Life cycle façade refurbishment for post-war residential buildings

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Preface

This thesis was written as a graduation work for the master Building Technology at the faculty of Architecture of the Technical University of Delft.

The focus of the research was to make a study of the life cycle energy use (operational and embodied energy) of a building, with the emphasis on the façade. By doing this also my own awareness on energy use was raised and I learned much on environmental aspects of materials.

This report describes my process throughout the past nine months which I have been working on this research, starting from the initial literature research needed to understand the different aspects up to the design, conclusions and future research.

I would like to thank my three mentors for their support and guidance during my graduation and helping me with my thesis.

I am also grateful for the assistance of the Housing Corporation Portaal, and especially Johan Damsteeg who gave a lot of information on the case study building I used.

Paressa Loussos

Delft, June 2013

Summary

Research focus

In recent years there is much more awareness of the environment because of greenhouse gas emissions, due to the use of fossil fuels. The building sector is a large consumer of these fossil-fuel-based energy systems and is therefore a good place to start improving. Residential buildings, especially homes made before 1975, have very high energy consumption. By refurbishment the energy performance of these homes can be improved, to lower the operation energy.

When looking at the life cycle energy, the operational energy as well as the embodied energy in materials needs to be considered, since the embodied energy can be a substantial part of the total. This life cycle energy can be measured in Joules.

In this thesis the following research question was answered:

How can the façade of a post-war residential building be refurbished, to make the operation energy and embodied energy (life cycle energy) as low as possible, while also considering other factors that influence the environmental impact?

By answering this question the complete life cycle energy (operation and embodied energy) can be decreased, which is a good step into the right direction.

Amongst other things, the research question was answered by making a Design Approach to lower the life cycle energy.

With the conclusions from this research recommendations could be given to designers about improving the operational energy of the building and the embodied energy use in materials. But also points for future research could be given.

Method

The thesis is divided into four parts: Introduction, Literature research, Case study design and Conclusions.

In the literature research, background information was collected of five different subjects: refurbishment, energy performance, example studies, materials and reusing and recycling.

In the case study design the Design Approach was tested, to see how much the life cycle energy could be lowered.

Apart from the conclusions and recommendations in general for designers, also recommendations could be given to the Housing Corporation Portaal, who owns the building and is planning to renovate it.

Results

The NIBE database of materials was used to create a database in Excel, to make the best choices of materials for the façade, also for other situations and different building life spans.

Four façade strategies were examined in the aspects: operational energy use, embodied energy use, environmental costs and building costs. Examples of the façade strategies are outside upgrading or complete façade replacement. The best choice depends on the future building life span, the current material of the façade and the shape/mass of the building.

The differences between the strategies over the long term were not very large concerning energy use; therefore also other factors were examined. This includes glass percentage, glass type, insulation thickness, thermal mass, infiltration rate and balcony use. These variation studies were made so that the best design decisions could be made concerning operational and embodied energy use.

Conclusions

The design approach was used to make the design, which gave important conclusions.

There are three steps to take to lower the operational and embodied energy as much as possible.

The first is by improving the building skin. This can be done by: using materials with a low embodied energy, insulating closed and glass parts well, keeping the old façade or reusing it, making the building mass more compact and lowering the infiltration rate.

The second step is to use efficient building services. Important points are to use heat recovery, installations with high efficiency and to look also at other aspects such as domestic hot water and insulation of pipes.

The third step is to use sustainable energy sources, such as PV-cells or solar cells. This can help lower the energy use even further, even to zero energy if there is enough space for the installations.

The energy use of the current building was very high, but when improving the building skin the energy use could be lowered 50%. When improving the façade and building services the energy consumption was decreased 75%. When not only improving the façade and installations, but when also PV-cells are used in the new design, the energy use could be made 90% lower compared to the current situation.

The design of the housing company of the case study building was good, because it used materials with a low embodied energy. But the operational energy use could be much lower by insulation better and using more efficient building services.

When comparing the own design to that of Portaal's, the energy consumption could be decreased 22% when improving the façade and building services. The energy use could be decreased 70% in total when also using PV-cells on the roof.

Future research

The main problem in the research was that the interaction between designing and calculation was difficult, because it took a long time to calculate the operational and embodied energy with each change. For designers it would therefore be useful to integrate the calculation of operational energy use, embodied energy use and also other factors such as building costs, into one program. Ideally this would be 3D software, which gives an impression of the building, while also giving an output of energy consumption at the same time. This way it is easier to make an environmentally sound building, as well as an architecturally pleasing one.

Table of Contents

1. INTRODUCTION

In this chapter a description will be given of the graduation plan. First some background information will be given on the subject of the thesis. Afterwards the problem statement, objective and research question will be given together with the boundary conditions for the research. Last a description of the method for the complete research will be given.

1.1 Background

Greenhouse gas emissions are the main factor responsible for recent global warming. Due to our reliance on fossil-fuel-based energy systems, the levels of these greenhouse gases rise in the atmosphere (Crawford, 2001). The building sector is a large energy consumer, contributing to these emissions. Increasing the energy performance of buildings can help with this problem.

The percentage existing (residential) building stock is much larger than the newly build. By refurbishment of these existing buildings, the total energy consumption can be lowered.

The embodied energy needed to refurbish a building is also a substantial part of the total life cycle energy. Lowering this energy would also help to reduce carbon dioxide emissions. The initial energy for a building can be 13-18% of the total, and with buildings that are very energy efficient this can be nearly 40% of the whole life energy requirements (Emmanuel & Baker, 2012).

The embodied energy in recycled building materials is generally less than that contained in new materials. Even though transportation, cleaning and sorting of these materials also requires energy, this energy is often far lower than manufacturing from virgin resources (Durmisevic, 2006). This is also true for the embodied energy by reusing of materials and also it reduces environmental damage by greenhouse gas production (Durmisevic, 2006).

1.2 Thesis

1.2.1 Problem statement

Greenhouse gas emissions, due to excessive use of fossil fuels, have recently led to global warming. The building sector is a large consumer of these fossil-fuel-based energy systems.

For some older residential buildings the energy consumption is very high, especially buildings made before 1975. By refurbishment the energy performance of these homes can be improved, to lower the operation energy.

To lower the complete life cycle energy, the operation energy needs to be considered together with the embodied energy (measured in Joule). The environmental impact also needs to be considered. This includes the embodied energy use, but also considers for example global warming and ozone depletion potential. To lower the environmental impact as much as possible, reusing and recycling of materials might be taken into consideration as well.

1.2.2 Objective/Goal

An approach will be developed that can be used for a residential building to improve the energy performance (operation energy), while also considering the embodied energy and other factors that influence the environmental impact. Also the effect of using recycled and reused materials on the environmental impact will be researched.

By literature study and example studies in different aspects (refurbishment, energy performance, materials and reusing and recycling) knowledge can be gained to develop this approach.

An overview can be made of materials that are good for the environment, while also improving the energy performance. By using the approach that was developed, this knowledge of materials will be implemented into a case study, which represents a certain part of the residential building stock.

A design for the case study will be made with this approach, and calculations will be made to try make the total life cycle energy and environmental impact as low as possible, compared to the old situation. Also the influence of using reused and recycled materials on these factors can be concluded. This way, recommendations can be given for other designers to use certain materials for building components for a façade refurbishment.

Boundary conditions

The research will focus on the following aspects:

- Refurbishment of residential buildings. A choice will be made for a certain type of building from a certain period for the case study to focus on, but the results and recommendations may also be applicable to other building types.
- Design for one case study, for the façade specifically, with a focus on the energy performance. Installations, heating/cooling and ventilation will be taken into consideration, but this will not be the main focal point.
- Assessment of possible building materials for certain components of the façade, considering material properties, energy performance and environmental impact, applicable for that specific case study.
- A lifetime of the building and façade of at least 20 years.
- EPC calculations for the energy use.
- Greencalc+ or hand calculations (NIBE database) for the environmental impact and the embodied energy.
- Thermal comfort can be considered (for example by a survey or by complaints of the residents) to see what improvements need to be made for the case study, but the comfort will not necessarily be assessed in the final design.

1.2.3 Research question

Main research question

How can the façade of a post-war residential building be refurbished, to make the operation energy and embodied energy (life cycle energy) as low as possible, while also considering other factors that influence the environmental impact?

Sub questions

Refurbishment	1.	What measures can be taken to improve the façade of a (residential) building with refurbishment?
Energy performance	2.	How can the façade be upgraded to increase the energy performance of a (residential) building?
Materials	3.	What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?
Reusing/recycling	4.	How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?
Case study building	5.	What type of building can best be used for the case study design?
Approach for design	6.	What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?

1.2.4 Method

In Figure 1-1 the structure of the thesis is shown. The numbered parts represent the different chapters of the thesis, organised in four sections: introduction, literature research, case study design and conclusions. In the first section an introduction is given, together with the graduation plan.

For the second section a (literature) study will be made on the different parts of this research, namely refurbishment, energy performance, materials and reusing and recycling. This is to get a theoretical background of these different aspects, but also to make a choice for a case study building and to be able to develop the approach to be used for the chosen type of building. Also it will help answer sub research questions 1 and 2.

Concerning *refurbishment* and *energy performance* a literature study will be done. Different strategies and principles to refurbish will be examined. Also a study will be made of different measures used to increase the energy performance by refurbishment. Finally a study will be made on different residential building periods and types, also to find the type that is to be examined in this thesis by the case study. For the two parts, refurbishment and energy performance, example studies will be analysed, to help answer some questions. With the help of this research a residential building type will be chosen, and certain tools to use in the approach will be assessed.

Another part of the research is the environmental impact and embodied energy of the *materials* used in refurbishment. Here also a literature study will be done, to see what tools can be best used to answer the research questions. Also LCA will be examined further, to see in what way this approach can help in this thesis. Examples will be analysed for this subject.

Also for the last part, *reuse and recycling*, a literature study will be done, together with examples and other case studies.

In part 3 an approach will be developed, with the help of the previous gained knowledge, to best handle the refurbishment design. This approach will be implemented into a case study, to make a refurbishment design with as low embodied energy, operation energy and environmental impact as possible (chapter 7). The approach depends on the type of building, so these two parts will have an evaluative loop, they might change during the process. Also during the development of the approach and case study design, the literature study needs to be evaluated and adjusted again, together with the inventory of materials.

In this research an emphasis will be put on different materials for different building components and the best strategies that can be used per façade part. This way, recommendations can be given in the last chapter that also can be used in other comparable projects.

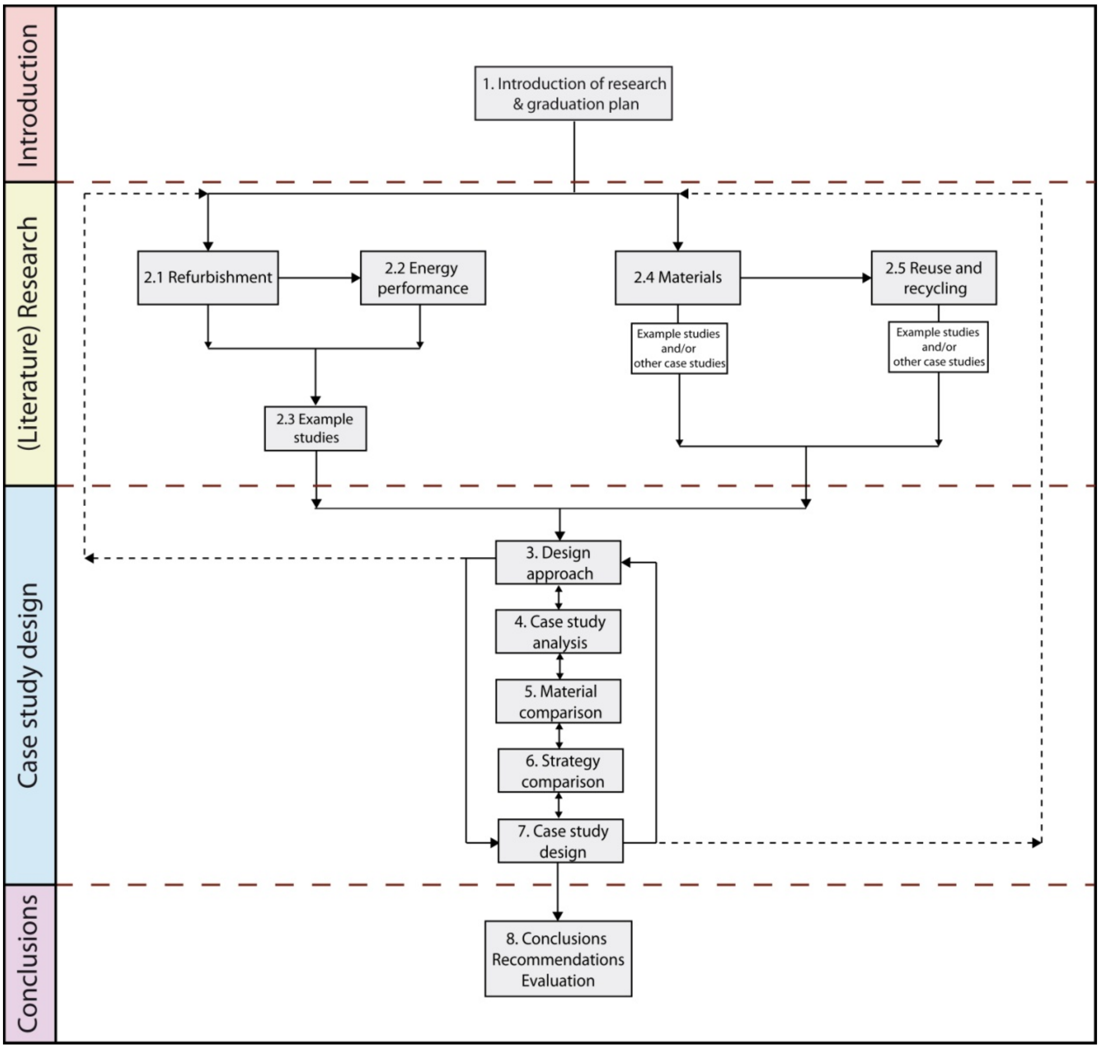


Figure 1-1: Research structure of this thesis, with chapter numbers

1.2.5 Time planning

		16 november **P1** 8 weeks	25 january Go/No go **P2** 10 weeks	9 April **P3** 5 weeks	14 May Go/No go **P4** 5 weeks P5
Introduction	-Preliminary graduation plan	-Final graduation plan -Introduction to thesis			
Research		-(Preliminary) **Literature research:** -Refurbishment -Energy performance -Materials -Reuse/recycling -**Example studies** and other studies	-Continue with **Research**	-Finish research	
Case study design		-Find a case study -What tools to use for assesment: -Operation energy -Embodied energy -Environmental impact -Preliminary design approach	**-Analysis case study:** -Building & Details -Energy use -Comfort -**Building materials overview**: -Analysis of possible materials and components in different aspects (embodied energy, building costs, environmental impact) -Best materials used for design strategies **-Strategy comparison:** -Global design different strategies -Analysis Operation & Embodied Energy per strategy -Conclusions strategies, which is best per façade part	-Perfecting strategy comparison & material overview **-New building design:** -Choice best strategy per facade part -Variation studies -Global detailing **-Calculations new design** -Operation energy -Embodied energy -Environmental impact **-Perfecting the design**	
Conclusions				-Start with conclusions	-Conclusions -Recommendations -Evaluation
Report		-P2 Report	-P3 Report	-P4 Report	-Final report
Presentation	-P1 Presentation: Powerpoint	-P2 Presentation: Powerpoint	-P3 Presentation: Powerpoint	-P4 Presentation: Powerpoint	-P5 Presentation: Powerpoint Posters?

Figure 1-2: General time planning from the thesis, parts explained

2. LITERATURE RESEARCH

This chapter is divided into five parts: Refurbishment, Energy performance, Example studies, Materials and Reuse and recycling. The chapter of refurbishment, energy performance and example studies will be used to give background information and answer sub research questions. The chapters materials and reuse and recycling will not answer any research question, but will only give background information of the subjects.

2.1 Refurbishment

In this chapter refurbishment of buildings, specified later for residential buildings, will be examined. First definitions will be made concerning refurbishment. With the later parts in this chapter, the following sub question can be answered:

1. What measures can be taken to improve the façade of a (residential) building with refurbishment?

This question will be answered by looking at the different parameters that are important for refurbishment. Also for different materials a study will be made; how can these be repaired or replaced? Sometimes complete replacement will not be necessary. Also different strategies are possible by refurbishment, which will be summarized.

To be able to see what building should be chosen as a case study, a study will be done into different residential building periods and building types. This can help make a conclusion for the choice of a case study.

2.1.1 Definitions

To understand exactly what refurbishment is and what degrees of refurbishment there are, definitions need to be made.

The following definitions for refurbishment are made by the book of Giebeler et al. (2009). According to them there are different terms for measures/intervention on an existing building. These different terms are: Reconstruction, restoration, deconstruction, demolition, renovation/maintenance, repairs/maintenance, partial refurbishment, refurbishment, total refurbishment, conversion and finally gutting/rebuilding with partial retention.

There are different degrees of *refurbishment* (Giebeler et al., 2009). First there is partial refurbishment, which includes only one component or part of the building, while the building is still in use. Secondly there is normal refurbishment, which covers an entire building or a clearly separate, autonomous part of the building. In this refurbishment also the fire protection, acoustic upgrading and thermal performance is improved. Last there is total refurbishment, where there is definitely building authority needed for permission. In this case the building is stripped to its load bearing frame. In this case the building needs to be upgraded completely to the new requirement standards.

The term that is applicable to the situation in this thesis, is refurbishment, which is in between repairs/maintenance and conversion (see Figure 2-1). Repairs/maintenance is limited to replacement or repair of defective building components. Conversion also affects the structure of the building (load-bearing members and/or the interior layout). Refurbishment does not include changes in the load-bearing structure. *In refurbishment not only the defective building components are repaired or replaced, but also the outdated components or surfaces* (Giebeler et al., 2009). With refurbishment there is upgrading of fire protection, acoustics and thermal performance.

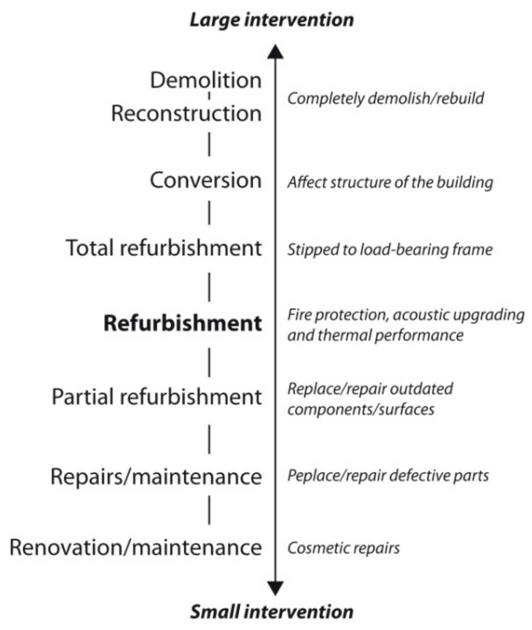


Figure 2-1: Intervention degrees for buildings

2.1.2 Why refurbishment?

There are different degrees of possible adaptations that can be made to the building. Small improvements can be made, but also large upgrading changes are possible. Why should a choice be made for larger improvements, which includes updating the building to the current standards?

Douglas gives advantages to adapt a building (Douglas, 2002): Economic, Technical, Spatial, Environmental and Social. Economically it is less expensive to adapt an existing building than to demolish it and redevelop it. Often the large internal spaces can be subdivided into smaller rooms, without compromising the architectural quality of the building. Further, due to the enhanced appearance of the building, it will also have a good effect on its surroundings. Due to the adapting, the less energy-efficient buildings can be made more environmentally friendly. Using old buildings is good for the architectural, cultural and historic value.

Douglas also explains five disadvantages to adapt a building (Douglas, 2002): Background, functional, technical, economic and environmental. Sometimes refurbishment is not the best solution, because in some situations demolishing the building can make way for new buildings. Also there are restrictions in the functional sense, because often there are problems concerning the layout of the building, heights etc. Some adapted buildings still have defects, because the adapting of the building is very complex. Economically, the costs of the refurbishment and maintenance have to be taken into account, because this has to be calculated into the user's costs. Also the potential of making the building more energy efficient has to be taken into account, because this can sometimes be low.

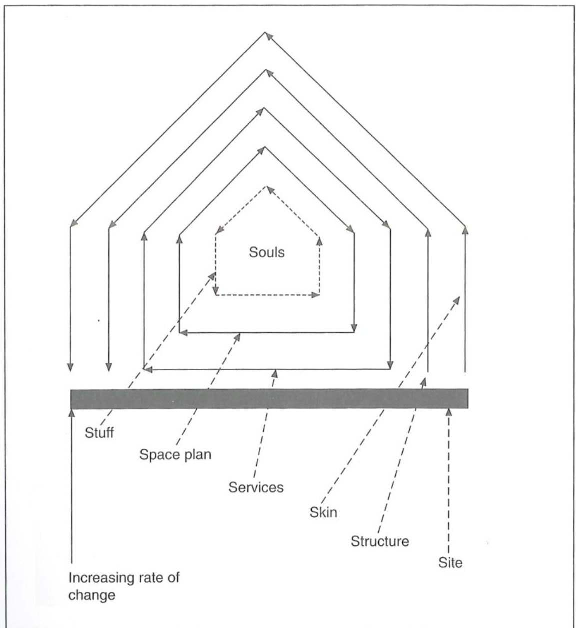
By greening existing buildings there can be savings in energy, water and waste expenses, but also in "soft" benefits like health, comfort, productivity of occupants, enhances marketing and public relations, risk mitigation, improved recruitment and retention and greater employee morale (Yudelson, 2010). With existing buildings the problem is that the energy use is already partly determined by scale, mass and orientation, so there are more challenges and sometimes it may not be economical to make the changes (Yudelson, 2010). Nevertheless greening buildings in certain aspects can still lower the energy consumption significantly.

2.1.3 Refurbishment principles

As can be seen in Figure 2-2, there are different layers to a building. The structure usually has a large lifespan, but the building skin has a far lower one. Therefore in this thesis the focus will not be on the structure, but on the skin and also partly the services, because these can help with a higher energy performance.

There are different aspects that need to be considered for refurbishment of a building: The fire resistance; the internal surfaces; the thermal performance; the acoustic performance; the moisture and dampness prevention; the air tightness, the façade; and the structure (Highfield, 2000).

Douglas gives different aspects to consider when adapting a building (see Figure 2-3). The façade is only a small aspect of the parts that can be improved, so these also need to be considered with refurbishment. These are: strength and stability; weather tightness; dampness (rising); thermal; fire; condensation; durability and maintenance; sound; habitability; function; and health and safety.



Shearing layers	Description	Typical lifespan/activity
Site	Location and context	Permanent
Structure	Bones	30–300 years
Skin	Envelope	20+ years
Services	Lifeblood	7–20 years
Space plan	Interior layout	3 years
Stuff	Furniture and equipment	Under 3 years
Souls	People	Daily

Figure 2-2: Shearing layers of change (Douglas, 2002), originally from Brand

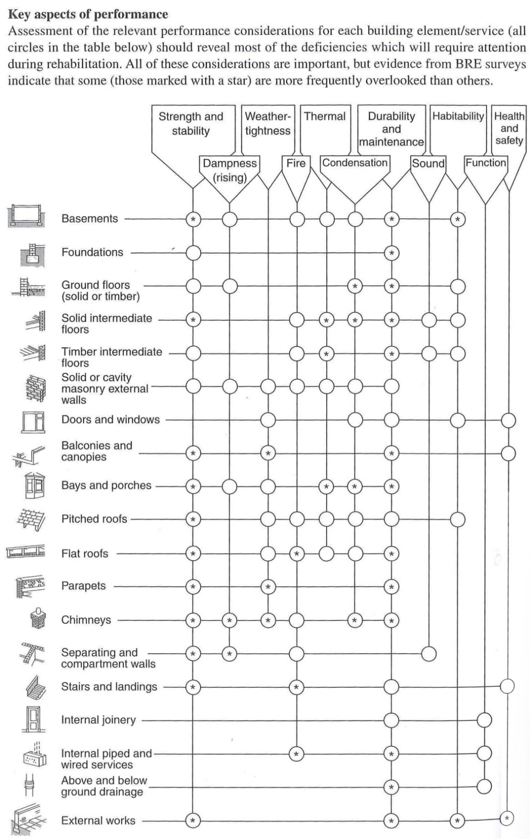


Figure 2-3: Key aspects for performance (Douglas, 2002)

2.1.4 Materials for refurbishment

For building materials in refurbishment Giebeler et al. (2009) give a division in three groups: load bearing structure, envelope and fitting-out. The building envelope and load-bearing structure usually cannot be separated from each other (Giebeler et al., 2009), but the focus of this report will be on the building envelope. Background research on this subject is given in Appendix A-1: Refurbishment of Materials, and a summary of that research is given in Table 2-1.

The maintenance of materials can prevent them needing to be completely replaced, while sometimes the materials are so damage that replacement will be needed. It needs to be assessed by a professional if this is possible for each separate situation. But sometimes replacement will be needed, if new requirements for the standards need to be met.

Table 2-1: Possible damages and maintenance measures of different materials, based on (Giebeler et al., 2009)

LOAD BEARING STRUCTURE		
Material	**Damage due to**	**Maintenance**
Timber	Poor maintenance, excessive absorption, constructional and building physics shortcomings	
Iron and steel	Rusting	Coatings and galvanizing processes
Reinforced concrete	Reinforcement corroding	Protective or substitute layer
Masonry	Moisture	Cleaning, removing parts, replacing and filling
BUILDING ENVELOPE		
Material	**Damage due to**	**Maintenance**
Roof: Flat roof	Bad waterproofing, fatigue embrittlement, blisters, corrugations	Insulation and waterproofing, solve parts locally for gullies, flashings, joints
Roof: Clay and concrete roof tiles	Mechanical damage, vegetation	Replacement of damaged parts
Roof: Metal roof coverings	Corrosion	Mechanical cleaning, adding surface protection, soldering
Wood: window frames/doors	Weather, moulds, light, moisture	Coating systems regularly, sanding, replacement
Glass	Stains, rust by other façade parts	Polishing, replacing if there are breakages or seal failures
Stone	Spalling, strength loss, dirt, plants, air pollution, discoloring	Cleaning by pressurized water jets, good detailing, treatment for water repelling
Render	Damage and cracking by substrate or structural movement, moisture	Waterproofing measures, repair parts and cracks
Paints and coatings	Moisture, poor substrates, poor drying of coating	Maintenance regularly
Insulating materials	Infiltration of water, animal pests, defective fixings	Replacements, filled in by in situ foam, additional layers
FITTING OUT		
Material	**Damage due to**	**Maintenance**
Plaster	Structural movements, poor repaired substrates, mechanical impacts, moisture	Better insulation, disinfectant plasters and paints, filling and reinforcements, new paints
Wooden floors	Mechanical, wear, changes of color, burn marks etc.	Sanding and sealing, repairing or replacing, sanding and finishing
Subfloors and terrazzo	Shrinkage cracks, unevenness, damage by loads, discoloration etc.	Grinding, repair by removing old and filling in new materials

2.1.5 Strategies for refurbishment

When refurbishment is needed, the best strategy for that specific building and situation can be chosen. An overview of different strategies will help make a decision for the way the case study building needs to be refurbished.

In Table 2-2 a summary is made for the different refurbishment possibilities. The magnitude of the refurbishment is shown, together with the advantages and disadvantages of the chosen refurbishment. Together with the magnitude also the lifetime of the new façade is shown. Small changes might only keep the façade updated for a few years, while larger changes can keep the façade up to date for 20 years of more. In Figure 2-4 the different refurbishment strategies are visualised schematically.

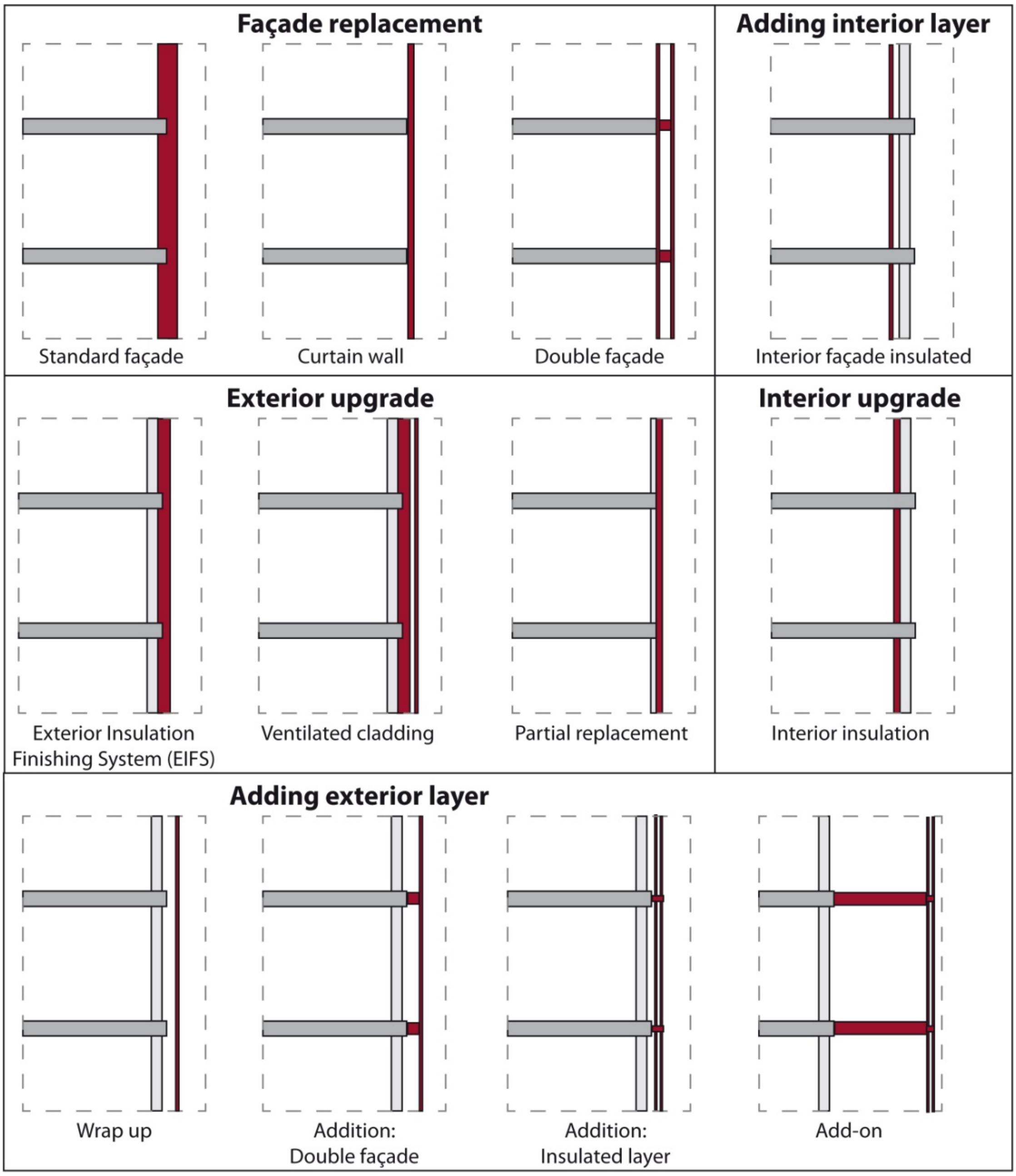


Figure 2-4: Possible refurbishment strategies, based on Ebbert and Konstantinou (Ebbert, 2010) (Konstantinou, 2012)

Table 2-2: Conclusion of possible refurbishment strategies, based on Konstantinou (2012), Ebbert (2010) and own insight

Refurbishment strategy	Refurbishment magnitude/new lifetime	Possibilities and advantages	Disadvantages
Complete Façade replacement	Large, complete façade removal	Any new type of façade is possible, large energy savings, new appearance	High cost and much waste from old façade
Exterior upgrade	Can vary from small to large	Remove out of date components, while still good components can be kept	Possibilities depend largely on specific building
Interior upgrade	Can vary from small to medium	Good to keep appearance for monuments	No new appearance for out of date buildings
Adding exterior layer	Can vary from medium to large	Complete insulation possible, many possibilities to new appearance, extra space possible, no waste (all old materials kept)	Construction needs to be strong enough
Adding interior layer	Can vary from medium to large	Outside appearance for monuments can be kept	No new appearance for out of date buildings

2.1.6 Measures for refurbishment

By the research in the previous paragraphs the first sub research question can be answered.

1. What measures can be taken to improve the façade of a (residential) building with refurbishment?

Different degrees of changes can be made to improve the building, ranging from maintenance to demolition/reconstruction. Depending on the situation the necessary improvement can be made. When the building has to be up to the current standards, refurbishment is needed to upgrade the thermal performance, acoustic performance and fire protection. The out of date parts are replaced.

When going for a refurbishment where the current standards need to be met, the following aspects need attention: the fire resistance; the internal surfaces; the thermal performance; the acoustic performance; the moisture and dampness prevention; the air tightness of the façade; and the structure.

Some parts of the façade might need to be replaced, while others can be repaired to maintain it. Different materials and façade parts need to be analysed to see if this is possible, or if they need to be replaced, also depending on the standard desired for the building.

When looking at the large picture of the façade refurbishment, different strategies are possible: façade replacement, exterior upgrade, interior upgrade, adding exterior layer and adding interior layer. The choice of these, amongst other things, depends on the money available, the desired performance and the outside appearance.

2.1.7 Building period analysis

In this building period analysis the focus will be put on the residential buildings in the Netherlands. This will help make a short overview of the development of housing throughout the years. Also conclusions can be made to see which building period can best be chosen to focus on in this thesis.

In 1901 a new law was made, the "Woningwet", to improve the living conditions, which were very unsanitary before that time. This law also made a basis for the social rent-sector (Van Boom, 2005).

Jellema 8 (Van Boom, 2005) gives the following subdivision in building periods:

- Public housing 1901-1940
- Industrial building 1940-1972
- Habitable city 1972-1990
- Vinex and restructuring 1990-now

1901-1940

Figure 2-5: Floor plan for a functionalistic residence for a gallery flat in Rotterdam (Van Boom, 2005)

The new law in 1901 mainly had an influence on the urban development (Van Boom, 2005). New housing was developed, while also giving attention to the public spaces and the architecture of the urban entity. The new housing was small, but they had more gardens.

There was also a movement which thought functionality and rationalism was most important, but this was not built much until after the Second World War. In this movement the following things were spear points: separation of functions in an urban scale; attention to traffic; health; green (Van Boom, 2005).

Due to the new housing law, the living conditions improved a lot concerning hygiene and space. There are many buildings from this period that have gotten a monumental status (Van Boom, 2005).

1940-1972

After the Second World War there was a housing shortage due to an increase in population (Van Boom, 2005). The main problem was that there were not enough building materials, due to the problems in the economy. A solution was to make temporary buildings, of about 20m^2 for a family with four children up to 47m^2 for a family with maximum of 8 children. After 1950 there was an increase in production of houses, due to the industrialisation, with new building systems and standardisation. In 1962 the millionth post-war residence was built (Van Boom, 2005).

Typical buildings for this period are blocks of flats with an entrance hall ("portiek flat") due to an increase in stacking of floors. Also gallery flats were very common in that time (Van Boom, 2005). Different areas were created, with public facilities in the middle. Also the functionalistic movement wanted more green around the buildings. All types of buildings had quite identical floor plans.

The building method was similar in the post-war period for most buildings. It was built up of an uninsulated brick cavity wall or sand-lime brick, or a stone wall with poured concrete elements as inner wall and an outside brick wall. Wooden window frames were usual, with load bearing inside walls of stone or concrete. With single-family dwellings the roof usually was made from wood, closed with cement-based straw-fibreboard plates, with ceramic roof tiles and zinc drains. Flat roofs were tar-based.

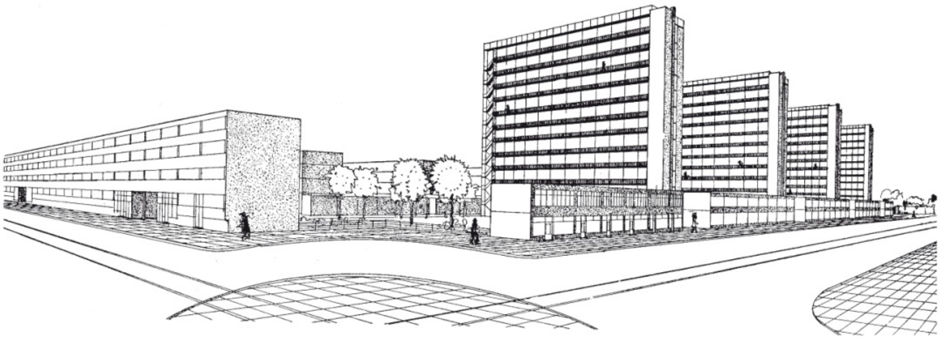


Figure 2-6: Contest design for cheap workers houses from 1933, by J.H. van den Broek (Van Boom, 2005)

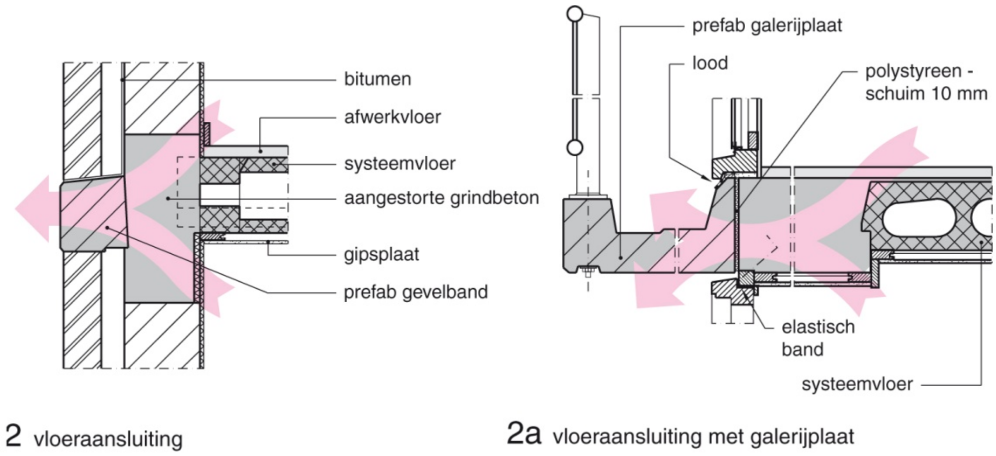


Figure 2-7: Examples of cold-bridges in post-war buildings (Van Boom, 2005)

Due to modular construction, housing could be built much quicker. There were mainly two types:

-"Stapelbouw": Made by separate building materials like brick, concrete, tiles and wood, metal, roof tiles. Some parts were brought prefab to the building site, like separating walls, floors and roofs.

- "Gietbouw": Building materials were made at work (by pouring concrete), which could realise up to ten floors high. The floor plans could be made a bit bigger.

After 1970 a critique was made on the post-war housing. Due to the mass, the individuality was lost and the buildings were too monotone and boring. There were also complaints concerning indoor comfort (bad insulation, moisture problems due to condensation, draught and acoustics). Cold bridges are a large problem in this period. Many building materials had asbestos in them.

1972-1990

After 1970, still more houses had to be built, but the use of the car allowed people to live further from the city core, also into towns and smaller cities (Van Boom, 2005). In this period more diversity was made into buildings. The older buildings before 1970 became cheaper for a lower income; this caused deterioration of these older areas and there was social segregation.

Due to the energy crisis in 1973, building more energy efficient was necessary. Also the heating became more energy efficient. More attention was given to indoor comfort, so better acoustics, better air-tightness and less cold bridges which lowered the chance of mould. Double glass became available and also better window frames and isolation was used more often.

Renovation became a larger issue in this period. Older buildings could be renovated by plastic or aluminium window frames and extra insulation like polystyrene, glass fibre and rock wool was used for existing buildings. Awareness of the damaging nature of asbestos became evident later in this period, also for some isolation used earlier it became evident that this gave health problems.

1990-now

(Van Boom, 2005) Around 1990 a lot more buildings were made at the edge of the cities. Vinex districts were developed, which all had their own identity.

Also the renovation and restructuring of the old post-war areas became necessary, due to moving of the people from the old post-war buildings to the newer developed areas and to bigger and better residences. Large improvements were made in some areas to make the older buildings safer and better looking. Also buildings with homes for multiple types of residents became available.

Another problem nowadays is the ageing population. Many existing buildings need to be upgraded to become suitable for this growing population (for example by adding elevators).

Nowadays there are much stricter regulations to make energy-efficient and environmentally friendlier buildings.

Conclusion

Buildings before 1940 often have a monumental status, which makes it more challenging to upgrade the energy performance.

Between 1940 and 1972 many blocks were built with poor insulation and the same type of construction. These types of buildings now often stand in problem neighbourhoods.

Between 1972 and 1990 the standard became higher and the energy performance and indoor comfort better.

After 1990 stricter regulations came in place concerning energy efficiency.

2.1.8 Building type analysis

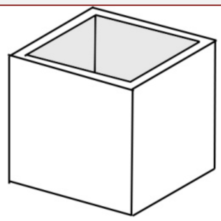
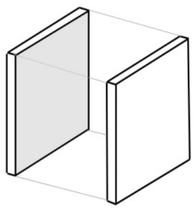
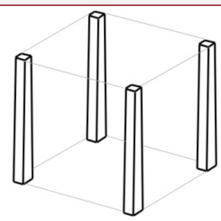
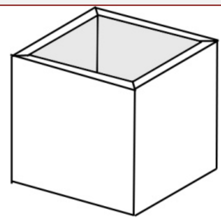
An analysis in different building types will be made, to see what the possibilities and restrictions are for refurbishment per façade type. Also it is then possible to see which type of building is best suitable for this research, for the case study building. An emphasis will be put on types that are easily changeable, because this is desirable for a refurbishment. Especially if the embodied energy of new materials is going to be research for refurbishment, it is preferable that old materials can be easily removed to be replaced with new materials (if this is going to be the strategy for the case study).

Load-bearing construction

A subdivision can be made according to Jellema 3 in Load-bearing construction: Stacking (massive wall, "stapelbouw"), casting (gietbouw), column structure and prefab floor and wall elements (Spierings, Van Amerongen, & Millekamp, 2004).

In Table 2-3 the possibilities and restrictions are shown. The load-bearing façades and elements are not very suitable for this research, because not many changes can be made in the façade, which restricts the research. For example it is more difficult to make extra window openings. 'Schijvenbouw' and a column structure are best suitable, but the load-bearing walls are more used in older residential buildings, so this is a better choice.

Table 2-3: Subdivision in load-bearing construction types, based on Spierings et. al. (2004)

	"Massieve structuur"	**"Gietbouw/Schij-venstructuur"**	**"Skeletbouw"**	**"Elementenbouw"**
Principle	 Stacking (stapelbouw)	 Casting (gietbouw)	 Column structure	 Prefab floor and wall elements
Used in housing?	Yes, on small scale housing	Yes, on simple large scale housing	No, mostly in commercial buildings	Yes, on complex large scale housing
Material possibilities	-Masonry with wooden floors -sand-lime brick or cellular concrete with concrete floors	-Concrete casting -Prefab concrete	-Wooden, concrete or steel columns and beams -Concrete floors	-Wooden elements -Concrete elements
Many possibilities for refurbish-ment?	No, not many changes can be made in windows and inside layer of façade	Yes, front façade can completely be changed, the sides of the building is more difficult	Yes, complete change on all sides of the façade	No
Suitable for this thesis research?	-	+	*+/- (not used much in residential buildings)*	-

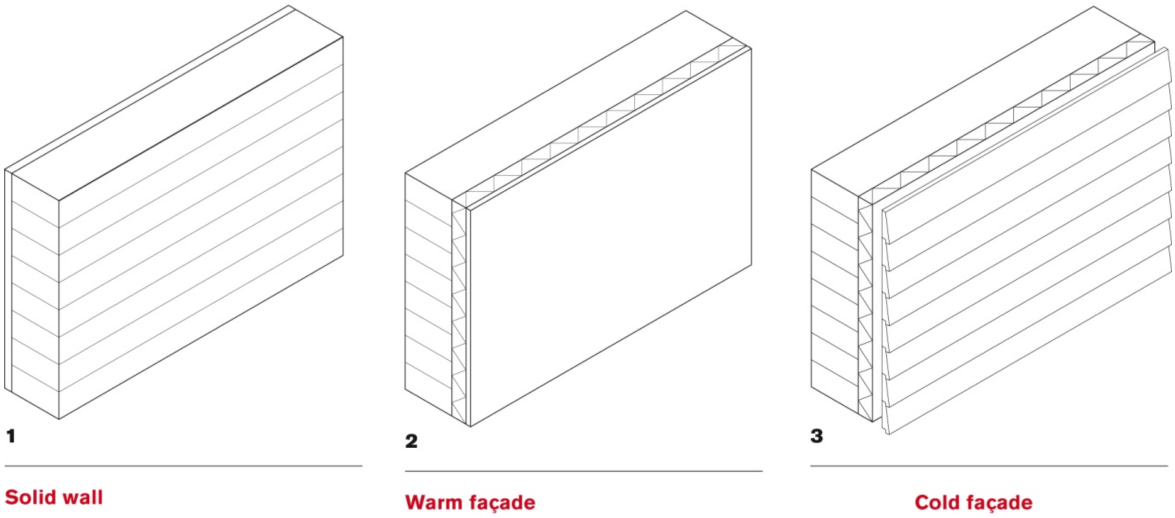


Figure 2-8: Three different types of façades (Knaack, Klein, Bilow, & Auer, 2007)

Façade construction

Generally a division in three types can be made for façades: Solid walls, warm façades and cold façades (Knaack et al., 2007), see Figure 2-8.

With the help of Jellema 4b, a more detailed examination is possible for different cladding types, which are often divided into the three building types that Knaack et. al. give in Figure 2-8.

Jellema 4b gives the following division in façade (cladding) types: Masonry, light plate materials, stone cladding, prefab concrete and active façades (Rentier, Reymers, & Salden, 2005).

Light plate material and stone cladding

Rentier (Rentier et al., 2005) gives a division into principles of light plate materials: wet and dry systems. Light plate materials can be materials like plaster (for wet systems), wood, metal, glass, stone, plastics and others. Table 2-4 shows the systems. Both the cold and warm systems are suitable for the façade of the case study.

Table 2-4: Façade construction types for light plate materials and stone cladding

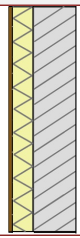
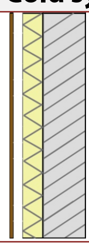
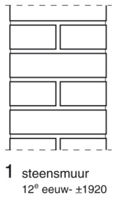
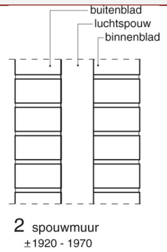
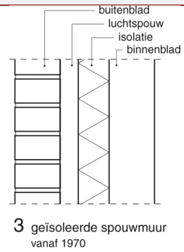
	Warm system	Cold system
Principle		
Possibilities for refurbishment	-Remove outside cladding, place new insulation and cladding on outside	-Remove outside cladding, extra insulation.
Suitable for this thesis research?	+	+

Table 2-5: Façade construction types with masonry, based on Rentier et al. (2005)

	Solid wall	**Cavity wall**	**Insulated wall with cavity**
Principle			
Possibilities for refurbishment:	-Inside insulation, outside cladding -Outside insulation and cladding -Remove wall (if not load-bearing, but often it is)	-Remove outside cavity wall, on the outside new insulation and cladding -Insulation in between cavity -Keep wall, put insulation on the outside and new cladding -Replacing whole wall	-Keep wall, extra insulation on outside and new cladding -Remove outside cavity wall, extra/new insulation and new cladding
Suitable for this thesis research?	- *(often load bearing walls)*	+/- *(often easiest solution is putting insulation in cavity)*	+/- *(often already insulated)*

<u>Masonry</u>

In Table 2-5 the type of masonry façades are seen. The solid wall does not give much freedom, and the cavity wall is in practice often filled with insulation in between the cavity, without changing the appearance.

<u>Prefab concrete façades: Non-load bearing</u>

The non-load bearing prefab façade types in Table 2-6 are good to research, especially the ones without insulation. When there is a cavity sometimes there is already insulation, so the energy gain might not be a lot by upgrading. Also if there is already a lot of insulation in the sandwich panel the energy gain might not be a lot.

Table 2-6: Non-load bearing prefab concrete façade types

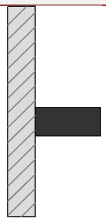
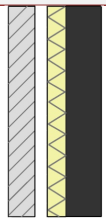
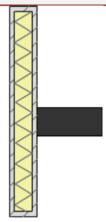
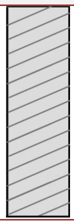
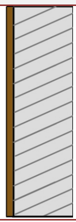
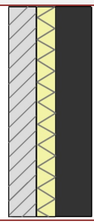
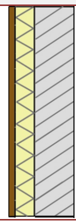
	No insulation	**Cavity with insulation**	**Sandwich**
Principle			
Possibilities for refurbishment	-Remove, new façade -Inside insulation new cladding -Outside insulation new cladding	-Remove outer layer, new cladding, extra insulation -Extra insulation outside, new cladding	-Remove, new façade -Extra insulation outside, new cladding
Suitable for this thesis research?	+	+/- *(if inner layer is load-bearing, there are less possibilities)*	+/-

Table 2-7: Load-bearing prefab concrete façade types

	Without cladding	With cladding, No insulation	Sandwich	With cladding, With insulation
Principle				
Possibilities for refurbishment	-Inside insulation -Outside insulation	-(Remove cladding,) outside insulation, new cladding -Inside insulation	-Insulation outside, new cladding -Inside insulation	-Remove cladding, extra insulation, new cladding -Inside insulation
Suitable for this thesis research?	- *(no changes can be made for example in window size)*	-	-	-

<u>Prefab concrete façades: Load-bearing</u>

The load-bearing prefab facades are not that suitable for this research, because there is less room for more drastic changes in the façade refurbishment.

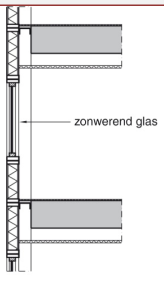
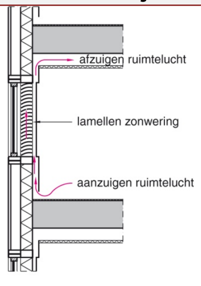
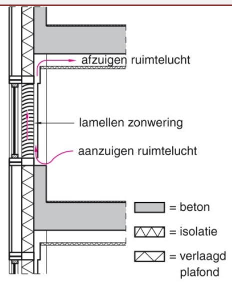
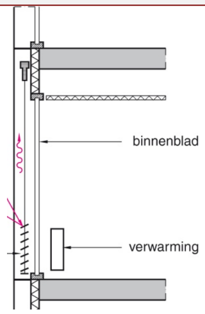
<u>Active façade</u>

Active façades are a much newer system and often already energy efficient enough. Only curtain walls which are badly insulated would be more suitable for the research.

Conclusions

- Buildings without load-bearing façades and with column structures are more interesting to research.
- Uninsolated solid walls have a lot of possibilities to improve, unless they are load-bearing.
- Interesting materials to research are prefab concrete and masonry (with cavity wall). Also plate materials with a warm or cold system are interesting, but only if they are very badly insulated.

Table 2-8: Active façade types, based on Rentier et al. (2005)

	Curtain wall	Climate façade	Climate window	Second skin
Principle				
Possibili-ties for refurbish-ment	-Remove façade, new façade -Extra insulation, add new cladding	-Remove complete façade, new façade -Remove cladding/ window, new insulation/ cladding	-Remove complete façade, new façade -Remove cladding, new insulation and cladding	
Suitable for this thesis?	+	- *(often already energy efficient)*	- *(often already energy efficient)*	- *(often already energy efficient)*

2.2 Energy Performance

This chapter will give information concerning the improvement of the energy performance by refurbishment. Definitions will be given, and important parameters like indoor comfort will be examined. This chapter will help answer the following sub research question:

2. How can the façade be upgraded to increase the energy performance of a (residential) building?

Also parts of this chapter will help to choose an adequate type of building for the case study.

2.2.1 Definitions

Primary energy [J] can be defined as: "The energy contained in the energy media that occur naturally on earth" (Hegger, Fuchs, Start, & Zeumer, 2008). These can be fossil fuels or renewable energy media. An energy medium can be described as "raw materials provided by nature, which owing to the convertible chemical or nuclear energy stored in them can be used to produce energy" (Hegger et al., 2008).

The primary energy factor (fp) can be expressed as: "the ratio of non-renewable primary energy input (including the losses during production, distribution and storage) to the final energy output" (Hegger et al., 2008). The lower this factor is the higher the efficiency.

Secondary energy [J] can be described as: "the energy remaining after converting the primary energy medium into so-called net energy media such as electricity, heating oil, district heat or wood pellets" (Hegger et al., 2008).

Final energy [J] is the quantity of energy that is available to the end user at the place of use after deduction all conversions and distribution losses and are usually the basis for the energy costs calculation (Hegger et al., 2008).

2.2.2 Indoor comfort

Upgrading a building can contribute to the thermal comfort in more ways (Giebeler et al., 2009). Better insulation can result in higher internal surface temperatures, which means that there will be less risk of radiant temperature asymmetry and cold air coming down the walls. Thermal insulation in the summer reduces the risks of overheating, especially for rooms beneath the roof. Better insulation of the openings around doors and winds can reduce draughts.

According to Hegger et al. (2008) there are physical, intermediary and physiological conditions that influence comfort (see Figure 2-9). Due to the physiological conditions the comfort cannot be quantified exactly, but is a individual empirical value for each human's experience (Hegger et al., 2008).

The focus in this research will be on the energy performance of the building, so the thermal factor from the physical conditions will be most important (see Figure 2-9). The other factors, like acoustic, visual and olfactory, always need to be taken into consideration in the design, but this will not be the main focal point. The olfactory factors are also important when considering the ventilation system of the residence. And the visual factor is important to see if a sunshade system is needed. If acoustics between the outside to the inside, or between two adjoining apartments, is a problem this also should be solved in a refurbishment design.

The four factors that influence thermal comfort are: interior air temperature, mean enclosing surfaces temperature, interior air humidity and air movements (Hegger et al., 2008). With older residential buildings these could be reasons why there are problems with the comfort, and by improving the energy performance and building services of the building these factors could be improved substantially.

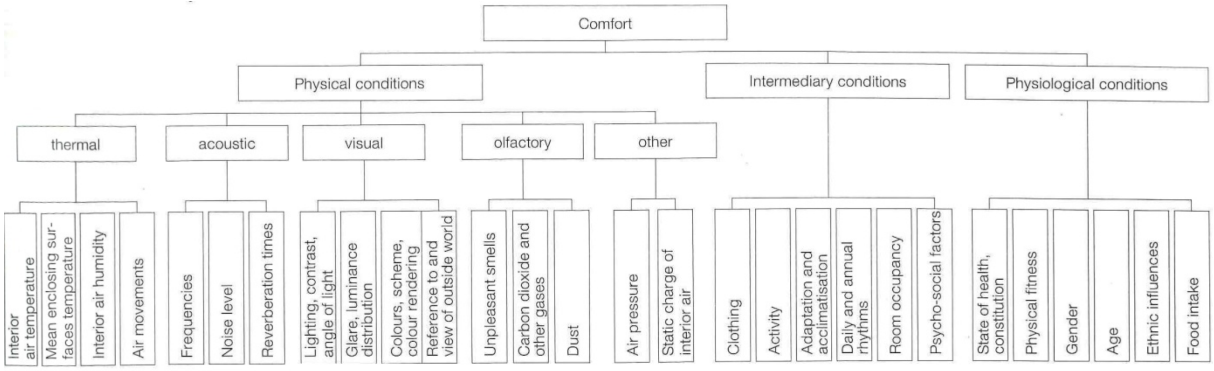


Figure 2-9: Systematic representation of comfort factors (Hegger et al., 2008)

2.2.3 Improving the energy performance by refurbishment

According to Burton (Burton, 2012), there are different components that can be outlined, for sustainable refurbishment, even though these different parts might need to be integrated. There are the following areas that need attention (Burton, 2012):

- **Improving the insulation of external elements**
- **Adequate and efficient ventilation**
- **Providing efficient space heating**
- Providing domestic hot water efficiently
- **Avoiding overheating**
- Utilizing daylighting, efficient lighting and control systems
- Installing efficient appliances and controls
- Minimizing water use
- **Reusing existing components and using new sustainable materials**

The focus in this report will put on the façade and the materialization of the façade for refurbishment: improving the insulation; adequate and efficient ventilation; avoid overheating; and reusing existing components. During the design and selection process of materials the other factors need to be taken into account also, but the emphasis will be put on the outside skin of the building.

Burton gives possible actions for certain components of the building, which are summarized in Table 2-9. This table answers the following sub research question:

2. How can the façade be upgraded to increase the energy performance of a (residential) building?

Some parts of the table are more important than others to answer the sub-research question, concerning the façade.

Table 2-9: Improvement possibilities or the energy performance by actions for certain components, based on Burton (2012)

Improving insulation	
Component	**Action**
Walls, floors, ceilings	Insulation on inside or outside or in cavity
Windows	Double or triple glazing with inert gas filling, coating, insulated frames
Doors	Insulated doors
Cold bridges at junctions and balconies	Careful detailing, external and internal insulation
Ventilation	
Component	Action
Cracks and air paths	Seal cracks, open joints, service entries, unused chimneys
Draught stripping	Draught-stripping doors and windows
Natural ventilation	Passive stack ventilation from kitchens and bathrooms
Mechanical ventilation	Efficient heat recovery
Avoid overheating	
Component	**Action**
Reducing internal heat gains	Insulating pipe work and storage cylinders, efficient electrical equipment
Reducing external heat gains	Solar shading
External landscaping	Trees, vegetation
Use of thermal mass	Internal thermal mass to reduce temperature swings, night ventilation
Adequate ventilation	Cross ventilation
Existing components and new sustainable materials	
Component	**Action**
Existing components	Reuse and restoration of components instead of replacement
New materials	Minimal embodied energy and environmental impact
Domestic hot water	
Component	**Action**
Solar water heating	Solar water system
District of block heating system	Linking to block or district heating, CHP
Gas and oil boilers	Efficient boilers
Heat pumps	Electrical heat pumps with high performance
Direct electric heaters	Small electric heaters for small use
Storage cylinders and pipe work	Insulate storage cylinders, short pipe work
Reducing hot water use	Reduced flow taps
Daylighting, efficient lighting and control systems	
Component	**Action**
Optimizing daylight	New windows and skylights in dark spaces
Light surfaces	Light paint
Efficient lamps and luminaries	LED
Switching	Individual switching, dimmer controls, sensors
Efficient appliances and controls	
Component	**Action**
Kitchen and utility equipment	Efficient equipment, gas cooking

2.2.4 Energy performance for different building types and periods

To make a choice for the case study building, different building types from different periods can be considered. The possibility to improve the energy performance can help make this choice.

Agentschap NL (Agentschap NL, 2011) gives example homes of different types, from different periods, which can represent groups of homes as part of the residential stock. They have done this with the help of WoON 2006 (module Energy), which is a study of the ministry VROM for the energetic quality of the Dutch building stock, containing data from 5.000 existing homes until the building year 2005.

Agentschap NL gives a subdivision in building periods, and housing types (Agentschap NL, 2011). This subdivision will be used to analyse the residential buildings of the Netherlands in general, to assess the energy performance in different building periods and different types of homes.

Based on the data from Agentschap NL the energy labels and Energy Index per building period and residence type can be made (see Appendix A, Table A- 1). AgentschapNL also give possibilities to upgrade the home's label and EI to a certain level, which can be seen in Table A- 2, Appendix A.

The information from AgentschapNL can be made into an overview in Table 2-10, which shows the current label and to which label it can be upgraded. Buildings up to 1964 have D to F label. Especially detached houses, terraced houses and maisonettes in that period have a very bad label. Gallery apartments from that period have the best label, D. For buildings from1965 to 1974, labels range from D to F. Here again the detached house is the worst. Most buildings can be upgraded up to A or B. Only Gallery apartments from 1965 to 1974 seem to have problems to upgrade higher than C label. The total percentage that can be improved for the EI is shown and the improvement in energy label. Before 1975 substantial energy saving can be made. Especially homes made before 1965 can be improved up to 64.9% energy savings. Only gallery flats have a very low potential to made more energy efficient.

Table 2-10: Possible percentage energy savings in Energy Index (based on AgentschapNL (Agentschap NL, 2011)

Residence types	**Building period**					**% of total building stock**
	Until 1945	**1946-1964**	**1965-1974**	**1975-1991**	**1992-2005**	
Detached house	64,2% G→B		56,6% F→A	35,0% D→B	7% B→B	14,2%
Duplex house	61,3% F→B		54,6% E→B	31,4% C→B	10,9% B→B	12,2%
Terraced house	62,6% G→B	53% F→B	43,3% E→B	28,7% D→B	3,8% C→B	41,8%
Maisonette house	64,9% G→B		42,9% D→A	25,5% C→B	3,4% B→B	5,6%
Gallery apartment	35,9% D→B		37,2% E→C	26,4% C→B	3,1% B→B	6,9%
Flat with entrance hall (portiek)	62,8% F→B	48,5% E→B	38,4% D→B	20,6% C→A	10,5% B→B	12,5%
Remaining flat types	47,8% E→B		35,9% E→C	27,5% C→B	2,5% B→B	7,1%

In Table 2-11 the percentage of the total building stock per type is shown. There are a lot of detached houses, terraced houses and portiek flats. These would be most interesting to investigate further, because all of these also have a large energy savings potential, as can be seen in Table 2-10.

Based on the data from AgentschapNL, Table 2-12 can be made. This shows how much percentage of glass is still single glazing per building type and period and what façade has still no extra insulation. Still a large part of the detached, terraced and portiek houses have no extra insulation. This means that in these three types of buildings there is still a lot that needs to be done for the existing building stock.

Table 2-11: Percentage of the total Dutch residential building stock of each division (based on Agentschap NL (Agentschap NL, 2011))

Residence types	**Building period**					
	Until 1945	**1946-1964**	**1965-1974**	**1975-1991**	**1992-2005**	**All periods**
Detached house	6,5%		1,8%	3,3%	2,6%	14,2%
Duplex house	4,2%		2,1%	3,3%	2,6%	12,2%
Terraced house	7,7%	7,0%	9%	12,9%	5,2%	41,8%
Maisonette house	3,3%		0,3%	1,4%	0,6%	5,6%
Gallery apartment	1,0%		2,6%	1,6%	1,7%	6,9%
Flat with entrance hall (portiek)	3,8%	3,9%	1,7%	2,1%	1,0%	12,5%
Remaining flat types	1,5%		1,8%	1,8%	2,0%	7,1%

Table 2-12: Percentage of the total building stock per type of building that still has single glazing or an uninsolated façade, based on (Agentschap NL, 2011)

Residence types	**Building period**		
	Until 1945	**1946-1964**	**1965-1974**
Detached house	29% glass 81% façade		17% glass 80% façade
Duplex house	28% glass 80% façade		25% glass 67% façade
Terraced house	38% glass 89% façade	28% glass 73% glass	22% glass 65% façade
Maisonette house	44% glass 95% façade		64% glass 86% façade
Gallery apartment	37% glass 89% façade		35% glass 87% façade
Flat with entrance hall (portiek)	47% glass 97% façade	29% glass 87% façade	25% glass 87% façade
Remaining flat types	23% glass 80% façade		63% glass 88% façade

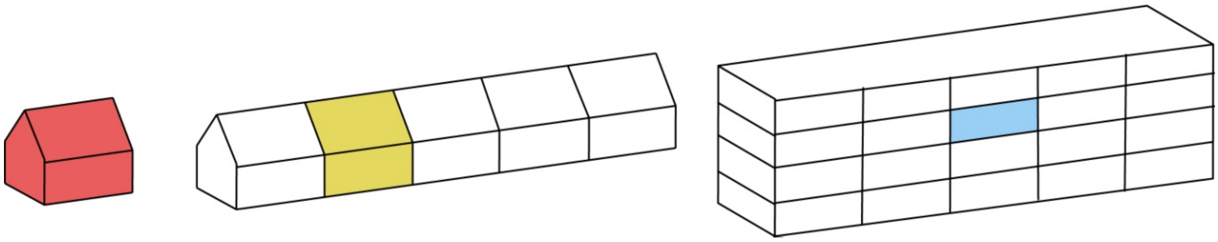


Figure 2-10: Comparison of different building types to the amount of façade surface

			Eigendom			
	Beschrijving	Bouwjaar	Aantal woningen	partikulier bezit	soc. Huur	par. Huur
1	Vrijstaande woning	voor 1966	502000	417000	30000	55000
2	Twee onder een kap	voor 1966	377000	245000	87000	41000
3	Rijtjeswoning	voor 1946	596000	358000	149000	107000
4	Rijtjeswoning	1946-1965	753000	452000	30000	264000
5	Galerijwoning	voor 1966	126000	82000	25000	19000
6	Portiekwoning	voor1966	502000	226000	176000	75000
7	Beneden-bovenwoning	voor 1966	220000	88000	77000	44000
8	Vrijstaande woning	1966-1988	333000	299000	12000	12000
9	Twee-onder-een-kap	1966-1988	282000	240000	28000	11000
10	Rijtjeswoning	1966-1976	659000	329000	264000	66000
11	Rijtjeswoning	1976-1980	232000	116000	104000	16000
12	Rijtjeswoning	1980-1988	546000	246000	246000	60000
13	Galerijwoning	1966-1988	245000	22000	184000	37000
14	Portiekwoning	1966-1988	17600	14000	132000	26000
15	Overige flatwoning	1966-1988	51000	20000	98000	30000
16	Woning jaren negentig	na 1988	546000	273000	246000	55000

Figure 2-11: Existing Dutch residential building stock (ISSO-publicatie 77, 2007)

In 2005 there were more than 6.8 million residences in the Netherlands (7.2 million in 2011). This puts the total of Row houses in 2005 at over 2.84 million houses.
It is apparent that the amount of row houses is the largest type.

Important is the social renting sector, because this way a large block of the same houses can be renovated in one time. A large amount of social houses are row houses up to 1988, portiek buildings up to 1988 and gallery apartments.

The detached houses before 1945 (64.2% energy savings) is also a possibility for the case study building. The problem with these buildings is that every detached house is different, so a different strategy is needed for each case. This is also the case with duplex houses.

Another problem is that the area of façade per residence is much larger than with apartment buildings. This means that the amount of embodied energy is probably also larger per residence for detached houses. The advantage of this is that by façade refurbishment the influence of the embodied energy on the total energy production will be higher. So it might be more influential to try and lower the embodied energy on the complete energy use.

The influence of the embodied energy in the following three housing types in Figure 2-10 will be examined further in the next chapter: Detached houses, terraced houses and flats.

Conclusions

Further research should be done to choose a building type for the case study for detached houses, terraced houses and portiek flats. These have the best potential to improve the energy performance and represent a large part of the existing building stock.

2.2.5 Study of 4 building types in Greencalc+

To see the effect of the environmental costs for the four different building types Greencalc+ will be used for assessment. This way the effect of the façade on the total environmental cost can be examined. When the effect of the façade is larger with a certain type of building, it might be better to use that one for a case study, because the focus is on the façade in this research.

Input in Greencalc+

The building type chosen is a residential building, in the North of Holland, with an average urbanization. The orientation for all buildings is North-South, with 20% of glass. The material index was used from the example buildings catalogue. The material-index 145-170 was used, which was the same in all types of buildings to be able to compare them. All homes are made 120m^2, but the terraced houses are 10 next to each other, and the lower portiek has 25 homes and the high flat 50 homes (see Figure 2-12). The detached houses as well as the terraced houses are 7.5x8 meters with 2 floors. The apartments are 12 meters (façade) by 10 meters deep, on one floor. All floors are 3.6 meter high, so the volume is the same for each home. See the overview below for more information per type.

The assessment that was made in Greencalc+ is very limited, since simplifications were used for the different building types, given in Greencalc. Standard materials indexes were used and no real designs were made. It is just a method to see the difference between different building types, if all other factors like materialization and floor area size per apartment are kept the same. This way the influence of the façade, roof and installations per type can be examined roughly.

Detached house: Total façade area 223,2m^2 Total roof area 60m^2 Total floor area 120m^2	**Terraced house:** 10 houses next to each other, 120m^2 per house Total façade area 1080m^2 Total roof area 600m^2 Total floor area 1200m^2
Portiek: 5 Storeys high, 5 houses wide with120m^2 per house. Total façade area 2520m^2 Total roof area 600m^2 Total floor area: 3000m^2	**Flat:** 10 storeys high, 5 houses wide with 120m^2 per house. Total façade area: 5040m^2 Total roof area 600m^2 Total floor area 6000m^2

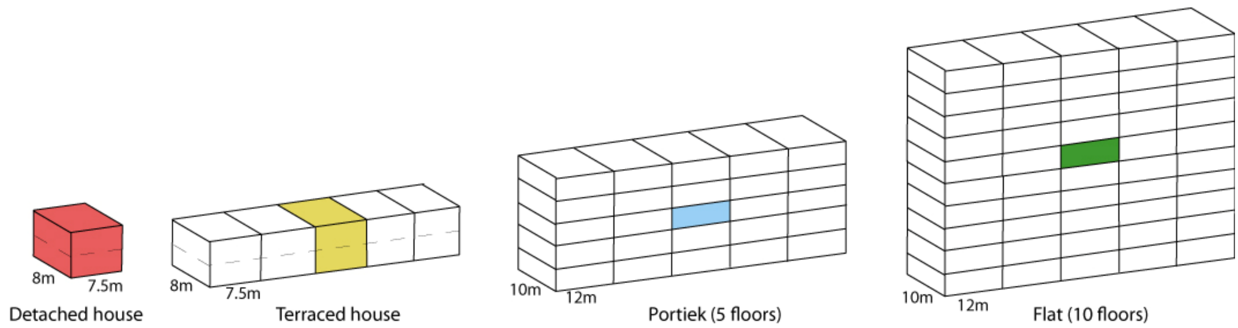


Figure 2-12: Building types that were researched with Greencalc+

Table 2-13: Overview of costs per building type, per m^2 living area

	Environmental cost material *(€ per m^2 living area)*	**Environmental cost energy** *(€ per m^2 living area)*	**Environmental costs of façade** *(€ per m^2 living area)*	**Environmental cost installation** *(€ per m^2 living area)*	**Environmental cost roof** *(€ per m^2 living area)*	**Greenhouse effect material** *(kg CO_2 eq. per m^2 living area)*
Detached house	1,49	4.5	0.76	0.125	0.15	10
Terraced house	0,97	3,86	0.29	0.122	0.05	6,60
Portiek (5 floors)	0,87	3,19	0,23	0.122	0.021	4,7
Flat (10 floors)	0,85	3,09	0,23	0,122	0,011	4,42

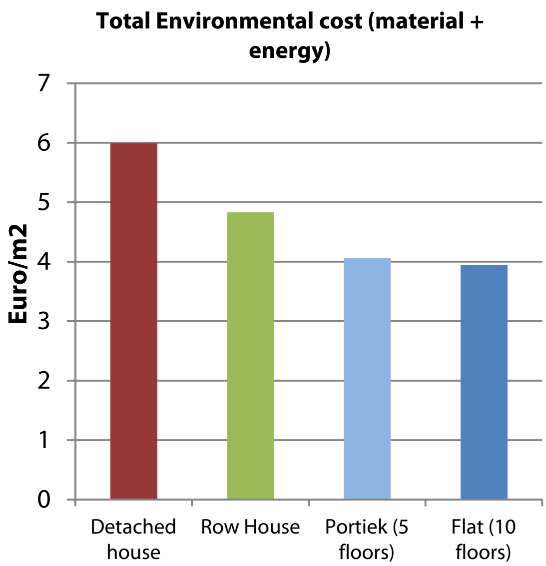


Figure 2-13: Environmental cost of material and energy for different building types

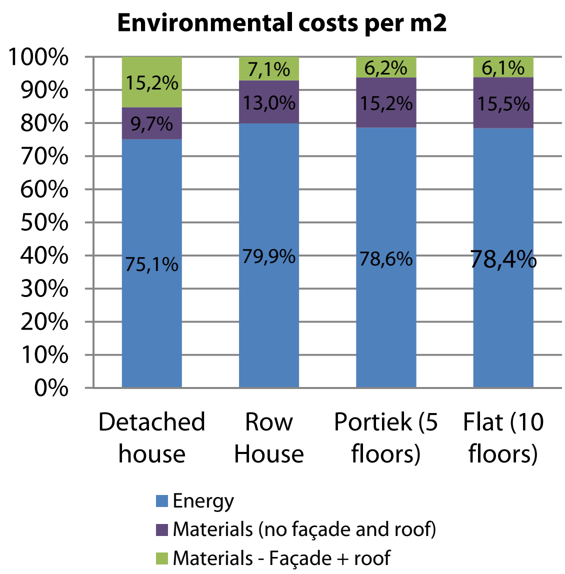


Figure 2-14: Environmental cost per building type separated for energy, façade+roof and the rest of the materials

It is evident in the figure above, that the total environmental cost is highest in detached houses. There is also a difference between row houses and portiek flat.

Figure 2-14 shows that the detached houses have the highest environmental costs in the façade and roof. The higher the building becomes, the lower the percentage that the façade and roof have on the total environmental cost. This means that lowering the environmental impact (and maybe also the embodied energy) of higher flats will have lesser effect on the total than with lower terraced houses.

2.2.6 Tool for calculating the Operation energy

To calculate the operation energy a value of Joule or kWh needs to be obtained, to be able to see what the energy use is per year. This way it can also be compared to the embodied energy and the total energy use within the buildings complete life cycle can be sketched. In this report the software ENORM v1.11 Student version will be used to calculate the EPC.

EPC (NEN 7120+C2, 2012)

EPC is an abbreviation for Energy Performance Coefficient and is used in the Dutch regulation to measure the energy performance of buildings.

There are 4 fields of application for determining the energy performance of buildings in EPC: new housing, existing housing, new commercial buildings and existing commercial buildings. There are differences in calculating the EPC in these different fields.

With the software ENORM only a new building can be calculated, but the EPC outcome for existing buildings will probably be the same when choosing a new building in the program. For new buildings the maximum allowable EPC value is 0.6. Currently it is not necessary to do an EPC calculation for existing buildings (only an Energy Index), but in this research the EPC software will be used, to try to get as close to the desired energy use of new buildings.

The characteristic energy use (E_{Ptot}) will be determined with the software. E_{Ptot} can be defined as: the sum of the to primary energy converted use of fossil fuels for heating, humidifying, ventilators, lighting, cooling, dehumidification, warm water and the helping energy for this, reduced by the primary energy potentially produced on the property of the building and used for the building, for example solar energy or electricity produced by a building bound CHP (Combined Heat and Power).

The characteristic energy use (E_{Ptot}) can be divided into the following parts in the EPC software: Heating, Domestic hot water, Cooling, Summer comfort, Humidification, Ventilators, Lighting.

2.3 Example studies

In this chapter example studies were made from other refurbishment projects, to help in the following aspects:

- See what type of refurbishment is done for different building periods and building types
- See what strategies for the façade are used for some refurbishment projects.
- See what strategies for the installations and for example sunshade are used.
- See the different levels of refurbishment (small versus many changes).
- To help determine what type of building and period can best be chosen for the case study building.

The example studies were assessed in the following points:

-*General information* (location, designers, commissioner)

-*Refurbishment* (Strategy, Façade structure, Construction, Upgrading acoustics & fire safety)

-*Energy performance* (Comfort, Installations, Energy use)

-*Environmental impact/embodied energy* (Materials used/products used, Reusing and recycling

-*General (*Inside layout, People, Costs)

2.3.1 Kroeven, Roosendaal (1960)

Figure 2-15: Kroeven Complex 505, before refurbishment (left) and after refurbishment (right) (DAT Architecten, 2007)

Figure 2-16: Kroeven complex 506 after refurbishment (Bol, 2010)

GENERAL INFORMATION

Location: Kroeven District in Roosendaal

Commissioner: Aramis AlleeWonen, Roosendaal

Design Complex 505: De Architectenwerkgroep Tilburg (DAT)

Design Complex 506: Franke Architecten bv Sliedrecht

REFURBISHMENT

Strategy

In the Kroeven area in Roosendaal, Aramis AlleeWonen decided to renovate 240 homes to make them passive houses (Bol, 2010). The row houses have two storeys with an attic.

There were two blocks, one of those blocks with 134 houses were designed by Architectenwerkgroep Tilburg (DAT) (complex 505) and 112 homes were designed by Franke Architecten (complex 506). To be able to meet the new EPC requirements and to lower the energy costs the building was renovated. But to keep the houses affordable, the energy costs had to be as low as possible, so there had to be a maximum energy performance, even better than normal new houses (Gulden Feniks, 2011).

The urban situation is improved by giving change in the one-sided building types, by making new buildings like apartments. New public spaces are made by demolishing some buildings and the line between public and private is redefined (DAT Architecten, 2007).

Facade structure

Complex 505

The total façade and roof has an Rc value of about 10m^{2}K/W (Bol, 2010). The old outside cavity wall and the complete roof is removed (Bol, 2010). New HSB elements with cellulose are placed against the inside cavity wall (Bol, 2010). The HSB elements are made prefab and are placed with window frames, roofs and rails for the stone (slate) cladding (Bol, 2010). The windows have triple glazing. The roofs have a PVC finishing. There is enough tolerance in the prefab elements, also for the window openings in the inside cavity wall (Bol, 2010).

Wooden window frames with triple glazing replace the existing window frames (DAT Architecten, 2007). The façades are stripped completely and a wood frame construction (with cellulose) is put on the outside, also the roof is replaced completely (Gulden Feniks, 2011). The cellulose isolation has an Rc value of 9m^{2}K/W (DAT Architecten, 2007). Complex 505 gets a slate cladding and complex 506 gets a plastered wall. The roofs are isolated with these panels as well (Gulden Feniks, 2011). The chimney and solar collectors are installed prefab (Bol, 2010).

Complex 506

The strategy of Franke is to keep both the inside and outside cavity brick wall. Outside of this new isolation of EPS Neopor is placed, with an Rc value of 9m^{2}K/W (Bol, 2010). Also in this case triple glazing is used. Also partly isolation of Kooltherm is used (Rc of 9.33 m^{2}K/W) and Vacuum Qasa isolation panels (Rc of 9,61m^{2}K/W) (Bol, 2010). Outside the isolation the façade is plastered.

The roof is isolated with prefab HSB panels with I-profiles, with cellulose isolation of 36cm (Rc 8.8 m^{2}K/W) and new roofing tiles are placed (Bol, 2010). Also here the chimney and solar collectors are installed as prefab elements (Bol, 2010).

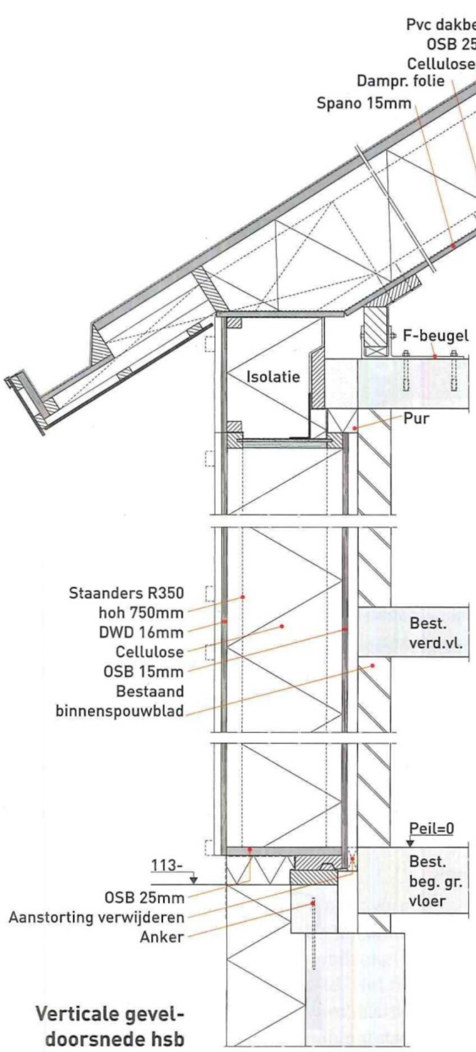


Figure 2-17: Vertical detail of the façade and roof of Kroeven complex 505 with HSB elements (Bol, 2010)

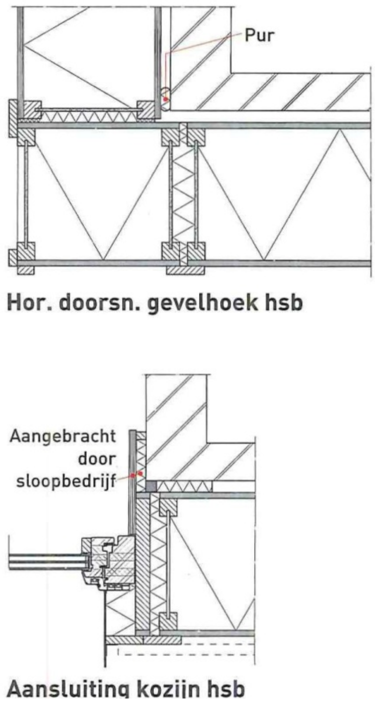


Figure 2-18: Horizontal detail of the façade of Kroeven complex 505 with HSB elements and triple glazing (Bol, 2010)

Figure 2-19: Kroeven 505 during refurbishment

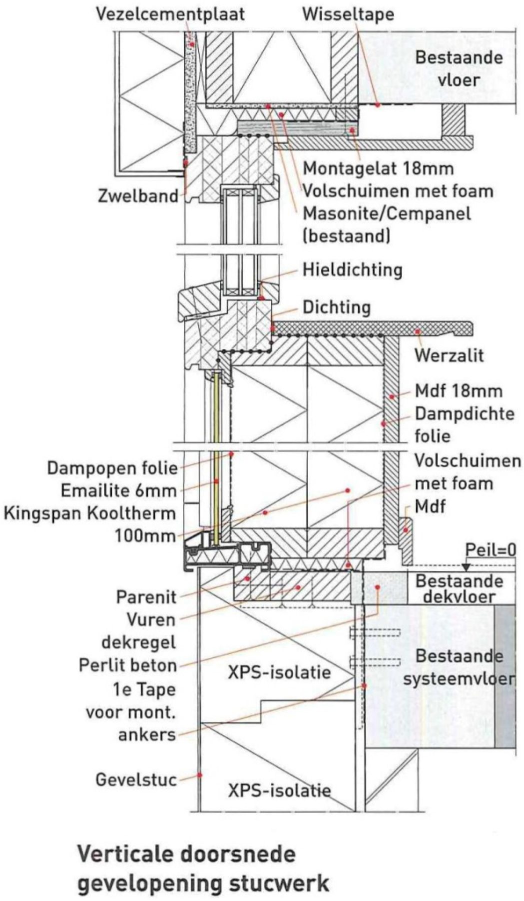


Figure 2-20: Vertical detail of Kroeven complex 506 at the façade opening (Bol, 2010)

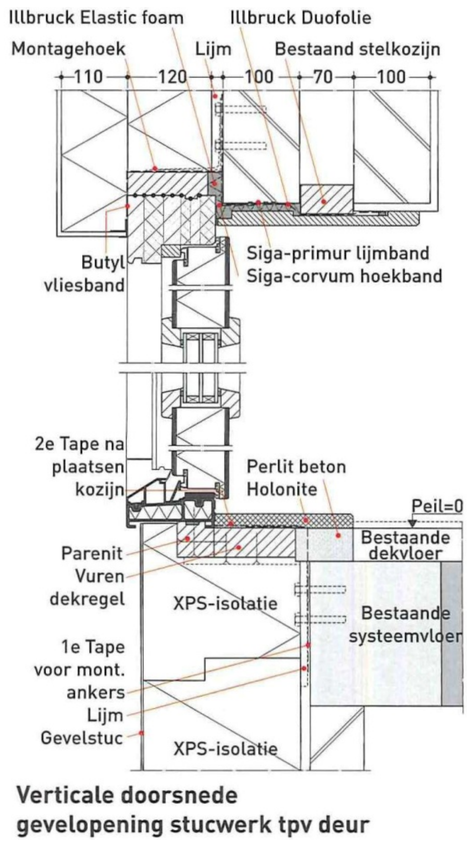


Figure 2-21: Vertical of Kroeven complex 506 at the door opening (Bol, 2010)

Construction

The existing construction of the building is load-bearing walls. The inner cavity wall of the façade is 100mm and the separating wall between houses is about twice as thick. These are not changed in the refurbishment, only the roof construction is removed.

Complex 505

The roof covering is supported by wooden purlins, which were not strong enough to carry the new HSB construction (Bol, 2010). This is why a new principal purlin was made to support the new HBS elements (Bol, 2010). The I-profiles inside the prefab panels replace the old wooden purlins (Bol, 2010). The foundation and the bottom of the ground floor slab are also isolated (Gulden Feniks, 2011).

Complex 506

The foundation and the bottom of the ground floor slab are isolated (Gulden Feniks, 2011). Like with complex 505 also HBS panels are used for the roof (Bol, 2010).

ENERGY PERFORMANCE

Installations

For both complexes a CV system is used and solar collector/boiler is placed (Gulden Feniks, 2011). Aquifers and a heat recovery ventilation system are installed (DAT Architecten, 2007).

Energy use

For both complexes the energy use for heating is reduced 75%, from 132kWh/(m^{2}a) to 25 kWh/(m^{2}a) and the total primary energy use (heating, warm water and electricity) is reduced from 368 kWh/(m^{2}a) to 133 kWh/(m^{2}a) (Gulden Feniks, 2011).

ENVIRONMENT

Materials and products used

Complex 505 (Bol, 2010)

They use a prefab system of HSB panels (wooden frame construction), with cellulose from VDM Woningen. On the outside there is a vapour open plate (DHF) and on the inside a vapour closed OSB-plate. The constructive I-profiles of wood make sure there are no cold bridges. With the Isofloc cellulose, with an Rc value of about 9m^{2}K/W make sure the change of warmth-leakage is very small. There is no vapour-open foil needed. Since cellulose is a natural material, it is very sustainable to use it and it has good fire-resistant properties (Ik leef groen, 2010).

Complex 506

An isolation package of EPS Neopor is used (Bol, 2010). Also Kooltherm is used, which is an environmentally friendly material with a NIBE certification from DUBO and also it has a good fire-resistance (Kingspan Insulation).

GENERAL

Layout

The layout of the floor plans does not seem to have changed in this situation, because there were only made changes on the outside. New construction was added in the roof, but for the rest all the additions were on the outside of the building so no floor space was lost.

People

Complex 505

Within 10 days everything can be done for the renovation per house, from the placing of the new walls to the finishing of the prefab construction (VDM woningen, 2012). Only one day the house needs to be open, to replace the windows and to replace the roof (VDM woningen, 2012). Within a week 4 houses can be given new HSB elements (Bol, 2010).

Complex 506

In one day a single house can be refurbished with the strategy of Franke.

Since in both complexes the roof was opened, and new windows were placed, people had shortly hindrance by the refurbishment, but since the process is so quick per house the people do not need to move out.

Costs

The total building costs were 2.5 million euro (excl. BTW) (Bol, 2010). The investment is around 100.000 euro, including installations, but excluding BTW (Debets, 2012) .

2.3.2 Koningsvrouwen Amsterdam (1938)

Figure 2-22: Old situation Koningsvrouwen (Archivolt Architecten bv, 2012)

Figure 2-23: New situation Koningsvrouwen (Archivolt Architecten bv, 2012)

GENERAL INFORMATION (Wind, 2011)

Location: Louise de Colignystraat/Charlotte de Bourbonstraat, Amsterdam

Original Design: 1932-1938 by G. Versteeg, commissioned by AWV.

Commissioner: Eigen Haard, Amsterdam

Designer: Archivolt Architecten bv, Amsterdam

Realization: 2010-2012

REFURBISHMENT

De monument "Koningsvrouwen van Landlust" in Amsterdam , build in 1938, was not up to the standards for fire safety, energy use, health and building type, therefore renovation was needed to make it better in these aspects, also concerning sustainability and by keeping the current outside appearance (Archivolt Architecten bv, 2012). The 243 "Portiek" homes that were renovated in this project were only 46m^2, which was normal for that time(Wind, 2011). In the 80's already a renovation was done, but this had a bad influence on the inside climate with moulds growing and there was asbestos in the sewer system (Wind, 2011). Eigen Haard gave the commission to start the renovation, with an aim to make it very energy efficient and comfortable (Wind, 2011).

Strategy

By using a "Box-in-box" strategy for the renovation the energy label changed to A++ (Archivolt Architecten bv, 2012). Sun shading (lamellas) were put underneath the balconies in the West (Archivolt Architecten bv, 2012).

The existing houses were small (46m^2), but for the renovation apartments were joined together to make them larger.

Façade structure

The Rc value of the façades are 4, and of the roof has become an Rc of 7, with a box-in-box strategy (Wind, 2011). This strategy was necessary due to the many cold bridges and due to the fact that the building is a monument outside insulation was impossible (Wind, 2011)The windows now have HR++ glass, with an U value of 1,2 W/m^{2}K (Feniks, 2011). Because of the insulation on the inside of the façade, now the heat and cooling accumulation became much lower, this is why overheating in the summer becomes an issue. This is why cooling in the summer became necessary, and why aquifers were used with heat pumps for storage of warm and cold storage in the ground (Wind, 2011).

In the façade 60mm pir-isolation is put inside the existing façade, with 50mm metal stud insulation extra on the inside, with a vapour REMMEND layer in between these two (Wind, 2011). Also around the window frame isolation was attached. A cavity was left between the old construction and the new insulation, to ventilate due to possible condensation there and the wooden floor construction was also extra treated with a saline solution to prevent rotting (Wind, 2011).

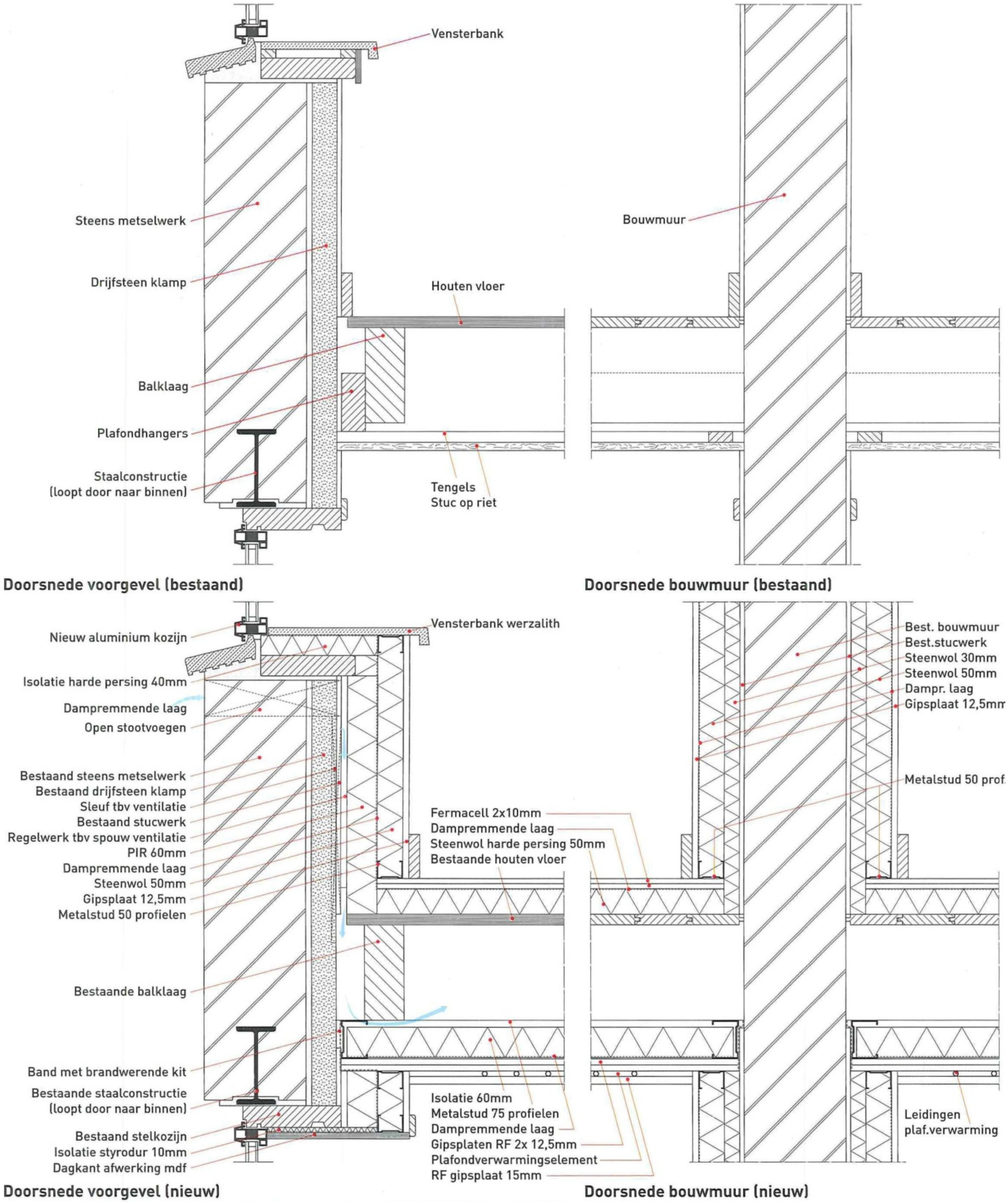


Figure 2-24: Details before (up) and details after (down) renovation, with outside façade (left) and inside separating wall (right) (Wind, 2011)

Figure 2-25: Sun shading in the new situation of Koningsvrouwen (Archivolt Architecten bv, 2012)

Construction

All the load-bearing masonry was kept, also due to the monumental nature of the building. The floors are made of a wooden construction. This construction was kept, bottom of the floor was removed and both the top and bottom were wrapped in insulation for the fire safety.

Upgrading acoustics & fire safety

For heating and cooling a climate ceiling is used, which is put underneath a package for fire safety and acoustic insulation (Wind, 2011). Also the floor was isolated by two plaster panels with mineral wool within (Wind, 2011). For the acoustic insulation, also the separating walls were insulated with 50mm metal stud with rock wool, which are not connected to the concrete walls due to extra 30mm rock wool (Wind, 2011). These metal stud insulation was also put in the façade (Wind, 2011).

ENERGY PERFORMANCE

Comfort

Before the renovation the indoor comfort was very bad, also due to mould growth in the building (Archivolt Architecten bv, 2012). Due to mechanical ventilation it can be assumed that this comfort will increase greatly. For heating and cooling with climate ceilings from 'Comfortplafond' are used, which work with radiation instead of convection, which does not cause draughts (Wind, 2011).

To avoid overheating also retractable sun shading was used on the balconies in the west (see Figure 2-25).

Installations

Before the renovation a collective High efficiency boiler was used for heating, which was replaced by a collective aquifer with an HR107 boiler (Feniks, 2011). Before there was no way to cool the building, but with the aquifer it is possible (Feniks, 2011). Before the renovation there was only natural ventilation possible, but this was improved to a balanced system (with heat recovery) (Archivolt Architecten bv, 2012). The pipes that were necessary for the comfort ceiling used for heating and cooling, were also integrated into the ceiling, so that all separate rooms can be regulated separately (Wind, 2011).

Energy use

The energy use for heating and cooling was lowered from 238kWh/m^2 to 40kWh/m^2, which is a G to an A-AA energy label (Feniks, 2011). The CO_2 emission reduced 78% from 20700kg/port./year to 4400kg/port./yr. (Feniks, 2011). PV-panels were put on top of the building for energy generation, which cannot be seen from the street (see Figure 2-26).

ENVIRONMENT

Materials used/products used

For insulation Rockwool was used mainly.

Figure 2-26: PV-panels on the roof of Koningsvrouwen (Archivolt Architecten bv, 2012)

GENERAL

Inside layout

Due to the integration of the comfort ceiling with the acoustic and fire safety insulation, the extra height needed for these parts were limited (Wind, 2011). But due to the high ceilings in this building the reduction of height due to these insulation panels was not a big problem (Wind, 2011).

Because of the fact that the apartments were very small, openings were made in the separating walls to join more apartments together (see Figure 2-27).

People

Due to the large changes made during the refurbishment all current residents would have to leave the apartments.

Costs

Total investment: 27.999.918 euro, per apartment 115.226 euro (Renda).

Figure 2-27: Floor plan before refurbishment (left) and after refurbishment (apartments in colour to the right) (Archivolt Architecten bv, 2012)

2.3.3 Acaciaplein, Gouda (1975)

Figure 2-28: Acaciaplein, old situation (Nationale Renovatie Prijs)

Figure 2-29: Acaciaplein, after renovation (Nationale Renovatie Prijs)

GENERAL INFORMATION

Location: Acaciaplein, Gouda

Commissioner: Mozaïek Wonen, Gouda

Designer: Topos Architecten, Waddinxveen

Floors: 6

Realization: May 2006

REFURBISHMENT

Mozaïk Wonen in Gouda commissioned the complex with 137 apartments in the Acaciaplein, from 1975, to be refurbished. The isolation was not up to the requirements, the ventilation possibilities were not enough and the materials of the façade were affected by the weather (De Vries, 2007).

The building had protruding balconies with wooden cladding, carried by HE-profiles (De Vries, 2007). The apartments are about $70m^2$ (Renda).

Strategy

Topos Architecten wanted to keep as many parts of the building as possible, not to give a whole new façade but to adjust the different parts, as to keep the current architecture (De Vries, 2007).

Façade structure

The closed façade parts were merely repaired, while the window openings were replaced and the roof was renewed (Renda).

The old (red) façade, which contained asbestos, were not up to date, and the rest of the façade was made of wooden window frames (De Vries, 2007). Also the current horizontal strip of glass in the façade was not fire safe, because of risk of flashover (De Vries, 2007).

New wooden window frames were placed (De Vries Kozijnen) and aluminium strips as window sill (De Vries, 2007). Red extruding window frames were used to give the same façade image as before with the red panels (De Vries, 2007). The balconies were merely painted over and not replaced.

Especially the roof was upgraded to an Rc value of 2.5, while the façade insulation is still quite thin (55mm). Due to the fact that this caused an extra layer on the roof, also the roof edge was heightened and a protruding part was made in some points of the roof to keep the façade protected more against the weather (De Vries, 2007).

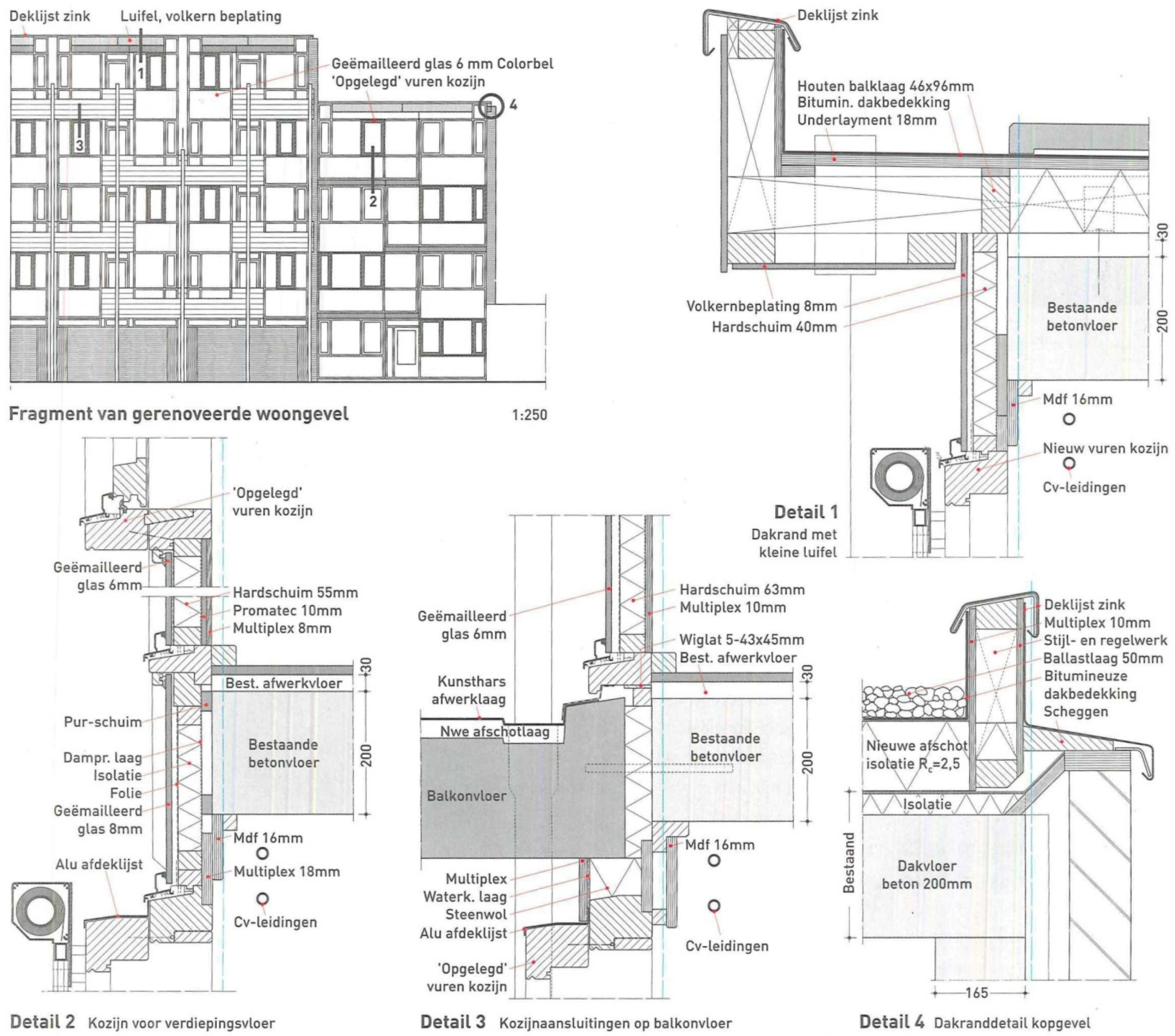


Figure 2-30: Details after the renovation of the Acaciaplein (De Vries, 2007)

Construction

The old construction was not changed, neither was the construction of the old balconies (De Vries, 2007). The concrete floors were quite thin (200mm for 5,7meter span), which caused the bend 3 to 4 cm and also the balconies were bend, so the water could no longer be drained well (De Vries, 2007). A new layer was put on the balcony to restore the right slope (De Vries, 2007).

Upgrading acoustics & fire safety

Extra attention was put in the redesign for fire-resistance, thermal insulation and acoustic insulation between the different apartments (De Vries, 2007). The outer façade is made out of different layers to make sure the acoustics are better and to meet the requirement to prevent flashover, together with 55mm of insulation made of resol hard foam.

GENERAL

Inside layout

The inside layout was not changed.

People

The façade replacement could take place in one day per apartment (De Vries, 2007)

Costs

3.700.000 Euro (excl. BTW) (De Vries, 2007)

Investment of 27.000 euro per apartment (Renda)

2.3.4 Prinses Beatrixlaan, Voorburg (1962)

Figure 2-31: Prinses Beatrixlaan old situation (Van Bokhoven, 2009)

Figure 2-32: Prinses Beatrixlaan, new situation (Van Bokhoven, 2009)

GENERAL INFORMATION

Location: Complex 1018 Prinses Beatrixlaan, Voorburg

Commissioner: WoonInvest

Designer: Overeem Architecten bv, Rijswijk (Jan Overeem)

Floors: 5

Realization: November 2006-Juli 2008

Residences: 3 blocks, in total 109 apartments

REFURBISHMENT

Strategy

Because WoonInvest wanted to upgrade the portiekflats in the Prinses Beatrixlaan, for older people to be able to life there in the future, a complete new layout was needed to allow new elevators to be installed. A choice was made to make a gallery entrance instead of a portiek. Also complete upgrade of insulation was done, replacement of the façade cladding, improving installations, replacing the existing windows.

Façade structure

The first step in the refurbishment was to remove the current window frames and replace them with HR++ glass made of FSC wood and some of plastic (except for the window where later the entrance would be placed). After that the isolation and ceramic façade tiling were installed. In the end the gallery construction was placed. After installing this gallery the last window was replaced to be made a door towards the gallery. Also the roof has gotten new insulation and roofing material (Van Bokhoven, 2009).

Construction

The new gallery construction and new enlarged balconies were made from a steel construction, with one steel column and an attachment to the façade (Wind, 2008). For the balcony floors prefab concrete slabs were used (Van Bokhoven, 2009)

The room the staircase first use to be had to be transformed into a bedroom. Wooden flooring was used for this (Wind, 2008)

Upgrading acoustics & fire safety

No changes could be made to the internal acoustics, because the height and size of the rooms was not enough to place insulation (Wind, 2008). Especially with the newly improves façades, the inside noise might be experienced even more by the residents than before (Wind, 2008).

Figure 2-33: New situation Beatrixlaan, new elevators between buildings (Van Bokhoven, 2009)

ENERGY PERFORMANCE

Installations

The old individual CV-systems were removed to install a collective heating and warm water system with solar collectors (Wind, 2008). Mechanical ventilation was installed in the apartments (Van Bokhoven, 2009).

Energy use

The refurbished building has an EPC of 0.98, with façades and roofs of 3,5m²K/W. The energy label went from F to A (Van Bokhoven, 2009)

ENVIRONMENT

Materials used/products used

The wooden window frames were made with FSC wood, which is a certification that the wood comes from a forest that is responsibly managed.

Reusing and recycling

Recyclable plastic frames were used for a part of the new windows (Wind, 2008).

GENERAL

Inside layout

Inside the kitchen, shower and toilet were replaced (Van Bokhoven, 2009). Because the portiek was removed, and a gallery was added, it was possible to add an extra bedroom where the staircase was in the old situation. Where first was the bedroom, now is the entrance hall.

The residents chose for a gallery that was slightly away from the façade, so people would not walk past their windows directly, which is also a better solution considering entrance of daylight (Wind, 2008).

3 New elevators were placed at the new galleries (Van Bokhoven, 2009).

Figure 2-34: Prinses Beatrixlaan, old floor plan (Van Bokhoven, 2009)

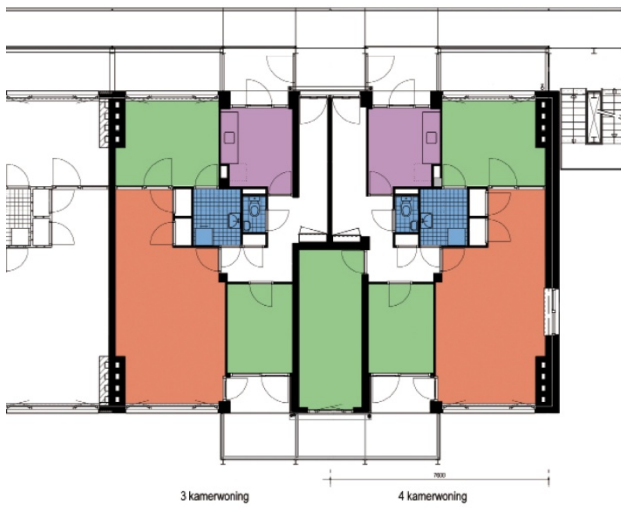


Figure 2-35: Prinses Beatrixlaan, new floor plan (Van Bokhoven, 2009)

Figure 2-36: New situation Beatrixlaan, balcony construction (Van Bokhoven, 2009)

People

First the new gallery staircases were built, so that the residents could enter their homes from that side. After that, it was possible to built new (wooden) flooring where the staircase had been. The objects could be then moved to the newly made bedroom. At that point new doors could be placed where the old bedroom had been (Wind, 2008).

By choosing this building order, it should have been possible for residents to keep living there. If the decision was made to demolish the building, maybe only 10% of the previous residents would have come back to live there (Van Bokhoven, 2009).

Costs

9.850.000 euro (excl. BTW) (Wind, 2008)

Per apartment (incl. BTW) 80.900 euro (Van Bokhoven, 2009)

2.3.5 Conclusion Example studies

Summary

Building name	Kroeven (Complex 505) (end of 60')	Kroeven (Complex 506) (end of 60')	Konings-vrouwen (1938)	Acaciaplein (1975)	Prinses Beatrixlaan (1962)
Building picture					
Number of residences	134	112	243	137	109
Problems	High energy use	High energy use	High energy use, fire safety, health (moulds)	Bad insulation, ventilation and materials façade (asbestos), fire safety	New layout needed for elevators and high energy use.
Strategy	Remove outside cavity wall and use prefab panels on façade. New roof. Insulate foundation.	Keep the current walls, and put new insulation in front of it. New roof. Insulate foundation.	Keep outside appearance, sun shading, join apartments together, inside insulation	Many parts repaired, replace window openings, roof renewed.	Change from a portiek flat to a gallery flat. Upgrading installations, insulation, installations, and windows.
Façade	Prefab HSB elements. Triple glazing. Stone cladding.	EPS insulation. Triple glazing. Plaster on outside façade.	Inside insulation 60mm PIR and 50mm Metal stud, HR++ glass. ventilated floor and between insulation and wall.	New wooden window frames, balconies only painted. New roof insulation. New cladding in some parts.	New window frames HR++ glass. Isolation and ceramic tiling. New gallery places. New insulation on roof and new roofing material.
Construction	Only changes to roof, extra reinforcement needed. Remove current purlins.	Only changes to roof, extra reinforcement needed. Remove current purlins.	Masonry kept, wooden floors kept mostly.	No changes, sagging of floor so slope was restored.	New steel construction needed for balconies and gallery on columns and existing wall. New floor needed due to change in layout.
Materials	HSB elements: Cellulose insulation, wooden frames. High Rc value (9). HSB for roof.	EPS insulation. High Rc value (9.6) Qasa and Kooltherm insulation panels. HSB for roof.	Rc of façade is 4, roof Rc is 7. Glass has U value of 1,2.	Rc roof 2,5, façade insulation only 55mm.	FSC wood used for window frames. EPC of 0.98, façades and roofs Rc of 3.5. Recyclable plastic window frames.
Acoustics & fire safety	No changes	No changes	Upgrade by insulating walls and floors.	Extra fire safety and acoustics of façade.	No changes acoustics, still bad.
Installations	CV system with solar collectors. Aquifers with heat recovery ventilation.	CV system with solar collectors. Aquifers with heat recovery ventilation.	Sun shading, aquifer and HR107 boiler, heat recovery ventilation, PV-panels	Unknown.	Collective heating and warm water, solar collectors. Mechanical ventilation.
Changes inside layout	No changes	No changes	Complete upgrade inside and changes to floor plans, bigger apartments.	No changes	Kitchen, shower and toilet replaced. Staircase and bedroom change place. New elevators.
Impact on residents	Only few days nuisance. Can keep living there.	Only few days nuisance. Can keep living there.	Had to move, but could come back.	Only few days for replacing windows.	Could stay living there with good planning.
Label, energy use or reduction CO_2	75% reduction energy use. Primary energy use from 368 to 133 kWh/ (m^2a).		Energy label G to A++. CO_2 emission reduced 78%, to 4400 kg/port/yr.	Unknown.	Energy label from F to A.
M^2 per residence	Unknown	Unknown	46m^2 (old layout)	70m^2	Unknown
Costs total	2.500.000 euro (excl. BTW)		27.999.918 euro	3.700.000 euro (excl. BTW)	9.850.000 euro (excl. BTW)
Costs/residence	100.000 euro		115.226 euro	27.000 euro	80.900 euro

Conclusions

-Changing the layout inside (new kitchens and bathrooms and joining apartments) is much more expensive

-Façade refurbishment in combination with more sustainable installations like heat recovery ventilation is often done

-With monuments inside insulation is done, but this causes problems with overheating in the summer and extra ventilation is needed.

-Not often the construction is adjusted, except when floors are added or when there is damage.

-Possible for residents to keep living in the apartment when it is well planned and no changes are made to the inside layout.

-Less drastic strategies for terraced houses, compared to flats (here for example larger balconies are added and elevators).

2.3.6 Choice building type and period for case study

Building period

Until 1945 most energy can be saved with refurbishment in houses. The problem with these types of houses is that often they have a monumental status.

From 1945-1974 many buildings were made that are now in urban problem-areas, due to fast development after the war. Often refurbishment gives them extra positive impulse in the neighbourhood. From 1965 untill1974 the energy performance is a bit better than 1945-1964, but there is still a lot of room for improvement. The period from 1945-1974 will be the period that will be examined.

Housing type

Detached houses:

- Difficult to improve easily on a large scale, because detached houses are often unique.
- More improvement possible concerning environmental impact
- Often not in an urban problem area, so refurbishment is mainly for energy-performance, not for social improvement
- Most energy and material environmental costs per m^2.Large part of costs are the materials of the façade.
- 14.2% of the residential building stock is a detached house.

Row houses:

- Refurbishment possible on a large scale, more houses in one time
- Sometimes can be in problem areas, so social impulse is needed
- Less possibilities for strategies (extra balconies are for example not necessary, no double façade needed etc.)
- Over 41.8% of the residential building stock are row houses

Portiek flats:

- Refurbishment possible on a larger scale, more houses in one time possible
- Often in problem areas, so social impulse is desired. More often renovation in flats.
- Often more possibilities for strategies due to more storeys (extra outside space, double facades etc.)
- More difficulties due to load-bearing construction
- Environmental costs of the façade are a smaller part of the total environmental cost.
- About 26.5% of the residential building stock is flat (gallery, portiek and others) and portiek with 12.5% has the most houses of the types.

Conclusion

By this summary of the research, the following question can be answered:

5. What type of building should be used for the case study?

Detached houses have the highest potential to improve energy use by embodied energy, but since every house is different, refurbishment on a large scale (multiple residences at the same time, with the same façade construction) and representing a large part of the building stock is difficult. In contrary to apartments, detached houses are more often owned by separate parties (not rented out by a housing company) and are therefore more difficult to refurbish on a larger scale at the same time.

The fact that the material energy of the façade and roof is higher with row houses than with flats (7.1% against 6.2%), means that embodied energy has a bigger impact on the total per household. The refining of the façade materials to have a lower embodied energy will therefore have a higher impact with row houses than with flats. But with row houses there are often more restrictions for refurbishment strategies due to the construction of the building types. With portiek flats up to 5 floors, which have "schijvenbouw" have more possibilities for different strategies.

A portiek flat needs to be found, with a construction that allows more adjustments to be made in the façade. Also this building should have a construction type that is representative for a large part of the total building stock, so the recommendations can be used in other refurbishment projects also. *Different materials or construction principles* in the façade are desired, to be able to broaden the research field. A building from the *period 1945-1975* has to be found, since these buildings often have a bad energy performance without the extra challenge of being a monument.

2.4 Materials

In this chapter the materials of façades will be examined concerning embodied energy and environmental costs. First definitions will be given. Also research will be done on embodied energy and environmental impact and how to lower these aspects for buildings. Finally other studies on the improvement of environmental impact will be examined, to see the influence of the embodied energy on the façade.

2.4.1 Definitions

The life cycle can be defined as consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (NEN-EN-ISO 14044, 2006)

Life cycle energy demand includes (Emmanuel & Baker, 2012):

- Embodied energy
  - -Initial embodied energy: Energy needed to produce the building initially (abstraction, processing, manufacturing of materials, transportation, and assembly on site)
  - -Recurring embodied energy: Energy needed to refurbish and maintain the building over its lifetime
- Operation energy:
  - Energy needed to operate the building (heating, cooling, lighting, power needed for appliances)
- Demolition energy:
  - Energy needed to demolish and dispose of the building at the end of its life

Embodied energy could be defined as follows: "The sum of energy input or work needed to make a product. Products with greater embodied energy usually have a higher environmental impact due to emissions and greenhouse gases associated with energy consumption. Recycled materials have lower embodied energy since they are not manufactured from raw materials" (Floyd, 2012).

The embodied energy is also described as Primary energy input by Hegger et al. (2008). The embodied energy can be measured as mega joule [MJ], and can also be called 'grey energy' (Hegger et al., 2008).

The global warming potential (GWP 100) [kg Co_2-eq] groups all greenhouse gases, which accumulate in the troposphere and lead to a temperature rise on earth, in relationship to the effect of carbon dioxide (considered over a period of 100 years) (Hegger et al., 2008).

Life cycle assessment (LCA) can be described as: "An evaluation of the environmental impacts of a building system (e.g. use of resources and environmental consequences) throughout its life cycle." (Floyd, 2012)

2.4.2 Embodied energy

The embodied energy can be reduced in the complete life cycle, by certain planning (see Figure 2-37) by maximising service lives, minimising materials flows, enabling further uses and maximising deconstruction options. This can be done by the choice of material, constructional design and construction.

Not only the embodied energy should be considered (which would result in a decrease in the use of materials), but also in combination with other measures, like using renewable materials, durable material, simple assemblies and comprehensive exploitation of material necessities (Hegger et al., 2008).

The primary energy input can be distinguished into two different consumptions: renewable and non-renewable energy consumption (Hegger et al., 2008). An example of a renewable raw material is wood.

In certain studies it is shown that the façade is a significant part of the total embodied energy (see Figure 2-38). The structure has the most embodied energy, which is often not removed with refurbishment. In Figure 2-39 the embodied energy of certain façade parts are shown.

2.4.3 Environmental impact of buildings

The embodied energy can be seen as part of the environmental impact. But the environmental impact also includes for example ozone depletion, global warming, eutrophication and acidification (NEN-EN-ISO 14025, 2010).

In his book, Crawford is describing a way to combine embodied energy theory with Life cycle assessment, to integrate it into a streamlined environmental assessment approach (Crawford, 2001). For improving the environmental performance of the built environment, with refurbishment also a few points can be taken into consideration, which can be seen in Table 2-14.

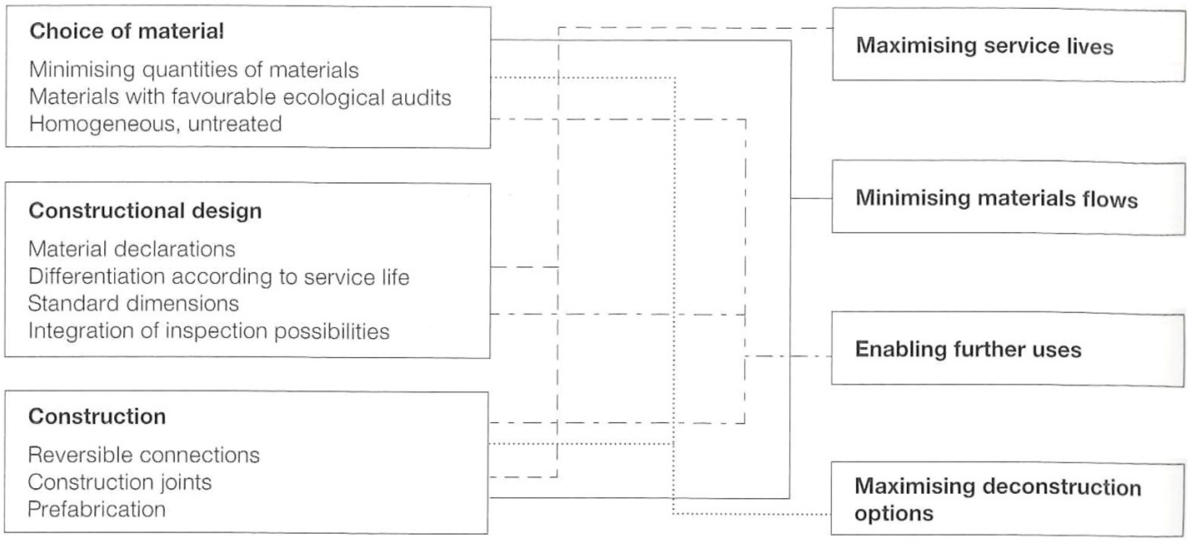


Figure 2-37: Themes for planning according to life cycles in order to reduce the embodied energy (Hegger et al., 2008)

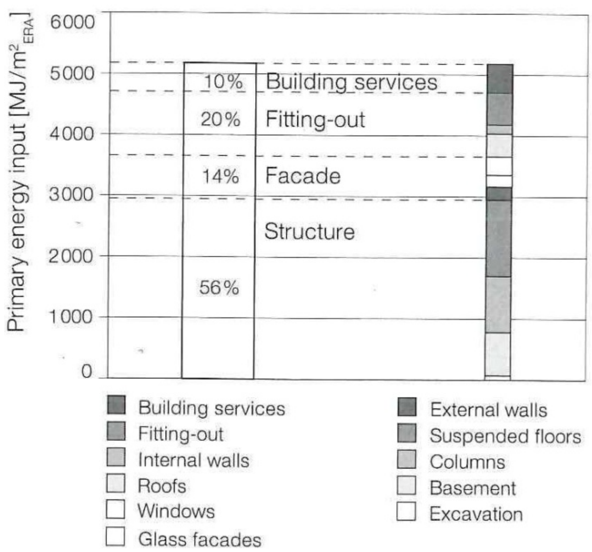


Figure 2-38: Primary energy input of the "Chriesbach Forum" according to building component groups (Hegger et al., 2008)

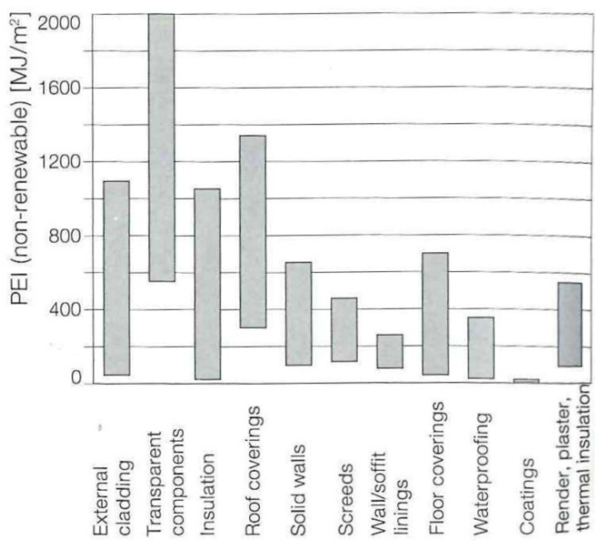


Figure 2-39: Primary energy input of various functional layers (Hegger et al., 2008)

Table 2-14: Own addition to the "strategies for improving the environmental performance of the built environment, based on Crawford (Crawford, 2001)

Strategy	Aim	Action
Resource efficiency	-Preservation of non-renewable resources -Sustainable consumption of renewable resources -Reduced waste production	-Improving thermal performance building envelope, by designing according to passive design principles (orientation, direct solar gain, artificial lighting, more energy efficient appliances -Upgrade manufacturing equipment to be more efficient, fewer raw materials and less energy and water
Minimize non-renewable resource use	-Preservation of non-renewable resources -Minimized emissions from energy production -Minimize impacts from processing, transportation	-Renewable sources of energy supply -Adapt/replace technologies and practices that rely on the non-renewable resources -Use naturally renewable resources sustainably so it's not depleted -Using local materials -Use of recycled or recyclable materials without compromising the overall performance of the building, by design for recyclability and disassembly
Minimize pollutant releases	-Maximized water, air and soil quality -Preservation ecosystems	-Minimize release of pollutants in every stage of the life cycle, acquiring, processes, manufacturing, disposing, landfill -Cleaner (industrial) production -Eliminating use in materials that result in pollutant releases in any stage of the life cycle.
Design for disassembly	-Preservation of natural resources -Maximized resource value -Reduced waste production	-Use fastening and joining techniques to ease disassembly -Minimizing weight of individual parts -Avoid composite materials, where separation of individual materials is difficult
Minimize (solid) waste production	-Minimize generation of waste associated with the built environment -Minimized landfill -Minimize soil and water contamination -Minimized resource value	-Recovery of waste materials by reuse or recycling -Designing in accordance with standards material dimensions -Waste management plan, controlling production and disposal of waste -Improving efficiency of manufacturing process, maximum raw material use
Design for recyclability	-Preservation of natural resources -Maximized resource value -Reduced waste production	-Make sure the building parts with a short lifetime can be recycled (like finishes) -Design building for easy separation for easy recyclability and reuse -Chose materials according to their recyclability or reusability performance
Design for durability	-Due to resource depletion, preservation of non-renewable resources -Reduce demand for raw materials, energy, water -Reduce waste production	-Long durability, while still maintaining their recyclability and reusability -No over-specification of materials, considering the intended life of the building -Durability depending on function -Good maintenance plan
Design for adaptive use	-Value of resources embodied energy in these elements can be maximized -Reduce demand of natural resources -Reduced demand for raw materials, energy, water -Maximize resource value -Reduce waste production	-Easily accessible service ducts and flexible internal configurations

2.4.4 Other studies

In a study for a Norwegian row house (Winther & Hestnes, 1999), for a very energy efficient house, the embodied energy of the building envelope only accounts for about 17% of the total embodied energy, and the technical installations accounted for 50% of the embodied energy (PV-system, heat pump, ground coil system). The rest was for the finishing. For this very energy efficient house, the total energy (embodied + operation) was much lower that for normal use of installations and insulation. Especially when buildings are made with a longer lifetime, the operation energy becomes more important. In this case, for a lifetime of 50 years the embodied energy was about 25% of the total energy use (see Figure 2-40). This makes the use of embodied energy for the building envelope only 4%.

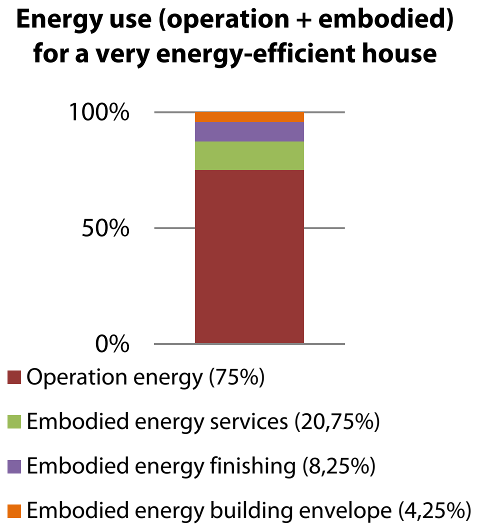


Figure 2-40: Energy use for a very energy efficient house, based on data from Winther & Hestnes (Winther & Hestnes, 1999)

The operation energy is the largest part of the energy use in a building, the embodied energy often only accounts for 10-15% in most cases according to Thormark (Thormark, 2002).

Studies have shown that there can be a division made in the embodied energy (Crowther, 1999). Approximately 5-13% is used on site to assemble the building. About 20-50% is used for the structure of the building. The remaining 50-70% is used for the building envelope, the fit out and finishes and the services. Studies have shown that due to refurbishment and maintenance, this energy can be 20-100% of the initial embodied energy. According to Crowther there are three ways to reduce the total energy consumption in the built environment:

- Reduce operation energy consumption by more energy efficient building and use of passive energy
- Reduce embodied energy consumption by use of low energy content building materials
- Reduce embodied energy consumption by reuse, recycling and remanufacturing of building materials

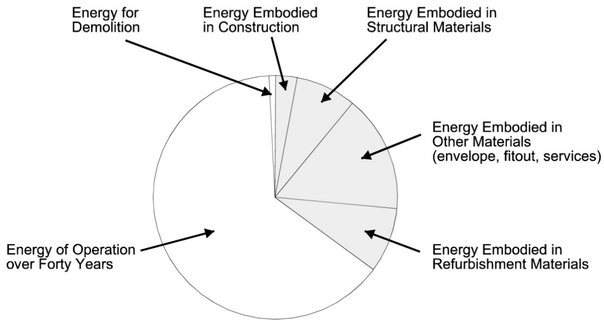


Figure 2-41: Total energy use over the forty year life of a typical office building, showing embodied energy as 30# of total energy (Crowther, 1999)

2.4.5 Tools for calculating the environmental impact

For this thesis there are three things that need to be calculated: Operation energy, embodied energy and environmental impact. The operation energy and embodied energy have the same unit (Joule) and can therefore be compared to each other. The environmental impact is also important for a complete picture of the life cycle impact. The tools to assess the environmental impact (and embodied energy) will be researched in this paragraph.

There are different methods to look at the environmental impact of materials in the Netherlands (Gommans, 2012): GPR-gebouw, Greencalc+, EcoQuantum, DuboCalc, Eco-install, BREEAM-NL. In foreign countries also other instruments are used (Gommans, 2012): LEED, SBTool, BREAAM. HQE, Athena, Energy Plus, Energy 10, SimaPro, Ecosoft, BEES, EPD, GEMIS. These instruments use different types of material databases, and therefore also the results from these different tools can differ, also because sometimes the system boundaries are defined differently (Gommans, 2012). A Dutch database is the NIBE's Basiswerk Milieuclassificatie Bouwmaterials (from the Dutch Institute for Building Biology and Ecology) (Gommans, 2012).

Greencalc

Greencalc+ could be used to calculate the environmental impact. Greencalc+ is a tool used in the Netherlands, and is also often used at the TU Delft. Greencalc is a computer program developed by NIBE and DGMR (Dutch consulting engineering firm), which can compare the environmental sustainability of buildings (Bunz, Henze, & Tiller, 2006).

Greencalc+ can make an assessment of the sustainability in three subjects: material use, water use and energy use, which can all be given in a score: the environmental index ("Greencalc", 2010). This way a conclusion can be made easily if the building is sustainable or not.
The following things can be derived with greencalc+:

Emissions:

- Global warming (CO_2 equivalents)
- Ozone depletion (CFC-11 equivalents)
- Humane toxicity (1,4-DB equivalents)
- Aquatic toxicity (freshwater) (1,4-DB equivalents)
- Terrestrial toxicity (1,4-DB equivalent)
- Photochemical oxidant formation (C2H4 equivalent)
- Fatty acid (SO2 equivalent)
- Eutrophication (PO4 equivalent)

Depletion:

- Biotic raw materials (mbp)
- Abiotic raw materials (mbp)
- Source of energy/fuel (mbp)

Environmental costs

In GreenCalc+ the environmental impacts and environmental effects are expressed in 'Environmental costs' ("Greencalc", 2010). These consist of 'shadow costs' and 'hidden environmental costs'. The costs are expressed in euro/money, as the money paid by society to make the environmental impact by those materials more sustainable.

NIBE

NIBE (Nederlands Instituut voor Bouwbiologie en Ecologie) is an initiator of Greencalc. Their book for façades (Haas, 2012) also uses LCA to determine the environmental impact for materials. This is easier to use in this research than the Greencalc program, because they give separate values for each material for the façade. They give the same values for emissions, depletion and environmental costs as Greencalc+.

LCA

The Life Cycle Analysis is used for the analysis in the environmental effects from NIBE for all the phases of the life cycle, from the cradle to the grave (NIBE, 2013). The LCA has the following steps (NIBE, 2013):

1. Goal and scope definition
2. Inventory of the environmental data
3. Impact assessment
4. Interpretation.

Bron tot Bron (B2B)

Since 2011 there is a new indicator added to the NIBE Basis work, to indicate how well a product fulfils to the cradle-to-cradle principle, expressed in percentages (NIBE, 2013). Especially the Material reutilization is useful to answer one of the research sub-questions about recycling and reusing.

There are different categories:

1. *Material Health*: In this factor the presence of certain harmful substances are examined, with the help of LCA, also the use of these substances for the processing of the materials. Also when the timber that is used is made from illegal cutting of trees this is taken into consideration for this factor.
2. *Material Reutilization*: In this factor the amount of recycled material counts for 1/3 and the amount that could be recycled at the end of its life is 2/3. Materials that are regrowable, like wood, are accounted as recycled materials.
3. *Renewable energy use*: The ratio between green and grey power is shown. The larger the factor is, the higher the use of green energy (for example wind and solar energy)
4. *Water Stewardship*: According to the limit value derived from the environmental value 'aquatic ecotoxicity of freshwater' these values are determined. This says how much water pollution the use of certain materials and products cause during their complete process, compared to other materials.
5. (*Social Responsibility*: there is no data yet available for this category)

2.5 Reusing and recycling

2.5.1 Definitions

Recycle and reuse of materials for façade refurbishment (Berge, 2001):

- Reuse: Reusing the whole component in the same function.
- Recycling: Smelting or crushing the component, after which it enters a new manufacturing process.

According to Floyd (Floyd, 2012), recyclable can be defined as: "a product's ability to be recycled after its useful life. Consideration should be given to the ease and accessibility of deconstruction and cost-effectiveness."

2.5.2 Other studies

In a study of a house (Thormark, 2000), Thormark looked at the embodied energy if the building that was made with a high portion of reused materials, and with completely new materials, with the use of LCA. She only looked at the primary energy use, not the operation use of energy. She showed that the environmental impacts were about 55% of the impacts if the materials had been new, mainly due to the reuse of clay bricks and roofing clay tiles. The total primary energy use was reduced to 60% of the case of new materials.

Current difficulty now to reuse building components is in separating materials and components. A solution would be to design for disassembly (Crowther, 1999).

3. APPROACH

In this chapter the approach that will be used for the case study is explained, which can be seen in Figure 3-1. This approach might also be useful for other refurbishment projects. The following sub research question will be answered with this design approach:

6. What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?

3.1 Steps of the design approach

In Figure 3-1 the complete design approach can be seen, with the four different steps and the parts that need to be done in these steps.

The first step in the approach is to analyse the building which is going to be refurbished. This can be done in different aspects, in this case: the context, building space, load-bearing structure, materials and detailing and building services. Also the current energy use can be calculated and a study can be done of the indoor comfort and the damages in the building. The current situation will be analysed, but also what plans the housing corporation Portaal, who owns the case study building, has for refurbishment. This case study analysis can be used to make a choice in building services and façade strategy.

The second step is to look at the building services possible. This can be analysed in different aspects: Ventilation, heating, cooling, lighting and electricity. Only the three first aspects are going to be researched in this study. By literature study the different possibilities for these aspects can be analysed. By making EPC calculations of different possibilities the best option of the building services can be chosen.

The third step in the design approach is to look at the façade. For façade refurbishment different strategies are possible. A few strategies that are best suitable for this case study will be chosen and the design of Portaal will be taken as another strategy. For each of these strategies a global design will be made.

For these strategies the best materials can be chosen, which is done by looking at different aspects: the R-value, the embodied energy that is needed for that R-value and the building and environmental costs. Depending on the desired design and the desired life span of the building, the best materials from this list can be chosen.

These materials can be implemented in the different facade strategies and per strategy the operation energy can be calculated with EPC or hand calculations. The embodied energy, environmental costs and building costs can be further analysed per strategy also. This way the best choice in strategy can be made. Perhaps a different strategy per facade part is best (the best strategy can be different for example for the roof than for the facade).

For all the different strategy possibilities the building services choice will be kept the same, so that the differences by the facade are more apparent.

Important to note is that the top corner apartment will be analysed for the second and third step. This way the energy use in the most extreme situation (most operation and embodied energy use) can be analysed. For the final design also the weighted average of all apartments will be calculated.

The conclusions from the building services and the façade strategies can be used to make the final refurbishment of the case study. Also variation studies will be made, to give a basis to the design choices for the final design. This will be done for building plans, glass percentage and glass type, thermal mass, infiltration, balconies and floor plans.

The final design can be compared to the current situation and Portaal's design. This will be done in different aspects: Embodied energy, Operation energy, Environmental costs and building costs.

Conclusions can be made from the designs, and recommendations can be given for other refurbishment projects, other designers and to the housing corporation Portaal. Also possibilities for future research will be examined.

After using this approach on the research and design, the effectiveness of this design approach will be assessed in the conclusions, Chapter 8. Also the points of improvement will be discussed.

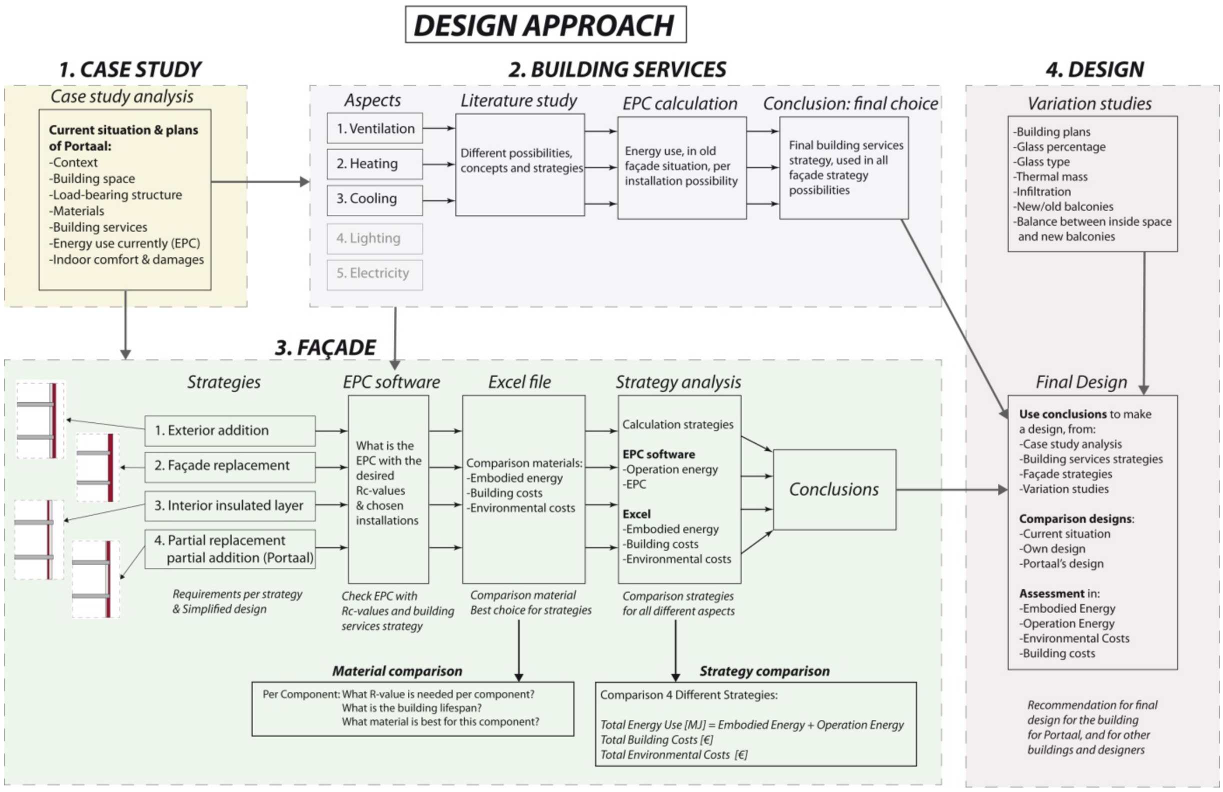


Figure 3-1: Approach steps for refurbishment

4. CASE STUDY ANALYSIS

In this chapter first an analysis will be made of the case study, the building owned by Housing Corporation Portaal, on the Marco Pololaan in Utrecht. After the analysis, research will be done on which Building services will be best suited for this building. Also possible façade strategies, which will be analysed in the later chapter, will be chosen.

4.1 Analysis current situation and plans of Portaal

The following chapter is divided in different parts for the analysis of the building: context, building space, load-bearing construction, materials and building services. These parts will be analysed as they are now in the current situation, but also the plans of Portaal will be analysed for each of these parts. Finally the current energy use will be shown in Energy Index and EPC, and the current indoor comfort will be assessed.

4.1.1 Context

Current situation

Building information

Location: Marco Pololaan, Utrecht

Build in: 1961

Function: Residential building

Storeys: 5 storeys, 48 apartments

Height : 13.8m, 5 floors

Living area: 3700m^2

Energy Label: G and F

The flat is situated in the city Utrecht, in the area Kanaleneiland. This area was built between 1954 and 1960. There were higher flats built in this area, but also combined with many terraced houses, green, water, roads and playgrounds in a repeating composition. Now there are also a lot of sporting possibilities, a mall and good public transport (tram). (Het wordt mooi, 2013)

The Housing Corporation Portaal has four (almost the same) flats in the Kanaleneiland South that they are planning to renovate in the coming years. The flat on the Marco Pololaan (see Figure 4-7) is the last on the list to be renovated. This building will be investigated further in this thesis.

Figure 4-1: Utrecht in the Netherlands

Figure 4-2: Kanaleneiland Zuid in Utrecht

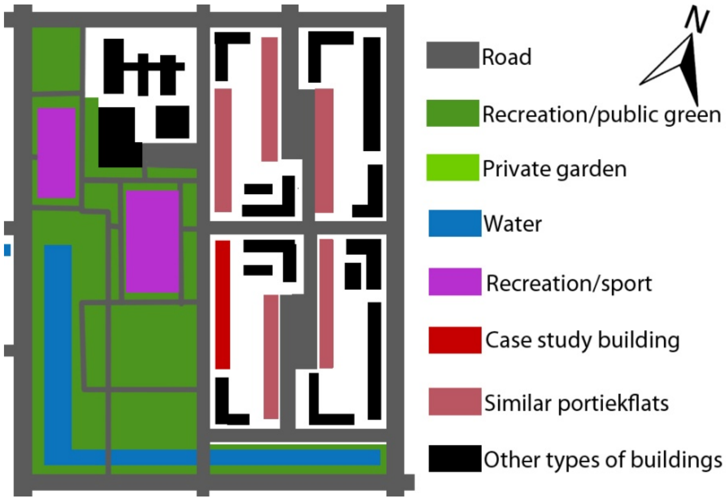


Figure 4-3: Analysis of the context of the Marco Pololaan (in red)

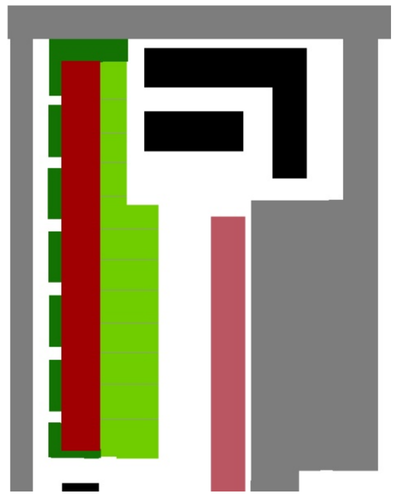


Figure 4-4: Zoomed into the Marco Pololaan

Figure 4-5: Front/west façade of the building (by author)

Figure 4-6: Back/east façade of the building (by author)

Figure 4-7: Context of the Marco Pololaan (in red), from Google Earth

Around the flat on the Marco Pololaan there is a lot of public green and water, with possibilities for recreation and sport. The flat is north-south orientated, which means that the rooms are on the East and West side. Next to the building itself there is part public green in the front, at the entrances. In the back of the building there are private gardens, for the residents that live on the ground floor and first floor (see Figure 4-4).

Future plans Portaal

Even though there are many good aspects of this neighbourhood (like the mixture of types of buildings and the green) the post-war neighbourhood Kanaleneiland needs to be renewed. The urban planning for this area now and in the future is to improve many of the buildings and also to break down and build new buildings for some parts. Especially the Housing Corporations in that area and the Gemeente (municipality) Utrecht are doing work to renew the area. New housing is being built and a new ROC school is going to be made. Also a new area for companies, new social facilities and houses are made. Another part of the renewal is to renovate the apartment buildings of the Housing Corporations. Also the current shopping centre is going to be renewed and expanded. (Het wordt mooi, 2013).

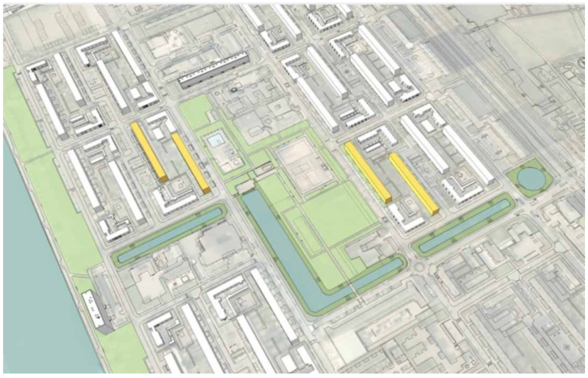


Figure 4-8: Plan for the renovation of 4 portiek flats in the Kanaleneiland (Portaal, 2012b)

In Figure 4-8 the Kanaleneiland South is shown. In this part of the neighbourhood there are many Intervam-flats, which are owned by the Housing Corporations Mitros (5 flats), Bo-Ex (4 flats) and Portaal (6 flats).

All these companies have different plans and aims for the renovation of their flats. The plans of Portaal will be examined further in the following chapters.

4.1.2 Building space

Current situation

In the building on the Marco Pololaan of Portaal there are different apartment types (see Figure 4-9). On the ground and first floor there are apartments that have two floors. They have rooms on the ground floor that also have private gardens, with their bathroom, kitchen and other rooms on the first floor. There are apartments there with either 5 or 6 rooms. From the 2nd to the 4th floor there are smaller apartments with either 3 or 4 rooms. The plan layout of all different types is shown from Figure 4-10 till Figure 4-13.

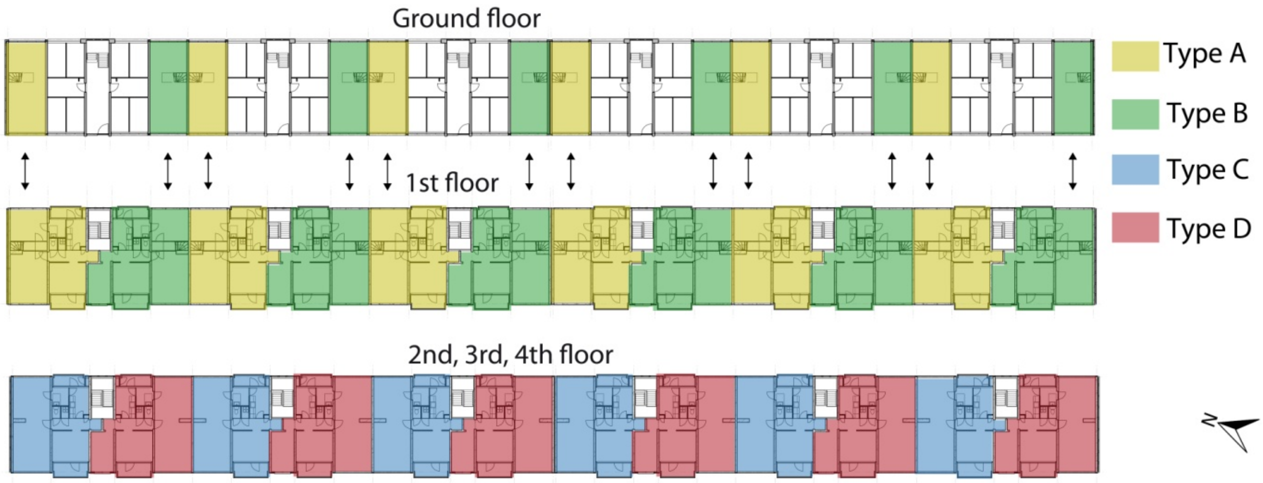


Figure 4-9: Apartment types in de Marco Pololaan (based on drawings of Portaal)

Table 4-1: Approximate living space area per apartment type

Apartment type	Nr. Of rooms	Total living space area	Amount of apartments
Type A	5	98,3m^2	6
Type B	6	107,7m^2	6
Type C	3	63,9m^2	18
Type D	4	73,3m^2	18
Total		3700m2	48

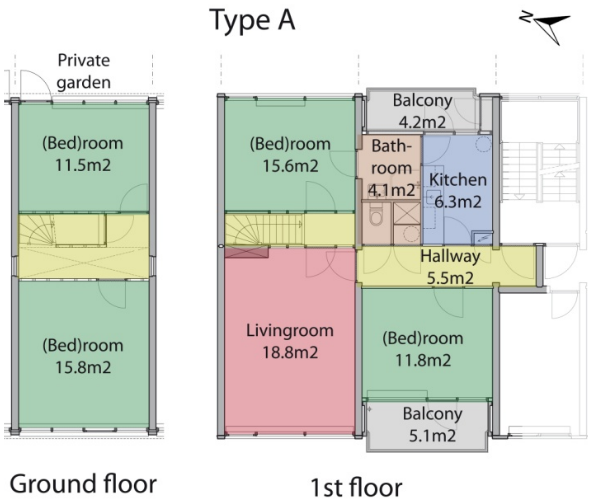


Figure 4-10: Apartment type A (based on drawings of Portaal)

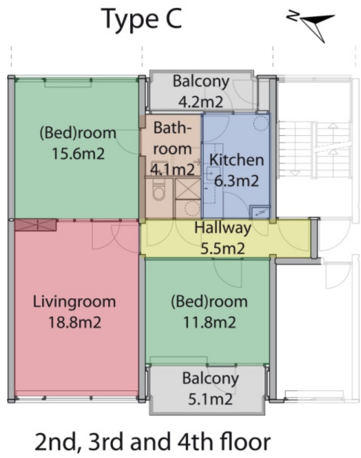


Figure 4-11: Apartment type C (based on drawings of Portaal)

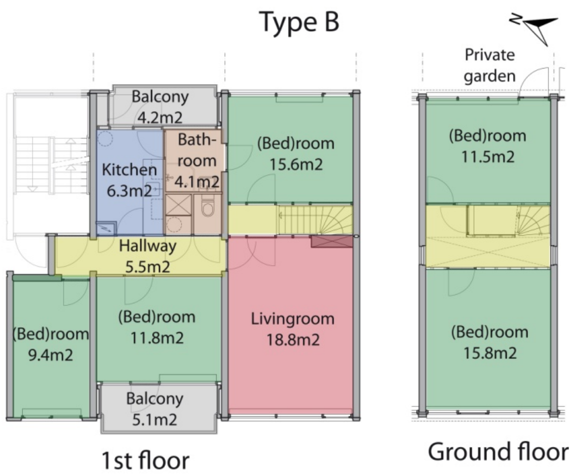


Figure 4-12: Apartment type B (based on drawings of Portaal)

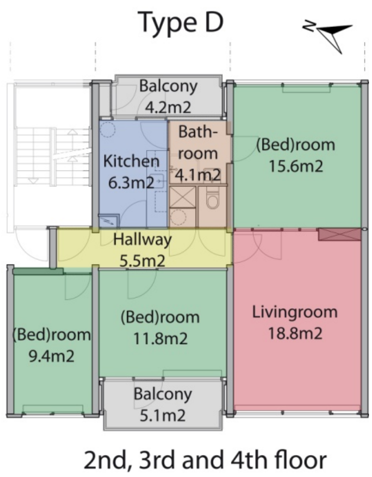


Figure 4-13: Apartment type D (based on drawings of Portaal)

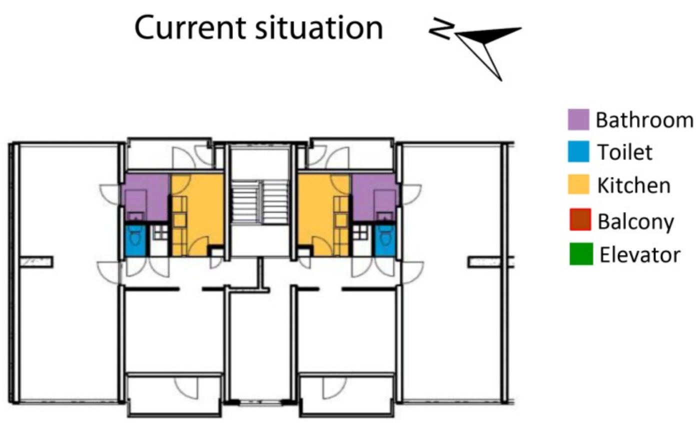


Figure 4-14: Part of the current floor plan of the case study apartments(Portaal, 2012a)

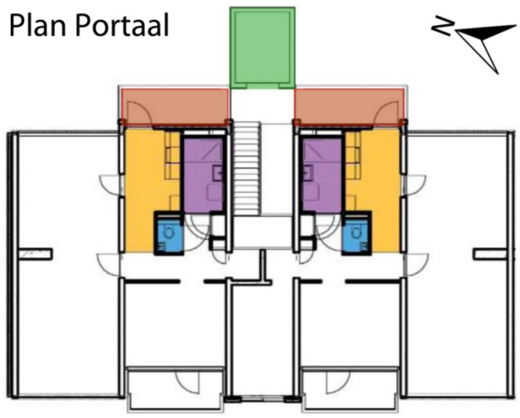


Figure 4-15: Part of the future floor plan of the case study apartment (Portaal, 2012a)

Future plans of Portaal

To make the apartments easily accessible for everyone, the plan of Portaal is to add elevators to the backside (east side) of the building. This means that 6 elevators will be added in one building, one for each block of a total of 8 apartments. On the back side of the building, apart from the elevators, also extra space will be added. The old balcony will be closed off with a new façade, and a new construction will be added for a new balcony. This means that the living area will increase a little, and the bathroom and kitchen can be made a bit larger. The placement of the kitchen and bathroom will be switched in position, as can be seen in Figure 4-14 and Figure 4-15.

4.1.3 Load-bearing structure

Current situation

The building has the Intervam building system, which was much used in Utrecht at that time. With the VAM building system, prefabricated elements were used for the construction. With buildings above 10 floors the stability was regulated by stability walls that had pre-tension (Van Elk & Priemus, 1970). Since this building is only 5 floors, not much attention was given to the stability.

Van Elk & Priemus give standard thicknesses of different elements of the buildings that were used. The load-bearing walls are between 18 or 20 cm, while the non-load bearing walls are 7 or 9 cm. The floors are made of 14cm thick reinforced concrete with a maximum width of 2.4 meters. The stability walls are either 16 or 22 cm thick and have a maximum width of 400cm. The separating walls between different apartments are 18, 23, 20 or 30 cm (Van Elk & Priemus, 1970).

In Figure 4-17 the load-bearing construction is shown in the floor plan. In red there are the load-bearing walls, which have a distance of 3.95 meters and 2.5 meters at the staircases.

The cross section in Figure 4-16 is taken at the black line in Figure 4-17. At that place there are large beams, which are there for the stability. The ground floor and the first floor are cast concrete, while the floors above that are prefabricated concrete.

In the future Portaal is not planning to make any changes to the current load-bearing structure. But they are planning to add a separate elevator and extra balconies, which have their own load-bearing construction with columns.

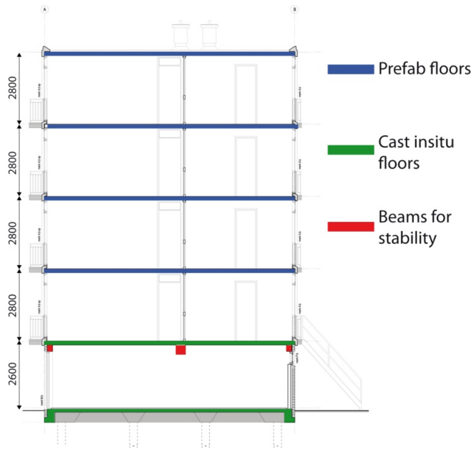


Figure 4-16: Structural cross section

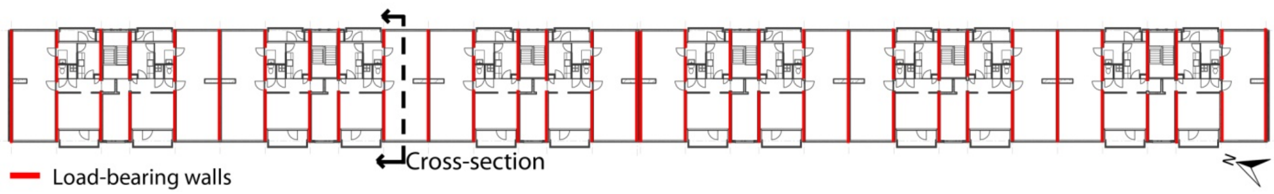


Figure 4-17: Load bearing walls of the Marco Pololaan building in a floor plan (based on drawings of Portaal)

4.1.4 Materials

Comparison to standard details Intervam

In Figure 4-18 and Figure 4-22 the details (based on the details that were given by Portaal) are shown and the standard VAM construction details are shown in Figure 4-19 and Figure 4-20. There are some differences in the materials, especially in the ground floor and the side façade where there is brick instead of prefab concrete. But apart from that, the way of connecting and detailing is very similar, with similar prefab elements. The window frames in standard details are made out of pine wood or hardwood (Van Elk & Priemus, 1970). Some parts of the bottom frame are made out of prefab concrete.

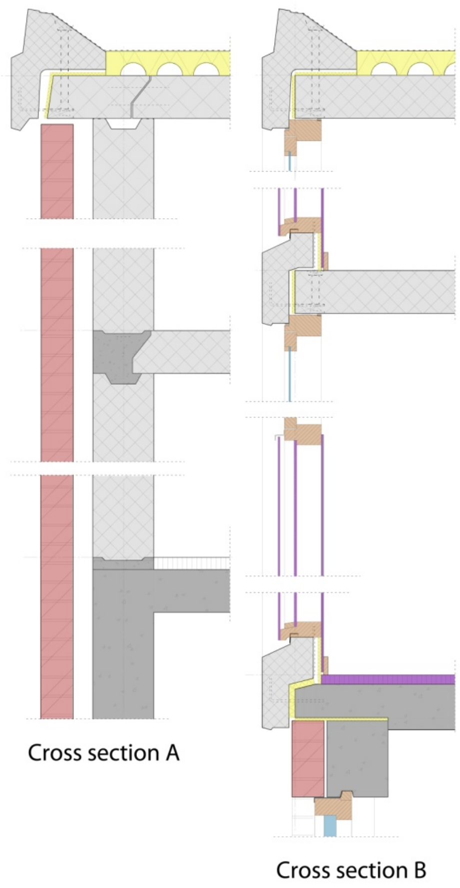


Figure 4-18: Details from the vertical cross section of the Kanaleneiland flats(based on the details of Portaal)

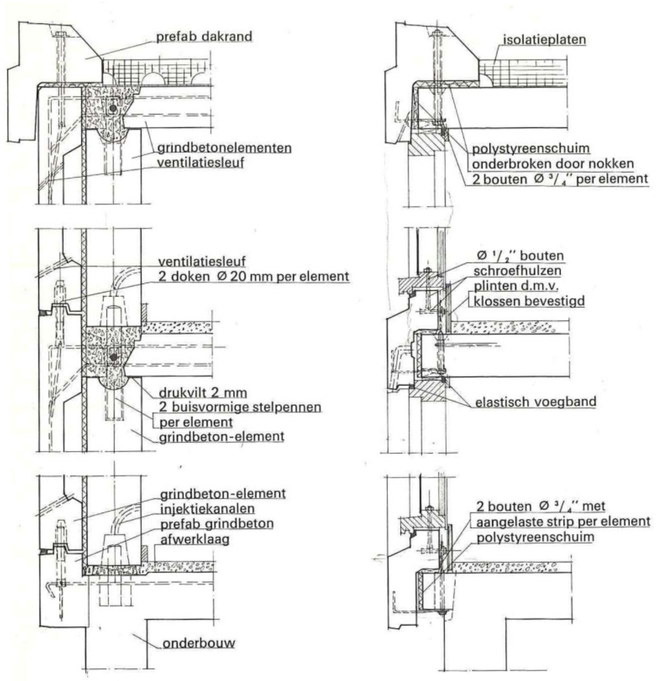


Figure 4-19: Standard vertical Vam details (Van Elk & Priemus, 1970)

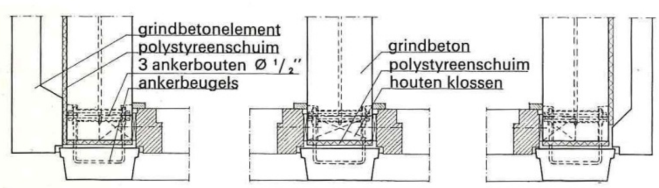


Figure 4-20: Standard horizontal Vam details (Van Elk & Priemus, 1970)

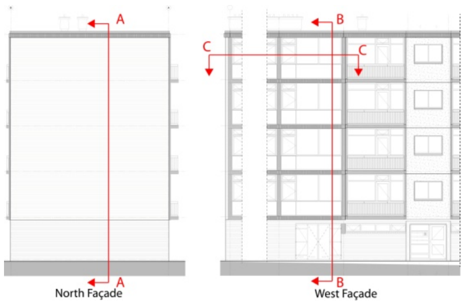


Figure 4-21: Place of the cross sections are shown in the North and West façade (based on drawings of Portaal)

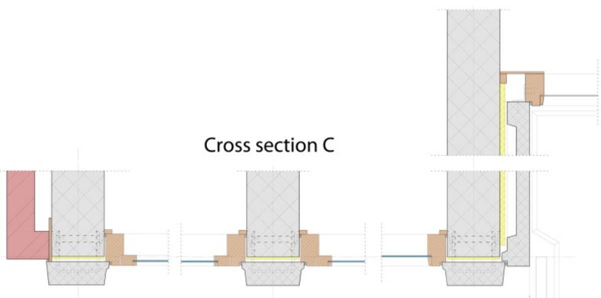


Figure 4-22: Details from the horizontal cross section of the Kanaleneiland flats(based on details of Portaal)

Figure 4-23: Part of the front/west façade of the portiekflat analyzed in façade materials

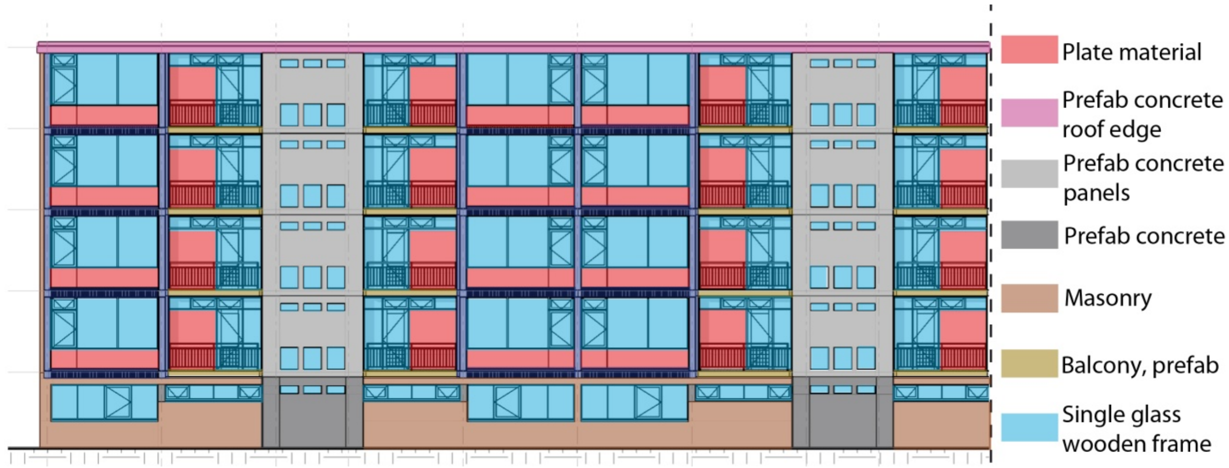


Figure 4-24: Part of the back/east façade of the portiekflat analyzed in the façade materials

Figure 4-25: Part of the current front/west façade, with placement of details (based on drawings of Portaal)

Figure 4-26: Part of the current back/east façade, with placement of details (based on drawings of Portaal)

Figure 4-27: Door at the balcony (by author)

Figure 4-28: Top of the window frame in the living room (by author)

Analysis existing façade

Current situation

In Figure 4-23 and Figure 4-24 the materialisation of the west and east façade is shown. All window frames are made of wood with single glass. The side façades (north and south) are made completely out of masonry, as well as the ground floors. The upper floors have prefab concrete panels and light plate materials.

Comparison details current situation to future plans of Portaal

In the following part the current details will be analysed, together with the future plans of Portaal. The top apartment is going to be analysed, since the apartment that is going to be used in this thesis is on the top floor. Details from other apartments on the lower floors are therefore not going to be analysed. In Figure 4-25 and Figure 4-26, part of the west and east façades are shown, with the details that are analysed further.

The elevation of a larger part of the building of the design of Portaal can be found in Figure C- 3, Appendix C.

Door & window frames

The door is made of wood, with partly glass inside a frame (see Figure 4-27). The window frames of the Intervam system are usually made out of pine wood or hardwood (Van Elk & Priemus, 1970). The quality of these window frames is still ok on this inside and outside, because the housing corporation has good maintenance for these parts (see Figure 4-28). But locally there are some damages, and there is draught due to cracks between walls and frames. A fixed value for wooden window frames is 0.1 W/m^{2}K.

The openable window frames are of the same material as the framing (see Figure 4-29 and Figure 4-30). Single glazing is used in the entire apartment of about 3-4 mm thickness. A standard U value for single glass is 5.8 W/m^{2}K (NEN 1068). The flashings present are made out of lead.

Roof

The roof is insulated with Schewill prefab insulation plates of 70mm (see Figure 4-29), which have hollow cores in them for ventilation. According to Van Elk & Priemus (1970) insulation was placed on the roof of insulated hollow core plates with at least a value of Rc=0.6, with a total Rc-value of the roof of 0.8, 1 or 1.5. Research from LBP Sight has shown that the roof is insulated with 70mm Schewill plates, which makes the Rc value of the roof 0.6 m^{2}K/W (De Jong & Versteeg, 9 december 2010).

Roof edge

The roof edge is made out of prefab concrete, and is attached to the prefab roof floor. Inside this roof edge there is 10mm polystyrene foam as insulation (see Figure 4-29).

Façade insulation

At most points there is a slight insulation used of polystyrene foam of 10 or 20mm between two different components. For example in the façade in Figure 4-29 and Figure 4-30 only 10mm insulation is used, but between the floor and balcony in Figure 4-32, 20mm insulation is used. In the cavity between the load-bearing wall and masonry wall there is no insulation used (see Figure 4-35).

Detail V1A

In Detail V1A the roof edge is going to be removed, as is the 10mm polystyrene foam. A new timber frame with insulation is added, with a prefab polyester concrete element to keep the current stone appearance. The openable window is replaced by a wooden frame with HR++ glass and ventilation by a Suskast. The Suskast ventilation systems have very good acoustic insulation. The insulation on the roof is kept, but an extra layer of 70mm insulation is added.

Detail V1B

Around the window frames and at the sides of the balcony walls, concrete elements are used as façade cladding (see Figure 4-30 and Figure 4-36). They are about 90mm thick and have 10mm polystyrene insulation. Behind the panels at the balcony there is 20mm insulation. They are attached to the load-bearing walls.

In detail V1B the prefab concrete elements are removed, together with the insulation, window frames and windows. Only the floor remains here. A new timber frame with plate material is added and wooden window frames again with a Suskast.

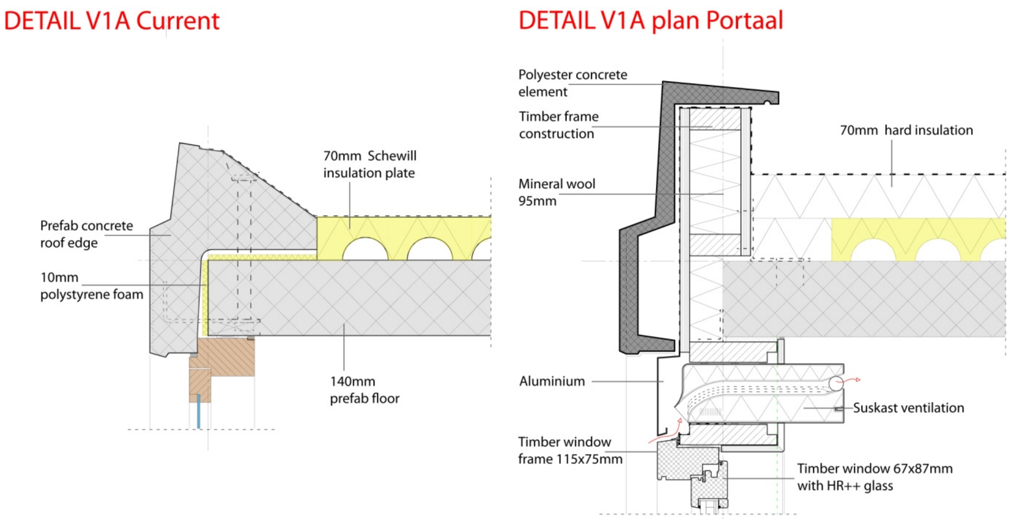


Figure 4-29: Detail V1A (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

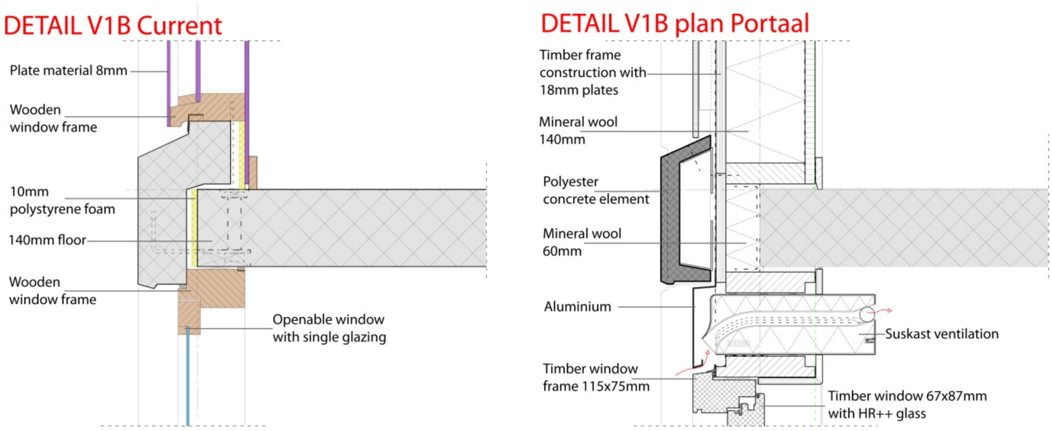


Figure 4-30: Detail V1B (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

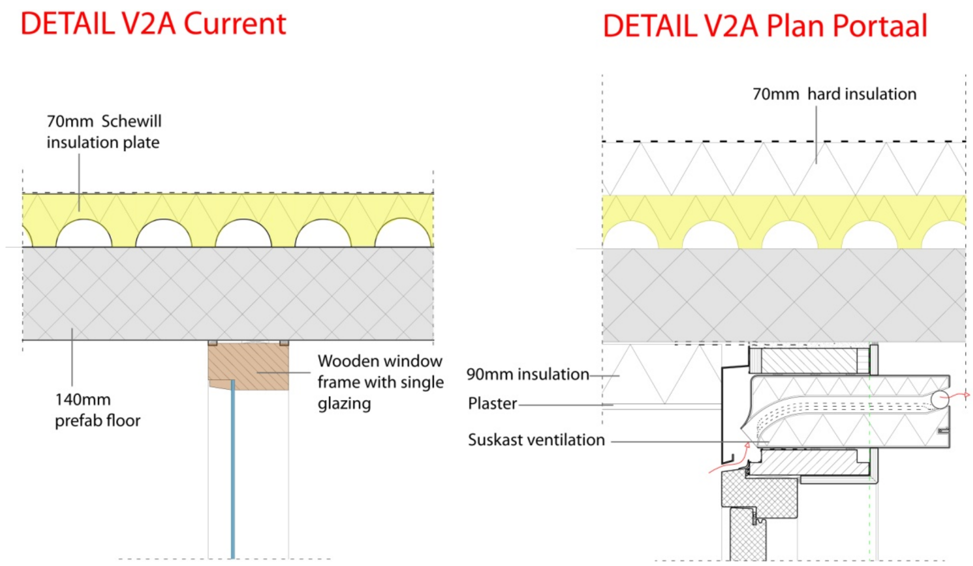


Figure 4-31: Detail V2A (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

Detail V2A

At the balcony, underneath the roof, the complete window frame is removed to be replaced by a wooden frame with HR++ glass and Suskast ventilation. This element is concealed by an aluminium plate.

Detail V2B

The balcony is put prefab into place, connected to the load-bearing walls on either side. In between the floor and balcony there is 20mm polystyrene foam (see Figure 4-32). At the floor it is attached with anchors.

At some parts of the façade, the parapet is made out of plate materials inside a wooden window frame (see Figure 4-32). In some situations these are three layers of plates and at the balconies there are only two layers. The panels on the façade of the living room and bedroom are not extra insulated, which makes those parts of the façade Rc=0.24 m^2K/W (De Jong & Versteeg, 9 december 2010).

Detail V2B

At the balcony in detail V2B, insulation is added above and underneath the element. The wooden frame is replaced by an isolated door with a plastic door step.

Detail V3A & V3B

Some parts of the façade are made out of sandwich panels, with insulation inside two layers (see Figure 4-33 and Figure 4-34).

The material of the façade with the VAM system is gravel concrete (grind beton). Usually the inside, underneath the window frame, is finished with a plinth. The sandwich panels are put prefab, connected on the sides to the load-bearing walls. They consist of 80 mm gravel concrete on the outside, 10mm polystyrene insulation foam in between and 60mm cellular concrete on the inside. These panels give many problems to the thermal comfort and problems due to condensation.

At some points in the façade (where there are sandwich panels used, see Figure 4-34) the window sills are made out of prefab concrete. These connect together with the sandwich panels.

At the parts where sandwich panels are used, in Detail V3A, the elements are kept. Panels with insulation and plaster are used in front of these. A polyester concrete sill is used between these panels and the roof edge.

The windows at the sandwich panels in V3B are removed and new insulation and plaster is used before adding the timber window frames with a polyester concrete sill.

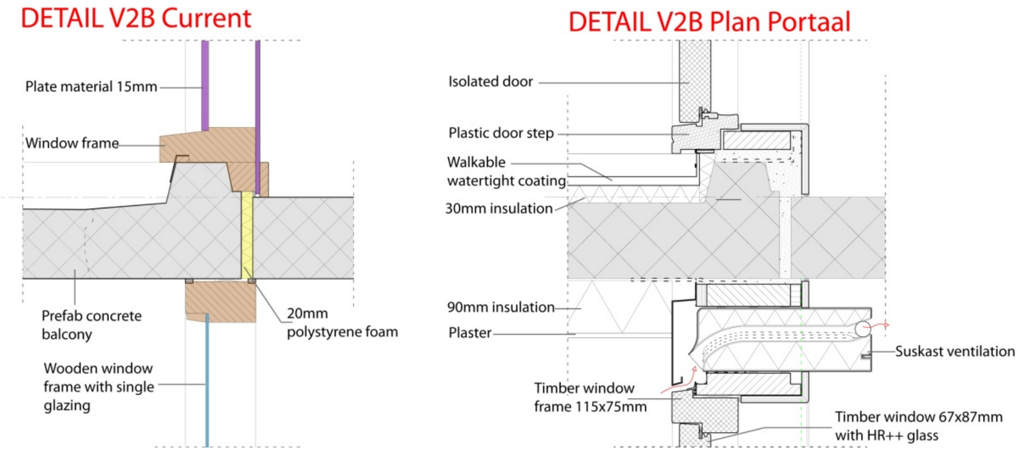


Figure 4-32: Detail V2B (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

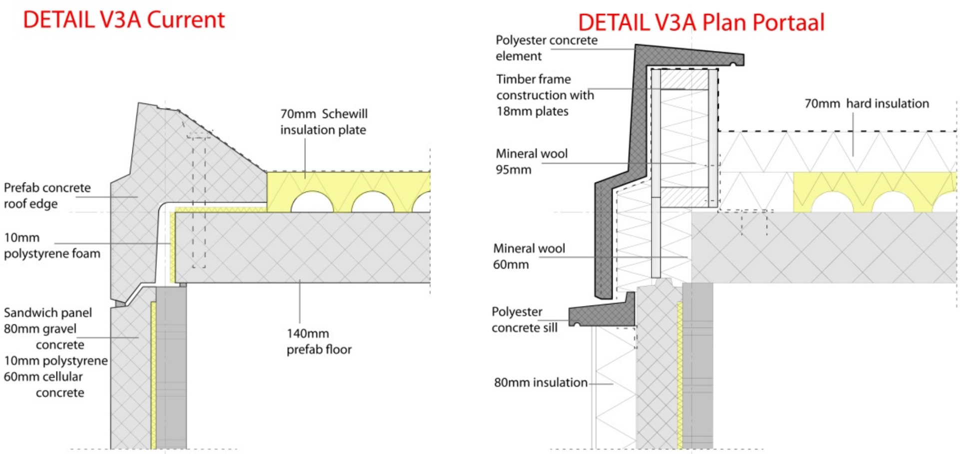


Figure 4-33: Detail V3A (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

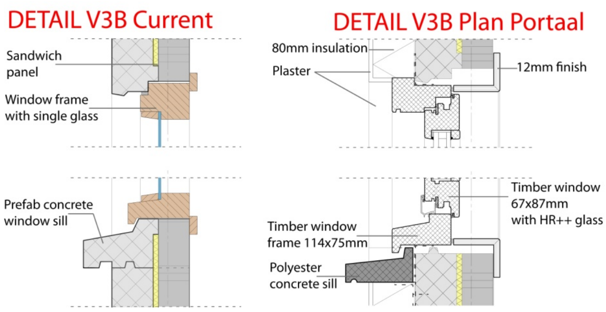


Figure 4-34: Detail V3B (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

Detail H1

On both side walls and on the ground floor there is masonry used as outside cavity wall (see Figure 4-35). The brick is 105mm thick and has a cavity of 65mm before reaching the prefab load-bearing walls of 200mm.

At the sides of the building the cavity between the load-bearing wall and masonry is filled with insulation, as can be seen in detail H1. The prefab concrete elements are removed and replaced by much thinner polyester concrete elements. This leaves room for insulation in between the wall and element.

Detail H3

In detail H3 the horizontal detail at the balcony is show. The concrete cladding element is removed there and replaced by insulation with plaster. The complete window frame is removed and replaced by insulation and HR++ glass in timber window frames.

Detail V4

In the east façade for a part the same strategy is used, except at the place of the balcony (see Figure 4-38). On this side the elevator is made, and an extra balcony is added. All materials are removed except for the floors and balcony, and a complete new timber frame and insulation is added. New columns are added for the new prefab concrete balcony.

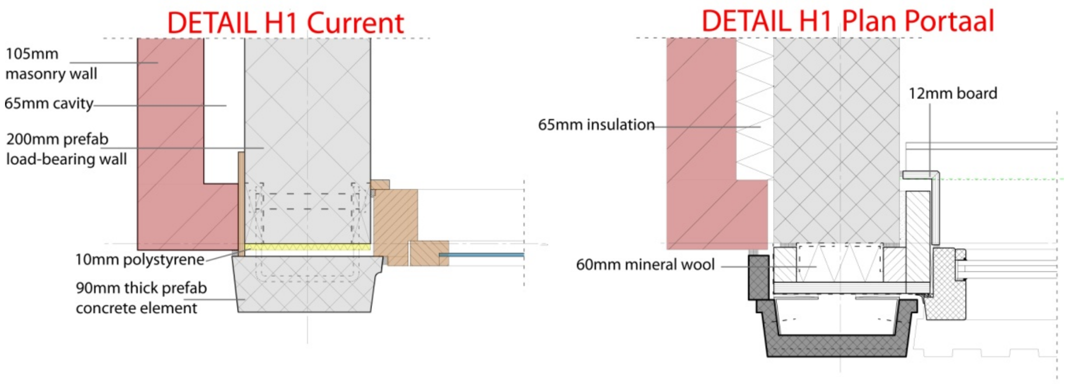


Figure 4-35: Detail H1 (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

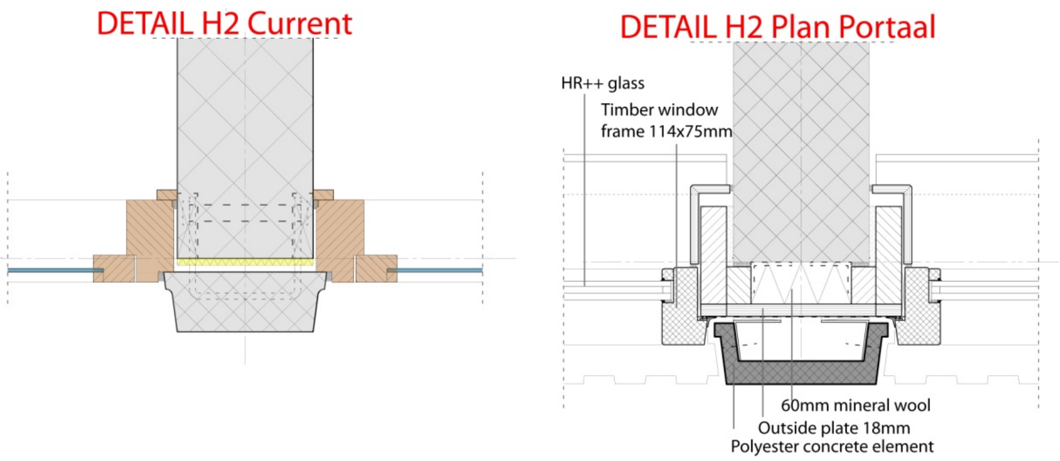


Figure 4-36: Detail H2 (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

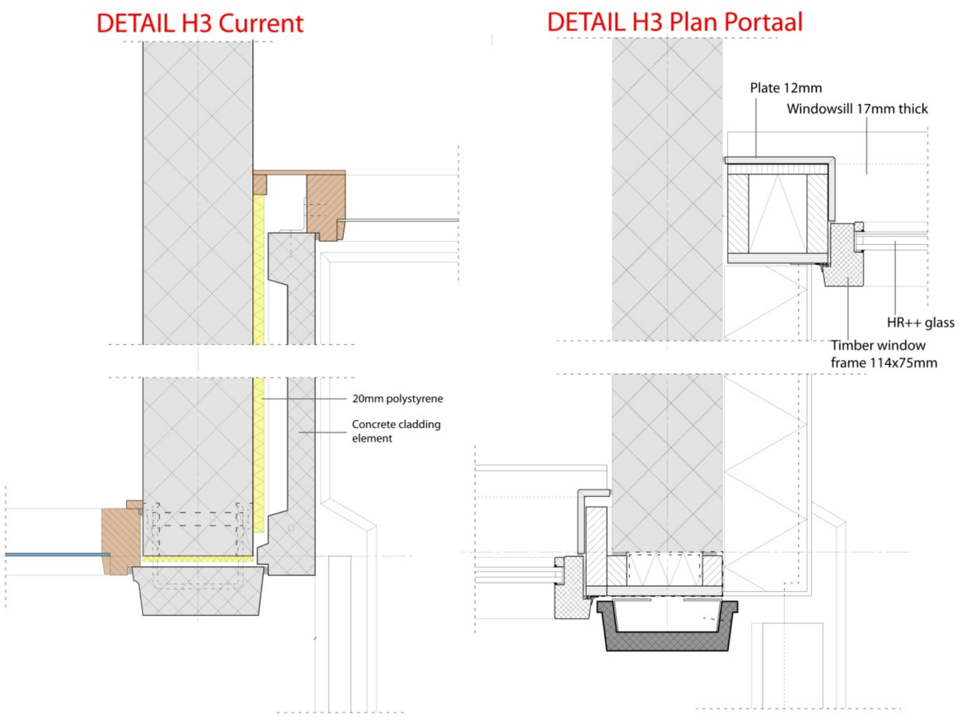


Figure 4-37: Detail H3 (based on drawings from Portaal), current situation (left) and as planned by Portaal (right)

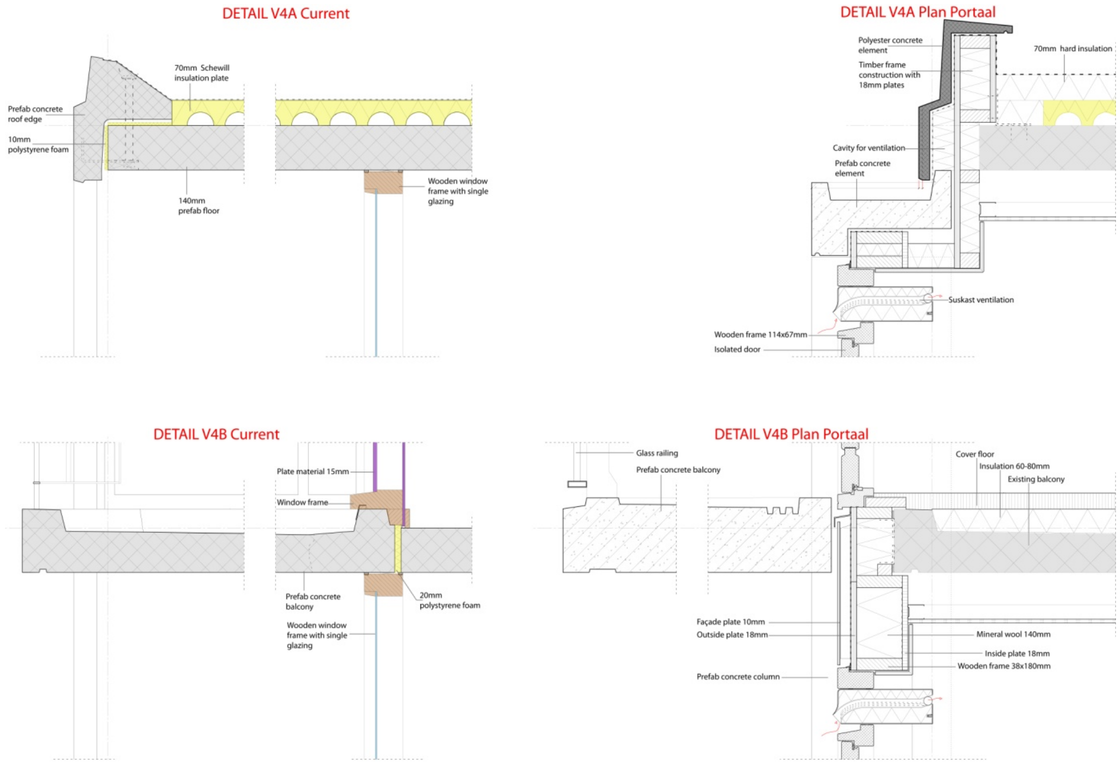


Figure 4-38: Details V4A and V4B on the east façade

4.1.5 Building services

Current situation

The heating in the buildings of Portaal is by district heating (by radiators) and the warm water is by an electric geyser (De Jong & Versteeg, 9 december 2010). Not all apartments have the same amount of radiators. The district heating has a efficiency of 173%(De Jong & Versteeg, 9 december 2010). But this efficiency cannot be used for the EPC calculation, because this has not been calculated in the standard way.

Future plans of Portaal

The company Climarad has given recommendations concerning ventilation and heating for the apartments in the Kanaleneiland. For the living room an automatic CO_2 and moisture control was recommended to be installed. Also in the bathroom and kitchen mechanical ventilation should be installed with pressure regulating suction ventilators according to Climarad. In the bedrooms there will be natural ventilation by grates.

In reality only mechanical exhaust in the kitchen and bathroom with new radiators in the rooms will be installed.

4.1.6 Energy Index

A research was made by LBP Sight, to look at the energetic properties of the VAM flats in the Kanaleneiland that are on the planning to be renovated. From this the following Energy Indexes were made for the building on the Marco Pololaan from Portaal, shown in a cross section of the building in Figure 4-39. Since the right top apartment (type D) has the worst EI value of 3.28, this apartment will be used further in this research.

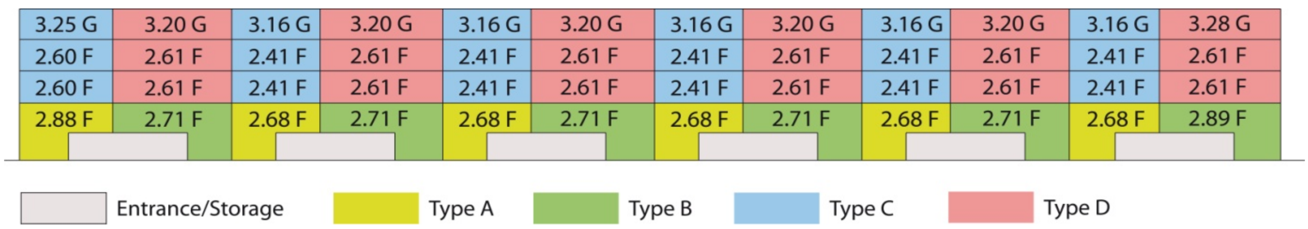


Figure 4-39: Energy labels of the Marco Pololaan, based on data from De Jong & Versteeg (9 december 2010)

Figure 4-40: Radiator in living room

Figure 4-41: Domestic hot water boiler in kitchen

4.1.7 Indoor comfort and damages current situation

The studies done by other companies for the housing corporations can help to grasp what the problems are in the façade and indoor comfort of the case study building.

Single glass

Due to the single glass it is difficult to get the rooms warm enough (some rooms have no radiators at all) and also the cold radiating from the glass gives hindrance (De Jong & Versteeg, 9 december 2010). Also the draught at the windows gives problems, there is moderate to no closing of the cracks around the window frames (De Jong & Versteeg, 9 december 2010).

Ventilation

The homes are naturally ventilated, with small openable windows in the living room, bedrooms and kitchen, which can give draught. In the bathroom there is sometimes mould (De Jong & Versteeg, 9 december 2010).

Cold bridges

The most damages by moisture is in the room behind the staircase, which causes moulding (Alblas & Van Drie, 13 december 2010). This is also due to large cold bridges in the façade, which need to be solved to increase the indoor comfort and health.

The most problematic points are at the room behind the staircase and at the balconies (De Jong & Versteeg, 9 december 2010). Cold bridge calculations have shown that a lot of points do not fulfil to the temperature facture, which needs to be at least 0.65 to prevent mould forming (and is advised at 0.5)

Acoustics

There are complaints by the residents of bad acoustic insulation of the façade (noise from the traffic) and from the inside by neighbours (De Jong & Versteeg, 9 december 2010).

4.1.8 Summary of the analysis

In the following table, the summary of the most important elements is shown in the current situation, with the material layers, the insulation value and the problems. Also the legal requirement is shown (for new buildings), together with what Portaal is planning to do with each of these elements.

The prefab concrete elements of the VAM method are made of gravel concrete (grindbeton) and the inside of the sandwich panel are 'gasbeton'. The properties of the different materials in the table can be found in Appendix C, Table C- 1.

Table 4-2: Summary of materials and building services in the current situation and the plans of Portaal

CURRENT SITUATION					PLAN PORTAAL	
COMPONENT	**Material**	**U or Rc-value**	**Problems**	**Requirements**	**Material**	**U or Rc-value**
Sandwich panel	80mm gravel concrete 10mm polystyrene 60mm cellular concrete	Rc =0,5 m²K/W	Too low insulation value	3,5 m²K/W	Old facade + Insulation 80mm + Plaster	2,92 m²K/W
Masonry	105mm brick 65mm cavity 200mm wall	Rc = 0,71 m²K/W	Too low insulation value	Rc = 3,5 m²K/W	Insulation inside cavity old facade	2,48 m²K/W
Plate material	3 plates of 8mm thick	Rc=0.24 m²K/W	Too low insulation value	Rc = 3,5 m²K/W	Wooden frame with 153mm insulation, cavity and plate cladding	4,68 m²K/W
Concrete (side of balcony	Concrete 50mm Cavity 80mm 200mm wall	Rc = 0,42 m²K/W	Insulation value	Rc = 3,5 m²K/W	Remove old cladding, add insulation 150mm + plaster	4,59 m²K/W
Roof	-140mm concrete -70 Schewill insulation	Rc=0.57	Insulation value	Rc = 3,5 m²K/W	Old insulation and floor + 80mm insulation	2,90 m²K/W
Roof edge	90mm concrete		Cold bridge	Rc = 3,5 m²K/W	Add 60mm insulation	
Window frame/glass	-5mm glass -Wooden frames	Glass: 5,8 W/m²K Window frame: 0,1W/mK	Single glass has too low insulation value	U = max 2,2 W/m²K	HR++ glass	
Door balcony	33 mm wood	Rc = 0,34 m²K/W	Insulation value		Insulated door	
Balcony			Cold bridge	Rc = 3,5 m²K/W	Insulation on top and bottom of floor	
VENTILATION	**Strategy**		**Problems**		**Strategy Portaal**	
Air tightness (cracks and air paths)	Via windows and bad insulation cracks		Draught Noise from outside		Closing cracks with double layer	
Natural/mech. ventilation	Natural via windows		Draught		Suskast ventilation	
SPACE HEATING	**Strategy**		**Problems**		**Strategy Portaal**	
Heating	District heating with radiators		Radiator tubes go through floor, causes acoustic problems with neighbours		Keep district heating, new radiators	
Hot water	Electro boiler		Low efficiency		?	
Passive solar heating	Large windows		None		No changes	
OVERHEATING	**Strategy**		**Problems**		**Strategy Portaal**	
Use of thermal mass	Large thermal mass, not much overheating		Less overheating		None	
Adequate ventilation	Natural ventilation		Not enough ventilation in kitchen and bathroom		Mechanical ventilation exhaust	
Glass surface (on south)	No glass surface on south, glass on east and west		None		None	
ACOUSTICS	**Strategy**		**Problems**		**Strategy Portaal**	
Façade	Very low insulation value		Noise from outside, especially when ventilating		Suskast ventilation, better insulation façade	
Inside walls and floors	Very low insulation value floors		Noise from neighbours		Keep as it is, but when residents move they place insulation on floor.	

4.1.9 EPC Calculation current situation

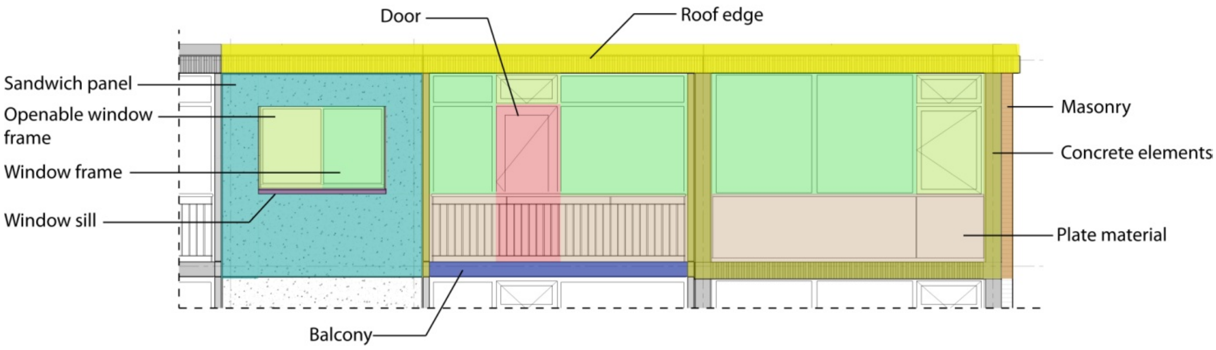


Figure 4-42: West façade of the apartment that is going to be researched with materials (based on drawings from Portaal)

Figure 4-43: Simplified current façade for the EPC calculation

The energy use of the current situation needs to be calculated, in order to compare it to the new design.

Boundary conditions

Software

The software EPC is used for the calculations. This program is used to calculate the Energy Performance Coefficient, which is needed for new buildings according to Dutch standards.

Apartment type

- Calculations are made for the top corner apartment. This apartment is chosen because it has all types of materials (roof, masonry, plate material, sandwich panel) and because it has the most energy use. This way in the most extreme case the energy use can be calculated, as well as the influence of the materials on the total energy.
- Floor area of 77m^2

Infiltration

- $q_{v10;spec}$ = 3 $dm^3/s \cdot m^2$
- Height of the building = 13.8m
- Standard façade type, multiple stories, top corner

Internal heat capacity

- Building type: traditional, mixed heavy

Insulation values:

Other

- Obstruction on the outside of the façade

Installations

- District heating (efficiency of 100%) for heating
- Electric boiler for domestic hot water with an efficiency of 75%
- The ventilation is by natural ventilation, with 92.5dm^3/s needed.

Façade

The façade components as they are now will be simplified for the EPC calculation, which are shown in Figure 4-43. The linear thermal bridges do not need to be taken into account for the EPC calculations.

Closed surfaces

Doors without glass or window frames without glass can be considered as a closed surface. The plate material has been simplified, with an average R-value of the frames, plate material and other materials with small surfaces. The eventual R-value is given in Appendix C- 1. The roof and masonry façade constructions have a single Rc-value.

Glass surfaces

A simplified method to assess the Uw (heat transfer coefficient of window) is chosen. The area of the window frame is in most situations about 30% of the whole area. The average U-value of the window frame is about 1.4 W/m^2K (the openable window frames are thinner). According to Figure 4-44 the U-w value will in that case be 4.4 W/m^2K. This will be taken as a standard value for all windows in the EPC calculation.

Doors

The door cannot be simplified as one component (as a glass door U_D), because the minimum surface of glass has to be 65% (NEN 1068, 2012), and in this case it the glass area is 55% . Therefore it will be taken as two different components. The glass part of the door is added to the surface of the 'Window total' surface in Figure 4-43.

Table F.1 — Thermal transmittances for vertical windows with fraction of the frame area 30 % of the whole window area and common types of glazing spacer bars

Type of glazing	U_g W/(m²·K)	Thermal transmittances for common types of glazing spacer bars U_f W/(m²·K)												
		0,8	1,0	1,2	1,4	1,6	1,8	2,0	2,2	2,6	3,0	3,4	3,8	7,0
Single	5,7	4,2	4,3	4,3	4,4	4,5	4,5	4,6	4,6	4,8	4,9	5,0	5,1	6,1
Double or triple	3,3	2,7	2,8	2,8	2,9	2,9	3,0	3,1	3,2	3,3	3,4	3,5	3,6	4,5
	3,2	2,6	2,7	2,7	2,8	2,9	2,9	3,0	3,1	3,2	3,3	3,5	3,6	4,4
	3,1	2,6	2,6	2,7	2,7	2,8	2,9	2,9	3,0	3,1	3,3	3,4	3,5	4,3
	3,0	2,5	2,5	2,6	2,7	2,7	2,8	2,8	3,0	3,1	3,2	3,3	3,4	4,2
	2,9	2,4	2,5	2,5	2,6	2,7	2,7	2,8	2,9	3,0	3,1	3,2	3,4	4,2
	2,8	2,3	2,4	2,5	2,5	2,6	2,6	2,7	2,8	2,9	3,1	3,2	3,3	4,1
	2,7	2,3	2,3	2,4	2,5	2,5	2,6	2,6	2,7	2,9	3,0	3,1	3,2	4,0
	2,6	2,2	2,3	2,3	2,4	2,4	2,5	2,6	2,7	2,6	2,9	3,0	3,2	4,0
	2,5	2,1	2,2	2,3	2,3	2,4	2,4	2,5	2,6	2,5	2,8	3,0	3,1	3,9
	2,4	2,1	2,1	2,2	2,2	2,3	2,4	2,4	2,5	2,5	2,8	2,9	3,0	3,8
	2,3	2,0	2,1	2,1	2,2	2,2	2,3	2,4	2,5	2,4	2,7	2,8	3,0	3,8
	2,2	1,9	2,0	2,0	2,1	2,2	2,2	2,3	2,4	2,3	2,6	2,8	2,9	3,7
	2,1	1,9	1,9	2,0	2,0	2,1	2,2	2,2	2,3	2,3	2,6	2,7	2,8	3,6
	2,0	1,8	1,9	2,0	2,0	2,1	2,1	2,2	2,3	2,5	2,6	2,7	2,8	3,6
	1,9	1,8	1,8	1,9	1,9	2,0	2,1	2,1	2,3	2,4	2,5	2,5	2,7	3,6
	1,8	1,7	1,8	1,8	1,9	1,9	2,0	2,1	2,2	2,3	2,4	2,6	2,7	3,5
	1,7	1,6	1,7	1,7	1,8	1,9	1,9	2,0	2,1	2,2	2,4	2,5	2,6	3,4
	1,6	1,6	1,6	1,7	1,7	1,8	1,9	1,9	2,1	2,2	2,3	2,4	2,5	3,3
	1,5	1,5	1,5	1,6	1,7	1,7	1,8	1,8	2,0	2,1	2,2	2,3	2,5	3,3
	1,4	1,4	1,5	1,5	1,6	1,7	1,7	1,8	1,9	2,0	2,2	2,3	2,4	3,2
	1,3	1,3	1,4	1,5	1,5	1,6	1,6	1,7	1,8	2,0	2,1	2,2	2,3	3,1
	1,2	1,3	1,3	1,4	1,5	1,5	1,6	1,6	1,8	1,9	2,0	2,1	2,3	3,1
	1,1	1,2	1,3	1,3	1,4	1,4	1,5	1,6	1,7	1,8	1,9	2,1	2,2	3,0
	1,0	1,1	1,2	1,3	1,3	1,4	1,4	1,5	1,6	1,8	1,9	2,0	2,1	2,9
	0,9	1,1	1,1	1,2	1,2	1,3	1,4	1,4	1,6	1,7	1,8	1,9	2,0	2,9
	0,8	1,0	1,1	1,1	1,2	1,2	1,3	1,4	1,5	1,6	1,7	1,9	2,0	2,8
	0,7	0,9	1,0	1,0	1,1	1,2	1,2	1,3	1,4	1,5	1,7	1,8	1,9	2,7
	0,6	0,9	0,9	1,0	1,0	1,1	1,2	1,2	1,4	1,5	1,6	1,7	1,8	2,7
	0,5	0,8	0,8	0,9	1,0	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,8	2,6

Figure 4-44: Uw-value for certain glazing and window frames (NEN-EN-ISO 10077-1, 2006)

Results

The exact input for the EPC of the current situation can be found in Appendix C- 1: EPC Software input current situation.

The results of the described input are an EPC of 2.99. The complete energy use Ep_{tot} = 137.952MJ. Ep_{tot} is the yearly energy use for heating, humidifying, ventilators, lighting, cooling, dehumidifying, domestic hot water and the energy needed for helping. Since the living area is 77m^2, the energy use per m^2 is 1791.6MJ/m^2, which is 498kWh/m^2. 72% is needed for heating, 21% for warm water, 4% for summer comfort and 3% for lighting.

Desired Insulation values

In Appendix C- 1 also the desired U and Rc-values are shown. For the façade the Rc-value chosen is 3.5m²K/W. This is currently the standard minimum value.

The desired glass U-value is 1.2W/m²K and for the window frames 2.4. According to Figure 4-44 the U-value of the window should be 1.85 W/m²K in that case. For the door an R-value of 1.2m²K/W is chosen. For the window sills a lower value of 3.5m²K/W is desired. The new ZTA value for double glazing (HR++) is normally between 0.6 and 0.7 (SBR Infoblad 006). For triple glazing this can be 0.55. An average value of 0.6 is taken as a desired value. The Suskast has an insulation value of around Rc = 0.5 m²K/W.

4.2 Strategy analysis Building Services

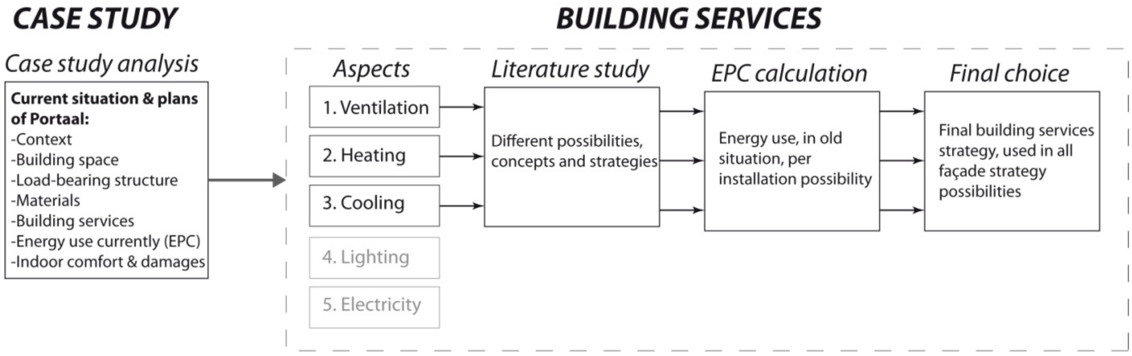


Figure 4-45: Methodology of the building services

While the thermal design of the building skin is the main focus point in this thesis research, also the building services are important to the energy use of the building. In this chapter an analysis will be made of these building services, to make the best choice for this building. In Figure 4-45 the steps to choose the building services are shown. Different aspects will be analysed, with the help of a literature study and EPC calculations. In the last part, a final choice for the building services will be made to be used in the design.

Hegger et al. give the following targets to optimise the building services of a building: Gaining and distributing heat, gaining cooling energy and dissipating heat; optimising (mechanical) ventilation, optimising the artificial lighting and generating electricity and using it efficiently (Hegger et al., 2008). The aspects chosen to research are based on these targets. The Lighting and electricity will not be considered here, but the ventilation, heating and cooling aspects will be analysed in this chapter. Of these aspects different steps need be taken, which can be seen in Figure 4-46.

Starting point

To be able to compare the different building services possibilities the EPC software ENORM will be used. All factors will be kept the same, so that the only variable is the building services. This way the EPC of the different possibilities can be compared. This can give an indication in the energy use per strategy, but it is also a limited research, because the EPC is only a number which is derived from certain equations input into the software. To find out the more detailed and correct energy use per installation, more extensive calculations should be made.

The following factors are the starting point of this variation study:

- The current situation was inserted into EPC, as can be found in Appendix C- 1. These insulation values were inserted into the EPC, but with the same façade surface areas as the current situation. These have the insulation values: $Rc_{façade}$ = 3.5m²K/W, Rc_{roof} = 5m²K/W and the U-value of the glass is 1.85W/m²K (which is normal for HR++ glass). The floor area is 77m². Calculations are made for the top corner apartment.
- The building services were as a standard kept as they are in reality now, with district heating (efficiency of 100%) and an electric boiler for hot water with an efficiency of 75%. The ventilation is by natural ventilation, with 92.5dm³/s needed.
- With this input the EPC was lowered to 1.59. This is the starting point to compare the influence of using other building services.

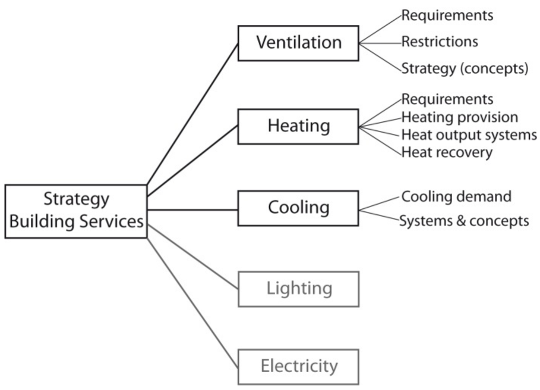


Figure 4-46: Aspects to analyse in the Building Services strategies

Table 4-3: Steps to determine the best strategy for ventilation

STEPS VENTILATION	Criteria	Parameters
1. Ventilation requirements	Ventilation capacity	Legal requirements for ventilation for the room size & function
2. Restrictions	Analysis cross section/floor plan/details	Space possibilities/restrictions
3. Ventilation strategy	Analysis ventilation concepts: natural/mechanical, inlet/outlet Analysis room conditioning: heating/cooling, heat recovery, air handling	Cost/maintenance Energy requirements/savings Indoor comfort
4. Conclusion	Overview of possibilities	Conclusion, depending on building services analysis and existing building restrictions

4.2.1 Ventilation

Ventilation systems are needed in domestic buildings to remove odours, pollutants, CO_2 and moisture. For buildings that are well insulated the ventilation heat losses are just as important as transmission heat losses (Hausladen, De Saldanha, Liedl, & Sager, 2005).

Table 4-3 shows the steps which will be taken for this chapter. First the ventilation requirements need to be determined with the help of legal requirements.

Secondly the restrictions due to the existing building need to be examined, like floor height and façade possibilities and existing ducts.

Last, the possible ventilation strategy (natural, mechanical or combined) will be analysed. Important parameters in this will be: energy use reduction, indoor comfort and costs. Costs should also be considered, because for a residence often very high tech expensive installations are not needed, due to the low amount of people using the residence.

The final choice of ventilation strategy will be made in chapter 4.2.4, when also the heating strategies have been analysed.

1. Ventilation capacity

According to Article 3.29 of the Dutch Bouwbesluit, a minimum of 25m^3/h per person for ventilation is recommended. With residences the ventilation is determined by the amount of people that the room is destined for (about 0.7-0.9 dm^3/s per m^2 area), with a minimum of 7 dm^3/s. For a toilet this is at least 7dm^3/s and for a bathroom at least 14dm^3/s. A kitchen needs to have ventilation capacity of at least 21dm^3/s. A hallway needs to have at least 0.5dm^3/s per m^2 for refreshment. (Bouwbesluitonline)

From the kitchen, bathroom and toilet the air should be refreshed directly to the outside. Here mechanical ventilation would be necessary. In the bedrooms and living room natural ventilation would still be possible. The total ventilation capacity is 92.5dm^3/s (for a floor area of 77m^2) and can be input into the EPC software (see Appendix C, Table C- 2 for the ventilation needs per room).

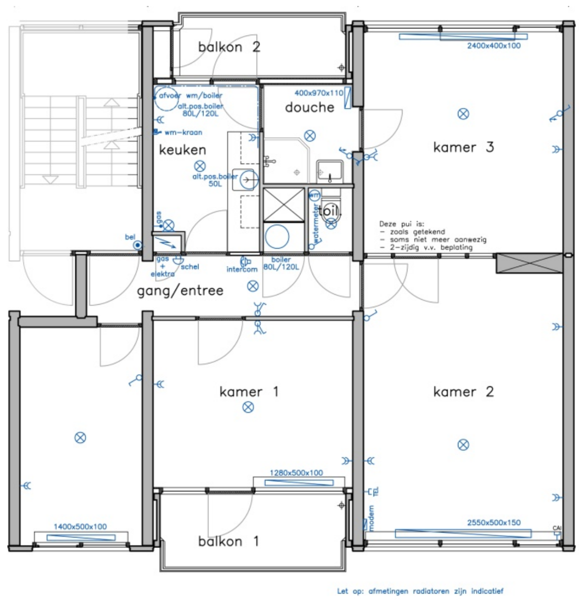


Figure 4-47: Floor plan of apartment type D, with placement of important installations (from documents of Portaal)

2. Ventilation restrictions

When ducting for a mechanical ventilation system needs to be installed to have a balanced ventilation system, the height of the room is a large restriction. The height is now 2.65meters, without finishing on the floor. According to Article 4.3 of the Bouwbesluit the height of a living function room needs to be at least 2.6 meters. This means that there is very little height left for ducts, which makes it difficult to place these at the ceiling. The shaft where the ducts could go through for ventilation is 650x775mm, which could also be a restriction (see Figure 4-47).

3. Ventilation strategies

Hausladen et al. give the following ventilation strategies for residential buildings: natural ventilation, exhaust air systems and supply and exhaust air systems. There are also other possibilities, like supply air through ducted mechanical ventilation and exhaust through the façade (Hausladen et al., 2005).

Natural ventilation

Natural ventilation is often limited, because it is hard to control and it often gives draught problems. To improve this, hardware should be used by adjusting according to the indoor climate, outdoor climate and air quality on the ventilation openings (Hausladen et al., 2005). This type of ventilation is not used anymore for new buildings. It is therefore not an option to keep using it for the new refurbishment design.

Exhaust air system (supply through façade, ducted mechanical exhaust)

With exhaust air systems the air is extracted by mechanical fans in the bathroom and kitchen, which also causes the air from the normal rooms to refresh. The disadvantage of this is that the heat in the air is lost, which can only be recovered by an exhaust air heat pump (Hausladen et al., 2005). Another possibility is the moisture controlled system, with which the air flow is controlled by the room air humidity without the necessity to open windows (Hausladen et al., 2005).

Ducted mechanical supply and exhaust air system

In this strategy the exhaust and supply air ducts are separated with different fans and they can have heat recovery (and preheat the supply air). This system can recover up to 90% of the heat (Hausladen et al., 2005). This type works better for a home occupied by several people, because the needed air changes is higher (Hausladen et al., 2005).

Supply and exhaust air by a local ventilation unit

This is a flexible system, but it has high maintenance cost. The supply and exhaust of air is through ventilation equipment in the façade, so that heat recovery is possible. The air is heated and cooled to a certain extend before entering the room. This is good for buildings that are naturally ventilated, but that need special requirements for the ventilation supply. (Hausladen et al., 2005) This system gives a better indoor comfort, since there is no draught.

4. Conclusions

The ventilation concept option depends on multiple factors, like the use of the building, the functional requirements of the façade and the plan layout (Hausladen et al., 2005). Also the combination of heating, ventilation and cooling needs to be considered to make the best choice.

The different ventilation possibilities were input into the EPC. This small analysis gives values which are explained in more detail in Appendix D- 2. The conclusions of this can be found in Table 4-4. A good EPC reduction is possible when using a wind pressure regulated system with natural supply and mechanical exhaust in the kitchen and bathrooms. When also using a CO_2 regulator, only in the living room and kitchen, an even lower reduction is possible.

Another possibility would be with a mechanical exhaust and supply with heat exchange, but this does not give a higher EPC reduction. The last good possibility is to use a local unit. This gives a high heat exchange rate and can also be controlled by CO^2 sensors. This has higher costs than a natural supply and mechanical exhaust system, but gives much better thermal comfort.

Table 4-4: Conclusions for the ventilation choice

	Comfort	Sound	Space use	Costs	Energy use system	Heat savings	EPC reduction
Natural	-	++	++	++	++	- -	None
Mech. Supply							+/-
Mech.Exhaust	+/-	+/-	+	+	+/-	+/-	+
Mechanical	++	-	- -	-	-	++	++
Local unit	++	-	+/-	-	+/-	+	+

4.2.2 Heating and domestic hot water

In Table 4-5 the steps that will be taken to select a good strategy for heating and domestic hot water is summarized.

The first step is to look at the heating provision. The criteria that need to be considered are the ones given by Hegger et al. They give as planning aspects for the heating of a building: use of fossil fuels, use of biomass, use of solar heat, use of ambient heat via heat pumps and heat storage, distribution and output (Hegger et al., 2008).

The second step, after making an overview of the heating provision possibilities, is the heat output systems.

The third step is to look at the possibilities of heat recovery, which is important to consider together with the ventilation system.

In the last step conclusions will be made. According to Hausladen et al. the criteria for the selection of the energy generator are: availability of the sources of energy, the system temperature of the heat transmission system and the output required by the building (Hausladen et al., 2005). With these criteria the conclusions of the different heating possibilities will be made. The final choice for the heating system will be made in Chapter 4.2.4, together with the selected ventilation system.

Table 4-5: Steps to determine the best strategy for hot water

STEPS HEATING	Criteria	Parameters
1. Heating provision	-Use of fossil fuels -Use of biomass -Use of solar heat -Use of ambient heat via heat pumps -Heat storage, distribution and output -Low/high temperature -Individual/collective	Choice best way of heat provision Criteria: -Availability of sources of energy -System temperature of the heat transmission system -Output required by the building
2. Heat output systems	Individual components Heated surfaces	
3. Heat recovery	Overview of possibilities	Conclusion, depending on building services analysis and existing building
4. Conclusions		Availability & costs Suitability with high or low T. Output Energy use reduction

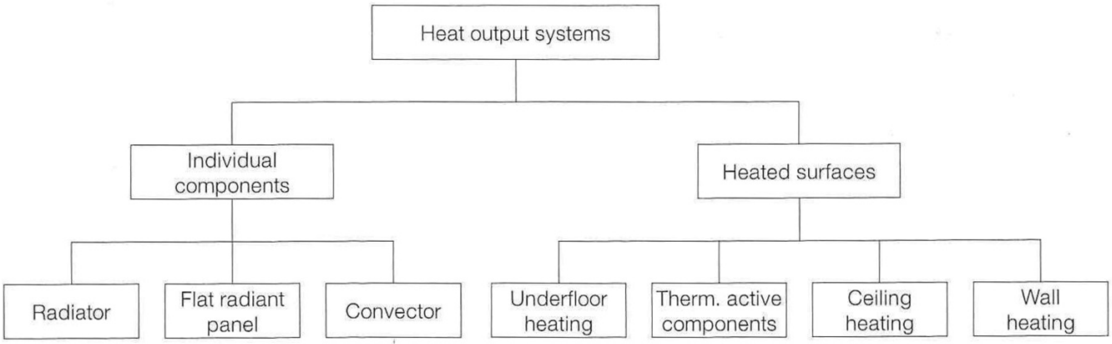


Figure 4-48: Systematic presentation of heat output systems (Hegger et al., 2008)

2. Heat provision

The heat provision types possible can be summarized as:

- Fossil fuels
- Biomass
- Solar heat
- Heat pumps
- Heat storage

The complete research that was done for these heat provision types can be found in Appendix D- 1: Research on heat provision types. In this Appendix each type is explained in more detail.

These different types are put in Table 4-6, with the suitability with different temperature systems, EPC reduction compared to the current situation and the availability and costs. The EPC reductions when using the different heat provision types can be found in Appendix D, Table D- 1.

3. Heat output systems

Hegger et al. give two different heat output systems (Hegger et al., 2008): individual components and heated surfaces. In these two systems there is also a division. For individual components there are the following possibilities: radiator, flat radiant panel and convector. For heated surfaces the possibilities are: under-floor heating, thermally active components, ceiling heating and wall heating.

The options of heat output systems are restricted by the heat output system. For example when using radiators and low temperature output, the area often needs to be very high (see Figure 4-48). Another heat output system might be more suitable in this case.

4. Heat recovery

The major losses in heating go through the ventilation of air, when the building is well insulated. When using supply and exhaust ventilation, heat exchange can be realized. But with ventilation by natural supply and mechanical exhaust this is a lot more difficult.

5. Conclusions

In Table 4-6 conclusions are given for the heating. In the last column the EPC reduction compared to the old situation is shown. The complete analysis of the EPC values can be found in Table D- 1, Appendix D.

Heating

At the moment district heating is used. A lower EPC is possible with a heat pump, either by air or ground compared to district heating (with 100% efficiency). When using extra storage of heat (and cold), the EPC can be reduced even further. Also using solar collectors helps with the EPC.

A research was done by BSP Sight (De Jong & Versteeg, 9 december 2010), which gave an efficiency of 173% for the district heating. When using this value the EPC is much lower than when using a standard value of external heat supply (100%). The EPC differs 0.3 between these two choices, and when using 173% the EPC is about the same as with a heat pump. But this value may not be used for the EPC calculation, since it is not made with a quality statement needed for the EPC.

Table 4-6: Conclusions for choices in heating strategy

	Sub type	Availability & Costs	Suitability with ventilation & heat output system		EPC reduction compared to old situation, district heating
			Low T	High T	
Fossil fuels	CV heating	+	+	+	+/-
Electric heating	CV heating	+	+	+	- -
Biomass	Wood/Biomass	+/-	+	+	+/-
Solar heat collectors	Unglazed	-	+	+	++
	Flat-plate	-	+	+	++
	Air collector	-	+	+	++
	Vacuum-tube	-	+	+	++
Combined Heat & Power	Micro CHP	-	+	+	+/-
	District heating	+	+	+	+/-
Heat pump	External air	+	+	-	++
	Shallow soil	- -	+	-	++
	Deep ground	+/-	+	-	++
	Ground/surface water	-	+	-	++
	Waste heat	+	+	-	+
Heat storage	Short-term	+/-	+	-	
	Long-term	-	+	-	++

Domestic hot water

In the current situation an electro-boiler is used, with an efficiency of 0.75. When the building is well insulated (Rc-values of 3.5m^{2}K/W and window of U-vale 1.85W/m^{2}K), there is an EPC of 1.59. The rest of the domestic hot water possibilities were compared to this situation, which can be found in Table D- 2, Appendix D.

For domestic hot water, natural gas or external heat is good to use for the EPC value. The best result (EPC of 0.96) is with a Micro CHP system, but also by a solar boiler with integrated after heating a good EPC can be reached (1,18). A good choice is a combination heat pump individually (1.10), but this will be very expensive for each apartment. A collective system with CHP is also good (1.03), which is already installed in the apartment.

4.2.3 Cooling

Hegger et al. give different building cooling strategies (Figure 4-49): natural heat sinks, evaporative cooling and refrigeration unit.

Refrigeration units should be avoided, due to the lower cooling demand of the building and the higher energy use.

Since there are no problems currently with overheating, cooling is not explicitly necessary. When the glass area of the façade is too high, additional sun shading could be added to prevent overheating.

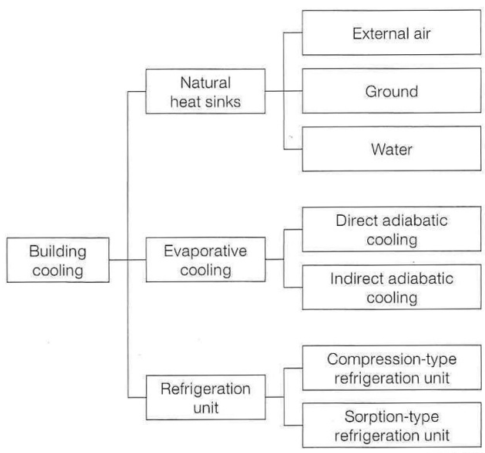


Figure 4-49: Building cooling options (Hegger et al., 2008)

4.2.4 Conclusions

Since the 173% efficiency of the current district heating system has not been proven as correct, a heat pump system with an aquifer would be a better choice.

For domestic hot water the existing district heating system could be used, since it is more energy efficient than the current boiler which is used.

A cheap possibility for the ventilation would be to use naturally supplied air with mechanical exhaust, CO_2 sensors and wind pressure regulation. This could be done with the current district heating system for domestic hot water and a new heat pump with groundwater storage for heating. Currently there are radiators present, but with the new transmission by insulation and ventilation there would not be enough area to heat in extreme conditions with this low temperature system. Therefore floor, ceiling or wall heating would be needed, but this is difficult to realize in an existing building which is currently being rented.

Another suitable possibility for the ventilation system is to use a local heating unit (for example Climarad), which looks like a radiator but can also supply mechanical ventilation. There can be heat recovery of the ventilation air and it can be CO_2 and moisture regulated. This gives a lower energy use than using mechanical exhaust and natural supply, but needs a higher investment. It also gives a much better thermal comfort.

The following Building Services Strategy was chosen, with which the EPC can be reduced most:

- A decentralized heating and ventilation unit with heat exchange for heating and ventilation with CO_2 regulation (for example Climarad, see Figure 4-50 and Figure 4-51).
- Rc value of at least 5m^{2}K/W for the roof and 3.5m^{2}K/W for facades. The U-value of the windows is 1.85W/m2K. An insulation value of at least 3.5 m^{2}K/W is the current standard for new buildings (Bouwbesluitonline).
- Heating: electrical heat pump and ground water heat storage.
- Domestic hot water by a collective CHP system (this district heating system is already present for heating at the moment).

If these changes are made, the EPC can be reduced from 1.59 to ***0.76*** for the top corner apartment. See Appendix C, Figure C- 2, for the output results of the EPC.

For this research only a reduction to an EPC of 0.76 will be made, but if the housing company is willing to make an extra investment for PV or Solar collectors, the EPC can be reduced to the necessary value for completely new buildings of 0.6. Even lower than that is possible, if enough PV-cells are placed.

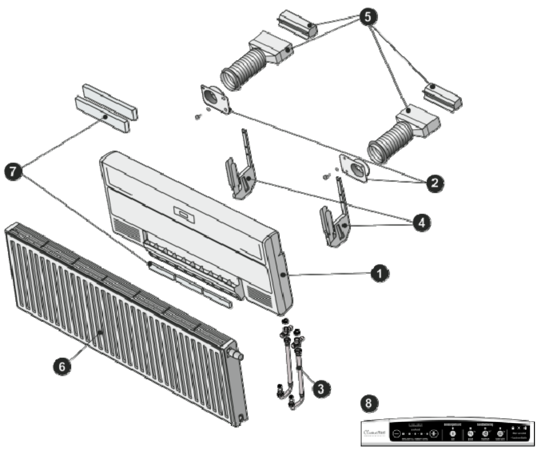


Figure 4-50: Different parts of the Climarad system(Climarad, 2013)

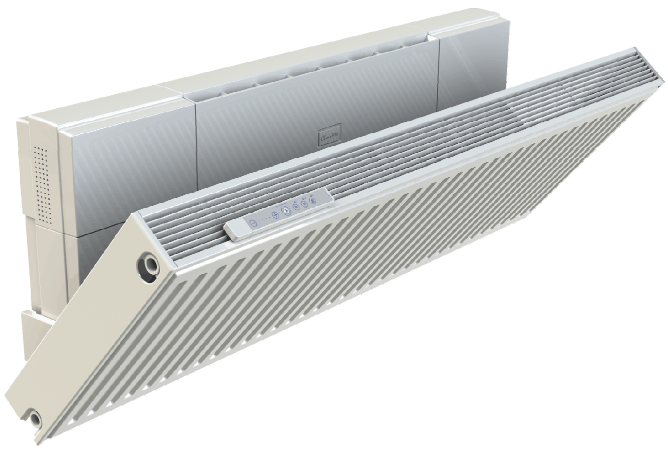


Figure 4-51: Climarad system, radiator and ventilation unit (Climarad, 2013)

4.3 Strategy choice façade

It was important to choose a facade strategy that is best suitable for the case study. But the emphasis of this research will be on the best materials for façade refurbishment. An important aspect in that research will be the different strategies possible. The choice of strategy will be based on the case study building, as well as the choices that Portaal has made for the design. Also studies by other students or PhD researchers have been made on different refurbishment strategies, which will be referred to in this chapter.

4.3.1 Façade refurbishment strategies

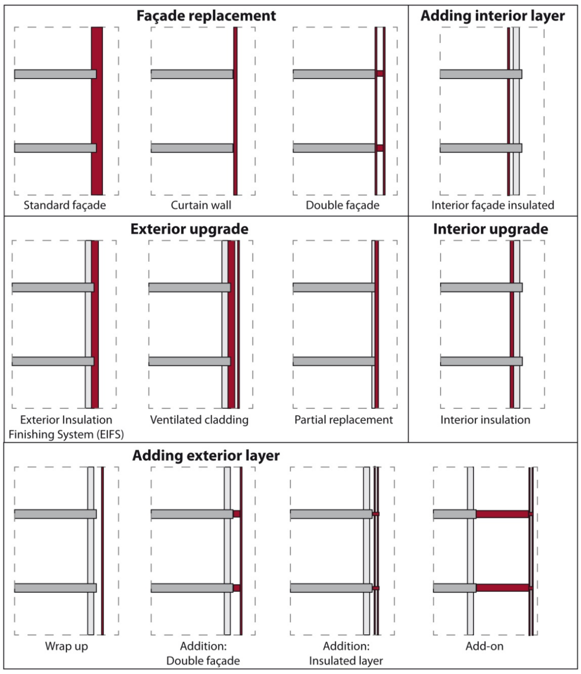


Figure 4-52: Possible refurbishment strategies

Possible façade strategies were already discussed in Chapter 2.1.5, which can be seen again in Figure 4-52.

Extreme measures, such as adding a double façade, are not often used for residential buildings, because of the costs (see Appendix F, Table F- 1), even though it is very good for comfort and insulation.

Measures such as façade replacement by a standard façade, interior upgrade, exterior upgrade and addition of an exterior layer are possible for housing. These suitable strategies for the case study building will be discussed in the following part.

Exterior upgrade/addition

When making an exterior upgrade it is also a possibility to close of the balconies. This has been proven by Loukopoulou as a good strategy to lower the CO_2 emissions and average heating demand (Loukopoulou, 2012). Also external insulation with insulated glazing proved to be a good strategy. Insulating the façade and removing cold bridges of the balconies by closing them off are the best solutions, shown in the research of Tensen (Tensen, 2011).

Complete façade replacement

Another option is to remove the old façade and replacing it with a new one. Only the load bearing construction is kept. This will give the building a whole new appearance, while having more freedom to make a new design. The costs are higher with this strategy, but the gains might be higher than the costs (see Appendix F, Table F- 1).

Interior insulation

Interior insulation gives problems in detailing, and it is more often used if the building is not a monument. An interior layer also does not give back its investment of costs when looking at the comfort. But this choice will be interesting to look at concerning operation and embodied energy use compared to the other strategies.

Portaal's Strategy

For the case study building Portaal already has a final design for the four buildings they are going to refurbish between 2013 and 2015. This strategy is also interesting to evaluate, compared the design that will be made in this thesis. Therefore also the plans of the Housing Corporation need to be considered in the strategy comparison. They use a combination of different strategies.

On the east side of building the plan is to make the balcony an internal space (the balcony is closed off with a new façade, so the old balcony is moved to the inside of the building envelope. A new balcony is added per apartment and an elevator is added per block of 8 apartments. So the strategy for one side of the building is to close of the balcony and adding new space as a balcony.

On the west side of the building there are different strategies used: replacement of façade components or adding new elements to the old façade.

Figure 4-53 gives an example of Portaal's design, where the construction of the roof floor is kept together with the current insulation, but extra insulation is added. Some parts of the outside façade are replaced completely, like the window frames and the plate material of the parapet. Also the roof edges are removed and replaced. The sandwich panel is kept and new insulation and finishing is used in front of it.

In all situations the glazing will be replaced, since single glazing has a very bad energy performance. HR++ glazing is a common choice, so this will be used to compare the different strategies.

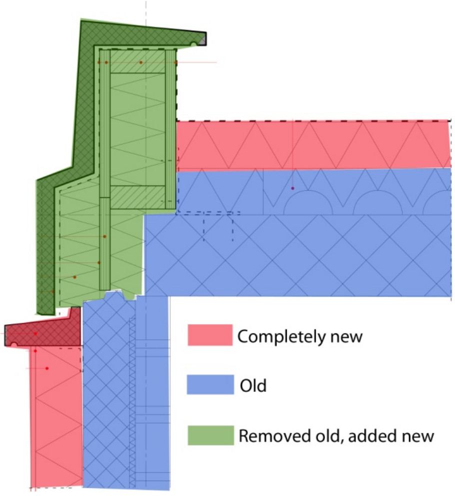


Figure 4-53: Based on a detail of the future plans, given by Portaal

4.3.2 Conclusions

The following strategies came out as the best strategies for a residence, combined with the strategy that portal is using. These strategies will be further developed in EPC calculations and the excel sheet of materials for comparison.

1. Exterior upgrade/addition of an insulated façade (keeping all current materials except of glass)

- Closing off the balconies with glazing or closed façade
- Replacement of glass by insulated glazing
- Exterior addition: insulation finishing system or ventilated cladding

2. Complete façade renewal/replacement, only the load-bearing construction is kept, but the whole façade replaced by new.

3. Additional insulated interior layer/interior upgrade

- Inside insulation where possible
- Replacement of glass by insulated glazing

4. Partial replacement, partial exterior addition (based on the strategy of Portaal)

- Replacing some parts of the façade
- Adding materials on some parts
- Closing off the balcony on one side and adding new balcony, on the other side insulation around balcony
- Replacement of glass by HR++ glazing

5. Covering up with a single or double glazing layer, while keeping all current materials

Strategy 5 is interesting, but difficult to investigate, because this solution will have a different ventilation strategy, insulation values and for example sun shading. Also in EPC it is difficult to input this, because the influence of these rooms can only be investigated in the more difficult way of calculation (not the fixed values used for thermal bridges for example). Because this strategy cannot be compared well to the other strategies it will not be researched further.

To be able to compare the different strategies, one design will be chosen, based on the plan Portaal has for the building. Also other factors that influence the best strategy choice will also be considered, such as the problems it gives in the detailing and the restrictions on the inside and outside space.

5. MATERIAL COMPARISON

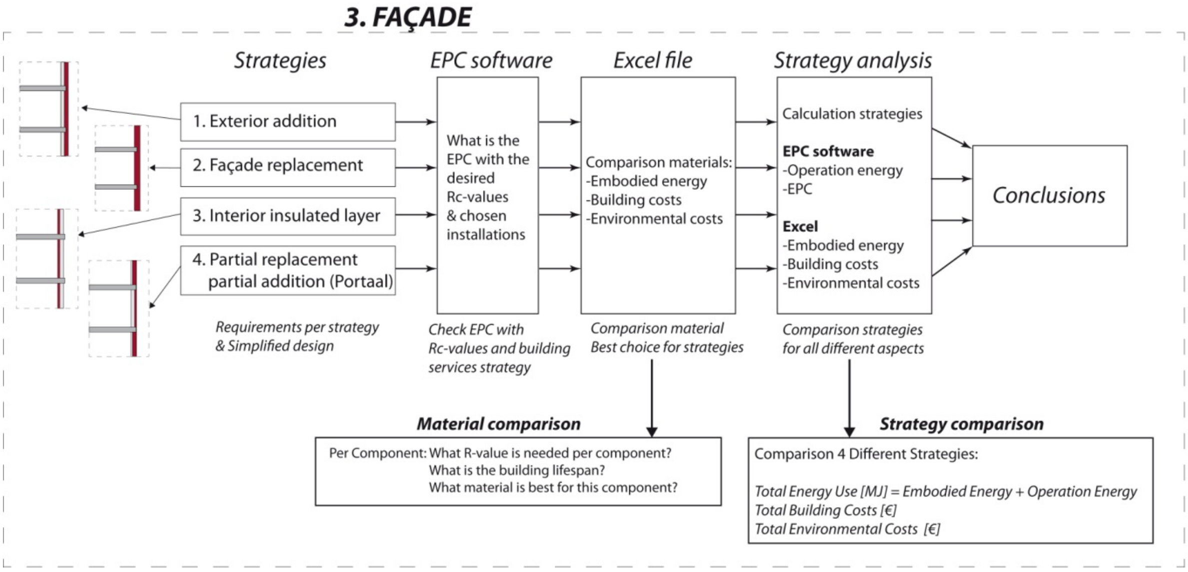


Figure 5-1: Methodology for the façade, material and strategy comparison

In Figure 5-1 the third step of the complete approach is shown, with the steps for the façade. The third step of this façade approach is to make an excel file to compare the materials, which will be done in this chapter.

The material comparison will be done based on the material database of NIBE (Haas, 2012), which gives data on different materials for certain components of the façade. Glass is not given in this database, and will therefore be calculated separately for energy use and costs. For the materials of the façade an analysis will be made to find out the best material per component. This will be used on the design for the four strategies.

In this chapter also the fourth research question will be answered, concerning reusing and recycling.

5.1 Glass type comparison

Window frames are given in the NIBE database, but glass itself is not given in this book. Therefore the different types of glass will be calculated separately. Conclusions will be made to use in the strategy comparison and in the final design.

Boundary conditions

A simplification will be made so that the operation and embodied energy of the different glass types can be calculated. This is not a precise calculation, but an indication so that the difference between the glass types can be assessed generally.

The following assumptions will be made:

- A lifespan of 35 years is calculated (the lifespan chosen by Portaal for the building after refurbishment).
- Only energy needed for heating by transmission losses and energy gain by solar energy is calculated, with the method from Swan Consult Herkenbosch. For example energy loss by ventilation is not taken into consideration for this comparison.

• Heating is only needed in the period between 1 October and 30 April (Swan Consult Herkenbosch).

• In this comparison the window is assumed to be 1.2 by 0.8 meters, with a window frame of 4 meter length, and a glass area of 0.96m^2 (rounded off to 1m^2).

• The embodied energy of glass is 15MJ/kg (Hammond & Jones, 2008). The density of glass is 2600kg/m^3 (Joostdevree).

• The use of U-glass values will be taken from the SBR website (SBR Infoblad 006). For example the thermal transmittance U_g of double glass is 2,8W/m^{2}K. The thermal transmittance of U_g of the whole window (glass + frame) will be taken from Figure 4-44, with a thermal transmittance of the window frame of 2.2W/m^{2}K. For double glass this will give an U_g of 2.8W/m^{2}K.

• The material of the old window frame is wood and of the new window frame it is also assumed to be wood (the best choice in material for embodied energy of an outside window frame is European Softwood, with an embodied energy of 2686MJ/m^3. This is derived from the own calculation with the kgCO_2eq from NIBE, see Chapter 5.2).

• When the old window frame is removed the embodied energy that is still left in that element needs to be considered. The building is 50 years old, but the aim is 75 years for a building. Therefore 1/3 of the initial embodied energy still needs to be taken into account when removing the old materials.

• The old window frame is 120x50mm, the new window frame 114x67mm.

• Only the embodied energy of the glass and window frames will be considered, not the rest of the embodied energy such as coatings, gas between the glass layers, energy needed for placement etc.

• The costs will be estimated by looking at the costs of the type of glass per m^2 (Source: (JLMglas, 2013)) and the costs by operation energy (1kWh costs 0,22€). This is a very rough approach, but it will give an indication of the price differences between the glass types. This is a limitation, because for example the installation costs and maintenance costs are not included in this price.

• West and east orientation, without sun shading, which is the case study situation.

Calculations

The heat loss of each glass type will be calculated with the method from Swan consult. See Appendix E- 1: Calculation of Energy use for glass (Swan Consult Herkenbosch) for the used equations and the calculations for each separate glass type. It should be noted that this method is based on the EPN (the Dutch Energy Performance Standard).

Triple glazing is given as a calculation example in this chapter, the rest of the calculations per glass type can be found in Appendix E- 1.

Calculation for 1 m^2 triple glass:

Energy loss by transmission is:

*Q_{loss} = 238 * 1*1*1.4*1 = 333.2 MJ per year*

The heat gain by solar energy during the heating season is:

*For 1 m^2 triple glass on the east/west: Q_{gain} = 850*0.56*1*0.55*1 = 261,8MJ*

Total energy need for 1m^2 is: 333.2 - 261.8 = 71.4 MJ per year

New glass layer

*One new glass layer of 4mm for 1m^2 area would be: 1*0,004*2600*15 = 156MJ.*

New window frame

A new window frame of 4 meter long, made out of European softwood would be:

*0,114m*0,067m*4m*2686MJ/m^3= 82.1MJ*

Removal old window frame

*When removing the old window frame and glass, the remaining embodied energy that needs to be taken into account would be: 82.1MJ*1/3 = 27.4MJ for the frame and 149.8MJ*1/3 = 49.9MJ for the glass, total of 77.3MJ.*

Results

In Table 5-1 the comparison of glass types can be seen, together with the input of U-values and thicknesses. The embodied energy + heating energy needed in total for 35 years are calculated. When using HR++ glass instead of single (as is currently used), the energy use drops 75% already. When using Triple glazing it is also a lot better than HR++, with a 43% reduction. Compared to single glazing the energy reduction is over 86% with triple glazing.

The embodied energy is about 3.8% (double glazing) up to 20% (for triple glazing) of the total energy use over 35 years.

To see the pay-back time Figure 5-2 is made, where the results of the glass types can be seen in a graph. The energy use difference becomes bigger when the building lifespan is longer. Already after 2 years the triple glazing is the best choice. Also after 2 years the investment of energy is won back, compared to the current situation of single glass.

In Figure 5-3 the costs can be seen after a certain time. The triple glazing is best, but it is more expensive initially. After 10 years the investment in money is won back compared to HR++ glass, when assuming that the energy performance will not reduce.

Conclusions

For the comparison of the different strategies, the choice is made to use HR++ glass up to a lifespan of 35 years. This is because this type is currently still often used, also for the design of Portaal.

For the final design, to make the energy use as low as possible, it would be best to use triple glazing, since the total energy use over the long term is much lower. Over the long term the operation energy is the important factor. Even though triple glazing has a higher embodied energy, the gain by lower operation energy costs causes the total energy over 35 years to be much lower.

Concerning costs it would also be best using triple glazing for the case study building, since the payback time is about 10 years with this calculation.

Table 5-1: Comparison of different glass types

Glass type	U-glass	U-glass+window U_f=2.2	ZTA	Thickness glass x nr of layers,	Window frame size	Embodied energy (MJ)	Energy needed in MJ 1m² (for East and West) per year	MJ for 35 years lifespan
Single (current)	5,8	4,4	0,8	4mm 1 layer	120mm x 50mm	0 for old glass and frame	666.4	23.324
Single + inside layer	2,8	2,8	0,70	4mm, 2 layers	120mm x 50mm	0 for old glass and frame, 156MJ new glass	333.2	11.818
Double glass	2,8	2,8	0,70	4 mm, 2 layers	114mm x 67mm	82.1 MJ frame, 312 MJ glass, 77.3MJ old Total: 471.4MJ	333.2	12.133
HR glass	2,0	2,3	0,65	4mm, 2 layers	114mm x 67mm	82.1MJ frame, 312MJ glass, 77.3MJ old Total: 471.4MJ	238	8.801
HR+ glass	1,6	2,1	0,65	4 mm, 2 layers	114mm x 67mm	82.1MJ frame, 312MJ glass, 77.3MJ old Total: 471.4MJ	190.4	7.135
HR++ glass	1,2	1,8	0,6	4mm, 2 layers	114mm x 67mm	82.1MJ frame, 312MJ glass, 77.3MJ old Total: 471.4MJ	142.8	5.469
Triple glass	0,7	1,4	0,55	4mm, 3 layers	114mm x 67mm	82.1MJ frame, 468MJ glass, 77.3MJ old Total: 627.3MJ	71.4	3126

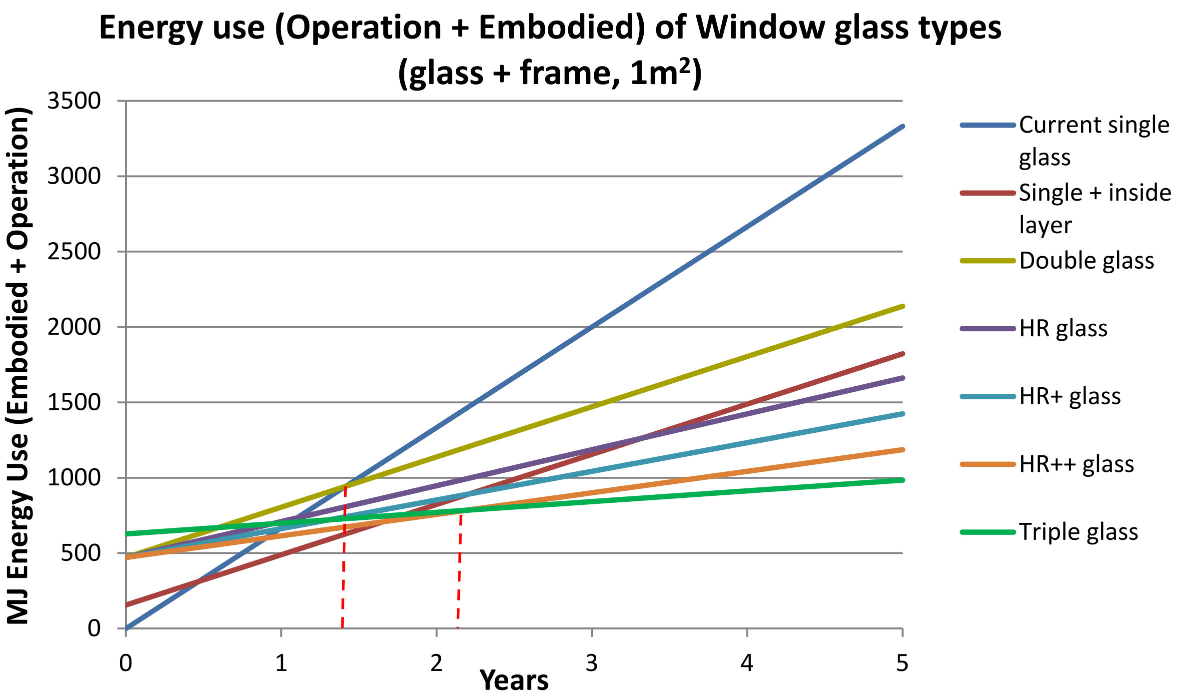


Figure 5-2: Energy use (Operation + Embodied) for different glass types

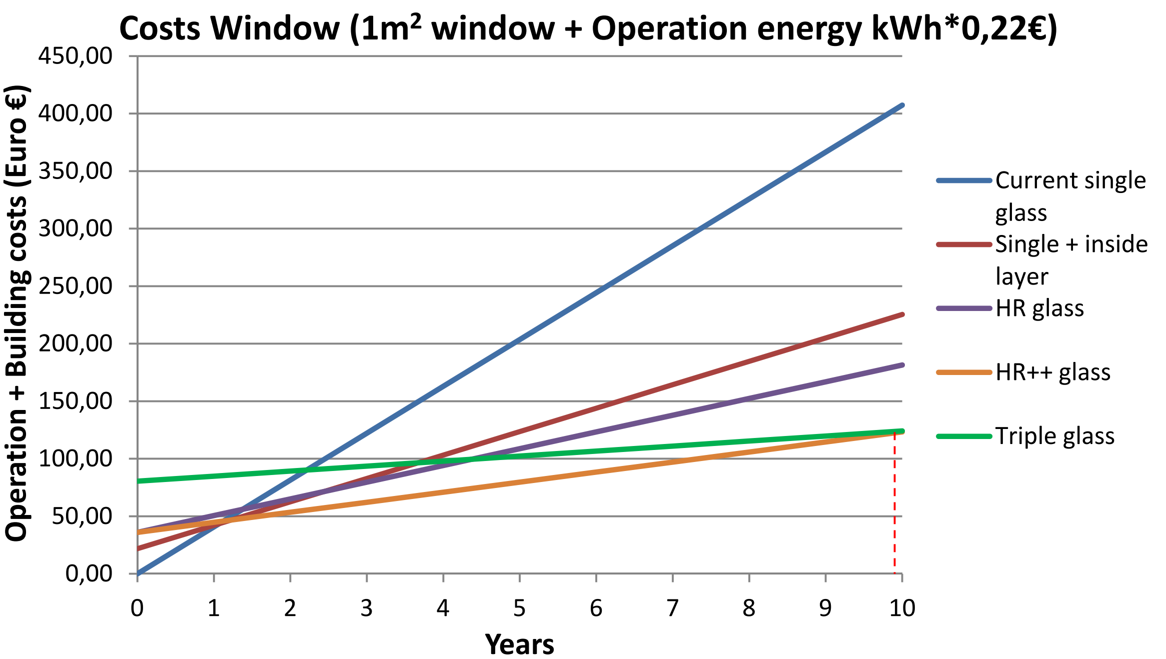


Figure 5-3: Costs of different glass types, m^2 window and operation energy costs

5.2 Material analysis

In this chapter the material comparison will be made per facade component. The data used is from the NIBE database, which is the Dutch Institute for Building Biology and Ecology. With this database the best material choice for different façade components will be assessed, mainly based on the embodied energy per material.

NIBE database

The division of components will be based on the database of NIBE (Haas, 2012). This includes components like cavity insulation, flat roof insulation, inside and outside window frame, doors, window sills and different types of cavity walls and facade cladding. Haas gives for each component different possibilities of materials, with data like U-values, thickness, environmental costs, building costs etc.

The materials per component need to be compared. This will be done in the following aspects:

- Embodied energy
- Environmental costs
- Building costs

The embodied energy will be the decisive factor, but the environmental costs and building costs may also influence the decision of designers, and therefore will also be assessed.

Building costs

The data of building costs is sometimes missing in the NIBE database, so this part is not complete. Therefore not always a good comparison can be made for the building costs, unless reliable data of these costs can be found on the internet. Therefore it is more an indication and will not be used in the final material choice. The building costs consist of the following aspects(Haas, 2012):

- Man-hours
- Materials
- Subcontractor costs
- Equipment

The building costs are made available by the Archidat database for building costs (www.Archidat.nl). The building costs are probably the initial prices, without considering the costs for maintenance. Also the building costs are very dependent on the date, every year the building costs can vary a lot. This aspect would in reality also influence the conclusions for the best material, since the building maintenance costs might be quite high also. But since no decisions are made for the materials concerning the building costs, this is not a problem. But for the designers that need to take the total costs into account, this aspect would need more investigation per material to make sure the building costs are up to date.

Environmental costs

The environmental costs are a summary of the following aspects:

- Emissions
- Raw materials
- Land use
- Hindrance

For the environmental costs some maintenance aspects are taken into account. For example with wood it is assumed that every 8 years an extra layer of paint is needed, which gives additional environmental costs.

Embodied Energy

Embodied energy is not given in the NIBE database. But kgCO_2equivalent is given, and this will be converted to Joule.

The CO_2 emissions in buildings in the NIBE database are due to ("Greencalc", 2010):

- Transport of raw materials, building materials and building elements
- Heating during production for example for production of cement, bricks and steel
- Electricity use during processes

This summary is also what is mainly considered for the embodied energy. An assumption is

made that the CO_2 emissions are mainly due to the burning of fossil fuels. In this thesis the embodied energy of materials will be calculated by the $kgCO_2eq$ value.
It is not completely correct to convert the $kgCO_2eq$ to embodied energy by a fuel conversion factor, because also other factors will influence the value of the Embodied energy. But to consider all factors while using the NIBE database would be too difficult. Since NIBE gives such extensive information about façade materials it is good to keep using this database, with a conversion factor, but it gives a restriction in how correct the data is.

Conversion $kgCO_2eq$ to Embodied energy

The conversion from $kgCO_2eq$ to Joule needs to be made, so that this embodied energy can be compared to the operation energy. Depending on the fuel type used, the CO_2 emissions are different. The percentage per fuel type used in the world is taken from IEA (IEA International Energy Agency, 2012). The conversion factors are taken from different sources and are often averages of ranges of conversion factors. The conversion from 1 $kgCO_2eq$ will be 15,545MJ, as can be seen in Table 5-2.

According Wikipedia, the Australian Government gives a global average of 1MJ = 0.098$kgCO_2$. This gives a lower embodied energy per $kgCO_2eq$ than converting it from the fuel sources, so it is better to use the own calculated conversion factor.

Component lifespan

The data that is given in the NIBE database is for a building with a lifespan of 75 years, with the FE (Functional unit) value. When giving the environmental costs for example, this is for 75 years. But also other building life spans should be considered in this analysis; therefore the data should be converted to values for one lifespan. A calculation example will be given in the next page for the environmental costs of cellular insulation plates. This method was used for all different materials from the NIBE database, with the help of Excel.

Table 5-2: Calculation for the conversion factor from $kgCO_2eq$ given in NIBE to MJ Embodied Energy

Primary energy supply 2010 Source: IEA	% of total (Source: IEA)	Conversion(carbon emission factor)			Source
		kWh	MJ	$kgCO_2eq$	
Coal/peat	27,3%	1	3,6	0,3	Carbon trust
Oil	32,4%	1	3,6	0,255	
Natural gas	21,4%	1	3,6	0,19	Carbon trust
Nuclear	5,7%	1	3,6	0,14	Time for change
Hydro	2,3%	1	3,6	0,14	Seinhurst, Synapse energy
Bio fuels and waste	10,0%	1	3,6	0,1485	Nottingham Energy Partnership
Other (renewable)	0,9%	1	3,6	0,04	Time for change
AVERAGE	100,0%	1	3,6	0,23159	

	MJ	**$kgCO_2eq$**
	15,545	1

	MJ	$kgCO_2eq$
Source: Wikipedia,	1	0,098
Australian Government	10,204	1

Cellular plates

Lifespan: 30 years (according to the NIBE database)

Environmental costs/FE for 75 years: 2.18€

1FE in this case is: The thickness required for an insulation value of Rc = 3.5m²K/W for 1 m²

Thickness cellulose plates 1FE = 0,14m

What are the environmental costs /m² for 1 lifespan?

Calculation:
Step 1: Environmental costs/m³ for 75 years:

(2.18€/1m²FE) /0.14m = 15.57€/m³

Step 2: Environmental costs/m³ for 1 lifespan:

15.57€/ ((75/30 years) rounded up) = 5.19€/m³

This calculation can be made easily in Excel for each material for every component type, for the building costs, environmental costs and embodied energy. This way the costs for 1m³ for 1 lifespan can be calculated for further calculations, since the lifespan of both the component and the building are important.

Building lifespan

Depending on the building lifespan, different materials might be the better option concerning embodied energy for example.

The calculation method to find the best material for a certain building lifespan for the cavity insulation will be shown.

In the case of materials of which the thickness is influence by the insulation value the method of

Table 5-3 is used. This includes components such as cavity insulation, roof insulation, inside window frames, outside window frames and window sills.

First the thickness needed for an Rc-value of 3.5m²K/W is calculated. This thickness is used to calculate the embodied energy. The total embodied energy also depends again on the lifespan of the component.

For example, when the building has a lifespan of 75 years, but the component only has a lifespan of 30 years, the component needs to be replaced 3 times during its life cycle. Therefore the embodied energy will be 3 times the initial embodied energy for one lifespan.

With some component types, such as the cavity insulation shown below, the lifespan of the building does not influence the best material choice.

Only embodied energy is shown here, but these results can also be made for environmental costs and building costs. But the embodied energy was the decisive factor. The complete results for all materials with this calculation are shown in Appendix E.

Table 5-3: Results for the Embodied energy for different lifespans, for different materials for Cavity insulation (green are best results)

		Embodied energy (MJ) for a certain lifespan (years)						
Material	**Thickness (m) needed for Rc-value = 3.5m²K/W**	***15***	***35***	***50***	***75***	***100***	***150***	***200***
Glass wool plates	0,123	83	83	83	83	166	166	249
BIO-EPS	0,133	202	202	202	202	405	405	607
EPS plates	0,140	256	256	256	256	511	511	767
Rockwool plates	0,123	157	157	157	157	315	315	472
Purfoam plates	0,081	279	279	279	279	559	559	838
Resolfoam plates	0,074	235	235	235	235	469	469	704
Wood fibre flexible insulation	0,133	115	115	230	230	346	461	576
Vlas-plates (incl. PE-foil)	0,123	118	118	236	236	355	473	591
Cellulose plates (incl. PE-foil)	0,137	89	179	179	268	358	447	626
Cellular glass	0,144	468	468	468	468	468	937	937
Cork plates, expanded	0,140	421	421	421	421	843	843	1264
XPS plates	0,133	984	984	984	984	1967	1967	2951
Sheep wool (incl. PE-foil)	0,123	2967	2967	2967	2967	5935	5935	8902

When looking at components that do not influence the insulation value, another method is used. An example is given of metal façade cladding (Table 5-4).

This time the thickness of the layer does not depend on the insulation value, but on the functional unit (FE). The FE thicknesses are given in NIBE, and the embodied energy is again calculated for each lifespan. As can be seen in Table 5-4, for different life spans other materials are best (the lowest embodied energy). Depending on the building lifespan the best material can be chosen by the designer.

Other choices might be better when also looking at the building costs and environmental costs. For example some choices may not be suitable for the design, because the costs are too high.

The complete results of all façade components and materials that were calculated are given in Appendix E, Table E- 1 to Table E- 26. Here all input data for these calculations and the results for Embodied energy, Building costs and Environmental costs for each lifespan can be found.

The previous calculations were also made for the components: Flat roof insulation, outside window frame, inside window frame, window sill, inside cavity wall, wood façade cladding, metal façade cladding, outside cavity wall, outside doors, profiles for inside element wall and inside insulation element.

Equations for further calculations

The total building costs are dependent on the lifespan. Materials have a certain lifespan and when the lifespan of the building is longer than that, the components need to be replaced again. This gives the following equation for the building costs:

$$\text{Building costs}/_{m2}\,[€] = nr.\,times\ replacement * Building\ costs\ 1\ lifespan$$

Also the environmental impact is dependent on the lifespan, and needs to be added again when the component needs to be replaced. This gives the following equation:

$$\text{Environmental costs}/_{m2}\,[€] = nr.\,times\ replacement * Environmental\ costs\ 1\ lifespan$$

When the material choice also influences the insulation value of the façade, also the operation energy needs to be considered. If the insulation value is not important, for example in façade cladding (there is a strongly ventilated cavity in between) only the embodied energy needs to be considered. The following formula shows how the energy comparison can be made:

$$\text{Total Energy use}/_{m2}\,[MJ] = nr.\,times\ replacement * Emb.Energy + Lifespan * \text{Operation Energy}/_{year}$$

Table 5-4: Results for the Embodied energy for different lifespans for different materials for Steel façade cladding (green is best result)

		Embodied energy (MJ) for a certain lifespan (years)						
Material	**Thickness needed for 1 FE (m)**	**15**	**35**	**50**	**75**	**100**	**150**	**200**
Steel, trapezium, coated	0,0007	148	296	296	445	593	741	1037
Steel, trapezium, galvanized and coated	0,0007	234	234	234	468	468	702	936
Aluminium, profile, not coated	0,0007	141	283	283	424	566	707	990
Aluminium, profile, coated	0,0007	225	225	451	451	676	902	1127
Aluminium, flat, sandwich-plastic core, coated	0,004	388	388	776	776	1164	1551	1939
Zinc, felsgevel	0,0008	389	778	778	1167	1557	2335	3113
Aluminium, flat, sandwich-aluminium core, coated	0,025	490	490	979	979	1469	1959	2448
Copper felsgevel	0,0006	253	253	253	253	253	507	507

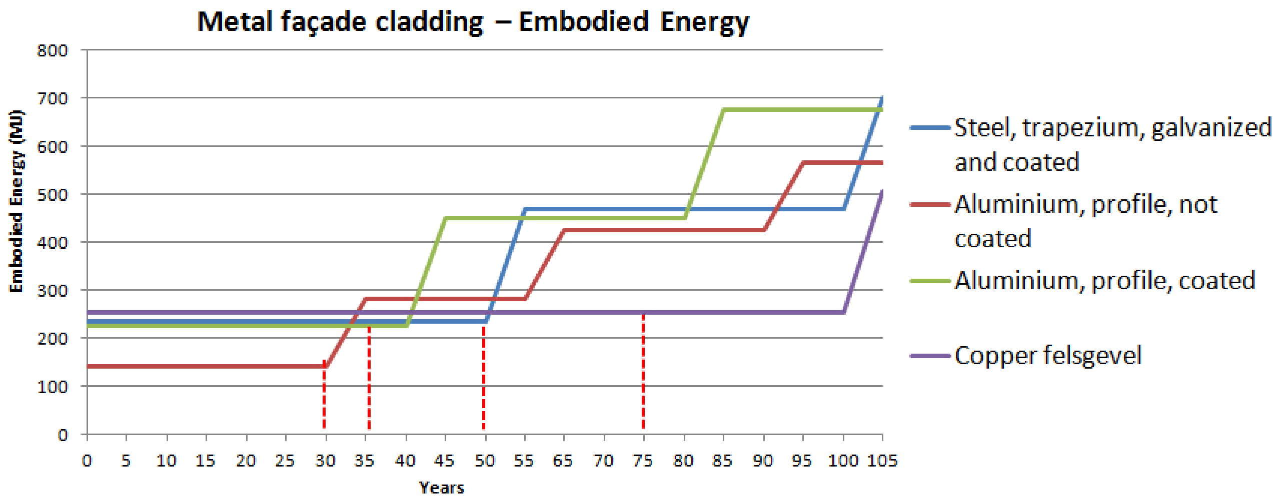


Figure 5-4: Visualisation of the total embodied energy after a certain amount of years, with the best choice in red dotted lines per chosen building lifespan

Conclusions

3. What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?

With the research that was done in this chapter, a choice can easily be made for a material of the façade, depending on the building life span. For example Figure 5-4 shows the best metal façade cladding choices. In such a figure the best material can easily be chosen, depending on the building lifespan.

The following materials came out as best from the research:

Cavity insulation: For the aspects embodied energy, building costs and environmental costs the *glass wool plates* score the best, for all life spans.

Flat roof insulation: The *EPS plates* score the best in all life spans and aspects.

Outside window frame: For the life spans 15 and 35 years the *European softwood,* renewably and normal grown, score the best for environmental costs and embodied energy. From 50 years and longer life spans the European hardwood scores better, because these are more durable and need to be replaced less. The PVC on steel core has the lowest building costs.

Inside window frame: For the inside window frames with a life span up to 35 years the *European softwood*, normally grown, is the best. After 50 years the European Hardwood, normally and renewably grown, are the best. Concerning prices the PVC on steel core is the cheapest, but after 100 years lifespan the European hardwood becomes cheaper than the PVC on steel core.

Window sill: The best choice in window sill for the embodied energy and environmental costs is *Pinewood*, for a lifespan up to 75 years. After 100 years the Robinia renewably grown is better. The building price of the Polyester concrete window sill is the best in all life spans. It should be taken into account when European softwood is used for the window frames the window sill is usually made of the same material.

Inside cavity wall: The *wooden frame, renewably grown*, is the best for the embodied energy and environmental costs. If a choice for a heavier construction is preferred due to the thermal mass, then *clay/mud brick* is the best choice for the embodied energy and environmental costs. For the price the best option is cellular/foam concrete blocks, but this has at least twice as high environmental cost and embodied energy than the others. All this is true for all life spans.

Wooden cladding: When looking for a wooden cladding*, Oak renewably grown* wins in all life spans. But the Robinia renewably grown comes very close to the embodied energy and environmental costs of the Oak and is therefore also a good option.

Metal cladding: Depending on the life span this type of cladding differs a lot for the best choice. For the embodied energy, with a life span of 15 years, aluminium profile not coated is the best. But for 35 years the *aluminium profile coated* is best. After 50 years the steel trapezium, galvanized and coated cladding is the best. After 75 years up to 200 years the copper facade is best. For the environmental costs in the life spans of 15 and 75 years the steel trapezium, coated, is best. For 35 and 50 years the steel trapezium, galvanized and coated is best. This is also the best after 100 years.

Stone of plastic cladding: When looking for a stone cladding, the *fibre cement plate* has the lowest embodied energy and environmental costs. The price is also relatively low.

Outside cavity wall: For masonry facades the *mud masonry* brick is the best option for almost all life spans concerning embodied energy and environmental costs.

Door: The best choice for an outside door for embodied energy and environmental costs is *tropical multiplex/tropical hardwood/PUR, renewably grown*. The price is also relatively low. For embodied energy and costs the same door but normally grown is also good, but the environmental costs are more than 6 times as high, so it is better not to choose it.

Materials for the strategy designs

In Figure 5-5 a simplified materialisation design is shown. The best materials from the previous conclusions were chosen for a lifespan of 35 years.

The design of the windows and placement of the ventilation grates are based on the design of Portaal. This way the different strategies can best be compared. The materialisation is based slightly on the existing situation, so the materials that were before stone or concrete are now also stone. The plate materials have now become wood. The masonry is still masonry, but now it is plastered, because this was the best material outcome of the masonry materials.

This materialisation will be kept the same in all strategies, so that a good comparison can be made of the different possibilities, without being influenced too much on the embodied energy of the materials.

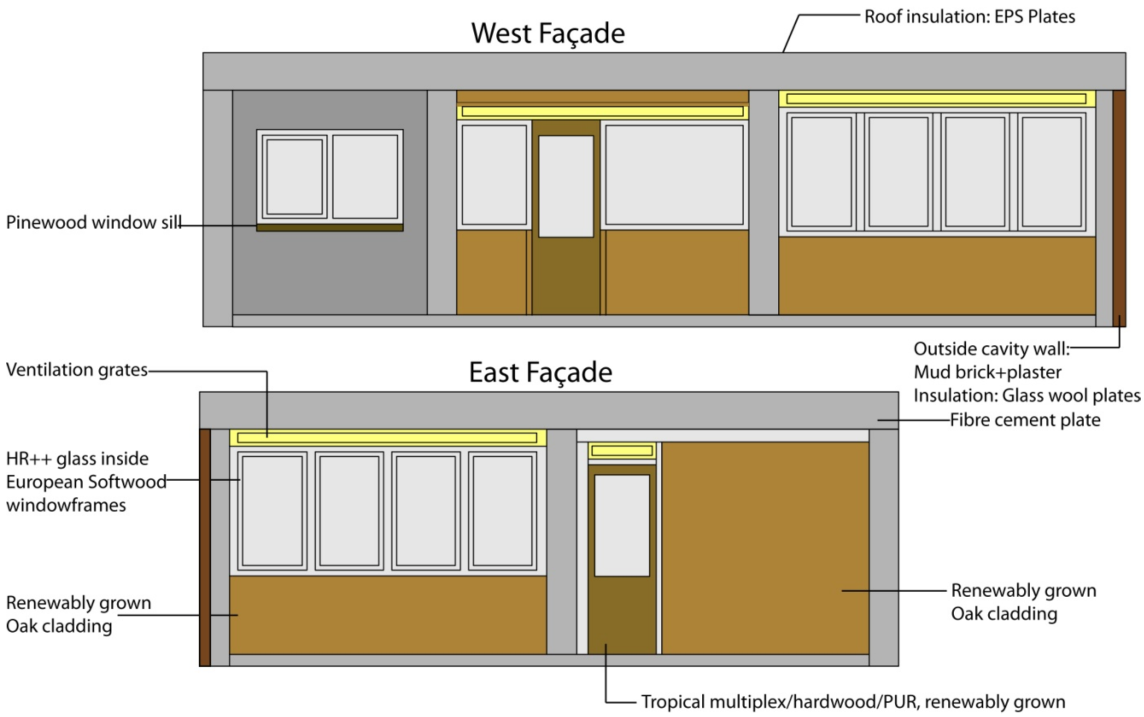


Figure 5-5: Design and material choice for the new façade for each strategy

Further possibilities for the Excel Tool

The best material choice for a real refurbishment project depends largely on the lifespan, the type of material you need (for example wood or metal cladding) and the maximum building costs you are willing to pay. More possibilities could be possible to pick the right materials, if the excel tool was developed further.

With extra additions of the excel file the best materials can be found, while having limitations in building costs or building life span for example. In Figure 5-6 an example can be seen, where you can pick the building component in question, for example the window frames. After that you choose the lifespan of the building, the maximum building and environmental costs and the desired R-value. With this data the calculator gives an output of the best material. This tool would work best if also the embodied energy is calculated, when inputting the R-value also. The energy consumption, (by the R-value) and embodied energy will be main decision factors, but maximums in other factors like building costs can influence the outcome.

Material calculator		
Building component		*For example: window frame or wooden cladding*
Lifespan building		*1-200 years*
Maximum costs/m2		*€*
Maximum environmental costs/m2		*€*
R-value		*K·m2/W*
	↓	
Result best material		*Material choice for the component*

Figure 5-6: Example for further development of the material choice calculator

5.3 Material reuse & recycling

One of the sub-research questions was as follows:

4. How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?

To answer this research question again the database of NIBE is useful. For each material they give a number from 0 to 100, with 100 as the best, which shows how well a material can be reused or recycled. The following analysis will be made based on this data.
Material Reutilization: In this factor the amount of recycled material counts for 1/3, and the amount that could be recycled at the end of its life is 2/3. Materials that are regrowable, like wood, are accounted as recycled materials (Haas, 2012).

As can be seen in Figure 5-7 and Figure 5-8 there is no clear relationship between the reuse/recyclability number that is given and the embodied energy or environmental costs. None of the other component materials show any relationship either. In this situation the wooden frame has the lowest embodied energy, but it has the lowest reuse/recyclability number.

When the embodied energy needs to be lowered further, the reuse and recyclability number needs to be increased. This can be realised by investigating ways to better recycle each of the components.

For each material the possibility to do this could be examined, to increase the reusability number and lower the embodied energy. For example in the case of wooden frames the possibilities of reusing could be investigated. The number of 20% that is now the case is quite low.

To research all the reuse and recycling possibilities for each material would go further than the scope of this research.

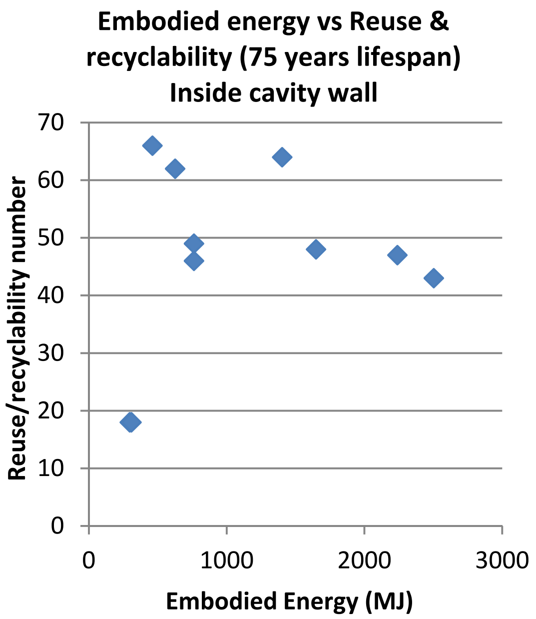


Figure 5-7: Correlation between reuse/recyclability and embodied energy

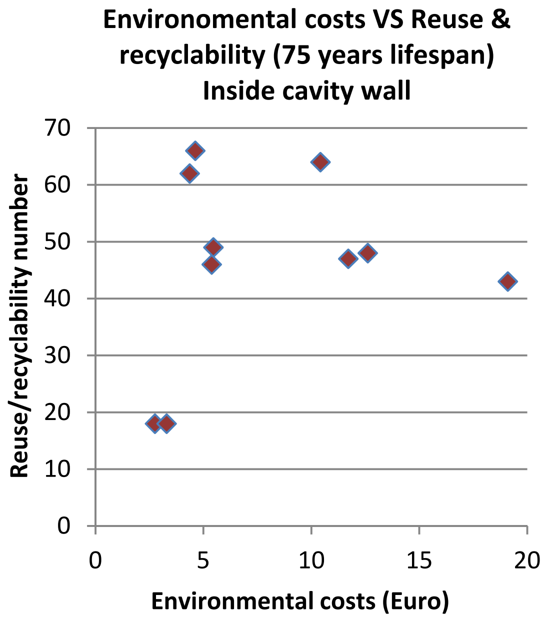


Figure 5-8: Correlation between reuse/recyclability and environmental costs

The embodied energy can be lowered by keeping façade materials that do not necessarily need to be removed.

An example can be given from the case study building. Research has shown that the masonry on the north and south side of the building need maintenance, but can afterwards still be kept (De Jong & Versteeg, 9 december 2010). Keeping this façade cladding might be the best option.

Another possibility would be for example to remove the plate materials that are now used as cladding and reuse them somewhere else, for example as inside finishing plates. This way the embodied energy that still needs to be counted (1/3 in this situation) can be ignored. The downside is that the embodied energy of the plate material is relatively small.

For other façade parts, such as the concrete prefab façade elements, the reusing/recycling would have a higher effect on the total embodied energy count. To reuse these in the building in another function is difficult, so keeping them underneath a new layer of insulation might be the best option. Again, the possibilities to better reuse/recycle these materials, which have not been taken into account already in the embodied energy, needs to be considered.

A final example is to use the single glazing from the windows (which are going to be removed) inside new railings on the balcony, as a parapet. The effect of this measure on the embodied energy will be examined now.

Calculation example balcony railing

The embodied energy of the balcony parts have been calculated with the kgCO_2eq values the NIBE database gives by using the conversion factor from Chapter 5.2.

Calculation railing with glass

The steel bars of the balcony railing have an embodied energy of 192MJ/m^1, opposed to 279MJ/m^1 when also adding glass. 766m^1 length of balcony is needed. About 900m^2 single glazing is removed from the building when the current windows are removed. This is enough to cover the entire balcony railing with glass, if it would be possible to reuse it there easily. If the glass would be removed without reusing, this would cost another 26MJ/m^2. In total this saves 23400MJ in the building, while also saving 66642MJ that would have been needed to use new glass inside the frame. This is a total saving of 1876MJ per apartment.

The embodied energy savings is about 4.4% of the total embodied energy used for an apartment. The energy that might be needed to reuse the glass, like cleaning, bringing to a workplace etc, has not been taken into account. This might make the energy savings significantly lower.

6. FACADE STRATEGY COMPARISON

In this chapter four strategies will be analysed, with the materialisation of Figure 5-5. The following strategies will be investigated: 1.Exterior addition of an insulated façade, 2.Complete façade replacement, 3.Interior upgrade, 4. Strategy of Portaal.

There will be two separate calculations made for the strategies. First hand calculations will be made for the Operation and Embodied energy, so that the difference in energy use per façade part can be investigated. Secondly the Operation energy will be calculated with EPC, so that the complete energy use can be calculated per strategy. The embodied energy will still be done with hand calculations.

By this strategy comparison certain conclusions and recommendations can be made for the final design of the case study building and for other refurbishment projects in general.

6.1 Calculation of Strategies in Excel and EPC

In Appendix F all the different construction parts are visualised in colours for each strategy, all with similar designs based on Portaal's design. By visualizing the facades and cross sections in colours, as can be seen in the adjoining figures, it was easy to calculate the area of each component for the embodied energy and operation energy. This way the different strategies on the case study building can be compared to each other.

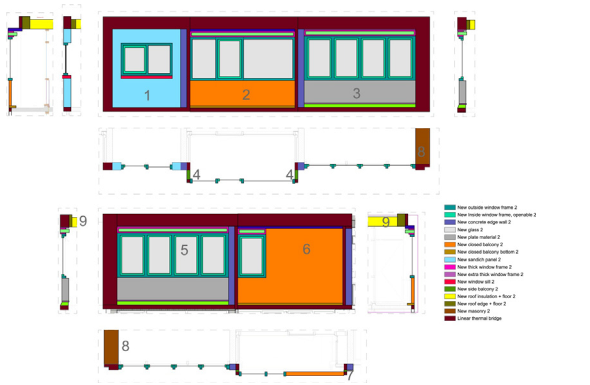


Figure 6-1: Different construction parts in the façade of strategy 1, external addition

The following method was used for all 4 strategies, but only the first strategy (external addition) will be shown in graphs and figures to explain how the calculations were made.

An example of the construction parts of the facade for strategy 1, external addition, can be seen in Figure 6-1. The façade is divided in facade parts, which are numbered from 1 to 9. This way the strategies can also be compared per façade part.

In the table in Appendix F, Figure F- 9, the Rc-value is shown specifically for smaller construction parts. But for the input in the EPC software the Rc-values of larger facade parts can be chosen. Therefore in Figure 6-2 and Figure 6-3 the simplified facade and output is shown. This way it can easily be put into the EPC software. The output is in MJ/year energy use in total for heating, domestic hot water, cooling, summer comfort, lighting, ventilators and electricity.

Figure 6-2: Simplified façade of strategy 1, external addition, for the EPC calculations

On the right side of Figure 6-3 the MJ use per year is shown per façade part for strategy 1. This is done so that the facade parts of different strategies can be compared. With the EPC software this is not possible, because only the energy use of the whole apartment is calculated.

In this chapter the four strategies will be calculated and results will be shown and compared for energy use, environmental costs and building costs. This was done for the top right apartment in the building.

6.1.1 Results per façade part, hand calculations

In this part the hand calculation method for the embodied energy will be explained. But also the hand calculations used to compare the façade parts of the different strategies will be given.

Embodied energy

The different construction parts, for example of strategy 1 in Figure 6-1, have certain facade construction layers. These layers have been put in excel, so that the R-value for a certain thickness would be calculated. Also the total embodied energy per layer was this way easily calculated per m^2. In Appendix F, Figure F- 7, the build-up of the construction parts for strategy 1 is shown.

These Rc-values and embodied energy/m^2 can be input in the excel file, so that the façade area with Rc-values can be seen. For the complete table for strategy 1, see Appendix F, Figure F- 9, the complete embodied energy per facade part can this way be calculated. The linear thermal bridges are not included for the operation energy, but are separately calculated for the embodied energy.

The embodied energy of parts that are removed of the old building account for 1/3 of the initial embodied energy, like explained before in chapter 5.1. The new facade parts use the complete initial embodied energy.

Boundary conditions façade

Insulation values:

• R_{roof} = 5m²K/W and $R_{façade}$ = 3,5m²K/W extra insulation on top of what is kept of the current façade.

• The insulation of strategy 4, Portaal, has different insulation values, based on the true design of the Housing Corporation.

• U_{Glass} = 1.85W/m²K, ZTA = 0.6, no sun shading, HR++ glazing

Calculating the U-value of cavity walls

For air cavities in between two façade layers the following rules apply (NEN 1068:2012, 2012):

• Non ventilated cavity: R_m=0,18m²K/W

• Weakly ventilated cavity: R_m=0,09m²K/W

• Strongly ventilated façade: R_m=0m²K/W. Façade materials outside of the cavity are also regarded as R=0m2K/W

Combination of materials

• Combination of glass wool plates and wooden frame renewably grown: About 11% of the wall is wood, so the lambda value will be: 0,035*0.89+0.2*0.11 = 0.05315W/mK. The embodied energy per m^3 will be calculated the same way.

Hand calculations Operation Energy

The calculation of the closed façade is made as follows:

• It is assumed that heating is only needed 7 months a year, from October to April (212 days). The average temperature (from www.weerstatistieken.nl) of these months is 6.13. The desired inside temperature is 20, so the ΔT is 13.87K.

• The Watt can be calculated by Surface [m²] * U-value [W/m²K] * ΔT.

• The MJ per year can be calculated by (Watt * 60seconds*60minutes*24hours*212 days)/1000000

This way in Excel the MJ use per year per facade part or facade construction can be calculated globally, when only looking at the transmission losses of the facade. In reality ventilation and internal heat, solar gain, are also factors. Only the solar gain will be looked at by the following equation for windows, given by Swan Consult. See Appendix E- 1: Calculation of Energy use for glass (Swan Consult Herkenbosch) how the calculation is done.

WEST FAÇADE	Constructions	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA	MJ use/year/ component	MJ energy use/year per facade part	MJ Total Embodied energy
Facadepart 1.A	Sandwich panel	4,03	4,12	0,24	West	Minimal	-	249	620	2938
Facadepart 1.B	Window total	1,90	0,54	1,85	West	Minimal	0,6	293		
Facadepart 1.C	Windowsill	0,17	0,97	1,04	West	Minimal	-	43		
Facadepart 1.D	Concrete edge	0,56	4,12	0,24	West	Minimal	-	35		
Facadepart 2.A	Closed balcony	3,28	3,68	0,27	West	Minimal	-	226	1191	3222
Façadepart 2.B	Window total	5,17	0,54	1,85	West	Minimal	0,6	800		
Facadepart 2.C	Suskast	0,97	1,50	0,67	West	Minimal	-	165		
Facadepart 3.A	Plate material	3,44	3,86	0,26	West	Minimal	-	227	1262	4025
Facadepart 3.B	Window total	5,61	0,54	1,85	West	Minimal	0,6	868		
Facadepart 3.C	Suskast	0,88	1,68	0,59	West	MInimal	-	133		
Facadepart 3.D	Concrete edge	0,56	4,12	0,24	West	Minimal	-	34		
WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA			
Facadepart 4.A	Side balcony	0,86	3,67	0,27	North	Minimal	-	60	120	330
Facadepart 4.B	Side balcony	0,86	3,67	0,27	South	Minimal	-	60		
EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA			
Facadepart 5.A	Plate material +	3,49	3,85	0,26	East	Minimal	-	230	1317	3915
Facadepart 5.B	Window total	5,61	0,54	1,85	East	Minimal	0,6	868		
Facadepart 5.C	Suskast	0,88	1,20	0,83	East	Minimal	-	186		
Facadepart 5.D	Concrete edge	0,54	4,12	0,24	East	Minimal	-	33		
Facadepart 6.A	Closed balcony	7,57	3,67	0,27	East	Minimal	-	524	821	2955
Facadepart 6.B	Window total	1,39	0,54	1,85	East	Minimal	0,6	215		
Facadepart 6.C	Suskast	0,46	2,41	0,42	East	Minimal	-	48		
Facadepart 6.D	Concrete edge	0,56	4,12	0,24	East	Minimal	-	35		
EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA			
Facadepart 7.A	Side balcony	0,17	3,67	0,27	North	Minimal	-	12	23	64
Facadepart 7.B	Side balcony	0,17	3,67	0,27	South	MInimal	-	12		
SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA			
Facadepart 8.A	Masonry	25,31	4,36	0,23	South	Minimal	-	1473	1473	19079
ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA			
Facadepart 9.A	Roof	77,04	5,57	0,18	-	Minimal	-	3514	3514	24132

Figure 6-3: EPC input for strategy 1, external addition

Table 6-1: Results in Operation energy and Embodied energy for a building lifespan of 35 years, per strategy

	Strategy 1 Adding		**Strategy 2 Replace**		**Strategy 3 Inside Insulation**		**Strategy 4 Portaal**	
	MJ O.E. / year	*MJ E.E. total*	*MJ O.E. / year*	*MJ E.E. total*	*MJ O.E. / year*	*MJ E.E. total*	*MJ O.E. / year*	*MJ E.E. total*
Facade part 1 (west)	620	2991	583	3674	*558*	*1433*	719	2992
Facade part 2 (west)	*1191*	3346	1427	5415	1780	*2996*	1796	3695
Facade part 3 (west)	*1262*	4183	1423	4368	1361	*2936*	1530	4388
Facade part 4 (west side balcony)	*120*	*330*	512	3140	430	1463	376	2523
Facade part 5 (east)	*1317*	4073	1424	5183	1354	*2893*	1501	3908
Facade part 6 (east)	*821*	3027	1010	5337	1026	*2484*	1144	4923
Facade part 7 (east side balcony)	*23*	*64*	173	1055	152	518	36	132
Facade part 8 (south masonry)	*1473*	19079	1593	42540	1526	*5587*	2591	2047
Facade part 9 (roof)	*3514*	*24132*	3723	36851	*3514*	24294	6744	12456
TOTAL	-	61.225	-	107.563	-	44.604	-	37.001

Table 6-2: Energy use of Embodied energy and Operation energy in MJ, in a lifespan of 35 years

Lifespan of 35 years	Ext. Addition Strategy 1 Total Energy use (MJ) 35 years	Replacement Strategy 2 Total Energy use (MJ) 35 years	Int. Insulation Strategy 3 Total Energy use (MJ) 35 years	Portaal Strategy 4 Total Energy use (MJ) 35 years
Facade part 1 (west)	24691	**24079**	**<u>20963</u>**	28157
Facade part 2 (west)	**<u>45031</u>**	**55360**	65296	66555
Facade part 3 (west)	**<u>48353</u>**	54173	**50571**	57938
Facade part 4 (west side balcony)	4530	21060	16513	15683
Facade part 5 (east)	**<u>50168</u>**	55023	**50283**	56443
Facade part 6 (east)	**<u>31762</u>**	40687	**38394**	44963
Facade part 7 (east side balcony)	869	7110	5838	1392
Facade part 8 (south masonry)	**70634**	98295	**<u>58997</u>**	92732
Facade part 9 (roof)	**<u>147122</u>**	167156	**147284**	248496
TOTAL	**<u>423160</u>**	522943	**454139**	612359

Results of calculations per façade part

The Operation energy and Embodied energy of the façade parts separately can be compared in Table 6-1. This was done with hand calculations. For many parts, addition is best concerning operation energy, due to extra insulation capacity of the existing structure. But when looking at the lowest embodied energy, the inside insulation is often the best, due to lower material needs, because there is no new external cladding needed.

The total results over 35 years, which are shown in Table 6-2, show differing best results per façade part. The best choices are made in bold and underlined, and the second best choices are made with bold letters. These results show that in different façade parts, other strategies might be best.

For most façade parts exterior additions is the best strategy, and interior insulation is second best. But for the south facade with masonry, the interior insulation has a much lower energy use, due to the high embodied energy of the new masonry needed for exterior addition (see Figure 6-4).

Discussion

For most of the strategies in Table 6-2, no definite conclusions can be made. This has multiple reasons.

First not all parameters were exactly the same. For example in façade part 2, the exterior addition strategy design had no door because it had no outside space. The other strategies did have a door, which caused a decrease in total insulation value of that façade. To be able to compare the different strategies completely correct, the design should be exactly the same (the same area of window, closed façades and doors).

Secondly there is sometimes a difference in façade area. For example in façade part 3, the area of the façade for strategy 1 is lower, due to the design of the strategy. This is also the case of the west and east side balconies, which sometimes almost disappear in the design. This problem does not count for the roof and masonry, where the surface area is kept the same in all situations.

Conclusions

Even though there are points for discussion, certain conclusions can be made.

The first thing to note is that by exterior addition of insulation on the existing structure, the insulation value of the old façade is also accounted. Therefore there is a higher total insulation value. You can see this well in the results of façade part 9 (the roof) where the interior and exterior insulation addition strategy have a better result than complete replacement (see Figure 6-5).

Secondly if you keep the old construction, the embodied energy needed for removal does not add up to the total, therefore exterior or interior addition would be better than replacement.

Third, the embodied energy of the old façade, like in façade part 8 (masonry), is very high. Also the new embodied energy for masonry very high (see Figure 6-4).

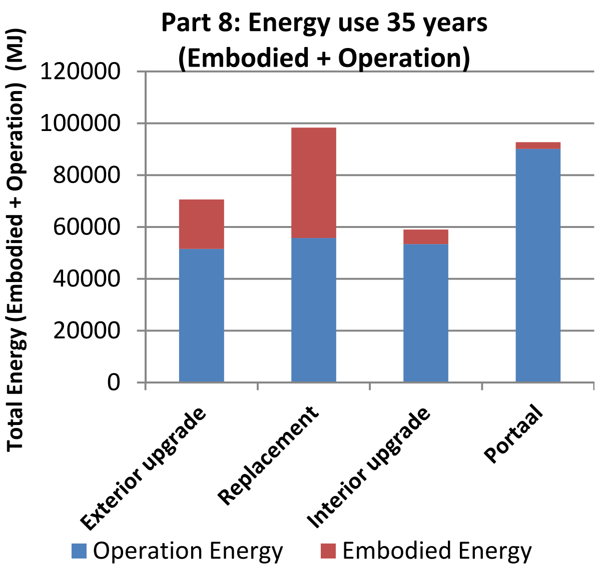


Figure 6-4: Energy use (Operation and Embodied) for façade part 8, south façade of masonry

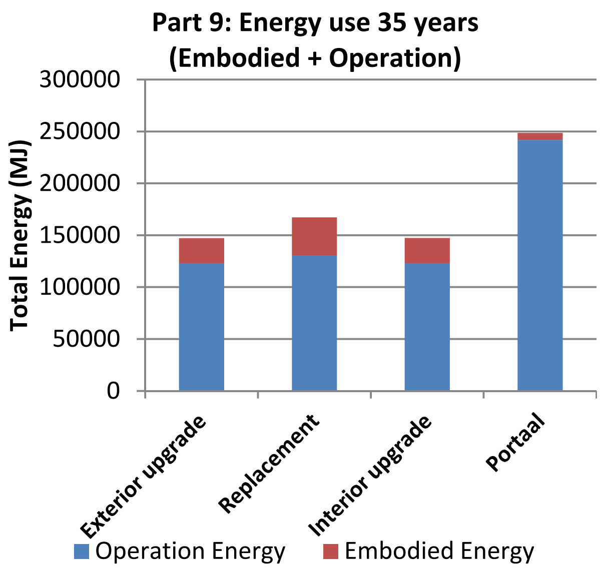


Figure 6-5: Energy use (Operation and Embodied) for façade part 9, the roof

6.1.2 Results per strategy with EPC

For the calculations of the complete design per strategy the EPC was used for operation energy. The results in energy use will therefore be different from chapter 6.1.1, because also other factors such as solar energy gain, ventilation heat losses etc. have been accounted for in the EPC. The embodied energy calculations were made the same way as in chapter 6.1.1 and are therefore the same.

Boundary conditions EPC

General information

• Calculations for the top corner apartment.

• Floor area depends on strategy.

• The operation energy is the total energy needed from the EPC (heating, cooling, ventilation, electricity etc.)

Infiltration

• qv10;spec = 3 $dm^3/s{\cdot}m^2$

• Height of the building = 13.8m

• Standard façade type, multiple stories, top corner.

Internal heat capacity

• Building type: traditional, mixed heavy.

Insulation values:

• R_{roof} = 5m^2K/W and $R_{façade}$ = 3,5m^2K/W extra insulation on top of what is kept of the current insulation.

• The insulation of strategy 4, Portaal, has different insulation values, based on the true design of the Housing Corporation.

• UGlass = 1.85W/m^2K, ZTA = 0.6, no sun shading, HR++ glazing.

Other

• Obstruction on the outside of the façade depends on the strategy design.

• The design of the façade is based on the design of Portaal, with slight changes depending on the strategy, but the percentage of closed and glass is kept almost the same.

Installations

• Heating with an electric heat pump groundwater, 35°C<T<=40°C, heat storage

• Domestic hot water with external heat supply, with an efficiency of 100%.

• No cooling

• Decentralized heating system for ventilation with heat exchange and CO_2 regulated with zoning.

Variable Parameters

• Per strategy the parameters that change can be found in Appendix F.

Results strategies 35 years

The operation and embodied energy of the four strategies have been calculated in EPC for a lifespan of 35 years, and summarized in Table 6-3. When looking at the strategies separately, Strategy 3 inside insulation has the best results. Secondly external addition is best, thirdly replacing and last the strategy of Portaal. The strategy of Portaal is higher in total due to the higher operation energy and the Replacing is high due to the higher initial embodied energy. For the energy needed only for heating, the subdivision in best choice is the same.

Energy use (Operational + Embodied Energy)

In Figure 6-6 the different strategies can be seen. Each year there is an addition of operational energy, while there is only once every few years a new embodied energy needed by refurbishment. For example after 75 years many materials need to be replaced, therefore there is a sudden increase in that year.

When using less environmental friendly materials with a higher embodied energy, the total energy use (mainly due to the embodied energy) can be higher by about 20% of the total energy use (operation + embodied) after 35 years. This can be seen in the example in Figure 6-7 in the orange line. In this case, a non-sustainable choice of materials was made, often with the cheapest materials and sometimes another choice that had a higher embodied energy. This proves that a good material choice has a big influence on the life cycle energy use.

Table 6-3: Operation energy per year and for 35 years, embodied energy for 35 years and total energy use per strategy

	Strategy 1 Adding	Strategy 2 Replace	Strategy 3 Inside addition	Strategy 4 Portaal
Operation energy use/year EPC (MJ)	35.758	33.632	32.834	36.434
Heating energy/year (MJ)	17938	17350	16996	19569
Operation energy 35 years (MJ)	1.218.035	1.177.120	1.163.680	1.257.690
Embodied energy after 35 years (MJ)	60.659	155.332	44361	41.506
Total energy use 35 years (MJ)	1.278.689	1.332.452	1.208.041	1.299.196
EPC	0.73	0.73	0.74	0.77
M² floor area	86,4	77	72,4	82,1
Dm³/s needed	104	92.5	87	99

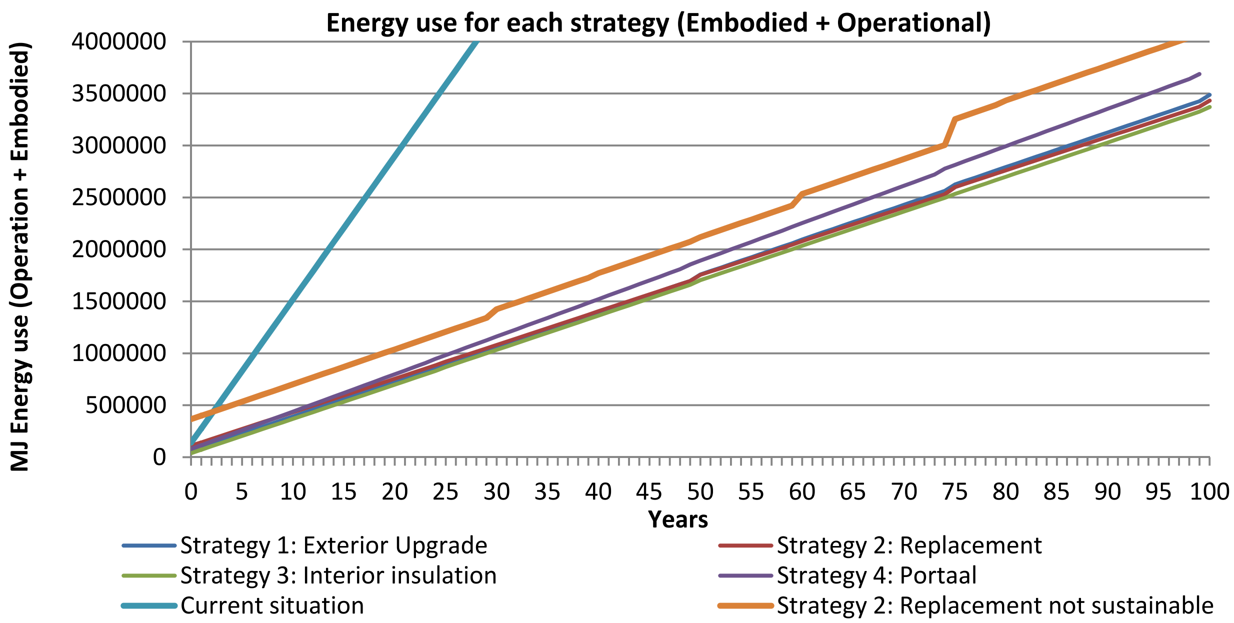


Figure 6-6: Energy use (operation + Embodied) for the different strategies, and strategy 2 with non-sustainable materials

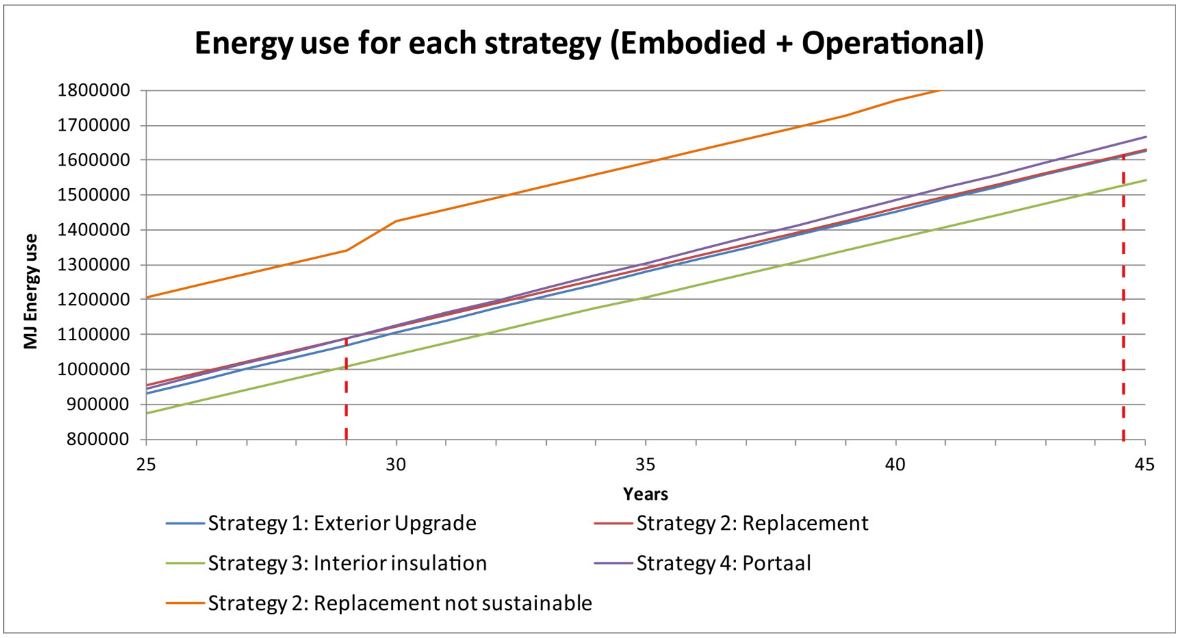


Figure 6-7: Zooming into 25-45 years of Figure 6-6

Energy use and building lifespan

In Figure 6-7 the best strategy depending on the building lifespan can be seen. Conclusions can be drawn from this, but the values are very close together, so the influence on the energy is not very large. This difference might be larger when less sustainable materials are used.

After a lifespan of 29 years, the strategy of Portaal becomes a less good choice compared to façade replacement. But for a lifespan below 29 years the strategy of Portaal is a better option than replacement.

After a lifespan of 45 years the strategy of complete façade replacement becomes a better option than Exterior upgrading. But since Portaal is planning on a lifespan of 35 years, the interior or exterior upgrading would be the best alternative.

Building Costs per strategy

The building costs per strategy have also been calculated with the Excel file by adding up the costs of each of the layers of the façade, just as with the embodied energy. The data from NIBE has been used, where the building costs account for the initial costs of man hours, materials, subcontractor costs and equipment. Some other costs such as maintenance are not included in this.

The results per façade strategy can be seen in Figure 6-9. Every few years certain façade materials need to be replaced, so there are again building costs, which are the increase in building costs after a certain amount of years each time. The building costs for the Replacement is the highest, but the Exterior Upgrading is also costly. The interior insulation and the strategy of Portaal have about the same building costs in all life spans.

It should be noted that the building costs are an indication, so that the strategies could be compared. In reality the costs would be much higher, since there are not only costs for the façade materials itself.

Environmental Costs per Strategy

In Figure 6-9 the environmental costs of the materials in the façade per strategy are shown. It is evident that strategy 2, complete replacement, is in all life spans the worst concerning environmental costs. The plan of Portaal is the best, but the Operation energy costs are higher. This is maybe because a more extensive refurbishment increases the costs too much for the housing company. The Exterior and Interior insulation have almost the same values concerning environmental costs.

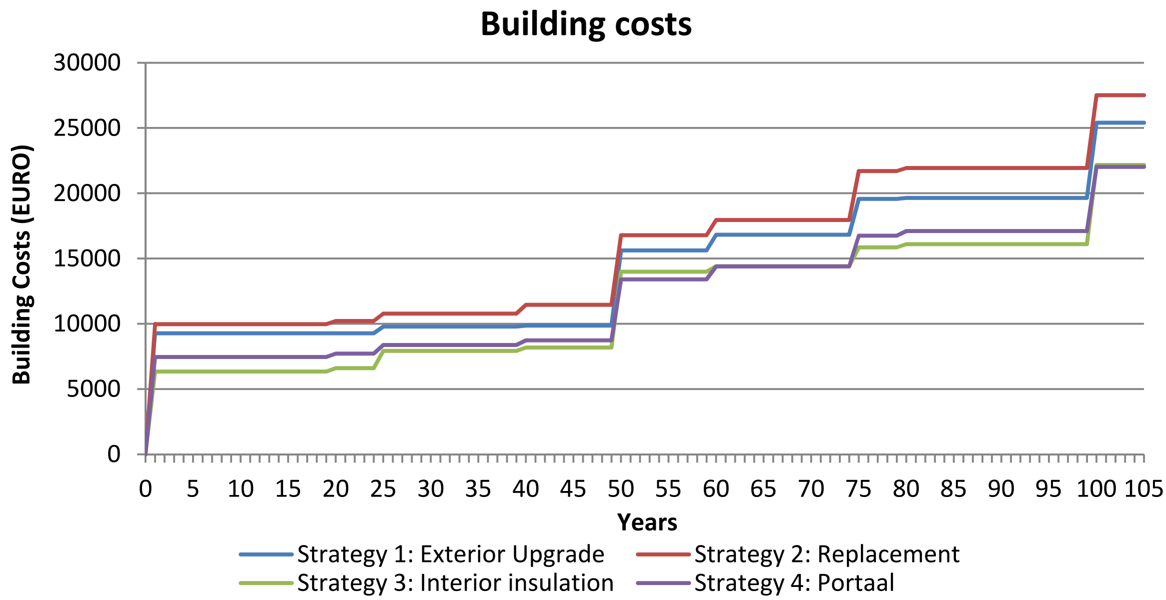


Figure 6-8: Building costs of the different strategies

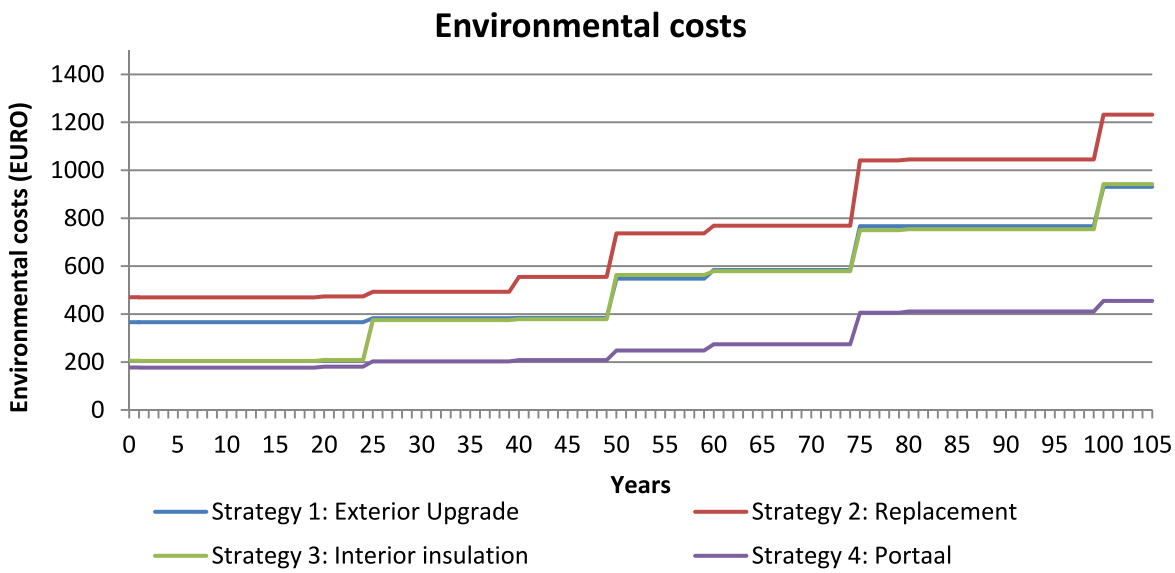


Figure 6-9: Environmental costs of the different strategies, for the façade

Total costs (Building Costs + Operation Energy Costs)

To see the influence of the total costs, so building costs + Operation energy costs, Figure 6-10 has been made. Operation energy costs are counted as 0.22€ per kWh.

Concerning the building costs up to 11 years lifespan the exterior upgrading is better than replacement, but the strategy of Portaal is the best. Up to 18 years Portaal is still best, but after that lifespan the strategy of complete replacement is a better option concerning the costs. In a life span of 35 years, the Replacement strategy is 5000 euro cheaper than the addition strategy, when looking at building and operation costs together. The graph from 0 to 100 years for the total costs can be found in Appendix F, Figure F- 28. Again it should be noted that the building costs also include other factor, and therefore in reality would be higher.

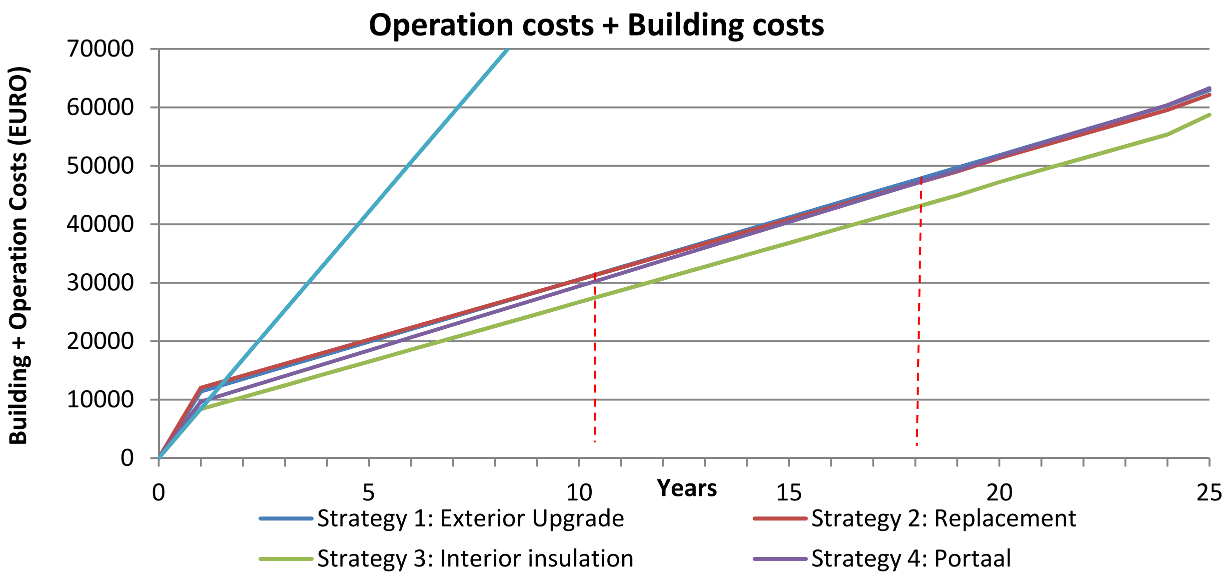


Figure 6-10: Operation energy costs + building costs, zooming in from 0 to 25 years

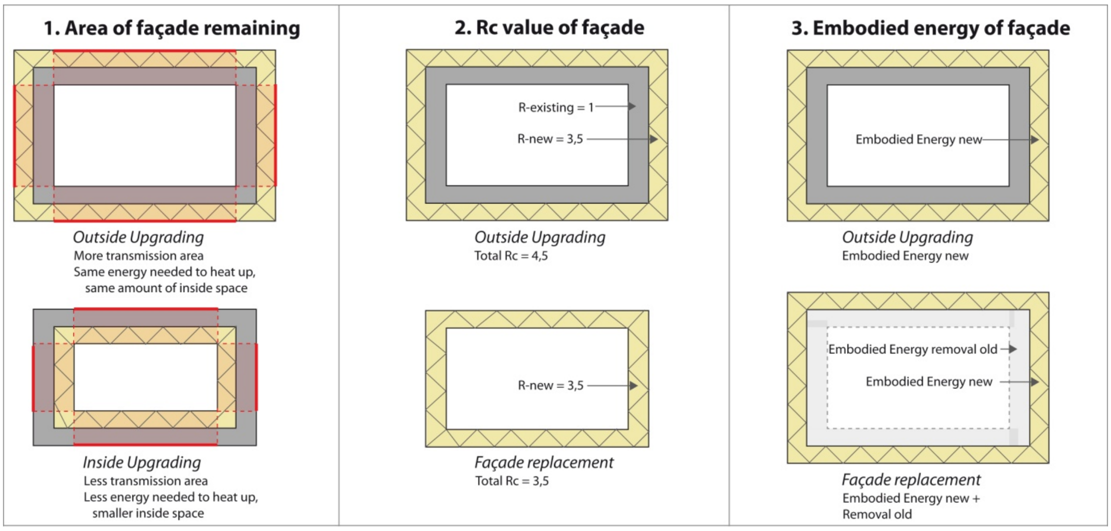


Figure 6-11: Parameters that influence the strategy comparison results

Explanation results energy use

The results of the energy use of the different strategies are due to three factors, which are summarized in Figure 6-11.

First the area of the remaining façade is important. When using outside upgrading, the area of the outside façade stays the same. But when using inside upgrading, the outside façade becomes smaller. This causes a smaller transmission area and therefore a lower energy use.

Secondly the Rc-value of the façade is important. The strategy of Portaal has of course a smaller Rc-value and therefore a higher energy use. But also the remaining insulation value of the façade is important. When using exterior upgrading, the insulation value of the old façade is added up to the new Rc-value. But when replacing the façade, there is only the new insulation value and therefore a higher energy use.

Thirdly the embodied energy of the façade is important. With replacement of the façade you have to remove the old façade, which costs embodied energy. But when using exterior upgrading this is not the case. Also by external addition you need embodied energy for the new cladding, with interior insulation this is not the case so the embodied energy is lower there.

6.1.3 Results per strategy: maximum possible

Maximum insulation values possible differ per strategy. This is because the inside and outside appearance often changes, which might not be desired. These possible limitations are shown in the table below. A maximum insulation value for façades of 7m²K/W is taken and 9m²K/W for the roof.

For some strategies, like the interior insulation, there are limitations due to the detailing and floor height, so not a lot of insulation is possible.

In Figure 6-12 an example of the restrictions is given. The rest can be found in the appendix F.

In Figure 6-12 in red circles the restrictions in the floor plans are shown for interior insulation. For example in the vertical cross section, it is evident that insulation gives problems underneath the roof, because there is a restriction in floor height. Also interior insulation gives problems, due to the window frames and loss of interior space. With façade replacement you also come across some problems, as can be seen in Figure 6-13. For example the balcony space is lost due to insulation on the sides of the balcony. You do not have this problem with strategy 1, exterior addition, since here the balcony is closed off.

Table 6-4: Maximum insulation possible per façade part and per strategy, depending on detailing restrictions

Façade part	**Strategy 1 Addition**		**Strategy 2 Replacement**		**Strategy 3 Inside insulation**	
	Max. Insulation (m²K/W)	Why?	Max. Insulation (m²K/W)	Why?	Max. Insulation (m²K/W)	Why?
Facade part 1 (west)	7	No restrictions	7	No restrictions	7	
Facade part 2 (west)	7	No restrictions	7	No restrictions	7	
Facade part 3 (west)	7	No restrictions	7	No restrictions	7	
Facade part 4 (west side balcony)	7	No restrictions	3,5	Less space in balcony	3,5	Changes placement of window frames
Facade part 5 (east)	7	No restrictions	7	No restrictions	7	
Facade part 6 (east)	7	No restrictions	7	No restrictions	7	
Facade part 7 (east side balcony)	7	No restrictions	3,5	Less space in balcony	3,5	Changes placement of window frames
Facade part 8 (south masonry)	7	No restrictions	7	No restrictions	3,5	Changes placement of window frames
Facade part 9 (roof)	9	No restrictions	9	No restrictions	5	Not enough space until ceiling

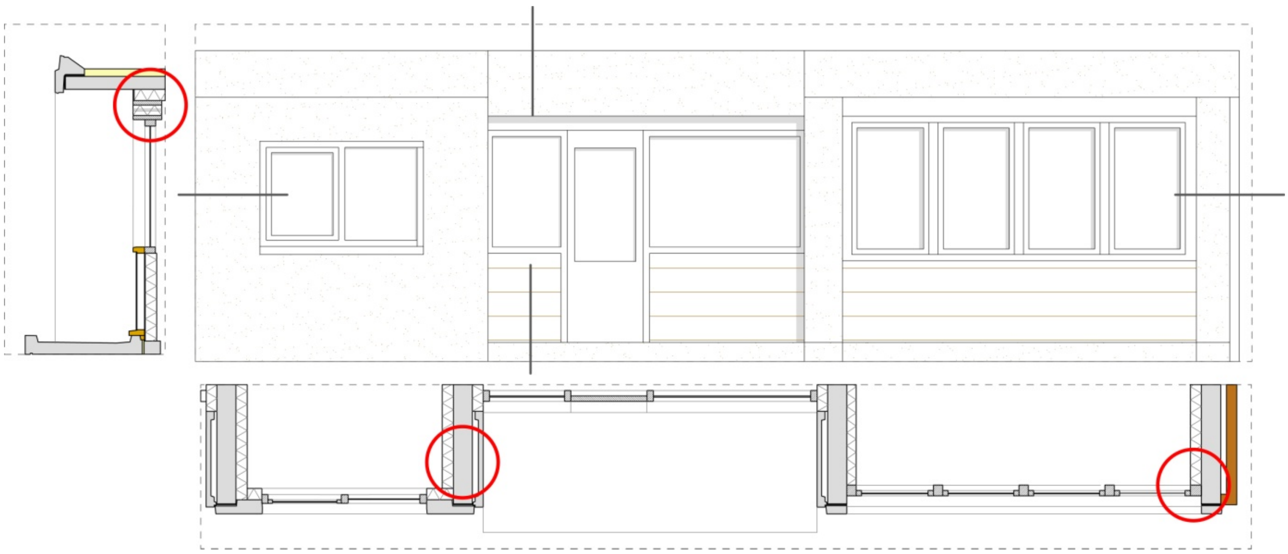


Figure 6-12: Design for strategy 4, interior upgrading, in more detail, with in red the restrictions in detailing

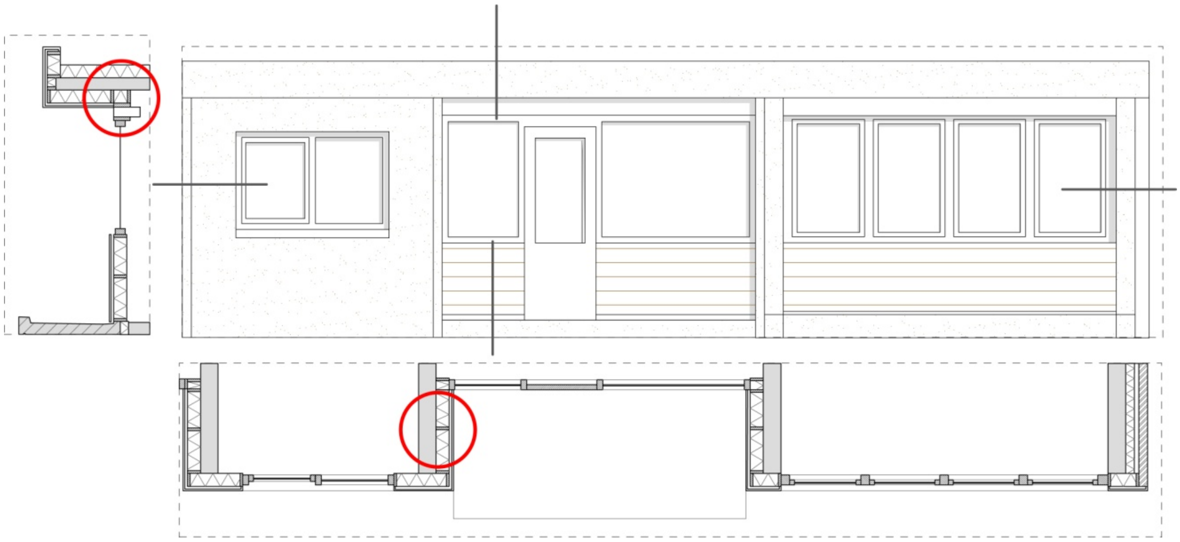


Figure 6-13: Design for strategy 3, façade replacement, in more detail, with in red the restrictions in the detailing

Results

In Figure 6-14 the difference between the maximum and minimum possible insulation is shown by the energy use after a certain lifespan. With interior insulation there is not much improvement possible in energy reduction. With exterior upgrade and replacement about 2% improvement is possible.

Conclusions

With interior insulation there are many restrictions in the detailing, so if a very well insulated building is desired this might not be possible in some places. With complete façade replacement and exterior insulation there are much less restrictions. When closing off the balconies (which is done with the strategy of exterior insulation), there are less problems concerning detailing. With façade replacement there is still the issue that the balcony becomes much smaller when it's insulated well. The strategy of closing off the balconies is then the best choice in that façade part.

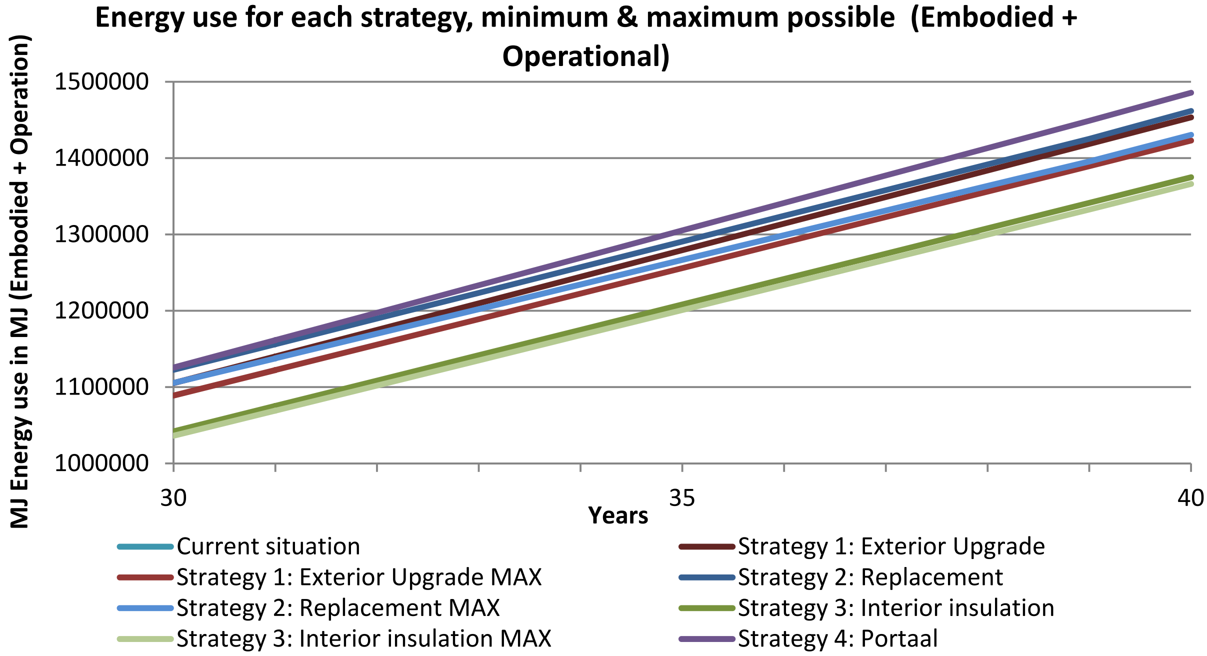


Figure 6-14: Energy use for minimum insulation and maximum insulation possible (Embodied + Operational), zoomed in

6.2 Conclusions façade strategies

A lifespan of 35 years is considered for the conclusions, since that is the lifespan Portaal has planned for the case study building. Also some conclusions for the materialisation are given, to be used in the final design.

Glazing

The investment of the triple glazing can be regained already after 2 years concerning energy use, and after 10 years in costs (building + operation), compared to HR++ glass.

Materials per component

Per component different materials are the best; Glass wool plates for cavity insulation; EPS plates for the roof; European Soft or Hardwood for window frames; Pinewood for window sills; Wooden frame for inside cavity wall; Renewably grown oak for wooden cladding; Aluminium profile coated metal cladding; Fibre cement plates for stone cladding; mud masonry brick for outside cavity wall; tropical multiplex/tropical hardwood/PUR for doors.

The best choice of cladding is wood (oak), but the fibre cement plates are the second best choice if another material than wood is desired.

Energy use per façade part

For a lifespan of 35 years, almost for all façade parts an exterior addition is the better choice, but a careful consideration needs to be made what strategy is used. For the masonry on the south part of the building interior insulation has a lower energy use, due to the fact that there is no embodied energy needed for new brick cladding.

A solution for the masonry would be to partly insulate inside the cavity and partly inside, to restrict the amount of inside space lost, see an example in Figure 6-15.

Energy use per façade strategy

For complete façade strategy with a lifespan of 35 years, the operation energy is the lowest with inside insulation. The embodied energy is lowest with the strategy Portaal has. But for the total energy use, inside insulation is best, followed by external addition, complete replacement and the strategy of Portaal. Inside insulation performs best in total, but not when looking at separate strategies. In that case the second choice of external addition is better, also concerning detailing to prevent problems with condensation for example.

Where possible, the current construction or materials should be kept, to keep the embodied energy lower. Factors that influence the outcome of best strategy are: Outside façade area (transmission losses), inside area (due to the energy needed to heat the space), the Rc-value of the façade (due to keeping old insulation of the façade) and the embodied energy of the new and removal of the old.

Building costs per strategy

The building costs of the strategy of interior insulation and of Portaal are almost the same and the lowest. Followed by external addition and last Replacement is the most expensive.

Operation + Building costs per strategy

When also looking at the operation energy costs together with the building costs, the interior insulation is again the best choice. Until 11 year the strategy of Portaal is second best, but after 16 years the complete replacement is the second best choice after interior insulation. After 18 years exterior addition is the third best choice.

Environmental costs per strategy

When looking at the different strategies concerning environmental costs the strategy of Portaal is the best, followed by exterior and interior addition, which have the same costs. It is not known if the use of good materials was a conscious choice for Portaal. The most expensive is again the complete façade replacement.

Recommendations

Portaal kept the added insulation low a lot of the times; this causes the operation energy use to be higher. By improving the insulation values, the energy use could be lowered significantly.

If the insulation value of the existing façade part is high, the existing façade should be kept and interior or exterior additions should be made. When the embodied energy of the existing façade is high, this is also the case. When the new embodied energy of the façade is very high, it should be considered to keep the old facade and make interior additions, such as with the south façade of masonry.

If the façade part has a low insulation value and a low embodied energy, the strategy of complete replacement could be considered, because this gives less problems in detailing and gives more possibilities for the design (for example other window placement is possible).

Future research

In the future, it is best to keep all parameters the same in the different strategies, such as placement of doors and windows. No mixture of designs should be used, like was done with strategy 1, where the balcony is closed off. This way the exact best strategy can be found for that façade part, depending on: Embodied energy needed to remove the old, embodied energy needed to construct the new façade layers and the additional insulation value the old construction provides.

With improvement of the excel file, maybe also by integrating it into a 3D software, the choice of strategy could be made very easily. It would save a lot of time if the computer could calculate the best strategy, instead of making designs and calculations by hand for each strategy.

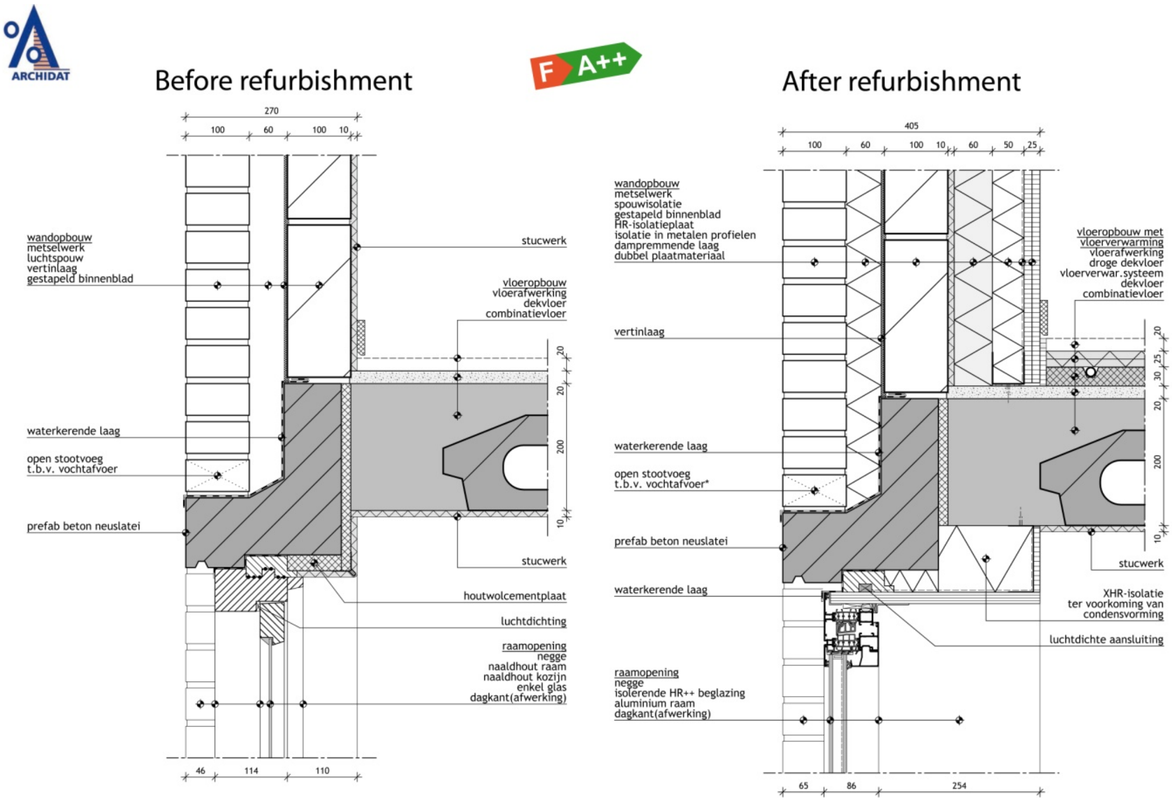


Figure 6-15: Solution of a masonry detail from Archidat (Van Duijn, 2012)

7. CASE STUDY DESIGN

A specific design will be made for the top corner apartment, but in the end also the energy calculations of the other apartment types will be made, to calculate the weighted average values

First variation studies will be done, to form a base for the design. Afterward the own design will be made and compared to the current situation and to Portaal's Design concerning energy use, environmental costs and building costs. In the end of this chapter conclusions will be made.

7.1 Perfecting the design with variation studies

Variation studies will be made, to see what the best results will be for this building concerning energy use. The EPC calculations give certain restrictions in what the possibilities are of these studies. The following aspects were chosen, based on what the possibilities were:

1. Glass percentage
2. Insulation thickness
3. Glass type
4. Thermal mass
5. Infiltration
6. New balconies
7. Balance between new balconies/new inside space

Variations in floor plans were made, to see the influence of the building plans, outside façade area and amount of balconies on the energy use. Important factors for the different options are assessed in Table 7-1. Option 3 has the best results in energy use, except for the material use of the balconies. The circled apartment in Figure 7-1 (on the top floor) is going to be examined further in this chapter, to find the best balance in the different aspects like glass percentage, insulation etc. Later the design will be perfected further.

Variations in building plans

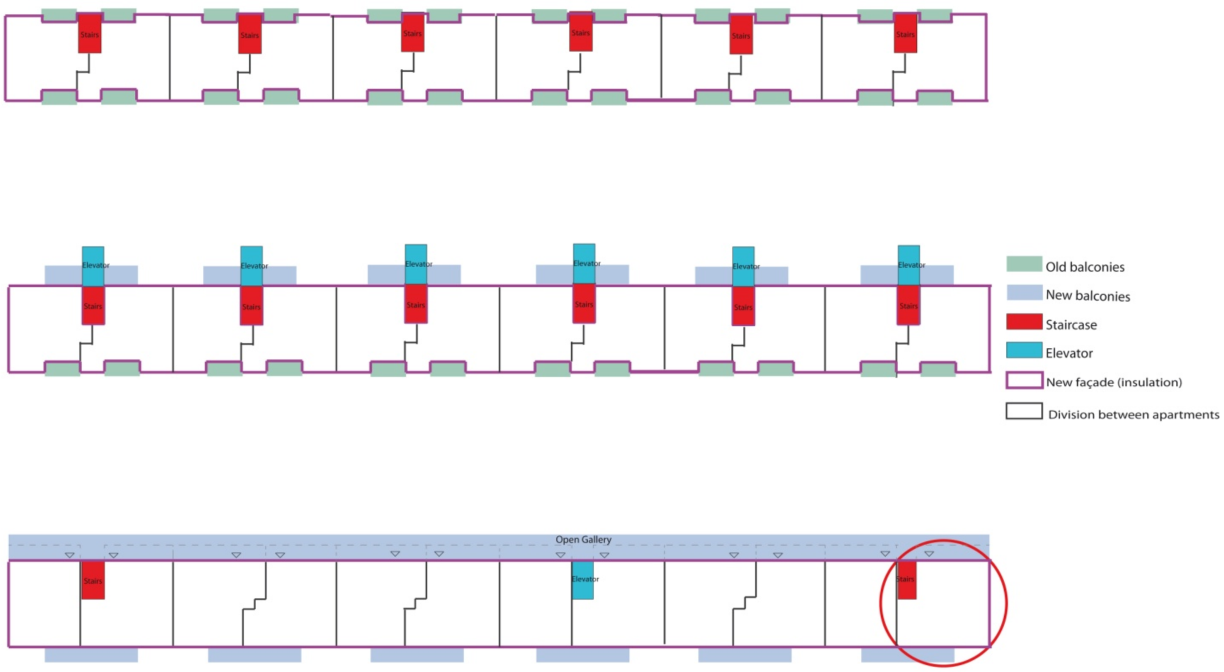


Figure 7-1: Different possibilities of building floor plans, with variations in balconies, staircases and elevators

Table 7-1: Variations in building plans, assessment of Figure 7-1

	Option 1 (minimum changes)	Option 2 (more changes)	Option 3 (extreme changes)
Outside insulation area needed	- (much insulation around balconies)	+/- (on one side less insulation area needed)	+ (less area needed to insulate)
Amount of extra balcony needed (extra Embodied Energy)	+ (Not much material needed)	+/- (on one side new balconies needed)	- (many new balconies)
Insulation of balconies cold bridge (extra Operation Energy)	- (still cold bridge)	+/- (on one side no cold bridge)	+ (no balcony cold bridges left)
Area of unheated adjoining rooms (not taken into account for EPC)	+/- (existing stairs is a cold room)	+/- (connected to staircase, which connects to outside elevator)	+ (Stairs are easily insulated)
Energy/money needed for elevators (Building costs and Embodied Energy)	+ (no extra elevators, but bad for reachability)	-- (many elevators extra needed, lot of material)	+ (only 1 elevator needed)
Inside space (Extra energy needed to heat, but extra space for residents)	- (no extra room created)	+/- (on one side extra inside space)	+ (area created by closing balconies, and removing most staircases)

Boundary conditions for the variation studies, starting point

General information

• Calculations for the top corner apartment

• Floor area of 95m², the existing balconies are closed off, so they come inside the building envelope

Infiltration

• qv10;spec = 3 dm³/s·m²

• Height of the building = 13.8m

• Standard façade type, multiple stories, top corner

Internal heat capacity

• Building type: traditional, mixed heavy

Insulation values:

• Rc_{roof} = 7m²K/W, $Rc_{façade}$ = 5m²K/W

• U_{Glass} = 1.4 W/m²K, ZTA = 0.55, no sun shading, triple glazing

Other

• Minimal obstruction on the outside

• The amount of area glass or closed depends on the variation, the amount of area per façade part is given in Figure 7-2.

Installations

• Heating with an electric heat pump groundwater, 35°C<T<=40°C, heat storage

• Domestic hot water with external heat supply, with an efficiency of 100%.

• No cooling

• Ventilation with natural supply, mechanical exhaust, CO_2 regulated in the living room and kitchen

Total area (m2)	WEST FAÇADE	Constructions	Surface (m2)
6,33	Facadepart 1.A	Glass	Depends on variation
	Facadepart 1.B	Closed	Depends on variation
10,47	Facadepart 2.A	Glass	Depends on variation
	Facadepart 2.B	Closed	Depends on variation
10,20	Facadepart 3.A	Glass	Depends on variation
	Facadepart 3.B	Closed	Depends on variation
	EAST FAÇADE	Constructions	Surface (m2)
10,35	Facadepart 5.A	Glass	Depends on variation
	Facadepart 5.B	Closed	Depends on variation
10,22	Facadepart 6.A	Glass	Depends on variation
	Facadepart 6.B	Closed	Depends on variation
	SOUTH FAÇADE	Constructions	Surface (m2)
25,35	Facadepart 8.A	Closed	25,35
	ROOF	Constructions	Surface (m2)
95,00	Facadepart 9.A	Roof	95,00

Figure 7-2: Façade area for the input in EPC for the variation studies

An important boundary condition to note is that the EPC software used for this variation study is very limited. The number the EPC gives is a factor that is influenced by many factors. Sometimes it is better to mainly look at the energy needed for heating, or the energy loss by transmission, because the EPC is a too general number.

The output given is in energy use of different aspects: Heating, cooling, domestic hot water, cooling, summer comfort, ventilators, lighting. The heating energy is the most important parameter in this variation study.

For the first variation study (glass percentages), the percentages of closed and glass will differ. But for the later studies the percentages will be 50/50.

7.1.1 Glass percentage

For the first variation the energy performance of different glass percentages will be assessed. This is important since the extra glass, which has a lower insulation value than closed surfaces, causes extra transmission losses. But they also cause a better vision to the outside and have more solar energy gain. The best balance between closed and glass surface for the façade will be examined here.

Boundary conditions

• The embodied energy of the sun shading has not been taken into account

• Variations: Current situation (varying from 30 to 60% glass per façade part), 0% glass, 20%, 40%, 50%, 60%, 80% and 100% glass on the west and east façade. The south façade and roof remain closed.

• Output in MJ energy use per year from the EPC software. The domestic hot water, ventilators and lighting stays the same in all variations, but the heating and summer comfort changes per variation. The total has been taken for a complete energy use overview.

• The energy losses by transmission are also given (QH;tr [MJ]).

Results

The results of this study can be seen in Table 7-2.

The best results are up to maximum 50% glass area for the energy use and EPC. Adding shading has mainly an influence above 60% glass.

The main reason for the higher energy use with more glass is not due to the higher heating costs, but due to the higher need in energy for the summer comfort. This is because you also have more energy gain in the winter, so the transmission energy losses are gained back by this extra energy.

The best EPC is between 20 and maximum 50% glass. After that extra shading is needed to lower the energy use, which is higher above 50%.

Above 80% glass percentage also with sun shading the energy use becomes much higher.

The energy loss by transmission is 55% lower when using 0% glass instead of 100% glass.

Conclusions

The glass surface area should be between 20 and 50% to keep the energy use lower, without the need of additional sun shading.

Table 7-2: Energy use and EPC for different variations in glass percentage of the façade

	Energy use/ year (MJ) variation 1.1 current	Energy use/ year (MJ) variation 1.2 0% glass	Energy use/ year (MJ) variation 1.3 20% glass	Energy use/ year (MJ) variation 1.4 40% glass	Energy use/ year (MJ) variation 1.5 50% glass	Energy use/ year (MJ) variation 1.6 60% glass	Energy use/ year (MJ) variation 1.7 80% glass	Energy use/ year (MJ) variation 1.8 100% glass
No shading	35056	32820	32744	33778	34672	35789	38576	41948
Automatic shading	33133	X	32526	32776	33026	33337	34108	35053
Manual shading	33561	X	32579	33001	33393	33886	35137	36697
Energy loss by transmission (QH;tr in MJ/year)	19786	11932	14904	17826	19263	20691	23507	26281
	EPC current 1.1	**EPC 0% glass**	**EPC 20% glass**	**EPC 40% glass**	**EPC 50% glass**	**EPC 60% glass**	**EPC 70% glass**	**EPC 100% glass**
No shading	0,67	0,63	0,63	0,65	0,66	0,68	0,74	0,8
Automatic shading	0,63	X	0,62	0,63	0,63	0,64	0,65	0,67
Manual shading	0,64	X	0,62	0,63	0,64	0,65	0,67	0,70

7.1.2 Insulation thickness

To see the influence of the insulation thickness on the operation energy use, embodied energy and the EPC, calculations were made for different variations.

Boundary conditions

• 50% glass and 50% closed façade was used, without sun shading

• The insulation of the triple glazing stays the same in all variations.

• Glass wool plates are used as insulation, with a heat transmission coefficient λ = 0.035W/mK .

• The embodied energy of the complete insulation is considered. The glass wool plates have an embodied energy of 677MJ/m^3 (calculated as specified in chapter 5.2 by the NIBE database). The plates have a lifespan of 75 years.

Results

In Table 7-3 the results are shown. When doubling the insulation (as it is in reality now) of Rc=0.5m^{2}K/W, the EPC and energy use decrease a lot. But when making the insulation thicker, the percentage that it improves becomes less every time. Also the embodied energy needed extra to realise this energy use reduction becomes higher. For the reduction between variation 2.0 and 2.1, where the energy use per year is reduced almost 20.000MJ, only an extra embodied energy of 1700MJ is needed. For the reduction of 1300MJ between variation 2.5 and 2.6 an embodied energy extra of more than 8600MJ is needed. The overall impact reduces each time the insulation is increased more.

An insulation value of Rc=3.5m^{2}K/W is the minimum required at the moment. Compared to variation 2.0 it improves the energy use 40%, and even when changing it to 5 and 7m^{2}K/W it increased a fair amount. The total energy use is lowest in the most extreme situation of 7 and 9m2K/W, but the decrease in energy use is almost negligible. The extra space needed for this insulation is 7 cm and the decrease in energy use is only 1.5%. So an insulation of at least 5 and 7m^{2}K/W will be taken (more is possible if it is easily applicable at certain façade parts).

Conclusions

When choosing variation 2.5, with an insulation Rc_{facade} = 5 m^{2}K/W and Rc_{roof} = 7m^{2}K/W the EPC is already reduced a lot. This is taken as the best choice. Increasing the insulation more only has a minimal effect on the EPC and the energy loss by transmission, especially when looking at the extra embodied energy needed for the insulation.

Of course it is better for the results to take a higher insulation value, but this also has influence on the building appearance and detailing, and might give problems due to the increased thickness of the layers.

Table 7-3: Top corner apartment, energy use for different insulation variations

	Variation2.0 Rcfac=0,5 Rcroof=0,5	Variation2.1 Rcfac=1 Rcroof=1	Variation2.2 Rcfac=1 Rcroof=2	Variation2.3 Rcfac=2 Rcroof=4	Variation2.4 Rcfac=3,5 Rcroof=5	Variation2.5 Rcfac=5 Rcroof=7	Variation2.6 Rcfac=7 Rcroof=9
Energy use/year (MJ)	61209	48706	43273	37729	35854	34672	33951
Energy loss by transmission (QH;tr in MJ/year)	63036	43119	34442	24837	21410	19263	17936
Embodied energy by insulation (MJ)	1708	3415	5666	11332	15330	21578	28408
75 years operation + 1xEmbodied energy	2144023	1708125	1520221	1331847	1270220	1235098	1216693
% better than the previous variation		20,33	11,00	12,39	4,63	2,77	1,49
% better than current, variation 2.0		20,33	29,09	37,88	40,76	42,39	43,25
EPC	1,17	0,93	0,83	0,72	0,69	0,66	0,65

Table 7-4: Energy results for variations in glass types, for 50% glass façade

	Variation 3.0 Single glass U =4,4, ZTA 0,8	Variation 3.1 Double glass U=2,8, ZTA 0,7	Variation 3.2 HR+ glass U=2,1, ZTA0,65	Variation 3.3 HR++ glass U=1,8, ZTA0,6	Variation 3.4 Triple glass U=1,4, ZTA 0,55
Energy loss by transmission (QH;tr in MJ/year)	36159	27353	23357	21615	19263
Energy use/year (MJ)	44417	39346	37091	36027	34672
% better than the previous variation		11,42	5,73	2,87	3,76
% better than current, variation 3.0		11,4	16,49	18,89	21,94
EPC	0,85	0,75	0,71	0,69	0,66

Table 7-5: Energy results with variations in amount of thermal mass

	Variation 4.1 All mud brick	Variation 4.2 1 wood, 4 mud brick	Variation 4.3 2 wood, 3 mud brick	Variation 4.4 3 wood, 2 mud brick	*Variation 4.5 4 wood, 1 mud brick*	Variation 4.6 All wood
m^3 mud brick extra	1,66	1,31	0,95	0,59	0,22	0,00
Heat capacity (kJ/K)	54627	54010	53386	52770	52138	51756
Energy use/year (MJ)	34120	34144	34168	34168	34216	34234
% worse than the previous variation		-0,07	-0,07	0,00	-0,14	-0,05
% worse than max, variation 3.0		-0,07	-0,14	-0,14	-0,28	-0,33
EPC	SAME IN ALL SITUATIONS					

7.1.3 Glass type

The influence of glass types on the operation energy, embodied energy and the payback time concerning building cost was discussed in the previous chapter. But also the energy use on a building scale is interesting, which will be examined in this part.

Boundary conditions

• 50% glass surface and 50% closed surface, except on roof and south façade.

• The embodied energy of the glass is not taken into consideration.

Results

Table 7-4 shows the difference between single glass and double glass, which is already very large. Even up to a change from HR++ to triple glass the change is still relatively large when looking at the percentage that the total energy consumption decreases.

The EPC with triple glazing is also lower, when comparing to HR++ glass.

Conclusions

Triple glass is advisable in this situation, since the energy performance still increases significantly when comparing it to HR++ glass.

7.1.4 Thermal mass

The load-bearing construction in the building is concrete, which already gives the building a large thermal mass. But also the façade parts can influence the heat capacity, which is assessed in this chapter.

Boundary conditions

• Calculation of the thermal mass is done according to Appendix H of NEN 7120. When using a stone inside cavity wall, the thermal capacity can be taken into account. When using a wooden construction this is not allowed

• Six different variations were considered: All outside façade walls of mud brick (this material was chosen in the previous chapters as the best material to use for an inside cavity wall) up to all wood construction with insulation. The 5 different façade parts on the west and east are varied. So variation 4.2 has 1 wood part and 4 mud brick parts and 4.3 has 2 wood parts and 3 mud brick parts.

• The initial heat capacity of the construction has also been taken into account. This is calculated as 23.44m^3 concrete.

• 50% glass and 50% closed for the west and east façade, 100% closed for the south and roof.

• Triple glazing U=1.4W/m²K, with $Rc_{façade}$=5m²K/W and Rc_{roof}=7m²K/W.

Results

As can be seen in Table 7-5 the EPC does not change in the different situation, and the energy use per year barely changes, because of the high existing thermal capacity. Therefore it does not matter if a wooden structure or a stone-based construction is used for the thermal mass.

Conclusions

It does not matter which type of façade is chosen concerning thermal mass, since the thermal mass already present in the construction of the load-bearing floors and walls is very high. Adding extra thermal mass in the façade does not have a significant influence on the energy use.

7.1.5 Infiltration

The energy losses in the building greatly depend on the ventilation losses. Apart from the ventilation needed to keep a healthy inside environment there are also losses due to infiltration. The different infiltration values and the influence on the energy consumption will be examined in this chapter.

Infiltration values

The infiltration of the building as it is currently must be very high, when looking at the detailing. It is difficult the assess the infiltration, but a few examples are given in NEN-EN 15242 (NEN-EN 15242, 2007), which can be seen in Figure 7-3.

Other examples are also given in Table B.1 of NEN-EN 15242. Especially the Q10Pa is important in the row 'multi family', which could be applied to the Marco Pololaan. It ranges in this section from 0,4 to 3,9, in m³/h per m². In ENORM it has to be given in qv10;spec [dm³/s*m²]. When translating it to this value, the range is from 0.28 to 2.8 dm³/s*m².

SBR (SBR Infoblad 012) gives a minimum of 0.15 dm³/s*m² for very good and used for passive houses. 0.4 dm³/s*m² can be used as a value that is realistic, for good air tightness. Since the building has local heat exchange units with a high efficiency, it is not unrealistic to go for an air tightness of 0.15 dm³/s*m² for a better energy performance.

Boundary conditions

• Ranging infiltration values from very bad (qv=6dm³/s*m²) to the value for passive houses (qv=0.15dm³/s*m²).

Results

In Table 7-6 the results with different infiltration values can be seen.

The energy use and EPC reduce a lot when comparing the worst case of qv=6dm³/s*m² to 0.15dm³/s*m². The energy loss by ventilation lowers 54% with this improvement.

The results improve significantly when changing the infiltration. Even up to qv=0.15dm³/s*m² the infiltration change causes EPC reduction.

Conclusions

By lowering the infiltration to 0.15dm³/s*m² the EPC of this corner apartment can be lowered to 0.6, which is the current standard. This value can also be used very well with the ventilation system chosen for the design, which is a heat exchange system. By lowering the infiltration to a minimum, the ventilation system can better be used more efficiently.

			m³/h per m² of outer enveloppe (exp n = 0,667)	
	leakages level	Q4Pa	Q10Pa	Q50Pa
single family	low	0,5	1	2,5
	average	1	2	5
	high	2	3,5	10
multi family ; non residential except industrial	low	0,5	1	2,5
	average	1	2	5
	high	2	3,5	10
industrial	low	1	2	5
	average	2	3,5	10
	high	4	7	20

Figure 7-3: Example of infiltration rates (Table B1) (NEN-EN 15242, 2007)

Table 7-6: Energy results with variations in infiltration

	Variation 5.1 qv=6dm²/s*m²	Variation 5.2 qv=2dm²/s*m²	Variation 5.3 qv=1,5dm²/s*m²	Variation 5.4 qv=1,0 dm²/s*m²	Variation 5.5 qv=0,4 dm²/s*m²	Variation 5.6 qv=0,15 dm²/s*m²
Energy loss by ventilation (QH;ve in MJ/year)	21041	15311	12373	11382	10184	9683
Energy use/year (MJ)	37095	34216	32821	32366	31822	31599
% better than the previous		7,76	4,08	1,39	1,68	0,98
% better than current, var. 5.1		24,03	27,13	28,14	29,35	29,84
EPC	0,71	0,65	0,63	0,62	0,61	0,60

7.1.6 New balconies

Different materials are possible for balconies. The main materials used are: concrete, steel or wood. The different choices will be assessed here, to see which one is better and what the differences are, to make the choice for the final design.

Boundary Conditions floors

• NIBE has an online database, where also information on (inside) floors can be found (NIBE, 2013). This information will be used for the assessment, even though in this case it concerns outside floors.

• Embodied energy is calculated by the kgCO_2eq given by NIBE per m², with the conversion factor to MJ given in Chapter 5. Material Comparison.

• The embodied energy needed for extra protection, due to being outside has therefore not been included.

• The floors have a thickness needed for a floor span of 5.4m.

Comparison floors

Timber hollow core slab (220mm thick):

-488,1MJ/m² floor

-Comparable to a beam structure with timber plate covering

Prefab concrete skin with I-profiles (IPE270 centre to centre)

-976,2MJ/m² floor

Massive wooden floor (201mm thick)

-898MJ/m² floor

Concrete hollow core slab (200mm)

-1400MJ/m² floor

Conclusions

Even though the extra embodied energy needed for maintenance of the wood in the case of the hollow core slab has not been taken into account, it is evident that the embodied energy/m² is much lower compared to the other possibilities. Therefore the timber hollow core slab construction for the balcony floors is taken as the best choice.

Boundary Conditions columns

• No calculations were made for the dimensions of the columns. The steel columns are taken as half the dimension of the concrete columns. For example, when a prefab column is 300x300mm the steel is usually 150x150mm hollow dimension (Spierings et al., 2004, p. 198).

• No extra maintenance needed is taken into account, for example for painting every few years. Only the energy needed for raw materials initially are taken into account.

• A solid concrete column is assumed, with the embodied energy given by the university of Bath (Hammond & Jones, 2008) of average values of concrete of 0.95MJ/kg. Concrete has a density of 2400kg/m² (Joostdevree).

• An embodied energy for steel of 24.40MJ/kg, which is an average value of all steels, given by the university of Bath (Hammond & Jones, 2008). Steel has a density of 7800kg/m³ (Joostdevree).

• The compressive strength of wood is about 1/10 of concrete, so the surface area should be 10 times higher.

• A general value for the embodied energy of timber of 8.5MJ/kg given by the university of Bath, with a density of 500kg/m³ (for pinewood).

• A starting point of concrete columns of 0.1x0.1m.

• Per column a maximum of 2.5m² is carried.

Comparison columns

Concrete

For 1 column of 2,8 meter height, 0.1x0.1meter:

$0,1*0,1*2,8*2400kg/m^3*0.95MJ/kg=40,86MJ/column$

Steel

For 1 column of 2.8 meter height and a wall thickness of 2mm (CFRHS 50x50x2):

$(0.05*0.05-0.046*0.046)*2.8*7800kg/m^3*24.40=204.6MJ/column$

Wood

For one column of 2.8 meter height, 0.3x0.3 meter:

$0.3*0.3*2.8*500kg/m^3*8.5MJ/kg = 1071\ MJ/column$

Comparison floor + columns

Concrete

$2.5m^2\ floor * 1400MJ/m^2 + 1\ column * 40.86MJ = 3540.9MJ$

Steel

$2.5m^2\ floor * 976.2MJ/m^2 + 1\ column * 204.6MJ = 2645.1MJ$

Wood

$2.5m^2\ floor * 488.1MJ/m^2 + 1\ column * 1071 = 2291.25\ MJ$

Conclusions

For the balcony the wooden floor and columns come out as the best combination. Of course also a combination would be possible (for example concrete columns + timber floor), but to keep the appearance the same, the floor and columns are kept the same material.

7.1.7 Balance between new balconies and new inside space

To see the influence of closing off balconies and adding new ones on the embodied energy and operational energy, 3 variations were made. These can be seen in Figure 7-4. The concrete construction type had the most embodied energy when comparing the material possibilities. Therefore cast in situ concrete will be taken into account in the calculations, because it is the worst case scenario for the floors, which cause the highest embodied energy.

The three variations of floor plans, given in the beginning of chapter 7.1 will be assessed for the differences in energy use by the balconies, see Figure 7-4.

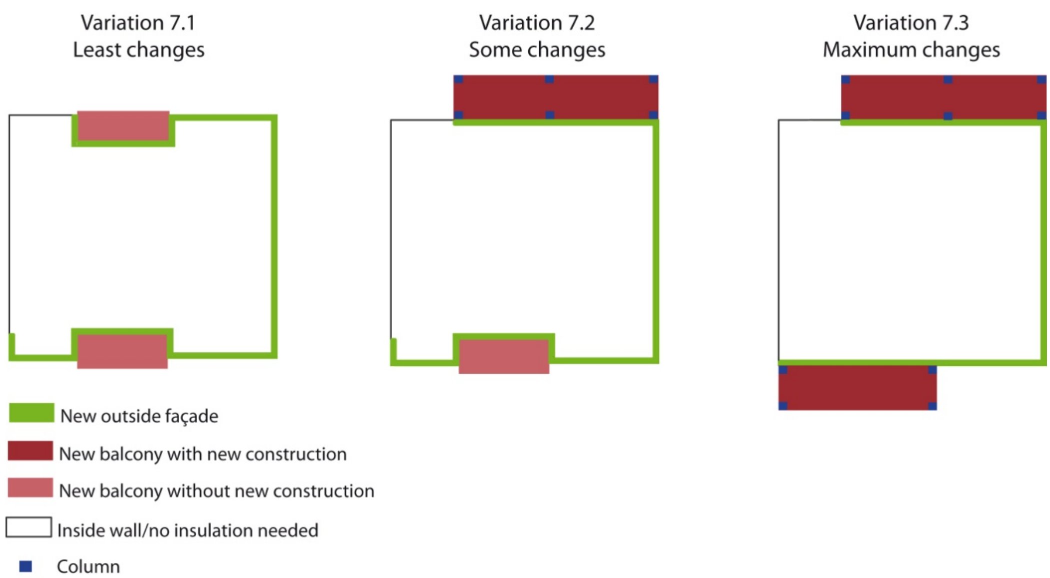


Figure 7-4: Three possibilities of balconies and outside façade area

Boundary conditions

• A distinction can be made between balcony types. First there is a new addition, which needs a new load bearing structure. Secondly there are new balconies on the existing places that need no extra load-bearing structure. In this simplification the new load-bearing structure for the balconies will be columns.

Embodied energy with simplified calculations:

• Since the thickness of the floors and columns should be less than in chapter 7.1.6, another type of calculation should be made. In this chapter a floor span of 5.6m is used.

• The floor span is 3.5 meters, this gives a concrete floor thickness of 0.14m when using a rule of thumb : thickness floor = 1/25*floor span.

• The floors and columns are assumed to be solid concrete with 0.95MJ/kg embodied energy (Hammond & Jones, 2008).

• The extra embodied energy needed for the maintenance and coatings is not taken into consideration.

• The Embodied energy per façade part is taken from the value of a complete new façade from the previous chapter and is taken as an average value (From the results of strategy 3, complete façade replacement).

Embodied energy according to data from chapter 5 and 6:

• Closed façade: Between 200 and 550MJ/m^2 (200 for plate materials and 550 for new masonry) →375MJ average

• Windows: wooden frame, triple glazing, 30% frames (1/3 inside, 2/3 outside window frame), 70% glass: 420MJ/m^2.

Roof: 310MJ/m^2

Operation energy with EPC calculations:

• For the glass surfaces a U-value of 1.4W/m^2K will be taken. For the closed façade an Rc-value of 5m^2K/W will be taken and for the roof Rc of 7m^2K/W.

Calculations

Per column 2.5m^2 is carried maximum, for 5 floors. The columns are made 0.08mx0.08m.

For one m^2 balcony is needed: 0.14* 1*1*2400kg/m^3*0.95MJ/kg = 319,2MJ/m^2 balcony

The important variable input for the EPC can be found in Table 7-7, together with the results in the end of the table.

Conclusions

In Table 7-7 the results of the variations can be seen. The embodied energy of the balconies in variation 7.3 is 10% of the total embodied energy. The total energy is the highest in that situation, due to the higher initial energy and the larger floor space. But the energy use per m^2 is smaller, because of the compact façade, which has less transmission.

7.1.8 Solar collectors and PV cells

When adding 15m^2 solar collectors, which is connected to the domestic hot water, and adding 22m^2 PV-cells for the top corner apartment, the total energy use will be 0MJ/year and the EPC will be 0. This way the operation energy can be lowered as much as possible. But when also looking at embodied energy, these collectors also need energy to make. There is also a limited amount of surface area on the roof.

The maximum possibility of this and the influence on the operation and embodied energy will be researched for the design in the next chapter.

Table 7-7: Results of Energy use of the three variations in Figure 7-4

	Variation 7.1	**Variation 7.2**	**Variation 7.3**
Floor area (m^2)	$77m^2$	$81\ m^2$	$88\ m^2$
New outside surface closed (m^2)	$55.1m^2$	$53.2\ m^2$	$50.8\ m^2$
New roof area	$77m^2$	$81\ m^2$	$88\ m^2$
Dm^3/s vent. Needed	92.5	97.3	105.7
New outside surface glass (m^2)	$30.3m^2$	$28.4\ m^2$	$26\ m^2$
Area new balcony (m^2)	$9.6m^2$	$19.9\ m^2$	$26.2\ m^2$
Number of columns needed	0	6	10
Operation energy/year (MJ)	30827	31463	32779
Operation energy/year/m^2 (MJ)	400.4	388.4	372
Operation energy/year/m^2 (kWh)	111	108	103
EPC	0,67	0,67	0,66
Embodied energy (balcony + closed façade + glass +roof)35 years (MJ)	319,2*9,6 + 375*55,1 + 420*30,3 + 77*310= 60323MJ	319,2*19,9 +6*40,86 +375*53,2 + 420* 28,4 + 81*310 = 63585	319,2*26,2 + 10*40,86 + 375*50,8 + 420*26 + 88*310 = 66022
CONCLUSIONS			
Total energy use (Oper.+Embodied) 35 years (MJ)	**1139268**	**1164790**	**1213287**
Total energy use (Oper.+Embodied) 35 years (MJ)/m^2	**14796**	**14380**	**13787**

7.2 Designs

Table 7-8: Weighted average of all apartments for the building in the current situation

Operation Energy/year (MJ)	118095 MJ
Total energy 35 years	4133339 MJ
EPC	2,87
Energy by transmission/year (MJ)	46036 MJ
Operation energy use/year/m²	1478 MJ/m² = 410.6kWh/m²

The conclusions made in the previous chapters will be used to make a design for the building, specifically detailed for the top corner apartment. For the embodied energy, operation energy, environmental costs and building costs the weighted average of all apartment types will be calculated, to be compared to the weighted average of the design of Portaal. This way conclusions and recommendations can be made.

As operation energy the EPC software will be used, which includes the energy for Heating, Domestic hot water, Cooling, Summer comfort, Humidification, Ventilators and Lighting.

Current situation energy use

The energy use of the current situation is given in the table below, as the weighted average of all apartments. The values per apartment type can be found in Appendix G, Figure G- 10. These weighted values in Table 7-8 can be used to compare to the new designs, to see how much it is going to improve. The same calculation method as in Chapter 4.1.9 was used.

7.2.1 New Design

Based on the conclusions drawn of the façade strategy analysis and the variation studies in the previous chapter part, a design was made.

The conclusions that are used are for a building lifespan of 35 years, which is the planned lifespan by Portaal.

Using conclusions of the strategy study

• Addition of external insulation and cladding where possible, addition of insulation on roof. The addition depends on if it's possible with the detailing and if the embodied energy of the existing façade materials is high.

• The masonry on the south and north should be kept and repaired, with cavity and inside insulation.

• Closing off balconies (so that the outside balcony comes into the building envelope) by adding a new facade, to prevent detailing problems and façade appearance

Using conclusions of variations study

• Gallery balconies, with 2 staircases and 1 elevator

• Glass percentage 50% or lower (if no sun shading is used)

• Extra façade insulation of R=5m²K/W, extra roof insulation of R=7m²K/W

• Triple glazing

• Infiltration value of maximum qv10= 0.15dm³/s/m²

• Closing off balconies to lower outside façade area, extra inside space, add new balcony space.

Floor plan new design

Based on the research in the previous chapter 7.1, a choice was made to add one elevator in the middle of the building and keep two staircases at the two ends of the building. The other staircases will be removed, and the space will be added to the apartments as new bedrooms. The entrances will be via a gallery balcony, which are accessed by the staircases and elevator. The gallery balcony can also be used for the residents as an outside space. This option for the floor plans came out as the best for the energy use (see Figure 7-5).

As can be seen in Figure 7-6 many private gardens on the east side are neglected at the moment. By renewing that façade, also with new balconies, that side of the building might also become alive more and maintained better.

By adding more and larger (private) balconies on the west side of the building there will be a nice view to the park at that side (see the context in Figure 7-7). Also the balconies on the east can be used. On this side there are only private gardens on the ground floor and will therefore be much more quiet and peaceful.

The current floor plans were outdated; the kitchen is far from the living room and separated by many doors. By the new gallery entrance the floor plans can also change. The placement of the bathroom and kitchen are kept the same, to prevent money spend on changing the position of these two rooms. But where first was a bedroom, now the living room is placed, so that an open connection between kitchen and living room is possible if desired. . In Figure 7-8 the floor plan of the top corner apartment can be seen.

Another door is added to the kitchen, so that also the gallery balcony can be used as outside space if desired. In the living room there are two glass doors, so that a good view to the outside is possible.

Balconies

In chapter 7.1.6 the best material for balconies was examined, with which timber constructions came out as the best results. Second best was the steel with concrete and last the concrete construction. But since timber constructions are not much used in the Netherlands for balconies in multi-storey apartments, a combination of steel construction with timber flooring will be used on the west and east side of the building. The railing is made of steel with a glass filling, which is chosen because it gives a more transparent view to the view on the park on the west side and the gardens on the east.

Façade design

The current architecture is kept of the materialisation; the concrete framing that was there in the old façade is materialized again with cement based elements. The old plate materials are replaced with wood, and the concrete sandwich panel is now also fibre cement plates (see the complete façades in Figure 7-9 and Figure 7-10). The slightly extruding concrete elements that were framing the façades are made more extremely extruding.

The exact façade materials that are used in the new design, came out as best options in Chapter 5.2 concerning embodied energy.

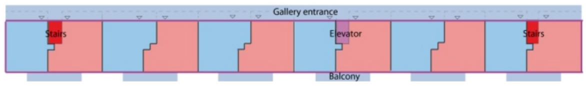


Figure 7-5: Simplified floor plan of the new design (4th floor)

Figure 7-6: Private gardens on the East side of the building

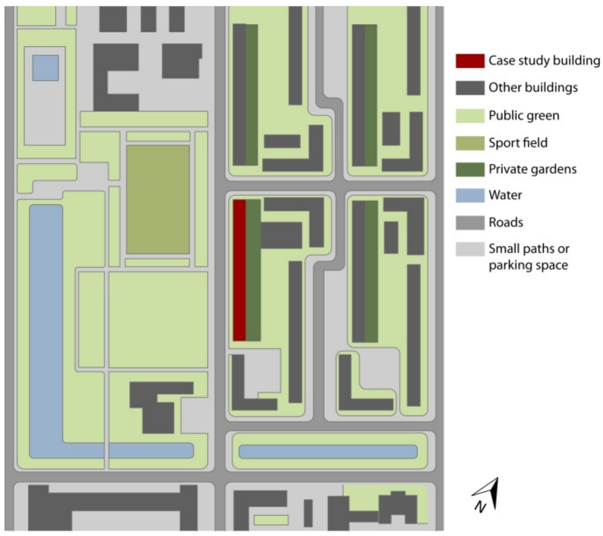


Figure 7-7: Context of the building

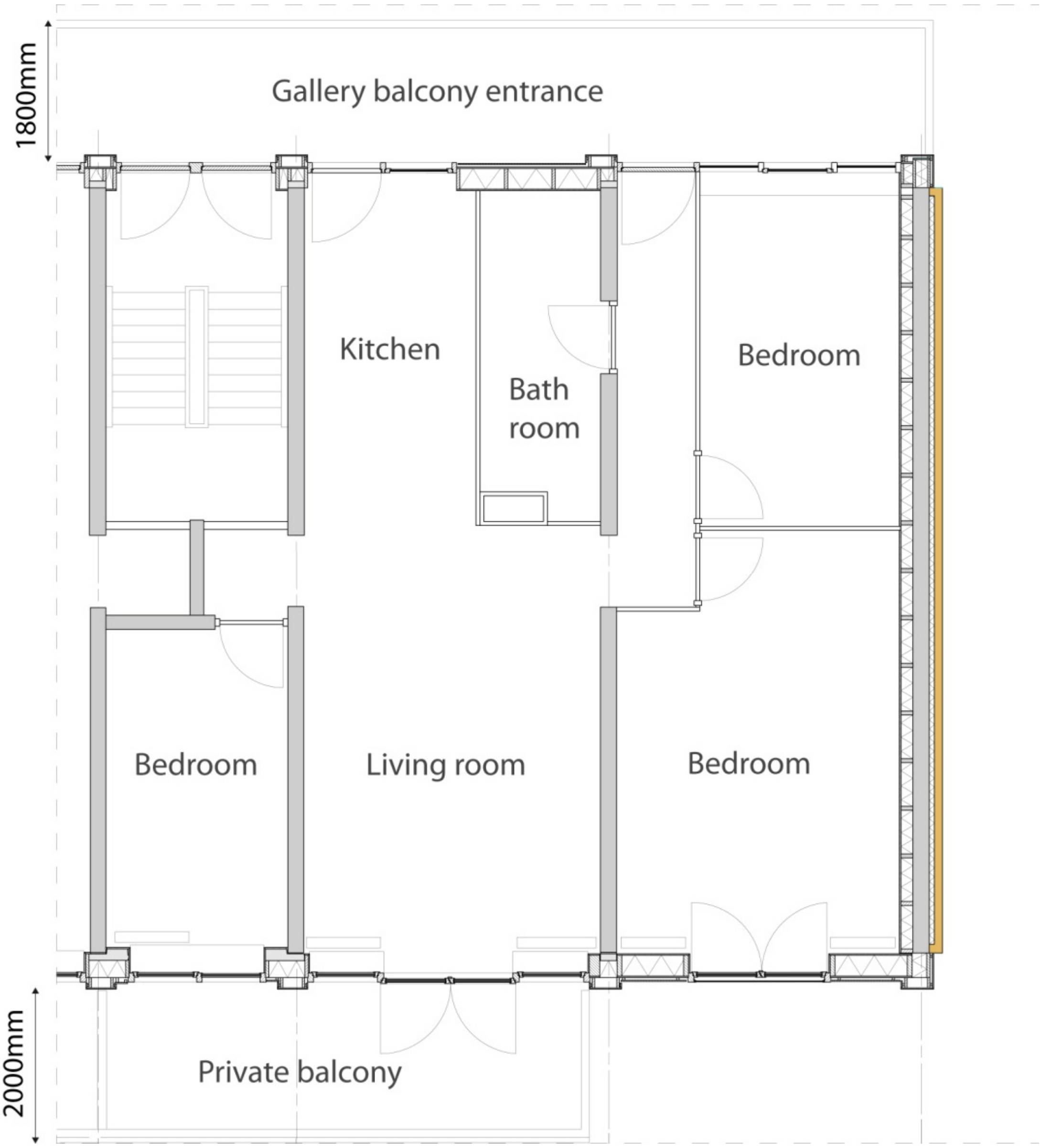


Figure 7-8: New design of the floor plan of the top corner apartment

Figure 7-9: Total west façade for the new design

Figure 7-10: Total east façade for the new design

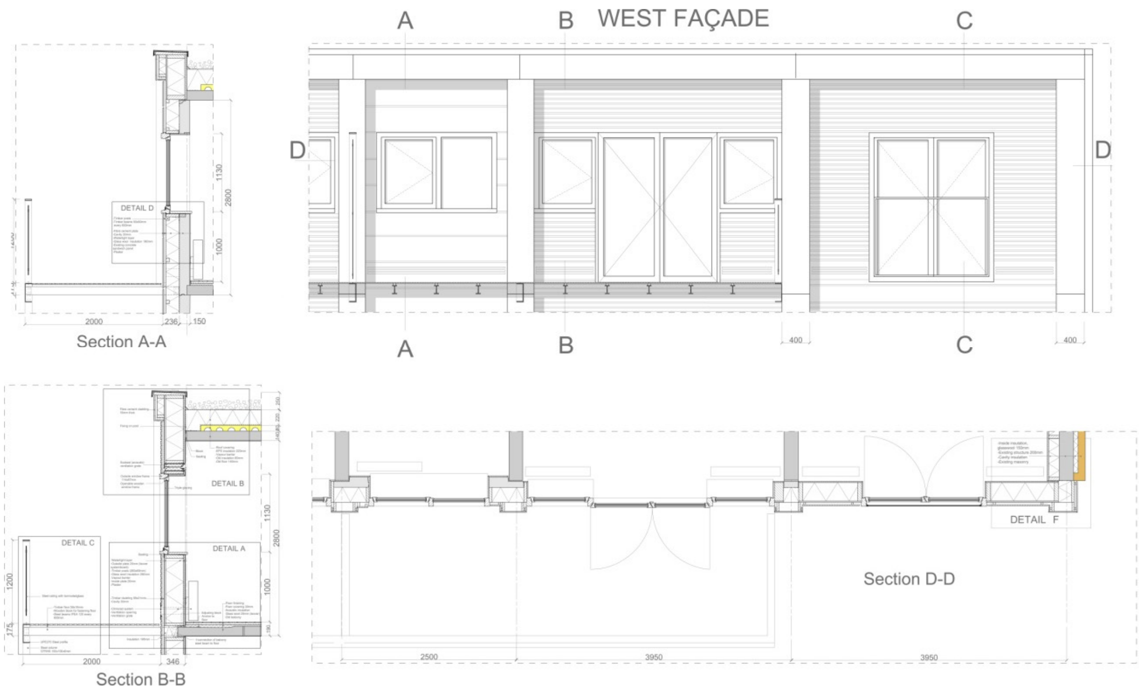


Figure 7-11: New design of the top right corner apartment with cross sections per façade part

Figure 7-12: West façade of the top corner façade

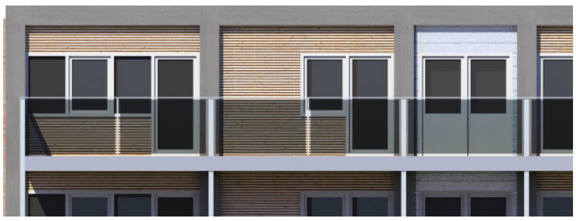


Figure 7-13: East façade of the top corner apartment

Figure 7-14: 3D view of the top corner apartment

Detailing of the design

The materials that are used in the design are based on the results in Chapter 5.2. The material use can be explained with the help of the details taken from Figure 7-15 to Figure 7-19. The details are taken from the elevation and cross sections of the west façade, shown in Figure 7-11. The larger figures of the design as well as the details can be found in Appendix G, Figure G- 1 to Figure G- 7.

Detail A in Figure 7-15 shows the new façade at the point where the old balcony used to be. This balcony is closed off with a new timber façade framing, with glass wool plates for insulation. These materials came out as the best options for these façade components in Chapter 5.2. Where there was first a plate material now wood is used. Oak proved to be the best option for timber concerning embodied energy, so this was used in the design.

The Climarad system, which regulates the ventilation air and also heating, is placed behind the façade. Ventilation openings need to be made, with a grate for supply and exhaust of the air.

Because noise from the inside of the building (neighbours) was a problem, a choice was made for glass wool acoustic floor (from the company Isover). An extra floor covering is needed to level it out, above which the floor finishing (for example laminate) can be placed.

From the research in chapters 5.1 and 7.1.3 triple glazing came out as the best option for glass for energy use and costs. This is used in a timber window frame of European softwood (renewably grown), which was the best options for a window frame with a lifespan of 35 years.

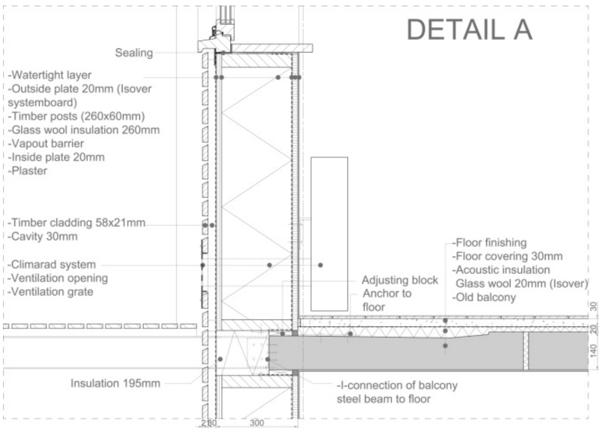


Figure 7-15: Detail A of the own design

In Figure 7-16, Detail B, the roof can be seen. EPS insulation was the best choice in the material analysis. From the research in chapter 6.1.1 the results showed that it was best to keep the current insulation on the roof, for the extra insulation value and less embodied energy.

Because noise from the outside was also a problem, a special acoustic ventilation grate is used above the windows. This allows the building to be ventilated in the times of the year that heating (so the Climarad system) is not used. This way ventilation is possible without excessive noise from the traffic outside.

The research in chapter 6.1 showed that it was best to keep the old elements, because this saves embodied energy. This was very difficult to realise, because this made the detailing too complex. For example at the floor of detail B there was a prefab concrete façade element. But the attachment of the new timber framing to the floor would be obstructed by the old elements. Therefore the choice was made to remove these, even though this makes the total embodied energy a bit higher.

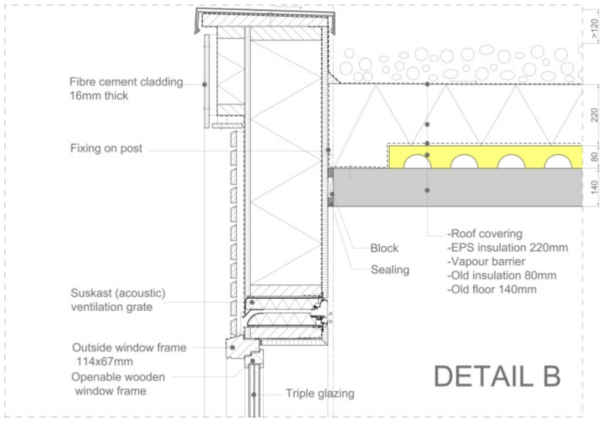


Figure 7-16: Detail B of the own design

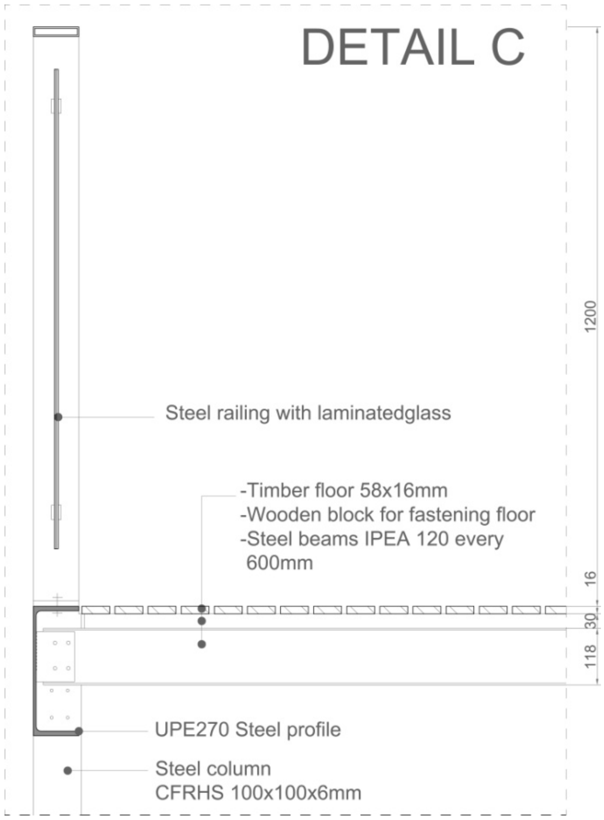


Figure 7-17: Detail C of the own design

As the balcony construction steel is used, since this proved to be a better choice than concrete (see the results from chapter 7.1.6). This steel construction can be seen in detail C, in the figure above. Steel columns are used, with UPE profiles to connect to the smaller beams. The UPE profiles are used because this allows a nicer view when looking from the outside (if I-profiles are used, this gives a less smooth view from the outside). Plates are welded to the UPE beams, which can be attached to the smaller IPEA 120 beams, which are needed every 600mm. On top of the IPEA profiles, wooden blocks are attached, on which the timber flooring can easily be nailed to. In Detail A the connection of the IPEA profiles to the floor can be seen, so that no additional columns are needed on that side.

As a railing, glass is used in a steel frame. This frame is attached to the UPE profiles.

In Detail D in the figure below, another part of the façade is shown. In this part there was first a concrete sandwich panel. The research results in Chapter 6.1 showed that it was best to keep the old construction. Therefore in this situation there is Glass wool insulation attached directly on the sandwich panel. In this façade part there was first a concrete façade. Therefore in the new situation also a stone element was used. The fibre cement plates were the best option from the material research, which is also used in the design. This material was used in the extruding elements in Detail B as well, which is a more extreme version of the current architecture.

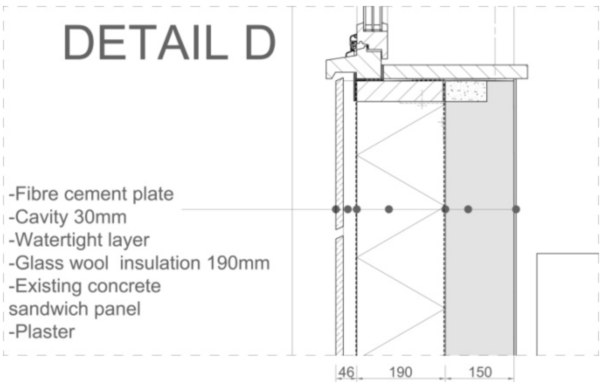


Figure 7-18: Detail D of the own design

Detail E shows the high windows at the largest bedroom. There is a French balcony attached to the window frame. According to the conclusions from Chapter 7.1.1 there was a maximum of 50% glass used in the new design. But with this shape of the balcony it is also possible to enjoy the nice view at this side of the building.

At this detail there were first also prefab concrete elements in front of the floor. According to the research made, these elements should be kept. But they needed be removed, because it gave too much problems in detailing to keep this.

To keep this façade part in the same line as the other façade elements, the timber framing needed to be in front of the floor. Because of this a special construction needs to be made, where the top frame is supported on top of the lower one, and attached with anchors together to the floor.

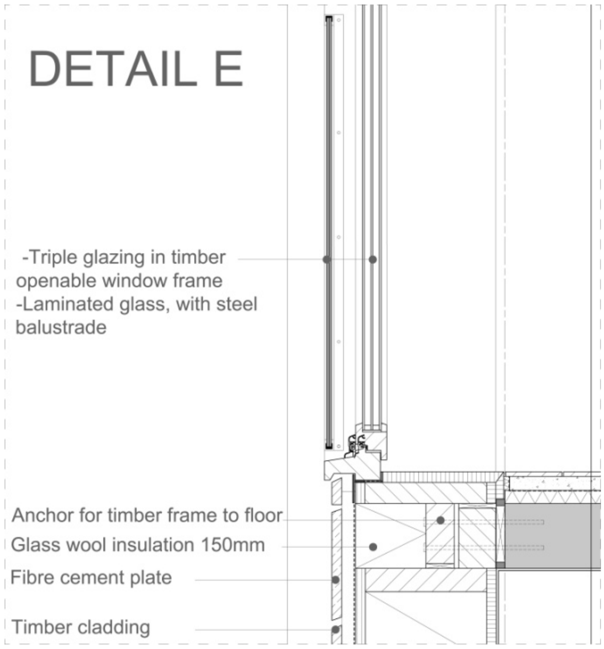


Figure 7-19: Detail E of the own design

Façade insulation

For new façade parts that have no old construction to support the cladding and insulation, a wooden frame was used. The glass wool plates have a heat transmission coefficient of λ=0.035W/mK, but since there is 15% wooden frames in this construction the coefficient becomes λ=0.035*0,85+0,2*0,15 = 0.05975W/mK. That means that for an insulation value of Rc=5m^{2}K/W a thickness of 0.3 meter is needed (see for example detail E in Figure 7-19). If special plates from Isover are used as an outside plate the insulation value will be even better.

For glass wool plates that are on a stone façade, the thickness needs to be at least 0.175m extra (see detail B in Figure 7-18), since there are no cold bridges because there is no timber framing.

When insulating inside the cavity of the masonry (see detail F in Figure 7-11), the insulation value is about $Rc=2.4m^2K/W$ already. An additional $2.6m^2K/W$ is needed. When insulating from the inside with glass wool plates and pinewood frame, the heat transmission coefficient is $\lambda=0.05226W/mK$. An additional 0.136mm is needed at the masonry (see Figure 7-11, section D-D).

The roof already has an insulation of $Rc=0.57m^2K/W$, so the needed extra insulation is $R=6.43m^2K/W$, which is a thickness of 0.22m with EPC plates, which have a heat transmission coefficient of $\lambda=0.03343W/mK$ (see Figure 7-16).

Boundary conditions building services EPC

The operational energy use (for heating, cooling, electricity etc.) is calculated with EPC Enorm, which has certain boundary conditions.

Installations

• Heating with an electric heat pump groundwater, 35°C<T<=40°C, heat storage.

• Domestic hot water with external heat supply, with an efficiency of 100%.

• No cooling.

• Ventilation with a balanced ventilation system with a decentralized heat exchange system per room.

Boundary conditions façade for EPC

• See Appendix G, Table G- 5, for an example input.

Infiltration

• qv10;spec = 0.15 $dm^3/s{\cdot}m^2$.

• Height of the building = 13.8m.

• Standard façade type, multiple stories, top corner.

Internal heat capacity

• Building type: traditional, mixed heavy.

Insulation values:

• At least $Rc_{roof}=7m^2K/W$ and $Rc_{façade}=5m^2K/W$.

• UGlass = 1.4 W/m^2K, ZTA = 0.55, no sun shading, triple glazing.

Boundary conditions embodied energy, building costs and environmental costs

• The self-made excel file is used to calculate the building costs and environmental costs given in the NIBE database.

• The building costs include: man-hours, materials, subcontractor costs and equipment, but other costs like maintenance.

• The environmental costs do include maintenance (for example paint every 8 years for wood).

• The embodied energy is calculated with the method from Chapter 5.2, with the excel file. The initial embodied energy is accounted for (not maintenance), but also replacement when the lifespan is over. The embodied energy still remaining in the old materials is accounted for when they are removed, but the demolition energy (energy needed to dispose of the materials) is not calculated.

Calculation of embodied energy balconies

The following boundary conditions were used for the calculation of the balconies for the design:

• For the balconies a steel construction is used with timber flooring.

• An embodied energy for steel of 24.40MJ/kg, which is an average value of all steels, given by the university of Bath (Hammond & Jones, 2008). Steel has a density of $7800kg/m^3$ (Joostdevree). This gives $190320MJ/m^3$ for steel. This is only for the steel, not for maintenance and painting.

• For the timber flooring, the same embodied energy as for timber façade cladding is used, with the same material (Oak, renewably grown) with an initial embodied energy of $35.984MJ/m^2$ (maintenance is not included in this).

<u>Calculation for balconies</u>

In total $1289.8m^2$ new timber flooring for the balconies is needed for the design. This is for all 48 apartments.

<u>Floors</u>

*$1289.8m^2$ → $1289.8m^2$*35.984MJ = 46412.2MJ → 966.92MJ per apartment for the flooring*

<u>Columns</u>

Amount of CFRHS 100x100x6mm columns: 220

*Volume of steel per column of 2.8 meter: 2800mm height * (100mm*100mm-94mm*94mm) = 3259200mm³ = 0.0032592m³*

Total mass of steels for all 48 apartments:

*0.0032592m³*220 = 0.7170m³*

Total embodied energy columns for all 48 apartments:

*0.7170m³*190320MJ/m³ = 136459.4 → 2842.9MJ per apartment.*

Beams

There are in total 864 beams IPEA 120, of a length of 2 meters, which gives a total of 1728meter IPEA 120 for all apartments. There are in total 1168.8meter UPE270 needed for the balconies in the total building.

*The IPEA 120 have a volume of 1.06384*10⁻⁶m³ per m¹ length of profile. The UPE270 have a volume of 3.369610⁻⁶m³ per m¹ length of profile.*

This gives the following calculation for the IPEA 120:

*1.06384*10⁻⁶m³*1728m¹ = 0.0018383m³*

For the UPE270 the calculation is:

*3.369610⁻⁶m³*1168.8m¹ = 0.003938 m³*

The total embodied energy for the beams is:

*(0.003938+0.0018383)*190320MJ/m³ = 1099.345MJ → 22.9MJ per apartment*

Railing

A steel balcony railing with glazing is calculated with the NIBE database as 279MJ/m¹. The total amount of balcony railing for the building was calculated as 766m¹.

*The embodied energy needed for the balcony railing is: 279MJ/m¹*766m¹= 213714MJ → 4452MJ per apartment.*

Total embodied energy per apartment

Per apartment there is a total of 8315MJ needed for the balconies, including railings, beams, columns and flooring. This is only the embodied energy needed initially for the steel and wood, so not for example for maintenance every few years and painting.

Energy by transmission losses

The number that the EPC gives is based on many factors, largely the installations. For example, according to the rules, the efficiency which has to be used for district heating is the standard value given by the EPC (100%), which makes the energy use much higher compared to when a heat pump is used. But when using a value of 173%, which was given by TNO as the efficiency in this case (De Jong & Versteeg, 9 december 2010), the energy use is almost similar with a heat pump. The value for the EPC needs to be calculated in a standard way, with a certain quality certification, which has not been done in this situation, so it might be too optimistic.

The most important factor, also together with the embodied energy for the façade, is the operation energy losses by transmission. This is independent of the installations used. Therefore it is a good measure to compare the energy use differences concerning the façade. This value can also be found in the EPC (QH;tr, which is the total heat loss by transmission per year in MJ).

Different apartment types

The calculations in the previous chapters were mainly done for the top corner apartment. But to give recommendations it is better to use a weighted average value of all the different apartment types. This was done for both the own design as well as the calculations in EPC of Portaal's design.

The new floor plans with different apartment types can be found in Appendix G, Figure G- 8.

Calculation results

The calculations for embodied energy, operation energy, environmental costs, buildings costs etc. were made for each apartment type; the results can be seen in Table G- 1, Appendix G.

The weighted average of all these apartment results was taken, and shown in Table 7-9.

The energy use per m² is in the current situation 410.6kWh/m² and in the new design it is 88.3kWh/m². This means that the energy use is lowered more than 75% in the new design per m².

PV Cells and Solar collectors

There is about 1000m² roof surface available for using solar collectors, this is about 20 m² per apartment. Wikipedia gives 4750MJ/m² embodied energy per m² for monocrystalline PV cells (Wikipedia, 2013). When 20m² PV cells is added this is 95000MJ per apartment. This is a very simplified calculation for the PV-cells, since also other parts of the PV-cells have an embodied energy.

Energy results in EPC when using PV-cells are shown in Table 7-10. The total energy use (embodied + operational) over 35 years lowers about 60% compared to not using PV-cells.

The parts that are not shown in Table 7-10, such as embodied energy of the façade and balconies, are the same as Table 7-9. The building and environmental costs have not been calculated for the design with the PV-cells.

7.2.2 Design Portaal

Boundary conditions

The design as Portaal is planning to make, can be found in detail in Chapter 4. Case study Analysis. More information on the design can be found in Appendix F, Figure F- 23 to Figure F- 27 and Figure C- 3 in Appendix C.

The following important factors were input into the EPC calculation:

• Air tightness of Qv=1dm³/s/m². According to SBR (SBR Infoblad 012) this is a good air tightness for mechanical exhaust and natural supply.

• District heating, standard efficiency of EPC (100%), for heating and domestic hot water.

• Extra savings for the shower water with heat exchange.

• The input of the EPC for the façade can be found in Appendix F, Figure F- 17, Figure F- 18 and Figure F- 22.

• The rest of the factors, such as embodied energy, building costs and environmental costs are calculated in the same way as in Chapter 6.1.2.

Balconies:

The balconies in Portaal's design are made of solid prefab concrete. Values that were calculated in Chapter 7.1.7 were used for this. These were 319.2MJ/m² for floors and 40.86MJ per 2.8m¹ column.

The total new area of balconies in Portaal's design is 391.2m2, divided over 48 apartments. The calculation for the embodied energy of the balconies is as follows:

*391,2m² → 391,2*319,2MJ = 124871MJ → 2601,5MJ per apartment*

*Amount of columns: 192 → 192*40,86 = 7845MJ → 163,4MJ per apartment*

*Balcony railing: 461m¹ railing needed → 279MJ/m¹*461 = 128619MJ → 2680MJ/apartment*

An example of the input for EPC, of the top corner apartment, type D4, can be found in Appendix G. The rest of the apartment types have a slightly different input (for example there is no roof or no masonry façade on the south). For apartment D4 also the output of the Embodied energy, Environmental impact and Building costs can be found in Appendix G, Table G- 8.

Calculation results

Again, the calculations were made for all different aspects and for all apartment types, to get the weighted average. The complete results of each calculation per apartment can be found in Appendix G, Table G- 2.

In Table 7-11 the weighted average of these results can be found. The energy use (operational + embodied) after 35 years is 29% higher, compared to the new design made. When also using PV-cells in the new design, Portaal's design has more than 3 times as high energy use.

Table 7-9: Weighted average of all apartments for the building of the own design

Embodied energy 35 years (MJ) façade	32231 MJ
Embodied energy 35 years (MJ) façade and construction balconies	40546 MJ
Operation Energy/year (MJ)	28698 MJ
Total energy (E+O) 35 years	1036647MJ
EPC	0,6635
Energy by transmission/year (MJ)	14976 MJ
Operation energy use/year/m²	317.9 MJ/m² =88,3kWh/m²
Environmental costs (euro)	€201,3
Building costs (euro)	€8958

Table 7-10: Weighted average of all apartments for the building with the new design, with 20m² PV-cells per apartment

Embodied energy total (façade, balconies, PV-cells) 35 years	135546 MJ
Operation Energy/year (MJ)	7557 MJ
Operation + embodied energy total 35 years	400041 MJ
EPC	0,18
Operation energy use/year/m²	83.7MJ/m2 →23,3kWh/m²

Table 7-11: Weighted average of all apartments for the building of Portaal's Design

Embodied energy 35 years (MJ) façade	46100 MJ
Embodied energy 35 years (MJ) facade + construction balconies	48865 MJ
Operation Energy/year (MJ)	36826 MJ
Total energy (E+O) 35 years	1335013 MJ
EPC	0,84
Energy by transmission/year (MJ)	19052 MJ
Operation energy use/year/m²	409,4MJ/m² = 113,7kWh/m²
Environmental costs (euro)	€199,0
Building costs (euro)	€7759

7.2.3 Conclusions

Apartment D4

For the top right apartment, the new design is about 4 times better than the current situation concerning energy use. Compared to the design of Portaal, the own design has 1/3 less energy use for operation and embodied energy (see Figure G- 10). The embodied energy of the own design is about 10% higher compared to the façade Portaal designed. The embodied energy after 35 years of energy use is 6% of the total.

Weighted average of apartments

Operation + Embodied energy

When looking at the weighted average of all apartments (see Figure 7-20), the final energy use (operation + embodied) after 35 years lifespan of the own design is about ¼ lower than the design of Portaal. When looking only at transmission through the façade the own design is 1/5 lower.

If the maximum possible PV-cells are used on the roof, the EPC can be lowered to 0.18. The initial Embodied energy costs are higher, but the investment is won back after 5 years. The energy use is 40% compared to no PV-Cells.

When looking separately at the embodied energy (see Figure 7-21) the total embodied energy of the façade of the own design is about 1/3 lower than that of Portaal. But there is more embodied energy needed for the construction of the balconies than with the design of Portaal. The difference in the embodied energy of the façade is because they sometimes use thicker and more materials, which causes a higher embodied energy. For example they use 3cm thick fibre cement plates, and therefore have 3 times more embodied energy than the own design. Also in the own design some façade elements were kept, which prevents the extra embodied energy of the demolition to be taken into account (the embodied energy still remained in the old materials when demolished is in this situation 1/3 of the initial embodied energy). Since Portaal often uses less insulation the embodied energy for that part is lower.

When looking at operation and embodied energy after 35 life span use, the influence of the embodied energy in the total can be seen. This is only about 4% influence of embodied energy on the total. But as can be seen in the previous chapter in Figure 6-6, the embodied energy is 20% of the total after 35 years in a situation where less environmental friendly materials are used.

Environmental costs

When looking at the environmental costs (Figure 7-23) Portaal's design is almost the same as the new design. Only a slight difference in more environmentally friendly materials causes the own design to lower in embodied energy, even though thicker insulation is used.

The environmental costs of the PV-cells scenario have not been calculated.

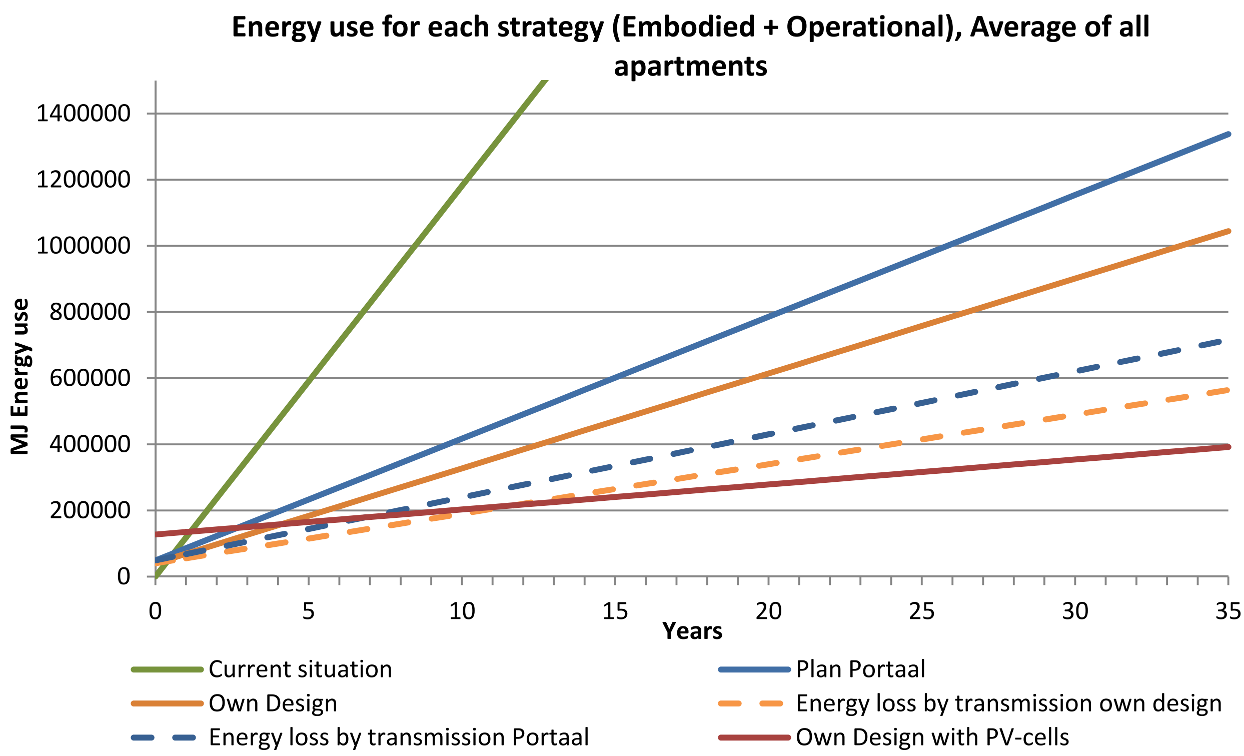


Figure 7-20: Embodied energy + Operation energy use for different situations, average of all apartments

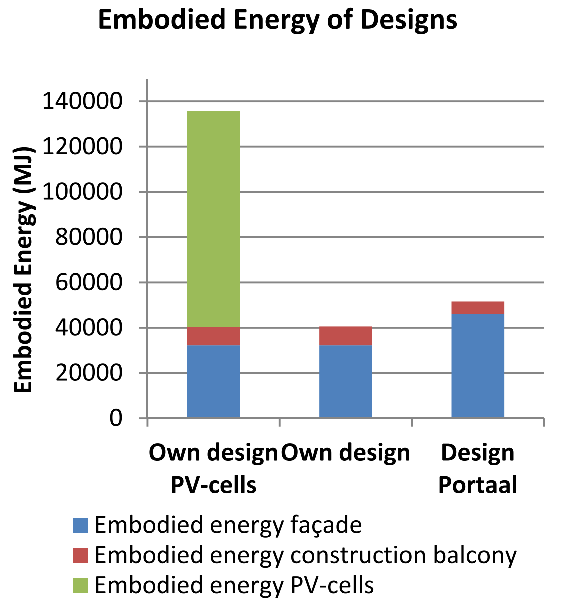


Figure 7-21: Embodied energy, average value, for 35 year lifespan

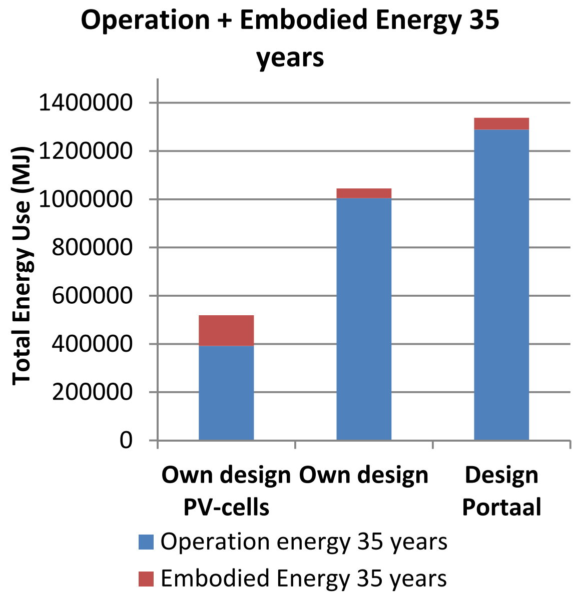


Figure 7-22: Operation + Embodied energy, average value, after 35 years lifespan

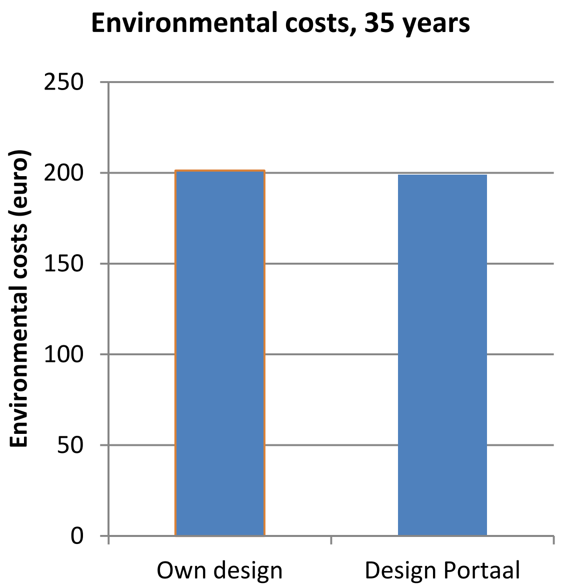


Figure 7-23: Environmental costs for the designs, average value for one apartment, for a lifespan of 35 years

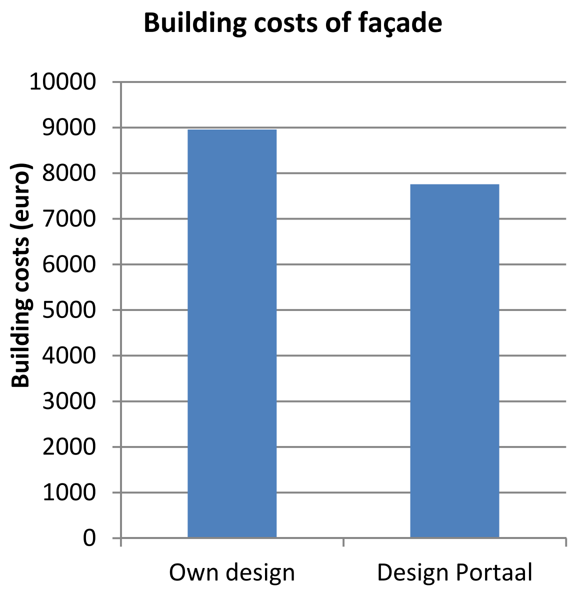


Figure 7-24: Building costs for the façade, average value for one apartment, for a lifespan of 35 years

Building costs

When looking at the building costs, initially the design of Portaal is less expensive than the new design (see Figure 7-24). But when looking at the costs in building and operation energy use together, the investment can be gained back after a few years (see Figure 7-25). These building costs are only for the new façade materials and are an indication. The true costs will be much higher, since there are also other factors to consider like building services costs.

When looking at the operation energy use per m^2, expressed in kWh/m^2, it is $88kWh/m^2$ for the new design and $114kWh/m^2$ for Portaal's design. The EPC is also significantly lower when comparing the own design with Portaal's (0.66 and 0.84 respectively).

The building costs for the PV-cells scenario have not been calculated.

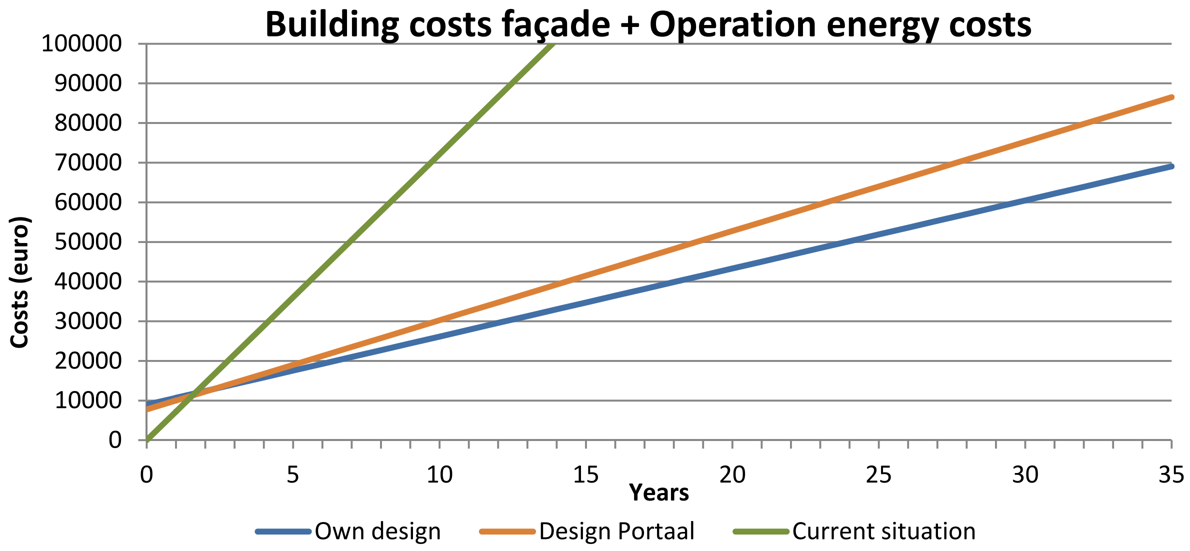


Figure 7-25: Building costs + operation energy costs for both designs

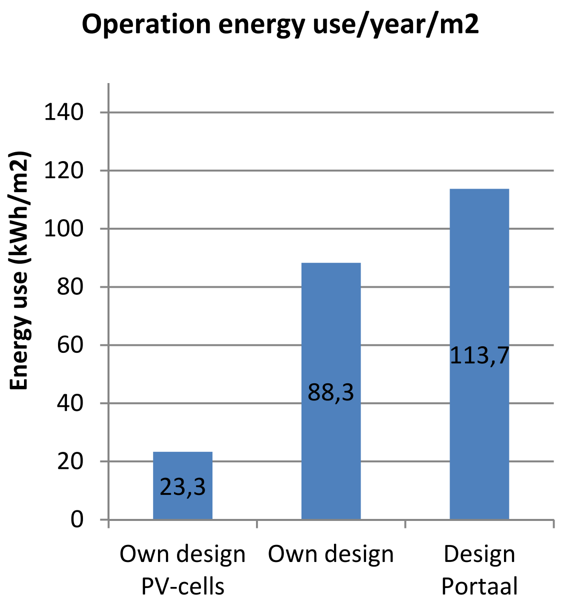


Figure 7-26: Operation energy in kWh/m² for the designs, average value of all apartments

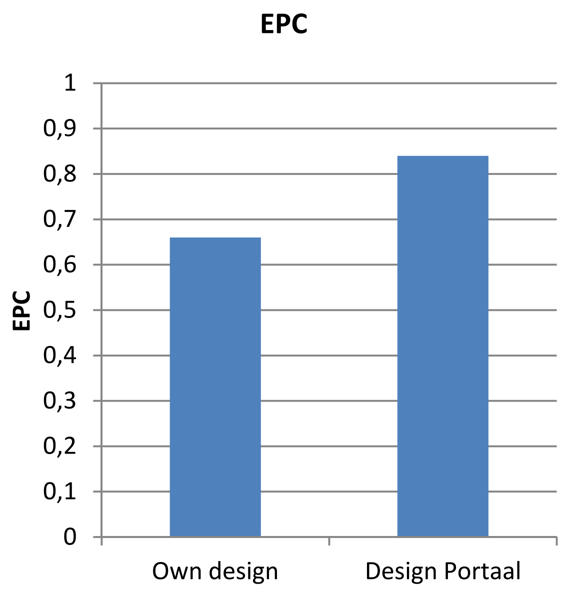


Figure 7-27: Average EPC of all apartments for both designs

8. CONCLUSIONS, RECOMMENDATIONS, EVALUATION

The final conclusions will be given by answering the sub and main research questions, as a summary of the information given earlier in the report. Based on these conclusions recommendations will be given for other refurbishment projects, other designers and the housing corporation Portaal. Also points for future research will be given. Finally a reflection on the graduation research will be made.

8.1 Conclusions and recommendations

In this part the six sub-research questions and the main research question will be answered, which lead to recommendations for Portaal and other designers.

Sub research questions

1. What measures can be taken to improve the façade of a (residential) building with refurbishment?

First the degree of adaptation needs to be considered, ranging from renovation or maintenance to demolition/reconstruction. With refurbishment the building is changed to get the current standards for fire protection, acoustics and thermal performance.

With refurbishment attention needs to be given to: the fire resistance, internal surfaces, thermal performance, acoustic performance, moisture and dampness prevention, air tightness and structure.

Maintenance or repair of certain materials and parts of the facade and structure might be possible, so that not everything needs to be replaced. This needs to be assessed for each situation and material.

Different strategies can be named for refurbishment: façade replacement, exterior upgrade, interior upgrade, adding exterior layer and adding interior layer. The choice depends on the desired performance and appearance.

The strategies were important in this research, to help answer the main research question.

2. How can the façade be upgraded to increase the energy performance of a (residential) building?

The energy performance of a building can be improved in the following aspects:

- *Improving insulation:* of walls, floors, ceilings, floors, cold bridges.
- *Ventilation:* sealing cracks and air paths, draught stripping, efficient natural or mechanical ventilation (heat recovery).
- *Avoid overheating*: by reducing internal and external heat gains, use of thermal mass, adequate ventilation and external landscaping.
- *Existing components and new sustainable materials:* reuse and restore existing components, minimal embodied energy and environmental impact in new materials.
- *Daylight, efficient lighting and control systems:* by optimizing daylight, light surfaces, efficient lamps, sensor switches.
- *Domestic hot water*: Solar water heating, district heating, efficient boiler, heat pumps, small electric heaters, insulate storage cylinders and pipe work, reducing hot water use.
- *Efficient appliances and controls* in kitchen and utility.

3. What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?

This depends for some materials on the lifespan. A lifespan of 35 years was taken now, because this is the lifespan Portaal is planning for the case study building. In this case the following materials are the best:

- Cavity insulation: Glass wool plates.
- Flat roof insulation: EPS plates.
- Outside and inside window frame: European Hardwood or Softwood, renewably grown.
- Window sill: Pinewood and Robinia, renewably grown.
- Inside cavity wall: Wooden frame (renewably grown) or clay/mud brick for heavier constructions.
- Wooden cladding: Oak (renewably grown) or Robinia (renewably grown).
- Metal cladding: Aluminium profile, coated.
- Stone/plastic cladding: Fibre cement plate.
- Outside cavity wall: Mud masonry brick
- Door: Tropical multiplex/tropical hardwood/PUR (renewably grown).

Concerning façade cladding, the wooden cladding comes as the best choice. But if another material is desired, than fibre cement plates are the second best choice.

4. How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?

The amount of reusability/recyclability doesn't have a direct relation to the embodied energy, but it can help to reduce the embodied energy. When the reuse or recyclability is increased in a higher degree than usual, this can be calculated extra in the embodied energy. The extra ability to reuse or recycle should be investigated for each material to see how much it is possible in reality.

When reusing façade parts, after the refurbishment, in another function, this can contribute to lower the embodied energy use. When for example reusing the single glazing of the windows, into the balcony balustrade, this can lower the embodied energy 4.4%. But extra embodied energy, for example for cleaning, reprocessing and making it suitable for its function has not been calculated in this.

5. What type of building can best be used for the case study design?

From the research the following aspects were important for the case study building:

- Build between 1945 and 1975.
- Many different façade materials and façade constructions.
- Also representative for other buildings.
- Portiek flat.

These requirements were met with the case study building on the Marco Pololaan.

6. What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?

The complete design approach as can be seen in Figure 8-1 was used for making the new design. This part will also be assessed in chapter 8.4: Reflection.

The four steps that were made for the design approach worked well. It is good to first do a thorough analysis of the current situation, to be able to make ground decisions for the building services and façade. The second step, to find the best building services for the situation, had a good process. But this could also be combined with façade decisions. For example the infiltration has a great influence on the energy use as well and is also dependent on the installation (with balanced ventilation the infiltration needs to be lower). The variation studies that were now made in the fourth step could have been done earlier in the process to optimize the energy use together with the building services.

In the third step the different strategies were assessed and the material analysis was made. This would probably not be necessary for all new designs, but the recommendations given (which can be found in the answer of the main research question and sub question 3) can be used also in other situations. From these conclusions already choices in façade strategies and material choices can be made in new projects to keep the embodied energy low.

For the final design the variation studies were used, which were useful to make certain choices for the final design. These variation studies are more dependent on the situation, therefore also useful to do in other refurbishment projects.

The assessment was made in different aspects, to compare them to the current situation and Portaal's design, which gave interesting results.

It is important to note that variations for the architectural design of the building were not made, so the design could be better in that aspect. So variations in the architectural appearance could be added to the design approach for the future.

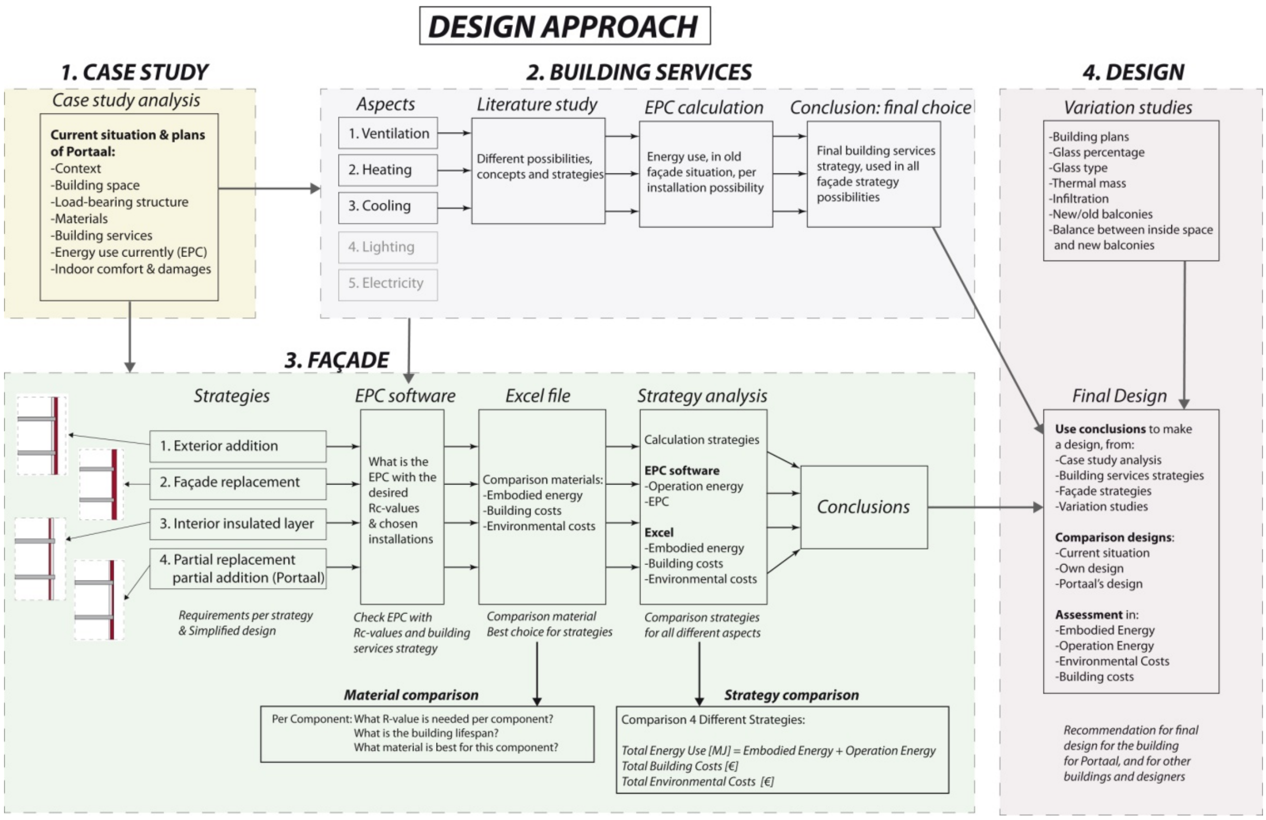


Figure 8-1: Design approach for the new design for the case study building

Main research question

How can the façade of a post-war residential building be refurbished, to make the operation energy and embodied energy (life cycle energy) as low as possible, while also considering other factors that influence the environmental impact?

There are 3 things that have an influence on the total energy use, which were examined here in different extends:

• The influence of the building skin on the total energy use
• The influence of installations on the energy use
• The influence of PV cells on the energy use.

First the influence of the building skin on the total energy use is limited. The embodied energy used can be lowered to a certain extent by the material use selection (see sub-question 3 for the best material choices), but the influence of this on the operation energy use over a long period of time is limited. When using unsustainable materials (for a lifespan of 35 years), the embodied energy of the façade is 20% of the total energy use (operation and embodied). When using sustainable materials this is only about 5%.

For the operation energy the main thing that can be done concerning the building skin is to limit the transmission and ventilation heat losses. The insulation needs to be made as thick as possible, while lowering the ventilation and infiltration.

Secondly the installation choice can have a large influence on the operation energy. But the influence of these installations on the embodied energy use has not been examined in this thesis.
If district heating comes out as a good choice, because the efficiency is counted as very high, this does not count the embodied energy needed for all the pipes. Also a heat pump has a very high efficiency, but maybe the operation energy gain is largely outweighed by the embodied energy needed to make the installation. Therefore for the installations no conclusions can be made concerning the life cycle energy (because the embodied energy is not accounted for).

These previous two factors can only lower the EPC to a certain extent, due to limitations in the efficiency of the installations at this time. The only way to lower the operation energy to zero is to use sustainable energy sources such as PV and solar cells. There are limitations in this as well, because especially for apartments the roof area is often not large. Other solutions, such as PV-cells in the façade, need to be considered if the energy use needs to be zero.

Building skin

For the building skin the following conclusions can be made, to lower the life cycle energy as much as possible in the case study building:

- Addition of new parts on the old façade if possible (keeping the old façade), to prevent higher embodied energy and to use the current insulation value of the façade.
- Reusing of façade parts to lower the new embodied energy, but also the old embodied energy still counted from the old façade part.
- Glass percentage between 20 and 50%. Automatic sun shading helps a lot above that percentage, below 50% it is not necessary (not much influence).
- Closing off old balconies and adding new ones has a higher initial energy use, but since the floor area increases and the mass is more compact, the energy use per m^2 is lower.
- Investment in triple glazing.
- Closing of cracks to lower the infiltration. If heat recovery is used the infiltration should be as low as possible.
- Keeping materials that have a higher new and old embodied energy by maintenance or repair. Insulation is then done in another way than external upgrading. For example, doing this with the existing masonry on the north and south side of the building saves a lot of embodied energy. But in some situations, it is not worth it to keep the old façade materials, if this gives a lot of problems in the new detailing.

Building Services

The heat output system, ventilation system and heat provision system are very interdependent. A good solution in the case study would be to use the current district heating with mechanical exhaust ventilation and radiators. The problem is that the true efficiency of the district heating is unclear and therefore the energy use still higher.
Another solution, which also increases the indoor comfort, is to use a heat pump with groundwater storage (aquifer) to lower the energy use. This could be used in combination with decentralized balanced ventilation and heating system (for example Climarad).
Other adjustments also help lower the energy use. For example using heat exchange of the domestic hot water, and insulating the pipes well. Also using sun shading has a good influence on the energy use in some cases.

PV Cells

Using the maximum amount of area on the roof for PV-cells reduces the EPC to 0,18 and the energy use is less than 10% of the current situation and 30-40% compared to the new designs. The investment in embodied energy of the PV-cells is gained back after a few years already.

The total energy use compared to the current situation can be lowered by 50% by improving the façade, an extra 25% by improving the building services and 15% extra with PV-cells.

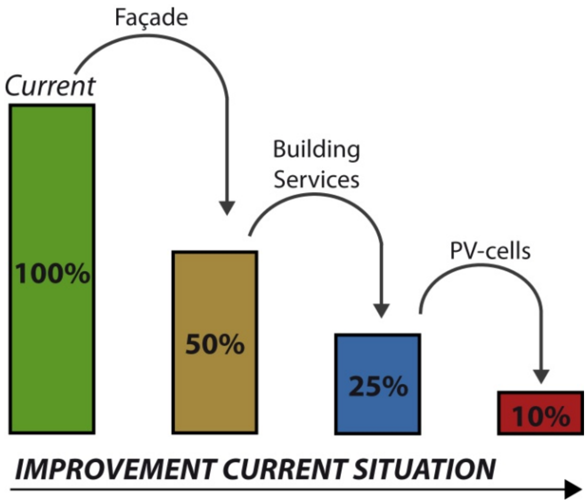


Figure 8-2: Improvements of the own design compared to the current situation

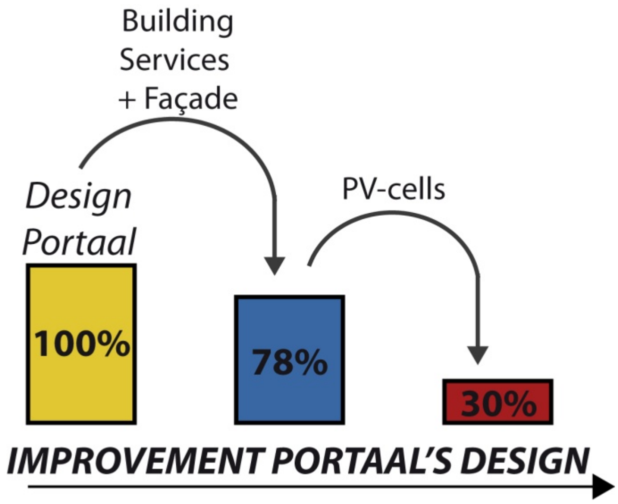


Figure 8-3: Improvements of the own design compared to Portaal's design

Comparison to Portaal's Design

Due to the lower insulation values in Portaal's design, the life cycle energy use over the long term (of 35 years) is higher than with the own new design. The total energy use of the new design is ¼ lower than that of Portaal's design. This can also be seen in the energy losses due to transmission, which is 1/5 lower in the new design compared to Portaal. This is the influence of the façade on the energy use.

The initial embodied energy is higher with Portaal's design, but the environmental costs are the same as the new design. This is due to the fact that some of the materials were kept in the new design, which makes the embodied energy lower. Also less thick materials were used in some parts (for example the fibre cement plates are less thick in the own design).

The building services have a large influence on the complete energy use, since a difference in efficiency of the district heating can make the energy use much lower.

In general the materials that Portaal chose for the façade are environmental friendly with a low embodied energy and environmental impact. They have made good decisions about the strategies, but if the insulation value was made higher in some points, the operation energy use could be lowered even more.

In the design of Portaal, as well as in the new design, the payback time if looking at the current situation, in Energy use and costs, is very short (1-3 years).

Recommendations

A recommendation to Portaal would be to consider taking PV-cells or Solar collectors, since this can reduce the energy use for the users a lot to an extra 48%.

Also it is recommended to see what the true efficiency of the district heating is. If this is 173%, which the other research showed, this is a very good choice to keep. But if the efficiency is much lower another installation for the heating should be considered, possibly with heat recovery, such as in the own new design.

Extra insulation should be used, to reduce the energy losses by transmission. In some parts of the façade, such as the masonry on the north and south side, the insulation value is still much too low. Internal insulation might be a possibility here.

The material use of the façade is good, so it is recommended to keep this materialization.

8.2 Further research

A large obstacle in this research was that it took a long time when making a design, to calculate all the different aspects such as building costs, embodied energy and operation energy. When making a design, every factor had to be input into the Excel file, which could calculate the final numbers. But this way it is difficult to design while also considering these factors. It would be ideal to be able to make small changes to the design and to see what influence this has on the embodied energy for example. This way the lowest values of the energy use can be realised far easier. A good way to do this would be to integrate the excel file into a 3D program, which integrates all the needed databases into one file for the design.

Software integration

In Figure 8-4 a possibility is given for further development of this research. This is subdivided in 4 steps, where eventually there will be an output of a design that has the best results.

The first step is to choose your aim. A user will have a different aim than for example a developer, building owner or renter. You can choose the factor which you want to be as low as possible, which is your main aim: Operation energy, Embodied energy, building costs or the total of these three.

The second step would be to input the building into 3D modelling software. An example of this is Revit, which is much used for BIM. In this software it is easy to detail out the building, since it already has a database of details. The current build-up of the façade can be input, as well as the state of the material. When the façade cladding is still in very good state, maybe it would be possible to keep using this. If it is in a bad state the choice of replacing might be better.

The third step is to input the new design. Important factors here are for example where you want the windows to be, or where new balconies should form. You can easily change certain parts of the design this way.

If the designer has not made a choice of materials for the façade yet, the material calculator tool can be used. In this tool the desired building lifespan can be chosen, the maximum building costs an R-value for example. The tool will give the best material choice. This tool could be derived of the self-made excel file, with which the best materials per life span were calculated (see Chapter 5.2). This excel file could be developed further to make this tool.

As an input of the new design you can choose the desired lifespan, which is important when calculating the best strategy (as was proven in Chapter 6.1.2). Also the maximum building costs can be inserted, since the budget might be important in many cases. Also the maximum energy use per year for the user can be added.

In the next step the software will start calculating. The best strategy will be chosen, for example exterior or interior upgrading, replacement or a combination of different strategies. The computer will calculate which strategy gives the lowest embodied energy, operation energy and building costs. This information can be calculated by the input of different software or databases.

For embodied energy this can be by taking the NIBE database and own Excel file by making a plug-in to use in the software. For operation energy the EPC calculation tool should be integrated into the 3D software. Last for the building costs another database should be used which gives current data on building costs. Revit already has a Life Cycle Costing tool available, but also other databases like Archidat could also be used.

The detail possibilities for the different should be derived from the Revit database for details.

In the last step you get the output of the building for the given design. Details can be given, which show the strategies used. Also the harder parts of the connections between different façade parts can also be made easily in Revit. There is also an output of Operation energy, embodied energy and building costs for that life span chosen.

When making the design slightly different, the calculation will be made again and the changes in the different parameters can easily be assessed. This way a good design can be made while also considering factors that influence the environment, such as energy use. There will be no need for difficult calculation steps, as was the case with the own design. This way also the architecture of the design can be considered more easily.

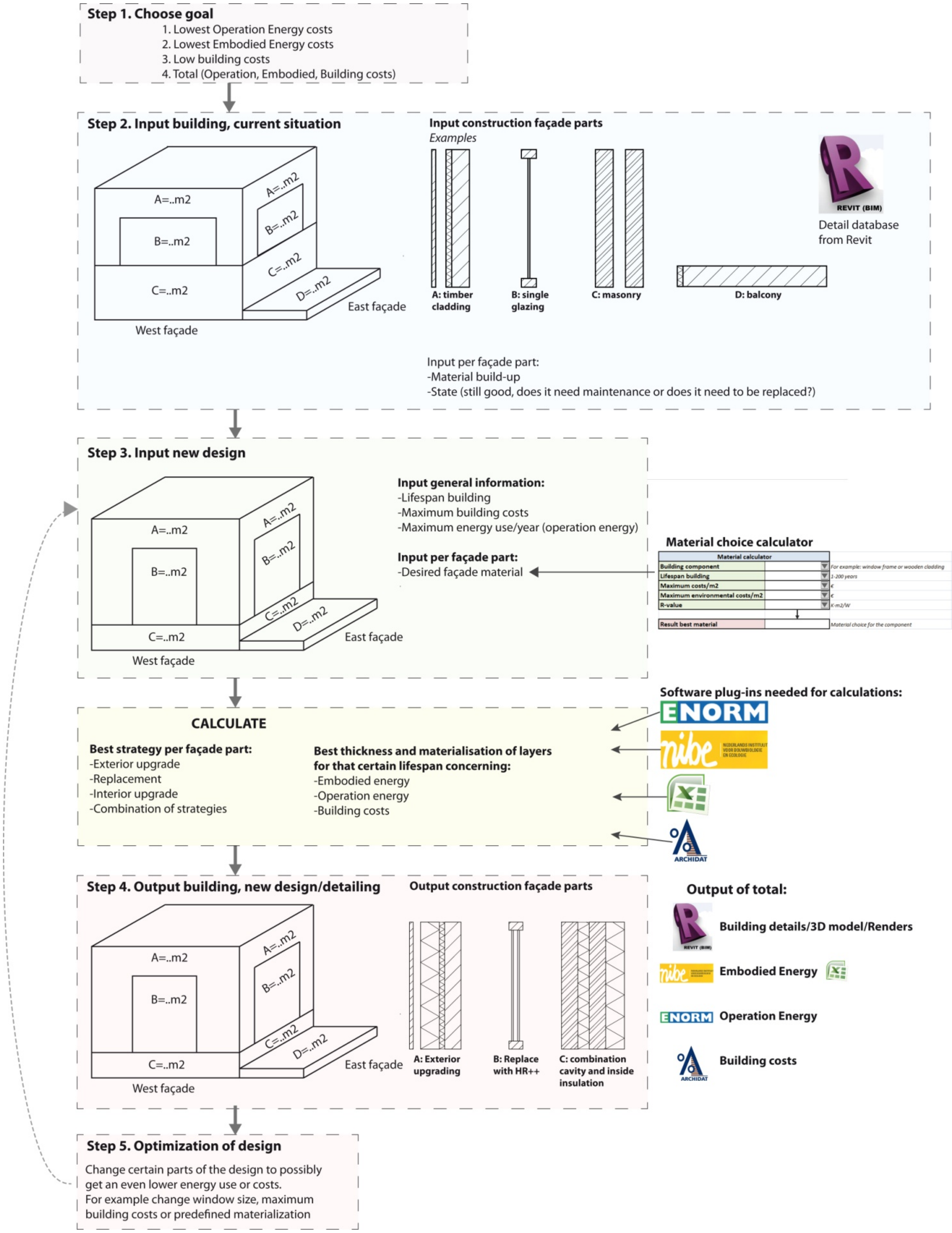


Figure 8-4: Possible further development of the research of this thesis and the Excel tool

8.3 Discussion

There are some parts of discussion and possible points for improvements in the research, which will be explained in this chapter.

EPC software choice

Because a lot of calculations had to be made for the different strategies and design possibilities the user-friendly software of the EPC, ENORM, was used. Because calculating the EPC is a mandatory part for new buildings in the Netherlands, this was a good tool to calculate the energy use of the refurbishment of the case study building.

When looking back at the EPC software, apart from the positive part of the easy use, it also has some disadvantages.

First it has a limitation in possible strategies or designs to input. For example the strategy of covering up with a glazed layer was difficult to calculate. This was only possible when the cold bridges of the building were not fixed (and therefore needed to be calculated manually). This calculation would cost a lot more time this way, and was therefore not made. In other programs such as Capsol this strategy would have been much easier to calculate. But this way the EPC could not have been calculated, which is representative for the total energy consumption of a building.

Secondly the total energy use given by the EPC calculations also gives other factors such as artificial lighting. This factor is not very important for this research, mainly the heating and cooling is, but is still given in the total energy use , because it gives a good indication of what users should pay in total for the energy use of their apartment. This total operation energy value was mostly used, but mainly heating, cooling and ventilation losses are important for this research, where façade is the main focal point.

Fixed values are used for the cold bridges in EPC, but when also calculating each cold bridge separately the results would have been more accurate. The linear cold bridges can contribute a lot to the energy losses. This depends also largely on the detailing. This aspect has been ignored in this research, but in reality is very important.

The EPC was used to calculate the best choice for building services strategies. But this was probably not the best choice, since there are also other tools to calculate this. For example the tool "De Uniforme Maatlat" was developed by W/E Adviseurs and AgentschapNL, to calculate the best option for building services, which uses EPC, but also other data to give the results for each choice.

NIBE database

The NIBE database gives a lot of information that is important for this research, such as CO_2 equivalent, environmental costs and building costs. But it is not always clear how they obtained this data, and when. When looking at the building costs for example, the data can range a lot per month, due to fluctuations. When using the data for the final tool, as is given in Figure 8-4, the data which is used should be updated often to keep the values as they are currently.

No embodied energy of installations was examined, which is a limitation of the research. If this part was also included in the total embodied energy other building services strategies might have come as the best option.

Assumptions have been made for the conversion of CO_2 from the NIBE database to embodied energy in MJ. Only the CO_2 emissions due to fossil fuel use have been assumed into the embodied energy, but also other factors might influence the embodied energy.

In the life cycle energy also the demolition energy should be included, but this aspect was discarded in this thesis. This is partly because it was more difficult to find a database on this, but also because it was not yet clear if it would be necessary to demolish the building after the lifespan of 35 years, or if another refurbishment might be done. But to calculate the complete life cycle energy, this aspect should also be taken into account for the future.

Excel file

During the development of the excel file, the data was input as precise as possible. But it is common that there are some mistakes in the data of such large files. The results were always checked, to see if there were no (large) mistakes, but it is difficult to make it completely accurate.

With the development of the integrated tool in Revit, these mistakes would be less common, since every part of the software is automated.

Design

Because a lot of emphasis was put on the research for the strategies and materials, there was less time to concentrate on making the design and detailing. The interaction between the input in EPC and the detailing was also important. For example the infiltration rate is very low in the building, but in the detailing it is also important to insert this fact.

8.4 Reflection

Process by the method and approach, relationship research and design

Initially the method for the research (which is given in Figure 1-1, Chapter 1) helped to structure the report and the complete graduation research. The division in four parts, introduction, literature research, design and conclusions, also helped the process. The first two parts were made before the P2, to make the framework of the research clear and to gain background information. For the last two parts the design approach as is given in Figure 8-1 was very useful.

The design approach was initially made in the beginning, when the case study building was chosen (just before the P2 presentation). During the time of the research, this design approach also changed and evolved to the current Figure 8-1. Parts were added or removed, to make the process more correct and to be able to give good arguments for (design) decisions. For example the variation studies were added, because not enough conclusions could be drawn from the façade strategy study to make a final design.

The complete approach helped a lot to make the design as good as was possible in the available time-frame. The different steps in the process made sure that enough attention was given to all different subjects which are important in the design to make its energy performance better. The literature background information helped to gain more knowledge on each subject, to make the final design in total and the façade and building services better.

In the approach the architectural design variations could have been taken into account to make a better design. This factor was not in the research question and was not the main focus point, and was therefore not assessed. But for future designers this aspect should also be taken into account for the design approach, by for example adding a part in variation studies of the façade.

Product

Large parts of the research were conclusions, which were made by calculating certain simplified designs. This way, recommendations could be given for other projects. But also the comparison to Portaal's Design was important, so that perhaps recommendations could be given to them how the refurbishment could be improved. A more detailed design was made to show that the strategy as it is in the new design is also actually possible in reality. Less emphasis was put on making an architecturally interesting building, since there was a lot of time put into the research and calculations. But with the recommendations given, to make a tool for architects where also calculations can be made very easily for energy use, this aspect should be a lot easier to do. It was difficult to make changes in the design each time and calculate the impact, since it took a lot of time to calculate it again. With the tool this would be easier.

Planning

The planning, which can be seen in Chapter 1, Figure 1-2, hadn't changed much since the P2. The planning was not very strict, but the products were made mostly within the time frame that was planned. More calculation subjects were added in the planning after the P2, but this was not a problem in the time management.

Initially it was not planned to work out the façade in much detail, since the conclusions that can be made from the calculations are the most important to give general recommendations. But since it is important that the detailing is correct with certain façade materials and façade strategies that were chosen, it was also good to make the design in a bit more detail after the P4.

Relevance

A research was made on facade materials, refurbishment strategies and possibilities to improve by refurbishment, with a focus on energy use (operation and embodied energy). By doing this recommendations could be given in general to lower the energy use, which has become very important due to the emission of greenhouse gasses and global warming. Also other factors that have an impact the environment are important, which have also been discussed in the report.

By doing this hopefully designers will become more aware of the steps they can take to easily lower the impact on the environmental, for example by choosing the environmental friendly materials which were researched here. Also designers might take into consideration to keep or reuse building materials inside another or the same building.

When also developing a tool, which is build further upon the research done in this thesis, the designers will have an easy way to consider the factors such as energy use, while also being able to design in a 3D program.

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10. APPENDIX

Appendix A: Background research

Appendix A- 1: Refurbishment of Materials

The following part has completely been compiled solely based on the book "Refurbishment manual" by Giebeler et al. (2009).

Load bearing structure

The load bearing structure can have different materials, with damages, which need to be met to the current standards after the refurbishment. Giebeler et al. give the following four subdivisions in materials: Timber, iron and steel, reinforced concrete and masonry.

Timber can be damaged by poor maintenance or excessive absorption of moisture due to constructional and building physics shortcomings.

For iron and steel in the structure rusting is the main problem. Coatings and galvanizing processes can prevent this.

Damage in reinforced concrete can be caused by carbonation in the cement paste, which leads to the reinforcement corroding. There are many strategies for repairing damaged concrete, but mainly it is repaired by protective or substitute layer.

Masonry is mainly damaged by moisture, which can for example lead to crumbling and cracking. This can be solved by first cleaning the masonry dry, removing defective parts and replacing and filling parts. The moisture load can be decreased by constructional measures like increasing eaves overhang.

Building envelope

The important functions that the building envelope fulfils are amongst other things: control passage of water from outside to inside, insulation and air tightness. There are different parts of the building envelope that have different kind of damages: Roofs, wood products, doors and windows, stone, render, paints and coatings and insulating materials.

Roofs

Flat roofs can have problems with waterproofing: inadequate falls (which lead to higher stresses), but also for example cracks due to high movement stresses. Fatigue embrittlement, blisters and corrugations can also be a problem. The thermal performance can be upgraded by insulation and waterproofing, which can also solve the problem with the falls. With more serious problems the complete roof system above the load bearing structure needs to be replaced. But if it is possible more locally parts can be solved, for example for gullies, flashings and sealing joints.

Clay and concrete roof tiles can have mechanical damage by something falling on it or by wind. Due to saturation the tiles can spall or become more porous, which can lead to vegetation. Vegetation on the tiles can cause embrittlement. This can be solved by replacement of damaged parts.

Metal roof coverings can have damage by corrosion. This can be solved by mechanical cleaning of the sheet metal, adding surface protection. Isolated flaws can be repaired by soldering.

Wood

Wood based products can be affected by the weather, causing photochemical, biological and physical processes. Biological processes are for example plants and animal pests. Moulds can form because of the moisture, but are fed by the light. Light can cause colouring on the wood, or the wood fibres can degrade. Due to swelling and shrinkage the wood can bulge, crack, become saturated and decay. The mechanical fasteners can cause parts that do not look desirable. The timber can be protected against the weather by coating systems regularly. By sanding the surfaces can be repaired, if not possible by decay they should be replaced.

Doors and windows

When window frames are made of wood, especially the lower parts can be affected by moisture, due to swelling and shrinking the moisture and fungus can get into the corners. Regular inspection and maintenance is needed to prevent this. Also the bottom rail of the wooden window frame could be made of a more durable material like oak.

The glass windows can be stained by deposits of other building materials (like rust), which can stain the surfaces. The glass can be polished for maintenance, but when they have breakages or edge seal failures they need to be replaced by new glass or complete window.

Stone

Water causes damage to stone by filling into the cracks and pores, and by freezing (and expansion) it can spall. Some rock types lose strength when saturated with water, or dissolve the binder out of the rock, which can lead to damage. Dirt on some stone types can cause spalling. Plants can cause cracks. Bacteria, algae and lichens cause chemical transformation processes. Sun, rain and wind can cause colour changes. Air pollution can cause problems with very porous rocks; some pollutants can cause dissolving of the stone or efflorescence. Compatibility of certain stones with other materials needs to be checked, because for example steel causes discolouring and spalling. Oak can cause discoloration of natural stone. Especially facades that are not in the prevailing direction of the weather cause a problem, due to accumulation of dirt.

Cleaning of stone can be done by water, pressurised water jets, steam etc. Good detailing of construction can prevent moulds by good drainage of rainwater for example. A treatment is possible for some stones, which reduces the absorption of water through the surfaces and makes it better water repellent.

Render

Damage and cracking in render can be caused by: the render itself or the substrate or the structural movements. Thermal bridges and splashing water can cause blemishes and discoloration. Due to too much moisture algae and fungi can grow, which cause chalking, dusting, erosion and spalling. Detachment can be caused by permanent wetting or drying, heating/cooling or poor adhesion. For older buildings the problem can be that the insulating material is not attached well with mechanical fasteners and can be detached together with the render. Uneven insulation can be a reason for forming of cracks.

Too much moisture can be repaired by horizontal damp-proof courses or other waterproofing measures. Loose parts of render must be removed and repaired with new material. Cracks can be repaired.

Paints and coatings

Coatings consist of binders, fillers, pigments, solvent or thinners and other additives. Most problems with paints on the façade are due to moisture, poor substrates or too rapid drying of the coating. Saturation can cause paint to flake off and can cause crystallization. Degradation of water-soluble paints is possible over the long-term. Discolouration, efflorescence, flaking, blistering and crystallization on the surface might be caused by moisture. Mould or algae can grow between undercoats and top coats. Due to the weather the surface become less shiny. Maintenance is needed regularly every five to eight years.

Old coats and paints can be removed by grinding or sanding and repainting. They can be removed mechanically (scraping, brushing, grinding, sanding), thermally (hot air) or chemically.

Insulating materials

Due to infiltration of water or by condensation, insulating materials can lose their insulating effect. Also animal pests can infiltrate the insulation and degrade it. Defective fixings can cause insulation materials to become detached. Very important is that older materials often do not fulfil to the standard requirements nowadays.

Replacement of damaged insulation materials is needed, while smaller voids can be filled with in situ foam. Additional layers are often needed in older buildings, on the inside or outside.

Fitting-out

Fitting-out components can show damage due to problems by the load-bearing structure of envelope, which can result in cracks and saturation (Giebeler et al., 2009). According to Giebeler, there can be a division made in the fitting-out materials: Plaster and gypsum materials; wooden floors; subfloors and terrazzo.

Plaster

There are different types of plasterboard: for general applications, with improved fire resistance, or with improved moisture resistance.

Damage to plaster is caused by structural movements, inconsistently and poor repaired substrates, mechanical impacts and moisture. Damage can for example be deflection of suspended floors and cracks in plasterboard walls and linings. Because of moisture there can be mould growth, efflorescence and degradation.

When there is moisture and movement damage refurbishment work is needed. Mould can be prevented by extra insulation, less moisture loads and by disinfectant plasters and paints. Smaller cracks and damage can be repaired by cutting materials and filling and reinforcement if needed. New cracks can be prevented with highly elastic dispersion paints.

Wooden floors

Damage can be: mechanical, wear, changes of colour, discoloration, burn marks. By drying out loose pieces and widened joints can become visible due to bulges, depressions and shrinkage.

Sanding and resealing can be done, but when more badly damaged it needs to be repaired or replaced. When there are sealed wooden floors they need to be sanded and finished in total.

Subfloors and terrazzo

Problems with this fitting-out is: shrinkage cracks due to the drying process, cracks, bulges, unevenness, damage by loads and dusting, loss of individual pieces and discoloration.

A refurbishment solution can be to grind to make it more even and remove adhesive residue. Small damages can be repaired by removing old and filling in new materials or by resin solution injection or coating. With terrazzo floors cracks can be chiselled out, widened and filled again. Grinding is possible with a finishing afterwards.

Table A- 1: Energy labels and Energy Index of different residence types and building periods (based on Agentschap NL (Agentschap NL, 2011))

Residence types	Building period				
	Until 1945	1946-1964	1965-1974	1975-1991	1992-2005
Detached house	G (2,96)		F (2,42)	D (1,63)	B (1,22)
Duplex house	F (2,79)		E (2,38)	C (1,56)	B (1,29
Terraced house	G (3,18)	F (2,49)	E (2,08)	D (1,64)	C (1,31)
Maisonette house	G (3,02)		D (1,82)	C (1,45)	B (1,17)
Gallery apartment	D (1,67)		E (2,18)	C (1,48)	B (1,28)
Flat with entrance hall (portiek)	F (2,90)	E (2,06)	D (1,72)	C (1,31)	B (1,24)
Remaining flat types	E (2,03)		E (2,20)	C (1,49)	B (1,22)

Table A- 2: Possibility to upgrade the home with possible Energy Index (based on Agentschap NL(Agentschap NL, 2011))

Residence types	Building period				
	Until 1945	1946-1964	1965-1974	1975-1991	1992-2005
Detached house	B (1,06)		A (1,05)	B (1,06)	B (1,13)
Duplex house	B (1,08)		B (1,08)	B(1,07)	B (1,15)
Terraced house	B (1,19)	B (1,17)	B (1,18)	B (1,17)	B (1,26)
Maisonette house	B (1,06)		A (1,04)	B (1,08)	B (1,13)
Gallery apartment	B (1,07)		C (1,36)	B (1,09)	B (1,24)
Flat with entrance hall (portiek)	B (1,08)	B (1,06)	B (1,06)	A (1,04)	B (1,11)
Remaining flat types	B (1,06)		C (1,41)	B (1,08)	B (1,19)

Appendix B: Example studies

Figure B- 1: Balconies and roof of Acaciaplein old situation (De Vries, 2007)

Figure B- 2: Balconies and roof of Acaciaplein after renovation (De Vries, 2007)

Appendix C: Case study analysis

Table C- 1: Properties of the different materials used for the current situation, together with the sources

	λ W/(mK)	Density ρ (kg/m³)	Source
PS/Polystyrene	0,08	1060	www.joostdevree.nl
Single glass	0,80	2500	www.joostdevree.nl
Air	0,024		www.wikipedia.nl
Plate material	0,2	550	www.joostdevree.nl
Grindbeton	1,4-1,8 (1,6 average)	2300-2500 (2400 aver.)	www.joostdevree.nl
Gasbeton/cellenbeton	0,20-0,24 (0,22aver.)	600-700 (650 aver.)	www.joostdevree.nl
Hardwood	0,20	800	www.joostdevree.nl
Masonry	1,28	2100	www.joostdevree.nl

Table C- 2: Ventilation needed per room of apartment type D, according to the Dutch regulations

	Area (m^2)	Regulation	Refreshment needed
Bedroom 1	9.4m^2	0.9$dm^3/s/m^2$	8,5dm^3/s
Bedroom 2	11.8 m^2	0.9 $dm^3/s/m^2$	10,6 dm^3/s
Bedroom 3	15.6 m^2	0.9 $dm^3/s/m^2$	14 dm^3/s
Living room	18.8 m^2	0.9 $dm^3/s/m^2$	16,9 dm^3/s
Kitchen	6.3 m^2	21dm^3/s	21 dm^3/s
Bathroom	2.5 m^2	14dm^3/s	14 dm^3/s
Toilet	1 m^2	7dm^3/s	7d dm^3/s
Hallway	5.5 m^2	0,5dm^3/s	0,5 dm^3/s

Appendix C- 1: EPC Software input current situation

In the EPC software ENORM, there are 7 tabs that are important: Project information, schematisation, building construction, installations, solar energy, lighting and results. The input of the current situation will be discussed here for each of these parts.

As project type, a new building had to be chosen, because with the version that is available (ENORM V1.11 Student version) existing buildings is not yet possible. The building type was a residential building, made in 1961. The requirements chosen in the Project information were standard for new buildings, so the EPC necessary is 0.6. For the thermal bridges fixed values are chosen in the EPC software, as well as the ventilators and lighting.

For the schematisation, the climate zones need to be chosen. In this case there is only one climate zone and one calculation zone of 77m^2, which is the total floor area of the apartment. The temperature needed is fixed as 20°C.

The input for the building construction is shown in Table C- 3. There is no floor input for beneath the apartment, because there is another apartment beneath it which is heated. Important factors here are the orientation and the obstruction. In some cases the façade has another balcony above it, which overhangs about 1 meter. The building type for the internal heat capacity is chosen as traditional, mixed heavy. The internal heat capacity is a fixed value by the software. The infiltration of air has a fixed value (qv10;spec = 3,010 dm^3/sm^2). The height of the building is entered as 13.80 meters, and as a building type of a multiple storey building, an apartment at the top corner of the building. The façade type is a standard facade (other options are for example a double facade). The ZTA value of the windows is entered as 0.8, because this is normal for single glazing.

Table C- 3 : EPC input, for the simplified façades for the current situation

WEST FAÇADE	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA	Desired RC-value	Desired U-value
Facadepart 1.A	Sandwich panel	4,05	0,62	1,62	West	Minimal	-	3,5	0,29
Facadepart 1.B	Window total	1,90	0,23	4,40	West	Minimal	0,8		1,85
Facadepart 1.C	Windowsill	0,17	0,40	2,53	West	MInimal	-	3,5	0,29
Facadepart 2.A	Plate material +	2,62	0,44	2,26	West	Overhang	-	3,5	0,29
Façadepart 2.B	Window total	5,70	0,23	4,40	West	Overhang	0,8		1,85
Facadepart 2.C	Door	1,05	0,34	2,99	West	Overhang	-	1,2	0,83
Facadepart 3.A	Plate material +	3,48	0,41	2,42	West	Minimal	-	3,5	0,29
Facadepart 3.B	Window total	6,48	0,23	4,40	West	Minimal	0,8		1,85
WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/	Orientation	Obstruction	ZTA	Desired RC	Desired U
Facadepart 4.A	Side balcony	4,86	0,42	2,40	North	Overhang	-	3,5	0,29
Facadepart 4.B	Side balcony	2,43	0,42	2,40	South	Overhang	-	3,5	0,29
EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/	Orientation	Obstruction	ZTA	Desired RC	Desired U
Facadepart 5.A	Plate material +	3,48	0,41	2,42	East	Minimal	-	3,5	0,29
Facadepart 5.B	Window total	6,49	0,23	4,40	East	Minimal	0,8		1,85
Facadepart 6.A	Plate material	4,85	0,44	2,26	East	Overhang	-	3,5	0,29
Facadepart 6.B	Window total	3,79	0,23	4,40	East	Overhang	0,8		1,85
Facadepart 6.C	Door	1,05	0,34	2,99	East	Overhang	-	1,2	0,83
EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/	Orientation	Obstruction	ZTA	Desired RC	Desired U
Facadepart 7.A	Side balcony	2,37	0,42	2,40	South	Overhang	-	3,5	0,29
SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/	Orientation	Obstruction	ZTA	Desired RC	Desired U
Facadepart 8.A	Masonry	25,31	0,71	1,40	South	Minimal	-	3,5	0,29
ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/	Orientation	Obstruction	ZTA	Desired RC	Desired U
Facadepart 9.A	Roof	77,04	0,57	1,75	-	Minimal	-	5	0,20

The installations tab is the next. For heating, a high temperature system is chosen, with individual regulation in the apartments. The heat generation is by external heat supply (district heating) by external heated water. The heat output system is a radiator, in front of a wall with an Rc-value of lower than 2.5.

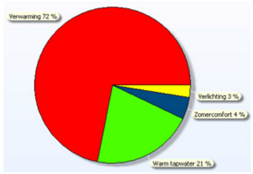
The domestic hot water is now heated by an electro-boiler, by electricity, for the bathroom and kitchen. There is no cooling system in the apartments.

For ventilation the current situation has natural supply and exhaust, with a standard ventilation system (no wind pressure system in the vents). The needed supply was before calculated as 92.50dm^3/s, which is entered in the software.

There are no extra solar collectors or PV-cells installed in the building, so this part is left empty. The lighting has fixed values.

Primair energiegebruik [MJ]	Waarde
Verwarming	99.170
Warm tapwater	29.038
Koeling	6.197
Bevochtiging	0
Ventilatoren	0
Verlichting	3.548
Totaal	**137.952**
Electriciteitsproductie gebouwgebonden	0
Afgenomen energie	**137.952**
Geëxporteerde energie	0
Electriciteitsproductie niet gebouwgebonden	0
EPtot	**137.952**
EP;adm;tot	27.735
Specifieke energieprestatie per m²	1792

Deelpost	Energiegebruik geconverteerd naar primaire energie [MJ]						
	elektriciteit	aardgas	stookolie	hout, biomassa	externe warmte	externe koude	Totaal
Verwarming	0	0	0	0	93.519	0	99.170
(hulpenergie)	5.651						
Warm tapwater	29.038	0	0	0	0	0	29.038
(hulpenergie)	0						
Koeling	0	0	0	0	0	0	0
(hulpenergie)	0						
Zomercomfort	6.197						6.197
Bevochtiging	0	0	0	0	0	0	0
Ventilatoren	0						0
Verlichting	3.548						3.548
Totaal	**44.434**	**0**	**0**	**0**	**93.519**	**0**	**137.952**
Geproduceerd (EPus)	0						0
Afgenomen energie	**44.434**	**0**	**0**	**0**	**93.519**	**0**	**137.952**
Geproduceerd (nEPus)	0						0
EPtot							**137.952**

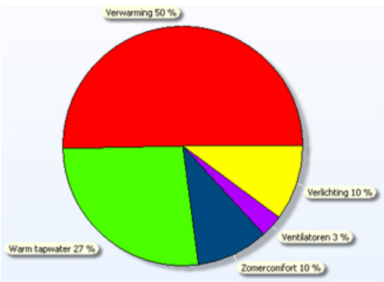


Deelpost	Energiegebruik per energiefunctie in kg CO2						
	elektriciteit	aardgas	stookolie	hout, biomassa	externe warmte	externe koude	totaal
K CO2 [kg/MJ]	0,1569	0,0506	0,0877	0,0000	0,0877	0,0877	
Verwarming	0	0	0	0	8.202	0	8.548
(hulpenergie)	346						
Warm tapwater	1.780	0	0	0	0	0	1.780
(hulpenergie)	0						
Koeling	0	0	0	0	0	0	0
(hulpenergie)	0						
Zomercomfort	380						380
Bevochtiging	0	0	0	0	0	0	0
Ventilatoren	0						0
Verlichting	217						217
Totaal	**2.723**	**0**	**0**	**0**	**8.202**	**0**	**10.925**
Geproduceerd (EPus)	0						0
Geproduceerd (nEPus)	0						0
M CO2							**10.925**

Deelpost	Energiegebruik - niet primair [MJ]					
	elektriciteit	aardgas	stookolie	hout, biomassa	externe warmte	externe koude
Verwarming	0	0	0	0	93.519	0
(hulpenergie)	2.208					
Warm tapwater	11.343	0	0	0	0	0
(hulpenergie)	0					
Koeling	0	0	0	0	0	0
(hulpenergie)	0					
Zomercomfort	2.421					
Bevochtiging	0	0	0	0	0	0
Ventilatoren	0					
Verlichting	1.386					
Totaal	**17.357**	**0**	**0**	**0**	**93.519**	**0**
Geproduceerd (EPus)	0					
Geproduceerd (nEPus)	0					

Figure C- 1: EPC results current situation

Primair energiegebruik [MJ]	Waarde
Verwarming	17 592
Warm tapwater	9 314
Koeling	3 434
Bevochtiging	0
Ventilatoren	1 038
Verlichting	3 548
Totaal	**34 926**
Electriciteitsproductie gebouwgebonden	0
Afgenomen energie	**34 926**
Geëxporteerde energie	0
Electriciteitsproductie niet gebouwgebonden	0
EPtot	**34 926**
EP;adm;tot	27 695
Specifieke energieprestatie per m²	454



Deelpost	Energiegebruik geconverteerd naar primaire energie [MJ]						
	elektriciteit	aardgas	stookolie	hout, biomassa	externe warmte	externe koude	Totaal
Verwarming	11 133	0	0	0	0	0	17 592
(hulpenergie)	6 459						
Warm tapwater	0	0	0	0	8 507	0	9 314
(hulpenergie)	807						
Koeling	0	0	0	0	0	0	0
(hulpenergie)	0						
Zomercomfort	3 434						3 434
Bevochtiging	0	0	0	0	0	0	0
Ventilatoren	1 038						1 038
Verlichting	3 548						3 548
Totaal	**26 419**	**0**	**0**	**0**	**8 507**	**0**	**34 926**
Geproduceerd (EPus)	0						0
Afgenomen energie	**26 419**	**0**	**0**	**0**	**8 507**	**0**	**34 926**
Geproduceerd (nEPus)	0						0
EPtot							**34 926**

Figure C- 2:EPC results after building service and insulation improvement

WEST FAÇADE

EAST FAÇADE

Figure C- 3: Part of the west and east façade of the design of Portaal (provided by Portaal)

Appendix D: Building services strategies

Appendix D- 1: Research on heat provision types

	Combination	System temperature heating system	Suitable heat transfer	Special characteristics
1 Low temperature boiler	5, 6, 7, 8	Feed temperature 40–75 °C	Radiators Radiant panel systems	Economic
2 Condensing boiler	5, 8	Return temperature if possible < 50 °C	Radiant panel systems are particularly suitable	Combustion gas flue, condensate outlet, current standard for gas
3 Wood chips	8	High system temperature possible	Radiators	Buffer store, storage space, transport, operation
4 Wood pellets	8	High system temperature possible	Radiators	Storage space, transport
5 Heat pumps	1, 2, 8	Feed temperature < 40 °C	Radiant panel systems required	Energy from ground water, earth, exhaust air, performance factor should be > 3
6 Small CHP	1	High system temperature possible	Radiators	Maintenance costs high, designed for approx. 20 % of the max. heat demand
7 Fuel cells	1	High system temperature possible	Radiators	Regenerative hydrogen production not yet market ready
8 Solar systems	1, 2, 3, 4, 5	Feed temperature very low	Radiant panel systems required	Mainly hot water, sloping roof

Figure D- 1: Characteristic of energy generators and combinations of systems(Hausladen et al., 2005)

Fossil fuels

Energy supply over the world is at the moment mainly met by fossil fuels like coal, oil and natural gas (Hegger et al., 2008). The efficiency of using an advanced boiler for heating is now much better, with which almost all the energy content of the oil or gas can be converted to useful heat (Hegger et al., 2008). But still the problem remains that the use of fossil fuels leads to global warming due to the greenhouses gasses that are released by the combustion. As can be seen in Figure D- 1, a low temperature boiler or condensing boiler is possible, together with radiators, but only in combination with heat pumps, small CHP, fuel cells or solar systems.

Also electricity can be used for space heating and hot water, with which no combustion is needed. Still this electricity is often generated by fossil fuels and there are still high conversion losses in this conversion (Hegger et al., 2008). Heating with electricity is only responsible when using an efficient system like a heat pump or when the electricity is made from renewable energy resources in central or decentralised installations (Hegger et al., 2008). Also electricity is a good choice for extremely low heating requirements (Hegger et al., 2008).

Biomass

Biomass is considered as a "CO_2-neutral" energy source (when it is grown and used sustainable), even though the fossil primary energy value of biomass is not zero due to the primary energy input from growth to usage (Hegger et al., 2008).

Biomass types in Europe can be divided into four areas according to Hegger et al.:

-Harvest residues (for example logging debris, low-strength wood)

-Organic by-products (residues from primary treatment processes for example scrap word)

-Organic waste (biogenic secondary energy sources remaining after final usage like sewage sludge and landfill gas)

-Energy crops (specially grown plants like rape, sunflowers and soya)

For buildings the oldest method is of turning biomass into energy. To get a higher efficiency (of up to 90%) there are special burners now available (Hegger et al., 2008). Larger centralised heating plants have the best economic advantages due to the low maintenance and feeding costs (Hegger et al., 2008).

Solar heat

A division of solar heat can be made into active and passive systems. With active solar heating 'the functions of solar energy absorption, conversion and storage are not carried out exclusively by the building or building components', so that the heat from the solar radiation can be decoupled from the using of this heat (Hegger et al., 2008).

Hegger et al. give different categories of solar collectors, which are further shown in Figure D- 2:

-Unglazed collectors

-Flat-plate collectors

-Air collector

-Vacuum-tube collector

-Special lenses or reflective surfaces, concentrating collectors. These collectors can reach up to 300°C, for heat to production processes and for solar thermal electricity generation

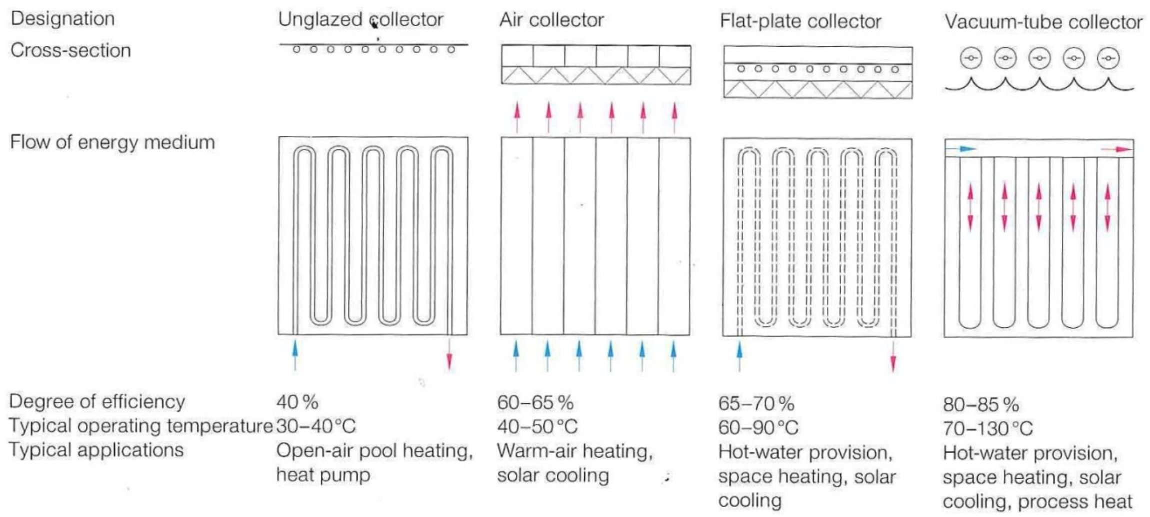


Figure D- 2: Typical collector types and their applications (Hegger et al., 2008)

Often the solar installations are most popular for hot water provision, but when also used for space heating, the installation must be enlarged (Hegger et al., 2008). An example is that 10-20m^2 is needed of collectors and 0.7-2.0m^3 storage volume for a four-person household in Germany, so that 20-30% of the total heating requirement can be covered (Hegger et al., 2008). Also a solar-powered group heating network with long-term heat storage at residences are possible, which are sensible for more than 100 housing units, where the excess solar heat in the summer can be stored for the long term (Hegger et al., 2008).

One flat has a total of 48 households, but since there are many more similar flats very close by, the total amount of apartments would easily exceed 100 apartments.

Heat pumps

Ambient heat can be used in a building, with the use of technical devises to prepare this ambient heat.

There is a difference in heat sources available for use (Hegger et al., 2008):

-*External air* in the direct vicinity of the heat pump or building. Directly via a heat pump or via heat exchanger indirectly into a fluid heat transfer medium

-*Ground/Soil*, tapped by constructional measures. Shallow pipes are possible, 1.5 meter underground. Also deeper to 100 meter is possible, where the temperature is constant during the year.

-*Groundwater or surface waters*

-*Waste heat* in the form of cooling water, waste gases, expelled air, etc.

Heat storage

Heat storage can be divided into thermal (sensible and latent heat) and chemical storage (reaction heat). Also there is a difference in short-term (few hours to a few days) and long-term (heat storage.

For short-term storage 0,02-0,03m^2 collector area per m^2 floor space is needed, with 0,4-0,5m^2 collector area per person for solar preheating systems are needed. About 0.05-0,08m^3 volume per m^2 collector are will be needed. It gives about 50-60% of the energy requirement for hot water and 10-20% of the annual heating requirement.

With long term storage 200-500 housing units should be in the heating network, there needs to be about 0,14-0,20m^2 collector area per m^2 floor space and 1.5-2.25m^3 per m^2 collector area storage volume. The solar energy contribution will be about 40-60% of the annual heating requirements.

Examples of short term storage are: passive solar energy gains and tank-in-tank principle.

Examples of long-term storage are: Hot water thermal storage, Gravel/water thermal storage, Borehole thermal storage, Aquifer thermal storage.

Appendix D- 2: Ventilation in EPC

Natural: Reduction possible of to 1.56 EPC if using a 'winddrukgestuurd' on 1Pa.

Mechanical supply: possible to reduce EPC to 1.53 when using a CO_2 regulator in the rooms. An EPC of 1.6 is possible when it is regulated depending on the tip.

Mechanical exhaust: An EPC of 1.60 is possible when 'winddrukgestuurd' on 1 Pa. When it is time regulated it can be 1.54. When also using CO_2 sensors it can be reduced to 1.53.

Mechanical exhaust and supply: When using heat exchange and CO_2 sensors the EPC can be reduced to 1.45.

Local unit: with mechanical supply and exhaust and heat exchange the EPC can be reduced to 1,50.

HEATING (low temperature):

Table D- 1: Analysis of the EPC for different installation choices for heating, compared to the old situation (EPC of 1.59)

Type of generation/Energy carrier	Electricity	Natural gas	Oil	Wood/ biomass	External heat	External cold
Individual CV heating	2,71	1,64	1,64	1,64	X	X
Collective CV heating	2,80	1,68	1,68	1,68	X	X
Local gas heating with removal	X	1,96	1,96	1,96	X	1X
Local gas heating without removal	X	7,44	7,44	7,44	X	X
Direct air heating	2,71	1,64	1,64	1,64	1,64	1,53
Local/central electrical heating	2,62	1,61	1,61	1,61	1,61	1,50
Electrical heat pump	1,48-1,28	X	X	X	X	X
Gas warmth pump	X	1,52	1,52	1,52	X	X
Micro WKK	2,79	1,62	1,62	1,62	1,62	1,49
External heat supply (100%)	X	X	X	X	1,59	1,48
External heat supply (173%)	X	X	X	X	1,21	1,13

DOMESTIC HOT WATER:

Individual system

Table D- 2: Analysis of the EPC for different installation choices for domestic hot water, compared to the old situation (EPC of 1.59)

Type of generation/Energy carrier	Electricity	Natural gas	Oil	Wood/ biomass	External heat	External cold
Warm water or combi appliance <70kw	2,53	1,58	1,58	1,58	1,58	1,47
Warm water appliance CW	2,14	1,42	1,42	1,42	1,42	1,35
Kitchen geyser	1,90	1,33	1,33	1,33	X	X
Warm water appliance HRww	1,72	1,26	1,26	1,26	1,26	1,21
Combi-appliance CW	1,90	1,33	1,33	1,33	1,33	1,27
Combi-appliance HR/CW	1,75	1,27	1,27	1,27	1,27	1,22
Combiappliance HRww	1,66	1,24	1,24	1,24	1,24	1,19
Combi appliance with micro WKK tap function	0,96	0,96	0,96	0,96	0,96	0,96
Electro boiler	1,59	X	X	X	X	X
Heat pump with retour air	1,30	1,10	1,10	1,10	1,10	1,07
Combi heat pump other than exhaust air	1,30	1,10	1,10	1,10	1,10	1,07

Solar boiler with integrated after-heating

Type of generation /Energy carrier	Electricity	Natural gas	Oil	Wood/ biomass	External heat	External cold
Conventional boiler	1,63	1,23	1,23	1,23	1,23	1,18
VR-boiler	1,59	1,21	1,21	1,21	1,21	1,17
HR100, HR104-boiler	1,55	1,19	1,19	1,19	1,19	1,16
HR-107 boiler	1,52	1,18	1,18	1,18	1,18	1,14
Electrical after heating	1,43	1,15	1,15	1,15	1,15	1,12

Collective system, with an insulation of 20mm of pipes etc. Without insulation it can be about 0,2 (natural gas) to 0,48 (electricity) EPC higher in some situations.

Type of generation/Energy carrier	Electricity	Natural gas	Oil	Wood/ biomass	External heat	External cold
Conventional boiler	1,78	1,32	1,32	1,32	1,32	1,27
VR-boiler	1,72	1,30	1,30	1,30	1,30	1,25
HR100, HR104-boiler	1,70	1,29	1,29	1,29	1,29	1,25
HR-107 boiler	1,65	1,27	1,27	1,27	1,27	1,23
WKK	1,03	1,03	1,03	1,03	1,03	1,03
External heat supply	1,45	1,17	1,17	1,17	1,17	1,13

Appendix E: Material analysis

Appendix E- 1: Calculation of Energy use for glass (Swan Consult Herkenbosch)

Calculation method:

Qloss – Qgainsun = Q needed

*Qloss = 238*b*a*U*A (MJ)*

b = 1 (for heated rooms)

a = 1 (for windows)

U = U-value window (W/m^{2}K)

A = surface window (m^2)

*Q need= 850*Zr*r*ZTA*A (MJ)*

850 = factor, depending on window frames, filth of glass, curtains. 850 is taken as a value.

Zr = factor depending on orientation (=between 0.56 to max 0.85 for West or East) Minimum value 0.56 is used

r = factor depending on shading, 1 for no shade, lower for more shade. Value of 1 is used

ZTA = Entering of sun factor, dependent on glass type

A = surface window (m^2)

Self made calculations for glass types:

Calculation for 1m^2 single glass:

*Qloss = 238*1*1*4.4*1 = 1047.2MJ*

*Qgain = 850*0.56*1*0.8*1 = 380.8MJ*

Qneed = 1047.2-380.8= 666.4MJ per year

Calculation for 1m^2 double glass:

*Qloss = 238*1*1*2.8*1 = 666.4MJ*

*Qgain = 850*0.56*1*0.7*1 = 333.2MJ*

Qneed = 666.4-333.2= 333.2MJ per year

Calculation for 1m^2 HR glass:

*Qloss = 238*1*1*2.3*1 = 547.4MJ*

*Qgain = 850*0.56*1*0.65*1 = 309.4MJ*

Qneed = 547.4-309.4= 238MJ per year

Calculation for 1m^2 HR+ glass:

*Qloss = 238*1*1*2.1*1 = 499.8MJ*

*Qgain = 850*0.56*1*0.65*1 = 309.4MJ*

Qneed = 499.8-309.4= 190.4MJ per year

Calculation for 1m^2 HR++ glass:

*Qloss = 238*1*1*1.8*1 = 428.4MJ*

*Qgain = 850*0.56*1*0.6*1 = 285.6MJ*

Qneed = 428.4-285.6= 142.8MJ per year

Cavity insulation

Table E- 1: Material input, based on NIBE, for Cavity Insulation

CAVITY INSULATION (m^2)	λ [W/mK]	$kgCO_2eq/m^3$ per life span	Embodied energy/m^3 MJ	Thickness for Rc 3,5 (m)	$kgCO_2eq$/ FE per 1 life span	$kgCO_2eq$/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs/FE (Euro for 75 years)	Building costs/m3 (euro) per life span	Building costs/FE (euro, rounded off)	Material reuse H
Glass wool plates	0,035	43,58	677	0,120	5,23	5,23	75	6,42	0,77	92	11	35
BIO-EPS	0,038	97,86	1521	0,140	13,7	13,70	75	7,79	1,09	0		3
EPS platen	0,040	117,50	1827	0,120	14,1	14,10	75	9,25	1,11	100	12	3
Rock wool plates	0,035	82,67	1285	0,120	9,92	9,92	75	10,33	1,24	108	13	7
Pur foam plates	0,023	223,17	3469	0,082	18,3	18,30	75	19,88	1,63	232	19	6
Resol foam plates	0,021	205,26	3191	0,076	15,6	15,60	75	23,16	1,76	316,48		3
Wood fibre flexible insulation	0,038	55,71	866	0,140	7,8	15,60	40	6,32	1,77	166,97		28
Vlas plates (incl. PE-foil)	0,035	62,08	965	0,120	7,45	14,90	40	8,63	2,07	128,67		0
Cellulose plates (incl. PE-foil)	0,039	42,14	655	0,140	5,9	17,70	30	5,19	2,18	0		0
Cellular glass	0,041	210,00	3264	0,140	29,4	29,40	100	21,29	2,98	386	54	36
Cork plates, expanded	0,040	193,57	3009	0,140	27,1	27,10	75	29,36	4,11	0		29
XPS platen	0,038	475,71	7395	0,140	66,6	66,60	75	31,00	4,34	293	41	3
Sheep wool (incl. PE-foil)	0,035	1558,33	24224	0,120	187	187,00	75	308,83	37,06	150	18	28

Table E- 2: Comparison of materials of cavity insulation for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,123	3,50	Glass wool plates	83	11,23	0,79	83	11,23	0,79	83	11,23	0,79	83	11,23	0,79	166	22,46	1,57	166	22,46	1,57
0,133	3,50	BIO-EPS	202	0,00	1,04	202	0,00	1,04	202	0,00	1,04	202	0,00	1,04	405	0,00	2,07	405	0,00	2,07
0,140	3,50	EPS plates	256	14,00	1,30	256	14,00	1,30	256	14,00	1,30	256	14,00	1,30	511	28,00	2,59	511	28,00	2,59
0,123	3,50	Rockwool plates	157	13,27	1,27	157	13,27	1,27	157	13,27	1,27	157	13,27	1,27	315	26,54	2,53	315	26,54	2,53
0,081	3,50	Purfoam plates	279	18,65	1,60	279	18,65	1,60	279	18,65	1,60	279	18,65	1,60	559	37,30	3,20	559	37,30	3,20
0,074	3,50	Resolfoam plates	235	23,26	1,70	235	23,26	1,70	235	23,26	1,70	235	23,26	1,70	469	46,52	3,40	469	46,52	3,40
0,133	3,50	Wood fibre flexible insulation	115	22,21	0,84	115	22,21	0,84	230	44,41	1,68	230	44,41	1,68	346	66,62	2,52	461	88,83	3,36
0,123	3,50	Vlas-plates (incl. PE-foil)	118	15,76	1,06	118	15,76	1,06	236	31,52	2,11	236	31,52	2,11	355	47,29	3,17	473	63,05	4,23
0,137	3,50	Cellulose plates (incl. PE-foil)	89	0,00	0,71	179	0,00	1,42	179	0,00	1,42	268	0,00	2,13	358	0,00	2,83	447	0,00	3,54
0,144	3,50	Cellular glass	468	55,35	3,05	468	55,35	3,05	468	55,35	3,05	468	55,35	3,05	468	55,35	3,05	937	110,70	6,11
0,140	3,50	Cork plates, expanded	421	0,00	4,11	421	0,00	4,11	421	0,00	4,11	421	0,00	4,11	843	0,00	8,22	843	0,00	8,22
0,133	3,50	XPS platens	984	38,95	4,12	984	38,95	4,12	984	38,95	4,12	984	38,95	4,12	1967	77,90	8,25	1967	77,90	8,25
0,123	3,50	Sheep wool (incl. PE-foil)	2967	18,38	37,83	2967	18,38	37,83	2967	18,38	37,83	2967	18,38	37,83	5935	36,75	75,66	5935	36,75	75,66

Flat roof insulation

Table E- 3: Material input, based on NIBE, for Flat roof insulation

FLAT ROOF INSULATION (m^2)	λ [W/mK]	$kgCO_2eq$/ m3 per life span	Embodied energy/m 3 MJ	Thickness for R 3,5 (m)	$kgCO_2eq$/ FE per 1 life span	$kgCO_2eq$/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs/FE (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
EPS plates	0,0343	117,50	1827	0,120	14,1	14,1	75	9,25	1,11	142	17	3
Resolfoam plates	0,021	233,75	3634	0,080	18,7	18,7	75	26,38	2,11	0		2
PUR (pentane blown)	0,023	293,75	4566	0,096	28,2	28,2	75	25,42	2,44	271	26	4
Cellular glass	0,0423	210,00	3264	0,150	31,5	31,5	75	21,27	3,19	427	64	36
Cork; expanded	0,04	193,57	3009	0,140	27,1	27,1	75	29,36	4,11	0		29
Rockwool plates	0,039	258,57	4019	0,140	36,2	36,2	75	32,21	4,51	150	21	7

Table E- 4: Comparison of materials of roof insulation for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,172	5,00	EPS plates	313	24,30	1,59	313	24,30	1,59	313	24,30	1,59	313	24,30	1,59	626	48,59	3,17	626	48,59	3,17
0,105	5,00	Resolfoam plates	382	0,00	2,77	382	0,00	2,77	382	0,00	2,77	382	0,00	2,77	763	0,00	5,54	763	0,00	5,54
0,115	5,00	PUR (pentane blown)	525	31,15	2,92	525	31,15	2,92	525	31,15	2,92	525	31,15	2,92	1050	62,29	5,85	1050	62,29	5,85
0,212	5,00	Cellular glass	690	90,24	4,50	690	90,24	4,50	690	90,24	4,50	690	90,24	4,50	1381	180,48	9,00	1381	180,48	9,00
0,200	5,00	Cork; expanded	602	0,00	5,87	602	0,00	5,87	602	0,00	5,87	602	0,00	5,87	1204	0,00	11,74	1204	0,00	11,74
0,195	5,00	Rockwool plates	784	29,25	6,28	784	29,25	6,28	784	29,25	6,28	784	29,25	6,28	1568	58,50	12,56	1568	58,50	12,56

Outside window frame

Table E- 5: Material input, based on NIBE, for Outside window frame

OUTSIDE WINDOW FRAME (per m[1])	λ [W/mK]	$kgCO_2eq$/ m3 per life span	Embodied energy/m 3	Dimensions (mmxmm)	$kgCO_2eq$/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 per 1 life span	Building costs (euro, rounded off)	Material reuse H
European Hardwood (renewably grown)	0,274	225,84	3511	114x67	1,725	3,45	50	30,11	0,46	6743	103	32
European Softwood (renewably grown)	0,274	176,75	2747	114x67	1,35	4,05	35	22,69	0,52	0		31
European Hardwood (normal grown)	0,274	225,84	3511	114x67	1,725	3,45	50	37,31	0,57	6415	98	32
European Softwood (normal grown)	0,274	172,82	2686	114x67	1,32	3,96	35	27,06	0,62	0		31
Tropical hardwood (renewably grown)	0,274	492,93	7662	114x67	3,765	7,53	50	84,45	1,29	7332	112	31
Aluminium 97% secondary, anodised	0,156	2201,14	34216	68x62	9,28	9,28	75	329,70	1,39	0		74
Aluminium 47% secondary, anodised	0,156	2198,77	34179	68x62	9,27	9,27	75	417,46	1,76	19450	82	63
Aluminium 97% secondary, coated	0,156	1954,46	30382	68x62	8,24	8,24	75	426,94	1,8	0		77
Aluminium 47% secondary, coated	0,156	1952,09	30345	68x62	8,23	8,23	75	514,71	2,17	19450	82	66
PVC on steel core	0,224	1166,29	18130	112x80	10,45	20,9	40	150,67	2,7	3795	68	51
Tropical hardwood (normal grown)	0,274	492,93	7662	114x67	3,765	7,53	50	571,48	8,73	6415	98	31

Table E- 6: Comparison of materials of outside window frame for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,114	0,42	European Hardwood (renewably grown)	400	768,66	3,43	400	768,66	3,43	400	768,66	3,43	800	1537,31	6,87	800	1537,31	6,87	1201	2305,97	10,30
0,114	0,42	European Softwood (renewably grown)	313	0,00	2,59	313	0,00	2,59	626	0,00	5,17	940	0,00	7,76	940	0,00	7,76	1566	0,00	12,94
0,114	0,42	European Hardwood (normal grown)	400	731,34	4,25	400	731,34	4,25	400	731,34	4,25	800	1462,69	8,51	800	1462,69	8,51	1201	2194,03	12,76
0,114	0,42	European Softwood (normal grown)	306	0,00	3,08	306	0,00	3,08	613	0,00	6,17	919	0,00	9,25	919	0,00	9,25	1531	0,00	15,42
0,114	0,42	Tropical hardwood (renewably grown)	874	835,82	9,63	874	835,82	9,63	874	835,82	9,63	1747	1671,64	19,25	1747	1671,64	19,25	2621	2507,46	28,88
0,065	0,42	Aluminium 97% secondary, anodised	2220	0,00	21,39	2220	0,00	21,39	2220	0,00	21,39	2220	0,00	21,39	4440	0,00	42,78	4440	0,00	42,78
0,065	0,42	Aluminium 47% secondary, anodised	2218	1261,96	27,09	2218	1261,96	27,09	2218	1261,96	27,09	2218	1261,96	27,09	4435	2523,92	54,17	4435	2523,92	54,17
0,065	0,42	Aluminium 97% secondary, coated	1971	0,00	27,70	1971	0,00	27,70	1971	0,00	27,70	1971	0,00	27,70	3943	0,00	55,40	3943	0,00	55,40
0,065	0,42	Aluminium 47% secondary, coated	1969	1261,96	33,40	1969	1261,96	33,40	1969	1261,96	33,40	1969	1261,96	33,40	3938	2523,92	66,79	3938	2523,92	66,79
0,093	0,42	PVC on steel core	1692	354,17	14,06	1692	354,17	14,06	3384	708,33	28,12	3384	708,33	28,12	5076	1062,50	42,19	6768	1416,67	56,25
0,114	0,42	Tropical hardwood (normal grown)	874	731,34	65,15	874	731,34	65,15	874	731,34	65,15	1747	1462,69	130,30	1747	1462,69	130,30	2621	2194,03	195,45

Inside window frame

Table E- 7: Material input, based on NIBE, for inside window frame

INSIDE WINDOW FRAME OPENABLE (per m^1)	λ [W/mK]	kgCO2eq /m3	Embodied energy/m 3	Dimensions (mmxmm)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
European Hardwood (renewably grown)	0,178	317,82	4940	74x54	1,27	2,54	50	40,04	0,32	5881	47	31
European Softwood (renewably grown)	0,178	372,87	5796	74x54	1,49	2,98	40	46,30	0,37	0		30
European Hardwood (normal grown)	0,178	317,82	4940	74x54	1,27	2,54	50	48,80	0,39	5631	45	31
European Softwood (normal grown)	0,178	248,58	3864	74x54	0,99	2,98	35	35,87	0,43	0		30
Tropical hardwood (renewably grown)	0,178	608,11	9453	74x54	2,43	4,86	50	98,85	0,79	6256	50	30
Aluminium 97% secondary, anodised	0,142	3309,96	51452	62x46	9,44	9,44	75	487,38	1,39	0		76
Aluminium 47% secondary, anodised	0,142	3250,35	50526	62x46	9,27	9,27	75	613,60	1,75	24544	70	64
Aluminium 97% secondary, coated	0,142	2934,78	45620	62x46	8,37	8,37	75	627,63	1,79	0		80
Aluminium 47% secondary, coated	0,142	2878,68	44748	62x46	8,21	8,21	75	757,36	2,16	24544	70	67
PVC on steel core	0,164	1959,93	30467	82x70	11,25	22,5	40	209,06	2,4	4791	55	21
Tropical hardwood (normal grown)	0,178	608,11	9453	74x54	2,43	4,86	50	626,88	5,01	5631	45	30

Table E- 8: Comparison of materials of inside window frames for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,074	0,42	European Hardwood (renewably grown)	366	435,19	2,96	366	435,19	2,96	366	435,19	2,96	731	870,37	5,93	731	870,37	5,93	1097	1305,56	8,89
0,074	0,42	European Softwood (renewably grown)	429	0,00	3,43	429	0,00	3,43	858	0,00	6,85	858	0,00	6,85	1287	0,00	10,28	1716	0,00	13,70
0,074	0,42	European Hardwood (normal grown)	366	416,67	3,61	366	416,67	3,61	366	416,67	3,61	731	833,33	7,22	731	833,33	7,22	1097	1250,00	10,83
0,074	0,42	European Softwood (normal grown)	286	0,00	2,65	286	0,00	2,65	572	0,00	5,31	858	0,00	7,96	858	0,00	7,96	1430	0,00	13,27
0,074	0,42	Tropical hardwood (renewably grown)	700	462,96	7,31	700	462,96	7,31	700	462,96	7,31	1399	925,93	14,63	1399	925,93	14,63	2099	1388,89	21,94
0,059	0,42	Aluminium 97% secondary, anodised	3044	0,00	28,83	3044	0,00	28,83	3044	0,00	28,83	3044	0,00	28,83	6088	0,00	57,66	6088	0,00	57,66
0,059	0,42	Aluminium 47% secondary, anodised	2989	1451,99	36,30	2989	1451,99	36,30	2989	1451,99	36,30	2989	1451,99	36,30	5978	2903,99	72,60	5978	2903,99	72,60
0,059	0,42	Aluminium 97% secondary, coated	2699	0,00	37,13	2699	0,00	37,13	2699	0,00	37,13	2699	0,00	37,13	5398	0,00	74,26	5398	0,00	74,26
0,059	0,42	Aluminium 47% secondary, coated	2647	1451,99	44,80	2647	1451,99	44,80	2647	1451,99	44,80	2647	1451,99	44,80	5294	2903,99	89,61	5294	2903,99	89,61
0,068	0,42	PVC on steel core	2082	327,38	14,29	2082	327,38	14,29	4164	654,76	28,57	4164	654,76	28,57	6246	982,14	42,86	8328	1309,52	57,14
0,074	0,42	Tropical hardwood (normal grown)	700	416,67	46,39	700	416,67	46,39	700	416,67	46,39	1399	833,33	92,78	1399	833,33	92,78	2099	1250,00	139,17

Window sill

Table E- 9: Material input, based on NIBE, for Window sills

WINDOW SILL (per m^1)	λ [W/mK]	kgCO2eq /m3 for 1 life span	Embodied energy/m 3	Dimensions (mmxmm)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE 75 years	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro)	Building costs (euro, rounded off)	Material reuse H
Pinewood (renewably grown)	0,2	297	4612	114x85	2,875	5,75	40	35,60	0,69	4040	78,3	25
Robinia (renewably grown)	0,2	356	5526	114x85	3,445	6,89	50	41,80	0,81	5779	112	25
Synthetic/plastic	0,43	3008	46751	114x70	24	48	50	230,58	3,68	0		6
Natural stone	3,5	5388	83762	114x70	43	86	50	387,84	6,19	3446	55	4
Polyester concrete	0,45	3966	61653	114x70	31,65	63,3	50	392,23	6,26	2694	43	4

Table E- 10: Comparison of materials of window sills for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,100	0,10	Pinewood (renewably grown)	461	404,02	3,56	461	404,02	3,56	922	808,05	7,12	922	808,05	7,12	1384	1212,07	10,68	1845	1616,10	14,24
0,100	0,10	Robinia (renewably grown)	553	577,92	4,18	553	577,92	4,18	553	577,92	4,18	1105	1155,83	8,36	1105	1155,83	8,36	1658	1733,75	12,54
0,100	0,10	Synthetic/plastic	4675	0,00	23,06	4675	0,00	23,06	4675	0,00	23,06	9350	0,00	46,12	9350	0,00	46,12	14025	0,00	69,17
0,100	0,10	Natural stone	8376	344,61	38,78	8376	344,61	38,78	8376	344,61	38,78	16752	689,22	77,57	16752	689,22	77,57	25129	1033,83	116,35
0,100	0,10	Polyester concrete	6165	269,42	39,22	6165	269,42	39,22	6165	269,42	39,22	12331	538,85	78,45	12331	538,85	78,45	18496	808,27	117,67

Inside cavity wall

Table E- 11: Material input, based on NIBE, for Inside cavity walls

INSIDE (CAVITY)WALL 1m²	λ [W/mK]	kgCO2eq /m3 for 1 life span	Embodied energy/m3 for1 life span	thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE 75 years	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Wooden frame 15% of wall (multiplex, frames, plasterboard), renewably grown	0,20	136	2110	0,14	19	19	75	19,64	2,75	450	63	18
Wooden frame 15% of wall (multiplex, frames, plasterboard), normal grown	0,20	141	2198	0,14	19,8	19,8	75	23,50	3,29	443	62	18
Sand-lime elements (incl. plaster)	1,00	402	6249	0,1	40,2	40,2	100	43,60	4,36	390	39	62
Clay/mud brick (incl. finishing)	0,35	211	3287	0,14	29,6	29,6	75	33,00	4,62	53		66
Sand-lime masonry (incl. plaster)	1,00	480	7468	0,102	49	49	100	52,75	5,38	461	47	46
Concrete stone masonry (incl. plaster)	1,30	490	7617	0,1	49	49	100	54,60	5,46	490	49	49
Concrete , reinforced (incl. plaster)	1,90	451	7011	0,2	90,2	90,2	100	52,10	10,42	0		64
Cellular/foam concrete blocks (incl. plaster)	0,23	960	14923	0,15	144	144	100	78,07	11,71	213	32	47
Brick, perforated, (incl. plaster)	0,43	757	11770	0,14	106	106	100	90,07	12,61	457	64	48
Brick masonry (incl. plaster)	0,73	1610	25027	0,1	161	161	100	191,00	19,1	750	75	43

Table E- 12: Comparison of materials of inside cavity walls for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,020	0,10	Wooden frame RG	42	9,00	0,39	42	9,00	0,39	42	9,00	0,39	42	9,00	0,39	84	18,00	0,79	84	18,00	0,79
0,020	0,10	Wooden frame NG	44	8,86	0,47	44	8,86	0,47	44	8,86	0,47	44	8,86	0,47	88	17,71	0,94	88	17,71	0,94
0,100	0,10	Sand-lime	625	39,00	4,36	625	39,00	4,36	625	39,00	4,36	625	39,00	4,36	625	39,00	4,36	1250	78,00	8,72
0,035	0,10	Clay/mud brick	115	1,86	1,16	115	1,86	1,16	115	1,86	1,16	115	1,86	1,16	230	3,72	2,31	230	3,72	2,31
0,100	0,10	Sand-lime masonry	747	46,08	5,27	747	46,08	5,27	747	46,08	5,27	747	46,08	5,27	747	46,08	5,27	1494	92,16	10,55
0,130	0,10	Concrete stone masonry	990	63,70	7,10	990	63,70	7,10	990	63,70	7,10	990	63,70	7,10	990	63,70	7,10	1980	127,40	14,20
0,190	0,10	Concrete , reinforced	1332	0,00	9,90	1332	0,00	9,90	1332	0,00	9,90	1332	0,00	9,90	1332	0,00	9,90	2664	0,00	19,80
0,023	0,10	Cellular/foam concrete blocks	343	4,91	1,80	343	4,91	1,80	343	4,91	1,80	343	4,91	1,80	343	4,91	1,80	686	9,81	3,59
0,043	0,10	Brick, perforated	506	19,66	3,87	506	19,66	3,87	506	19,66	3,87	506	19,66	3,87	506	19,66	3,87	1012	39,31	7,75
0,073	0,10	Brick masonry	1827	54,75	13,94	1827	54,75	13,94	1827	54,75	13,94	1827	54,75	13,94	1827	54,75	13,94	3654	109,50	27,89

Metal façade cladding

Table E- 13: Material input, based on NIBE, for Metal façade cladding

FACADE CLADDING METAL	λ [W/mK]	kgCO2eq /m3	Embodied energy/m3	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/FE per life span	Environmental costs (Euro for 75 years)	Building costs per FE (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Steel, trapezium, coated		13619	211704	0,0007	9,53	28,6	30	1,24	3,72	0		59
Steel, trapezium, galvanized and coated		21500	334211	0,0007	15,05	30,1	50	2,03	4,06	0		59
Aluminium, profile, not coated		13000	202081	0,0007	9,10	27,3	30	2,17	6,5	25	75	65
Aluminium, profile, coated		20714	321998	0,0007	14,50	29	40	5,77	11,54	38	75	64
Aluminium, flat, sandwich-plastic core, coated		6238	96960	0,004	24,95	49,9	40	6,24	12,47	0		39
Zinc, felsgevel		31292	486420	0,0008	25,03	75,1	25	8,01	24,02	40	120	51
Aluminium, flat, sandwich-aluminium core, coated		1260	19586	0,025	31,50	63	40	12,73	25,46	0		73
Copper felsgevel		27167	422298	0,0006	16,30	16,3	100	59,65	59,65	0		55

Table E- 14: Comparison of materials of metal façade claddings for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,0007	0,00	Steel, trapezium, coated	148	0,00	1,24	296	0,00	2,48	296	0,00	2,48	445	0,00	3,72	593	0,00	4,96	741	0,00	6,20
0,0007	0,00	Steel, trapezium, galvanized and coated	234	0,00	2,03	234	0,00	2,03	234	0,00	2,03	468	0,00	4,06	468	0,00	4,06	702	0,00	6,09
0,0007	0,00	Aluminium, profile, not coated	141	25,00	2,17	283	50,00	4,33	283	50,00	4,33	424	75,00	6,50	566	100,00	8,67	707	125,00	10,83
0,0007	0,00	Aluminium, profile, coated	225	37,50	5,77	225	37,50	5,77	451	75,00	11,54	451	75,00	11,54	676	112,50	17,31	902	150,00	23,08
0,0040	0,00	Aluminium, flat, sandwich-plastic core, coated	388	0,00	6,24	388	0,00	6,24	776	0,00	12,47	776	0,00	12,47	1164	0,00	18,71	1551	0,00	24,94
0,0008	0,00	Zinc, felsgevel	389	40,00	8,01	778	80,00	16,01	778	80,00	16,01	1167	120,00	24,02	1557	160,00	32,03	2335	240,00	48,04
0,0250	0,00	Aluminium, flat, sandwich-aluminium core, coated	490	0,00	12,73	490	0,00	12,73	979	0,00	25,46	979	0,00	25,46	1469	0,00	38,19	1959	0,00	50,92
0,0006	0,00	Copper felsgevel	253	0,00	59,65	253	0,00	59,65	253	0,00	59,65	253	0,00	59,65	253	0,00	59,65	507	0,00	119,30

Stone façade cladding

Table E- 15: Material input, based on NIBE, for Stone façade cladding

FACADE CLADDING PLASTIC/STONE	λ [W/mK]	kgCO2eq /m3	Embodied energy/m3	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/ FE per life span	Environmental costs (Euro for 75 years)	Building costs per FE (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Fibre cement plate		713	11089	0,01	7,13	21,4	25	0,69	2,06	20,67	62	7
Pressed Rockwool plate with plastic coating		1675	26037	0,01	16,75	33,5	40	2,09	4,17	27,00	54	12
Natural stone slate		1995	31012	0,01	19,95	39,9	40	2,85	5,7	42,50	85	2
Ceramic tiles (hollow)		1627	25286	0,03	48,80	48,8	75	6,09	6,09	43,00	43	64
Natural stone plates, granite		1743	27100	0,03	52,30	52,3	75	7,45	7,45	0,00		3
Glass plates with RVS fastening		3688	57321	0,016	59,00	118	40	23,93	47,85	0,00		47

Table E- 16: Comparison of materials of stone façade cladding for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,010	0,00	Fibre cement plate	111	20,67	0,69	222	41,33	1,37	222	41,33	1,37	333	62,00	2,06	444	82,67	2,75	665	124,00	4,12
0,010	0,00	Pressed rockwool plate with plastic coating	260	27,00	2,09	260	27,00	2,09	521	54,00	4,17	521	54,00	4,17	781	81,00	6,26	1041	108,00	8,34
0,010	0,00	Natural stone slate	310	42,50	2,85	310	42,50	2,85	620	85,00	5,70	620	85,00	5,70	930	127,50	8,55	1240	170,00	11,40
0,030	0,00	Ceramic tiles (hollow)	759	43,00	6,09	759	43,00	6,09	759	43,00	6,09	759	43,00	6,09	1517	86,00	12,18	1517	86,00	12,18
0,030	0,00	Natural stone plates, granite	813	0,00	7,45	813	0,00	7,45	813	0,00	7,45	813	0,00	7,45	1626	0,00	14,90	1626	0,00	14,90
0,016	0,00	Glass plates with RVS fastening	917	0,00	23,93	917	0,00	23,93	1834	0,00	47,85	1834	0,00	47,85	2751	0,00	71,78	3669	0,00	95,70

Timber cladding

Table E- 17: Material input, based on NIBE, for wooden façade cladding

FACADE CLADDING WOOD $1m^2$	kgCO2eq/m3	Embodied energy/m3	Thickness FE (m)	kgCO2eq/FE per 1 life span	kgCO2eq/FE	Life span (years)	Environm. Costs/FE per life span	Environmental costs (Euro for 75 years)	Building costs per FE (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Oak (renewably grown)	145	2249	0,016	2,32	4,63	60	0,37	0,73	0		37
Robinia (renewably grown)	154	2395	0,016	2,47	4,93	60	0,39	0,78	0		37
European pine wood, wax impregnated (renewably grown)	366	5686	0,019	6,95	13,9	60	0,92	1,83	0		7
Pine/Fir, thermally treated (renewably grown)	330	5127	0,019	6,27	18,8	30	0,90	2,7	19	57	38
Multiplex okoumé (renewably grown)	1029	15989	0,007	7,20	21,6	30	1,09	3,27	13	39	29
Wood fibre cement plate (renewably grown)	1147	17825	0,01	11,47	34,4	25	1,10	3,29	15	46	7
Multiplex Pine/Fir (renewably grown)	803	12480	0,0093	7,47	22,4	30	1,13	3,4	0		29
Lariks (renewably grown, unpreserved)	267	4156	0,019	5,08	25,4	15	0,79	3,97	11	53	33
Western red cedar (renewably grown)	509	7918	0,016	8,15	16,3	60	2,24	4,47	27	53	34
HPL-plate (renewably grown)	779	12112	0,008	6,23	18,7	25	1,50	4,51	25	75	31
Meranti parts (renewably grown)	825	12824	0,016	13,20	26,4	40	2,48	4,95	0		33
Western red cedar (normal grown)	509	7918	0,016	8,15	16,3	60	2,58	5,16	26	51	37
Multiplex okoumé (normally grown)	1067	16581	0,007	7,47	22,4	30	11,19	33,57	12	35	29
Meranti parts (normally grown)	822	12776	0,016	13,15	26,3	40	18,29	36,57	0		33

Table E- 18: Comparison of materials of timber façade cladding for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,016	0,00	Oak (renewably grown)	36	35,00	0,37	36	35,00	0,37	36	35,00	0,37	72	70,00	0,73	72	70,00	0,73	108	105,00	1,10
0,016	0,00	Robinia (renewably grown)	38	0,00	0,39	38	0,00	0,39	38	0,00	0,39	77	0,00	0,78	77	0,00	0,78	115	0,00	1,17
0,019	0,00	European pine wood, wax impregnated (renewably grown)	108	0,00	0,92	108	0,00	0,92	108	0,00	0,92	216	0,00	1,83	216	0,00	1,83	324	0,00	2,75
0,019	0,00	Pine/Fir, thermally treated (renewably grown)	97	19,00	0,90	195	38,00	1,80	195	38,00	1,80	292	57,00	2,70	390	76,00	3,60	487	95,00	4,50
0,007	0,00	Multiplex okoumé (renewably grown)	112	13,00	1,09	224	26,00	2,18	224	26,00	2,18	336	39,00	3,27	448	52,00	4,36	560	65,00	5,45
0,010	0,00	Woodfibre cement plate (renewably grown)	178	15,33	1,10	356	30,67	2,19	356	30,67	2,19	535	46,00	3,29	713	61,33	4,39	1069	92,00	6,58
0,009	0,00	Multiplex Pine/Fir (renewably grown)	116	0,00	1,13	232	0,00	2,27	232	0,00	2,27	348	0,00	3,40	464	0,00	4,53	580	0,00	5,67
0,019	0,00	Lariks (renewably grown, unpreserved)	79	10,60	0,79	237	31,80	2,38	316	42,40	3,18	395	53,00	3,97	553	74,20	5,56	790	106,00	7,94
0,016	0,00	Western red cedar (renewably grown)	127	26,50	2,24	127	26,50	2,24	127	26,50	2,24	253	53,00	4,47	253	53,00	4,47	380	79,50	6,71
0,008	0,00	HPL-plate (renewably grown)	97	25,00	1,50	194	50,00	3,01	194	50,00	3,01	291	75,00	4,51	388	100,00	6,01	581	150,00	9,02
0,016	0,00	Meranti parts (renewably grown)	205	0,00	2,48	205	0,00	2,48	410	0,00	4,95	410	0,00	4,95	616	0,00	7,43	821	0,00	9,90
0,016	0,00	Western red cedar (normal grown)	127	25,50	2,58	127	25,50	2,58	127	25,50	2,58	253	51,00	5,16	253	51,00	5,16	380	76,50	7,74
0,007	0,00	Multiplex okoumé (normally grown)	116	11,67	11,19	232	23,33	22,38	232	23,33	22,38	348	35,00	33,57	464	46,67	44,76	580	58,33	55,95
0,016	0,00	Meranti parts (normally grown)	204	0,00	18,29	204	0,00	18,29	409	0,00	36,57	409	0,00	36,57	613	0,00	54,86	818	0,00	73,14

Outside cavity wall

Table E- 19: Material input, based on NIBE, for Outside cavity walls

OUTSIDE (CAVITY) WALL	λ [W/mK]	kgCO2eq /m3 1 life span	Embodied energy/m3	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE 75 years	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Concrete stone masonry (hydrophobic)	1,40	487	7570	0,1	48,7	48,70	100	53,80	5,38	830	83	51
Sand lime brick masonry (hydrophobic)	1,50	510	7925	0,102	52	52,00	75	55,88	5,7	559	57	52
Mud brick masonry (incl. plaster finishing)	0,93	262	4069	0,14	36,65	73,30	50	31,79	8,9	0		52
Hollow brick masonry	0,46	893	13881	0,1	89,3	89,30	75	104,30	10,43	0		46
Brick masonry	1,30	1530	23783	0,1	153	153,00	100	180,50	18,05	730	73	51
Natural stone masonry	3,50	1527	23732	0,15	229	229,00	75	223,87	33,58	0		60

Table E- 20: Comparison of materials of outside cavity walls for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			35			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,140	0,10	Concrete stone masonry (hydrophobic)	1060	116,20	7,53	1060	116,20	7,53	1060	116,20	7,53	1060	116,20	7,53	1060	116,20	7,53	2120	232,40	15,06
0,150	0,10	Sandlime brick masonry (hydrophobic)	1189	83,82	8,38	1189	83,82	8,38	1189	83,82	8,38	1189	83,82	8,38	2377	167,65	16,76	2377	167,65	16,76
0,093	0,10	Mud brick masonry (incl. plaster finishing)	378	0,00	2,96	378	0,00	2,96	378	0,00	2,96	757	0,00	5,91	757	0,00	5,91	1135	0,00	8,87
0,046	0,10	Hollow brick masonry	639	0,00	4,80	639	0,00	4,80	639	0,00	4,80	639	0,00	4,80	1277	0,00	9,60	1277	0,00	9,60
0,130	0,10	Brick masonry	3092	94,90	23,47	3092	94,90	23,47	3092	94,90	23,47	3092	94,90	23,47	3092	94,90	23,47	6184	189,80	46,93
0,350	0,10	Natural stone masonry	8306	0,00	78,35	8306	0,00	78,35	8306	0,00	78,35	8306	0,00	78,35	16612	0,00	156,71	16612	0,00	156,71

Outside doors

Table E- 21: Material input, based on NIBE, for Outside doors

DOORS, OUTSIDE (2315x930mm)	λ [W/m K]	kgCO2eq /m3 per life span	Embodied energy/m 3	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
MDF panel, massive European softwood (RG)	0,14	272,67	4238,52	0,054	31,7	63,4	40	32,43	7,54	5093	550	26
European softwood, massive, laminated (RG)	0,10	272,09	4229,61	0,054	31,6	94,9	25	35,78	12,48	0		29
MDF panel, massive European softwood (NG)	0,14	272,67	4238,52	0,054	31,7	63,4	40	61,59	14,32	4630	500	26
Tropical hardwood, massive (RG)	0,11	427,06	6638,57	0,054	49,7	99,3	40	61,93	14,4	6019	650	29
Plate steel panels, galvanized and coated, PUR filling	0,05	546,19	8490,41	0,054	63,5	127,0	50	69,41	16,14	0		60
Tropical multiplex/tropical hardwood/PUR (RG)	0,04	260,19	4044,64	0,054	30,3	121,0	20	38,15	17,74	2222	480	27
PVC on steel/PUR filling, flat	0,11	387,07	6016,83	0,070	58,3	175,0	25	46,34	20,95	5000	1050	49
HR++ isolation glass in aluminium frame	0,06	346,93	5392,86	0,054	40,3	121,0	25	68,90	24,03	3580	580	51
HDF-alu-HDF/tropical hardwood/PUT,flat (RG)	0,04	584,90	9092,09	0,054	68,0	204,0	25	72,63	25,33	3704	600	25
HDF-alu-HDF/tropical hardwood/PUT,flat (NG)	0,04	584,90	9092,09	0,054	68,0	204,0	25	186,34	64,99	3272	530	25
Tropical multiplex/tropical hardwood/PUR (NG)	0,04	260,19	4044,64	0,054	30,3	121,0	20	245,85	114,33	1944	420	27
Tropical hardwood, massive (NG)	0,11	427,06	6638,57	0,054	49,7	99,3	40	532,52	123,82	5370	580	29
RVS/PUR filling, flat	0,05	2029,95	31554,91	0,054	236,0	472,0	50	2806,92	652,66	0		59

Table E- 22: Comparison of materials of outside doors for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,168	1,20	MDF panel, massive European softwood (RG)	714	858,00	5,46	714	858,00	5,46	1428	1716,00	10,93	1428	1716,00	10,93	2142	2574,00	16,39	2856	3432,00	21,85
0,117	1,20	European softwood, massive, laminated (RG)	493	0,00	4,17	987	0,00	8,35	987	0,00	8,35	1480	0,00	12,52	1973	0,00	16,69	2960	0,00	25,04
0,168	1,20	MDF panel, massive European softwood (NG)	714	780,00	10,38	714	780,00	10,38	1428	1560,00	20,75	1428	1560,00	20,75	2142	2340,00	31,13	2856	3120,00	41,50
0,136	1,20	Tropical hardwood, massive (RG)	903	819,00	8,43	903	819,00	8,43	1807	1638,00	16,86	1807	1638,00	16,86	2710	2457,00	25,28	3614	3276,00	33,71
0,065	1,20	Plate steel panels, galvanized and coated, PUR filling	550	0,00	4,50	550	0,00	4,50	550	0,00	4,50	1100	0,00	9,00	1100	0,00	9,00	1651	0,00	13,49
0,052	1,20	Tropical multiplex/tropical hardwood/PUR (RG)	210	115,20	1,98	419	230,40	3,96	629	345,60	5,93	839	460,80	7,91	1048	576,00	9,89	1677	921,60	15,82
0,134	1,20	PVC on steel/PUR filling, flat	809	672,00	6,23	1617	1344,00	12,46	1617	1344,00	12,46	2426	2016,00	18,68	3235	2688,00	24,91	4852	4032,00	37,37
0,078	1,20	HR++ isolation glass in aluminium frame	419	278,40	5,36	839	556,80	10,71	839	556,80	10,71	1258	835,20	16,07	1677	1113,60	21,43	2516	1670,40	32,14
0,052	1,20	HDF-alu-HDF/tropical hardwood/PUT,flat (RG)	471	192,00	3,76	943	384,00	7,53	943	384,00	7,53	1414	576,00	11,29	1885	768,00	15,06	2828	1152,00	22,59
0,052	1,20	HDF-alu-HDF/tropical hardwood/PUT,flat (NG)	471	169,60	9,66	943	339,20	19,32	943	339,20	19,32	1414	508,80	28,98	1885	678,40	38,64	2828	1017,60	57,96
0,052	1,20	Tropical multiplex/tropical hardwood/PUR (NG)	210	100,80	12,74	419	201,60	25,49	629	302,40	38,23	839	403,20	50,98	1048	504,00	63,72	1677	806,40	101,96
0,136	1,20	Tropical hardwood, massive (NG)	903	730,80	72,46	903	730,80	72,46	1807	1461,60	144,93	1807	1461,60	144,93	2710	2192,40	217,39	3614	2923,20	289,86
0,065	1,20	RVS/PUR filling, flat	2045	0,00	181,89	2045	0,00	181,89	2045	0,00	181,89	4090	0,00	363,78	4090	0,00	363,78	6134	0,00	545,66

Profiles for element wall (inside)

Table E- 23: Material input, based on NIBE, for Profiles for inside element walls

PROFILES FOR ELEMENT WALL (2700mm high)	λ [W/mK]		Embodied energy/FE 1m2	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/FE per life span	Environmental costs (Euro for 75 years)	Building costs/FE (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Pinewood/Fir (RG)	0,00		7,93	46x71mm	0,5	1,53	25	0,08	0,24	0,42	1,25	37
Pinewood/Fir (NG)	0,00		7,93	46x71mm	0,5	1,53	25	0,11	0,33	0,40	1,2	37
Steel profiles	0,00		23,63	37x73,5mm	1,5	4,56	25	0,21	0,62	1,03	3,1	63

Table E- 24: Comparison of materials of profiles for inside element walls for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
46x 71mm	0,00	Pinewood/Fir (RG)	8	0,42	0,08	16	0,83	0,16	16	0,83	0,16	24	1,25	0,24	32	1,67	0,32	48	2,50	0,48
46x 71mm	0,00	Pinewood/Fir (NG)	8	0,40	0,11	16	0,80	0,22	16	0,80	0,22	24	1,20	0,33	32	1,60	0,44	48	2,40	0,66
37x 73,5mm	0,00	Steel profiles	24	1,03	0,21	47	2,07	0,41	47	2,07	0,41	71	3,10	0,62	95	4,13	0,83	142	6,20	1,24

Inside insulation for element wall

Table E- 25: Material input, based on NIBE, for Inside insulation for element walls

INSIDE INSULATION ELEMENT WALL	λ [W/mK]	kgCO2eq /m3	Embodied energy/m3	Thickness (m)	kgCO2eq/ FE per 1 life span	kgCO2eq/ FE	Life span (years)	Environm. Costs/m3 per life span	Environmental costs (Euro for 75 years)	Building costs/m3 (euro) per 1 life span	Building costs (euro, rounded off)	Material reuse H
Cellulose, blown	0,045	33,40	519	0,050	1,67	5,01	25	4,87	0,73	0		0
Glass wool plates	0,034	43,53	677	0,050	2,18	6,53	25	6,47	0,97	52	7,8	35
Vlas plates	0,041	60,33	938	0,050	3,02	9,05	25	8,73	1,31	84	12,6	0
Rockwool plates	0,035	82,67	1285	0,050	4,13	12,40	25	10,33	1,55	59	8,8	7
PUR/PIR foam plates (pentane blown)	0,025	236,00	3669	0,050	11,80	35,40	25	19,40	2,91	96	14,4	0
Cork, expanded	0,038	177,33	2757	0,050	8,87	26,60	25	26,87	4,03	0		29
Sheep wool	0,041	1553,33	24146	0,050	77,67	233,00	25	308,40	46,26	60	9	29
Glass wool plates + Pinewood (RG) frame	0,052		603,4				25	5,76		46,33		

Table E- 26: Comparison of materials of inside insulation for element walls for different life spans, for embodied energy (E.E.), Building Costs (B.C.) and Environmental Costs (E.C.), in green the lowest values are shown

		Lifespan (years)	15			30			50			75			100			150		
THICK-NESS (m)	R-VALUE	Material	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C	E.E.	B.C	E.C
0,158	3,50	Cellulose, blown	82	0,00	0,77	164	0,00	1,53	164	0,00	1,53	245	0,00	2,30	327	0,00	3,07	491	0,00	4,60
0,119	3,50	Glass wool plates	81	6,19	0,77	161	12,38	1,54	161	12,38	1,54	242	18,56	2,31	322	24,75	3,08	483	37,13	4,62
0,144	3,50	Vlas plates	135	12,05	1,25	269	24,11	2,51	269	24,11	2,51	404	36,16	3,76	538	48,22	5,01	808	72,32	7,52
0,123	3,50	Rockwool plates	157	7,19	1,27	315	14,37	2,53	315	14,37	2,53	472	21,56	3,80	630	28,75	5,06	944	43,12	7,60
0,088	3,50	PUR/PIR foam plates (pentane blown)	321	8,40	1,70	642	16,80	3,40	642	16,80	3,40	963	25,20	5,09	1284	33,60	6,79	1926	50,40	10,19
0,133	3,50	Cork, expanded	367	0,00	3,57	733	0,00	7,15	733	0,00	7,15	1100	0,00	10,72	1467	0,00	14,29	2200	0,00	21,44
0,144	3,50	Sheep wool	3465	8,61	44,26	6930	17,22	88,51	6930	17,22	88,51	10395	25,83	132,77	13860	34,44	177,02	20790	51,66	265,53

Appendix F: Façade Strategies

Table F- 1: Qualities of the different refurbishment strategies, based on the analysis made by Ebbert (Ebbert, 2010)

Refurbishment strategy	Costs construction	Costs operation	Material use	End of life	Insulation	Comfort
A1: Replacement of a curtain wall	+/-	++	-	+	++	++
A2: Replacement with a double façade	-	+	-	+	++	+
B1: Cover-up	+/-	+	+	++	+	+/-
B2: Exterior addition of a multi-storey façade	+/-	+/-	+	+/-	+	+/-
B3: Exterior addition of a partitioned double façade	+/-	+/-	+/-	+/-	++	++
B4: Exterior addition of an insulated façade	+	++	+	+/-	+	+/-
C1: Exterior insulation finishing system	++	++	+	-	++	+/-
C2: Ventilated cladding	+	++	+	++	++	+
C3: Partial replacement	++	+	++	+	+/-	+/-
D: Interior insulation	+	++	++	+/-	+/-	-
E1: Additional insulated interior layer	+	+/-	+/-	+/-	+	+/-
E2: Additional non-insulated interior layer	+/-	+/-	+	+	+	+/-

Current façade

Figure F- 1: Current façade, with façade components

Figure F- 2: Current façade, simplified for EPC calculations

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thicknes	EBE	Layer 2	λ	R-value	Thicknes	EBE
Cur Cons Balcony	Outside Airflow	0,04	Grindbeton old	1,600	0,075	0,1200	319,68	Polystyrene old	0,080	0,250	0,0200	46,80
Cur Cons Upper concrete edge	Outside Airflow	0,04	Grindbeton old	1,600	0,075	0,1200	319,68	Weakly ventilated cavity	0,000	0,090	0,0165	0,00
Cur ConsLower concrete edge	Outside Airflow	0,04	Grindbeton old	1,600	0,056	0,0900	239,76	Weakly ventilated cavity	0,000	0,090	0,0100	0,00
Cur Cons outside window frame	Outside Airflow	0,04	Hardwood old	0,200	0,600	0,1200	186,00					
Cur Cons Inside window frame	Outside Airflow	0,04	Hardwood old	0,200	0,180	0,0360	55,80					
Cur Cons Door	Outside Airflow	0,04	Hardwood old	0,200	0,165	0,0330	51,15					
Cur Cons Single glass	Outside Airflow	0,04	Single glass old	0,800	0,003	0,0020	78,00					
Cur Cons Plate material	Outside Airflow	0,04	Plate old	0,200	0,040	0,0080	12,40	Weakly ventilated cavity	0,000	0,090	0,0800	0,00
Cur Cons Roof edge+window frame	Outside Airflow	0,04	Grindbeton old	1,600	0,056	0,0900	239,76	Hardwood old	0,200	0,525	0,1050	162,75
Cur Cons Sandwich panel	Outside Airflow	0,04	Grindbeton old	1,600	0,050	0,0800	213,12	Polystyrene old	0,080	0,125	0,0100	23,40
Cur Cons Thick window frame	Outside Airflow	0,04	Hardwood old	0,200	0,860	0,1720	266,60					
Cur Cons Window Sill	Outside Airflow	0,04	Grindbeton old	1,600	0,063	0,1000	266,40	Polystyrene old	0,080	0,125	0,0100	23,40
Cur Cons Side balcony	Outside Airflow	0,04	Grindbeton old	1,600	0,031	0,0500	133,20	Weakly ventilated cavity	0,000	0,090	0,0800	0,00
Cur Cons Masonry	Outside Airflow	0,04	Masonry old	0,781	0,134	0,1050	2497,26	Weakly ventilated cavity	0,000	0,090	0,0650	0,00
Cur Cons Roof floor + insulation	Outside Airflow	0,04	Polystyrene old	0,080	0,313	0,0250	58,50	Grindbeton old	1,600	0,088	0,1400	372,96
Cur Cons linear cold bridge concrete	Outside Airflow	0,04	Grindbeton old	1,600	0,050	0,0800	213,12	Polystyrene old	0,080	0,125	0,0100	23,40
Cur Cons linear cold bridge masonry	Outside Airflow	0,04	Masonry old	0,781	0,134	0,1050	2497,26	Weakly ventilated cavity	0,000	0,090	0,0650	0,00
Cur Cons linear cold bridge balcony	Outside Airflow	0,04	Grindbeton old			1,3000	3463,20					

Name Constr	Layer 3	λ	R-value	Thicknes	EBE	Layer 4	λ	R-value	Thicknes	EBE	Inside Airflow	R-Value	Rc-value (m2.K/W)	Total U-Value (W/m2.K)	Total EBE
Cur Cons Balcony	Nothing				0	Nothing				0,00	Inside Airflow	0,13	**0,50**	**2,02**	366,48
Cur Cons Upper concrete edge	Polystyrene old	0,080	0,125	0,0100	23	Plate old	0,200	0,0400	0,0080	12,40	Inside Airflow	0,13	**0,50**	**2,00**	355,48
Cur ConsLower concrete edge	Polystyrene old	0,080	0,125	0,0100	23	Grindbetoı	1,600	0,0375	0,0600	159,84	Inside Airflow	0,13	**0,48**	**2,09**	423,00
Cur Cons outside window frame											Inside Airflow	0,13	**0,77**	**1,30**	186,00
Cur Cons Inside window frame											Inside Airflow	0,13	**0,35**	**2,86**	55,80
Cur Cons Door											Inside Airflow	0,13	**0,34**	**2,99**	51,15
Cur Cons Single glass											Inside Airflow	0,13	**0,17**	**5,80**	78,00
Cur Cons Plate material	Plate old	0,200	0,040	0,0080	12						Inside Airflow	0,13	**0,34**	**2,94**	24,80
Cur Cons Roof edge+window frame											Inside Airflow	0,13	**0,75**	**1,33**	402,51
Cur Cons Sandwich panel	Gasbeton old	0,220	0,273	0,0600	137						Inside Airflow	0,13	**0,62**	**1,62**	373,02
Cur Cons Thick window frame											Inside Airflow	0,13	**1,03**	**0,97**	266,60
Cur Cons Window Sill	Grindbeton old	1,600	0,038	0,0600	160						Inside Airflow	0,13	**0,40**	**2,53**	449,64
Cur Cons Side balcony	Grindbeton old	1,600	0,125	0,2000	0						Inside Airflow	0,13	**0,42**	**2,40**	133,20
Cur Cons Masonry	Grindbeton old	0,625	0,320	0,2000	533						Inside Airflow	0,13	**0,71**	**1,40**	3030,06
Cur Cons Roof floor + insulation											Inside Airflow	0,13	**0,57**	**1,75**	431,46
Cur Cons linear cold bridge concrete	Gasbeton old	0,220	0,273	0,0600	137						Inside Airflow	0,13	**0,62**	**1,62**	373,02
Cur Cons linear cold bridge masonry	Grindbeton old	0,625	0,320	0,2000	533						Inside Airflow	0,13	**0,71**	**1,40**	3030,06
Cur Cons linear cold bridge balcony											Inside Airflow	0,13	**0,17**	**5,88**	3463,20

Figure F- 3: Build-up of the construction parts of the current situation per m²

WEST FAÇADE	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission loss (W)
Facadepart 1.1	**Cur Cons Sandwich panel**	4,05	0,62	1,62	65
Facadepart 1.2	**Cur Cons Window Sill**	0,17	0,40	2,53	4
Facadepart 1.3	**Cur Cons outside window frame**	0,39	0,77	1,30	5
Facadepart 1.4	**Cur Cons Inside window frame**	0,16	0,35	2,86	4
Facadepart 1.5	**Cur Cons Single glass**	1,36	0,17	5,80	79
Facadepart 2.1	**Cur Cons Plate material**	2,00	0,34	2,94	59
Façadepart 2.2	**Cur Cons Thick window frame**	0,21	1,03	0,97	2
Facadepart 2.3	**Cur Cons Balcony**	0,21	0,50	2,02	4
Facadepart 2.4	**Cur Cons Door**	1,05	0,34	2,99	31
Facadepart 2.5	**Cur Cons outside window frame**	1,27	0,77	1,30	16
Facadepart 2.6	**Cur Cons Inside window frame**	0,10	0,35	2,86	3
Facadepart 2.7	**Cur Cons Single glass**	4,54	0,17	5,80	263
Facadepart 3.1	**Cur Cons Plate material**	2,67	0,34	2,94	79
Facadepart 3.2	**Cur Cons Thick window frame**	0,13	1,03	0,97	1
Facadepart 3.3	**Cur Cons Upper concrete edge**	0,46	0,50	2,00	9
Facadepart 3.5	**Cur Cons outside window frame**	1,15	0,77	1,30	15
Facadepart 3.6	**Cur Cons Inside window frame**	0,29	0,35	2,86	8
Facadepart 3.7	**Cur Cons Single glass**	5,15	0,17	5,80	298
Facadepart 3.8	**Cur Cons Roof edge+window frame**	0,12	0,75	1,33	2
WEST BALCONY SIDES	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission (W)
Facadepart 4.1	**Cur Cons Side balcony**	7,29	0,42	2,40	175
EAST FAÇADE	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission (W)
Facadepart 5.1	**Cur Cons Plate material**	2,68	0,34	2,94	79
Facadepart 5.2	**Cur Cons Thick window frame**	0,13	1,03	0,97	1
Facadepart 5.3	**Cur Cons Upper concrete edge**	0,46	0,50	2,00	9
Facadepart 5.5	**Cur Cons outside window frame**	1,14	0,77	1,30	15
Facadepart 5.6	**Cur Cons Inside window frame**	0,29	0,35	2,86	8
Facadepart 5.7	**Cur Cons Single glass**	5,15	0,17	5,80	299
Facadepart 5.8	**Cur Cons Roof edge+window frame**	0,12	0,75	1,33	2
Facadepart 6.1	**Cur Cons Plate material**	3,68	0,34	2,94	108
Facadepart 6.2	**Cur Cons Thick window frame**	0,22	1,03	0,97	2
Facadepart 6.3	**Cur Cons Balcony**	0,22	0,50	2,02	4
Facadepart 6.4	**Cur Cons Door**	1,05	0,34	2,99	31
Facadepart 6.5	**Cur Cons outside window frame**	1,66	0,77	1,30	22
Facadepart 6.6	**Cur Cons Inside window frame**	0,26	0,35	2,86	7
Facadepart 6.7	**Cur Cons Single glass**	2,61	0,17	5,80	151
EAST BALCONY SIDES	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission (W)
Facadepart 7.1	**Cur Cons Side balcony**	2,37	0,42	2,40	57
SOUTH FAÇADE	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission (W)
Facadepart 8.1	**Cur Cons Masonry**	25,31	0,71	1,40	354
ROOF	**Construction**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Transmission (W)
Facadepart 9.1	**Cur Cons Roof floor + insulation**	77,04	0,57	1,75	1352
Linear cold bridge					
Linear cold bridge west	**Cur Cons linear cold bridge concrete**	8,72	-		
Linear cold bridge east	**Cur Cons linear cold bridge concrete**	6,42	-		
Linear cold bridge south concr	**Cur Cons linear cold bridge concrete**	2,675	-		
Linear cold bridge masonry	**Cur Cons linear cold bridge masonry**	2,675	-		
Linear cold bridge balcony	**Cur Cons linear cold bridge balcony**	0,97	-		

Figure F- 4: Façade build up complete of the current situation, with Rc-values per façade parts and façade components

Strategy 1: External upgrading

Figure F- 5: Design for strategy 1, external upgrading, with façade components

Figure F- 6: Design for strategy 1, external upgrading, simplified for EPC calculations

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thickness	EBE
New sandwich panel 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New window sill 2	Outside Airflow	0,04	Pinewood (renwably growr	0,200	0,5700	0,1140	525,78
New outside window frame 2	Outside Airflow	0,04	European Softwood (renew	0,274	0,4167	0,1140	313,21
New inside window frame 2	Outside Airflow	0,04	European Softwood (renew	0,274	0,2705	0,0740	203,31
New closed balcony 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New glass 2	Outside Airflow	0,04	HR++ glass	1,200	0,8333	1,0000	299,60
New suskast ventilation 2	Outside Airflow	0,04	Suskast	1,088	0,3125	0,3400	0,00
New thick window frame 2	Outside Airflow	0,04	European Hardwood (renev	0,274	0,6579	0,1800	631,92
New balcony roof 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	110,89
New side balcony 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New plate material 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New roof insulation + floor 2	Outside Airflow	0,04	EPS plates	0,034	5,0000	0,1715	313,25
New masonry 2	Outside Airflow	0,04	Mud brick masonry (incl. pl	0,930	0,1505	0,1400	569,71
New extra thick window frame 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New closed balcony bottom 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New concrete edge wall 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New upper concrete edge 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New linear cold bridge concrete 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New linear cold bridge masonry 2	Outside Airflow	0,04	Mud brick masonry (incl. pl	0,930	0,1505	0,1400	569,71

Name Constr	Layer 2	λ	R-value	Thickness	EBE	Layer 3	λ	R-value	Thickness	EBE
New sandwich panel 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Grindbeton old	1,600	0,050	0,0800	0,00
New window sill 2	Grindbeton old	1,600	0,063	0,1000	0,00	Polystyrene old	0,080	0,125	0,0100	0,00
New outside window frame 2										
New inside window frame 2										
New closed balcony 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	Glaswool plates + v	0,053	3,5000	0,1860	155,26
New glass 2										
New suskast ventilation 2										
New thick window frame 2										
New balcony roof 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	EPS plates	0,034	3,5000	0,1201	219,27
New side balcony 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	Glaswool plates + v	0,053	3,5000	0,1860	155,26
New plate material 2	Glaswool plates + woo	0,053	3,5000	0,1860	155,26	Plate old	0,200	0,040	0,0080	0,00
New roof insulation + floor 2	Polystyrene old	0,080	0,313	0,0250	0,00	Grindbeton old	1,600	0,088	0,1400	0,00
New masonry 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Masonry old	0,781	0,134	0,1050	0,00
New extra thick window frame 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	Glaswool plates + v	0,053	3,5000	0,1860	155,26
New closed balcony bottom 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	Glaswool plates + v	0,053	3,5000	0,1860	155,26
New concrete edge wall 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Grindbeton old	1,600	0,050	0,0800	0,00
New upper concrete edge 2	Stronly ventilated cavi	0,000	0,0000	0,0500	0,00	Glaswool plates + v	0,053	3,5000	0,1860	155,26
New linear cold bridge concrete 2	Glaswol platen	0,035	3,5000	0,1225	82,99					
New linear cold bridge masonry 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Masonry old	0,781	0,134	0,1050	0,00

Name Constr	Layer 4	λ	R-value	Thickness	EBE	Layer 5	λ	R-value	Thickness	EBE	Inside Airflow	R-Value	Rc-value (m2.K/W)	Total U-Value (W/m2.K)	Total EBE
New sandwich panel 2	Polystyrene old	0,080	0,125	0,0100	0,00	Gasbeton old	0,220	0,273	0,0600	0	Inside Airflo	0,13	**4,12**	**0,24**	304,76
New window sill 2	Grindbeton old	1,600	0,038	0,0600	0						Inside Airflo	0,13	**0,97**	**1,04**	525,78
New outside window frame 2											Inside Airflo	0,13	**0,59**	**1,70**	313,21
New inside window frame 2											Inside Airflo	0,13	**0,44**	**2,27**	203,31
New closed balcony 2											Inside Airflo	0,13	**3,67**	**0,27**	191,25
New glass 2											Inside Airflo	0,13	**1,00**	**1,00**	299,60
New suskast ventilation 2											Inside Airflo	0,13	**0,48**	**2,07**	0,00
New thick window frame 2											Inside Airflo	0,13	**0,83**	**1,21**	631,92
New balcony roof 2											Inside Airflo	0,13	**3,67**	**0,27**	330,16
New side balcony 2											Inside Airflo	0,13	**3,67**	**0,27**	191,25
New plate material 2	Weakly ventilated c	0,000	0,090	0,0800	0,00	Plate old	0,200	0,040	0,0080	0	Inside Airflo	0,13	**3,84**	**0,26**	191,25
New roof insulation + floor 2											Inside Airflo	0,13	**5,57**	**0,18**	313,25
New masonry 2	Weakly ventilated c	0,000	0,090	0,1650	0,00	Grindbeton old	0,625	0,320	0,2000	0	Inside Airflo	0,13	**4,36**	**0,23**	652,71
New extra thick window frame 2	Hardwood old	0,200	0,860	0,1720	0,00						Inside Airflo	0,13	**4,53**	**0,22**	35,99
New closed balcony bottom 2	Grindbeton old	1,600	0,094	0,1500	0,00						Inside Airflo	0,13	**3,76**	**0,27**	35,99
New concrete edge wall 2	Polystyrene old	0,080	0,125	0,0100	0,00	Gasbeton old	0,220	0,273	0,0600	0	Inside Airflo	0,13	**4,12**	**0,24**	304,76
New upper concrete edge 2	Grindbeton old	1,600	0,094	0,1500	0,00						Inside Airflo	0,13	**3,76**	**0,27**	35,99
New linear cold bridge concrete 2											Inside Airflo	0,13	**3,67**	**0,27**	304,76
New linear cold bridge masonry 2	Weakly ventilated c	0,000	0,090	0,1650	0,00	Grindbeton old	0,625	0,320	0,2000	0	Inside Airflo	0,13	**4,36**	**0,23**	652,71

Figure F- 7: Build-up of the construction parts of Strategy 1, external addition per m^2

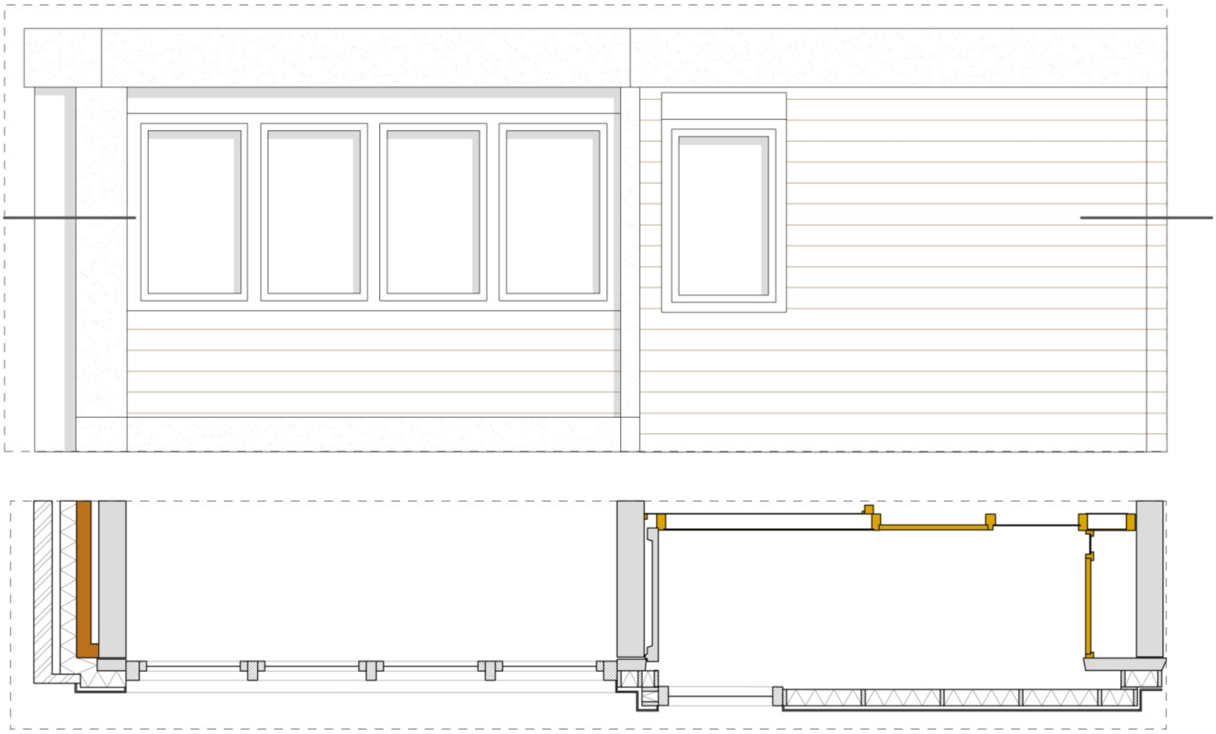


Figure F- 8: Design for strategy 1, external upgrading, in more detail

WEST FAÇADE	Construction part	Surface (m2)	Rcvalue	Embodied Energy (MJ)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 2	4,03	4,12	1228,20	0,24	
Facadepart 1.2	New concrete edge wall 2	0,56	4,12	170,55	0,24	
Facadepart 1.3	New window sill 2	0,17	0,97	86,75	1,04	62
Facadepart 1.4	New outside window frame 2	0,48	0,59	149,81	1,70	
Facadepart 1.5	New inside window frame 2	0,20	0,44	41,56	2,27	
Facadepart 1.6	New glass 2	1,21	1,00	363,77	1,00	
Facadepart 2.1	New closed balcony 2	3,03	3,67	579,44	0,27	
Façadepart 2.2	New balcony roof 2	0,28	3,67	91,35	0,27	
Facadepart 2.3	New thick window frame 2	0,31	0,83	197,92	1,21	
Facadepart 2.4	New closed balcony bottom 2	0,25	3,76	8,87	0,27	216
Facadepart 2.5	New suskast ventilation 2	0,38	0,48	0,00	2,07	
Facadepart 2.6	New outside window frame 2	0,94	0,59	292,95	1,70	
Facadepart 2.7	New inside window frame 2	0,22	0,44	45,03	2,27	
Facadepart 2.8	New glass 2	4,01	1,00	1201,82	1,00	
Facadepart 3.1	New plate material 2	2,89	3,84	552,63	0,26	
Facadepart 3.2	New extra thick window frame 2	0,25	4,53	9,06	0,22	
Facadepart 3.3	New upper concrete edge 2	0,43	3,76	15,37	0,27	
Facadepart 3.4	New thick window frame 2	0,35	0,83	218,52	1,21	
Facadepart 3.5	New suskast ventilation 2	0,41	0,48	0,00	2,07	210
Facadepart 3.6	New concrete edge wall 2	0,56	4,12	169,69	0,24	
Facadepart 3.7	New outside window frame 2	1,23	0,59	385,16	1,70	
Facadepart 3.8	New inside window frame 2	0,91	0,44	184,18	2,27	
Facadepart 3.9	New glass 2	3,47	1,00	1040,90	1,00	
WEST BALCONY SIDES		Surface (m2)	Rcvalue	Embodied Energy (	U-value (W/m2.K)	E.E. removal old
Facadepart 4.1	New side balcony 2	1,73	3,67	330,29	0,27	0
EAST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (	U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	New plate material 2	2,90	3,84	555,10	0,26	
Facadepart 5.2	New extra thick window frame 2	0,25	4,53	9,05	0,22	
Facadepart 5.3	New upper concrete edge 2	0,46	3,76	16,63	0,27	
Facadepart 5.4	New thick window frame 2	0,34	0,83	216,94	1,21	
Facadepart 5.5	New suskast ventilation 2	0,41	0,48	0,00	2,07	210
Facadepart 5.6	New concrete edge wall 2	0,54	4,12	165,18	0,24	
Facadepart 5.7	New outside window frame 2	1,24	0,59	387,82	1,70	
Facadepart 5.8	New inside window frame 2	0,90	0,44	182,53	2,27	
Facadepart 5.9	New glass 2	3,47	1,00	1040,90	1,00	
Facadepart 6.1	New closed balcony 2	7,33	3,67	1401,24	0,27	
Facadepart 6.2	New balcony roof 2	0,27	3,67	87,49	0,27	
Facadepart 6.3	New thick window frame 2	0,10	0,83	60,10	1,21	
Facadepart 6.4	New suskast ventilation 2	0,10	0,48	0,00	2,07	
Facadepart 6.5	New concrete edge wall 2	0,56	4,12	170,97	0,24	0
Facadepart 6.6	New closed balcony bottom 2	0,25	3,76	8,87	0,27	
Facadepart 6.7	New outside window frame 2	0,35	0,59	108,90	1,70	
Facadepart 6.8	New inside window frame 2	0,22	0,44	45,03	2,27	
Facadepart 6.9	New glass 2	0,82	1,00	245,22	1,00	
EAST SIDE WALL		Surface (m2)	Rcvalue	Embodied Energy (	U-value (W/m2.K)	E.E. removal old
Facadepart 7.1	New side balcony 2	0,33	3,67	63,59	0,27	0
SOUTH FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (	U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	New masonry 2	25,31	4,36	16518,04	0,23	0
ROOF		Surface (m2)	Rcvalue	Embodied Energy (	U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	New roof insulation + floor 2	77,04	5,57	24132,42	0,18	0
Linear cold bridge		Surface (m2)		Embodied Energy (MJ)		
Linear cold bridge west 1	New linear cold bridge concrete 2	2,74	-	835,05		
Linear cold bridge west 2	New linear cold bridge concrete 2	1,93	-	588,19		
Linear cold bridge west 3	New linear cold bridge concrete 2	4,07	-	1238,86		
Linear cold bridge east 5	New linear cold bridge concrete 2	3,71	-	1130,67		0
Linear cold bridge east 6	New linear cold bridge concrete 2	2,71	-	826,82		
Linear cold bridge south concr 8	New linear cold bridge concrete 2	2,68	-	815,24		
Linear cold bridge south masonry	New linear cold bridge masonry 2	2,68	-	1745,99		

Figure F- 9: Façade build up complete of strategy 1, external addition, with Rc-values and embodied energy per façade part

WEST FAÇADE	Constructions	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 1.A	New sandwich panel 5	3,31	3,31	0,30	West	Minimal	
Facadepart 1.B	New window sill 5	0,17	3,90	0,26	West	Minimal	
Facadepart 1.C	New window total 5	1,90	0,54	1,85	West	Minimal	0,6
Facadepart 2.A	New plate material 5	2,58	3,68	0,27	West	Overhang	
Façadepart 2.B	New door 5	1,09	1,37	0,73	West	Overhang	
Facadepart 2.C	New suskast 5	0,71	0,76	1,32	West	Overhang	
Facadepart 2.D	New window total 5	4,66	0,54	1,85	West	Overhang	0,6
Facadepart 3.A	New plate material 5	3,47	3,76	0,27	West	Minimal	
Facadepart 3.B	New suskast 5	0,76	0,77	1,31	West	Minimal	
Facadepart 3.C	New window total 5	5,35	0,54	1,85	West	Minimal	0,6
WEST BALCONY SIDE	Constructions	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 4.A	New side balcony north 5	4,42	3,92	0,26	North	Overhang	
Facadepart 4.B	New side balcony south 5	2,21	3,92	0,26	South	Overhang	
EAST FAÇADE	Constructions	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 5.A	New plate material 5	3,48	3,84	0,26	East	Minimal	
Facadepart 5.B	New suskast 5	0,75	0,76	1,31	East	MInimal	
Facadepart 5.C	New window total 5	5,35	0,54	1,85	East	Minimal	0,6
Facadepart 6.A	New balcony facade 5	6,59	3,67	0,27	East	Overhang	
Facadepart 6.B	New door 5	1,10	1,37	0,73	East	Overhang	
Facadepart 6.C	New suskast 5	0,20	0,84	1,19	East	Overhang	
Facadepart 6.D	New window total 5	1,21	0,54	1,85	East	Overhang	0,6
EAST BALCONY SIDES	Constructions	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 7.A	New side balcony 5	2,35	3,92	0,26	South	Overhang	
SOUTH FAÇADE	Constructions	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 8.A	New masonry 5	25,31	4,21	0,24	South	Minimal	
ROOF	Constructions	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 9.A	New roof 5	77,04	5,57	0,18	-	Minimal	

Figure F- 10: Façade build up simplified for EPC of strategy 1, external addition

Strategy 2: Façade replacement

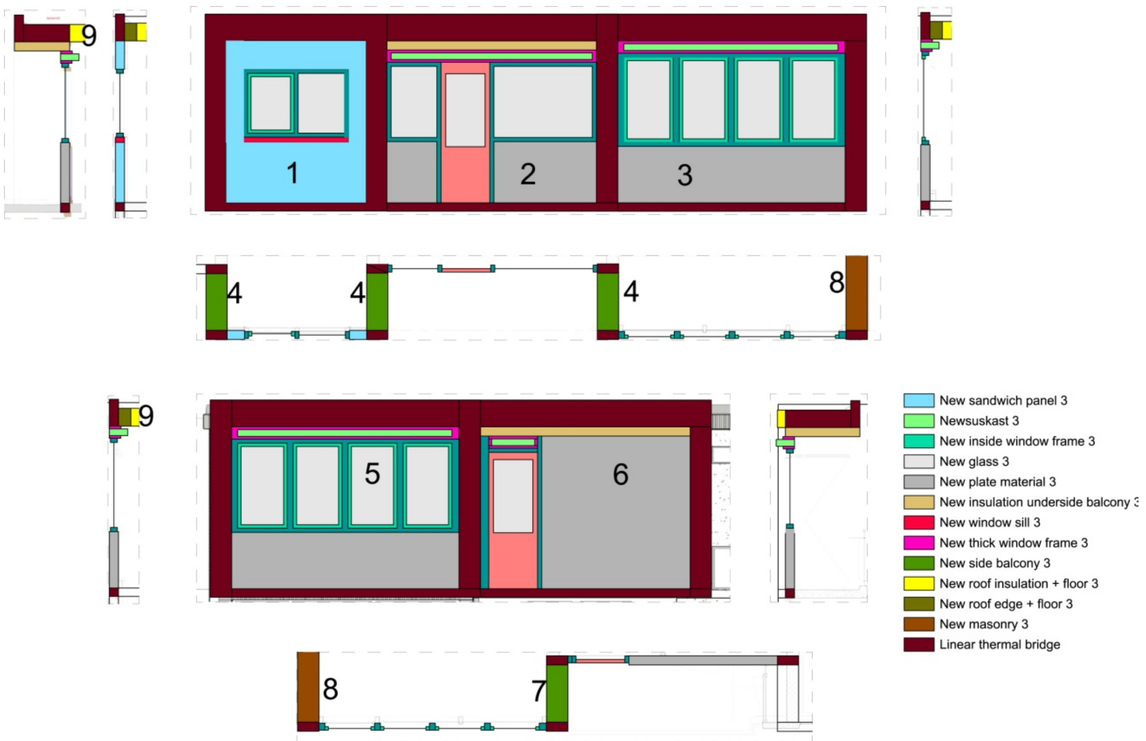


Figure F- 11: Design for strategy 2, façade replacement, with façade components

Figure F- 12: Design for strategy 2, façade replacement, simplified for EPC calculations

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thickness	EBE
New sandwich panel 3	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New window sill 3	Outside Airflow	0,04	Pinewood (renwably growi	0,200	0,5700	0,1140	525,78
New outside window frame 3	Outside Airflow	0,04	European Hardwood (rene	0,274	0,4167	0,1140	400,22
New inside window frame 3	Outside Airflow	0,04	European Hardwood (rene	0,274	0,2705	0,0740	259,79
New door 3	Outside Airflow	0,04	Tropical multiplex/tropical	0,043	1,2000	0,0518	419,35
New glass 3	Outside Airflow	0,04	Tripple glass	0,700	1,4286	1,0000	449,40
New suskast ventilation 3	Outside Airflow	0,04	Suskast	1,088	0,3125	0,3400	0,00
New thick window frame 3	Outside Airflow	0,04	Wooden frame 15% of wa	0,200	0,9000	0,1800	379,74
New insulation underside balcony 3	Outside Airflow	0,04	Glaswol platen	0,035	26,0000	0,9100	616,52
New side balcony 3	Outside Airflow	0,04	Aluminium, profile, coated	0,000	0,0000	0,0007	225,40
New plate material 3	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New roof insulation + floor 3	Outside Airflow	0,04	EPS plates	0,034	5,0000	0,1715	313,25
New masonry 3	Outside Airflow	0,04	Mud brick masonry (incl. pl	0,930	0,1505	0,1400	569,71
New linear cold bridge concrete 3	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New linear cold bridge masonry 3	Outside Airflow	0,04	Mud brick masonry (incl. pl	0,930	0,1505	0,1400	569,71
New linear cold bridge balcony 3	Outside Airflow	0,04	Balcony concrete			1,3000	3463,20
New linear cold bridge roof 3	Outside Airflow	0,04	EPS plates	0,034	5,0000	0,1715	313,25

Name Constr	Layer 2	λ	R-value	Thickness	EBE	Layer 3	λ	R-value	Thicknes	EBE
New sandwich panel 3	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswol platen	0,035	3,5000	0,1225	82,99
New window sill 3	Clay/mud brick (incl. finishing)	0,350	0,4000	0,1400	460,12					
New outside window frame 3										
New inside window frame 3										
New door 3										
New glass 3										
New suskast ventilation 3										
New thick window frame 3										
New insulation underside balcony 3										
New side balcony 3	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + woode	0,060	3,5000	0,2091	174,54
New plate material 3	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + woode	0,05975	3,5000	0,2091	174,54
New roof insulation + floor 3	Grindbeton old	1,600	0,0875	0,1400	0,00					
New masonry 3	Weakly ventilated cavity		0,090	0,1000	0,00	Glaswol platen	0,035	3,5000	0,1225	82,99
New linear cold bridge concrete 3	Glaswol platen	0,035	3,5000	0,1225	82,99					
New linear cold bridge masonry 3	Glaswol platen	0,035	3,5000	0,1225	82,99					
New linear cold bridge balcony 3										
New linear cold bridge roof 3										

Name Constr	Layer 4	λ	R-value	Thickness	EBE	Layer 5	λ	R-value	Thicknes	EBE	Inside Airflow	R-Value	Rc-value (m2.K/W)	Total U-Value (W/m2.K)	Total EBE
New sandwich panel 3	Clay/mud brick (	0,350	0,4000	0,1400	460,12						Inside Airflow	0,13	**4,07**	**0,25**	304,76
New window sill 3											Inside Airflow	0,13	**1,14**	**0,88**	985,90
New outside window frame 3											Inside Airflow	0,13	**0,59**	**1,70**	400,22
New inside window frame 3											Inside Airflow	0,13	**0,44**	**2,27**	259,79
New door 3											Inside Airflow	0,13	**1,37**	**0,73**	419,35
New glass 3											Inside Airflow	0,13	**1,60**	**0,63**	449,40
New suskast ventilation 3											Inside Airflow	0,13	**0,48**	**2,07**	0,00
New thick window frame 3											Inside Airflow	0,13	**1,07**	**0,93**	379,74
New insulation underside balcony 3											Inside Airflow	0,13	**26,17**	**0,04**	616,52
New side balcony 3											Inside Airflow	0,13	**3,67**	**0,27**	399,94
New plate material 3											Inside Airflow	0,13	**3,67**	**0,27**	210,53
New roof insulation + floor 3											Inside Airflow	0,13	**5,26**	**0,19**	313,25
New masonry 3	Grindbeton old	1,600	0,1250	0,2000	0,00						Inside Airflow	0,13	**4,04**	**0,25**	569,71
New linear cold bridge concrete 3											Inside Airflow	0,13	**3,67**	**0,27**	304,76
New linear cold bridge masonry 3											Inside Airflow	0,13	**3,82**	**0,26**	652,71
New linear cold bridge balcony 3											Inside Airflow	0,13	**0,17**	**5,88**	3463,20
New linear cold bridge roof 3											Inside Airflow	0,13	**5,17**	**0,19**	313,25

Figure F- 13: Build-up of the construction parts of Strategy 2, façade replacement, per m²

WEST FAÇADE	Construction	Surface (m2)	Rcvalue	Embodied Energy (MJ)	Building costs (Euro)	Environmental costs (Euro)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 3	4,03	4,07	1227,28	241,65	27,30	0,25	
Facadepart 1.3	New window sill 3	0,15	1,14	144,93	68,80	1,28	0,88	
Facadepart 1.4	New outside window frame 3	0,43	0,59	171,69	329,75	1,47	1,70	590
Facadepart 1.5	New inside window frame 3	0,18	0,44	46,76	89,81	0,40	2,27	
Facadepart 1.6	New glass 3	1,32	1,60	594,11	106,35	0,00	0,63	
Facadepart 2.1	New plate material 3	2,52	3,67	530,53	157,28	5,07	0,27	
Façadepart 2.2	New insulation underside balcony 3	0,52	26,17	318,74	43,13	3,02	0,04	
Facadepart 2.3	New thick window frame 3	0,32	1,07	123,00	26,24	1,15	0,93	
Facadepart 2.4	New door 3	1,08	1,37	452,90	248,83	4,27	0,73	277
Facadepart 2.5	New suskast ventilation 3	0,37	0,48	0,00	0,00	0,00	2,07	
Facadepart 2.6	New outside window frame 3	0,80	0,59	321,34	617,15	2,76	1,70	
Facadepart 2.7	New glass 3	3,56	1,60	1599,41	286,32	0,00	0,63	
Facadepart 3.1	New plate material 3	3,47	3,67	731,14	216,75	6,98	0,27	
Facadepart 3.2	New thick window frame 3	0,36	1,07	136,48	29,11	1,27	0,93	
Facadepart 3.3	New suskast ventilation 3	0,39	0,48	0,00	0,00	0,00	2,07	315
Facadepart 3.4	New outside window frame 3	1,21	0,59	485,62	932,69	4,17	1,70	
Facadepart 3.5	New inside window frame 3	0,94	0,44	245,09	470,71	2,10	2,27	
Facadepart 3.6	New glass 3	3,58	1,60	1608,13	287,88	0,00	0,63	
WEST BALCONY SIDES		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 4.1	New side balcony 3	7,40	3,67	2958,76	480,22	54,86	0,27	323
EAST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	New plate material 3	3,47	3,67	730,34	216,52	6,98	0,27	
Facadepart 5.2	New thick window frame 3	0,36	1,07	136,48	29,11	1,27	0,93	
Facadepart 5.3	New suskast ventilation 3	0,39	0,48	0,00	0,00	0,00	2,07	315
Facadepart 5.4	New outside window frame 3	1,22	0,59	487,36	936,02	4,18	1,70	
Facadepart 5.5	New inside window frame 3	0,94	0,44	245,22	470,96	2,10	2,27	
Facadepart 5.6	New glass 3	3,58	1,60	1609,26	288,08	0,00	0,63	
Facadepart 6.1	New plate material 3	6,14	3,67	1292,52	383,18	12,35	0,27	
Facadepart 6.2	New insulation underside balcony 3	0,52	26,17	319,17	43,18	3,02	0,04	
Facadepart 6.3	New thick window frame 3	0,08	1,07	31,23	6,66	0,29	0,93	
Facadepart 6.4	New suskast ventilation 3	0,08	0,48	0,00	0,00	0,00	2,07	270
Facadepart 6.5	New outside window frame 3	0,56	0,59	223,44	429,14	1,92	1,70	
Facadepart 6.6	New door 3	1,02	1,37	429,71	236,09	4,05	0,73	
Facadepart 6.7	New glass 3	0,78	1,60	349,18	62,51	0,00	0,63	
EAST SIDE WALL		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 7.1	New side balcony 3	2,49	3,67	997,45	161,89	18,50	0,27	105
SOUTH FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	New masonry 3	25,31	4,04	14417,75	284,18	132,51	0,25	25561
ROOF		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	New roof insulation + floor 3	77,04	5,26	24132,42	1871,75	122,21	0,19	11080
Linear cold bridge		Surface (m2)		Embodied Energy (MJ)				
Linear cold bridge west 1	New linear cold bridge concrete 3	3,60	-	1097,15	189,23	7,77		
Linear cold bridge west 2	New linear cold bridge concrete 3	2,01	-	612,58	105,65	4,34		
Linear cold bridge west 3	New linear cold bridge concrete 3	4,46	-	1359,25	234,43	9,63		
Linear cold bridge east 5	New linear cold bridge concrete 3	7,129	-	2172,66	374,72	15,39		
Linear cold bridge east 6	New linear cold bridge concrete 3	3,138	-	956,35	164,94	6,78		6037
Linear cold bridge south concr 8	New linear cold bridge concrete 3	2,675	-	815,24	140,60	5,78		
Linear cold bridge south masonry 8	New linear cold bridge masonry 3	2,675	-	1745,99	30,04	14,01		
New balcony 2	New linear cold bridge balcony 3	0,485	-	1679,65	0,00	0,00		
New balcony 6	New linear cold bridge balcony 3	0,485	-	1679,65	0,00	0,00		
Linear cold bridge roof 9	New linear cold bridge roof 3	5,23	-	1638,27	127,07	8,30		

Figure F- 14: Façade build up complete of strategy 2, façade replacement, with Rc-values and embodied energy per façade part

WEST FAÇADE	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 1.A	New Sandwich panel total 3	4,03	4,07	0,25	West	Minimal	
Facadepart 1.B	New window total 3	1,93	0,54	1,85	West	Minimal	0,6
Facadepart 1.C	New window sill 3	0,15	1,14	0,88	West	Minimal	
Facadepart 2.A	New balcony cladding 3	2,66	3,67	0,27	West	Overhang	
Façadepart 2.B	New door 3	1,08	1,37	0,73	West	Overhang	
Facadepart 2.C	New suskast 3	1,21	11,61	0,09	West	Overhang	
Facadepart 2.D	New window total 3	4,23	0,54	1,85	West	Overhang	0,6
Facadepart 3.A	New plate material 3	3,47	3,67	0,27	West	Minimal	
Facadepart 3.B	New window total 3	5,74	0,54	1,85	West	Minimal	0,6
Facadepart 3.C	New suskast 3	0,75	0,76	1,31	West	Minimal	
WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 4.A	New side balcony north	4,93	3,67	0,27	North	Overhang	
Facadepart 4.B	New side balcony south	2,47	3,67	0,27	South	Overhang	
EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 5.A	New plate material 3	3,47	3,67	0,27	East	Minimal	
Facadepart 5.B	New window total 3	5,74	0,54	1,85	East	Minimal	0,6
Facadepart 5.C	New suskast 3	0,75	0,76	1,31	East	Minimal	
Facadepart 6.A	New balcony cladding 3	6,66	5,42	0,18	East	Overhang	
Facadepart 6.B	New door 3	1,02	1,37	0,73	East	Overhang	
Facadepart 6.C	New suskast 3	0,16	0,78	1,28	East	Overhang	
Facadepart 6.D	New total window 3	1,85	0,54	1,85	East	Overhang	0,6
EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 7.A	New side balcny	2,49	3,67	0,27	South	Overhang	
SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 8.A	New masnry 3	25,31	4,04	0,25	South	Minimal	
ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 9.A	New roof 3	77,04	5,26	0,19	-	Minimal	

Figure F- 15: Façade build up simplified for EPC of strategy 2, façade replacement

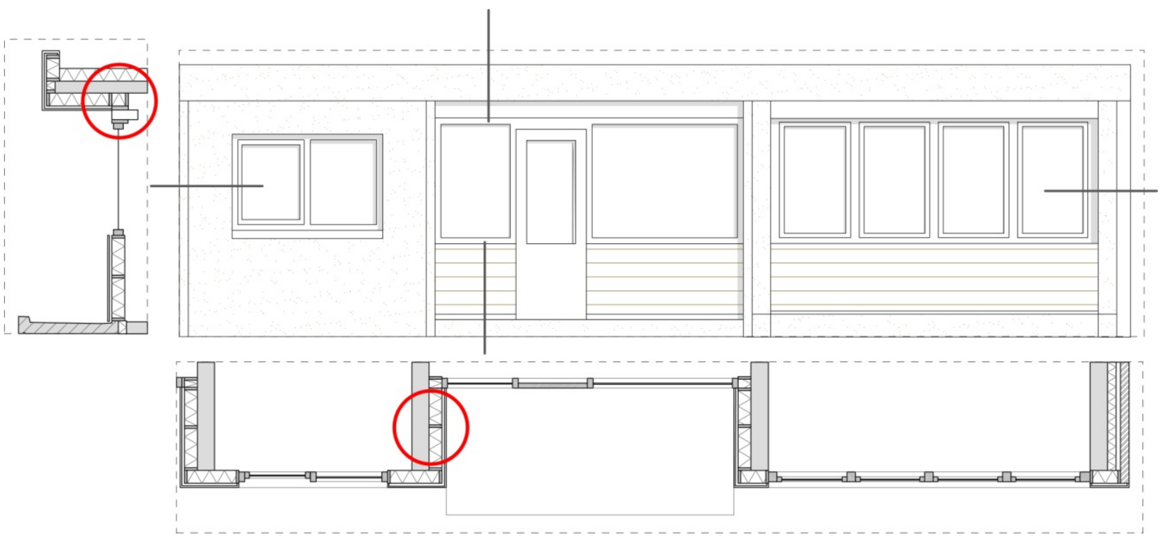


Figure F- 16: Design for strategy 2, façade replacement, in more detail, with in red the restrictions in the detailing

Strategy 3: Interior upgrading

Figure F- 17: Design for strategy 3, interior upgrading, with façade components

Figure F- 18: Design for strategy 3, interior upgrading, simplified for EPC calculations

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thickness	EBE	Layer 2	λ	R-value	Thickness	EBE	Layer 3	λ	R-value	Thickness	EBE
New sandwich panel 5	Outside Airflow	0,04	Grindbeton old	1,600	0,050	0,0800	0,00	Polystyrene old	0,080	0,125	0,0100	0,00	Gasbeton old	0,220	0,273	0,0600	0
New window sill 5	Outside Airflow	0,04	Grindbeton old	1,600	0,063	0,1000	0,00	Polystyrene old	0,080	0,125	0,0100	0,00	Grindbeton old	1,600	0,038	0,0600	0
New outside window frame 5	Outside Airflow	0,04	European Hardwood (rene	0,274	0,4167	0,1140	400,22										
New inside window frame 5	Outside Airflow	0,04	European Hardwood (rene	0,274	0,2705	0,0740	259,79										
New door 5	Outside Airflow	0,04	Tropical multiplex/tropical	0,043	1,2000	0,0518	419,35										
New glass 5	Outside Airflow	0,04	Tripple glass	0,700	1,4286	1,0000	449,40										
New suskast ventilation 5	Outside Airflow	0,04	Suskast	1,088	0,3125	0,3400	0,00										
New thick window frame 5	Outside Airflow	0,04	Wooden frame 15% of wa	0,200	0,9000	0,1800	379,74										
New balcony facade 5	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden frame	0,060	3,5000	0,2091	174,54
New side balcony 5	Outside Airflow	0,04	Grindbeton old	1,600	0,031	0,0500	0,00	Weakly ventilated cavity	0,000	0,090	0,0800	0,00	Grindbeton old	1,600	0,125	0,2000	0
New plate material 5	Outside Airflow	0,04	Plate old	0,200	0,040	0,0080	0,00	Weakly ventilated cavity	0,000	0,090	0,0800	0,00	Plate old	0,200	0,040	0,0080	0
New roof insulation + floor 5	Outside Airflow	0,04	Polystyrene old	0,080	0,313	0,0250	0,00	Grindbeton old	1,600	0,088	0,1400	0,00	Glasswool plates + Pinewood (RG	0,052	5,0000	0,2613	315,34
New masonry 5	Outside Airflow	0,04	Masonry old	0,781	0,134	0,1050	0,00	Weakly ventilated cavity	0,000	0,090	0,0650	0,00	Grindbeton old	0,625	0,320	0,2000	0
New lower concrete edge 5	Outside Airflow	0,04	Grindbeton old	1,600	0,075	0,1200	0,00	Weakly ventilated cavity	0,000	0,090	0,0165	0,00	Polystyrene old	0,080	0,125	0,0100	0

Name Constr	Layer 4	λ	R-value	Thickness	EBE	Layer 5	λ	R-value	Thickness	EBE	Inside Airflow	R-Value	Rc-value (m2.K/W)	Total U-Value (W/m2.K)	Total EBE
New sandwich panel 5	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74						Inside Airflow	0,13	**4,12**	**0,24**	220,74
New window sill 5	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74						Inside Airflow	0,13	**3,90**	**0,26**	220,74
New outside window frame 5											Inside Airflow	0,13	**0,59**	**1,70**	400,22
New inside window frame 5											Inside Airflow	0,13	**0,44**	**2,27**	259,79
New door 5											Inside Airflow	0,13	**1,37**	**0,73**	419,35
New glass 5											Inside Airflow	0,13	**1,60**	**0,63**	449,40
New suskast ventilation 5											Inside Airflow	0,13	**0,48**	**2,07**	0,00
New thick window frame 5											Inside Airflow	0,13	**1,07**	**0,93**	379,74
New balcony facade 5											Inside Airflow	0,13	**3,67**	**0,27**	210,53
New side balcony 5	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74						Inside Airflow	0,13	**3,92**	**0,26**	220,74
New plate material 5	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74						Inside Airflow	0,13	**3,84**	**0,26**	220,74
New roof insulation + floor 5											Inside Airflow	0,13	**5,57**	**0,18**	315,34
New masonry 5	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74						Inside Airflow	0,13	**4,21**	**0,24**	220,74
New lower concrete edge 5	Plate old	0,200	0,0400	0,0080	0,00	Glasswool plates + Pinewood (RG) frame	0,052	3,5000	0,1829	220,74	Inside Airflow	0,13	**4,00**	**0,25**	220,74

Figure F- 19: Build-up of the construction parts of Strategy 3, interior upgrading, per m^2

WEST FAÇADE	Construction	Surface (m2)	Rcvalue	Embodied Energy New (MJ)	Building costs (Euro)	Environmental costs (Euro)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 5	3,31	4,12	730	56	7	0,24	
Facadepart 1.3	New window sill 5	0,17	3,90	36	3	0	0,26	
Facadepart 1.4	New outside window frame 5	0,43	0,59	173	333	1	1,70	62
Facadepart 1.5	New inside window frame 5	0,16	0,44	43	82	0	2,27	
Facadepart 1.6	New glass 5	1,30	1,60	584	105	0	0,63	
Facadepart 2.1	New plate material 5	2,20	3,84	485	37	5	0,26	
Façadepart 2.2	New door 5	1,09	1,37	456	251	4	0,73	
Facadepart 2.3	New thick window frame 5	0,50	1,07	188	40	2	0,93	
Facadepart 2.4	New suskast ventilation 5	0,38	0,48	0	0	0	2,07	216
Facadepart 2.5	New lower concrete edge 5	0,22	4,00	50	4	0	0,25	
Facadepart 2.6	New outside window frame 5	0,81	0,59	324	623	3	1,70	
Facadepart 2.7	New glass 5	3,84	1,60	1728	309	0	0,63	
Facadepart 3.1	New plate material 5	2,88	3,84	637	49	6	0,26	
Facadepart 3.2	New thick window frame 5	0,49	1,07	186	40	2	0,93	
Facadepart 3.3	New suskast ventilation 5	0,39	0,48	0	0	0	2,07	
Facadepart 3.4	New lower concrete edge 5	0,46	4,00	102	8	1	0,25	210
Facadepart 3.5	New outside window frame 5	1,08	0,59	433	832	4	1,70	
Facadepart 3.6	New inside window frame 5	0,87	0,44	226	435	2	2,27	
Facadepart 3.7	New glass 5	3,40	1,60	1527	273	0	0,63	
WEST BALCONY SIDES		Surface (m2)	Rcvalue	Embodied Energ			U-value (W/m2.K)	E.E. removal old
Facadepart 4.1	New side balcony 5	6,63	3,92	1463	112	14	0,26	0
EAST FAÇADE		Surface (m2)	Rcvalue	Embodied Energ			U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	New plate material 5	3,48	3,84	769	59	7	0,26	
Facadepart 5.2	New thick window frame 5	0,36	1,07	136	29	1	0,93	
Facadepart 5.3	New suskast ventilation 5	0,39	0,48	0	0	0	2,07	210
Facadepart 5.4	New outside window frame 5	1,16	0,59	466	895	4	1,70	
Facadepart 5.5	New inside window frame 5	0,86	0,44	222	427	2	2,27	
Facadepart 5.6	New glass 5	3,33	1,60	1498	268	0	0,63	
Facadepart 6.1	New balcony facade 5	6,59	3,67	1388	184	13	0,27	
Facadepart 6.2	New door 5	1,10	1,37	463	254	4	0,73	
Facadepart 6.3	New thick window frame 5	0,12	1,07	46	10	0	0,93	270
Facadepart 6.4	New suskast ventilation 5	0,08	0,48	0	0	0	2,07	
Facadepart 6.5	New outside window frame 5	0,52	0,59	207	397	2	1,70	
Facadepart 6.6	New glass 5	0,69	1,60	311	56	0	0,63	
EAST SIDE WALL		Surface (m2)	Rcvalue	Embodied Energ			U-value (W/m2.K)	E.E. removal old
Facadepart 7.1	New side balcony 5	2,35	3,92	518	40	5	0,26	0
SOUTH FAÇADE		Surface (m2)	Rcvalue	Embodied Energ			U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	New masonry 5	25,31	4,21	5587	429	53	0,24	0
ROOF		Surface (m2)	Rcvalue	Embodied Energ			U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	New roof insulation + floor 5	77,04	5,57	24294	1865	232	0,18	0

Figure F- 20: Façade build up complete of strategy3 , interior upgrading, with Rc-values and embodied energy per façade part

WEST FAÇADE	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 1.A	New sandwich panel 5	3,31	3,31	0,30	West	Minimal	
Facadepart 1.B	New window sill 5	0,17	3,90	0,26	West	Minimal	
Facadepart 1.C	New window total 5	1,90	0,54	1,85	West	Minimal	0,6
Facadepart 2.A	New plate material 5	2,58	3,68	0,27	West	Overhang	
Façadepart 2.B	New door 5	1,09	1,37	0,73	West	Overhang	
Facadepart 2.C	New suskast 5	0,71	0,76	1,32	West	Overhang	
Facadepart 2.D	New window total 5	4,66	0,54	1,85	West	Overhang	0,6
Facadepart 3.A	New plate material 5	3,47	3,76	0,27	West	Minimal	
Facadepart 3.B	New suskast 5	0,76	0,77	1,31	West	Minimal	
Facadepart 3.C	New window total 5	5,35	0,54	1,85	West	Minimal	0,6
WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 4.A	New side balcony north 5	4,42	3,92	0,26	North	Overhang	
Facadepart 4.B	New side balcony south 5	2,21	3,92	0,26	South	Overhang	
EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 5.A	New plate material 5	3,48	3,84	0,26	East	Minimal	
Facadepart 5.B	New suskast 5	0,75	0,76	1,31	East	MInimal	
Facadepart 5.C	New window total 5	5,35	0,54	1,85	East	Minimal	0,6
Facadepart 6.A	New balcony facade 5	6,59	3,67	0,27	East	Overhang	
Facadepart 6.B	New door 5	1,10	1,37	0,73	East	Overhang	
Facadepart 6.C	New suskast 5	0,20	0,84	1,19	East	Overhang	
Facadepart 6.D	New window total 5	1,21	0,54	1,85	East	Overhang	0,6
EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 7.A	New side balcony 5	2,35	3,92	0,26	South	Overhang	
SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 8.A	New masonry 5	25,31	4,21	0,24	South	Minimal	
ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 9.A	New roof 5	77,04	5,57	0,18	-	Minimal	

Figure F- 21: Façade build up simplified for EPC of strategy 3, interior upgrading

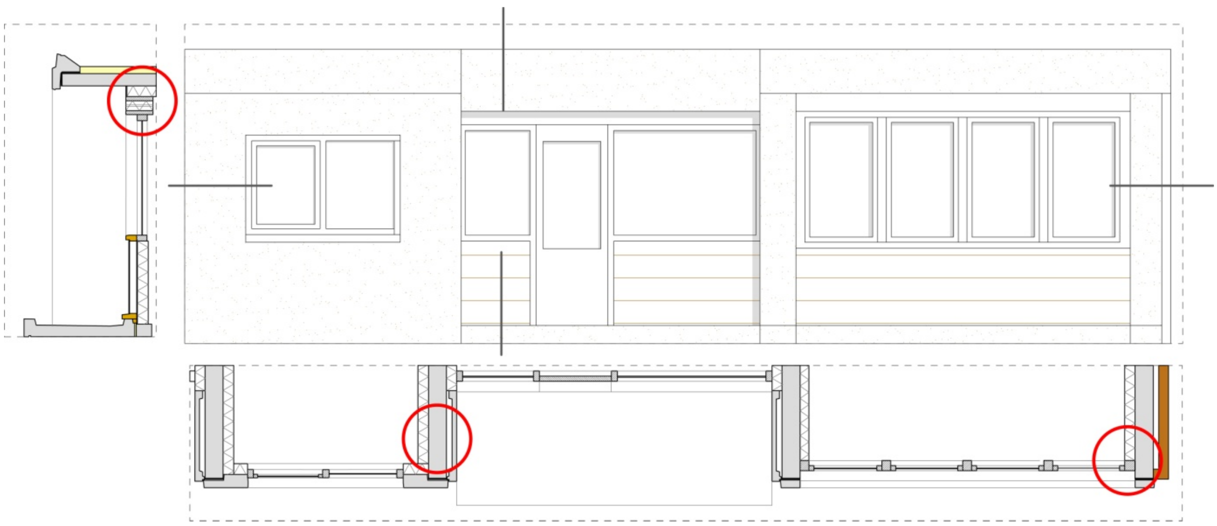


Figure F- 22: Design for strategy 3, interior upgrading, in more detail, with in red the restrictions in the detailing

Strategy 4: Portaal's Design

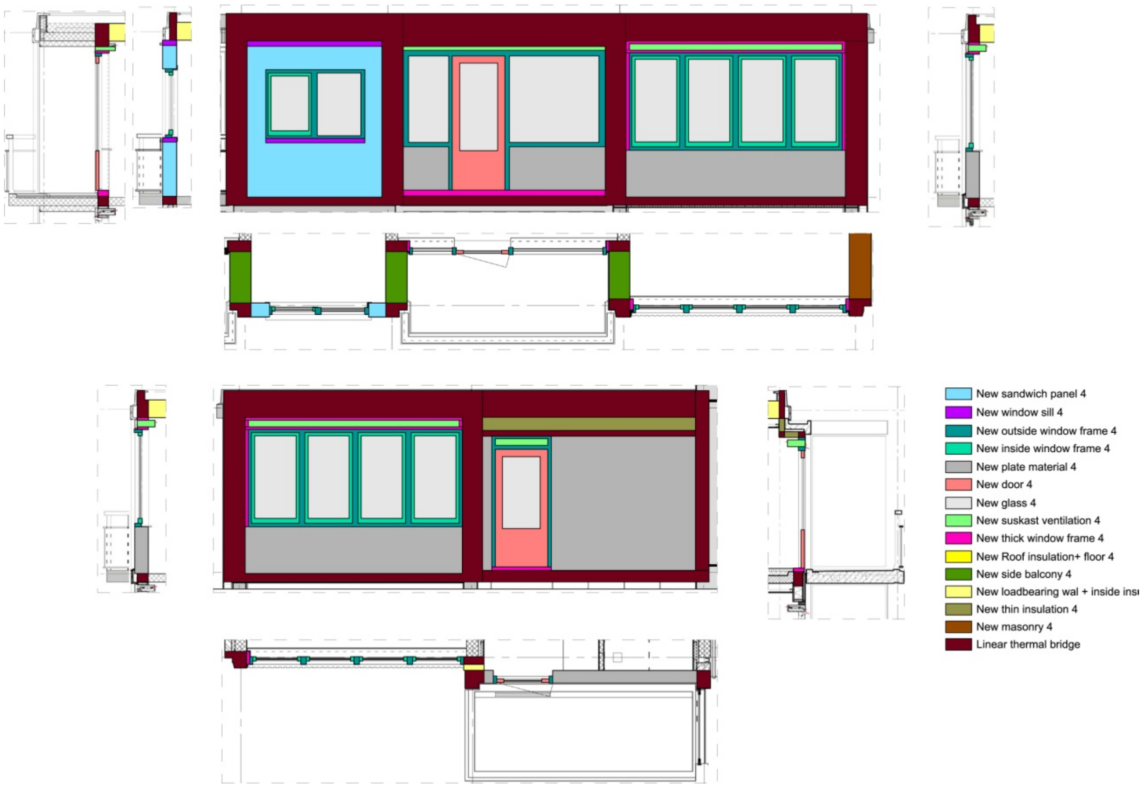


Figure F- 23: Design for strategy 5, with façade components

Figure F- 24: Design for strategy 5, simplified for EPC calculations

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thickness	EBE
New sandwich panel 4	Outside Airflow	0,04	Plaster	0,580	0,0000	0,0350	0,00
New window sill 4	Outside Airflow	0,04	Pinewood (renwably grown)	0,200	0,4000	0,0800	368,97
New outside window frame 4	Outside Airflow	0,04	European Hardwood (renewably grown)	0,274	0,4167	0,1140	400,22
New inside window frame 4	Outside Airflow	0,04	European Hardwood (renewably grown)	0,274	0,2449	0,0670	235,22
New plate material 4	Outside Airflow	0,04	Multiplex Pine/Fir (renewably grown)	0,000	0,0000	0,0100	249,61
New door 4	Outside Airflow	0,04	HDF-alu-HDF/tropical hardwood/PUT,flat (RG)	0,043	1,2500	0,0540	981,95
New glass 4	Outside Airflow	0,04	HR++ glass	1,200	0,8333	1,0000	299,60
New suskast ventilation 4	Outside Airflow	0,04	Suskast	1,088	0,3125	0,3400	0,00
New thick window frame 4	Outside Airflow	0,04	Wooden frame 15% of wall (multiplex, frames, plasterbc	0,200	0,9000	0,1800	379,74
New roof insulation + floor 4	Outside Airflow	0,04	EPS plates	0,034	2,3324	0,0800	146,12
New side balcony 4	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0350	776,20
New loadbearing wall + inside insul. 4	Outside Airflow	0,04	Grindbeton old	1,600	0,1250	0,2000	0,00
New thin insulation 4	Outside Airflow	0,04	Plate new	0,200	0,0900	0,0180	0,00
New masonry 4	Outside Airflow	0,04	Masonry old	0,781	0,1344	0,1050	0,00
New linear cold bridge concrete 4	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0350	776,20
New linear cold bridge masonry 4	Outside Airflow	0,04	Glaswol platen	0,035	1,857	0,0650	44,04
New linear cold bridge balcony constr4	Outside Airflow	0,04	Balcony concrete			1,5000	0,00
New linear cold bridge roof 4	Outside Airflow	0,04	EPS plates	0,034	2,3324	0,0800	146,12
New linear cold bridge balcony insul 4	Outside Airflow	0,04	EPS plates	0,034	2,9155	0,1000	182,65

Name Constr	Layer 2	λ	R-value	Thickness	EBE	Layer 3	λ	R-value	Thickness	EBE
New sandwich panel 4	Glaswol platen	0,035	2,286	0,0800	54,20	Grindbeton old	1,600	0,0500	0,0800	0,00
New window sill 4	Grindbeton old	1,600	0,050	0,0800	0,00	Polystyrene old	0,080	0,1250	0,0100	0,00
New outside window frame 4										
New inside window frame 4										
New plate material 4	Stronly ventilated cavity	0,000	0,000			Glaswool plates + wooden frame	0,060	3,0126	0,1800	300,47
New door 4										
New glass 4										
New suskast ventilation 4										
New thick window frame 4										
New roof insulation + floor 4	Polystyrene old	0,080	0,313	0,0250	0,00	Grindbeton old	1,600	0,0875	0,1400	0,00
New side balcony 4	Glaswol platen	0,035	4,286	0,1500	101,62	Grindbeton old	1,600	0,1250	0,2000	0,00
New loadbearing wall + inside insul. 4	Glasswool plates + Pinewood (RG) frame	0,052	1,5882	0,0830	100,16					
New thin insulation 4	Glaswol platen	0,035	1,714	0,0600	40,65	Plate new	0,200	0,0400	0,0080	0,00
New masonry 4	Glaswol platen	0,035	1,857	0,0650	44,04	Grindbeton old	0,625	0,3200	0,2000	0,00
New linear cold bridge concrete 4	Glaswol platen	0,035	3,5000	0,1225	82,99					
New linear cold bridge masonry 4										
New linear cold bridge balcony constr4										
New linear cold bridge roof 4										
New linear cold bridge balcony insul 4										

Name Constr	Layer 4	λ	R-value	Thickness	EBE	Layer 5	λ	R-value	Thickness	EBE	Inside Airflow	R-Value	Rc-value (m2.K/W)	Total U-Value (W/m2.K)	Total EBE
New sandwich panel 4	Polystyrene old	0,080	0,125	0,010	0,00	Gasbeton old	0,22	0,273	0,0600	0,00	Inside Airflow	0,13	**2,90**	**0,34**	54,20
New window sill 4	Gasbeton old	0,22	0,273	0,060	0,00						Inside Airflow	0,13	**1,02**	**0,98**	368,97
New outside window frame 4											Inside Airflow	0,13	**0,59**	**1,70**	400,22
New inside window frame 4											Inside Airflow	0,13	**0,41**	**2,41**	235,22
New plate material 4											Inside Airflow	0,13	**3,18**	**0,31**	550,07
New door 4											Inside Airflow	0,13	**1,42**	**0,70**	981,95
New glass 4											Inside Airflow	0,13	**1,00**	**1,00**	299,60
New suskast ventilation 4											Inside Airflow	0,13	**0,48**	**2,07**	0,00
New thick window frame 4											Inside Airflow	0,13	**1,07**	**0,93**	379,74
New roof insulation + floor 4											Inside Airflow	0,13	**2,90**	**0,34**	146,12
New side balcony 4											Inside Airflow	0,13	**4,58**	**0,22**	877,82
New loadbearing wall + inside insul. 4											Inside Airflow	0,13	**1,88**	**0,53**	100,16
New thin insulation 4											Inside Airflow	0,13	**2,01**	**0,50**	40,65
New masonry 4											Inside Airflow	0,13	**2,48**	**0,40**	44,04
New linear cold bridge concrete 4											Inside Airflow	0,13	**3,67**	**0,27**	859,19
New linear cold bridge masonry 4											Inside Airflow	0,13	**2,03**	**0,49**	44,04
New linear cold bridge balcony constr4											Inside Airflow	0,13	**0,17**	**5,88**	0,00
New linear cold bridge roof 4											Inside Airflow	0,13	**2,50**	**0,40**	146,12
New linear cold bridge balcony insul 4											Inside Airflow	0,13	**3,09**	**0,32**	182,65

Figure F- 25: Build-up of the construction parts of Strategy 4, design of Portaal, per m²

WEST FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)	Building costs (Euro)	Environmental costs (Euro)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 4	3,79	2,90	205,42	27,79	1,95	0,34	
Facadepart 1.2	New window sill 4	0,34	1,02	123,71	108,38	0,96	0,98	
Facadepart 1.3	New outside window frame 4	0,39	0,59	157,05	301,62	1,35	1,70	62
Facadepart 1.4	New inside window frame 4	0,19	0,41	44,76	85,97	0,38	2,41	
Facadepart 1.5	New glass 4	1,39	1,00	416,44	0,00	0,00	1,00	
Facadepart 2.1	New plate material 4	1,78	3,18	976,93	83,81	9,06	0,31	
Façadepart 2.2	New suskast ventilation 4	0,23	0,48	0,00	0,00	0,00	2,07	
Facadepart 2.3	New door 4	1,08	1,42	1063,45	433,20	8,49	0,70	277
Facadepart 2.4	New thick window frame 4	0,35	1,07	131,35	28,02	1,22	0,93	
Facadepart 2.5	New outside window frame 4	1,11	0,59	442,64	850,13	3,80	1,70	
Facadepart 2.6	New glass 4	4,22	1,00	1263,11	0,00	0,00	1,00	
Facadepart 3.1	New plate material 4	2,94	3,18	1618,32	138,83	15,01	0,31	
Facadepart 3.2	New suskast ventilation 4	0,42	0,48	0,00	0,00	0,00	2,07	
Facadepart 3.3	New thick window frame 4	0,53	1,07	200,12	42,69	1,86	0,93	315
Facadepart 3.4	New outside window frame 4	1,01	0,59	403,82	775,57	3,46	1,70	
Facadepart 3.5	New inside window frame 4	1,02	0,41	240,39	461,69	2,06	2,41	
Facadepart 3.6	New glass 4	3,98	1,00	1191,21	0,00	0,00	1,00	
WEST BALCONY SIDES	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 4.1	New side balcony 4	6,80	4,58	5969,20	374,57	15,88	0,22	323
EAST FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	New plate material 4	2,94	3,18	1618,32	138,83	15,01	0,31	
Facadepart 5.2	New suskast ventilation 4	0,41	0,48	0,00	0,00	0,00	2,07	
Facadepart 5.3	New thick window frame 4	0,42	1,07	159,87	34,10	1,49	0,93	315
Facadepart 5.4	New outside window frame 4	1,01	0,59	402,22	772,50	3,45	1,70	
Facadepart 5.5	New inside window frame 4	1,07	0,41	251,92	483,83	2,16	2,41	
Facadepart 5.6	New glass 4	3,96	1,00	1185,82	0,00	0,00	1,00	
Facadepart 6.1	New plate material 4	5,97	3,18	3284,49	281,77	30,45	0,31	
Facadepart 6.2	New thin insulation 4	1,76	2,01	71,58	9,69	0,68	0,50	
Facadepart 6.3	New suskast ventilation 4	0,10	0,48	0,00	0,00	0,00	2,07	
Facadepart 6.4	New thick window frame 4	0,06	1,07	23,01	4,91	0,21	0,93	270
Facadepart 6.5	New door 4	1,00	1,42	977,23	398,08	7,81	0,70	
Facadepart 6.6	New outside window frame 4	0,36	0,59	145,04	278,56	1,24	1,70	
Facadepart 6.7	New glass 4	0,79	1,00	236,47	0,00	0,00	1,00	
EAST SIDE WALL	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 7.1	New loadbearing wall + inside insul. 4	0,27	1,88	26,54	2,04	0,25	0,53	105
SOUTH FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	New masonry 4	25,31	2,48	1114,45	150,79	10,56	0,40	0
ROOF	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	New roof insulation + floor 4	77,04	2,90	11257,46	873,14	57,01	0,34	0
Linear cold bridges		Surface (m2)		Embodied Energy (MJ)				E.E. removal old
Linear cold bridge west 1	New linear cold bridge concrete 4	3,75		3218,53	196,90	8,09		
Linear cold bridge west 2	New linear cold bridge concrete 4	2,473		2124,78	129,99	5,34		
Linear cold bridge west 3	New linear cold bridge concrete 4	4,8		4124,12	252,30	10,37		
Linear cold bridge east 5	New linear cold bridge concrete 4	3,43		2947,03	180,29	7,41		
Linear cold bridge east 6	New linear cold bridge concrete 4	4,24		3642,97	222,87	9,16		2775
Linear cold bridge south concr 8	New linear cold bridge concrete 4	2,675		2298,34	140,60	5,78		
Linear cold bridge south masonry 8	New linear cold bridge masonry 4	2,675		117,80	15,94	1,12		
New balcony 6	New linear cold bridge balcony constr4	0,7114		0,00	0,00	0,00		
Linear cold bridge roof 9	New linear cold bridge roof 4	8,2		1198,19	92,93	6,07		
Linear cold bridge balcony insulation 4	New linear cold bridge balcony insul 4	4,76		869,42	67,43	4,40		

Figure F- 26: Façade build up complete of strategy4 , design of Portaal, with Rc-values and embodied energy per façade part

WEST FAÇADE	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
Facadepart 1.A	New Sandwich panel total 3	3,79	2,90	0,34	West	Minimal	
Facadepart 1.B	New window total 3	1,97	0,54	1,85	West	Minimal	0,6
Facadepart 1.C	New window sill 3	0,34	1,02	0,98	West	Minimal	
Facadepart 2.A	New balcony cladding 3	2,12	2,84	0,35	West	Overhang	
Façadepart 2.B	New door 3	1,08	1,42	0,70	West	Overhang	
Facadepart 2.C	New suskast 3	0,23	0,48	2,07	West	Overhang	
Facadepart 2.D	New window total 3	5,32	0,54	1,85	West	Overhang	0,6
Facadepart 3.A	New plate material 3	2,94	3,18	0,31	West	Minimal	
Facadepart 3.B	New window total 3	6,01	0,54	1,85	West	Minimal	0,6
Facadepart 3.C	New suskast 3	0,94	0,81	1,23	West	Minimal	
WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
Facadepart 4.A	New side balcony north	2,27	4,58	0,22	North	Overhang	
Facadepart 4.B	New side balcony south	4,53	4,58	0,22	South	Overhang	
EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
Facadepart 5.A	New plate material 3	2,94	3,18	0,31	East	Minimal	
Facadepart 5.B	New window total 3	6,03	0,54	1,85	East	Minimal	0,6
Facadepart 5.C	New suskast 3	0,83	0,78	1,28	East	MInimal	
Facadepart 6.A	New balcony cladding 3	5,97	3,18	0,31	East	Minimal	
Facadepart 6.B	New door 3	1,00	1,42	0,70	East	MInimal	
Facadepart 6.C	New suskast 3	0,16	0,70	1,43	East	MInimal	
Facadepart 6.D	New total window 3	1,15	0,54	1,85	East	MInimal	0,6
Facadepart 6.E	Newthin insulation	1,76	2,01	0,50	East	Minimal	
EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
Facadepart 7.A	New side balcny	0,27	1,88	0,53	South	Minimal	
SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
Facadepart 8.A	New masnry 3	25,31	2,48	0,40	South	Minimal	
ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
Facadepart 9.A	New roof 3	77,04	2,90	0,34	-	Minimal	

Figure F- 27: Façade build up simplified for EPC of strategy 4, Portaal's design

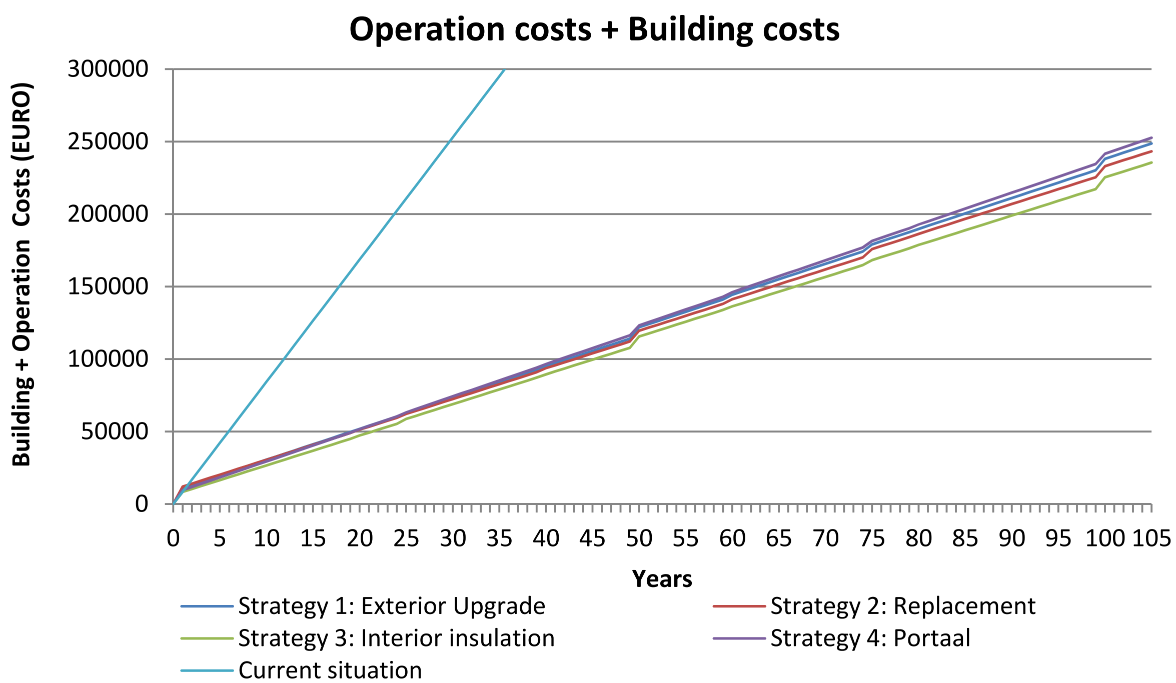


Figure F- 28: Operation energy costs + building costs for the different strategies

Appendix G: Design

Figure G- 1: Floor plan of the new design

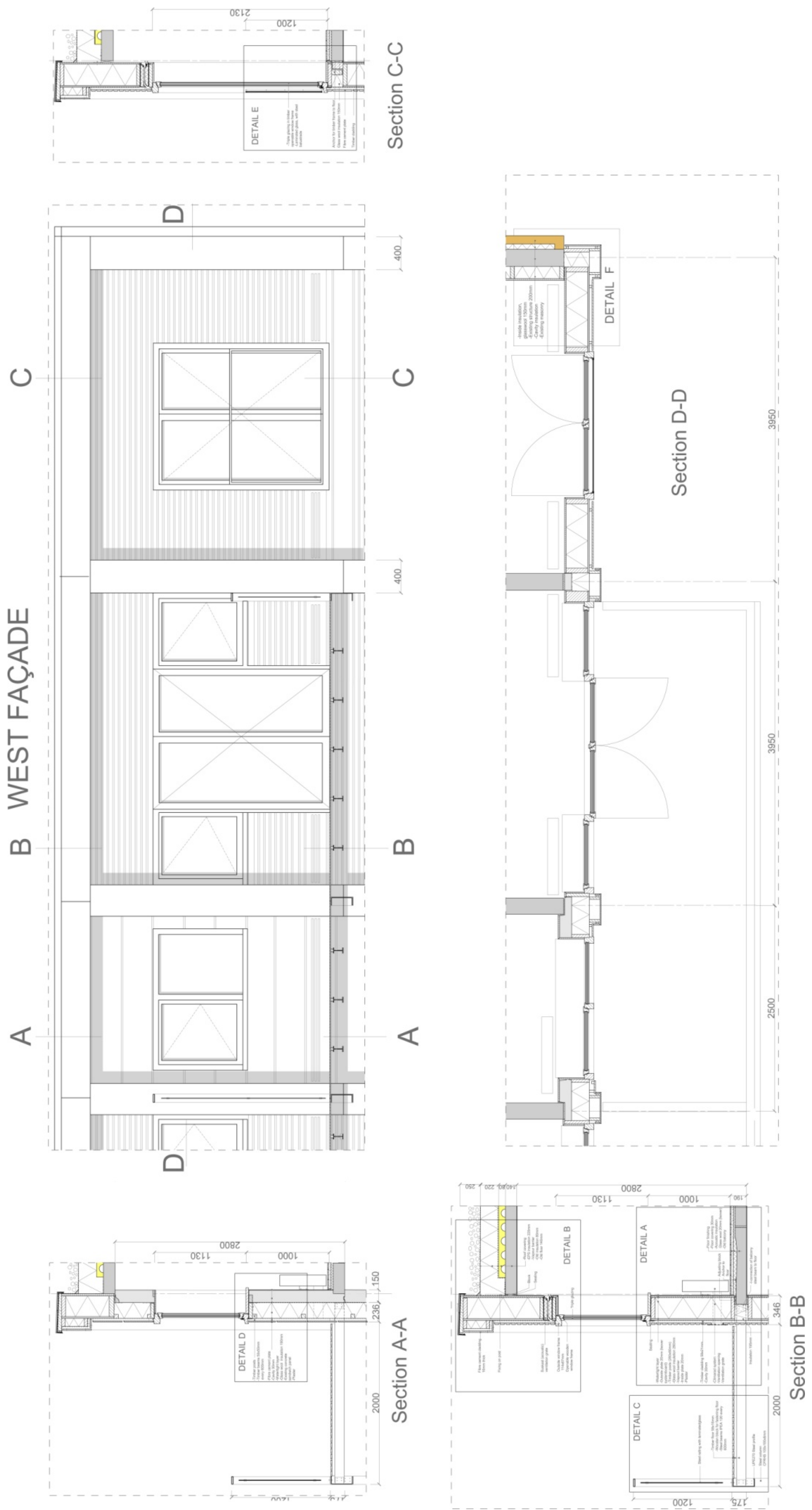


Figure G- 2: Façade with cross sections of own design

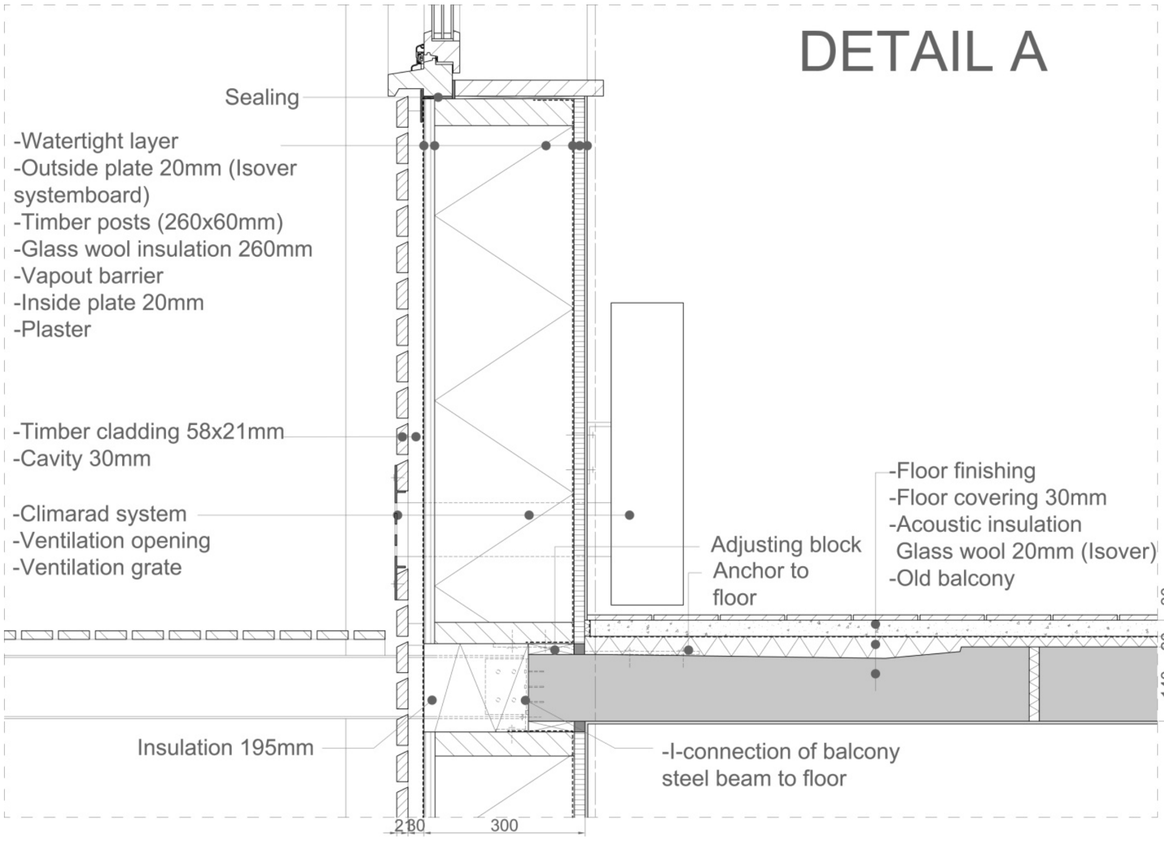


Figure G- 3: Detail A of the own design, larger figure

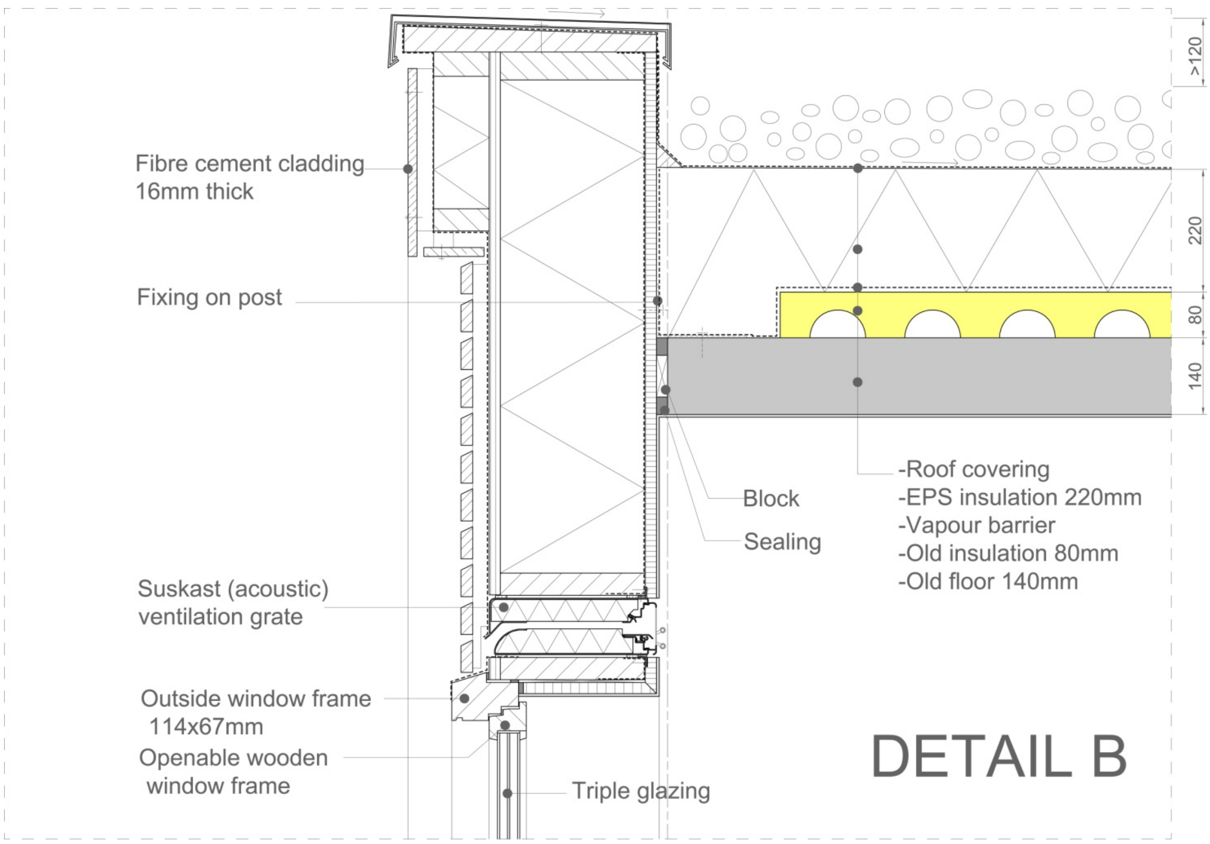


Figure G- 4: Detail B of the own design, larger figure

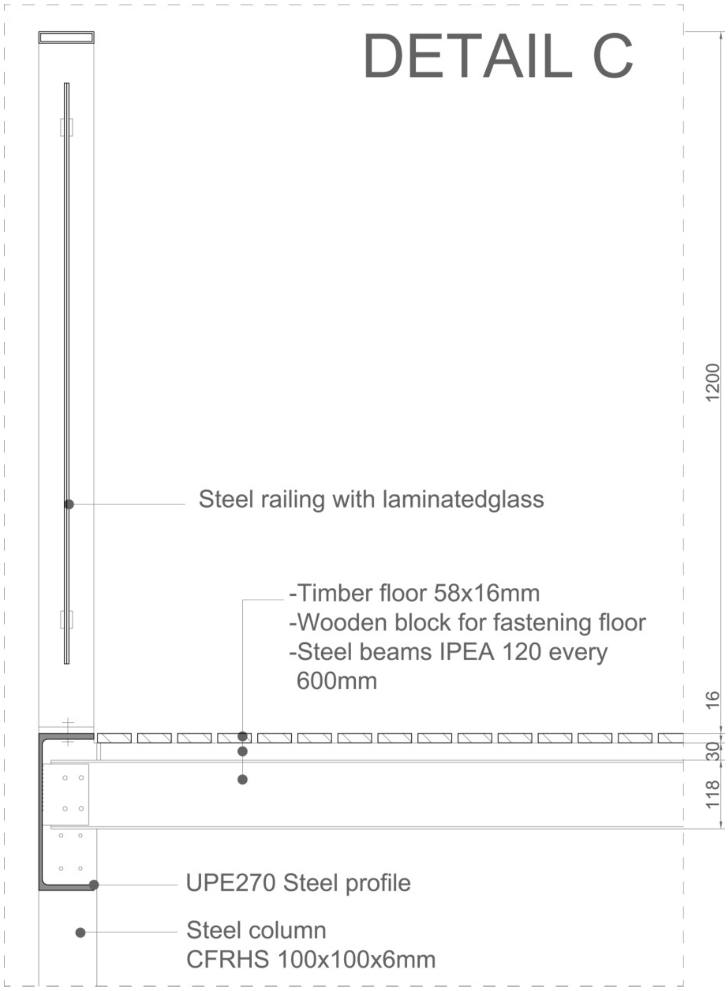


Figure G- 5: Detail C of the own design, larger figure

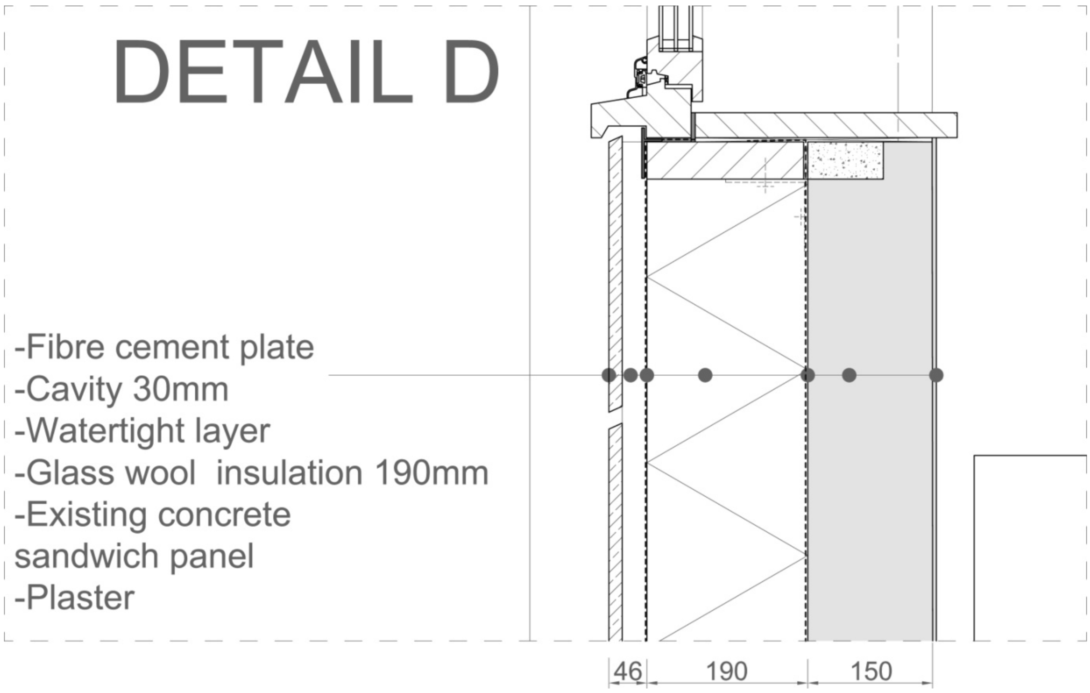


Figure G- 6: Detail D of the own design, larger figure

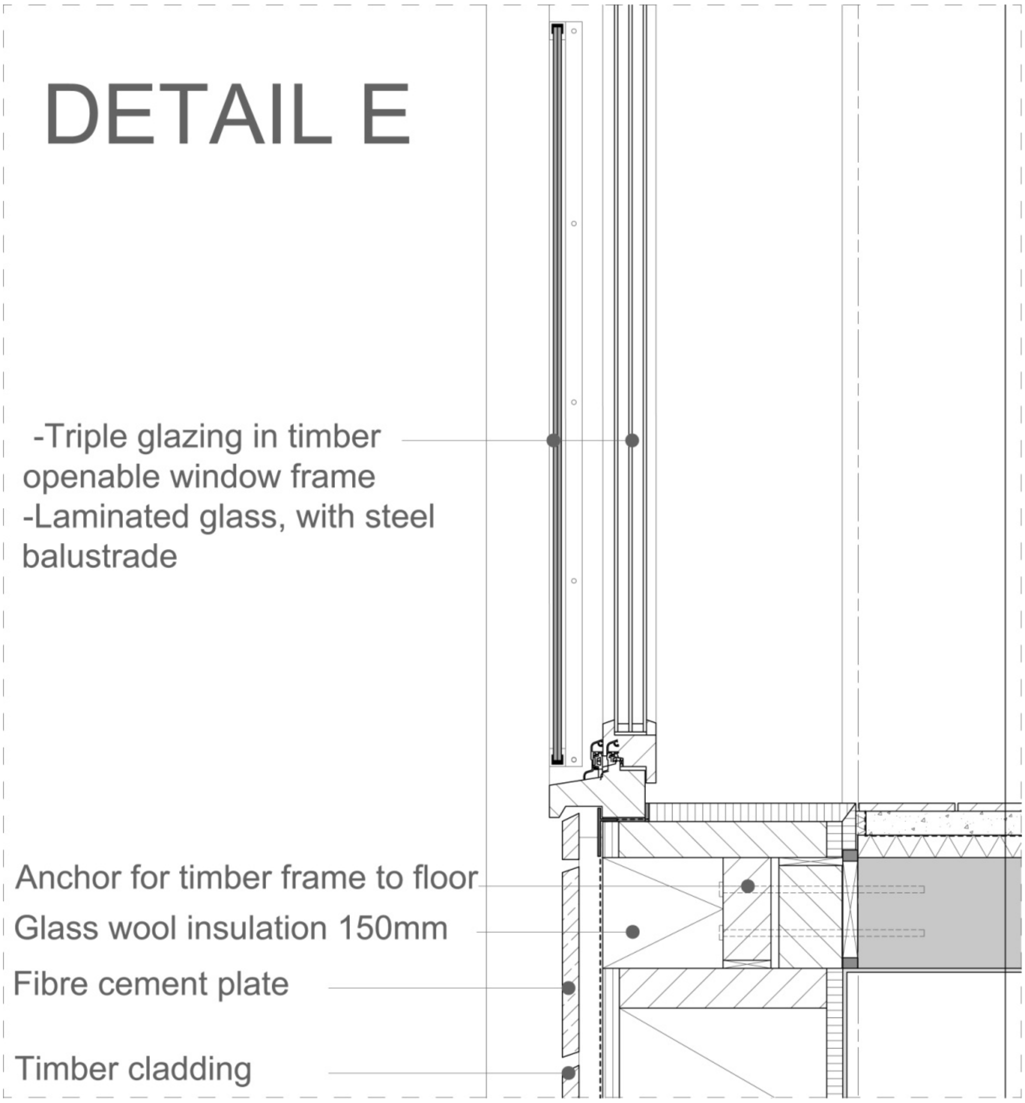


Figure G- 7: Detail E of the own design, larger figure

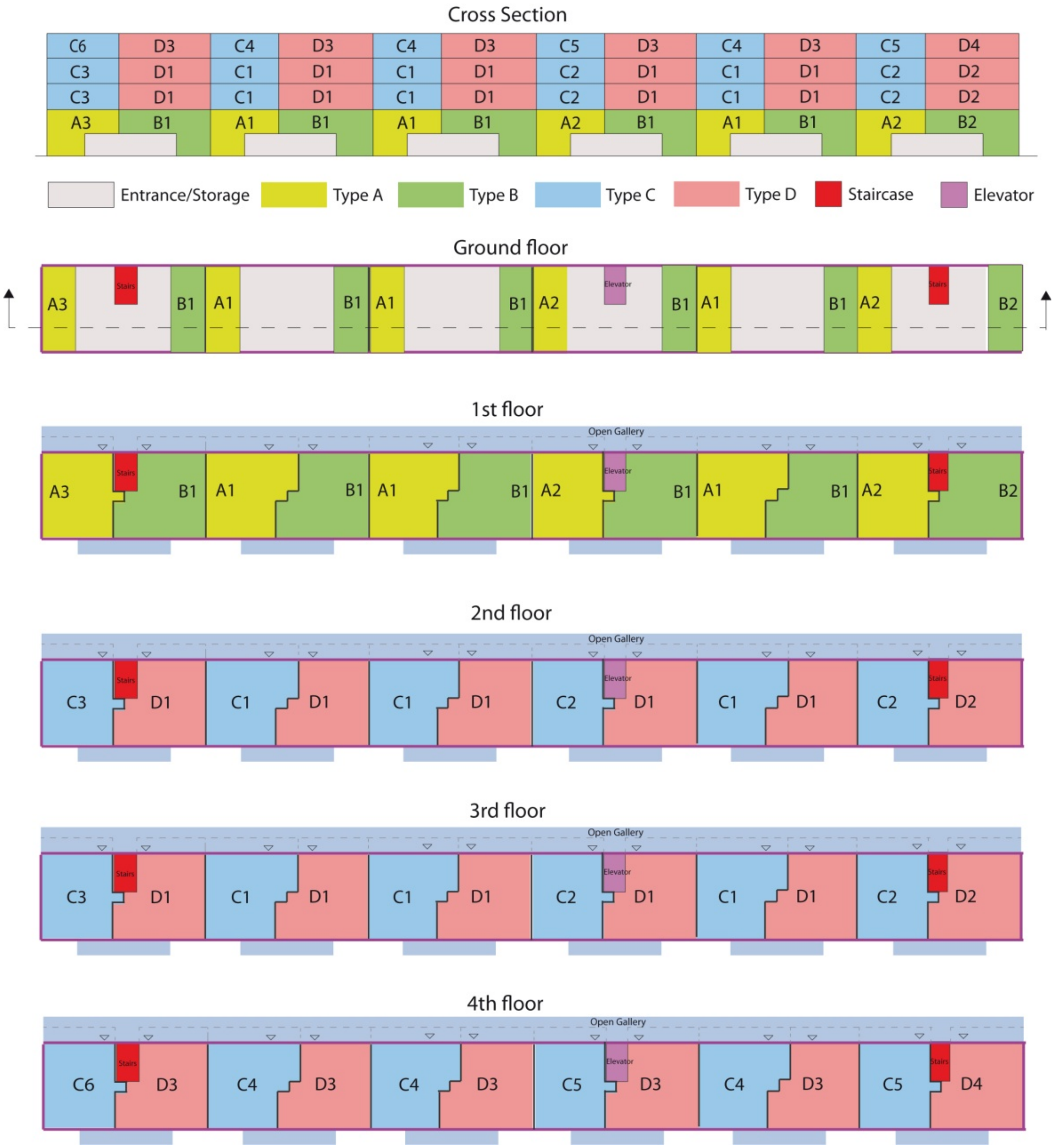


Figure G- 8: Cross section and floor plans of the different apartment types used for the energy calculations, for own design

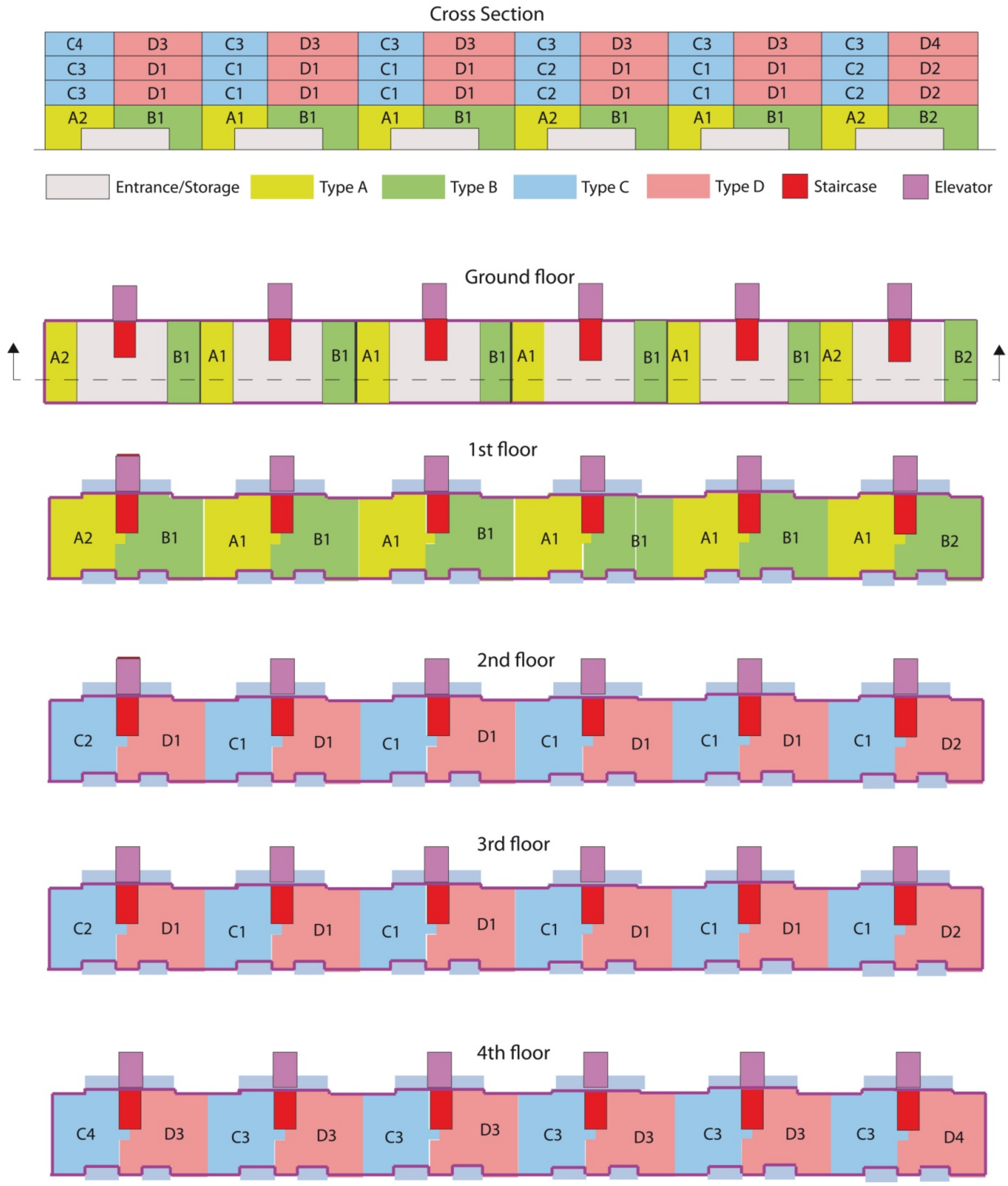


Figure G- 9: Cross section and floor plans of the different apartment types used for the energy calculations, for the design of Portaal

Table G- 1: Calculation results for the own design, for all different apartment types

	A1	A2	A3	B1	B2	C1	C2	C3	C4	C5	C6	D1	D2	D3	D4
Floor area (m²)	117	107,5	107,5	117	117	84	74,5	74,5	84	84	74,5	84	84	84	84
Dm3/s ventilat.	140,6	129,1	129,1	140,6	140,6	100,9	89,5	89,5	100,9	100,9	89,5	100,9	100,9	100,9	100,9
Emb. Energy 35 years (MJ)	28055	23625	38787	27845	42255	20092	16624	23725	56930	53462	63134	20092	27193	59630	66603
Oper. Energy/ year(MJ)	33707	32290	32913	33842	34609	26977	25616	25855	28194	26734	27189	26964	27260	28190	28667
Total E+O, 35 years (MJ)	1207800	1153775	1190742	1212315	1253570	964287	913184	928650	1043720	989152	1014749	963832	981293	1046280	1069948
EPC	0,66	0,68	0,64	0,66	0,63	0,69	0,72	0,68	0,61	0,63	0,61	0,69	0,66	0,61	0,59
Energy/ year by transmis. (MJ)	17382	16189	19910	17382	21105	12356	11152	13031	17464	16249	18054	12356	14237	17464	19277
Oper. Energy use/year /m²	288	300	306	289	296	321	244	347	336	359	365	321	325	336	341
Envir. Costs (euro)	188	166	307	188	328	131	110	180	318	296	367	131	201	318	388
Building costs (euro)	11567	10682	12430	11567	13315	8152	7267	8140	11009	10124	10997	8152	9025	11009	11883
Nr. of homes	3	2	1	5	1	6	4	2	3	2	1	10	2	5	1

Table G- 2: Calculation results for the design of Portaal, per apartment type, district heating standard value in EPC

	A1	A2	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4
Floor area (m²)	113	113	123	123	77	77	77	77	87	87	87	87
Dm3/s ventilat.	135,7	135,7	147,8	147,8	92,5	92,5	92,5	92,5	104,5	104,5	104,5	104,5
Emb. Energy 35 years (MJ)	53213	55147	54223	57544	34054	35228	58063	59177	34349	35464	65565	60186
Oper. Energy/ year(MJ)	41130	46889	43865	49278	29876	32720	39098	42036	32269	34965	41572	44305
Total E+O, 35 years (MJ)	1492763	1696262	1589498	1782274	1079714	1180428	1426493	1530437	1163764	1259239	1520585	1610861
EPC	0,83	0,88	0,83	0,86	0,82	0,85	0,89	0,91	0,80	0,83	0,88	0,89
Energy/ year by transmis. (MJ)	20997	27083	22567	28670	13417	16490	22658	25528	15005	18090	24303	27203
Oper. Energy use/year/ m²	364	415	357	401	388	425	508	546	371	402	478	509
Environ. Costs (euro)	248	275	253	280	147	158	238	249	151	161	236	254
Building costs (euro)	9875	10265	10399	10789	6154	6313	7765	7916	6641	6792	8132	8440
Nr. of homes	5	1	5	1	10	2	5	1	10	2	5	1

Table G- 3: Calculation results for the current situation, per apartment type, in EPC

	A1	A2	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4
Floor area (m^2)	103	103	113	113	67	67	67	67	77	77	77	77
Dm3/s ventilat.	124,0	124,0	135,7	135,7	80,5	80,5	80,5	80,5	92,5	92,5	92,5	92,5
Oper. Energy/ year(MJ)	13457 9	147741	14427 3	157541	95524	102088	121691	127765	105278	111922	131765	137952
Heating energy/ye ar (MJ)	89868	102936	97654	110817	59813	66337	84955	90869	67671	74265	93137	99170
Total 35 years (MJ)	47102 65	5170935	50495 55	5513935	3343340	3573080	4259185	4471775	3684730	3917270	4611775	4828320
EPC	2,88	2,90	2,87	2,89	2,79	2,80	2,98	2,97	2,81	2,83	2,99	2,99
Energy/ year by transmis. (MJ)	49973	62481	53423	66022	33660	39907	54668	60235	37110	43432	58432	64122
Oper. Energy use/year/ m^2	1307	1434	1277	1394	1426	1524	1816	1907	1367	1454	1711	1792
Nr. of homes	5	1	5	1	10	2	5	1	10	2	5	1

Table G- 4: Calculation result for the own design, for different apartment types with PV cells

	A1	A2	A3	B1	B2	C1	C2	C3	C4	C5	C6	D1	D2	D3	D4
Floor area (m^2)	117	107,5	107,5	117	117	84	74,5	74,5	84	84	74,5	84	84	84	84
Dm3/s ventilat.	140,6	129,1	129,1	140,6	140,6	100,9	89,5	89,5	100,9	100,9	89,5	100,9	100,9	100,9	100,9
Emb. Energy 35 years (MJ), no PV cells	28055	23625	38787	27845	42255	20092	16624	23725	56930	53462	63134	20092	27193	59630	6660 3
Oper. Energy/ year(MJ)	12976	1159	12182	13112	13767	6246	4885	5124	7463	6003	6458	6243	6529	7459	9084
EPC	0,26	0,25	0,24	0,26	0,25	0,16	0,14	0,14	0,16	0,14	0,15	0,16	0,16	0,16	0,19
Oper. Energy use/year /m^2	111	11	113	112	118	74	66	69	89	71	87	74	78	89	108
Nr. of homes	3	2	1	5	1	6	4	2	3	2	1	10	2	5	1

Table G- 5: EPC input for Own design for apartment type D4

TYPE D4	***WEST FAÇADE***	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
	Facadepart 1.A	Sandwich panel	5,96	5,62	0,18	West	Overhang	-
	Facadepart 1.B	Window total	1,76	0,71	1,40	West	Overhang	0,55
	Facadepart 2.A	Closed balcony	4,27	5,18	0,19	West	Overhang	-
	Façadepart 2.B	Window total	4,28	0,71	1,40	West	Overhang	0,55
	Facadepart 2.C	Suskast	2,72	0,78	1,28	West	Overhang	-
	Facadepart 2.D	Door	1,32	1,37	0,73	West	Overhang	
	Facadepart 3.A	Plate material	5,21	5,33	0,19	West	Minmal	-
	Facadepart 3.B	Window total	4,69	0,71	1,40	West	Minimal	0,55
	Facadepart 3.C	Suskast	0,66	0,78	1,28	West	MInimal	-
	EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m	Orientation	Obstruction	ZTA
	Facadepart 5.A	Plate material	4,21	5,32	0,19	East	Overhang	-
	Facadepart 5.B	Window total	4,55	0,71	1,40	East	Overhang	0,55
	Facadepart 5.C	Suskast	0,68	0,78	1,28	East	Overhang	-
	Facadepart 6.A	Closed balcony	6,97	5,17	0,19	East	Overhang	-
	Facadepart 6.B	Window total	4,00	0,71	1,40	East	Overhang	0,55
	Facadepart 6.C	Suskast	0,68	0,78	1,28	East	Overhang	
	Facadepart 6.D	Door	1,16	1,37	0,73	East	Overhang	
	SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m	Orientation	Obstruction	ZTA
	Facadepart 8.A	Masonry	25,11	5,35	0,19	South	Minimal	-
	ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m	Orientation	Obstruction	ZTA
	Facadepart 9.A	Roof	84,00	7,57	0,13	-	Minimal	-

Table G- 6: Excel output for apartment type D4 for Own design, for calculation Embodied energy, Environmental and Building Costs

WEST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)	Building costs (Euro)	Environmental costs (Euro)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	DESIGN sandwich panel	5,96	5,62	2028,24	341,93	14,88	0,18	
Facadepart 1.2	DESIGN outside window frame	0,36	0,59	142,80	274,26	1,22	1,70	
Facadepart 1.3	DESIGN inside window frame	0,22	0,44	57,62	110,67	0,49	2,27	62
Facadepart 1.4	DESIGN glass	1,18	1,60	531,73	95,19	0,00	0,63	
Facadepart 1.5 L.C.B	DESIGN L.T.B. Sandwich panel	0,80	5,62	271,76	0,00	1,99	0,18	
Facadepart 1.6 L.C.B	DESIGN Stone material	1,10	5,22	374,16	63,08	2,74	0,19	
Facadepart 2.1	DESIGN closed balcony	3,65	5,17	1042,60	270,98	9,93	0,19	
Façadepart 2.2	DESIGN door	1,32	1,37	552,03	303,30	5,21	0,73	
Facadepart 2.3	DESIGN suskast ventilation	0,67	0,48	24,25	23,58	0,25	2,07	
Facadepart 2.4	DESIGN outside window frame	0,62	0,59	249,78	479,72	2,14	1,70	
Facadepart 2.5	DESIGN inside window frame	0,73	0,44	190,68	366,22	1,64	2,27	690
Facadepart 2.6	DESIGN glass	2,92	1,60	1311,21	234,73	0,00	0,63	
Facadepart 2.7	DESIGN Stone material	0,62	5,22	210,14	35,43	1,54	0,19	
Facadepart 2.8 L.C.B	DESIGN L.T.B. Stone material	1,50	5,22	332,12	85,92	3,74	0,19	
Facadepart 2.9 L.C.B	DESIGN L.T.B. Closed balcony	1,04	5,17	37,37	77,02	2,82	0,19	
side balconies parts 4 and 7								
Facadepart 3.1	DEISIGN plate material	4,60	5,34	710,82	234,76	6,84	0,19	
Facadepart 3.2	DESIGN suskast ventilation	0,66	0,48	23,92	23,26	0,24	2,07	
Facadepart 3.3	DESIGN Stone material	0,62	5,22	209,50	35,32	1,54	0,19	
Facadepart 3.4	DESIGN outside window frame	0,70	0,59	280,11	537,98	2,40	1,70	210
Facadepart 3.5	DESIGN inside window frame	1,00	0,44	260,08	499,51	2,23	2,27	
Facadepart 3.6	DESIGN glass	2,98	1,60	1341,32	240,12	0,00	0,63	
Facadepart 3.7 L.C.B	DESIGN L.T.B. Closed balcony	1,03	5,17	37,16	76,59	2,81	0,19	
Facadepart 3.8 L.C.B	DESIGN L.T.B. Stone material	2,92	5,22	647,17	167,43	7,28	0,19	
EAST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	DEISIGN plate material	3,63	5,34	561,21	185,35	5,40	0,19	
Facadepart 5.2	DESIGN door	1,16	1,37	486,11	267,08	4,58	0,73	
Facadepart 5.3	DESIGN suskast ventilation	0,68	0,48	24,59	23,92	0,25	2,07	
Facadepart 5.4	DESIGN outside window frame	0,78	0,59	311,81	598,86	2,67	1,70	
Facadepart 5.5	DESIGN inside window frame	0,76	0,44	197,34	379,00	1,69	2,27	210
Facadepart 5.6	DESIGN glass	3,00	1,60	1347,62	241,25	0,00	0,63	
Facadepart 5.7	DESIGN Stone material	0,58	5,22	196,13	33,07	1,44	0,19	
Facadepart 5.8 L.C.B.	DESIGN L.T.B. Closed balcony	1,04	5,17	37,54	77,36	2,83	0,19	
Facadepart 5.9 L.C.B.	DESIGN L.T.B. Stone material	2,93	5,22	649,88	168,13	7,32	0,19	
Facadepart 6.1	DESIGN closed balcony	5,58	5,17	1591,69	413,70	15,15	0,19	
Facadepart 6.2	DESIGN door	1,31	1,37	549,26	301,78	5,18	0,73	
Facadepart 6.3	DESIGN suskast ventilation	0,84	0,48	30,38	29,55	0,31	2,07	
Facadepart 6.4	DESIGN outside window frame	0,47	0,59	188,94	362,88	1,62	1,70	
Facadepart 6.5	DESIGN inside window frame	0,25	0,44	64,38	123,64	0,55	2,27	270
Facadepart 6.6	DESIGN glass	1,52	1,60	685,02	122,63	0,00	0,63	
Facadepart 6.7	DESIGN Stone material	1,39	5,22	473,84	79,88	3,48	0,19	
Facadepart 6.8 L.C.B	DESIGN L.T.B. Closed balcony	1,02	5,17	36,76	75,75	2,77	0,19	
Facadepart 6.9 L.C.B.	DESIGN L.T.B. Stone material	1,58	5,22	351,33	90,89	3,95	0,19	
SOUTH FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	DESIGN masonry	25,11	5,35	5650,08	498,46	53,88	0,19	0
Facadepart 8.2 L.C.B	DESIGN L.T.B. Stone material	6,54	5,22	1450,38	375,23	16,33	0,19	
ROOF		Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	DESIGN roof insulation + floor	84,00	7,57	36837,66	2857,19	186,56	0,13	0

Table G- 7: EPC input for Portaal's design for apartment type D4

Type D4	**WEST FAÇADE**	**Constructions**	Surface (m2)	Rcvalue m2K/W	U-value (W/m2.K)	Orientation	Obstruction	ZTA
	Facadepart 1.A	New Sandwich panel total 3	3,79	2,90	0,34	West	Minimal	
	Facadepart 1.B	New window total 3	1,97	0,54	1,85	West	Minimal	0,6
	Facadepart 1.C	New window sill 3	0,34	1,02	0,98	West	Minimal	
	Facadepart 2.A	New balcony cladding 3	2,12	2,84	0,35	West	Overhang	
	Façadepart 2.B	New door 3	1,08	1,42	0,70	West	Overhang	
	Facadepart 2.C	New suskast 3	0,23	0,48	2,07	West	Overhang	
	Facadepart 2.D	New window total 3	5,32	0,54	1,85	West	Overhang	0,6
	Facadepart 3.A	New plate material 3	2,94	3,18	0,31	West	Minimal	
	Facadepart 3.B	New window total 3	6,01	0,54	1,85	West	Minimal	0,6
	Facadepart 3.C	New suskast 3	0,94	0,81	1,23	West	Minimal	
	WEST BALCONY SIDE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
	Facadepart 4.A	New side balcony north	2,27	4,58	0,22	North	Overhang	
	Facadepart 4.B	New side balcony south	4,53	4,58	0,22	South	Overhang	
	EAST FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
	Facadepart 5.A	New plate material 3	2,94	3,18	0,31	East	Minimal	
	Facadepart 5.B	New window total 3	6,03	0,54	1,85	East	Minimal	0,6
	Facadepart 5.C	New suskast 3	0,83	0,78	1,28	East	MInimal	
	Facadepart 6.A	New balcony cladding 3	5,97	3,18	0,31	East	Minimal	
	Facadepart 6.B	New door 3	1,00	1,42	0,70	East	MInimal	
	Facadepart 6.C	New suskast 3	0,16	0,70	1,43	East	MInimal	
	Facadepart 6.D	New total window 3	1,15	0,54	1,85	East	MInimal	0,6
	Facadepart 6.E	Newthin insulation	1,76	2,01	0,50	East	Minimal	
	EAST BALCONY SIDES	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
	Facadepart 7.A	New side balcny	0,27	1,88	0,53	South	Minimal	
	SOUTH FAÇADE	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
	Facadepart 8.A	New masnry 3	25,31	2,48	0,40	South	Minimal	
	ROOF	**Constructions**	Surface (m2)	Rcvalue	U-value (W/m2	Orientation	Obstruction	ZTA
	Facadepart 9.A	New roof 3	77,04	2,90	0,34	-	Minimal	

Table G- 8: Excel output for apartment type D4 for Portaal's design, for calculation Embodied energy, Environmental and Building Costs

WEST FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)	Building costs (Euro)	Environmental costs (Euro)	U-value (W/m2.K)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 4	3,79	2,90	205,42	27,79	1,95	0,34	
Facadepart 1.2	New window sill 4	0,34	1,02	123,71	108,38	0,96	0,98	
Facadepart 1.3	New outside window frame 4	0,39	0,59	157,05	301,62	1,35	1,70	62
Facadepart 1.4	New inside window frame 4	0,19	0,41	44,76	85,97	0,38	2,41	
Facadepart 1.5	New glass 4	1,39	1,00	416,44	0,00	0,00	1,00	
Facadepart 2.1	New plate material 4	1,78	3,18	976,93	83,81	9,06	0,31	
Façadepart 2.2	New suskast ventilation 4	0,23	0,48	0,00	0,00	0,00	2,07	
Facadepart 2.3	New door 4	1,08	1,42	1063,45	433,20	8,49	0,70	277
Facadepart 2.4	New thick window frame 4	0,35	1,07	131,35	28,02	1,22	0,93	
Facadepart 2.5	New outside window frame 4	1,11	0,59	442,64	850,13	3,80	1,70	
Facadepart 2.6	New glass 4	4,22	1,00	1263,11	0,00	0,00	1,00	
Facadepart 3.1	New plate material 4	2,94	3,18	1618,32	138,83	15,01	0,31	
Facadepart 3.2	New suskast ventilation 4	0,42	0,48	0,00	0,00	0,00	2,07	
Facadepart 3.3	New thick window frame 4	0,53	1,07	200,12	42,69	1,86	0,93	315
Facadepart 3.4	New outside window frame 4	1,01	0,59	403,82	775,57	3,46	1,70	
Facadepart 3.5	New inside window frame 4	1,02	0,41	240,39	461,69	2,06	2,41	
Facadepart 3.6	New glass 4	3,98	1,00	1191,21	0,00	0,00	1,00	
WEST BALCONY SIDES	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 4.1	New side balcony 4	6,80	4,58	5969,20	374,57	15,88	0,22	323
EAST FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 5.1	New plate material 4	2,94	3,18	1618,32	138,83	15,01	0,31	
Facadepart 5.2	New suskast ventilation 4	0,41	0,48	0,00	0,00	0,00	2,07	
Facadepart 5.3	New thick window frame 4	0,42	1,07	159,87	34,10	1,49	0,93	315
Facadepart 5.4	New outside window frame 4	1,01	0,59	402,22	772,50	3,45	1,70	
Facadepart 5.5	New inside window frame 4	1,07	0,41	251,92	483,83	2,16	2,41	
Facadepart 5.6	New glass 4	3,96	1,00	1185,82	0,00	0,00	1,00	
Facadepart 6.1	New plate material 4	5,97	3,18	3284,49	281,77	30,45	0,31	
Facadepart 6.2	New thin insulation 4	1,76	2,01	71,58	9,69	0,68	0,50	
Facadepart 6.3	New suskast ventilation 4	0,10	0,48	0,00	0,00	0,00	2,07	
Facadepart 6.4	New thick window frame 4	0,06	1,07	23,01	4,91	0,21	0,93	270
Facadepart 6.5	New door 4	1,00	1,42	977,23	398,08	7,81	0,70	
Facadepart 6.6	New outside window frame 4	0,36	0,59	145,04	278,56	1,24	1,70	
Facadepart 6.7	New glass 4	0,79	1,00	236,47	0,00	0,00	1,00	
EAST SIDE WALL	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 7.1	New loadbearing wall + inside insul. 4	0,27	1,88	26,54	2,04	0,25	0,53	105
SOUTH FAÇADE	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 8.1	New masonry 4	25,31	2,48	1114,45	150,79	10,56	0,40	0
ROOF	**Construction**	Surface (m2)	Rcvalue	Embodied Energy (MJ)			U-value (W/m2.K)	E.E. removal old
Facadepart 9.1	New roof insulation + floor 4	77,04	2,90	11257,46	873,14	57,01	0,34	0
Linear cold bridges		Surface (m2)		Embodied Energy (MJ)				E.E. removal old
Linear cold bridge west 1	New linear cold bridge concrete 4	3,75		3218,53	196,90	8,09		
Linear cold bridge west 2	New linear cold bridge concrete 4	2,473		2124,78	129,99	5,34		
Linear cold bridge west 3	New linear cold bridge concrete 4	4,8		4124,12	252,30	10,37		
Linear cold bridge east 5	New linear cold bridge concrete 4	3,43		2947,03	180,29	7,41		
Linear cold bridge east 6	New linear cold bridge concrete 4	4,24		3642,97	222,87	9,16		2775
Linear cold bridge south concr 8	New linear cold bridge concrete 4	2,675		2298,34	140,60	5,78		
Linear cold bridge south masonry 8	New linear cold bridge masonry 4	2,675		117,80	15,94	1,12		
New balcony 6	New linear cold bridge balcony constr4	0,7114		0,00	0,00	0,00		
Linear cold bridge roof 9	New linear cold bridge roof 4	8,2		1198,19	92,93	6,07		
Linear cold bridge balcony insulation 4	New linear cold bridge balcony insul 4	4,76		869,42	67,43	4,40		

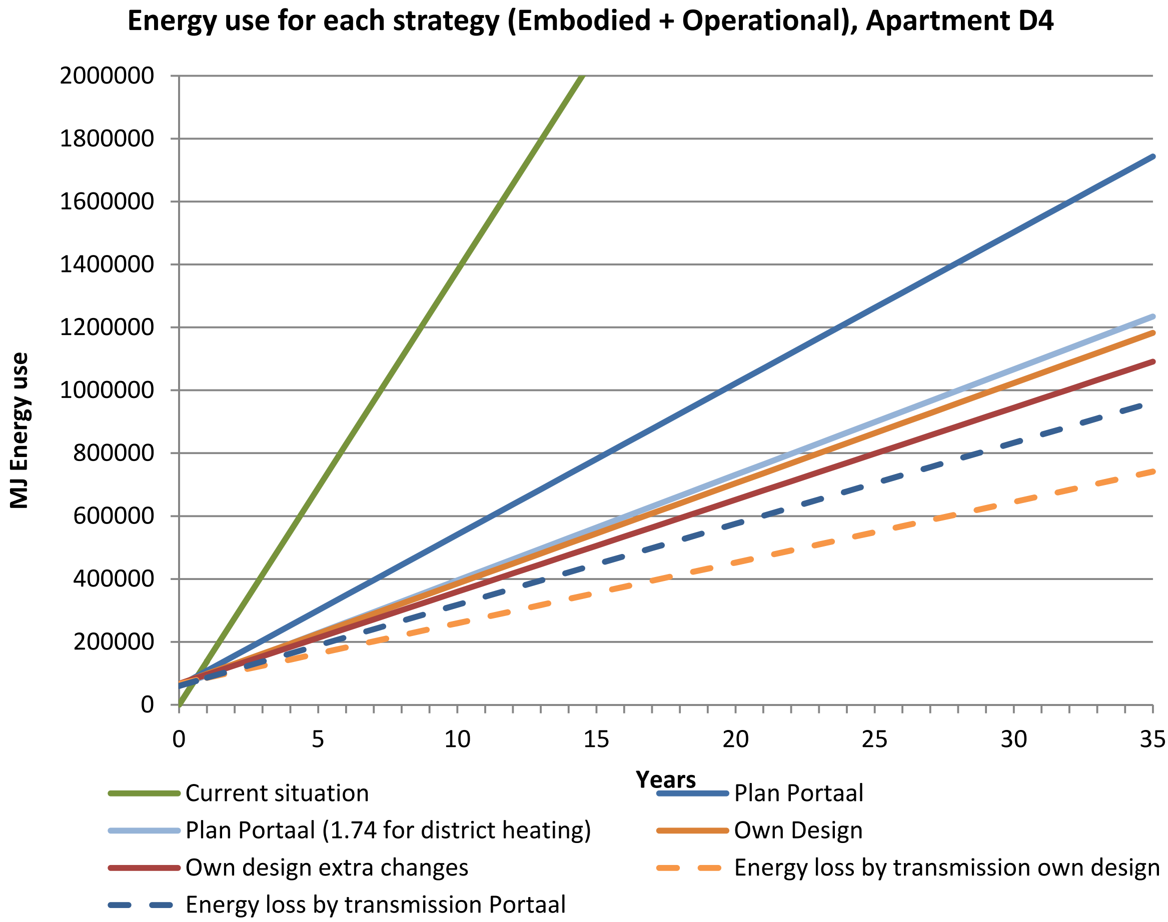


Figure G- 10: Embodied energy + Operation energy use for different situations, for top right apartment (D4)