ZEHR-Ø

SERVICE INTEGRATION IN FAÇADES FOR ZERO-ENERGY HOME REFURBISHMENT

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Master of Science (MSc) Thesis Delft University of Technology

ZEHR-Ø - Service Integration in Façades for Zero Energy Home Refurbishment

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Preface

This is the thesis 'ZEHR-Ø - Service Integration in Façades for Zero Energy Home Refurbishment'. The research continuous on the 2ndSKIN project and is written for my graduation from Delft University of Technology - Faculty of Architecture and the Built Environment.

My first mentor Thaleia Konstantinou helped me formulate this research. It ended up being complex and sometimes difficult, but Thaleia together with my second mentor Peter van den Engel always helped me further. I could count on their guidance, good directions, useful discussions and therefore I like to express my gratitude.

further, I like to thank my family and friends for always being there for me, without them I could have never done this. Especially my parents, who made this all possible and always knew how to make me feel better during difficult times.

Abstract

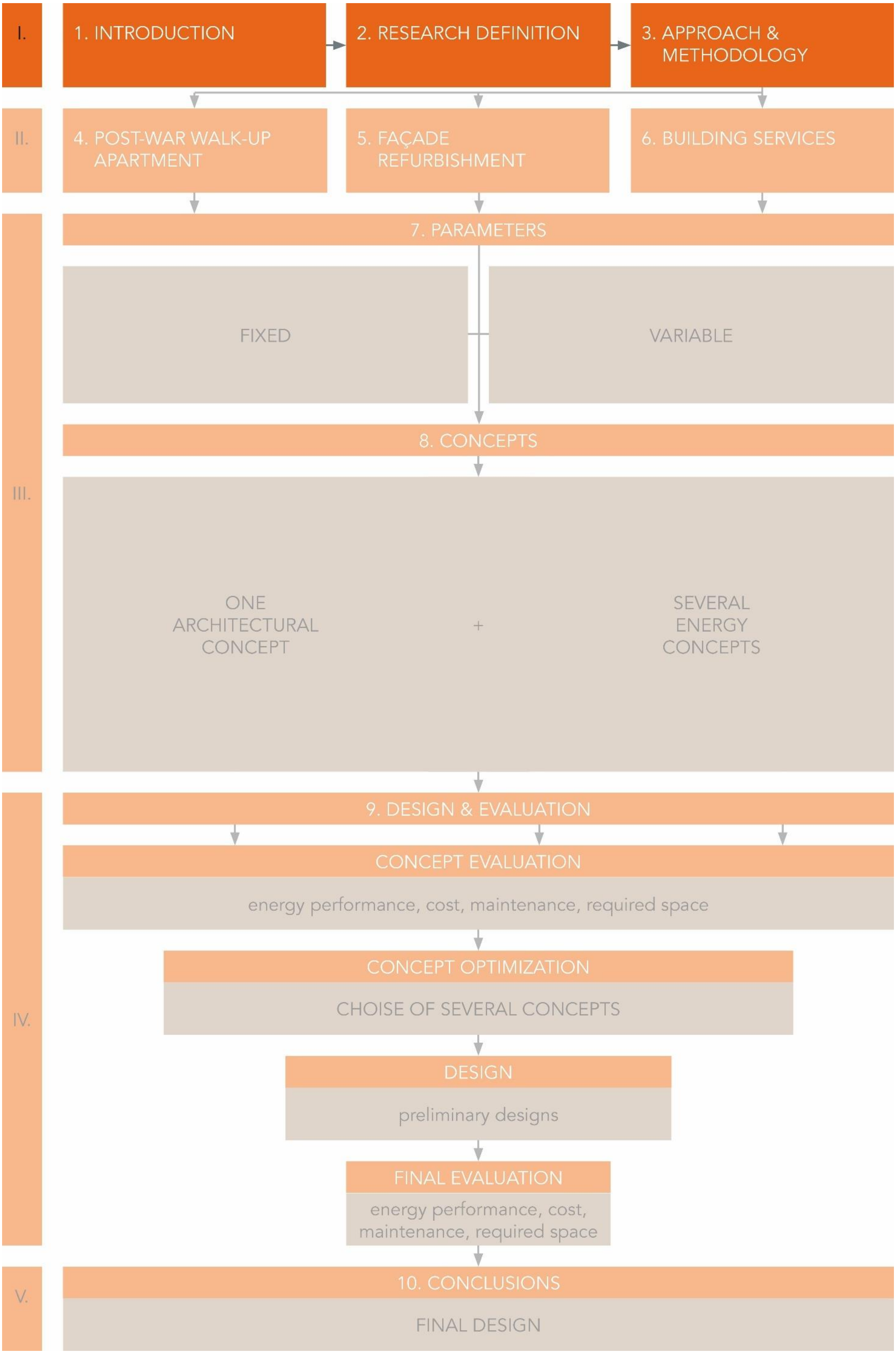
"The Dutch built environment - both residential properties of private owners, corporations and investors, as well as offices, schools, shops and commercial real estate – is largely outdated and not energy efficient" (Platform 31, n.d.).

This research is about making the built environment more sustainable by refurbishing the building envelope in a smart energy efficient way. A focus is placed on post-war walk-up apartments of which 635.000 were constructed in the Netherlands. Renovation (zero-energy) methods for this specific building type are still missing. In this described context the '2ndSKIN' project already conducted research for a new renovation method that integrated building services in the building's envelope and was therefore used as a starting point. However, in the end the 2ndSKIN project was not efficient enough in terms of costs and space. Therefore, the goal of this research is the design of a new zero-energy renovation method that improves the current method.

The approach they used is still promising and it is often seen in other renovation projects. Therefore, it will be used as the base for the new renovation method in this thesis. In addition to the research on the 2ndSKIN project, other renovations methods that involve upgrading the envelope were investigated together with building services and the post-war walk-up apartment typology, forming the first part of this research: the literature review. From the review, different conclusions were found that formed parameters for the design process. There are fixed parameters like, building layout, structure type, size and orientation but also variables such as ventilation systems and heating systems. The parameters form the base for different concepts, that are introduced in the design phase and that lead to the conclusion of this thesis: *the design of a new prefabricated zero-energy renovation concept for post-war walk-up apartments, that integrates the building-services in a space and cost-efficient way.*

CONTENTS

PHASE I


I.
1. INTRODUCTION
2. RESEARCH DEFINITION
3. APPROACH & METHODOLOGY
II.
4. POST-WAR WALK-UP APARTMENT
5. FAÇADE REFURBISHMENT
6. BUILDING SERVICES
III.
7. PARAMETERS
FIXED
VARIABLE
8. CONCEPTS
ONE ARCHITECTURAL CONCEPT
+
SEVERAL ENERGY CONCEPTS
IV.
9. DESIGN & EVALUATION
CONCEPT EVALUATION
energy performance, cost, maintenance, required space
CONCEPT OPTIMIZATION
CHOISE OF SEVERAL CONCEPTS
DESIGN
preliminary designs
FINAL EVALUATION
energy performance, cost, maintenance, required space
V.
10. CONCLUSIONS
FINAL DESIGN

1 INTRODUCTION

1.1 Background

Context of the research project - The need for energy reduction in the Dutch housing market and post-war walk-up apartments

"Multiple studies published in peer-reviewed scientific journals show that 97 percent or more of actively publishing climate scientists agree: Climate-warming trends over the past century are extremely likely due to human activities" (NASA, 2016).

To reduce climate change, the Dutch government has set the objective of reducing greenhouse gas emissions by 49 percent compared to in the year 1990 (Rijksoverheid, n.d.-a). The most important greenhouse gas is CO_2 and the amount that must be reduced is laid down in the Dutch '*Climate Act*' (klimaatwet). In June 2018, a proposal for the Climate Act was submitted, proposing that there should be a 95 percent CO_2 reduction by 2050 and 49 percent by 2030.

How to reach these goals exactly is outlined in the Dutch '*energy agenda*' (energieagenda). A major way to reduce climate change in this agenda, is the drastic reduction of fossil fuel usage to almost zero in the year 2050. Electricity will then be generated sustainable, buildings will be mostly heated by geothermal energy and people will no longer cook on gas (Ministerie van Economische Zaken, 2016). However, the energy agenda also notices the small impact of new, more sustainable buildings. The construction of these future sustainable buildings only has a limited effect on making the built environment more sustainable. The biggest challenge is that of heating existing buildings with low CO_2 producing measures. In order to have a big impact on achieving the climate goals, existing buildings must be renovated so that they consume fewer fossil fuels and therefore produce less CO_2.

Energy reduction within the Dutch housing market

"The Dutch built environment - both residential properties of private individuals, corporations and investors, as well as offices, schools, shops and commercial real estate – is largely outdated and not energy efficient" (Platform 31, n.d.).

Platform 31 also states that most of these buildings will still be there in 2050. The fact that most of the Dutch housing market is generally energy-insufficient is largely due to the fact that more than half of the homes were built before the outbreak of the oil crisis in 1973 (Bouwformatie, 2012). These homes represent 3,9 million houses out of the 7,5 million in total. Of those 3,9 million homes, only 3,3% have a label A or B and are considered to be energy efficient.

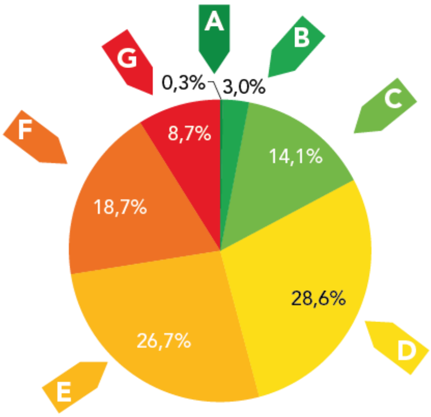


Figure 1.1.1: Label distribution regarding 2016 housing stock in the Netherlands, Source: Compendium voor de Leefomgeving 2017

With an energy label buyers and tenants can instantly see whether a house is energy efficient (label A) or inefficient (label G). This is convenient, because choosing an energy efficient home means that people will have lower energy bills, more living comfort and less CO_2 emissions. The energy performance also determines the amount of 'renting points'. These points determine the maximum amount of rent that house owners can ask of their tenants. To stimulate energy reduction in the built environment, the Dutch government and representatives of the rental sector signed the '*convenant energiebesparing huursector*'. In this covenant it is agreed that by the year 2020, the total social rental housing stock will be renovated to an average energy-index of 1,25 (energy label B) and 80 percent of the private rental stock will have an energy label of C or higher (Rijksoverheid, 2012).

However, '*deep*' renovation is shown to be a more promising strategy when it comes to achieving the 2050 climate targets than '*shallow*' renovations (Hermelink and Müller, 2010). "*The depth of the refurbishment is related to the level of energy or greenhouse gas emission savings that are achieved when refurbishing a building. A renovation is specified as 'deep' when energy savings of 60-90% are achieved*" (Konstantinou, 2015). Atanasiu and Kouloumpi (2013) describe an effective renovation plan as being long-term and providing a deep transformation of the existing building stock in order to significantly improve its actual energy performance and to achieve nearly zero-energy levels. Having a 'Zero-energy Building' means that the housing complex generates the amount of renewable energy that is needed both for the homes and the tenants on an annual basis (Climate-KIC, 2017). The attention to this kind of renovation is growing and it is especially social housing organisations that are very interested clients for Zero Energy Renovation (Climate-KIC, 2017).

Post-war-walk-up apartments

"A varied mix of construction types exists, from traditional to modern, from low rise to high-rise. A common characteristic, however, is that the buildings were generally poorly insulated at the time of construction and that there is a need for renovation" a conclusion from Itard and Meijer (2008) on dwellings built after World War II and before the oil crisis.

Figure 1.1.2: Typical walk-up apartment, Source: Agentschap NL, 2011

Different periods in time are characterized by their own style of construction. In 2012 Archidat published a manual (Bouwformatie, 2012) with an overview of the Dutch housing stock. It distinguished the following construction periods:

Pre-war homes	built until 1945
Early post-war homes	built between 1946 and 1964
Housing shortage homes	built between 1965 and 1974
Energy crisis houses	built between 1975 and 1991
Building code houses	built from 1992

As mentioned above, 3,9 million houses were built before the outbreak of the oil crisis in 1973 and require refurbishment. Of these houses, the walk-up apartment housing type makes up with 635.000 houses, 16 percent of its total amount (Agentschap NL, 2011). Deep renovation concepts for these particular types of buildings are still missing. TKI/ENERGO (2016) explains how this is due the variance in shape, design and quality of walk-up apartments.

building period	quantity	social rental	private rental	own property
<1945	256.000	37%	40%	23%
1946-1964	267.000	66%	17%	17%
1965-1974	112.000	76%	7%	17%
1975-1991	142.000	76%	10%	14%
1992-2005	70.000	62%	4%	33%

Figure 1.1.3: Distribution of walk-up apartments according to building period, quantity and ownership, **Source:** (Agentschap NL, 2011)

For the most part, the pre-war walk-up apartments were already 'deeply' renovated in the 1980s. This was because many of these buildings form essential parts of the historic cityscape (Liebregts, 2014). Liebregts states that most problems, with walk-up apartments, are therefore found in those built between 1945 and 1974.

1.2 Basic problem – The 2ndSkin project

"*In the process of making the existing building stock energy neutral, stacked houses pose a considerable challenge. Renovation methods for low-rise buildings, are usually not applicable for walk-up apartments*" (Itho Daalderop, 2018).

From the previous paragraph it can be concluded that there is a considerable demand for lowering CO_2 emissions. The built environment can make a big contribution to this demand by deeply renovating existing energy-insufficient houses towards (nearly) zero-energy levels. It also appears that for post-war walk-up apartments, deep renovation methods are still missing.

In this context, the 2ndSkin project brings together different stakeholders of the building industry, with the aim of integrating their expertise and objectives into an innovative building retrofitting concept (TKI/ENERGO, 2016). The focus of the second skin project is the low-rise walk-up apartments. To reach zero-energy, the 2ndSkin uses the 'trias energetica' as a design principle. This means preventing the use of energy, then use sustainable energy sources as widely as possible (renewable) and, finally, if the use of finite (fossil) energy sources is inevitable, they must be used efficiently and compensated with 100% renewable energy (RVO, 2015). The design focuses on a reference building that offers the best market and carbon emission reduction opportunities, given its poor thermal quality and the number of units in the Netherlands.

The retrofitting concept from 2ndSkin project offers a prefabricated and integrated façade module that improves the energy performance to zero-energy, while keeping the occupants' disturbance, during and after the renovation, to a minimum. This is important because, a landlord may not change its property without the tenant's consent (Rijksoverheid, n.d.). If the complex consists of fewer than ten homes, then the landlord needs the consent of all the tenants. If the complex consists of more than ten homes, then the landlord needs the consent of at least 70% of the tenants. If the occupants' disturbance is reduced to a minimum, they will be more favourable for renovation.

The prefabricated façade module combines the building envelope upgrade with the use of building systems and the generation of energy (TKI/ENERGO, 2016). A demonstration project was realised in Vlaardingen, the Netherlands. A collaboration of TU Delft , BIK Bouw, TU München, Provincie Utrecht, Waterweg Wonen Housing, STO Isoned, ITHO Daalderop and Kingspan with the support of Climate-KIC work resulted in 12 refurbished, zero-energy buildings (Climate-KIC, 2017). The buildings are provided with excellent insulation and sealing; the new window frames contain three-layer insulation glass and the insulated roof panels are fully covered with solar panels. The buildings are disconnected from the gas network and an installation box provides heating, ventilation and hot water.

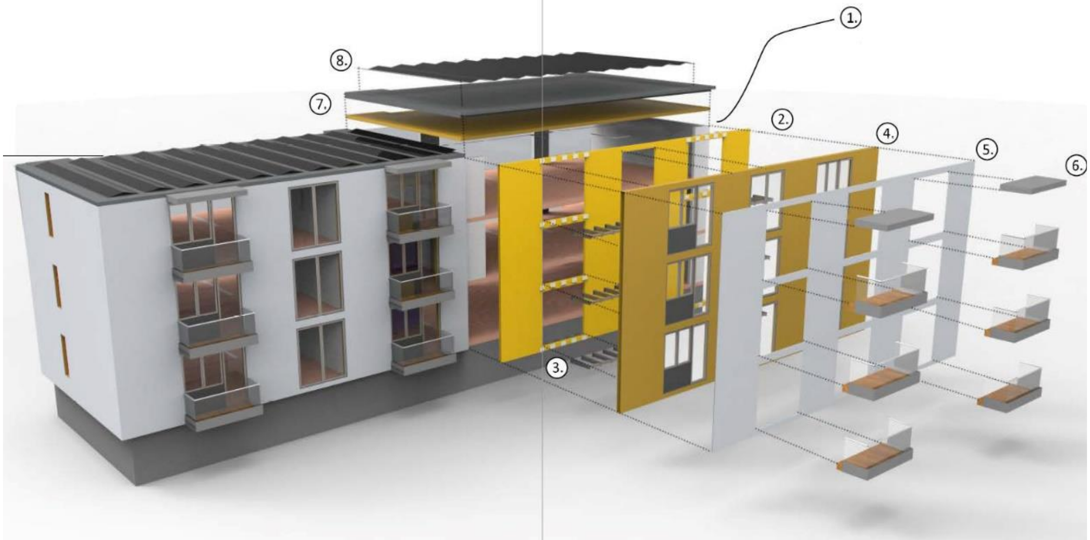


Figure 1.2: 2ndSkin project: upgrading the building's envelope, Source: TKI/ENERGO, 2016

The boxes are in the skin, on a new, enlarged balcony. Solar panels, geothermal sources, and heat pump installations provide electricity for all domestic use, heating and warm water (Climate-KIC, 2017).

However, the 2ndSkin project could not be finished the way it was planned. More research and development is needed to end up with affordable solutions (TKI/ENERGO, 2016). Some key findings in the performance report 2017 of the EIT-Climate-KIC 2ndSKIN Demonstrator are:

- The investment costs of zero-energy solutions are high, stepwise renovation methods allow for this investment to be spread in time.
- The high investment should be tackled before large-scale implementation can take place.

Recommendations were:

- The new balcony is a costly investment and needs a separate foundation. However, it provides a good space for the building services and it delivers an extra benefit for the users by making it bigger than the existing slap construction. More research can optimise this construction.

- Placing the building services on the balcony is a promising approach. *"In the case of the project Soendalaan, kitchen and bathroom are located at that side of the building, so the internal distribution of pipes can be hidden in small suspended ceiling elements here without disturbing the living quarters."* However, "*attention should be given to the heat pump concept*". The ground-to-air type as was used in the project is efficient but installing the two ground loops is challenging and causes the outside paving to be 'dug up' up and this creates a 'terrible mess'. The possibility might not always be given. "*The development of smaller and cheaper heat pumps would have a great potential. Especially if those would be installed within the new façade layer, including a water storage system.*"

- The chosen external insulation layer from expanded polystyrene with plaster is extremely flexible because it is made onsite and can adjust to all tolerances coming from the existing building construction, the roof and window systems and the installations. It was the only possibility to stay within the budget and the given time. However, the system scores bad in terms of circularity and it is believed that on the longer term **a more prefabricated system can reach similar cost levels and at the same time provide higher quality and building speed**.

2 RESEARCH DEFINITION

From the previous chapter, it can be concluded that with deep renovation of existing energy-insufficient houses towards (nearly) zero-energy levels, the built environment can make a big contribution in the demand to lower CO_2 emissions. In case of post-war walk-up apartments (a significant share of the energy-insufficient houses) deep renovation methods are still missing. This leads to the main problem for which this thesis will provide a solution. In this chapter the research that will be conducted to provide that solution is defined.

2.1 Problem statement

Main problem

The 2ndSkin project came up with a new renovation method. However, one of the projects conclusions is:

"The technologies available for integration as sub-systems in 2ndSKIN are currently still ***voluminous****, heavy and* ***costly****. The various subsystems still need be scaled down, to become not only smaller, but also fitting to the actual demand, lighter and better integrated in the skin."*

This research continuous with finding a deep renovation method for post-war walk up apartments that integrates different sub-systems because this is a promising solution for deep renovation. This will be further explained in Chapter 5.3. The main problem that will be tackled is:

"The current renovation methods that integrate heating, ventilation and hot water in the buildings envelop are still too big and costly to constitute realistic renovation methods for post-war walk-up apartments."

Sub-problems

From the previous research, a couple of sub-problems can be deduced:

- High investment cost needs to be tackled before large-scale implementation will take place.
- Balcony construction possibly has more potential than how it is currently used;
- Current simple and less expansive façade system does not have the potential a new façade system would have.
- Ground-to-air heat pumps create a 'terrible mess' and air-to-air are less effective and are oversized when installed per relatively small apartments.

2.2 Objectives

General objective

The general objective of this research will be *the design of a new prefabricated zero-energy renovation concept for post-war walk-up apartments, that integrates the building-services in a space and cost-efficient way.*

As a case, the same building as the 2ndSKIN project in the Soendalaan will be used. This allows the comparison of the 2ndSKIN project with the result of this research.

Sub-objectives

From the different problems and sub-problems these sub-objectives were derived:

- Find current methods of façade refurbishment
- Look for different building services concept, heat pump alternatives and possibilities of integrating them in the façade
- Optimization of balcony construction with integration of building-services;
- Design of new façade system.

2.3 Hypotheses – starting point

As a starting point, it is assumed that if the renovation measures are integrated in a new façade layer, the cost will lower, and residents' participation will become more favourable. This can be seen in the 2ndSkin project but in this project the sub-systems were still voluminous and costly. If this could be reduced, the method could possibly become more feasible. Another big challenge is the integration of heat pump systems. It is possible that such systems can be more space and cost efficient if an alternative to the current type of heat pump were implemented. It is also assumed that by integrating the solution into a prefabricated system, the time on the construction site with the disturbance from it and the total costs could be reduced. This research will only focus on renovating post-war walk-up apartments to zero-energy housing.

2.4 Research questions

Main research question

How can the integration of building services in façades, for zero-energy renovation methods in Dutch post-war walk-up apartments, be optimised in terms of space and costs?

Sub-questions

To answer the main research question, first an answer must be found for different sub-questions:

1) What are characteristics of post-war walk-up apartments?
    a) How is the case in Vlaardingen constructed?
    b) What typologies are there?

2) What are current methods of energy efficient renovation?
    a) How can a building be designed energy efficiently?
    b) What are the different refurbishment strategies?
    c) What are the advantages and limitations of prefabrication?
    d) How has it been done in the past?

3) What buildings services are there and what concepts can be used?
    a) What are alternatives for heat pumps?
    b) How can building services be integrated in the façade?

4) How do building services contribute in becoming zero-energy?

5) How can the research be translated into a new renovation method?

6) What are alternatives for the placement of a new balcony?

3 APPROACH AND METHODOLOGY

The general objective of this research is to design a new prefabricated zero-energy renovation concept for post-war walk-up apartments that integrates building-services in a space and cost-efficient way. The question "*How can the integration of building-services in façades, for zero-energy renovation methods in Dutch walk-up apartments, be optimised in terms of space and costs?*" will be explored and answered. The research required to answer the main question will be divided in different phases, providing a step-by-step approach leading to the conclusion of this thesis. How these steps and phases look like and what they include is described in this chapter.

3.1 Step-by-step research approach

In order to achieve the different objectives stated in Chapter 2, the research will consist of five different phases:

I. Research definition

To organize the research, first the background, problem, objective, hypotheses and research questions are determined and described during the first phase.

II. Literature review

Secondly, a literature review will be done. The background and the problem are already described in the research framework, but for further research, more in-depth knowledge is required. In this review, the problem, its context and possible solutions will be further explored. An answer will be given to research questions 1 to 4 that will act as parameters in the next phase.

III. Determinations of the different parameters and concepts

In this phase different parameters will be identified from the reviewed literature. Some of which will be fixed, and others will be variable. This allows the comparison of different parameters to take place and the possibility to see in how they contribute in achieving the main objective. This can later be used to make different design concepts that will answer sub-question 5. The concepts will be tested and further developed in the next phase.

IV. Design and evaluation

This phase will use the UNIEC 2.2 program that can make energy performance calculations according to the NEN 7120. Besides making calculation, this phase will also include the further architectural development of the most energy efficient concepts. Integrating the different building services in a new renovation method. These concepts will then be evaluated on the criteria's cost, maintenance and required space to see which one or which combination of concepts is the most effective for the final renovation concept. During this phase an answer will be sought for the last sub-question. The result of this phase will be a design brief that can be used in the conclusion phase.

V. Conclusion

In the conclusion, two concepts will be combined into a final renovation concept. A new prefabricated zero-energy renovation concept for post-war walk-up apartments, that integrates the building-services in a space and cost-efficient way will be presented.

How the different phases look graphically, is shown in Figure 3.1. The different steps mentioned can be seen from top to bottom on the left. Each different step provides input for the next one(s).

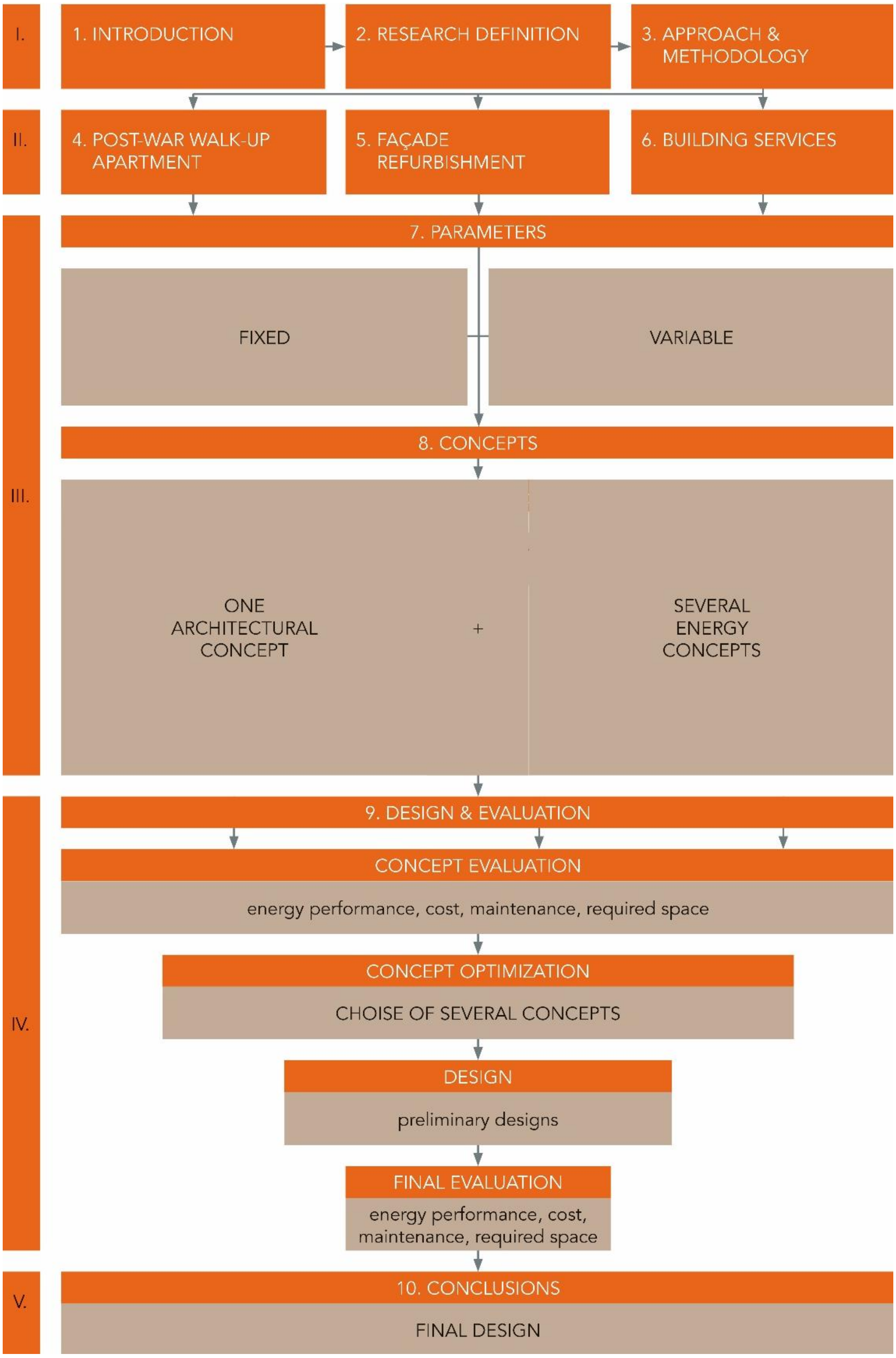
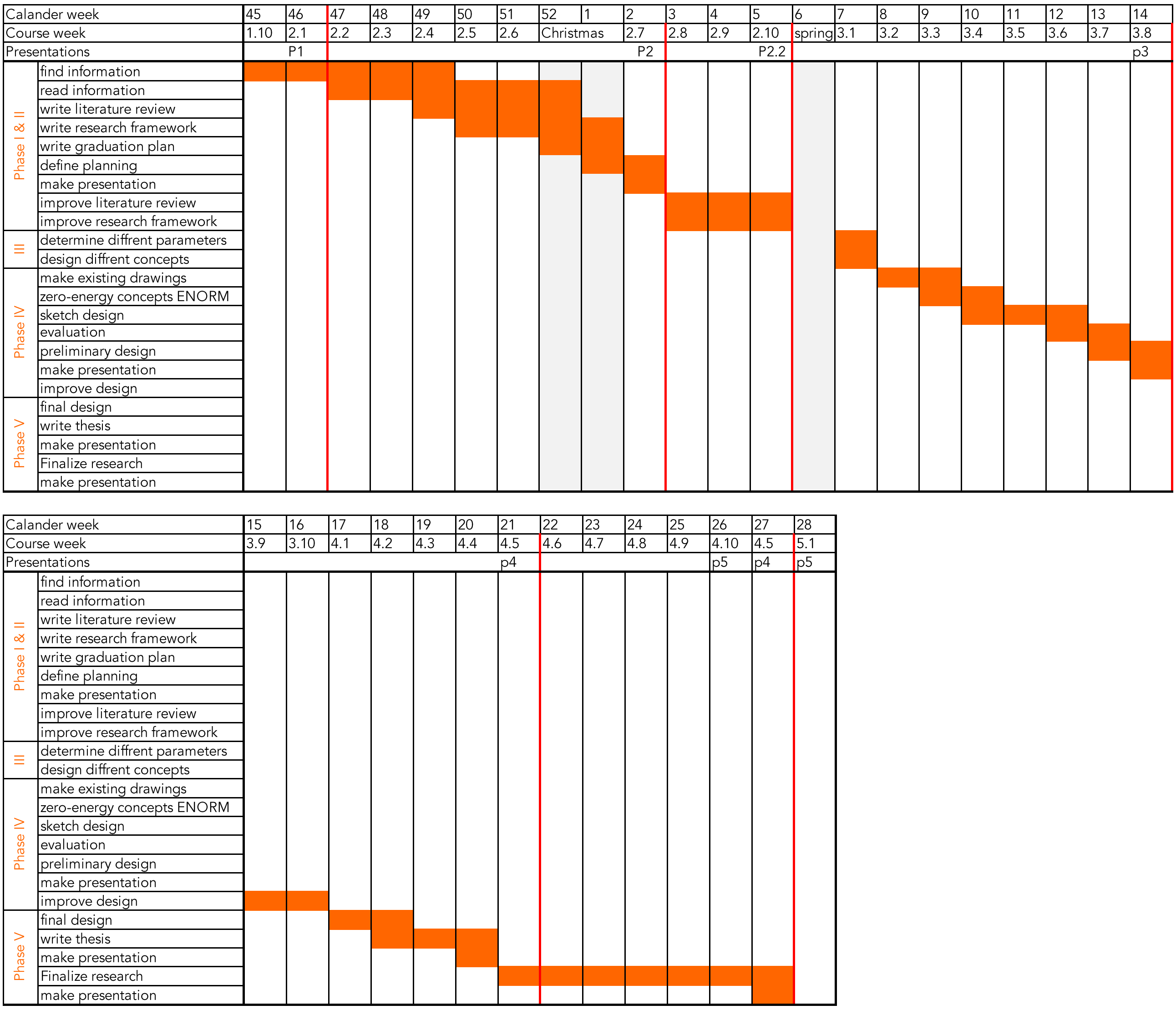


Figure 3.1: Research design, Source: own illustration

3.2 Research approach into planning with timelines

A scheme of the division of the workload of the graduation project in the given timeframe.



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	make presentation																						
	Finalize research																						
	make presentation																						

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Course week		3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.5	5.1
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	improve research framework														
III	determine diffrent parameters														
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Phase IV	make existing drawings														
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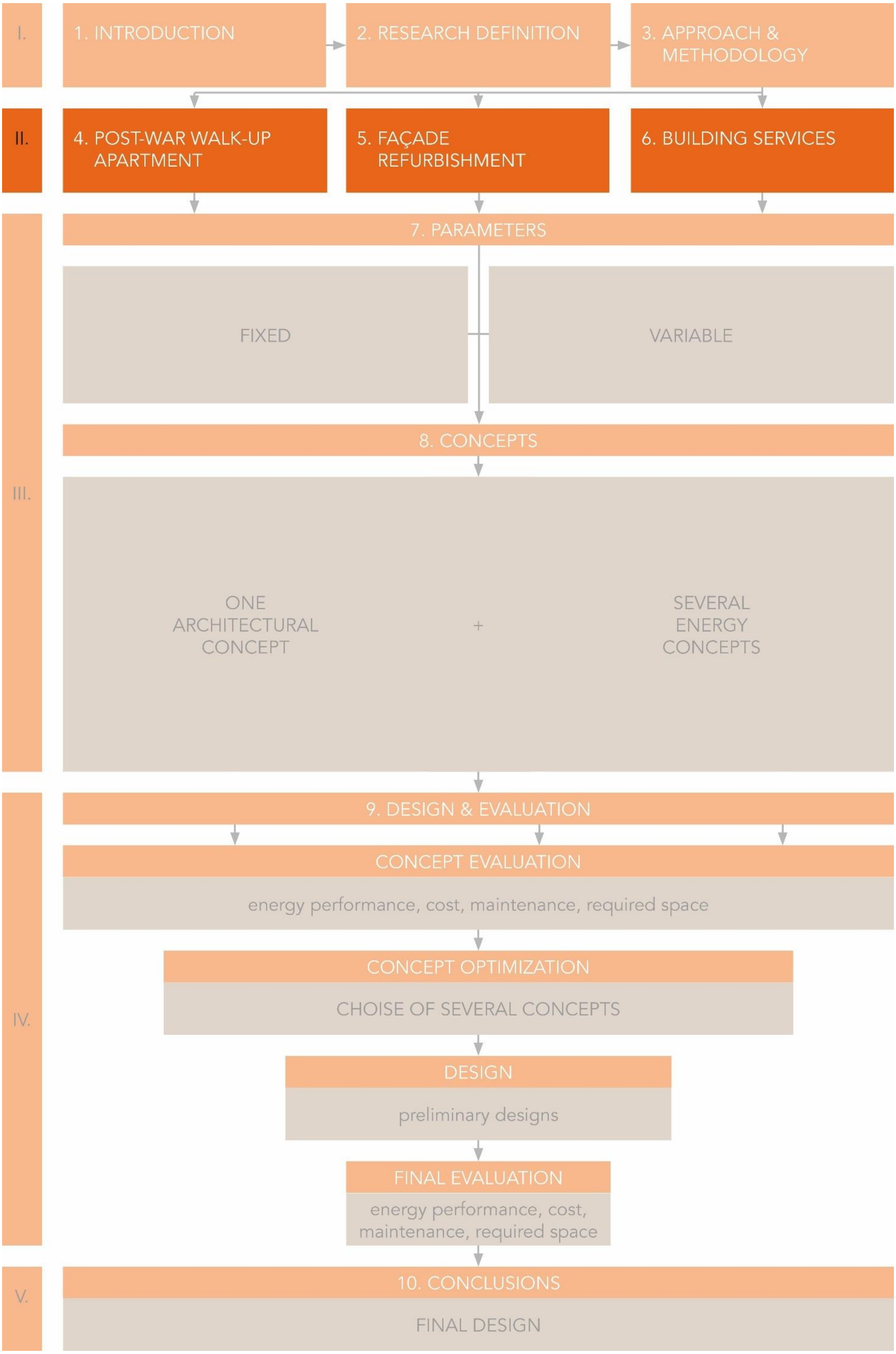
Figure 3.2: Research planning, Source: own illustration

PHASE II



Research approach into planning with timelines

4 POST-WAR WALK-UP APARTMENTS

In the first chapter, the relevance of post-war porch-apartments was explained. In this chapter, the characteristics of this type of housing will be investigated to find an answer to the questions:

1) What are characteristics of post-war walk-up apartments?
    a) How is the case in Vlaardingen constructed?
    b) What typologies are there?

First the case will be analysed so it can be compared with other post-war walk-up typologies. This way a comparison can be made between the characteristics of the case and the main typologies. By doing this, it can be seen if the design result in the conclusion of this thesis is applicable for other post-war walk-up apartments as well.

4.1 Case in Vlaardingen

For the design of a new refurbishment concept, the original 2ndSKIN post-war walk-up apartments will be used as a case. The direct relation with the 2ndSKIN project allows comparison. Also because of the availability of drawing and other information.

The building was constructed in 1951 (Kadaster, n.d.) and is located in the Soendalaan in Vlaardingen (Figure 4.1.1). In the neighbourhood, 31 similar building blocks can be found. They are marked with an A in Figure 4.1.1 and indicate the relevance of up scaling for the renovation concept.

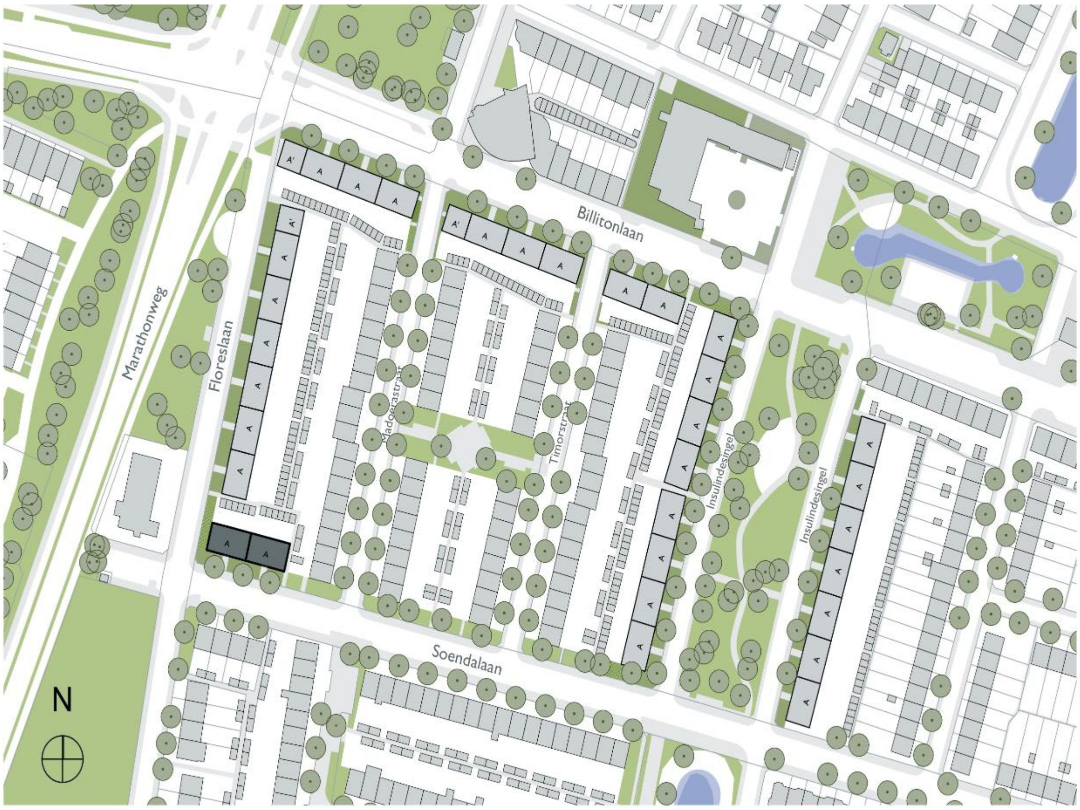


Figure 4.1.1: Location of the case (dark grey) in Vlaardingen, Source: Climate-KIC, 2017.

One building block consists of two apartments per floor, spread over three building layers bringing the total to six apartments. In the Soendalaan two blocks (Figure 4.1.2) are located bringing the total to 12 apartments. The two front entrances are located at the south façade and leads to a shared entrance hall.

Figure 4.1.2: Case in Vlaardingen on June 2014 before 2ndSKIN renovation, Source: Google Maps.

Each apartment has 52,50 m^2 of floor area and contain an entrance hall leading to the living room, two bedrooms, the toilet and the kitchen. Behind the kitchen is a balcony and the bathroom (Figure 4.1.3). Underneath the roof is an attic, but this space is not accessibly.

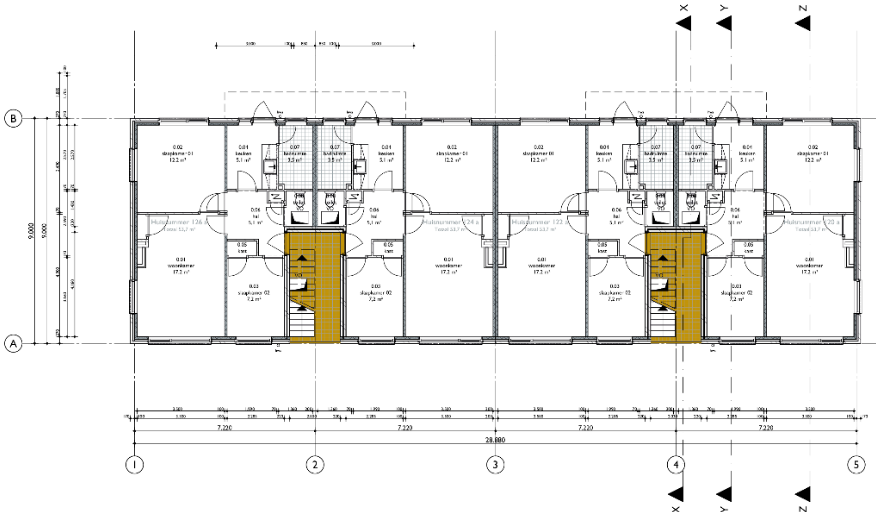
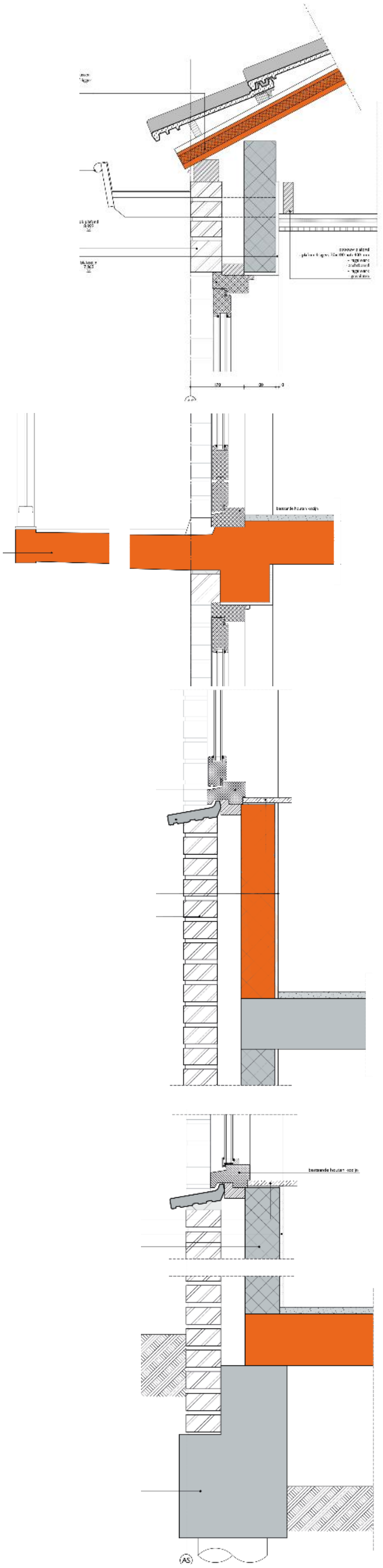


Figure 4.1.3: Floorplan with shared space in yellow, Source: Climate-KIC, 2017.

The construction method used for the apartment block in the case study is called 'simplex method'. This system uses prefabricated story high concrete elements that form the interior wall and structural layer of the building with a lot of repetition to simplify the construction process (Simmering, 2019). In Appendix A, a complete drawing set of the original situation displaying the layout, elevations, sections and details can be found. Four main details will now be analysed in Figure 4.1.4.



Roof:
The roof consists of ceramic tiles on a sub layer of wood wool cement slabs between wooden T-beams. This insulation value of this construction is not good enough for zero-energy levels.

Balcony:
The balcony consists of continuous concrete slab, forming a major thermal bridge.

Windows:
The wooden windows contain double glazing, so probably it has already been replaced. However, it is not good enough for zero-energy levels.

Wall:
The cavity wall is not insulated. The inner wall is made of concrete and the exterior wall is brick masonry.

Ground floor:
The concrete ground floor is not insulated, nor the crawl space beneath it.

Foundation:
The foundation rests on poles and the foundation beams are not insulated, forming a thermal bridge.

Figure 4.1.4: overview building components, Source: Climate-KIC, 2017.

The building services can be seen in the photos in Figure 4.1.5 that are taken on site. The apartments are ventilated by natural air from the outside that is exhausted mechanically through the toilet, bathroom and kitchen. Heating is provided by a gas boiler and distributed by radiators.

Figure 4.1.5: Building services exhaust: pipes, gas boiler and radiator, Source: Climate-KIC, 2017.

4.2 Typologies

Agentschap NL (2011) published a brochure ‘voorbeeld woningen 2011 bestaande bouw’ with examples of housing types in the Netherlands. It distinguishes five building periods of walk-up apartments. The ones built between 1946 and 1964 often have 2 to 4 rooms and are part of a residential building with multiple floors, without elevator. The homes are accessible via a closed porch (89%) and are mostly inhabited by young households: under 35 (43%) and 35-54-year olds (30%). The houses are mainly occupied by singles (51%) and double households without children (21%). In this period there were no requirements for the energy efficiency of homes. Therefore, most homes were not insulated.

The houses from these post-war period were mostly constructed as “non-traditional” but in an industrial way, because of the housing shortage in this period of time (Agentschap NL, 2011). The emphasis was on a more efficient construction process for the large amount of new buildings to be realised. An answer was found in labour-saving concrete constructions like in element building methods or cast in-situ methods (TKI/ENERGO, 2016). Those building systems were usually developed and named after the construction companies that invented and applied them. The Simplex method is developed in the same fashion.

The 2ndSkin design needs to applicable for many buildings and therefore it is important to know the construction characteristics. In the TKI/ENERGO report, an overview of the 6 most popular building systems of the characteristic’s was given (Figure 4.2). In the overview, the concrete elements, poor insulation and thermal bridges can be seen. It also seems that different ways of constructing the balconies were used.

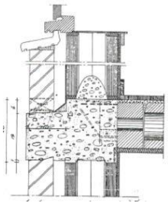
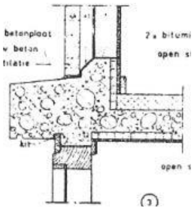
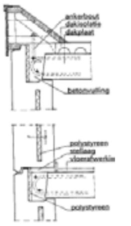
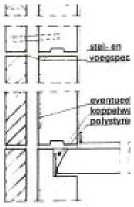
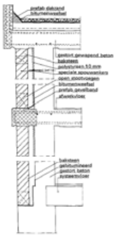
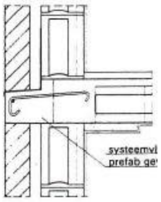
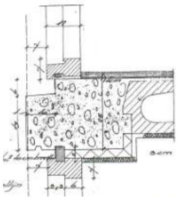
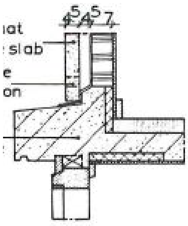
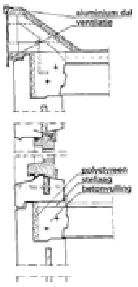
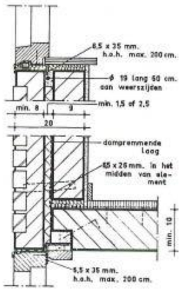
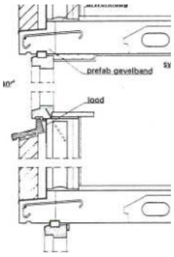
	MUWI	R.B.M.	Coignet groep	B.M.B.	EBA-gietbouw	Pronte
						
Number of dwellings	37.831	32.292	31.378	29.369	19.291	17.836
Percentage of post-war systems	11%	9%	9%	9%	6%	5%
Balcony type	Half-logia	cantilever	loggia	Loggias and cantilever	cantilever	Mostly cantilever
Façade detail wall						
Façade detail window					-	
Percentage of openings (approximately)	60% (parapet in the façade panel)	30-60% (varies significantly between walk-up and gallery flats)	30%	30%	-	60%
Wall construction	Cavity wall: MUWI wall (stacked concrete blocks with poured in-situ concrete) Brick wall exterior	Cavity wall: Lightweight concrete and brick wall exterior	Sandwich concrete panels with 2-2,5 cm polystyrene	Cavity wall: Prefab concrete, prefab brick masonry	Cavity: Siporex 1cm polystyrene, brick masonry	Cavity wall: Prefab concrete elements Brick masonry exterior

Figure 4.2: Overview of layout and construction characteristics of the six most popular non-traditional systems, Source: TKI/ENERGO, 2016.

5 FAÇADE REFURBISHMENT

To achieve the main objective of designing a new prefabricated zero-energy renovation concept for post-war walk-up apartments, a study has been conducted on the first part of the main objective: a prefabricated zero-energy renovation concept. In this study, answers will be sought for the first research questions:

2) What are current methods of energy efficient renovation?
    a) How can a building be designed energy efficiently?
    b) What are the different refurbishment strategies?
    c) What are the advantages and limitations of prefabrication?
    d) How has it been done in the past?

To do this, this chapter will first look at energy efficient design strategies after which the research will zoom in at renovation strategies and prefabrication. Finally different case studies will be examined.

5.1 Energy efficient design

The total annual energy consumption of all Dutch households combined fluctuated around 430 petajoules in the years between 1990 and 2012 (Figure 5.1.1)(ISSO, 2015). This occurred despite the increase in the number of households from 6 to more than 7,5 million in that period (Figure 5.1.1).

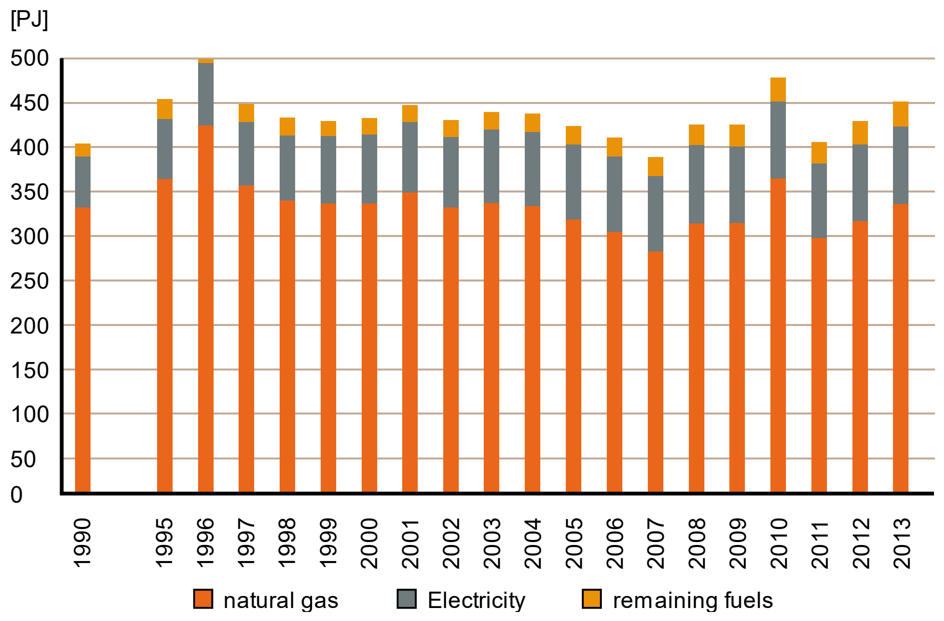


Figure 5.1.1: Total energy consumption Dutch households, Source: ISSO Figure 1.8, 2015

The more or less constant total energy consumption can be explained by the decrease in average annual energy consumption for space heating per household (Figure 5.1.2).

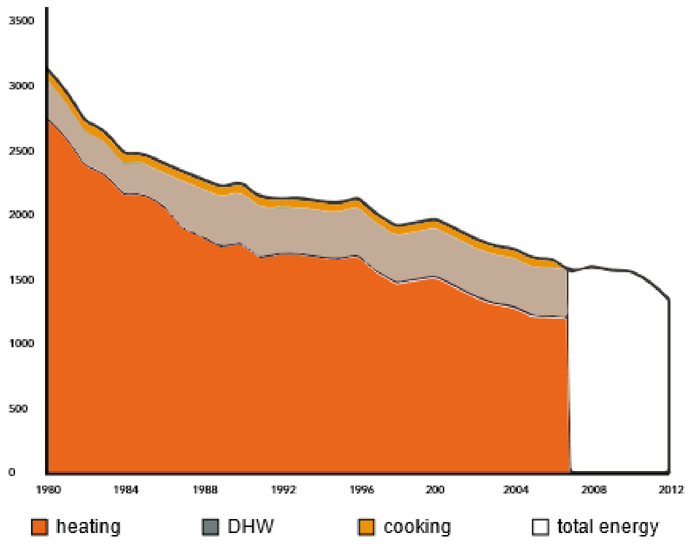
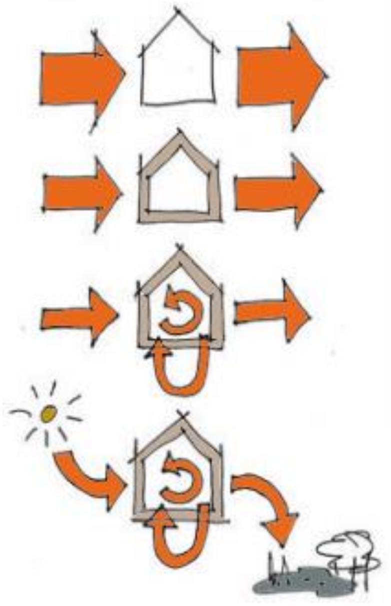


Figure 5.1.2: Average gas consumption Dutch households, Source: ISSO Figure 1.8, 2015

A decrease in energy demand, can be achieved by employing different methods and techniques. For example, the 2ndSKIN project made use of the ‘trias energetica’ explained in Chapter 1.2. Based on this strategy, the New step strategy was developed (Vera Yanovshtchinksy, Kitty Huijberts, 2013). This strategy consists of different steps:



Step 1: reduce the energy demand

Step 2: reuse rest flows

Step 3a: Resolve the remaining
energy demand in a sustainable way

Step 3b: waste = food.

Figure 5.1.3: New step strategy, Source: Vera Yanovshtchinksy, Kitty Huijberts, 2013.

Step 1 demands a passive and smart design. Optimising the use of the area, orientation, surroundings and the architectural design. Specifically, the architectural design is interesting in relation to refurbishment. Optimising the use of the architectural design in refurbishment means the optimising the glass surface area, using insulation, possibly introducing natural ventilation and having passive elements.

Step 2 is about the use of rest flows, the aim being to create closed cycles. This can possibly mean that the energy ‘waste’ of one flow can feed another flows energy demand.

Step 3a consists of reducing the remaining energy flow using sustainable measures.

Step 3b concerns the remaining waste, which cannot disturb the surroundings but perhaps feed into that.

By following these steps, energy reduction can be achieved. The passive measures that can be used will be discussed next. The active measures of steps two and three will be discussed in Chapter 6.

Passive and smart Design

In a passive design, different principles can be used to minimise the building's energy demand. This can be achieved by considering the local climate and context, material and building plan (Konstantinou, 2014). The façade refurbishment toolbox breaks passive design down in the three basic functions: heat protection, passive solar use and the preventing of overheating.

The first function is about reducing the heating demand by making it possible for the building envelope to prevent or minimise the heat flow from the inside to the outside in Winter. In Summer the direction it is the other way around. This can be done by increasing the airtightness and thermal resistance of the building envelope, eliminating thermal bridges with additional insulation on the wall, basement, roof and the replacement of windows (Konstantinou, 2014). To improve the thermal resistance and eliminate thermal bridges, a simple first step is to use insulation. However, this step does not necessary increases the airtightness of a building. Airtightness is the infiltration or leakage from air through leaks, crack or other openings in the envelope to the outside. This can lead to energy loses and other problems like moisture damage. Ensuring air tightness can be achieved by careful implementation of strategy throughout the design process (Konstantinou, 2014). In the Netherlands, three different classes of airtightness are distinguished:

class	level	Airtightness at 10 Pascal ($q_{v;10}$)
1	Basic	$q_{v;10}$ > 0,6 $dm^3/s \cdot m^2$, meets the building code, no special requirements.
2	Good	$q_{v;10}$ between 0,3 and 0,6 $dm^3/s \cdot m^2$ = energy-efficient building
3	Outstanding	$q_{v;10}$ <approx. 0.15 $dm^3/s \cdot m^2$ = passive construction or other forms of highly energy-efficient construction

Figure 5.1.4: Different classes of airtightness, Source: Nieman, n.d.

The second function is about using solar heat. During the Winter, solar energy can be harvested with minimal use of mechanical equipment to collect, store and distribute solar energy. A shortcoming of using passive heating is that it mainly occurs in a building's south part (Konstantinou, 2014). When designing new buildings, this does not have to be a problem but with refurbishment the orientation is mostly fixed. Besides using the sun for heating, the sun can also be used for illumination.

The third function is preventing overheating. To use the sun for heating and illumination, you want to have the sun in your house. However, in the summer season when you do not need heating this can cause the problem of overheating. This can be prevented with the use of shading devices.

5.2 State of the art refurbishment strategies

The façade acts as main component in a building architectural expression and in the energetical performance of a building. This means that renovating the façade can have big impact on a building's lifespan. Related to façade, this chapter presents the state of the art in terms of refurbishment strategies, materials and component retrofit measures as found in the Façade refurbishment toolbox by T. Konstantinou (2014). It also will briefly tell something about the use of prefabrication.

Refurbishment strategies

In the toolbox, five different strategies for refurbishment are defined:

	replace	add-in	wrap-it	add-on	cover-it
description	Old façade elements removed and replaced with new ones	Upgrade from the inside	'Wrapping' the building in a second layer	New structure is "added on" to the existing building	Cover parts or entire internal and external courtyards and atria
benefits	Replace the entire façade Replace parts	Internal insulation Cavity insulation Box window	External insulation, Cladding of the balconies Second skin façade	Small intervention, such as adding new balconies New building as an extension Additional floor	Cover parts or entire Heated or unheated space
limitations	Great impact on users Higher costs	Critical connection thermal bridging need attention Big disturbance for users	Not applicable to monumental buildings Possible space limitation	Needs to be combined with other strategies for façades non-adjacent to new structure Structural limitation	Not applicable to all cases Depending on layout and function of the building Overheating risk

Figure 5.2.1: Refurbishment strategies, Source: Konstantinou table 4.1, 2014.

Especially the strategies that approach the building from the outside are interesting. This way the disturbance on the inside can be reduced to a minimum as seen in the 2ndSKIN project in which the building was wrap-it in a new skin. As add-on balconies were changed which creates an opportunity for more space per housing unit.

The Replace strategies can also be interesting because old elements are replaced for better performing elements. However, the costs are greater and also the nuisance impact on tenants. In the case studies from the next chapter, an example in which the Replace strategy was successfully used is shown.

Materials and components

This paragraph will investigate how the different refurbishment strategies can be materialised. Each material needs to fulfil a range of different criteria. The toolbox provides an overview of materials:

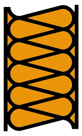
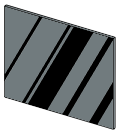
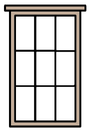
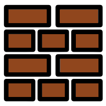
	Insulation	Glazing	Window frames	Sealants	Finishing
					
Design principle	Heat protection	Heat protection Passive solar heating Sun protection	Heat protection Ventilation	Heat protection/airtightness Weather proofing	Protect the construction underneath Heat protection/airtightness

Figure 5.2.2: Toolbox's overview of materials, Source: Konstantinou table 4.2, 2014.

Insulation is required to reduce heat transfer as mentioned in the previous paragraph. Glazing also needs to reduce the heat transfer but on the other hand must allow solar heat to enter when needed and block when not needed. Glazing is place in a window frame that can be made of different materials. It should also provide heat protection but in some cases also allow for ventilation. In many cases sealant is used around windows in connection with the wall to prevent air and water leakages. As final protection layer there is the façade finishing. It is in direct connection with the outside elements and can come in many different variants.

For the decision of component retrofitting measures the toolbox first distinguishes the components: External wall, Windows, Balcony, Roof and Ground floor. These three levels of decision act as parameters in the refurbishment process and it is therefore needed to carefully take them in account.

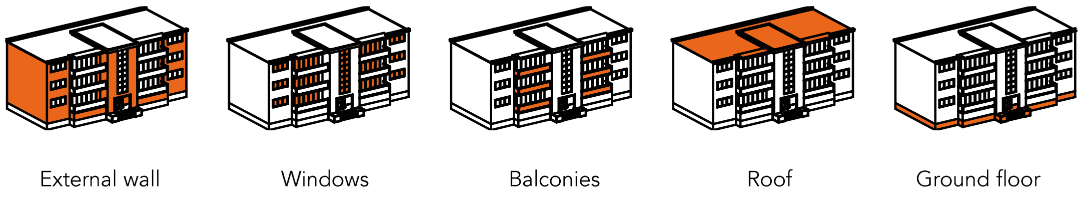


Figure 5.2.3: Overview façade component, own illustration.

Prefabrication

In addition to the different levels of decision there is also the decision of using prefabricated element. Using prefabricated elements in the construction process, has the big advantage of lowering the construction time on site. In refurbishment, this can significantly reduce the nuisance for the inhabitant. Especially when elements are only placed on the outside and work on the inside is minimalized. Prefabrication also has the advantage of providing a constant quality due the factory conditions. This also limits the dependency of weather conditions. However, prefabrication does require significantly more preparation time before the construction phase. It requires a detailed survey of the existing building.

5.3 Case studies

In this chapter different renovation methods will be investigated. First a closer look on how the renovation in the 2ndSKIN project has been done, will be provided. After this a similar renovation method will be investigated that gives more information about the technical aspect. Then a prefabricated renovation element that is used in practise will be analysed to show the possibly of prefabrication on renovation projects. The final case consists of a housing concept that uses as much passive measures as possible, whilst still achieving good energy performance.

2nd SKIN project

Figure 5.3.1: Situation before and after retrofitting, Source: Climate KIC, 2017.

The retrofitting concept from 2ndSkin project offers a prefabricated and integrated façade module that improves the energy performance to zero-energy, while keeping the occupants' disturbance, during and after the renovation, to a minimum. The prefabricated façade module combines the building envelope upgrade with the use of building systems and the generation of energy. It consists of a cupboard with different building services inside as shown in the Figure below:

Ground floor cupboard First floor cupboard Second floor cupboard

Figure 5.3.2: 2ndSKIN cupboard per level, Source: (Berkhout, 2018).

The cupboard contains a ground source heat pump, a buffer and a ventilation heat recovery unit on the ground floor. On the second floor it contains a booster heat pump, a buffer and also a ventilation heat recovery unit. The cupboard on the third floor only contains a buffer and a ventilation heat recovery unit.

For the building services, an all-electric solution was chosen. This meant that the buildings can be completely disconnected from the gas network.

Ventilation: For the ventilation system, a mechanical system with heat recovery up to 95% is chosen (Climate-KIC, 2017). Ventilation pipes run from the heat recovery unit on the balcony trough the kitchen or bathroom and hallway. Inlet air comes from the Livingroom, bedrooms and kitchen. The ventilation system can be seen in the image below:

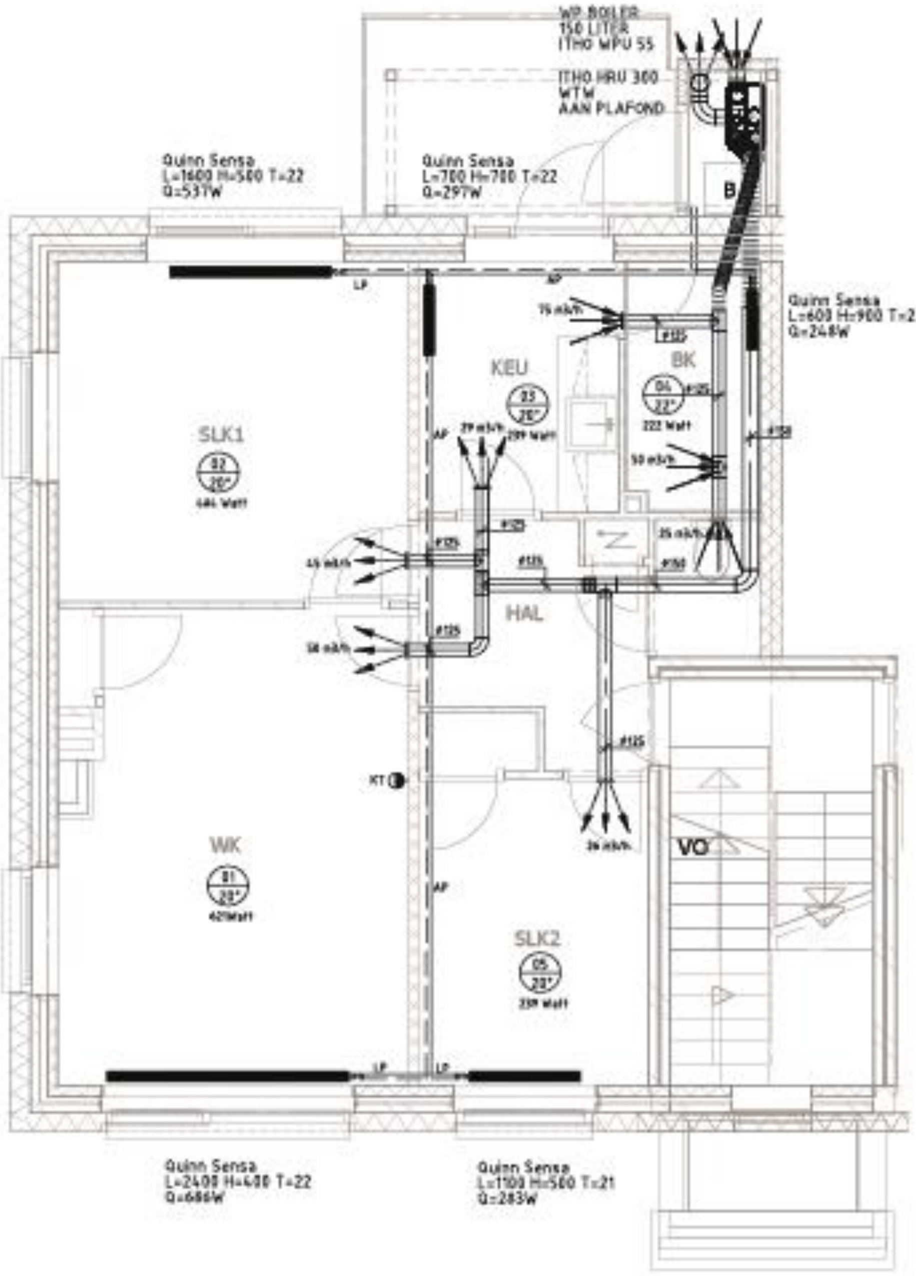


Figure 5.3.3: 2ndSKIN ventilation scheme, Source: Climate KIC, 2017.

Heating & DHW: The existing gas boiler is removed and replaced for a ground-to-water type heat pump per three apartments. The heat pump supplies hot water for heating and domestic hot water (DHW) with a COP (more on this in chapter 6) of 6,00 respectively 3,00. For the DHW, an additional heater is required per apartment. Low temperature heating is used with new radiators. The reasons only one heat pump was used for three apartments is because the ground energy source is efficient enough to cover three apartments. The pump is located on the ground floor with buffer tanks installed on the apartment's installation boxes.

Energy: To reach zero-energy levels, energy needs to be generated on the site. Therefore PV panels with a capacity of 300 Wp are installed on North and South sides of the roof.

On the three decision levels composing solutions for different building components, seen in the previous chapter, decisions had to be made to improve the energy performance.

External wall: The external wall had to be upgraded to reduce heat losses. This meant the façade had to achieve the following insulation values:

Element	Specifications
Roof	U = 0,14 W/Km^2 (Rc = 7,0)
Façade elements	U = 0,16 W/Km^2 (Rc = 6.0)
Ground floor	U = 0,28 W/Km^2 (Rc 3.5)
Window	Uw = 1 ggl = o,8 Rc = 0.8
Infiltration	0.3 dm^3/s·m^2
Ventilation system	Balanced ventilation efficiency 0.95

Figure 5.3.4: Thermal conductivity coefficients of the building envelope, Source: Table 1 Climate KIC, 2017.

In case of the 2ndSKIN project, this meant a rigid expanded polystyrene insulation with a thickness of 19 centimetres (Climate-KIC, 2017). The façade was finished with a plaster cladding:

Figure 5.3.5: New insulation layer with plaster, Source: Figure 1 Climate KIC, 2017.

Windows: The existing windows are replaced with new high performing u-PVC frames and triple glazed panes. The window removal and replacement took place while the houses were still occupied.

Balconies: The balconies were made of a continuous concrete slab resulting in a thermal bridge. The balconies were therefore removed and replaced with a new construction. The balconies are also designed to accommodate for the new installation space.

Figure 5.3.6: Removal of old balconies and the placement of the new ones, Source: Climate KIC, 2017.

Ground floor: Because placing insulation on top of the ground floor slab would mean a decrease in space and being a big interior intervention whilst having a crawl space underneath, the crawl space was filled with expanded polystyrene insulation in granulated form.

Roof: The new roof consists of insulated Kingspan panels. The existing timber roof structure and sheeting is preserved, but the old ceramic tiles are removed. The PV panels system is mounted directly on the prefabricated panels.

Renovation train

Figure 5.3.7: the houses before and after retrofitting, Source: Rover, 2014.

In the same context as the 2ndSkin project, lowering CO_2 emissions demand by renovating existing energy-insufficient houses to more sustainable houses with minimum disturbance to the occupants, the "renovatie trein" (renovation train) concept retrofitted 150 single-family terraced houses in Kerkrade, the Netherlands to near Zero-energy standards (Rovers, 2014).

The housing corporation 'Heemwonen' (formerly Hestia) started a large-scale pilot project, to retrofit homes to near-zero energy levels. It was part of "De bestaande wijk van morgen" (The existing district of tomorrow) which is a large transformation plan on city district level deigned to create a 'new' district. The pilot project involved 150 terraced houses with typical 1970's non-load-bearing front and rear façades (Rovers, 2014). To be able to start this project, at least 70% of the inhabitants had to sign an agreement stating that part of the energy savings could be used as investment money. To get so many inhabitants to agree, involving them in the process at an early stage and convincing them of the advantages was essential. It was also necessary to reduce the nuisance to a minimum, meaning that inhabitants would not be temporarily rehoused, and that construction time was minimised. Eight days were planned for the renovation but later it was adjusted to ten days.

Like the 2ndSkin project, the renovation train concept basically consisted of renovating the skin and various internal building services and not touching the rest of the house. This basically meant a renovation of the façades, roof and several building services.

Prefabricated elements were used in which some of the required pipes and connections were already integrated. The existing foundation was not sufficient and therefore the new façade elements were placed on small steel supports attached to the foundation plinth. The roof elements were placed on top of the old roof framework and only the old roof tiles were removed. This had the advantage of improving the insulation and it also allowed for the inside to be untouched. Old building services were replaced by a modern heating boiler system with a storage tank for the collected solar heat, a PV inverter system and a ventilation heat exchanger. This was the main indoor work and it was made easier by the integrated connections and pipes in the prefab elements. However, in the first design the elements had 28 connections which were reduced to eight in order to make the renovation less time-consuming. The energy reduction is currently being monitored in 65 houses. No measures for reducing electricity consumption were introduced except for an information campaign. The work on site required very careful planning and one disruption could mean the 10-day renovation schedule might not be achieved. This resulted in a process like a train with activities, moving from house to house.

In the end, the budget of €100.000,- per house was exceeded, but it was still a viable business case since the houses got a prolonged lifetime of 50-years (Rovers, 2014). The inhabitants had a €100, - cost reduction on their energy bill, €60, - of which went towards rent increase, leaving them with a net profit of €40, -. As a follow up, six housing corporations and four consortia of co-makers have worked out a plan to renovate another 100.000 houses.

Cocoonz

Figure 5.3.8: Cocoon renovation method: existing and new situation, Source: NBU Nederlandse Bouw Unie, 2016.

Cocoonz is a renovation method that uses frameless façade elements which are placed in front of an existing façade ('*voorzetgevel*'). This system is used for the renovation of different terraced houses (Figure 5.3.8). Like mentioned, this system does not use a frame structure in the elements, making it a lighter than other similar systems. This reduces the nuisance for the inhabitants of the houses that will be renovated. It also has the advantage of making it easier to transport, process on site and this way the elements do not need an additional sub-structure.

Figure 5.3.9: Façade element Cocoonz renovation method, Source: NBU Nederlandse Bouw Unie, 2016

The elements do contain insulation and possible new ventilation pipes for both the façade and the roof. It can reach zero-energy levels and it also improves the sound insulation. Old cold bridges in the existing façade are completely removed. Important is the linear cold bridge of the foundation. Here the new façade will be insulated against the foundation underneath the ground and this will conceal the cold bridge. The elements consist of different layers, which are in case of zero-energy levels from the inside to the outside:

	Share (%):	Thickness (mm):	λ (W/mK):	R (m^{2}K/W)
Inside				0,129
Internal wall (old)		105	0,8	0,131
Insulated cavity		50	0,035	1,429
External wall (old)		105	0,8	0,131
Cavity				0,170
Polyester		3	0,2	0,015
Composite	4,6	140	0,8	0,006
PU insulation	95,4	140	0,022	6,071
Polyester		1	0,2	0,005
Brick slips		7	0,8	0,009
Outside				0,043
			Rc:	7,967
			Rtot:	8,139

Figure 5.3.10: Different layers in Cocoonz element, Source: (Cocoonz, n.d.).

The appearance of a brick façade can be achieved with the help of so called 'brick slips'. These slips *"absorb virtually no dirt and are available in all brick structures and colours"* (NBU Nederlandse Bouw Unie, 2016). Other facade finishes are also possible, such as wood or stucco.

Brabant woningen

Figure 5.3.11: Image Brabant houses, Source: Archiservice.nl

The final investigated case that is the so-called Brabant home. This is not a renovation project but a project in which a new home was designed. The intention was to be sustainable, affordable, comfortable and applicable on a large scale and although energy neutrality was pursued, it could not be achieved at the expense of a high comfort and healthy living (van Bavel, 2011). This is an interesting approach, because often sustainability in building projects must be achieved no matter the expense.

Especially the ambition to be sustainable, healthy and comfortable is an interesting one. The climate – building services concept of the houses places the emphasis on limiting the use of energy required for heating, domestic hot water and for cooling (G4C4, 2011). Limiting the use of energy for heating has the following effect on the building components:

Element	Specifications:
Closed façade parts	Rc ≥ 8,0 m^{2}K/W
Roofs	Rc ≥ 8,0 m^{2}K/W
Ground floor	Rc ≥ 5,0 m^{2}K/W (no ventilation of potential crawl space)
Windows	U (glass + frame) ≤0,80 W/m^2·K ggl = 0,50.
Front door	U (door + frame) ≤1,29 W/m^2·K
Infiltration	qv;10 = < 30 dm^3/s
Waterworks	Diameter water pipes kitchen is max. 10 mm.

Figure 5.3.12: Thermal conductivity coefficients of the building envelope, Source: (G4C4, 2011).

To use the sun in a passive way, solar collectors are used for DHW and heating and the sun is allowed to enter through the glass in winter. PV panels reduce the remaining energy demand to 0 kWh / m^2 / year. Energy is also reused by heat recovery of ventilation air by an air-to-water heat pump on the ventilation exhaust retour air and from the shower water. Heating is done with low temperature.

Ventilation is natural provided and mechanically exhausted with energy efficient vents. If heavy ventilation takes place by opening all the windows, the house should have enough mass to quickly regain heat inside. The air inlet is designed for use of the Coanda effect. This effect 'stucks' air to the ceiling before it falls down, which gives it time to blend with heated air in the room and preventing 'cold fall' (Berkhout, 2018).

Active cooling is not possible. This means sun shading is placed on E, SE, S, ZW and W orientations. Using vegetation to limit the sun and use for cooling.

The entire building circulation system is shown in Figure 5.3.13.

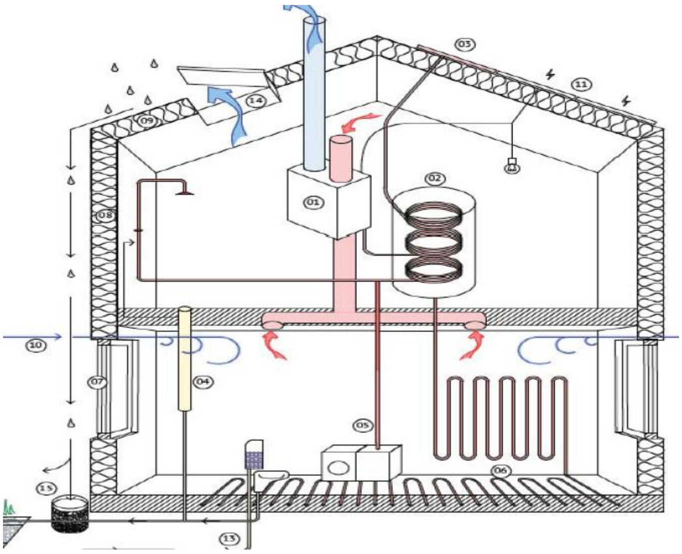


Figure 5.3.13: entire building circulation system, Source: (Berkhout, 2018).

6 BUILDING SERVICES

Besides passive measures that reduce the heat demand, active measures are needed to produce and distribute energy needed for heating, cooling, ventilation, domestic hot water (DHW), lighting and appliances. These measures are also known as building services, but what building services are there and how can they contribute in energy efficient refurbishment? Ventilation, Heating and DHW will be investigated in this chapter as well as collective systems. These measures will be integrated in the new renovation method and determine whether the building will be zero-energy or not. This chapter will provide an answer to the first part of the third sub-question: '*what building services are there*'?', so that in Chapter 8 an answer can be given to the second part of the question: *'what concepts can be used?'*.

6.1 Ventilation

Ventilation has a big impact on indoor air quality and is therefore of great importance to occupant's health. It also has a great effect on the energy use of a building. If central heat recovery takes place from the ventilated air, the ventilation losses (including infiltration losses) are still roughly half of the transmission losses (ISSO, 2015). Therefore, it is important to find a good balance between having enough ventilation and the reduction of energy consumption, but also the influence from the ventilating behaviour of the resident(s).

There are different ways to ventilate a building, NEN 1087 (2001) distinguishes four (basic) systems (Figure 6.1.1) that apply different combinations of natural and mechanical ventilation. System X is added for 'other systems' that involve combinations of the four basic systems.

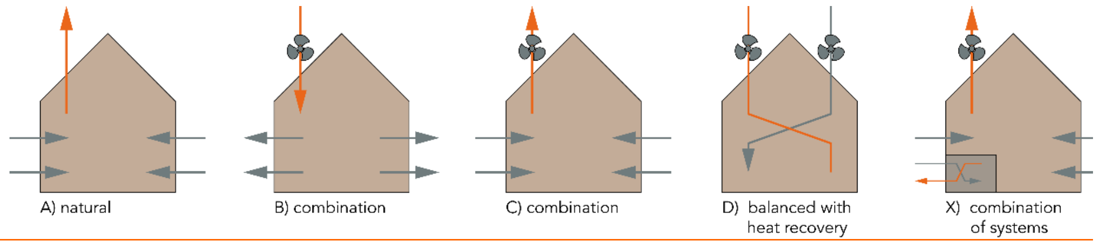


Figure 6.1.1: Overview of ventilation systems according to NEN 1087, Source: own illustration.

Other groups include System C+ and E. System C+ naturally supply through demand-regulated vents, with mechanical exhaust with which vents can be regulated through CO_2 or humidity sensors to vent only when necessary, thus keeping ventilation and heat loss to a minimum. System E, also known as 'system D (decentralized)' with mechanical supply and exhaust through a decentralized ventilation unit (in the façade) in which every room has its own ventilation unit (Ter Haar, 2015). System B is almost never applied and is therefore not considered in the further research.

Knowledge institute ISSO published a report titled 'Energie Vademecum 2015' containing guidelines and tools for the design of energy efficient homes. In this several ventilation systems are compared to a reference house with ventilation system D3. This system consists of balanced ventilation with heat recovery and CO_2

control on the exhaust. Table 6.1.2 indicates whether a system scores better (+), worse (-) or equal (0) on several aspects compared to the reference house.

From the table it can be concluded that systems with natural supply are in general less expansive, require less maintenance, do not produce noise, are robust and space efficient. However, the more mechanical ventilation systems produce more energy saving.

ventilation system	adjustment	system	cost	energy saving	maintenance	ease of use	fresh air / draft	sound system	outside noise	robustness	required space
natural supply by self-regulating grates + natural exhaust	manual on supply	A2a	+	--	++	-	-	++	-/--	++	0/+
natural supply by self-regulating grates + mechanical exhaust	manual / multi-function switch	C2a	+	--	+	-	-	+	-/--	+	++
	time-controlled	C3b	+	--	++	0	-/0	+	-/--	+	++
	CO$_2$ control on exhaust per zone	C4c	0/+	-	0	+	+	+	-/--	-	+
balanced ventilation (central mechanical supply and exhaust) + 100% bypass	multi-function switch, no zoning	D2	0	0/-	0	-	0	0	0	0/+	0
	CO$_2$ control on discharge, no zoning	D3	0	0	0	0	0	0	0	0	0
	CO$_2$ control per zone	D5a	-	++	-	0	+	0	0	-	-
decentralized balanced ventilation with heat recovery in rooms + central mechanical exhaust in sanitary	CO$_2$ / rv control per zone	D5b	--	++	--	0	+	0/-	-	-	0/+
natural supply by self-regulating grates or air supply units + hybrid exhaust; only mechanical exhaust if required	CO$_2$ control per zone	X	0/-	-	+	0	+	+	-/--	0	+

Figure 6.1.2: Comparison ventilation systems, Source: Energie Vademecum 2015 Figure 6.8.

6.2 Heating

In this paragraph the different aspects of heating will be investigated. Three different topics will be discussed:

- Delivery systems
- Heat generation
- Domestic hot water

This investigation will be based on "Energievademecum" that is published by ISSO. The Vademecum aims to provide a clear overview of the knowledge about energy-conscious designs into a coherent whole.

Delivery systems

To get a comfortable indoor temperature in the heating season, a heating system is necessary. If excellent insulation is applied, only limited capacity will be needed for heating. Delivery systems that are associated with this are low temperature systems such as low temperature radiators and convectors, underfloor heating and wall heating.

The 2015 report 'Energie Vademecum' includes a table, containing the most important criteria that should be considered when choosing a heating system. Different properties are compared with traditional heating radiators with a high efficiency combi boiler in the attic or in the storage room. The table indicates if criteria are very favourable (++), favourable (+), neutral (0), unfavourable (-) or very unfavourable (--).

		radiator (reference)	LT-radiators	convectors	LT convectors	floor heating	wall heating	one zone system	multiple zone system	façade heater	gas-fireplace
architectural / spatial requirements	space pipes	0	0	0	0	0	0	-	--	0	-
	space heating elements	0	-	0	-	+	+	+	+	0	0
	required air tightness (- = extra)	0	0	0	0	+	+	-	-	+	+
	required insulation (- = extra)	0	0	0	0	-	-	-	-	0	0
comfort	heating time	0	0	0	0	0	-	0	0	+	++
	regulation per zone	0	0	0	0	0	0	--	0	+	+
	temperature comfort	0	+	-	-	++	++	-	0	-	0
	noise	0	0	0	0	0	0	0/-	0/-	-	-
	draft	0	0	0	0	+	+	-	-	0	0
	indoor air quality	0	+	0	+	++	++	-	0	-	0
miscellaneous	energy demand	0	+	0	+	++	++	--	-	0	+
	Maintenance	0	0	0	0	0	0	-	-	0	+
	investment	0	-	0	-	--	--	-	-	+	+

Table 6.2.1: Comparison ventilation systems, Source: Energie Vademecum 2015 Figure 7.1.

In the table it can be seen that, compared to traditional radiators, floor and wall heating score well in terms of temperature comfort, little draft, indoor air quality and energy demand. Although these systems require little space, they do require a major intervention when refurbishing and a large financial investment. An alternative can be the LT-radiator. This system requires more space than a regular radiator, but it can be placed at the same place near the façade. It provides good temperature comfort, indoor air quality and has a low energy demand. The investment is slightly lower than the floor and wall heating system.

Heat generation

In this paragraph different heat generators will be discussed. To generate heat, energy is required. This can be done with fossil fuels, electricity, a combination of both or with solar energy. The most common generator of heat is the heating boiler. It is possible to combine room heating and DHW with a so-called combi-boiler. With this system, less space and auxiliary energy is needed, and it is also less expansive.

Heating boiler

A heating boiler is a logical choice for people on a limited budget and people whose homes are poorly insulated, because (many) sustainable installations in a house with air leaks are not profitable. An average central heating boiler is less expansive (including installation around € 1.700) than an average heat pump or pellet stove (Marijke & Gonnie, n.d.).

\+ Limited budget required
\+ Suitable to bridge a few years to a more definitive solution
\- Not environmentally friendly
\- No subsidy

An alternative for the heating boiler is the heat pump. This device that converts heat from a low temperature to a high temperature, which can be used for space heating and DHW. For an independent heat pump, houses must be well-insulated (energy label B) and low-temperature heating must be possible (Marijke & Gonnie, n.d.).

Heat pump

To convert heat from a low to a high temperature, a relatively small amount of electricity with a heat pump. The efficiency of the heat pump is expressed in the Coefficient Off Performance (COP). There multiple sources of energy for a heat pump: ventilation air, the soil, groundwater, surface water (river, lake, sea, etc.), outside air or rest heat. Efficient sources such as groundwater or the soil are relatively expensive for individual applications because of the necessary installations.

To reduce costs, the capacity of a heat pump is usually dimensioned rather small. A buffer or additional heating is then required to absorb peak demands (ISSO, 2015).

A heat pump is an energy-efficient device and ensures an even temperature in the house. The purchase costs are high with costs between € 6.000 and € 20.000, including installation, excluding subsidy. Also, there should be enough space for an indoor and, with an air / water heat pump, an outdoor unit. The outdoor unit makes a sound that is comparable to the buzzing of a freezer. Sound suppressing cabinets might be required for this (Marijke & Gonnie, n.d.).

And although the gas demand lowers (or is reduced), the power consumption rises. Possibly, heavier connections are required in the meter cupboard. Solar panels can compensate for the extra power consumption.

+ Energy-efficient and sustainable
+ Even temperature in the house
+ Subsidy available
  (amount depending on the type of device and energy performance)
- High cost
- Certain amount of space is required

While the individual heat pump does not require gas, there is also an option for combining a gas using heat boiler with an integrated heat pump.

Hybrid heat pump

The heat pump will supply the basic heat demand and when a large amount of heat is needed, the gas-powered heating boiler will switch on for the peak demand. Many organisations think that heating in the future should also be able with biogas and hydrogen, this is however still an ongoing discussion and for this research it will be assumed that people will be disconnected from the gas network.

If a house is moderately isolated (many dwellings from 1945 to 1980), then a hybrid heat pump is a good option. It is less expensive than an independent heat pump with a cost between € 3.000 and € 5.000, including installation, excluding central heating boiler and subsidy. In addition, the heating installation and the meter box does not need to be adjusted.

A hybrid heat pump can be combined with existing radiators, but with low-temperature heating, it delivers the highest efficiency. Usually the hybrid heat pump consists of an indoor and outdoor unit, but they can also be integrated. The indoor unit is placed in the vicinity of the central heating boiler and therefore it requires space to be paced. The outdoor unit produces a lot of noise when the pump is running at full power and this must also be taken in account.

+ Very suitable for existing buildings
+ Also suitable for moderately insulated houses
+ No structural adjustments required
+ Subsidy available
  (amount depending on the type of device and energy performance)
- Still needs natural gas (for now)

In addition to the boiler or heat pump, a solar water heater can be used.

Solar water heater

With a solar water heater, solar energy is actively used for hot water. For those who use a lot of hot water (homeowners with a rain shower), this system is a financially interesting choice. The heater is an addition to the boiler or heat pump and only heats the bath, shower and tap water.

A household of four people can save about 190 cubic meters of gas per year with a solar water heater. The device costs about € 3.300 (excluding subsidy) including installation.

\+ Saves on energy consumption for hot water
\+ Subsidy available (depending on type of device and energy performance)
\- Space is required for a hot water storage tank and a solar collector on the roof

There is also the possibility to generate electricity besides heat:

HRe-boiler

This is done with an HRe-boiler. The advantage of such a boiler is that the total efficiency is much higher than the separate production of heat and electricity or of a traditional CHP (Combined Heat and Power) (ISSO, 2015).

Or to heat water only using electricity with an electric boiler.

Electric boiler

For those who do not want to use gas, an electric boiler (with boiler for hot water) is a possibility. It is a costly choice, but a heat pump is more expensive. A heat pump is however more environmentally friendly than an electric boiler. This installation uses a lot of power but is more sustainable when solar panels are used.

\+ No gas connection required
\- Not environmentally friendly
\- Expensive in use
\- A (solar) boiler is required for hot water
\- No subsidy

Besides the previous mentioned heat production generators there are also fewer common types of generators but for the completeness of this research are still worth mentioning. Earlier the CHP was mentioned. Combined heat and Power or cogeneration are when heat is released during the generation of electricity and is then used for heating purposes. The fuel savings can be up to approximately 30% compared to the consumption with separated generation. The CHP is mostly uses on the level of housing blocks with projects from around 200 homes with a preference for at least 300 houses (ISSO, 2015). For smaller projects, the mentioned HRe-boiler can be a solution.

It is also possible to cascade the earlier mention solution, creating a larger output. This is less expansive, because smaller units are produced in masses which lowers the costs. A cascade also requires less energy to bring the boiler on temperature compared to a big boiler which requires more of energy to bring on temperature than the actual DHW demand.

Then there is the biomass boiler. In this boiler, biomass like wood blocks, wood chips, wood pellets or bio liquid as frying fat or rapeseed oil is burnt. The flue gases are less clean than natural gas. The investment for a biomass installation is high, but operating costs are usually low. Also maintenance of the installation is more than of a gas installation (ISSO, 2015).

Pellet stove

A pellet stove burns granules (pellets) of pressed wood and it can heat one room or a whole house (pellet stove CV). The installations in which also logs or wood chips in addition to pellets can be burned are called biomass boilers. Sometimes a biomass boiler is also called 'pellet cv boiler'.

Although all these appliances burn more efficiently than a wood-burning stove, they still emit a lot of fine dust that can cause inconvenience.

A pellet stove for one room costs about € 2.000. On top of that comes the costs for constructing the gas channel: also about € 2.000. A pellet stove CV is about € 3.000. The installation, the construction of the channel and the buffer vessel also cost around € 3.000. A biomass boiler costs around € 6.000, and installation costs are also added. It is possible to apply for a subsidy when purchasing these devices.

+ More efficient than wood stove
+ Subsidy available
  (amount depending on type of device and energy performance)
- Emits fine dust

And lastly there is the use of an aquifer. The deeper in the earth's crust, the warmer it gets. At a depth of 2 kilometres, the temperature will be 70 °C (ISSO, 2015). This is a good temperature to heat up houses. In order to do this, an aquifer is needed so heat can be extracted from the water. However, the investment required is quite high and it is only relevant for a couple of thousand houses.

Domestic hot water (DHW)

The energy consumption for heating tap water is in the same order as that for space heating. The energy consumption for domestic hot water is determined by the quantity hot water that is used, the requested water temperature, the pipe losses and the efficiency of the hot water appliance.

To reduce energy consumption, pipes should be short and isolated pipes, the appliances should have a high efficiency, the water demand should be low and water-saving facilities should be applied (ISSO, 2015). Also, heat can be recovered (shower WTW) and sustainable sources can be used (solar energy, ventilation air).

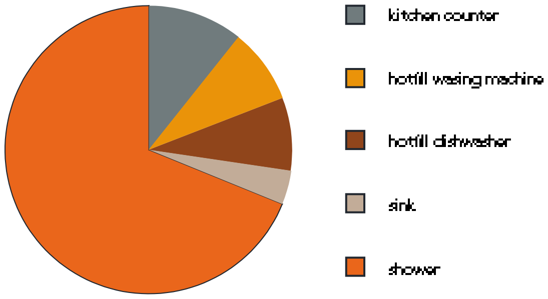


Figure 6.2.2: Distribution of DHW usage per day per average household, Source: Energie Vademecum 2015 Figure 9.1.

In Figure 6.2.2 showers require a large amount of DHW. However, water-saving facilities (both for cold and hot water) are relatively cheap to realise. The payback period is often shorter than a year (ISSO, 2015). ISSO published a table (table 6.2) of different measures to indicate the possible energy savings per household:

	Water saving m^3/yr.	Energy saving m^3 a·e·/yr.
Savings shower class Z 10 40	10	40
Flow limiters on cranes	2 - 3	10
Cranes with economical arrangement	1 - 2	5
Optimization pipes	0 – 10	0 – 45
Hot fill washing machine	0	10 – 30
'Normal' dishwasher as a hot fill	0	5 - 20
WTW shower water	0	60

Table 6.2.3: Indication of possible water savings per household per year through water and energy saving facilities, Source: Energie Vademecum 2015 Figure 9.3.

The DHW can be supplied by a so-called combi boiler or heat pump. In case of low temperature heating, the water of approximately 45°C needs to be upgrade to 60°C to prevent the forming of legionella. This is done by an electric element but can also be done with a so-called booster heat pump. Depending on the installation concept it might be more energy efficient to use the booster heat pump instead of the electric element.

Collective systems

With collective heating, several houses are supplied with heat from one central station. This can include a limited number of homes in a residential building, but also a large number in a residential area.

ISSO (2016) sums up a couple of advantages:

- The larger scale of a collective system can save on required capacity and investment cost of the energy generation system: With an individual central heating boiler, the capacity is 10 to 20 kW; with a collective system, only 3 to 6 kW per home is required.
- Cascading, like mentioned in the heat generation paragraph, smaller units allows for the use of less expansive more efficient components.
- Collective systems generally cause less environmental pollution, because of the more efficient generation of energy or heat and the better maintenance.
- There is no heat source for space heating in the home itself. This has the benefits of being safer, easier maintenance (the maintenance of the heat source does not necessarily have to take place per house) and less use of space in the home.

It also recognises some disadvantages:

- Investments in the distribution network are generally high.
- The heat losses in the distribution network are often very high. The losses are highly dependent on the quality of the insulation and the height of the temperature.
- The gas network is often omitted. Residents then have to cook electrically which has a higher energy consumption (100 m^3 gas equivalent to 65 m^3 gas) and additional costs.

With collective systems, individual heat measurement is a 'must'. For existing housing complexes such a heat measurement provides an annual energy saving of 15 to 20% compared to the situation without individual measurement (ISSO, 2015).

It is also of great importance that the total costs are distributed fairly among the different apartments. There are various options for this. It concerns the distribution of the heating costs for general areas and pipe losses, but also for heat transfer between houses. Between neighbouring houses with a different temperature, heat transfer takes place through the partition wall or floor. In well insulated homes, this is a very significant part of the total consumption (ISSO, 2015). Someone who wants a low temperature, hardly needs to heat, because the neighbours will do it. This effect can only be prevented by insulating the housing divisions.

In terms of consumption measurement, a distinction can be made between:

- Consumption measurement per radiator or convector;
- Consumption measurement per home.

6.3 Service integration in the façade

To answer the question ‘how can building services be integrated in the façade?’, different products will be analysed. Some product may not seem suitable in case of the post-war walk-up apartments, but the products can possibly be adapted to fit the concept. The first product is a complete façade element in which the other products are forms of ventilation system X or a form of decentral ventilation and heating.

TEmotion

“TEmotion is an intelligent façade concept developed by WICONA, incorporating active and stand-alone building technology” (Wicona, n.d.).

This modular façade system improves energy efficiency by reacting to in- and outdoor conditions, such as temperature and light. The TEmotion integrates heating, air-conditioning, sun protection and ventilation in order to prevent overheating (Figure 6.3.1). Photovoltaic elements can also be integrated in the façade. An example of this system can be seen in the Capricorn Haus in Düsseldorf. Wicona states that it is also ideal for renovation project, because all the technology is already integrated.

Figure 6.3.1: TEmotion façade system and Capricorn house, Sources Wicona, n.d. & Archdaily

The Brink Advance

The Advance is a stand-alone ventilation concept in which the ventilation unit is installed in a room and the ventilation air is supplied and discharged directly through the façade. This system uses a single box for air supply and exhaust, with CO_2 and moisture sensors, a heat- and moisture recovery system, filters and fans. It is applicable for dwellings and renovation and has a very good heat recovery rate of 90% (Econvice Nederland, n.d.).

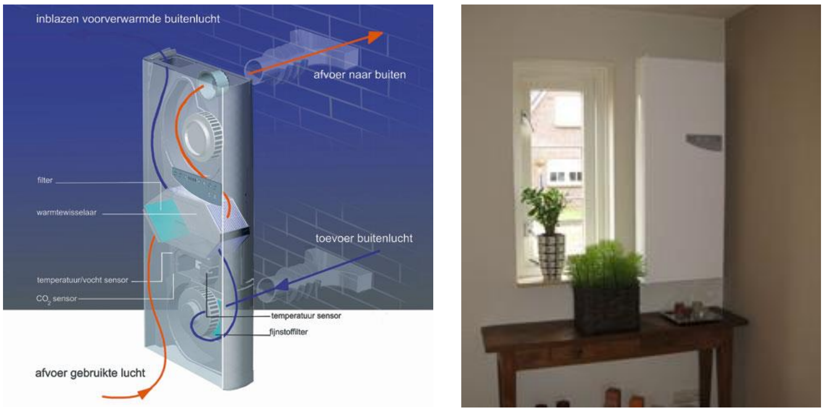


Figure 6.3.2: The Brink Advance, Source: Brinkverwarming.nl

Provent D-luxe

The Provent D-luxe is a decentral ventilation system with mechanical controlled air supply and exhaust, but also with heat recovery. The heat recovery rate of this system is 90% and the ventilation supply and exhaust can be adjusted separately in each room. The insulation value is 0.57 W / m²K. The enclosure is fully implemented in sound insulating EPP to make the entire process as silent as possible. It is very maintenance friendly (Moens, 2013).

Figure 6.3.3: Provent D-luxe, Source: architectura.be

Climarad

The Climarad is also a decentral solution which uses a radiator that is mounted on the wall. It then supplies and exhausts air through the façade. Inside there is a heat exchanger but also supply and exhaust fans and sensors for CO_2, humidity and temperature. It also allows for cooling (Climarad, n.d.).

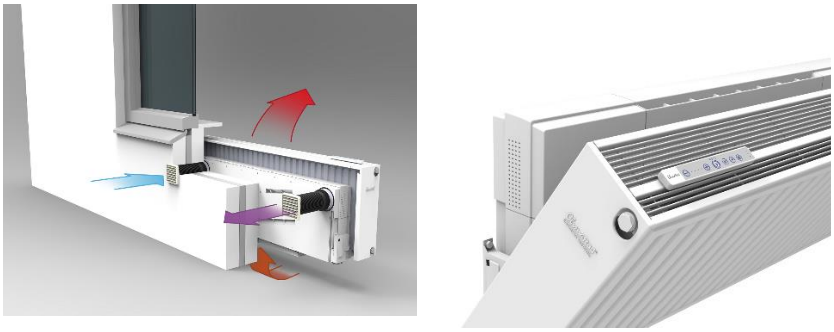


Figure 6.3.4: Climarad, Source: climarad.nl

Jaga oXygen2 system

Similar with the Climarad there is also the Jaga Oxygen2, a radiator by Jaga. In an energy-efficient manner it creates a cycle of clean air inside the house. The air supply comes directly from the outside via a lockable wall terminal with a filter system. This way, long air ducts are not required. The combination with the heating ensures a comfortable indoor climate throughout the year with a pleasant temperature and fresh air. The built-in CO2 sensor provides dosed ventilation per room. Oxygen2 works decentral and is suitable for use in renovation projects and new construction. (Jaga, n.d.)

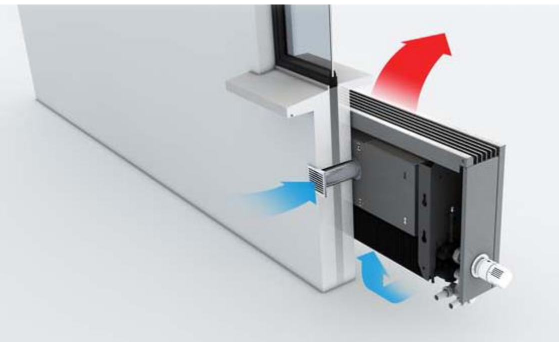
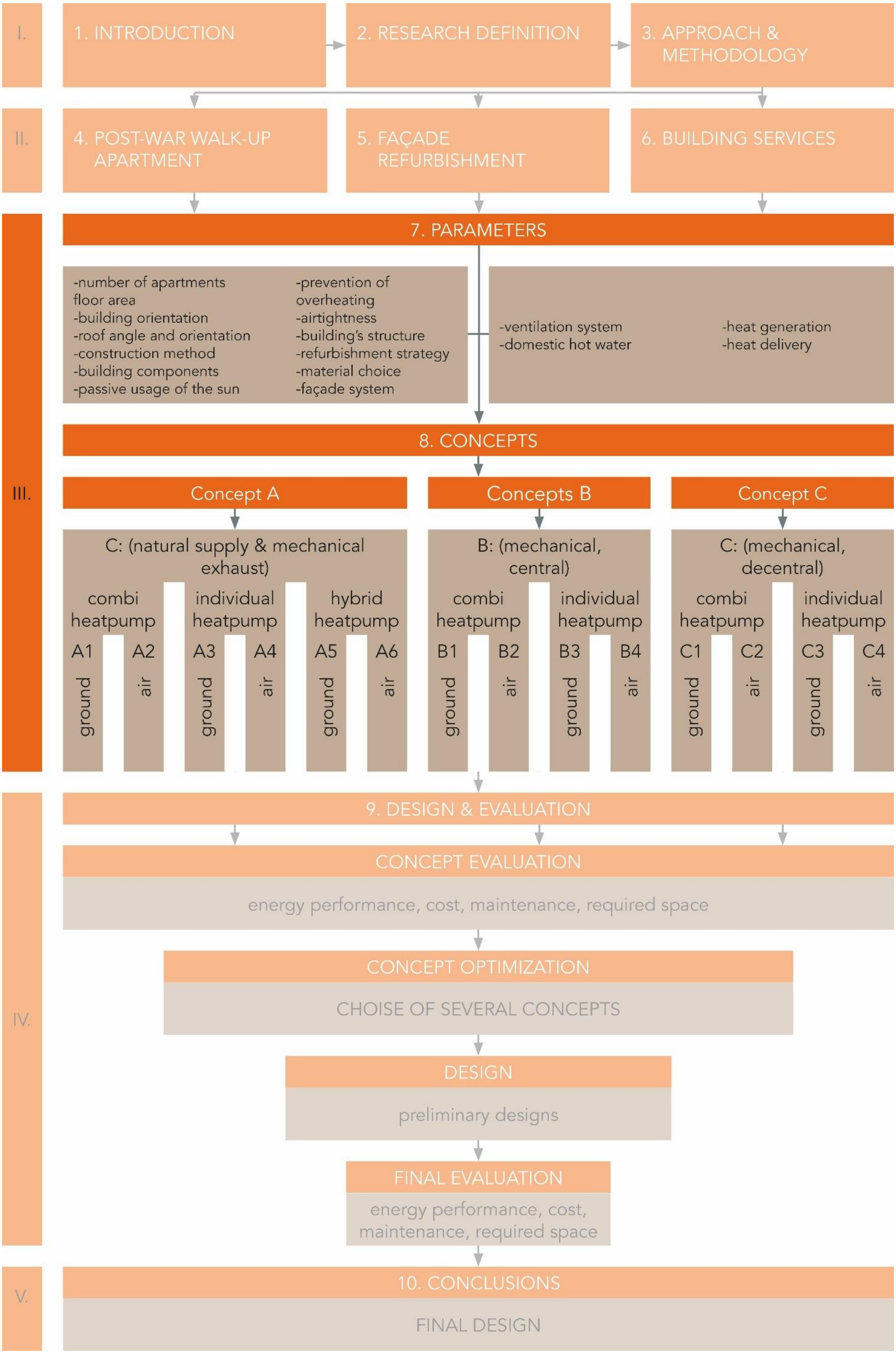


Figure 6.3.5: JagaoXygen2, Source: jaga.nl

The different products all have their pros and cons. The TEmotion from Wicona is a good solution for offices. It might be possible to be adjusted for use in dwelling when there are large non-bearing façade elements and the TEmotion can replace that element. The Brink advance can be easily placed in closed façade parts. The Provent D-luxe can be easily applied with new window frames in a new façade layer. The Climarad and Jaga oXygen2 is a good solution for parapets and for situations in which the more traditional radiator is wanted.

PHASE III



I.

1. INTRODUCTION

2. RESEARCH DEFINITION

3. APPROACH & METHODOLOGY

II.

4. POST-WAR WALK-UP APARTMENT

5. FAÇADE REFURBISHMENT

6. BUILDING SERVICES

III.

7. PARAMETERS

-number of apartments
floor area
-building orientation
-roof angle and orientation
-construction method
-building components
-passive usage of the sun

-prevention of overheating
-airtightness
-building's structure
-refurbishment strategy
-material choice
-façade system

-ventilation system
-domestic hot water

-heat generation
-heat delivery

8. CONCEPTS

Concept A

C: (natural supply & mechanical exhaust)

combi heatpump: A1 ground, A2 air

individual heatpump: A3 ground, A4 air

hybrid heatpump: A5 ground, A6 air

Concepts B

B: (mechanical, central)

combi heatpump: B1 ground, B2 air

individual heatpump: B3 ground, B4 air

Concept C

C: (mechanical, decentral)

combi heatpump: C1 ground, C2 air

individual heatpump: C3 ground, C4 air

IV.

9. DESIGN & EVALUATION

CONCEPT EVALUATION

energy performance, cost, maintenance, required space

CONCEPT OPTIMIZATION

CHOISE OF SEVERAL CONCEPTS

DESIGN

preliminary designs

FINAL EVALUATION

energy performance, cost, maintenance, required space

V.

10. CONCLUSIONS

FINAL DESIGN

7 PARAMETERS

This chapter will conclude the literate review and forms the beginning of the next phase. The literature review will be concluded by answering sub research questions one to four. A distinction will be made between fixed and variable parameters that can be used to make different design concepts in the next chapter. The fixed parameters are the ones that have the lowest freedom of alteration whereas the variable parameters have the most freedom. At the end of Chapter seven, an overview of the identified parameters is provided.

7.1 Fixed parameters

Post-war walk-up apartments

The case in Vlaardingen was further investigated in Chapter 4. The building block is located in an area with similar buildings and each block consists of six apartments. The one on Soendalaan has two blocks so 12 apartments of which each apartment has 52,50 m^2. It is constructed following the Simplex building method that used prefabricated concrete elements that form the interior wall and structural layer. It has a lot of repetition to simplify the construction process, something that was very common in that time period because of the housing shortage. This event placed the emphasis on a more efficient construction process for the large amount of new buildings to be realised. In this construction method, simple structural solutions created building details which are now considered as energy inefficient due the forming of thermal bridges and the use of none to limited insulation. Also in the case in Vlaardingen. The walls, ground floor and foundation are not insulated, and the roof is just poorly insulated. There is a big thermal bridge located at the balconies. The windows have been replaced in the past, so they have double glazing now. This is however not efficient enough for the zero-energy objective.

The building services that are used are: a gas boiler for heating and domestic hot water witch radiators to distribute the heat. Ventilation is system C, natural inlet and mechanical exhaust. No heat is recovered. So, to answer the questions:

1) **What are characteristics of post-war walk-up apartments?**

The houses built in the post-war period were mostly constructed as "non-traditional" but in an industrial way with an emphasis on a more efficient construction process for the large amount of new building. This was done with labour-saving concrete constructions like in element building methods or cast in-situ. They often have two to four rooms and are part of a residential building with multiple floors, without elevator and accessible via a closed porch. The houses are mostly inhabited by young households under 35 who are singles and double households without children. In this period there were no requirements for the energy efficiency of homes thus most homes were not insulated.

a) **How is the case in Vlaardingen constructed?**

The case in Vlaardingen is built in a similar method as is described above. It followed the Simplex building method.

b) What typologies are there?

Other typologies which are most common are: MUWI, R.B.M., Coignet, B.M.B. EBA- and Pronte.

Façade refurbishment

In Chapter 5, different aspects of energy efficient renovation and design with a special focus on the building's envelope were investigated. It turns out that modern buildings use less energy compared to older ones. Especially energy used for heating. A method for energy reduction is the new step strategy developed by Vera Yanovshtchinksy, Kitty Huijberts et al. This strategy involves different steps, namely: *reduce the energy demand, reuse rest flows, resolve the remaining energy demand in a sustainable way* and a sub-step that concerns the remaining waste. By following those steps, energy reduction can be achieved.

Continuing on this research are the different principles of a passive design to minimise a buildings energy demand. The façade refurbishment toolbox by T. Konstantinou breaks passive design down in three basic functions*: heat protection, passive solar use* and *preventing overheating*. Comparable with the new step strategy's first step, the first function of heat protection is about reducing the heating demand by preventing or minimizing the buildings heat flow from the inside to the outside. This comes down to increasing the airtightness and thermal resistance of the building envelope, eliminating thermal bridges, with additional insulation on the wall, basement, roof and replacement of the windows (Konstantinou, 2014). However, this does not necessarily decreased infiltration from air through leaks, crack or other openings in the envelope with the outside that can lead to energy loses and other problems. In the Netherlands, three different classes of airtightness are distinguished: basic, good and outstanding.

The second function is about using the heat of the sun. This depends a lot on the orientation, which in case of the situation in Vlaardingen is already determined. The third function is preventing overheating. This can be prevented with the use of shading devices.

In addition to energy efficient design, research was conducted on state-of-the-art refurbishment strategies. Leading in this research was the *Façade refurbishment toolbox* by T. Konstantinou. In the toolbox, five different strategies for refurbishment are defined: *replace, add-in, wrap-it, add-on* and *cover-it*. The different refurbishment strategies need to be materialised, where each material need to fulfil a range of different criteria. The materials that the toolbox distinguished are *insulation, glazing, window frames, sealants* and *finishing*. And lastly the Toolbox distinguishes five different building components: *External wall, Windows, Balcony, Roof* and *Ground floor* for which a refurbishment measure needs to be chosen.

After the theoretical research, different case studies were examined. First of all the 2ndSKIN project that is used as the starting point of this research. The retrofitting concept from 2ndSkin project offers a prefabricated and integrated façade module that improves the energy performance to zero-energy, while keeping the occupants' disturbance, during and after the renovation, to a minimum. This is also seen in the refurbishment method of the renovation train. To reach zero-energy levels, the 2ndSKIN project used the specification seen in Figure 5.3.4, which were processed in an easy and quick façade system. This was the only possibility to stay within the budget and the given time. However, the renovation train did manage to process it in a more prefabricated method. This has the advantage of lowering the construction time on site and significantly reducing the nuisance for the inhabitant. In addition, prefabrication has the advantage of providing a constant quality due the factory conditions. However, it does require significantly more preparation time before the construction phase and a detailed survey of the existing building.

An example of a prefabricated element was seen with the Cocoonz renovation method. It uses frameless façade elements which are placed in front of an existing façade. The elements contain insulation, possible new ventilation pipes for both the façade and the roof and it can reach zero-energy levels. The different layers of an element can be seen in Figure 5.3.10 providing a total Rc-value of 8.0 m^2K/W

After finalising this research, an answer can be given on the first research questions:

2) **What current method of energy refurbishment can be used for the new prefabricated zero-energy renovation concept?**

   a) **How can a building be designed energy efficiently?**
   A building can be designed energy efficient by following the new step strategy and considering the principles of a passive design.

   b) **What are the different refurbishment strategies?**
   A building can be refurbished by following one or more strategies mentioned in the façade toolbox: *replace, add-in, wrap-it, add-on* and *cover-it.*

   c) **What are the advantages and limitations of prefabrication?**
   The advantage of prefabrication is low construction time on site, reduced nuisance for the inhabitant and it can provide a constant quality. Limitation are the requirement of significantly more preparation time before the construction phase and a detailed survey of the existing building is required.

   d) **How has it been done in the past?**
   Past refurbishment project that have been analysed; all included some form of prefabricated elements that can integrate different building services that improve energy performance to (near) zero-energy whilst keeping the disturbance for the occupant low.

So a new prefabricated zero-energy renovation concept can use the new step strategy whilst considering the principles of a passive design and using either the *replace, add-in, wrap-it, add-on* and *cover-it* strategy in a prefabricated manner.

7.2 Variable parameters

In Chapter 6 ventilation, heating, domestic hot water and solar energy are investigated to see how they can be used in the new renovation concept.

Building services

It turns out that ventilation has a big impact on the indoor air quality and is of great important for the occupant's health. It has a considerable effect on the energy usage of a building. Buildings can be either ventilated naturally, mechanically or by a combination of both. The five different systems that can be distinguished are A, B, C, D and X. A research was conducted by knowledge institute ISSO in which they compared the different systems. They concluded that systems with natural supply are generally less expansive, require less maintenance, do not produce noise, are robust and space efficient but that the more mechanical systems provide more energy saving.

It also turned out that heating can be divided in three different subjects: delivery systems, heat generation and DHW. If excellent insulation is applied, only limited capacity is needed for heating. Delivery systems that are associated with this are low temperature systems such as low temperature radiators and convectors, underfloor heating and wall heating. Knowledge institute ISSO compared different delivery systems to traditional radiators on different criteria. It could be seen that some system requires a major intervention in case of refurbishment but that the LT-radiator provides a good alternative. It can be placed at the same place as the original radiator near the façade and it provides good temperature comfort, indoor air quality with a low energy demand.

The heat required for the delivery system can be generated with different systems. The most common generator of heat is the heating boiler and it is possible to combine room heating and DHW with a so-called combi-boiler. With this system, less space and auxiliary energy is needed, and it is also less expansive. Other variants of heat generators are individual or hybrid heat pumps, solar heaters, HRe boiler, electric boiler and the pellet stove. In case of the situation in Vlaardingen where there are 12 apartments a form of heat pump is the most suitable choice.

Building services can be integrated in the façade with a variety of systems. A complete façade element is the TEmotion developed by Wicona. Other systems are based on the principle of local heat recovery and providing fresh heated air.

The energy demand required for the building services need to be compensated by a system that supplies energy. However, it should be kept in mind that the theoretical calculated values can be different than ones that can be seen after the renovation.

3) What buildings services are there and what concepts can be used?

Building services can be divided in heat generation, heat delivery, domestic hot water and ventilation. Different concepts can be made, this can be seen in the next chapter.

a) What are alternatives for heat pumps?

There are different heat pump alternatives. There is the individual heat pump that only provides space heating and there is the combi heat pump that provides DHW besides space heating. The heat pump can be all electric or used in combination with a gas boiler. This is called a hybrid heat pump. As a source of energy, the heat pump can either use air, ventilation air in combination with outside air, ground water and the soil.

b) How can building services be integrated in the façade?

Building services can be integrated in the façade with a whole façade element or by smaller products. These products are mostly variants of combining heating and ventilation with a decentral heat recovery unit. Other forms of integration can be seen in prefabricated façade elements that contain ventilation pipes, like in the 2ndSKIN and the Renovation train project.

7.3 Conclusion – overview parameters

In conclusion, the following parameters were found in the literature and will influence the design concepts:

fixed	number of apartments
	floor area
	building orientation
	roof angle and orientation
	construction method
	building components
	passive usage of the sun
	prevention of overheating
	airtightness
	building’s structure
	refurbishment strategy
	material choice
	façade system
variable	ventilation system
	domestic hot water
	heat generation
	heat delivery

Figure 7.3: overview different parameters, Source: own illustration

8 DESIGN CONCEPTS

Based on the found parameters, one architectural concept and three energy concepts are made. The architectural concept is based on the fixed parameters found in the literature review of the post-war walk-up apartments and the façade refurbishment whereas the energy concepts are determined by the variable parameters from the building services. The architectural concept is used in the three different energy concepts, which are made to determine the most effective combination of building services. The design and evaluation phase will determine which energy concepts will be further evaluated into preliminary designs.

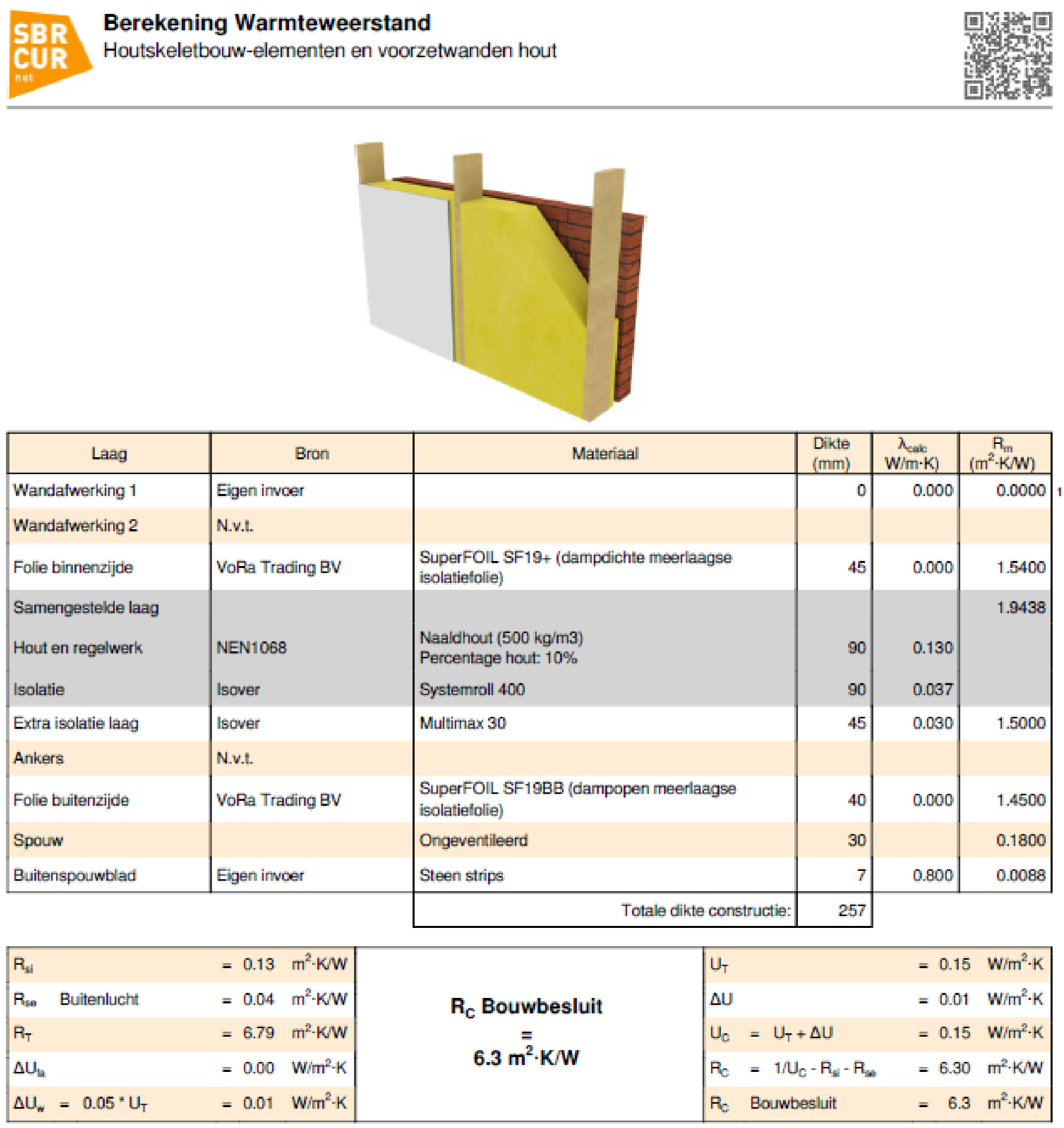
8.1 Architectural concept

Based on the conclusion in Chapter seven, an architectural concept is composed. The original floorplan will not be altered to keep the disturbance to the inhabitants to a minimum, meaning that the number of apartments and the floor area will remain the same. Instead the most alterations will be done on the building's envelope:

Figure 8.1.1: Architectural concept, Source: own illustration

The first step in the new step strategy is to reduce the energy demand. This is done by following the wrap-it strategy from the facade refurbishment toolbox. It means that new components will be placed on the existing external wall that integrate building services and improve the buildings energy performance. The new façade system is prefabricated like how it is done in the Cocoonz system. This will reduce construction time, occupant's disturbance and the thickness of the total external wall.

An alternative method is using wooden sandwich panels, However, to get the same Rc value, a thickness of at least 257 mm is needed (Figure 8.1.2) whereas the Cocoonz system only needs 150 mm. Ludo Peeter who works at Cocoonz told me the price of 1 m^2 Cocoonz cost about 440, - euro. Planner Anniek van Keulen who works at Burgt Bouw told me that a wooden sandwich panel costs only 240, - euro per square meters. This means Cocoonz cost about 65,79 euro per square meter and wooden sandwich panels 62,10 euro per square meter. This means the cost are almost equal, but a smaller system is preferred, since the inhabitants otherwise lose quite some space on the balcony.



SBR CUR net

Berekening Warmteweerstand

Houtskeletbouw-elementen en voorzetwanden hout

Laag	Bron	Materiaal	Dikte (mm)	λ_{calc} W/m·K)	R_m (m^2·K/W)
Wandafwerking 1	Eigen invoer		0	0.000	0.0000 [1]
Wandafwerking 2	N.v.t.				
Folie binnenzijde	VoRa Trading BV	SuperFOIL SF19+ (dampdichte meerlaagse isolatiefolie)	45	0.000	1.5400
Samengestelde laag					1.9438
Hout en regelwerk	NEN1068	Naaldhout (500 kg/m3) Percentage hout: 10%	90	0.130	
Isolatie	Isover	Systemroll 400	90	0.037	
Extra isolatie laag	Isover	Multimax 30	45	0.030	1.5000
Ankers	N.v.t.				
Folie buitenzijde	VoRa Trading BV	SuperFOIL SF19BB (dampopen meerlaagse isolatiefolie)	40	0.000	1.4500
Spouw		Ongeventileerd	30		0.1800
Buitenspouwblad	Eigen invoer	Steen strips	7	0.800	0.0088
		Totale dikte constructie:	257		

R_{si} = 0.13 m^2·K/W

R_{se} Buitenlucht = 0.04 m^2·K/W

R_T = 6.79 m^2·K/W

ΔU_{ia} = 0.00 W/m^2·K

ΔU_w = 0.05 * U_T = 0.01 W/m^2·K

R_C Bouwbesluit = 6.3 m^2·K/W

U_T = 0.15 W/m^2·K

ΔU = 0.01 W/m^2·K

U_C = $U_T + \Delta U$ = 0.15 W/m^2·K

R_C = $1/U_C - R_{si} - R_{se}$ = 6.30 m^2·K/W

R_C Bouwbesluit = 6.3 m^2·K/W

Figure 8.1.2: Wooden sandwich element alternative, Source: SBR CURnet

For the insulation, the values from the 2ndSKIN project, seen in Figure 8.1.3, will be used, since they provided enough insulation for the project to reach zero-energy levels.

Part	Insulation value
Roof	Rc = 7,0 m²K/W
External wall	Rc = 6,0 m²K/W
Windows	U = 1,0 W/m²K ggl = 0,8
Ground floor	Rc = 3,5 m²K/W

Figure 8.1.3: Insulation values used in the 2ndSKIN, Source: Table 1 Climate KIC, 2017

The windows allow passive use of solar energy in the winter while sun shading on the South, West and East façade prevent overheating in summer. Another passive measure is the infiltration value which will be good (0.3 $dm^3/s·m^2$) just like in the 2ndSKIN project.

The building components can be refurbished in different ways. Multiple measures have been evaluated in terms of cost, energy performance and space as shown in Figure 8.1.4.

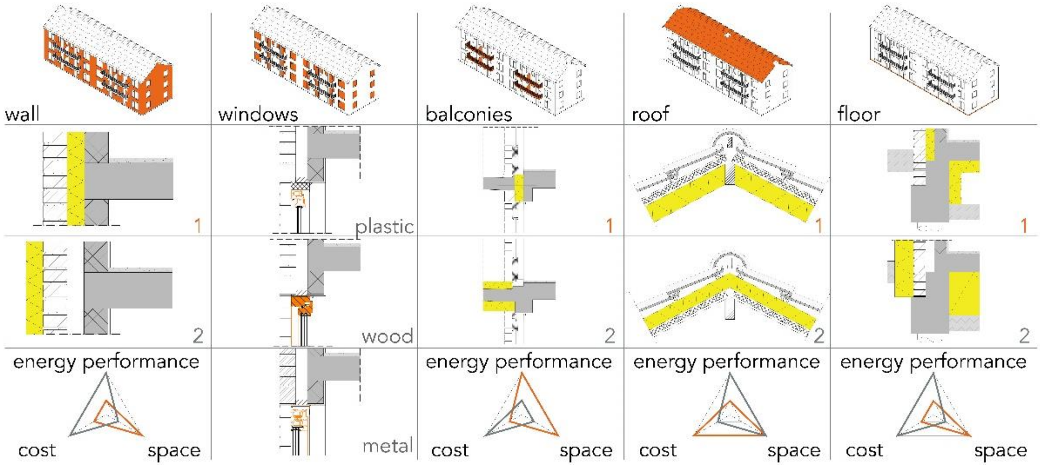


Figure 8.1.4: Refurbishment options of the different building components, Source: own illustration.

External wall

The wall can be insulated in the cavity or from the outside. If the cavity is insulated it does not require much space, but it will have limited effect on the energy performance. To limit the amount of space it is also possible to do both, but since the outside is already insulated in a prefabricated manner it is probably less expansive to perform one action instead of two. The cladding can be done with brick slips to keep the same architectural expression.

Balcony

The blacony can be removed and replaced to eliminate the cold bridge like they did in the 2ndSKIN project. However, the performance report 2017 of the EIT- Climate-KIC 2ndSKIN Demonstrator recommended to search for an alternative and therefore the balcony will be wrapped-in just like the rest of the building.

Roof

The roof can also be insulated from the inside or the outside. It is cheaper to place insulation on the inside, but it would be more energy efficient to replace the roof for a new one. This way, the provision for PV panels can immediately be integrated in a new roof panel, which is probably cheaper doing in a factory than doing it on side. In the 2ndSKIN it is done the same way. In Figure 8.1.1 it can be seen that the roof allows the placement of 68 PV panels under an 31° angle per roof plane.

Ground floor

The floor can be filled with insulation, after which it is not accessible anymore, or it can be insulated from underneath by a person with insulation spray. It is cheaper and easier to do the first option just like they did in the 2ndSKIN.

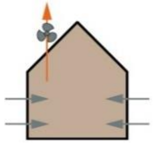
8.2 Energy concepts

The energy concepts are based on the variable parameters which are related to the building services. The different parameters are ventilation, heating system and domestic hot water.

Ventilation

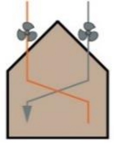
For the different energy concepts, three different ventilation systems will be considered: *ventilation system B: natural supply and mechanical exhaust, ventilation system D: total mechanical ventilation* and *ventilation system X: a variant of system D with decentral units*. This provides the three energy concepts shown in Figure 8.2.1. The reason that only these three ventilation systems are considered, is because of system A: natural supply and exhaust will, will probably not reach zero-energy levels and because ventilation system B is almost never used.

Concept A



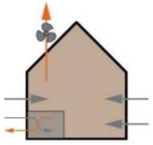
Uses natural air as supply and mechanical exhaust with CO_2 sensors to reduce the energy demand. With these sensors, air is only ventilated when CO_2 levels get too high. This system is chosen because it is less expansive due to the fact it doesn't require much pipes and machinery. However, it has limited capabilities of improving the energy performance.

Concept B



Uses a mechanical system to supply and exhaust air. This system will also have CO_2 sensors but in addition it will recover heat from exhausted air and use zoning to further reduce the energy demand. Zoning makes sure that there will not be too much air extraction from one room, and thus reducing energy demand. It is a more expansive system, but it also allows for more capabilities in improving the buildings energy performance.

Concept C

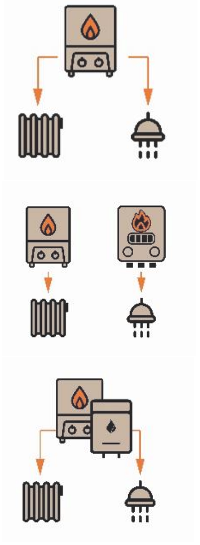


Concept C's ventilation system is similar to that of concept B. It uses a mechanical system to supply and exhaust air. However, this system will use decentral heat recovery units. This reduces the length of the pipes and thus reduces cost and space. It allows for a very precise and effective ventilation system. On the other hand, of the three chosen systems, this one is the most expensive and requires more maintenance and know how.

Figure 8.2.1: Energy concept A, B & C, Source: own illustration

Heating & cooling

Secondly, three different heating are distinguished.



Combi heat pump
The first system uses a combi heat pump which provide heating and domestic hot water.

Individual heat pump + booster heat pump
The second system uses an individual heat pump for heating and booster heat pump for domestic hot water.

Hybrid heat pump
The third system uses a hybrid heat pump. Like mentioned in Chapter 6.2 this system still uses gas. This system is a good option for renovation projects and will therefore be taken to the evaluation phase, to indicate the energy performance of this system.

Figure 8.2.2: Heating system, Source: own illustration

As an energy source for the heat pump, two sources will be compared.

Air as a source is less effective but is also less expensive than using the ground as a source.

Figure 8.2.3: Energy sources heat pump, Source: own illustration

By making these parameters variable, 14 different concepts can be determined:

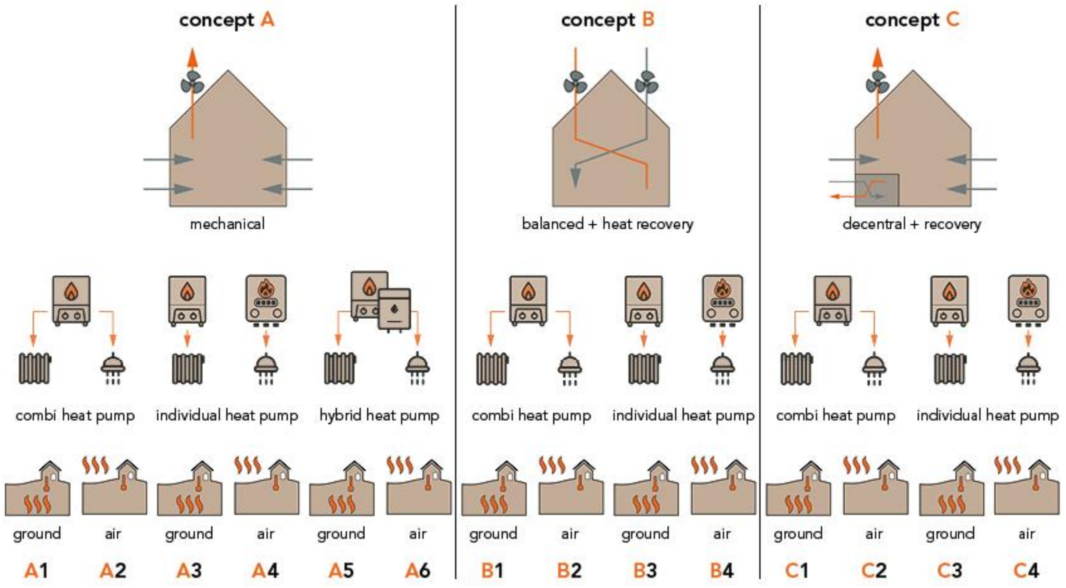
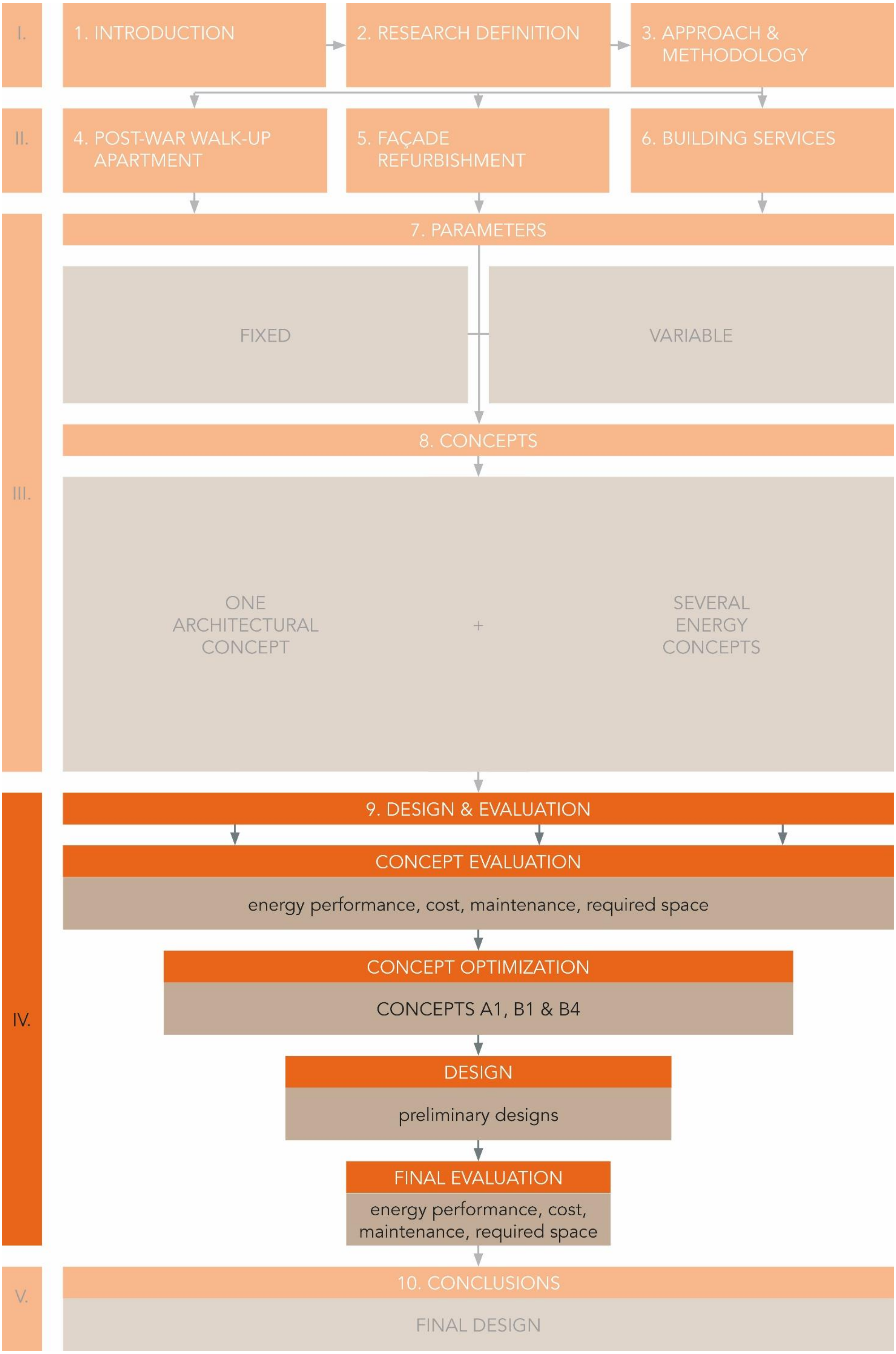


Figure 8.2.4: Overview energy concepts, Source: own illustration

PHASE IV


I.
1. INTRODUCTION
2. RESEARCH DEFINITION
3. APPROACH & METHODOLOGY
II.
4. POST-WAR WALK-UP APARTMENT
5. FAÇADE REFURBISHMENT
6. BUILDING SERVICES
III.
7. PARAMETERS
FIXED
VARIABLE
8. CONCEPTS
ONE ARCHITECTURAL CONCEPT
+
SEVERAL ENERGY CONCEPTS
IV.
9. DESIGN & EVALUATION
CONCEPT EVALUATION
energy performance, cost, maintenance, required space
CONCEPT OPTIMIZATION
CONCEPTS A1, B1 & B4
DESIGN
preliminary designs
FINAL EVALUATION
energy performance, cost, maintenance, required space
V.
10. CONCLUSIONS
FINAL DESIGN

9 DESIGN & EVALUATION

In this chapter three concepts will be further elaborated. The concepts will first be tested in how well they perform in terms of energy performance. To do this, first a hand calculation will be made to get some rough numbers on the energy demand and to determine the heat pump capacity. Then Uniec 2.2 will provide the final energy numbers, which will be used in the further evaluation of the concepts. This will be done together with the criteria maintenance, cost and space. After that, three concepts were chosen. These concepts are first optimised to boost the energy performance, after which they are used for a preliminary design. The designs in combination with the current solution are then once more evaluated with the same criteria in order to answer the main question in the next chapter.

9.1 Concept evaluation

Hand calculation energy demand for heating and domestic hot water

To determine the amount of energy required for heating and domestic hot water, a hand calculation will first provide some rough numbers (see appendix B) that can be used as a reference in the next calculations. The results give an estimation of the heat requirement on a winters day in order to determine the required heat pump capacity. This 'heat lose calculation' and can be made according ISSO-publication 51 and it is calculated with the formula (seen in the building physic lectures):

Heat demand = a · (Qtransmission + Qventilaton) - b · (Qsun – Qin) [kWh]

The letters a and b in this equation represent coefficients for correcting the dynamic influence of internal heat capacity in the construction and overheating. The coefficients are determined based on comparisons with calculation results of a dynamic computer program. In case of traditional, mixed heavy constructions these values are respectively 0,91 and 0,76. The Qtransmission is calculated with:

Qtransmission = A · U · (Tin-Tout) · time / 1000

In which:	A	= surface construction part	[m^2]
	U	= insulation value of construction part (Not Rc!)	[$W/m^2 \cdot K$]
	ΔT	= temperature difference inside and outside	[K]
	Time	= number of hours in heating season	[h]

In Appendix C the surface parts can be found with their respective insulation values. For the Qtransmission, the linear line losses also need to be taken in account. The values for these losses can be found in Chapter 9.2. The heat losses caused by this parameter need to be subtracted from the result of A · U · (Tin-Tout) · time / 1000 and will provide a total Qtransmission. The next step is calculating the ventilation losses, Qventilation.

This can be done with the formula:

Qventilation = $\rho \cdot c \cdot D \cdot (Tin\text{-}Tout) \cdot time / 1000$
[kWh]

In which: ρ = density air = 1200 [kg]

c = specific heat air = 1000 [J/kg·K]

D = air flow [m3/s]

There are ventilation losses through infiltration and the ventilation system. These can be calculated according ISSO-publication 51 Chapter 3.6.1, 3.6.2 and ISSO-publication appendix C. In it, the air flow is calculated with the formula:

Dinfiltration = $A_u \cdot q_{is} \cdot z$

In which: A_u = total envelope surface = 1132,9 [m^2]

q_{is} = value conform ISSO = 10 · 10^-5 [m^3/s per m^2]

Z = fraction = 0,5 [-]
(for walk-up apartments)

Dventilation system = qv · fv

In which: q_v = volume flow ventilation [m^3/s]
= 0,0009 · GO

fv = correction value [-]
$= \frac{\theta i - \theta t}{\theta i - \theta e}$

θ_i = design indoor temperature [°C]
θ_e = design outside temperature [°C]
θ_t = design ventilation air temperature [°C]
$= \eta\theta \cdot (\theta_r - \theta_e) + \theta_e$
θ_r = return temp. WTW = θ_i (because unknown) [°C]
$\eta\theta$ = efficiency WTW [-]

After calculating the losses, the heat gain will be calculated. First Qsun:

Qsun = $A \cdot qze \cdot ggl \cdot time / 1000$ [kWh]

In which: A = window surfaces [m^2]

qze = average solar radiation [W/m^2]

ggl = solar entry factor [-]

This provides a heat gain in which no shading included. Combined with the Qinternal which is determined by an average value for internal heat sources multiplied with the total user surface, gives a total heat production.

For DHW, the heat pump also has to provide heating. The capacity is calculated according ISSO-publication 55. The formula for this is:

$$Q = c \times \rho \times (\theta b - \theta c) \times V$$

In which	ρ	= density cold water = 1	[kg]
	c	= specific heat water = 4190	[J/kg·K]
	Th	= temperature hot water	[°C]
	Tc	= temperature cold water	[°C]
	V	= amount of hot water during normative period of use	[m3/s]

DHW=	**ρ** [kg/m3]	**.**	**c** [J/kg·K]	**.**	**V** [m3/s]	**.**	**(Th-Tc)** [K]			
shower	1	x	4190	x	0,099	x	27	=	11200	
kitchen	1	x	4190	x	0,003	x	50	=	629	
Heat demand DHW									**11828**	**W**

From the literature review it can be concluded that the houses are mainly occupied by singles and double households without children. In this case a shower of 49,5 litre per person is assumed and 3 litres of hot water in the kitchen (Waternet, 2016).

To determine the capacity of the heat pump for domestic hot water, the formula:

Capacity = Q / time required to heat up boiler + heat demand

Assuming the boiler heat during the day or the night is having eight hours (or 8 x 3600 seconds) to heat up again. This gives the following result:

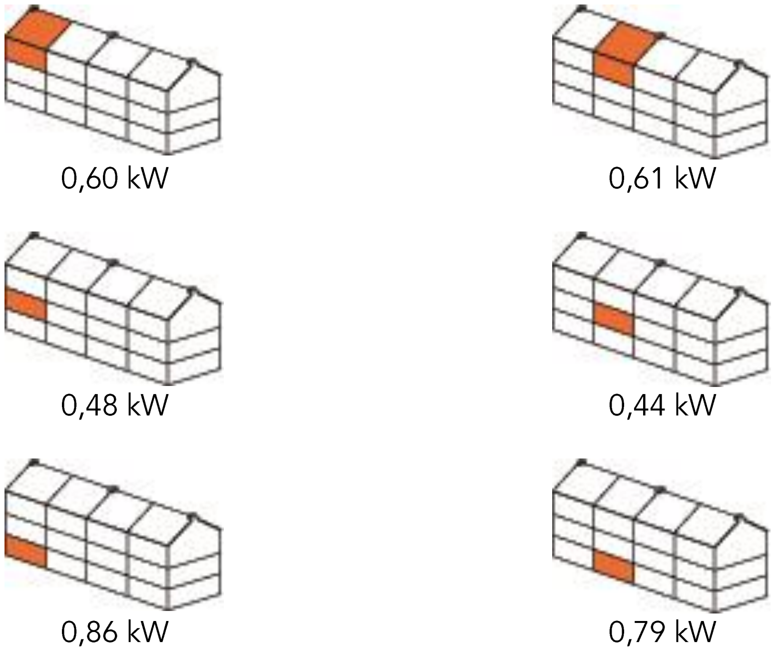


Figure 9.1.1: heat pump capacity per apartments, Source: own illustration

If a heat pump is shared with three apartments, it will need least 0,60 + 0,48 + 0,86 = 1,94 kWh for the most energy consuming apartments.

Energy performance

All the mentioned parameters in the design concept were put in Uniec 2.2. In Appendix C the different dimensions, surface areas and insulation values can be found. In the first calculations the linear line heat losses are calculated with forfaitair values. Other values that are assumed are:

Building services:		
air tightness class:	LUKA C	
cooling generator:	heat pump	
type PV panel:	BenQ SUNVIVO PM060MB2 MONO 300WP ALL BLACK	
peak power PV panels:	300 wP / panel	
number of PV panels:	68 South	68 North
RFpv:	South = 1,0	North = 0,6
electricity production (kWh):	32.837	
supply temperature (θsup):	40 < θsup ≤ 45°	
delivery system:	convector forfaitair	
design & supply temperature:	≤ 50°	
pipe length bathroom	0-2 m	

Figure 9.1.2: Input building services energy calculations Uniec 2.2, Source: own illustration

Considering the energy production, solar panels with a Watt peak of 300 Watt are assumed. This gave an energy demand as shown below in Figure 9.1.3. The yellow line illustrates the amount of energy that can be produced annually in kWh with PV panels. The bars indicate the total amount of electricity that has to be delivered to this building annually for each concept. This is not the primary energy, but the energy that has to be delivered. Only the four orange bars require less energy than they produce and are therefore zero-energy.

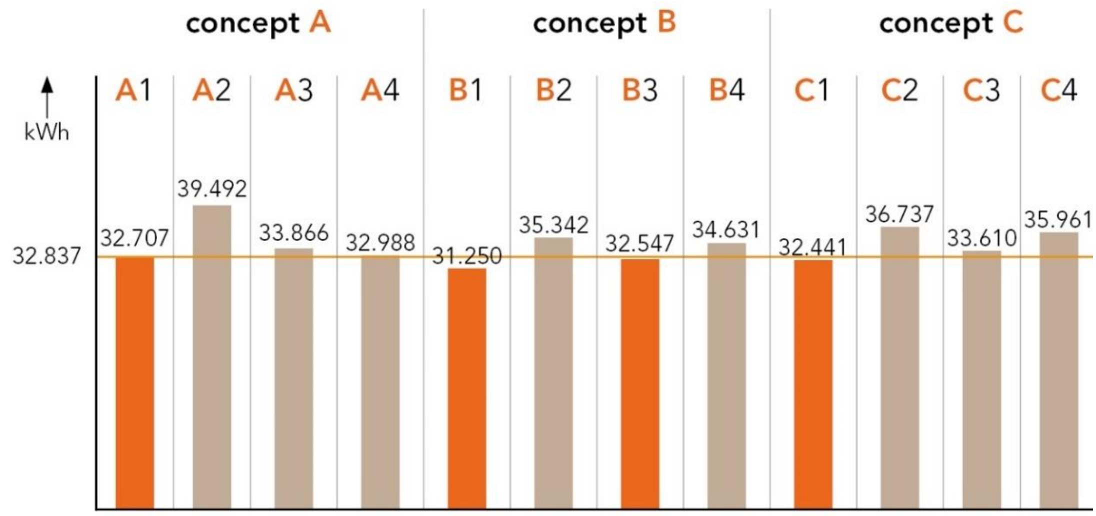


Figure 9.1.3: Results energy calculations Uniec 2.2, Source: own illustration

Concepts A5 and A6 were also calculated and the energy demand after reducing the energy production is respectively 151 kWh a year and -1.976 kWh a year. However, it assumed that buildings in the future will be disconnected from the gas network and therefore these concepts are not considered for the new renovation method. Despite they can reach zero-energy levels and might be a good renovation method if homeowners do not want to invest too much money in the replacement of their existing gas boiler.

Evaluation

Figure 9.1.4 shows the result of the concept evaluation in how well they perform in terms of cost, maintenance, space and energy performance. Although maintenance is not part of the main research question it can still tell something about possible future costs. If a concept requires a lot of maintenance or know how, it can still become an expansive concept in the future. The further the line is from the centre the better the concept performs. In this stage the values are more qualitatively evaluated than quantitatively.

Because of the natural ventilation system Concept A in general requires less cost, maintenance and space. No heat recovery box is needed nor the ducts for the inlet which reduces the cost, space requirement and maintenance of this concept. The mechanical ventilation system of Concept B on the other hand, requires more cost, maintenance and space because this system does need a heat recovery box and the required inlet ducts. The same goes for Concept C, only that concept also has additional units for decentral heat recovery. Therefore it requires less ducts, but the units are rather expansive. To put it in perspective, a ClimaRad Sensa Horizontal wall costs 1.755,- euro (ClimaRad, 2019) while a standard radiator - for example the Compact 4 Plus – costs 113,53 euro (Afium, n.d.).

Concepts A1, A3, B1, B3, C1 and C3 use a ground source heat pump. The costs of this heat pump are in case of a vertical source - like the 2ndSKIN uses – between the 15.000 euro and the 25.000 euro, while an air-to-water heat pump costs between the 10.000 and 15.000 euros (Zonnepanelen-weetjes, n.d.). The ground source heat pump requires less space because the source is underneath the ground while the airt type heat pump needs an outdoor unit. The combi heat pumps from Concepts A1, A2, B1, B2, C1 and C2 require less pace because only one generator is used, which also lowers the costs and maintenance.

The energy performance of all the concepts can be seen in the previous paragraph. After comparing the different criteria, the result in Figure 9.1.4 can be concluded.

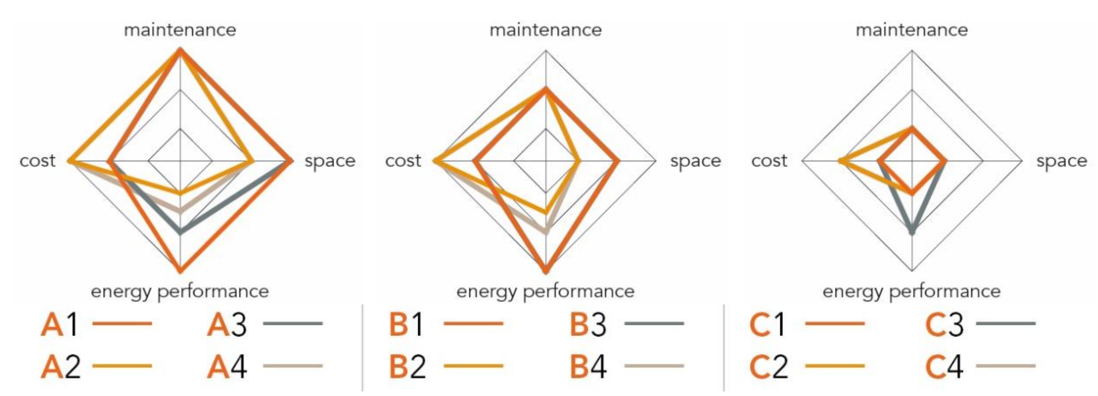


Figure 9.1.4: Evaluation concepts, Source: own illustration

For the next phase, Concepts A1, B1 and B4 will be proceed with. Concept A uses ventilation system C and Concept B uses mechanical ventilation. Concept A1 and B1 use a ground source combi heat pump and concept B4 an individual air type heat pump with a booster for domestic hot water. Because of the natural ventilation system Concept A1 requires the least amount of space and maintenance. Making it interesting to proceed with. B1 is chosen because it performs best in terms of energy. Concept B1 uses the same system as used in the 2ndSKIN project, making it also an interesting reference. Although concept B4 is not yet zero-energy, it is chosen to see if it is possible to integrate a less expansive air type heat pump for zero-energy renovation. Nothing was chosen from concept C. The system is rather expansive, and the energy performance is not as good as was firstly expected.

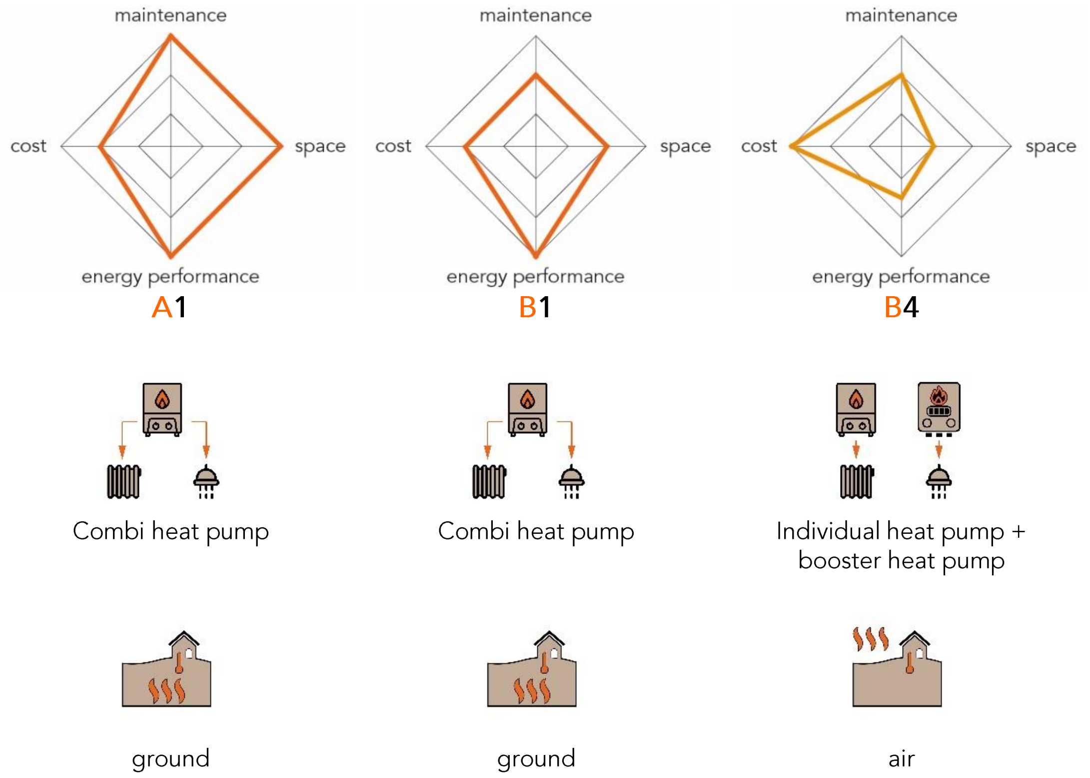


Figure 9.1.5: Chosen concepts, Source: own illustration

9.2 Concept optimization

The three chosen concepts will be further developed by looking more into the details. First the forfaitair values that were used in the energy calculation of the sketch design will be changed to values seen in the practise. This will provide a more accurate number for the energy demand whilst also giving the architectural design more input.

Psi-values

By changing the linear line heat losses or psi-values of different building components from being forfeiter to values from the practise, an energy saving of 1.280 kWh can be achieved. In Figure 9.2.1 an overview of the chosen linear line heat losses can be seen. The values are an average the respective building components published in the manual road2zer0 EPC ≤ 0,4 (Bouwformatie, 2015). These values provide a good indication of psi-values that can be achieved in energy efficient buildings.

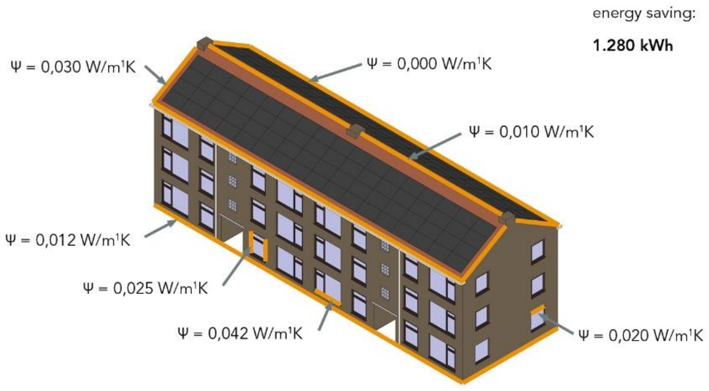


Figure 9.2.1: overview chosen psi-values, Source: own illustration.

Other elements that can be improved are the different building components described in Chapter five.

Windows

The U-value in the first calculation were entered manually. To get a more accurate energy number, real product with their tested and certified insulation values must be used in further calculation. On the information page from Cocoonz is stated specifically that plastic windows can be placed in the prefabricated elements (Cocoonz, n.d.). Therefore the plastic window that give the best energy performance in Uniec 2.2 is chosen. This is the S9000 NL produced by Gealan. By changing the manual input to this system, the energy performance stays approximately the same. However, it gives a good directing for the detail phase. The design of the window layout can also be improved from an architectural perspective.

External wall

The external wall will be wrapped-in a layer of prefabricated Cocoonz elements. Because it is not desired to insulate the existing cavity, the layers from Chapter 5.3 will not be the same. The existing cavity will not be insulated. Reducing the R value to 8,138 – 1,429 = 6,71 which will have a Rc of approximately 6,5. This only improves the energy consumption a little. The layers are shown underneath in Figure 9.2.2

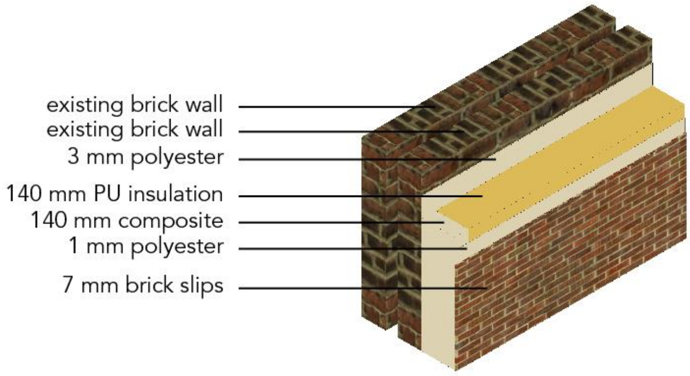


Figure 9.2.2: overview new layers, Source: own illustration.

The big advantage of these elements is that they do not need an internal frame making them very lightweight and thin, because almost the entire element (95,4%) is insulation. They still need to transfer their load to the foundation. Because there is not enough space there, a provision needs to be made.

Balconies

Instead of replacing the balcony, the recommendation of the 2ndSKIN report is followed to not do it. This will reduce cost, nuisance and construction time. However, to eliminate the cold bridge the balcony will also have to be wrapped in. How this is done, can be seen bellow in Figure 9.2.3

Figure 9.2.3: balcony construction, Source: own illustration.

The top layer can be insulated with Kingspan vacuum OPTIM-R insuluation (Kingspan, n.d.). This is a suitable soluation for cases with limited space.

Roof

The roof will use the same elements as are used in the 2ndSKIN project. This solution will not lower the cost or space efficiency, but it has a good insulation value and enough space for 90 PV panels per roof surface. This will provide an additional 10.600 kWh per year.

Figure 9.2.4: roof construction with additional PV panels, Source: own illustration.

Ground floor

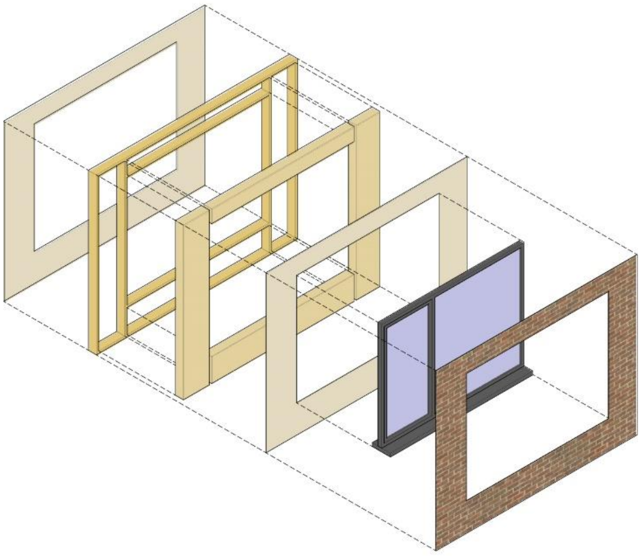
The ground floor does not allow for much cost and space reduction and therefore the same method as in the 2ndSKIN will be used. Under the floor slab in the crawl space, expanded polystyrene insulation in granulated from will be blown in.

Figure 9.2.5: Ground floor insulation, Source: Figure 5 from (Climate-KIC, 2017).

9.3 Preliminary design

After evaluating the different concept, three concepts were chosen. These concepts were further optimised which effect the design of the construction details. Now the overall design will be further elaborated on, so in the end, the three concepts can be compared in terms of cost, space, maintenance and energy performance.

The Building will get a new façade layer similar to the Cocoonz method. Information about the system was provided by Ludo Peeter who works for Cocoonz. The different layers were discussed in the previous chapter and will now be elaborated. The elements do not require a frame like other more traditional prefabricated elements, but some framework is required for the integration of windows, as is shown below:



Layers from left to right:

3 mm polyester
140 mm composite (4,6%)
140 mm PU-insulation (95,4%)
1 mm polyester
Plastic window
7 mm stone strips

Figure 9.3.1: Cocoonz element, Source: own illustration.

The polyester layer provides structural integrity while the composite allows for the building connection in the same way as wooden beams in a sandwich element. The composite posts and beams have a dimension of 40 x 140 mm. Between the element and the existing wall, there is cavity of approximately 3 cm that give the element some tolerances. Underneath the ground a different system is used. Here a rigid insulation is placed, similar to how it is done in the 2ndSKIN project.

The elements are carried by three steel angels of 200 x 100 mm with a ‘seeker’ that connects the elements. The maximum size is determined by the dimension that can fit on a truck. Therefore the façade needs to be divided into elements. This can be seen in Appendix D and on the next page:

Figure 9.3.2: Facade elements North and East facade, Source: own illustration.

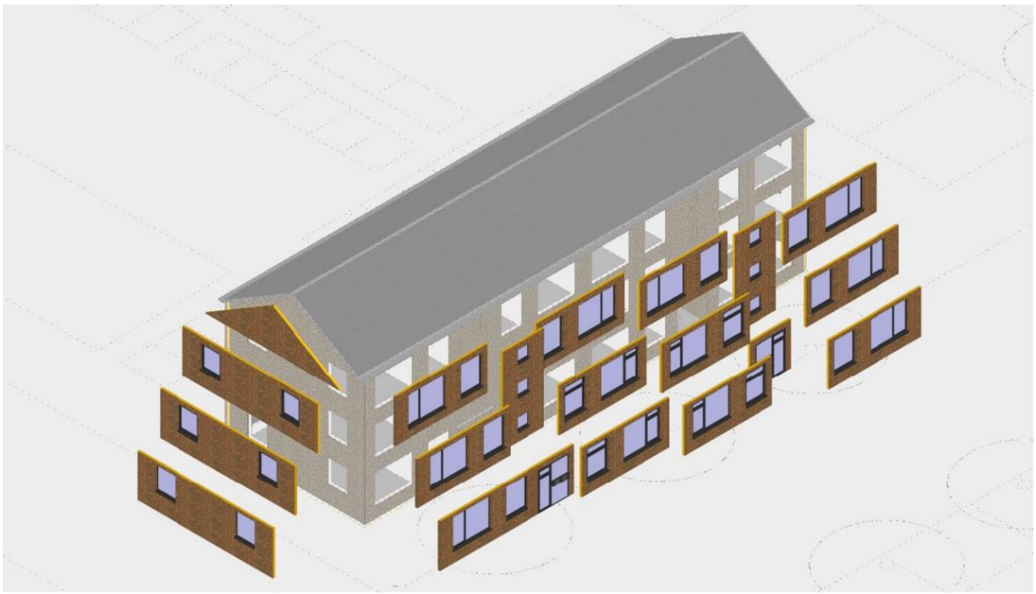


Figure 9.3.3: Facade elements South and West facades, Source: own illustration.

The balconies must accommodate the new building services and therefore a different solution is needed. Here a wooden frame will be placed that can be easily adjusted to the size of the Cocoonz elements.

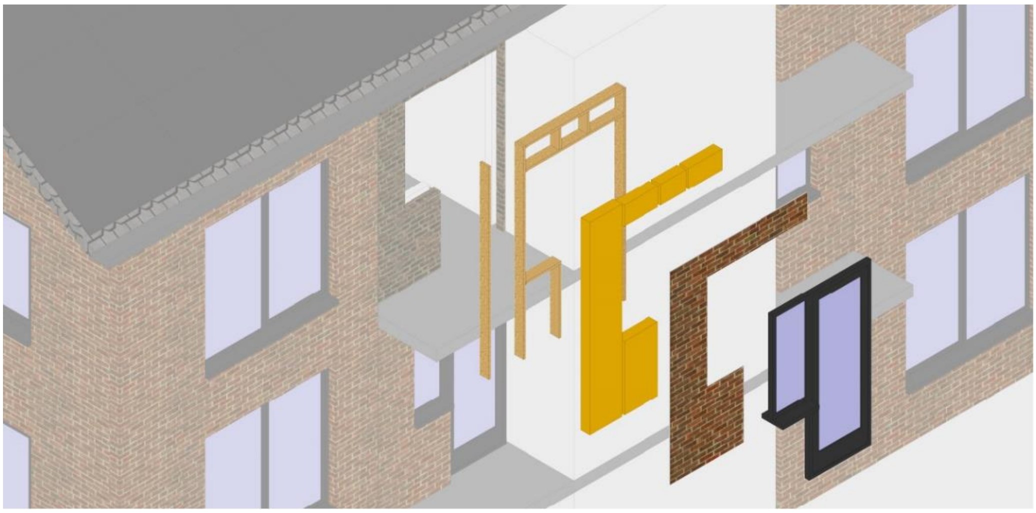
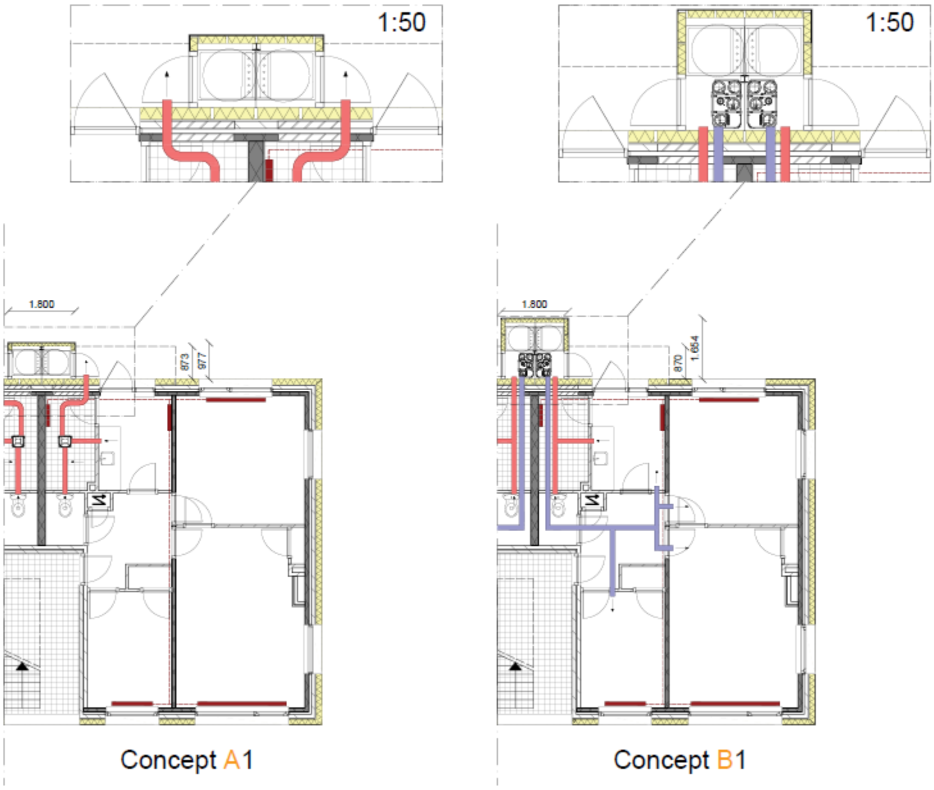


Figure 9.3.4: Facade element balcony construction, Source: own illustration.

After the new façade is placed, the roof can be replaced. The PV panels are not directly installed, but the provisions are already in place (Figure 9.2.4).

Concepts A1 and B1 both use a ground source heat pump like in the 2ndSKIN project. This means that three apartments share one heat pump. The heat pump is located on the ground floor in a 'cupboard', which also provides room for a buffer and in the case of B1 a ventilation unit. This is illustrated bellow and in Appendix D.



Concept A1

Concept B1

Figure 9.3.5: New floorplan with building services, Source: own illustration.

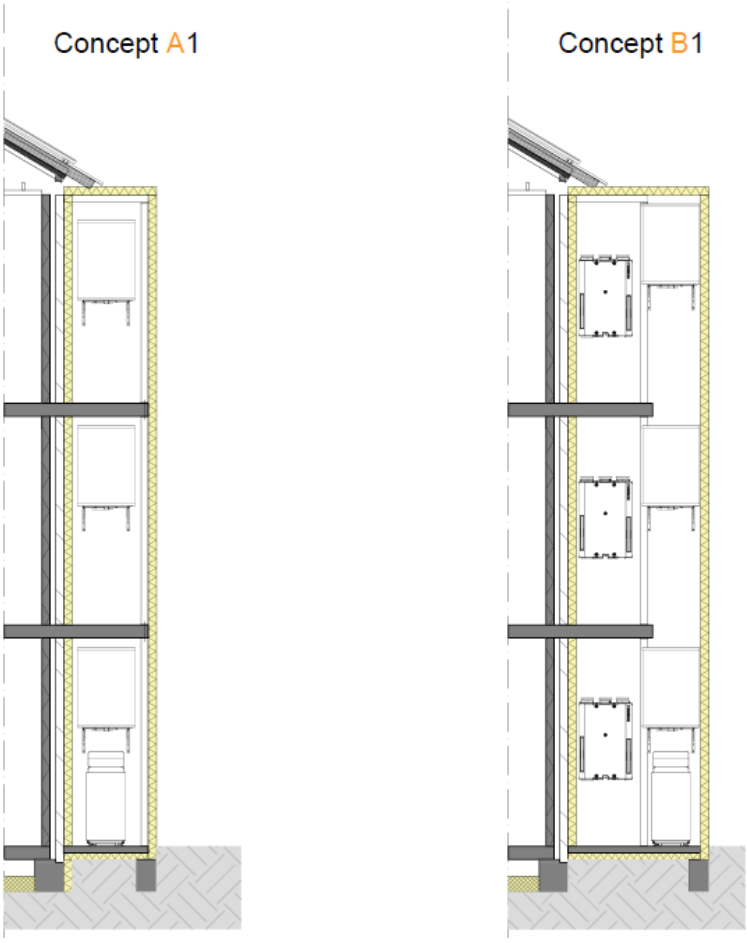


Figure 9.3.6: New sections with building services, Source: own illustration.

Figure 9.3.7: Cupboard structures A1 left and B1 right, Source: own illustration.

As shown in the Figure above, an additional steel column (dark red) is added. Rosanne Berkhout explains in her thesis that according the Eurocode: NEN-EN 1991-1-1 National annex *"an existing balcony can carry around 200 to 300 kg per m^2, but for balconies build post-war this number will most likely closer to 200 then 300"* (Berkhout, 2018). To add the necessary strength to the existing building, a steel frame with a new foundation similar to the one used in the 2ndSKIN is added.

Concept B4 uses an air type heat pump that will be placed on the empty attic. The heat pump requires an outside unit that produced some noise, so you want to place it as far away as possible. The setup is illustrated below.

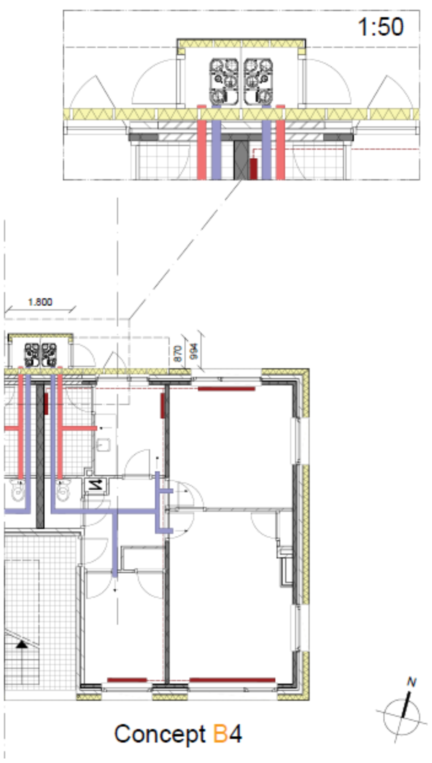


Figure 9.3.8: New floorplan Concept B4 with building services, Source: own illustration.

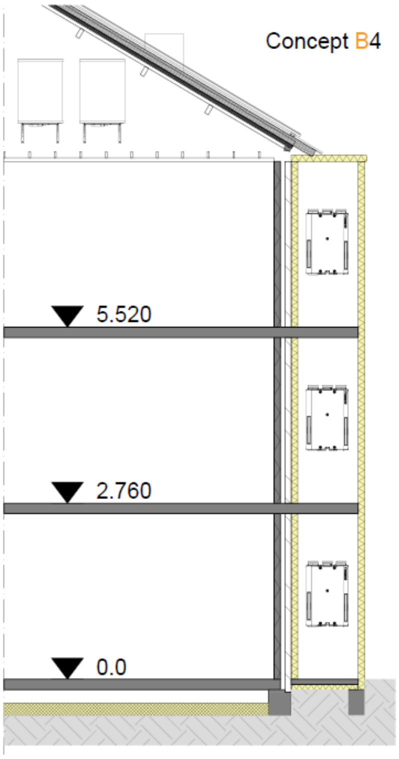


Figure 9.3.9: New section Concept B4 with building services, Source: own illustration.

By placing the whole installation on the attic, the length of ducts between the inside and outside unit can be reduced and the outside unit can be covered in a 'chimney' as shown in Figure 9.3.10. However, this does limit the amount of space for PV panels.

Figure 9.3.10: Air heat pump 'chimney', Source: Breman Schoorsteentechniek.

Since the appliances are already placed on the attic, the buffer can immediately be placed there as well. However, the floor of wooden beams is not strong enough to carry the load of the building services and therefore they will be hung to the 200 mm thick concrete wall as shown in Figure 9.3.11.

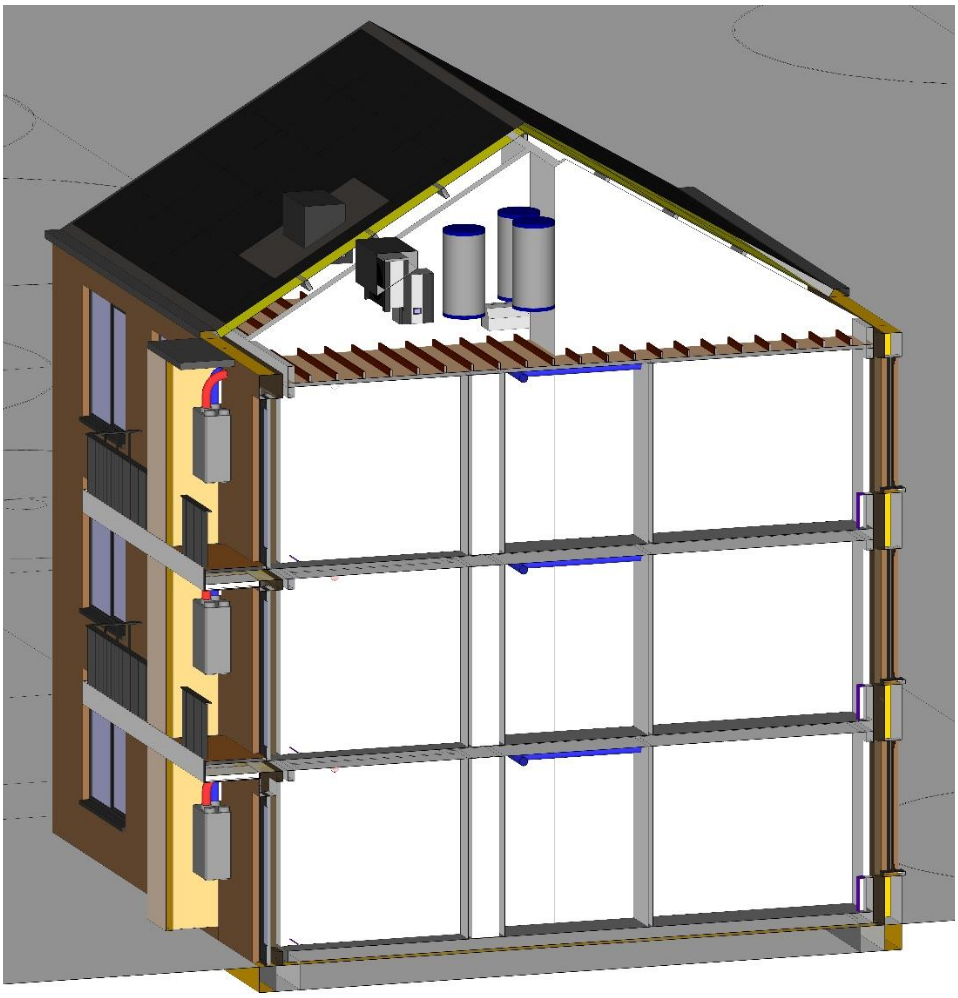


Figure 9.3.11: Building services concept B4, Source: Breman Schoorsteentechniek.

By placing the building services on the attic, the size of the cupboard can be reduced. In case of Concept B4, it only must contain the ventilation heat recovery units and the heating pipes. A downside of this concept is the long length of those pipes, especially to the bottom apartments.

Energy performance

The three design concepts, mentioned in this chapter, have been entered in Uniec 2.2 that then calculated the following energy demand annually **for the whole building** per design (again, not the primary energy):

	Design A1	Design B1	Design B4
Building related energy [kWh]	10.606	10.257	17.102
Assumed user related energy [kWh]	20.404	20.404	20.404
Total:	**31.010**	**30.661**	**37.507**

Figure 9.3.12: Energy demand per concept, Source: own illustration.

The energy demand is then compared to the energy production of 90 PV panels on the South orientation and 90 panels on the North orientation in case of Concepts A1 and B1 and 90 PV panels South and 82 PV panels North in case of B4. The results can be seen below in Figure 9.3.13 in which the yellow bars indicate the annual energy production and the coloured bars the annual energy demand per concept. The energy demand is again the amount of electricity that has to be supplied on an annual basis for this building.

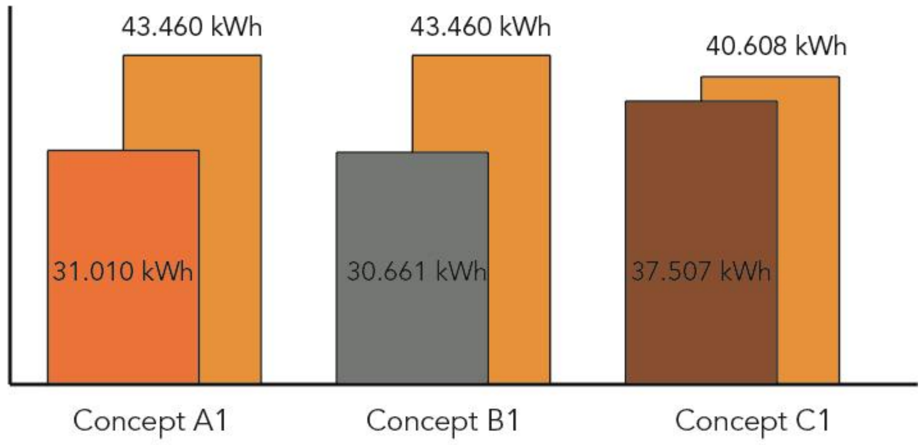


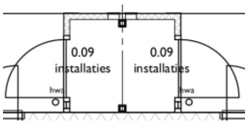
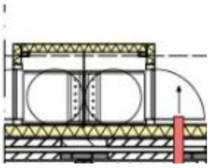
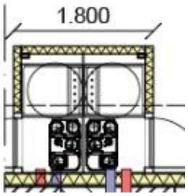
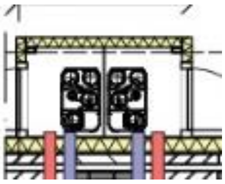
Figure 9.3.13: Overview energy performance, Source: own illustration.

In the Figure it can be seen that al the concepts reach zero-energy levels, since the annual energy production is larger than the annual energy demand. The input that was used the calculation can be found in Appendix E.

Evaluation

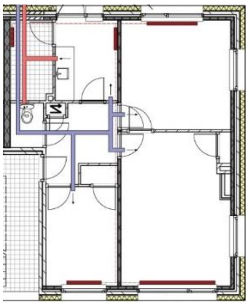
Now the three different concepts will be compared and evaluated in terms of space cost and maintenance. The costs of the Itho Daalderop building services were found in the price list of 2019 and the images can be found in their product sheets on their website.

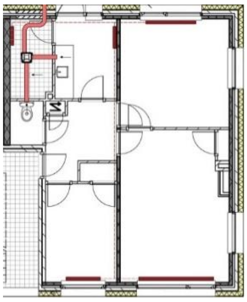
SPACE EVALUATION

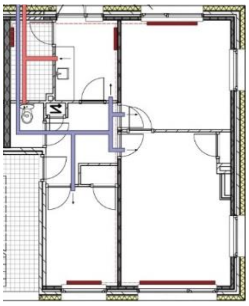
2ndSKIN	Concept A1	Concept B1	Concept B4
			
23,8 m^3	15,1 m^3	23,8 m^3	15,1 m^3

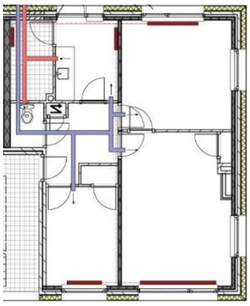
The different designs, all require a certain amount of space for the cupboard that hold the building services. B1 requires the same amount as the 2ndSKIN project because it used the same building services while Concept A1 and B4 require less space since there is fewer building services in the cupboard.

In the new concepts the balcony is kept intact, this means that the inhabitants will lose some balcony space. In the 2ndSKIN project, the whole balcony was replaced. In the end, this left the inhabitants with a bigger outside space.







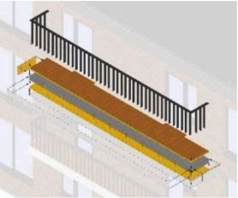
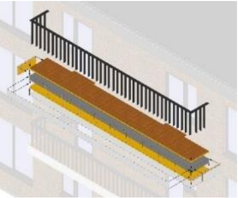
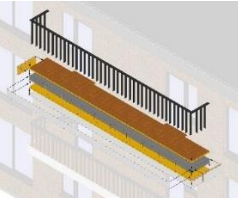


Due different ventilation concepts, the different design require a certain amount of duct lengths. It also means that certain adjustments to the ceiling has to be made. This can either be a suspended ceiling or in the form of a cove. The fully mechanical system requires the most ducts (inlet and outlet) while the ventilation system from concept A1 requires considerately less amount of space. The adjustments inside the apartments also contribute in higher nuisance for the inhabitants.

COST EVALUATION

2ndSKIN	Concept A1	Concept B1	Concept B4
			-

The first three designs require a new foundation and a steel structure to support the weight of the building services placed on the balcony. Especially the weight of the heavy buffers. The costs of the structure will be in the same prize order.

The balcony was replaced in the 2ndSKIN project. The investment required for this operation was not found in the literature, but one of the conclusions was that it was a costly one. In the performance report 2017 of the EIT- Climate-KIC 2ndSKIN Demonstrator, it was recommended to do more research to optimise this construction. This is done in the new Concepts. They do not replace the balcony, but instead they preserve it by adding new insulation. This will lower the investment costs for the balcony construction.

Ground source heat pump	Ground source heat pump	Ground source heat pump	Air source heat pump + BHP
			
€ 60.000 – 100.000	€ 60.000 – 100.000	€ 60.000 – 100.000	€ 40.000 – 60.000 + € 8.000

The first three designs make use of a ground source heat pump costing between the 60.0000 and 100.000 euros for 4 heat pumps. The air type heat pump in concept B4 costs between the 40.000 and 6.000 euros for 4 heat pumps and 8.000 euros for 4 booster heat pumps.

HRU ECO 300	Itho CVE-S ECO	HRU ECO 300	HRU ECO 300
			
€ 35.100	€ 6.720	€ 35.100	€ 35.100

The HRU ECO 300 integrates a heat recovery unit making it significantly more expensive than the Itho CVE-S ECO that has no heat recovery and only exhaust air.

MAINTENANCE EVALUATION

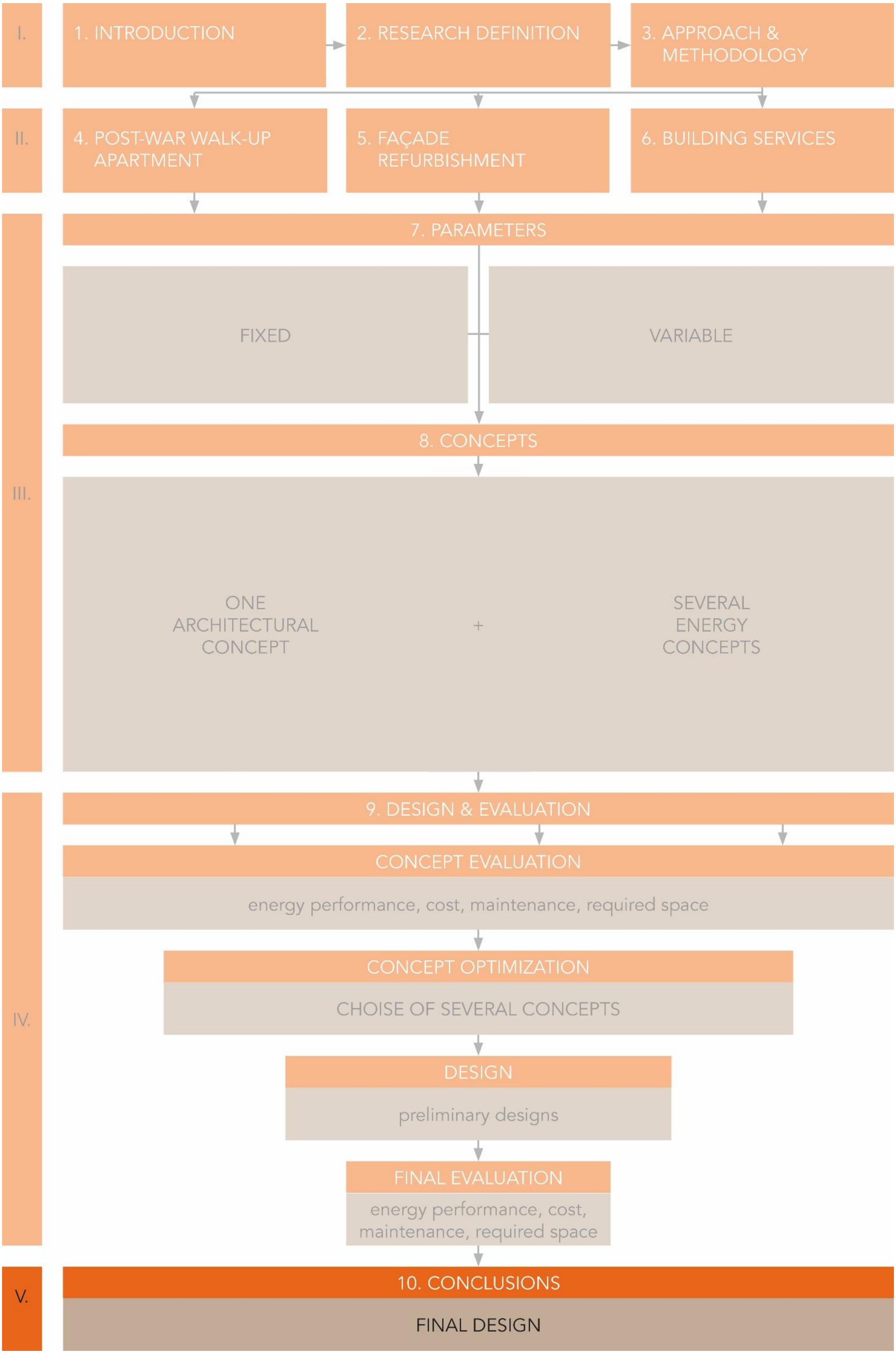
2ndSKIN	Concept A1	Concept B1	Concept B4

In case of maintenance it is assumed that the less systems are required the less maintenance is needed.

All designs use a heat pump of which it is assumed that the maintenance is more or less the same.

The design that use a ventilation system with more components than concept A1, require more maintenance.

PHASE V


I.
1. INTRODUCTION
2. RESEARCH DEFINITION
3. APPROACH & METHODOLOGY
II.
4. POST-WAR WALK-UP APARTMENT
5. FAÇADE REFURBISHMENT
6. BUILDING SERVICES
III.
7. PARAMETERS
FIXED
VARIABLE
8. CONCEPTS
ONE ARCHITECTURAL CONCEPT
+
SEVERAL ENERGY CONCEPTS
IV.
9. DESIGN & EVALUATION
CONCEPT EVALUATION
energy performance, cost, maintenance, required space
CONCEPT OPTIMIZATION
CHOISE OF SEVERAL CONCEPTS
DESIGN
preliminary designs
FINAL EVALUATION
energy performance, cost, maintenance, required space
V.
10. CONCLUSIONS
FINAL DESIGN

10 CONCLUSIONS

10.1 Final design

From the evaluation in the previous chapter, it can be concluded that concept B4 is the least expansive solution. The cost of building services is slightly higher than those of A1 and B1 but Concept B4 does not require a new structure for the cupboard which were a big cost item in the 2ndSKIN project. It also requires the least amount of space, because it uses the empty space from the attic. This also means that people will have a slightly bigger balcony than is the case with the other concepts.

Another interesting concept is A1. Because of its natural ventilation inlet it does not require a big costly ventilation unit. Reducing space and cost while the energy performance is only slightly less.

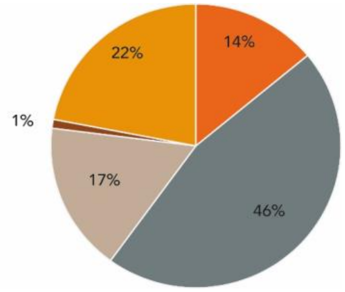
Both the concepts will be used in the final design. It will use an air to water type heat pump like Concept B4, because in case of the post-war walk-up apartments in Vlaardingen this is the most space and cost-efficient method. It will use the ventilation system of Concept A1 that uses natural air inlet and mechanical exhaust. CO_2 sensors will be placed in the living room and the main bedroom. This is again the most space and cost-efficient method.

Energy performance

The combination of both concepts is entered in Uniec 2.2 and gives the following energy performance:

Primary energy consumption annually for whole building (12 apartments)

🟧	heating	EH;P	17.288	MJ	
	auxiliary energy		3.697	MJ	
⬛	domestic hot water	EW;P	35.041	MJ	
	auxiliary energy		34.755	MJ	
⬜	cooling	EC;P	25.142	MJ	
	auxiliary energy		-	MJ	
🟫	vents	EV;P	1.555	MJ	
🟨	lighting	EL;P	33.541	MJ	+
		Total:	**151.019**	**MJ**	



Annually electricity demand and production for whole building (12 apartments)

Produced energy	40.608	kWh			
Building related energy	16.387	kWh		1.366	kWh per apartment
User related energy	20.404	kWh	-	1.700	kWh per apartment
Exported energy	**3.817**	**kWh**			

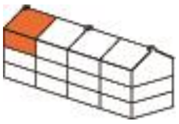
Figure 10.1.1: Overview energy performance, Source: own illustration.

The total primary energy demand annually is 151.019 MJ and consist mostly of energy required for domestic hot water. The amount of electricity that is delivered annually to the building minus the electricity that is produced gives a surplus of 3.817 kWh per year. This means that the building will reach zero-energy levels.

For comparison with other building, the primary energy demand is split per apartment:

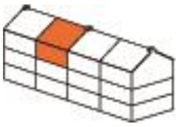
Primary energy consumption annually per apartment

second floor corner apartment



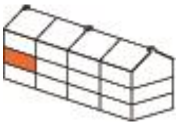
Primary			
heating	EH;P	1.372	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	1.995	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**12.417**	**MJ**
	=	**3.449**	**kWh**

second floor corner apartment



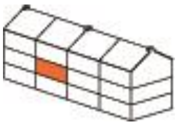
Primary			
heating	EH;P	1.395	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	2.029	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**12.473**	**MJ**
	=	**3.465**	**kWh**

first floor corner apartment



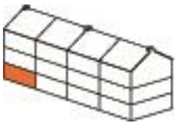
Primary			
heating	EH;P	1.098	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	1.596	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**11.743**	**MJ**
	=	**3.262**	**kWh**

first floor corner apartment



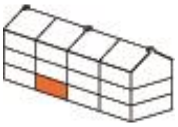
Primary			
heating	EH;P	1.006	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	1.463	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**11.519**	**MJ**
	=	**3.200**	**kWh**

ground floor corner apartment



Primary			
heating	EH;P	1.967	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	2.860	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**13.876**	**MJ**
	=	**3.854**	**kWh**

ground floor corner apartment



Primary			
heating	EH;P	1.807	MJ
auxiliary energy		308	MJ
domestic hot water	EW;P	2.920	MJ
auxiliary energy		2.896	MJ
cooling	EC;P	2.627	MJ
auxiliary energy		0	MJ
vents	EV;P	130	MJ
lighting	EL;P	2.795	MJ
	Total:	**13.483**	**MJ**
	=	**3.745**	**kWh**

The Itho Daalderop HP-S 55 heat pumps will be placed on the attic as is presented in Figures 10.1.2. and 10.1.3. The whole system will be attached to the 200 mm thick concrete walls. Next to it are the SVV 200 type buffers and the Itho Daalderop booster heat pump (BHP). Also attached to the wall. This can be seen in Figure 10.1.2 and 10.1.3 on the next page (all the drawing can be seen in Appendix F)

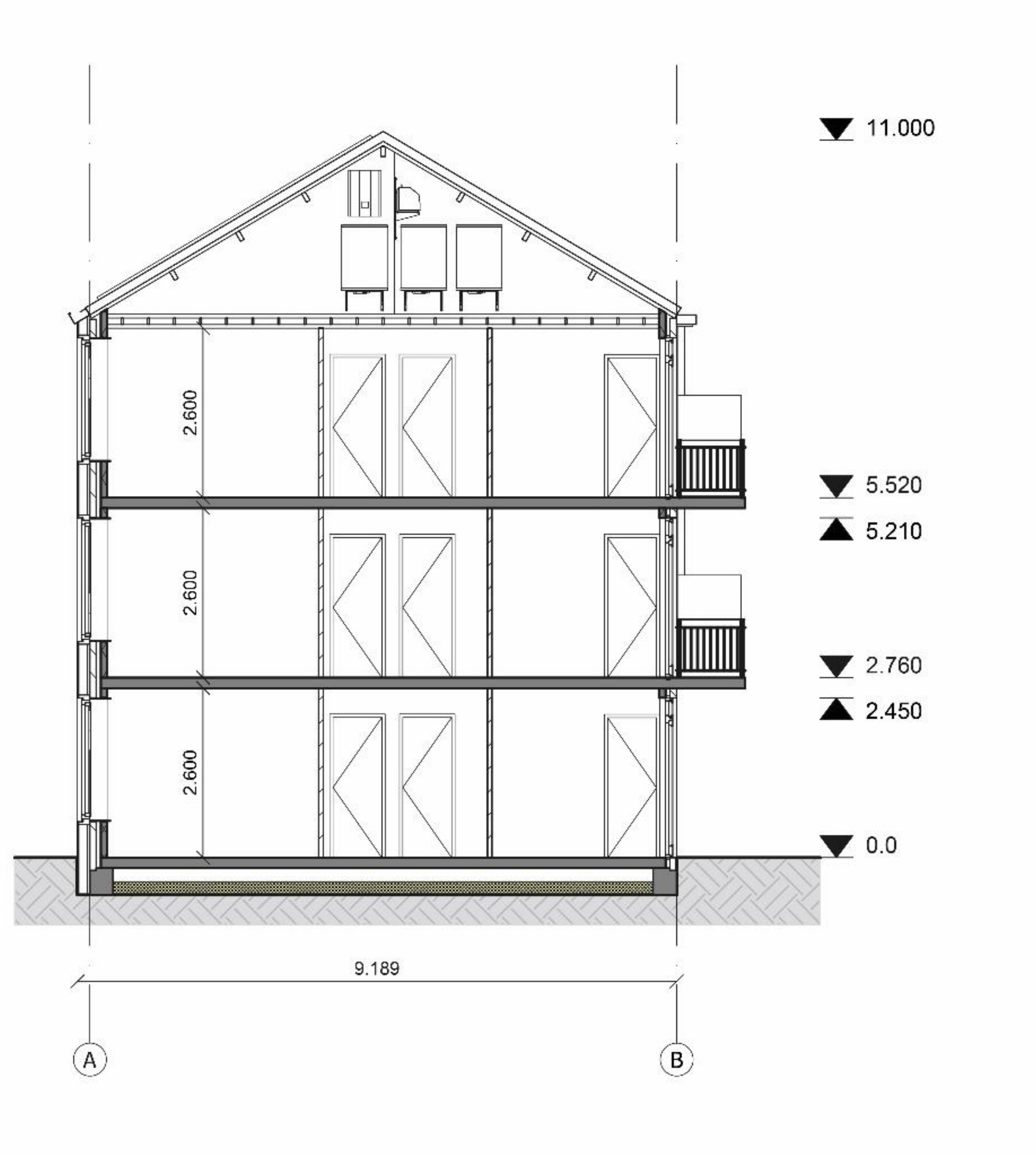


Figure 10.1.2: Section building Final design with building services on the attic, Source: own illustration.

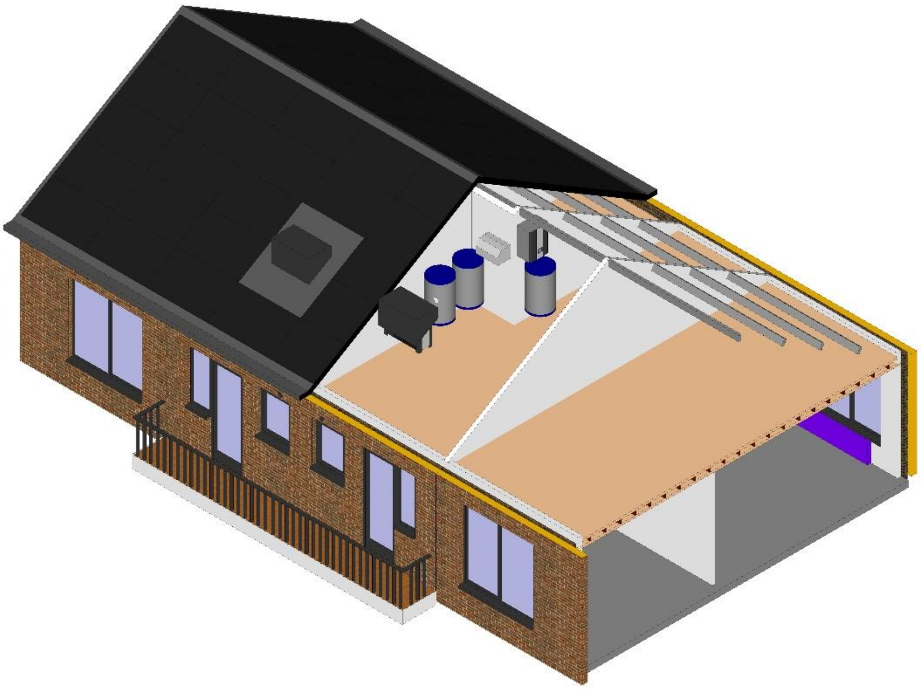


Figure 10.1.3: 3D impression Final design with building services on the attic, Source: own illustration.

The ventilation system only requires a CVE-S ECO ventilation unit that can be placed above the suspended ceiling in the bathroom. The windows allow for fresh air to enter the building while this unit ventilates the air out. The ventilation uses CO_2 censors in the main bedroom and the living room to adjust the amount of air that is ventilated in order to lower the energy demand, but it can also be manually operated. Both systems can be seen in the Figure bellow. The heating pipes can be placed internally in a new shaft. This way the balcony can remain unchanged.

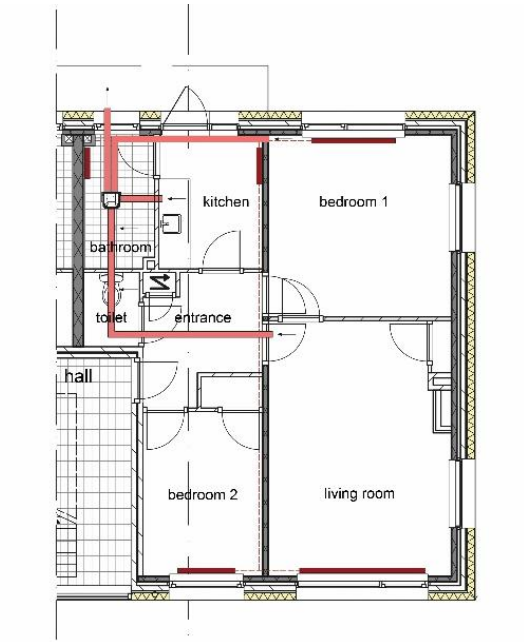


Figure 10.1.4: Floorplan building Final design with ventilation system, Source: own illustration.

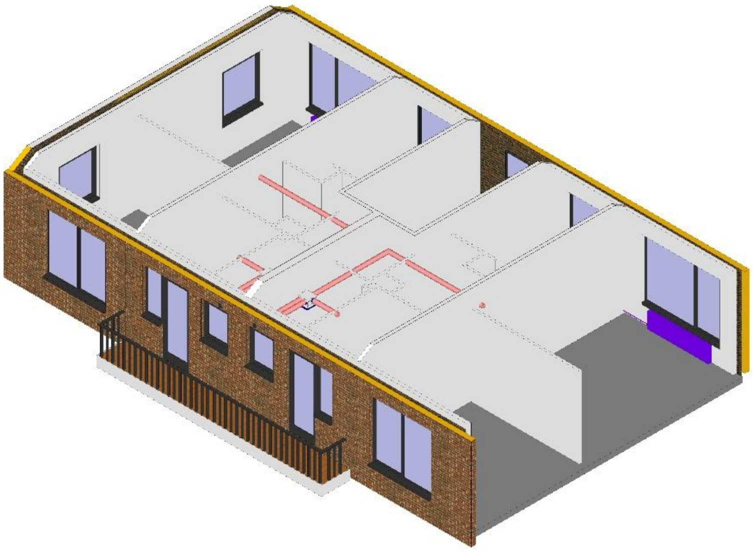


Figure 10.1.5: 3D impression Final design with ventilation system, Source: own illustration.

10.2 Conclusions

"How can the integration of building services in façades, for zero-energy renovation methods in Dutch post-war walk-up apartments, be optimised in terms of space and costs?"

A good solution to integrate building services, is by placing them in a cupboard module on the balcony. Based on this idea, the research in this report introduced three concepts that place different variations of building service systems on the balcony. The concepts have a big impact on the building in order to function. When all the building services are placed on the balcony, it must either be replaced or be structurally improved due to the weight and size of the services. In both cases, new structural elements are required for the high load. Both methods require a relatively high investment and take quite a lot of space. Although preserving the balcony will leave the residents with a reduced balcony surface, it requires the smallest investment.

The research also concluded, that the building services have the highest impact in reaching zero-energy levels. The different variations that were introduced, all have their pros and cons considering their energy efficiency compared to the amount of space they consume, and the investment price they require. Concepts using a ground source heat pump, generally have a good energy performance, but they also require a larger investment. Air type heat pumps require a smaller investment while the energy performance is still well enough to reach zero-energy levels. The same goes for ventilation systems with heat recovery and for systems without. Systems with heat recovery have a better energy performance than systems without, but also require a larger investment. Systems without heat recovery are less energy efficient but can still reach zero-energy levels.

To conclude: the integration of building services in the facade for zero-energy renovation methods in Dutch post-war walk-up apartments, can be optimised in terms of space and costs. This is done by making and comparing different variations of building services that reach zero-energy levels in terms of space and cost.

With this knowledge, one final design with the best option was presented in the end. In the case of Vlaardingen, the best concept is to split the building services in ventilation and heating. By placing the ventilation local, with natural supply and a mechanical exhaust, the size and cost of the system will be lower compared to doing both mechanically, whilst still having a good energy performance. The heating system can be placed on the attic. This space is not accessible for the residents and will not be 'wasted' with this solution. This way no space that could go to the resident is needed nor an expansive structure to carry the load from the building services. The design continuous with the recommendation of the 2ndSKIN project to improve the balcony construction, look for ground type heat pump alternatives, and to find a more prefabricated system.

By following the presented strategy that was translated in the design of a new prefabricated zero-energy renovation concept for post-war walk-up apartments -, the total costs will be lower, and the required space will be less. The building services are less integrated in the façade, but the new renovation concept does provide an integrated approach that optimises the use of space and the investment costs.

10.3 Recommendations

The research in this thesis, could benefit from additional research on the following aspects:

Financial feasibility: The total cost estimation can be further researched in order to see what the total investment will be exactly. Will the new renovation method of this research lower the cost such that it will reach acceptable heights for housing corporations? This can be done whilst also taking in account the up-scale possibility in combination with prefabrication.

Comfort: This was not one of the criteria in this research, but it is important to take it in account. People want to have a comfortable indoor environment, even if it is not the most energy efficient.

User behaviour: The behaviour of occupants also needs to be taken in account when designing a building service concept. More research on this part can improve the energy performance. Especially when this research is done in combination with the comfort part.

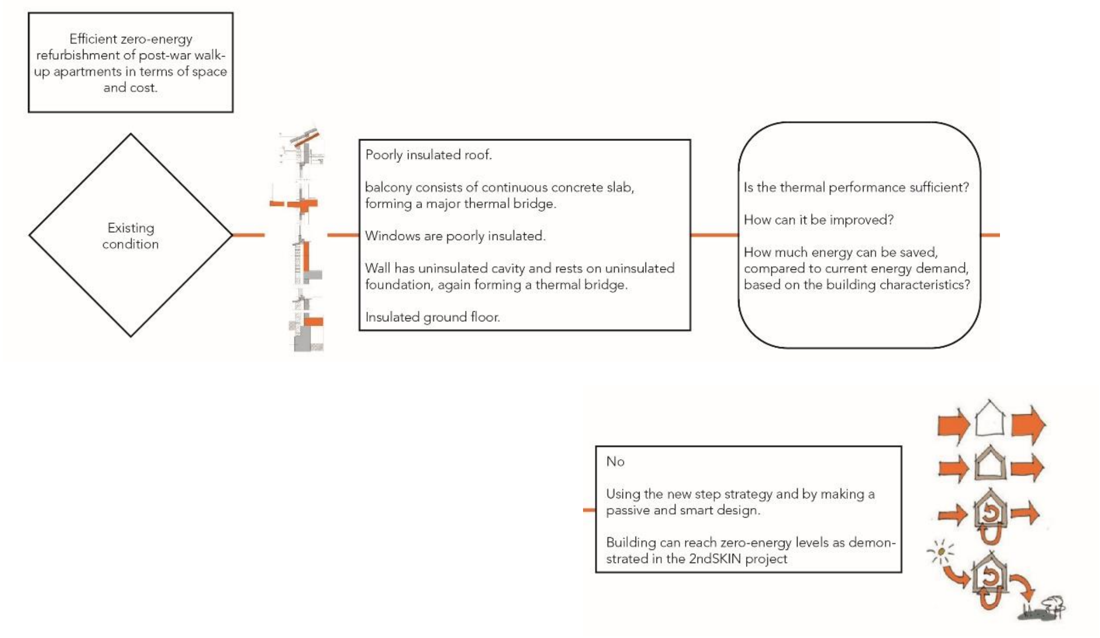
Circularity: This topic is becoming more and more important in the design of sustainable buildings. This can be useful to research to see if it is possible in a renovation concept.

Impact of building service systems: there are different options for the building services. Each has a certain impact on the user and the house. For example, the effect of a collective or individual system. What system is more desired in terms of cost distribution?

10.4 Discussion

The objective of this thesis is the design of a new prefabricated zero-energy renovation concept for post-war walk-up apartments, that integrates the building-services in a space and cost-efficient way. This concept should help support different refurbishment stakeholders to come up with cost, space and energy efficient refurbishment strategies. Therefore, the purpose of this discussion is to describe the significance of the key findings in this research:

In a refurbishment process it is first of all important to know the existing condition of the building. This will be demonstrated with the aid of this research. So the first key point is that can be seen in Figure 10.4.1 is the existing condition. In the case of the building at the Soendalaan, the existing building was poorly insulated. In that case you have to ask the questions how the situation is and how it can be improved. In this research the 2ndSkin project was used as a reference project and in this project, it was demonstrated that the building could reach zero-energy levels by following the next step strategy.



Efficient zero-energy refurbishment of post-war walk-up apartments in terms of space and cost.

Poorly insulated roof.

balcony consists of continuous concrete slab, forming a major thermal bridge.

Windows are poorly insulated.

Wall has uninsulated cavity and rests on uninsulated foundation, again forming a thermal bridge.

Insulated ground floor.

Is the thermal performance sufficient?

How can it be improved?

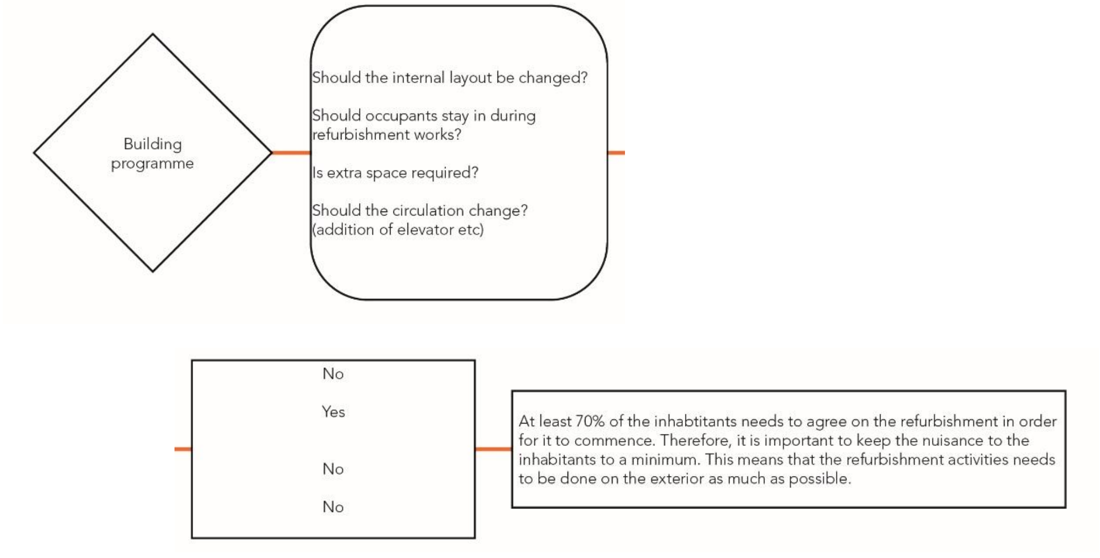
How much energy can be saved, compared to current energy demand, based on the building characteristics?

Using the new step strategy and by making a passive and smart design.

Building can reach zero-energy levels as demonstrated in the 2ndSKIN project

Figure 10.4.1: 1st Key point, Source: own illustration.

The next key point is the building programme as illustrated in Figure 10.4.2. This point concerns in internal layout of the building. Because of the importance of reducing nuisance to the tenants, the internal layout could not be altered. This decision determined a lot of other choices in the further design process.



Should the internal layout be changed?

Should occupants stay in during refurbishment works?

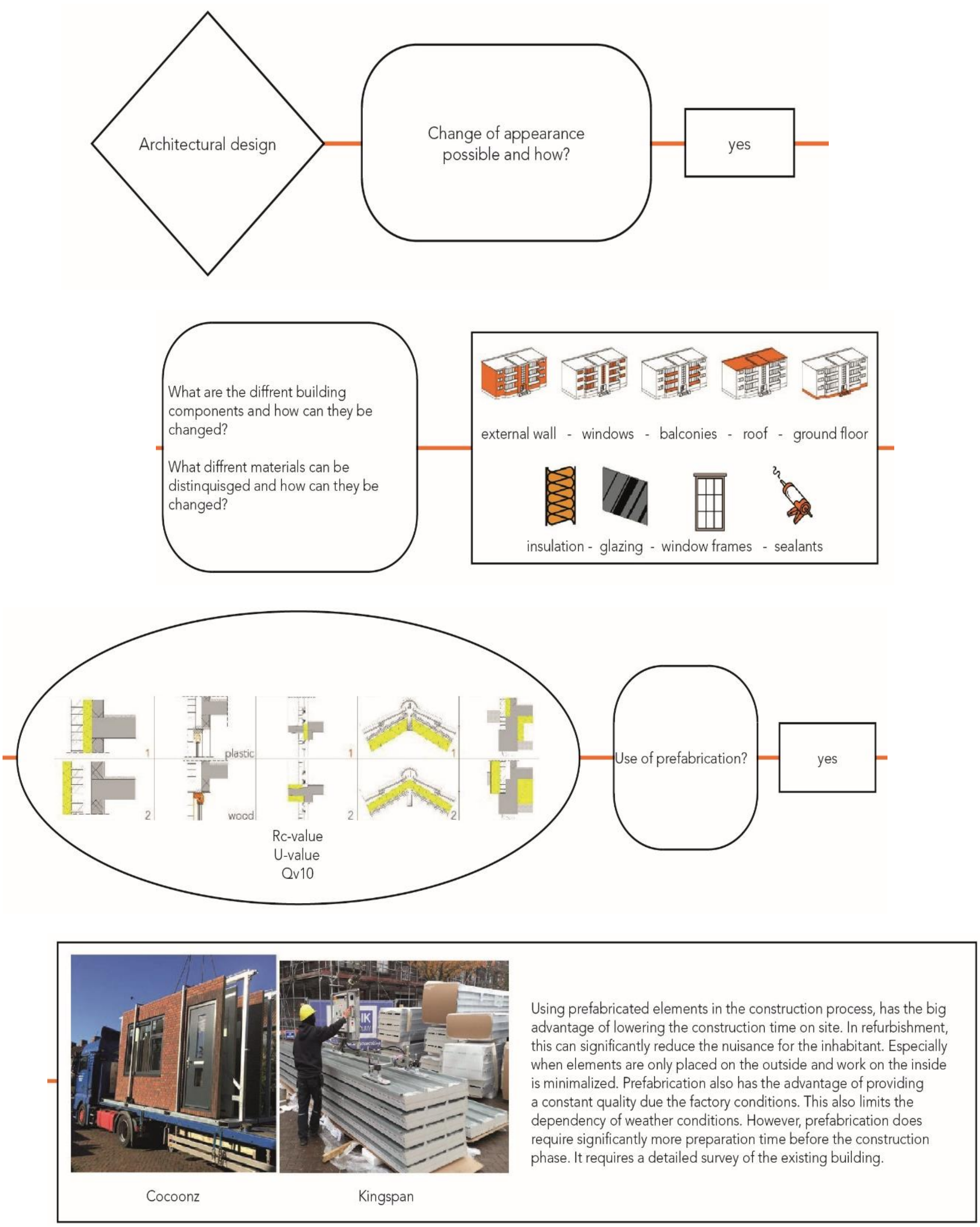
Is extra space required?

Should the circulation change? (addition of elevator etc)

At least 70% of the inhabtitants needs to agree on the refurbishment in order for it to commence. Therefore, it is important to keep the nuisance to the inhabitants to a minimum. This means that the refurbishment activities needs to be done on the exterior as much as possible.

Figure 10.4.2: 2nd Key point, Source: own illustration.

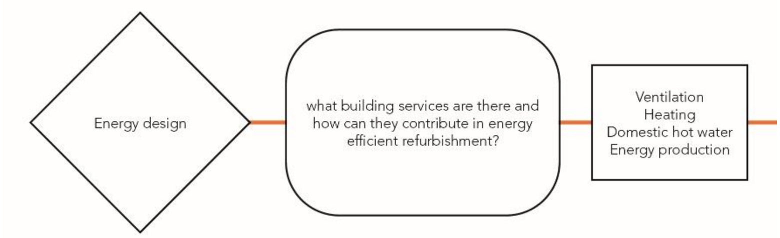
The third key point is about the architectural design. Is a change in architectural design possible? And if yes, like in this research, what different component and materials van be distinguished and how can they be refurbished? Since it was not possible to change the inside, all the alteration had to be made to the outside in a wrap-in approach. It was desired to do it in a prefabricated manner.



Using prefabricated elements in the construction process, has the big advantage of lowering the construction time on site. In refurbishment, this can significantly reduce the nuisance for the inhabitant. Especially when elements are only placed on the outside and work on the inside is minimalized. Prefabrication also has the advantage of providing a constant quality due the factory conditions. This also limits the dependency of weather conditions. However, prefabrication does require significantly more preparation time before the construction phase. It requires a detailed survey of the existing building.

Figure 10.4.3: 3th Key point, Source: own illustration.

The fourth key point is about the energy design. The major components in the energy design are building services.



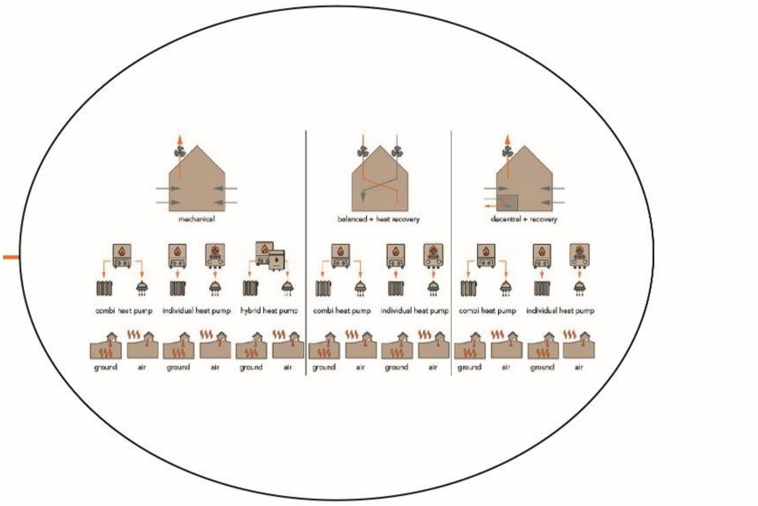
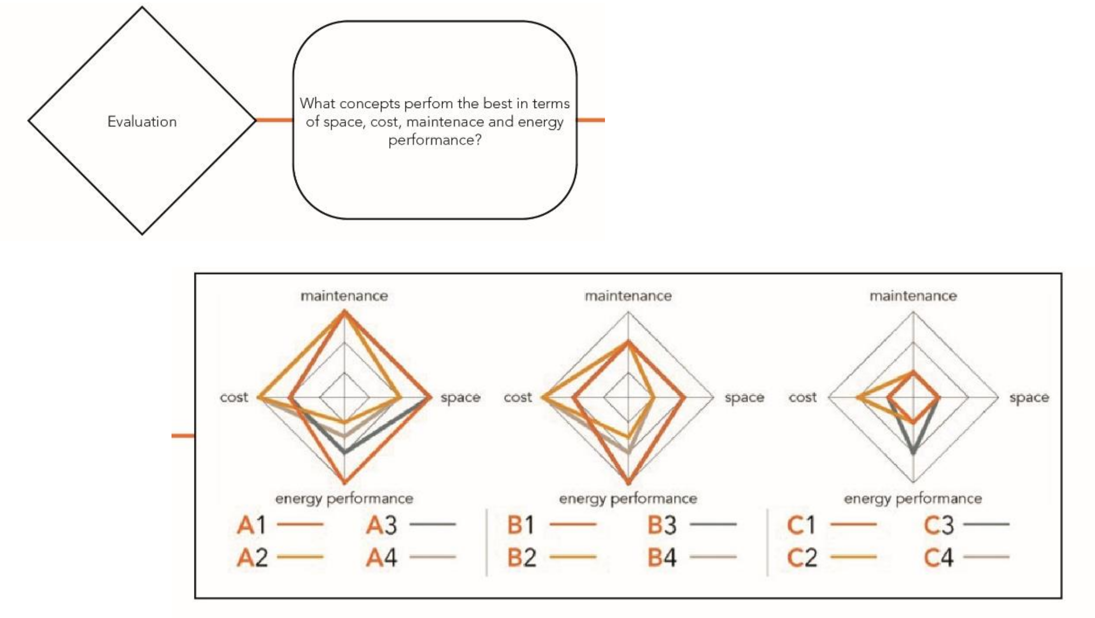


Figure 10.4.4: 4th Key point, Source: own illustration.

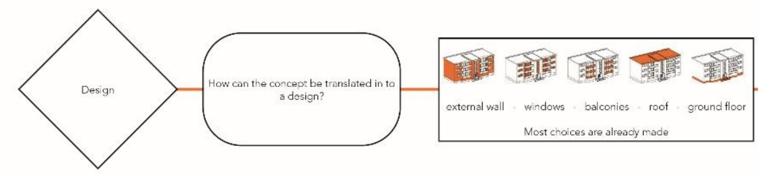
The building services need to be carefully evaluated in the terms that are important and, in this research, this meant cost, space and energy performance. This will be done in the fifth point.



What concepts perfom the best in terms of space, cost, maintenace and energy performance?

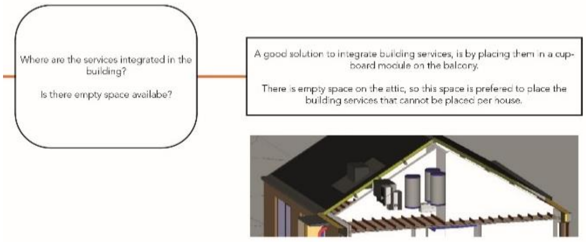
Figure 10.4.5: 5th Key point, Source: own illustration.

Then finally all the information can be processed into one or multiple designs:



How can the concept be translated in to a design?

Most choices are already made



Where are the services integrated in the building?

Is there empty space availabe?

A good solution to integrate building services, is by placing them in a cupboard module on the balcony.

There is empty space on the attic, so this space is prefered to place the building services that cannot be placed per house.

Figure 10.4.6: 6th Key point, Source: own illustration.

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ILLUSTRATIONS

Figure 4.1.1 – Google

https://www.google.com/maps/@51.911487,4.3276034,3a,75y,25.45h,88.97t/data=!3m6!1e1!3m4!1sIJNn_O-WZaT1O_4hUavjZQ!2e0!7i13312!8i6656

Figure 4.1.3 Nieman

https://www.nieman.nl/vakgebieden/luchtdicht-bouwen/eisen-luchtdicht-bouwen/

Figure 5.3.11

http://www.archiservice.nl/?cat=7

Figure 6.3.1 - Archdaily

https://www.archdaily.com/476935/capricorn-house-medienhafen-dusseldorf-gatermann-schossig/52fd522de8e44e54820000f4-capricorn-house-medienhafen-dusseldorf-gatermann-schossig-photo

Figure 6.3.2 – Brinkverwarming.nl

http://brinkverwarming.nl/index.php?cat=80

Figure 6.3.3 architectura.be

http://www.architectura.be/nl/nieuws/5561/provent-d-luxe-energie-efficient-decentraal-ventilatiesysteem

Figure 6.3.4 – climarad.nl

https://www.climarad.nl/producten/actueel/climarad-2.0/

Figure 6.3.5 – jaga.nl

http://www.jaga.nl/oxygen

Figure 8.1.3 – SBR CURnet

https://rekentoolwarmteweerstand.sbrcurnet.nl/

Figure 9.3.6 – Breman Schoorsteentechniek

https://www.bremanschoorsteentechniek.nl/product/luchtwarmtepomp-lwp-buitenopstelling/

APPENDICES

A. Drawings original situation

B. Hand calculations energy demand for heating and DHW

C. Drawing of the Energy Building

D. Drawings Preliminary design

E. Results energy calculations Uniec 2.2

F. Final design