Chapter 7.4, references for the final energy consumption of the existing building are listed. To validate the model in Uniec$^{2.2}$ the final energy consumption of the simulation can be compared with the ones from the references. The results are shown in Table 14. The range of the references is 10.592 – 15.310 kWh/dwel/yr. The simulated final energy consumption in Uniec$^{2.2}$ is 13.903 kWh/dwel/yr, this is in the range of the final energy of the references. So it can be said that the model is validated.

2ndSKIN based on WoOn (Silvester et al., 2016, p. 14)		**2ndSKIN (Silvester et al., 2016, p. 22)**		**Klimaatmonitor (Rijkswaterstaat, 2017)**		**Uniec$^{2.2}$**	
Heating [kWh]	11.671	Gas [m^3]	1.231,8 m^3 12.033 kWh	Gas [m^3]	900 m^3 8.792 kWh	Gas [m^3aeq]	1.200 m^3aeq 11.736 kWh
DHW [kWh]	1.333	Electricity [kWh]	2.306	Electricity [kWh]	1.800	Building related [kWh]	661
Appliances [kWh]	2.306					User-related [kWh]	1.506
Total	**15.310 kWh/ dwel/ yr**	**Total**	**14.339 kWh/ dwel/ yr**	**Total**	**10.592 kWh/ dwel/ yr**	**Total**	**13.903 kWh/ dwel/ yr**

Table 14: Final energy consumption in kWh/dwelling/year in Uniec$^{2.2}$ compared to references

8.4 Results

This paragraph shows the results of the simulation in Uniec$^{2.2}$. First, it gives the primary energy consumption for every apartment in kWh (converted from MJ). After that, the final energy consumption and the produced electricity will be given.

8.4.1 Results primary energy consumption

After the simulations have run in Uniec$^{2.2}$ now the results can be shown. Figure 32 shows the primary energy consumption per apartment in kWh (converted from MJ) for all concepts plus the existing situation. The total primary energy consumption consists of heating, DHW, cooling, summercomfort and lighting. When analysing the results a few things stand out, these will be listed below. Starting with the individual components of the primary energy consumption and ending with the total energy consumption.

Individual components

It can be said that the energy needed to provide heating is higher in the low impact variant than in the high impact variant. This can be clarified by the change in R_c-values in the low and high impact variant. This is directly related to the primary energy needed to provide heating.

The primary energy needed to provide DHW is in the low impact and high impact variant the same value since the use of DHW is not dependent on the different R_c-values of the building envelope. The use of DHW is not dependent on the different R_c-values of the building envelope. What grabs attention is the peak in energy demand at concept C. The value is around double the value for DHW of the other concepts, this can be clarified by the lower COp of the heat pump compared to the heat pumps used in the other concepts.

Cooling is only possible in concept C since the outdoor air is at a temperature that it can be used in Summer to cool the building. This is not possible with the other concepts since the delivery temperature of the systems is too high to use it for cooling.

When applying cooling in concept C, the energy needed for summercomfort is much lower compared to the other concepts.

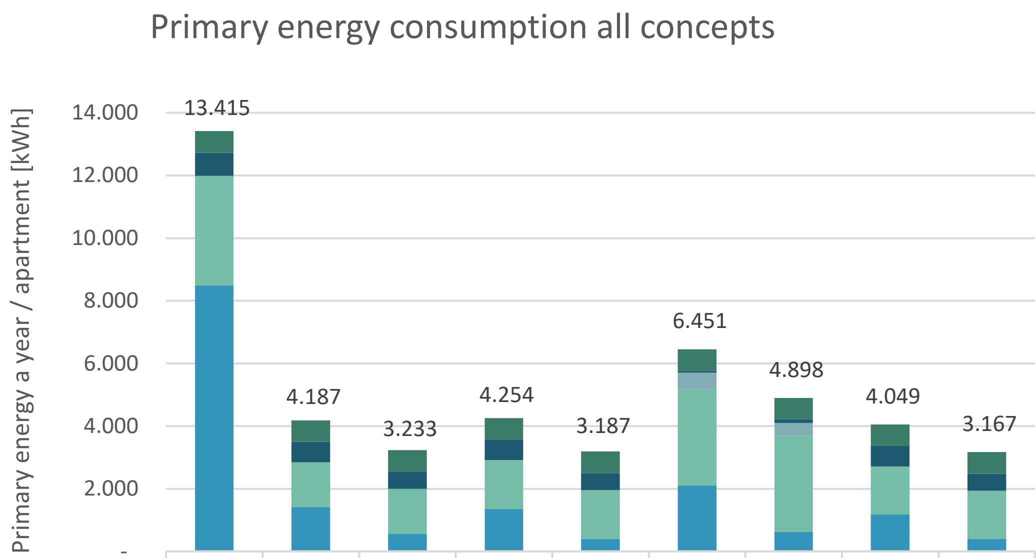
What grabs attention is the higher primary energy consumption for summercomfort at concept C. High comparing to concept C. Low. The other concepts show a decrease in the primary energy for summercomfort with an increase in the R_c-values, only concept C shows an increase in the primary energy.

The primary energy demand needed to provide lighting is in all concepts the same since Uniec$^{2.2}$ takes a standard value for calculating the primary energy needed for lighting.

Total primary energy consumption

Overall it is noticeable that the primary energy consumption is lower in the high impact variant compared to the low impact variant. This is due to the increase of the R_c-values of the building envelope.

When analysing the low impact variant of all concepts, it is noticeable that the primary energy consumption of concept A. Low, B. Low and D. Low is around the same. Concept C. Low has a higher value compared to the other Low concepts, this is the same compared with the High concepts. This can be clarified by the high primary energy for DHW, which result in a higher overall primary energy consumption for concept C.



	Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
Lighting [kWh] converted from MJ	688	688	688	688	688	688	688	688	688
Summercomfort [kWh] converted from MJ	742	654	546	654	546	61	107	654	546
Cooling [kWh] converted from MJ	0	0	0	0	0	532	416	0	0
DHW [kWh] converted from MJ	3.491	1.432	1.432	1.554	1.554	3.064	3.064	1.532	1.532
Heating [kWh] converted from MJ	8.493	1.413	567	1.357	399	2.105	622	1.175	401

Figure 32: Primary energy consumption per apartment in kWh for all concepts and the existing situation

8.4.2 Results Final energy consumption

Figure 33 shows the final energy consumption per apartment in kWh for all concepts plus the existing situation. The total final energy consumption consists of user related energy, building related energy, external heat supply (converted from MJ) and the gas usage (converted from m^3). The user and building related energy are given by Uniec$^{2.2}$. The external heat supply and gas usage can be derived from the primary energy consumption. As stated in Chapter 5.1 Principles of energy systems the energy consumption can be calculated at different points. To go from primary energy consumption to final energy consumption the norm values from table 5.4 in NEN 7120 needs to be used (Normcommissie 351 074 "Klimaatbeheersing in gebouwen", 2011). This norm is for both external heat supply and gas $f_{P;del;ci}$ = 1,0 and for electricity $f_{P;del;ci}$ = 2,56. The straight line in the graph shows the electricity that is produced by the PV panels (concept A-B-C) or the PVT panels (concept D). When analysing the results a few things stand out, these will be listed below. Starting with the individual components of the final energy consumption and ending with the total final energy consumption.

User related electricity is the electricity that is used for appliances (television, laptop, blender). The building related electricity is the electricity that is used for the building services that provide heating, cooling, DHW, auxiliary energy and lighting.

Individual components

As can be seen in the graph, the user related electricity is a standard value in Uniec$^{2.2}$. The norm value given by NEN 7120 is for dwellings 28 kWh/m^2.

The electricity needed for building related energy is in concept A lower compared to the other concepts. This can be clarified by that heating is provided by an external heat supply. Which results in a factor for external heat supply, what the other concepts not have.

The building related electricity in concept C is the highest of all concepts. This concept uses outdoor air as a heat source for the heat pump and therefore the COp of the heat pump is lower than the heat pumps in the other concepts.

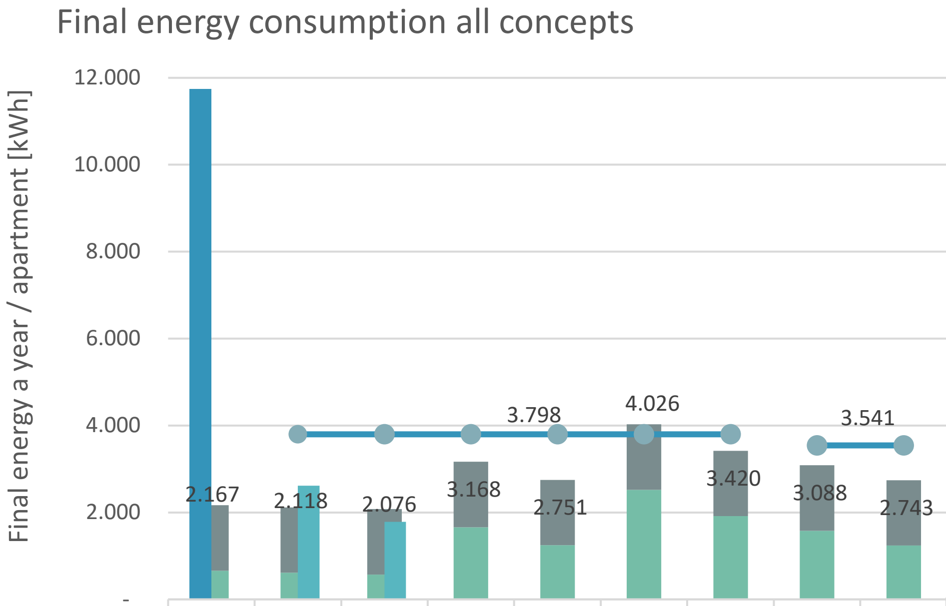
The produced electricity is in concept D is lower than the other concepts. In concept D the electricity is produced by PVT panels, those have a lower energy efficiency than the PV panels used in the other concepts.

Total final energy consumption

Overall it is noticeable that the total final energy consumption is lower in the high impact variant compared to the low impact variant. This can be clarified by the difference in R_c-values of the building envelope and the different efficiency of the building services.

Concept B and concept D have around the same values for the building related electricity. Concept B has an external heat supply of ≈20˚C. And concept D has PVT panels as a heat source for the heat pump. It is possible that the average temperature of the PVT panels is around 20˚C and therefore has around the same value for the building related electricity as concept B.

Except for concept C. Low, all concepts produce more electricity than the building uses.



	Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
User related electricity [kWh]	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506
Building related electricity [kWh]	661	612	570	1.662	1.245	2.520	1.913	1.582	1.237
Gas usage [kWh] (converted from m3)	11.736	0	0	0	0	0	0	0	0
External heat supply [kWh] (converted from MJ)	0	2.616	1.782	0	0	0	0	0	0
Produced electricity [kWh]	0	3.798	3.798	3.798	3.798	3.798	3.798	3.541	3.541

Figure 33: Final energy consumption per apartment in kWh for all concepts and the existing situation

8.4.3 Results BENG regulations

As already mentioned in the strategy is that the goal of the simulation is to meet the BENG regulations. The low impact variant should meet BENG 2 and 3. The high impact variant should meet all BENG regulations. As a reminder the BENG regulations are as follow:

BENG 1 The maximum energy demand ≤ 25 kWh/m^2
BENG 2 The maximum primary fossil energy consumption ≤ 25 kWh/m^2
BENG 3 The minimum part renewable energy ≥ 50 %

Figure 34, Figure 35 and Figure 36 show the results of the simulations. The horizontal line in the graph shows the required value of the BENG regulations.

It can be seen in Figure 34 that only the high impact variant meets the requirement of BENG 1. The low impact variant is double the required value. The existing situation is extremely high above the required value. The energy demand is directly related to the R_c-values of the building envelope.

Figure 35 shows BENG 2 where the maximum primary fossil energy consumption should be below 25 kWh/m^2. All concepts have a negative value. The low impact variants have a slightly higher value compared to the high impact variants, but still, the value is negative. A negative value can be clarified by the fact that BENG 2 consists of all primary energy use but also takes into account the part renewable energy. If the part renewable energy is high, the primary energy use can become negative.

Figure 36 shows BENG 3 where the part renewable energy should be above 50%. All concepts meet the requirement. In the existing situation, there is no production of renewable energy. The number of PV panels is in all concepts the same. Since in the low impact variant the total energy consumption of the building is higher, compared to the high impact variant, the part renewable energy is lower. Note that in concept D half of the roof is covered by PVT panels with another energy efficiency.

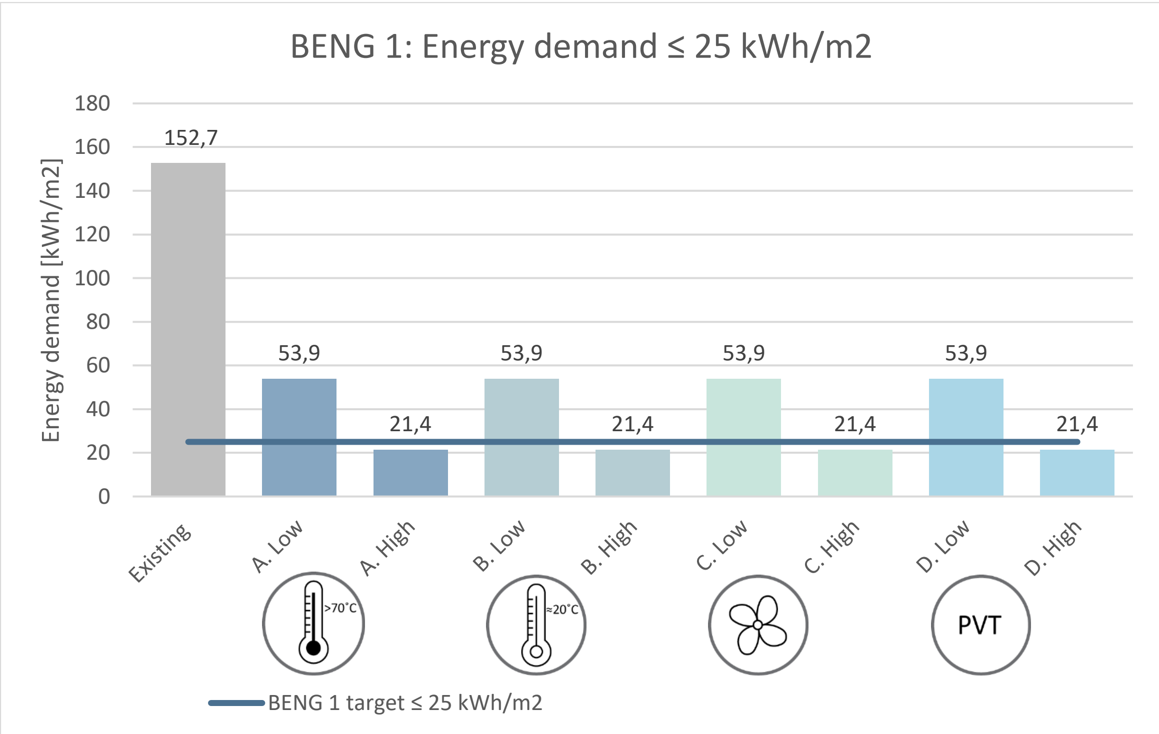


Figure 34: Results of BENG 1 were the energy demand should be below 25 kWh/m2

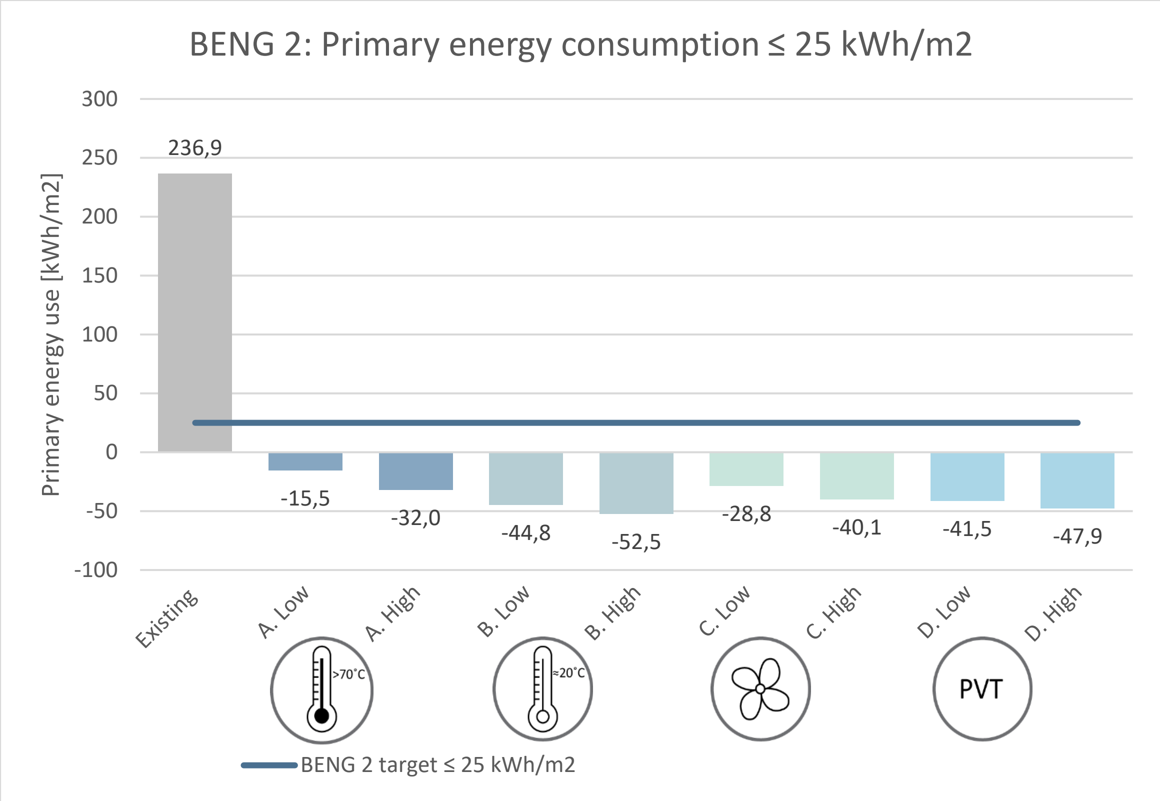


Figure 35: Results of BENG 2 were the primary energy use should be below 25 kWh/m2

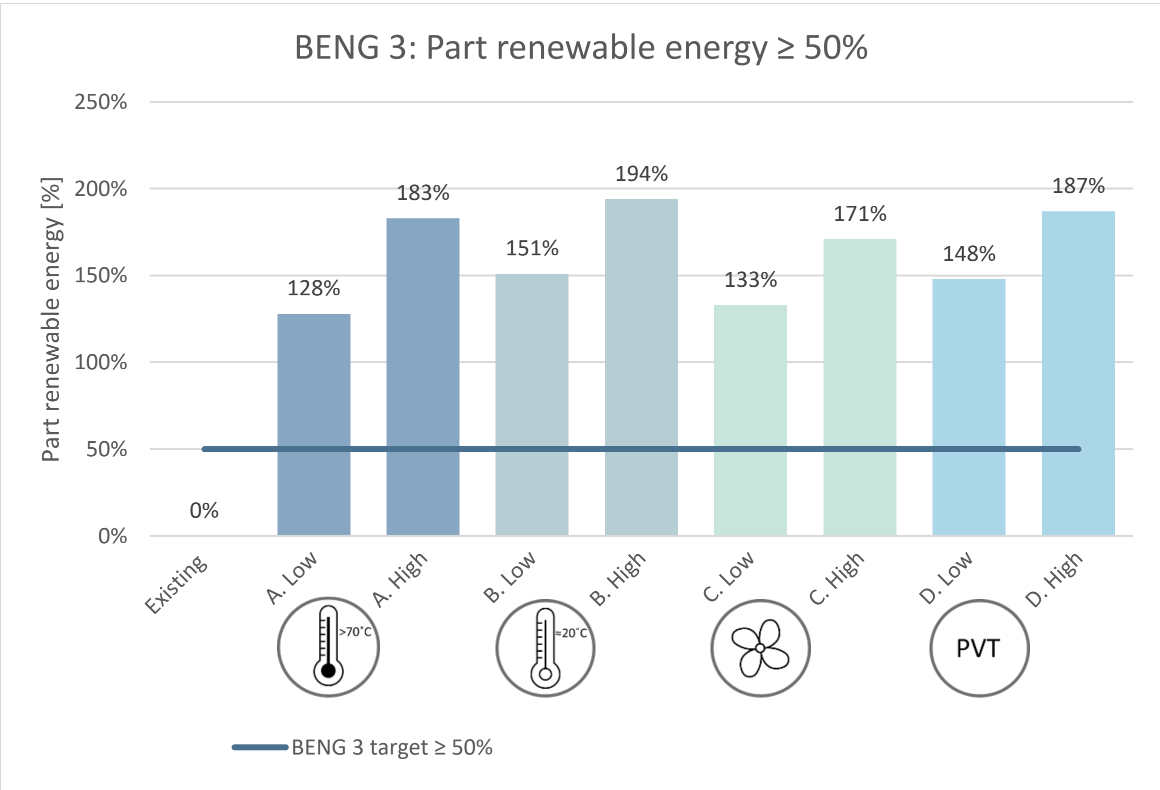


Figure 36: Results of BENG 3 were the part renewable energy should be above 50%

8.5 Conclusion

8.5.1 BENG regulations

After analysing the results, a conclusion of the simulations can be derived. As mentioned at the beginning of this chapter the goal is to meet the BENG regulations. The low impact variant should meet BENG 2 and 3. The high impact variant should meet all BENG regulations. As can been seen in Figure 37 this goal has been achieved. The low impact variant does meet BENG 2 and 3 with all concepts. The high impact variant does meet all BENG regulations with all concepts.

In appendix B and C the input for the simulation in Uniec[2.2] is given. This information is very important for the next phase of this research. The design criteria will be given in the next chapter and will consist of R_c-values and dimensions and requirements of the building services for each concept. The design criteria are a result of the simulation phase and are direct input for Phase 4: Design.

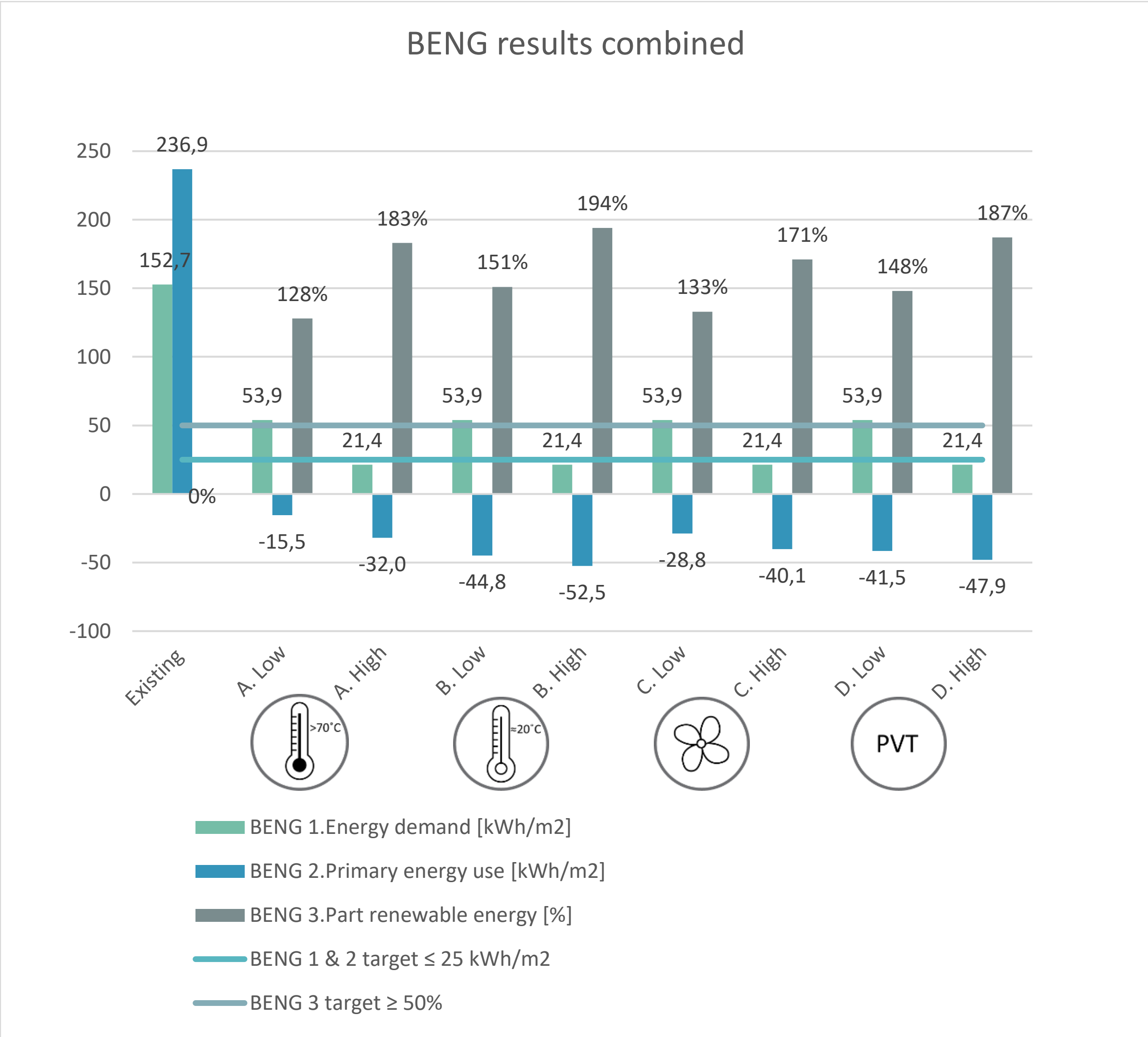


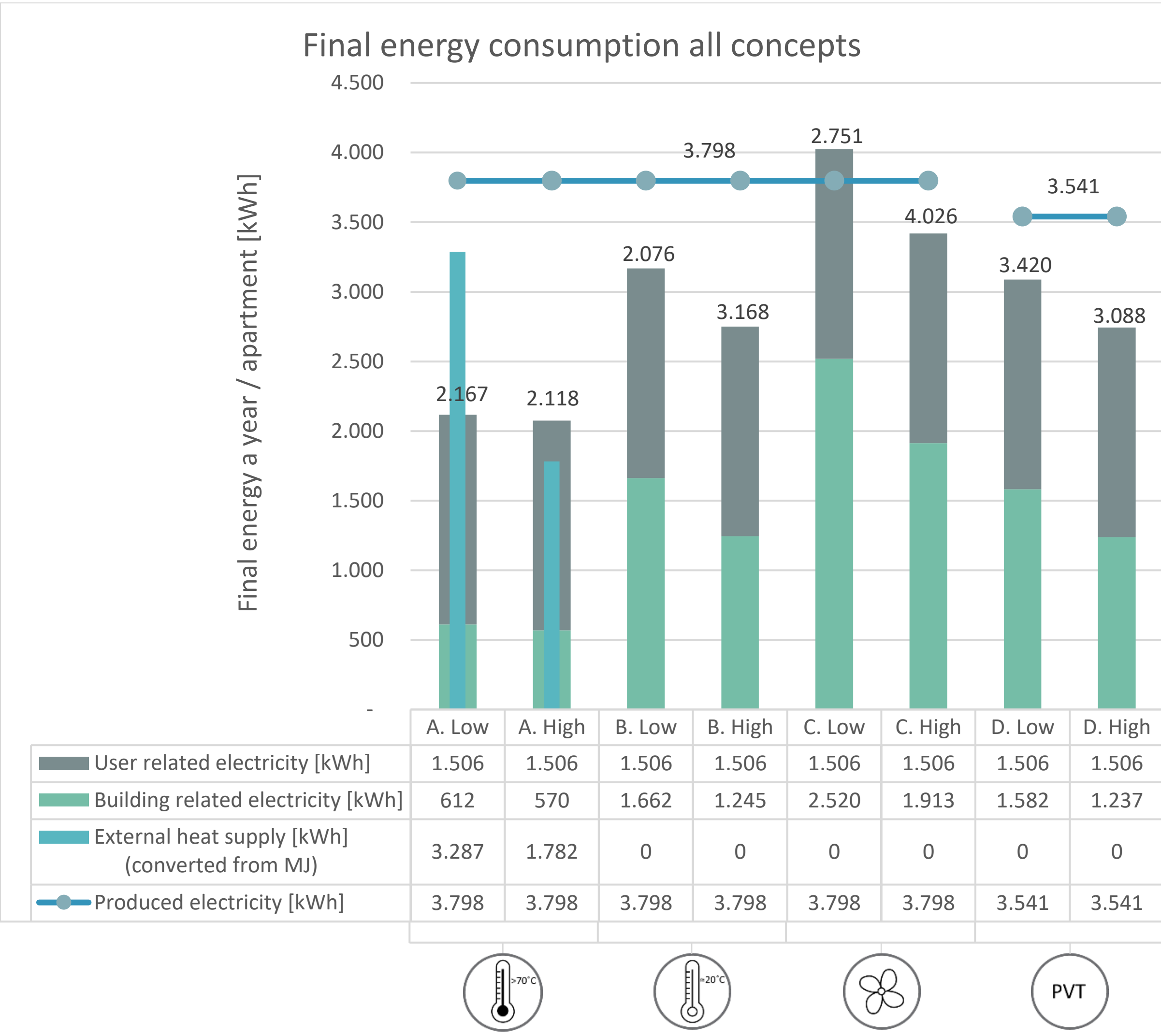
Figure 37: BENG regulations combined

8.5.2 Energy neutral or zero energy?

The goal of the simulation is not to become energy neutral or zero energy, but it is possible to say something about this. First, it is necessary to define what energy neutral or zero energy is. The building is energy neutral when it produces enough electricity to fulfil the electricity needed for the building related electricity. The building is zero energy when it produces enough electricity to fulfil the electricity needed for the building related plus the user related electricity. Looking in

Figure 38 the conclusion can be drawn that Concept A, B, C. High and D are all zero energy. Concept C. Low is not zero energy, but is energy neutral.

This graph is the same graph as shown in Figure 33, the only difference is that the existing situation is removed and therefore the axis could have a different scale.



	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
User related electricity [kWh]	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506
Building related electricity [kWh]	612	570	1.662	1.245	2.520	1.913	1.582	1.237
External heat supply [kWh] (converted from MJ)	3.287	1.782	0	0	0	0	0	0
Produced electricity [kWh]	3.798	3.798	3.798	3.798	3.798	3.798	3.541	3.541

Figure 38: Electricity needed versus electricity produced

DESIGN CRITERIA

Design criteria

This chapter consists of the design criteria that can directly be used as input for the design phase. The design criteria are the result of the simulation phase and literature research. It is separated into two different components for all simulated concepts: the building envelope and the building services. Note that the criteria mentioned in Chapter Energy systems were input for the simulation phase. The design criteria are composed after the simulation phase and can diver from the input criteria. This chapter is more about how the criteria can be implemented in the design.

First criteria that influence the design will be described. Those criteria are set by the design approach and the criteria given by the case-study. Secondly, measures that should be implanted in the low and high impact are described. Finally, dimensions and requirements for the building services, resulting from the simulation phase, will be given.

9. Criteria that influence the design

There are some criteria that influence the design but are set by the approach of the research and by the case-study that will be used to implement the design. Since the aim of the design is to upscale refurbishment, it is necessary that the design can be implemented in multiple cases. So some criteria given by the case-study will be neglected since they are too specific.

Given by approach

- Post-war walk-up apartments
- Occupied apartments
- Inclined roof ≈ 30˚
- Room around plot to extend

Given by case-study

- Cavity wall
- Crawl space height < 400 mm
- Unoccupied attic
- N-S orientation of the building
- Symmetric façade layout

9.1 Building envelope

Phase 3: Simulation gives criteria consisting of R_c-values for the building envelope. Simulations show that the building envelope should meet the criteria in Chapter Energy systems to meet the goal of the simulations. The low impact variant does meet BENG 2 and 3. The high impact variant does meet all BENG regulations.

	Floor	**Façade**	**Roof**	**Façade openings**
Low impact	2,6 $m^2{\cdot}K/W$	2,1 $m^2{\cdot}K/W$	6,1 $m^2{\cdot}K/W$	1,38 $W/m^2{\cdot}K$
High impact	4,3 $m^2{\cdot}K/W$	4,6 $m^2{\cdot}K/W$	6,1 $m^2{\cdot}K/W$	0,93 $W/m^2{\cdot}K$

Table 15: Design criteria for building envelope

But how can those R_c-values be achieved in the design? In the next paragraphs options to insulate each building component will be explained.

9.1.1 Floor

There are multiple possibilities to increase the R-value of the floor: floor insulation under the floor construction, floor insulation above the floor construction and ground insulation. The choice is dependent on the accessibility and the height of the crawl space. Figure 39 shows a schematic view of the possibilities.

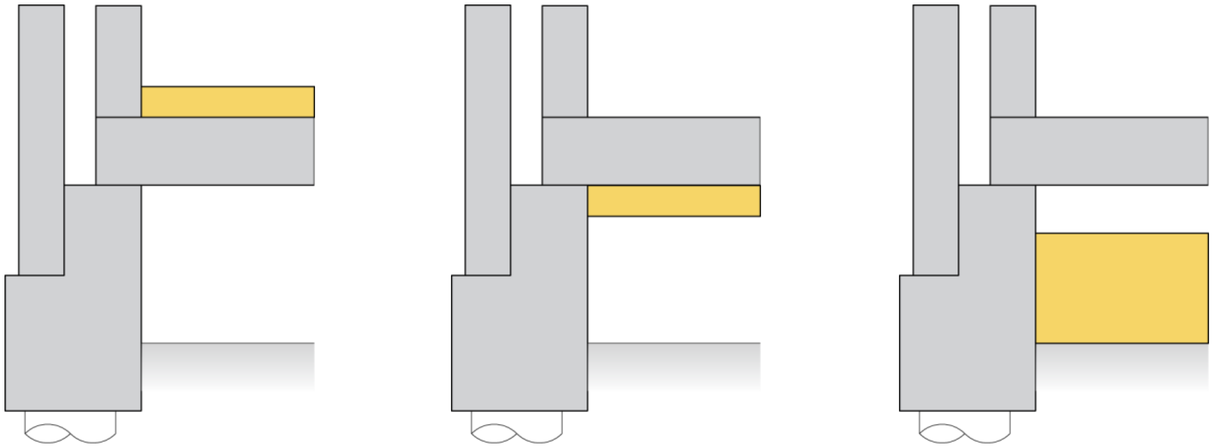


Figure 39:
1.Floor insulation above construction floor
2. Floor insulation under construction floor
3. Ground insulation

Since the apartments are occupied during the renovation and the crawl space has a limited height, the ground will be insulated. Small components can be injected into the crawl space with a hose in the crawl hatch. Possible materials are: shells, EPS chips and EPS pearls. Table 16 shows the properties of the different materials that can be used for ground insulation.

Material	Thickness [mm]	R-value [m2·K/W]	Weight [kg/m²]	Lambda [W/m·K]
1. Shells	300	3	150	0,1
2. EPS chips	300	4	5	0,075
3. EPS pearls	300	9	3	0,033

Table 16: Properties of different ground insulation materials (Isoschelp, 2019) (Isolatie-info.nl, n.d.) (Isolatiehandel Van den Berg, n.d.)

Figure 40: Chips for insulating the crawl space. Reprinted from (Traas Ongedierte Bestrijding, 2019)

9.1.2 Façade

The apartments are occupied during the renovation so it is not possible to place insulation on the inside. In the low impact variant, only the cavity of 700mm width will be filled with insulation material if it is not polluted. The R_c-value that will be achieved with only filling the cavity is limited. The cavity can be filled by making a little hole in the mortar to inject the insulation material. Materials like EPS chips or EPS pearls can be used. In the high impact variant, a wooden framework filled with insulation will be placed.

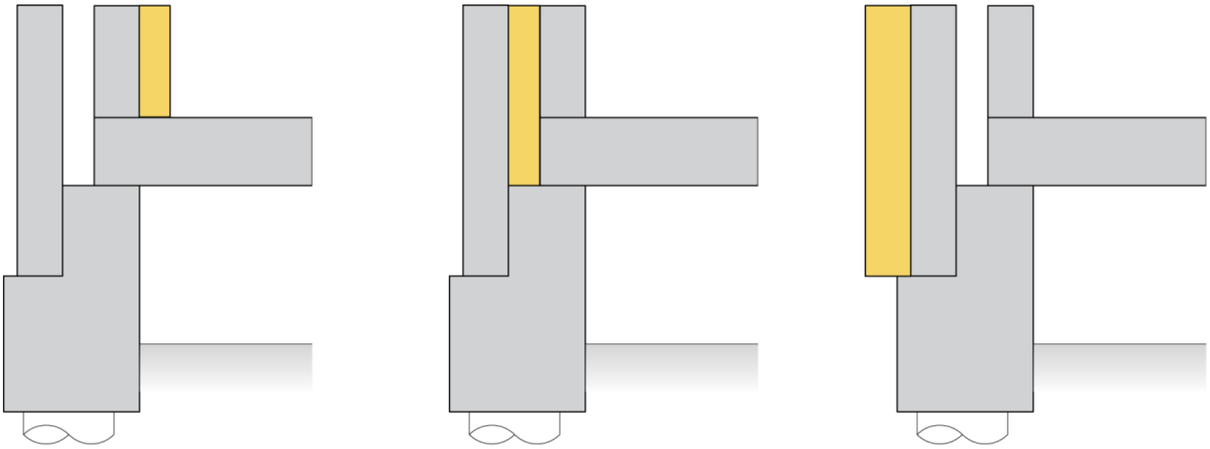


Figure 41:
1.Inside insulation *2. Cavity insulation* *3. Outside insulation*

Figure 42: Hole in the mortar to fill the cavity with EPS pearls. Reprinted from (Isolatie-info.nl, n.d.)

9.1.3 Roof

Research of Bokel and Van den Ham (2010) shows that for unheated attics, insulation in the ceiling of the top floor is more effective than roof insulation. So attic insulation will be used in the low impact variant. In the high impact variant outside insulation will be placed on the existing roof structure, to achieve a higher insulation value than in the low impact variant.

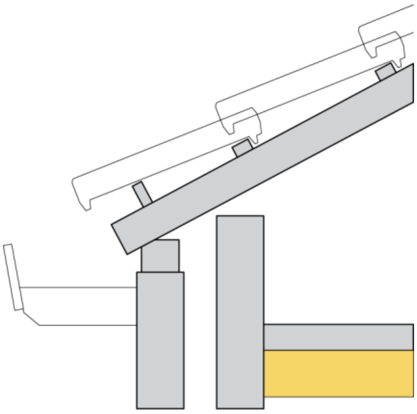
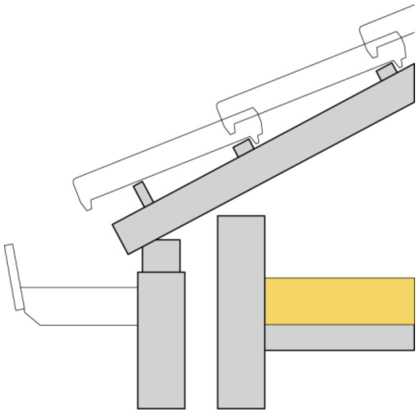
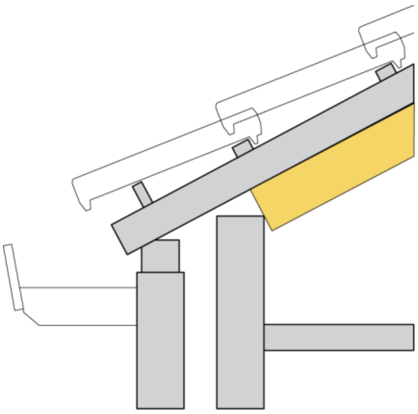


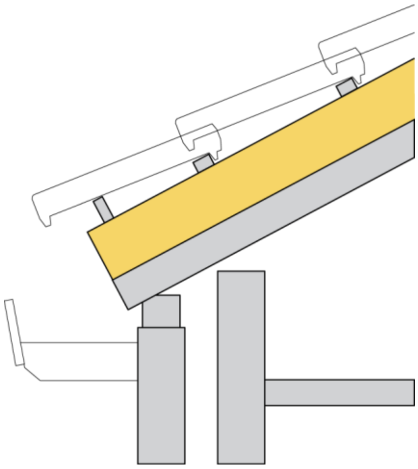
Figure 43:
1. Ceiling insulation



2. Attic insulation



3. Roof insulation inside



4. Roof insulation outside

9.1.4 Decision for different building components

Konstantinou (2014) designed the Façade Refurbishment Toolbox shown in Table 17. This toolbox is a database of possible measures that can be implemented in refurbishment projects. The measures are scaled according to effort and level of intervention. With this toolbox, the criteria of the case-study and the topics mentioned above a distinction can be made according to the low and high impact variant. The grey cells show the existing building, the green cells show the low impact variant and the blue cells show the high impact variant.

	Building envelope					**Building services**	
	Exterior wall	*Window*	*Balcony*	*Roof*	*Ground floor*	*Ventilation*	*Heat source*
Existing construction	Masonry/ cavity wall no insulation	Single glazing	Continuous slab, no insulation	Pitched roof, timber rafters no insulation/ occupied loft	Slab on ground, no insulation	Natural ventilation	Gas stove
	Lightweight concrete/ hollow brick, no insulation	Early, double glazing	Separate slab no/ little insulation	Pitched roof, timber rafters no insulation/ unheated loft	Basement unheated. Concrete slab, no insulation		Fossil fuel boiler in each dwelling
	Little/ outdated insulation			Concrete slab, no/little/ outdated insulation	Little/ outdated insulation	Trickle ventilation	Fossil fuel boiler per block
Retrofitting measures	Cavity insulation	Upgrade windows	Insulate balcony slab	Pitched roof, no insulation/ unheated loft	Insulation on top of ground/ first floor slab	Natural inlet/ mechanical exhaust	Replace existing boiler in each dwelling, high efficiency
	Internal insulation	Secondary glazing single	Cut off balcony	Pitch roof insulation	Insulation under existing floor	Mechanical inlet/ natural exhaust	Replace existing boiler in each block, high efficiency
	Exterior insulation and finishing systems	Secondary glazing double	Balcony cladding – single glazing	Insulation of top floor slab		Mechanical ventilation	CHP installation
	Ventilated façade		Balcony cladding- double glazing	Flat roof		Ventilation system with heat recovery	Heat pump
	Timber-frame wall	Replace windows (double pane)		Green roof			
	Second façade/ single glazing	Replace windows (triple pane)					
	Second façade/ double glazing	Shading adjustable					Biomass boiler
RES	BIPV's			Photovoltaic			Solar collectors
Spatial interventions	Additional space/ second façade integrated	Shading fixed	Integrated balcony				Geothermal
	Lift addition	Enlarged windows	New balcony	Additional floor/ occupied loft	Additional floor/ occupied basement		District heating

Table 17: The toolbox matrix. Adapted from (Konstantinou, 2014)

In Figure 44 and Figure 45 a schematic overview is given of measures for the building envelope to increase the insulation value. A distinction is made between the low and high impact variant.

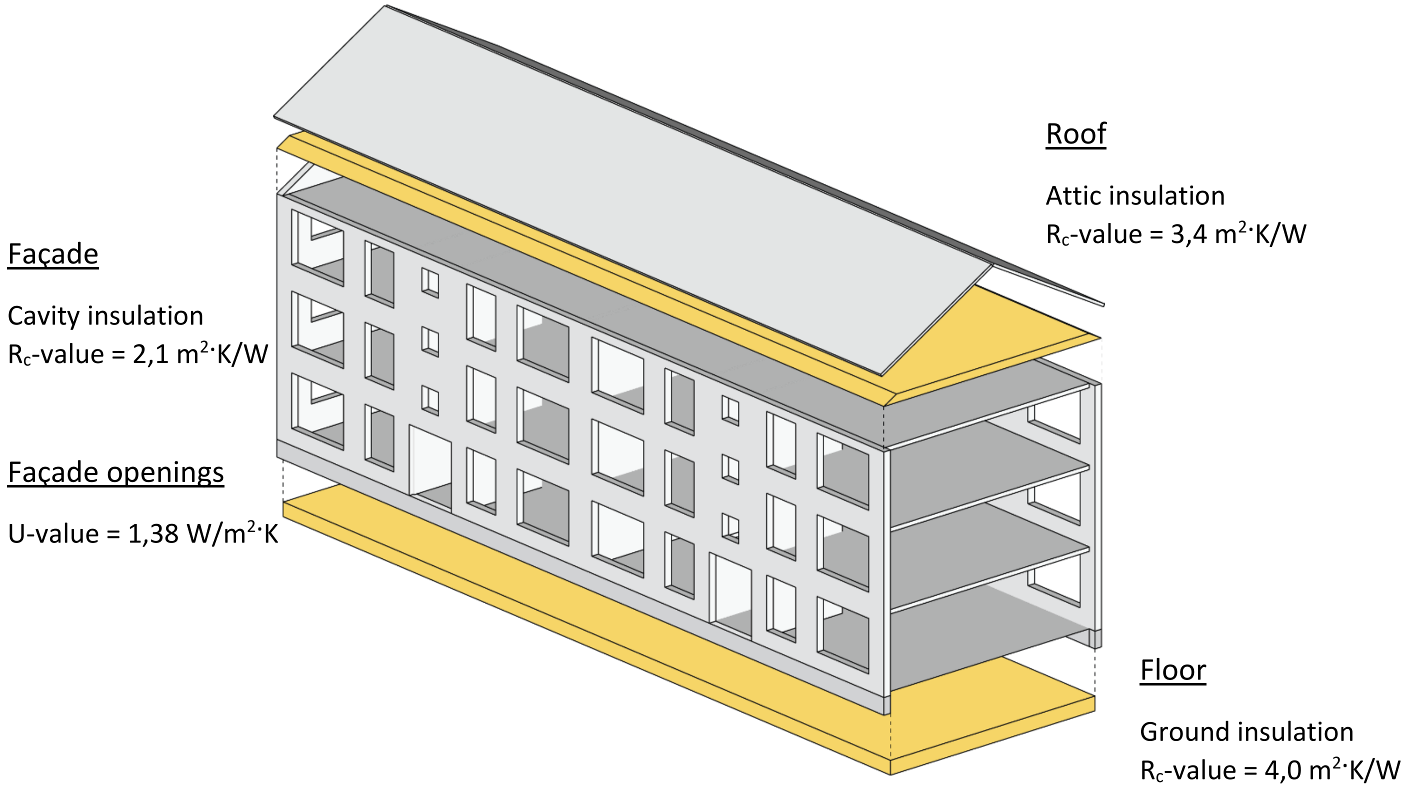


Figure 44: Increasing insulation value of building envelope for low impact variant

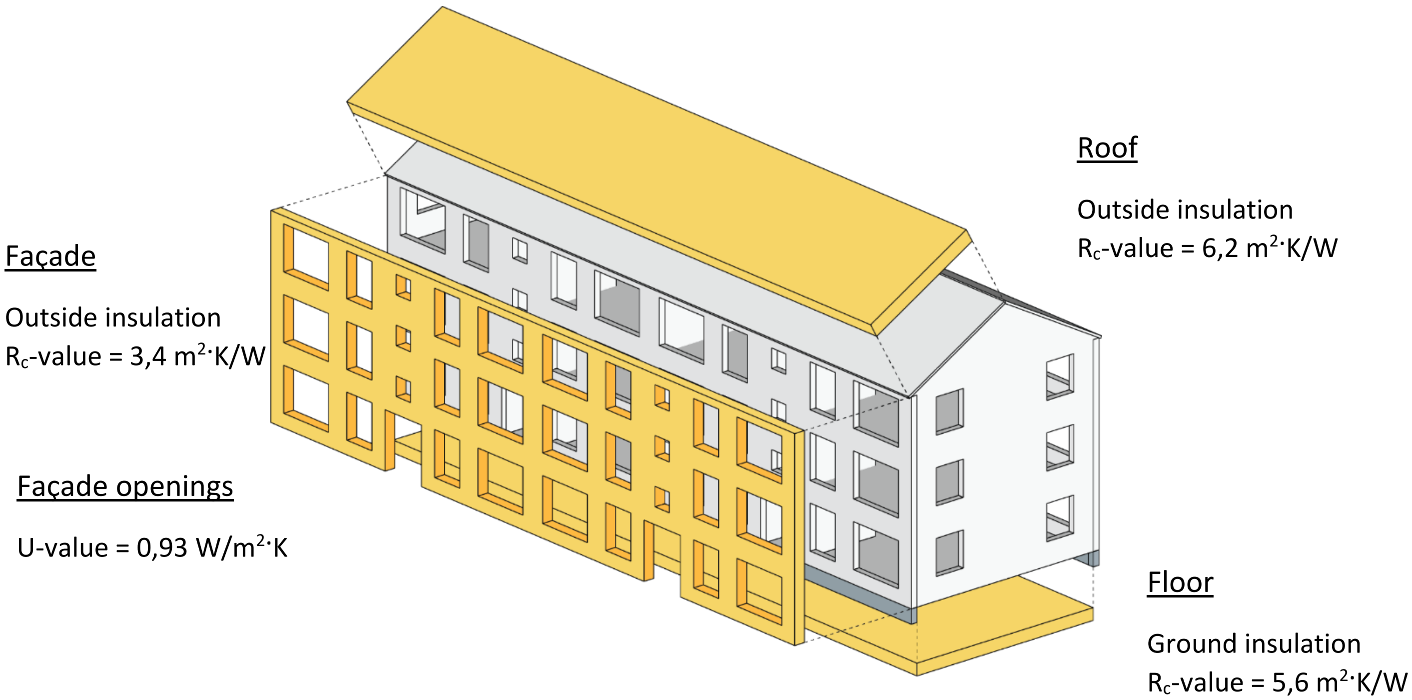


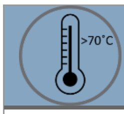
Figure 45: Increasing insulation value of building envelope for high impact variant

9.2 Building services

After the simulation phase, there is now more information about the building services related to the concepts. This paragraph will give more information about the dimensions and weight of the building services. Secondly, the information will be given about the requirements of the building services. Does it need electricity, water connection or outdoor air? This will be input for the design phase.

9.2.1 Dimensions, weight and requirements

In Table 18, Table 19, Table 20 and Table 21 dimensions and weights for each specific building service is given. Each table represents one concept, it consists of the low and high impact variant. The figures in the table are a visual representation of the dimensions of the building services. When there is a block behind another block it means that it can be the one in front or the one behind, but not both. In almost all cases the first row is the low impact variant and the second one is the high impact variant.

	**Concept A: External heat supply >70˚C**	**Dimensions [mm] L x W x H**	**Weight [kg]**	**Requirements estimation**
1. Sub-station EcoMechanic		588 x 258 x 493	9	Inlet – outlet city grid
2. Ventilation	2a. CO2 regulated Itho Daalderop Optima Flow system	355 x 294 x 350	3,5	Electricity, air outlet
	2b. WTW Itho Daalderop HRU ECO 200 E	597 x 290 x 916	12	Electricity, air outlet, air inlet, condensation drain
3. PV CSUN 255-60P	1 panel	990 x 35 x 1640	18,3	Electricity

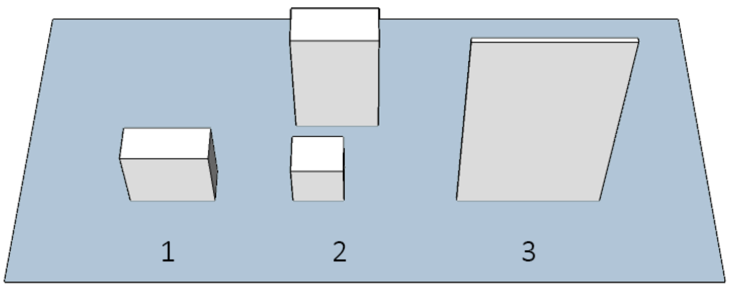


Figure: Visual representation of the dimensions of the building services Concept A

Table 18: Dimensions and weights of building services for Concept A (HSF, 2019) (Itho Daalderop, 2012) (CSUN, n.d.)

Concept B: External heat supply ≈20˚C		**Dimensions [mm] L x W x H**	**Weight [kg]**	**Requirements estimation**
1. Sub-station EchoMechanic		588 x 258 x 493	9	Inlet – outlet city grid
2. Heat pump Itho Daalderop WPU 5G	2a. Heat pump only	600 x 600 x 830	85	Electricity, water inlet, water outlet
	2b. Optional: Buffer tank Itho Daalderop I-SVV 200l	*1486,5 x Ø595*	*56 (empty)*	*Electricity, water inlet, CV supply, CV outlet*
	2c. In combination with buffer tank 200l	600 x 600 x 2103		Electricity, water inlet, CV supply, CV outlet
3. Ventilation	3a. CO_2 regulated Itho Daalderop Optima Flow system	355 x 294 x 350	3,5	Electricity, air outlet
	3b. WTW Itho Daalderop HRU ECO 200 E	597 x 290 x 916	12	Electricity, air outlet, air inlet, condensation drain
4. PV CSUN 255-60P	1 panel	990 x 35 x 1640	18,3	Electricity

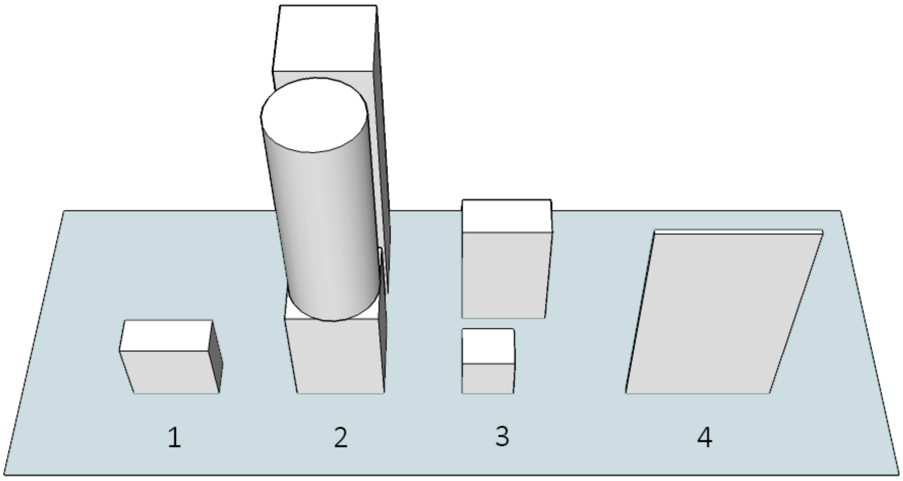


Figure: Visual representation of the dimensions of the building services Concept B

Table 19: Dimensions and weights of building services for Concept B (HSF, 2019) (Itho Daalderop, 2012) (CSUN, n.d.)

Concept C: Outdoor air		**Dimensions [mm] L x W x H**	**Weight [kg]**	**Requirements estimation**
1. Heat pump Itho Daalderop HP-s 55	1a. Indoor unit	505 x 288 x 790	45	Electricity, outdoor air, CV supply, CV outlet
	1b. Outdoor unit	934 x 354 x 753	62,5	Electricity, outdoor air, air outlet
2. Buffer tank Itho Daalderop I-SVV 200l		1486,5 x Ø595	56 (empty)	Electricity, water inlet, CV supply, CV outlet
3. Ventilation	3a. CO2 regulated Itho Daalderop Optima Flow system	355 x 294 x 350	3,5	Electricity, air outlet
	3b. WTW Itho Daalderop HRU ECO 200 E	597 x 290 x 916	12	Electricity, air outlet, air inlet, condensation drain
4. PV CSUN 255-60P	1 panel	990 x 35 x 1640	18,3	Electricity

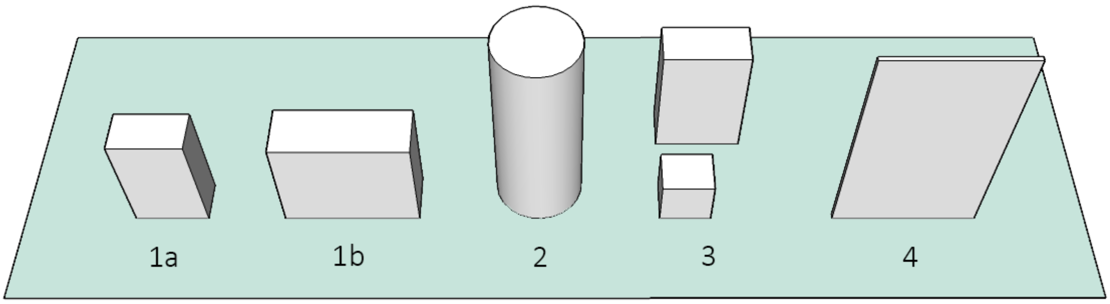


Figure: Visual representation of the dimensions of the building services Concept C

Table 20: Dimensions and weights of building services for Concept C (Itho Daalderop, 2012) (CSUN, n.d.)

PVT **Concept D: PVT**		**Dimensions [mm] L x W x H**	**Weight [kg]**	**Requirements estimation**
1. Heat pump NIBE-F1255-6	In combination with buffer tank 180l	600 x 620 x 1800	240	Electricity, water inlet, water outlet, CV supply, CV outlet
2. Ventilation	2a. CO2 regulated Itho Daalderop Optima Flow system	355 x 294 x 350	3,5	Electricity, air outlet
	2b. WTW Itho Daalderop HRU ECO 200 E	597 x 290 x 916	12	Electricity, air outlet, air inlet, condensation drain
3. PVT Triple Solar M2 285 165	1 panel	995 x 65 x 1668	27	Electricity, water inlet, water outlet

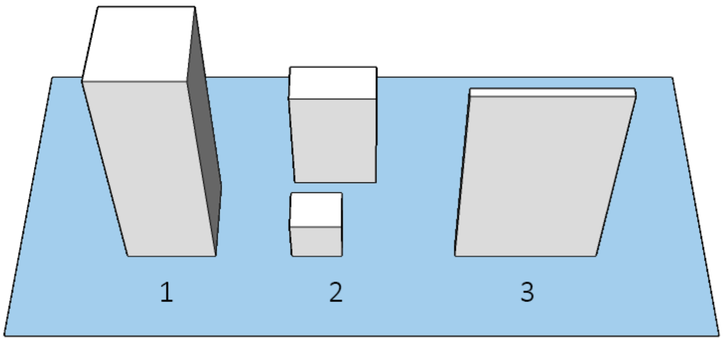


Figure: Visual representation of the dimensions of the building services Concept D

Table 21: Dimensions and weights of building services for Concept D (NIBE, n.d.) (Itho Daalderop, 2012) (Triple Solar B.V., 2019)

PHASE 4: DESIGN

Phase 4: Design

In this phase of the research, all earlier obtained knowledge plus the results of the simulations will come together in a design. For this design, a case-study at the Soendalaan in Vlaardingen is used. Since the different energy concepts ask for different energy sources, the context of this case-study is abstract.

Different from the structure in other parts of the research is that in this part the building services will be described before the building envelope. There is chosen for this structure since the design of the building services will have an influence on the design of the building envelope. Therefore it is useful to first design the building services so that they can be used in the design of the building.

Since there are a lot of concepts, impacts and variants a clarification of those are shown in Figure 46. The renovation approach for a post-war walk-up apartment building consists of a low and high impact variant. These variants have the most influence on the building envelope of the building. The building services are divided into four main concepts. These concepts are the same for the low and high impact variant and can be individual or collective.

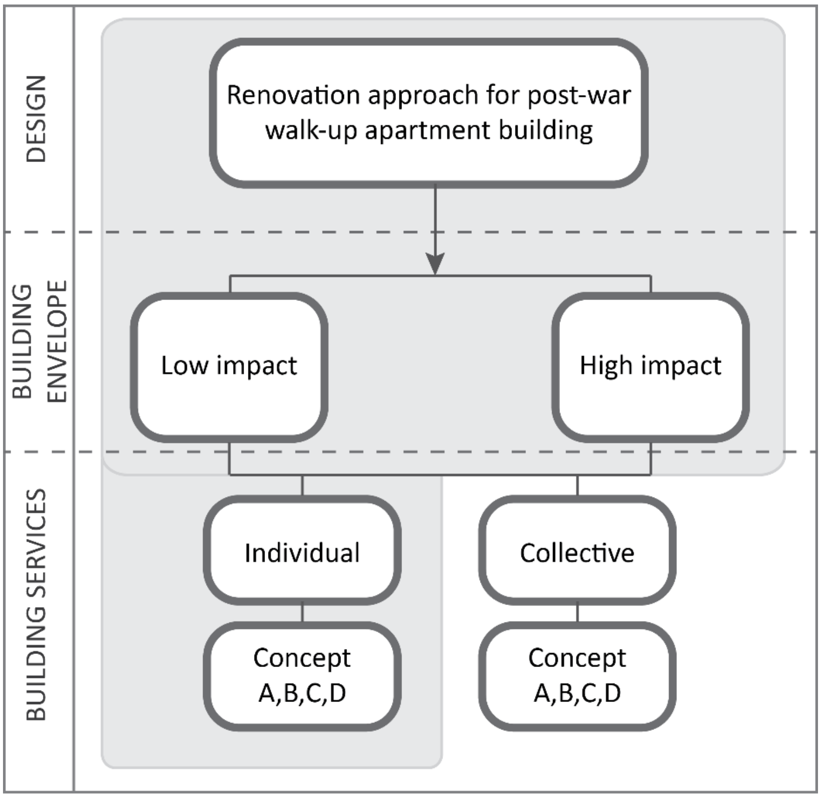


Figure 46: Diagram different variants and concepts

10. Building services

10.1 Individual services

During the simulation in Uniec[2.2,] it is assumed that every apartment has its own building services. So each apartment has an individual heat pump and a buffer tank. The system for the provision of ventilation is collective. In the next paragraphs, it will be explained where those building services can be located and how the building services unit will look like.

10.1.1 Location of building services unit

A result of the simulation phase are the different building services for each concept. Some ventilation ducts can be integrated into the façade, but there is no place to integrate the building services itself in the façade. There are different possibilities for the placement of the building services. In this chapter two options will be analysed that should meet the following criteria points:

- Do not change the appearance of the South façade (no extra units or extensions);
- Remain original façade openings;
- Building services need to be accessible from outside or inside;
- Location of building services unit should be close to the location where they are needed (kitchen, bathroom);
- Every apartment will have its own building services.

Option 1

The corner apartments have a unit with building services on the West or East façade. It is located on the opaque part of the façade. The middle apartments have the units with building services next to each other on the North façade. Figure 47 shows a schematic floorplan of this option. Pros and cons are listed related to the criteria points mentioned above.

+ South façade remains the same;
+ Façade openings remain the same;
+ Every apartment individual building services;
+ Possible vertical piping in the unit;

- Not accessible from inside (demolition not possible, since façade construction is loadbearing);
- Not connected to location where building services are needed, therefore long pipe distances inside the apartment;
- Possible disturbance (noise or vibrations) in bed or living room by building services.

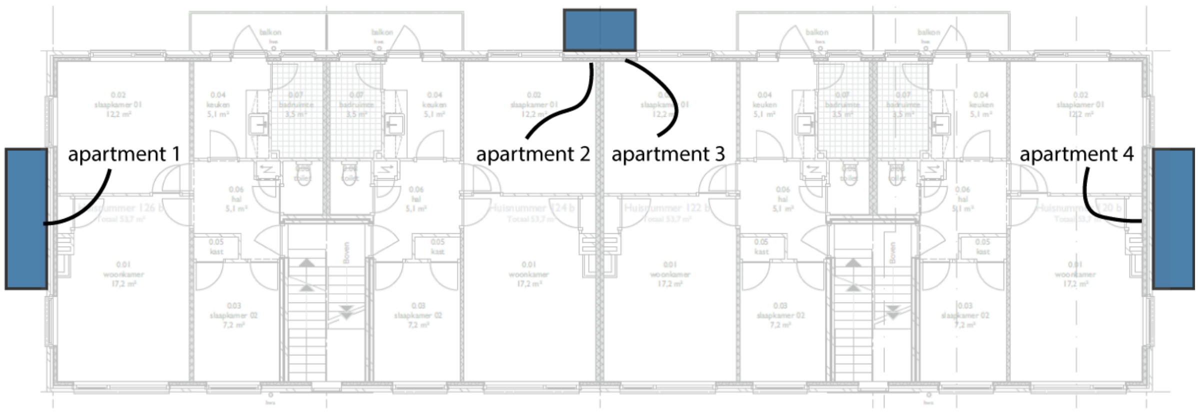


Figure 47: Option 1 location building services, side and North facade

Option 2
The unit with building services is in this option placed on the balcony at the North façade of the building. It is located in front of a façade opening so this opening will close in this situation. In Figure 48 a schematic floorplan is shown. Pros and cons are listed related to the criteria points mentioned earlier.

+ South façade remains the same;
+ Every apartment individual building services;
+ Possible vertical piping in the unit;
+ Accessible from balcony;
+ Connected to the kitchen and bathroom;
+ Clear distinction between balconies of different apartments;

- Removal of façade opening in bathroom;
- Balcony needs to be replaced;
- Possible disturbance (noise or vibrations) due to outdoor unit of the heat pump.

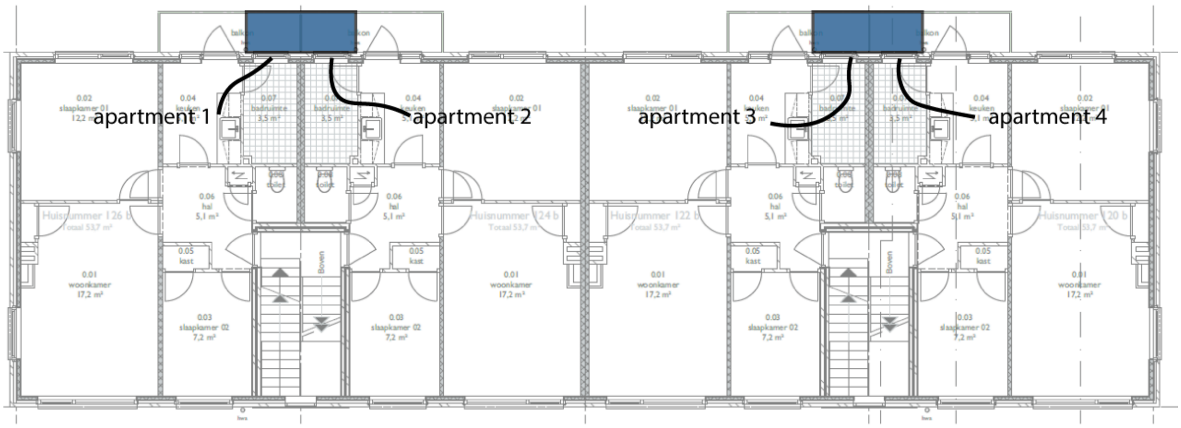


Figure 48: Option 2 location building services, North facade

Conclusion
From the two options, there is chosen to elaborate more on option 2. With this option, the building services are connected to the bathroom and kitchen and it will be accessible from the balcony. The only disadvantage is that one façade opening will be removed since the unit with building services will be placed in front of this façade opening. Elaboration is needed if the balcony can carry the loads of the building services.

10.1.2 Design of building services unit

In Chapter Design criteria the different building services related to the four concepts are mentioned. With these building services, the apartments can be connected to different energy systems. As mentioned in the paragraph above they will be placed in the backyard, close to the functions that require the building services.

Concept A

Concept A is connected to an external heat supply > 70˚C and needs a substation to extract the heat from the grid. This substation can be integrated into the North façade. On the same place as where the building services unit from the other concepts will be placed. In Figure 49 a visual representation of the substation integrated into the façade is given. In the next chapter, there will be more elaborated on the façade element.

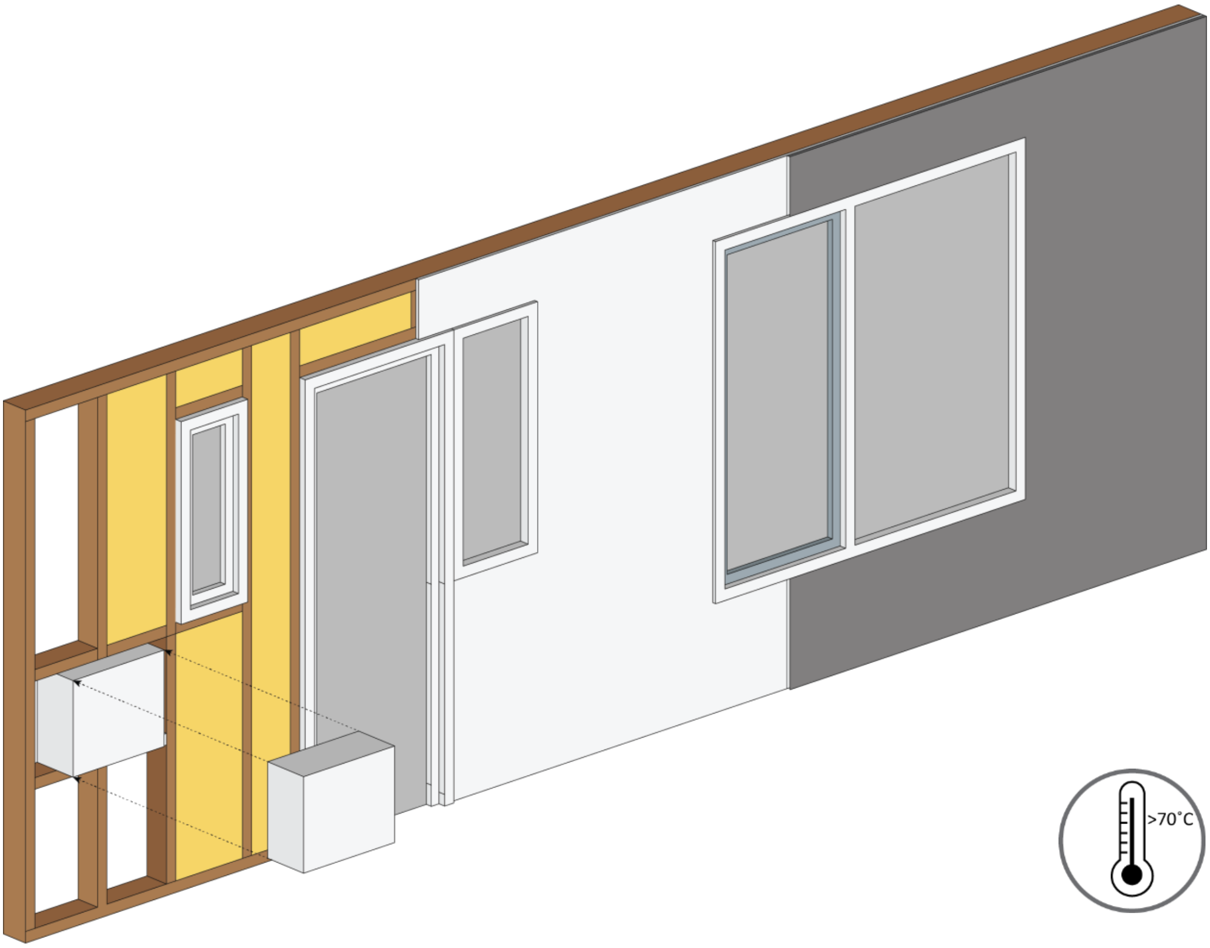


Figure 49: Integration of substation in façade for concept A

Concept B

Concept B is connected to an external heat supply ≈ 20˚C, therefore a heat pump is required to heat up the source to use it in the apartment. It is necessary to place a building services unit in the backyard, consisting of a heat pump, buffer tank and a substation. The CO_2-regulated ventilation unit or the heat recovery system will be placed in the unoccupied attic of the building. Figure 50 shows a visual representation of the building services unit for concept B. The unit will have the same height as the floor height of the building.

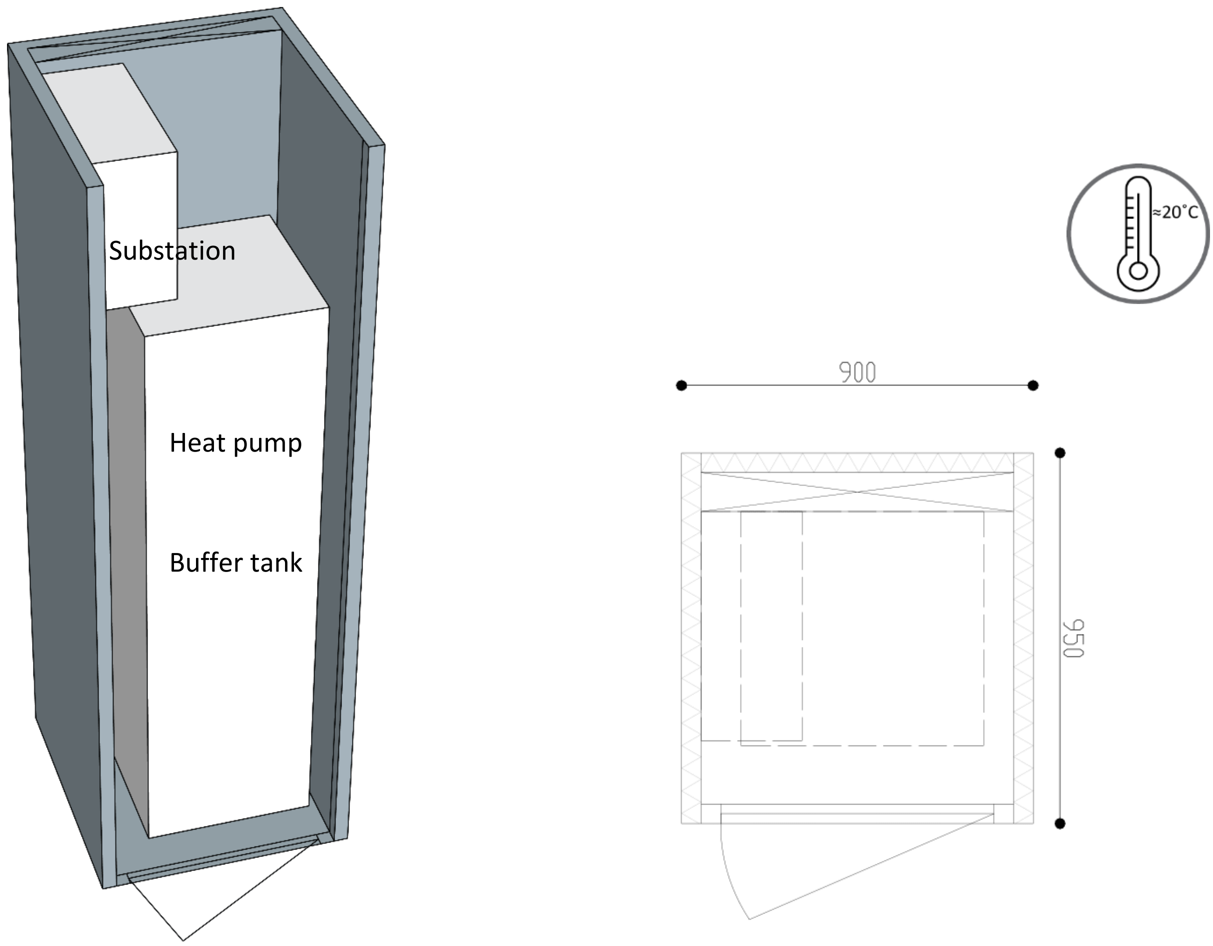


Figure 50: Visual representation of building services unit for concept B

Concept C

Concept C uses the outdoor air as a heat source for the heat pump. The building services unit will be placed in the backyard and consists of a buffer tank and an indoor and outdoor unit for the heat pump. Again the system for providing ventilation will be placed in the unoccupied attic of the building. In Figure 51 a visual representation of the unit is given.

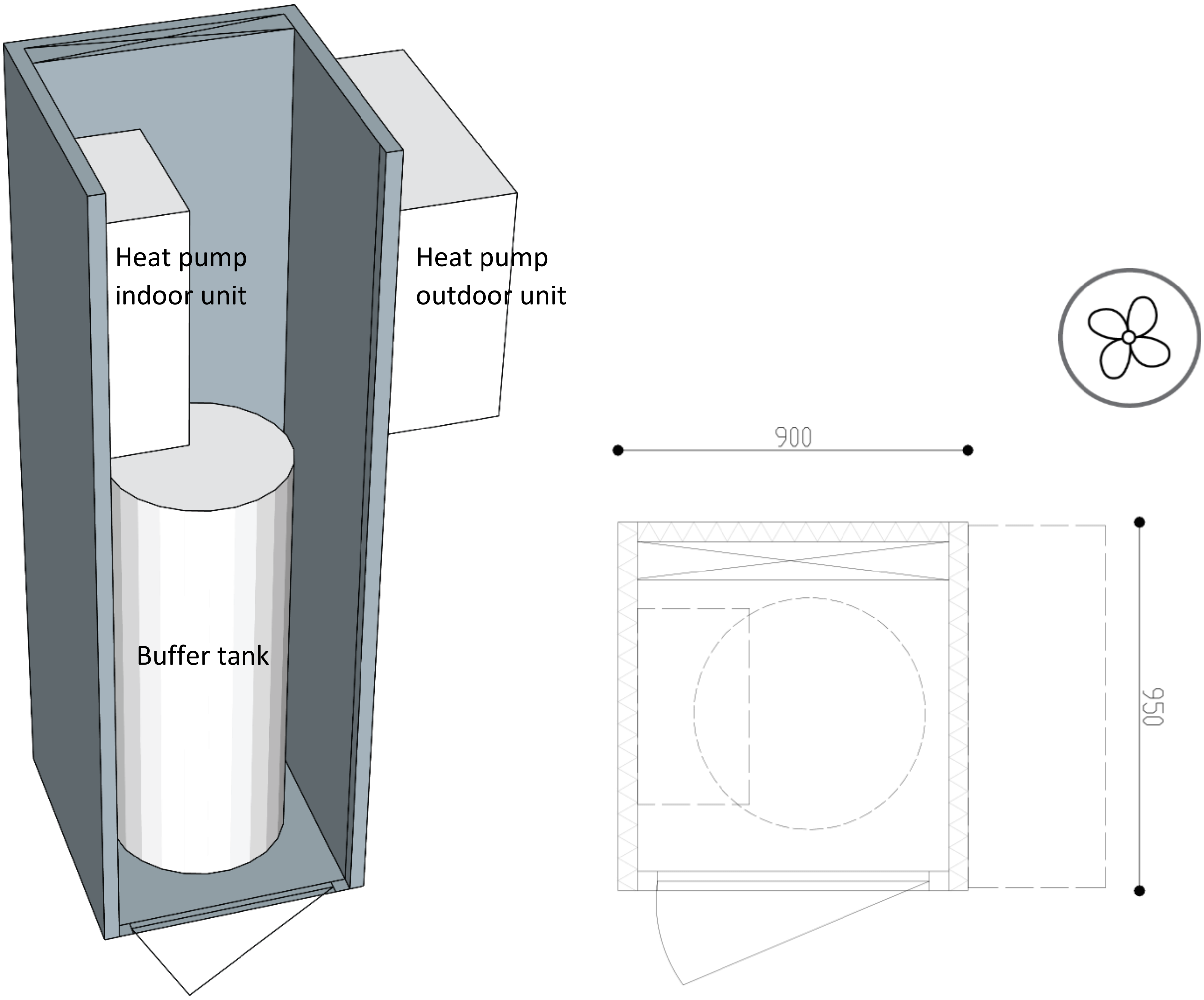


Figure 51: Visual representation of building services unit for concept C

Concept D
Concept D uses the PVT panels as a heat source for the heat pump. The PVT panels are placed on the roof in South direction. The hot water will be transported via pipes in the shaft to the heat pump. The building services unit is placed in the backyard and only consists of the heat pump. The system for providing ventilation will be placed in the unoccupied attic of the building. A visual representation of the building services unit is given in Figure 52.

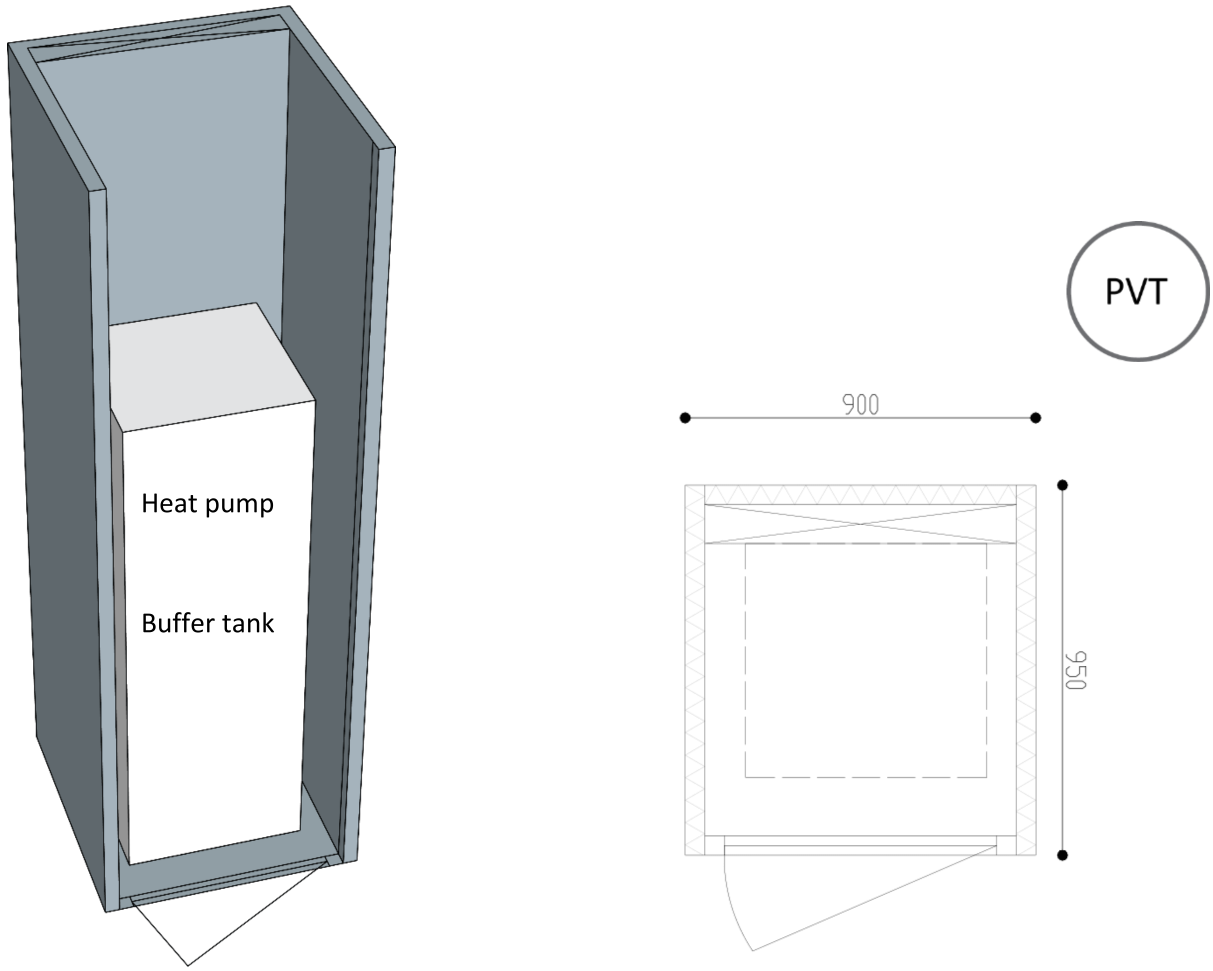


Figure 52: Visual representation of building services unit for concept D

10.1.3 Providing ventilation
Different from the other individual building services is the collective provision of ventilation. This system is collective considering that the mechanical exhaust is already collective in the current situation. Together with the unoccupied attic, it is a good solution to place the system on the attic and to connect the exhaust. The ventilation will be provided in two ways for the low and high impact:

Low impact
For the low impact variant, the ventilation will be provided by a CO_2-regulated exhaust. This exhaust will start working when the CO_2-level in the apartment is too high. The unit is situated on the attic. The system will be connected to the existing exhaust ducts.

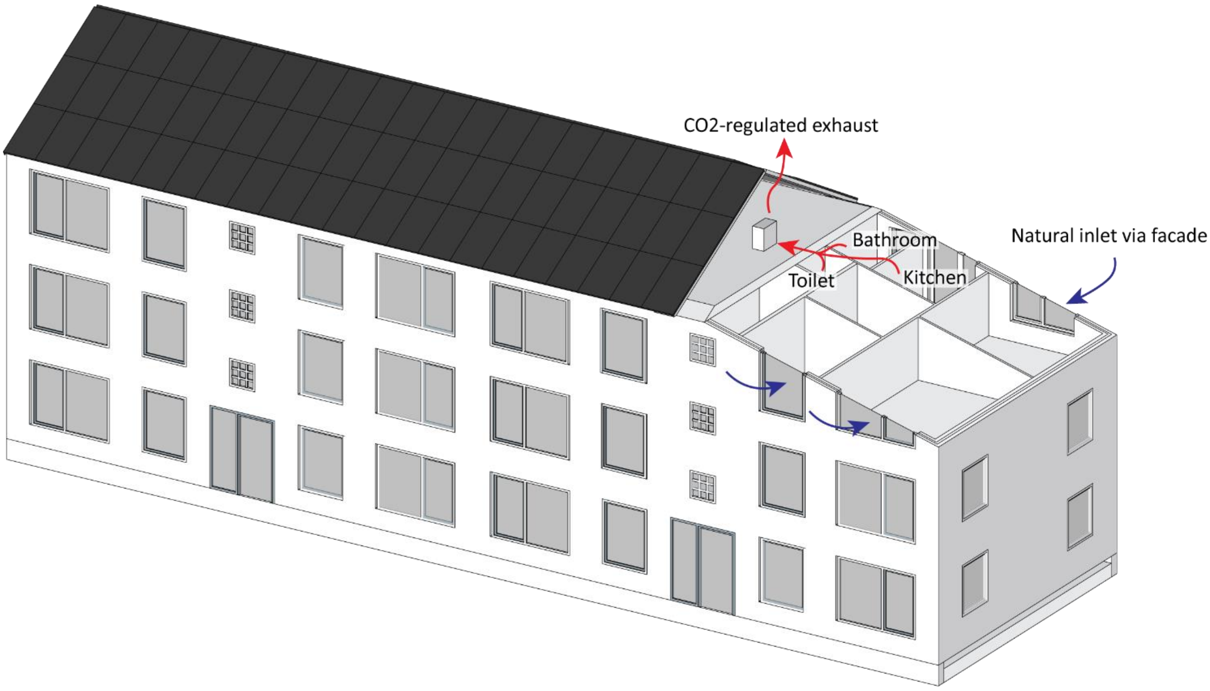


Figure 53: Provision of ventilation with CO_2-regulated exhaust in low impact variant

High impact

In the high impact variant, ventilation will be provided by a heat recovery system. This system is also placed on the attic of the building. The inlet ducts will be integrated into the façade and the existing exhaust will be used to return the air to the system. The system extracts the heat from the exhaust air and uses it to preheat the fresh air. How the inlet ducts will be integrated into the façade will be explained in the next chapter.

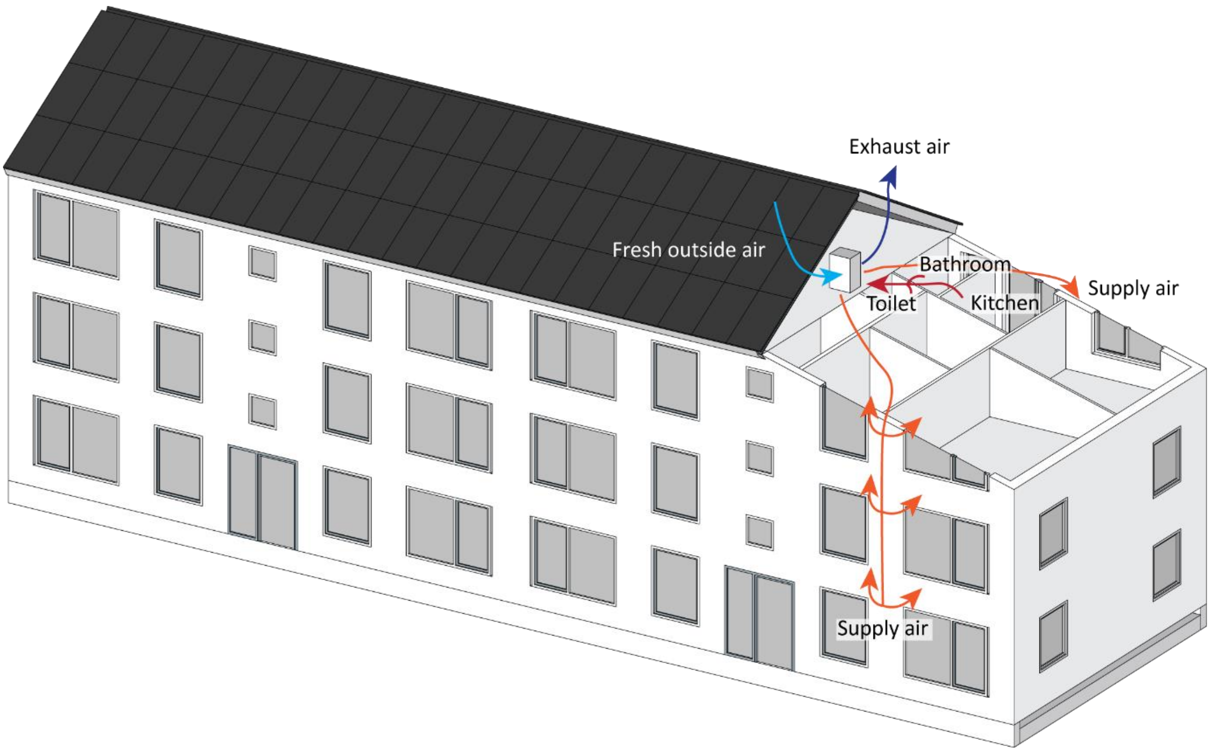


Figure 54: Provision of ventilation with heat recovery system in high impact variant

10.2 Collective services

In the previous paragraph, individual building services for each apartment are explained, but it is also possible to share some of the building services. It is possible to share the heat pump, buffer tank and system that provides ventilation with three apartments or with the entire building. In this paragraph, a short elaboration will be done on collective building services. Since for up-scaling the system this is not preferred, there will be no elaboration on this topic.

10.2.1 Location of building services

The collective building services can be placed on the unoccupied attic of the building. There are some side notes for collective services. The building services needs to be placed on the attic, right know the attic is not accessible. If the building services cannot be placed via the staircase or the apartments then it may be necessary to disassemble a part of the roof. Secondly, if the building services are placed on the attic maybe some extra pipework in the apartments is necessary. There is also an individual meter needed at every apartment to make it possible to pay the energy bill per apartment. Finally, a loft ladder is needed to have access to the attic so that the building services can be maintained. Figure 55 shows the possible solution for collective building services.

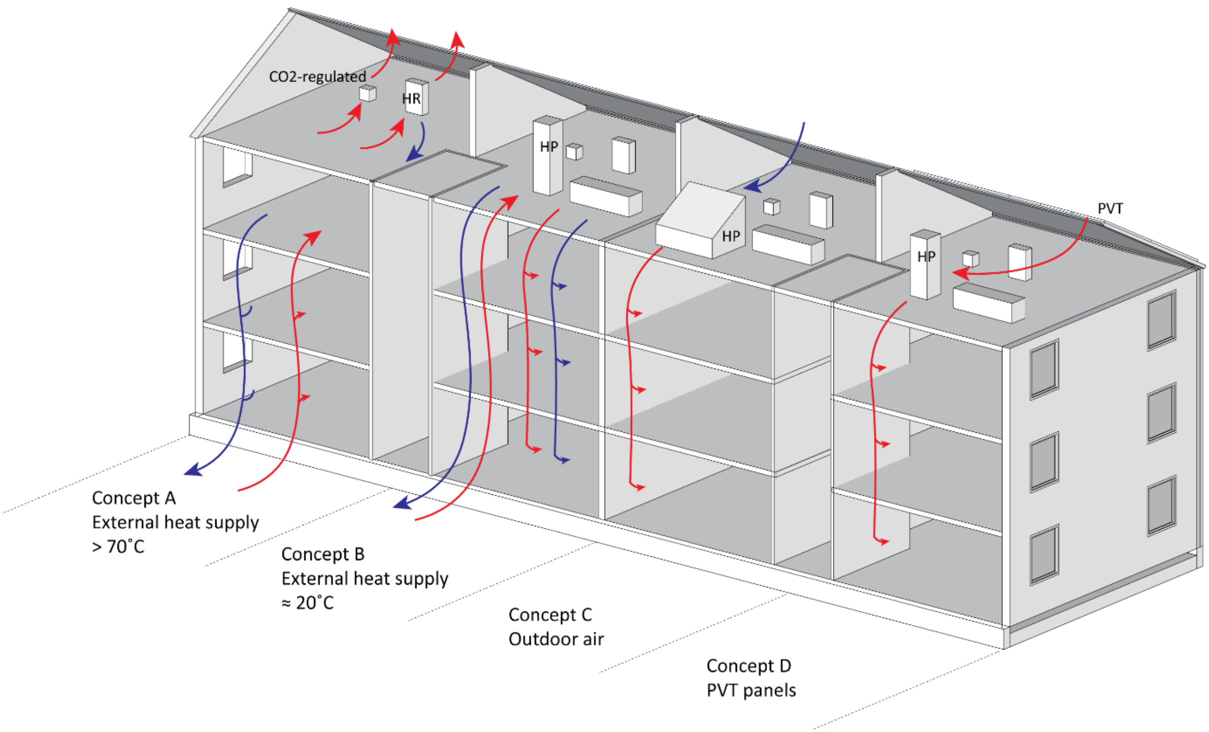


Figure 55: Collective building services for every concept

11. Low impact

Before the simulation phase, it was decided to simulate a low and a high impact variant. The impact level can be dependent for example on the impact on the building, labour time and costs. They have different R_c-values and U-value for the building envelope. Also, the provision of ventilation is different. In the low impact variant, the inlet of air is natural and the exhaust is CO_2-regulated with a collective system. In the high impact variant, the ventilation is fully mechanical provided via a collective heat recovery system. The other systems that provide room heating and DHW are in the different variants the same. The low impact variant will meet BENG 2 and 3 (primary energy consumption and part renewable energy). This variant will not meet BENG 1 (energy demand).

In principle, the low impact variant takes fewer interventions than the high impact variant, which results in lower R_c-values of the building envelope. Which interventions will be explained by the different components of the building envelope.

11.1 Floor

Since the crawl space of the case-study has a limited height, the only option to increase the insulation value is to insulate the ground. As mentioned in Chapter Design criteria this can be done by several materials. These materials are small components that need to be injected into the crawl space via a hose in the crawl hatch. To make a distinction between the low and high impact variant there is chosen for different materials with different R_c-values and costs. The low impact variant will be filled with EPS chips, which will lead to an R_c-value of 4,0 $m^2 \cdot K/W$.

11.2 Façade

Cavity insulation

As mentioned in Chapter Design criteria only the cavity of the façade will be filled with insulation. A check is necessary to see if the cavity is polluted with material, otherwise, cavity insulation may not be possible. The cavity will be filled with small components: EPS Thermo pearls. They will be injected via a little hole at different spots of the façade to fill the entire cavity. This will lead to an R_c-value of 2,1 $m^2 \cdot K/W$.

Remain window frames

The existing window frames will remain in the low impact variant. Considering that the type of the existing glazing is unknown, it might be necessary to replace them for another glazing.

Remain balcony

To save costs and to make a distinction between the low and high impact variant, the balcony will not be replaced. This means that the building services unit has to be placed at another location than with the high impact variant. The new location of the unit will be explained in the next paragraph.

11.3 Roof

Research of Bokel and Van den Ham (2010) shows that for unheated attics, insulation in the ceiling of the top floor is more effective than roof insulation. Therefore is chosen to keep the roof package of the existing building intact. Insulation will be placed on the attic of the building since it is unoccupied. This will lead to an R_c-value of 3,4 $m^2 \cdot K/W$. PV or PVT panels will be placed on the existing roof.

11.4 Building services unit

As mentioned above the balcony will remain the same to save costs and to make a distinction between the low and high impact variant. Eurocode NEN-EN 1991-1-1 says that a balcony can carry around 2,5 kN/m^2, approximately 250 kg/m^2. But the building services unit will have a higher weight, mostly due to the buffer tank. Therefore another location needs to be found. In Figure 56 the location of the building services unit for the low impact variant is indicated. It will be placed next to the balcony. But the dimensions of the unit are bigger than the dimensions available next to the balcony. So a substructure is designed to transfer the loads of the unit, but the unit will have a small overhang on the balcony. Therefore it will be accessible via the balcony. This is shown in Figure 57. Firstly, the substructure will be placed and finally, the building services unit will be slide in the substructure. It is necessary to have some tolerances to place the unit in the right place.

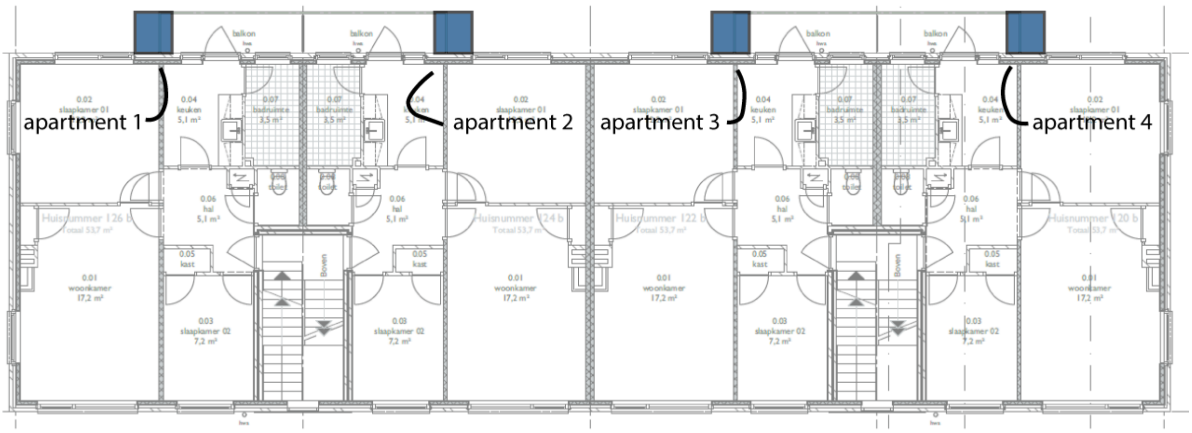


Figure 56: Extra option location building services, North facade

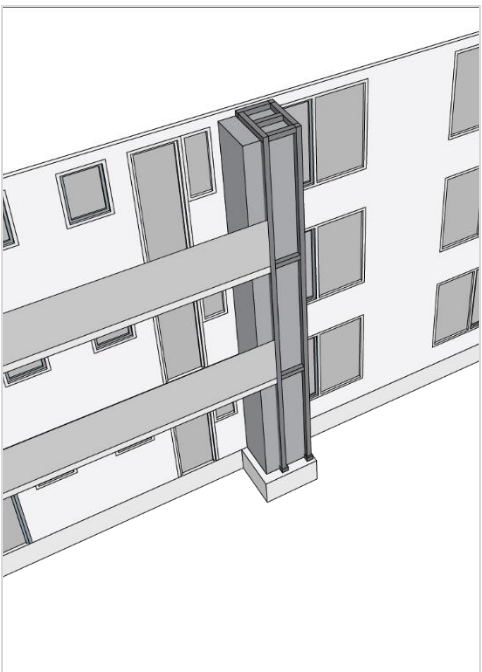


Figure 57: Substructure to transfer loads of building services unit

11.5 Components of refurbishment

In Figure 58 and Figure 59 the different components of the refurbishment phase of the South and North façade are shown. Firstly, insulation will be added in the crawl space via a hose in the crawl hatch. Secondly, the cavity will be filled with insulation. These will be injected via multiple holes in the mortar of the brickwork. Insulation will be added on the attic of the building, to prevent heat loss via the roof. PV or PVT panels will be placed to produce electricity. Finally, a window frame will be placed for the main entrance, to continue the insulation line and prevent heat losses.

Table 22 shows an overview of the R_c-values of the final design for the low impact variant. With those values, the Dutch requirements for refurbished buildings will be met.

	Floor	**Façade**	**Roof**
Low impact	4,0 $m^2 \cdot K/W$	2,1 $m^2 \cdot K/W$	3,4 $m^2 \cdot K/W$

Table 22: R_c-values low impact final design

11.6 Final simulation after the design phase

The R_c-values of the design criteria are used as an input for the design phase but those R_c-values has changed during this process. Therefore the energy consumption is simulated again to check if the BENG regulations are still met.

The outcome of this simulation is stated in appendix G. It can be seen that the difference between the simulation phase and design phase are small. The low impact variant does still meet BENG 2 and 3 (primary energy consumption (2), part renewable energy (3)).

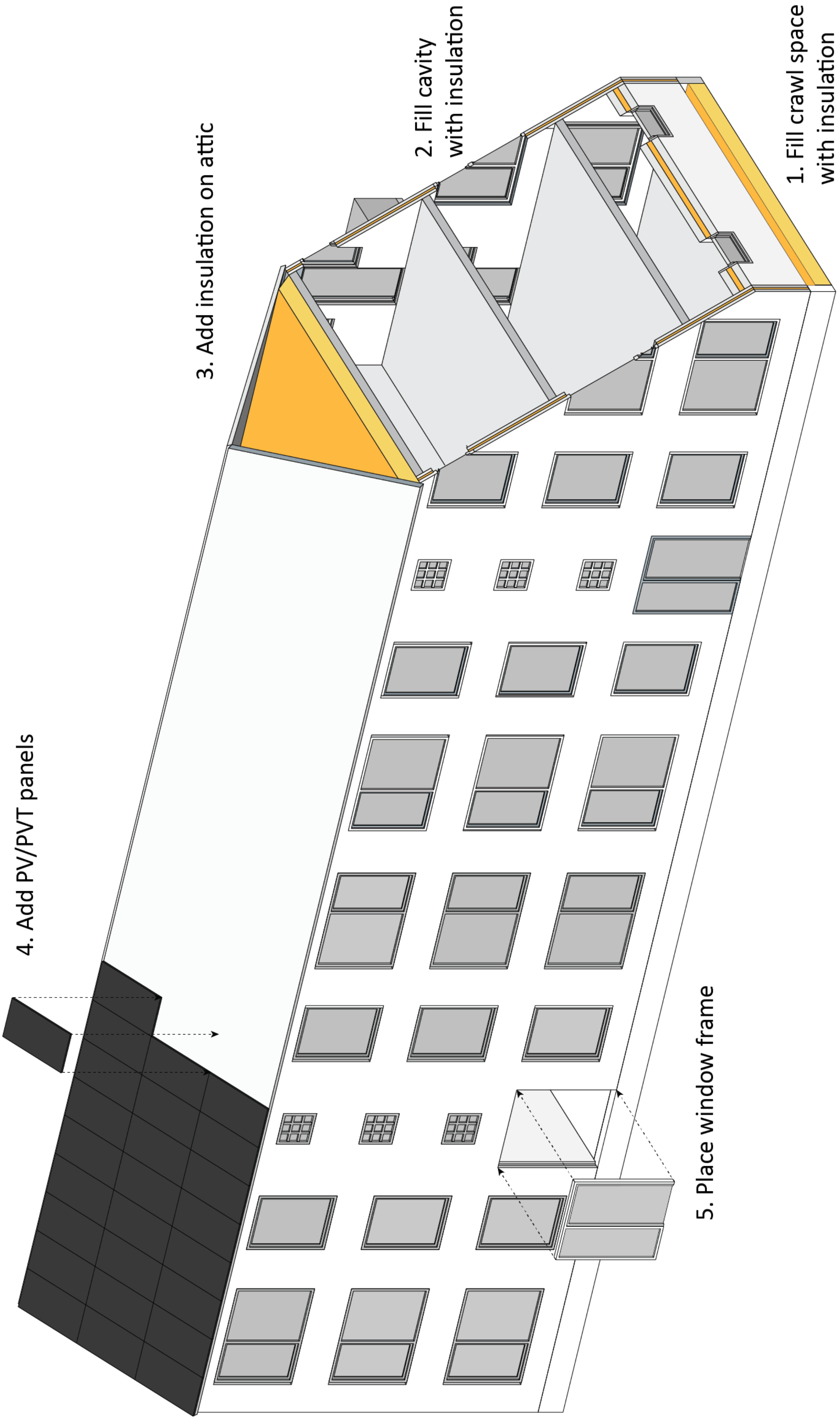


Figure 58: Low impact components refurbishment of the South façade

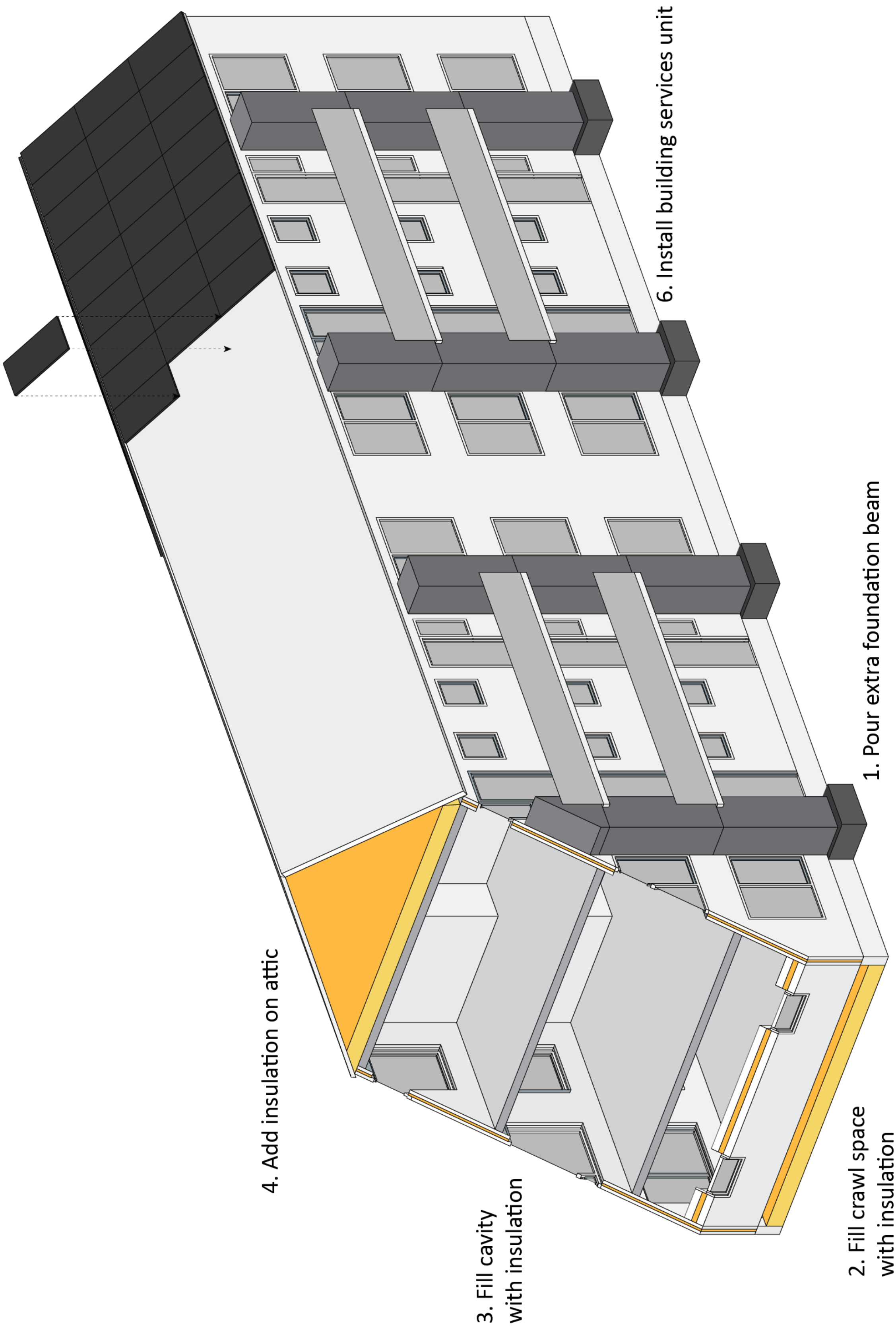


Figure 59: Low impact components refurbishment of the North façade

12. High impact

This chapter will consist of the design of the high impact variant. Simulations show that this variant will meet all BENG regulations (energy demand, primary energy consumption and part renewable energy). The content of the high impact variant will be explained in the next paragraphs. The interventions will be explained by the different components of the building envelope. Since this variant asks for more interventions this will be more designed in detail compared to the low impact variant.

12.1 Floor

To increase the insulation value of the floor, ground insulation will be placed. It is not possible to use floor insulation since the height of the crawl space is limited. Different materials can be used as mentioned in Chapter Design criteria. These materials must be made of small components so that they can be injected into the crawl space via a hose in the crawl hatch. The high impact variant will be filled with EPS Thermo pearls, which will lead to an R_c-value of 5,6 $m^{2}\cdot K/W$.

12.2 Prefabrication vs in-situ made façade elements

Before a choice can be made on how the design will look like in detail, an analysis of prefabricated elements vs. in-situ made elements needs to be made. Schwehr, Fischer and Geier (2011) designed 10 steps towards a prefab renovation module. They give three different options for renovation strategies that are not fully prefabricated but can still be the best solution for a renovation concept. These are respectively variations 2-4 in Table 23. Variation 5 is a fully prefabricated façade module. Different parameters concerning the building envelope and parameters on the building site are compared. Since the case-study derives itself to only fill the cavity with insulation material, an extra variation is added (1. Cavity insulation).

For the design of a prefabricated approach where different energy systems can be applied, a decision needs to be made on the prefabrication level of the approach. Since the design consists of a low and high impact variant two prefabrication or in-situ made levels can be chosen. The low impact variant should reach an R_c-value of 2,14 $m^{2}\cdot K/W$, as stated in the previous chapter this can be reached by filling the cavity with insulation. Only filling the cavity with insulation results in a very short construction time, which is one of the main criteria points. Plus the apartments can be occupied during the renovation.

Another choice that needs to be made is the level of prefabrication of the high impact variant. Since the main criteria point is the construction time and the occupancy of the apartments. The following options are excluded: 1. cavity insulation, 2. external composite insulation + plaster and concept 3. framework + cladding added manually. These options are made in-situ and therefore not an option if a short construction time is one of the main criteria points. The difference between variation 4 and variation 5 is that in variation 4 the insulation layer and the cladding will be placed in-situ. Variation 5 is fully prefabricated and consists already of the insulation layer plus the cladding. In variation 4 it is possible to integrate the building services in-situ and fill the remaining space with insulation. In variation 5 the building services need to be integrated in the factory. Therefore, there is less space for adjustments on site. Since construction time is one of the main criteria points there is chosen for variation 5. This means that the prefabricated elements need to be very accurate and that there need to be tolerances for adjustments on site.

The next paragraph focusses on the separation of the façade in prefabricated elements and if the façade will be fully prefabricated or semi-prefabricated.

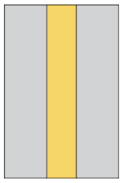
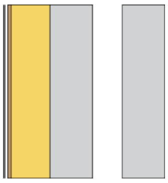
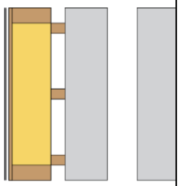
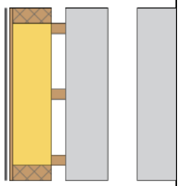
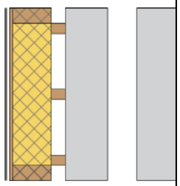
		1. Cavity insulation	2. External composite insulation + plaster	3. Framework + cladding added manually	4. Partly prefab without cladding and insulation	5. Prefab with cladding
	Schematic representation					
Building envelope	**Thermal characteristics**	Thickness of insulation is limited.	Thickness of insulation layer is limited.	Thickness of insulation is unlimited. Possible ventilation by cavity.	Thickness of insulation is unlimited. Possible ventilation by cavity.	Thickness of insulation is unlimited. Possible ventilation by cavity.
	Constructive characteristics	No additional loads for existing wall.	No additional loads for existing wall.	Existing wall and foundation have to be improved.	Existing wall and foundation have to be improved.	Existing wall and foundation have to be improved.
	Architectural appearance	Existing wall	Plaster or brick slips.	Lightweight cladding fixed manually.	Lightweight cladding fixed manually.	Lightweight cladding fixed in factory.
Building site	**Occupancy**	No restrictions.	Restrictions and discomfort for occupancy.	Restrictions concerning long time-span.	Shorter construction time with minimized influences for occupancy.	Minimized restrictions and discomfort for occupancy.
	Construction time	Very short construction time-span.	Long construction time-span.	Long construction time-span.	Shorter construction time-span.	Very short construction time-span.
	Delivery	Company car.	Truck-standard	Truck-standard	Lorry or truck, dependent on element size.	Lorry or truck, dependent on element size.
	Area for set-up and mounting	Area for ladder/ scaffolding necessary.	Area for scaffolding necessary.	Area for scaffolding necessary.	Building, mobile or truck-mounted crane.	Building, mobile or truck-mounted crane.
	Process	Inspection of cavity on site.	Surface has to be in the range of evenness tolerance.	Uneven surfaces can be compensated with substructures.	Uneven surfaces can be compensated with substructures.	Careful digital scan of building.

Table 23: Prefabricated vs. in-situ made façade elements. Adapted from (Schwehr, Fischer, & Geier, 2011)

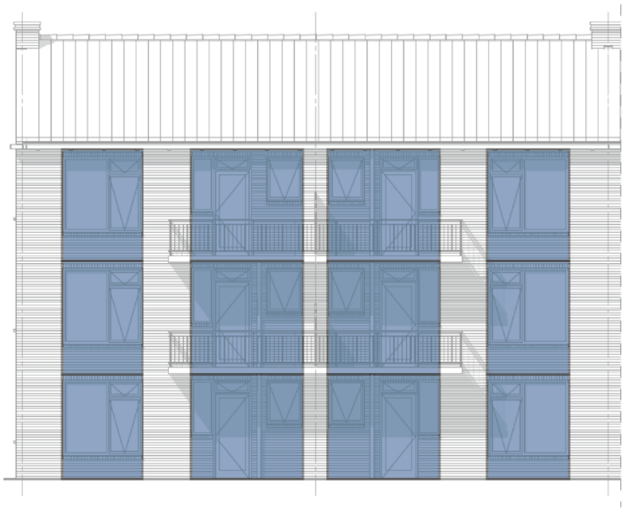
12.3 Division prefabricated façade elements

In the previous chapter is decided to prefabricate the façade elements. To which curtain level is dependent on the integration of the building services and will be decided in a later chapter. The prefabricated elements can have different sizes so the façade can be divided into different parts. In this chapter different divisions of the prefabricated elements will be analysed by using the lay-out of the façade of the apartment building in Vlaardingen. There are two types of prefabrication: semi-prefabricated elements and fully prefabricated elements.

12.3.1 Semi-prefabricated elements

With the semi-prefabricated elements, smaller elements of the façade will be prefabricated. For example floor height window elements or only the opaque elements of the façade, as can be seen in Figure 60 and Figure 61. The other parts that are not highlighted are elements that will be made in-situ. Pros and cons will be mentioned for each division.

Semi-prefabricated: only window elements



+ Difficult connections in façade are prefabricated;
+ Vertical piping can be connected in-situ;

- Small elements;
- Construction time is long.

Figure 60: Semi-prefabricated: only window elements

Semi-prefabricated: only opaque elements

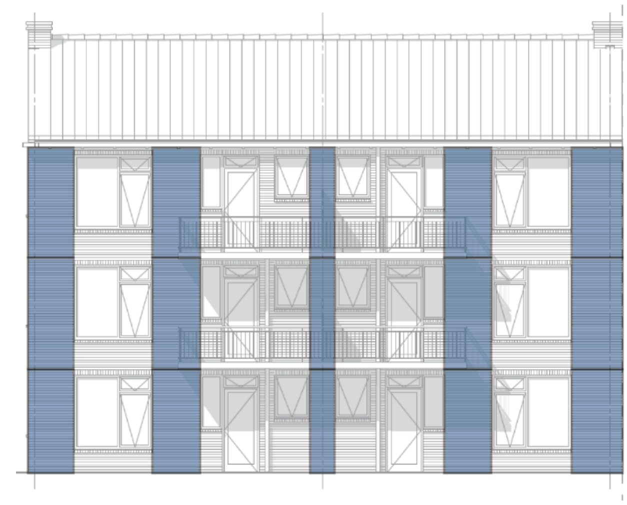


Figure 61: Semi-prefabricated: only opaque elements

+ Easy adjustment for different heights of windows;
+ Vertical piping can be prefabricated;

- Small elements;
- Construction time is long;
- Framework is still needed for windows.

12.3.2 Fully prefabricated elements

With the fully prefabricated elements, the entire façade will be prefabricated, as can be seen in Figure 62 and Figure 63. Those fully prefabricated elements can be made of small elements or for the entire width and height of the apartment. The elements that are not highlighted will be made in-situ. For each division of the façade pros and cons will be mentioned.

Fully prefabricated: small elements

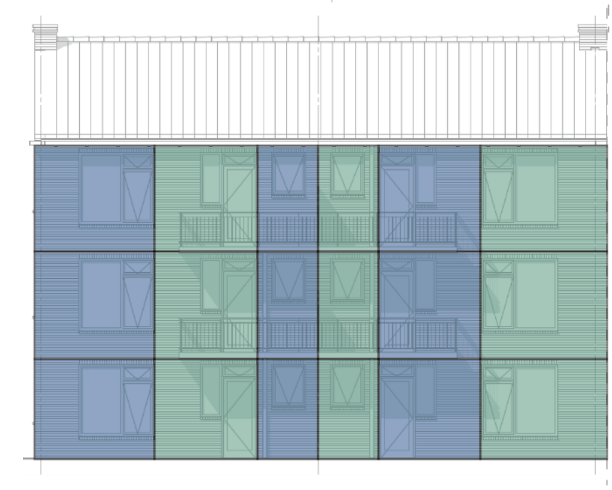
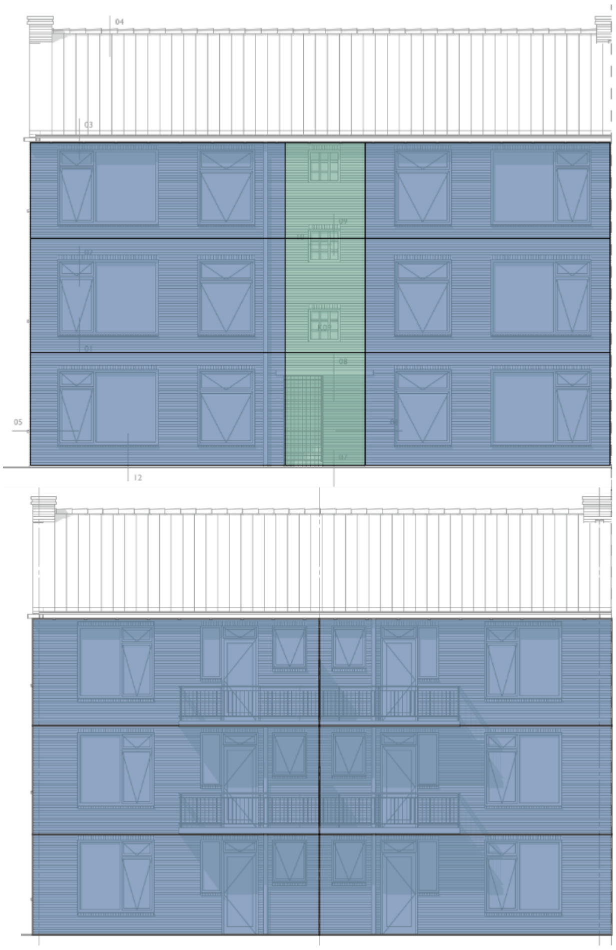


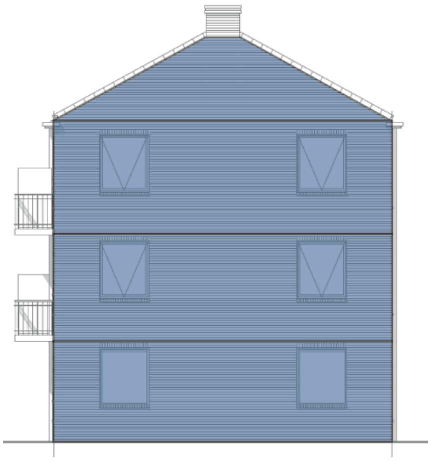
Figure 62: Fully prefabricated: small elements

+ Less weight of elements compared to the apartment width elements;
+ Vertical piping is prefabricated;

- More connections compared to the apartment width elements;
- Construction time is longer (more crane work).

Fully prefabricated: elements apartment width





+ Difficult connections in façade are prefabricated;
+ Vertical piping is prefabricated;
+ Construction time is shorter;

- High weight of element.

Figure 63: Fully prefabricated: elements apartments width

After the analysis of the different divisions of the façade, a choice needs to be made to start with the design of the prefabricated renovation approach. Important criteria points are the construction time (therefore less disturbance for the occupants) and the possibility to integrate building services into the façade. It is both possible to integrate the building services into the façade with a fully or a semi-prefabricated façade. The building services can be prefabricated or they can be placed in-situ. When they will be placed in-situ the construction time will increase.

With the fully prefabricated elements, the construction time will be less than with the semi-prefabricated elements. The measurements of the existing building need to be very accurate since there is not much space left for adjustments during the placement of the elements. With the semi-prefabricated elements, the adjustments can be made in the parts that will be made in-situ.

Since construction time is the most important criteria point, there is chosen to design fully prefabricated elements that are apartment width. The construction time will be the shortest which results in less disturbance for the occupants. Extra attention is needed for the adjustments of the elements on site.

12.4 Design prefabricated element

As stated in the previous paragraph the element is fully prefabricated and is apartment width. In Figure 64 and Figure 65 the different layers of the prefabricated element can be seen. The first layer is an insulation layer with a thickness of 20mm. Since the existing façade will not be completely flat, this layer is needed to absorb tolerances of the existing façade. The second layer is the wooden framework, it consists of wooden posts of 140 x 60mm. The ventilation duct will be integrated into the wooden framework. Later it will be filled with insulation and finished with a wooden plate. Then the new plastic window frames with triple glazing will be placed. The last layer is the cladding of the building. In this situation, brick strips are used, but it is also possible to finish the element with another type of cladding. The total package has an R_c-value of 4,6 $m^2 \cdot K/W$ and a thickness around 200mm, dependent on the type of cladding. A specific calculation can be found in appendix E. With this value, the prefabricated elements meet the Dutch building regulations of new buildings.

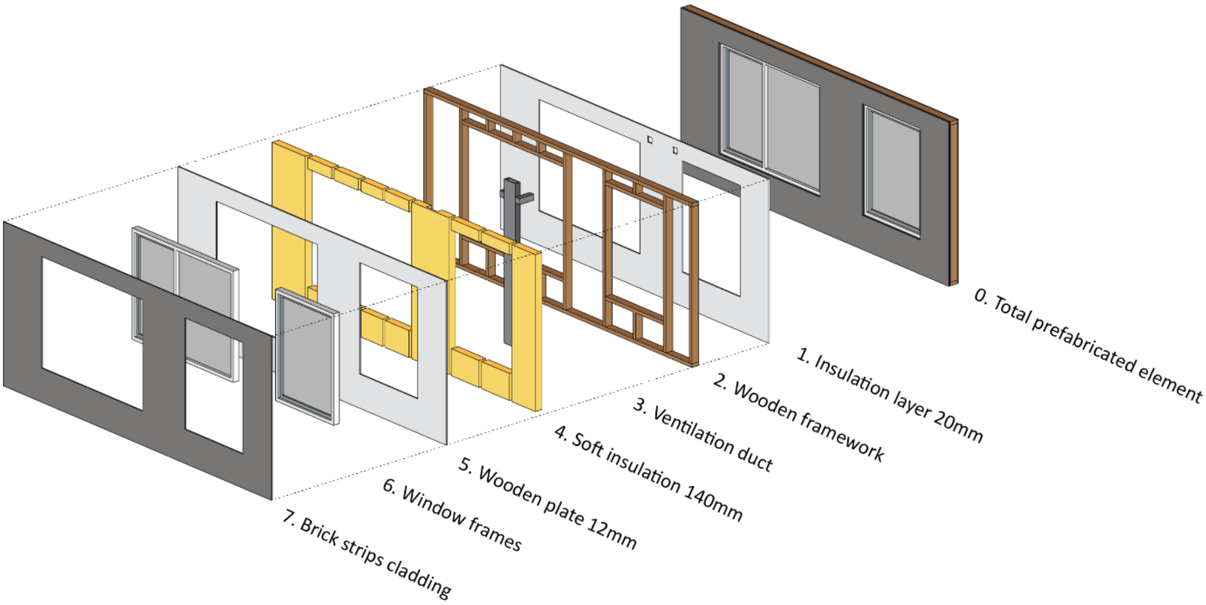


Figure 64: Layers of the prefabricated element of the South façade

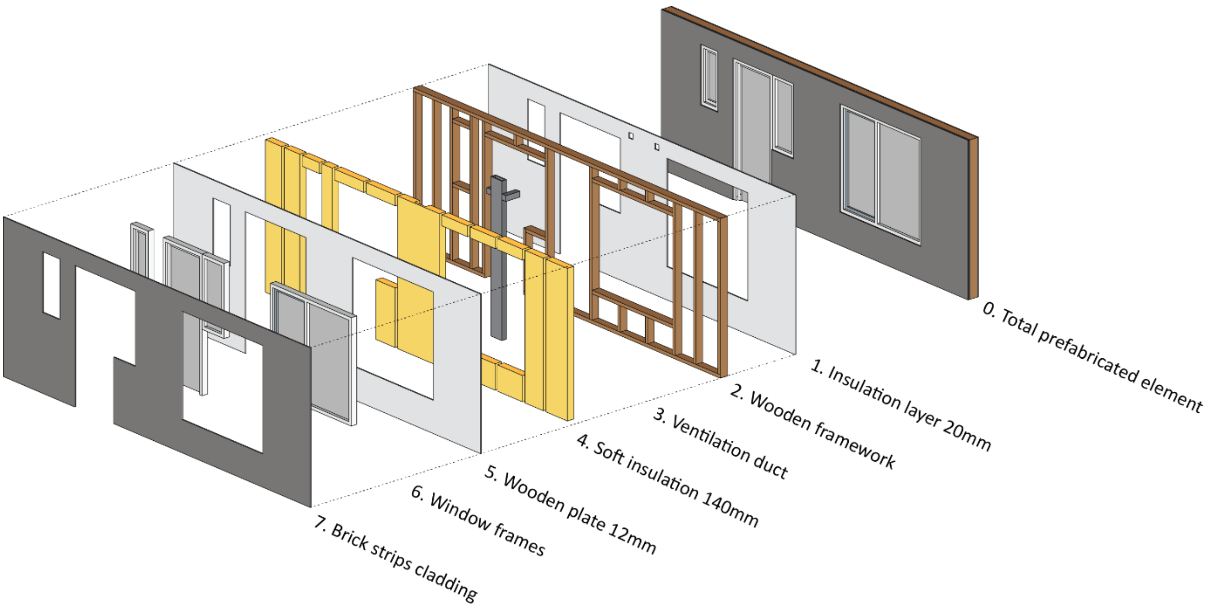


Figure 65: Layers of the prefabricated element of the North façade

12.4.1 Tolerances

Since the existing building will be wrapped up with a new façade skin, it is necessary to take tolerances into account. Extensive building measurements are important for the prefabrication of the elements. But still, there is a chance that some tolerances need to be taken on site. The prefabricated element needs to absorb the tolerances. The prefabricated elements need to be levelled out in the horizontal and vertical direction. Some extra elaboration is needed to see how this can be made possible in detail.

12.4.2 Structural interventions (foundation)

It is not possible to transfer the loads from the prefabricated elements to the existing construction of the building. The existing construction is not calculated to transfer the extra loads from the prefabricated elements. So another solution is necessary to transfer the loads of the elements. An extra foundation needs to be poured that is chemically anchored to the existing foundation. In Figure 66 a visual representation is given.

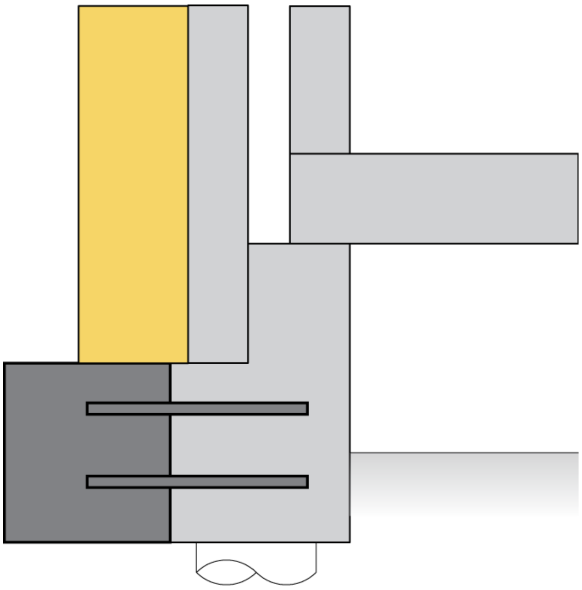


Figure 66: Extra foundation to transfer loads of prefabricated element

12.4.3 Integration of ventilation ducts

In the new design, a heat recovery unit will provide ventilation. This unit will be placed in the attic of the building. Ventilation ducts with fresh air will be integrated into the façade. The dimensions of these ducts are dependent on the required ventilation that is needed for the apartments. Each apartment will have two integrated ducts for the supply of fresh air. Those ducts are each on another side of the façade and are connected to the living room – bedroom 2 or the kitchen - bedroom 1. By integrating the ducts in these parts of the façade, the distance is as short as possible. It requires less work inside the apartments and therefore less disturbance for the occupants. There is an existing mechanical exhaust in the toilet, kitchen and bathroom.

First, it is necessary to calculate the required ventilation for each apartment with the requirements from the Dutch building regulations. The calculation can be found in appendix F. Each apartment has a required ventilation of 259,7 m^3/h. Since there are two ducts for each apartment this value can be divided by two: 259,7 m^3/h / 2 = 129,8 m^3/h. Every pipe in the façade provides three apartments with fresh air, so the value should be multiplied with 3: 129,8 m^3/h x 3 = 389,5 m^3/h. The dimension of the ducts can be calculated with this value plus an excel sheet from Brussé (2009). The maximum allowable speeds of air should be between 3 - 4 m/s (Innozaam, 2017). With this requirement together with the thickness of the façade package, the dimension of the duct will be 270 x 100 mm. In Figure 67 the ventilation principle of one apartment is shown.

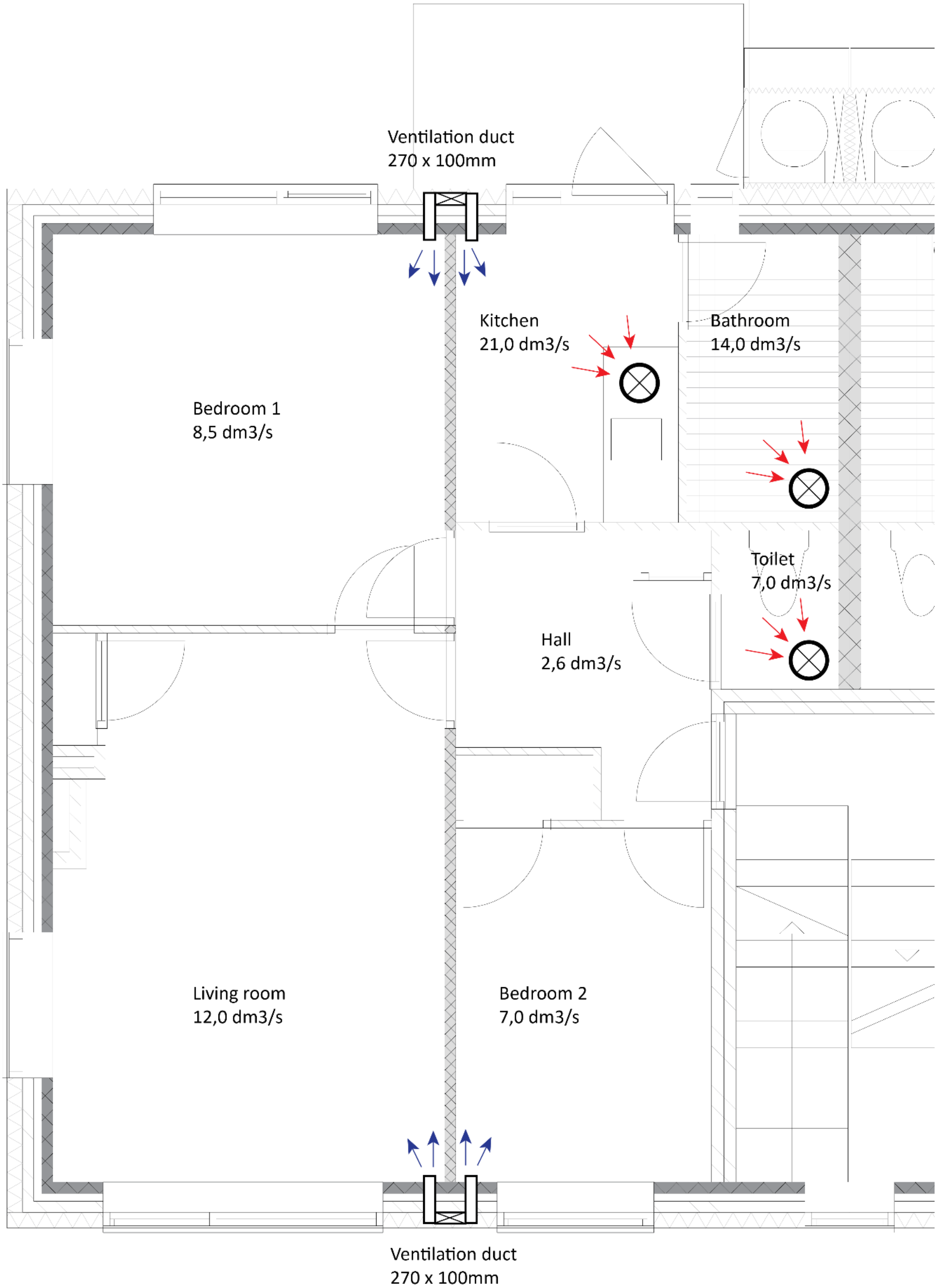


Figure 67: Ventilation system for one apartment

12.4.4 New window frames

To reach the U-value of 0,93 $W/m^2 \cdot K$, that is given by the simulation phase, it is necessary to replace the old window frames. New plastic window frames with triple glazing will be placed. The window frames will fill the existing façade openings. Only one façade opening in the bathroom will be covered by the new building services unit. But since a façade opening in the bathroom is desirable, a new window frame will be placed next to the old one. This one will be smaller as the previous one, but it is possible to maintain a façade opening in the bathroom.

12.5 Replacement of balcony

It is necessary to replace the existing balcony with a new one for several reasons. Firstly the prefabricated façade elements take around 200mm of the existing balcony, this will drastically decrease the space on the balcony. Finally, the existing balcony is cold connected to the concrete structure of the building. By replacement of the balcony, a thermal disconnection with the construction can be made, what prevents the cold bridge. Of course, the replacement of the balcony will lead to more disturbance for the occupants. But after the 2ndSKIN refurbishment, the occupants were very satisfied with their new and bigger balconies.

12.6 Roof

The roof will be insulated with outside insulation. The existing roof cladding material will be removed and the new insulation panels will be placed on top of the existing roof construction. The insulation panels will lead to an R_c-value of 6,2 $m^2 \cdot K/W$. Afterwards, new roof cladding will be placed and on top the PV or PVT panels for electricity production.

12.7 Components of refurbishment

Figure 68 and Figure 69 show the different components of the refurbishment phase of the South and North façade. Firstly an extra foundation beam needs to be poured, this will carry the new prefabricated façade elements. The crawl space will be filled with insulation via a hose in the crawl hatch. Thirdly, the old roof cladding will be removed. Afterwards old window frames and the old balcony will be removed. Then it is necessary to drill holes in the construction of the building. These will be used for the connection of the rooms with the ventilation ducts in the façade element. A new balcony will be placed and a new roof package including PV or PVT panels will be installed. The prefabricated façade elements will be placed and finally, the building services unit will be installed.

Table 24 shows an overview of the R_c-values of the final design for the high impact variant. With those values, the Dutch building regulations for new buildings will be met.

	Floor	**Façade**	**Roof**
High impact	5,6 $m^2 \cdot K/W$	4,6 $m^2 \cdot K/W$	6,2 $m^2 \cdot K/W$

Table 24: Rc-values high impact final design

12.8 Final simulation after the design phase

The R_c-values of the design criteria are used as an input for the design phase but those R_c-values has changed during this process. Therefore the energy consumption is simulated again to check if the BENG regulations are still met.

The outcome of this simulation is stated in appendix G. It can be seen that the difference between the simulation phase and design phase are small. The high impact variant does still meet all BENG regulations (energy demand (1), primary energy consumption (2), part renewable energy (3)).

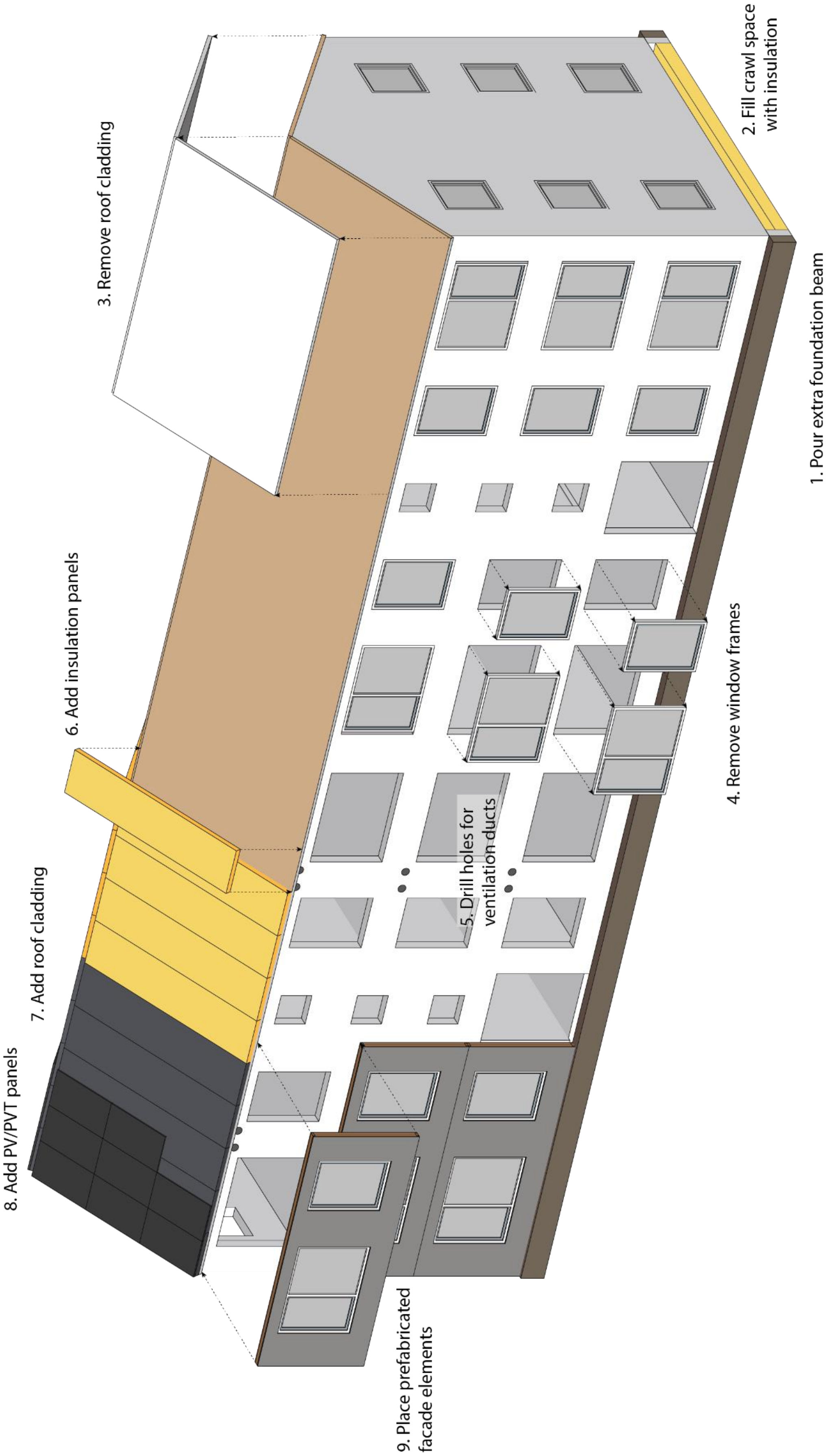


Figure 68: High impact components refurbishment of the South façade

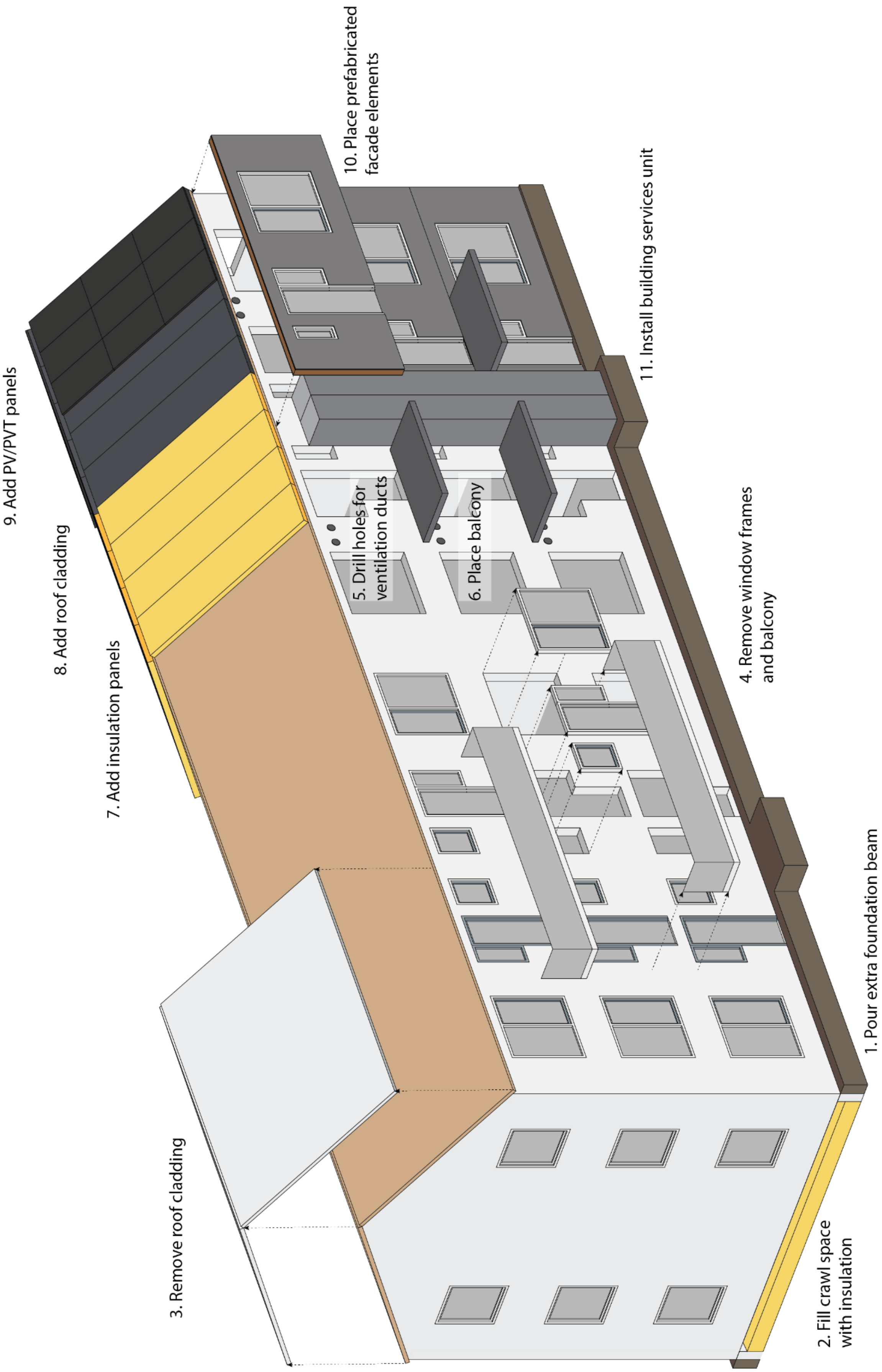


Figure 69: High impact components refurbishment of the North façade

DECISION MAKING

Decision making

This chapter will focus on how the earlier obtained knowledge, from the simulation and design phase, can be applied in different scenarios. Which parameters are dependent on choosing an energy system and will the low impact or high impact variant be applied? This chapter presents a decision-making diagram for answering these questions.

13. Design choice

In the research four main energy concepts are simulated and designed, but how can a housing corporation or a homeowner association choose between the energy concepts? In order to answer this question a decision-making diagram is developed, which can be seen in Figure 70. This diagram includes different parameters and gives alternatives in case the answer is yes or no. This diagram leads to an energy system and a design solution, depending on the different energy sources and context characteristics of the existing building.

13.1 Parameters in decision-making diagram

The starting point of the diagram is the main goal of the refurbishment. The choice for the main goal will influence the path in the diagram. Depending on the path, the first parameter is if the refurbishment is for more than 10 years. If the answer is no, district heating is a good option with a low intervention on building level. However, there will still be an energy bill. So if the refurbishment is for more than 10 years, it is likely to be more cost efficient to choose for a different energy system, since there will be no energy bill anymore. This parameter is dependent on the availability of district heating in the neighbourhood, which cannot be influenced by the housing corporation or homeowners association. District heating is not included in the path of the most sustainable refurbishment since the heat source for district heating is mostly from non-sustainable powerplants.

The second parameter is the availability of excess heat. This heat can be used to heat up the apartments. When using an ATES, an equal demand for heating and cooling is necessary. Therefore, this option depends on the available excess heat or cooling from other buildings, like a supermarket or an office building. If excess heat is available, the possibility to make a network should be considered. This parameter is dependent on the context and cannot be influenced by the decision maker.

The third parameter is the suitability of the roof for PVT panels. If the orientation of the roof is suitable for PVT panels, it is more energy efficient to use them as a heat source for the heat pump compared to the outdoor air. This decision should be made by the housing corporation or homeowners association.

The choice between the low and high impact variant is dependent on considerations of the housing corporation or the homeowners association. In the decision-making diagram, the most important considerations are included. On the next page, they will be listed and explained in the form of a question. Answering those questions will lead to a choice between the low or high impact variant.

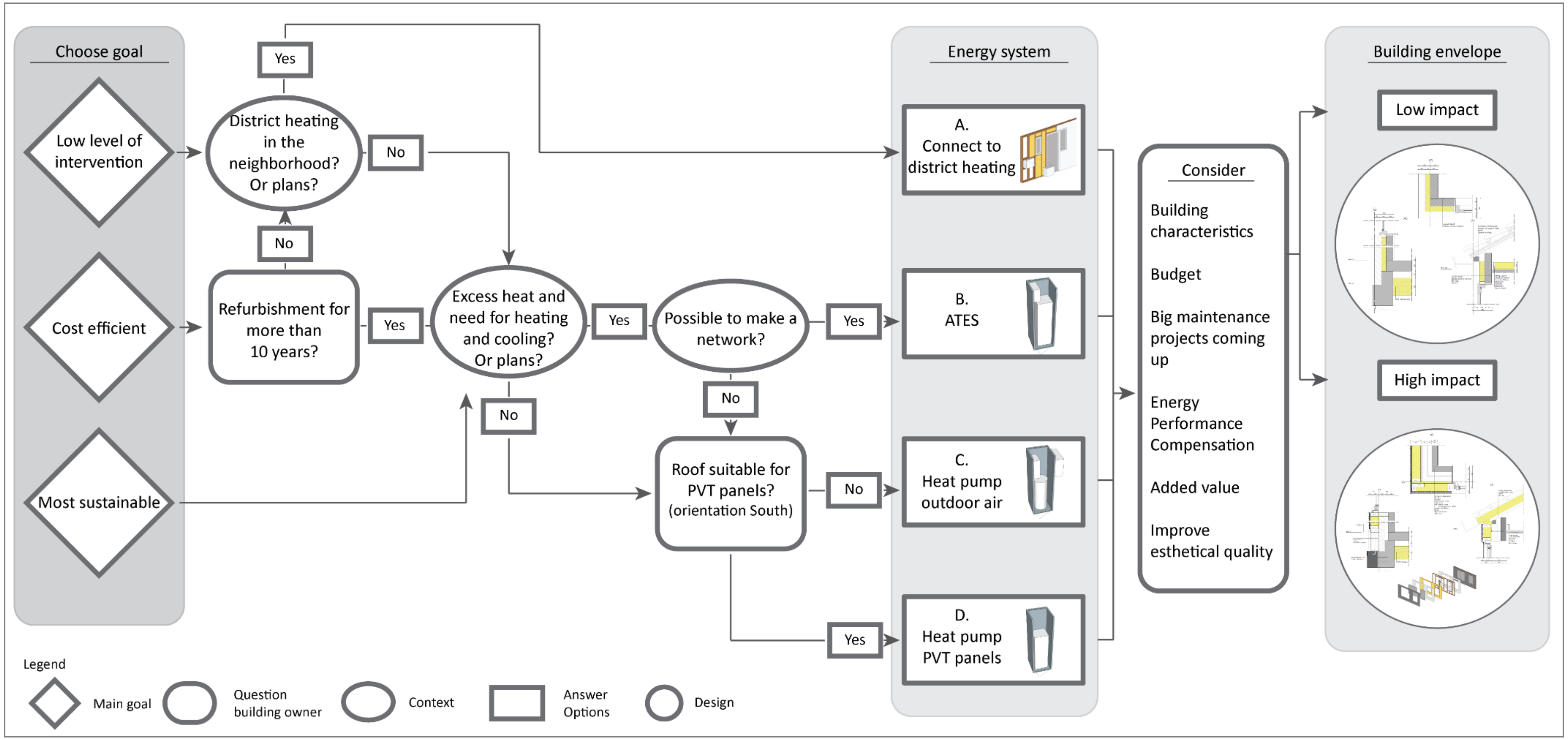


Figure 70: Decision-making diagram

What are the building characteristics?
Important characteristics of the building are a cavity wall and an unoccupied and uninsulated attic. If one of these characteristics is present than the low impact variant is an option, otherwise not.

Is there enough budget for intensive refurbishment?
Since the high impact variant has more intensive energy saving measures, it will require more budget compared to the low impact variant.

Are big maintenance projects coming up?
If big maintenance projects of the building envelope are coming up, it can be more cost efficient to choose for the high impact variant. Because in the high impact variant prefabricated façade elements with new window frames will cover the existing building envelope. In the low impact variant, the appearance from the existing building envelope will remain untouched.

Want to get an EPV (Energie Prestatie Vergoeding [Energy Performance Compensation])? (Consideration only for housing corporations)
When the building is energy neutral, the tenant will not have an energy bill anymore. Since the housing corporation made an investment for the refurbishment of the building, they can make an agreement called EPV. The tenant will pay the same rent but will have a more sustainable and comfortable apartment. One of the requirements to get an EPV is that the heat demand should be below 50 kWh/m^2. When it is below 30 kWh/m^2 the maximum EPV is €1,40/m^2 (RVO, 2016).

If the housing corporation wants the EPV, they should choose for the high impact variant, because with this variant the heating demand will be below 30 kWh/m^2. With the low impact variant, the EPV requirements are not achieved because the heating demand will still be above 50 kWh/m^2.

Is it necessary to give the building added value after refurbishment?
By giving the building added value by different measures, it is possible to increase the pleasure of living of the residents and therefore the rent of the tenants can be increased. The appearance of the building envelope will not change in the low impact variant. Also, the existing balcony will remain intact. If adding value due to refurbishment is desirable, there can be chosen for the high impact variant where the balcony will be replaced by a larger one, which will increase the pleasure of living.

Is it necessary to improve the esthetical quality of the building?
If it is necessary to improve the esthetical quality of the building, there should be chosen for the high impact variant. Here the existing building envelope will be covered with new prefabricated façade elements. The esthetical quality will remain the same with the low impact variant.

13.2 Roadmap case-study

For the different phases of this research, a case-study of a walk-up apartment building at the Soendalaan in Vlaardingen is used. The same case-study will be used to explain the decision-making diagram in Figure 70 of the last paragraph. Since there are more of the same walk-up apartment in the neighbourhood, the decision-making will be done on a broader scale. A comparison between the final energy consumption of the existing building and the refurbished buildings will be made at the end of this paragraph.

The decision-making will be done by making three different scenarios. Although there is no district heating or excess heat in the neighbourhood, it will be assumed that this is available to make it possible to compare the different energy concepts with each other.

The neighbourhood 'Indische Buurt' has 195 similar walk-up apartments. The buildings have a North-South orientation or an East-West orientation. All highlighted buildings in Figure 71 have the same lay-out, building construction, appearance and are built around the same year as the case-study. The numbers represent the number of apartments in each building.

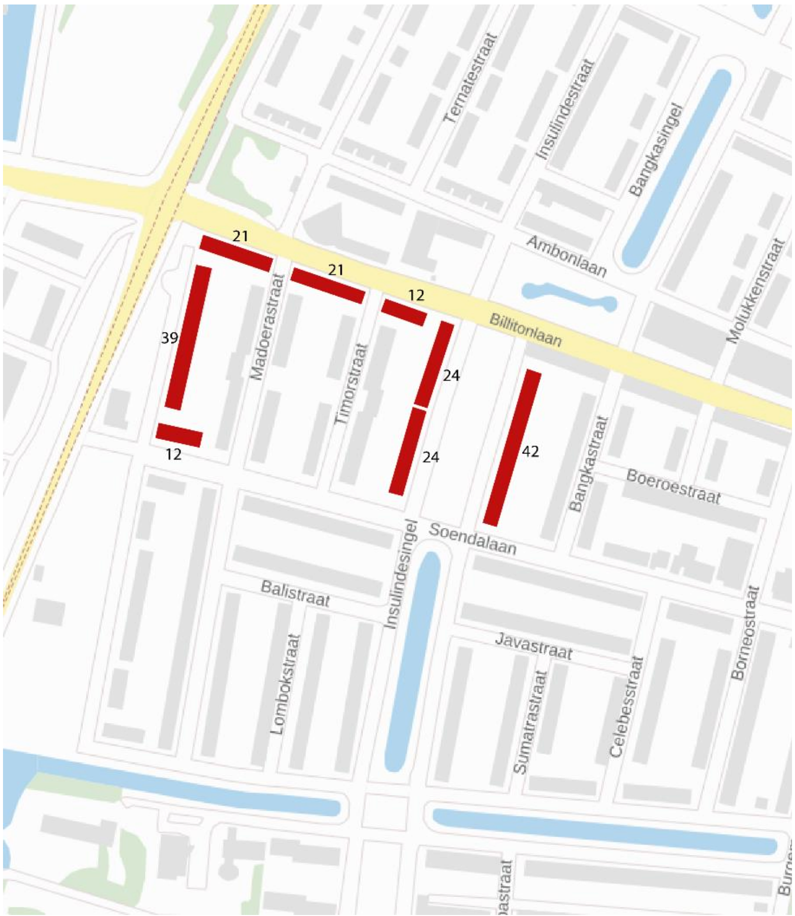


Figure 71: Walk-up apartment buildings in 'Indische Buurt' in Vlaardingen

Scenario 1: Housing corporation with low level of intervention goal

In the first scenario all walk-up apartment buildings are in the possession of a housing corporation. It is assumed that there is district heating in the neighbourhood. They want to refurbish the buildings with a low level of intervention. Which will lead to an energy system connected to the district heating.

To choose between the low and high impact variant for the building envelope the low level of intervention is leading. There is a small budget for the refurbishment. The buildings do have a cavity wall, so there is chosen for the low impact variant.

Energy system:
A. District heating

Building envelope:
Low impact

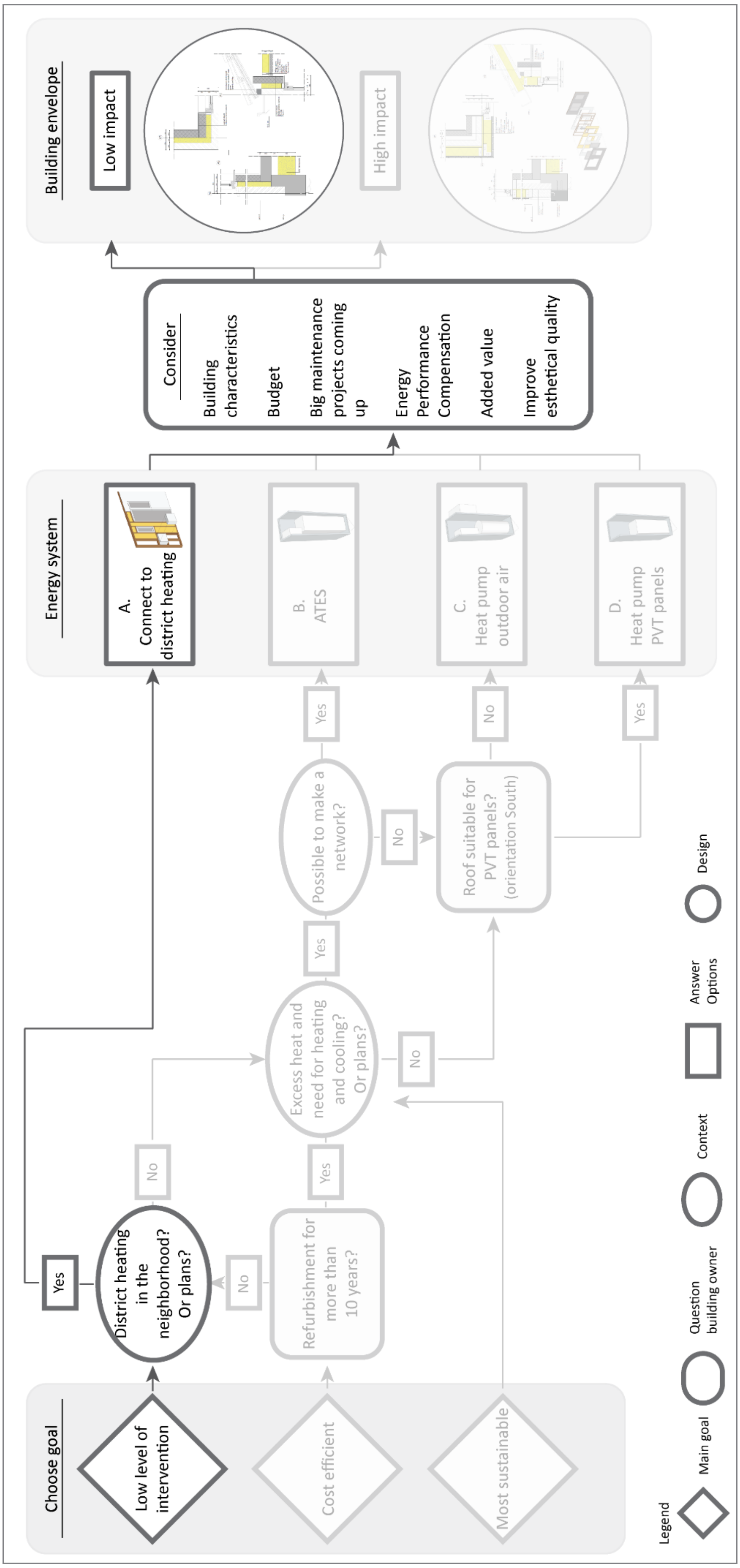


Figure 72: Decision-making diagram for scenario 1

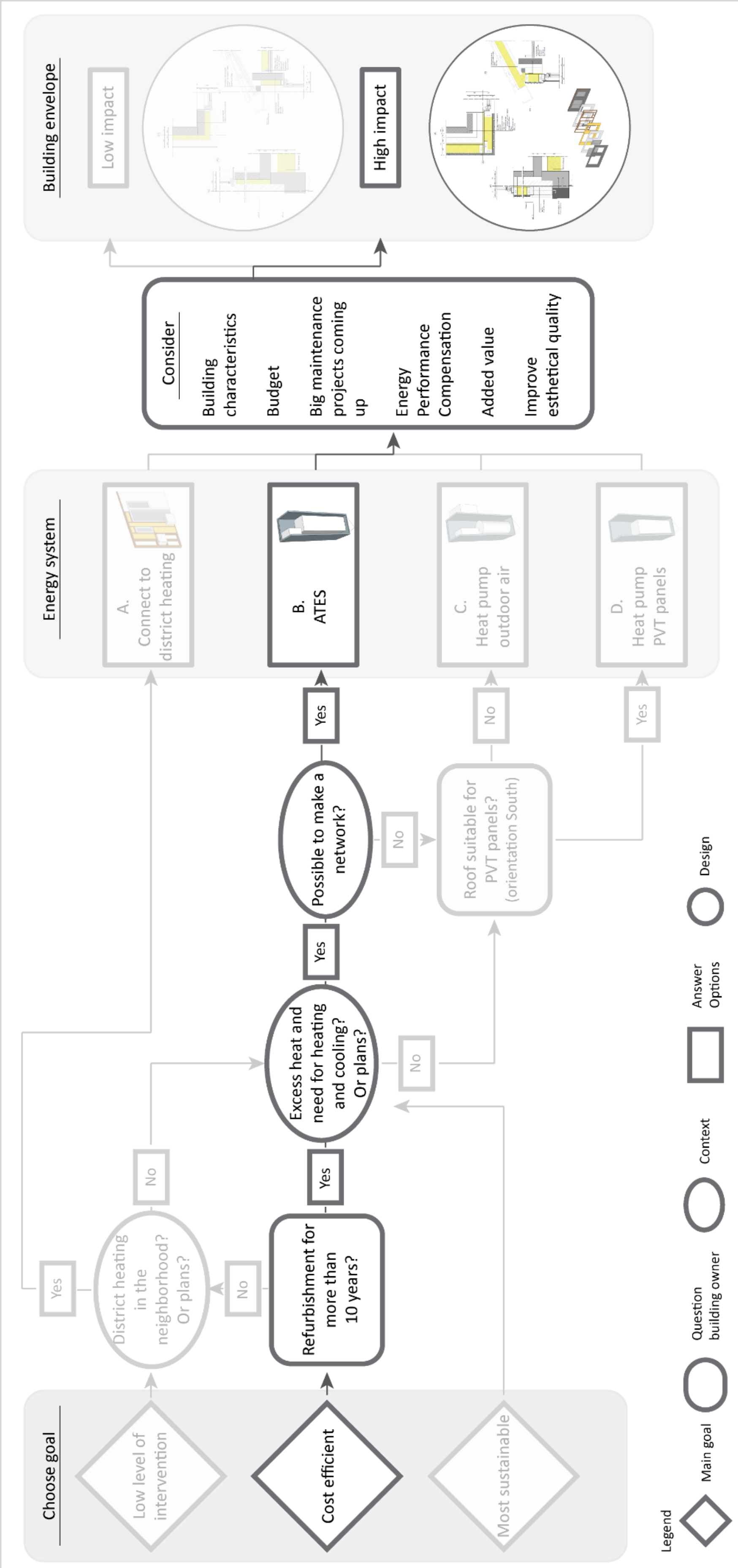


Figure 73: Decision-making diagram for scenario 2

Scenario 2: Housing corporation with most cost efficient goal

In the second scenario all walk-up apartment buildings are in the possession of a housing corporation. It is assumed that there is available excess heat in the neighbourhood. They want to have the most cost efficient refurbishment and want to make the investment for more than 10 years. Which will lead to an energy system connected to an ATES.

To choose between the low and high impact variant for the building envelope, the costs of the refurbishment is leading. Since there are big maintenance projects on the building envelope coming up, it is the most cost efficient to choose for the high impact variant.

Energy system:
B. ATES

Building envelope:
High impact

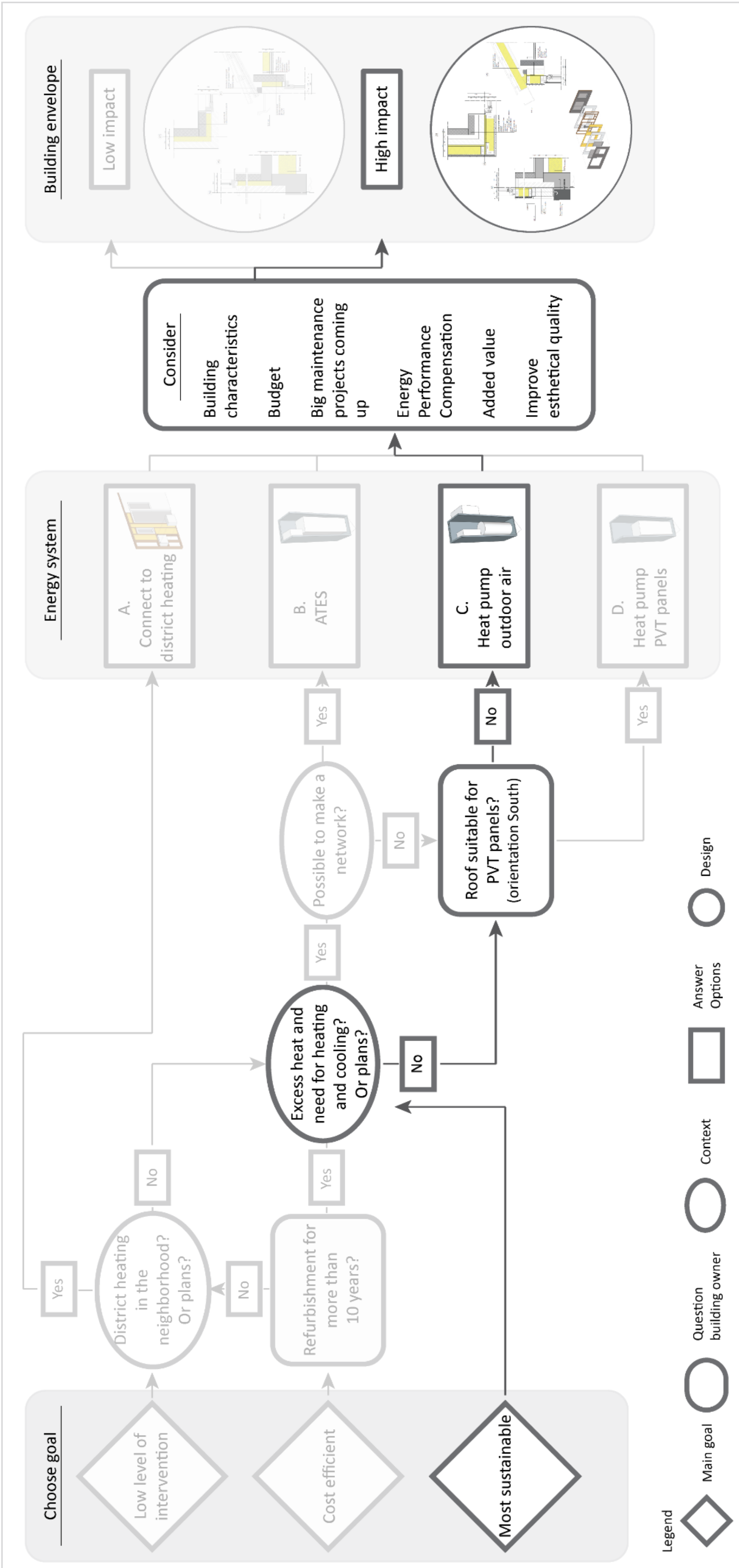


Figure 74: Decision-making diagram for scenario 3: E-W orientated apartments

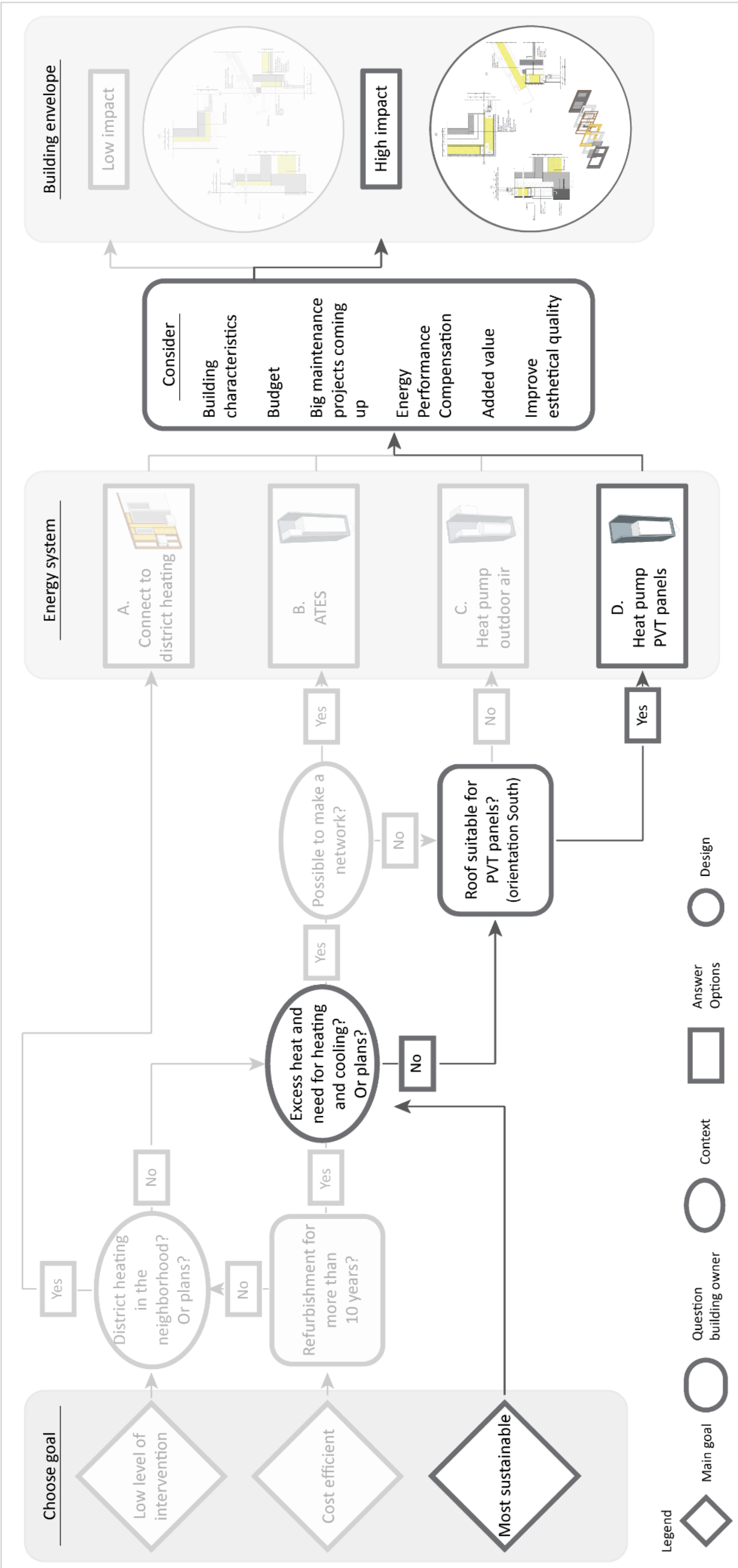


Figure 75: Decision-making diagram for scenario 3: N-S orientated apartments

Scenario 3: Homeowners association with most sustainable goal

In the third scenario all walk-up apartment buildings are in a homeowners association. They want to have the most sustainable refurbishment, but there is no excess heat. 129 apartments have an East-West orientation and are therefore not ideal for PVT panels. So those apartments will be connected to a heat pump with the outdoor air as a heat source. 66 apartments have a North-South orientation, these will be connected to a heat pump with PVT panels.

The leading consideration between the low and high impact variant is the energy performance of the building. The apartments will not have an energy bill anymore after refurbishment and the building will have added value and an improved esthetical quality. Which will increase the prices of the apartments.

Energy system:
129 apartments E-W:
C. Outdoor air
66 apartments N-S:
D. PVT

Building envelope:
High impact

	Energy component	One Apartment	195 Apartments	Total [kWh]	Improvement factor compared to existing
Existing situation					
	Gas [m^3]	1.200	234.000 (=2.288.520 kWh)	2.711.085	1 x
	Building related electricity [kWh]	661	128.895		
	User related electricity [kWh]	1.506	293.670		
Scenario 1					
District heating low impact	External heat supply [MJ]	9.666	1.884.870 (=523.575 kWh)	937.560	2,9 x
	Building related electricity [kWh]	617	120.315		
	User related electricity [kWh]	1.506	293.670		
Scenario 2					
Excess heat High impact	Building related electricity [kWh]	1.245	242.775	536.445	5,0 x
	User related electricity [kWh]	1.506	293.670		
Scenario 3					
			129 apartments		
Outdoor air High impact	Building related electricity [kWh]	1.912	246.648	621.960	4,4 x
	User related electricity [kWh]	1.506	194.274		
			66 apartments		
PVT panels High impact	Building related electricity [kWh]	1.237	81.642		
	User related electricity [kWh]	1.506	99.396		

Table 25: Comparing final energy consumption existing situation with three scenarios

In Table 25 the final energy consumption of the existing situation is compared with the three different scenarios. The data for one apartment is the result of the simulation phase. The different scenarios with each their own goal for the refurbishment have different outcomes on the final energy consumption of the entire neighbourhood. All scenarios are an improvement of the existing situation, scenario 2 has even used 5 times less electricity as opposed to the existing situation.

Important to consider is that the costs of making an ATES or a district heating network are not included in the decision-making diagram. Setting up a network will require extra investment costs. Not only the costs are important for making an ATES or a district heating network, but it also requires different stakeholders that provide or maintain those networks.

13.3 'Extra' produced electricity

It can be seen in Appendix G that the four energy concepts produce more electricity than the building will use, except for concept C. Low. This 'extra' produced electricity can be used for other purposes than the energy that is required by the building. In this paragraph, different options will be discussed.

13.3.1 Serve more apartments

In this research, the case-study at the Soendalaan in Vlaardingen is used, which consists of 12 apartments. During this research, a prefabricated renovation approach is designed, which can also be applied to other buildings. Those buildings can consist of more apartments. An analysis is made to see how many 'extra' apartments can be served with the same roof area as the case-study (and therefore the same electricity production).

The 'extra' produced electricity is divided by the need for electricity for one apartment. This is done for each concept. Table 26 shows the values and the 'extra' apartments that can be served with the 'extra' electricity that is produced. Note that the number of apartments per floor is leading. This is only an indication of how many 'extra' apartments can be served if the building that needs refurbishment consist of more apartments compared to the case-study.

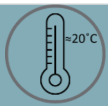
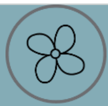
							PVT	
	A. Low	**A. High**	**B. Low**	**B. High**	**C. Low**	**C. High**	**D. Low**	**D. High**
Total produced electricity [kWh/building]	45.576	45.576	45.576	45.576	45.576	45.576	42.492	42.492
'Extra' electricity [kWh/building]	20.095	20.631	7.405	12.555	0	4.552	5.166	9.573
1 apartment [kWh]	2.123	2.079	3.181	2.752	4.016	3.418	3.110	2.743
'Extra' apartments [≈ unit]	**9**	**9**	**2**	**4**	**0**	**1**	**1**	**3**

Table 26:'Extra' apartments that can be served with 'extra' electricity

13.3.2 Use it for EV cars

The ‘extra’ electricity that is produced can also be used to fill the battery of EV cars. EV cars use around 17,6 kWh/100 km. This is an average value over 69 different types and brands of EV cars (Electric Vehicle Database, 2019).

The ‘extra’ produced electricity per apartment is divided by the average consumption of EV cars. The answer is the distance that can be driven by the ‘extra’ produced electricity per year for each apartment. This is done for each concept. Results can be seen in Table 27. The distances that can be driven with the ‘extra’ produced electricity are quite small but note that this is the amount for each apartment. So the distances can be shared and divided with the other residents in the building.

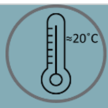
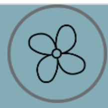
							PVT	
	A. Low	**A. High**	**B. Low**	**B. High**	**C. Low**	**C. High**	**D. Low**	**D. High**
‘Extra’ electricity [kWh/apartment]	1.675	1.719	617	1.046	0	380	431	798
Distance [km/year/ apartment]	**9.517**	**9.767**	**3.505**	**5.943**	**0**	**2.159**	**2.448**	**4.534**

Table 27: Distance that can be driven by EV cars with the 'extra' electricity

13.3.3 Rent roof area out to other buildings

Another option is to rent the ‘extra’ PV panels to other buildings in the neighbourhood. This will be buildings that cannot produce their own electricity, for example if the roof is not suitable for electricity production or if the buildings have a monumental status. However, the ‘extra’ produced electricity is preferably used in the same building that produces electricity.

13.3.4 Replace PV/PVT for solar collectors

There is ‘extra’ electricity produced since the entire roof is filled with PV or PVT panels. It is also an option to replace the ‘extra’ PV or PVT panels with solar collectors. Those can be used for the provision of room heating or DHW.

LIMITATIONS, CONCLUSIONS & RECOMMENDATIONS

Limitations

Besides some advantages of this research, there are also some limitations. The limitations of the study are analysed and listed below:

Multiple energy systems
In this research, there was chosen to analyse four energy concepts with extremes concerning the temperature of an external heat grid or concepts with the most potential. Other energy concepts, like heating grids with other temperatures or the ground heat pump that has been used in the 2ndSKIN approach, are not in the scope of this research.

Efficiency district heating network
Every district heating network has its own heating efficiency for the primary or secondary grid. This heating efficiency influences the energy demand of the building. The district heating network from Almere (Amsterdam Zuid-Oost) is used for the simulation of Concept A. If there was chosen for another district heating network than the energy demand of Concept A would also be different.

Software Uniec$^{2.2}$
The software Uniec$^{2.2}$ is used during the simulation phase. Concept D uses PVT panels as a heat source for the heat pump, but in Uniec$^{2.2}$ it was not possible to select PVT panels as a heat source. Therefore, there was chosen for a ground heat pump with a heat source with a high temperature. This limitation of the software may have had an effect on the results compared to the real situation.

It is also not possible to choose an external heat supply of ≈ 20˚C in Uniec$^{2.2}$. Therefore, a heat pump with groundwater as a heat source is chosen for concept B. The groundwater has a supply temperature of ≈ 20˚C and is therefore comparable with the external heat supply. However, it is not possible to see the external heat supply separately as can be done with concept A.

Currently, there is one heat pump on the market that uses PVT panels as a heat source. As a result, no other considerations regarding other products could be taken during the simulation phase.

Final energy consumption per apartment
The final energy consumption for one apartment is calculated by simulating the entire building block and divide the result by 12. However, there will be a difference in the final energy for the different apartments. The apartment on the top floor will have a different final energy compared to the apartment on the ground floor. The same applies to an apartment in the corner compared to an intermediate apartment. This is caused by different temperatures around the apartment, this can be the inside temperature from another apartment or it can be the outside air.

New energy system requires behavioural changes
A new energy system for the building requires behavioural changes of the users so that the system can function optimally. The heat pump has a different control system than the conventional HR-boiler. The heat pump operates the most energy efficient when there are not too many temperature changes (no setback temperature during night hours). This requires a different usage of the building services by the residents.

Capacity power grid
Most existing dwellings in the Netherlands have a gas-fired heating boiler. These systems can be replaced by heat pumps, but heat pumps function better in dwellings that slowly cool down on a cold day. Which involves a good insulation value of the building envelope. The power grid is not designed to heat dwellings with heat pumps on cold winter days, as the gas network is intended for this purpose. When massively gas-fired boilers are replaced by heat pumps, it may be necessary to adjust the power grid to fulfil those peak demands (RVO, 2018). This is a transition that needs to be made if more and more dwellings are using a heat pump for the provision of heating.

Since some energy concepts produce more electricity than they need, some electricity will be given back to the power grid. This will mostly occur during the daytime when the sun is shining and when the need for electricity is low. The current power grid is not designed to get a high amount of electricity back. It may be necessary to adjust the power grid to those peak demands or to store electricity more locally per apartment, building or neighbourhood. So that it is possible to use the electricity at a moment when the demand is high.

Probably renewed BENG regulations in 2020
In this research, the BENG regulations from 2015 are used, but they will be renewed from 1 July 2020. The renewed BENG regulations will be determined by the NTA 8800, instead of the NEN 7120. One of the differences between the documents is the primary energy factor (PEF). The PEF represents the ratio between the amount of fossil energy required to produce the energy supplied to the building and the amount of energy delivered to the building. In the NTA 8800, the primary energy factor (PEF) for electricity has changed from $f_{P;del;ci}$ = 2,56 to $f_{P;del;ci}$ = 1,45. This will have a big influence on the difference between the primary energy consumption of concept A compared to the other concepts. Now, concept A looks very energy efficient since it has an external heat supply with $f_{P;del;ci}$ = 1,00. If the other concepts will have a lower $f_{P;del;ci}$ than the difference will become smaller.

Conclusions

After elaborating on the different phases of this research, it is now possible to answer the main question:

What prefabricated renovation approach for post-war walk-up apartments is applicable to accommodate energy saving measures, depending on different energy systems?

By increasing the insulation value of the building envelope with: ground insulation, prefabricated façade elements and roof insulation, it is possible to decrease the energy demand of the building. The remaining demand will be provided by new building services that are placed in a unit in the backyard. The building services inside the unit can differ to make the post-war walk-up apartments applicable to different energy systems. With those energy saving measures, it is possible to reach the BENG regulations (Bijna Energie Neutrale Gebouwen [Almost Energy Neutral Buildings]). Except for one concept, all other concepts are even zero-energy.

Phase 1: Inventory
The literature study showed that several existing renovation approaches become zero-energy by using a heat recovery system for the provision of ventilation and an air-water heat pump for room heating and DHW. The location of the building services was different in all approaches.

The literature study on different energy systems resulted in four main energy concepts. These are: external heat supply of >70˚C, external heat supply of ≈20˚C, heat pump with outdoor air and a heat pump with PVT panels. The choice for these systems was dependent on the supply temperature. The extremely low (20˚C) and extremely high temperature (70˚C) are chosen for simulation since the energy demand will have the biggest difference.

Phase 2: Context
The analysis of the case-study at the Soendalaan in Vlaardingen showed that the building is built with a ‘non-traditional building method’ called the Simplex system. Therefore, it is not possible to remove parts of the façade since it is load-bearing. Secondly, it showed that the building services are located at the North façade, where the kitchen, bathroom and toilet are located. So the North façade has the most potential for the new building services.

Phase 3: Simulation
The simulation of the four energy concepts showed that the high impact variant does meet all BENG regulations (energy demand (1), primary energy consumption (2), part renewable energy (3)). The low impact variant does meet BENG 2 and 3 (primary energy consumption (2), part renewable energy (3)). The difference between those two variants are the R_c-values and the U-value of the building envelope and how ventilation is provided in the apartment (or a CO_2-regulated exhaust or via a heat recovery system).

Phase 4: Design
The derived knowledge is applied on a case-study at the Soendalaan in Vlaardingen. Since the different energy concepts ask for different energy sources, the context of this case-study is abstract. The design can be distinct in the building services and the building envelope. The building services will be named first because they are the same for the low and high impact variant.

Building services
The building services are placed in a unit, which has the same dimensions for each energy concept. The unit is located at the North façade, close to the location where the building services are needed. Ventilation is provided via a collective system that is placed on the unoccupied attic. PV or PVT panels are placed on the roof of the building.

Low impact
The low impact refurbishment of the building resulted in ground, cavity and attic insulation. The window frames remain the same, only glazing will be replaced if necessary. The balconies remain the same to save costs and therefore create another distinction between the low and high impact variant. As the building services unit cannot be placed on the balcony, a substructure is needed to transfer the loads. The low impact variant does meet the R_c-values of the Dutch building regulations for refurbished buildings.

High impact
The high impact renovation approach resulted in ground, outside façade and outside roof insulation. The façade is insulated via prefabricated elements that are just as wide as a single apartment. Ventilation ducts, that provide fresh air, are integrated into the façade. New roof cladding and insulation panels are placed on the existing roof structure. New window frames and a new balcony is placed to increase the R_c-value of the building envelope. An extra foundation beam is necessary to transfer the loads of the building services unit and the new balconies. The high impact variant does meet the R_c-values of the Dutch building regulations for new buildings.

Decision-making diagram
The different energy concepts and variants for the building envelope have been included in a decision-making diagram. With this diagram, housing corporations or homeowners associations can choose between the different concepts. This diagram includes different parameters and gives alternatives in case the answer is yes or no. This diagram leads to an energy system and a design solution for the building envelope, depending on the different energy and context characteristics of the existing building.

Recommendations

Realization of the prefabricated renovation approach will depend on further research in several domains. Recommendations for potential further research are described below:

Upscaling the approach
Existing renovation approaches have mostly a zero-on-the-meter/ all-electric system. The aim of this research was to upscale existing renovation approaches by making it suitable for different energy systems. Further research can be done on how the approach can be made suitable for different building types. Which differences are there between building types and is the approach influenced by them.

Executive cost assessment of renovation approach
As stated in the decision-making diagram, budget/costs are one of the most important factors to choose between the low or high impact variant for the building envelope. An executive cost assessment is necessary to say more about the differences in costs. Also, the investment for making a district heating network or an ATES should also be included in this executive cost assessment.

The circularity of the system
It is necessary to think about the disassembling of the prefabricated renovation approach since the lifespan of the façade is not infinite. Is it possible to disassemble parts of the façade and can they be reused for another purpose.

The gap between simulated and actually used energy
There is a difference between the simulated energy and the actually used energy by the residents. By simulations, an estimation is made how much energy the building will use. By monitoring refurbished buildings, it is possible to say something about this difference and the causes.

Collective building services
In the design phase, there is chosen to focus only on the individual building services. However, it is also possible to have collective building services. In this research, a short elaboration on the location of the building services is given. But more elaboration is necessary to say something about the difference in primary energy consumption, final energy consumption and the energy demand of the apartments.

Probably renewed BENG regulations in 2020
In this research, the BENG regulations from 2015 are used, but they will be renewed from 1 July 2020. During the timespan of this research, it became known that the goal of starting in 2020 with renewed regulations, will not be achieved. Therefore the deadline is postponed to 1 July 2020. The new software for calculating the BENG regulations is not finished yet. When the software is available, it would be useful to see if the approach still meets the renewed BENG regulations (RVO, 2019).

Construction/ Foundation beam
In the low and high impact variant, it is necessary to pour an extra foundation beam. This foundation beam is needed to transfer the loads of the building services unit and the prefabricated façade elements. Pouring a foundation beam will require more time on the construction site and will increase the total costs of the refurbishment. Since this construction is probably a big part of the investment, further research is necessary to see if there are other possibilities to solve this problem.

Insulate façade locally

In this research, the entire façade, in the low and high impact variant, is insulated. It might be possible to still reach the same energy efficiency by insulating only parts of the façade. For example in the low impact, fill only the cavity of the opaque parts and replace window frames and glazing. And do not fill the cavity underneath and above the window frames, as shown in Figure 76. Insulating only parts of the façade might save costs, but will still reach the same or even higher energy efficiency, therefore it is recommended for further research.

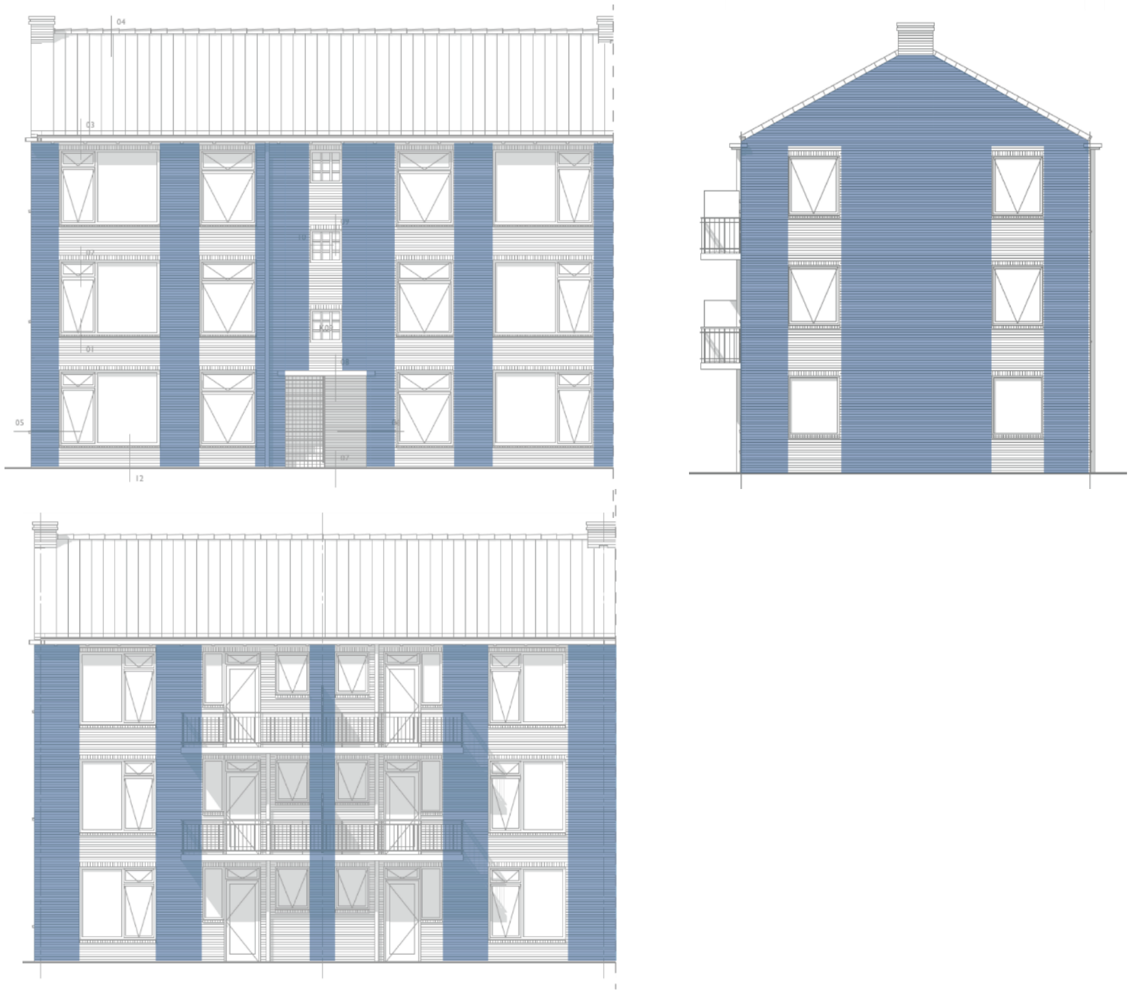


Figure 76: Insulate façade locally at opaque parts

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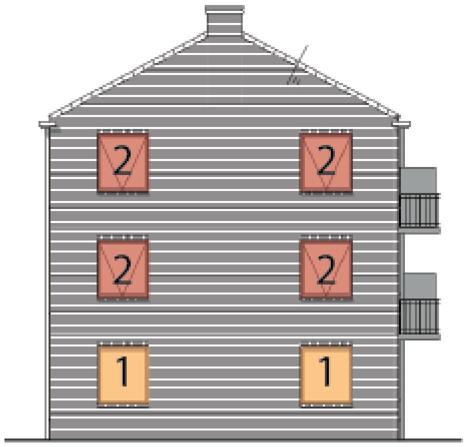
APPENDIX

Appendix

A. Input areas in Uniec[2.2]

East façade

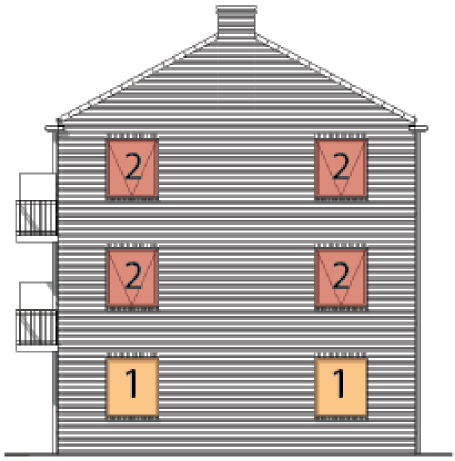
EAST FACADE Openings	Facade openings [m2]	Glazing [m2]	Window frames [m2]	Pieces [#]	All facade openings [m2]	All glazing [m2]	All window frames [m2]
Window 1	2,0	1,7	0,3	2	4,0	3,4	0,6
Window 2	2,0	1,5	0,5	4	8,0	6,0	2,0
TOTAL OPENINGS AREA [m2]					**12,0**	**9,4**	**2,6**



TOTAL FACADE AREA	85,8	
TOTAL OPENINGS AREA [m2]	12,0	-
TOTAL CLOSED AREA	73,8	

West façade

WEST FACADE Openings	Facade openings [m2]	Glazing [m2]	Window frames [m2]	Pieces [#]	All facade openings [m2]	All glazing [m2]	All window frames [m2]
Window 1	2,0	1,7	0,3	2	4,0	3,4	0,6
Window 2	2,0	1,5	0,5	4	8,0	6,0	2,0
TOTAL OPENINGS AREA [m2]					**12,0**	**9,4**	**2,6**

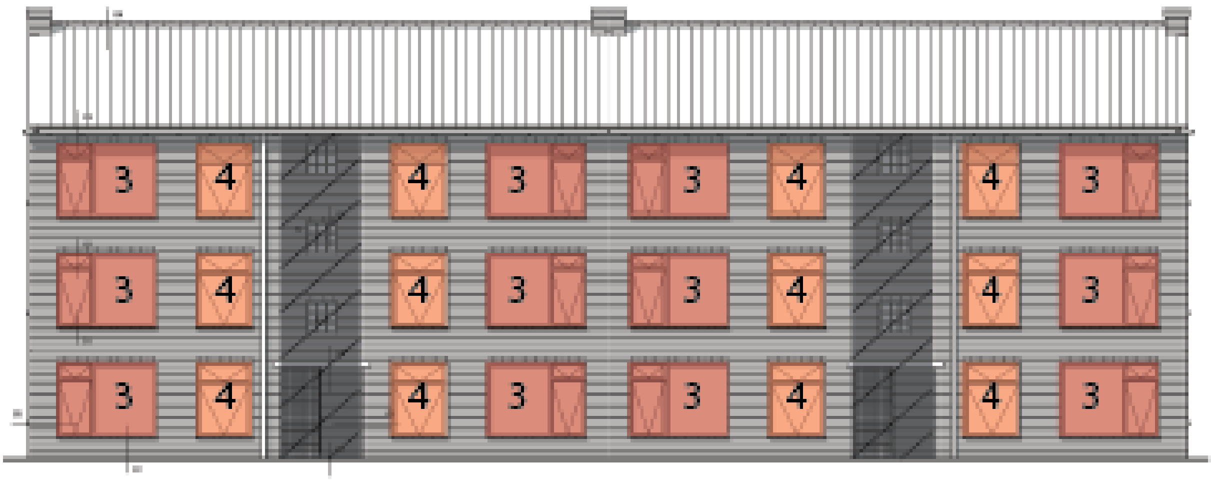


TOTAL FACADE AREA	85,8	
TOTAL OPENINGS AREA [m2]	12,0	-
TOTAL CLOSED AREA	73,8	

South façade

SOUTH FACADE Openings	Facade openings [m2]	Glazing [m2]	Window frames [m2]	Pieces [#]	All facade openings [m2]	All glazing [m2]	All window frames [m2]
Window 3	4,7	3,8	0,9	12	56,4	45,6	10,8
Window 4	2,7	1,9	0,8	12	32,4	22,8	9,6
TOTAL OPENINGS AREA [m2]					**88,8**	**22,8**	**9,6**

TOTAL FACADE AREA	373,0	
TOTAL OPENINGS AREA [m2]	88,8	-
TOTAL CLOSED AREA	284,2	

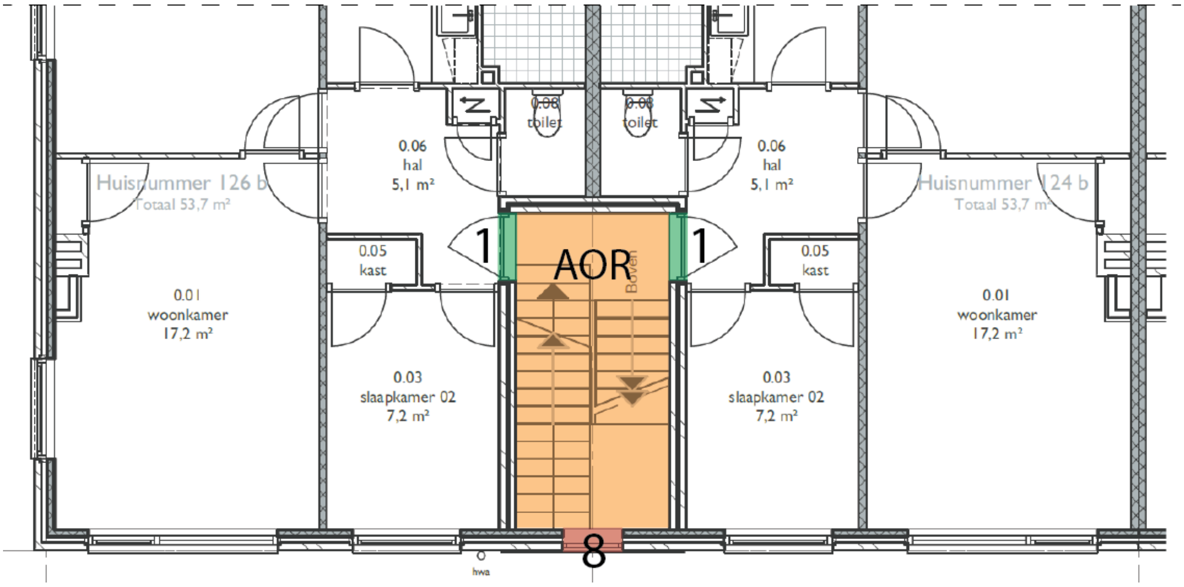


North façade

NORTH FACADE Openings	Facade openings [m2]	Glazing [m2]	Window frames [m2]	Pieces [#]	All facade openings [m2]	All glazing [m2]	All window frames [m2]
Window 5	3,7	2,9	0,8	12	44,4	34,8	9,6
Window 6	0,8	0,6	0,2	12	9,6	7,2	2,4
Window 7	1,0	0,7	0,3	12	12,0	8,4	3,6
Door 2	2,3	1,3	1,0	12	27,6	15,6	12,0
TOTAL OPENINGS AREA [m2]					**93,6**	**66,0**	**27,6**

TOTAL FACADE AREA	238,0	
TOTAL OPENINGS AREA [m2]	93,6	-
TOTAL CLOSED AREA	144,4	

AOR



Entrance AOR	Length [m]	Width [m]	Contour [m]	Pieces [#]	Total contour [m]	Total length [m]	Total width [m]
Door 1	2,3	0,9	6,4	12	76,8	55,2	10,8
Window 8	0,85	0,8	3,3	6	19,8	10,2	4,8
TOTAL CONTOUR [m]					**96,6**	**65,4**	**15,6**

Total building

TOTAL BUILDING	[m]	[m2]
Length	28,9	
Width	9,0	
Height	11,0	
User surface one apartment		52,5
Roof surface South		150
Roof surface North		150

B. Input R_c-values in Uniec[2.2]

Current situation

CURRENT SITUATION Floor	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Sand	0	0,15		0,00
	2	Air	0,3	0,18		0,18
	3	Concrete	0,125	1,03		0,12
	4	Dekvloer	0,03	1,16		0,03
	Ri					0,13
Total Rc;constr.						**0,50**
	Rc = (Rc;constr./1,05) - 0,04 - 0,13 =					0,30

CURRENT SITUATION Facade	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Masonry	0,1	1,3		0,08
	2	Air				0,18
	3	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**0,49**
	Rc = (Rc;constr./1,05) - 0,04 - 0,13 =					0,29

CURRENT SITUATION Roof	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Roof tiles	0,05	1,28		0,04
	2	Air				0,18
	3	Insulation	0,025	0,21		0,12
	Ri					0,13
Total Rc; constr.						**0,51**
	Rc = (Rc;constr./1,05) - 0,04 - 0,13 =					0,31

CURRENT SITUATION Ceiling	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Softboard	0,013	0,08		0,16
	2	Air				0,18
	3	Plasterboard	0,013	0,16		0,08
	Ri					0,13
Total Rc; constr.						**0,58**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				0,39

CURRENT SITUATION Internal wall	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Concrete	0,1	1,7		0,06
	2	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**0,29**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				0,10

Low impact

LOW IMPACT Floor	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Sand	0,11	0,15		0,73
	2	HR++-Termoparels	0,06	0,033		1,82
	3	Concrete	0,125	1,03		0,12
	4	Dekvloer	0,03	1,16		0,03
	Ri					0,13
Total Rc;constr.						**2,87**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				2,56

LOW IMPACT Facade	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Masonry	0,1	1,3		0,08
	2	HR++-Termoparels	0,07	0,033		2,12
	3	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**2,43**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				2,14

High impact

HIGH IMPACT Floor	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Sand	0,11	0,15		0,73
	2	HR++-Termoparels	0,12	0,033		3,64
	3	Concrete	0,125	1,03		0,12
	4	Dekvloer	0,03	1,16		0,03
	Ri					0,13
Total Rc;constr.						**4,69**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				4,29

HIGH IMPACT Facade	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Insulation	0,08	0,031		2,58
	2	Masonry	0,1	1,3		0,08
	3	HR++-Termoparels	0,07	0,033		2,12
	4	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**5,01**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				4,60

HIGH IMPACT Roof	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Roof tiles	0,05	1,28		0,04
	2	Kingspan Quadcore	0,12			6,40
	3	Insulation	0,025	0,21		0,12
	Ri					0,13
Total Rc;constr.						**6,73**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				6,24

C. Input building services in Uniec$^{2.2}$

OVERVIEW Measures in Uniec$^{2.2}$	Existing situation
Building envelope	
Rc-value Floor	1,00
Rc-value Facade	0,29
Rc-value Roof	0,47
Rc-value internal wall	0,1
U-value glazing	2,8
Heating systems	
System	HR combi boiler
Product	Nefit Topline AquaPower HRC 25 CW 4
COp heating	0,95
COp DHW	0,6
Delivery temperature	>50˚C
Ventilation	
System	Inlet: Natural Exhaust: Mechanic
Product	Itho Daalderop CO2 Optima NGG

OVERVIEW Measures in Uniec$^{2.2}$	Concept A External heat supply >70˚C	
	A. Low	A. High
Building envelope		
Rc-value Floor	2,6	3,7
Rc-value Facade	2,1	4,6
Rc-value Roof	6,1	6,1
Rc-value internal wall	0,1	0,1
U-value glazing	1,2	0,7
Heating systems		
External heat supply	City grid Amsterdam Zuid-Oost - primary grid	
Delivery temperature	>50˚C	
Ventilation		
System	Inlet: Natural Exhaust: Mechanic	Inlet: Mechanic Exhaust: Mechanic

Product	Itho Daalderop CO2 Optima NGG	Itho Daalderop HRU ECO 350 Optima 2 CO2
PV panels		
Peak power	180 Wp/m2	
RFpv	Z=1,00 N=0,70	
Number/orientation	150m2 29˚	

OVERVIEW **Measures in Uniec[2.2]**	**Concept B** **External heat supply ≈20˚C** **B. Low**	**B. High**
Building envelope		
Rc-value Floor	2,6	3,7
Rc-value Facade	2,1	4,6
Rc-value Roof	6,1	6,1
Rc-value internal wall	0,1	0,1
U-value glazing	1,2	0,7
Heating systems		
System	Combi-heat pump	
Source	Groundwater	
Product	Itho Daalderop WPU 25 5G + buffertank WPV150	
COp heating	4,85	5,70
COp DHW	3,45	3,70
COp additional heating	1,00	1,00
Supply temperature	50˚ < Θsup ≤ 55˚	35˚ < Θsup ≤ 40˚
Delivery temperature	>50˚C	≤ 50˚C
Ventilation		
System	Inlet: Natural Exhaust: Mechanic	Inlet: Mechanic Exhaust: Mechanic
Product	Itho Daalderop CO2 Optima NGG	Itho Daalderop HRU ECO 350 Optima 2 CO2
PV panels		
Peak power	180 Wp/m2	
RFpv	Z=1,00 N=0,70	
Number/orientation	150m2 29˚	

OVERVIEW **Measures in Uniec$^{2.2}$**	**Concept C** **Outdoor air**	
	C. Low	**C. High**
Building envelope		
Rc-value Floor	2,6	3,7
Rc-value Facade	2,1	4,6
Rc-value Roof	6,1	6,1
Rc-value internal wall	0,1	0,1
U-value glazing	1,2	0,7
Heating systems		
System	Combi-heat pump	
Source	Outdoor air	
Product	Itho Daalderop HP-S 55 + buffertank SVV 200l	
COp heating	3,80	4,20
COp DHW	1,75	1,75
COp additional heating	1,00	1,00
Supply temperature	50˚ < Ɵsup ≤ 55˚	35˚ < Ɵsup ≤ 40˚
Delivery temperature	>50˚C	≤ 50˚C
Cooling		
System	Compression cooling machine	
Specification	HT-delivery system	
Ventilation		
System	Inlet: Natural Exhaust: Mechanic	Inlet: Mechanic Exhaust: Mechanic
Product	Itho Daalderop CO2 Optima NGG	Itho Daalderop HRU ECO 350 Optima 2 CO2
PV panels		
Peak power	180 Wp/m2	
RFpv	Z=1,00 N=0,70	
Number/orientation	150m2 29˚	

PVT — OVERVIEW Measures in Uniec$^{2.2}$	Concept D PVT panels — D. Low	D. High
Building envelope		
Rc-value Floor	2,6	3,7
Rc-value Facade	2,1	4,6
Rc-value Roof	6,1	6,1
Rc-value internal wall	0,1	0,1
U-value glazing	1,2	0,7
Heating systems		
System	Combi-heat pump	
Source	Ground	
Product	Nibe F1255-6 (PC) with Triple Solar source	
COp heating	5,05	
COp DHW	3,50	
COp additional heating	1,00	
Supply temperature	30˚ < ϴsup ≤ 35˚	
Delivery temperature	> 50˚C	≤ 50˚C
Ventilation		
System	Inlet: Natural Exhaust: Mechanic	Inlet: Mechanic Exhaust: Mechanic
Product	Itho Daalderop CO2 Optima NGG	Itho Daalderop HRU ECO 350 Optima 2 CO2
PV panels		
Peak power	180 Wp/m2	
RFpv	S=1,00 N=0,70	
Number/orientation	75 m2 (S) 150m2(N) 29˚	
PVT panels		
Peak power	165 Wp/m2	
RFpv	S = 1,00	
Number/orientation	75m2 29˚	

D. Results simulation in Uniec$^{2.2}$

			Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
				External heat supply >70˚C	External heat supply >70˚C	External heat supply ≈20˚C	External heat supply ≈20˚C	Outdoor air	Outdoor air	PVT	PVT
Building	Rc value floor [m2·K/W]		1,0	2,6	4,3	2,6	4,3	2,6	4,3	2,6	4,3
	Rc value wall [m2·K/W]		0,29	2,1	4,6	2,1	4,6	2,1	4,6	2,1	4,6
	Rc value roof [m2·K/W]		0,47	6,1	6,1	6,1	6,1	6,1	6,1	6,1	6,1
	U-value glazing [W/m2·K]		2,8	1,38	0,93	1,38	0,93	1,38	0,93	1,38	0,93
	ψ value		0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
Building services	Heating		HR -combi boiler	External	External	Heatpump W/W	Heatpump W/W	Heatpump A/W	Heatpump A/W	Heatpump PVT	Heatpump PVT
	DHW		HR -combi boiler	External	External	Heatpump W/W	Heatpump W/W	Heatpump A/W	Heatpump A/W	Heatpump PVT	Heatpump PVT
	Cooling		No	No	No	No	No	Cooling	Cooling	No	No
	Ventilation		Mechanical exhaust	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW
	Solar panels		No	PV	PV	PV	PV	PV	PV	PVT	PVT
Primary energy a year	Heating [MJ]		355.633	64.590	14.800	52.844	12.314	79.532	16.711	50.751	17.330
	Auxiliary energy [MJ]		11.268	9.688	9.688	5.786	4.919	11.399	10.168	0	0
	DHW [MJ]		150.829	77.847	61.878	67.151	67.151	132.384	132.384	66.192	66.192
	Auxiliary energy [MJ]		0	0	0	0	0	0	0	0	0
	Cooling [MJ]		0	0	0	0	0	19.217	14.208	0	0
	Auxiliary energy [MJ]		0	0	0	0	0	3.778	3.778	0	0
	Summercomfort [MJ]		28.540	25.623	18.944	25.623	18.944	0	0	25.623	18.944
	Ventilators [MJ]		3.526	2.645	4.639	2.645	4.639	2.645	4.639	2.645	4.639
	Lighting [MJ]		29.711	29.711	29.711	29.711	29.711	29.711	29.711	29.711	29.711
	Total [MJ]		579.507	210.104	139.660	183.760	137.678	278.666	211.599	174.922	136.816
Final energy a year	Gas usage [m3aeq]		14.400	0	0	0	0	0	0	0	0
	External heat supply [MJ]		0	142.000	77.000	0	0	0	0	0	0
	Building related energy [kWh]		7.926	7.342	6.834	19.939	14.939	30.237	22.960	18.980	14.845
	User related energy [kWh]		18.074	18.074	18.074	18.074	18.074	18.074	18.074	18.074	18.074
	Produced energy [kWh]		0	45.573	45.573	45.573	45.573	45.573	45.573	42.486	42.486
	Exported energy [kWh]		0	20.157	20.665	7.560	12.560	-	4.539	5.432	9.567
BENG	Indicator	Target									
	BENG 1.Energy demand [kWh/m	≤ 25	152,7	53,9	21,4	53,9	21,4	53,9	21,4	53,9	21,4
	BENG 2.Primary energy use [kWh	≤ 25	236,9	-2,9	-32,0	-44,8	-52,5	-28,8	-40,1	-41,5	-47,9
	BENG 3.Part renewable energy [	≥ 50	0%	104%	183%	151%	194%	133%	171%	148%	187%

E. R_c-values design phase

Low impact

LOW IMPACT Floor	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Sand	0,11	0,15		0,73
	2	EPS chips	0,25	0,075		3,33
	3	Concrete	0,125	1,03		0,12
	4	Dekvloer	0,03	1,16		0,03
	Ri					0,13
Total Rc;constr.						**4,38**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				4,01

LOW IMPACT Facade	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Masonry	0,1	1,3		0,08
	2	HR++-Termoparels	0,07	0,033		2,12
	3	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**2,43**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				2,14

LOW IMPACT Ceiling	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Mineral wool	0,1	0,032		3,13
	2	Softboard	0,013	0,08		0,16
	3	Air				0,18
	4	Plasterboard	0,013	0,16		0,08
	Ri					0,13
Total Rc; constr.						**3,71**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				3,36

High impact

HIGH IMPACT Floor	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Sand	0,11	0,15		0,73
	2	HR++-Termoparels	0,25	0,05		5,00
	3	Concrete	0,125	1,03		0,12
	4	Dekvloer	0,03	1,16		0,03
	Ri					0,13
Total Rc;constr.						**6,05**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				5,59

HIGH IMPACT Facade	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Insulation	0,14	0,031		4,52
	2	Masonry	0,1	1,3		0,08
	3	Air				0,18
	4	Concrete	0,1	1,7		0,06
	Ri					0,13
Total Rc;constr.						**5,00**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				4,59

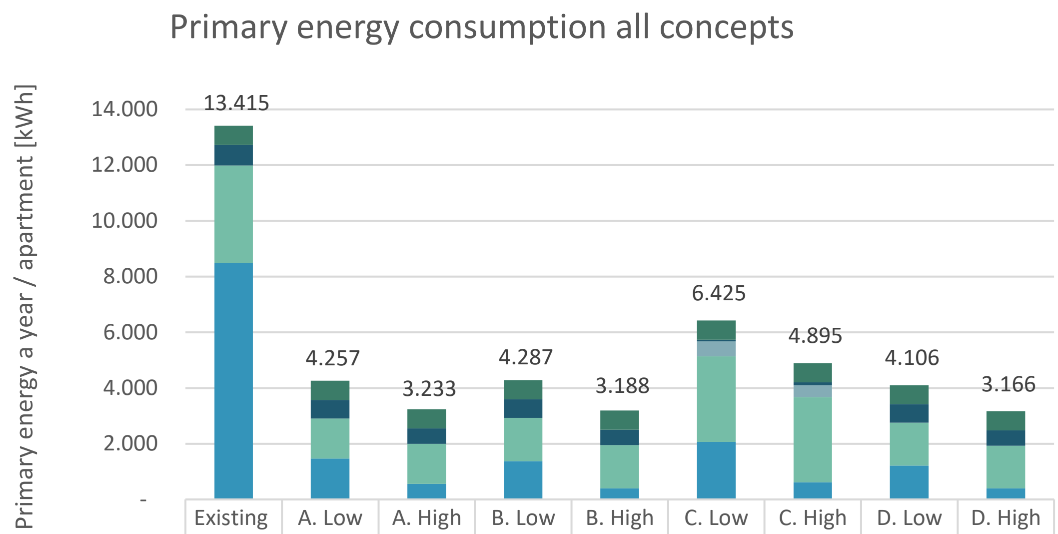
HIGH IMPACT Roof	Layer	Material	Thickness [m]	Lambda [W/mK]	U-value [W/m2K]	R-value [m2K/W]
	Re					0,04
	1	Roof tiles	0,05	1,28		0,04
	2	Kingspan Quadcore	0,12			6,40
	3	Insulation	0,025	0,21		0,12
	Ri					0,13
Total Rc;constr.						**6,73**
		Rc = (Rc;constr./1,05) - 0,04 - 0,13 =				6,24

F. Required ventilation

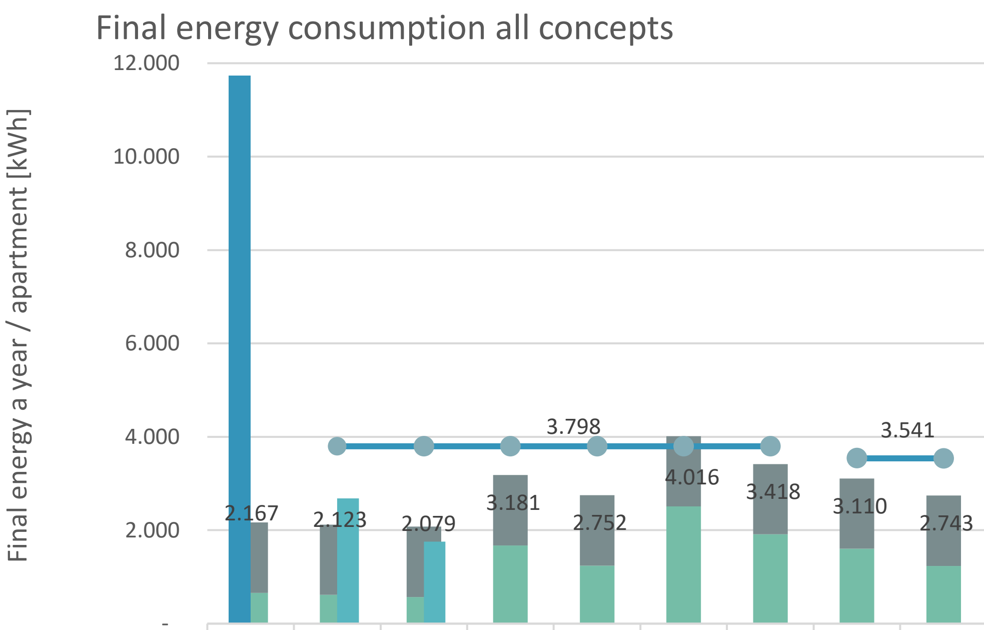
One apartment	Required ventilation [dm3/s]	Required ventilation per m2 [dm3/s]	Area [m2]	Ventilation per room [dm3/s]	
Living room	7	0,7	17,2	12,0	
Kitchen	21	0,7	5,1	21,0	
Bedroom 1	7	0,7	12,2	8,5	
Bedroom 2	7	0,7	7,2	7,0	
Bathroom	14	0,7	3,5	14,0	
Toilet	7	0,7	1,5	7,0	
Hall		0,5	5,1	2,6	
Total				**72,1**	**dm3/s**
				259,7	**m3/h**

G. Outcome final simulation of design phase

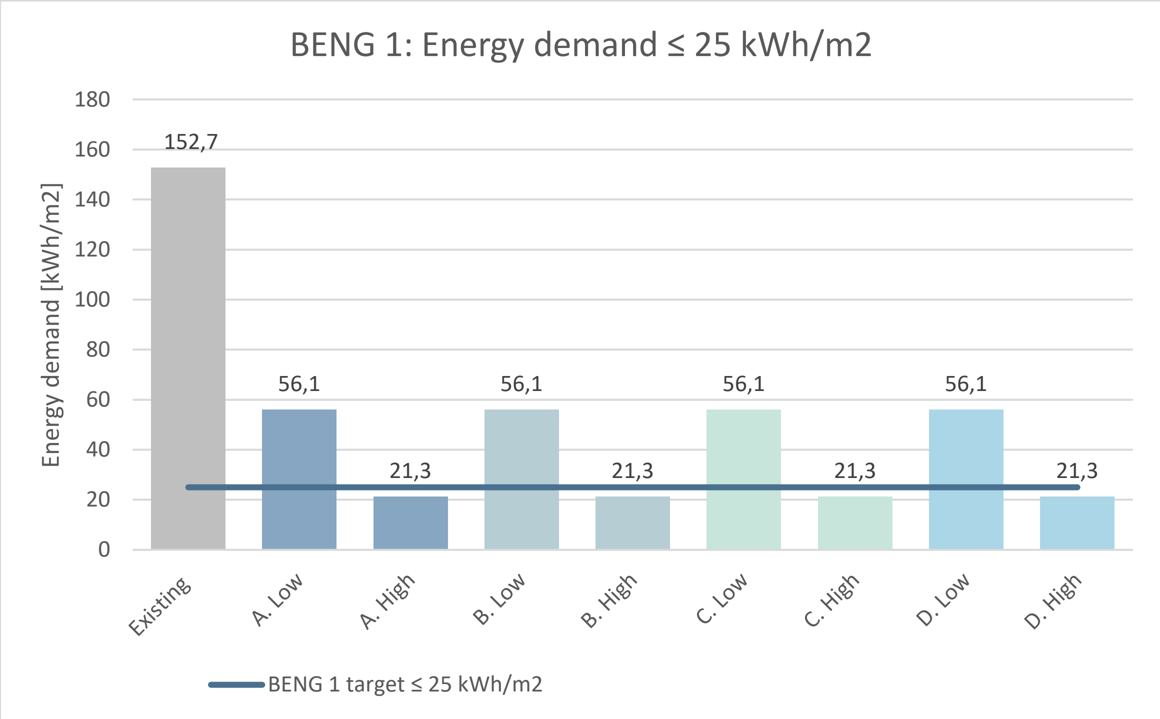
			Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
				External heat supply >70˚C	External heat supply >70˚C	External heat supply ≈20˚C	External heat supply ≈20˚C	Outdoor air	Outdoor air	PVT	PVT
Building	Rc value floor [m2·K/W]		1,0	4,0	5,6	4,0	5,6	4,0	5,6	4,0	5,6
	Rc value wall [m2·K/W]		0,29	2,1	4,6	2,1	4,6	2,1	4,6	2,1	4,6
	Rc value roof [m2·K/W]		0,47	3,3	6,2	3,3	6,2	3,3	6,2	3,3	6,2
	U-value glazing [W/m2·K]		2,8	1,38	0,93	1,38	0,93	1,38	0,93	1,38	0,93
	ψ value		0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
Building services	Heating		HR -combi boiler	External	External	Heatpump W/W	Heatpump W/W	Heatpump A/W	Heatpump A/W	Heatpump PVT	Heatpump PVT
	DHW		HR -combi boiler	External	External	Heatpump W/W	Heatpump W/W	Heatpump A/W	Heatpump A/W	Heatpump PVT	Heatpump PVT
	Cooling		No	No	No	No	No	Cooling	Cooling	No	No
	Ventilation		Mechanical exhaust	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW	Mechanical exhaust	All mechanical WTW
	Solar panels		No	PV	PV	PV	PV	PV	PV	PVT	PVT
Primary energy a year	Heating [MJ]		355.633	53.776	14.481	53.690	12.048	77.986	16.351	52.637	16.957
	Auxiliary energy [MJ]		11.268	9.688	9.688	5.804	4.914	11.426	10.168	0	0
	DHW [MJ]		150.829	61.878	61.878	67.151	67.151	132.384	132.384	66.192	66.192
	Auxiliary energy [MJ]		0	0	0	0	0	0	0	0	0
	Cooling [MJ]		0	0	0	0	0	19.642	14.446	0	0
	Auxiliary energy [MJ]		0	0	0	0	0	3.778	3.778	0	0
	Summercomfort [MJ]		28.540	26.189	19.261	26.189	19.261	0	0	26.189	19.261
	Ventilators [MJ]		3.526	2.645	4.639	2.645	4.639	2.645	4.639	2.645	4.639
	Lighting [MJ]		29.711	29.711	29.711	29.711	29.711	29.711	29.711	29.711	29.711
	Total [MJ]		579.507	183.887	139.658	185.190	137.724	277.572	211.477	177.374	136.760
Final energy a year	Gas usage [m3aeq]		14.400	0	0	0	0	0	0	0	0
	External heat supply [MJ]		0	116.000	76.000	0	0	0	0	0	0
	Building related energy [kWh]		7.926	7.404	6.868	20.094	14.944	30.118	22.947	19.246	14.839
	User related energy [kWh]		18.074	18.074	18.074	18.074	18.074	18.074	18.074	18.074	18.074
	Produced energy [kWh]		0	45.573	45.573	45.573	45.573	45.573	45.573	42.486	42.486
	Exported energy [kWh]		0	20.095	20.631	7.405	12.555	-	4.552	5.166	9.573
BENG	Indicator	Target									
	BENG 1.Energy demand [kWh/m	≤ 25	152,7	56,1	21,3	56,1	21,3	56,1	21,3	56,1	21,3
	BENG 2.Primary energy use [kWh	≤ 25	236,9	-14,4	-32,1	-44,5	-52,5	-29,0	-40,1	-41,0	-47,9
	BENG 3.Part renewable energy [	≥ 50	0%	126%	183%	149%	195%	132%	171%	146%	188%

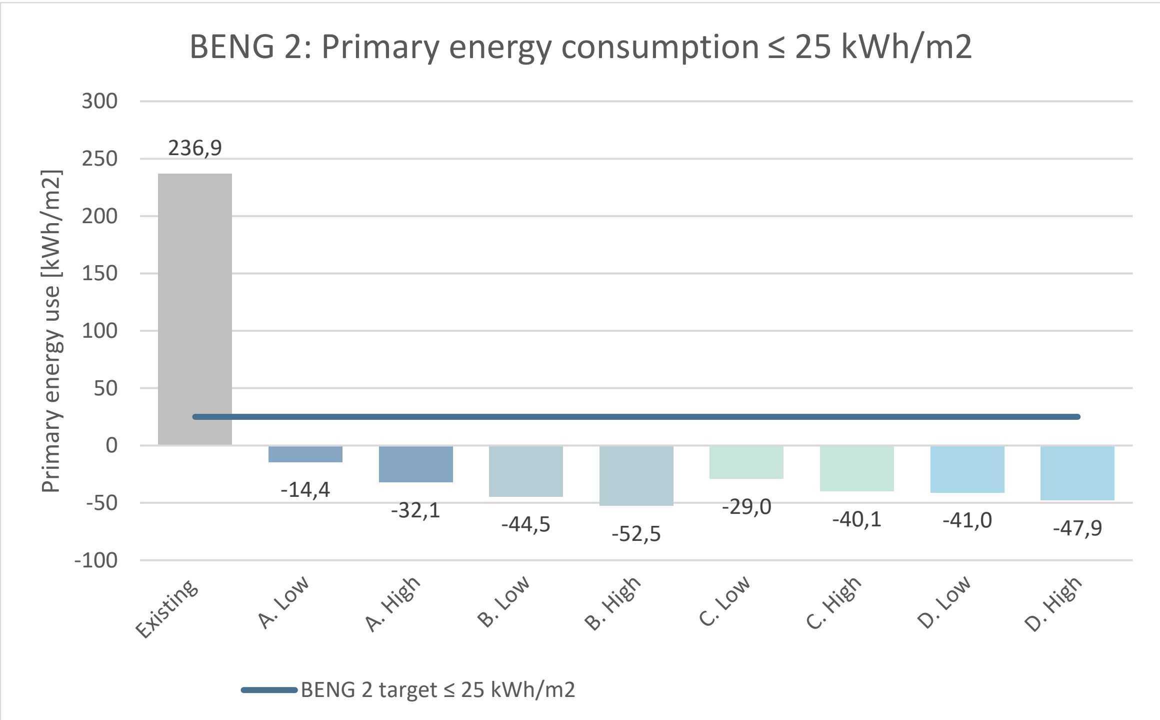


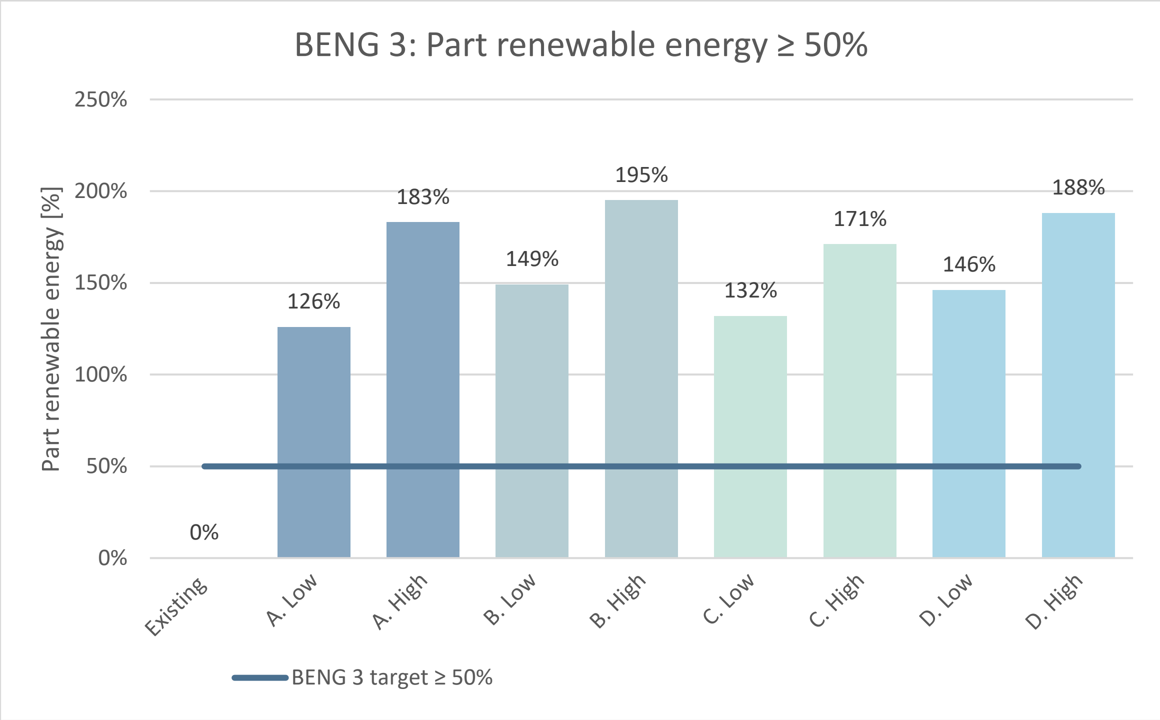
	Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
Lighting [kWh] converted from MJ	688	688	688	688	688	688	688	688	688
Summercomfort [kWh] converted from MJ	742	667	553	667	553	61	107	667	553
Cooling [kWh] converted from MJ	0	0	0	0	0	542	422	0	0
DHW [kWh] converted from MJ	3.491	1.432	1.432	1.554	1.554	3.064	3.064	1.532	1.532
Heating [kWh] converted from MJ	8.493	1.469	559	1.377	393	2.070	614	1.218	393



	Existing	A. Low	A. High	B. Low	B. High	C. Low	C. High	D. Low	D. High
User related electricity [kWh]	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506	1.506
Building related electricity [kWh]	661	617	572	1.675	1.245	2.510	1.912	1.604	1.237
Gas usage [kWh] (converted from m3)	11.736	0	0	0	0	0	0	0	0
External heat supply [kWh] (converted from MJ)	0	2.685	1.759	0	0	0	0	0	0
Produced electricity [kWh]	0	3.798	3.798	3.798	3.798	3.798	3.798	3.541	3.541


BENG 1: Energy demand ≤ 25 kWh/m2
Energy demand [kWh/m2]
180
160
140
120
100
80
60
40
20
0
152,7
56,1
21,3
56,1
21,3
56,1
21,3
56,1
21,3
Existing
A. Low
A. High
B. Low
B. High
C. Low
C. High
D. Low
D. High
BENG 1 target ≤ 25 kWh/m2


BENG 2: Primary energy consumption ≤ 25 kWh/m2
Primary energy use [kWh/m2]
300
250
200
150
100
50
0
-50
-100
236,9
-14,4
-32,1
-44,5
-52,5
-29,0
-40,1
-41,0
-47,9
Existing
A. Low
A. High
B. Low
B. High
C. Low
C. High
D. Low
D. High
BENG 2 target ≤ 25 kWh/m2



BENG 3: Part renewable energy ≥ 50%
Part renewable energy [%]
250%
200%
150%
100%
50%
0%
0%
126%
183%
149%
195%
132%
171%
146%
188%
Existing
A. Low
A. High
B. Low
B. High
C. Low
C. High
D. Low
D. High
BENG 3 target ≥ 50%