Zero Energy Building Refurbishment & Energy Neutral Urban Clusters in Haarlem

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Zero Energy Building Refurbishment & Energy Neutral Urban Clusters in Haarlem

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Preface

This thesis is the final part of the building technology master within the faculty of Architecture at Delft University of Technology. This research covers the last 9 months of my master studies and values as the graduation work from the masters.

The focus of the research had been to successfully refurbish a row house in Ramplaankwartier, Haarlem to deliver annual Zero Energy Balance, while sustaining or improving the comfort conditions of the people within the building and to apply the obtained strategy to a cluster of buildings to elaborate on the possible advantages and disadvantages. The research is integrated to Smart Urban Isles project on going in Haarlem Ramplaankwartier to create energy responsive neighborhoods, which produce energy and consume less to balance or surpass the energy import & export deficit of the buildings in the cluster.

Throughout the thesis progress I have interacted with physical condition of building envelope, refurbishment strategies for façade sections, building services, ventilation systems and provisions, user patterns in dwellings, heating, cooling, human comfort in space and energy generation on building scale. All the steps measures used have increased my understanding on the complexity of refurbishing existing buildings to achieve zero energy balance.

I would like to thank my mentors *Regina M. J. Bokel* and *Thaleia Konstantinou* for their support and guidance through the graduation process and most importantly for not holding out from pointing out my weaknesses in certain aspects.

Above all else, I am most grateful for the support of my mother under all conditions as well as giving me the opportunity to follow my aims in obtaining further knowledge on things that really matter.

Faik Nebil Balkuv

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Abstract

In recent years the world is becoming more aware on the burden of the fossil fuels on the planets ecosystem as well as climate. One of the major reasons is, due to greenhouse gasses in which most of them are caused by carbon release by consumption of fossil fuels. The building sector in almost every country is a major contributor to the consumption of carbon-based fuels either for space conditioning, water heating or for electricity.

Operational energy in buildings must be lowered by bold measures to a point or the building should generate as equal as renewable energy as they consume. However it is not realistic to match the consumed energy if the building does not go through an energy refurbishment to reduce operational energy consumption. Refurbishment of ill performing building gives an advantage on not only reducing the operational energy consumption but also user comfort could be increased in the building.

Refurbishment in the report is integrated with the SUI project, which aims to create zero energy neighborhoods in Ramplaankwartier, Haarlem. The building to be refurbished is selected accordingly f and natural gas usage is aimed to be eliminated while annual energy balance is sustained in the building.

The report starts with a thorough literature research on four different topics. First of the topics is zero energy building definitions globally defined along with most commonly used zero energy building definitions in the Netherlands to highlight the important aspects in defining a zero energy design approach. Second topic is refurbishment strategies for the building envelope regarding different applications and scales are checked to determine viable options.

Third one is the regulations for refurbishment applications, necessary thermal performance values in the refurbishment buildings and the necessary comfort conditions in the buildings. Lastly the final topic is a to check refurbishment examples on row-houses in the Netherlands to highlight possible measures of refurbishments, their application and detailing, impact on residents and consumed energy reduction.

Case study design is based on achieving annual zero energy balance in case study building. Application of refurbishment strategies for the building envelope is divided into two for increasing the varieties of measures later on these measures are given detail on how they could be executed in real life.

The case study measures aim to influence the building envelope composition such as Insulation levels, glazing thermal performance with passive solar gain and the infiltration rate of the building skin. Comfort in primary spaces will be tinkered to achieve necessary user comfort requirements in dwellings, while ventilation system is determined along with comfort provision in space.

After comfort measures are applied, building services will be evaluated to systems will be switched to full electricity to eliminate natural gas usage for space heating and domestic heated water. With the lowered energy consumption, energy generation on site will be utilized to create annual balance for the building to achieve zero energy building criteria's.

Eventually all the refurbishment and energy generation measures will be applied to neighboring buildings to evaluate the advantages of application of energy generation in combination with the other refurbished buildings rather than individual generation. Effects of individual and group application of energy generation measures will be compared to determine advantages of each approach.

It is possible to use different measures for energy refurbishment to reduce space and heating energy and possibly energy on lighting itself. Usage of higher insulation values, better glazing, lower infiltration is always an option in building refurbishments however it all comes to the application of the theoretical measures accepted through calibration and the execution of these accepted measures is important to deliver accurate conditions in the refurbished buildings.

Different energy generation methods can be applied besides PV panels. Integration of wind energy for electrical building systems can be interesting. Totally integrated building services and on-site generation system with wood pellets and boiler system for individual or larger scale to provide zero energy balance for a group of buildings in a constant period of time. Energy storage for photovoltaic options could be used to eliminate seasonal energy mismatch for operational energy in a large scale for the neighborhood or for individual purposes with batteries.

Table of Content

1.0 Introduction 11
1.1 Research Question 12
1.1.1 Research Sub Questions 12
1.1.2 Literature Sub-Questions 12
1.2 Boundary Conditions 12
1.3 Research Methodology 12
2.0 Literature Study 17
2.1 Zero Energy Buildings 17
2.1.1 Introduction 17
2.1.2 Global Overview of Zero Energy Definitions 18
2.1.2.1 Boundary Conditions of Zero Energy Buildings 18
2.1.2.2 Different Zero Energy Metrics 19
2.1.2.3 Elements in Zero Energy Balance & Balancing Period 21
2.1.2.4 Prescriptive or Performance Method 21
2.1.2.5 Energy Production 22
2.1.3 Most Commonly Used Zero Energy Building Definitions in the Netherlands 23
2.1.3.1 Energie Prestatie Coëfficient (EPC) &Energie Maatregelen op Gebied (EMG) 24
2.1.3.2 Leadership in Energy and Environmental Design (LEED) 26
2.1.3.3 BREEAM 27
2.1.3.4 Nul op de Meter 30
2.1.3.5 Passive House 30
2.1.4 Conclusion 30
2.1.4.1 Zero Energy Definition for the Research 33
2.2 Zero Energy Design 34
2.2.1 The New Stepped Strategy 34
2.3 Refurbishment 35
2.3.1 Introduction 35
2.3.2 Different Levels of Refurbishment 36
2.3.3 Envelope Refurbishment Strategies 37
2.3.4 Conclusion on Envelope Refurbishment Strategies 37
2.3.5 Certain Measures in Building Refurbishment 38
2.3.6 Selected Refurbishment Strategies 39
2.3.7 Refurbishment Regulations in the Netherlands 40
2.3.8 Energy Conversion Rates in the Netherlands 42
2.4 Indoor Comfort 42
2.4.1 Indoor Environmental Comfort in the Built Environment 42
2.4.2 Thermal Comfort 44
2.4.3 Indoor Air Quality & Ventilation 45
2.4.4 Acoustical Comfort 45
2.4.5 Daylight 46
2.5 Refurbishment Examples 47
2.5.1 Kroeven Roosendaal 47
2.5.2 Nul op de Meter Renovation Melick, Limburg 49
2.5.3 Hof van Egmond Slacthuisbuurt, Haarlem 50
2.5.4 Poorters van Moonfoort, Woerden 51
2.5.5 Menno Simoszhof Melick, Hilversum 52
2.5.6 Conclusion 54
2.6 General Conclusion on Literature Study 55

3.0 Approach 57
3.1 Design Approach 57
4.0 Case Study Analysis & Model Validation 59
4.1 Context 59
4.1.1 Building(s) Information 59
4.1.2 Building Space 60
4.1.3 Building Elevation & Section 62
4.2 Energy Performance 63
4.2.1 Building Envelope 64
4.2.2 Building Services 67
4.3 Simulation Model Validation 68
4.3.1 DesignBuilder 68
4.3.2 Location & Climate & Building Model 69
4.3.3 Technical Specifications 70
4.3.4 Zone Activity & HVAC & Lighting 72
4.3.5 Validation Conclusion 74
5.0 Passive Measures for Refurbishment 77
5.1 Building Envelope & Insulation 77
5.1.1 Refurbishment-1 | Insulation & Building Envelope 78
5.1.2 Refurbishment-2 | Insulation & Building Envelope 81
5.1.3 Insulation Results & Conclusion 84
5.2 Glazing Type & Window Composition 86
5.2.1 Glazing & Openings Simulations 87
5.2.2 Glazing Simulations Conclusion 89
5.3 Infiltration & Airtightness 92
5.3.1 Infiltration Rate Calculations & Conversions 92
5.3.2 Infiltration Simulations 93
5.3.3 Conclusion 95
6.0 Zone Based Comfort Optimization 98
6.1 Refurbishment-1 Comfort Optimization 98
6.1.1 Heating Optimization of Refurbishment-1 | Winter Season 98
6.1.2 Overheating Optimization of Refurbishemnt-1 | Summer Season 106
6.1.3 Ventilation System of Refurbishment-1 108
6.1.4 Comfort Optimization Conclusion 109
6.2 Refurbishment-2 Comfort Optimization 110
6.2.1 Heating Optimization of Refurbishment-2 | Winter Season 110
6.2.2 Overheating Optimization of Refurbishment-2 | Summer Season 117
6.2.3 Ventilation System of Refurbishment-2 125
6.2.3.1 Mechanical Ventilation Sizing 127
6.2.3.2 Extensive Ventilation 130
6.2.4 Comfort Optimization Conclusion 133
6.3 Energy Consumption of Optimized Refurbishment Strategies 134
7.0 Building Services 136
7.1 Application of Building Services 136
7.2 Conclusion on Building Services 137
8.0 Energy Balance 139
8.1 Annual Balance for Zero Energy Refurbishment 139
8.1.1 Photovoltaic Panel Options 140
8.1.2 Annual Balance Energy Output 141
8.1.3 Photovoltaic Panel Sizing & Application 142

8.1.4 Annual Balance Conclusion 147
8.2 Cluster Application **144**
8.2.1 Cluster Application Calculations & Sizing 145
9.0 Final Design **147**
9.1 Refurbishment-1 **147**
9.2 Refurbishment-2 **154**
9.3 Final Design Conclusion **161**
10.0 Conclusions & Recommendations & Reflection **164**
10.1 Conclusions **164**
10.2 Recommendations **167**
10.3 Future Research **168**
10.3 Reflection **169**
11.0 References **171**
12.0 Appendices **175**
Appendix A 175
Appendix B 176
Appendix C 177
Appendix D *179*
Appendix E 188

List of Abbreviations

Abbreviation	Explanation
DD	Design Days
DHW	Domestic Heated Water
ZEB	Zero Energy Building
PV	Photovoltaic Panel
Ref-1	Refurbishment-1
Ref-2	Refurbishment-2

Table 0: Explanation of Abbreviation

1.0 Introduction

The climate change has become a reality and is the most important problem of the 21st century to be tackled. Based on conducted research throughout the decade, Climate change has been expected for now and for the future. Main reasons behind climate change have been highlighted as CO_2 emissions based on fossil fuel consumptions. The Netherland's energy mix is dominated by fossil fuels, which represent more than 90% of TPES (IEA, 2014). CO_2 emissions by fossil fuels are causing climate change as well as resource depletion, however even resource depletion threat is not slowing down fossil fuel consumption habits and energy transition to renewable energy is becoming a necessity for tackling climate change problems. Energy transition plans on the horizon for European countries Netherlands also have to play their part in tackling European ambitions for reducing green house gasses (GHG) in the atmosphere.

In 2012, commercial and residential sectors represented 19.9% and 16.9% of total final consumption (TFC), respectively. Natural gas is the main source of energy in both sectors combined (63.7%), as almost all households and commercial buildings use gas for heating, followed by electricity (26.8%) and heat (4.8%) (IEA, 2014). Resulting in heavy fossil fuel consumption and CO_2 release in built environment to generate living conditions for the people. However, 90% of the building stock existing today (2016) will still exist by 2050. The European government leaders in the European Council set a target of greenhouse gas emissions in the EU by 2050, 80 to 95% lower than in 1990 (Klimaatbrief 2050, 2011). In order to comply with the European ambitions, transition to renewable energy generation or preservation of the generated energy must be prioritized and energy refurbishment of 150.000 buildings a year has to be completed.

In order to reduce energy consumption in the first place it is necessary to renovate dwellings energy efficiently or in energy neutral ways while increasing the renewable energy shares. There are certain pathways for renovation based on shallow and deep approaches. However reduction of energy is never enough and buildings must generate their own renewable energy to compensate for the remaining energy consumption, while increasing their share in total renewable energy percentage.

Refurbishment is a necessity for poorly performing buildings but not only for energy consumption reduction purposes. 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, 2009). Eventually refurbishment can equally focus on comfort and energy. Resulting in multiple improvements by single intervention. Helping with physical and physiological condition of people and the buildings.

While most of the efforts are focusing on only retrofitting the building typologies and generating electricity on the rooftops or on the footprint of the building, energy generation potentials of the surroundings of the buildings are neglected for achieving actual Energy Neutral buildings as a cluster. Considering that the Netherlands has to reach 14% renewable energy sources in 2020 and 23% in 2023 from 6% in 2012, it is important to consider energy neutral urban clusters to reach expectations consistently. Therefore `on-site` must be redefined in order to compensate for a total solution on energy neutrality of buildings in a cluster where all of the buildings are offered optimal chances of energy generation and energy storage regardless of their geo-location, sun exposure of their roofs or their limited spaces in privately defined borders. Eventually reducing unchangeable parameters in refurbishment designs for renewable energy sources to minimum, as well as reducing the inevitable extra electricity load on national grids caused by privately owned photovoltaic panels.

1.1 Research Question:

What are possible refurbishment solutions for a cluster of Dutch row houses in Haarlem, Ramplaankwartier built before 1945 to achieve annual energy neutrality including energy generation and energy exchange within the selected cluster?

1.1.1 Research Sub-Questions:

- How to refurbish a Dutch terraced house into energy neutral building, focusing on optimal indoor environmental comfort with passive and active refurbishment measures, following the new stepped strategy?
- How to apply the refurbishment strategy to a cluster of terraced houses to achieve annual energy neutrality in buildings based on on-site renewable energy potentials in Haarlem?

1.1.2 Literature Sub-Questions:

On Zero Energy Building:

- What is a ZEB building and how is it defined?
- What are the most common Zero Energy Definitions in use in the Netherlands?
- Which calculable on-site solutions are considered for energy generation?

On Refurbishment:

- Why Refurbishment is required and how is it defined?
- What are the envelope refurbishment strategies for energy reduction?
- Which refurbishment measures can be adopted and optimized in order to reduce energy consumption in a building?
- What are the existing retrofit measures for Dutch terraced houses and what are their shortcomings and advantages?

On Energy and Comfort:

- What are the necessary Indoor Environmental Comfort (IEQ) requirements in a Dutch Dwelling based on the type of living spaces?
- What are the energy performance requirements of building services and building envelope in the Netherlands for building refurbishment?
- How to determine optimum levels for comfort requirements?

On On-Site Energy Generation:

- What are the on-site renewable energy potentials for energy generation and storage in Haarlem?
- How can on-site potentials be applied to a refurbishment project cluster as the final step for energy neutrality?

1.2 Boundary Conditions:

The research will be based on the following aspects:

- Refurbishment will be conducted over a cluster of buildings with same typology and context within Ramplaankwartier, Haarlem.
- Refurbishment will be developed and optimized based on energy efficiency and comfort regulations over a single building and will be applied to the rest of the buildings.
- Design will be focusing on passive measures on building scale and active measures on building and neighborhood scale.
- On-site energy solution will be influential for the whole cluster based on heating and electricity as well as energy storage, however instead of collective solutions, auxiliary individual solutions can be implemented regarding design choices.
- Daily energy balances will be conducted over extreme days for a dwelling.

- Energy, thermal and daylight optimization will be made over Design Builder. Daily and yearly balance will be calculated by hand and excel software.
- Hand calculations will be used for acoustical calculations of building envelopes, depending on their layering based on refurbishment strategy.

1.3 Research Methodology

Research methodology, defines the process of how research questions will be answered and how design will reach intended goals in given time period. There are three sequential research phases following the introduction of the thesis. Introduction of the paper describes intentions, problem statement, research questions and research goals to be reached. These sequential research phases are:

- Literature Research
- Case Study Design
- Conclusion & Elaboration

The process in general resembles the design approach of the research. Considering that design decisions rely upon technical input gathered from extensive research on certain variables. Research is in with requirements, goals, design and simulations in a consistent relation of defined design steps further on in this chapter. Diagram for methodology and time plan are given in *figure 1-0.*

First topic of the literature study is zero energy building design definitions available globally and the ones mostly used in the Netherlands. Necessary parameters of defining zero energy design are discussed along with types of metric; periods of balance and energy efficiency measures for different types of approaches are evaluated.

Hereafter, a conclusion is settled on the zero energy design definition of the thesis with necessary framework steps. Additional site studies will be conducted during case study design on on-site renewable energy potentials to balance energy consumption with generation and storage. Zero energy design strategies are evaluated such as the New Stepped Strategy, which is integrated to the case study design for achieving energy efficient refurbishment and eventually energy neutral.

Second topic is about refurbishment of row houses, possibilities, strategies and design variables in refurbishments & examples in the Netherlands. Different levels of refurbishments will be discussed depending on their scale of intervention on the building. Possible refurbishment strategies for the buildings' envelope will be researched and defined regarding applicability, intervention scale and the outcome of first phase of literature study.

Several existing refurbishment projects in the Netherlands will be assessed for passive and active measure applications, refurbishment scales, strategies, energy efficiencies and design variables. These design variables are further defined in case study design and how they will be used as design parameters.

Third topic of literature study is focusing on the necessary indoor environmental comfort levels in a dwelling. Levels of comfort enforced by national standards are researched for setting requirements in a dwelling as design parameters. Thermal, acoustic, daylight comfort and indoor air quality of the dwellings are assessed regarding required values set by Dutch government for refurbishment projects.

Literature study is to use conclusions from each research topic to form the design goals, requirements in dwellings and certain strategies that will be followed in order to reach specific sub goals and the main goal of annual and daily energy balance in a row house cluster.

Case study design is specifically on a row house previously provided via the smart urban isles project in Ramplaankwartier, Haarlem. Within the case study chapter energy neutral upgrade is to achieve will be concluded over the approach developed from the conducted literature study upon refurbishment strategies, zero energy definitions and design, applications for reducing energy consumption in real life refurbishment strategies and possible energy generation options.

Case study design chapters are divided to specific research topics with individual criteria's for evaluation. All conclusions within separated chapters create the final design *(chapter 9.0)* of refurbishments, which would reach Zero Energy Balance with refurbishment. In addition to zero energy refurbishment within the case study design, user comfort will be evaluated and optimal conditions will be satisfied for the users of the building.

Throughout the case study research two different refurbishment strategies will be developed for the building envelope as well as for certain building services components. It is aimed to achieve similar conditions of operational energy reduction, optimal comfort levels and energy generation to create variety of applications for the same building in which these measures are compared for their advantages or disadvantages regarding certain criteria's. This way it is possible to highlight the value of intervention per measure included in the path for energy neutral building.

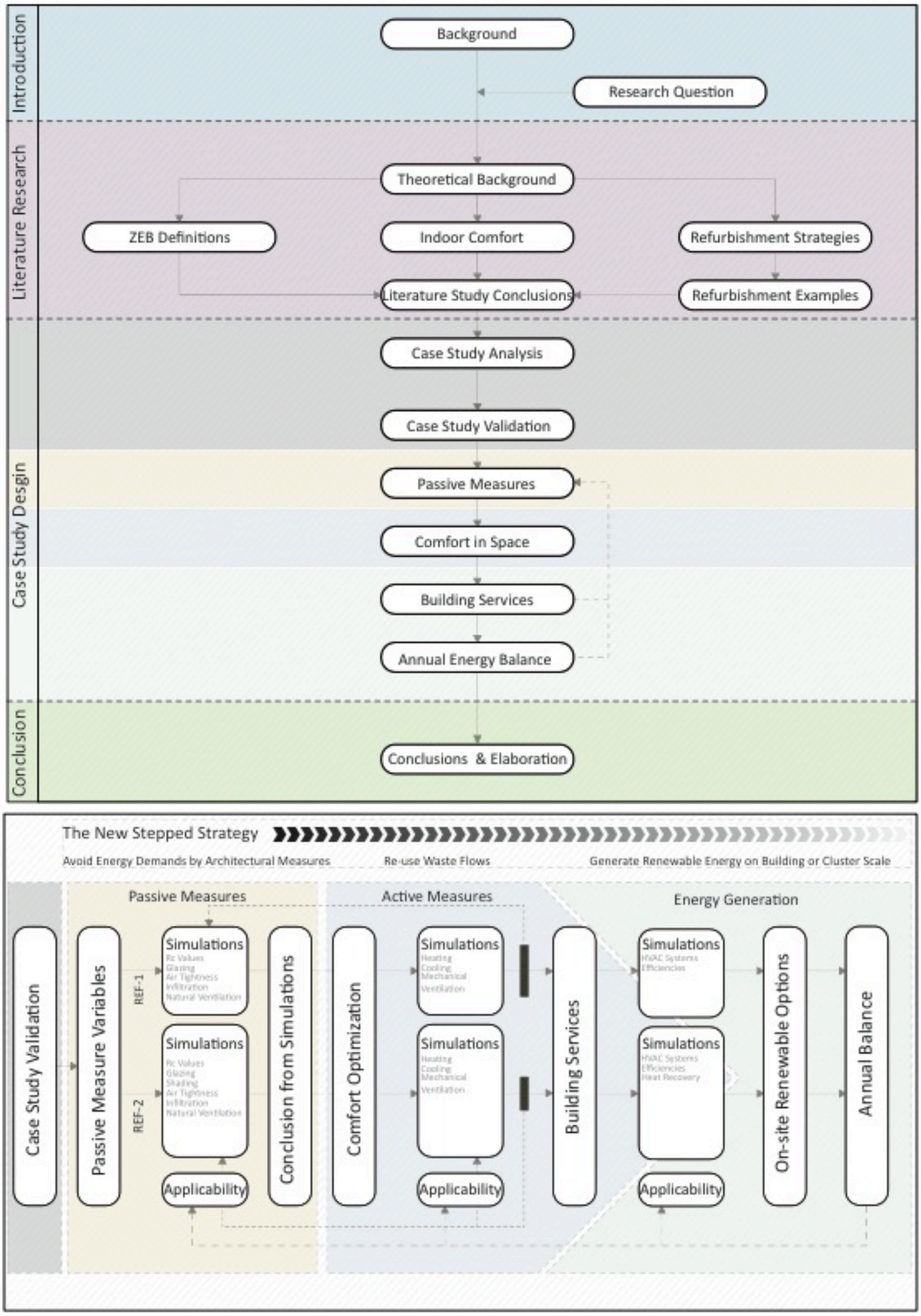


Figure 1-0: Research methodology and integration of the New Stepped Strategy into the research.

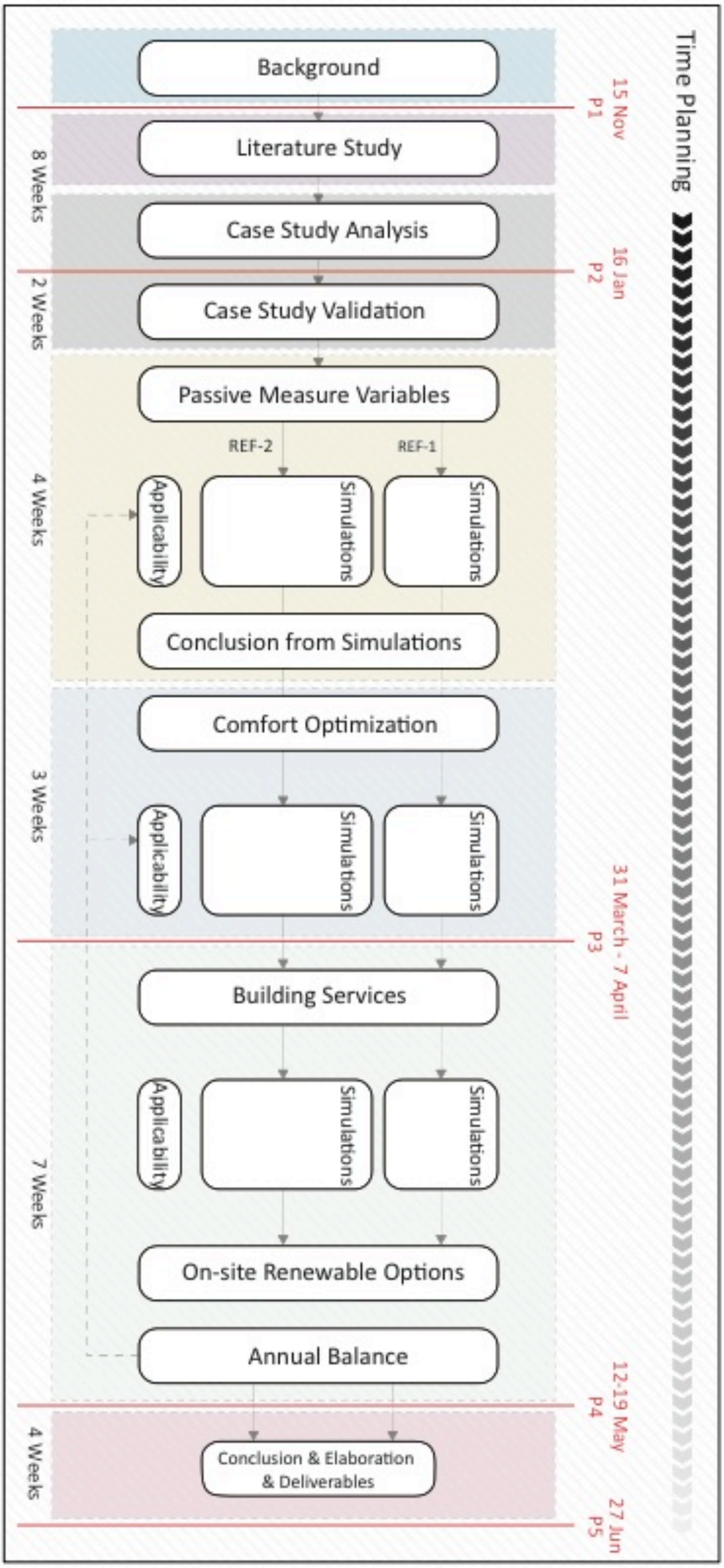


Figure 1-1: Estimated time schedule for the research.

2.Literature Study

2.1. Zero Energy Buildings

In this chapter of the literature study, questions: ***What possible energy demand reduction definitions are available? & What is a ZEB building and how is it defined?*** will be clarified. Aiming to reveal different definitions for zero energy building concepts, create a framework and to highlight necessary parameters for Zero Energy Buildings.

2.1.1 Introduction

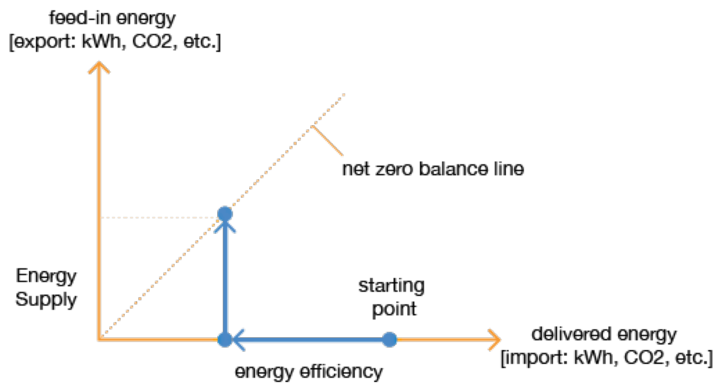


Figure 2-0: Zero Energy Building Balance

There are two different definitions to Zero Energy Buildings, one being Net Zero Energy (ZEB/NET ZEB) and other being Nearly Zero Energy (nZEB), where they can all be included to ZEB definition. In concept, a net ZEB is a building with greatly reduced energy needs through efficiency gains such that, the balance of the energy needs can be supplied by renewable technologies. (Torcellini, Pless, & Deru, 2006). However, the term ZEB is used commercially without a clear understanding and countries are enacting policies and national targets based on the concept without a clear definition in place. (Satori, et al., 2010). The EPBD, for example, states that "nearly zero energy building means a building that has a very high energy performance" and that "The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby". (Satori, et al., 2010) Lack of clearly defined standards are influential on the critical design decisions and increases the possible solution measures as well as gives flexibility to designer to define their own framework for reaching `zero` or `nearly zero` energy.

Conceptually, it is understood that a Net ZEB is a building with greatly reduced energy demand that can be balanced by an equivalent on-site generation of electricity, or other energy carriers, from renewable sources. (Satori, et al., 2010). The approach to problems should always be based on possible reduction of energy consumption before advancing to how to generate necessary energy, since always easier to reduce energy consumption. Therefore a ZEB should be as energy efficient as possible and it should match or surpass the reduced delivered energy with renewable energy solutions. However a ZEB should only surpass delivered energy under one condition which is, without putting extra stress to national grid in order to avoid triggering nationwide infrastructure upgrade. Reduction of energy can be made over passive and active measures based on refurbishment strategy, comfort regulations or aspects taken into account as design parameters. Refurbishment strategies with active and passive measures are further discussed on *chapter 2.3.3 Envelope refurbishment strategies.*

The net zero definition requires a medium for exchange to happen, in regard to the necessity of exchange, net zero balance is only possible, if the building is connected to the energy infrastructure. To this respect the term Net ZEB can be used to refer to buildings that are connected to the energy infrastructure, while the term ZEB is more general and may include as well autonomous buildings (Satori, et al., 2010). The zero energy balance over the energy grid is accepted as a necessity due to energy mismatch caused by different seasonal demands and energy generation potentials. Most of the times energy is balanced yearly, it is also possible to create daily balances however, energy generation measures necessary for daily balance is drastically different compared to yearly balance as well as daily balanced buildings will become autonomous. It is possible to create autonomous buildings; however achieving a ZEB without the grid would be very difficult, as the current generation of storage technologies is limited (Torcellini, Pless, & Deru, 2006).

The energy grid is necessary for addressing balance between energy carriers imported and exported such as: electricity, heating, cooling, gas pipes, biomass, and biofuels to PV systems or other preferred on site renewable energy options. However most of the ZEB applications prefer PV systems for matching the demand because, it's an individual solution with better efficiency in energy/m^2 though it is highly dependent on solar irradiation, orientation and seasonal climate values.

A building or a cluster of buildings, depending on where the system boundary is put, is characterized by a certain load, but also by some sort of energy generation in case of Net ZEB. (Satori, et al., 2010). A balance between building load and generated energy is a must and has to be tackled. Load in the building includes technical installation efficiency and net energy demand. The generation includes storage and conversional losses. There are differences in the types of energy carriers and it must be addressed before a balance could be set a crediting system converts the physical units into other metrics, e.g. primary energy or equivalent carbon emission, in order to evaluate the effect of the entire energy chain, including the properties of the natural sources, the conversion processes and the distribution grids. (Satori, et al., 2010)

$$\text{Net ZEB: } |\ export\ | - |\ import\ | \geq 0$$

With;

$$import = \textstyle\sum_i delivered\ energy(i)\ x\ credits(i)\ \text{X}\ \Delta\ \text{time}$$
$$export = \textstyle\sum_i feed\ in\ energy(i)\ x\ credits(i)\ \text{X}\ \Delta\ \text{time}$$

Where `Δ time`= hourly, seasonal, monthly, yearly
Where `$i$` = energy carriers

2.1.2 Global Overview of Zero Energy Definitions

A zero energy building can be defined in several ways, depending on the boundary and the metric. (Torcellini, Pless, & Deru, 2006). However ZEB definitions only based on boundary and metric are generic approaches, for a healthier ZEB definition certain criteria's must be defined regarding the scope of ZEB project and aims. According to (Satori, et al., 2010) a ZEB can be defined in a framework for describing relevant characteristics, so that a ZEB definition should be fine-tailored not picked. This way evaluation of the criteria and selection of the related options becomes a methodology for elaborating sound Net ZEB definitions in a formal, systematic and comprehensive way (Satori, et al., 2010).

2.1.2.1 Boundary Conditions of Zero Energy Buildings

Boundary conditions of a ZEB are the context of the intervened building, its location, usage, typology and the scale and scope of intervention. For zero energy refurbishment, depth of refurbishment must be addressed. The amount of buildings has to be defined regarding the site boundary of the cluster in which on-site renewable potentials are influential. The middle row house in Ramplaankwartier district is used as a three-story dwelling.

Climate information of the intervention area is necessary for design strategies as well as the influence over energy consumption and type of energy consumed. To calculate and prove is the building net zero energy or is it nearly ZEB, the criteria has to be established, what could be different in each country, bringing own rules concerning local climate, technology level, commercial conditions etc. (Todorovic, 2011). However a buildings energy use is not only influenced by climate but user comfort and user related loads as well.

User comfort conditions are important since they influence the energy demand of the buildings as well as building services and envelope, depending on the retrofit strategy followed. However, in the ZEB definitions the topic of indoor environment quality is almost fully neglected, though it is an important issue (Marszal & Heiselberg, 2011). Most of the times projects comply with necessary requirements unaware after refurbishment. Not only comfort information is important for thermal performance of the building but also for later stage measurements to see if the building is in correlation with national defined standards based on physical comfort requirements. In the Netherlands comfort regulations of the built environment are defined in **NEN-EN 15251.**

2.1.2.2 Different Zero Energy Metrics

Credit metrics are influential over the type of ZEB directly, which is affecting the type of renewable energy source on-site and scale of measures taken on the way to design a ZEB. For example, how the choice would affect the required PV installed capacity. (Satori, et al., 2010). Based on most commonly defined credit metrics, generic definition of the ZEBs over metrics are:

- **Site ZEB** :(end-use energy) Where end use of energy is matched with on-site energy generation.

Import Energy ≤ Export Energy

- **Source ZEB** :(Primary energy) Compensates for the energy losses in transition between imported and exported energy carriers. Ex: Coal to electricity Source to site balance of energy quality. (Candanedo, et al., 2010)

*Import Energy*Conversional Multipliers ≤ Export Energy*Conversional Multipliers*

- **Cost ZEB** :(Cost coverage for reduced, neutralized energy bill) Imported energy cost is equal or lower compared to exported energy cost.

Utility Cost Imported ≤ Utility Cost Exported

- **Emissions ZEB** :(CO_2 based | amount of CO2 based energy imported has to be matched with CO_2 free energy on-site)

$|Exported\ Energy\ CO_2| - |Imported\ Energy\ CO_2| \geq 0$

DEFINITION	PLUSSES	MINUSSES	OTHER ISSUES
Site ZEB	- Easy to implement. - Verifiable through on-site measurements. - Conservative approach to achieving ZEB. - No externalities affect performance, can track success over time. - Easy for the building community to understand and communicate. - Encourages energy-efficient building designs	- Requires more PV export to offset natural gas. - Does not consider all utility costs (can have a low load factor). - Not able to equate fuel types. - Does not account for nonenergy differences between fuel types (supply availability, pollution).	
Source ZEB	- Able to equate energy value of fuel types used at the site.	- Does not account for nonenergy differences between fuel types	- Need to develop site- to-source conversion factors, which require

	- Better model for impact on national energy system. - Easier ZEB to reach.	(supply availability, pollution). - Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates). - Source energy use accounting and fuel switching can have a larger impact than efficiency technologies. - Does not consider all energy costs (can have a low load factor).	significant amounts of information to define.
Cost ZEB	- Easy to implement and measure. - Market forces result in a good balance between fuel types. - Allows for demand-responsive control. - Verifiable from utility bills	- May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid. - Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges. - Highly volatile energy rates make for difficult tracking over time.	- Offsetting monthly service and infrastructure charges require going beyond ZEB. - Net metering is not well established; often with capacity limits and at buyback rates lower than retail rates.
Emissions ZEB	- Better model for green power. - Accounts for nonenergy differences between fuel types (pollution, greenhouse gases). - Easier ZEB to reach.		

Table 2-0: Pros & Cons of ZEB's based on their credit metrics **(Torcellini, Pless, & Deru, 2006)**

Choices upon credit system can be made regarding pros and cons on given metric types as well as the design parameters previously defined for ex: size limitation, on-site definition, availability. It must be stated that different ZEB metrics make a reasonable difference on the design outcome of the building since metrics influence the amount of energy considered in the building. It's important to realize the differences they create on the final design and calculations. Difference in outcome can be seen in table 2.

Building and PV System (DC Rating Size)	Site Energy Use (w/o PV) (MWh/yr)	Source Energy Use (w/o PV) (MWh/yr)	Actual Roof Area (footprint) (ft^2)	Flat Roof Area (ft^2) Needed for Source ZEB and Site ZEB with PV	PV System DC Size Needed for Source ZEB and Site ZEB
CBF-4.2 kW	365.2	1,142.0	15,500	25,316 Source ZEB 25,640 Site ZEB	282 kW Source ZEB 286 kW Site ZEB
TTF-No PV	83.5	192.5	10,000	4,010 Source ZEB 5,550 Site ZEB	45 kW Source ZEB 62 kW Site ZEB
BigHorn-8.9 kW	490.4	901.0	38,923	18,449 Source ZEB 31,742 Site ZEB	206 KW Source ZEB 354 kW Site ZEB

Table 1-1: Comparison of Different projects with different ZEB approaches **(Torcellini, Pless, & Deru, 2006)**

Site and source energy are different from each other even though energy efficiency measures are the same for each metric type. Source energy imported to building is higher due to compensation and addition of losses and conversional rates of processes until the primary energy becomes end-use energy. However site energy is only taking end-use energy into account therefore has a lower value. This is also influential on the energy required to offset imported energy, PV area needed to match site ZEB is higher than Source ZEB because conversional rate of solar energy compensates for the source energy much more efficiently, while site ZEB has to match everything on 1 to 1 basis to create the balance.

Primary energy as a metric is influential over energy types used in the balance, primary energy is compensating for conversional losses from primary to secondary to final-use energy as well as delivery losses on the grid. Primary energy is giving more flexibility for energy balance between different energy types (fuel switching), possible solutions and a better metric for collective approaches in creating ZEB clusters.

2.1.2.3 Elements in Zero Energy Balance & Balancing Period

It is crucial to define the consumption side of the equation in a dwelling, based on user and building related loads. Typical loads included in the equations are mostly building related loads such as, Cooling/Heating, ventilation and auxiliary energy. While, user related loads are explained as, domestic hot water, lighting, plug loads and cooking and may be in the future electric vehicles and anything that have significant impact on energy consumption. However, many studies focus only on one demand neglecting the other (Marszal & Heiselberg, 2011). Elements of balance are not only based on directly building or user related energy usage, as indicated by (Satori, et al., 2010) as long as the interaction with the energy results in positive environmental impact, these loads can be included in the equation as well.

Imported energy has to be balanced with on or off-site generated renewable energy, however there has to be a period of time when the balance has to occur. These balancing periods can be annual, seasonal, monthly and daily. Among all four of different time periods, annual balance is the most commonly used due to the fact that its easier and more convenient to create yearly balance to compensate for the energy mismatch considering most of the energy production measures include PV panels for individual solutions. Daily balance is the hardest to achieve considering that daily energy use has to be matched with on-site renewable options, however to create a daily balance for an individual building is not feasible and realistic considering the daily peak loads, season based energy source availability, necessity of long term energy storage and high exergy demands such as electricity.
On the other hand daily energy balance would be feasible for a cluster buildings, where every building shares energy generation and storage system in harmony within a smart neighborhood scale energy grid.

2.1.2.4 Prescriptive or Performance Method

Determining the energy efficiency can be based on two approaches, one being prescriptive method consists in giving specific technical requirements for a set of envelope and technical system elements or characteristics (Candanedo, et al., 2010) Other method is the performance method and consists of giving limitations on energy demand for certain types of loads. Prescriptive method is mostly used for conventional buildings, as an element for early design decisions and includes certain parameters as restrictions. These restrictions can be based on specific energy Labels preferred by the designer, such as: Energy Star, EPDB labels of A, B or EPC values in the Netherlands.

However performance method is mostly suitable for certain solutions, where possible envelope or installation values cannot be applied for determining energy performance. Ex: In double skin façade construction u-value loses its significance or 50% reduction from previous state (Candanedo, et al., 2010).

Parameter	Heating DD	Cooling DD	Low Energy Building			Passive House Building (global)		
Peak heating load [W/m2] ≤	-	-	-			10		
Air tightness n50 [ach] ≤	2000	-	1.0			0.6		
	1500	-	1.0			1.0		
U-values [W/m2K] ≤			Wall,Roof	Floor	Window	Wall,Roof	Floor	Window
	3000	-	0.15-0.18	0.13	1.2	0.10-0.15	0.13	0.8
	1500	-	-			0.15-0.30	0.35	1.2-1.5
	500	-	-			0.25-0.40	0.5-0.17	1.5-2.0
Thermal bridges ψ [W/mK] ≤	500	-	≤ 0.03			≤ 0.01		
Windows shading effectiv. (S, E, W) ≥	-	500	70%			70%		
Opaque env. displacement (S,E,W, Hor.) [h] ≥	-	500	10			10		
Thermal admittance Y [W/m2K] ≤	-	500	0.1			0.1		
Heat recovery efficiency ≥	-	-	70%			80%		
Specific Fan Power SFP [kW/(m^3/s)] ≤	-	-	2.0			1.5		

Table 2-2:Technical Requirements Prescriptive Method (Indicative values) **(Candanedo, et al., 2010)**

Energy	Heating DD	Cooling DD	Low Energy Building [kWh/m2a]	Passive House Building [kWh/m2a]
Energy need for heating ≤	4000	-	30-50 or	20-30
		-	EU Labels A/B	
	500		EU Labels A/B	15
Energy need for cooling ≤		1000	15 or EU Labels A/B	
Primary energy ≤	-	-	-	120

Table 2-3: Energy Requirements Performance Method (indicative values) **(Candanedo, et al., 2010)**

2.1.2.3 Energy Production

Energy supply signifies the options for generating credits based on renewable energy sources (RES) for the balance in order to create a Net ZEB and most importantly Energy Neutral Building. A building is energy neutral when there is no net use of fossil fuels or nuclear energy, measured over the whole year. Energy from renewable sources can compensate use of fossil fuels, as long as this energy is produced within the building context (RVO, 2015). The building context can be defined as the on-site definition of ZEB project. Most commonly the footprint of the building is considered as on-site definition and further scaled as the privately owned land towards possible off-site measures. It is important to define on-site scale of the project for a single dwelling or a cluster of dwellings for RES usage. The Netherlands and Bulgaria have defined it as RES installed at a maximum distance of 10 and 15 km respectively. (Erhorn & Erhorn-Kluttig, 2015)

Options for on-site generation of energy to match demand are numerous and influenced by the type of refurbishment strategy, what is available on the site, feasibility of the measure and most importantly the metric of balance. However only the refurbishment strategy influences the type of energy carrier for on-site generation but the energy carrier for on-site measure also influences the refurbishment strategy.

A hierarchy of reliability can be useful for possible measures and how capable they are to determine their functionality. A list of measures has been given by (Torcellini, Pless, & Deru, 2006) in *table 5*

Shows what can be applied in steps and priority of measures to be if one of the steps is not possible to comply with. However the reliability of the measures must be addressed as well and it is equally important for design decisions, which is given in *table 6*. Another major issue is the definition of the site and what the measure is applicable for such as: a single house or a cluster of buildings? Where the type of energy carrier is influenced by the amount of buildings and it has a direct effect on the refurbishment strategies of building services for the buildings.

Option Number	ZEB Supply-Side Options	Examples
0	Reduce site energy use through low-energy building technologies	Day lighting, high-efficiency HVAC equipment Natural v (Satori, et al., 2010) ventilation, evaporative cooling, etc.
On-Site Supply Options		
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
2	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro and wind located on-site, but not on the building.
Off-Site Supply Options		
3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

Table 2-4: Hierarchy of preference for energy supply options depending on on-site definition and accessibility

Option Types	Proven Capability	Transition Phase	Future Potential
	Hydropower	Wind	Advanced Turbines
Geothermal	Hydrothermal	Hydrothermal	Hot dry rock Geopressure Magma
Biomass / Biofuels	Direct Combustion Gasification	Ethanol from Corn Municipal Wastes	Methane
Passive Solar	Building	-	-
Active Solar	-	Buildings Process Heat	-
Solar Thermal	-	Thermal/gas hybrid	Advanced Electricity High-Temperature Pump
Photovoltaic	Small Remote Specialty Products	Remote Power Diesel Hybrids	Utility Power

Table 2-5: Feasibility and reliability of Renewable Energy Sources **(Dinçer, 2000)**

2.1.3. Most Commonly used Zero Energy Building Design Definitions in the Netherlands

In addition to ZEB framework definition, where every parameter of necessary elements are tailor made based on site conditions, building context, data availability, preferred metric, possible energy supply and energy efficiency measure there are other comprehensive definitions for Zero Energy Building design. These methods have different focuses in regard to each other with much wider definitions for environmental impact of built environments to cost efficiencies in energy efficiency upgrades.

2.1.3.1 Energie Prestatie Coëfficient (EPC) & Energie Maatregelen op Gebied (EMG)

In the Netherlands a non-metric number is used for building energy performance determination. EPC Can be considered as a Dutch replacement of ZEB definition, however EPC focuses on energy efficiency of the buildings and values of improvement are based on individual components instead of a global definition or a global target. Based on the energy efficiency performance of the buildings, every building gets a letter from A++, A+ and A to G. The main idea behind that is, the lower the EPC, the more energy efficient the building should be. The EPC is determined by dividing the calculated energy requirement of a building by a standardized energy performance, which is based on the heat-transfer surface and the total heated area of the dwelling (Nieboer & Filippidou, 2014). The calculation of the EPC should follow the norm NEN 7120: Energy Performance of buildings – Determination method ("Energieprestatie van gebouwen – Bepalingsmethode", in short EPG), which also allows using the prenorm NVN 7125 Energy Performance Standard Measures at District Level ("Energieprestatienorm Maatregelen op Gebiedsniveau", in short EMG). (Nieboer & Filippidou, 2014)

$$\frac{Calculated\ Energy\ Requirement}{Standardised\ Eenrgy\ Performance} = EPC$$

EPC

The EPC was introduced in 1995 to set a minimal standard regarding the energy efficiency of new buildings (for existing buildings, a different coefficient is used). Over the years the EPC standard has been tightened to improve the energetic quality of new buildings (Nieboer & Filippidou, 2014). The EPC standard has started as 1.4 then within years reduced to 0,4 for all newly built buildings after 2015. Dutch government is trying to issue an EPC standard for ZEB, that is accepted to be around 0,0 but it is meant to be available on 2018 for governmental buildings and on 2020 for generic buildings. This level is defined as 'nearly energy neutral' ("bijna-energieneutraal"), but the exact value is still unknown (Nieboer & Filippidou, 2014). All of the refurbishment projects based on energy consumption upgrade has to be made according to EPC levels or at least previously determined component performance requirements associated with a particular EPC value. Ex: U Value 1,00 W/m^2K for windows and R_c>5 m^2K/W for envelope as minimum requirements based on nZEB norms given by [AgentschapNL, 2013b]. For the moment mostly housing associations regard a renovation to a certain label as a corporate strategy. These associations consider an improvement of two label steps or a renovation to label B already as ambitious, although frontrunners demonstrated the feasibility of renovating towards label A+ or A++ (COHERENO, 2013). As the requirements for the EPC become stricter over time, the percentage of renewable energy will automatically be- come increasingly important in order to fulfill the requirement (Nieboer & Filippidou, 2014). However none of these upgrades define ZEB. In theory it is always possible to reach ZEB values with EPC as long as on-site generation can compensate for the amount of energy retrieved from the grid regardless of any energy upgrade for building envelope. However consequences such as extreme costs, grid vulnerability after excessive PV usage must be taken into consideration.

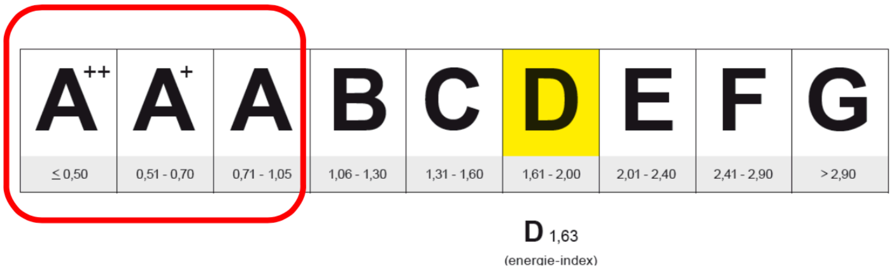


Figure 2-1: EPC Labels based on their energy performance **(COHERENO, 2013)**

For EPC based energy efficiency measures it must be stated that there are certain points, which influences previously mentioned criteria's.

- The energy use is determined for standard use and climate conditions.
- Only the building related energy use is valued in the energy performance.
- If applicable, district related energy use could be valued with EMG.
- The production of energy can take place inside or outside of building.
- The net use is determined on a yearly basis.
- Primary energy is used as credit metric

	Years	2013	2015	2020 (nZEB)
	EPC Demand	0.6	0.4	≈ 0
Construction	R_c Value [m^2K/] for:			
	- Walls	3.5	4.5	5.0
	- Roof	4.0	6.0	6.0
	- Floor	3.5	3.5	5.0
	U Value [W/m^2K] for: Window and Frame	1.65	1.65 /HR++	1.0
Installations	Heating	Solar collector system (2.3 m^2) with pre-and after heater	Solar collector system (2.3 m^2) with pre-and after heater	High efficiency gas boiler (107HR) with central heating
	Heating Generation Efficiency	1.340	2.430	0.975
	Cooling	No cooling System	No cooling System	No cooling System
	Hot Tap Water	Combined with heating system	Combined with heating system	Solar Collector system (5.5 m^2) with pre-and after heater
	Hot tap Water Generation Efficiency	0.700	2.425	0.825
	Ventilation	Mechanical (Supply and Discharge)	Mechanical (Supply and Discharge)	Mechanical (Supply and Discharge)
	Electricity Generation	-	-	PV system (25.5 m^2)
	EPC	0.59	0.4	0.01

Table 2-6: Thermal resistance & efficiency of envelope components and building services according to EPC values.

EMG

EMG is the district to city scale of EPC and basis itself on renewable energy distribution, applicability and availability. In contrast with EPC, EMG doesn't enforce any technical requirements for envelope components and building services, but acts as an additional measure for reducing EPC value for individual buildings in the built environment with a collective energy distribution approach. There are certain parameters where EMG can apply to, first of all availability of district heating or cooling system infrastructure and energy supply source. Boundary condition for applicability relies upon 10km distance from intervened building in every direction, creating a 10km radius circle around the building. However applicability of the system also relies upon the effectiveness of the district heating/cooling system. If the system is in 10km radius of the building but not effective enough to distribute energy, system is not utilized for usage. This is due to extensive sprawling of infrastructure, high demands in the vicinity. If EMG is not utilizable around the building then the EPC requirement of the building can be higher by 33% than enforced value of 0,4, which results in 0,532.

Heat networks are divided into primary and secondary networks. Primary network has higher efficiency equivalent because of reduced distributional losses within the system. Dwellings are mostly connected to secondary networks because of lower individual demand, however large buildings are connected to primary networks.

EMG has four different installation infrastructures these are based on heating, cooling, on-site solar and wind farms to generate collective power.

- Heat Network
- Circulating Hot Water System
- Collective Cooling Network
- Collective Power

2.1.3.2 Leadership in Energy and Environmental Design (LEED)

LEED, or leadership in energy and environmental design, is a globally recognized symbol of excellence in green building. The non-profit U.S. Green Building Council (USGBC) developed this certification and LEED is among the most popular crediting labels for buildings or built spaces in the world. LEED is aiming to reduce energy consumption, while minimizing environmental effects of dwellings, complex projects or even neighborhoods. LEED certificate can only be obtained by newly built buildings, however refurbishment projects cannot.

LEED certification ensures electricity cost savings, lower carbon emissions and healthier environments for the places we live, work, learn, play and worship. LEED's global sustainability agenda is designed to achieve high performance in key areas of human and environmental health, acting on the triple bottom line - putting people, planet and profit first. (USGBC, 2016) Third party technical reviewers award these certificates to the buildings based on their lifecycle over the impact on environment. LEED Labels consists of 4 different levels based on building performance these labels are:

- Certified (40-49 points)
- Silver (50-59 points)
- Gold (60-79 points)
- Platinum (80+ points)

LEED certification categories are based on points the building gets in regard to nine different performance criteria's. These credits are optional elements, or strategies that projects pursue to gain points toward LEED certification. (USGBC, 2016) Credits are developed through assessment by the board of USGBC and public comments in collaboration. LEED doesn't state any prescriptive methods, however it gives minimum requirements based on three predefined topics based on environmental design approach and project scope of LEED.

- **All LEED projects must be permanent on where they are built.** Movable buildings are not eligible for LEED. This includes boats and mobile homes. Prefabricated or modular structures and building elements may be certified once permanently installed as part of the LEED project (USGBC, 2014).
- **LEED projects must use reasonable LEED boundaries**. The LEED project boundary must include all contiguous land that is associated with the project and supports its typical operations. This includes land altered as a result of construction and features used primarily by the project's occupants, such as hardscape (parking and sidewalks), septic or stormwater treatment equipment, and landscaping. The LEED boundary may not unreasonably exclude portions of the building, space, or site to give the project an advantage in complying with credit requirements. The LEED project must accurately communicate the scope of the certifying project in all promotional and descriptive materials and distinguish it from any non-certifying space. (USGBC, 2014)
- **LEED projects must comply with size requirements**:
- **LEED BD+C and LEED O+M Rating Systems**: The LEED projei fct must include a minimum of 1,000 square feet (93 square meters) of gross floor area.
- **LEED ID+C Rating Systems**: The LEED project must include a minimum of 250 square feet (22 square meters) of gross floor area.
- **LEED for Neighborhood Development Rating Systems**: The LEED project should contain at least two habitable buildings and be no larger than 1500 acres.
- **LEED for Homes Rating Systems**: The LEED project must be defined as a "dwelling unit" by all applicable codes. This requirement includes, but is not limited to, the International Residential Code stipulation that a dwelling unit must include "permanent provisions for living, sleeping, eating, cooking, and sanitation." (USGBC, 2014)

Figure 2-2: Available LEED Certificates.
Source: http://www.interfacecutthefluff.com/tag/buildings/

Energy Efficiency of LEED

LEED project is focused on reducing energy use in buildings with measures, however these measures are not defined and most of the preferred methods are related to material usage instead of design features. Since LEED doesn't strictly enforce an energy consumption limit or a requirement for balance in designed buildings. LEED does not focus on final energy performance as part of the points system, and focus more on the materials used for the project. It is not simple to deploy LEED for Zero Energy Building design as an applicable framework object.

In regard to the information given above, a research was conducted by (Scofield, 2009) in order to see if LEED buildings are actually energy efficient or not. Within the research he has compared LEED certified buildings to non- LEED certified buildings based on source and site energy credits. The outcome of the conducted research was that smaller buildings have a reduction on their energy consumption also because they were using PV's, however large buildings didn't have any significant reduction and in general LEED average didn't reduce any energy consumption. The 35 LEED office buildings include three relatively small buildings (<34,000 sf) with on-site photovoltaic (PV) arrays that lower their purchased energy by from 2% to 17%. (Scofield, 2009) He further states his conclusions as: focusing on source energy, which accounts both for energy used on-site and the off-site losses associated with the generation and distribution of electric energy, I find that LEED-certified commercial buildings, on average, show no significant primary energy savings over comparable non-LEED buildings. (Scofield, 2009) It must be stated that energy efficiency protocol of LEED is not sufficient enough to define and design a ZEB building.

2.1.3.3 BREEAM

Breeam is the most commonly used environmental assessment measure for the built environment in the world. It sets the standard for best practice in sustainable design and has become the de facto measure used to describe a building's environmental performance. (DGBC, 2014) Breeam-NL is the adaptation of Breeam to the Netherlands. Scope of Breeam is not only energy related but, it approaches to the problems from a larger scale and energy is only one of the sub-sections need to be tackled.

Aims of Breeam:

- Reducing the impact of buildings to the environment
- Providing a credible, environmental label for buildings
- Enabling buildings to be recognized according to their environmental benefit
- Raise awareness and increase the demand for sustainable buildings

Objectives of Breeam:

- To provide market recognition to low environmental impact buildings
- To ensure optimum environmental practice is present in the buildings

- To raise awareness of the owners, occupants, designers and operators of the benefits of with building with reduced impact on the environment. (DGBC, 2014)

The assessment of the buildings is based on credits defined by Breeam. These standards are issued in the following categories: Management, Health & Well Being, Energy, Transportation, Water, Materials, Waste, Land use and Ecology, Pollution. Each issue seeks to mitigating the impact of a new or refurbished building on the environment by defining a target performance and Credit criteria that must be met to confirm the target has been achieved (DGBC, 2014). Sustainability objective of Breeam is in correlation with national regulations and actually use the as minimum for each standard. Breeam aims to top-up national regulations to reach higher standards by the initiative of building owner/client. These credits are free of choice and there is a minimum standard in each one of them. As they get fulfilled based on requirements the project obtains a certain score towards the certificate. If all subjects within a category are assessed, then a score category can be determined, to which an environmental weighting is applied (DGBC, 2014). The assessment of all these categories successfully results in a Breeam certificate depending on the requirement they fulfill in each category for point based grading. Energy has the highest performance share however, when compared to the rest of the categories a project still can get 5 stars even if its lacking in energy ratings. This is a more significant problem with lower ratings.

Category	Weighting		Breeam-NL Rating	Stars	Score
Management	12%		Pass	1	≥ 30%
Health & Comfort	15%		Good	2	≥ 45%
Energy	19%		Very Good	3	≥ 55%
Transport	8%		Excellent	4	≥ 70%
Water	6%		Outstanding*	5	≥ 85%
Materials	12.5%				
Waste	7.5%				
Land Use & Ecology	10%				
Pollution	10%				

Table 2-7: Categorization of performance assessment and quality outcome in BREEAM

Definition of Buildings & Project types

In Breeam every type of building is defined based on its function and typology regarding that function. Ex residential row house. Assessment of buildings is based on Architectural Elements, Installations, Finishing and the plot/site.

With Breeam it is possible to assess newly built buildings, large-scale renovations (energy renovations) and extensions to buildings. There are certain parameters for a renovation to be credited by Breeam and it includes change to building envelope, new building services and life extension of the building. However renovations, which exclude energy, are not accepted by Breeam to be accredited considering that small-scale renovations don’t improve environmental impact of the building.

Applicability of Breeam to ZEB Context

Breeam within a ZEB concept can be accepted as a toolbox of categories to consider for achieving Zero Energy. For example aim of BREEAM in energy efficiency is to encourage buildings that are designed to minimize their operational energy consumption (Zeylanova, 2011). Every ZEB has to be accepted in its own context such as, Site ZEB, Source ZEB, LC-ZEB, Cost ZEB and CO_2 ZEB; Breeam should be incorporated for energy efficiency or for total environmental measures in order to create the ZEB. However Breeam doesn't set any definitions or minimums for certain points crucial for designing ZEBs. Ex. Air infiltration rate, energy performance for building services…

Breeam not only influences the energy performance of the building but also the indoor environmental quality, building services, energy supply measures, materials and how they are obtained and the total construction management for building renovations. However a ZEB is always defined in its metric, energy efficiency, net zero balance and energy supply measures previously stated, therefore whole scope of Breeam is too extensive for ZEB definitions. Total utilization of Breeam would require a new ZEB definition, which wouldn't be named ZEB since energy performance will be a small portion among the total requirements.

Energy Performance in Breeam for Renovated Residential Buildings

Energy performance of the buildings in Breeam is based on sub-criteria's. Every criterion has its own weighted point. Among these criteria's CO_2 reduction has the highest share and is a must to comply to get a performance star. Energy performance of the building is based on reduced CO_2 consumption according to Breeam, however there are other aspects influential over the total energy performance such as, external lighting, thermal skin performance and interior lighting and renewable energy supply. Breeam has extensively defined energy requirements based on criterions; these requirements are derived from national regulations and accepted as minimum to be provided in a building renovation.

Building renovations are only assessed if the renovation is 25% or higher than the property value. This relates to the large-scale addressing of the building installations and to thereby achieve a significant improvement in the building-related energy consumption. (DGBC, 2014) Energy calculations for renovation projects are done in compliance with EPC. This EPC calculation is an equivalent solution for the energy label of the building for 10 years. (DGBC, 2014). However EPC is only considered to calculate the Energy performance (EP) coefficient. EP coefficient signifies the improvement based on a percentage and defines the standard for the point project gets for Breeam certificate. Energy performance assessment of the buildings are based on a calculation method, this method is in accordance with NEN 7120.

EP improvement = {1 – EPC residence / EPC requirements; residence} * 100 [%] (DGBC, 2014)

#	Point	New Building	Renovation	#	Point	New Building	Renovation
1	1 point	6%	-30%	9	9 points	44%	35%
2	2 points	14%	-15%	10	10 points	51%	38%
3	3 points	20%	-5%	11	11 points	58%	51%
4	4 points	23%	4%	12	12 points	64%	64%
5	5 points	25%	0%	13	13 points	77%	77%
6	6 points	29%	14%	14	14 points	89%	89%
7	7 points	34%	20%	15	15 points	100%	100%
8	8 points	38%	32.5%				

Table 2-8: Energy Performance Crediting According to EP improvement from previous state **(DGBC, 2014)**

Thermal skin of the buildings is assessed over energy performance and air infiltration rate. However for renovation there are no necessary standards defined as minimum. Building services and indoor environmental qualities are included under Health & Comfort Category. Even though these components and standards are influential in the energy performance of a refurbished building, within Breeam there is no energy-based criterion given for these functions. Energy efficiency of the building services are assessed under EPC calculation, as long as services comply with minimum standards, their energy efficiency can be related to Dutch regulations.

Energy Supply for buildings is assessed under Use of Renewable Energy. RES usage is only based on encouragement for the projects instead of setting a minimum requirement based on either a percentage of the energy consumed in the building or a certain amount surface space. For renovation there is no specific information given, however complying all the sub-criteria's gives points for Breeam crediting.

2.1.3.4 Nul op de Meter

Nul op de Meter is focusing on reducing energy up to EPC 0,0 and supplying the building with energy efficient technologies. New technologies are aiming to stop the usage of natural gas for good from the houses considering that good insulated houses require very little gas consumption. Instead of natural gas Nul op de Meter approach is basing all technical applications and building related loads to electricity in generation (PV) as well as consumption (heat pump).

However energy efficiency is not the only aspect Nul op de meter is focusing on. It is important to reduce energy bill as much as possible where, the possible savings over a certain amount of time become equal or more to investment cost of the refurbishment. Not only the energy bill is matched but also energy generated on site will compensate for energy consumption at the same time over an annual period to create a zero energy building in EPC standards.

Contractors and real estate companies in the Netherlands apply Nul op De Meter. Buildings are retrofitted less than 10 days including floor heating while people live in them regardless of total building services change. Constructions are done in a clean way because every component for the envelope is prefabricated and simply constructed without extra effort and material on site. Refurbishment measures are complying with Dutch indoor environmental comfort regulations, while buildings are made airtight for reduced energy loss.

EPC performance of the buildings are remarkable with below 0,0 EPC values when PV's are applied. The energy performance of the buildings and applications are subject to change depending on the buildings age, condition and of course the package company offers. However all retrofit measures must follow the building code as minimum. Which is 3,5 R_c (floor), 4,5 R_c (facade), 6,0 R_c (roof) with 1,65 U_{value} (Window) for the building envelope at the moment. Some companies apply 5,0 (floor), 8,0 R_c (façade) and 10 R_c (Roof) with HR++ or triple glazing with 0,5 – 0,9 U_{value} different construction techniques. However it is stated that according to (RVO, 2015) up to 6,0 Rc is sufficient enough for the envelope considering that higher R_c values are not reducing energy loss significantly. Heating systems in the buildings are mostly heat pumps either from air to air or buried to the ground with pipes for geothermal. However buildings are relying on excessive amount of electricity during heating season not to mention PV panels are putting high peak loads during summer time to the grid. In order to apply the electricity focused concept to a cluster of buildings whole electricity grid infrastructure must be upgraded.

Electricity mismatches and high peak loads forcing infrastructure upgrade is not the only issue the concept is facing. Nul op de Meter basis its business on net metering of energy in other words electricity generated on building level sold to the national grid. However, net metering will be limited and even completely set aside in the near future by the Dutch government because it's not profitable anymore. The concept will therefore become outdated in 2020 when net metering will be more sober or completely abolished (Schootstra, 2015).

2.1.3.5 Passive House

Passive house is a building with very low energy demand, where heating and cooling is regulated by post heated or cooled fresh air mass to achieve indoor air quality conditions. Thermal comfort is achieved to a maximum extent through passive measures (insulation, heat recovery, passive use of solar energy and internal heat sources) (IPHA, 2015)**.** However Passive House is technically not a Zero

Energy Building because it doesn't generate renewable energy on site to compensate for consumed energy in definition. Since passive house doesn't include any renewable energy generation affordability of the concept is higher than the ones with energy generation.

The concept requires an airtight building for regulating air movements in the building space. Where ventilation plays a major role on heating, cooling of the space. The building needs to be equipped with a highly efficient heat recovery system. Ventilation and heat recovery systems are the backbone of the Passive House system if there are only very low net heat losses. Hence passive house buildings need to be insulated greatly especially for cold climates to keep warm air inside the building. There is a specific calculation method for determining required level of insulation.

Passive house can reduce heating and cooling related energy loads by 90% compared to a similar building. However passive house can be deployed on both heating and cooling dominated locations with the same efficiency on energy reduction. Air supply, which provides heating and cooling, also provides the necessary amount of air volume per hour for indoor air quality.

Energy Efficiency

Passive house requires less than 15kWh/(m^2yr) for heating or cooling. Along with total primary energy use per year 120 KWh/(m^2a). In order to secure these values Passive houses require certain improvements on building envelope and building services.

Insulation of the envelope is critical for passive house functions and energy efficiency. Building has to be thermal bridge free and with very limited air infiltration ($n50 < 1{,}0$-$0{,}6$). All round insulation values accepted for passive house are between 10 – 6,7 R_c value. Due to really high R_c values on the building envelope interior surface temperature of the walls are almost the same with interior air temperature. However for reaching 7,7 R_c value, 30 cm thick typical insulation material is needed leaving a mark on the extensiveness of the refurbishment. There are no distinctive differences of envelope components such as roofs, walls and floors all these elements are accepted with single value in overall resulting in overly insulated portions in the building. Considering that most of the heat lost in Row houses is because of poorly insulated roofs instead of floors.

Windows in passive houses have triple pane double low-e glazing with 0,8 U-value. Overhangs are used as architectural measures for reducing solar gain during summer time. Ventilation system with a heat exchanger is the most critical part of a Passive House, it supplies the required air, heating and cooling within the same system, without using any boilers or heat pumps for additional heating need. Efficiency of heat recovery system is in between 75-95%.

Passive house is reducing energy consumption in buildings greatly however it is not creating an energy balance between consumed and produced on site. Even though the investment cost of Passive House is lesser than of regular ZEB, costs for only energy reduction measures are higher for Passive House. Usage of single system for ventilation, heating and cooling may seem revolutionary however, users need to adapt to climates regulated by only heated or cooled air mass, not to mention a failure would require additional systems.

2.1.4 Conclusion

Globally, zero energy design definition has to express a delicate balance over a certain amount of time in between imported energy and exported energy in a way export energy stream is clean energy. For zero energy design period of balance, energy efficiency measures (prescriptive and performance methods) and load types are the most important aspects. Hence zero energy buildings require good thermal behavior for reducing the consumption in order to make it feasible to match with on-site renewable energy generation potentials.

	EPC & EMG	LEED	BREEAM	Passive House	Nul op de Meter
Energy Efficiency	Energy efficiency based on prescriptive method, definitions are along with national requirements as well as based on specific EPC Labels and expectancies.	Energy efficiency is regulated however not enforced with any extra requirements. Total energy consumption is validated with specific crediting method.	Energy efficiency is regulated however not enforced with any extra requirements. Total energy consumption is validated with specific crediting method.	Energy efficiency is based on performance method and very high-end technical requirements are enforced for building envelope and services.	Basis energy efficiency on EPC labeling and focuses on EPC 0,0 as concept.
Balance Period	Consumption period is accepted as yearly.	Yearly consumption of energy is accepted.	Yearly consumption of energy is accepted.	Consumption period is annual consumption.	Consumption period is accepted as yearly.
Metric Type	Primary Energy.	CO_2 emissions, Primary and Final Energy.	CO_2 emissions, Primary and Final Energy.	Primary Energy.	Primary Energy.
Load Types	Heating, cooling, DHW, Ventilation, fixed lighting.	Operational Energy	Operational Energy	Heating, cooling, HVAC, fixed lighting	Heating, cooling, DHW, Ventilation, fixed lighting
Energy Production	Included in several definition, for specific use (ex. DHW). PV panels	Renewable energy sources are encouraged and credited.	Renewable energy sources are encouraged and credited.	Energy production for balance is not included.	PV panels produce energy. Solar collectors for DHW. Geothermal Heat pump
Balance Definition	Not stated, however it is possible with on-site applications.	Not stated, only renewable energy sources are encouraged for usage.	Not stated, only renewable energy sources are encouraged for usage.	Not stated however it is possible with on-site applications.	Annual energy balance and energy bill balance.
Refurbishment Applicability	Yes, used as an encouragement for energy refurbishment for dwellings in the Netherlands. Prescriptive methods can be adapted for energy efficiency in zero energy designs.	LEED is preferred for mostly new buildings	It is possible to refurbish with BREEAM. However it is extensive and doesn't only focus on energy performance. BREEAM/NL is defined according to national standards of the Netherlands	Yes however, mostly new buildings are passive houses. Refurbishment is only done by passive house materials in small scale and requires extensive measures. Performance method can be adapted for Zero energy designs.	Yes, totally based on refurbishment projects. Applied in the Netherlands by different contractors and housing firms as well as in UK and France.
District Application	EMG focuses on district applications and district based energy distribution systems for energy efficiency and consumption balance	Not enough information.	Not enough information.	Refurbishment is based on individual aspects. Buildings are accepted individually, renewable energy options are not included	No possible district application for renewables, refurbishment is limited to individual.

Table 2-9: Comparison of different definitions zero energy designs

Some of the holistic design definitions directly influence energy reduction with technical requirements from building components, while some of them leave it flexible regarding efficiency choices and focus their energy reduction and validation to crediting systems of their own. For this example LEED and BREEAM are extensive definitions for environmental impact of the built environment focusing on energy, water, waste and many more numerous sub categories of validation including Load types based on building related and user related loads. However, LEED and BREEAM are not specifically defining zero energy design or the necessity of import export balance in building scale but encouraging energy efficiency in the buildings only. In addition to lacking balance definitions and guidance of LEED and BREEAM they are mostly used for new buildings and their crediting system includes energy exterior elements, which makes it complicated for usage therefore not suitable for this research.

On the other hand definitions such as EPC and Passive House define very specific technical requirements for building components for energy consumption reduction and possible usable measures for refurbishment in buildings. For Passive house given Even though EPC and Passive house don't enforce a very specific energy balance in between import and export, they provide possibility for a zero energy balance by extensively focusing on reducing energy consumption on a yearly basis. Creating a foundation to build upon for on-site renewable options to balance the total energy consumed in buildings based on primary energy metric. It is possible to say EPC and Passive House definitions are for energy efficiency in buildings rather than directly focusing on energy balance in the built environment, however their prescriptive and performance methods create a useful basis for energy efficiency in Zero Energy Designs. This energy efficiency defined by EPC is directly put into use by Nul op de Meter.

All of the zero energy design definitions have their strong points, however they are lacking a comprehensive definition for zero energy balance. Several conditions for a zero energy balance have not been taken into consideration and must be filled in order to create a concrete balance definition regarding what is in the balance, what are the balancing elements, what is the metric of balance and the period of balance along with possible energy efficiency measures.

2.1.4.1 Zero Energy Definition for the Research

Following up from the conclusion the zero energy definition for the research will be the combination of all the strong points of previously defined zero energy design definitions; with the necessary aspects to form a deliberate and comprehensive zero energy definition for the case study buildings. In compliance with the

Energy metrics in five different definitions include Final energy (site ZEB), CO_2 emissions (Emissions ZEB) and Primary energy (Source ZEB). Primary energy is the metric type for the research considering that it is able to equate energy value of fuel types consumed and produced at site. Therefore primary energy can create the most accurate energy balance for national energy systems. As well as primary energy is being used in all five of zero energy design definitions previously mentioned, which makes primary a viable crediting metric for zero energy definition for this research.

Zero energy balance period is annual and daily regarding design alignment and aims for tackling daily energy balance problems in a dwelling cluster. Considering the fact that energy storage for daily energy balancing is not feasible for individual applications for; collective approach for energy storage could prove feasible for the community.

All of the zero energy design approaches use operational energy in the balance as a condition. Operational energy accepted in this research is heating, cooling, ventilation, plug loads, DHW and fixed lighting. However user related energy loads such as plug loads and fixed lighting will be accepted as electricity usage based on the national average per capita. As well as domestic heated water will be following national average of heated water usage considering that DHW is also user related.

Energy efficiency of the zero energy definition will be directly influencing envelope thermal behaviors and building services and efficiencies. There are two zero energy design definitions with specific technical requirements one is EPC and other one is Passive House, however there are differences in between each other depending on the flexibility of scale and possibility of defining a pitch of measures. Therefore energy efficiency measures of the Zero energy definition will be based on EPC's technical requirements because it is not limited with the lowest possible requirements. EPC has technical requirements based on EPC Labeling and there are two different requirement definitions one is being used by the Dutch government (2015 EPC=0,4) and other one is being legislated for 2020 (EPC≅0,0). The energy efficiency of the definition will be a spectrum of possibilities lowest being the 2015, EPC=0,4 and highest being 2020, EPC≅0,0 technical requirements depending on required energy consumption reduction. These requirements are given as minimum and maximum for flexibility to secure necessary energy balance without extensive measures. Requirements can be found in chapters *2.1.3.1 Energie Prestatie Coëfficient (EPC) & Energie Maatregelen op Gebied (EMG) and 2.2.5 Refurbishment Regulations in the Netherlands.*

2.2 Zero Energy Design

2.2.1 The New Stepped Strategy

Trias Energetica is an energy efficiency strategy for the built environment in the Netherland since 1980s. It forms the guideline for a logical, environmentally conscious approach but in the twenty years that I has been used it has not led to the required sustainability (Dobbelsteen, 2009). Where energy consumed in built environment is evaluated on three main steps based on reducing energy consumption as first step, generating renewable energy on building footprint as second step and to generate energy clean and efficiently with fossil fuels on the building scale as final step. Sustainable building in the Netherlands mainly concentrates on step 3, which in practice is often to be step 1 (Dobbelsteen, 2009). Based on these facts very little use is made of sun, wind and other renewable energy potentials is because of a disruption between steps and need of reformulation.

The New Stepped Strategy adds an important intermediate step in between reduction in consumption and the development of sustainable sources, and incorporates a waste products strategy (partially inspired by the Cradle-to- Cradle philosophy) (Dobbelsteen, 2009). These steps are utilized in the built environment:

- **Reduce the Demand**: *Avoid energy demand by architectural measures* (step1)
- **Utilize Waste Flows**: *Re-use waste flows on the building scale* (Step2)
- **Generate Sustainability**: *Generate renewable energy on the building scale* (step3)

Stepped strategy makes use of the waste streams in the building consisting of waste heat, wastewater and waste material. This strategy is not restricted to individual buildings but also on a citywide scale. Waste streams chains can be used in between themselves and be cascaded energy wise. For example, wastewater can be purified and the silt fermented to form biogas, which can be reused in the energy chain (Dobbelsteen, 2009).

In addition to formulating necessary steps for energy efficient buildings, The New Stepped Strategy also rearranges energy use in city scale and cascades it based on necessary energy grade and exergy. A gas flame of 1.200 – 1.500C is much more appropriate for high-grade industrial processes (that actually require such high temperatures) than for heating a home to 20C (Dobbelsteen, 2009). Therefore energy from power plant has to be redirected to a high grade energy demanding process, such as heavy industry and from industry to horticulture to dwellings, hotels and offices, where energy necessary to provide thermal comfort is no more than 25-20^{o}C if building envelopes energy performance is sufficient.

The New Stepped Strategy can be applied to a larger scale than a single building *figure 5*. It can be scaled up to neighborhood, district and city scale providing more opportunities for energy cascading, re-use of waste streams, energy storage and better energy integration for clusters. When the strategy is applied to a neighborhood scale change from step 2 to step 3 can be less demanding investment wise than applying to an individual building considering the potentials of surroundings.

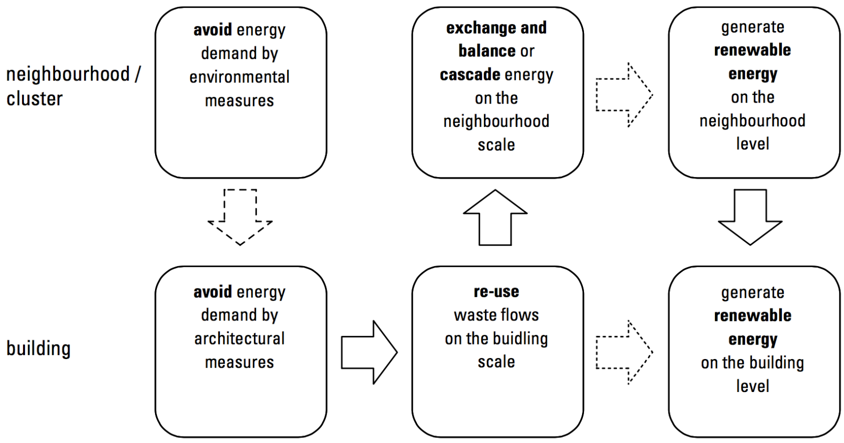


Figure 2-3: Stepped strategy cycle from building to neighborhood scale (Dobbelsteen, 2009)

2.3 Refurbishment

In this chapter of the literature study, questions: **Why Refurbishment is required and how is it defined? *& What are the envelope refurbishment strategies for energy reduction? & Which refurbishment measures can be adopted and optimized in order to reduce energy consumption in a building?*** will be clarified. In order to create guidance for possible refurbishment strategies as well as to understand necessity of refurbishment for energy performance upgrade in buildings.

2.3.1 Introduction

There is no universally applicable term that covers all building measures on existing buildings and is also understood as such (Giebeler, 2009). Refurbishment in practice includes a package of measures for building upgrade. The degree of change, compared to the extent of the building fabric to be retained, varies greatly – from minor repairs to total refurbishment of the entire building (Giebeler, 2009). Depending on the desired change, purpose of the refurbishment changes accordingly. It is important to define the range of change for the necessary upgrades and what the upgrade refers to within intervention scale.

In many cases more than one term applies to a building project because either the terms overlap to a certain extent or several measures are carried out simultaneously (Giebeler, 2009). Depending on the measures to be taken for the project scope. These scopes can be labeled aesthetic, technical or functional. Refurbishment doesn't include major changes however extend of refurbishment definitions differs enormously.

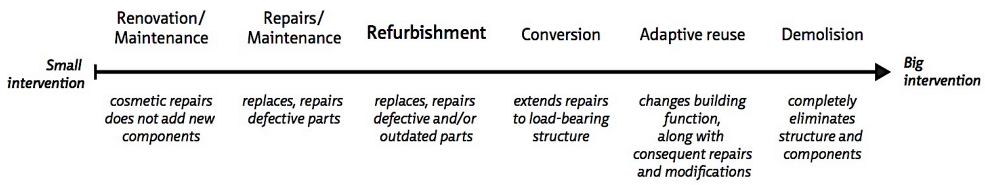


Figure 2-4: Extensive description of Refurbishment Measures based on intervention scale **(Konstantinou, 2014)**

2.3.2 Different Levels of Refurbishment

Partial Refurbishment

Partial refurbishment involves only one component or one part of the building, e.g. the facade, the ground floor or the east wing (Giebeler, 2009). These projects have to be extensively prepared since; occupants of the refurbished building will be still using it while construction is being carried.

Normal Refurbishment

Normal refurbishment measures encompass an entire building or least a part of the building that already exists as a clearly separate, autonomous element (Giebeler, 2009). Demolition of components or surfaces can only take place if fire protection, energy performance or acoustic performance of the building is to be upgraded. Additions and changes to the existing infrastructure are typical, but their complete replacement less common (Giebeler, 2009).

Total Refurbishment

Within total refurbishment most of the measures include exposure of load bearing structure. Construction measures return the building to its load-bearing carcass, however the load bearing structure is not altered. Typical measures include the complete replacement of the infrastructure and the upgrading of all building components to meet the requirements of the latest legislation and standards (Giebeler, 2009). Since most of the components in the building are replaced with more efficient or durable ones, measures for the undertaking is costly.

Necessity of Refurbishment

Most of the energy is consumed in the building stock, especially those buildings built before the 1st Thermal Insulation Act (WSVO) came into force in 1977 (Giebeler, 2009). Refurbishment in buildings is necessary especially for energy performance upgrade. After the 1st Thermal Insulation Act in 1977 buildings had to have an insulated layer on their envelope for reduced energy exchange through the façade components. However not every building complied with the act, since the agreement only enforced insulation for the buildings after 1977 but not for the buildings before. In order to reduce energy consumption in buildings besides deploying savings measure for users, it is necessary to refurbish building envelope and if necessary upgrade building services in order to save most valuable energy.

2.3.3 Envelope Refurbishment Strategies

It is important to have an insight about possible refurbishment strategies for building envelope in order to form a basis to build upon for design decisions. All strategies may not be applicable for the building, therefore it is important to pick most valuable solutions, as it will affect how the refurbishment will be made drastically.

An overview for the possible façade refurbishment solutions is derived from the PhD of (Konstantinou, 2014). The purpose of the overview is not to present all possibilities, but categorize them by identifying the basic principle and highlight benefits and limitations in each case, in order to help deciding on the type of intervention, which is a first important step to shape the refurbishment solution (Konstantinou, 2014). Different options for envelope refurbishment are derived and illustrated in *figure 2.5.*

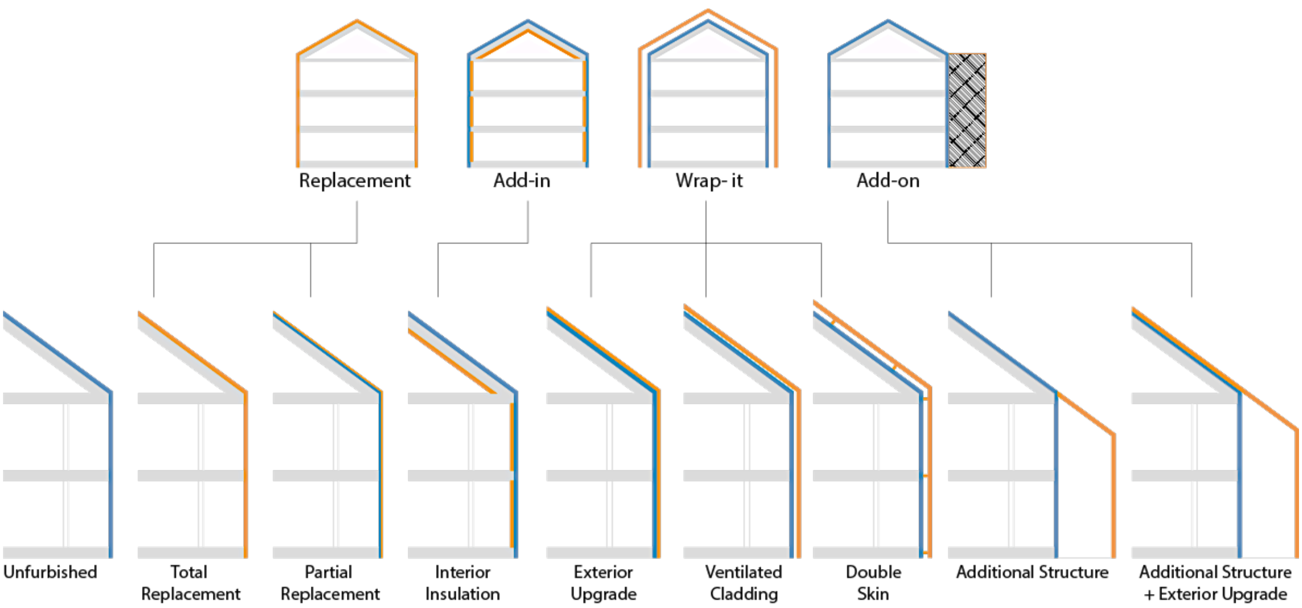


Figure 2-5: Possible Refurbishment Strategies for Building Envelope based on (Konstantinou, 2014)

		Description	Refurbishment Scale	Advantages	Disadvantage
Replacement	Complete Façade Replacement	Old façade or old elements are replaced with new one(s)	Extensive, total façade surface is replaced, Large to very large	New appearance and Better insulation, total airtightness, more variables for energy optimization and flexible design for WWR	Cost is relatively high, too much waste (embodied energy of existing materials), impact on users
Add-in	Interior Upgrade	Façade is upgraded from inside (insulation)	Depends on intervention, small to medium	Monument exteriors are un-touched	Problems with airtightness, cold bridges and space loss
	Additional Interior Layer	Extra façade is added in front of existing façade	Depends on intervention, small to medium	Monument exteriors are un-touched	Appearance not changed, space loss, user disturbance and increased amount of critical detailing
Wrap-it	Exterior Upgrade	Existing façade is partially replaced, still functional parts remain intact	Depends on intervention, medium to large	New appearance and large energy savings, only out of date pieces are removed	Applicability depends on the structure and the façade of the existing building
	Additional Exterior Layer	Building covered with a secondary layer	Depends on intervention, medium to large	Better insulation, total airtightness, new façade appearance, and little impact on users.	Construction has to be structurally viable, High costs, depends on existing structure conditions heavily, no change on WWR ratio, crucial detailing. Additional layer of façade can be limited within legal statements.
Add-on	Additional Structure	Additional structure is added to the building in front of the inferior façade or facades	Depends on intervention, medium to large	Added value, better insulation, total airtightness and Functionally utilizable space	Strategy combination is required, totally dependent on existing building structure

Table 2-10: Evaluation of different facade strategies based on their pros & cons **(Konstantinou, 2014)**

2.3.4 Conclusion on Envelope Refurbishment Strategies

Choice for envelope strategies is dependent on the applicability of a certain approach to the building as well as to the expected energy savings in the building. For energy savings the least applicable envelope refurbishment strategy would be add-in category. Considering that interior insulation and additional interior layer strategies are reducing usable space in the building, leaving thermal bridges around slab to façade connections and not significantly reducing air infiltration rates makes add-in strategies an unviable choice for energy refurbishment.

On the other hand it is possible to tackle air infiltration and energy loss problems with replacement, add-on and wrap-it approaches in much consistent and efficient way. However certain strategies such as add-on is totally dependent plot availability, regulations and load bearing structure of the building. Add-on strategy is only changing a portion of the envelope and requires other strategies to increase energy efficiency of the remaining building envelope, therefore different strategies must be combined for a total solution.

Strategies such as wrap-it and replacement are changing the outer layer of façade of the building. Therefore building is getting a better functioning thermal and airtight skin. However wrap-it apply a new skin over the existing envelope, increasing the thickness of the outer skin of the building substantially. Certain vulnerable parts of the pre existing wall or roof are still intact and building is restricted to its façade layout by the positioning of windows as well as wall to window ratio of spaces. Within replacement strategy, buildings outer skin is totally replaced with a fully new design, which is totally flexible when compared to wrap-it. Only concern for replacement strategy is that, users have to leave the house during construction works.

The strategy for total refurbishment step in the research paper will be full replacement of the building envelope. Therefore façade and roof designs will be more variable. Also the chances of orientation based optimizations and window to wall ratio flexibility is possible, which directly influences daylight availability in primary spaces.

2.3.5 Certain Measures in Building Refurbishment

Measures to be used in refurbishment projects are numerous. These measures define the possible variables that can be used in energy optimization of buildings. To secure an environmental design approach for refurbishment projects it is important to adopt steps in the new stepped energy methodology previously mentioned. These steps, when converted to possible interventions can be labeled as two different headings as passive and active measures in a refurbishment project.

Passive Measures

Passive design includes principles that are used to minimize the energy demand of the building. This is made possible with proper consideration of the local climate, building layout and material properties (Konstantinou, 2014). These measures can only be deployed on the skin of the building and they are considered non-mechanical, therefore not consuming energy. However passive measures are reducing or minimizing the rate of the heat exchange in between inside outside constantly.

Reducing the heat transmittance in between mediums with different temperature conditions is vital for achieving energy efficient refurbishments. It can be achieved by increasing the airtightness and thermal resistance of the building envelope, eliminating thermal bridges, with additional insulation on the wall, basement, roof and replacement of the windows (Konstantinou, 2014).

Insulation materials are capable of reducing the heat exchange over building skin as well as increase or reduce the interior surface temperatures of the building depending on seasons. Which results in reduced heat loss during ventilation. For transparent openings on the envelope of the building, it is possible to use better glazing, less conductive gas and several emission based coatings to reduce energy loss. However insulation and glazing technology of the building skin is not sufficient enough by itself to secure energy efficiency in the building, if air tightness is not present.

Air tightness is a necessity for reducing energy consumption in buildings, if air tightness is not present or reduced to acceptable values, it would degrade the effectiveness of the insulation and allow moisture to penetrate into the building. Reducing air leakage in envelope also contributes to sound insulation in building fabric. Infiltration rates for building envelopes are enforced by governments in specific standards, in certain conditions reduced air leakage in old buildings may also reduce supply of fresh air in the building and thus oblige in mechanical solutions.

In addition to reducing final energy loss through building envelope it is also possible to harness solar energy in a passive way. Solar energy can be absorbed by indirect gain. These methods involve usually a transparent outer layer and a heat-absorbing element between the incident solar radiation and the space to be heated, normally wall of high thermal capacity (Konstantinou, 2014). Harnessing solar power is restricted to the orientation of the building and the season. Shortcoming of passive heating is that it primarily occurs in the south part of the building. In a dwelling level, this is normally not a big problem, as the heat gains can be distributed in short distances and reduce the overall heating loads (Konstantinou, 2014).

It is important to avoid overheating during summer period, either for only insulated skins or passive solar energy utilized skins. There are design techniques to avoid usage of mechanical solutions for overheating problems. Sun control and natural ventilation, particularly combined with high thermal mass, are such techniques (Konstantinou, 2014). However passive measures are not sufficient enough to achieve expected energy levels. Passive measures aim at minimizing the heating demand (Konstantinou, 2014). Therefore distribution of energy must be carried by another measure.

Active Measures

Active measures in buildings represent the building services, which require energy to operate. Building services are components that produce and distribute necessary energy for heating, cooling, DHW, ventilation, lighting and appliances. In refurbishment project, updating the building services with more sustainable and efficient technologies, along with energy generation, should be an important consideration and should happen in parallel with building envelope upgrade (Konstantinou, 2014). The active measures that can be incorporated in a refurbishment strategy are related with the use of renewable energy sources, particularly electricity generation with the use of PV cells or Combine Heat Power units, as well as heat generation from renewable sources. Resulting in an integrated energy refurbishment with in between building services and on-site renewable potentials in which this thesis focuses on.

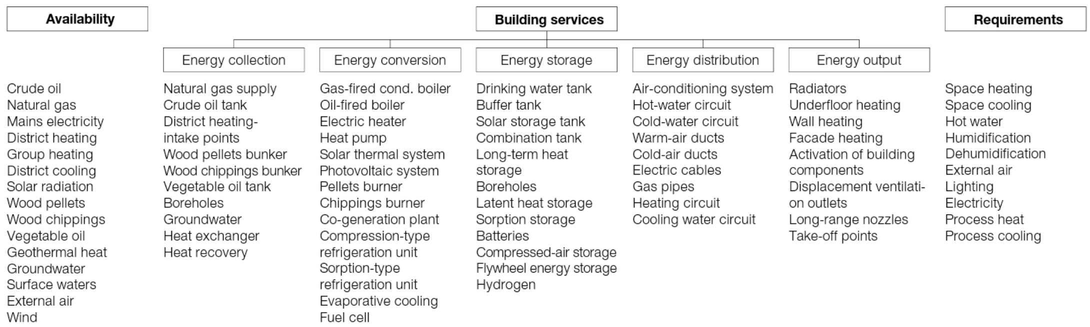


Figure 2-6: Building & Utility Services based on energy type according to **(Hegger, Fuchs, Stark, & Zeumer, 2008)**

2.3.6 Refurbishment Strategies

Two different refurbishment strategies are used in the research for highlighting a realistic and an extensive refurbishment option. Strategies are determined regarding construction scale, depth of intervention, building services replacement, building regulations and construction method. Information regarding the refurbishment strategies and their scale of intervention is obtained from chapters *2.3 Refurbishment & 2.5 Refurbishment Examples.*

Refurbishment-1

Refurbishment-1 is the realistic approach for the refurbishment of Hospeslaan-24 with moderate intervention on construction and simplistic replacement or covering options. During energy refurbishment users of the building should be affected by the renovations work as little as possible and must not be forced to leave the building. Therefore construction heavy options such as new building systems or HVAC options are neglected along with total replacement of façade elements.

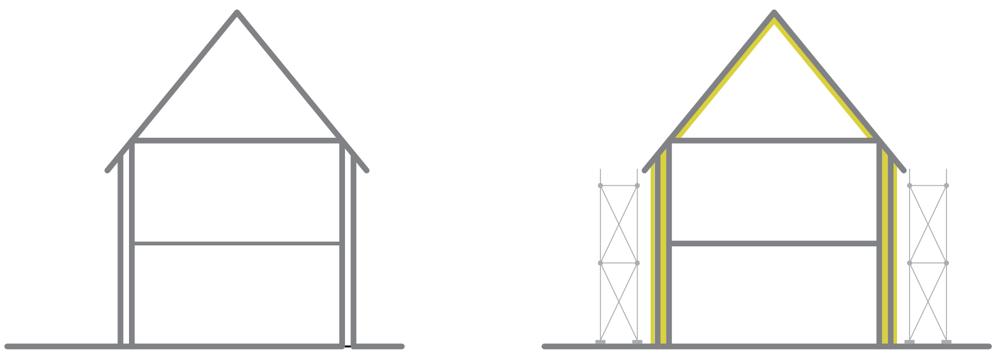


Figure 2-7: Simple figurative diagram for envelope refurbishment scope

Refurbishment-2

Refurbishment-2 is the extensive refurbishment option for Hospeslaan-24 with large-scale interventions to envelope and interior systems. Within this refurbishment strategy, measures for energy optimization are state of the art and more responsive towards the New Stepped Strategy. It is possible to intervene with building services along with total envelope replacements. Users of the building are displaced for a few days (max 10 days) for the renovation work and new building system installments.

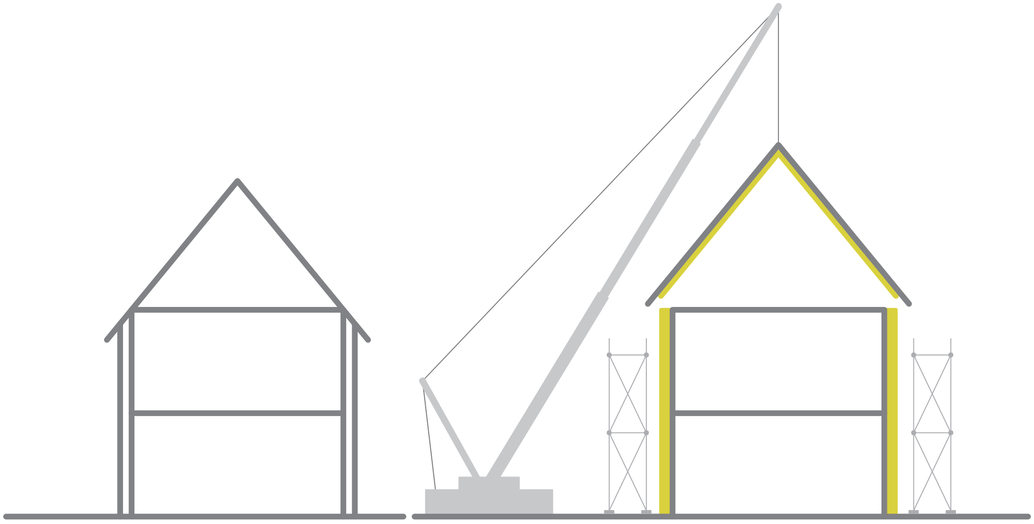


Figure 2-8: Figurative diagram for the refurbishment scope & depth

2.3.7 Refurbishment Regulations in the Netherlands

Regulations for energy related refurbishments in Bouwbesluit (Dutch building act) are divided into two different topics regarding the intervention scale on the building envelope. If a refurbishment project is influential on more than 25% of the existing building envelope, refurbishment scale is accepted as deep refurbishment, if it's lower than 25% it becomes partial refurbishment. Different definitions for refurbishments require different energy performance measures within their defined flexibility of intervention.

Within Bouwbesluit, if a building is deeply renovated, it is defined as a new construction. Buildings that are major renovations are subject to Article 5.3 and 5.4 under chapter 5 of Bouwbesluit. Therefore refurbishment is subject to state of the art technical requirements defined by EPC 0,4 for thermal performance but not to EPC 0,4 energy performance.

However if an intervention falls in partial refurbishment definitions in the Dutch regulations, special conditions apply and it is not subject to EPC 0,4 requirements but certain minimums are given for envelope components.

Thermal Insulation & Building Envelope

There are two different technical specification definitions depending on the intervention scale of the refurbishment projects. For major renovations EPC requirement of 0,4 does not directly apply for refurbishment projects however technical requirements of EPC 0,4 for envelope compositions must be complied with. Energy performance of building skin is enforced by minimum standards in NEN 1068, these standards are:

- Ground Floor: 3,5 m^2K/W
- Façade: 4,5 m^2K/W
- Roof: 6,0 m^2K/W
- Window: 1,65 W/m^2K *including frame. Frame can be maximum 2,2 W/m^2K*
- Door: 1,65 W/m^2K *including frame. Frame can be maximum 2,2 W/m^2K*

In addition to these technical specifications, there are certain indications within Bouwbesluit regarding when and where given technical specifications would apply in building context. Unheated spaces in the building must be accepted as façade and they have to be insulated with 4,5 m^2K/W. These given values can be topped up depending on expected energy performance from the building as well as targeted energy reduction.

For refurbishments defined as partial and have limited intervention, EPC 0,4 is not applicable, however there are certain specific requirements for envelope components for thermal insulation quality. For partial refurbishments minimal thermal insulation figures are given as:
- Ground Floor: 2,5 m^2K/W
- Façade: 1,3 m^2K/W
- Roof: 2,0 m^2K/W
- Window: 2,22 W/m^2K *& HR++ glazing*
- Door: 2,22 W/m^2K

These values are only applicable if the intervention level is lower than 25% of the surface of the whole building envelope. Given minimum values are accepted as the composition of envelope components and insulation values can differ from the total composition.

Infiltration of the building envelope is crucial for energy consumption regarding heating requirements in building space. Air permeability of a building cannot be measured until the building is virtually completed (Praktijkboekbouwbesluit2012, 2011). Certain classifications are given for newly built buildings in ***NEN 2687*** regarding infiltration rates of the buildings and which quality they comply with.

Air infiltration limits are defined regarding ventilation systems in the dwellings, these systems are given in *table 10.* Building envelope leakages/infiltrations are measured at a 10pa pressure difference with blower door method. The outcome of measurements must be in compliance with *table 11* regarding corresponding building spaces and ventilation type. Even though there are only three classes, upgrade to class 3 is passive house airtightness standard (0,6 ACH^{-1}@50pa)

Class	Ventilation System
1	Natural Ventilation (A) – Natural Supply and Mechanical Extraction (C)
2	Mechanical Supply and Natural Outlet (B) – Mechanical Supply and Extraction (D)

Table 2-11: Ventilation System Classifications for Infiltration definitions according to NEN 1087. **(Nederlands Normalisatie Instituut, 1989)**

Class	Property Volume m^3		q_{v10}	q_{v10}/m^2	q_{v10}
1	Greater than	Up to and Including	Maximum (dm^3/s)	($dm^3/s.m^2$)	Minimum dm^3/s
	-	250	100	1,0	30
	250	500	150	1,0	50
	500	-	200	1,0	50
2	-	250	50	0,6	-
	250	-	80	0,4	-
3	-	250	15	0,15	-
	250	-	30	0,15	-

Table 2-12: Infiltration/Leakage requirements for renovations and newly built buildings in the Netherlands based on qv 10.

2.3.8 Energy Conversion Rates in the Netherlands

Energy conversion is a necessity to compare different types of energy carriers. Primary energy form of an energy source is the condition where no conversion or transformation has applied to it. The primary energy source is broken down to energy carriers by energy system components for different usages such as heating or electricity for dwellings. Broken down energy source is processed in energy system components and distributed to end-users.

During the energy processing to shape the primary energy into usable energy certain losses occur due to downgrading and efficiency. Additional losses are applied along with distribution of the energy to end-users. In order to highlight the differences between energy processing and distribution factors, conversional rates are used to convert all energy types into the same unit. Conversional rates apply differently for every country. Accepted conversion factors for different energy carriers are given in *table 2-12*.

Energy Carriers	Delivered Energy (Source to Site)	Site Produced Energy	Site Exported Energy
Electricity	2,48	2,48	2,0
Natural Gas	1,0	Non	Non
Fuel Oil	1,0	Non	Non
Biomass for Boilers	0,0	Non	Non
Biomass for Boilers (Minimum combustion quality & Maximum emission)	0,5	Non	Non
Biomass for Boilers (Not included in above mentioned criteria's)	1,0	Non	Non
External Heat Supply (District Heating)	1,0	Non	Non
External Cooling (District Cooling)	0,833	Non	Non
On site Heat Generation	-	-	Non
On Site Cold Generation	-	-	Non

Table 2-12: Conversion factors to primary energy for different energy carriers and energy systems. (Nederlands Normalisatie-instituut, 2016)

2.4 Indoor Comfort

This chapter of literature study is intended to identify necessary comfort conditions that are influential on the energy performance as well as human comfort in closed spaces. Therefore questions; **what are the necessary Indoor Environmental Comfort (IEQ) requirements in a Dutch Dwelling based on the type of living spaces? & How to determine optimum levels for comfort requirements?** Will be answered.

2.4.1 Indoor Environmental Comfort in the Built Environment

The well being of a person is based on his or her subjective perception of a number of external influences (Hegger, Fuchs, Stark, & Zeumer, 2008). Perceptions of people are constantly influenced and subject to change depending on spaces they occupy and their activities as well as clothing. Users develop an understanding for their spatial environment, insert this into their wealth of experience and at the same time transfer the specific context of each situation to their current perception (Hegger, Fuchs, Stark, & Zeumer, 2008). Buildings must guarantee a healthy and comfortable indoor climate as Men spend about 90% of their time inside closed spaces (Silvia & Almeida, 2010). However, too little importance is attached to the aspect of better comfort when considering the advantages of a well-insulated building (Giebeler, 2009). While building envelopes are being upgraded for better energy efficiency, living conditions are improved as well, however this improvement is done unaware. It could become challenging to improve both conditions nonetheless living conditions should never be looked over. Therefore, heating, cooling, daylight availability, indoor air quality, acoustic behavior and energy reduction strategies should be meshed at an early stage with the other requirements to ensure the buildings overall comfort conditions and energy efficiency (Silvia & Almeida, 2010).

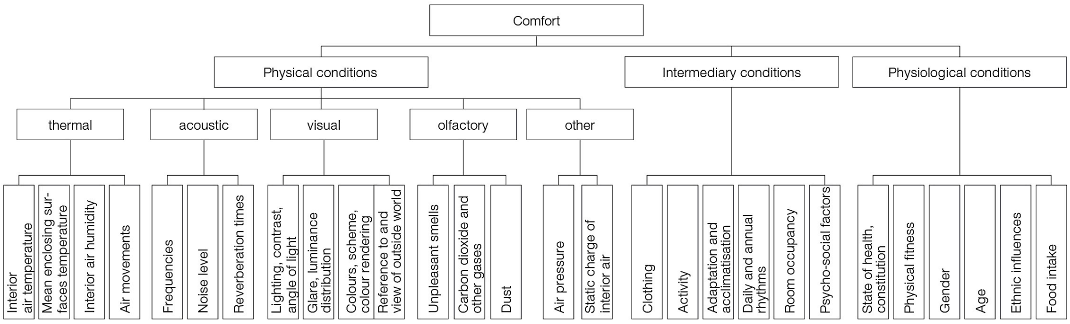


Figure 2-7: Necessary Conditions for Human Comfort **(Hegger, Fuchs, Stark, & Zeumer, 2008)**

There are several conditions influential on a person's comfort; these are given in the chart…. However not all of them are considered within this Thesis. Subjects that are influential on design decisions will be assessed under physical conditions and they will be; Thermal comfort, Air Quality & Ventilation, Acoustical Comfort and Visual comfort (daylight). In order to arrange pleasant living and working conditions, an interior climate that is agreeable in terms of thermal, acoustic, visual and olfactory aspects must be guaranteed (Hegger, Fuchs, Stark, & Zeumer, 2008) To achieve an adequate IEQ it is necessary to consider either the overall comfort conditions (thermal, acoustic, visual and Indoor Air Quality) as well as energy efficiency in buildings. It is then essential to optimize the building envelope, by improving construction solutions and insulation levels, glazing type and shading devices, optimizing the thermal and acoustic behavior, the natural ventilation and daylight use techniques through an appropriate design (Silvia & Almeida, 2010).

Necessary Comfort values within buildings are regulated by governmental norms, within Europe Comfort requirements regarding previously stated topics are given within *NEN-EN 15251*. These regulations are branched to several categories depending on the expected level of Indoor Environmental Quality, typology, intervention and user profile.

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Table 2-13: Labeling based on expected performance in buildings **(Nederlands Normalisatie-instituut, 2007)**

For refurbishment, category II has be to accept for the necessary standards in comfort to be applied in the refurbishment projects. Standards for Thermal Comfort, Ventilation, Acoustical Comfort and Daylighting will be set under Definitions/Requirements chapter.

2.4.2 Thermal Comfort

Thermal comfort is directly related with energy consumed in specific spaces in the building as well as indoor air quality depending on flow rates and building services provided. While human body perceives a certain temperature range depending on intermediary conditions, optimum standards within thermal comfort are influencing the air change rate, heating, cooling of the space. Considering that human thermal comfort range is not wide it is crucial to keep spatial conditions in optimum levels not to cause disturbance or irritation to people. If the temperature of the interior air is too high or too low, the risk of accidents increases and manual dexterity, productivity and mental abilities decrease rapidly (Hegger, Fuchs, Stark, & Zeumer, 2008). A thermally comfortable environment is therefore primarily due to physical influencing factors such as the temperature of the interior air and the average temperature of the external air (not too cold, not too hot), the humidity of the interior air (not too dry, not too humid) and the movement of the air (no draughts) (Hegger, Fuchs, Stark, & Zeumer, 2008). However with optimum temperatures for living, it is not possible to satisfy everyone using the space with the consideration of intermediary conditions. In order to take account of these individual, subjective, varying human factors, the thermal perception is specified in terms of the PMV (Predicted Mean Vote) value (Hegger, Fuchs, Stark, & Zeumer, 2008). With PMV value it is possible to determine PPD (Predicted Percentage of Dissatisfied) value, which is the percentage of who could be irritated by the provided thermal conditions. Due to the individual evaluation of the interior climate conditions, even with a PMV value of 0 (comfortable), the number of dissatisfied persons will still be 5% (Hegger, Fuchs, Stark, & Zeumer, 2008).

The movement of the air in a room also exerts a noticeable influence on a person's heat balance and hence his or her well being (Hegger, Fuchs, Stark, & Zeumer, 2008). Even though air velocity is influential on thermal comfort, air change within space has to be optimized depending on the number of occupants and volume of the space to ensure not only optimal thermal conditions but also fresh air supply for the users. This supply of air could be based on natural or mechanical ventilation or a hybrid system. **Recommended design values of the indoor Operative temperature for design of buildings an HVAC systems based on *Category II* in *NEN-EN 15251*:**

Criteria for the thermal environment shall be based on the thermal comfort indices PMV-PPD (predicted mean vote - predicted percentage of dissatisfied) with assumed typical levels of activity and thermal insulation for clothing (winter and summer) as described in detail in EN ISO 7730 (Nederlands Normalisatie-instituut, 2007).

For category II PMV value acceptable is: *PPD < 10%,* *- 0,5 < PMV < + 0,5*

Residential Buildings (Bedrooms, drawing room, kitchen, etc.) Sedentary 1,2 met
- Minimum for heating (winter season) ≅ *1.0clo: 20,0C*
- Maximum for Cooling (Summer season) ≅ *0.5clo: 26,0C*

Residential Buildings (Storage, Halls) Standing walking 1,6 met
- Minimum for heating (winter season) ≅ *1.0clo: 16,0C (issued by WHO as minimum temperature before immune system decline)*
- Maximum for Cooling (Summer season) ≅ *0.5clo: Non*

Recommended Indoor Operative Temperatures for Energy Calculation Based on *Category II* in *NEN-EN 15251*:

Residential Buildings (Bedrooms, drawing room, kitchen, etc.) Sedentary 1,2 met
- Range for heating *= 1.0clo: 20,0 - 25,0C*
- Range for Cooling *= 0.5clo: 26,0 - 26,0C*
-

Residential Buildings (Storage, Halls) Standing walking 1,6 met

- Range for Heating = *1.0clo: 16,0 - 25,0C*
- Range for Cooling = ***not stated***

2.4.3 Indoor Air Quality & Ventilation

Ventilation within building is important for providing healthy conditions in a dwelling depending on specific use and density of the spaces. For old buildings change of air within space is sufficient enough with air infiltration rate, however for refurbished buildings extra measures must be taken considering air infiltration has major role in heat loss through building envelope and it has to be reduced. The air change required for the specific spaces can be based either on natural ventilation or mechanical ventilation depending on design measures and requirements within the building as well as targeted energy performance upgrade and building status. Even though naturally ventilated air is not preheated as mechanical ventilation supply, in a comparison of mechanically and naturally ventilated rooms, the aforementioned studies reveal that people in a naturally ventilated environment accept a wider range of temperatures; the statutory comfort limits can therefore be expanded (Hegger, Fuchs, Stark, & Zeumer, 2008). Natural ventilation could be implemented in order to supply fresh air into the building however, mechanical extraction is a necessary to close waste cycles.

For providing Indoor Air Quality in a space, air velocity in the occupied zone should be equal or lower than 0.2 m/s not to cause draft (Praktijkboekbouwbesluit2012, 2011). A minimum ventilation rate between 0,05 to 0,1 l/sm2 during un-occupied hours is recommended if no value is given at national level (Nederlands Normalisatie-instituut, 2007). National Standards given in ***Bouwbesluit 2012*** for ventilation in indoor spaces correspond to Category III in ***NEN-EN 15251*** and therefore neglected***. Standards considered for ventilation quality are based on Category II of NEN-EN 15251 and they are as follows:***

Air Change Rate		Living room and bedrooms Fresh air Mandatory		Exhaust air flow		
L/s,m2	ach	L/s, pers	L/s/m^2	Kitchen	Bathroom	Toilet
0,42	0,6	7	1,0	20 L/s	15 L/s	10 L/s
-		25,2 m^3/h, pers	3,6 m^3/h/m^2	72 m^3/h	54 m^3/h	36 m^3/h

Table 2-14: Ventilation Standards for Category II based on NEN-EN 15251 **(Nederlands Normalisatie-instituut, 2007)**

The supply air to kitchens, bathrooms and toilets may be the transfer air from the bedrooms and living rooms (Nederlands Normalisatie-instituut, 2007). In addition to standards given in ***NEN-EN 15251***, there are indicated ventilation requirements for housing due to ventilation and summer time cooling within ***NEN 5066*** based on specific space type and usage, these are:

- Living room: at least 75 m^3/h up to 150 m^3/h, or Equal to total ventilation in bedrooms
- Kitchen <10 m^2: 75 m^3/h
- Kitchen >10 m^2: 100 m^3/h (mechanical)
- Open Kitchen: 150 m^3/h (mechanical)
- Bathroom: 50 m^3/h (mechanical)
- Storage: 3,6 m^3/m^2/ h

2.4.4 Acoustical Comfort

Sound is propagated as a result of the smallest pressure and density fluctuations in an elastic medium (e.g. air, solid body) (Hegger, Fuchs, Stark, & Zeumer, 2008). Humans can distinguish and process sounds in 1000 to 5000 Hz. Sound pressure represents the measurable range of sound, calculated by logarithm and described as [dB]. The range of measured sound stretches from 0 to 160 [dB]. A sound pressure level difference of 3 dB can be readily perceived at moderate to high volumes and frequencies (Hegger, Fuchs, Stark, & Zeumer, 2008). Also the difference of 10[dB] is perceived as twice as loud. The sound insulation of a wall depends on the soundproofing (R_A) of the individual elements. (Praktijkboekbouwbesluit2012, 2011)

In a refurbishment project it is important to consider the location of the building. If the building is in contact with a road, railway or industrial sound, acceptable [dB] inside dwelling changes accordingly to the functions near by. Airborne sound incoming from external sources has to be absorbed or reduced by proper detailing on envelope, better insulation material and reduced air infiltration. Airborne sound is not only related to outdoor sources but TV's, people talking, building services and any other sound generating item within the building. However if the source of airborne sound is within the house, building envelopes acoustic performance is only relevant if sound is travelling to the adjacent dwellings. In addition to airborne sound, impact sound has to be taken into consideration. Impact related sound is based on footsteps or anything coming in contact with a surface, which would generate sound when their motion is halted. Impact sound is only considered inside the building space. Both airborne and impact sound has to be taken into consideration for indoor acoustical comfort however, this thesis is focusing on the envelope of the building and it must be stated that indoor activity related sounds will be neglected in refurbishment. In other words, transmission of sound between different spaces in the building will not be prevented in refurbishment project. Therefore disturbing sounds such as flushing, showering and TV will not be included within this thesis aims. However sound disturbance caused by building services will be considered and they will be kept within limits defined by **Bouwbesluit2012** due to the fact that building services are directly influential on energy efficiency of the building and human well-being. Noise regulations based on ***Bouwbesluit2012*** is as follows:

Types of exterior noise maximum allowed inside Living Spaces adopted by the law noise nuisance or the infrastructure act:

	Basic Value ($G_{A,k}$)	Road & Railway		Industrial	
Function	VG	VG	VR	VG	VR
Unit	[dB]	[dB]	[dB]	[dB]	[dB]
Values	20	33	35	35	37

Table 2-15: Maximum acceptable noise values in dwellings **(Praktijkboekbouwbesluit2012, 2011)** *VG= Verblijfsgebied, VR= Verblijfsruimte*

2.4.5 Daylight

Visible perception generates the formation of an identity via the unmistakability of the design. Optimum level of perception can be guaranteed by; daylight or artificial light or both of them together. However, natural daylight creates more comfortable conditions because it includes all the colours of the spectrum (Hegger, Fuchs, Stark, & Zeumer, 2008) Daylight is necessary for increasing productivity, mood of the people as well as the spatial quality of the building.

Daylight quality is based on the depth & height of the space, proportion of the transparent opening to the wall (WWR), positioning of the building and position of the window opening. The possible minimum window opening based on daylight penetration in dwellings according to ***Bouwbesluit2012*** can be 10% of the floor surface within the room, with a minimum of $0.5m^2$ of opening on the corresponding wall of the room.

2.5 Refurbishment Examples

Within this chapter literature question; **what are the existing retrofit measures for Dutch Terraced Houses and what are their shortcomings and advantages?** Will be clarified. Refurbishment strategies, energy efficiencies, envelope components and active measures in buildings will be highlighted in order to create an insight about current applications in the Netherlands. How problems are tackled in refurbishment will be assessed to realize a realistic solution in energy refurbishment. Energy improvement according to refurbishment scale and solutions for on-site renewable energy in practice will be identified.

2.5.1. Kroeven Roosendaal

- Location: Kroeven District, Roosendaal
- Commissioner: Aramis AlleeWonen, Roosendaal
- Design Complex 505: De Architectenwerkgroep Tilburg (DAT)
- Design Complex 506: Franke Architecten bv Sliedrecht

Figure 2-9: Existing and new building conditions **(Bos, 2012)**

In Kroeven area of Roosendaal, Aramis AlleeWonen decided to renovate 240 old terraced buildings into passive houses. The project aim was to improve the public and private definitions in the area all together with energy performance of the houses (DATarchitecten, 2007). De Architectenwerkgroup Tilburg designed 134 of the houses in complex 505, while Franke Architecten designed 112 of the buildings in complex 506. The approach was to create an airtight, very well insulated building with minimum need for energy to operate. In order to achieve their targets they have set a strategy for refurbishment.

There are two different strategies for the façade upgrade:

- DAT architects has removed the outer leaf of the cavity wall and the complete roof to its load bearing structure in order to replace every responsive component including ground floor insulation, foundation and the entire roof with HSB elements. 505 Complex
- Franke Architecten isolates all the vertical parts of the existing building shell from foundation to rafters to external wall insulation. 506 Complex

505 Complex

HSB elements are prefabricated, supplied and constructed by VDMWoningen (Bos, 2012). HSB elements spanned from foundation to the edge of the rafter on the roof (Bos, 2012). Each house required 2 x 2 HSB elements for front and backside of the façade (Bos, 2012). These elements are placed on the stone slates of the building right in front of the inner cavity wall with enough tolerance in between. HSB elements layering consists of a vapor permeable fibreboard on exterior facing side and an OSB panel in the inside facing side, which is vapor tight (Bos, 2012). With slim `I` profiles, heat bridges are minimized in the project (Bos, 2012). Each HSB prefabricated panel is filled with cellulose for insulation purposes without breather foil, since insulation and building components can regulate moisture and evaporate it out (Bos, 2012). These façade elements and the roof have R_c *value of 10.0* m^2K/W. With the extra structural load of the new roof elements, they had to change the structure of the roof (Bos, 2012). Solid new ridge purlin was chosen to hang the roof elements (Bos, 2012). The most critical point for insulation and air tightness is where the façade meets the roof elements and outmost care has been taken in order to secure airtightness of the building on the edge of the attic. Wooden window frames with triple glazing replace the existing window frames (DATarchitecten, 2007). With this approach it is possible to refurbish the façade of four houses in a week (Bos, 2012). After renovation, primary energy consumption in the building reduced by 75% from 368 kWh/(m²a) to 133 kWh/(m²a) (GuldenFeniks, 2011).

506 Complex

In 506 Complex the façade is kept with outside and inside cavity wall, and Neopor EPS is put in front of it (Bos, 2012). The Neopor EPS product has R_c Value of *9.0* m^2K/W. The façade is combined with triple glazing the same in 505 complex. For dense part of the façade Kooltherm (Rc-value 9.33 m2K / W), and Qasa Vacuum insulation panels (Rc-value 9.61 m2K / W) are used (Bos, 2012). The finishing of the façade is stucco, however it's an expensive solution. The new HSB-prefabricated roof elements with wooden I-beams are factory insulated with 36 cm cellulose (RC-value 8.8 m2K / W) (Bos, 2012). The pace of this method is an average of one property per day.

Envelope	Before Renovation	After Renovation
Ground Floor	Non-Insulated Floor	Rc = 4.10 m^2K/W *(insulation thickness ≥ 100 mm CF ISSO 82.1)*
Long Masonry Walls	Cavity wall depth 60mm non -insulated	Rc = 8.58 m^2K/W *(insulation thickness ≥ 230 mm CF ISSO 82.1)*
End Masonry Walls	Cavity wall depth 60mm non -insulated	Rc = 8.58 m^2K/W *(insulation thickness ≥ 230 mm CF ISSO 82.1)*
Pitched Roof	Wooden roof deck with prefab concrete roof tiles	Rc = 9.49 m^2K/W *(insulation thickness ≥ 230 mm CF ISSO 82.1)*
Glazing	Single and Double glazing	Total Replacement with Triple glazing
Window Frames	Wooden Frames	Wooden Frames- U≤0.80 W/m^2K
Front Door	Non-Insulated Door	Isolated Door - U ≤0.80 W/m^2K
Air-Tightness	Moderate or Poor	Airtightness= Passive House
Attic	Unheated	Heated
Orientation	Various	Various

Table 2-16: Envelope features before and after renovation **(Nieman Bouwfysica, techniek en regelgeving, 2015)**

Installations	Before Renovation	After Renovation
Heating	VR-Boiler	Green Passive House Appliance
Domestic Hot Water	Kombi tap VR	Green Passive House Appliance
Pipe Spring	> 5 Meters	> 5 Meters
Ventilation	Natural Inlet/Outlet	Balanced ventilation with heat recovery
Sun-Energy	-	Solar water heater with 2.28 m2 collector surface
Result (EPC)	Not given	A++ (energy reduction by 90%)/ Passive house Standards

Table 2-17: Building services features before and after renovation **(Nieman Bouwfysica, techniek en regelgeving, 2015)**

2.5.2. Nul op de Meter Renovation Melick, Limburg

Figure 2-10: Before and after renovation with Nul op de Meter Strategy. **(RVO, 2014)**

Renovation in Melick, Limburg is a project based on stroomversnelling. 60 buildings in Melick were renovated with Nul op de Meter strategy. The project started in 2014 and completed in the same year. Building owners were given choices for their new façade with new colors and materials depending on their preferred finishing. In addition to façade flexibility, refurbishment strategy of the company Volker Wessels included additional extensions to the building if owners opted for it. Building have 104,2 m^2 usable space and an extra 1,24 m^2 outdoor space.

60 buildings in 4 blocks have been renovated with all electric building services. Installations of the buildings are collected in a portal outside the building on the porch. Building components are totally replaced. Heating system is replaced with individual air to water heat pump and instead of radiators, low temperature floor heating is installed to the building. Ventilation is totally mechanical supply and extraction with heat recovery. 29.4 m^2 PV panels are used for balancing energy consumption in the building with on-site renewable options. PV panels are not only used for balancing energy but also with net metering option, they contribute to the energy bill of the house.

Building is insulated from top to bottom with ground floor to roof to form a highly insulated skin for reduced energy loss. Façade is refurbished with highly insulated sandwich panels with R_c value of 8,93 m^2K/W. Ground floor is insulated with R_c value of 8,72 m^2K/W and roof is insulated with R_c value of 8,79 m^2K/W. Openings on the envelope have an U-value of 1,40 W/m^2K including the frames and triple glazing. With all the changes on the building envelope and building services energy consumption in the building reduced to 8,876 MJ/year and building is given EPC (NEN7012) = 0,17.

Envelope	**Before Renovation**	**After Renovation**
Ground Floor	Wooden Floor not insulated	Rc = 8,72 m^2K/W *180 mm insulation*
Long Masonry Walls	Cavity wall depth 60 mm	Rc = 8,93 m^2K/W *180 mm insulation*
End Masonry Walls	Cavity wall depth 60 mm	Rc = 8,93 m^2K/W *180 mm insulation*
Pitched Roof	Wooden roof deck	Rc = 8,79 m^2K/W *180 mm insulation*
Glazing	Single and double glazing	Triple Glazing U value = 1,40 W/m^2K
Window Frames	Wooden Frames	Wooden frames
Front Door	Non-Insulated Door	Isolated Door U value = 1,40 W/m^2K
Air-Tightness	Moderate or Poor	Existing
Attic	Unheated	Heated
Orientation	Front Façade South	Front façade South

Table 2-16: Envelope features before and after renovation **(Nieman Bouwfysica, techniek en regelgeving, 2015)**

Installations	Before Renovation	After Renovation
Heating	VR-Boiler with HT warming	Air to water heat pump and low temperature floor heating
Domestic Hot Water	Badgeiser	Air to water heat pump
Pipe Spring	> 5 Meters	> 5 Meters
Ventilation	Natural Inlet/Outlet	Balanced ventilation with heat recovery
Sun-Energy	-	29.4 m^2 PV panels
Result (EPC)	No given	A++ (0,17)

Table 2-17: Building services features before and after renovation **(Nieman Bouwfysica, techniek en regelgeving, 2015)**

2.5.3. Hof van Egmond Slacthuisbuurt, Haarlem

Figure 2-11: Application of renovation **(Beton, 2013)**

154 dwellings have been renovated in project Hof van Egmond. Buildings in Slacthuisbuurt have municipal monument status as they date back to 1924-1928. Monumental status of the buildings made renovation a challenge and much more rigorous than it would have been. Project focused on high-level monument renovation and preserved the monuments facades and volumes, as it was demanded from the municipality. Buildings have 75,64m^2 of usable space with a flat roof for easy PV mounting and orientating.

Building skin is optimized in an economically responsive way as a whole. Monument façade is insulated with R_c value 3,11 m²K/W, however they are monumental so insulation measures have been slightly different and less efficient for the building walls. Flat roof of the building is highly insulated for reducing thermal loss in the building. Floor of the building is given an insulation layer of 4,40 m²K/W. Normally in buildings floor insulation level is lower than of the façade however in this situation monumental façade of the building proved it wrong. Openings on the building envelope are replaced with insulated counterparts. Windows were changed into HR++ with U-value 1,8 W/m²K including the frame and door is replaced with U-value 2,0 W/m²K.

Building services were not extensively interpreted however; outdated boiler is replaced with a brand new electric heat pump for utilizing geothermal heat. Ventilation in the building wasn't changed majorly but a mechanical element was installed for necessary supply of air considering that buildings airtightness was increased after envelope refurbishment. For further improving buildings EPC level 38,4 m^2 of PV panels were installed.

Envelope	Before Renovation	After Renovation
Ground Floor	Wooden Floor not insulated	Rc = 4.40 m^2K/W *170mm insulation*
Long Masonry Walls	Non insulated wall	Rc = 3.11 m^2K/W *110 mm insulation*
End Masonry Walls	Non insulated wall	Rc = 3.11 m^2K/W *110 mm insulation*
Flat Roof	Wooden roof deck with prefab concrete roof tiles	Rc = 5,22 m^2K/W *200mm insulation*

Glazing	Single glazing	HR++ double glazing U value = 1,8 W/m²K with frame
Window Frames	Wooden Frames	Wooden frames
Front Door	Non-Insulated Door	Isolated Door - U = 2.0 W/m²K
Air-Tightness	Moderate or Poor	Existing
Attic	Unheated	Heated
Orientation	East/West	East/West

Table 2-18: Envelope features before and after renovation

Installations	Before Renovation	After Renovation
Heating	VR-Boiler	Geothermal heat pump with floor heating
Domestic Hot Water	Badgeiser	Heat boiler
Pipe Spring	> 5 Meters	> 5 Meters
Ventilation	Natural Inlet/Outlet	Demand controlled ventilation
Sun-Energy	-	38.4 m² PV panels
Result (EPC)	F	A++

Table 2-19: Building services features before and after renovation

2.5.4 Poorters Van Montfoort, Woerden

Figure 2-12: Additional structure in refurbishment **(Stichting Living Daylights, 2017)** *&* **(RVO)**

The company aimed to improve the condition of 92 houses by energy retrofitting them for better efficiency. These buildings had energy label (EPC) E and they have been only 40 years old by the time of renovation, which is after oil crisis. This means that buildings had to have a little amount of insulation based on, much lower standards to nowadays.

Due to their excellent position, especially as the spacious apartment with high future value, Bouwhulpgroep renovated these 92 buildings to higher energy performance. 82 buildings were upgraded to energy label A. Properties requiring high maintenance have been upgraded to energy label C. Ten of the houses were selected as a pilot project for the first time in the Netherlands and these buildings were further refurbished with the focus on comfortable indoor climate based on the renovation concept of VELUX and Danfoss.

Unique design of these 10 buildings was based on a balance between energy performance, indoor comfort and environmental impact. The renovation has limited the demand of energy in the buildings and eventually CO_2 emissions related to it. Application of more daylight and increased fresh air resulted as an improvement in the living comfort of the residents. Pilot houses were upgraded to A++ energy label. Therefore buildings offer more living space, natural light and indoor comfort.

Active house has been separated to 9 different evaluation aspects as: Space quality, energy conservation, indoor quality, visual quality, daylight quality, water management and equipment.

These aspects are crucial steps for design and which the design was influenced from to create the pilot houses.

ENVELOPE	BEFORE RENOVATION	AFTER RENOVATION
Ground Floor	Concrete Floor Non-Insulated	Insulation Thickness 120mm R_c value 3.15 m²K/W
Long façade (GF 1st)	Cavity wall depth 60mm non -insulated	Insulation Thickness 140mm
Long façade (2nd)	Cavity wall depth 60mm non -insulated	Insulation Thickness 110mm
End Masonry Walls	Cavity wall depth 60mm non -insulated	Insulation Thickness 70mm (R_c value 3.40 m^2K/W
Façade Extension	Cavity wall depth 60mm non -insulated	Insulation Thickness 140mm
Pitched Roof	Wooden roof deck with prefab concrete roof tiles (skylight on rear)	Insulation Thickness 110mm R_c value 4.47m²K/W
Pitched Roof	Wooden roof deck with prefab concrete roof tiles	Insulation thickness 170 mm
Pitched Roof	Wooden roof deck with prefab concrete roof tiles	Insulation thickness 235 mm
Glazing	Single Glazing	Triple Glazing U value 0,79 W/m²K
Skylights	Single Glazing	HR ++ Glass
Window Frames	Wooden Frames	Wood/PVC
Panel Frames	Non-Insulated	Insulation Thickness 70mm
Front Door	Non-Insulated Door	Standard Door non-Insulated
Back Door	Non-Insulated Door	Standard Door non-Insulated
Air-Tightness	Moderate or Poor	Present

Table 2-20: Envelope Features before and after renovation **(Nieman Bouwfysica, techniek en regelgeving, 2015)**

Installations	Before Renovation	After Renovation
Heating	VR-Boiler	Ground Connected Heat Pump with floor heating
Domestic Hot Water	Combitap VR	Ground Connected Heat Pump
Pipe Spring	> 5m	Length to kitchen > 5m
Ventilation	Natural Inlet/Outlet	Demand Controlled Ventilation
Fan Type	-	DC
Solar Energy	-	4.5 m^2 solar Collector (north-east, 60°)
Solar Energy	-	19,5 m^2 PV cells (south-west, 30°)
Results (EPC)	All Houses EPC = E	A+ (82 houses), A++ (10 Pilot Houses)
Energy Index (EI)	-	0,51 / 0,52

Table 2-21: Building services features before and after renovation (Nieman Bouwfysica, techniek en regelgeving, 2015)

2.5.5. Menno Simonszhof Melick, Hilversum

Figure 2-13: Renovation houses **(RVO)**

Menno Simonszhof is in Kerkelanden district of Hilversum. There are 97 houses in the neighborhood and all of these houses are designed for mentally disabled people. These row houses are 130 m^2 and have three floors and a garden with a cold attic, which was not heated before renovation. What makes the renovation project different from other applications in this thesis paper is that refurbishment measures are very limited in comparison. Considering that building went through a partial refurbishment and almost every measures was done by outside; occupants of the building were not obstructed with their living in dwellings. After refurbishment was completed buildings EPC value has risen to B from E.

Partial refurbishment of the building didn't change the façade outlook or altered the façade detail. However; ventilated cladding of the façade was filled with insulation material in order to increase wall R_c value to 1,86 m²K/W from non-insulated cavity wall with 60mm cavity. Wooden ground floor is replaced and insulated with 200mm XPS. Wooden roof deck with concrete tiles is insulated with 90mm of insulation ending up in R_c value 2,90 m²K/W. Buildings already had double and single glazed windows. All of the single glazing windows were replaced with wooden framed HR++ double-glazing windows. Airtightness of the building is improved with several crack and cavity fillings.

Active systems in the building were not altered majorly however out dated components are replaced with more efficient ones. Heating system is changed with HR-107 boiler but heating distribution in the buildings was not changed and relies on pre-existing radiators. No additional mechanical units were added to the building. Ventilation is based on natural ventilation and regulated by the users. Cooling is relying on natural ventilation in the buildings. With all the improvements in the buildings energy consumption is reduced to 66.754 MJ/a per dwelling.

Envelope	Before Renovation	After Renovation
Ground Floor	Wooden Floor not insulated	Rc = 3.10 m^2K/W *200mm insulation*
Long Masonry Walls	Cavity wall with 60mm cavity	Rc = 1.86 m^2K/W *cavity filling*
End Masonry Walls	Cavity wall with 60mm cavity not insulated	Rc = 3.11 m^2K/W *110 mm insulation*
Pitched Roof	Wooden roof deck with prefab concrete roof tiles	Rc = 2,90 m^2K/W *90mm insulation*
Glazing	Single and double glazing	HR++ double glazing U value = 1,8 W/m²K with frame
Window Frames	Wooden Frames	Wooden frames
Front Door	Non-Insulated Door	Insulated Door - U = 2.90 W/m^2K
Air-Tightness	Moderate or Poor	Improved
Attic	Unheated	Heated
Orientation	Front façade Southeast	Front façade Southeast

Table 2-22: Envelope features before and after renovation

Installations	Before Renovation	After Renovation
Heating	VR-Boiler	HR-107 Boiler
Domestic Hot Water	VR Boiler	HR-107 Boiler
Pipe Spring	> 5 Meters	> 5 Meters
Ventilation	Natural Inlet/Outlet	Natural Inlet/Outlet
Sun-Energy	-	-
Result (EPC)	E	B

Table 2-23: Building services features before and after renovation

2.5.6. Conclusion

Refurbishment examples are derived and summarized into several sub categories that are critical steps of energy retrofit projects for row houses. These steps are highlighting the intervention scale of the projects, their decisions for passive and active system upgrade, impact of refurbishment on building condition and energy consumption improvement after intervention.

	De Kroeven 505	Wonen Limburg	Hof van Egmond	Poorters Van Montfoort	Menno Simonszhof
Number of Dwellings	134	60	154	82 houses + 10 Better Houses	97 Dwellings
Problems	Energy performance	Energy performance	Energy Performance and comfort	Energy performance and comfort	Energy performance
Strategy	Outside cavity wall is replaced with prefabricated highly insulated façade elements. New roof and active measures.	Existing façade is wrapped with prefabricated façade components elements. Roof is totally renewed and building services switched to all electric	Building is demolished but the monumental façade is kept. All frames and glazing were changed on the monumental façade. Building systems are totally replaced	Building is totally refurbished. Additional space extension for daylight and increased property value. Refurbishment focused on comfort and daylight in spaces.	Building is partially refurbished with certain amount of measures without altering façade of the building. Roof is insulated. Some building services are replaced.
Facade	New façade composition R_c 8.58 m^2K/W with 230mm insulation and triple glazing, improved airtightness to passive house standards	New façade composition R_c 8,93 m^2K/W with 180mm insulation, Triple glazing 1,40 U value. Improved airtightness	Monumental Façade is kept but insulated from inside without thermal bridges. R_c 3.11 m^2K/W 110 mm insulation	Every façade is insulated in between 3,15 - 3,40 R_c m^2K/W Windows are triple glazing with U value 0,79 W/m^2K. Skylights are double glazing HR++	Cavity wall is filled with insulation. R_c 1.86 m^2K/W. Single glazing windows upgraded to Double glazing HR++ U value 1,8 W/m^2K
Roof	Prefabricated roof elements, R_c 9.49 m^2K/W	New roof R_c 8,79 m^2K/W 180 mm insulation	New Roof construction with R_c 5,22 m^2K/W 200mm insulation	Different pitched roofs with total insulation.	Insulation is laid in between wooden roof decking and concrete roof tiles. R_c 2,90 m^2K/W 90mm insulation
Floor	Insulated floor R_c 4.10 m^2K/W	Insulated floor R_c 8,72 m^2K/W with 180 mm insulation	R_c 4.40 m^2K/W with 170mm insulation	Concrete floor is insulated 120mm R_c value 3.15 m^2K/W	Floor is insulated R_c 3,10 m^2K/W with 200 mm insulation
Construction	Roof construction is altered for new prefabricated panels	New façade elements are attached to load bearing system	Building is totally changed besides the monumental façade. Load bearing system rebuilt. No change in building spaces	Space extension over existing roof for additional space.	Load bearing system is not altered
Active Measures	Passive house components, aquifers and ventilation system with heat recovery.	Air to water heat pump for floor heating and DHW. Mechanical ventilation with heat recovery for supply and extraction.	Geothermal heat pump with floor heating. Mechanical ventilation.	Geothermal heat pump for heating and domestic heated water. Mechanical ventilation supply and extraction.	Outdated boiler changed, boiler is used for heating and domestic heated water.
Renewable Options	Solar water heater 3,28 m^2	PV panels 29,4 m^2	PV panels 38,4 m^2	4,5 m^2 solar collector and 19,5 m^2 PV panels optimized	No options

				angles.	
Impact on Residents	Only few days of interruption	Few days of nuisance quick construction with prefabricated panels	Complete change, residents had to move for some months	Not given	Construction done from outside, residents were not effected
Energy Label & Improvement	**75% reduction energy use.** Primary energy use from 368 to 133 kWh/(m2a).	EPC A++ (0,17)	EPC, F to A++	82 Houses A+, 10 Houses A++ from Label E	EPC, G to B

Table 2-24: Summary of certain features in refurbishment projects

The necessity of renovation of row houses in the Netherlands is highly related poor energy performances of the dwellings. These buildings are upgraded to better energy efficiency condition with several refurbishment strategies. Construction companies retrofit most of the row houses in clusters in order to reduce relative cost of intervention for individual applications. Considering that row houses are single-family homes with high, envelope to living space ratio, therefore cost of the refurbishment for desired energy level becomes more expensive.

During refurbishment of the projects, neither living spaces rearranged nor the load bearing structure is altered. There are several situations where structure of the building is altered in order to install envelope components such as prefabricated roof elements or insulation but these changes are limited to a portion of the building.

Refurbishment applications are based on the intervention level of the project and expected energy improvement. Most of the applications of façade improvement are highly insulated layer of prefabricated elements put in front of existing façade or fillings in cavity walls without altering the façade outlook.

Passive and active systems in the building are improved or additional systems are installed. Most of the passive applications include higher level of insulation and better glazing depending on energy reduction targets. Mechanical ventilation system is installed to most of the refurbishments because of reduced air infiltration through façade after refurbishment. Therefore buildings are not supplied with fresh air anymore from cracks and loose details of the old façade. Ventilation systems feature heat recovery for further optimizing building energy consumption with reduced heated air loss. Heating system in buildings replaced with either a high efficiency boiler or heat and geothermal pumps depending on preferred energy currency in the buildings.

Renewable energy applications on building level are limited to PV panels and solar collectors for DHW. PV panels are generating electricity for site use and net metering for energy bill benefits. Most of the PV panel applications are focusing on only improving the EPC level of buildings and to generate electricity to be sold back to the grid in order to compensate for the refurbishment cost.

2.6 General Conclusion on Literature Study

Literature study has been influential on the structuring of research methodology & approach for the graduation work to define constraints, create boundaries on certain applicable measures as well as to determine the scope of refurbishment along with possible strategies to execute expectancies.

Zero energy balance definition and aspects influential on the definition of zero energy balance are evaluated to highlight important criteria's on creating a zero energy building, regarding energy generation, energy consumption level, balance period and boundary conditions derived from the building condition. Additional information on the applications of Zero Energy Balance in the

Netherlands have been derived to see real life executions, methods and how aspects are defined regarding building performance such as thermal performance of the building skin, energy production, building services and if applicable refurbishment strategies.

Refurbishment strategies for the building envelope as well as for the whole building scale are examined to create a database of possible interventions on the upgrade for the building thermal skin applicable for row houses. Certain applications are selected to create diversity as well as the highlight different refurbishment strategies and measures for achieving zero energy balance in buildings. Possible measures for energy upgrade are evaluated for the research methodology as well as for usage in the study case over the refurbishment examples in real life applications in the Netherlands specifically for row houses.

Building regulations for refurbishment, requirements for the thermal skin, building services, glazing quality, building services efficiencies and ventilation quality gathered as information for creating a starting point or an aim towards for refurbishment criteria's to set at least minimum of the expectancies. Required conditions for thermal comfort in space regarding the function of space is checked to form temperature ranges to deliver user satisfactory conditions in space. Not only the temperature but also possible applications of passive measures are looked for tackling bound problems on overheating.

Through literature study understanding of the case is increased and course of the search is set, background information on necessities in a building are gathered for guidance in the upcoming design steps. Along with constrains and research methodology, research question is adjusted regarding the outcome of Literature study.

3.0 Approach

Within this chapter the case study approach is elaborated and clarified regarding steps to be followed as well as the tools to be used to execute the design goals. Literature study conclusions have been used for defining the steps of design approach to reach certain goals as well as to comply with necessities within research questions.

Design approach will be used for both of the refurbishment strategies. Goals for both refurbishment strategies regarding reduction on energy consumption are derived from the literature study. Refurbishment-1 approach will aim to reach 60% [1] primary energy reduction in the building as minimum due to reduced flexibility of change on the building envelope. Refurbishment-2 will target 75%[2] total primary energy consumption reduction as minimum by allowing total replacement of passive and active measures in the dwelling.

3.1 Design Approach

First step of the design approach will be based on case study analysis. This will be conducted in several steps. First, the context of the building regarding location, orientation and amount of similar buildings will be defined. Secondly, passive components defining thermal performance of the building will be listed such as: walls, roofs, windows and ground floor with corresponding detailing of envelope sections. Thirdly, heating and domestics heating water, cooling and ventilation systems will be assessed over type and efficiency. Last step is the validation of 3D model in DesignBuilder regarding consumption values previously provided. Minimum 90% accuracy of 3D model is required to proceed to the design step.

Second step of the design approach includes, passive measures and their variables. Specifically, focusing on R_c values of Wall, Roof and Floor components glazing type, Air tightness, Infiltration, natural ventilation in design builder simulations. Technical requirements for Wall, Roof, Floor, Glazing, Air tightness and infiltration variables will be selected from a range of minimum and maximum values defined by EPC 2015 (minimum) and Passive House standards (maximum) derived from literature study. Simulation method is given in *figure 3-0* for passive measures. These figures are extended versions of research the methodology.

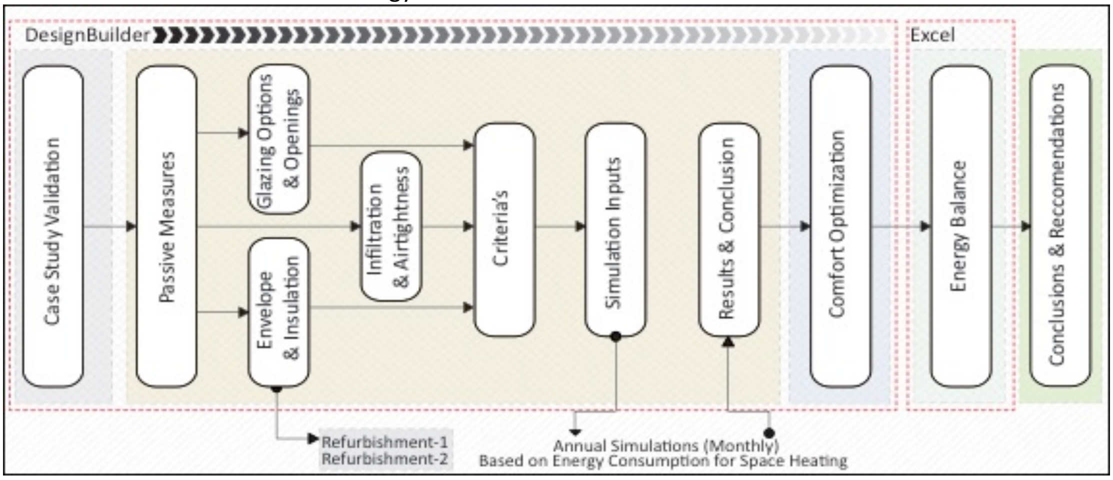


Figure 3-0: Passive measures design approach and procedure of simulations. Extended versions of research methodology charts due to more comprehensive explanation of the process of decision-making.

[1] 60% is based on energy savings offered by the Dutch Government to Row Houses built before 1945 as a nationwide savings option. *http://www.rvo.nl/sites/default/files/bijlagen/4.%20Brochure%20Voorbeeldwoningen%202011%20bestaande%20bouw.pdf page 37*

[2] 75% is following the total primary energy reduction of De Kroeven refurbishment project for single dwelling.

Third step of case study design is to provide optimal conditions for human comfort in space. Every primary and secondary zone regarding winter and summer season will be optimized for comfort based on criteria's expected. Comfort in space will be conducted over heating and cooling provision, application of shading and ventilation measures. Options for ventilation are quantified as natural ventilation for summer & winter season and mechanical ventilation & natural ventilation combination to provide necessary conditions. Simulation method is illustrated in *figure 3-1* for comfort optimization with the addition of season ranges.

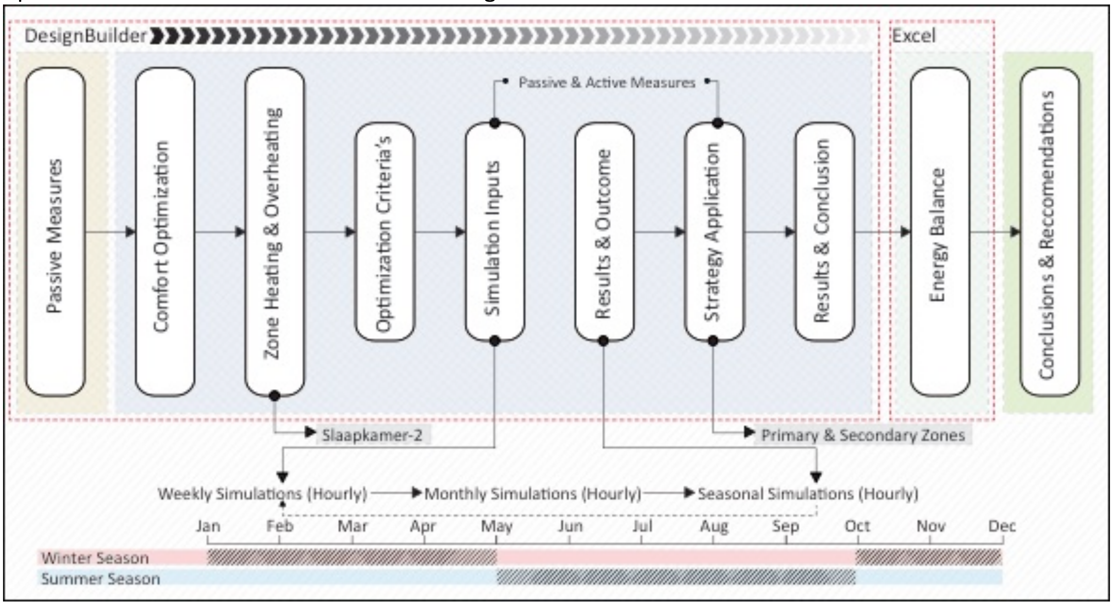


Figure 3-1: Comfort Optimization design approach and the process of decision-making. Simulation seasons and the periods taken into account are more comprehensive due to hour-based optimization.

The Final step is energy balance in buildings. It is crucial to provide energy generation options on-site to create a Zero energy building refurbishment. This will be optimized in two steps within *figure 3-2* approach is illustrated for the balance. First, operational energy after refurbishment measures of the building will be offset by photovoltaic panels for creating the annual balance of energy. Energy balance as well as photovoltaic panel sizing will be done for both of the refurbishments within the final step. In addition to individual application of energy generation measures, strategy will be applied to a cluster of structures, which have the same typology. With the cluster application, advantages and disadvantages of using common options will be checked to see if it is possible to physically reduce amount of panels, utilize an area more effectively and balance energy consumption with putting lower peak hour stress over the national grid.

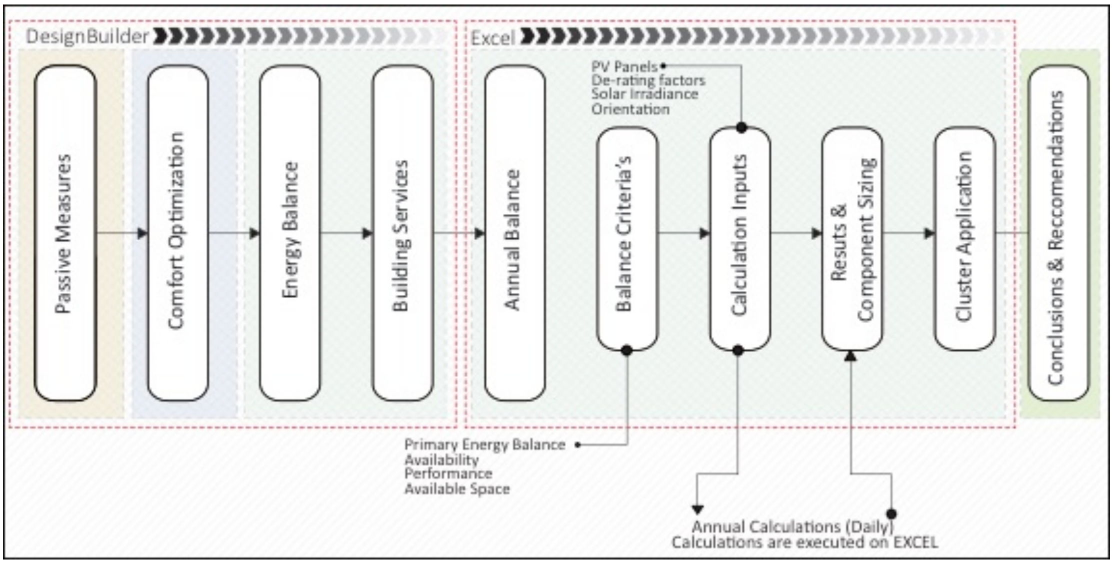


Figure 3-2: Energy balance design approach and procedure of simulations.

4.0 Case Study Analysis & Model Validation

Within this chapter case study building(s) in Ramplaankwartier, Haarlem will be analyzed under different headings for their context, energy performance and indoor environmental comfort. Building components such as the building envelope (passive) and building services (active) will be assessed regarding their thermal performance and they will be listed with their existing condition. Building details will be analyzed for possible refurbishment interventions as well as to highlight defects on the building envelope for fixing in later stage to provide better air-tightness and thermal performance.

Refurbishment will be focusing on a single building. Therefore information regarding building(s) will be limited to the case study building, however buildings within Ramplaankwartier with similar spatial features and envelope will be included on a later stage for annual energy balance.

4.1 Context

The following chapter will be highlighting generic information for the case study building. Even though there will be several buildings Short building description, energy performance, building location, orientation and similar buildings within Ramplaankwartier are analyzed to form background information about the case study building(s).

4.1.1 Building(s) Information

Location:	Hospeslaan 24, Haarlem	**Building Type:**	Row House
Building Function:	Residential	**Built Year:**	1937
Usable Space:	118,4 m^2 (130,19 m^2)	**Energy Label:**	E (2,16 EI)

Ramplaankwartier was used for agricultural purposes in order to produce flower bulbs till the area was planned for a suburban city extension for Haarlem. In 1927 Ramplaankwartier got annexed by the municipality of Haarlem to expand city boundaries. Within Ramplaankwartier residential expansions were mostly row houses with gardens. Case study house, which is the three-story row house with pitched roof, was built in 1937 in Hospeslaan in Ramplaankwartier *figure 4-0*.

Building is the middle portion of a row house complex. Therefore building is only exposed to outside conditions from four sides instead of six. However buildings energy performance is also related to two inner separation walls in between different dwellings thou they have relatively lower impact compared to building skin exposed to climate conditions. Building has possible extension locations with gardens on both sides of the building envelope. Density in the district is quite low compared to city center of Haarlem or other city expansions around the city. This is due to dominant building typology in the district, large recreational areas for the people and private & public greenery.

The main façade of the case study building is facing towards slightly northwest. Front and back façade of the building is shaded with trees for at least two stories, which could have significant effect against solar gain in the building.

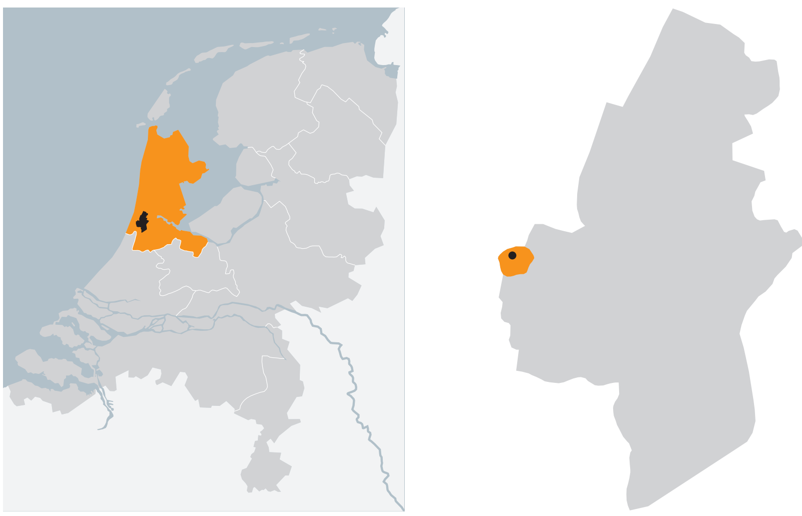


Figure 4-0: Location of Haarlem & Ramplaankwartier & Case study Building in the Netherlands

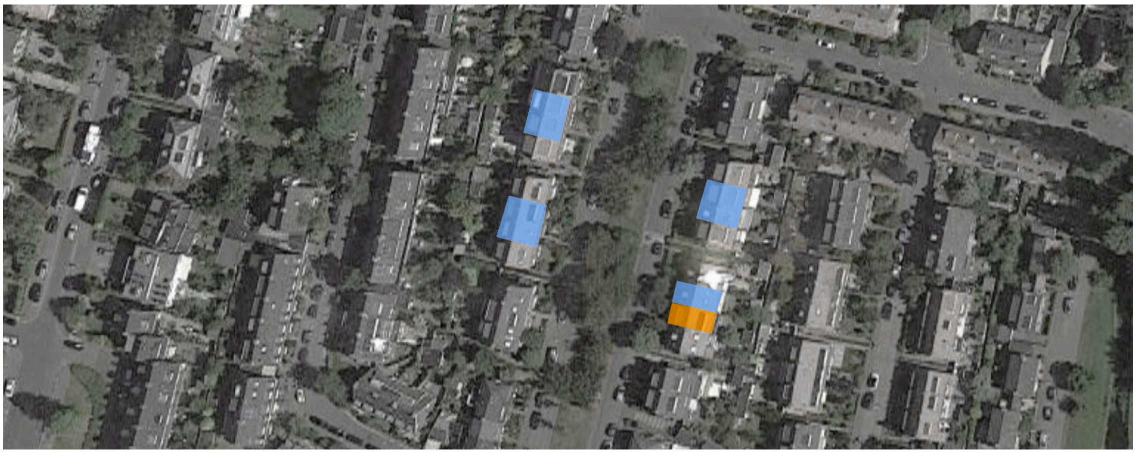


Figure 4-1: Location of case study building in Ramplaankwartier - Hospeslaan 24 (orange) and similar typologies - Hospeslaan 26,27,29,32,34,35,37 (blue). Image from Google Earth

4.1.2 Building Space

Building has 118,4 m^2 usable space as stated previously. Occupied surface area is shared between the ground floor, first floor and the attic and respectively divided into 44.5 m^2, 42.90 m^2 and 42.90 m^2. There is an additional crawlspace below the ground floor however it is not accepted as an occupied space for the users. All of the spaces are sharing walls with adjacent buildings. Building has a shaft on the south shared wall for the piping coming from the machinery in the attic.

Ground Floor

Ground floor has the daily living spaces of the dwelling. Kitchen, dining room, living room, small toilet, circulation space with staircase and the building entrée are located at this floor. Dining room and kitchen gives access to a private garden and a patio at the back (east facing) of the building.

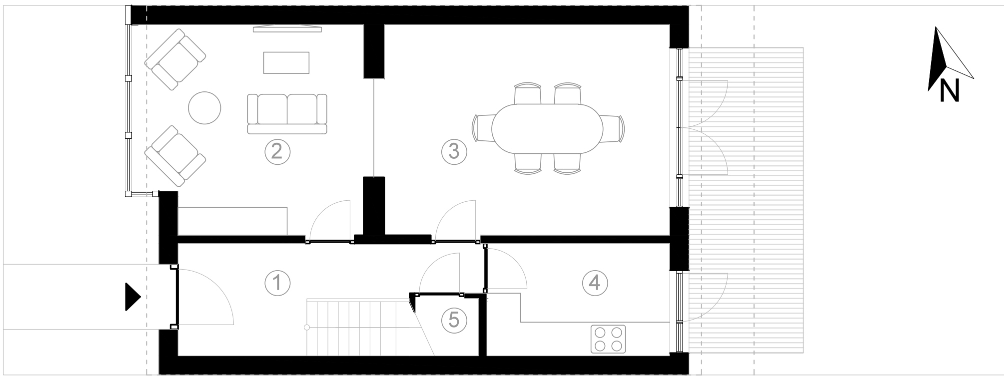


Figure 4-2: Ground floor plan of Hospeslaan 24

	Occupied Surface Area m^2	Gross Surface Area m^2	Label
Entrée and Circulation	8,3	9,5	1
Living Room	13,0	14,2	2
Dining Room	16,6	18,4	3
Kitchen	5,7	6,8	4
Toilet	1,0	1,2	5
TOTAL	44,5	50,0	Ground Floor

Table 4-0: Division of total surface spaces for Hospeslaan24.

First Floor

First floor has all the sleeping rooms of the dwelling. In addition to the sleeping rooms, there is a bathroom and a staircase access to the building attic. Sleeping rooms have three different sizes and the largest sleeping room has a balcony access at the back of the building, over shadowing the patio down below. Smallest sleeping room however has very small glazing on the very edge of the external façade.

Figure 4-3: First floor plan of Hospeslaan 24

	Occupied Surface Area m^2	Gross Surface Area m^2	Label
Sleeping Room-3	4,6	5,6	6
Sleeping Room-1	11,5	13,1	7
Sleeping Room-2	14,0	15,8	8
Circulation	6,4	6,8	9
Bathroom	5,8	6,9	10
TOTAL	42,9	48,10	First Floor

Table 4-1: Division of total surface space for Hospeslaan 24.

Attic

Building attic hosts the storage space and the machinery such as washing machine and boiler for heating. Attics usable space was increased after an intervention with dormer installments after the building was constructed. Dormers increased the space and the amount of daylight in the space as well as increased the volume to be conditioned in the building. The shaft on the South shared wall connects all the floors to the attic, however that shaft was built for the fireplace in the building which is not being used anymore.

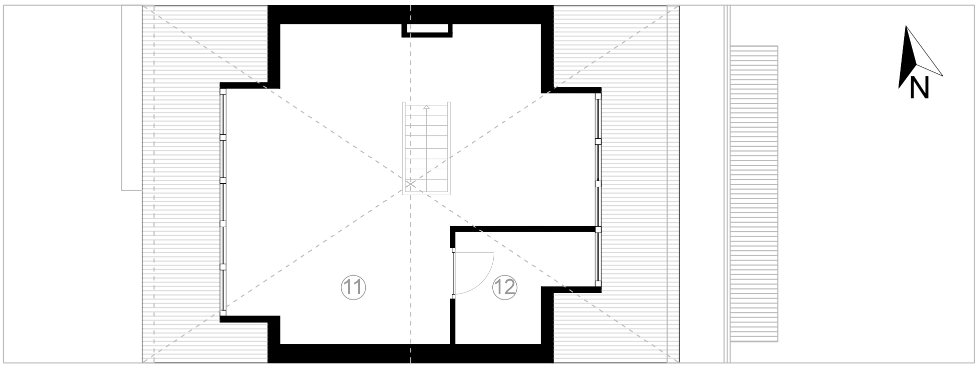


Figure 4-4: Attic plan of Hospeslaan 24

	Occupied Surface Area m^2	Gross Surface Area m^2	Label
Storage Space	36,3	41,1	11
Washing Room	6,2	7,3	12
TOTAL	42,9	48,4	Attic

Table 4-2: Division of total surface space for Hospeslaan 24 Attic.

4.1.3 Building Elevations & Section

Building elevations are provided for showing the positioning of openings and to give an idea of for the proportions of the building. Openings of the building envelope are labeled in order to keep easier track in the upcoming chapters, when technical specifications of components are given in batches according to their corresponding orientation.

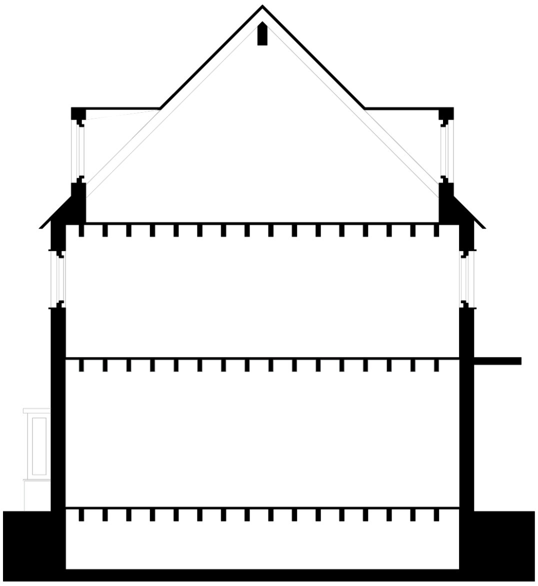


Figure 4-5: Section cut of Hospeslaan 24

Figure 4-6: Elevations of Hospeslaan 24 and the labeling of the openings. West (on the left) & East (on the right)

ELEVATION		Opening Label	Corresponding Space	Space Label	Representation
	WEST	1	Ground Floor - Entrée & Circulation	1	W-1-1
		2	Ground Floor - Living Room	2	W-2-2
		3	First Floor - Sleeping Room	7	W-3-7
		4	First Floor - Sleeping Room	6	W-4-7
		5	Attic - Storage Space	11	W-5-11
		6	Attic - Machine Room	12	W-6-12
		Opening Label	Corresponding Space	Space Label	Representation
	EAST	1	Ground Floor - Dining Room	3	E-1-3
		2	Ground Floor - Dining Room	3	E-2-3
		3	Ground Floor - Dining Room	3	E-3-3
		4	Ground Floor - Kitchen	4	E-4-4
		5	Ground Floor - Kitchen	4	E-5-4
		6	Ground Floor - Kitchen	4	E-6-4
		7	First Floor - Sleeping Room	8	E-7-8
		8	First Floor - Sleeping Room	8	E-8-8
		9	First Floor - Bathroom	10	E-9-10
		10	Attic - Storage Space	11	E-10-11

Table 4-3: Labeling system of envelope openings for further detailing in a later stage.

4.2 Energy Performance

Information on the building annual energy performance and the technical specifications regarding building components were derived through the inspection of the building. SalecoGroep has conducted the building inspection and information is collected and delivered for usage in the building refurbishment (SalecoGroep, 2010).

Building has EPC label E and 2,16 in energy index. EPC level of the building is better than the national average of Row houses built before 1945, which is level G. Building is using two types of energy, gas for heating with a boiler and electricity for lighting excluding electronic appliances. Energy Consumption of the building is given in *table 4-4*. Total primary energy consumption of the building is 97448 MJ, which reflects the actual energy consumption in terms of energy type dedicated for electricity or for heating purposes.

Electricity consumption in the building is low due to reduction from a collective photovoltaic array application. Energy generated with the PV array is shared between households and generated energy deduces the actual electricity consumption of the building. Photovoltaic array is located on the roof of Fablo Hallen, Ramplaankwartier.

Row Houses	EPC	Primary Energy	Gas	Electricity
Hospeslaan (case Study) built in 1937	E	97448 MJ	2504 m^3	1017 kWh+ Fablo
National Average built before 1945	G	142772 MJ	3337 m^3	895 kWh

Table 4-4: Comparison between Hospeslaan 24 and the National average of the same typology and built era **(Agentschap NL, 2011)**

Excessive energy consumption in the case study house is directly related to poorly performing building components. Thermal resistance and transmittance of the envelope components such as wall compositions and windows are not sufficient enough to restrict thermal exchange rate in between living spaces and outside.

Active systems in the building are outdated and need to upgraded with much more efficient ones depending on type of energy use preferred in the building. Ineffective passive and active measures are resulting in energy losses for space conditioning. Usage of fossil fuels must be avoided to eliminate additional CO_2 emission.

4.2.1 Building Envelope

Facade

Façade is the vertical separation layer of the building, which isolates the building from outside conditions, therefore constantly exposed to climatic changes. Thermal performance of a façade is directly related to R_c value of wall compositions, glazing to wall ratio, glazing type, airtightness and infiltration.

However energy performance of a building envelope is not only responsible for heat transfer but also for solar gain, which results in greenhouse effect in usable space. Solar heat gain is affected from positioning and type of shading, shading coefficient of the glazing and wall to glazing ratio. Certain façade components in the building are given in *table 23* with their technical specifications.

Facade	EAST	Opaque	**Wall**			
			Surface m^2	**R_c value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			10,7	0,36 m^2K/W	4,5 – 10,0 m^2K/W	-
		Openings	**Glazing**			
			Surface m^2	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			0,75	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-8-8 / Sleeping room
			0,75	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-8-8 / sleeping room
			1,77	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-4-4 / kitchen
			1,6	2,9 W/m^2K	1,65 – 0,8 W/m^2K	E-9-10 / Bathroom
			0,6	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-6-4 / Kitchen
			1,25	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-3-3 / Dining room
			0,8	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-2-3 / Dining room
			0,8	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-2-3 / Dining room
			1	5,2 W/m^2K	1,65 – 0,8 W/m^2K	E-5-4 / Kitchen
			Doors			
			Surface m^2	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			3,6	3,5 W/m^2K	-	E-1-3 / Dining room
			3,6	3,5 W/m^2K	-	E-7-8/ Sleeping room
		WWR	**Totals m^2**			
			Wall & door	**Glazing**	**Wall to Window Ratio**	**Labels / Corresponding Space**
			17,8	13.84	43,74%	-
	EAST	Opaque	**Wall**			
			Surface m^2	**R_c value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			25,1	0,36 m^2K/W	4,5 – 10,0 m^2K/W	-
		Openings	**Glazing**			
			Surface m^2	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			3,3	5,2 W/m^2K	1,65 – 0,8 W/m^2K	W-3-7 / Sleeping room
			1,1	2,9 W/m^2K	1,65 – 0,8 W/m^2K	W-4-6 / Sleeping room
			4,7	5,2 W/m^2K	1,65 – 0,8 W/m^2K	W-2-2 / Living room
			Doors			
			Surface m^2	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
			2,3	3,5 W/m^2K	-	W-1-1 / Entrée & Circulation
		WWR	**Totals m^2**			
			Wall & door	**Glazing**	**Façade Total**	**Wall to Window Ratio**
			27,4	4,3	31,7	14%

Table 4-5: Provided technical specifications of the facade of Hospeslaan 24

Total façade surface of the building is 63,30 m^2, which is equally divided on west and east orientation. There is a major Wall to window ratio difference between east and west facades. East façade has 44%

of WWR, while west façade has 14%. Differences between east and west WWR is either related to plan layout of the building or utilizing solar gain for the building.

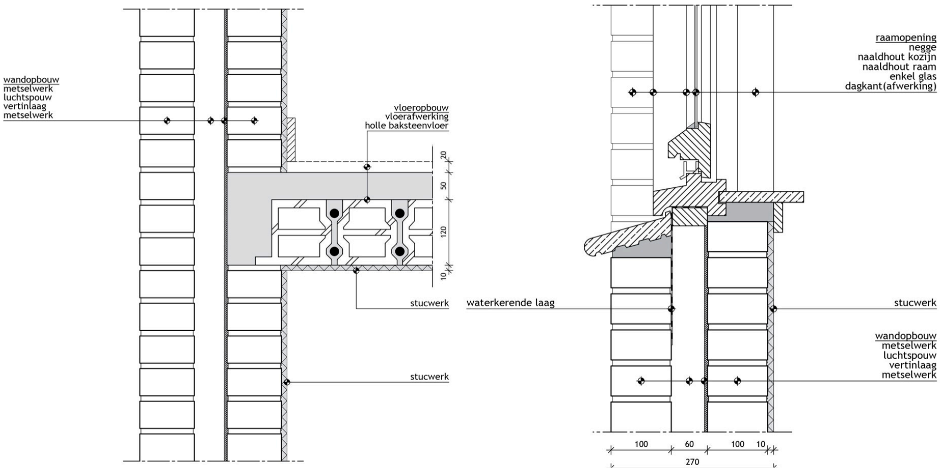


Figure 4-7: Reference details acquired from Archidat for wall composition and fenestration connection **(Archidat, 2012)**

Composition of the walls is not stated. However a detailing reference for the row houses built before 1945 can be accepted as a viable option regarding the wall roof and foundation compositions. This information is derived from (Archidat, 2012) and the detail is given in *figure 4-7.*

Roof

Roofs are the horizontal or angled elements isolating the building space from outside conditions. Roofs are always subject to changes in climatic conditions. Thermal performance of a roof is related to the U value of the openings, R_c value of roof compositions and airtightness of the whole roof construction.

Dwelling has sloped gable roofs with 45° degree from the edges of the building, however gables are shared with adjacent buildings. The roof is very steep due to an attic, which is used for storage purposes. The attic is 42,9 m^2 however not all the space can be used in the attic due to inclining roofs. Despite the very high inclination of the roof usable space with comfort is still limited. In order to further increase the usable space height in the attic, users implemented dormers facing east and west with flat roofing and additional side surfaces which is not included in original plans of the building from 1937. With the additions of the dormers usable space became 31,1 m^2. Technical specifications regarding roof components can be founded in *table 4-6.*

Roof	EASt	Roof	**Pitched Roof**			
Roof	EASt	Roof	**Surface m^2**	**R_c value**	**Range for Refurbishment**	**Labels / Corresponding Space**
Roof	EASt	Roof	25,50	0,89 m^2K/W	6,0 – 10,0 m^2K/W	Storage
Roof	EASt	Dormer	**Glazing**			
Roof	EASt	Dormer	**Surface m^2**	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
Roof	EASt	Dormer	4,60	2,90 W/m²K	1,65 – 0,8 W/m²K	E-10-11 / Storage
Roof	EASt	Dormer	**Flat Roof**			
Roof	EASt	Dormer	**Surface m^2**	**R_c value**	**Range for Refurbishment**	**Labels / Corresponding Space**
Roof	EASt	Dormer	5,4	2,53 m^2K/W	6,0 – 10,0 m^2K/W	Storage
Roof	EASt	Dormer	**Sides – north/south**			
Roof	EASt	Dormer	**Surface m^2**	**U value**	**Range for Refurbishment**	**Labels / Corresponding Space**
Roof	EASt	Dormer	1,55	2,53 W/m²K	4,5 – 10,0 m^2K/W	Storage
Roof	ES	o o	**Pitched Roof**			

	Surface m^2	R_c value	Range for Refurbishment	Labels / Corresponding Space
	26,40	1,22 m^2K/W	6,0 – 10,0 m^2K/W	Storage
Dormer	Glazing			
	Surface m^2	U value	Range for Refurbishment	Labels / Corresponding Space
	2,8	2,9 W/m^2K	1,65 – 0,8 W/m^2K	W-5-11 / Storage
	0,9	2,9 W/m^2K	1,65 – 0,8 W/m^2K	W-6-12 / Machine room
	Flat Roof			
	Surface m^2	R_c value	Range for Refurbishment	Labels / Corresponding Space
	3,4	2,53 m^2K/W	6,0 – 10,0 m^2K/W	Storage
	1,1	2,53 m^2K/W	6,0 – 10,0 m^2K/W	Washing room
	Sides – north/south			
	Surface m^2	R_c value	Range for Refurbishment	Labels / Corresponding Space
	0,8	2,53 m^2K/W	4,5 – 10,0 m^2K/W	Storage
	0,8	2,53 m^2K/W	4,5 – 10,0 m^2K/W	Washing room

Table 4-6: Provided technical specifications of the roof of Hospeslaan 24

Roof surfaces without the dormers for east and west orientation are respectively 25,50 m^2 and 26,4 m^2, in total 51,9 m^2. Roofs have different R_c values regarding their orientation. R_c values of the pitched roofs are 1,22 m^2K/W for east and 0,89 m^2K/W for west. Considering that R_c values of the traditional pitched roofs are very low and according to the reference detailing for row houses before 1945 from (Archidat, 2012), roofs are lacking insulation material and only composed of Dutch roof tiles, wooden battens, wooden roof plating and wooden rafters. Structural members and battens of the roof are neglected in R_c compositions because they are not forming a continuous surface between layers. Therefore roof tile, wooden roof plating and the air gap between tiles and the plating are determining the R_c value of the building roof.

Dormer facing east is relatively larger than the west facing dormer, considering that these dormers are built after the building was constructed they have better U and R_c values for transparent and opaque parts compared to other components of the façade or roof. Glazing of the dormers is double layered with 2,90 W/m^2K including the window frame. Sidewalls of the dormers share the same R_c values with the flat roof composition.

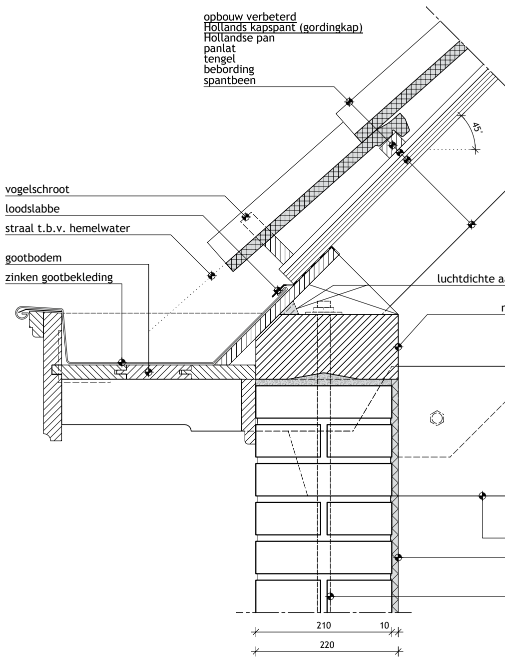


Figure 4-8: Figurative, roof & gutter and wall connection detail **(Archidat, 2012)**

Ground Floor

Ground floor slab and construction is the separation layer between soil and building interior, therefore has significant importance considering, the heat transfer in two differently conditioned mediums. Even though the floor is close to the ground, technically it is not constructed directly on the soil. According to the reference details for row houses before 1945, there is a crawlspace in between the actual soil and the ground floor slab of the building, which is constantly ventilated by passive ventilation canals. Therefore the outer surface of the ground floor has the same temperature as air temperature, however ground floor is not affected by climatic conditions such as rain, wind and solar heat gain.

Usable area of the ground floor is 44,4 m^2 with 0,32 R_c value due to non-insulated floor composition. The floor consists of wooden slabs and rectangular wooden battens for horizontal support to prevent deformation on slabs. R_c value of the floor slab is very low compared to current standards required from refurbished buildings and must be upgraded. R_c value of the ground floor is the thermal conductivity and the thickness of the wooden slab considering that wooden slab is the only continuous horizontal surface separating two differently conditioned mediums. Existence of a crawlspace it is possible to insulate the ground floor without too much effort and any alteration on building layout.

Ground Floor Slab		
Surface m^2	R_c value	Range for Refurbishment
44,40 m^2	0,32 m^{2}K/W	3,5 m^{2}K/W – 7,7 m^{2}K/W

Table 4-7: Technical specification of ground floor elements of Hospeslaan 24

4.2.2 Building Services

Building is heated individually with Hr-100 boiler and dependent on natural gas. Therefore the building is connected to the national gas distribution grid. Air required for combustion is retracted from a pipe through the roof, where all the machinery is located.

Coefficient of performance or the brand of the boiler is not provided; therefore the operational efficiency of the boiler is unknown and operational energy consumption of the boiler is not stated. However the machinery cannot date back for too long due to functional years of boiler components, therefore the efficiency of the boiler is accepted as 85%, which is according to (Energia) accepted as the minimum efficiency in modern boilers. Domestic heated water is also provided with the Hr-100 boiler for faucets and shower. Consumption of 2504 m^3 natural gas is including DHW and heating system in the building.

The building is ventilated naturally through operable windows or air infiltration from the ill-maintained envelope cracks and seams. Ventilation of the building totally relies on user-based control and it is not regulated. There was no extraction fans reported for the wet spaces of the building in the document of SalecoGroep. Therefore spaces such the toilets and the kitchen are accepted to be naturally ventilated and they do not comply with the Dutch building regulations. Lack of exhaust fans increase the thermal capability of the building envelope since a fan located on the façade would expose the indoor conditions to outdoor climate on permanent basis.

Electricity usage in the building is only measured over the fixed lighting elements and heating components. Appliances such as PC, sockets, TV, washing machines are not included in the calculated consumption amount, which is stated in the report by (SalecoGroep, 2010) however the report is in disclosure. Electricity consumption regarding previously stated components is 1017 kWh and directly drawn from the national grid.

Figure 4-9: Standard radiator for heating distribution
Source: http://www.adurad.nl

Figure 4-10: HR-Ketel positioned in attic
Source http://www.van-trigtinstallaties.nl/site/cv-ketel-onderhoudscontract

4.3 Simulation Model Validation

Simulation models on 3D environment have numerous variables to be controlled for heating, natural ventilation, occupied surface areas and volumes, technical specifications of envelope and building services components and many more. In respect to numerous amounts of variable data, it is important to start with what is provided such as building dimensions, technical specifications of components and the location. After provided data is implemented into the 3D models it is possible to further optimize consumption values in DesignBuilder.

Simulation inputs for validating the 3D model will be derived from chapters *4.3.3 Technical Specifications and 4.3.4 Zone Activity & HVAC & Lighting.* The ultimate target for the simulations is to match consumption data of real life building with the simulation model for proceeding to refurbishment stage of the building. Unknown infiltration value of the building is determined along with the process of consumption data matching.

Validation Criteria's

Certain criteria's for simulation model validation are to reach the annual consumption values by minimum 90% precision for electricity and natural gas use. However while doing so, provided technical specifications are not subject to change.

4.3.1 DesignBuilder

The DesignBuilder software is an advanced graphical user interface that has been specially developed to run EnergyPlus simulations. DesignBuilder enables energy calculations and optimizations for buildings in a simple manner with numerous variables implemented in the program. Variables are computerized in a sequence ending up in the simulated results from the steps followed. Depending on the outcome of the simulated results, it is always possible to step back and optimize for further accuracy to validate the model. There are certain steps to be followed for healthy 3D model making and defining pre existing information regarding technical specifications of the building envelope components.

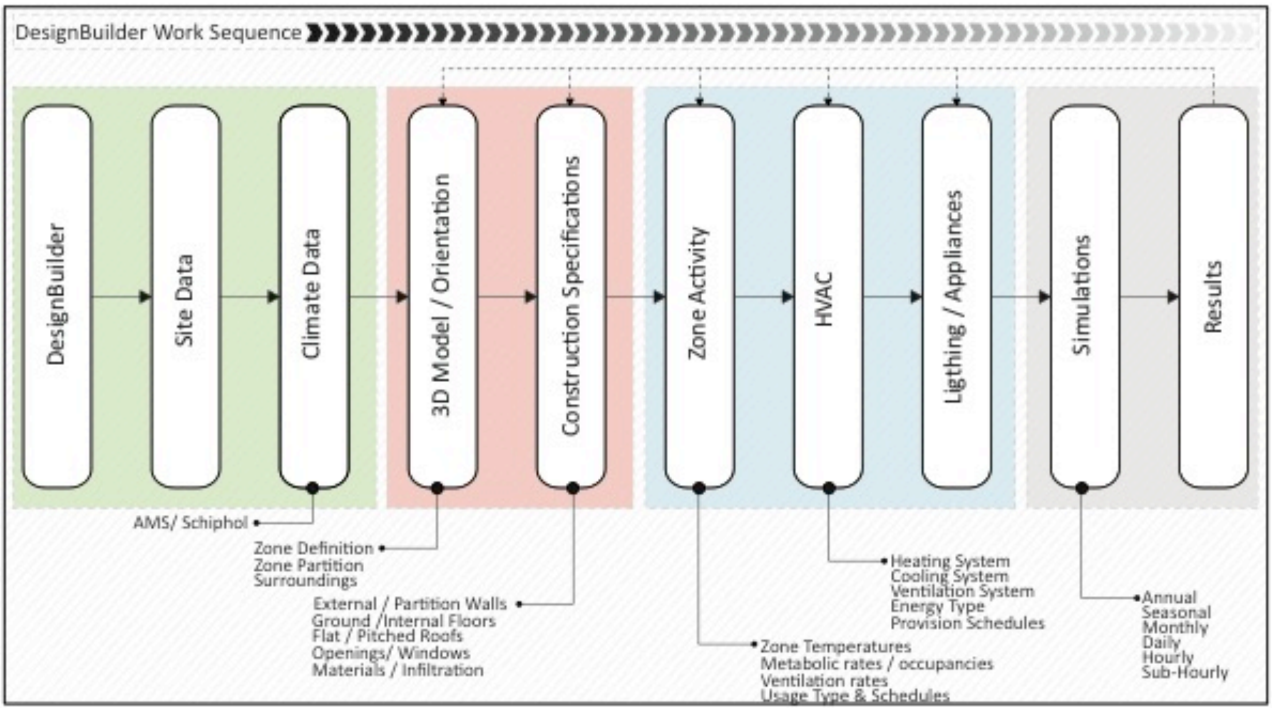


Figure 4-11: DesignBuilder flow chart for energy simulations in 3D software

4.4.2 Location & Building Model

Block surfaces are defined regarding their exposure to climatic condition and positioning on the whole block context automatically, however it can be manually overwritten. Once the building zones and external surfaces were secured, building openings were defined for every floor zone.

It is possible to have building openings as default in DesignBuilder. Whenever an external wall is defined in a block, DesignBuilder generates an opening with given specifications. However for Hospeslaan 24 it is not possible to follow this approach because every opening is custom and not ideally shaped. Therefore all of the openings either transparent or opaque were manually drawn in respect to their specific surface area and positioning on the building envelope. Once openings on the building envelope were defined, building model took its final shape in *figure 4-12* with greyed out volumes are excluded from thermal calculations however used for shading purposes.

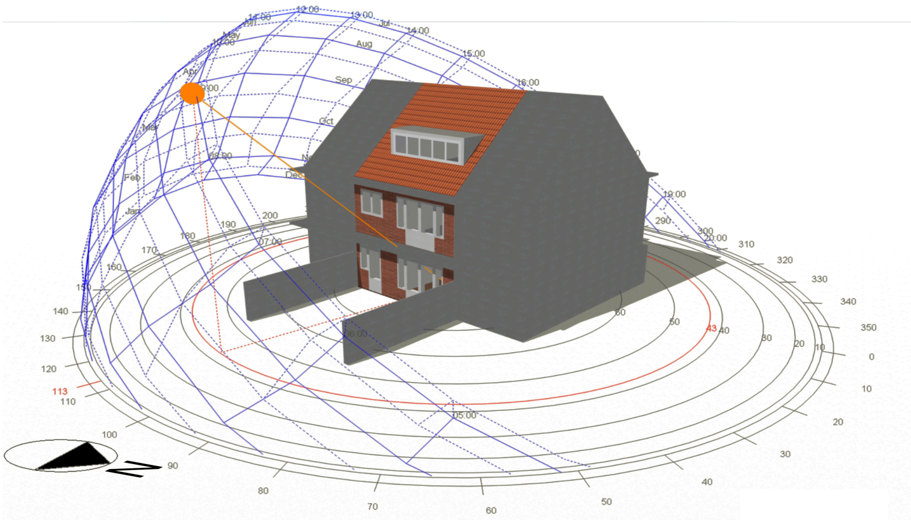


Figure 4-12: 3D model of Hospeslaan24 in DesignBuilder. Dark grey portions are not included in energy calculations and only used for posing shading on the structure for increasing the accuracy of daylight, passive solar gain calculations.

4.3.2 Technical Specifications

Externally exposed elements, such as pitched and flat roofs, external walls and openings are given their technical specifications previously provided for a precise energy simulation. This information is computerized in four steps from walls and ground floor to openings to roof and building partition elements. Elements defined in these steps are used as the simulation inputs for validating the simulation model.

External Walls & Ground Floor

External walls are all accepted as 0,36 m^2k/W value for Hospeslaan 24. In order to define the specific R_c values for the building envelope a new wall had to be defined only comprised of masonry brickwork and plasterboard interior finishing.

One of the challenges of defining 0,36 m^2k/W value was that building external wall thickness (310 mm) multiplied by R_c value of 1mm brickwork was not matching with 0,36 R_c value. In order to reach the provided R_c value it is required to reduce the thickness of the brick wall. For the necessary R_c value external wall thickness must be reduced to 115mm.

$$R_C\ Brickwork\ x\ 115\ mm + R_C Plasterboard\ x\ 10\ mm = 0{,}359\ R_C\ External\ Wall$$

However reducing external wall thickness to 115 mm is not possible for a cavity wall construction. Also reduction on the wall thickness will result in increased zonal area in the simulations, which would reduce the precision of the simulations. Therefore the wall R_c and the thickness are accepted are 0,806 and 310 mm respectively. The construction of the cavity wall will comprise of 60 mm outer brickwork – 60mm air cavity – 190 mm brickwork inner leaf resulting in the following R_c value.

$$R_C Brick\ x\ 125\ mm + R_C Air\ x\ 60\ mm R_C + \ R_C Brick\ x\ 125\ mm = 0{,}806\ R_C\ External\ Wall$$

Ground floor thermal resistance value is 0,32 m^2K/W. Information derived from the reference detail of the ground floor shows that floor slab is only comprised of wooden plates and horizontally spanning battens. Floor thickness is neglected and fixed to 0,00 mm in order not to reduce occupied volume and fixed floor thickness has no effect on thermal performance of the ground floor slab. However thermal simulations are not effected from the fixed condition of the floor.

$$R_C\ Wood\ (HF - B7)\ x\ 13\ mm = 0{,}32\ R_C\ Ground\ Floor\ Slab$$

Hospeslaan 24 is a row house, with two adjacent buildings on both sides. Walls on north south orientation are accepted as adiabatic assuming that conditions on the both sides of the wall are the same. In reality it is not possible to assume a partitioning wall in between two different building as adiabatic because user consumption patterns and occupancy are different from each other.

However it is not possible to predict the consumptions of adjacent buildings. Therefore walls are accepted to have same conditions on both sides, nullifying the possibility of thermal transmittance between different mediums. Even though an adiabatic wall doesn't allow thermal exchange, it is recognized as a thermal mass.

Openings

Building has 13 different transparent openings and 3 different opaque openings. 13 different glazing are separated into two different glazing layering, 8 of them are single glazing and 5 of them are double glazing with u values of 5,2 W/m^2K and 2,9 W/m^2K respectively including the frame. All of the doors share the same U value of 3,50 W/m^2K.

Definition of glazing type in DesignBuilder is only precise if all of the information about the window composition is provided. Which means specific information on U value of frame and size, glazing type including coating on specific surface(s) and thermal bridging coefficient (Ψ). Therefore window compositions cannot be defined single handedly by only average U value provided per window.

$$\frac{U_{frame}\ x\ A_{external\_frame} + U_{glazing}\ x\ A_{glazing} + \Psi_{glazing}\ x\ L_{glazing}}{A_{external\_frane} +\ A_{glazing}} = U_{window}$$

Considering that U_{window} and window surface areas are provided, a specific single glazing and wooden frame u value is taken from DesignBuilder material database in order to determine the frame and glazing surface area of all the single glazing fenestration composition. With the calculated glazing U value and selected U value of the frame hand calculations are conducted to determine the frame and glazing surface areas.

According to (Feldmeier, 1999) as long as window components such as glazing and frame have low thermal performance; thermal bridging coefficient has no significance in determining the total U value of the window. Therefore within this calculation process thermal bridging coefficient is neglected. Within *table 4-8* inputs for the windows configuration are given for DesignBuilder simulation.

$$\frac{U_{frame}\ x\ A_{external\_frame} + U_{glazing}\ x\ A_{glazing}}{A_{external\_frane} +\ A_{glazing}} = U_{window}$$

- For single glazing: U-single = 6,121 / Single clear glass 6 mm
  SHGC = 0,819, Light Transmission = 0,881
- For Wooden frame: U-frame = 3,633 / painted wooden frame
- For double glazing: U-double = 2,531 / 6-10-12 clear glass + argon
  SHGC = 0,731, Light Transmission = 0,755
- For double glazing frame: U-frame = 3,47 / UPVC

Label	U-window	S-window	U-glass	S-glass	U-frame	S-frame
W-2-2	5,2 W/m²K	4,65 m²	6,121 W/m²K	2,80 m²	3,633 W/m²K	1,85 m²
W-3-7	5,2 W/m²K	3,28 m²	6,121 W/m²K	1,81 m²	3,633 W/m²K	1,47 m²
W-4-7	2,9 W/m²K	1,01 m²	2,531 W/m²K	0,6 m²	3,47 W/m²K	0,41 m²
W-5-11	2,9 W/m²K	2,83 m²	2,531 W/m²K	1,75 m²	3,47 W/m²K	1,08 m²
W-6-12	2,9 W/m²K	0,94 m²	2,531 W/m²K	0,63 m²	3,47 W/m²K	0,31 m²
E-2-3 x 2	5,2 W/m²K	0,80 m²	6,121 W/m²K	0,48 m²	3,633 W/m²K	0,32 m²
E-3-3	5,2 W/m²K	1,23 m²	6,121 W/m²K	0,76 m²	3,633 W/m²K	0,47 m²
E-5-4	5,2 W/m²K	0,66 m²	6,121 W/m²K	0,35 m²	3,633 W/m²K	0,31 m²
E-6-4	5,2 W/m²K	0,62 m²	6,121 W/m²K	0,37 m²	3,633 W/m²K	0,25 m²
E-8-8 x 2	5,2 W/m²K	0,73 m²	6,121 W/m²K	0,377 m²	3,633 W/m²K	0,353 m²
E-9-10	2,9 W/m²K	1,57 m²	2,531 W/m²K	0,86 m²	3,47 W/m²K	0,71 m²
E-10-11	2,9 W/m²K	4,60 m²	2,531 W/m²K	2,75 m²	3,47 W/m²K	1,85 m²

Table 3-8: Accepted U values and outcome of surface areas of glazing and frames per window type & simulation inputs (highlighted)

Opaque openings such as doors have the same u value of 3,50 W/m²K for all of them and don't require any calculation. They are accepted as single material with continuous surface all around. Thickness of the openings does not influence the occupied surface area; therefore openings are not given any fixed thicknesses.

$$U - Wood\ (HF - B7)\ x\ 15\ mm = 3{,}504\ U - Door$$

Roof

Roof of Hospeslaan 24 has a gabled-pitched roof where gables are shared with adjacent buildings. Pitched roofs have two different R_c values for east and west respectively 1,22 m^2K/W and 0,89 m^2K/W. These roofs are composed of tiles, air gap and wooden slabs differentiating in their thicknesses regarding their total R_c values. In order to reach the necessary R_c values in DesignBuilder material thicknesses are altered and global roof thickness is fixed for not influencing building occupied surface area and volume.

$$R_C Tiles\ x\ 50\ mm + R_C Airgap\ \ x\ 10\ mm + R_C Wood\ x\ 11{,}5\ mm = 1{,}22\ R_C\ Pithed\ Roof$$

$$R_C Tiles\ x\ 50\ mm + R_C Airgap\ \ x\ 10\ mm + R_C Wood\ x\ 7{,}5\ mm = 0{,}89\ R_C\ Pithed\ Roof$$

Pitched roofs have additional dormers on both sides facing west and east. These dormers have flat roofs and have better R_c value than pitched roofs since they were an addition to the original plan of the dwelling in a later stage. Flat roofs and side facades of dormers share the same R_c value of 2,53 m^2K/W. Roof thicknesses are not influencing the occupied usable area and significance of change in occupied volume is very limited since surface areas of dormers are only 5,36 and 4,52 m^2. Thickness of the wooden cladding is not included automatically in dormer side calculation by the DesignBuilder.

$$R_C Mastic\ finishing\ x\ 2\ mm + R_C R_{11}\ insulation\ \ x\ 85\ mm = 2{,}53\ R_C\ Flat\ Roof$$

$$R_C EPS\ x\ 90\ mm + R_C Aluminium\ \ x\ 2\ mm = 2{,}53\ R_C\ Dormer\ Sides$$

After roof technical specifications are defined in DesignBuilder all of the components used in thermal calculations are given their provided thermal transmittance and resistance values. The only unknown value in the composition of the building envelope is the airtightness/infiltration rate of the building, which will be determined via the building validation simulations.

Up to this point all of the computerized information is not subject to change since they are defining the existing condition of the building besides adjacent adiabatic walls. However partition walls between dwellings must be accepted as adiabatic because those walls are not affected by climate conditions in real life situation therefore there are not effects rain and wind on the wall apart from temperature changes.

4.3.3 Zone Activity & HVAC & Lighting

Zone based activities are defining the certain provisions to the space in order to create living conditions. Under the tab of activity it is necessary to define the usage type of the space, occupancy of the space, heating temperatures, fresh air supply either by mechanical or natural ventilation and domestic heated water usage depending on type of space.

Zonal Activity

Zones must be defined in the building depending on their functions in order to regulate heating and cooling distribution, fresh air provision and domestic heated water consumption as well as metabolic and clothing values for comfort calculations. Ones zones are defined as either 'bedroom' or 'bathroom' regarding their function, every space is given an operation schedule for ventilation, heating/cooling and spatial occupancy which regulates the usage frequency and intensity of certain components in the building. Most of the times schedules differ accordingly with seasonal changes, different behaviors are all given in compact schedules of DesignBuilder. Definition of zonal functions used in Hospeslaan 24 can be found in *table 3-10.*

Considering that the temperature provisions for different spaces in Hospeslaan 24 were not given, all spatial heating provisions were assumed and calibrated accordingly to the minimum allowed temperature range given in chapter *2.4.2 Thermal Comfort*. Certain temperatures defined for different types of zones in the building regarding their function can be found in *table 4-9.*

Air change per hour (ACH^{-1}) in a space defines the quality of ventilation and therefore must be taken into consideration for energy simulations no matter what the air supply strategy is. In Hospeslaan 24 air supply is manually regulated and depends on natural ventilation, therefore for simulations minimum required air flow is provided to corresponding spaces mentioned in *2.4.3 Indoor Air Quality & Ventilation.*

However spaces such as toilet, kitchen and bathroom are not provided with additional ventilation equipment due to their unknown state regarding ventilation status prior simulation, for these spaces only natural ventilation is provided regarding their occupancy and amount of air is assumed over people using the space at maximum occupancy levels.

Domestic heated water is calculated over daily consumption of shower, bathtub and cooking and had washing clothes. Therefore DHW is only used in wet spaces, kitchen toilet and bathrooms. According to (Vitens, 2013) in the Netherlands water usage per person for a day for showering, bathing, cooking and hand washing clothes are respectively 51,17 L; 2,38 L; 3,57 L and 3,57 L.

These values are defined in DesignBuilder under their corresponding zone functions, which can be seen in *table 4-9.* These values can be altered if not found reflecting correct consumption data in later stages of simulation.

Zones	Label	Activity	Occupancy	Heating (C)	Heating Set Back (C)	Minimum Fresh Air	DHW (L/m^2)
Entrée	1	Circulation	1	18	12	Non - No opening / supply demand	Non
Living Room	2	Lounge	4	21	12	7x4=40l/s	Non
Dining Room	3	Eating	4	21	12	7x4=40l/s	Non
Kitchen	4	Kitchen	2	21	12	1x7=7l/s no additional equipment	3.57 x 2 two people cooking
Toilet	5	Toilet	1	21	12	Non - No opening / supply demand	3,57x2L/m^2 1 person daily hand wash clothes
Sleeping Room	6	Bedroom	1	21	12	7x1=7l/s	Non
Sleeping Room	7	Bedroom	1	21	12	7x1=7l/s	Non
Sleeping Room	8	Bedroom	2	21	12	7x2=14l/s	Non
Corridor	9	Circulation	1	18	12	Non - No opening / supply demand	Non
Bathroom	10	Bathroom	1	21	12	7x1=7l/s no additional equipment	(3x51,17+2,38)L/zone m^2 3 people daily shower 1 people daily bath
Attic	11	Circulation	1	18	12	7x1=7l/s unless occupied	Non
Crawlspace	12	Semi exterior/ Non conditioned- Subject to outside conditions, wind and infiltration					

Table 4-9: Certain simulation inputs for model validation regarding zonal activities

HVAC

HVAC tab defines the type of zone conditioning components such as heating, cooling, ventilation type and many more depending on preference in building. Hospeslaan 24 has only a heating system provided by a boiler at 85% efficiency (0,85) for zone heating and domestic heated water supply. No additional mechanical component is present in the building therefore HVAC comprised of a heating only system.

Under heating tab type of the heating provision is picked as boiler as well as the efficiency of the heating system. The boiler is supplied by natural gas. Component electricity is not included in consumption data simulations.

Lighting

Lighting in Hospeslaan 24 is only comprised of fixed lighting apparels inside the building. Even though no information was provided for the types of lighting or the number of appliances DesignBuilder template for the Netherlands under the lighting tab provides a certain value for the lighting appliances. Therefore for the first simulations Netherlands template is selected with 3,50 W/m^2-100 Lux.

4.3.5 Validation Conclusion

Predefined simulation inputs for the condition of the building envelope in previous chapters, zone sizes, building volume, DHW in the building and inputs highlighted (blue) in *table 3-10* are not changed during the calibration process of the annual energy consumption. However rest (orange) of the inputs were subject to change and have been changed to deliver as high precision as possible with accurate reasoning.

Indoor air temperatures are checked in the for the winter and summer season to highlight any low indoor air temperatures which would effect the simulation outcome for natural gas consumption. However the heating system of the building automatically sized itself in simulations according to outdoor conditions and sustained relevant indoor air temperatures.

	Dining Room	Living Room	Bedroom1	Bedroom2	Bedroom3	Bathroom & Toilet	Circulation & Attic	Kitchen
Zone Type	Conditioned	Conditioned	Conditioned	Conditioned	Conditioned	Conditioned	Conditioned	Conditioned
m^2	16,57	12,98	11,46	14,21	4,61	Bathroom- 5,76 Toilet- 0,98	-	
Occupancy	4	4	1	2	1	1	1	2
Density	0,24	0,308	0,0873	0,0704	0,21	0,17-Bathroom 1,02 Toilet	-	0,02
Schedule*	Dew_Dom Dining_Occ	Dew_Dom Living_Occ	Dew_Dom Bed_Occ	Dew_Dom Bed_Occ	Dew_Dom Bed_Occ	Dew_Dom Bath/toilet_Occ	Dew_Dom CommonAreas_Occ	Dew_Dom Kitchen_Occ
Metabolic	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer	1,0-winter 0,5-summer
Zone Conditioning (COP= 0,85 for Boiler)								
Heating Temperature	21	21	20	20	20	21	18	21
Heating Set-back	15	15	15	15	15	15	15	15
Cooling	Non	Non	Non	Non	Non	Non	Non	non
Mechanical	Non	Non	Non	Non	Non	Non	Non	Non

Ventilation								
Fresh Air l/s Per Person	7 l/s	7 l/s	7 l/s	7 l/s	7 l/s	7 l/s Extraction not reported	7 l/s	7 l/s No extraction
Lighting								
W/m^2-100 Lux	3,45	3,45	3,45	3,45	3,45	3,45	3,45	3,45
Lighting Template	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
Infiltration								
AC/H@50pa	16	16	16	16	16	16	16	16
DHW (COP= 0,85 for Boiler)								
Water (L/m^2)	Non	Non	Non	Non	Non	27,0-Bathroom 1,02-Toilet	Non	1,259

Table 4-10: Finalized zonal inputs used for simulation model validation.
** Schedules are defining user patterns in space as well as technical provisions.*

Schedules are defining the frequency of usage of a building technical component or of the corresponding space. With schedules in DesignBuilder it is possible to set heating, cooling, occupancy and air provision patterns of a space. Schedules can define the previously mentioned functions for a period of hours, to seasons.

Every zone regarding its purpose is given a corresponding schedule to simulate accurate results in consumption of the building regarding human behaviors. Within table 4-10 given schedules are defining the occupancy frequency of every zone with their specific function. Defined occupancy of the zone also determines the heating, cooling and the ventilation pattern, as it would be fallacious to provide heating when space is not occupied. Detailed numerical information for occupancy, ventilation, heating and cooling schedules are given in *appendix A.*

Due to accurate DHW consumption, sufficient indoor air temperatures and unalterable specifications of construction only infiltration rate and lighting power of the appliances are fine-tuned to deliver desired precision. Infiltration of the building had to be increased to 16 AC/H @50pa to increase the volume of the natural gas consumption of the building.

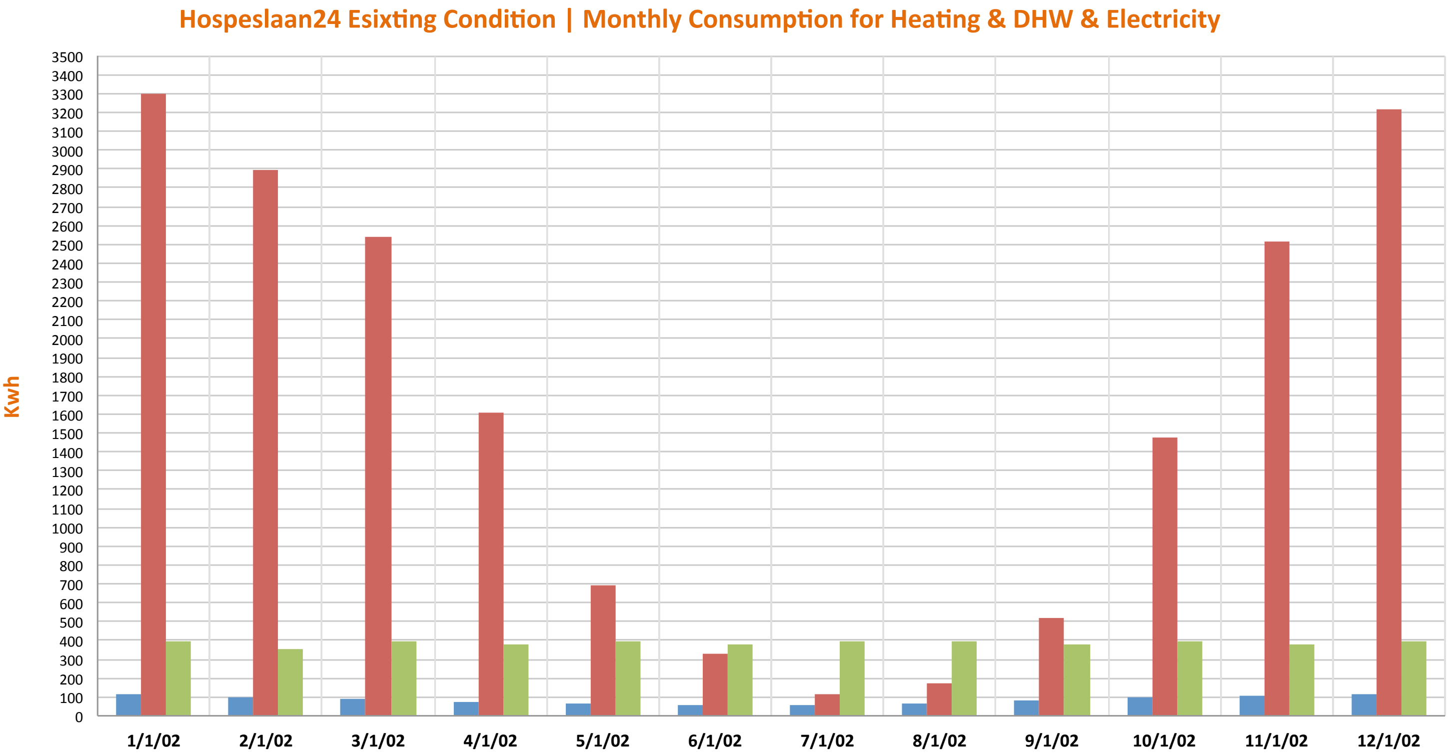
It is possible to have a building in Europe to have 16 AC/H@50pa or even higher infiltration rate through its envelope. According to (Konstantinou, 2014) current building stock in Europe has an infiltration rates range from 1,2 AC/H@50pa up to 16 AC/H@50pa as overall observation, while it is always possible to go even further as passive house infiltration rate is 0,6 AC/H@50pa.

Instead of using infiltration rate to increase the natural gas consumption it is possible to decrease the efficiency of the Boiler, therefore the system would require higher volumes of natural gas to deliver desired conditions. However the standard efficiency in DesignBuilder is 0,85; new standard technology boilers are do not have efficiencies lower than 0,85. Therefore boiler efficiency is not altered in the building. On the other hand lightning power has been reduced to 3,45 from 3,50 W/m^2-100 Lux to decrease the electricity consumption to reasonable values.

After the calibration of the simulation model, consumption values of the outcome are given in *table 4-11.* Consumption of the total natural gas for space heating and DHW has a precision of 98% for annual consumption. Electricity usage for fixed lighting appliances in the building is higher than the real-life consumption by 0.1%. The reflection monthly consumption in the building for the validated model is in *figure 4-13.*

Result Comparison	Delivered Natural Gas (kWh)	Natural Gas Volume (m^3)	Lighting (kWh)	Total Primary Energy (MJ)
Hospeslaan-24	24461,5 Assumed	2504 m^3	1017	97448
Simulation Model	23977 (98%)	2454,38 m^3 (98%)	1018,10 (0.1%)	95409 (98%)

Table 4-11: Calibrated simulation consumption, compared to real-life data



	1/1/02	2/1/02	3/1/02	4/1/02	5/1/02	6/1/02	7/1/02	8/1/02	9/1/02	10/1/02	11/1/02	12/1/02
Lighting	113.7801	94.05369	89.4676	71.6047	62.01896	55.75201	59.18607	69.12656	80.80164	101.4029	105.6485	115.1744
Heating (Gas)	3299.589	2897.045	2537.841	1608.19	689.1248	325.6043	110.5327	170.5139	520.8744	1472.137	2514.809	3219.914
DHW (Gas)	391.6888	353.7834	391.6888	379.0537	391.6888	379.0537	391.6888	391.6888	379.0537	391.6888	379.0537	391.6888

Figure 4-13: Monthly operational energy consumption per type in Hospeslaan24 validated simulation model.

5.0 Passive Measures for Refurbishment

Passive measures are based on reducing the energy consumption for space heating inside the building. Certain passive measures are insulation and the upgrade of building envelope, Openings & glazing replacement and reduction of envelope infiltration.

Measures are not only meant for reducing the energy consumption in space but to offer practical solution and to improve the condition of corresponding components of the building, including architectural aspect of intervention. Certain applications are in regard to the refurbishment strategies determined for Hospeslaan-24 to highlight different methods and possibilities

Within the following chapters building envelope & insulation, openings & glazing and infiltration of the envelope are evaluated differently under their own respective chapters with separate conclusions and simulation steps.

5.1 Building Envelope & Insulation

Building envelope & insulation step covers the quality of thermal resistance of the total building skin composition including walls, roofs, dormers and ground floor while excluding transparent openings on the envelope. Opaque sections for the building envelope are evaluated over their thermal performances and the application possibilities are elaborated regarding accepted refurbishment strategies for the envelope sections.

Not only the insulation values are taken into account but also the architectural qualities of the building envelope. Such as the exterior rendering, application possibilities, connections of wall edges for reduced thermal bridges and junction points. The building envelope is taken into account as a whole unit besides just the insulation thickness.

Detailing of the building envelopes are given in chapter *9.0 Final Design* for the purpose of defining all the aspects influential on the state of the envelope or the flooring before tinkering the possible real life application of the accepted state of the building skin and adjacent surfaces.

Simulation & Decisions Criteria's

Simulation criteria's determine the simulated inputs or the expected output from the optimization step. For insulation and the building envelope certain criteria's are applicability, commonly used materials for dwelling refurbishment, Dutch building regulations (chapter *2.3.7 Refurbishment Regulations in the Netherlands)* and corresponding refurbishment strategy and their construction scale.

For the upper limit of insulation, 6,0 R_c is determined as the cost effective tipping point for building insulation amount if so buildings desire a further upgrade than already very high Dutch insulation regulations. This limit is accepted according to the statement by (RVO, 2015).

Simulation purposes all the wall compositions are simplified within DesignBuilder to their thermal resistances due to insignificant values of rendering applications, bonding materials or surface leveling applications. However components with high importance are given as input in DesignBuilder with precision for higher accuracy on energy calculations.

5.2 Refurbishment 1 – Insulation & Building Envelope

External Wall

For insulation, mineral wool and cellulose are used for low production energy and construction constraints. When compared to oil derivative rigid board insulation elements, which can be used for surface insulation such as expanded (108 MJ/kg) & extruded (95 MJ/kg) polystyrene and polyurethane (101 MJ/kg); mineral wool (16,8 MJ/kg) and cellulose (7,6 MJ/kg) have lower embodied energy (16,8 MJ/kg) (Konstantinou, 2014).

Mineral wool is used on the exterior brickwork while the cavity wall is insulated with loose cellulose filling. The existing envelope is kept and insulation is applied over or in between layers. No heavy components or major alterations are applied for simple construction. Brick strips are used for keeping the same façade look. Detailed information for envelope inputs are given in *table 5-0*. Intervention on the envelope is illustrated in *figure 5-0*.

External Wall	Existing Construction	Material layers & mediums	Thickness	Rc Value	Rc Required	Refurbished State	Material layers & mediums	Thickness*	Rc Value
		Masonry cavity wall with brick on outer and inner leafs. Brick 60 mm – Air Cavity 60 mm – Brick 190mm. Load bearing for only itself. Inner leaf spans from slab to slab while outer leaf is connected to inner leaf at certain points.	310 mm from drawings	0,806	4,5		Cavity of the wall is insulated with loose filling cellulose and additional insulation is added to exterior brickwork with High-density mineral wool. Steen strips are used over with additional bonding materials to preserve the authentic look of the construction year.	- 25mm outer finishing steen strips (20 mm) with bonding material and structural fabric - High density mineral wool battens with 90mm thickness Brick 60 mm – Loose filling cellulose 60mm – 190mm Brick masonry inner leaf of cavity wall. - Plasterboard and interior finishing. **- Total Thickness 440mm without interior finishing**.	4,5

Table 5-0: Simulation inputs & materials choices for refurbishment-1 external wall.

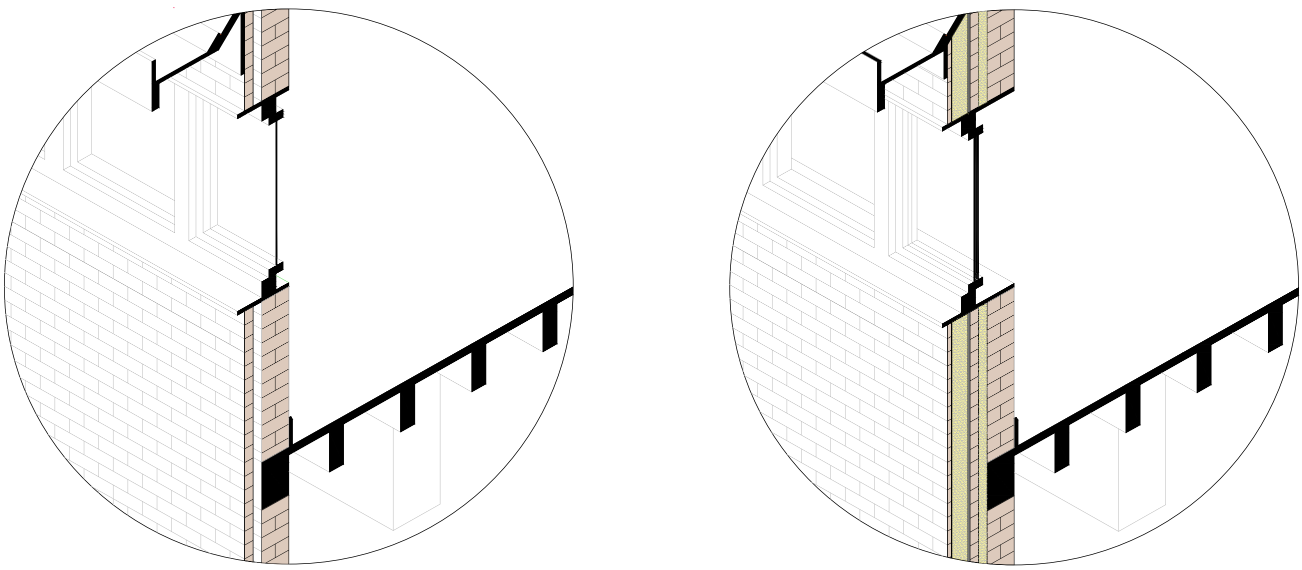


Figure 5-0: Refurbishment diagram of external walls | REF-1

Roof & Dormers

Roof insulation applied as an add-in strategy for refurbishments. Mineral wool insulation is applied from inside covering the roof slabs with 200mm thick mineral wool to provide an R_c value of 6,0 m^2k/W. Roof is insulated from the inside to reduce extensive construction work, as well as not to raise roof structural height, which would compromise the function of dormers. It is possible that insulation from inside could leave small thermal bridges on the connection edge of external walls and the roof structure. Inputs for Roof and dormers are given in *table 5-1.*

Dormers are not refurbished even though they do not comply with the Dutch regulations. Construction scale is the driving factor for not refurbishing dormers, as building should be usable under all conditions during refurbishment work for a realistic approach. Simple illustration of the roof & dormers upgrade intervention is given in *figure 5-1.*

		Material layers & mediums	Thickness	Rc Value	Rc Required		Material layers & mediums	Thickness	Rc Value
Pitched Roof	Existing Construction	Wooden construction pitched roof with Dutch roofing tiles 30mm – wooden battens 50x50mm – watertight membrane 3-4mm – plywood roofing slab 30mm.	310 mm	East Side roof 0,89 West Side Roof 1,18	6,0 for both pitched roof	Refurbished State	Dutch tiles 30mm with 50x50mm wooden battens watertight membrane 3-4mm and insulated construction: plywood roofing slab 30mm - 200mm mineral wool fiber blanket, vapor membrane gypsum board and interior finishing.	- 10mm PVC roof sheeting - 50x50mm wooden battens - 250mm prefabricated roof construction with 210mm insulation. - 26mm Vapor membrane, Plasterboard and interior finishing. **- Total Thickness 310mm without interior finishing.**	6,0
Dormer Flat Roof & Sides	Existing Construction	**Flat Roof:** Sandwich panel with expanded polystyrene 85mm with mastic roofing for watertight finishing. **Side Façade:** Sandwich panel with expanded polystyrene insulation 90mm and 100mm siding finishing.	310 mm	Flat Roof 2,53 Rc Side Facades 2,53 Rc	6,0 for flat roof 4,5 for side facade	Refurbished State	No change to dormers.	310 mm	6,0 for flat roof Side Facades 4,5

Table 5-1: Simulation inputs & material choices for roof refurbishment

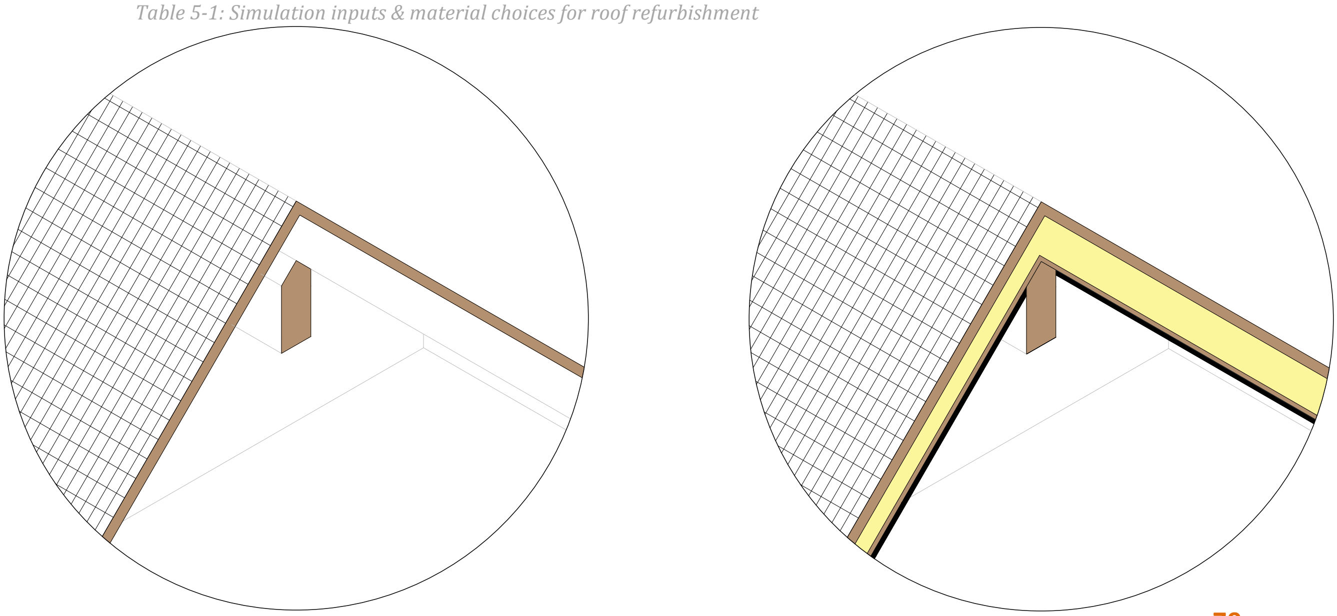


Figure 5-1: Refurbishment diagram of roof & dormers | REF-1

Ground Floor

Ground floor is insulated with mineral wool blanket, which covers the exposed slab and structural members along with crawlspace sidewalls retaining the soil on the foundation. Crawlspace is insulated from inside as well as from outside to prevent possible thermal bridges through foundation structure. With the application of insulation to exterior as well as to the interior of the foundation retaining walls possibility of thermal bridge is avoided minimizing the possibility of outside climate exposure of the building due to detailing malfunction.

Refurbishment complies with the Dutch regulations as a whole composition of ground floor. Within table… inputs and material details are given for ground floor along with refurbishment diagram in *table 5-2.* Diagram in *figure5-2* is illustrating the insulation application.

Ground Floor & Crawlspace	Existing Construction	Material layers & mediums	Thickness	Rc Value	Rc Required	Refurbished State	Material layers & mediums	Thickness	Rc Value
		Wooden slab with horizontal wooden beams for support and floor finishing 2-5mm.	2x13 mm only slab 26mm 2x13+ 60mm with beams 86mm	Ground floor 0,36 Rc	3,5 for ground floor		Wooden slab with horizontal wooden beams for support and floor finishing 2-5mm. Mineral wool blanket 120mm thickness covering for slab and beams and crawlspace walls.	2x13 mm with 120mm additional insulation thickness: **146-150mm thickness with finishing.**	3,5 ground floor

Table 5-2: Simulation inputs & materials choices for ground floor refurbishment

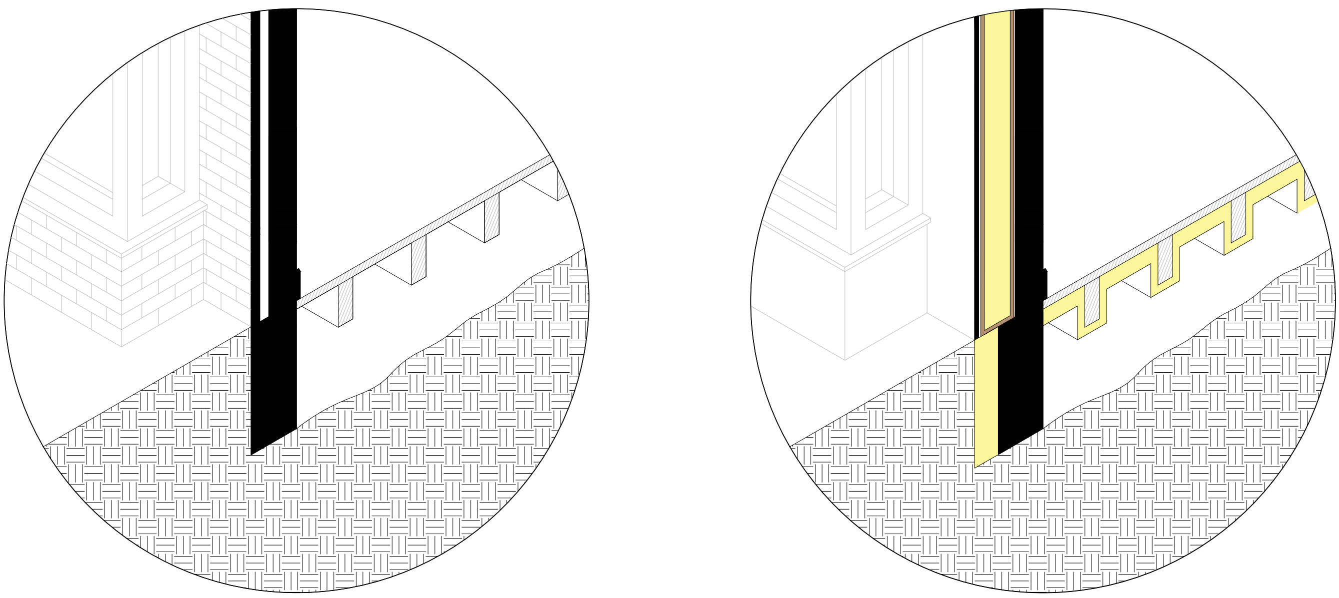


Figure 5-2: Refurbishment diagram of ground floor (crawlspace) | REF-1

5.3 Refurbishment 2 – Insulation & Building Envelope

External Wall

Insulation material for external wall is the same as refurbishment-1. Mineral wool is fixed in between two layers of OSB for increased rigidity as well as for prefabrication to reduce on-site work time. Whole composition and the simulation inputs of the existing and renewed state is given in *table 5-3* with materials used for the whole wall compositions from outside to interior finishing. Illustration in *figure 5-3* gives the application of the measures and the composition of the external walls.

Flexible application for exterior finishing is possible with prefabricated panels. The necessary surface and mechanical attachment can be implemented to the detailing easier increasing possible finishing and treatment for the building envelope. Prefabricated panels reduce the infiltration rate of the building by decreasing the number of junction by removing the outer leaf of the masonry wall thus upgrading the first line of defense and minimizing the impact of cracks, seams and misalignments of components after years of usage.

External Wall	Existing Construction	Material layers & mediums	Thickness	Rc Value	Rc Required	Refurbished State	Material layers & mediums	Thickness	Rc Value
		Masonry cavity wall with brick on outer and inner leafs. Brick 125 mm – Air Cavity 60 mm – Brick 1250mm. Load bearing for only itself. Inner leaf spans from slab to slab while outer leaf is connected to inner leaf at certain points.	310 mm	0,806	4,5		Outer leaf of the masonry wall is replaced with prefabricated insulated external wall component. OSB 15mm – 150mm Mineral Wool – OSB 15mm + 190mm inner brick leaf from existing construction. White paint finishing with mortar rendering.	- 6mm-10mm External Wall finish & Rendering. - 180mm Prefabricated wall panel with 150mm insulation. - 125mm Brick masonry inner leaf of cavity wall. - 30mm Rendering mortar for surface leveling, plasterboard and wall finishing. **- Total Thickness 370mm without interior finishing**.	4,5

Figure5-3: Simulation inputs & materials choices for refurbishment-1 external wall

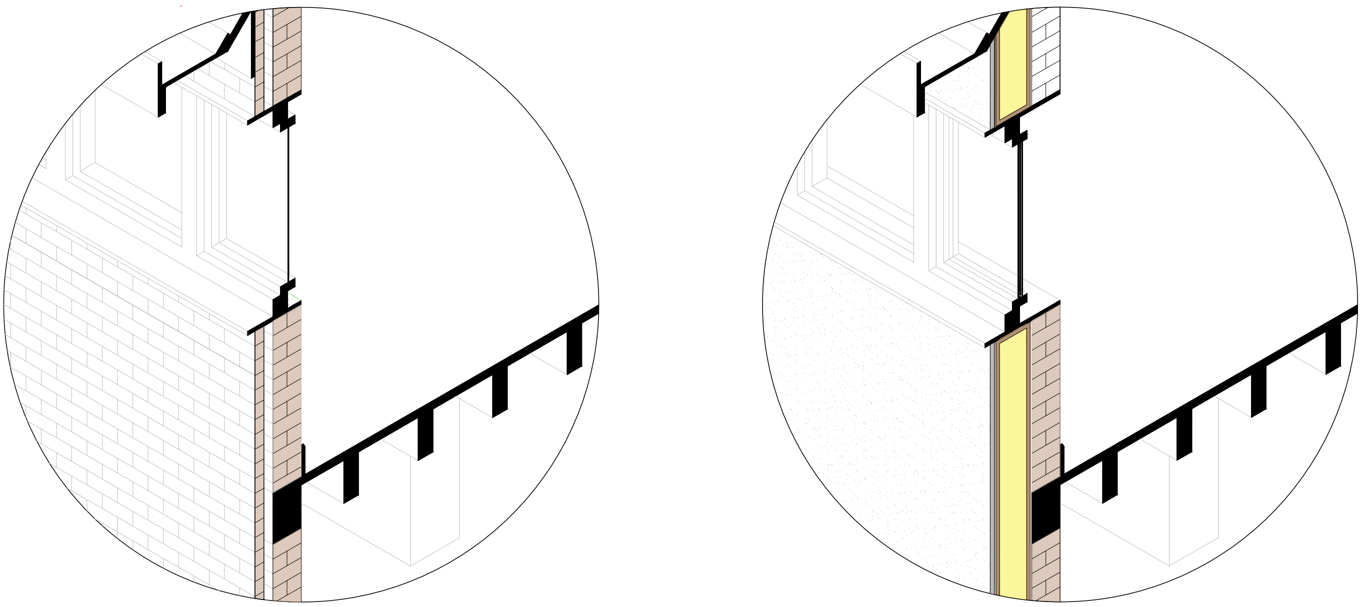


Figure 5-3: Refurbishment diagram of external walls | REF-2

Roof & Dormers

Within refurbishment-2 roof structure is prefabricated as insulated block for quick installation on site. Existing roof structure is removed from the building to be replaced with prefabricated construction.

Roof finishes of exterior and interior are constructed on site. Inputs of roof and the dormers are given in *table 5-4.* Due to additional weight of the prefabricated construction with insulation, bracing may be required for existing roof load bearing members. Dormers and pitched roof are constructed together as one prefabricated unit and moved to the construction site. Roof insulation of dormers is the continuation of the pitched roof construction. Diagram in *figure 5-4* illustrates the construction application.

		Material layers & mediums	Thickness	Rc Value	Rc Required		Material layers & mediums	Thickness	Rc Value
Pitched Roof	Existing Construction	Wooden construction pitched roof with Dutch roofing tiles 30mm – wooden battens 50x50mm – watertight membrane 3-4mm – plywood roofing slab 30mm.	310 mm	East Side roof 0,89 West Side Roof 1,18	6,0 for both pitched roof	Refurbished State	Prefabricated insulated roof construction. Dutch tiles 30mm with 50x50mm wooden battens watertight membrane 3-4mm and insulated construction: Water resistant plywood 25mm- 210mm mineral wool- OSB 15mm. Interior finishing vapor membrane with plasterboard render.	- 10mm PVC roof sheeting - 50x50mm wooden battens - 250mm prefabricated roof construction with 210mm insulation. - 26mm Vapor membrane, Plasterboard and interior finishing. **- Total Thickness 310mm without interior finishing.**	6,0
Dormer Flat Roofs & Side Facade		**Flat Roof:** Sandwich panel with expanded polystyrene 85mm with mastic roofing for watertight finishing. **Side Façade:** Sandwich panel with expanded polystyrene insulation 90mm and 100mm siding finishing.	310 mm	Flat Roof 2,53 Rc Side Facades 2,53 Rc	6,0 for flat roof 4,5 for side facade		**Flat Roof:** Similar Roofing construction with pitched roof **Side Façade:** Prefabricated insulated construction. Plywood 15mm – mineral wool 160mm – OSB 15mm and plasterboard finishing.	**Flat Roof:** Roof thickness is similar to pitched roof thickness. **Total Thickness 310mm without interior finishing.** **Side Façade:** 200mm Prefabricated insulated construction with 100mm exterior siding. Plasterboard interior with fine finishing. **Total Thickness 300mm without interior finishing.**	6,0 for flat roof Side Facades 4,5

Table 5-4: Simulation inputs & material choices for roof refurbishment

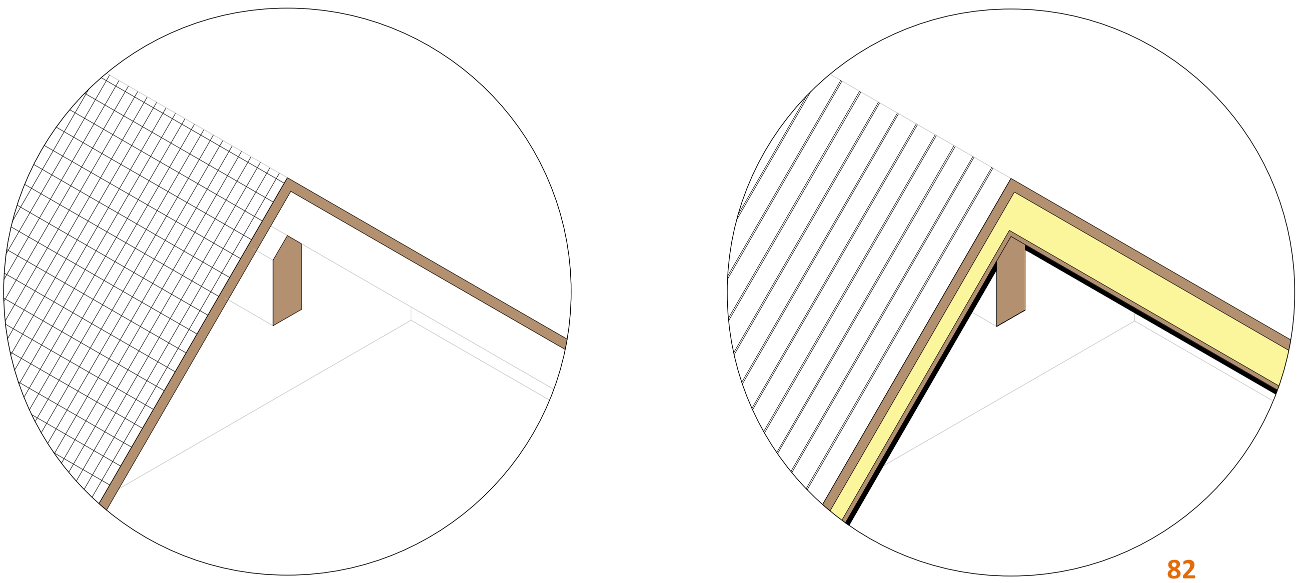


Figure 5-4: Refurbishment diagram of roof & dormers | REF-2

Ground Floor

Ground floor is insulated with mineral wool blanket, which covers the exposed slab and structural members along with crawlspace sidewalls retaining the soil on the foundation. Crawlspace is insulated from inside as well as from outside to prevent possible thermal bridges through foundation structure. Refurbishment complies with the Dutch regulations as a whole composition of ground floor. Within *table 5-5* inputs and material details are given for ground floor along with refurbishment diagram in *figure 5-5.*

		Material layers & mediums	Thickness	Rc Value	Rc Required		Material layers & mediums	Thickness	Rc Value
Ground Floor & Crawlspace	Existing Construction	Wooden slab with horizontal wooden beams for support and floor finishing 2-5mm.	2x13 mm only slab 26mm 2x13+ 60mm with beams 86mm	Ground floor 0,36 Rc	3,5 for ground floor	Refurbished State	Wooden slab with horizontal wooden beams for support and floor finishing 2-5mm. Mineral wool blanket 120mm thickness covering for slab and beams and crawlspace walls.	2x13 mm with 120mm additional insulation thickness: **146-150mm thickness with finishing.**	3,5 ground floor

Table 5-5: Simulation inputs & materials choices for ground floor refurbishment

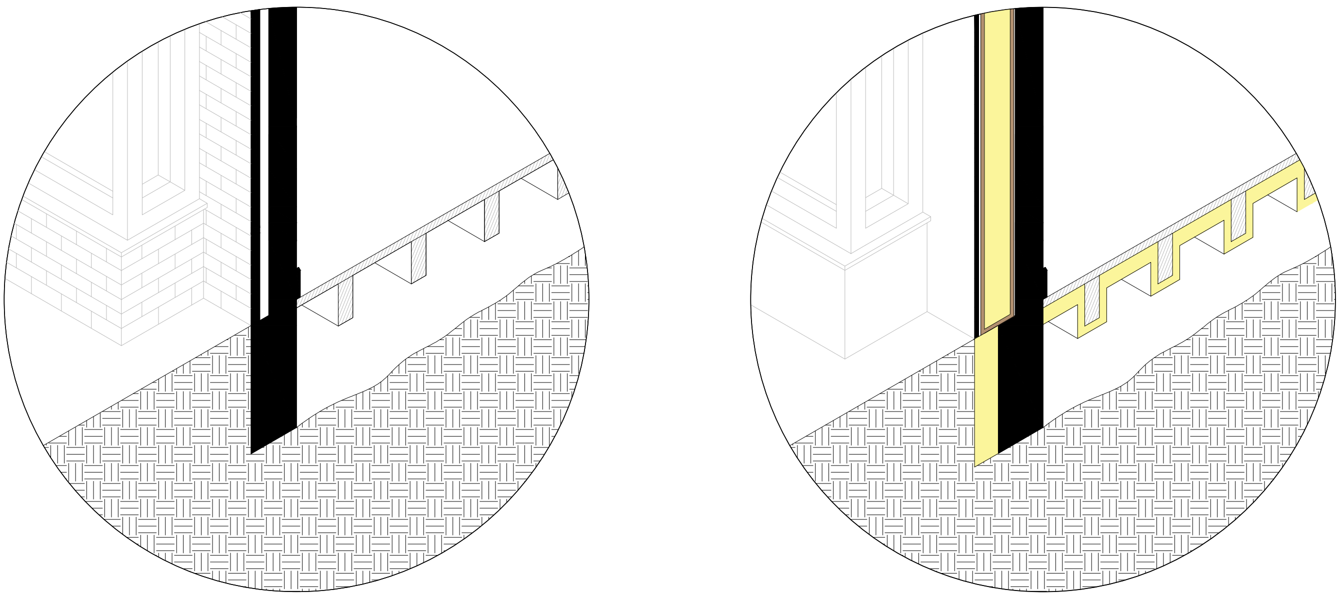


Figure 5-5: Refurbishment diagram of ground floor (crawlspace) | REF-2

5.4 Insulation Results & Conclusion

Insulation of a building is the most common solution for energy refurbishments in order to reduce energy consumption for heating, balancing temperature fluctuations inside building zones and reducing the impact of outdoor conditions on interior living space. *Table 5-6* gives the improvement rates of insulation applications depending on refurbishment strategies.

Minimum levels of Dutch insulation regulations result in 25% reduction for refurbishment-2. When all envelope sections (External Walls & Ground Floor) are increased to R_c 6,0 m^2K/w in refurbishment-2alt. annual gas consumption is reduced by only 159,2 kWh which is 1% improvement from the previous step of refurbishment.

When the insulation amount is increased, reduction on energy consumption for heating is not as effectively reduced compared to already given minimum values. Therefore insulation is only applied to comply with regulations instead of surpassing the minimum with extensive insulation measures on the envelope. Gas consumption for heating per month is given in *figure 5-6* for refurbishment-1 and refurbishment-2 along with pre-insulated state of the building for comparison.

Two different insulation approaches were followed for two different refurbishment strategies. Aim of different insulations have been to deliver necessary regulation conditions, therefore materials and their thicknesses were picked accordingly. Insulation and the building envelope upgrades are not only a building physics solution but also an architectural approach.

Refurbishment Strategy	Existing Annual Gas Consumption (heating Only)	Post Insulation Annual Gas Consumption (heating Only)	Consumption Reduction (%)
Refurbishment-1 (sim-1)	19366,1 kWh	14717,5 kWh	24%
Refurbishment-2 (sim-2)	19366,1 kWh	14563,0 kWh	25%
Refurbishment-2alt. (sim3) Every section upgraded 6,0 R_c	19366,1 kWh	14403,7 kWh	26%

Table 5-6: Annual consumption values for delivered natural gas per refurbishment option with additional refurbishment-2alt to highlight full 6,0 R_c insulation for every envelope section.

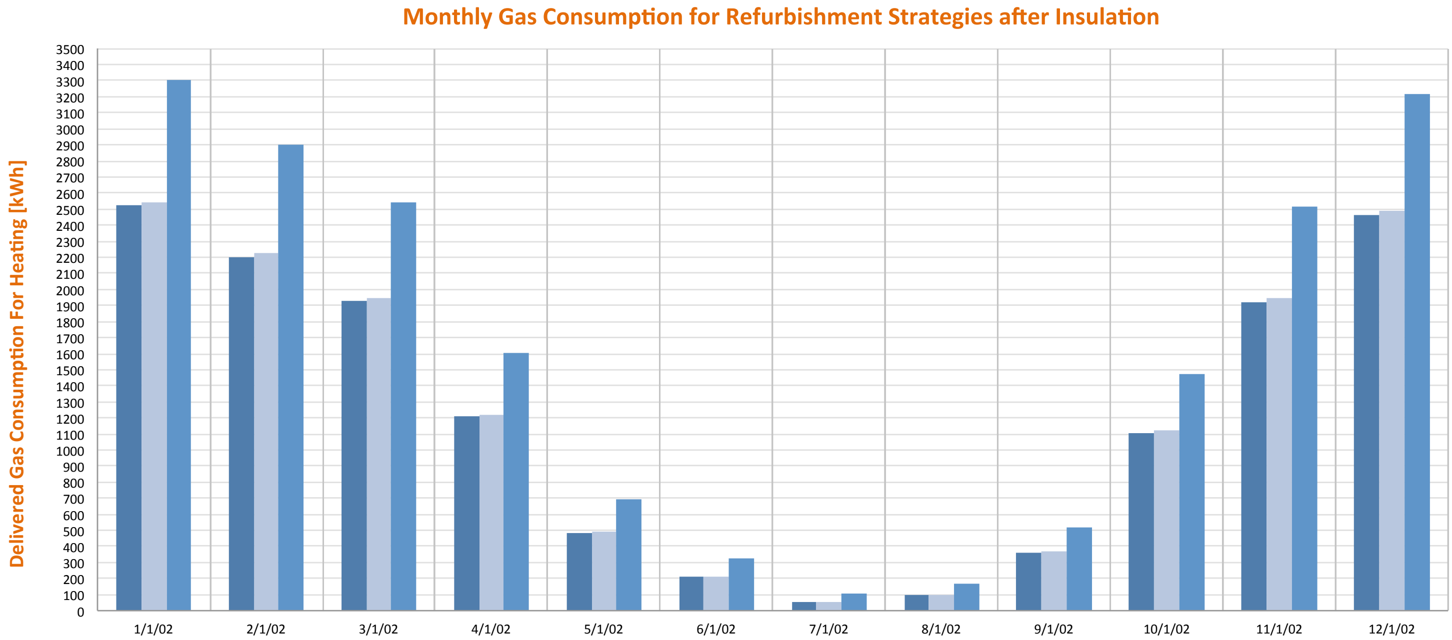
Ideally both refurbishment-1 and refurbishment-2 are possible candidates to be accepted as a refurbishment solution for Hospeslaan24 envelope for a final design. Both of the strategies result in very limited differences for space heating consumption due to complying with the minimum requirements of the Dutch building regulations for envelope thermal resistances.

Difference between the annual gas consumption for space heating is caused by the insulation of dormers and the thermal mass of the whole wall, roof compositions in refurbishment strategies. Within refurbishment-1 dormers are not insulated due to resulting construction complexity, while refurbishment-2 offers total insulation for roof components for being more flexible.

Thermal mass is a distinct factor, which distinguish refurbishment strategies from each other impacting on their effectiveness on space heating reduction. Even though thermal mass is not evaluated in the research, it adds to the character of refurbishment strategy of the envelope components.

Refurbishment strategies are distinguished by their possibility of reducing infiltration levels in the building. Refurbishment-2 is completely replacing the outer leaf of the building with a new durable and effective thermal skin along with the building roof, which reduces the junction points of the total building skin. Reduction on critical junction points along with reduced on site work for possible leakage points enables refurbishment-2 to have a better (lower) infiltration rate compared to refurbishment-1 considering that refurbishment-1 is highly dependent on on-site work and the existing envelope is still preserved.

For final design both of the refurbishment are possible to be selected for their performance similarities. However for going beyond and reducing limitations on applications, refurbishment-2 is much more ideal compared to refurbishment-1 measures. Within the following steps both of the refurbishment strategies for the building envelope will be kept to highlight the final results. Thou if a selection had to be made it would have been refurbishment-2.



	1/1/02	2/1/02	3/1/02	4/1/02	5/1/02	6/1/02	7/1/02	8/1/02	9/1/02	10/1/02	11/1/02	12/1/02
Refurbishment-2	2520.063	2200.557	1929.047	1206.769	486.4041	208.0677	52.66912	98.82877	363.6024	1108.684	1922.797	2465.531
Refurbishment-1	2544.091	2222.615	1948.69	1220.75	493.6945	211.2228	53.59639	100.6542	369.6091	1121.719	1942.052	2488.856
Existing Situation	3299.589	2897.045	2537.841	1608.19	689.1248	325.6043	110.5327	170.5139	520.8744	1472.137	2514.809	3219.914

Figure 5-6: Gas consumption per month for refurbishment options after opaque envelope sections upgrade

5.2 Glazing Type & Window Composition

Window and glazing options are based on real life fenestration option and selected from companies regarding their different physical & thermal capabilities. Selected window options are generated in DesignBuilder regarding their glazing composition, frame thickness & material and insulation material if applicable.

Simulation & Decision Criteria's

Certain criteria's for glazing and openings options are utilizing passive solar gain effectively to reduce energy consumption for heating in space, reduce energy consumption; minimize the reduction on visibility and daylight properties inside the building, optimization regarding orientation and solar exposure and cost effective selection, while complying with the Dutch building regulations given in chapter *2.3.7 Refurbishment Regulations in the Netherlands.*

5.2.1 Glazing types and inputs

Fenestration options are selected according to their U glazing, composition of glazing including coatings, frame material and insulation, glass transmittance, SHGC (solar heat gain coefficient) and U-window of the total composition.

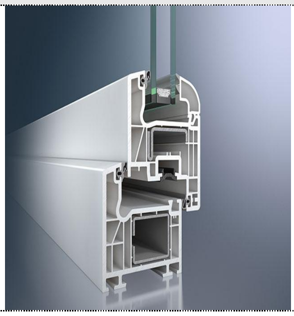
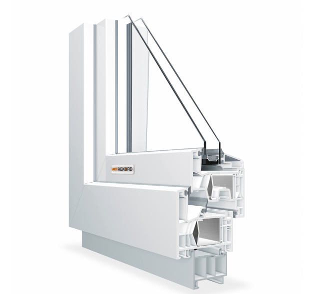
WINDOWS				
Technical Info	Schueco Corona CT 70	Rekord Basic	Internorm HF 210	Geneo PHZ
Image				
Image Source	http://www.admegatec.com/sites/default/files/styles/vierkant/public/ramen-deuren/ct70-classic.jpg?itok=4BeesDiK	http://www.oeko-therm-systems.at/media/img/de/fenster-tueren-einrichten/holzalu-holzfenster/Basic_Profil_76_Neu_Schatten.jpg	https://www.internorm.com/uk-en/products/home-soft-windows-doors/windows/timber-aluminium/hf-210.html	https://www.rehau.com/at-de/handwerker/fenster-tueren/fenstersysteme/geneo-phz-fenster
Frame Material	PVC	PVC	Wooden frame with AL cladding and PUR insulation between cladding and frame	PVC with PUR insulated fixed and wing frame
Fixed Frame	70mm x 70mm	76mm x 82mm	85mm x 85mm	85mm x 85mm
Wing Frame	70 mm x 120mm +fixed	76 mm x 120mm +fixed	85mm x 114mm+fixed	85mm x 115mm+fixed
U-window	1,3 W/m^{2}K in accordance with DIN *EN 12412-2*	1,3 W/m^{2}K in accordance with *DIN EN 12412-2*	0,67 W/m^{2}K in accordance with *DIN EN 12412-2*	0,9 W/m^{2}K in accordance with *DIN EN 12412-2*
U-glass	1,1 W/m^{2}K 24mm	1,0 W/m^{2}K 24mm	0,66 W/m^{2}K 52mm	0,9 W/m^{2}K 52mm
Glass Configuration	4-16-4 90% Argon filling AGC 4mm iplus – 16mm Ar – 4mm Planibel Low E pos.3	4-16-4 90% krypton filling AGC 4mm iplus – 16mm Kr – 4mm Planibel Low E pos.3	8-16-4-16-8 90% krypton filling AGC 8mm planibel Low E pos.2 – 16mm Kr – 4mm Planibel Clearvision – 16mm Kr - 8mm planibel Low E pos.5	8-16-4-16-8 90% krypton filling AGC 8mm Planibel Clearvision – 16mm Kr – 4mm Planibel Clearvision – 16mm Kr - 8mm planibel Low E pos.5
U-frame	1,2 W/m^{2}K	1,1 W/m^{2}K	0,73 W/m^{2}K	0,79 W/m^{2}K
Acoustics	32 dB	33 dB	47 dB	47 dB

Table 5-7: Technical Specifications of window compositions used in simulations

5.2.2 Glazing & Openings Simulations

Existing Condition- Single Glazing

Existing condition is accepted as the base point for every simulation. Base point of the glazing simulations is the step after insulation application and values in table 5-8 reflect the outcome of the simulation results of single glazing configuration with applied insulation.

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	14717,5	1015,6	5415,9	0,82	0,83	4,6
Refurbishment-2	14563,0	1015,6	5415,9	0,82	0,83	4,6

Table 5-8: Existing condition after insulation & building envelope upgrade

Throughout the simulations it is expected to reduce heating consumption, balance solar gain in space without increasing electricity consumption too much as well as keeping glass transmittance as high as possible for visual comfort. It must be noted that glass transmittance and passive solar gain in this step cannot be increased any further considering that windows are single glazing.

Simulation 1 – Schueco Corona CT70 | All Round

For Refurbishment 1 and refurbishment 2 all the windows are upgraded to Schueco Corona CT70 on all orientations (East-West). For an accurate comparison of different simulations, changes to windows in every step are kept the same with their previous one.

Window frame thicknesses and their U-values are defined accordingly into every opening along with the glazing configuration given in *table 5-9.* It is expected to balance the solar gain through openings and heating consumption reduction in the building, without compromising visual comfort in the space, which is monitored with the electricity consumption increase or decrease in building overall.

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	9489,3	1022,9	4585,1	0,71	0,74	1,17
Refurbishment-2	9190,8	1022,9	4585,1	0,71	0,74	1,17

Table 5-9: Results after first simulation inputs

Annual simulation outcome has shown that the glazing configuration of Schueco Corona has reduced daylight penetration through the opening due to high performance low-e coating. One of the reasons of electricity increase to 1047,8 kWh is the glass average transmittance reduction to 0,747 from 0,836. However glazing upgrade has reduced gas consumption in the building by 35.5% for ref-1 and 36.5% for ref-2

Simulation 2- Rekord Basic | All Round

Rekord Basic has better glazing and frame U-value with higher glass transmittance therefore it is expected to have higher amount of solar penetration to the space along with reduced heating loss through glazing configuration. Change of glazing configuration has given the results in *table 5-10.*

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	9313,6	1017,0	5289,2	0,74	0,800	1,1
Refurbishment-2	9139,1	1017,0	5289,2	0,74	0,800	1,1

Table 5-10: Results after second simulation inputs

Upgrade of window glazing to 1,0 W/m^{2}K U and high glass transmittance compared to simulation-1 inputs has reduced gas consumption by 36.5% for ref-1 and 37.2% for ref-2. Reduction on the gas consumption between simulation-1&2 is the results of increased passive solar gain and reduced U-window.

Simulation 3- Internorm HF 210 | All Round

Internorm HF 210 triple glazing with Passive house certification is used to assess if a high performance triple glazing could be a possible solution for the building energy consumption. Triple glazing is expected to reduce heating consumption with very low U value for window, however low-e coatings for first (2nd surface) and third (5th surface) glass are a necessity for a triple glazing to reach 0,6 W/m^{2}K eventually reducing passive solar gain due to increased reflection in first glass sheet.

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	9661,0	1043,9	2231,2	0,360	0,523	0,61
Refurbishment-2	9185,9	1043,9	2231,2	0,360	0,523	0,61

Table 5-11: Simulation results Internorm HF 210

Simulation results are given in *table 5-11.* Triple glazing decreased passive solar gain by 58.8%. Even though the U-window is improved to 0,66 k/Wm^2 reduction in gas consumption for heating is reduced by 35% for ref-1 and 37% for ref-2. The simulation also reflects that solar gain during certain periods are compensating for the heating provision in to a space. Increased space temperature due to solar radiation from windows is providing additional sensible heating to the space and therefore reducing the provided heating for certain periods throughout the year. However Internorm HF 210 is neither increasing passive solar gain nor reducing annual total gas consumption as effectively as simulation-2.

Simulation 4- Rehau Geneo

It is required to sustain a low U-value for the window along with high solar heat gain coefficient to allow additional passive solar gain. Therefore in simulation 4, a window with triple glazing but single low-e coated glass sheet configuration is used. Simulation-4 is conducted for the possibility of reducing the heating consumption below simulation 2 levels, along with solar gain to find a balance in heating reduction without compromising the building for overheating.

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	9045,0	1026,7	4154,8	0,65	0,686	1,06
Refurbishment-2	8844,0	1025,4	4154,8	0,65	0,686	1,06

Table 5-12: Simulation results for Rehau Geneo fenestration option

Results of the simulation are in *table 5-12*. Gas consumption for heating is reduced by 38.5% for ref-1 and 39.2% for ref-2. Electricity consumption is lowered compared to simulation-3 results. Reduction of heating consumption along reduced solar gain reflects a balanced situation between solar gain and heating provision for all the building spaces. However triple glazing solutions are costly compared to standardized double-glazing windows, therefore a combination of double and triple glazing can be preferred unless this combination comes close to simulation-4 performance.

Simulation 5- Rehau Geneo & Rekord Basic

When considering the orientation of the building, east and west facing envelopes could address the heating consumption performance of a building depending on their opening ratio, type of window and effective glazing. Therefore in simulation-5 two different glazing types are considered for east and west orientations of the building. Windows from simulation-2 and 4 are picked for assessment of performance to perform better than simulations conducted prior.

West facing façade has a higher wall to window ratio than east facing façade therefore in order to maximize passive solar gain in the spaces facing west, Rekord Basic (U-window 1,3 W/m^2K) is used. While on east facing façade Rehau Geneo (U-window 0,9 W/m^2K) is used to balance out solar gain and heating consumption due to thermal loss. Results are given in *table 5-13.*

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment-1	9220,4	1022,6	4783,5	0,69	0,723	1,080
Refurbishment-2	9070,0	1022,6	4783,5	0,69	0,723	1,080

Table 5-13: Simulation results for Rehau Geneo (east) & Rekord Basic (west) combination.

Regardless of the orientation of the different glazing applications, increased global U-window results in higher annual heating consumption compared to simulation-4 1.5% for ref-1 and 1.7% for ref-2. Additional passive solar gain has not balanced or decreased the consumption due to seasonal mismatches in passive solar gain amounts.

Simulation 6- Rekord Basic & Rehau Geneo

Based on the outcome of simulation 5, glazing configuration is reversed. Rekord Basic (U-window 1,3 W/m^2K) is used on east facing envelope to maximize solar gain through east facing façade, while Rehau Geneo (U-window 0,9 W/m^2K) is used on west facing façade.

Strategy	Heating Usage - Gas (kWh)	Electricity Consumption (kWh)	Solar Gain (kWh)	Averaging Glass SHGC	Averaging Glass Transmittance	Averaging Glass U factor
Refurbishment 1	9078,8	1020,1	5067,3	0,65	0,686	1,07
Refurbishment-2	8907,0	1020,1	5067,3	0,65	0,686	1,07

Table 5-14: Simulation results for reversed application of window options

Results for simulation-6 are in *table 5-14.* The global U-window is increased in the simulation and it is expected to reflect increased heating consumption. However, the decrease of thermal resistance of the window is matched with increased passive solar gain. The balance between passive solar gain in building and annual heating consumption regarding building orientation and glazing type is optimized with simulation 6.

Solar gain is effectively reduced compared to simulation-2 by and despite the heating consumption reduction amount did not reach simulation 4 levels, simulation 6 has become a cost effective alternative for totally triple glazed option.

4.2.2 Glazing Simulations Conclusion

Within *table 5-15,* preference of glazing is given depending on the simulation results, cost effectiveness, electricity and visibility outcome. When selection of the window composition is only based on energy consumption for heating, replacing all the windows with Rehau Geneo has the best performance with all around triple glazing reducing consumption by 38.5% for Ref-1 and 39.2% for Ref-2.

Daylight performance of different window compositions is determined by the increase in electricity usage in the building. Simulation-2 has the best performance with 0.4% increase in lighting, however when compared regarding energy consumption, simulation-4 performs better for both refurbishment options and priority of reducing space heating is more significant than daylight quality in space.

		Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6
Glazing type		Schueco Corona Double Glazing	Rekord Basic Double Glazing	Internorm HF 210 Triple Glazing	Rehau Geneo Triple Glazing	Rehau Geneo East / Rekord Basic West	Rehau Geneo West / Rekord Basic East
U-Glass		1,16 W/m^2K	1,1 W/m^2K	0,6 W/m^2K	1,06 W/m^2K	1,080 W/m^2K effective average	1,070 W/m^2K effective average
Delivered Gas Reduction	**Ref1**	5228,2 kWh – **35,5%**	5403,8 kWh – **36.5%**	5056,5 kWh – **35%**	5672,5 kWh – **38.5%**	5494,63 kWh – **37%**	5638,72 kWh – **38.3%**
	Ref2	5372,13 kWh- **36.5%**	5423,89 kWh- **37.2%**	5377,10 kWh- **37%**	5718,92 kWh- **39.2%**	5493,525kWh- **37.5%**	5656,02 kWh- **39%**
Lighting (Electricity)		1024,68 kWh – **0.7%** increase	1021,62 kWh – **0.4%** increase	1138,6 kWh – **2.5%** increase	1028,86 kWh – **1%** increase	1027,15 kWh – **0.9%** increase	1023,67 kWh – **0.6%** increase
Passive Solar Gain		4585,1 kWh - **15%** lower	5189,2 kWh - **4%** lower	2231,2 kWh- **59%** lower	4154,883 kWh- **23%** lower	4551,219 kWh- **19%** lower	5067,319kWh- **6.5%** lower
Daylight		Low reflectance single coating good daylight penetration	Low reflectance single low-e coating good daylight penetration	High reflectance with glazing type, double low-e coating	Medium reflectance with glazing type, low-e single coating	Medium to low reflectance with glazing type, low-e single coating	Medium to low reflectance with glazing type,single low-e coating
Maintenance		No regular maintenance needed for PVC frame	No regular maintenance needed for PVC frame	Regular maintenance needed for wooden frame / low lifespan	No regular maintenance needed for PVC frame	No regular maintenance needed for PVC frame	No regular maintenance needed for PVC frame
Cost		Moderate- PVC frame standard double glazing	Moderate- PVC frame standard double glazing	Very High- composite frame with passive house triple glazing	High- triple glazing with single low-e coating, PVC – PUR insulated frame	High - Moderate Combination of double and triple glazing	Moderate – High Combination of double and triple glazing

Table 5-15: Summary of performance for every glazing individually and in combination under simulation steps of 1-6

Passive solar gain is utilized to reduce energy consumption in the building with the usage of low u-values for the window composition. Simulation-2 maximizes passive solar gain by reducing it only by 4% however it is not ideal increase passive gain due to possible overheating during summer season. Therefore a balance is crucial between passive solar gain and the total u-value of the window composition. Simulation-4 & simulation-6 creates the balance between average u-window and reduced solar gain in space, however in both conditions for heating energy reduction and passive solar gain balance, simulation-4 performs better than simulation-6 inputs given in *table 5-15.*

However cost is a driving factor for fenestration choices. Even though simulation-4 in *figure 5-7 & 5-8* has the most effective energy performance; replacing all the openings with triple glazing is costly. Combination of triple and double-glazing in simulation-6 is performing as equal as simulation-4 with 0.2% off for Ref-1 and 0.3% off for ref-2 regarding annual gas consumption reduction.

Even though the passive solar gain in the building is balanced better in simulation-4 it is possible to eliminate or minimized the impact of solar gain in summer season with shading elements. Therefore inputs of simulation-6 are selected as the fenestration solution for both of the refurbishments. Differences between the energy reductions of refurbishment strategies are caused due to different application of insulation and the resulting thermal mass from insulation and building envelope differences.

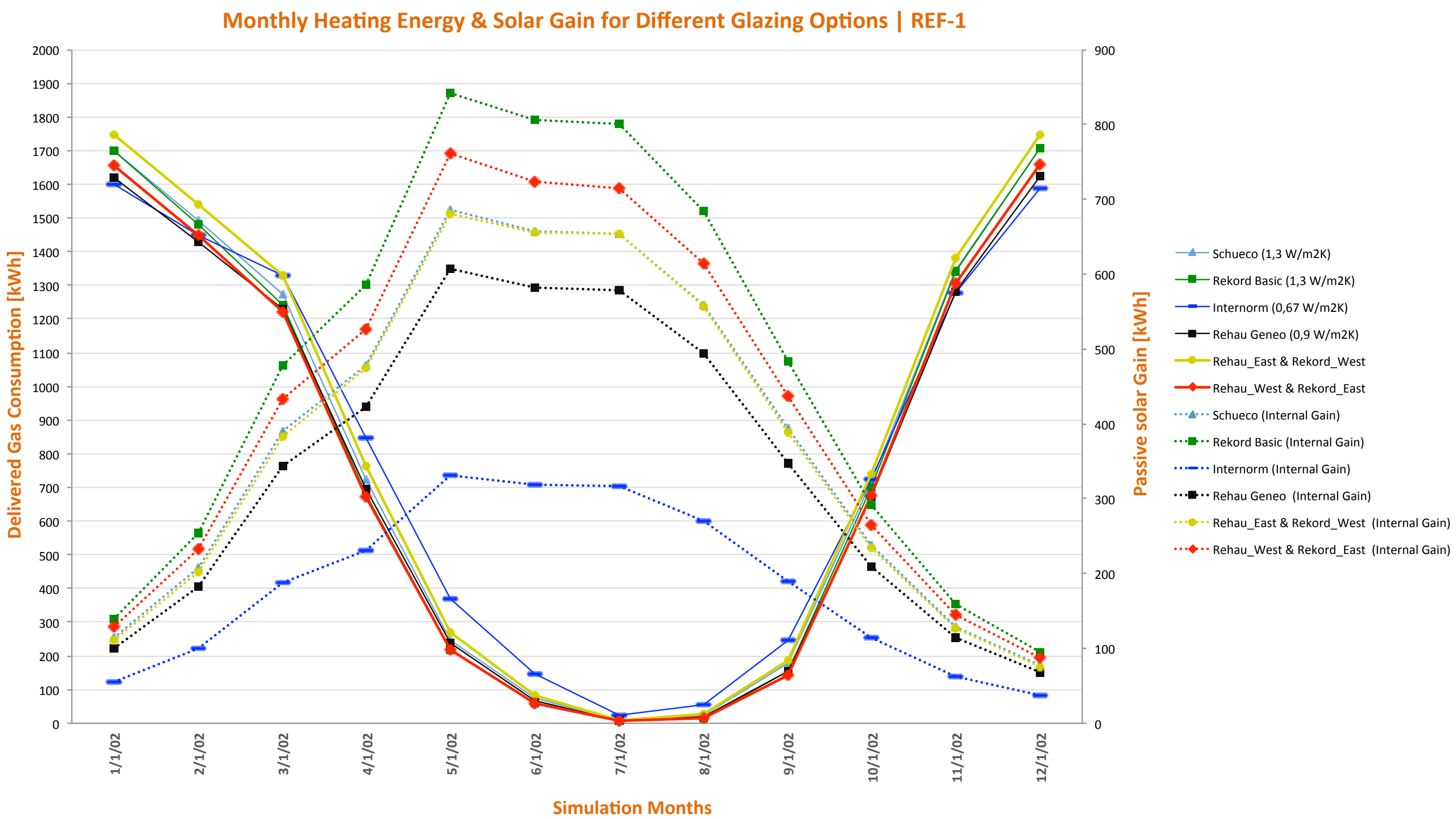


Figure 5-7: Monthly gas consumption & solar gain for Refurbishment-1 in all simulation steps

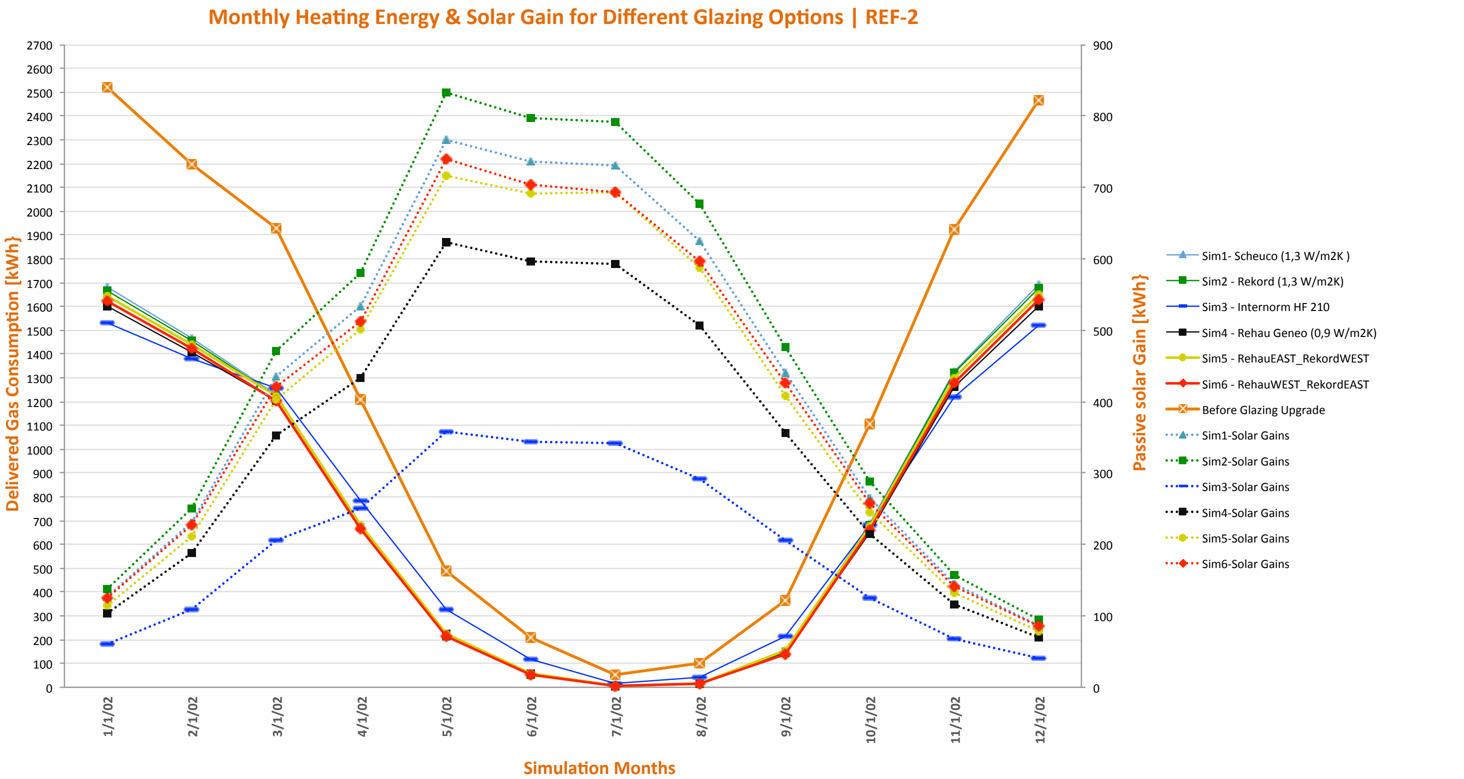


Figure 5-8: Monthly gas consumption & solar gain for Refurbishment-2 in all simulation steps.

5.3 Infiltration & Airtightness

Air infiltration in buildings is accepted as unwanted coming through the building envelope cracks or ill maintained connections. Air coming in is not controlled by any means of thermal regulation; therefore air infiltration causes unpredictable changes in air temperature of the space and increases heating use in the long run.

However air infiltration brings in fresh air to the dwelling and aids natural ventilation, though this air is not preconditioned. Infiltration must be reduced as much as possible for achieving a Zero Energy building as well as stabilizing indoor thermal conditions.

Simulation & Decisions Criteria's

Infiltration criteria's are dependent on the Dutch building regulations given in chapter *2.3.7 Refurbishment Regulations in the Netherlands*; therefore simulation inputs are determined according to the regulations. Refurbishment scales determine the depth of airtightness possible in an existing building. Refurbishment-1 strategy within the thesis can reduce air infiltration through the envelope up to a certain point due to restrictions on construction scale.

On the contrary total refurbishment approach gives flexibility to intervene with critical junction details on the building envelope; therefore better airtightness levels are aimed for in the total refurbishment strategy of Hospeslaan 24. With the acquired flexibility, junctions such as wall to roof edge and ground floor to wall connections will be addressed in a precise manner.

5.3.1 Infiltration Rate Calculations & Conversions

Accepted infiltration rate of the building @50pa is 16 ACH^{-1}, this value is the outcome of DesignBuilder validation simulations. The value obtained from the simulation does not reflect the equal in Dutch system of Q10pa (dm^3/m^2) however; the value can be converted from Q10pa to Q50pa and from Q50pa to ACH^{-1}@50pa. Conversion from Q10pa to Q50pa is a ratio obtained in the *table 5-16* provided in *Appendix B.*

Leakage Level		M^3/h per m^2 of outer envelope (exp n = 0,667)			
		Q4pa	Q10pa	Q50pa	Q10pa to Q50pa Ratio
Single Family	Low	0,5	1	2,5	2,5
	Average	1	2	5	2,5
	High	2	3,5	10	2,857
Average Ratio					**2,619**

Table 5-16: Relation between different pressure levels given in NEN 15242:2007 as an example for highlighting changes from certain levels to levels.

In order to calculate the Q50pa equal of the Dutch requirements, numerical units must be converted to $m^3/h.m^2$ from $dm^3/h.m^2$. To do so every requirement, which is converted, to Q50pa in the previous step must be multiplied with 3,7 (1/1000 dm^3 to m^3 /0,00027 second to hour) for corrected units.

$$\frac{1dm^3}{s.m^2}\ x\frac{1}{1000}\ x\ \frac{1}{0{,}00027} = \frac{1m^3}{h.m^2}$$

Conversion from Q50pa ($m^3/h.m^2$) to ACH^{-1}@50pa requires a calibration where the total exposed surface (A_E) of the building and the total interior volume (V_E) of the building are taken into account. The formula for executing this conversion is:

$$nQ50pa\ \ xA_E/\ V_E = ACH^{-1}@50pa$$

For Hospeslaan 24, building has six sides however only four sides of the building are exposed to climate conditions given in *figure 5-9.* Considering that side separation walls are accepted as adiabatic in validation simulations these walls are not included in the total external envelope surface calculation, which is 167,6 m^2 including exposed ground floor, externally defined walls in DesignBuilder and the pitched roof (including dormers). Total interior volume of the building is 329,4 m^3, resulting in 0,450 in A_E / V_E.

Converted values for every step can be found in *table 5-17.* In addition to converted requirements, current state of the building and passive house standard is also included in the process.

Leakage Levels	Q10/m^2 ($dm^3/h.m^2$)		Q50/m^2 ($dm^3/h.m^2$)		Q50/m^2 ($m^3/h.m^2$)		AC/H @50pa
Hospeslaan 24*	3,6		9,60630		35,54334		16
Basic	1,0		2,619		9,6903		4,93
	1,0		2,619		9,6903		4,93
	1,0	x 2,619	2,619	x 3,7	9,6903	X 0,450	4,93
Good	0,6		1,5714		5,81418		2,95
	0,4		1,0476		3,87612		1,97
Excellent	0,15		0,39285		1,453545		0,739
	0,15		0,39285		1,453545		0,739
Passive house**	0,12		0,31863		1,1789549		0,6 min

Table 5-17: Conversion process of Q10 to AC/H @50pa and corresponding values.
** Value is calculated in reverse process from AC/H @50pa to Q10/m².*
*** Passive House standard is the possible maximum to have in a building and calculated according to Hospeslaan24 building features.*

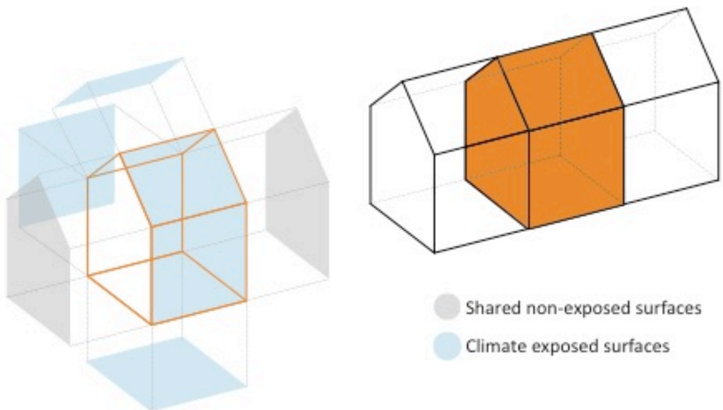


Figure5-9: Diagrammatic illustration of the envelope exposure of Hospeslaan 24

5.3.2 Simulations

Existing Condition- 16 ACH^{-1} @50pa | After Glazing Options

Existing condition of the building is reflected upon the previous steps of improvement, insulation and glazing preferences. Air Infiltration simulations are built upon accepted conditions from previous simulations regarding glazing and insulation type.

Strategy	Heating Usage - Gas (kWh)	Ventilation (Infiltration & Natural & Mechanical)	Required Ventilation (Building Average)	Loss from Infiltration (kWh)	External Ventilation Loss (kWh)
Refurbishment 1	9078,8	1,14 ACH^{-1} annual average	1,13 ACH^{-1}	-7738,9	-4539,0
Refurbishment-2	8907,0	1,14 ACH^{-1} annual average	1,13 ACH^{-1}	-7589,2	4192,3

Table 5-18: Existing condition per refurbishment strategy after glazing option

Within existing situation average ventilation for the building is sufficient with infiltration and natural ventilation supply, considering that there is no mechanical ventilation available. However loss of energy due to infiltration levels is too high to compensate for the necessary fresh air coming in and it must be reduced for providing proper living conditions and balanced heat fluctuations in the building.

Infiltration and natural ventilation are given in the same context, however these two rates are balancing the necessary air required in the whole building for four people. The average is 1,14 ACH^{-1}, which is the required minimum. Heating consumption in the building is directly addressed by the infiltration rate of the envelope.

Simulation 1- 4,93 ACH^{-1} @50pa | Basic

First simulation is based on the expected minimum from the building envelope by Dutch government. Components replaced on the envelope are sealed tightly and details of the construction are executed in a precise manner to reduce heat loss from building cracks, certain joineries and detail junctions.

Strategy	Heating Usage - Gas (kWh)	Ventilation (Infiltration & Natural & Mechanical)	Required Ventilation (Building Average)	Loss from Infiltration (kWh)	External Ventilation Loss (kWh)
Refurbishment 1	4597,6	0,65 ACH^{-1} annual average	1,13 ACH^{-1}	-2779,0	-4877,4
Refurbishment-2	4424,9	0,65 ACH^{-1} annual average	1,13 ACH^{-1}	-2784,8	-4873,8

Table 5-19: Simulation-1 results per refurbishment strategy

Reduced infiltration rate decreases unconditioned air entry to space limiting the impact of outdoor conditions on indoor air temperature especially during winter period in *figure 5-16.* Gas consumption for heating has reduced by 50% for ref-1 and 50,3% for ref-2. However given in table 5-19 air change per hour in the building is halved due to tightened building envelope. Therefore in order to sustain minimum air quality in the building additional supply is required per space.

Simulation 2- 2,95 ACH^{-1} @50pa | Good

Medium level of infiltration accepted by the Dutch government is simulated in step-2. Infiltration rate of 2,95 ACH^{-1} @50pa is used for the envelope. Infiltration rate reduction is crucial for stabilizing indoor air temperature fluctuations inside the building.

Strategy	Heating Usage - Gas (kWh)	Ventilation (Infiltration & Natural & Mechanical)	Required Ventilation (Building Average)	Loss from Infiltration (kWh)	External Ventilation Loss (kWh)
Refurbishment 1	3840,6	0,55 ACH^{-1} annual average	1,13 ACH^{-1}	-1740,1	-4995,7
Refurbishment-2	3675,7	0,55 ACH^{-1} annual average	1,13 ACH^{-1}	-1746,7	-4999,3

Table 5-20: Simulation-2 results per refurbishment strategy

Results are given in *table 5-20* for simulation-2. Gas consumption for heating is decreased due to reduced loss from infiltration. However reduced infiltration rate has further decreased the average air change per hour inside the building. After a certain level of infiltration it is necessary to switch to active ventilation solutions to provide necessary comfort conditions inside the building, if the building is to be energy efficient. For refurbishment strategy-1, infiltration rate of 2,95 ACH @50pa is the lowest limit given by the Dutch government that allows natural air supply and mechanical extraction.

Simulation 3- 0,739 ACH^{-1} @50pa | Excellent

Infiltration rate of 0,739 ACH^{-1}@50pa is the lowest level of air leakage accepted by the Dutch government. Mechanical supply is necessary for the level of air tightness on envelope.

Strategy	Heating Usage - Gas (kWh)	Ventilation (Infiltration & Natural & Mechanical)	Required Ventilation (Building Average)	Loss from Infiltration (kWh)	External Ventilation Loss (kWh)
Refurbishment-2	2859,8	0,45 ACH^{-1} annual average	1,13 ACH^{-1}	-476,2	-5173,5

Table 5-21: Simulation-3 results for Refurbishment-2

Heating consumption in the building is reduced by 68% without any thermal comfort optimization or additional heat recovery machinery. There is a certain increase in external ventilation loss in *table 5-21* when compared to previous simulation, reflecting that ventilation through the openings has increased in the building. Even though ventilation through the openings is increased resulting air change per hour is the one third of the existing situation.

Minimized infiltration rate has a toll on ventilation rate in the dwelling and it has reduced to a point natural ventilation would not effectively supply the necessary fresh air in to the building spaces. It is necessary to use mechanical systems to provide fresh air and extract it with an option to recover the heated air for pre conditioning the supply air for further reducing heating consumption in the building.

5.3.3 Conclusion

Outcome of the simulation steps have been summarized in *table 5-22.* High infiltration rates in Hospeslaan 24 results in excessive consumption on natural gas in order to provide required living conditions in space. However, high infiltration rate in any zone of the building results in severe temperature fluctuations and in certain periods consumed gas is not sufficient to deliver desired living conditions.

In *figure 5-10* indoor air temperatures of all simulated infiltration rates according to a certain week is given. High infiltration of 16AC/H@50pa; is not only resulting in low indoor temperatures but, high delivered gas consumption is not sufficient enough to provide required temperatures. As infiltration is reduced so does the gas consumption on the contrary to reduced gas consumption, indoor air temperatures are increased due to airtight envelope.

Low Infiltration rates are more effective with better envelope insulation. Within table 5-22 percentages in heating consumption reduction is higher for refurbishment-2 when compared to refurbisment-1. *Figures 5-11 & 5-12,* prove that airtightness is a necessity for winter period, while in summer season high infiltration could reduce indoor air temperature to required temperature ranges unless outdoor temperature is not higher than indoor air temperature.

When infiltration rate of air through the building envelope is decreased so does the fresh air availability inside the living space. As the air change is reduced so does the comfort level of the users. It is always a possibility to provide air through natural ventilation or mechanical ventilation. However higher natural ventilation increases the exposure of conditioned space outdoor conditions eventually resulting in increased heating consumption especially in winter season, temperature fluctuations and low or high indoor air temperature for living comfort.

Infiltration AC/H@50pa	Strategy	Gas Consumption (kWh)	Heating Reduction	Air Change Per Hour	External Losses (kWh)
16,0 AC/H	Ref-1	9078,8	-	1,14 yearly building average	12278,0
	Ref-2	8907,0	-	1,14 yearly building average	12255,3
4,93 AC/H	Ref-1	4597,6	49%	0,62 yearly building average	7656,5
	Ref-2	4424,9	50%	0,62 yearly building average	7658,7
2,93 AC/H	Ref-1	3840,6	58%	0,52 yearly building average	6735,8
	Ref-2	3675,7	59%	0,52 yearly building average	6746,0
0,739 AC/H	Ref-2	2859,8	68%	0,46 yearly building average	5649,8

Table 5-22: Conclusions of simulated infiltration rates per refurbishment strategy

Considering the aim of the two-refurbishment strategies to achieve minimized energy consumption; the scale of intervention on the building envelope as well as strategy of air provision is influential on the achievable airtightness level of a building. For partial and total refurbishment strategies of Hospeslaan 24 renovation, it is viable to accept infiltration rates of 2,95 ACH^{-1}@50pa and 0,739 ACH^{-}

^{1}@50pa consecutively due to scale of refurbishment measures that correspond to different strategies. The main obstacle in reducing the infiltration rate is the execution of the envelope construction, simplified detailing and careful junction design for the building envelope, where different components come together to form the thermal skin as an impregnable shell by outdoor conditions.

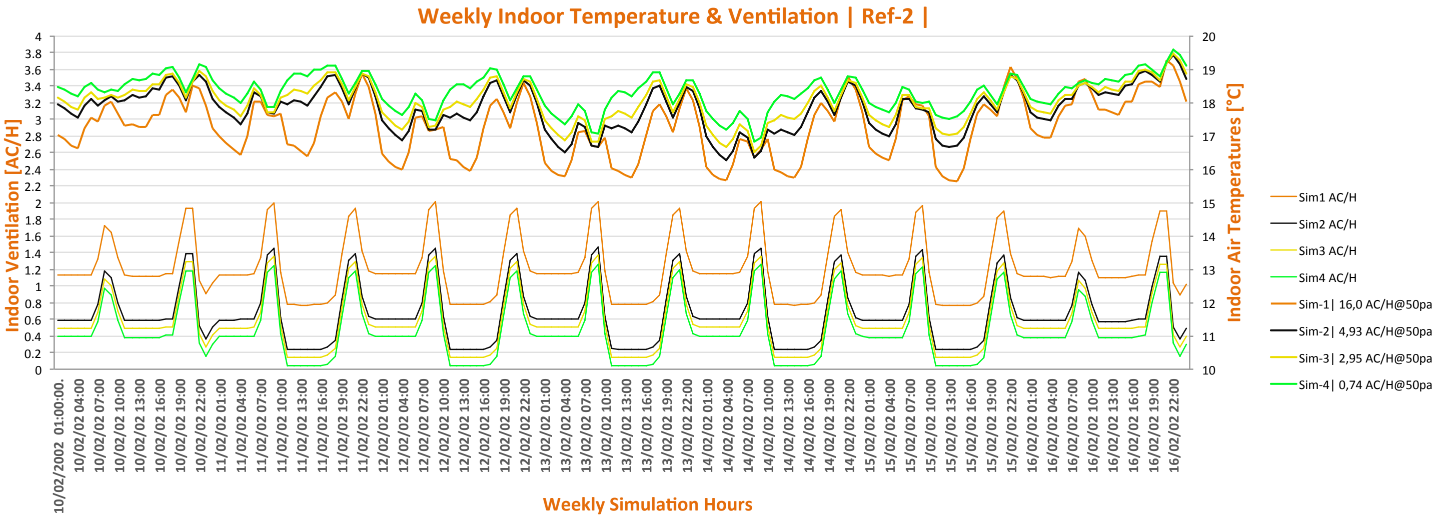


Figure 5-10: Indoor air temperature and air change per hour for every simulation for Refurbishment-2

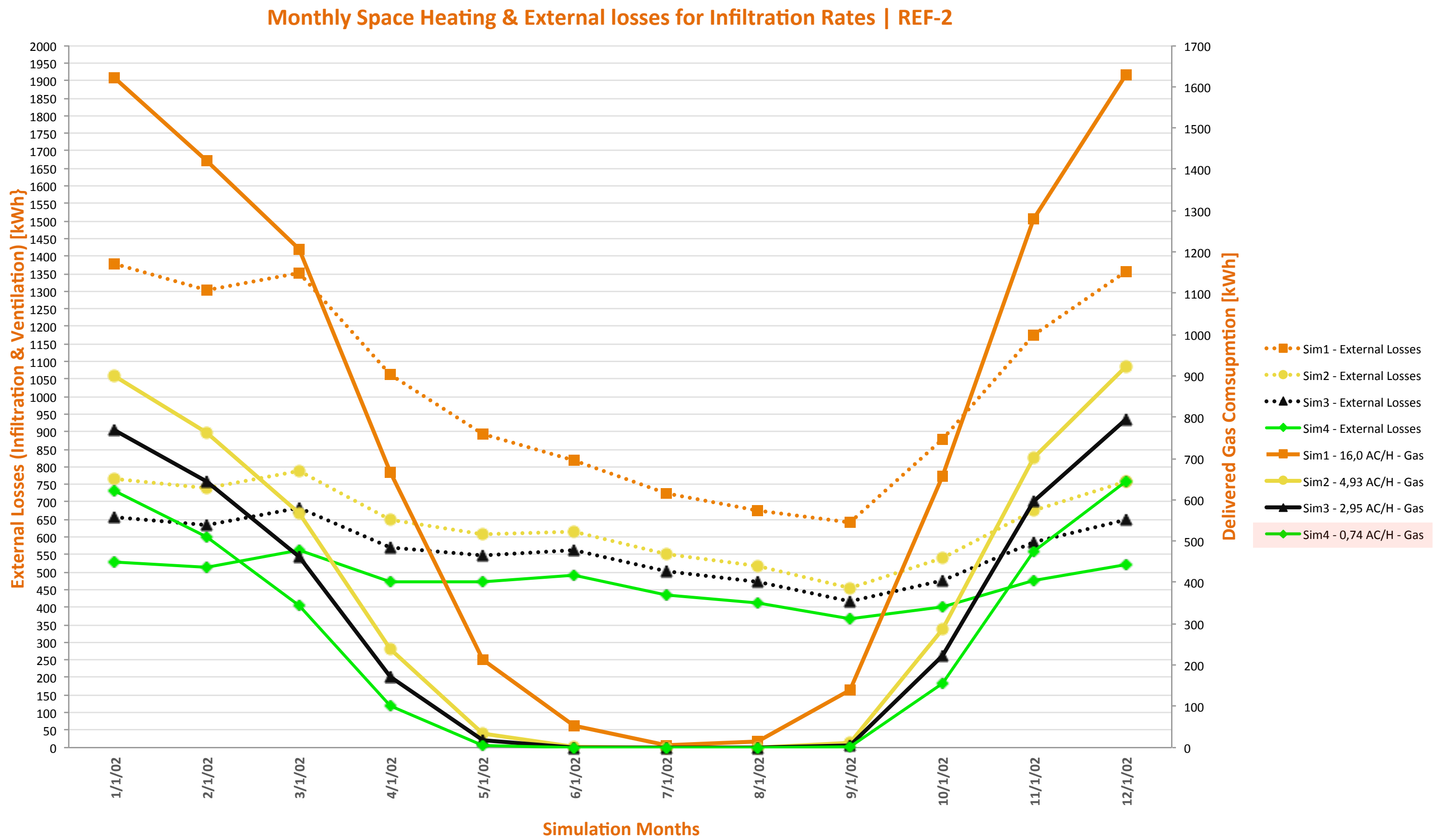


Figure 5-11: Monthly gas consumption and external losses for Refurbishment-2 in every simulation

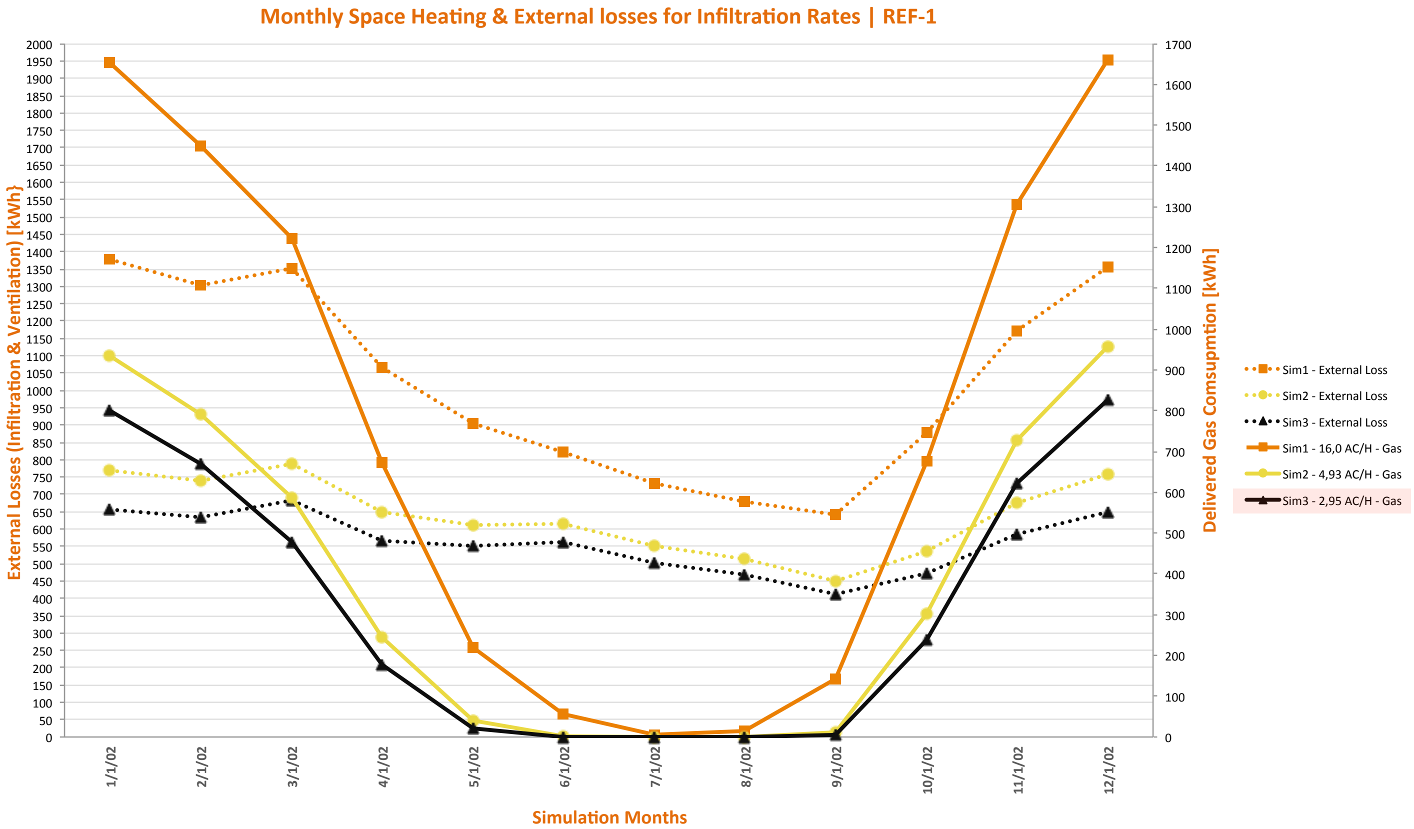


Figure 5-12: Monthly gas consumption and external losses for refurbishment-1 in every simulation

6.0 Zone Based Comfort Optimization

Comfort optimization of the zones in the building is based on steps of simulation as inputs aiming to reach the necessary criteria for human comfort depending on the season as well as the specific zone. Hourly simulations are conducted for a week after the week was optimized same conditions were applied to the month to highlight different behaviors due to outdoor dry bulb temperature differences. Ones the month was optimized, strategy is applied to seasonal simulations for every zone differently. First sleeping -2 is optimized and the conclusions are applied to rest of the spaces.

Comfort Criteria's

Criteria's for heating and cooling season comfort in a dwelling is based on the Dutch building regulations on human comfort in closed spaces. Regulations for Indoor human comfort is in chapter *2.4 Indoor Comfort*. Simulation inputs are given accordingly to the regulations and fine-tuned as every simulation outcome is used for the next one to successfully provide human comfort in the dwelling. Energy consumption for heating is kept minimum for further reduction on annual consumption.

Comfort optimization simulations are conducted separately for refurbishment-1 and refurbishment-2 regarding different applications and measures required to provide necessary conditions. Due to high insulation rate of the building, indoor air temperatures are taken into account for respective temperature balances in the spaces instead of operative temperature. If there are any additional differences to the accepted temperatures, they are specified under zone optimization.

6.1. Refurbishment-1 Comfort Optimization

6.1.1 Heating Optimization of Refurbishment-1 | Winter Season (1OCT – 30APR)

Ref-1- Sleeping 2 Heating | Reference Zone

Technically April is not included in the winter season for simulation purposes, however due to very cold monthly average of April it is necessary to include it as a portion of the heating season. Thermal comfort of Sleeping 2 for winter season is balanced based on required thermal range for indoor air temperature and minimum air supply per person. Certain inputs are used in five different simulations. These inputs for all the simulations steps are given in *table 6-0* and the highlighted ones are the simulation steps accepted as suitable conditions for zone heating and fresh air supply regarding optimization weeks and seasonal calculations.

Sleeping 2	Simulation1	Simulation2	Simulation3	Simulation4	Simulation5	Simulation6
Heating Temperature	21° C	**22° C**	**23° C**	23° C	**23,5° C**	**20° C**
Set-back Temperature	15° C	15° C	15° C	**No Set-back**	No Set-back	No Set-back
Minimum Fresh Air	12.5 l/s Per person	12.5 l/s Per person	12.5 l/s Per person	12.5 l/s Per person	12.5 l/s Per person	12.5 l/s Per person
Minimum Indoor Air Temperature	No Restriction	No Restriction	No Restriction	No Restriction	No Restriction	Non
Minimum Outdoor Air Temperature	Non	Non	Non	Non	Non	Non
Mechanical Ventilation	Non	Non	Non	Non	Non	Non

Table 6-0: Simulation inputs for weekly & seasonal optimization in sleeping -2 blue background (coldest week optimization) & orange background (typical winter week inputs)

Simulation-1 is defining the condition of the zone after all the passive measures have been concluded to be a base point of comparison for simulation steps as well as the calibration of air supply to the zone. Supply of fresh air had to be reconsidered after the envelope upgrade due to decreased infiltration rate and high insulation.

Minimum fresh air supply is determined based on the air change per hour in a space to provide the minimum air supply necessary to reduce excessive exposure of space to outdoor conditions during winter period. Air change per hour is calibrated in DesignBuilder simulations for all the optimized zones according to their specific zone volumes and required amount of fresh air based on building regulations. Calculations of the air change per hour for optimized zones are in *appendix C.*

Week with coldest average air temperatures is optimized (04/01-11/01) within the simulations steps along with a typical winter design week (03/02-09/02).

Within *figure 6-0* simulation-1 input of 21° C is not sufficient to provide necessary comfort conditions in a sleeping room during sleep time therefore higher heating temperatures must be provided to optimize the corresponding week.

It is possible to increase indoor air temperature in space by restricting fresh air supply in the space however; reduced air change in space will result in high CO_2 build up in space. Reduced minimum fresh air supply is not a possibility for optimizing indoor air temperatures.

22° C heating temperature in *figure 6-0* is able to increase the indoor air temperature to required temperature range for a small period between 06/01-09/01. Even though the period of 06/01-09/01 represents the coldest outdoor dry bulb temperatures, heating temperature 22° C can not provide necessary indoor conditions. This could be either due to climate conditions besides dry bulb temperature such as rain or the constant cold during the specific period given. There are 17 days with very cold outdoor conditions through out the year that results in low indoor air temperatures and the period of 06/01-09/01 reflects their behavior, Therefore temperature optimization of the period in simulation week (04/01-11/01) would be the necessary solution for all 17 days.

Under simulation-3 23° C heating temperature is given for providing the necessary comfort conditions. Within *figure 6-0,* 23° C falls slightly short of the required range of indoor air temperature for sleeping rooms for the period of 06/01-09/01 and for the rest of the week provided heating temperature is resulting in high temperatures inside the space. It is important not to provide excessive heating temperature to optimize energy consumption for heating.

Provided Setback temperature in simulation-4 has no effect on the indoor air temperature during occupied hours for the winter season. Therefore in *figure 6-0* simulation-3&4 reflect same results for thermal comfort as well as for annual gas consumption for heating. During the provision of heating certain indoor air temperature peaks occur, these peak points in indoor air temperature are due to introduction of natural ventilation. Heating of space starts prior to occupancy of the zone to condition the space for the users on the time of usage, however natural ventilation is introduced to the space when there is occupancy to provide fresh air, which reduces the indoor air temperature slightly due to being unconditioned air. The procedure repeats itself after the occupancy of zone returns to none.

23,5°C is required for providing thermal conditions in the space for the period of 06/01-09/01 in slaapkmamer-2. Within *figure 6-1,* optimized condition of the selected simulation week is given with different temperatures in certain periods due to differentiating outdoor dry bulb temperatures. It could be possible to provide only 23,5° C for the simulation week however excessive heating will result in high indoor air temperatures for winter season and high gas consumption for the wee

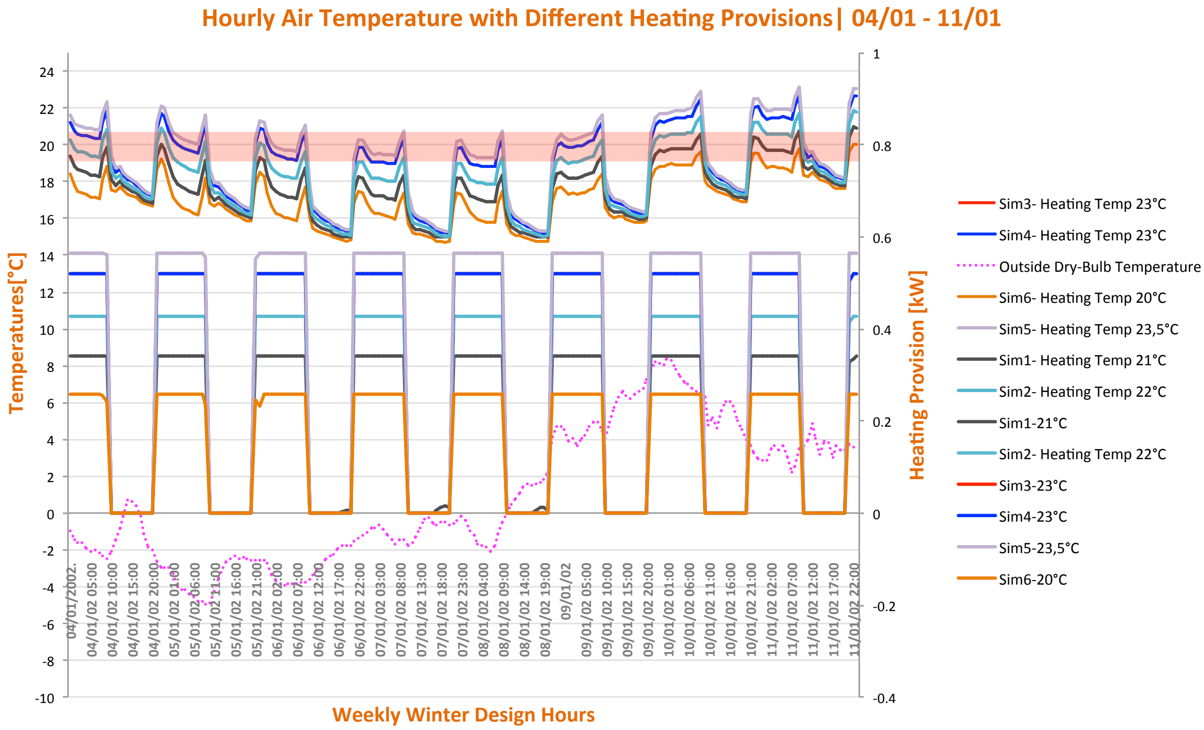


Figure 6-0: Different Air temperatures among simulation steps for coldest optimization week

It is possible to balance out the temperature differences along with certain temperature peaks between consecutive hours, with increased thermal mass to the building envelope or a high capacity material on the walls besides bricks. However construction of the envelope and the amount of usable space is restricting flexibility of choices along with the depth of refurbishment.

Heating temperatures given in simulations-1 to 5 are providing high indoor temperatures for a typical winter week in *figure 6-2* therefore simulation-6 is conducted to highlight a typical week optimization for winter season.

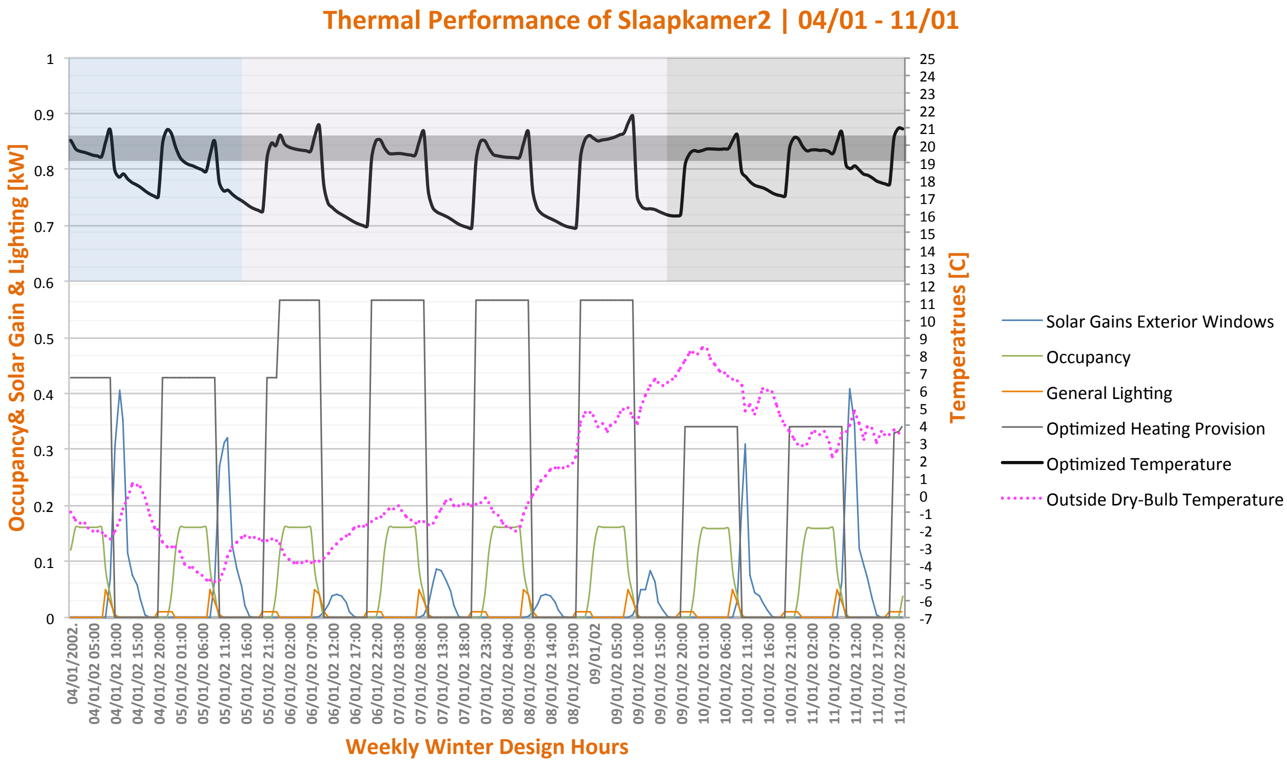


Figure 6-1: Optimized cold simulation week for sleeping -2; colors represent the simulation temperatures from figure 6-1

20°C heating temperature provision is sufficient to provide necessary comfort conditions in Sleeping -2 under conditions of a typical winter week. Heating optimization for typical week is necessary to reduce excessive gas consumption in space. Optimized condition of the week is given in *figure 6-3*.

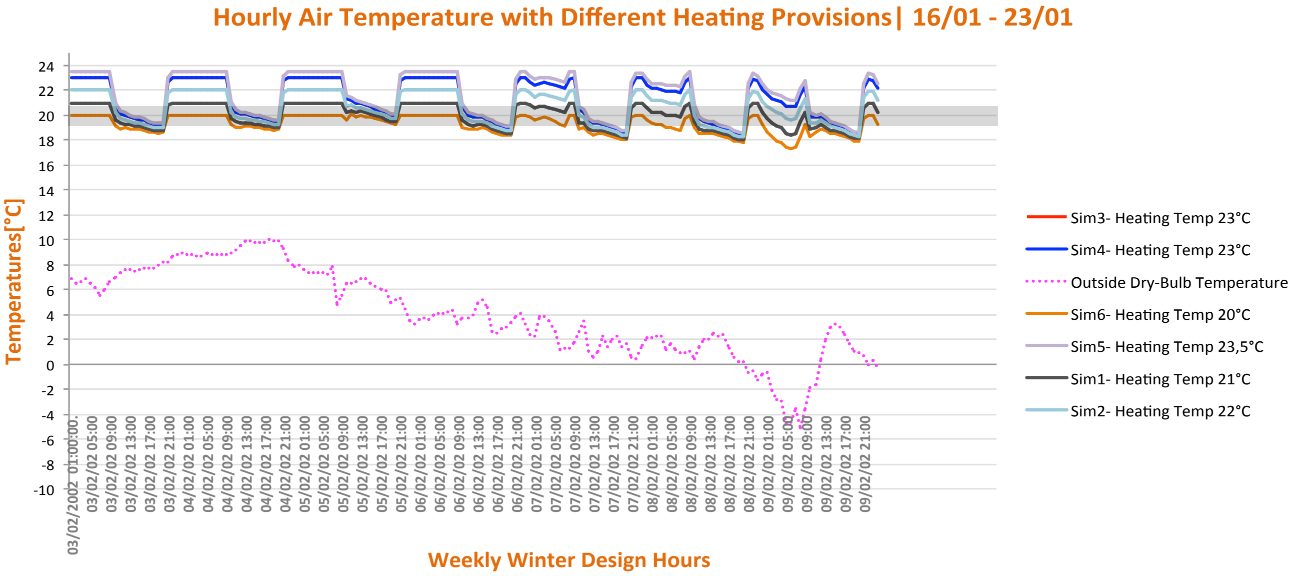


Figure 6-2: Typical winter week indoor air temperature regarding different simulation inputs

In an ideal situation 20°C heating temperature is sufficient to provide necessary thermal living conditions in a space for the winter season unless, hourly outdoor temperatures do not fall below -3°C or keep a constant momentum below 0°C. As highlighted before for very cold 17 days, 23,5°C heating temperature is required to deliver desired conditions. For seasonal simulation 20°C is used for heating temperature to simplify simulation results. Due to similar thermal comfort demands Sleeping -3 and sleeping -1 are included in *appendix D*.

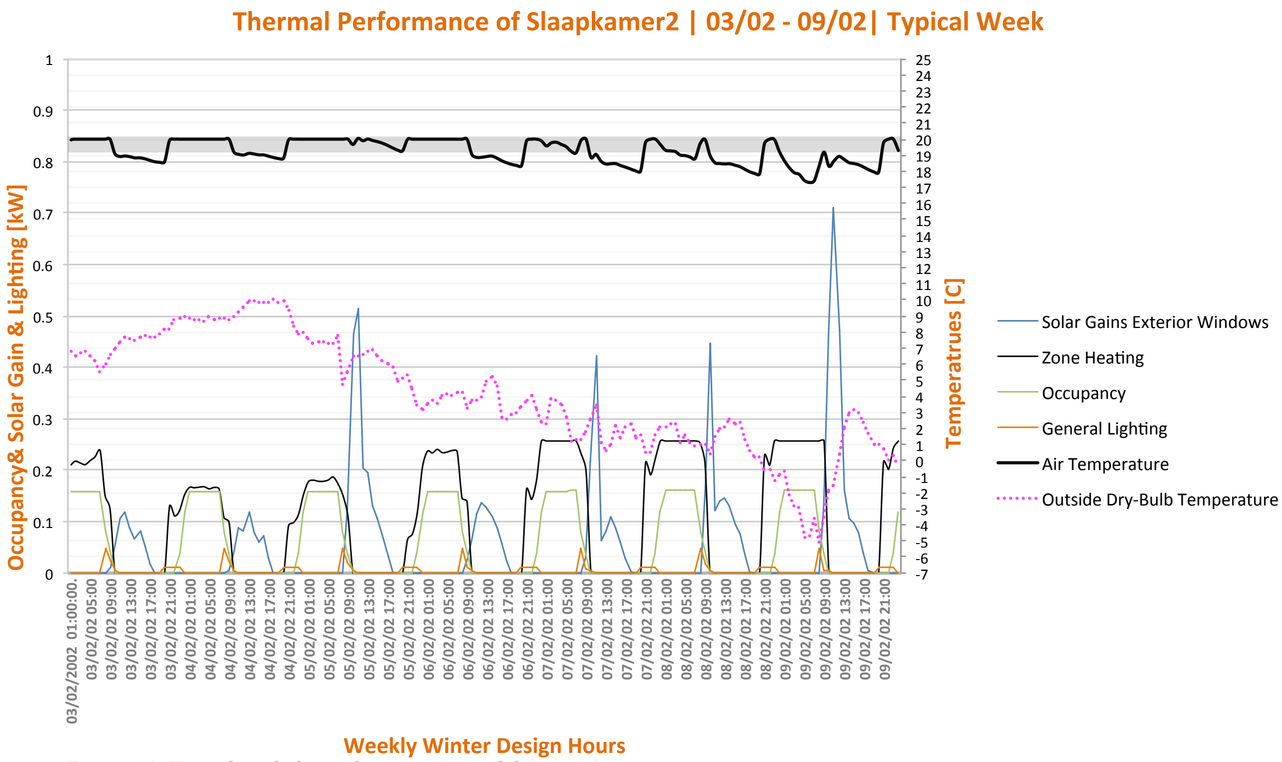


Figure 6-3: Typical week thermal optimization of sleeping -2

Indoor air temperature in sleeping rooms are subject to change regarding the space usage and user schedule. According to World Health Organization stated (Peeters, Hensen, D'Haeseleer, & de Dear, 2009)by 16 °C indoor air temperature could be sustained in space during sleeping time when people are under the sheets. However 16 °C indoor air temperature is low for providing comfort in space and can be accepted applicable only for unique conditions.

When the schedule in the simulations is concerned which is from 24:00 to 08:00; 19-19,5°C temperature range is sufficient to sustain thermal comfort during the heating season because schedule corresponds to the sleeping period. Therefore when people are under the sheets and their activities are reduced to minimum it is possible to reduce indoor temperatures almost to 19°C. Unless overheating is subject in the sleeping room due to passive solar gain or very high outdoor temperatures indoor air temperatures are acceptable between 19-19,5°C if schedule is fixed to sleeping period only.

However user patterns are subject to differ as the space could be utilized for study purposes. When the space is used for study the schedule as well as the required minimum temperature changes in the corresponding space. If the space is utilized as study, the indoor air temperature has to be between 20-21°C. Within table…. conditions of all sleeping rooms are given along with the corresponding energy consumption if the space is converted into a study room instead of sleeping.

	Sleeping Function			Study Function		
Zones	**Schedule**	**Typical Temp.**	**Gas (kWh)***	**Schedule**	**Typical Temp.**	**Gas (kWh)***
Sleeping -1	12:00-08:00	20°C	19,6 kWh	17:00-22:00	21°C	24,1 kWh
Sleeping -2	12:00-08:00	20°C	17,71 kWh	17:00-22:00	21°C	21,8 kWh
Sleeping -3	12:00-08:00	20°C	4,9 kWh	17:00-22:00	21°C	7,8 kWh

Table 6-1: Zone conditions for different functions along with consumption behavior due to function change.

When the purpose of the spaces are switched to study from sleeping the consumption of gas increases even though the heating period of spaces are reduced. Within the typical week change is natural gas consumption per space is 36% when switched to study function due to increased heating temperature and the necessity to sustain higher indoor air temperatures in space. Therefore even if one of the three spaces were accepted as study it would result in increased heating energy consumption for the winter season.

Ref-1- Living Room Heating

Living Room Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	2,1 l/s Per person	No restriction	No restriction	Non
Simulation2	22° C	0° C	2,1 l/s Per person	No restriction	No restriction	Non
Simulation3	23° C	0° C	2,1 l/s Per person	No restriction	No restriction	Non
Simulation4	23° C	0° C	2,1 l/s Per person	No restriction	No restriction	Non
Simulation5	21° C	0° C	2,1 l/s Per person	No restriction	No restriction	Non

Table 6-2: Simulation inputs for weekly & seasonal optimization in Living Room blue background (coldest week optimization) & orange background (typical winter week inputs)

Thermal comfort of Living Room requires higher temperatures compared to rest of the primary spaces in the dwelling. When occupied Living Room must deliver 20-21° C indoor air temperature with a tendency towards 21° C throughout the whole winter season if the outdoor dry-bulb temperatures are not higher than indoor air temperatures.

Simulation-1 is conducted to balance the ventilation rate of the space. Living Room and Dining Room are connected spaces with a large opening in between two spaces resulting in one very large space. Therefore the calculation of air change per hour for both of the zones are based on the 31,65m^2 instead of 15,45m^2 thus resulting in 2,1 l/s per person air supply. Calculation of AC/H and the air supply to the space is explained in detail in *appendix C.*

For the coldest week delivering the desired thermal conditions without hampering natural ventilation it is necessary to provide three different sets of heating temperatures. Fine-tuned state of the simulation week requires the temperatures from simulations-2, 3 and 4. Typical week however requires only 21° C heating temperature to balance thermal comfort in space during occupancy. *Figure 6-4* gives the indoor air temperature response in typical winter week.

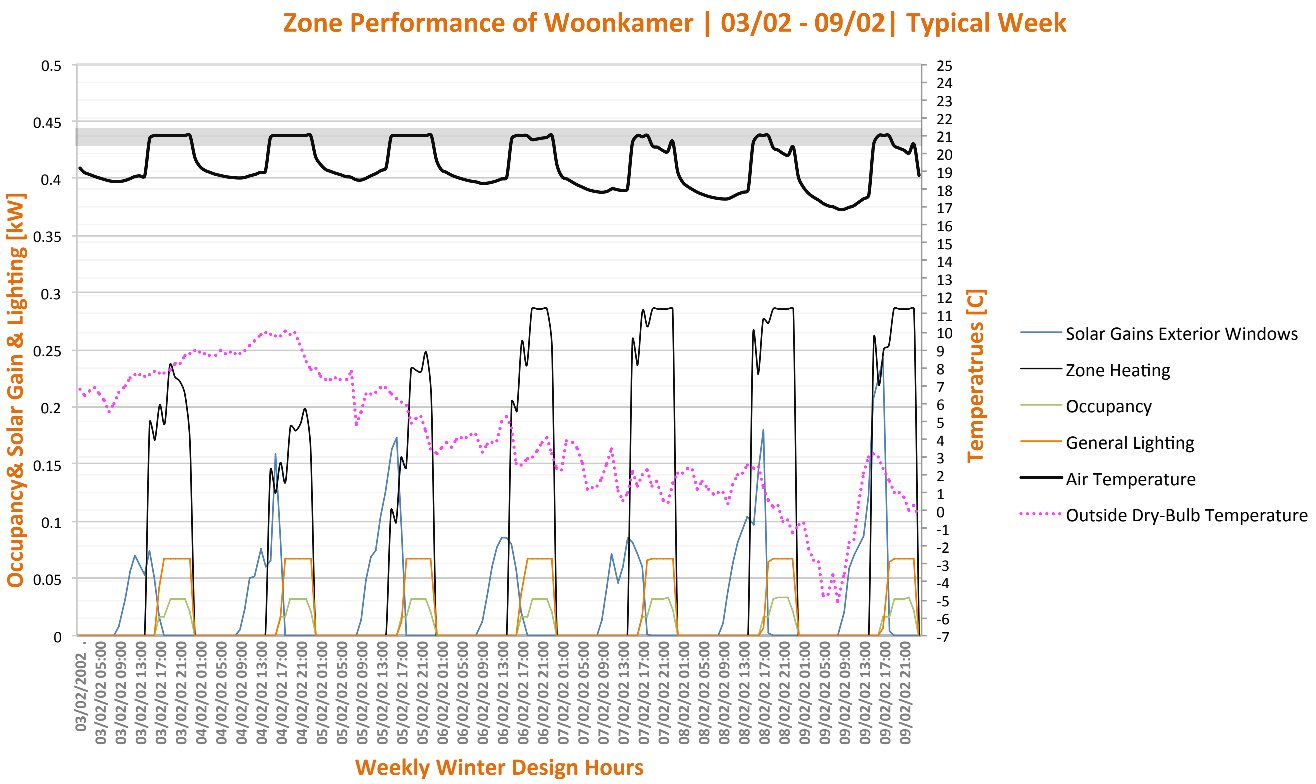


Figure 6-4: Typical week thermal performance of Living Room for winter comfort optimization

Ref-1- Dining Room Heating

Dining Room Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	4,0 l/s Per person	No restriction	No restriction	Non
Simulation2	21° C	0° C	4,0 l/s Per person	No restriction	No restriction	Non
Simulation3	22° C	0° C	4,0 l/s Per person	No restriction	No restriction	Non
Simulation4	23° C	0° C	4,0 l/s Per person	No restriction	No restriction	Non
Simulation5	21° C	0° C	4,0 l/s Per person	No restriction	No restriction	Non

Table 6-3: Simulation inputs for weekly & seasonal optimization in Dining Room blue background (coldest week optimization) & orange background (typical winter week inputs)

Thermal comfort optimization of Dining Room is the reflection of Living Room as they practically share the same total space in the building with different functions. Thermal balance of the space has to be between 20-21° C air temperature. Differences between Living Room and Dining Room are based on their occupancy during the day, their volumes and passive solar gains due to orientation and glazing ratio of the envelope.

Thermal comfort of the coldest simulation week is obtained by the inputs in *table 6-3* highlighted by blue background. The radical temperature difference between Living Room and Dining Room heating temperatures for the coldest optimization week is based on the exposure to solar gain of the space. East orientation of Dining Room is resulting higher passive solar gain resulting in lower heating temperature requirement.

Simulations-3, 4 and 5 are conducted to optimize the coldest week period. Inputs from simulation-2 highlight the seasonal input accepted due to stabilized thermal conditions in space in typical week simulations. Within *figure 6-5* performances of simulation-2 inputs are given as resulting indoor air temperatures and heating intensity.

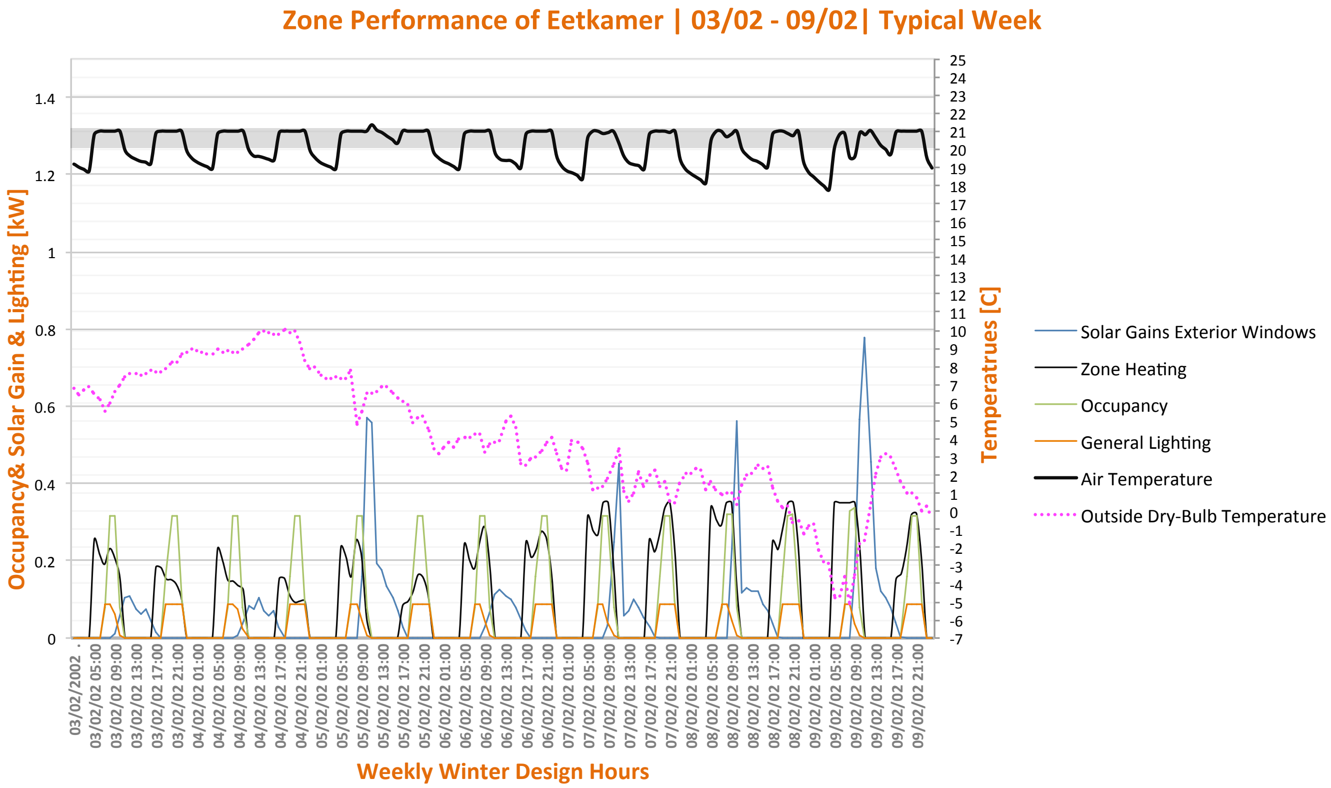


Figure 6-5: Typical week thermal performance of Dining Room

Ref-1 Wet Spaces Heating

Wet Spaces Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation	Pump Power
Bathroom							
Simulation1	21° C	0° C	No provision	No restriction	No restriction	2,5 l/sm^2 Extraction	
Kitchen							
Simulation1	21° C	0° C	No provision	No restriction	No restriction	3,5 l/sm^2 Extraction	
Toilet							
Simulation1	21° C	0° C	No provision	No restriction	No restriction	10,2 l/sm^2 Extraction	

Table 6-4: Simulation inputs for seasonal optimization in Wet spaces orange background (typical and coldest winter week inputs)

Wet spaces in Hospeslaan24 consist of Bathroom, Kitchen and Toilet. These spaces are provided with mechanical extraction and no natural ventilation. Therefore they are not exposed to unconditioned air and air supply of these spaces are provided with the circulating, already conditioned air coming from bedrooms, living or circulation spaces. Extraction in wet spaces is crucial to prevent moisture, CO_2 build up and condensation if space is adjacent to the building envelope.

Simulation inputs for Bathroom are given in the *table 6-4*. Within DesignBuilder single point extraction can only be defined under detailed HVAC options. Therefore the extraction is defined as supply to simulate accurate comfort conditions and thermal calculations.

With mechanical extraction and no exposure to unconditioned air Bathroom inputs result in a constant balance of temperature when occupancy is at full. Within the weekly simulation in *figure 6-6* 21° C of air temperature is not effected from the outside conditions compared to the primary zones of the building. Zones Kitchen and toilet are given in appendix D.

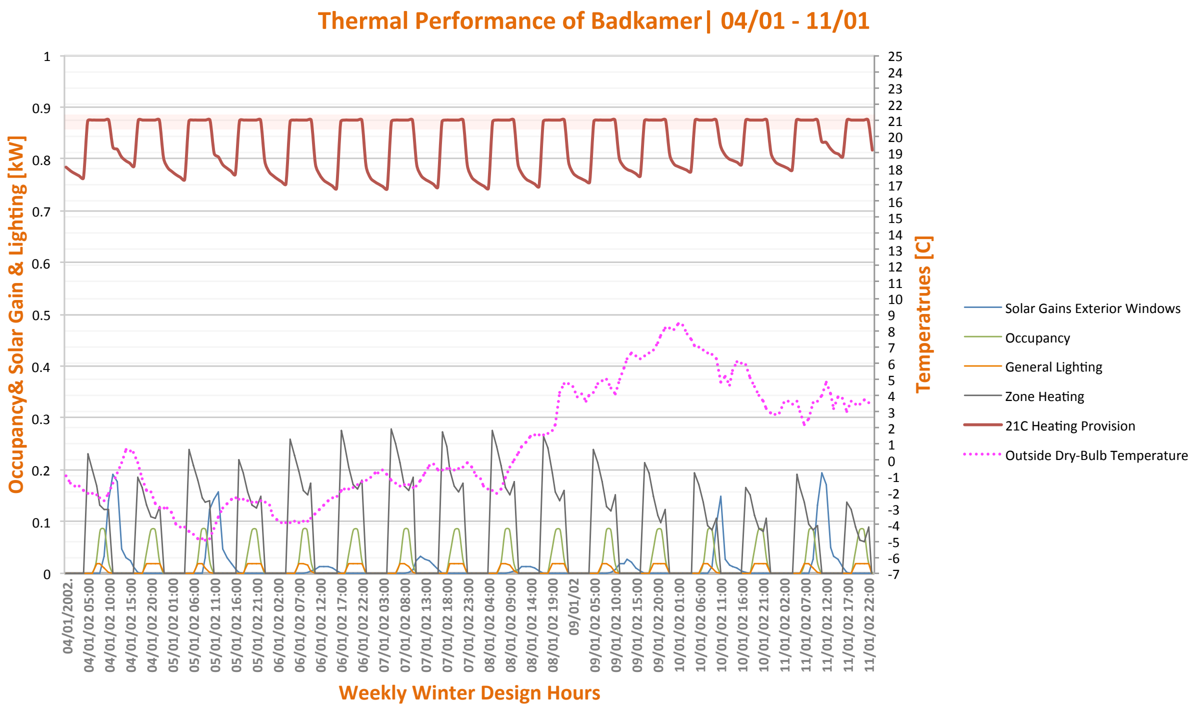


Figure 6-6: Coldest week thermal performance of Bathroom.

6.1.2 Overheating Optimization of Refurbishment-1 | Summer Season (1 MAY – 30 SEP)

Thermal optimization of zones for overheating in refurbishment-1 has the same strategy & approach as refurbishment-2 with same shading application and ventilation system. Optimization of thermal comfort for the summer season is done extensively for primary and secondary spaces in chapter *6.2.2 Overheating Optimization of Refurbishment-2*; therefore steps for optimization of the refurbishment-1 won't be explained deliberately in order not to repeat similar strategy applications.

Inputs of optimization simulations are given along with the resulting overheating hours for the season for every zone in *tables from 6-5 to and 6-11.*

Ref-1- Sleeping 2 Overheating| Reference Zone

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Natural Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	12,5 l/s	-	-
Simulation2	Rekord Basic	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	12,5 l/s	Outside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,25 m^2	61 L/s per person	On 24/7	21° C	Non
Overheating Hours Pre-Refurbishment		Overheating hours Pre-Optimization			Overheating Hours Post Optimization	
210		2166 Hours			89 Hours	

Table 6-5: Simulation inputs & results for comfort optimization during summer season for Sleeping -2 (overheating period). Highlighted simulation inputs are used for seasonal simulation

Ref-1- Sleeping 1 Overheating

Sleeping -1 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Natural Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	5,5 l/s	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	5,5 l/s	Outside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,1 m^2	51 L/s per person	On 24/7	21° C	Non
Simulation4	Simulation-2 inputs	0,2 m^2	85 L/s per person	On 24/7	21° C	Non
Overheating Hours Pre-Refurbishment		Overheating hours Pre-Optimization			Overheating Hours Post Optimization	
160		1528 Hours			52 Hours	

Table 6-6: Simulation inputs & results for comfort optimization during summer season for Sleeping -1 (overheating period). Highlighted simulation inputs are used for seasonal simulation

Ref-1- Sleeping 3 Overheating

Sleeping -3 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Natural Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	6,0 l/s	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	6,0 l/s	Outside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,15 m^2	41 L/s per person	On 24/7	21° C	Non

Overheating Hours Pre-Refurbishment	Overheating hours Pre-Optimization	Overheating Hours Post Optimization
140	351 Hours	27 Hours

Table 6-7: Simulation inputs & results for comfort optimization during summer season for Sleeping -3 (overheating period). Highlighted simulation inputs are used for seasonal simulation

Ref-1- Living Room Overheating

Living Room Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Natural Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	21 l/s	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	21 l/s	Outside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,45 m^2	41 L/s per person	On 24/7	22° C	Non
Overheating Hours Pre-Refurbishment		Overheating hours Pre-Optimization			Overheating Hours Post Optimization	
126		505 Hours			14 Hours	

Table 6-8: Simulation inputs & results for comfort optimization during summer season for Living Room (overheating period). Highlighted simulation inputs are used for seasonal simulation.

Ref-1- Bathroom Overheating

Bathroom Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	21 l/s	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	21 l/s	Outside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,1 m^2	31 L/s per person	On 24/7	22° C	Non
Overheating Hours Pre-Refurbishment		Overheating hours Pre-Optimization			Overheating Hours Post Optimization	
199		386 Hours			17 Hours	

Table 6-9: Simulation inputs & results for comfort optimization during summer season for Bathroom (overheating period). Highlighted simulation inputs are used for seasonal simulation.

Ref-1- Dining Room Overheating

Dining Room Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Natural Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	2,1 l/s	-	-
Simulation2	Rekord Basic	High Reflectance	On (07:00-20:00) for 6-7-8th Months	2,1 l/s	Inside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,2 m^2	20 L/s per person	On 24/7	22° C	Non
Overheating Hours Pre-Refurbishment		Overheating hours Pre-Optimization			Overheating Hours Post Optimization	
175		399 Hours			34 Hours	

Table 6-10: Simulation inputs & results for comfort optimization during summer season for Dining Room (overheating period). Highlighted simulation inputs are used for seasonal simulation.

Ref-1- Kitchen Overheating

Kitchen Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	3,5 l/sm^2	-	-

Simulation2	Rekord Basic	High Reflectance	On (07:00-20:00) for 6-7-8th Months	3,5 l/sm^2	Inside	-
Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation3	Simulation-2 inputs	0,3 m^2	27 L/s per person	On 24/7	22° C	Non
Overheating Hours Pre-Refurbishment			Overheating hours Pre-Optimization		Overheating Hours Post Optimization	
174			256 Hours		18 Hours	

Table 6-11: Simulation inputs & results for comfort optimization during summer season for Kitchen (overheating period). Highlighted simulation inputs are used for seasonal simulation.

6.1.3 Ventilation System of Refurbishment-1

Ventilation scheme of the refurbishment-1 is determined according to the optimization steps for comfort along with the applied passive measures during the envelope upgrade. The infiltration rate accepted for the building gives way for using natural ventilation so does the thermal optimization simulations for winter conditions. However natural ventilation is also used to highlight the realism behind the refurbishment-1 strategy. Ventilation scheme of refurbishment-1 for summer and winter seasons is simply illustrated in *figure 6-7.*

During winter season minimum air supply is achieved with natural ventilation through the building envelope with the help of airings. A steady stream of air is supplied to the space during the occupied hours of specific zones. However certain zones require mechanical extraction to avoid foul air, moisture and condensation therefore the system for the building is natural supply and extraction along with mechanical extraction in wet spaces.

During summer season excessive ventilation is taking place through the envelope openings. Indirect ventilation is used with very small openings to avoid burglary attempts while providing comfort conditions in space. Excessive ventilation is cooling the building down 24/7 deliver desired living conditions. The ventilation system of the building is automated for summer season to regulate indoor air temperature conditions and the volume of air coming in to the space to avoid additional heating.

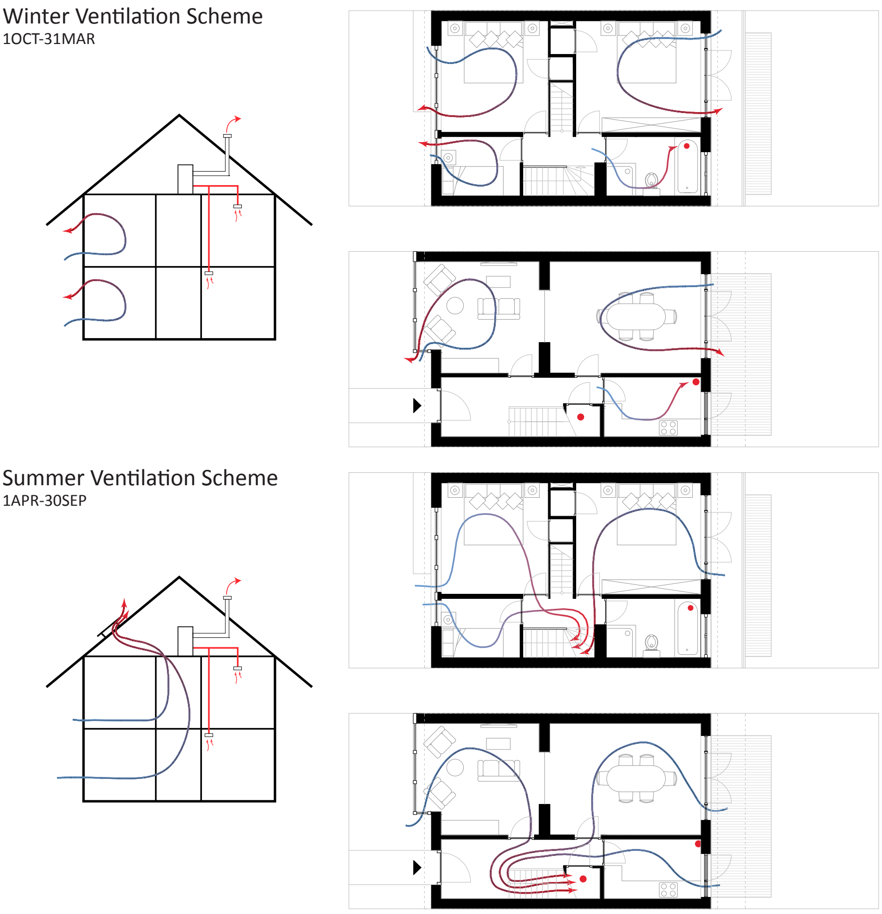


Figure 6-7: Ventilation schemes per comfort optimization seasons.

6.1.4 Comfort Optimization Conclusion | Refurbishment-1

Natural ventilation is causing high indoor temperature fluctuations during the coldest week of the winter season. To avoid uncomfortable conditions in space it is required to provide almost three or two different heating temperatures within the week. However for a typical winter week only one heating temperature is sufficient to deliver desired conditions. These temperatures are summarized in *table 6-12.*

Zones	Heating Temperature (Seasonal simulation)	Heating Set-back Temperature (Seasonal)
Sleeping -2	20° C – Natural Ventilation	0° C -Not required for winter season
Sleeping -1	20° C – Natural Ventilation	0° C- Not required for winter season
Sleeping -3	20° C – Natural Ventilation	0° C- Not required for winter season
Bathroom	21° C – Mechanical Extraction	0° C- Not required for winter season
Living Room	21° C – Natural Ventilation	0° C- Not required for winter season
Dining Room	21° C – Natural Ventilation	0° C- Not required for winter season
Kitchen	21° C – Mechanical Extraction	0° C- Not required for winter season
Toilet	21° C – Mechanical Extraction	0° C- Not required for winter season
Circulation	18° C – Circulating air in spaces	0° C- Not required for winter season

Table 6-12: Input summary for heating temperature provision in winter season per zone

Provided comfort conditions are within the range of allowed indoor temperatures, however these indoor temperatures provided are close to the lowest limit of the temperature range for reducing the excessive heating energy consumption in winter season.

During the heating season it is possible to encounter warm days or irregularities due to unexpectedly high passive solar gains, or high outside temperatures especially during seasonal change periods, however it is not possible to identify every possible condition for comfort. Therefore seasonal simulations are accepted as the typical week for every zone. Typical week & seasonal simulation heating temperatures for every zone are in *table 6-13.*

Zones	Overheating Hours Pre-Optimization	Overheating Hours Pre-Optimization	Overheating Hours Post Optimization
Sleeping -2	210	2166	89
Sleeping -1	160	1528	52
Sleeping -3	140	351	27
Bathroom	199	386	17
Living Room	126	505	14
Dining Room	175	399	34
Kitchen	174	256	18

Table 6-13: Overheating hours per optimized zone and their comparison with their previous state

Comfort optimization for summer season is based on extensive ventilation, however this ventilation is conducted as indirect to provide burglarproof ventilation system. High volumes of air supply are needed per zone to reduce indoor air temperatures. Shading elements can only help up to a certain point to prevent heat build up on space by minimizing passive solar gain in the building. While high insulation values of the building keeping the heat inside for winter season, it so does for the summer as well resulting in overheating in space.

Comfort optimizations for summer and winter season regarding secondary and primary zones are the final step before proceeding to the building services upgrade and the energy balance for annual and daily consumption. Thus the finalized energy consumption regarding the optimized state of the building zones and the upgraded building skin for refurbishment-1 is evaluated in *chapter 6.3 Energy Consumption of Optimized Refurbishment Strategies.*

6.2 Refurbishment-2 Comfort Optimization

6.2.1 Heating Optimization of Refurbishment-2 | Winter Season (1 OCT – 30 APR)

Ref-2- Sleeping 2 Heating | Reference Zone

Thermal comfort of Sleeping -2 for winter season is balanced based on required thermal range for indoor air temperature and minimum air supply per person. Simulation steps are used with different inputs to highlight the effect of possible changes to provided temperatures, method of air supply as well as the impact of envelope components. Inputs in *table 6-14* represent the certain variables included into research for optimizing thermal comfort in winter season. Highlighted steps are the simulation inputs accepted as suitable zone provisions for zone heating and fresh air supply.

Sleeping 2	Heating Temperature	Set-back Temperature	Minimum Fresh Air	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation	Wall Insulation (G)
Sim1	21° C	15° C	13,5 l/s Per person	No Restriction	No Restriction	No provision	4,5 R_c
Sim2	**23° C**	15° C	13,5 l/s Per person	No Restriction	No Restriction	No provision	4,5 R_c
Sim3	**26° C**	15° C	13,5 l/s Per person	No Restriction	No Restriction	No provision	4,5 R_c
Sim4	**25° C**	15° C	13,5 l/s Per person	No Restriction	No Restriction	No provision	4,5 R_c
Sim5	25° C	**No Set-back**	13,5 l/s Per person	No Restriction	No Restriction	No provision	4,5 R_c
Sim6	25° C	No Set-back	13,5 l/s Per person	No Restriction	No Restriction	No provision	**6,0 R_c**
Sim7	**24° C**	No Set-back	13,5 l/s Per person	No Restriction	No Restriction	No provision	6,0 R_c
Sim8	24° C	No Set-back	No provision	No Restriction	No Restriction	**1,0 l/sm²**	4,5 R_c
Sim9	**19,5° C**	No Set-back	No provision	No Restriction	No Restriction	1,0 l/sm²	4,5 R_c

Table 6-14: Simulation inputs for comfort optimization in sleeping -2. Highlighted simulation has the selected input for seasonal optimal conditions.

Simulation-1 is the existing state of Sleeping -2 and represent the default temperature rates with natural ventilation and 21° C heating temperature provision in space as well as the optimal fresh air provision to the space. Calculation of air provision is in *appendix D.*

In order to balance the indoor air temperatures and increase them to necessary range of 19,0 – 20,0°C heating provision is increased to 23° C in simulation-2. Even-though indoor air temperatures are increased for the simulation week compared to simulation-1; in *figure 6-8* increased air temperatures are still not sufficient to provide necessary thermal comfort especially during the period of 06/01-09/01 representing a portion of the very cold 17 days.

Within simulation-3 heating temperature is increased to 26° C for improving the indoor conditions during very cold days in the simulation week. In *figure 6-8* indoor air temperatures for cold days are increased above the necessary range for thermal comfort. Whenever indoor air temperatures would rise above 20° C will result in excessive gas consumption in space unless indoor air temperature is not provided by natural gas but passive solar gain.

Provided heating temperature is reduced to 25° C in simulation-4 for eliminating excessive heating consumption in very cold days in the simulation week. As a result within *figure 6-8* indoor air temperatures have receded to necessary temperature range for comfort in winter season. In another step to reduce excessive heating consumption, set back temperature is disabled for Sleeping -2 under simulation-5. However gas consumption during winter season did not between two different steps and provided temperatures are the same as simulation-4. Therefore the indoor temperatures are have not changed in *figure 6-8* Resulting from the simulation, setback temperature has no significance during winter season.

Increasing wall insulation could reduce the heating temperature required to provide necessary comfort levels. However, in simulation-6&7 insulation increase is resulting in only 1° C reduction on heating temperature for very cold days with additional global annual gas consumption reduction by 1,5%. Impact of insulation improvement from 4,5 R_c to 6,0 R_c has limited effect on thermal comfort, in *figure 6-8* simulation-7 is giving low indoor air temperatures and cannot be utilized.

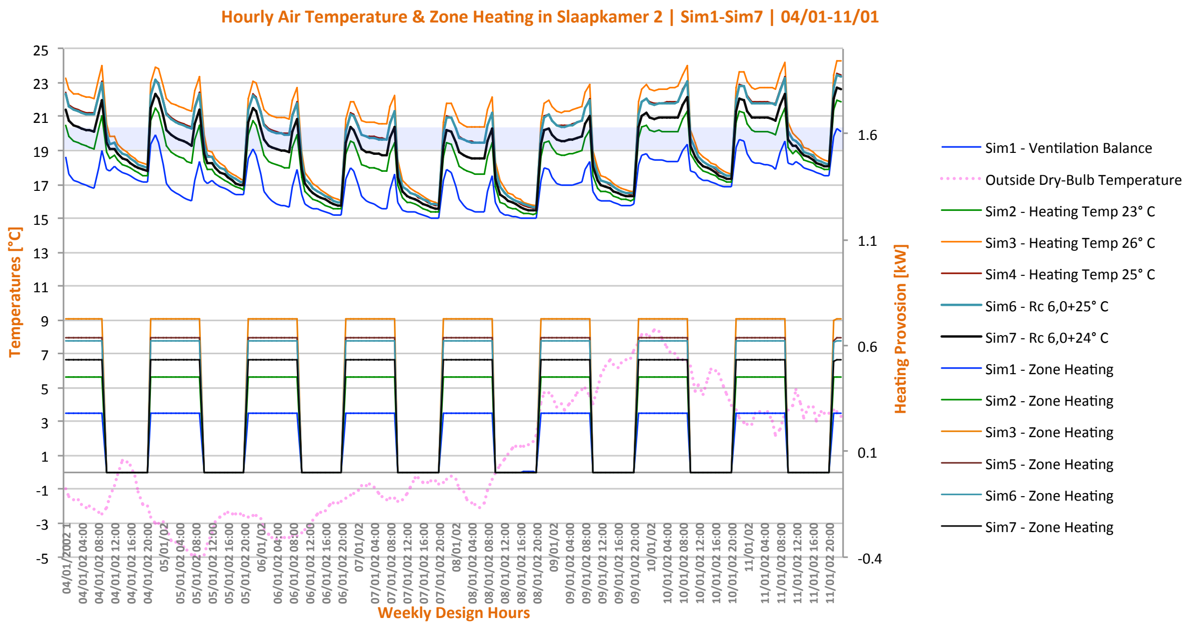


Figure 6-8: Indoor air temperatures with different heating temperature provisions.

Indoor air temperatures and their corresponding simulation inputs in *figure 6-8* for winter simulation week are giving high indoor air temperatures in hours when outdoor temperature is above -2,5° C resulting in unbalanced heating provision with unstable comfort conditions. Optimization of thermal comfort in space for Sleeping -2 is requiring constant change in heating temperature provision due to high exposure to unconditioned air from outside, decreasing the control over the indoor temperature.

When compared to Sleeping -2 optimization in chapter *6.2.1 Ref-1- Sleeping 2 Heating*, same simulation inputs for heating temperatures are not providing the similar comfort levels in *figure 6-9.* Infiltration rate of 2,93 AC/H@50pa and 0,74 AC/H@50pa are altering the impact of similar inputs. Low infiltration rate is increasing air supply (13,5 L/s per person) while moderate infiltration level only requires lesser (12,5 L/s per person). Therefore as the natural air supply increases, effectiveness of heating temperatures on indoor air comfort is reducing.

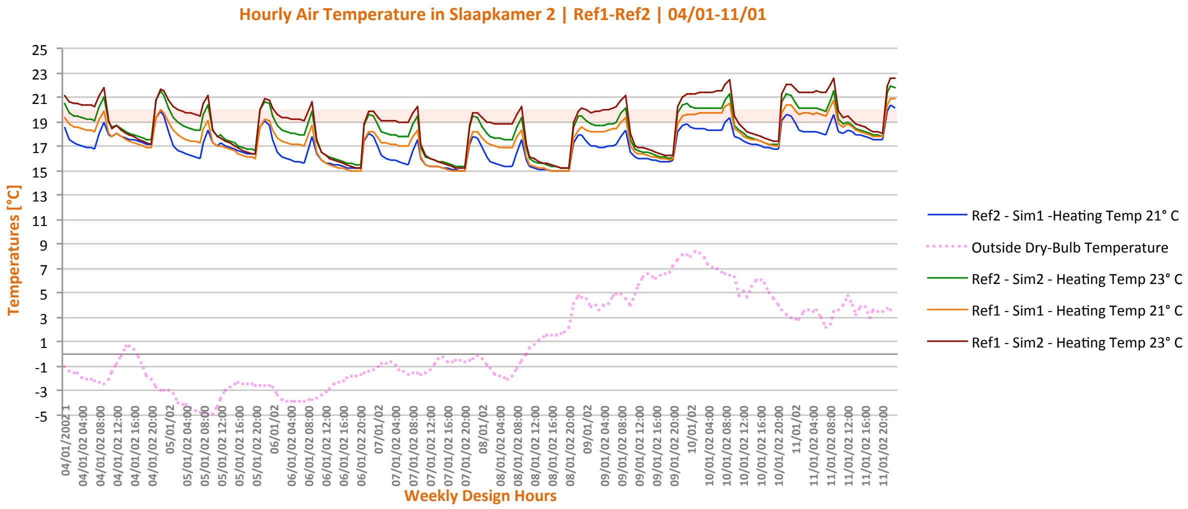


Figure 6-9: Comparison between Ref-1 and Ref-2 simulation results for sleeping -2

As the infiltration rate is improved (lowered) natural ventilation in space has to be increased to provide required amount of fresh air, resulting in additional unconditioned air entry to space in a concentrated period thus reducing indoor air temperature. Switching the ventilation system to mechanical supply and extraction would eliminate the problem of temperature fluctuations in *figure 6-9,* as the unconditioned air provision to space will be averted. Resulting in stable and low indoor air temperatures.

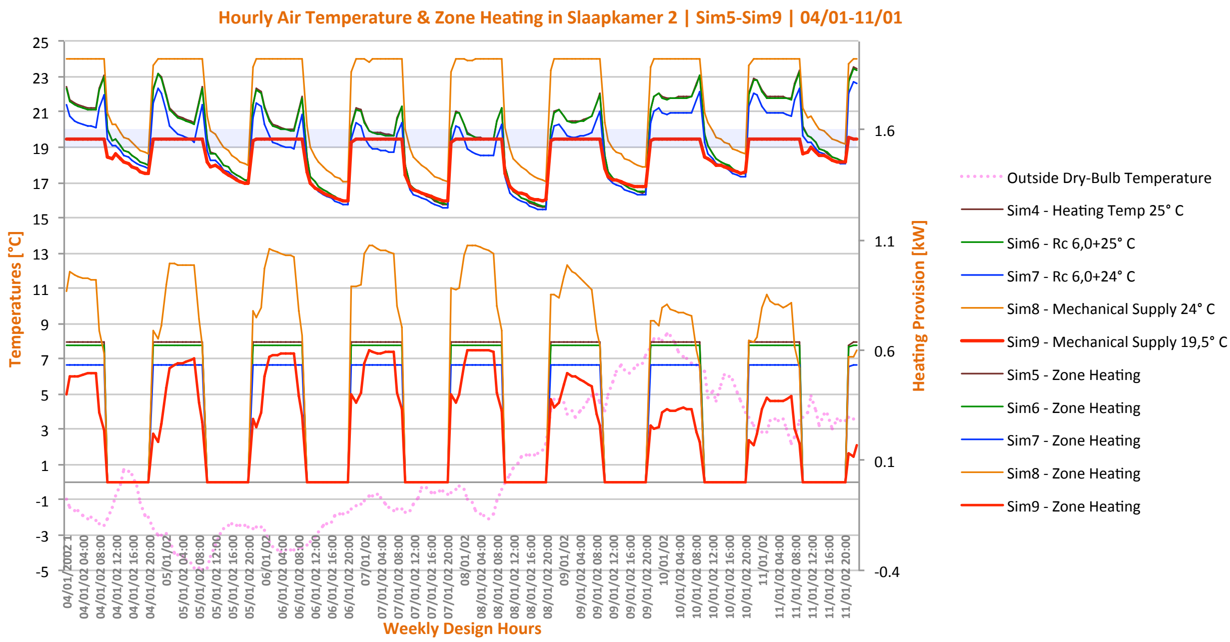


Figure 6-10: Comparison of indoor air temperatures for mechanical air supply in sleeping -2

With mechanical air supply into the space in *figure 6-10* indoor air temperatures have stabilized during occupied hours, regardless of outdoor conditions due to conditioned air supply. Conditioning of the outdoor air is combined with zone heating for simulation-8&9, therefore indoor air temperatures are always stable throughout the simulation week and certain peaks of heating provisions are due to the conditioning process of outdoor air temperature intake.

However heating temperature of 24° C is too high within required comfort levels. As mechanical ventilation is stabilizing the indoor air temperature in space due to conditioned air supply; under simulation-9 final heating temperature is given as 19,5° C to provide all-round thermal condition in Sleeping -2 for winter season.

Inputs of simulation-9 are used for final optimization for Sleeping -2 user comfort. Reflection of the simulation week and seasonal application of the inputs are in *figure 6-11.*

Highlighted period with blue in *figure 6-12* is the optimization week; indoor air temperature of the week is below required temperatures due to the daily average, however throughout the week Sleeping -2 is thermally comfortable during occupied hours. After optimizing the hourly temperatures for the simulation week as well as for winter season, heating consumption has been reduced compared to simulation-1 by 4,4% seasonally and thermal comfort has been achieved in space.

Heating and indoor air temperature of 19,5° C may seem fractionally low for the space however, temperatures given are provided during occupied hours and occupied hours are the period of 24:00-08:00 the period where people are at sleep. Outcome of Sleeping -2 thermal optimization for winter season will be applied to other primary spaces in the building regarding their specific required thermal conditions.

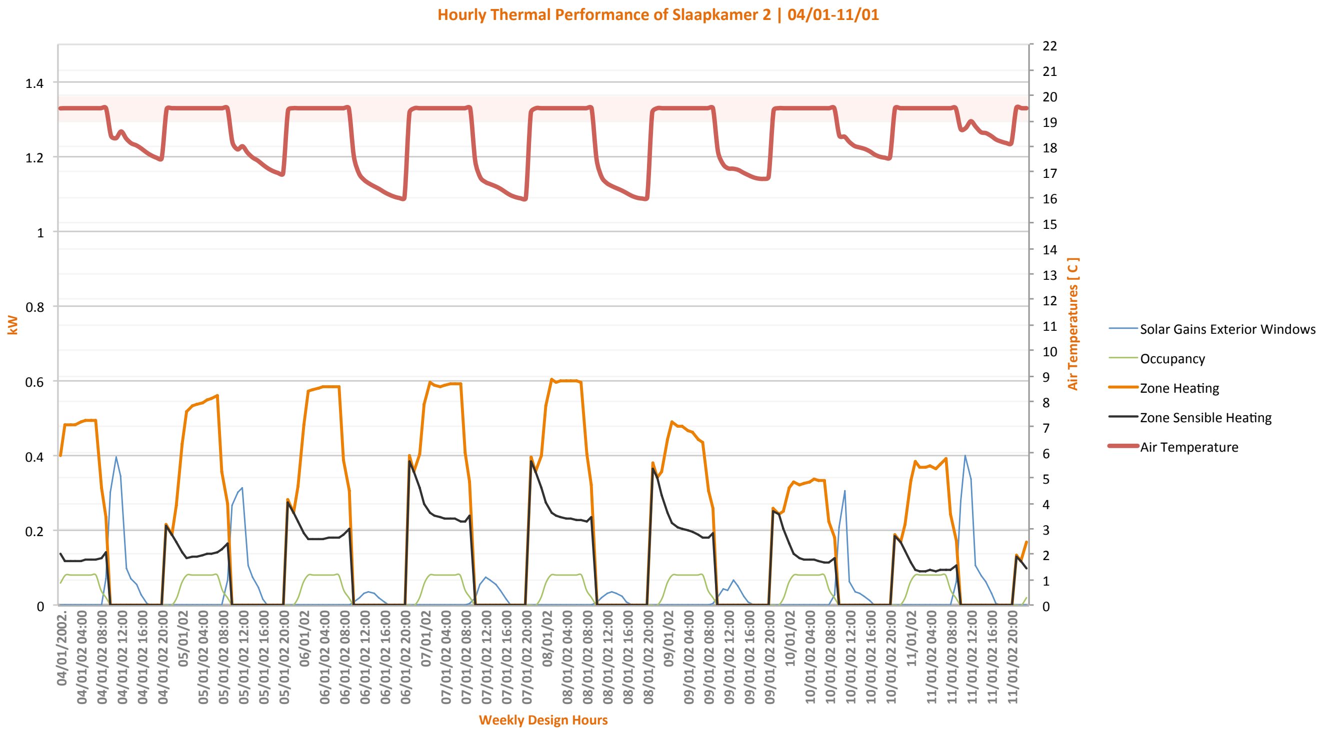


Figure 6-11: Zone thermal performance for winter season with mechanical air supply.

Ref-2- Living Room Heating

Living Room Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	2,5 l/s Per person	No restriction	No restriction	Non
Simulation2	21° C	0° C	No provision	No restriction	No restriction	0,825 l/sm^2

Table 6-15: Simulation inputs for comfort optimization in Living Room. Highlighted simulation has the selected input for seasonal optimal conditions.

Living Room and Dining Room are sharing the calculation volume for air change per hour. *Table 6-15* has the simulation inputs for Living Room seasonal comfort optimization. Having a major undisturbed connection between two of the spaces, results in a larger volume for calculation and air supply is divided between Living Room and Dining Room depending on their actual non-amassed volumes.

Mechanical supply of space is arranged according to air change per hour, total AC/H value is the summation of infiltration rate and mechanical supply, therefore air supply of 0,825 l/sm^2 is the required supply amount for delivering required AC/H of 1,097 in Living Room.

Inputs of simulation-2 are applied to the space resulting in stable indoor air temperatures in *figure 6-12* for the optimization week. Adaptation of mechanical supply into Living Room has increased the delivered gas consumption by only 4,5 kWh for the winter season without application of heat recovery. Significant changes to indoor air temperatures are the result of passive solar gain through the glazing and increase in outdoor temperature.

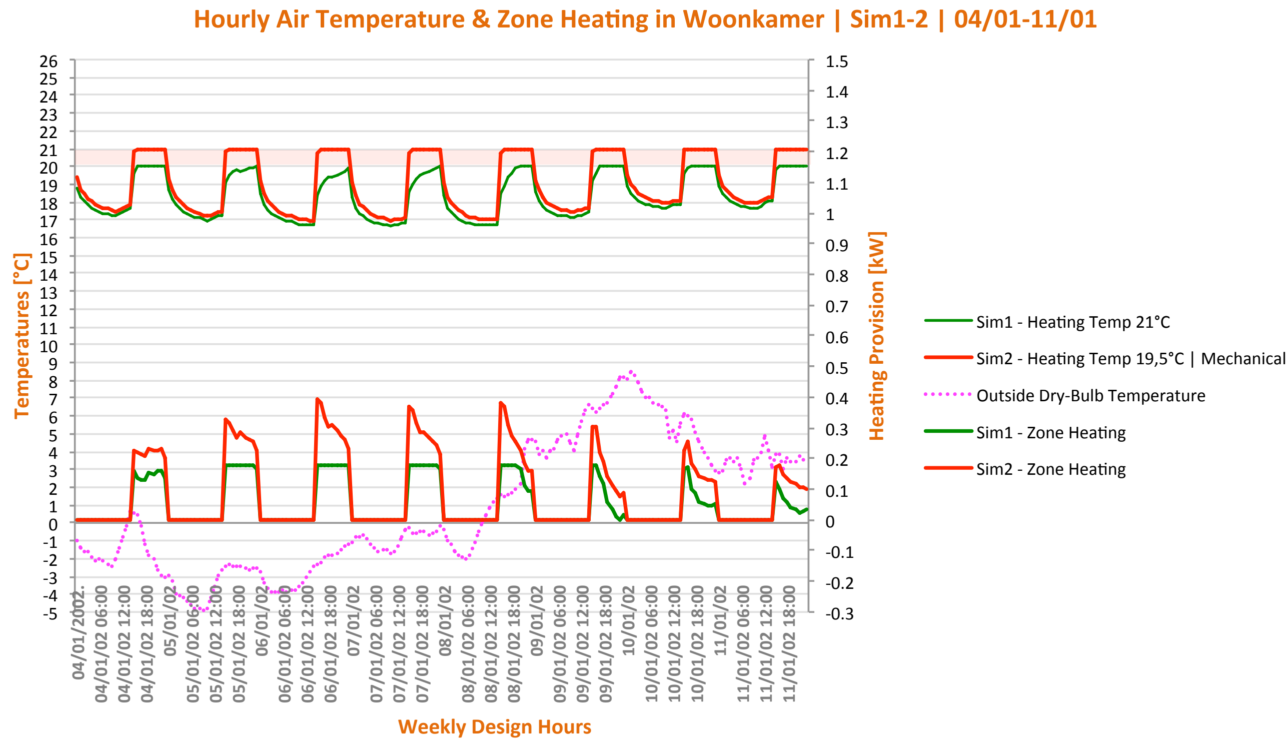


Figure 6-12: Thermal performance of Living Room under coldest simulation week.

Ref-2- Dining Room Heating

Dining Room Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	4,3 l/s Per person	No restriction	No restriction	Non
Simulation2	23° C	15° C	4,3 l/s Per person	No restriction	No restriction	Non
Simulation3	21° C	0° C	No provision	No restriction	No restriction	1,1 l/sm^2

Table 6-16: Simulation inputs for comfort optimization in Dining Room. Highlighted simulation has the selected input for seasonal optimal conditions.

Air supply of the space is determined along with Living Room due to connected spaces and assumption on the circulation of air in the greater volume of the connected spaces rather than sub spaces. Simulation-1 determines the amount of air provision to the space to deliver a portion of the necessary air change per hour. Inputs in *table 6-16* are used for the space optimization for providing comfort.

Mechanical ventilation is applied to the space to provide conditioned air for minimizing the effect of unconditioned air supply to the space. With the provision of conditioned air to the space indoor air temperatures have been stabilized for thermal comfort along with satisfactory air quality during occupied hours. Within *figure 6-13* zone heating for the simulation with mechanical ventilation is responsive to the outside dry bulb temperature, this is related to the necessary energy to preheat the outside air to supply 21° C constantly.

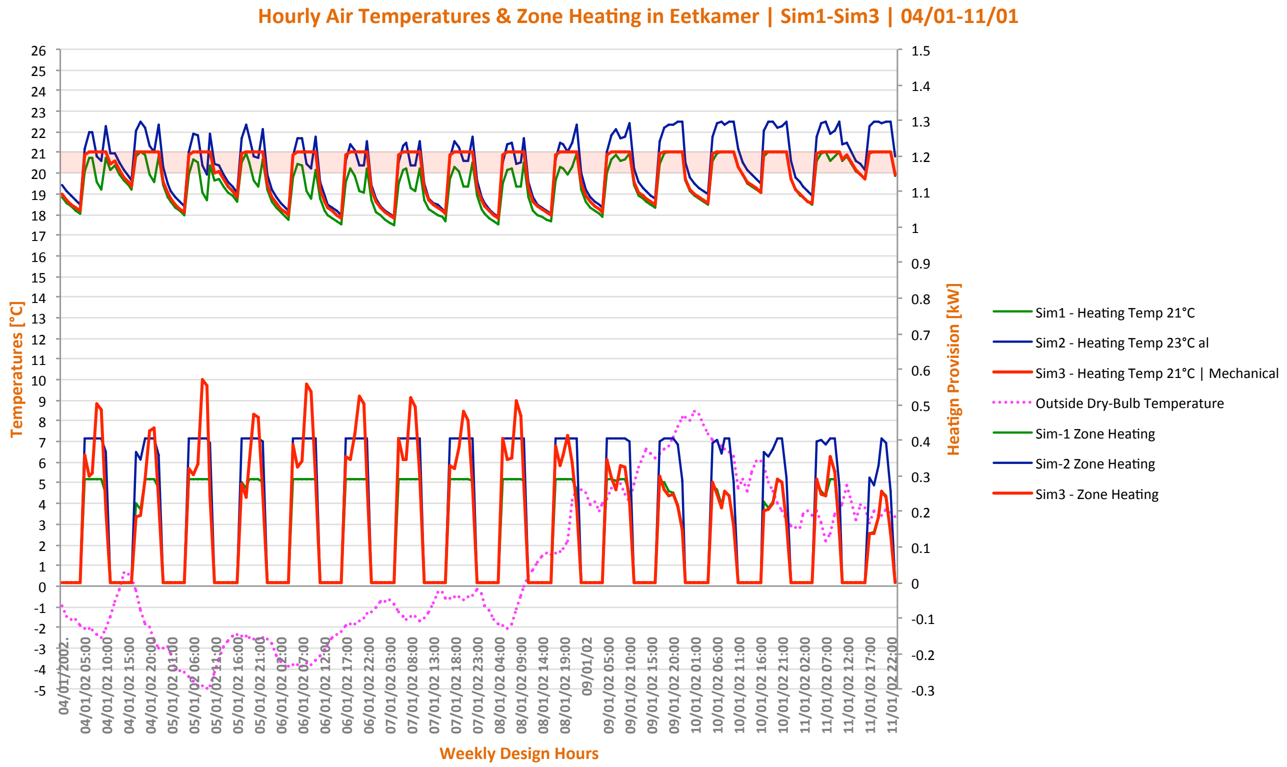


Figure 6-13: Optimized thermal performance of Dining Room under coldest simulation week.

Ref-2- Wet Spaces Heating

Wet Spaces Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Bathroom						
Simulation1	21° C	0° C	No provision	No restriction	No restriction	2,60 l/sm^2 Extraction
Kitchen						
Simulation1	21° C	0° C	No provision	No restriction	No restriction	4,41 l/sm^2 Extraction
Toilet						
Simulation1	21° C	0° C	No provision	No restriction	No restriction	10,3 l/sm^2 Extraction

Table 6-17: Simulation inputs for comfort optimization in wet spaces. Highlighted simulation has the selected input for seasonal optimal conditions.

Mechanical extraction is applied to wet spaces for providing necessary removal rates in specific zones. Spaces such as Bathroom, Kitchen and Toilets can be supplied with circulating air from sleeping rooms, living and dining rooms; therefore wet spaces only require extraction points. Inputs providing the optimal conditions in the space are given in *table 6-14.*

Simulations are directly applied to all the zones however certain thermal conditions have been kept in check such as the temperature balance for comfort. Every zone requires 20-21° C indoor air temperature with a tendency towards 21° C, Bathroom could require higher indoor air temperature when users are saturated due to showering or bathing. Only the thermal performance of Bathroom is given *figure 6-14*. Other spaces are not given due to similar conditions. Optimized conditions of Kitchen and toilet are given in *appendix D*.

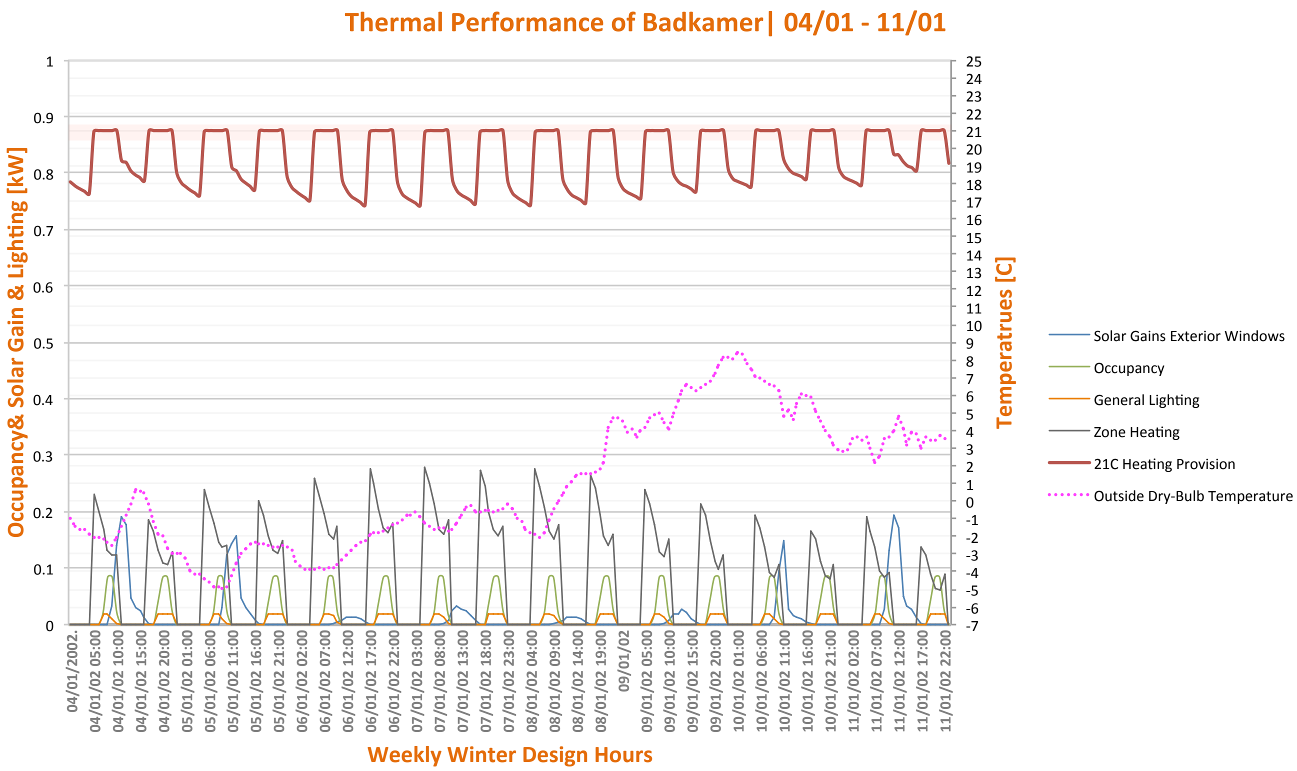


Figure 6-14: Optimized thermal performance of Bathroom under coldest simulation week.

6.2.2 Overheating Optimization of Refurbishment-2 | Summer Season (1 MAY – 30 SEP)

Ref-2- Sleeping 2 Overheating| Reference Zone

Thermal optimization for overheating period is necessary to provide optimal living conditions for the users. In order to solve the overheating problem in space passive measures are taken into consideration not to rely on energy consuming methods of building services. Firstly different shading elements are evaluated regarding previously defined criteria's for optimal solution to be applied. Shading elements used per simulation are given in *table 6-18.*

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Positioning	Operable Shading Schedule	Mechanical Ventilation	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	No restriction	1,1 l/sm^2	1021,52 kWh
Simulation2	Rekord Basic	Roller Shades (Opaque)	Outside	On (07:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1031,37 kWh
Simulation3	Rekord Basic	Venetian Blinds (diffusive)	Outside	On (08:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1023,29 kWh
Simulation4	Rekord Basic	Roller Shades (Opaque)	Inside	On (08:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1031,37 kWh
Simulation5	Rekord Basic	Overhang+ Side fins (0,5m) + Roller shades	Outside	On (08:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1036,89 kWh
Simulation6	Rekord Basic	Overhang+ Side fins (1,0m) + Roller shades	Outside	On (08:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1040,96 kWh
Simulation7	Internorm HF 210	Overhang+ Side fins (1,0m) + Roller shades	Outside	On (08:00-20:00) for 6-7-8th Months	1,1 l/sm^2	1042,89 kWh

Table 6-18: Different shading & glazing elements used for reducing solar gain in space to reduce indoor air temperatures for summer season (01/04-30/09). Highlighted simulations are used for final inputs.

Simulation week is based on the warmest week of summer season, which is 05/06-12/06. This week is determined according to the level of indoor air temperatures. Simulation-1 is conducted to reflect the state of Sleeping -2 prior to application of measures for comparison purposes. Shading elements are most effective when placed on the outside of the glazing element.

Shading elements are applied to reduce solar gain in space, which is causing overheating along with high outdoor temperatures. Within *figure 6-15* it can be seen that inputs of simulation-4 are resulting in the highest interior air temperatures. Therefore interior applications of shading elements are neglected for the dwelling. This is caused due to released absorbed heat into the space by the interior-shading element after reaching very high temperatures. Heat absorbed is trapped between the glazing and the shading element and moves inside resulting in increased indoor air temperatures.

Shading elements in simulations 5-7 and simulation-2 are resulting in similar indoor air temperatures within *figure 6-15* Additional applications of permanent shading elements such as side fins and overhangs under simulations 5&6 and have not resulted in lowered indoor air temperatures compared to outside positioned roller shades in simulation-2. Changed glazing application to Internorm HF 210 in simulation7 is has no significant difference compared to simulation-2 inputs, rather than increased annual electricity consumption due to hampered light transmittance due to glazing configuration.

Considering the impact of the shading applications to hourly indoor air temperatures in simulation week and annual visual quality under simulation steps, shading inputs of simulation-2 are selected to proceed for further optimization of summer season comfort in Sleeping -2.

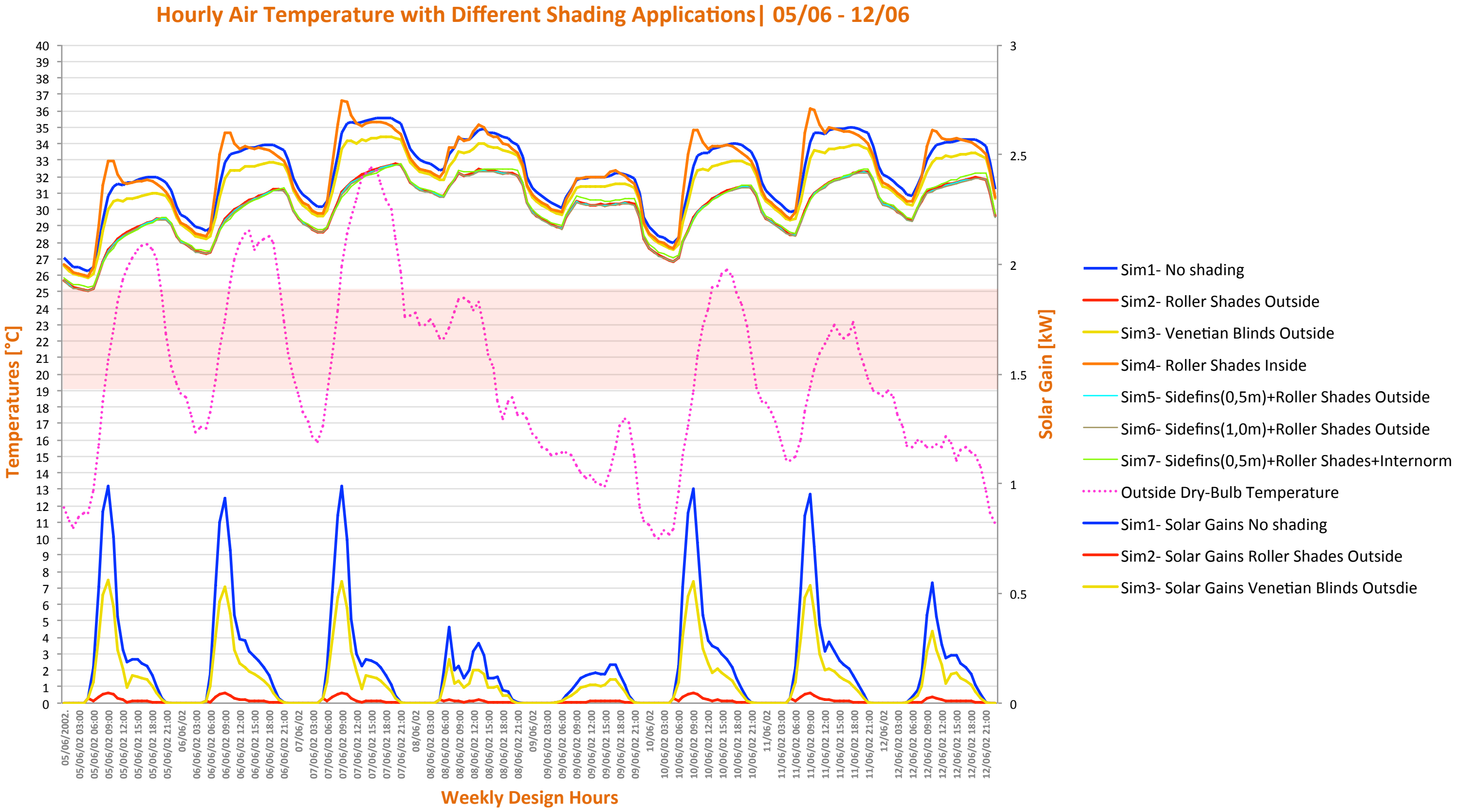


Figure 6-15: Indoor air temperatures for different shading options and their affectivity for reducing solar gain inside sleeping -2

Roller shades positioned outside are not sufficient by themselves to reduce the indoor air temperatures for the given optimization week as well as for the summer season. Therefore natural ventilation is considered for reducing indoor temperatures by daytime and nighttime cooling in the building. Different simulations are conducted for different air supplies through stack ventilation in to the space. Inputs for further thermal optimization of the space are given in *table 6-19.*

Mechanical supply is cancelled for summer season for extensive natural ventilation provision. Stack ventilation is applied through the openings in the attic where height and indoor – outdoor air temperature are causing pressure difference resulting in airflow in to the space.

Amount of air supply in to the space with stack ventilation is determined according to the smallest temperature difference in between indoor air temperature and outdoor dry bulb temperatures within the period of selected simulation week to highlight to worst-case scenarios for overheating in space.

Simulations determine the highest amount of air supply required by natural ventilation to provide necessary comfort conditions. Automated ventilation system will regulate the amount of air volume entry to space by sizing the openings, with conditions of not supplying air higher than the accepted simulation inputs per zone.

Burglary resistant ventilation openings are either addition to the space openings or conversion of a portion of already existing transparent openings. Within *chapter 6.2.3 Ventilation System of Refurbishment-2* opening conversion of every optimized zone is given with comparison between previous state and refurbished state.

Difference between indoor and outdoor air temperature is based on 07/06 daily average of temperatures for simulation purposes. Temperatures are fixed in order to change only one variable, which is the opening size of ventilation system in the zone. Calculation of air supply per zone per simulation per input can be found in *appendix C.*

Sleeping -2 Inputs	Shading & Glazing Application	Ventilation Opening	Resulting Air supply in space	Natural Ventilation	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature
Simulation8	Simulation-2 inputs	Standard	13,5 L/s (min rate) per person	On 24/7	21° C	Non
Simulation9	Simulation-2 inputs	0,1 m^2	35 L/s per person	On 24/7	21° C	Non
Simulation10	Simulation-2 inputs	0,5 m^2	71 L/s per person	On 24/7	21° C	Non
Simulation11	Simulation-2 inputs	0,7 m^2	92 L/s per person	On 24/7	20° C	Non

Table 6-19: Simulation inputs for further thermal optimization in sleeping -2. Additional air supply to space..

Simulation-8 represents the state indoor air temperature if minimum amount of air change per hour is to be provided in space with 24/7 ventilation schedule. Within *figure 6-16* indoor air temperatures of every simulation step is given.

As the opening surface area is increased so does the amount of air coming in to the space, resulting in reduced indoor air temperatures for the simulation week. Indoor air temperature in Sleeping -2 is following the pattern of outdoor temperature, due to constant daytime and nighttime cooling and the ventilation availability is restricted, if outdoor air temperature is higher than indoor air temperature unless high outdoor temperature collide with user occupancy.

However it is important to keep the excessive ventilation in balance with indoor air temperature therefore, a minimum indoor air temperature criteria is given for simulations not to reduce interior temperatures below 21° C in order not to trigger heating in space during warm summer days. Within *figure 6-16,* certain air change rate for Sleeping is reduced when indoor air temperature reaches or gets close to 21° C to prevent heating usage, reduced air change rate applies to the whole season however supply of air is never short of the required minimum of 13,5 L/s for the space.

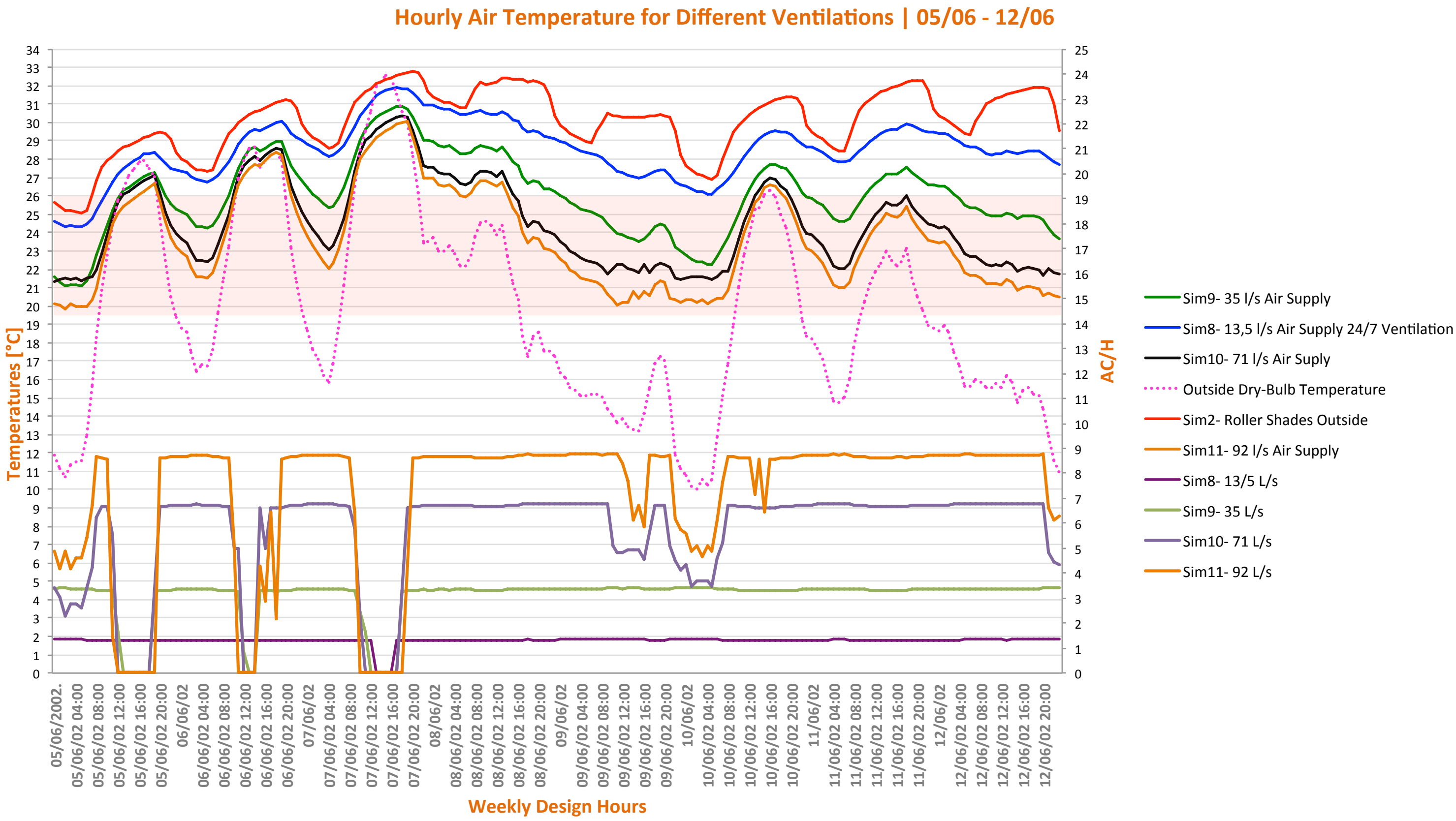


Figure 6-16: Indoor air temperature in sleeping -2 with different air change per hour in space with excessive ventilation

Therefore simulation-11 inputs result in the optimal thermal comfort for Sleeping -2 and used for seasonal simulation and weekly optimization. Within *figure 6-17* weekly-optimized state of Sleeping -2 can be seen with 92 l/s air supply to space, and reduced solar gain with outside positioned roller shades. In *figure 6-18* relation between the occupancy and air change in space is given. When there is no air change, outside dry bulb temperature is higher than indoor air temperature therefore ventilation is halted.

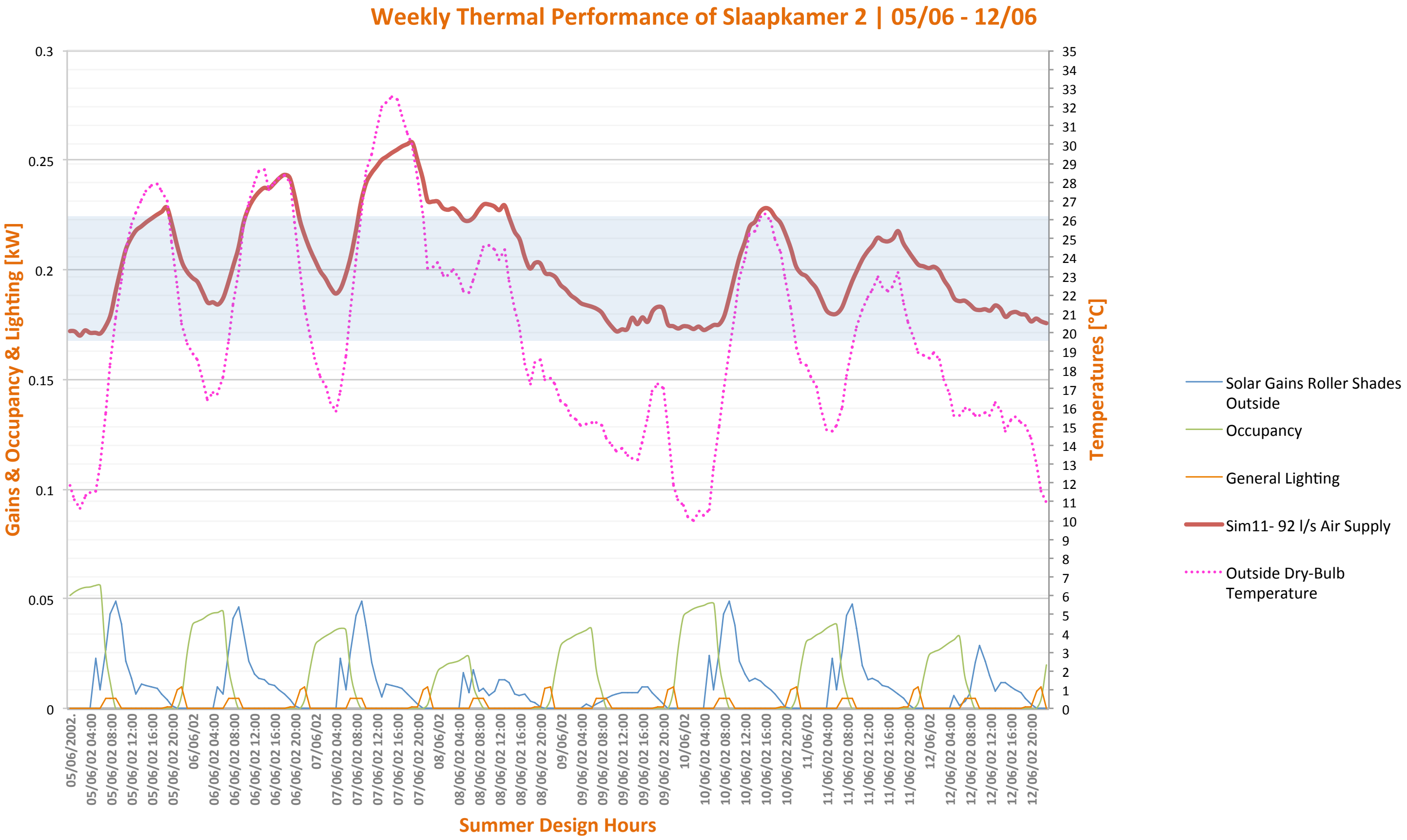


Figure 6-17: Weekly optimized condition of sleeping -2 with indoor air temperature and solar gain results from selected simulation inputs

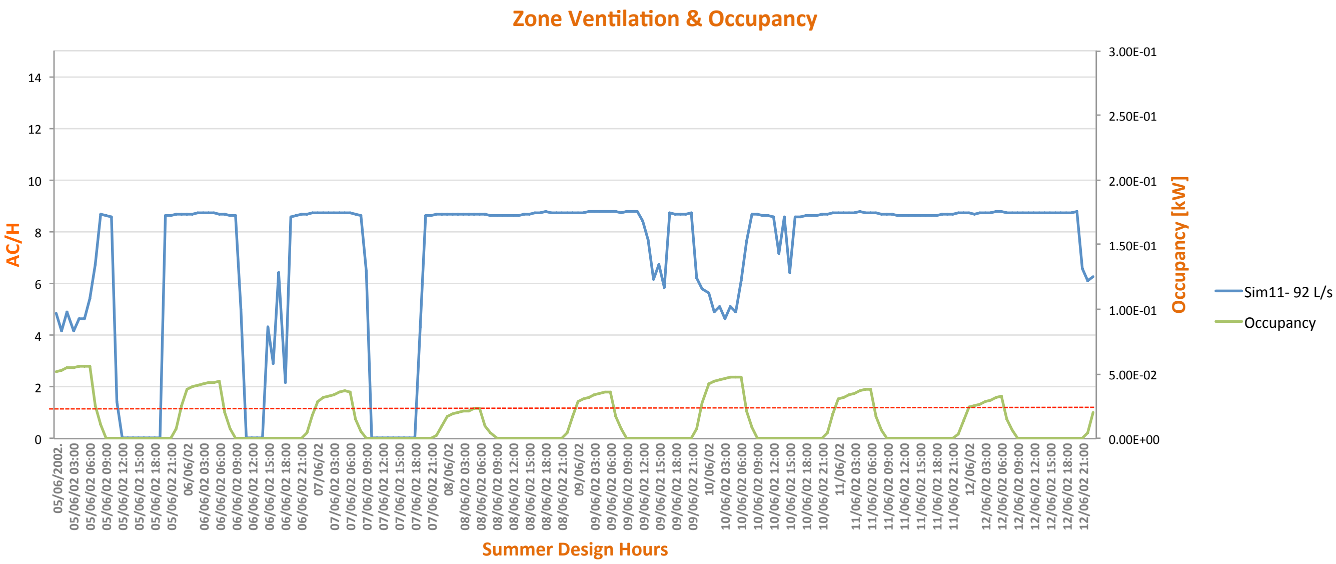


Figure 6-18: Relation between the occupancy and ventilation in sleeping -2 throughout the optimization week

Ref-2- Living Room Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	1,525 l/sm^2	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6th-7th-8th Months	1,525 l/sm^2	Outside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Air Supply Period**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation3	Simulation-2 inputs	0,1 m^2	2,5 L/s (min rate) per person	On 24/7	22° C	Non
Simulation4	Simulation-2 inputs	0,45 m^2	28 L/s per person	On 24/7	22° C	Non

Table 6-20: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted.

Outside positioned Roller Shades are applied to the building zone for reducing solar gain through the transparent openings in order to reduce overheating temperatures up to certain point. Excessive ventilation is applied to further reduce indoor air temperatures during summer season to deliver thermal comfort to users in space. Inputs on ventilation are given in *table 6-20.*

Within *figure 6-19* indoor air temperatures of ventilation simulations-3&4 are given along with the previous simulation steps. 28 L/s air per person is supplied according to 0,45 m^2 ventilation opening which conditions the space successfully to deliver desired thermal conditions for the simulation week as well as for the summer season. Simulation-3 is conducted to highlight effect on indoor air temperature if minimum air change per hour is provided to the space in a constant manner through out the week and it is not sufficient to deliver desired criteria's.

Inputs of simulation-2 and simulation-4 are accepted as variables delivering the optimal conditions for Living Room in optimization week and for the season. After the application of accepted simulation inputs overheating hours in space has reduced to 24 from 735 hours.

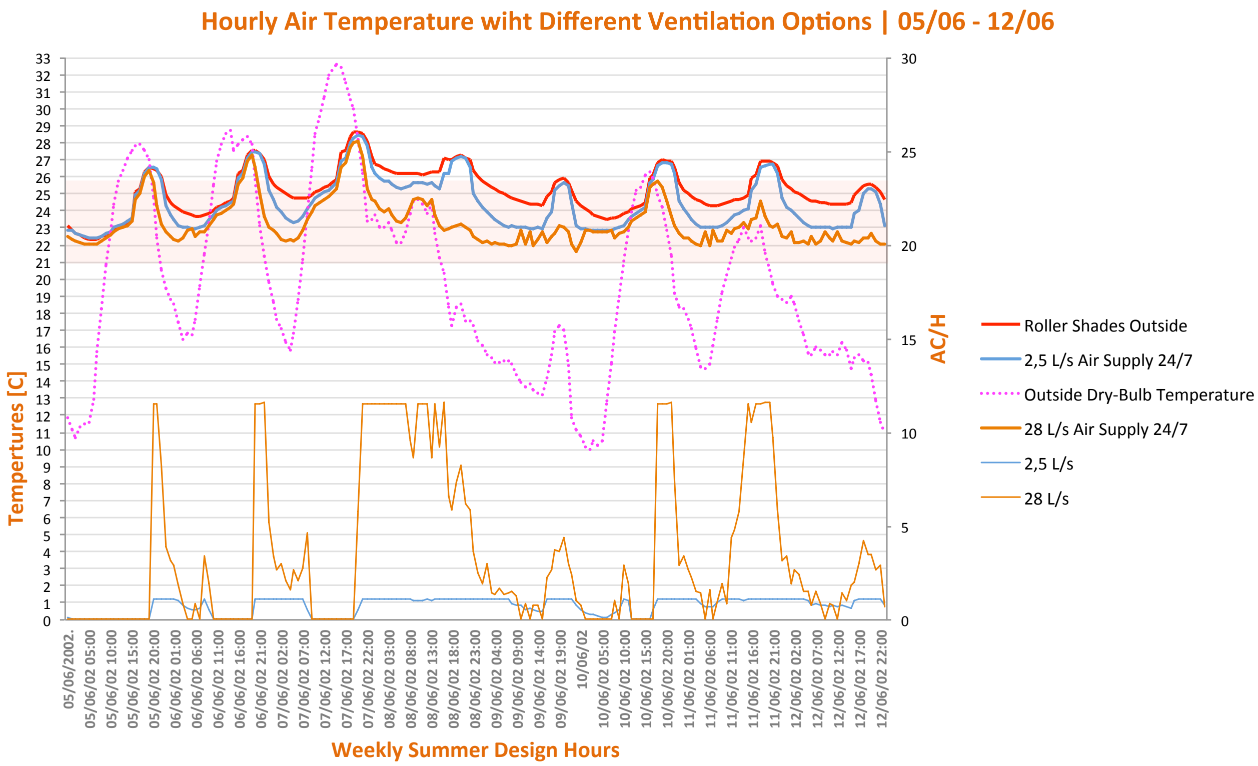


Figure 6-19: Indoor air temperature per simulation step with different ventilation rate in Living Room

Ref-2- Bathroom Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Extraction	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	2,6 l/sm^2	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	2,6 l/sm^2	Outside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Air Supply Period**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation3	Simulation-2 inputs	0,3 m^2	30 L/s per person	On 24/7	22° C	Non
Simulation4	Simulation-2 inputs	1,2 m^2	70 L/s per person	On 24/7	22° C	Non

Table 6-21: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted

Roller shades are used for reducing solar gain in space for Bathroom. In addition to solar shades natural ventilation is used 24/7 with indoor air temperature limitation to regulate the air change in space. Within *table 6-21* simulation inputs are given for the space optimization.

Excessive ventilation is used for reducing indoor air temperature in space to provide optimal comfort temperatures. Inputs of simulation-3&4 are within *figure 6-20* with resulting indoor air temperatures. Simulation-4 is conducted to highlight the possible impact of increased ventilation on the indoor air temperature. If 70 L/s is supplied to the space, indoor air temperatures fall below the optimal thermal limit for comfort, which triggers heating in space and causes inconvenience regarding user comfort with low temperatures.

Simulation-3 input of 30L/s per person signifies the highest amount of air supply to the space throughout the season. Automated ventilation system will regulate the indoor air temperature along with the air entry to space not to supply air higher than 30L/s to cause irregularities in space.

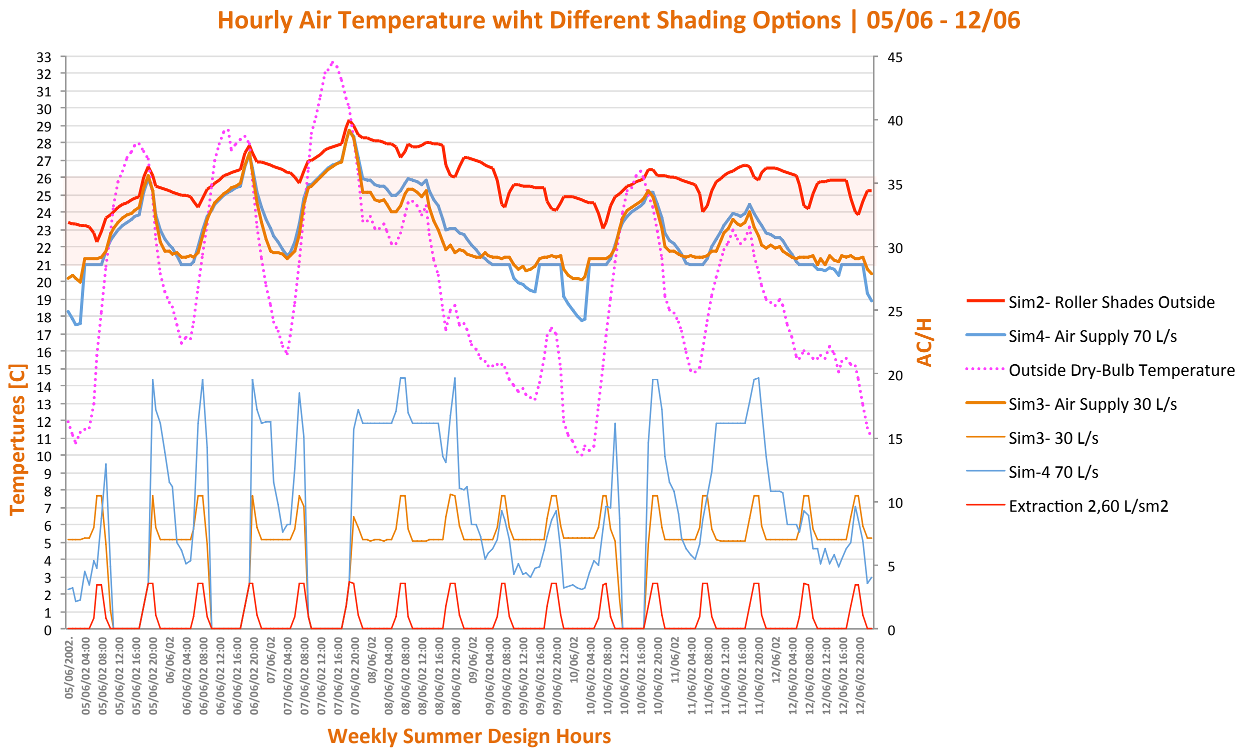


Figure 6-20: Indoor air temperature per simulation step with different ventilation rate in Bathroom

Ref-2- Dining Room Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	1,525 l/sm^2	-	-
Simulation2	Rekord Basic	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	1,525 l/sm^2	Outside	-
Simulation3	Rekord Basic	High Reflectance	On (07:00-20:00) for 6-7-8th Months	1,525 l/sm^2	Inside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Air Supply Period**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation4	Simulation-2 inputs	0,4 m^2	27 L/s (min rate) per person	On 24/7	22° C	Non
Simulation5	Simulation-2 inputs	0,7 m^2	40 L/s per person	On 24/7	22° C	Non

Table 6-22: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted

Shading application for Dining Room is different compared to other. No exterior shading is required due to 1,0 m extending balcony, permanent shading the glazing of Dining Room and Kitchen. In addition to the balcony effect, exterior shading would hamper the access to the inner garden from Dining Room and Kitchen.

Inputs for space optimization simulations are given in *table 6-22* and in *figure 6-21* indoor air temperature and interior solar gain of different shading options are given in the optimization week. Simulation-3 input of high reflectance shading results in higher indoor air temperatures than roller shades, however most of the periods interior temperatures are within the comfort range and further reduction can only be executed by ventilation.

Solar gain avoidances of shading applications are performing similarly in *figure 6-21* with the exception of outdoor temperature peaks at certain periods, which signify high solar radiation exposure of the building.

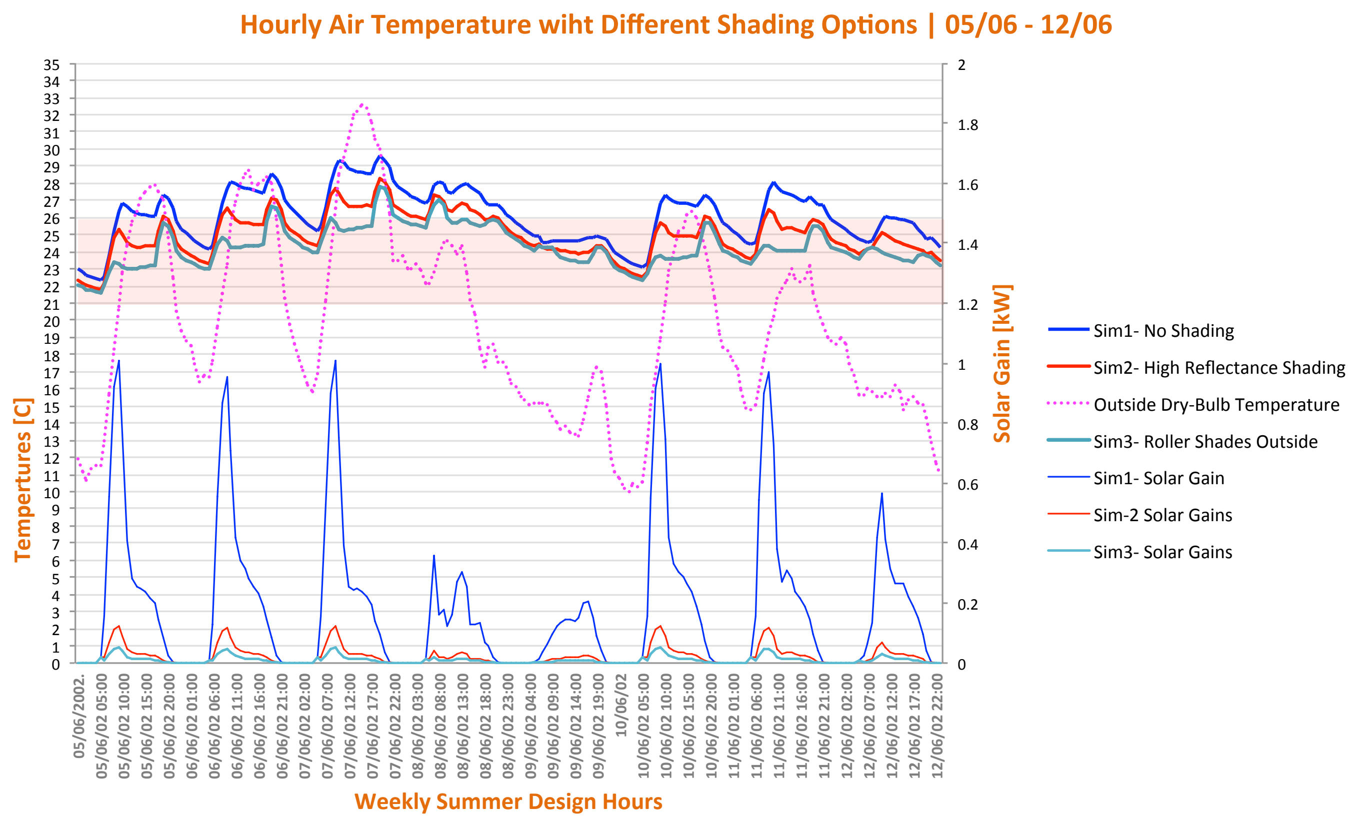


Figure 6-21: Different shading options for Dining Room. This zone already has a permanent shading element (balcony extending 1,0 m)

summer season. *Figure 6-22* gives the indoor air temperatures after different air supply provisions to the space under simulation-4 and 5. Simulation-5 gives better results for the indoor temperatures and overheating hours for the whole season is reduced from 279 to 18 hours.

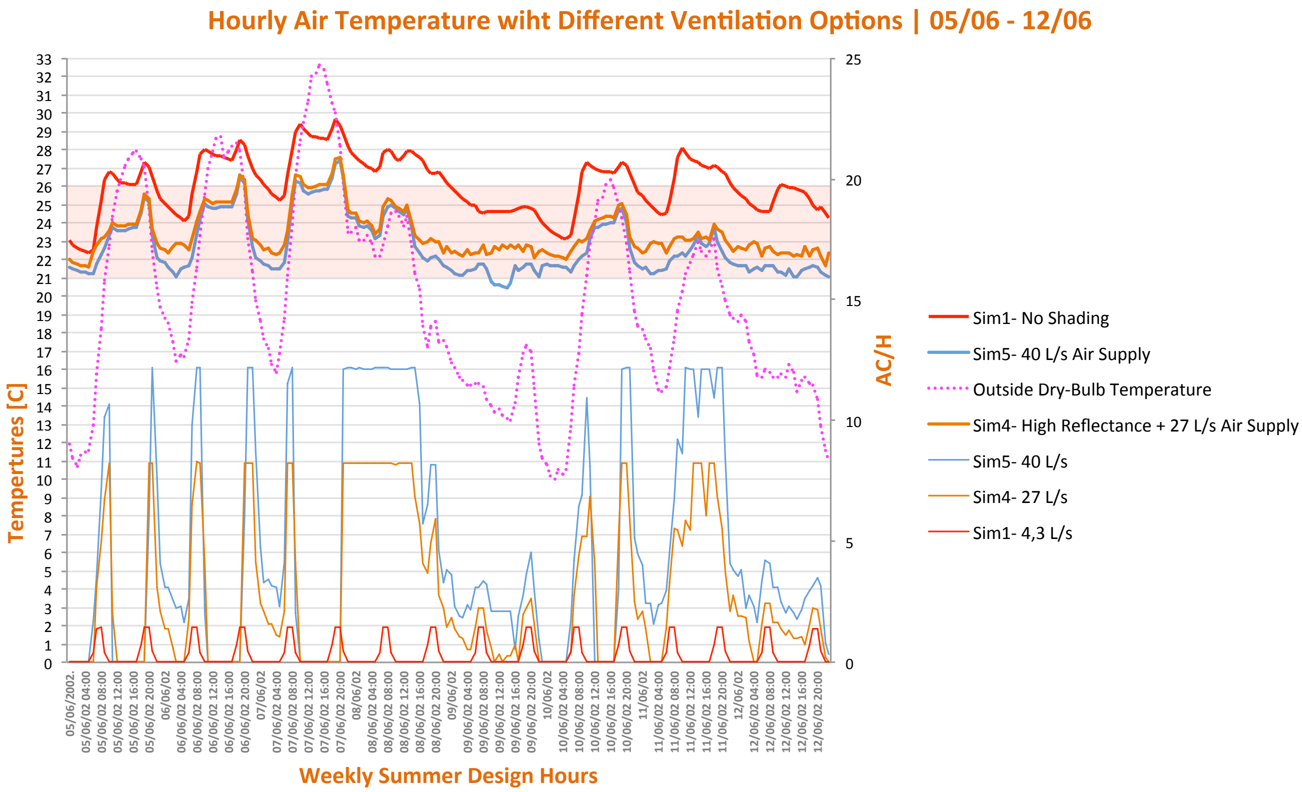


Figure 6-22: Indoor air temperature per simulation step with different ventilation rate in Dining Room

Ref-2- Kitchen Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Extraction	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rekord Basic	Non	Non	3,5 l/sm^2	-	-
Simulation2	Rekord Basic	High Reflectance	On (07:00-20:00) for 6-7-8th Months	3,5 l/sm^2	Inside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Air Supply Period**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation3	Simulation-2 inputs	0,1 m^2	12 L/s per person + 3,5 l/sm^2	On 24/7	22° C	Non
Simulation4	Simulation-2 inputs	0,6 m^2	52 L/s per person + 3,5 l/sm^2	On 24/7	22° C	Non

Table 6-23: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted

Kitchen is has the same shading input as Dining Room regarding similar concerns on garden access and permanent shading caused by the balcony. Simulation inputs for overheating optimization of Kitchen are in *table 6-23.*

Shading is applied in simulation-2 to reduce solar gains through the transparent openings of the envelope. Within *figure 6-23* impact of shading element on indoor air temperature and interior solar gain is given for the optimization week. For further air temperature decrease in space excessive ventilation is applied on 24/7 basis regulated by indoor air temperature limits provided in *table 6-26.*

Simulation-3 inputs of 12L/s for air supply in space has resulted in very limited improvement in thermal comfort in the week within *figure 6-23.* Therefore supplied air had to be increased. Simulation-4 inputs reflect the optimized condition of the simulation week for indoor air temperature, which makes a significant difference from simulation-3 results when outdoor dry bulb temperature is lower than indoor air temperature.

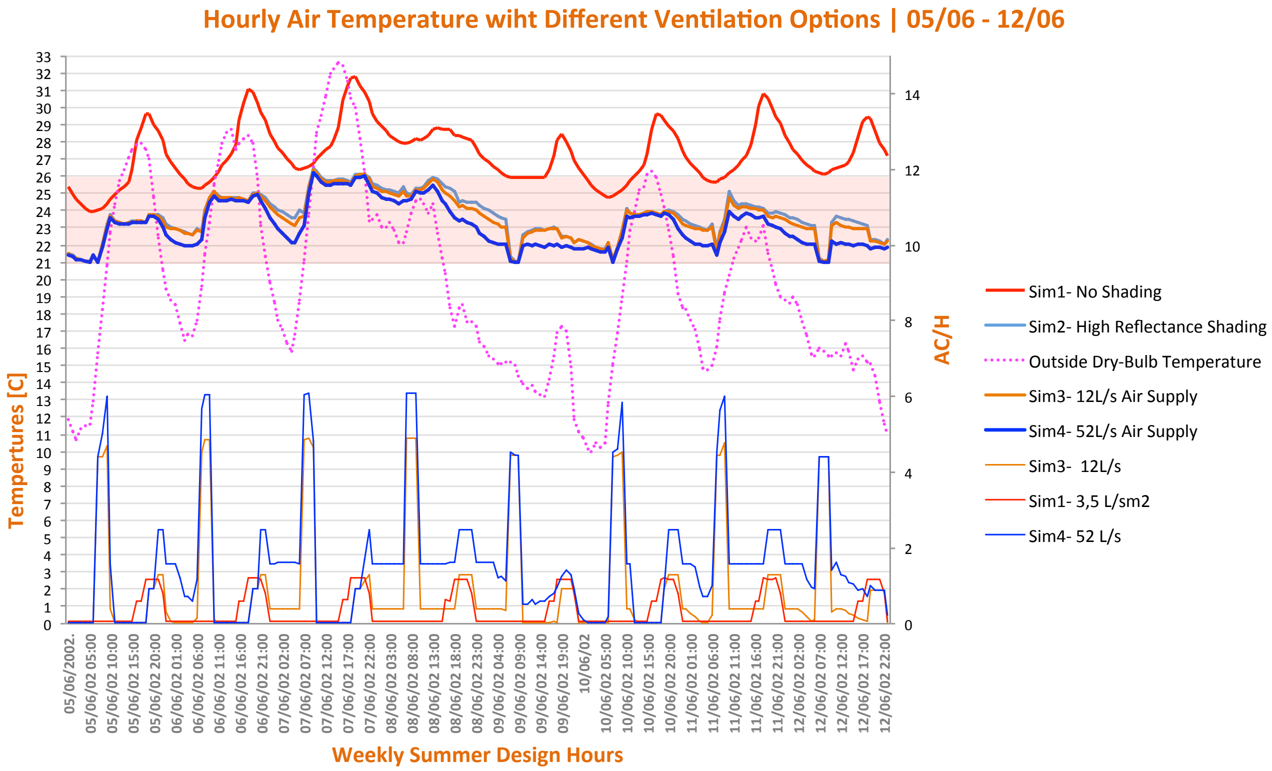


Figure 6-23: Indoor air temperature per simulation step with different ventilation rate in Kitchen.

6.2.3 Ventilation System of Refurbishment-2

Ventilation system of the building is decided along the steps made in passive measures as well as comfort optimization steps. A hybrid system is used for the annual ventilation scheme, however there are two different schemes for two different seasons.

Resulting ventilation system for winter season in the building is based on mechanical supply and extraction. Due to very low infiltration through the building envelope mechanical ventilation has become a necessity to sustain thermal conditions without increasing space heating. For good insulated buildings with low infiltration rate, only way to lose energy for heating is via ventilation. In order to further reduce energy consumption for heating mechanical supply is used in the building.

During winter season supply air is preconditioned and provided to the space to limit energy loss in the building due to ventilation. Mechanical ventilation also makes it possible to recover the heat during extraction process to condition the air coming in thus reducing energy consumption for heating purposes by recycling the waste; one of the key points in the New Stepped Energy strategy.

During summer season excessive ventilation is taking place through the envelope openings. Mechanical ventilation is cancelled due to reduced temperature differences between inside and the outside of building along with the necessity to constantly provide high volumes of air to cool the building down.

Envelope openings are automated to regulate the volume of airflow in space in regard to indoor and outside air temperature. Seasonal schemes of ventilation are given in *figure 6-24.*

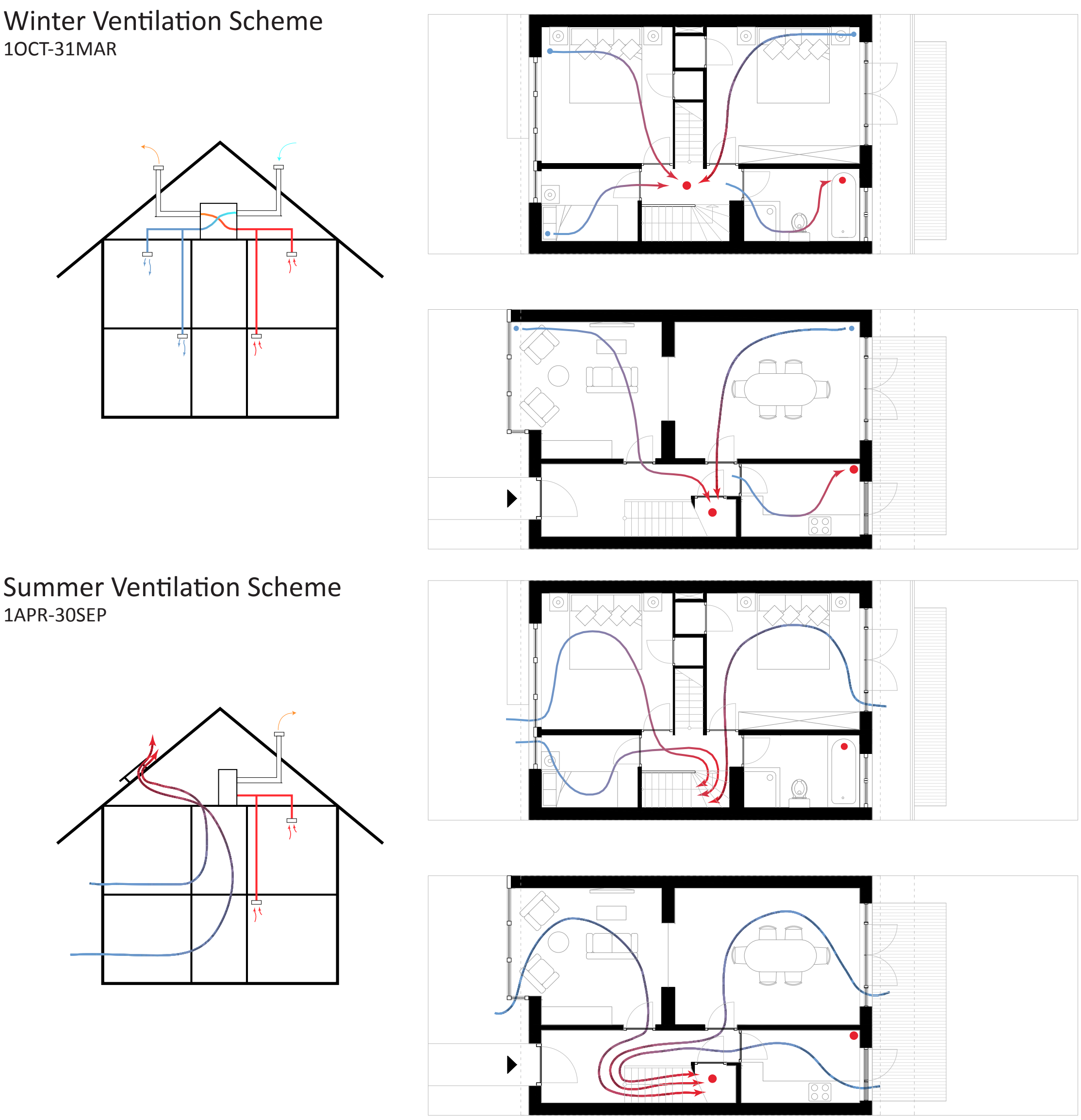


Figure 6-24: Ventilation scheme for optimized simulation seasons.

Heat Recovery

Heat recovery is the recirculation of the warm extracted air from space to condition (warm) the intake of supply air. Recovery of heat is generated in the heat exchanger unit of the ventilation system and type of the recuperator determines the efficiency of the unit.

Recovery of waste or purposeless energy is an essential part of the New Stepped Strategy and the most effective and easiest way of repurposing waste heat in a housing unit cycle is via ventilation. There are other options of recycling waste heat in building scale. Shower heat recovery, recycling boiler flue gasses and heat recovery from standard taps. However in refurbishment only the recovery from conditioned air will be used.

One of the drawbacks of the system is the frosting problem for cold climates, when the system senses a possible frosting due to outside air intake it can either use dampers to function as only exhaust or heat the air with electrical resistances. However all the measures for preventing frosting is reducing the sensible recovery efficiency of the system and higher the actual efficiency, higher the reduction on efficiency of the component.

Heat recovery is labeled accordingly to their efficiency and 70% efficiency for sensible heat recovery is the standard condition for a ventilation system, there are 80% and 90% efficient heat exchangers as well. For reducing the final consumption for space heating in Refubishment-2 heat recovery is applied. Within *table 6-27* efficiencies of the applied recovery systems and the final consumption in the building is given along with the recovery efficiency accepted.

Simulations (Annual)	Heat Recovery (%)	Space Heating (kWh) Gas	Improvement (%)	Recovered Heat Sensible (kWh)
Simulation-1	Non	2384,19	-	-
Simulation-2	70%	868,80	63,5%	1363,37
Simulation-3	80%	722,56	69,7%	1526,73
Simulation-4	90%	606,17	74,5%	1671,30

Table 6-24: Energy consumption for heat recovery efficiencies simulated.

Comparing the results in *table 6-27* shows that 90% heat recovery is the most effective solution, however the resulting efficiency of the simulation-4 inputs are the lowest. Simulation-2 with 70% heat recovery gives the standard condition of a heat recovery system and it's the most effective (gap between recovery efficiency and space heating reduction). However 80% heat recovery reduces the energy even further and it is much more efficient than 90% recovery and reduces space heating even lower than 70%.

70% heat recovery is the standard value for heat exchanging in mechanical systems and it is possible to reach up to 90-95% recovery however, heat recovery is only efficient depending on the outside conditions and 90% efficiency for heat recovery cannot be sustained for the whole year. Therefore heat recovery with 90% efficiency is not feasible.

6.2.3.1 Mechanical Ventilation Sizing

Mechanical ventilation is sized according to the necessary amount of air to be handled by the central distribution and extraction unit. However not only the capacity of the system is set but the ducts and the nodes regarding their positioning and available space in the ceiling or partition walls.

Sizing is based on the peak demand of air volume within hourly period. Machinery has to handle the peak workload in an hour to sufficiently execute the necessary air circulation in the building. Peak demands of every zone supplied or extracted with mechanical systems are given in *table 6-25.*

However the periods of the peak loads per zone do not match due to different schedules and usage patterns therefore for the accuracy of calculations, demand for air supply and extraction per hour must be superposed per zone. The calculation of peak loads per hour and the superposed state of the total demand is given in *appendix D-3*.

Zones	Air Supply / Extract (L/sm^2)	Supply Period*	Zone Area m^2	L/s to m3/h	Peak Air Volume for an Hour
Sleeping -1	0,84	Appendix D-3	11,46	x 3,6	24,8 m^{3}h
Sleeping -2	1,37	Appendix D-3	14,2	x 3,6	51,1 m^{3}h

Sleeping -3	2,05	Appendix D-3	4,6	x 3,6	25,3 m^3h
Dining Room	1,45	Appendix D-3	13,0	x 3,6	65,6 m^3h
Living Room	1,15	Appendix D-3	16,6	x 3,6	38,6 m^3h
Bathroom	3,45	Appendix D-3	5,8	x 3,6	53,9 m^3h
Kitchen	4,47	Appendix D-3	5,7	x 3,6	72,5 m^3h
Toilet	13,1	Appendix D-3	1	x 3,6	36,3 m^3h
Highest Air Supply & Extract Volume (Building Total)					
All Peak loads (non superposed periods)	368 m^3/h				
Superposed Periods (at 8:00-9:00)	318 m^3/h(155 m^3 fresh & 163 m^3 exhaust)				

Table 6-25: Air supply and extraction demand and highest loads per zone in Hospeslaan 24 with mechanical ventilation systems

According to the superposed air supply and extraction demand between 8:00-9:00 has the highest volume provision compared to the rest of the time periods. It is essential to circulate minimum 317,5 m^3 of air from which 49% is fresh air in sleeping rooms, living and dining room and 51% exhaust from wet spaces. Therefore the air handling capacity of the ventilation machinery has to be larger than 318 m^3 with minimum 80% heat recovery capacity.

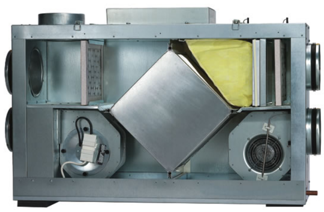
Mechanical Ventilation Options			
Technical Information	**Allergy Plus DV150 SE**	**Helios KWLC 350**	**Zehnder Comfort Air Q350**
Image			
Image Source	http://www.archiexpo.com/prod/airflow-lufttechnik-gmbh/product-73849-1098977.html	https://www.buildingservicesindex.co.uk/entry/44222/AllergyPlus/Helios-KWLC-350-heat-recovery-ventilation-units/	http://www.zehnder.nl/ventilatie-units/warmteterugwinning/luchthoeveelheden-tot-600-m³h/zehnder-comfoair-q350-st
Airflow Capacity	432 m^3/h	350 m^3/h	350 m^3/h
Heat Recovery	80% minimum	Up to 90%	94% maximum
Size	1000 mm Length 600 mm Width 350 mm Height	1000 mm Length 600 mm Width 350 mm Height	723 mm Length 578 mm Width 850 mm Height
Duct Connections	4 connections 160mm diameter	4 connections 160mm diameter	4 connections 160mm diameter
Summer by pass	Available	Available	Available
Anti Frost	Electric Pre-Heater	Electric Pre-Heater	Electric Pre-Heater
Humidifier / dehumidifier	No humidifier or dehumidifier addition available	No humidifier or dehumidifier addition available	Yes. Attachable additions including cooling and earth duct heating
Extraction [dB]*	Not provided	44	34-38
Supply [dB]*	Not provided	58	46-51

Table 6-26: Technical inputs regarding different mechanical ventilation centrals

Selection of the mechanical ventilation system is based on the heat recovery capacity, size add-on options, acoustical disturbance during peak supply and extraction periods and most importantly the airflow capacity of the unit along with standardized features such as anti frost application and summertime air bypass. Certain whole house mechanical ventilation solutions are given in *table 6-26* based on real life companies' products.

According to the given parameters of performance Zehnder Comfort Air Q350 is the best option. Airflow capacity of the system is 350 m^3/h, which is higher than the required amount of 318 m^3/h by 10% for redundancy or possible efficiency resolve through out the years of service. Small size of the air-handling unit makes it a compact solution for the attic space of the building.

Among the given options Zehnder has the lowest disturbance values when on full capacity workload for providing necessary means of air quality during the period of 8:00-9:00. In addition to its low disturbance and high efficiency of heat recovery (94%), attachable options to the main battery of air handling unit makes it a viable choice if the users decide for an upgrade of the system regarding higher comfort via humidification or dehumidification of the fresh air or recoupling the main battery to an earth duct for pre-heating and cooling of the supply air.

Size of the air supply and extraction ducts is dependent on the supply amount of the system. Most of the times the main supplier or extractor duct, which is connected directly to the ventilation machinery is thicker to compared to the end ducts.

Ducts Regarding Zones	Peak Loads-m^3/h (q)	Air Speed-m/s (v)	Duct Cross Section-m^2 (A)	Duct Diameter-m	Effective Duct Diameter-m	Effective Duct Cross Section-m^2 (A)
Main Supply	160	1	0,037	0,13	0,16	0,08
Sleeping -1	25	0,7	0,010	0,04	0,10	0,03
Sleeping -2	52	0,7	0,021	0,07	0,10	0,03
Sleeping -3	26	0,7	0,010	0,04	0,10	0,03
Dining Room	66	0,7	0,26	0,09	0,10	0,03
Living Room	39	0,7	0,015	0,05	0,10	0,03
Main Extraction	170	1	0,039	0,14	0,16	0,08
Bathroom	55	0,7	0,022	0,08	0,10	0,03
Kitchen	73	0,7	0,029	0,10	0,10	0,03
Toilet	37	0,7	0,015	0,05	0,10	0,03

Table 6-27: Calculated sizes of the ducts and their corresponding Cross section areas

Duct sizes are determined according to zone based peak demands of fresh air supply and foul air extraction, along with the air speed in ducts. Certain limitations are applied such as the limitation on the size of the duct diameter and the air speed in ducts. Differences between the calculated duct size and the available duct size for application are given in *table 6-27*. Calculations of duct sizes are given in a more elaborate way in *appendix D-3*.

Duct sizes are limited to 100 mm as possible minimum application for air distribution. In addition to the size limitation air speed in 100 mm ducts can only be lowered to 0,7 m/s beyond the given value distribution of air is interrupted. When the high demand of air supply and extraction are broken down to zone specific demands, duct sizes can be selected among the smallest available for all the spaces. Dimension of the ducts and the ventilation system are given in *figure 6-25* and the application of the whole system to Hospeslaan 24 is illustrated in *figure 6-26.*

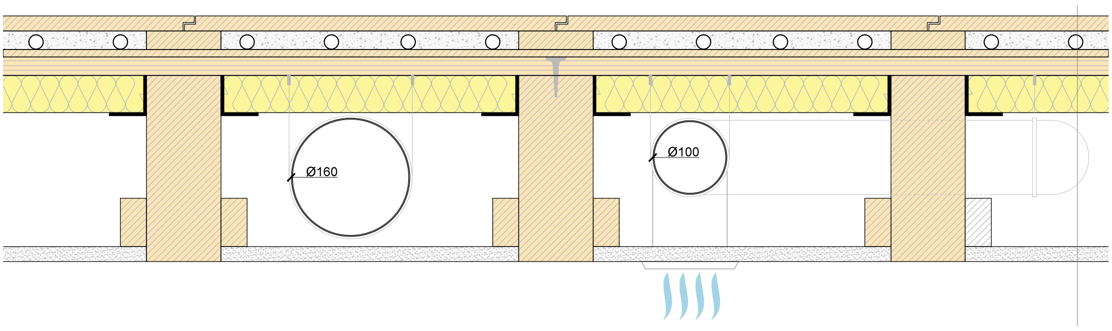


Figure 6-25: Application of ventilation ducts through the floor system of Hospeslaan24 after refurbishment measures are executed fully.

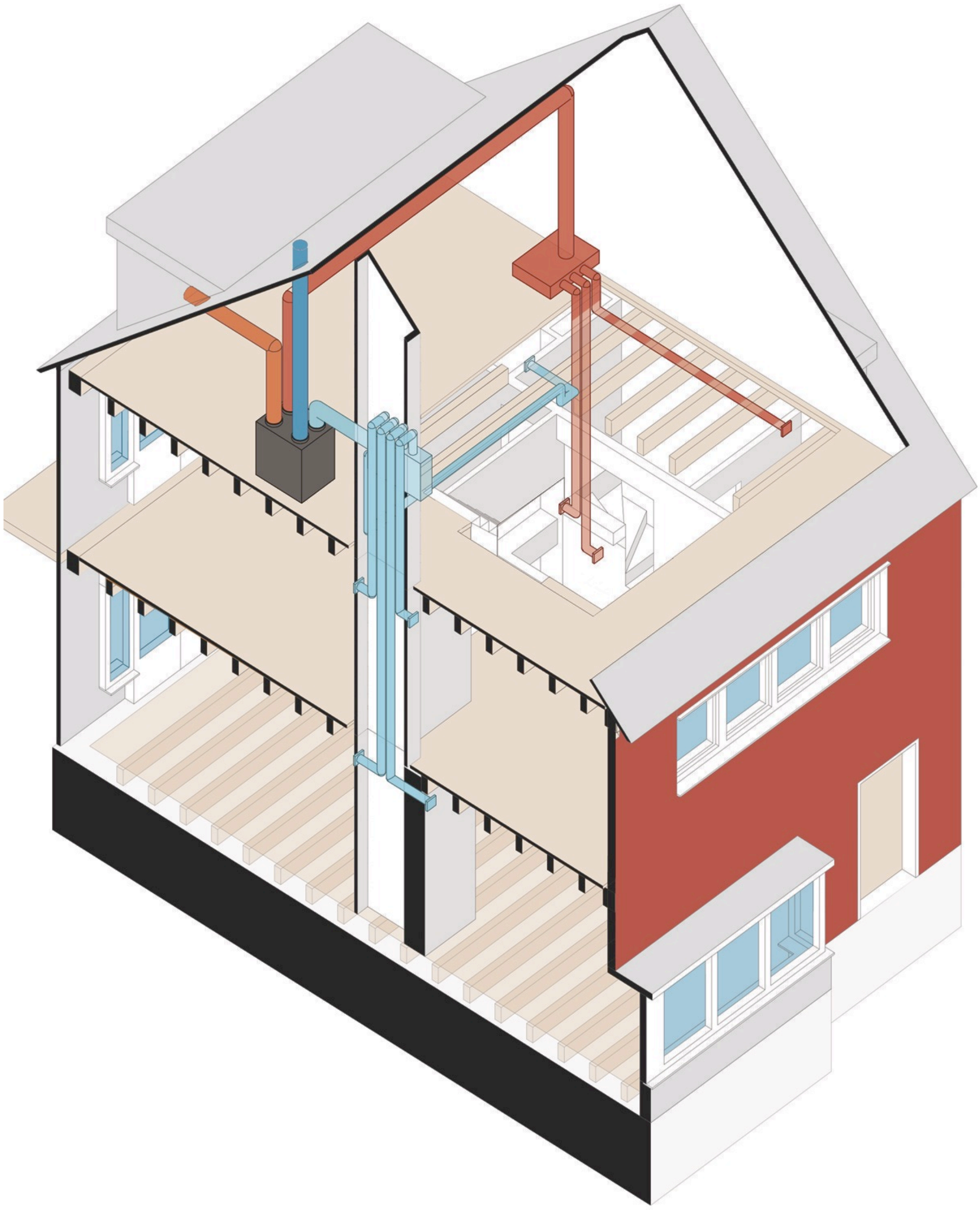


Figure 6-26: Application of mechanical ventilation system with heat recovery for supply and extraction in the building.

6.2.3.2 Extensive Ventilation

During summer season mechanical air supply is bypassed and only natural ventilation is used for fresh air supply in space. Extensive ventilation is to secure the indoor air temperature of primary zones to be low enough to comply with necessary comfort levels.

Ventilation system is based on stack ventilation caused by the pressure difference generated by height difference and temperature difference on both ends of the airshafts or the air circulation path. Difference between two ends generate negative pressure on the higher opening resulting in suction through the lower openings which are located on primary zones of the building. With the created suction, cooler outside air is introduced to the space for reducing high indoor air temperatures.

The ventilation system is automated with temperature sensors regarding indoor and outdoor temperatures and the ventilation openings are motorized to respond to autonomous commands of the building management system to minimize the user impact on thermal comfort. However the users in the building can always overwrite the system and open windows, regarding their own preferences. Certain products for air temperature sensors are given in *figure 6-27 & figure 6-28*. When the outdoor temperature is higher than indoor temperature ventilation is stopped however if there is occupancy in space ventilation continues regardless of indoor, outdoor temperatures.

Figure 6-27: Indoor temperature sensor from Honeywell
Source: https://forwardthinking.honeywell.com/products/wireless/wireless_products.html

Figure 6-28: Outside air temperature sensor
Source: http://www.ventilation-system.com/item/7399/NDT/#parameters

Openings are the most crucial part of the ventilation system as they are supposed to be burglarproof and to be operable 24/7 by an autonomous system without any hindrance on operation. Therefore burglarproof ventilation system is applied either to a portion of pre-existing transparent opening or an additional opening is included without interfering with the existing one. Product for the openings is selected from DUCO and shown in *figure 6-29.* Instead of having an insulated opaque automated section, altered version has an automated glazing with shading and burglarproof grills.

Figure 6-29: Duco Nightvent burglarproof ventilation system
Source: http://www.duco.eu/nieuws/Duco-valt-in-de-prijzen-op-Franse%20vakbeurs

Figure 6-30: Glazing application to night vent operable wing
Source: http://www.knipping.nl/kozijnen/

Application of the ventilation system differently for zones in the building is due to the architectural restrictions as well as concerns for reduced visual comfort. Changes in the transparent openings surface area for every zone is given in *table 6-28* and illustrated in *figure 6-31.*

Zones	Existing Opening Surface (m^2)	Refurbished State of Opening Surfaces (m^2)	Applied Ventilation Surface (m^2)	Effective Operable (angle 30°)	Effective Ventilation Surface	Max. Amount of Ventilation (L/s)
Sleeping -2	3,90	3,90	0,7	X 0,6	0,45	85
Sleeping -1	3,25	3,75	0,5	X 0,6	0,3	70
Sleeping -3	1,10	1,60	0,5	X 0,6	0,3	45
Bathroom	1,60	1,95	0,5	X 0,6	0,3	45
Living Room	4,65	4,65	0,7	X 0,6	0,45	110
Dining Room	5,50	5,50	0,8	X 0,6	0,5	110
Kitchen	2,30	2,30	0,66	X 0,6	0,4	75

Table 6-28: Size of the openings after comfort optimization

Resulting natural ventilation for cooling the space is indirect ventilation. If users would desire direct ventilation for their own comfort sensation it is possible to override the system and open the ventilation opening or any other window manually for direct ventilation to the space.

However application of the opening do not reflect on a significant changes on comfort within the space due to the effective shading of the burglar proof ventilation component along with optimized conditions of every primary and secondary zone. Resulting overheating after the application of the opening change is given in table in chapter *6.2.4 Comfort Optimization Conclusion | Refurbishment-2.*

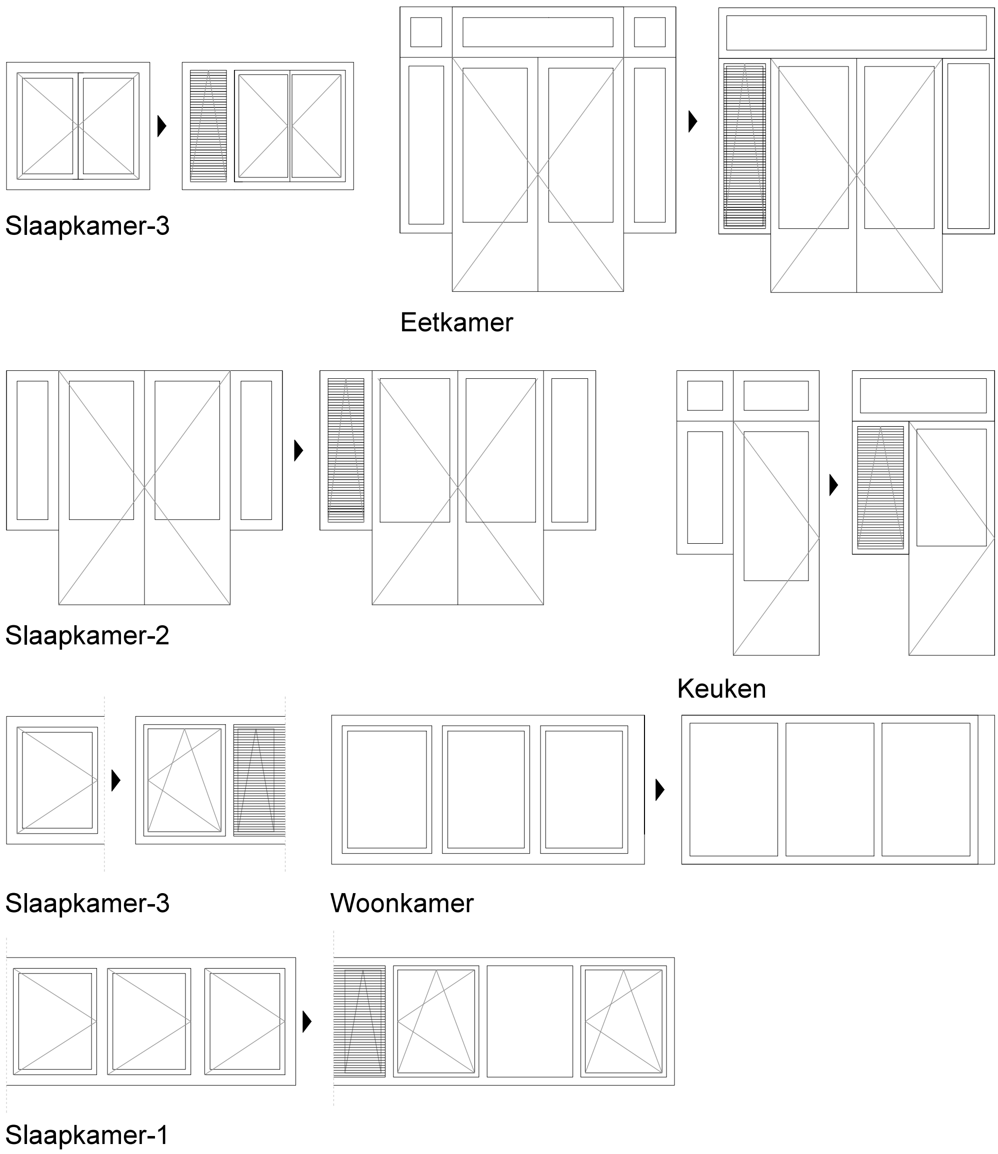


Figure 6-31: Changes in envelope openings for ventilation purposes

6.2.4 Comfort Optimization Conclusion | Refurbishment-2

After a certain amount of building skin optimization natural ventilation is becoming the only option for exposing the conditioned indoor space to unconditioned outdoors medium. Therefore mechanical ventilation minimizes the impact of outside temperatures on the indoor air temperatures and effectively reduces space heating energy consumption.

Regardless of the outside conditions, indoor air temperatures are stabilized as long as it does not result in overheating. Therefore winter period thermal comfort can be provided with single zone specific heating temperature.

Zone specific ventilation for minimum fresh air is not interrupted do to steady supply of air by the mechanical system. Mechanical systems increase the electricity load of the building. However with high insulation and air tightness rate with heat recovery system energy consumption for space heating can be reduced effectively.

Zones	Heating Temperature (Seasonal)	Heating Set-back Temperature (Seasonal)
Sleeping -2	19,5° C – Mechanical Supply	0° C - Not required for winter season
Sleeping -1	19,5° C – Mechanical Supply	0° C- Not required for winter season
Sleeping -3	19,5° C – Mechanical Supply	0° C- Not required for winter season
Bathroom	21° C – Mechanical Extraction	0° C- Not required for winter season
Living Room	21° C – Mechanical Supply	0° C- Not required for winter season
Dining Room	21° C – Mechanical Supply	0° C- Not required for winter season
Kitchen	21° C – Mechanical Extraction	0° C- Not required for winter season
Toilet	21° C – Mechanical Extraction	0° C- Not required for winter season
Circulation	18° C – No Ventilation	0° C- Not required for winter season

Table 6-29: Optimized heating temperatures input for seasonal simulations for Refubishment-2

Mechanical supply makes it possible to provide low temperature heating in space. Seasonal heating temperature provision for every zone is given in *table 6-29* after ventilation is switched to mechanical. These given heating temperatures are used for the seasonal simulations to determine energy consumption in space. Heat recovery is bypassed if the outside temperatures are higher than required indoor air temperatures or the provision temperatures.

Zones	Overheating Hours Existing Condition	Overheating Hours Pre-Optimization	Overheating Hours After-Optimization	Overheating Hours After-Opening Application
Sleeping -2	210	2623	91	85
Sleeping -1	160	1763	56	62
Sleeping -3	140	363	17	23
Bathroom	199	793	27	27
Living Room	126	735	24	20
Dining Room	175	279	18	18
Kitchen	174	215	25	25

Table 6-30: Overheating hours after every optimization and application per significant zones.

Thermal comfort in summer is dependent on excessive ventilation however minimum air supply is never a problem due to very high air volume availability in space at almost all time and always during occupancy. It is always possible to provide large amounts of air through natural ventilation however volume of air would result in undesired low temperatures thus would trigger heating in space.

In order to avoid the problem, natural ventilation should be regulated according to lowest comfortable limits of indoor air temperatures to restrict unnecessary cooling in space and removing heating for summer season at least for warmest three months June, July and August.

Ventilation and shading in summer is required for reducing the overheating hours per zone adjacent to an external wall and has an opening; excluding the attic due to usage for storage. Overheating hours per optimized zone is given in *table 6-30* with the addition of the extensive ventilation openings to the building skin composition. However provided conditions can only be applied if user interference is minimized.

6.3 Energy Consumption of Optimized Refurbishment Strategies

After the application of insulation, openings upgrade and airtightness non-operational building skin has taken shape for different refurbishment strategies. With the finalized applications for user comfort in space, annual and monthly operational energy of the refurbishment strategies can be calculated to highlight the global impact of the passive and active refurbishment measures used so far.

Operational energy of the building includes the lighting, space heating, DHW and pump energy. Among the given consumption types, lighting and pump energy are based on electricity while space heating and DHW on delivered natural gas due to no change in the building services. Energy consumptions per refurbishment strategy are given in the *table 6-31.*Primary energy conversion of the energy types given in table 6-31 are calculated accordingly to *chapter 2.3.8 Energy Conversion Rates in the Netherlands.* Calculations made in excel are in *appendix D.*

Strategy (Annual Consumptions)	Space Heating (kWh) Gas	Change (%)	DHW (kWh) Gas	Change (%)	Lighting (kWh) Electricity	Change (%)	Pump Energy (kWh)	Change (%)	Cooling (kWh) Electricity*	Change (%)
Validated Model	19366,1	-	4611,8	-	1018,1	-	0,0	-	-	-
Refurbishment-1	3331,4	81%	4611,8	-	1099,3	8%	20,9	100%	53,4	100%
Refurbishment-2	722,56	96%	4611,8	-	1103,8	8.5%	98,5	100%	84,2	100%

Total Consumptions

Strategy	Delivered Natural Gas (kWh)	Natural Gas Volume (m^3)	Lighting + Pumps (kWh)	Primary Energy- With Cooling (kWh)	Primary Energy- Without Cooling (kWh)
Hospeslaan-24	24461,6**	2504 m^3	1017	-	26983,8
Validated Model	23978,0	2454,4 m^3	1018,1	-	26502,9
Refurbishment-1	8668,4	887,3 m^3	1120,2	11554,7	11446,5
Refurbishment-2	5333,6	546,0 m^3	1202,3	8524,9	8316,2

Table 6-31: Consumption Summaries per Refurbishment Strategy regarding Energy type and resulting primary energy.

Within Refurbishment-1 strategy applied measures for energy refurbishment and comfort optimization have reduced the consumption for space heating by 79%. However electricity has increased due to extensive shading usage during June, July and August with additional mechanical extraction in wet spaces. Monthly consumption pattern of refurbishment-1 is given in *figure 6-32.*

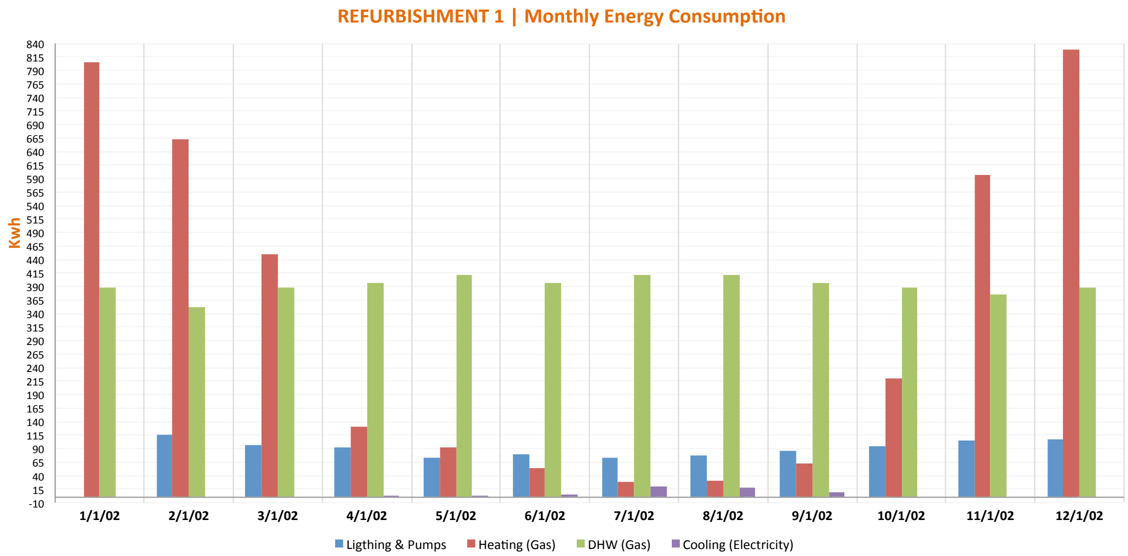


Table 6-32: Monthly Operational Energy Consumption in Refurbishment-1 per consumption type.

In order to compare the differences of total energy consumption in the strategies, consumed energy is transformed to their energy carrier, which is the primary energy. Refurbishment-1 total annual source energy for all consumption types is 11554,7 kWh if cooling is included. Source energy of refurbishment-1 is 56% lower than the validated model consumption, which is 26502,9 kWh.

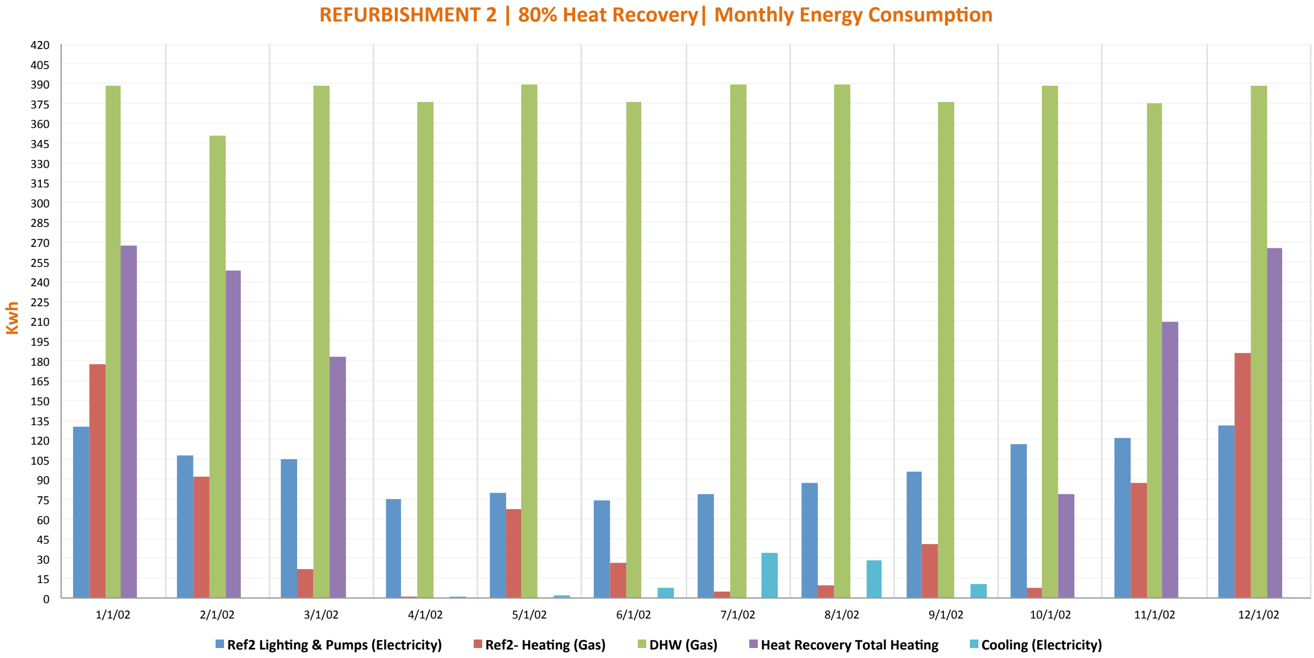


Table 6-33: Monthly Operational Energy Consumption in Refurbishment-2 per consumption type.

supply and extraction with 80% heat recovery and higher insulated surface amount in attic. Cooling is applied to the building and electricity load increases by 84,1 kWh to balance resulting overheating hours after the comfort optimization. Monthly consumption of the summarized loads

Annual primary energy of the refurbished state of the building is 8524 kWh if cooling is applied and if cooling is absent it is 8316 kWh. Primary energy reduction of refurbishment-2 is 69% without cooling application and 68% if cooling applied. For further optimization refurbishment-2 with cooling load will be taken as the final consumption. Monthly consumption of the summarized loads in the paragraph is given in *figure 6-33*.

DHW consumption in the building has not reduced, this is because refurbishment measures up to this point were focused on the reduction of space heating and arranging human comfort in the insulated space. For improvement in the DHW consumption and further improvement on space heating consumption in the dwelling, building services must be upgraded regarding the efficiency, type of energy carrier and the energy transformer to achieve a Zero Energy Building.

7. Building Services

Three different heating & cooling configurations are used as new building services in both of the refurbishment strategies. These configurations are specified with their corresponding efficiencies and applications. Efficiency and the provision type of the building services are used as simulation inputs in DesignBuilder to highlight the affectivity of every application.

Building Services Criteria

Certain criteria's for building services are based on the system that most effectively reduces the operational energy for both of the refurbishment strategies. Primary energy is used as the currency for comparison therefore total reduction on primary energy is taken as the final consumption.

7.1 Application of Building Services

Three different building services options provided are applied for further reducing the operational energy consumption in the building. System changes are expected to reduce energy consumptions for DHW and the space heating, while lighting and the pump energy are not affected by building system changes due to direct connection to national grid.

Simulations in DesignBuilder are conducted without detailed HVAC options. Reasons behind the simulation strategy are that, detailed HVAC in DesignBuilder requires adequate knowledge and total control over the specific building systems being used for simulation along with the necessary information on component connections, heating loops, Provided temperatures and complications for the ventilation systems for refurbishment-2. Simulated building services inputs are given in *table 7-0* and the diagrammatic explanation of the systems are in *figure 7-0*.

SUI Option 1a: Individual Heat Pump (Air Source)		
Item	**Description**	**Efficiency**
E	Electricity connection to the grid	100%
SH	Air-Water Heat Pump - 90% Electrical Back-up - 10%	COP: 3,1 COP: 1
DHW	Air-Water Heat Pump – 100%	COP: 2,4
C	Air-Water Heat Pump	COP: 4
SUI Option 1c: Individual Heat Pump		
Item	**Description**	**Efficiency**
E	Electricity connection to the grid	100%
SH	Ground-Water Heat pump - 90% Electrical Back-up - 10%	COP: 4,3 COP: 1,0
DHW	Ground-Water Heat pump - 90% Electrical Back-up - 10%	COP: 2,4 COP: 1,0
C	Direct Cooling – 100%	COP: 12
SUI Option 2: Individual Heat Pump (LT Source)		
Item	**Description**	**Efficiency**
E	Electricity connection to the grid	100%
SH	Water-Water Heat pump - 90% Electricity Back-up - 10%	COP: 5,1 COP: 1,0
DHW	Water-Water Heat pump - 90% Electrical Back-up - 10%	COP: 2,4 COP: 1,0
C	Direct Cooling - 100%	COP: 12

Table7-0: Simulation inputs for Refurbishment-1&2 for building services applications

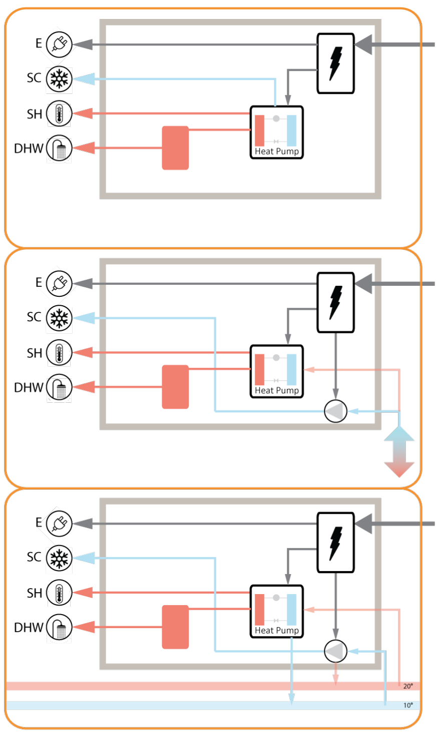


Figure 7-0: System diagrams for SUI options.

Every option is identified with the type of the building system in use. Efficiencies for heating and cooling are unique to the type of corresponding component. Electrical back up for the air and heat pump systems is used if the outside temperatures become extremely low that the heat pump becomes insufficient to supply the necessary temperatures for space heating and DHW in the building.

7.2 Conclusion on Building Services

All scenarios for building system options are dependent on the gird. Zero energy design for the building is conducted over the national grid and design is not aiming for an autonomous zero energy building. System components are dependent on the electricity supply from the grid. One of the reasons for not creating an autonomous zero energy building is that unpredictable weather profiles, energy generation / consumption mismatch and difficulty of energy storage.

Electrical back up is increasing the energy consumption for space heating and DHW due to its efficiency. However the period electrical back up is activated is very short compared to the different heat pump options under three simulations therefore the impact of electrical back up on the space heating and DHW are very little.

Refurbishment-1							
Annual Energy	**Space Heating (kWh)**	**DHW (kWh)**	**Lighting & Pumps (kWh)**	**Cooling (kWh)**		**Total Primary Energy (kWh)**	**Reduction (%)**
Post Comfort Opt.	3331,4 (G)	4611,8 (G)	1120,2 (E)	53,1 (E)	Primary Energy	10853,1	-
SUI Option 1a	858,5 (E)	1731,1 (E)	1120,2 (E)	94,1 (E)		9325,8	14%
SUI Option 1c	648,9 (E)	1731,1 (E)	1120,2 (E)	16,9 (E)		8718,8	20%
SUI Option 2	563,6 (E)	1731,1 (E)	1120,2 (E)	16,9 (E)		8510,7	22%
Refurbishment-2							
Annual Energy	**Space Heating (kWh)**	**DHW (kWh)**	**Lighting & Pumps (kWh)**	**Cooling (kWh)**		**Total Primary Energy (kWh)**	**Reduction (%)**
Post Comfort Opt.	722,6 (G)	4611,8 (G)	1202,4 (E)	83,6 (E)	Primary	8523,9	-
SUI Option 1a	198,3 (E)	1731,1 (E)	1202,4(E)	94,1 (E)		8034,0	6%
SUI Option 1c	178,9 (E)	1731,1 (E)	1202,4 (E)	39,2 (E)		7853,2	8%
SUI Option 2	158,6 (E)	1731,1 (E)	1202,4 (E)	39,2 (E)		7803,6	9%

Table7-1: Operational energy and total primary energy per building system. Highlighted options are selected for the next phase. (G)=Gas, (E)= Electricity

After the application of building systems all energy consumptions are converted to electricity. The operational total energy can be surveyed in *table 7-1* for every application along with pre-application condition of both refurbishment strategies.

Building services upgrade for Refurbishment-1 has the highest total energy consumption reduction efficiency. Comparison between operational energy consumption in the aftermath of system upgrade for all options is in *figure 7-1;* with upgraded building systems winter season consumptions in the building have reduced drastically. Reflection of the operational energy reduction is minimum by 14% when converted to primary energy. Primary energy calculations for all of the options per refurbishment are in *appendix E.*

Water to water Heat pump and direct cooling system reduces the annual total primary energy of the building by 22% despite using electricity for DHW and Space heating. However the efficiency of the water-water heat pump with low temperature source has reduced the space heating and DHW consumption. Therefore for energy balancing the optimal condition of SUI option-2 is selected.

Differences between space heating and cooling final energy are related to the corresponding electrical efficiencies of the given systems. Lighting and pump energy are not affected from the system COP's due to being supplied directly by the grid without additional component therefore they are subject to no change between steps of simulation. Due to constant efficiency for DHW, there is no change between the steps of refurbishment-1 or refurbishment-2 despite the reduced energy consumption compared to gas fired boiler in post comfort optimization.

Refurbishment-2 changes in building services resulted in total primary energy reduction, which is caused by reduced space heating, and cooling loads. However the total energy reduction has not been as effective as refurbishment-1 due to already highly reduced space heating energy. Within *figure 7-2* when all options are compared SUI options-2 gives the lowest operational energy per month. This is because of the usage of low temperature space heating with high efficiency energy conversion systems of the option; therefore water-water heat pump is selected for refurbishment-2.

Application of Water-to-Water Heat Pump with Low temperature source requires installation of low temperature emitters for conditioning the building space. It is possible to install low temperature heating provision due to very airtight and highly insulated building skin. These emitters could be a replacement to high temperature radiators or a total system change to under floor heating for the building.

Therefore for refurbishment-1, low temperature radiators are selected for the replacement of existing system and for refurbishment-2 under floor heating. No thermal performance differences are evaluated between the heating provision elements and their replacement to low temperature emitters is a necessity for effective usage of water-to-water heat pump with low temperature source. Differences between two different low temperature emitters are evaluated over application scale and reliability within *chapter 9.0 Final Design*.

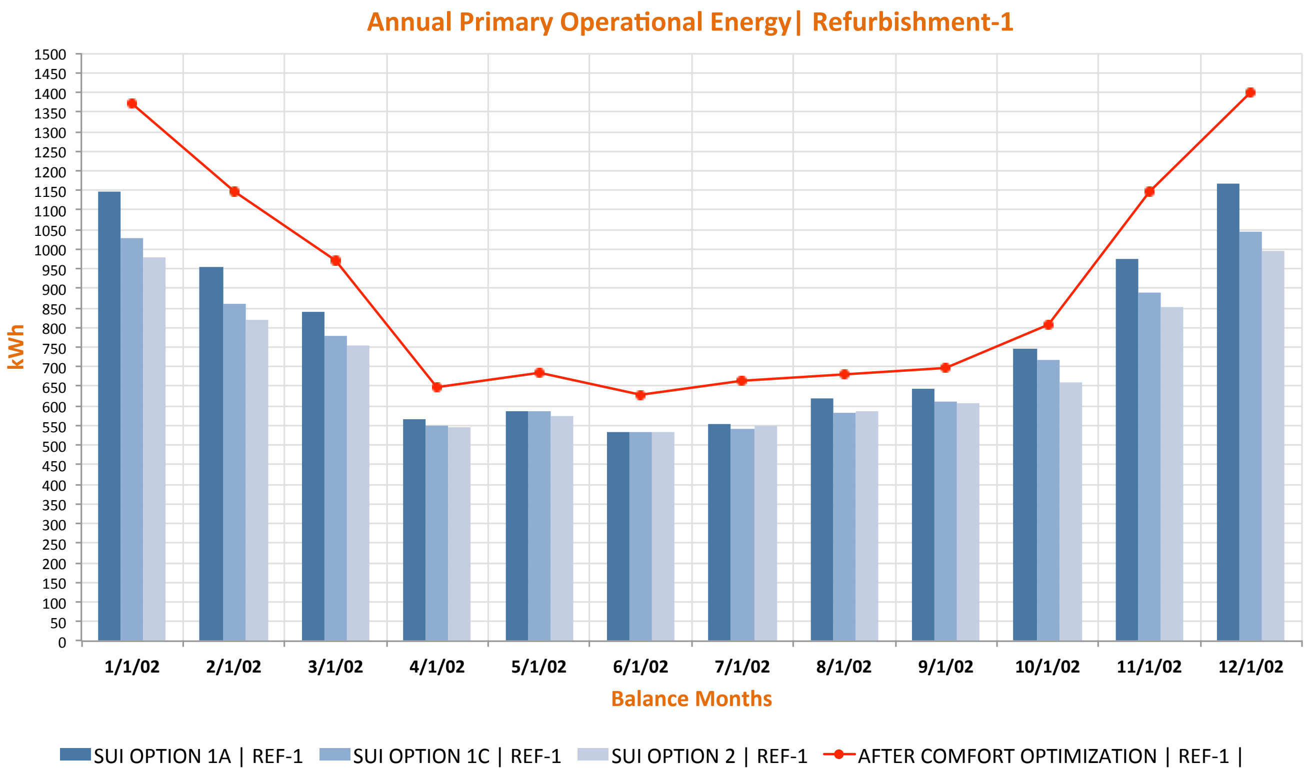


Figure 7-1: Monthly operational energy in refurbishment-1 per building services option

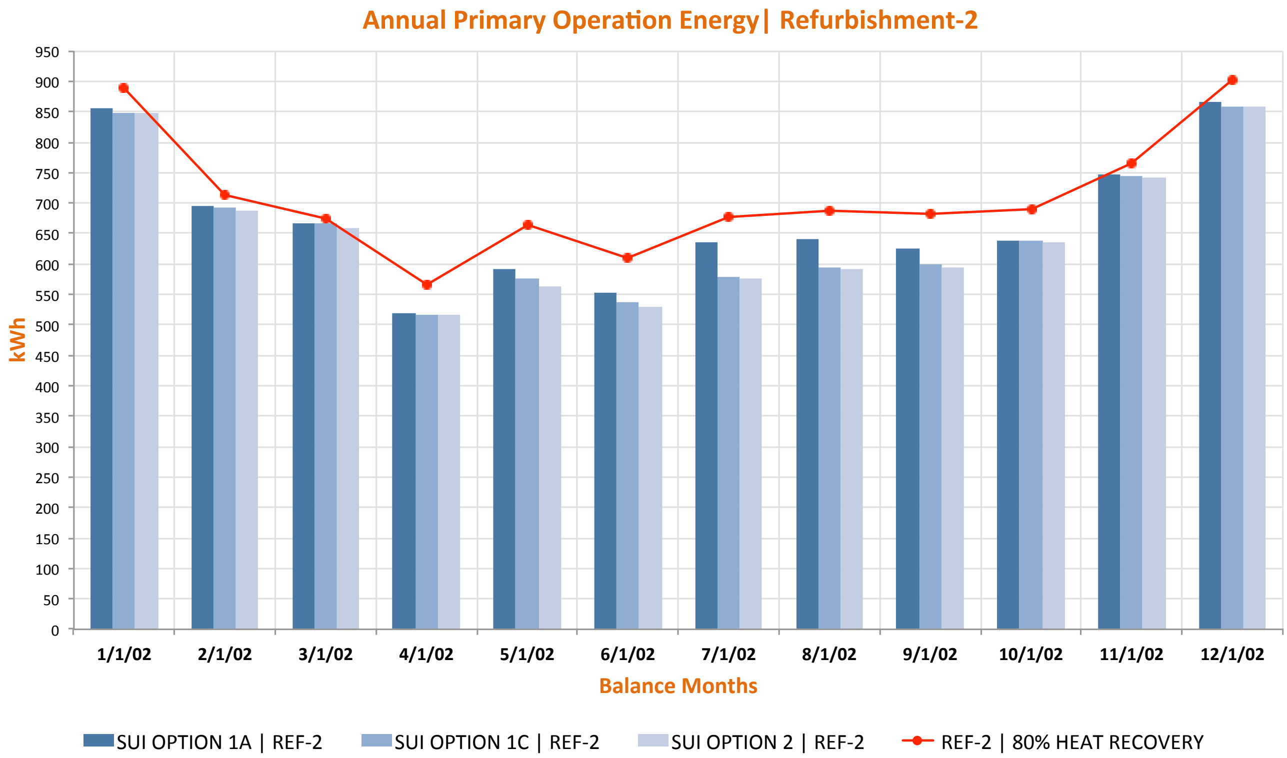


Figure 7-2: Monthly operational energy in refurbishment-2 per building services option

8. Energy Balance

8.1 Annual Balance for Zero Energy Refurbishment

Energy generation on building level is the final step for creating a zero energy building, within the New Stepped Strategy. Applied passive and active measures under both refurbishment strategies to minimize energy consumption in the building while concerning human comfort have reduced the operational energy to a certain level where on-site generation can offset the imported energy.

Due to complete electricity usage by the building systems as energy carrier, output of the on-site generation system is preferred to be electricity as well as to resolve the conversional penalty between primary energy sources. In order to conduct a reliable energy balance between consumption and generation photovoltaic panels are used as a common, individual and site friendly solution.

Balance Criteria's

Most important criteria for balancing the annual energy is to yield the minimum necessary energy when all de-ratings are applied. It is important to generate the final energy, which is supplied back to the national grid. In addition to the energy generation certain criteria's are minimized surplus and optimal use of available surface for optimal component sizing to successfully integrate the photovoltaic panels on the roof surface.

8.1.1 Photovoltaic Panel Options

Four different photovoltaic panels will be used for matching the imported operational energy to the building. These different panels are picked according to their efficiencies, core material, thermal coefficient, sizing and nominal power. Selected panels and their technical information for evaluation are given in *table 8-0.*

Calculations are conducted for refurbishment-1 and refurbishment-2 to highlight the most suitable option for energy generation on-site with photovoltaic panels. Among selection, sizing is an important point due to limited availability of sun irradiation exposed surfaces, which are not shadowed by any foliage or structure.

Due to limited optimal space availability PV panels are located on top of the roof surface where they are not interfered with either shadowing problems however their positioning is fixed and has a toll on the possible maximum output of the component.

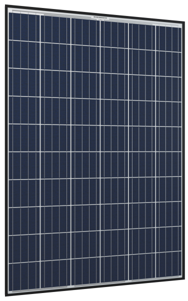
Photovoltaic Panel Options				
Technical Information	**Sunpower – X21-345**	**Q.Plus BFR-G4.1 280**	**Panasonic VBHN330Sj47**	**First Solar FS-4122-3**
Image				
Image Source	http://generation819.com/installations/san-diego/vista/12-42-kw-home-system-sunpower-x21-panels/	http://www.q-cells.nl/producten/zonnepanelen/qplus_bfr_g41.html	https://eu-solar.panasonic.net/nl/solar-module-vbhn325sj47-vbhn330sj47.htm	http://www.barysol.de/eng/referenz3.html
Absorber Technology	Si (large Crystalline)	Si (Polycrystalline)	Si (crystalline)	CdTe (Thin-film)
Size	1559 mm Length 1046 mm Width 46 mm Thickness	1670 mm Length 1000 mm Width 32 mm Thickness	1590 mm Length 1053 mm Width 35 mm Thickness	1200 mm Length 600 mm Width 35 mm Thickness
Application on Roof	Rack Type Mount	Rack Type Mount	Rack Type Mount	Rack Type Mount
Panel Efficiency	21.5%	17.1%	19,7%	17,0%
Nominal Power (W)*	345 W	280 W	330 W	122,5 W
Outside Temperature de-rating Efficiency	-2,5%/ ° C	-0,4%/ ° C	-0,29%/ ° C	-0,28%/ ° C
Weight (kg)	18,6 kg	18,8 kg	18,5 kg	12 kg
Array Application	Yes	Yes	Yes	Yes

Table 8-0: Different PV options and their specifications

8.1.2 Annual Balance Energy Output

Energy output of photovoltaic systems for refurbishment-1 and refurbishment-2 are expected to deliver at least the annual primary energy consumed in the building. Annual primary energy consumption values for refurbishment-1 and refurbishment-2 are 8510,7 kWh and 7803,6 consecutively.

Therefore optimization of the PV panels are made accordingly to the necessary energy output, available space on the roof and optimal usage of the roof space regarding the PV system selected for both refurbishment strategies to reach Zero Energy Buildings annually. Results on the photovoltaic options are given in *table 8-1* for both refurbishment strategies.

East Facing Roof						
Panel Type	**Energy Yield East Facing (kWha/m^2)**	**Required Panel Amount for Annual Balance**		**Effective Surface Area (m^2)**		**Available Roof Surface East Only (45°)***
		Ref-1	**Ref-2**	**Ref-1**	**Ref-2**	
Sunpower-X21-345	135,4	16	15	26,0	24,5	23m^2
Q.Plus BFR-G4.1 280	122,6	17	16	28,4	26,7	23m^2
Panasonic VBHN330Sj47	145,1	15	13	25,1	21,8	23m^2
First Solar FS-4122-3	131,9	37	34	26,6	24,5	23m^2
West Facing Roof						
Panel Type	**Energy Yield East Facing (kWh/m^{2}a)**	**Required Panel Amount for Annual Balance**		**Effective Surface Area (m^2)**		**Available Roof Surface West Only (45°)***
		Ref-1	**Ref-2**	**Ref-1**	**Ref-2**	
Sunpower-X21-345	116,3	19	17	31,0	27,7	24m^2
Q.Plus BFR-G4.1 280	105,7	20	18	33,4	30,6	24m^2
Panasonic VBHN330Sj47	125,2	17	16	28,5	26,8	24m^2
First Solar FS-4122-3	113,8	42	39	30,2	28,0	24m^2

Table 8-1: Summary of PV option calculations and the selected PV system

Calculation of photovoltaic panel annual energy yields based on the output of the panel, efficiency, de-rating effects such as high ambient temperatures, dirt build up, DC to AC conversion, cables and manufacturing defects. These specific calculations are made for grid connected Zero Energy Buildings, for seasonal energy storage, annual yield must be calculated accordingly.

Due to different sizing and different efficiencies of the photovoltaic panels, required amount panels differ every option. Within *table 8-1* the highest panel requiring application to match the operational energy is First Solar FS-4122-3 with 37 panels for Ref-1 if all of them are located on the East orientated roof. However the available surface is not enough for accommodating the amount of photovoltaic panels. Therefore surface availability is key for sizing the PV system.

Panasonic VBHN330Sj47 has the best performance among the considered options of photovoltaic panels due to high efficiency and low temperature related performance deterioration. Panasonic requires 15 panels for Ref-1 and the available surface must be shared between East and West facing roofs.

Considering the constraints on available surface on the roof it is ideal to consider options with the smallest surface occupation and highest output therefore *Panasonic VBHN330Sj47* is selected for usage in both refurbishment strategies.

8.1.3 Photovoltaic Panel Sizing & Application

It is possible to generate surplus of energy with photovoltaic panel applications in a building. However as the surplus increases so does the required sizing for inverters, losses regarding DC/AC conversion and the number of the inverters due to generated peak voltages from photovoltaic panels especially in summer conditions. Therefore it is ideal to size the components to surpass the annual operational energy only to minimize resulting surplus.

Refurbishment-1	East Facing Roof		West Facing Roof		Operational Energy (kWh)		Annual Photovoltaic Yield (kWh)		Energy Surplus (kWh)	
	Surface	#	Surface	#	Primary	EL	Primary	EL	Primary	EL
Panasonic VBHN330Sj47	18,4 m^2	9	6,7 m^2	6	8459,6	3411,1	8541,3	3444,0	81,7	323
Refurbishment-2	East Facing Roof		West Facing Roof		Operational Energy (kWh)		Annual Photovoltaic Yield (kWh)		Energy Surplus (kWh)	
	Surface	#	Surface	#	Primary	EL	Primary	EL	Primary	EL
Panasonic VBHN330Sj47	18,4 m^2	11	5,02	3	7803,6	3146,6	8187,0	3301,2	383,5	155

Table 8-2: Optimal Sizing of the PV array per refurbishment strategy and the resulting annual yield after application. EL= Electricity, #=Amount of panels

In order to balance the operational energy in the building 16 panels are required for refurbishment-1 and 14 panels are required for refurbishment-2. However required panels cannot be accommodated on the east-facing roof due to unavailable space. Therefore application of photovoltaic panels had to be broken into east and west.

Ideal approach has been to optimally use the available space on the east-facing roof due to higher solar irradiation per m^2. In *table 8-2* amount of panels required for the optimal condition are given. 9 Panels have been the maximum to be placed without major hindrance on panel performance due to possible shading from dormers, while the other 6 had to be stationed on west facing roof without any space problem due to large surface availability and fewer panels.

Within *figure 8-0* positions of the panels for refurbishment-1 are given to illustrate the optimal positioning of the panels on the roof. Only refurbishemnt-1 is given as drawings for having the higher amount of panels to be accommodated on the available roof surface.

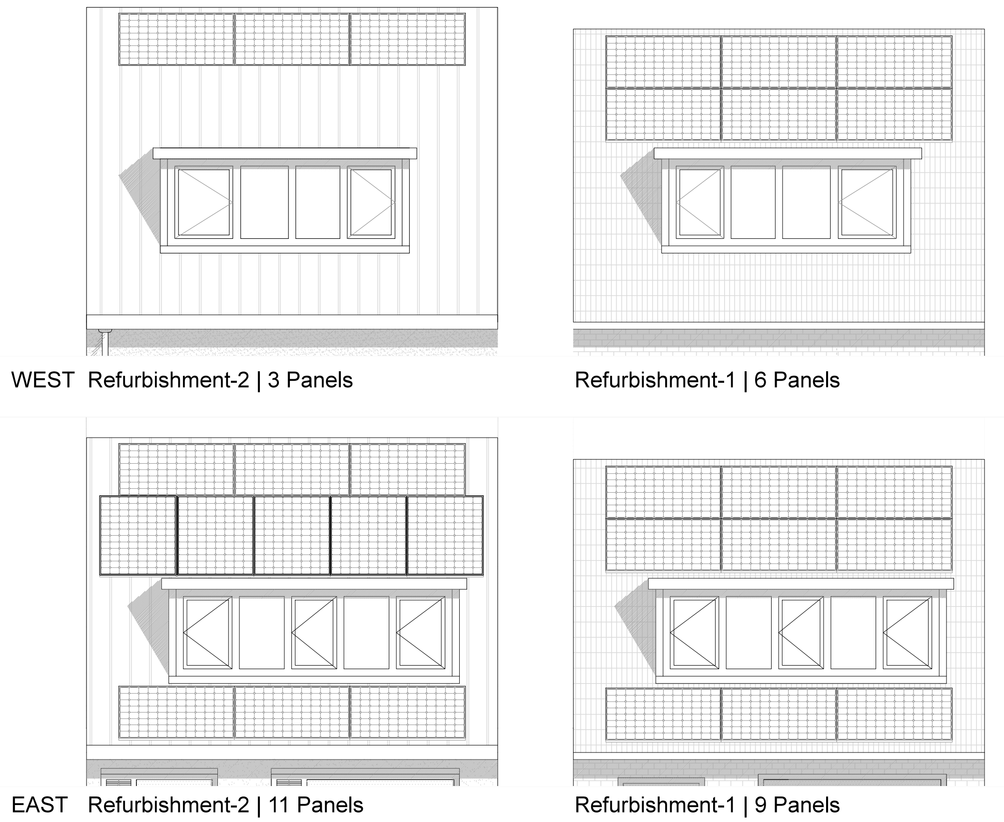


Figure 8-0: Configuration of PV panel arrays on the roofs per refurbishment strategy

16 panels for refurbishment-1 are yielding 8541,3 kWh primary energy, while 14 panels for yielding 8187,0 kWh primary energy for refurbishment-2. Within *figures 8-1 & 8-2* operational energy consumption of the building with the photovoltaic array yields are given per month in primary energy form.

Annual operational energy balance is created according to the least amount photovoltaic panels with the same size, however for both conditions the optimal photovoltaic options have resulted in energy surplus. Applied photovoltaic panels are generating surplus of 33,0 kWh electricity for refurbishment-1 and 154,6 kWh electricity for refurbishment-2.

Due on-grid state of the ZEB, surplus energy is directly fed in to the national grid, however it could also be stored in battery system for re-use in building scale. The surplus of energy is also a guarantee for the possible malfunctioning of the PV array; unpredictable weather conditions, seasonal anomalies and reduced annual yield due to deteriorated conditions of the PV panels through out the years

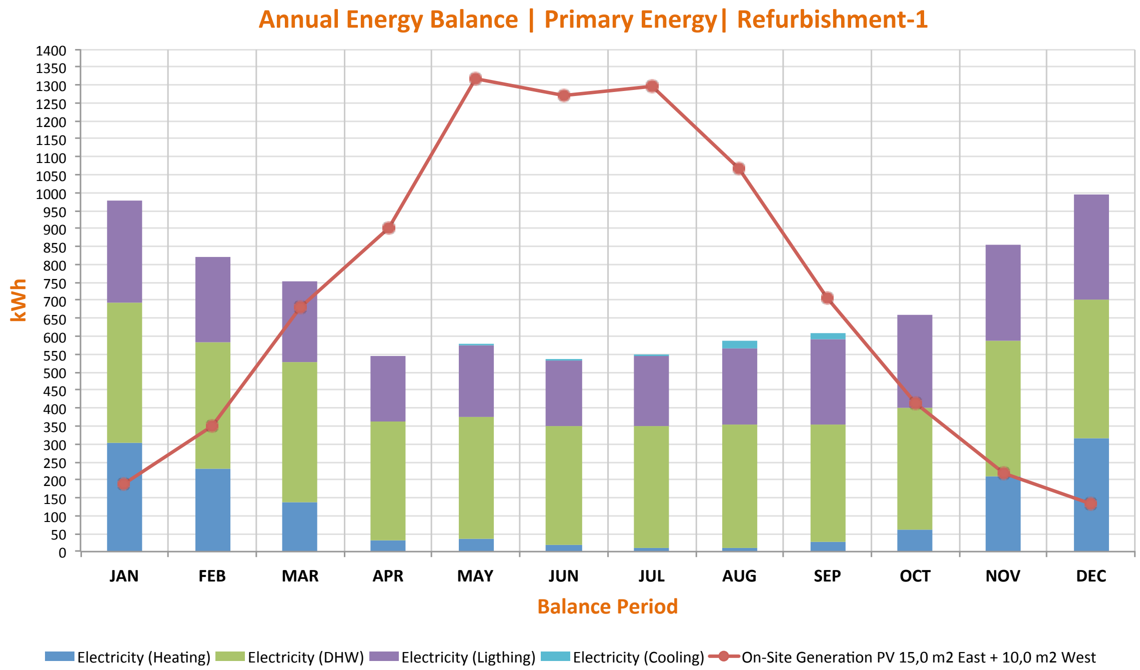


Figure 8-1: Annual yield from PV array and operational energy of refurbishment-1 (monthly)

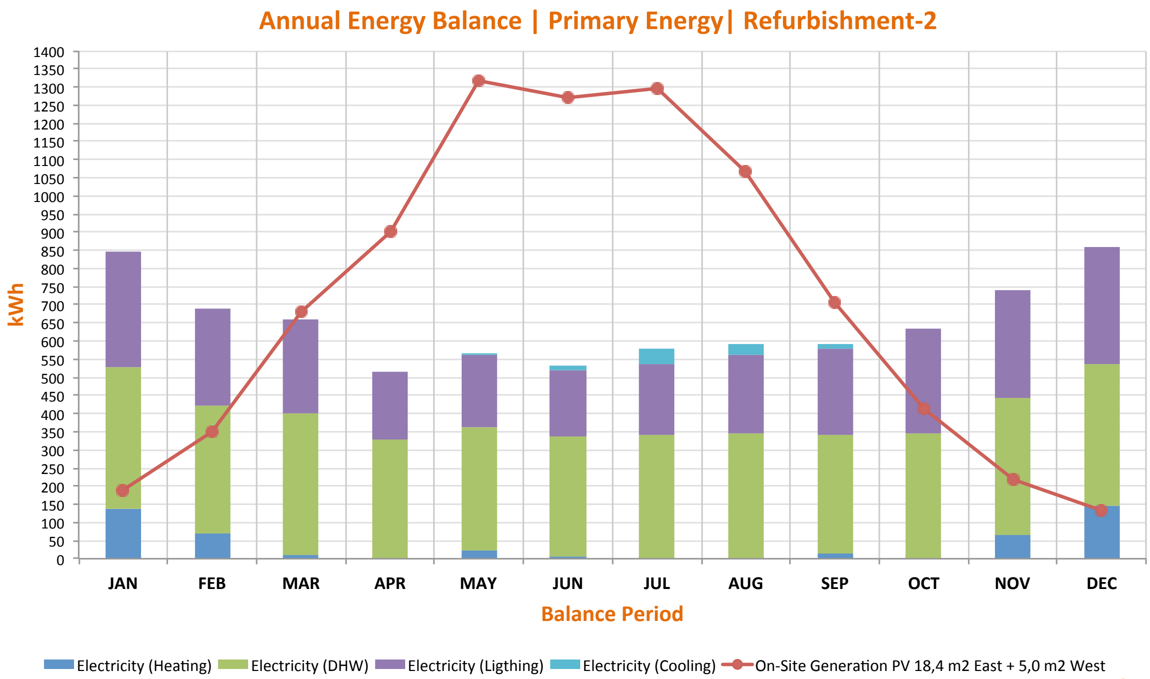


Figure 8-2: Annual yield from PV array and operational energy of refurbishment-2 (monthly)

One of the major site related inputs in balancing the energy in a refurbishment project to create an annually balanced Zero Energy Building is the fixed orientation of the building. Hospeslaan 24 building due to orientation restrictions periodical solar irradiance exposure of the sloped roofs has been very limited. Within June 21st solar exposure of the east-facing roof has been from 07:00 to 13:00 due to orientation of the building.

Due to the orientation disadvantage the solar array for operational energy balance had to be large in numbers to generate enough energy for balance. Creation for the annual energy balance with photovoltaic panels requires grid-connected buildings due to generation and consumption mismatch between seasons. Therefore the generation in summer season has to support the energy consumption in winter period. Within *figure 8-3,* generated surplus energy in summer season and he distribution of energy is given to compensate for the import-export energy deficit in winter season.

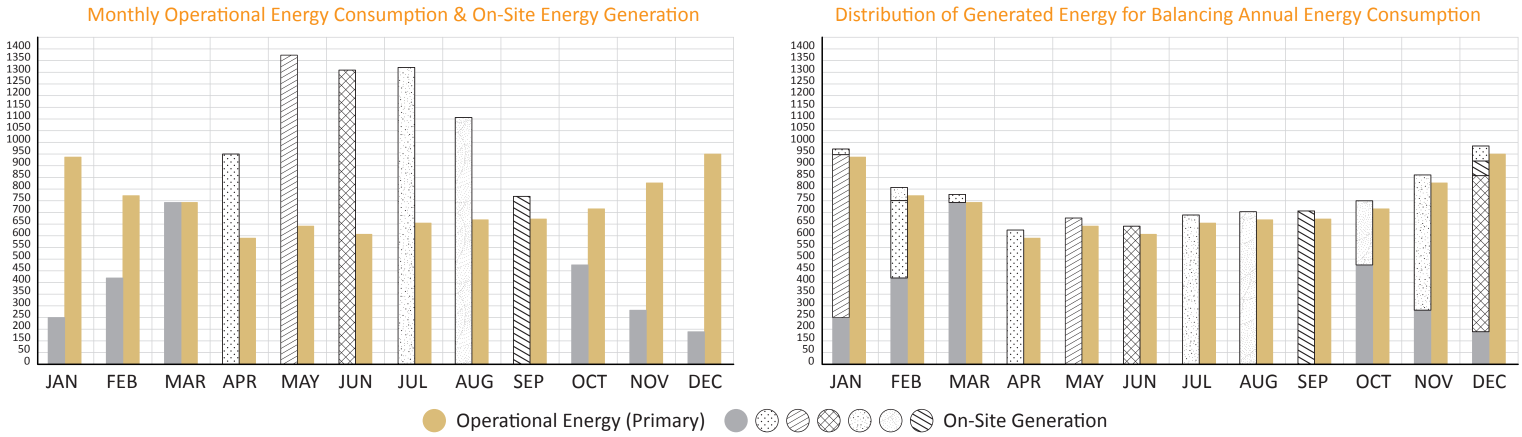


Figure 8-3: Energy mismatch during annual balance with PV options and which monthly generation compensates for which month for Refurbishment-2.

The resulting surplus in the building system can be averted by specially sizing the photovoltaic panels. However the application of specially sized photovoltaic panels will result in higher costs and the unpredictable climate conditions may render the affectivity of PV array for the specific season.

After the application of the optimized PV panel options for both refurbishment strategies all refurbishments become 100% annual Zero Energy Buildings. With the additional surplus within the system refurbsihemnt-1 becomes 101% ZEB and refurbishment-2 becomes 105% ZEB due to usage of standardized sizes for photovoltaic panels.

8.2 Cluster Application

Application of the refurbishment measures specified for Hospeslaan 24 is also possible to apply to other row houses within Hospeslaan Street due to being the same building by size, envelope, construction and structure. The only difference between these buildings is their roof, which has gone alteration throughout the years based on user preference with addition of dormers or skylights.

It is crucial to pay attention to orientation-based decisions such as PV panels for offsetting the operational energy, shading applications and window & glazing options. Buildings and their appearances regarding altered roof spaces are given in figure... Cluster of buildings consist of the middle section of the row houses and divided into 4 groups and among them one group is elaborated on regarding possible reduction of PV panel usage with utilizing bigger roof space and better position, this group is the one with Hospeslaan-24. Application is executed for both refurbishment strategies.

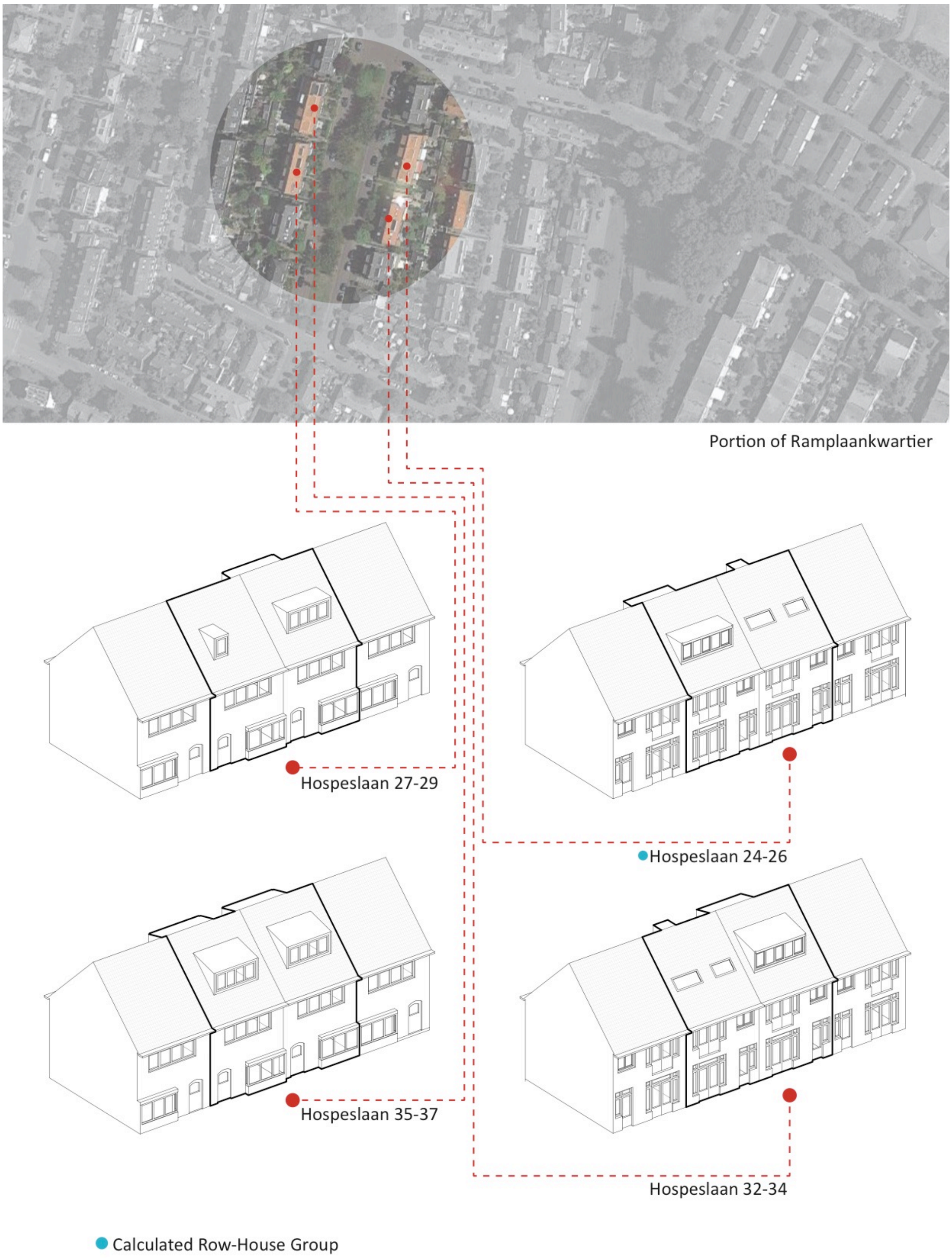


Figure 8-4: Groups of row houses in Ramplaankwartier with the same typology as Hospeslaan24. Group of Hospeslaan 24 is the calibrated group.
Image Source: Google Maps, 2017

8.2 Cluster Application Calculations & Sizing

Cluster application is based on utilizing the roof space of both building in a collaborative way to maximize the surface area potential of East facing roof space to reduce PV panel amounts, surplus of energy and the peak time load on national electricity grid while ensuring both buildings are minimum annually 100% Zero Energy Building.

Refurbishment measures regarding both of the strategies are applied to Hospeslaan-26 building to obtain the possible operational energy consumption of the building. With the application of both strategies Hospeslaan-26 building has 8272,0 kWh for Ref-1 and 7630,9 kWh for Ref-2 annual operational energy consumption. The energy consumption difference between Hospeslaan-24 and Hospeslaan-26 within the same refurbishment strategies is due to window application and dormer sizes of the roof structures.

Refurbishment Strategy				Energy Consumption	Individual Application			Cluster Application		
	Buildings		Roof Area (m^2)	Annual Operational Energy (kWh)	PV Panel #		Annual PV Yield (kWh)	PV Panel #		Annual PV Yield (kWh)
					East	West		East	West	
Ref-1	Hospeslaan-24	Primary Energy		8459,6 kWh	9	6	8541,3 kWh	24	3	**16822,4 kWh** = 90,8 kWh Total Surplus
	Hospeslaan-26			8272,0 kWh	12	2	8493,3 kWh			
Ref-2	Hospeslaan-24			7803,6 kWh	11	3	8187,0 kWh	25	-	**15528,6 kWh** = 94,1 kWh Total Surplus
	Hospeslaan-26			7630,9 kWh	13	-	8074.9 kWh			

Table 8-3: Optimized energy generation for cluster application and amount of PV panels for the energy offset.

If both buildings regardless of the refurbishment strategy apply PV panels individually to their own private roofs users would have to have 29 PV panels for refurbishment-1 and 27 PV panels for refurbishment-2. However if PV panels are applied and positioned with the advantage obtained by merging both roof spaces of Hospeslaan-24 & 26 reduces the necessary PV panel amount for offsetting the operational energy by 2 for both refurbishment strategies.

Utilization of the roofs are crucial for positioning the PV panels as effectively as possible for East facing roof surface. An illustration of the application for individual and collective roof usage is given in *figure 8-5* for both of the refurbishments.

When compared to individual application of PV panels based on standardized size photovoltaic usage, cluster application reduces the energy surplus in the yield of on-site energy generation applications. Optimized number of photovoltaic panels with the combined roof usage is an effective method for reducing refurbishment costs to achieve 100% Zero Energy Refurbishment as well as cutting back excessive electricity surpluses. With the reduced surplus system alleviates the unnecessary peak hour load pressure on the national grid.

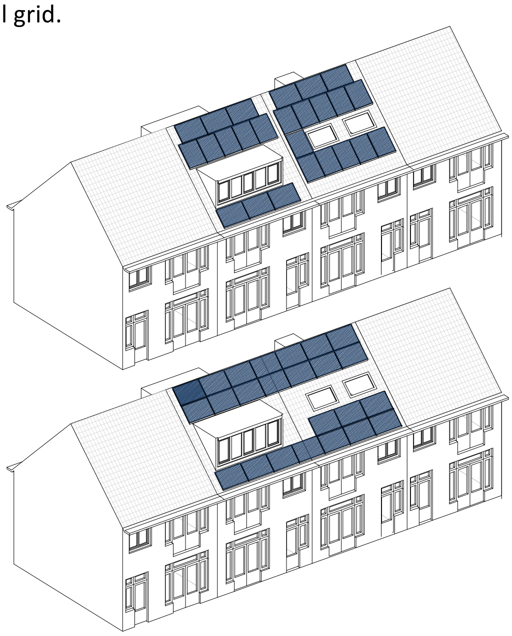


Figure 8-5: Positioning of PV panels facing east after cluster application. Refurbishment-2 above & Refurbishment-1 low. Refurbishment-1 has additional 4 PV panels facing west.

9. Final Design

Within the final design chapter, finalized choices on the building refurbishment are given for both of the refurbishment strategies to summarize as well as to point out the building condition after refurbishment. Information on the upgraded state of the building regarding both refurbishment strategies will be highlighted; real life applications will be compared for advantages and disadvantages of certain measures when applicable.

All applications for energy upgrade in the refurbishment strategy are collected to highlight and create a list of measures for the changes on the existing building components from building envelope to building services to successfully deliver the Zero Energy Building conditions elaborated in the previous chapters.

Components in use for building services will be given with the application of ventilation, positioning of certain machinery, ducts and the sizing of components responsible for comfortable ventilation conditions.

Means of energy generation and their amounts, attachments to roof structure and surface coverage are all highlighted within the chapter with different applications of refurbishment-1 and refurbishment-2. Final energy consumptions regarding type of energy carriers and generated amount are stated as the accepted condition of energy balance in refurbishment strategies.

Even though refurbishment measures for building envelope or services are used under certain strategies specifically, they create a pool of possible individual applications for the energy refurbishment of the houses in Hospeslaan, Ramplaankwartier. Applicable individual measures can be fit together to create different combinations of refurbishment design, with different envelope refurbishment strategies, ventilation systems and building detailing.

9.1 Refurbishment-1

Refurbishment measures used for energy consumption reduction, comfort optimization, changes in building services and possible application of the building detailing regarding refurbishment strategies for the building envelope are all summarized throughout the chapter. Final energy of the building after all accepted measures are applied to the building is given in table 9-0 in a comparison with existing condition of the building.

	Natural Gas	Electricity	Energy Generation	Primary Energy	Balance
Existing Condition	- 24461 kWh	- 1017 kWh	Fable Hall	- 97448 kWh	No Balance
Refurbishement-2	-Non	- 3411,1 kWh	3444 kWh + Fable Hall	+ 81,7 kWh	101% ZEB

Table 9-0: Energy consumption values before after energy refurbishment.

Building Envelope

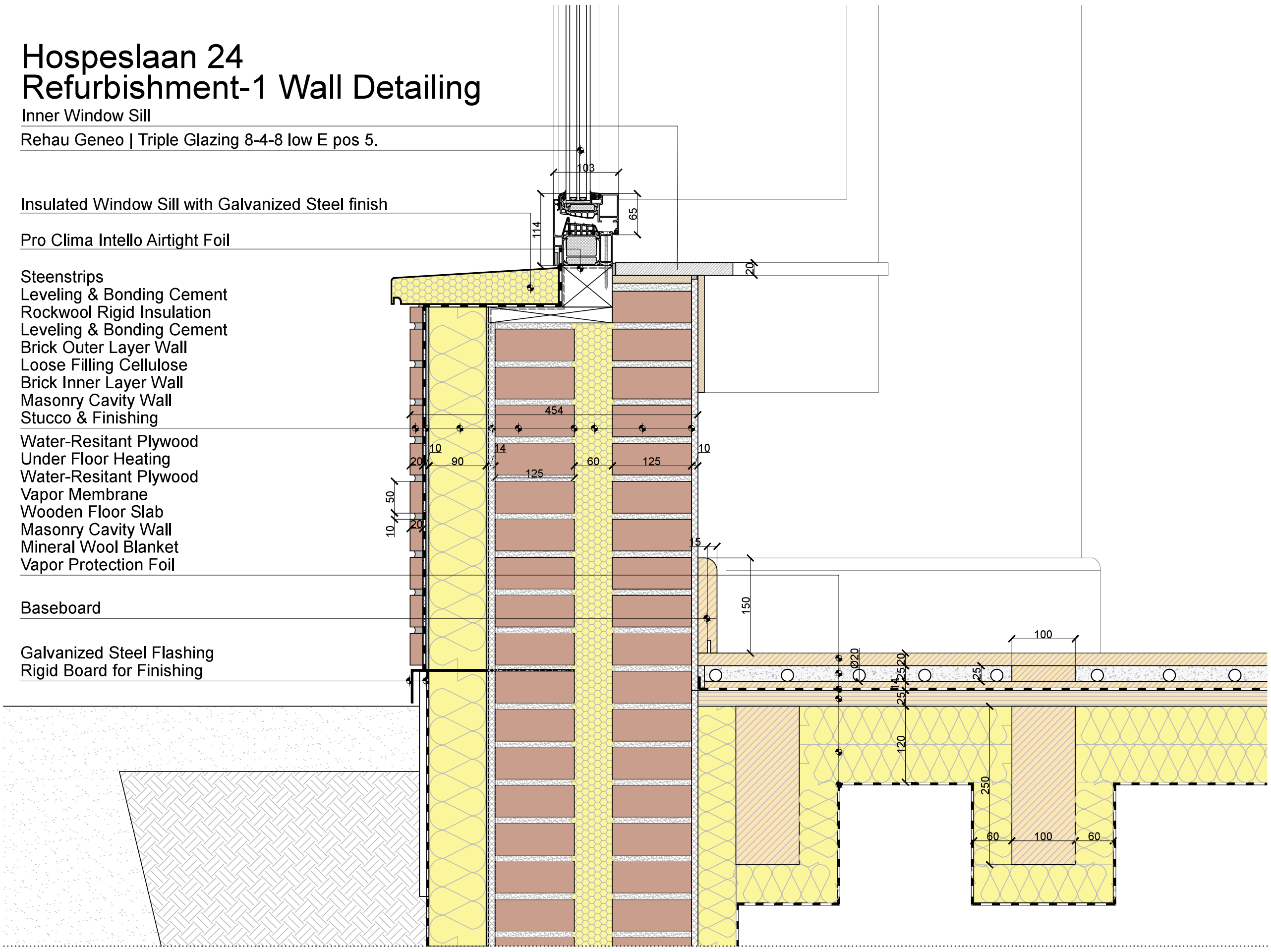
Building envelope is upgraded with the combination of several envelope refurbishment strategies to reduce the scale of intervention on the envelope to secure limited obstruction on the living. Changes on the building envelope for refurbishment are given in *table 9-1* with extensive description of the measures for all the components included.

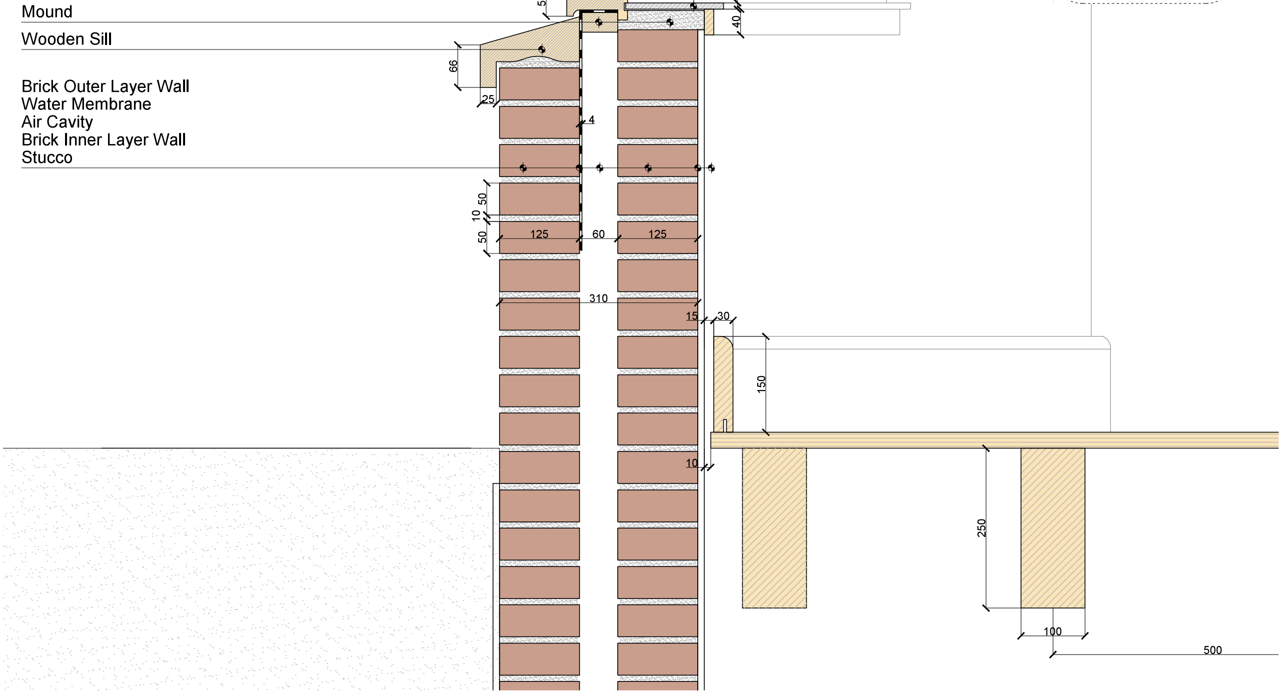
Detailed application of the theoretical refurbishment measures on building envelope is given in figures…. Details are prepared to highlight how the building envelope upgrade can be executed with the accepted strategies and thermal performances, while considering all the necessary applications for the attachment of different components, such as insulation, masonry wall, glazing, sills and wall finishing and most importantly the existing condition of the building envelope.

	Construction	Description	U-Value	R_c - Value
Existing Condition	**External Wall**	All round Masonry cavity wall with plaster and architectural interior finishing 125-60-125mm layering for the construction and additional 10mm finishing and stucco application. No insulation. Cement filling connection with the foundation block below crawlspace level.	1,25 W/m^{2}K	0,8 m^{2}K/W
	Ground Floor / Crawlspace	Single layer painted wooden Floor lab 25mm, absent insulation, supported by wooden beams spanning north-south direction from partition walls between housing units.	3,1 W/m^{2}K	0,32 m^{2}K/W
	Pitched Roof	Dutch Roof tiles, water membrane and wooden roof slab. No insulation. Roof supported by wooden rafters spanning over the building façade. Main beam spans north-south direction from partition walls between housing units.	**East Roof:** 1,1 W/m^{2}K **West Roof:** 0,8 W/m^{2}K	**East Roof:** 0,9 m^{2}K/W **West Roof:** 1,2 m^{2}K/W
	Flat Roof (Dormers)	Built after the construction of the building roof. Wooden framing with limited mineral wool insulation and sprayed PUR application for the junction point with pitched roof for water-airtightness. Roof exterior finishing with mastic roofing. Exists on both sides.	0,4 W/m^{2}K	2,53 m^{2}K/W
	Sides (Dormers)	Same construction with Flat roof, exterior finishing includes weatherboard.	0,4 W/m^{2}K	2,53 m^{2}K/W
	Infiltration	High infiltration rate determined by validation 16 ACH^{-1}@50pa	-	-
	Glazing	All Single glazing windows with the expectation of Dormer and bathroom double glazing windows.	**Single:** 6,1 W/m^{2}K **Double:** 2,5 W/m^{2}K	**Single:** 0,16 m^{2}K/W **Double:** 0,4 m^{2}K/W
	Window Frames	Wooden window frames for single glazing windows and UPVC frames for double glazing windows.	**Wood:** 3,6 W/m^{2}K **UPVC:** 3,4 W/m^{2}K	**Wood:** 0,27 m^{2}K/W **UPVC:** 0,29 m^{2}K/W
	Doors	Non-insulated Doors	3,5 W/m^{2}K	0,28 m^{2}K/W

	Construction	Description	Strategy	U-Value	R_c - Value
After Renovation	**External Wall**	Loose Cellulose filling for wall cavity 60mm, high-density mineral wool battens (90mm) application on outer leaf, water membrane, bonding material and exterior finishing with steenstrips. Additional sandwich panels are applied for windowsill to insulate and minimize thermal bridges on junction points.	Wrap-it & Cavity Fill	0,22 W/m^{2}K for total composition	4,5 m^{2}K/W for total composition
	Ground Floor / Crawlspace	Ground floor is insulated from the crawlspace with mineral wool fiber blanket (120mm). Crawlspace walls are insulated from both inside and outside to reduce thermal bridges through the building foundation.	Wrap-it & Add-in	0,28 W/m^{2}K for total composition	3,5 m^{2}K/W for total composition
	Pitched Roof	Roof is insulated from inside with 200mm mineral wool blanket. Existing construction is kept with the exterior finish. Vapor membrane is applied with interior finishing of plasterboard and paint	Add-in	0,15 W/m^{2}K for total composition	6,0 m^{2}K/W for total composition
	Flat Roof (Dormers)	No change in the condition of Dormers. Airtight applications	No change	0,4 W/m^{2}K	2,53 m^{2}K/W
	Sides (Dormers)	No change in the condition of Dormers. Airtight applications	No change	0,4 W/m^{2}K	2,53 m^{2}K/W
	Infiltration	Reduced to 2,95 ACH^{-1}@50pa with envelope upgrade.	Airtight	-	-
	Glazing	Triple glazing (Rehau Geneo) on West and Double Glazing (Rekord Basic) on East facing façades. With exterior translucent roller shades for solar control and privacy.	All windows are replaced	**Rekord:** 1,0 W/m^{2}K **Rehau:** 0,9 W/m^{2}K	**Rekord:** 1,0 m^{2}K/W **Rehau:** 1,1 m^{2}K/W
	Window Frames	PVC framing for both glazing applications. Different thermal values for different window compositions. Frame insulation with PUR for Rehau Geneo	All windows are replaced	**Rekord:** 1,1 W/m^{2}K **Rehau:** 0,78 W/m^{2}K	**Rekord:** 0,9 m^{2}K/W **Rehau:** 1,3 m^{2}K/W
	Doors	Doors are replaced with insulated alternatives. Internorm AT 400 PE	Exterior door replaced	0,75 W/m^{2}K	1,33 m^{2}K/W

Table 9-1: Refurbishment measures for the building envelope and corresponding components, application strategy and their comparison to their previous state.





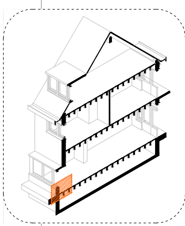
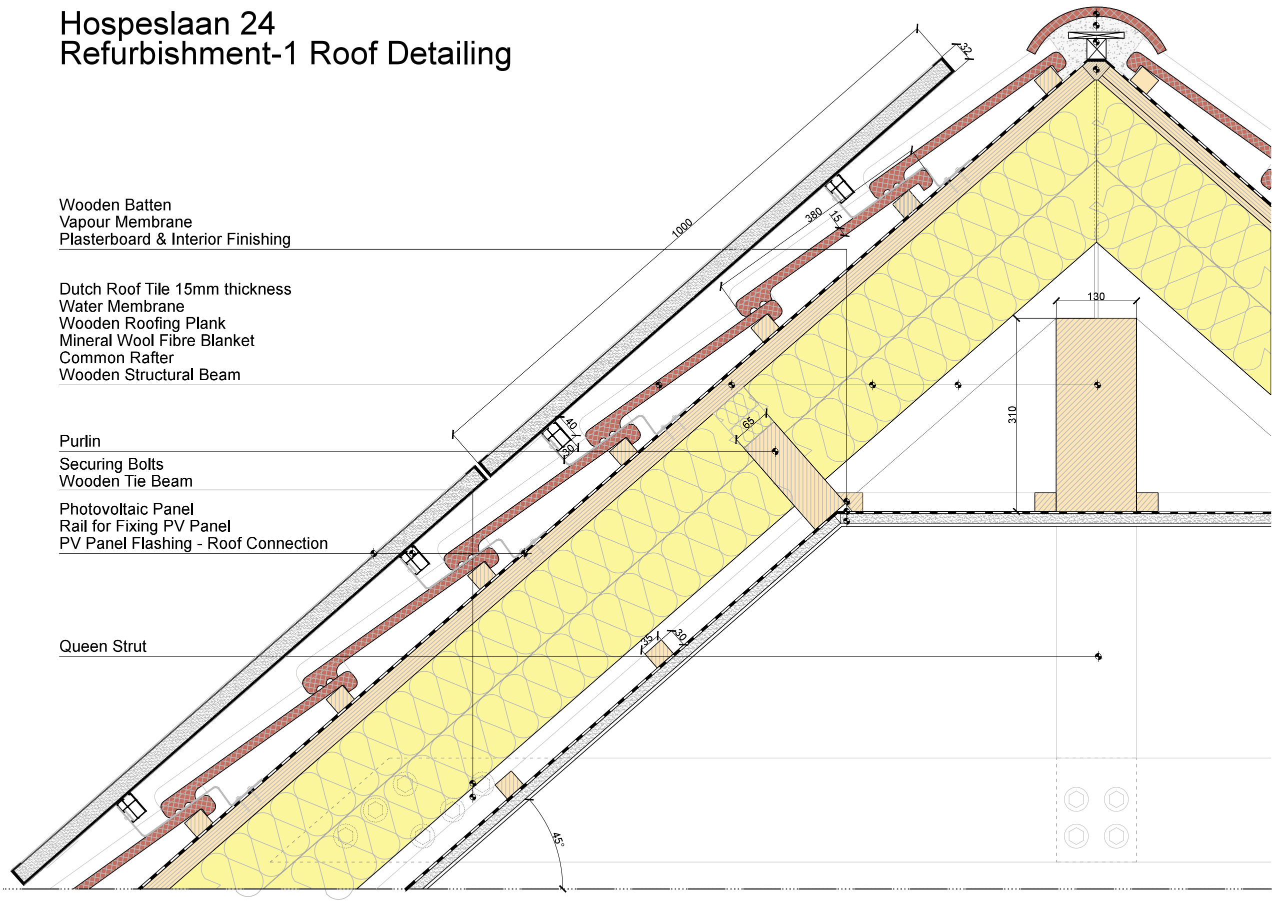


Figure 9-0: External wall and ground floor detailing for achieving necessary thermal performances regarding accepted refurbishment strategies



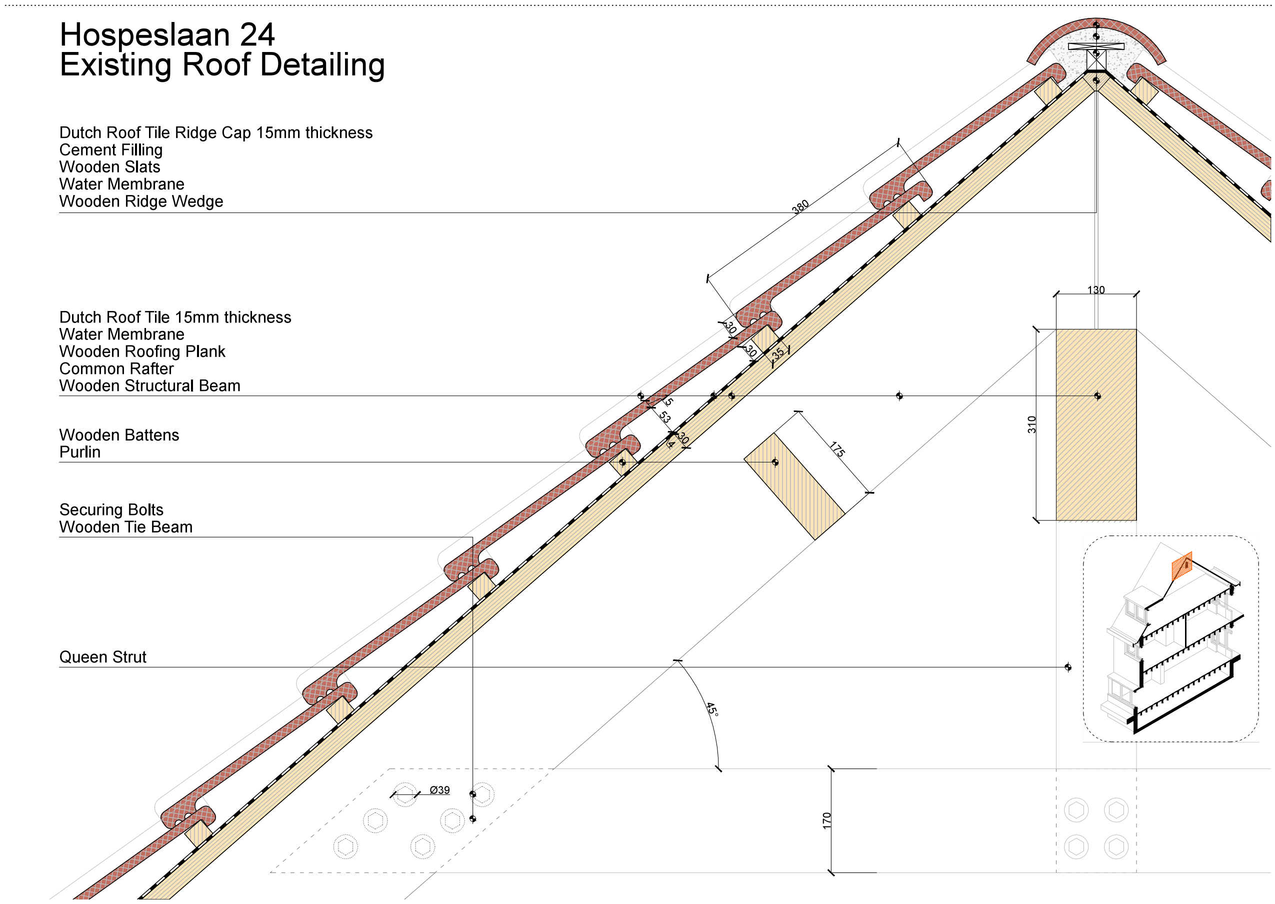
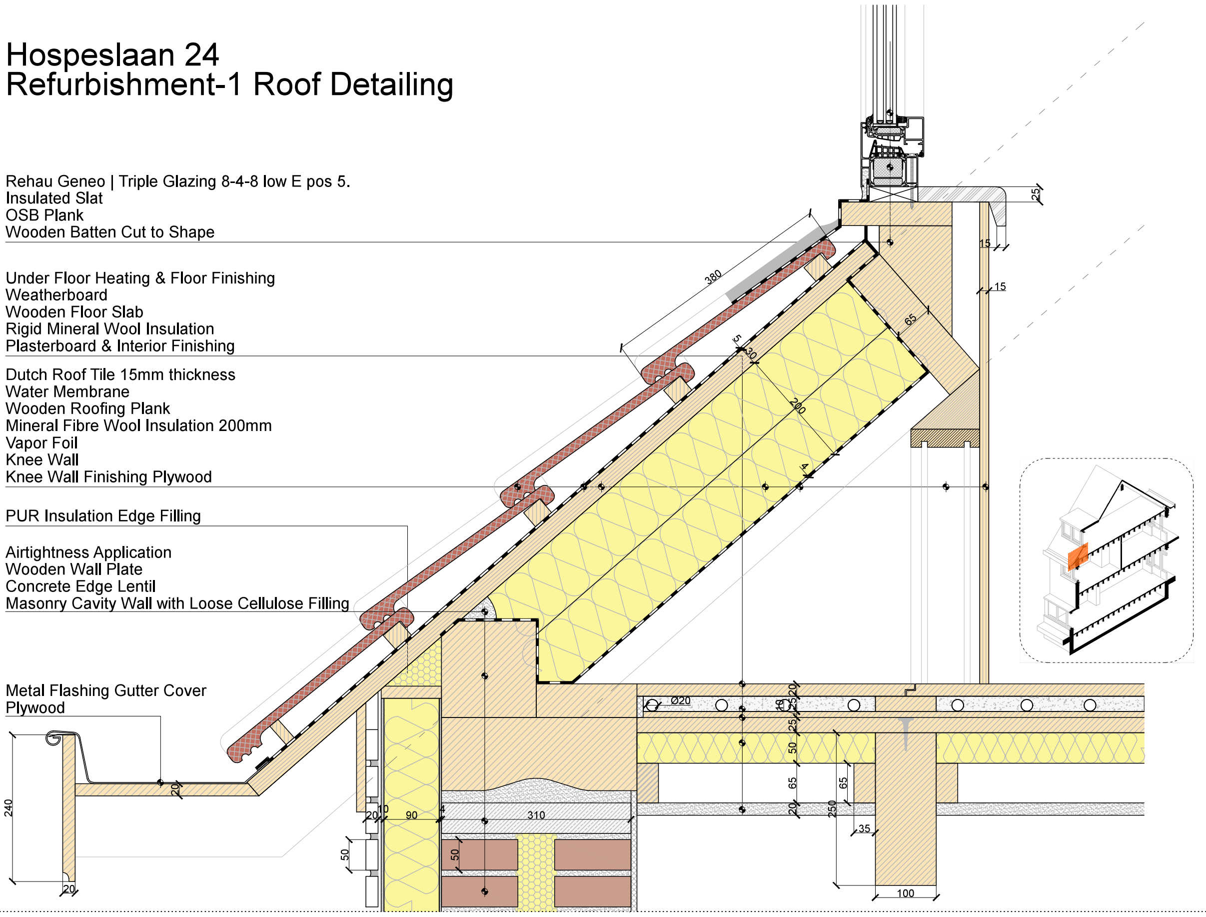


Figure 9-1: Roof ridge detailing for achieving necessary thermal performances regarding accepted refurbishment strategies

Hospeslaan 24
Refurbishment-1 Roof Detailing



Hospeslaan 24
Existing Roof Detailing

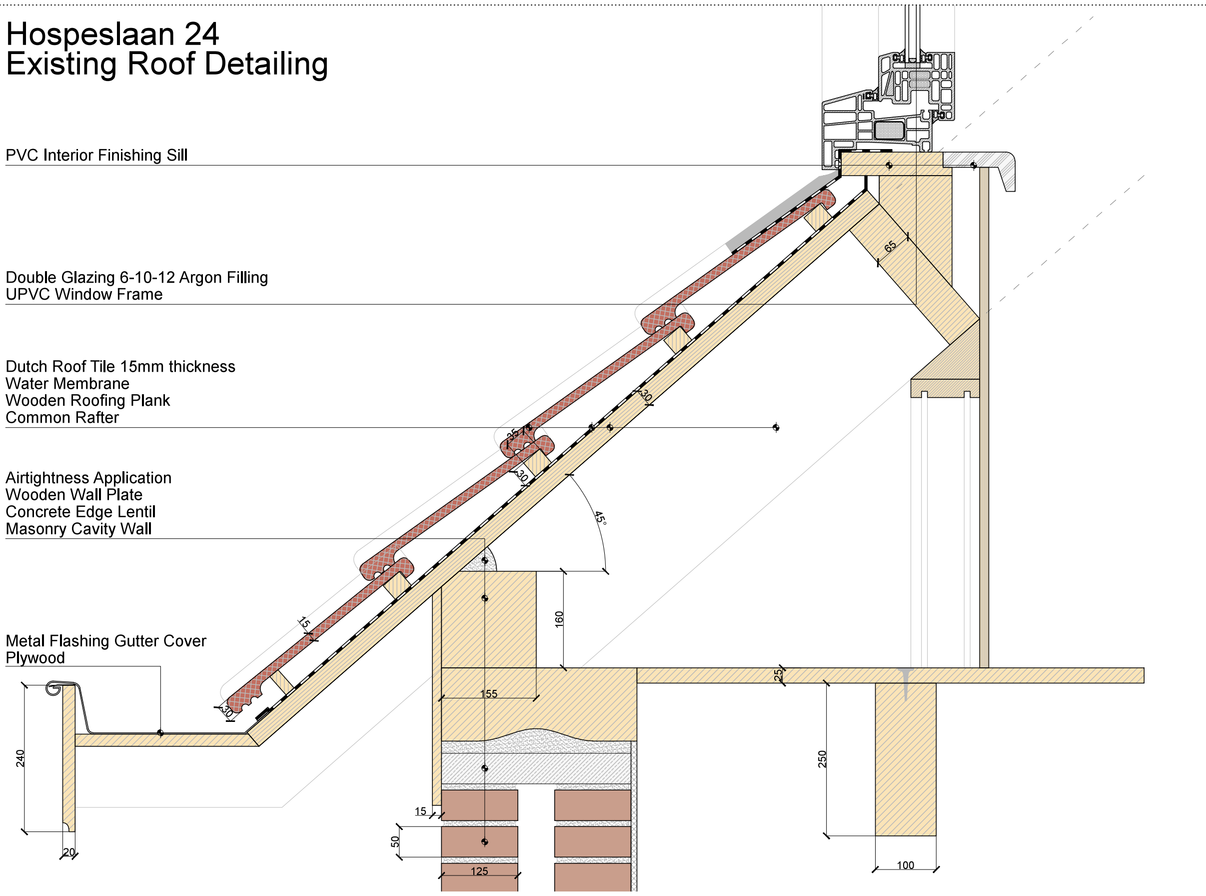


Figure 9-2: Roof edge detailing for illustrating how external wall insulation connects with the roof to leave no thermal bridges and minimize air leakage

Building Services

Installations within the building are upgraded to full electric consumption from natural gas to eliminate fossil fuel delivery to the building for energy provision. Upgraded version of heating and DHW system has better efficiency compared to existing heating system with reduced loss within the system itself. Changes in the system are given in *table 9-2 and illustrated in figure 9-3*.

Application of Low temperature source for water-to-water heat pump requires low temperature space heating. Therefore low surface temperature radiators are integrated to the refurbishment. Ventilation system is switched to mechanical extraction, natural provision. Extraction is based on user demand to regulate foul air drag in wet spaces. Direct cooling system is only applicable if excessive ventilation fails to provide necessary indoor air conditions.

	Building Services	Description	Component Efficiency	Location of Component
Existing	Heating	HR100 Boiler with high temperature radiators. Natural gas fired.	COP: 85% for space heating & DHW	Attic
Existing	DHW	HR100 Boiler, natural gas consumption. Temperature provision 65°C		
Existing	Cooling	No cooling system reported	-	-
Existing	Ventilation	Natural ventilation for primary spaces provided by façade openings. No additional ventilation is reported for wet spaces such as toilet, kitchen and the bathroom. Fully Natural inlet / Outlet	-	-
After Renovation	Heating	Water-to-Water heat pump with low temperature source. High temperature radiators are replaced with low surface temperature radiators for space conditioning.	COP: 5,1	Attic & Applied over floor slabs
After Renovation	DHW	Water-to-Water heat pump with low temperature source. Water heating is used for shower, bathtub and taps.	COP: 2,4	Attic
After Renovation	Back-up	Electrical Back-up system integrated with Water-to-Water heat pump for very cold outdoor conditions to support heat generation.	COP: 1,0	Attic
After Renovation	Cooling	Direct Cooling system. Only active if excessive ventilation cannot reduce indoor air temperatures effectively.	COP: 12,0	Zone Specific
After Renovation	Ventilation	Natural inlet / Mechanical extraction located in wet spaces. Demand controlled in wet spaces. Excessive ventilation during summer if applicable	-	Attic & Wet spaces
After Renovation	Ventilation Piping	Single zone extraction pipes 10 cm diameter. Main extraction pipe 16 cm diameter	No heat recovery	Between floor slab & ceiling
After Renovation	Energy Generation	East facing roof 18,4 m^2 photovoltaic (9 panels at 45°), West facing roof 6,7 m^2 photovoltaic (3 panels at 45°)	19.7% Solar Efficiency	Applied over pitched Roofs

Table 9-2: Building services upgrade in refurbishment-1 strategy to achieve zero energy building.

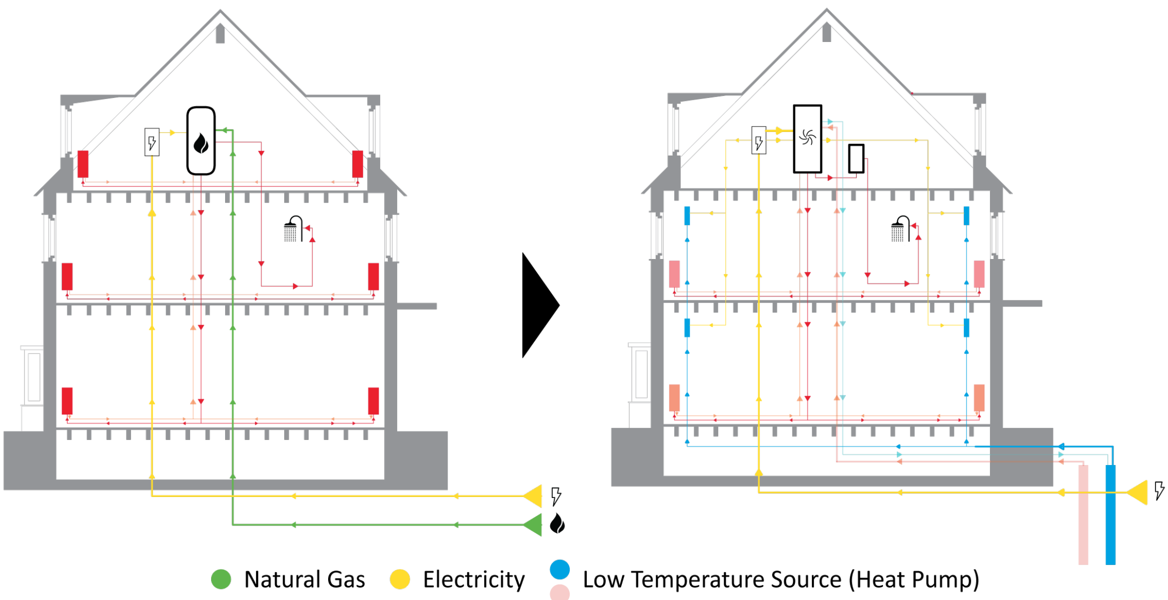
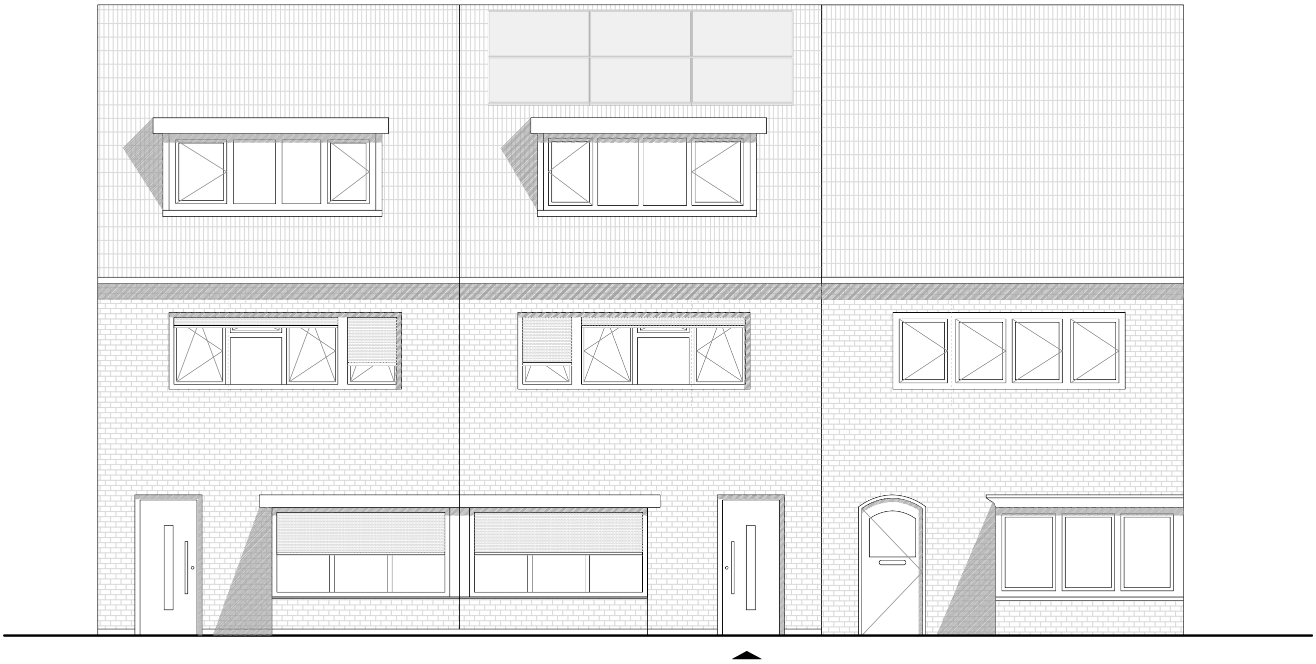


Figure 9-3: Building Services diagram for existing condition and after renovation.

Building Elevations & Visualization

Building elevation and visualizations are to illustrate how Hospeslaan24 dwelling would look after all the refurbishment measures have been executed to achieve annual Zero Energy Balance. Elevation of the building is given in *figure 9-4* and Renders regarding refurbished state of the building are in *figure 9-5.*

Refurbishment-1 | West Elevation



Refurbishment-1 | East Elevation

Figure 9-4: Elevation of refurbishment-1 after all measures applied to the building envelope

Figure 9-5: Visualization of the executed refurbishment measures on the building envelope.

9.2 Refurbishment-2

All applications for energy upgrade in the refurbishment strategy are collected to highlight and create a list of measures for the changes on the existing building components from building envelope to building services to successfully deliver the Zero Energy Building conditions elaborated in the previous chapters. Resulting energy balance after all measures are applied is given in *table 9-3.*

	Natural Gas	Electricity	Energy Generation	Primary Energy	Balance
Existing Condition	- 24461 kWh	- 1017 kWh	Fable Hall	- 97448 kWh	No Balance
Refurbishement-2	-Non	- 3146,6 kWh	3301 kWh + Fable Hall	+ 383 kWh	105% ZEB

Table 9-3: Energy consumption values before after energy refurbishment.

Building Envelope

Refurbishment-2 offers bold approach towards envelope refurbishment by the partial and when applicable total replacement of the building skin. Changes on the building skin and any component influential on the building thermal skin are given in *table 9-4.*

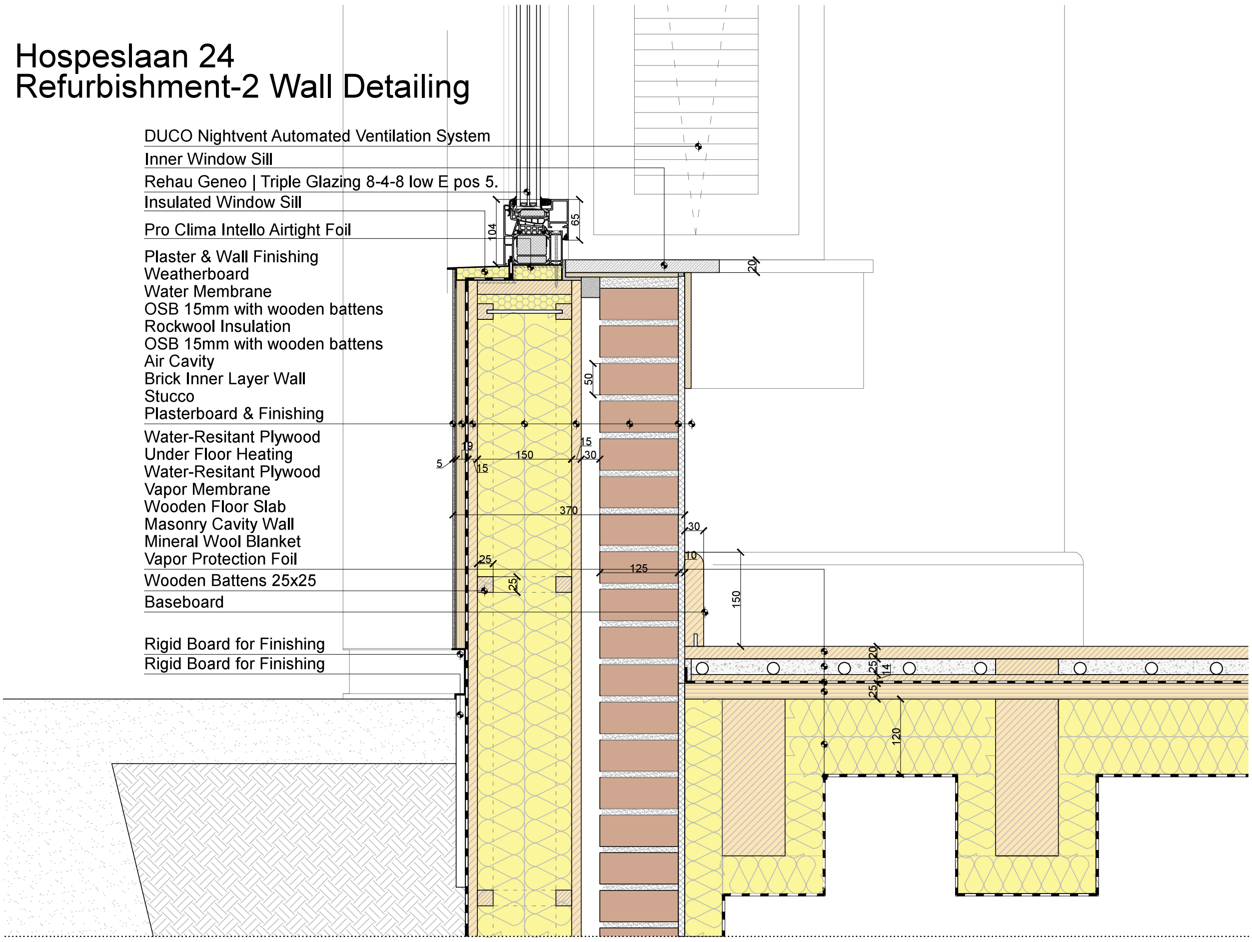
Details on the execution of the building envelope regarding corresponding refurbishment strategies accepted per section can be found in figures… For a healthy and precise construction to reduce infiltration rates along with to apply 6,0 m^2K/W, 4,5 m^2K/W, 3,5 m^2K/W values for roofs, walls and ground floor, detailing is important describe important solutions for junction points, connections and the composition of envelope sections.

	Construction	Description	U-Value		R_c - Value	
Existing Condition	External Wall	All round Masonry cavity wall with plaster and architectural interior finishing 125-60-125mm layering for the construction and additional 10mm finishing and stucco application. No insulation. Cement filling connection with the foundation block below crawlspace level.	1,25 W/m^{2}K		0,8 m^{2}K/W	
	Ground Floor / Crawlspace	Single layer painted wooden Floor lab 25mm, absent insulation, supported by wooden beams spanning north-south direction from partition walls between housing units.	3,1 W/m^{2}K		0,32 m^{2}K/W	
	Pitched Roof	Dutch Roof tiles, water membrane and wooden roof slab. No insulation. Roof supported by wooden rafters spanning over the building façade. Main beam spans north-south direction from partition walls between housing units.	**East Roof:** 1,1 W/m^{2}K	**West Roof:** 0,8 W/m^{2}K	**East Roof:** 0,9 m^{2}K/W	**West Roof:** 1,2 m^{2}K/W
	Flat Roof (Dormers)	Built after the construction of the building roof. Wooden framing with limited mineral wool insulation and sprayed PUR application for the junction point with pitched roof for water-airtightness. Roof exterior finishing with mastic roofing. Exists on both sides.	0,4 W/m^{2}K		2,53 m^{2}K/W	
	Sides (Dormers)	Same construction with Flat roof, exterior finishing includes weatherboard.	0,4 W/m^{2}K		2,53 m^{2}K/W	
	Infiltration	High infiltration rate determined by validation 16 ACH^{-1}@50pa	-		-	
	Glazing	All Single glazing windows with the expectation of Dormer and bathroom double glazing windows.	**Single:** 6,1 W/m^{2}K	**Double:** 2,5 W/m^{2}K	**Single:** 0,16 m^{2}K/W	**Double:** 0,4 m^{2}K/W
	Window Frames	Wooden window frames for single glazing windows and UPVC frames for double glazing windows.	**Wood:** 3,6 W/m^{2}K	**UPVC:** 3,4 W/m^{2}K	**Wood:** 0,27 m^{2}K/W	**UPVC:** 0,29 m^{2}K/W
	Doors	Non-insulated Doors	3,5 W/m^{2}K		0,28 m^{2}K/W	

	Construction	Description	Strategy	U-Value		R_c - Value	
After Renovation	External Wall	Outer leaf of the masonry brick wall is removed; prefabricated insulated panel is positioned before the inner leaf of the wall. 150mm mineral wool battens insulation trapped between 25mm & 15mm OSB backed by wooden framework. Water membrane and weatherboard is attached to exterior to provide surface for textured rendering.	Partial Replacement of External walls with prefabricated elements	0,22 W/m^{2}K for total composition		4,5 m^{2}K/W for total composition	
	Ground Floor / Crawlspace	Ground floor is insulated from the crawlspace with mineral wool fiber blanket (120mm). Crawlspace walls are insulated from both inside and outside to reduce thermal bridges through the building foundation.	Wrap-it & Add-in	0,28 W/m^{2}K for total composition		3,5 m^{2}K/W for total composition	
	Pitched Roof Flat Roof (Dormers) Sides (Dormers)	Roof is totally removed and replaced with prefabricated insulated panel. 210mm mineral wool is trapped between two OSB layers with wooden framework. External finishing is PVC roofing. Replacement of roof with prefabricated insulated panel includes replacement of dormers as well.	Total Replacement of Roof & Dormers with prefabricated roof block.	**Pitched & Flat Roof:** 0,15 W/m^{2}K for total composition **Dormer Sides:** 0,22 W/m^{2}K		**Pitched & Flat Roof:** 6,0 m^{2}K/W for total composition **Dormer Sides:** 4,5 m^{2}K/W	
	Infiltration	Reduced to 0,74 ACH^{-1}@50pa with envelope upgrade.	Very airtight	-		-	
	Glazing	Triple glazing (Rehau Geneo) on West and Double Glazing (Rekord Basic) on East facing façades. With exterior translucent roller shades for solar control and privacy.	All windows are replaced	**Rekord:** 1,0 W/m^{2}K	**Rehau:** 0,9 W/m^{2}K	**Rekord:** 1,0 m^{2}K/W	**Rehau:** 1,1 m^{2}K/W
	Window Frames	PVC framing for both glazing applications. Different thermal values for different window compositions.	All windows are replaced	**Rekord:** 1,1 W/m^{2}K	**Rehau:** 0,78 W/m^{2}K	**Rekord:** 0,9 m^{2}K/W	**Rehau:** 1,3 m^{2}K/W
	Doors	Doors are replaced with insulated alternatives. Internorm AT 400 PE	Exterior door replaced	0,75 W/m^{2}K		1,33 m^{2}K/W	

Table 9-4: Refurbishment measures for the building envelope and corresponding components, application strategy and their comparison to their previous state.

Hospeslaan 24
Refurbishment-2 Wall Detailing



Hospeslaan 24
Existing Wall Detailing

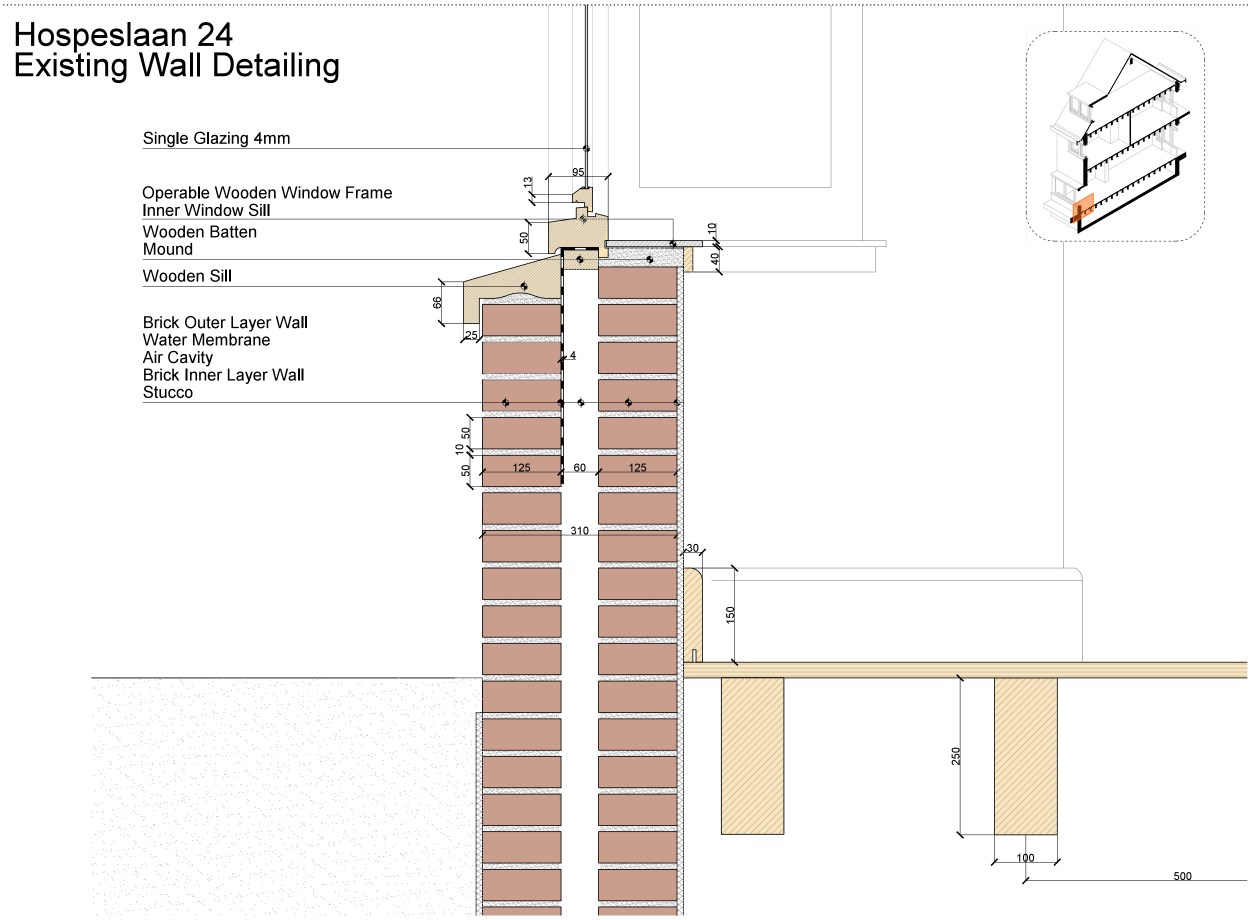
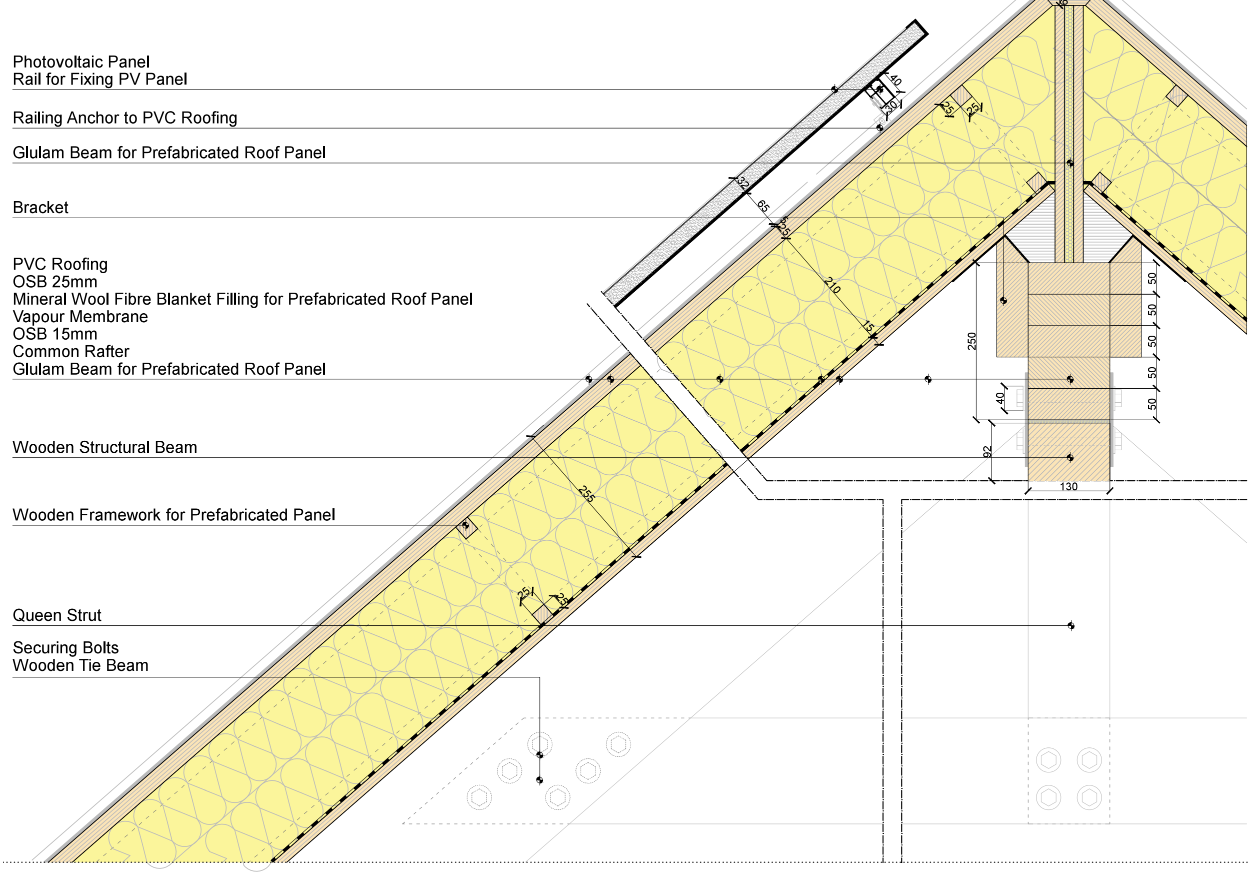


Figure 9-6: External wall and ground floor detailing for achieving necessary thermal performances regarding accepted refurbishment strategies for both envelope sections.

Hospeslaan 24 Refurbisment-2 Roof Detailing



Hospeslaan 24 Existing Condition Roof Detailing

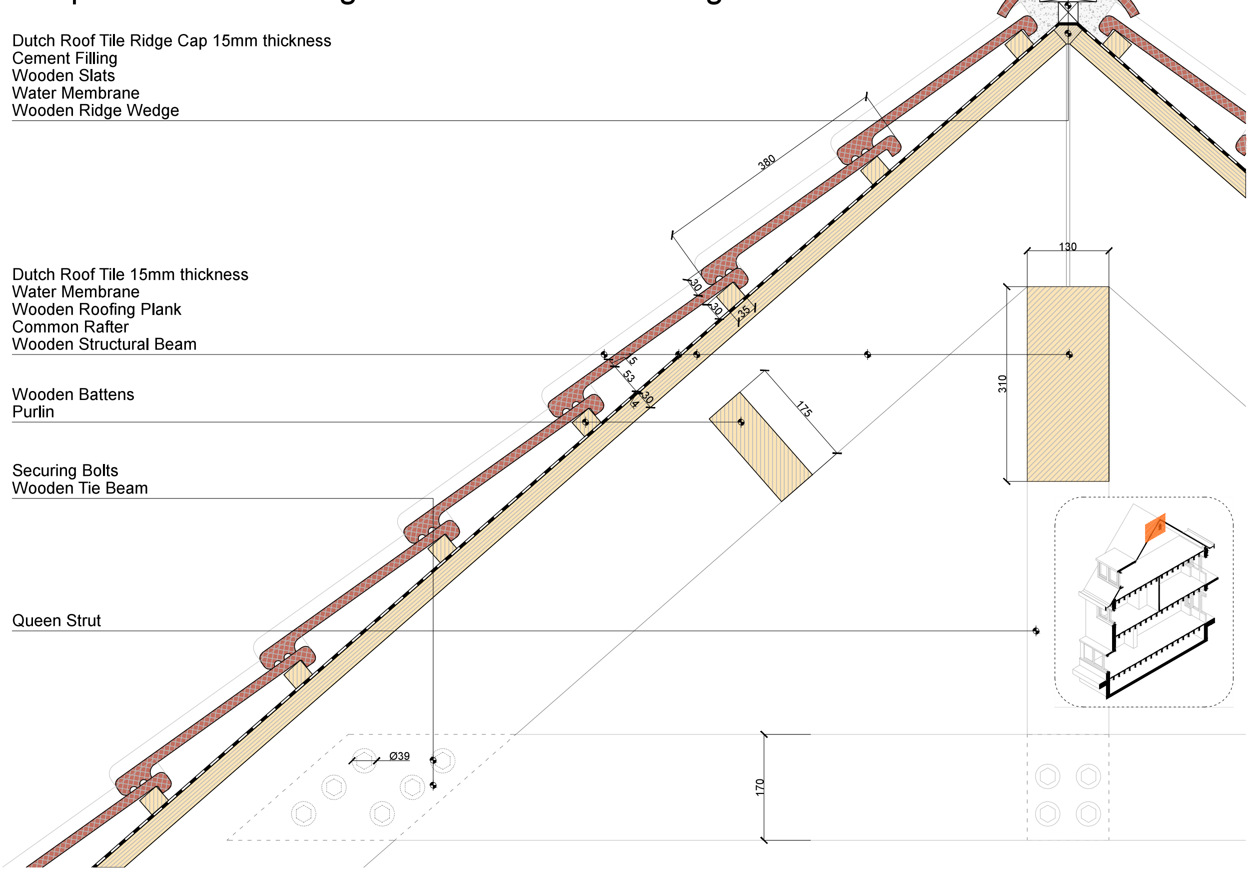
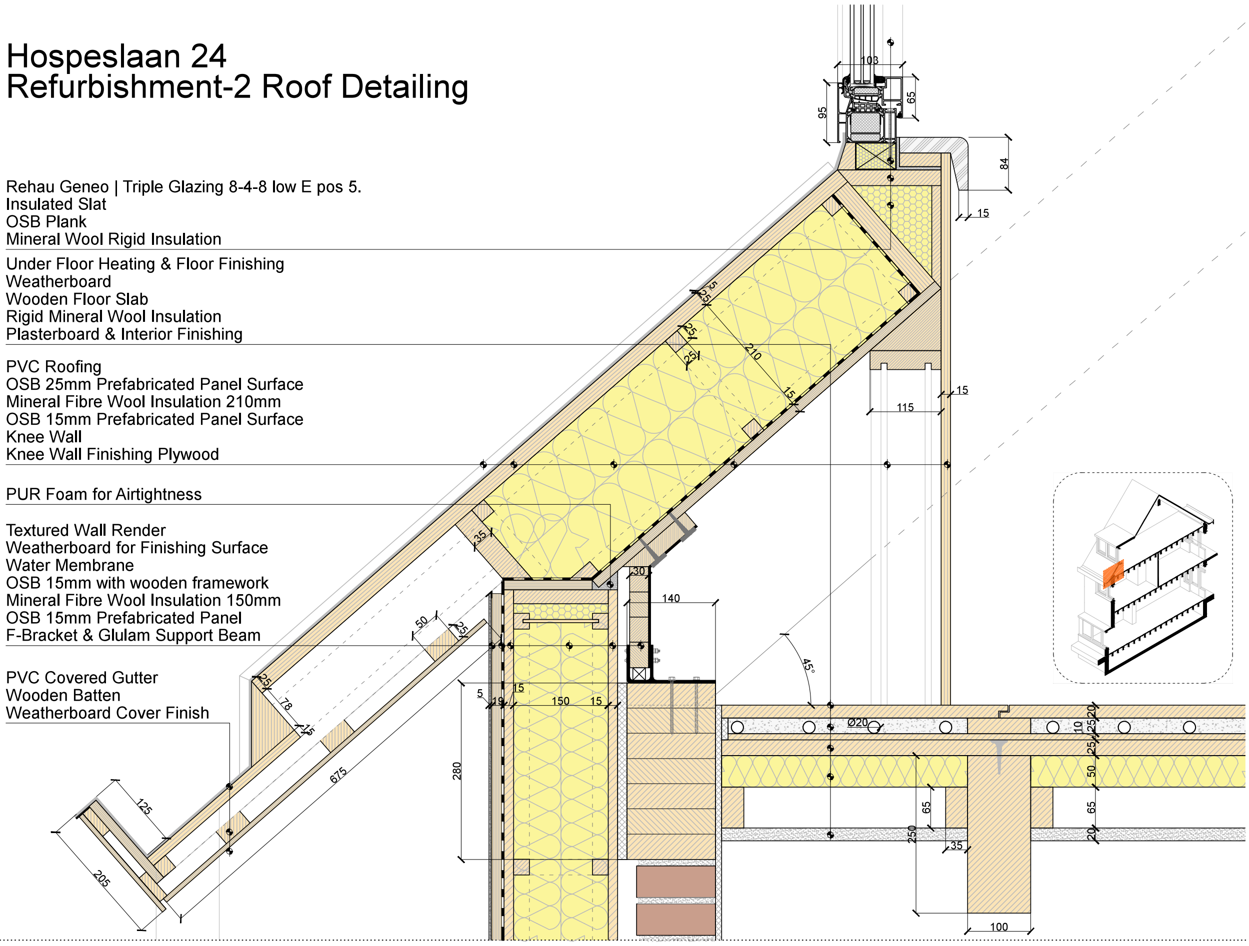


Figure 9-7: Roof ridge detailing for achieving necessary thermal performances regarding accepted refurbishment strategies

Hospeslaan 24
Refurbishment-2 Roof Detailing



Hospeslaan 24
Existing Roof Detailing

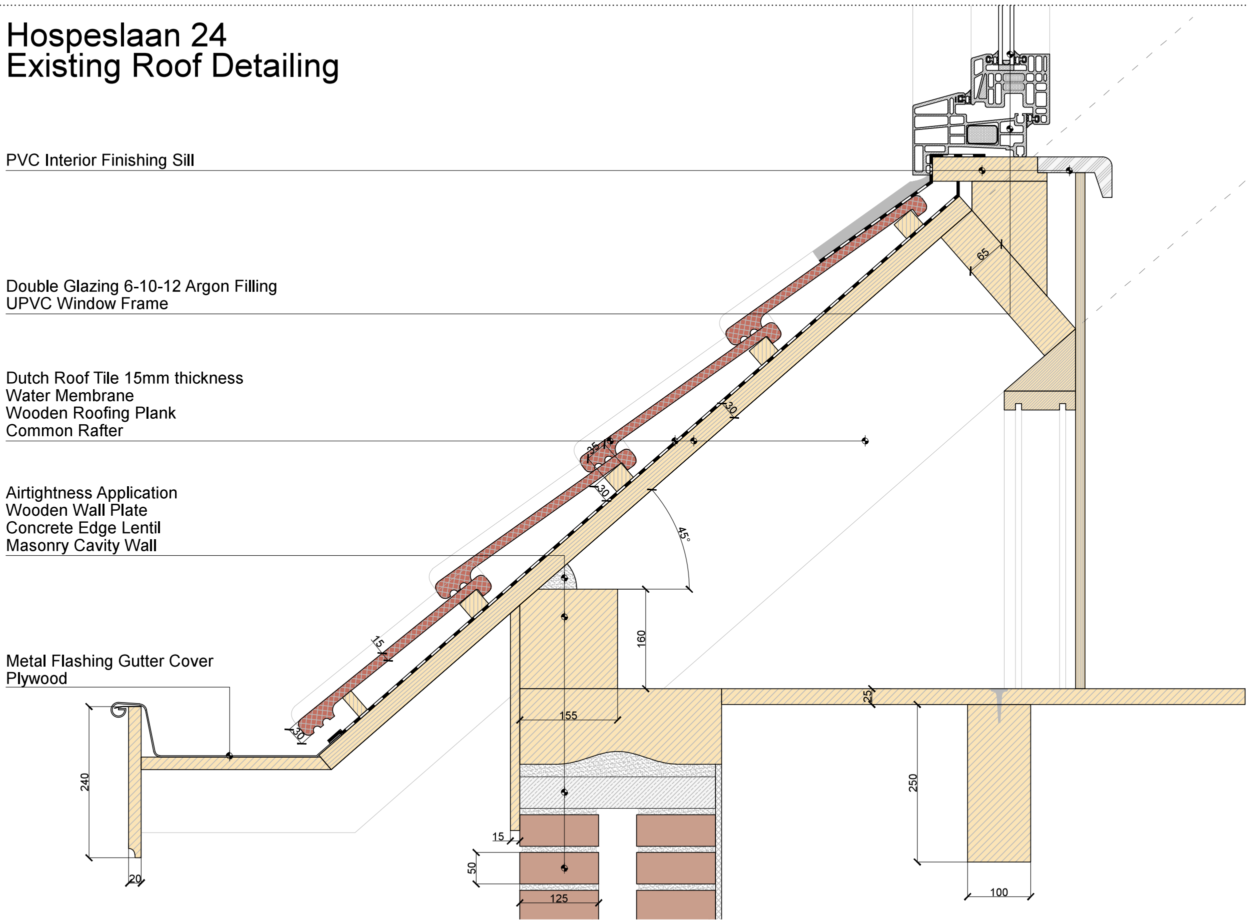


Figure 9-8: Roof edge detailing for illustrating how external wall insulation connects with the roof to leave no thermal bridges and minimize air leakage

Building Services

Installations within the building are upgraded to full electric consumption from natural gas to eliminate fossil fuel delivery to the building for energy provision. Upgraded version of heating and DHW system has better efficiency compared to existing heating system with reduced loss within the system itself. Changes in the system are given in *table 9-1 and illustrated in figure 9-9.*

Application of Low temperature source for water-to-water heat pump requires low temperature space heating. Therefore under floor heating is integrated to the refurbishment. Ventilation system is switched to mechanical extraction and supply with heat recovery for recycling waste heat in the system. Ventilation of spaces is demand controlled and based on occupancy. Direct cooling system is only applicable if excessive ventilation fails to provide necessary indoor air conditions.

Building Services		Description	Component Efficiency	Location of Component
Existing	Heating	HR100 Boiler with high temperature radiators. Natural gas fired.	COP: 85% for space heating & DHW	Attic
Existing	DHW	HR100 Boiler, natural gas consumption. Temperature provision 65°C		
Existing	Cooling	No cooling system reported	-	-
Existing	Ventilation	Natural ventilation for primary spaces provided by façade openings. No additional ventilation is reported for wet spaces such as toilet, kitchen and the bathroom. Fully Natural inlet / Outlet	-	-
After Renovation	Heating	Water-to-Water heat pump with low temperature source. Building heating system is switched to under floor heating for utilizing low temperatures in space heating.	**COP:** 5,1	Attic & Applied over floor slabs
After Renovation	DHW	Water-to-Water heat pump with low temperature source. Water heating is used for shower, bathtub and taps.	**COP**: 2,4	Attic
After Renovation	Back-up	Electrical Back-up system integrated with Water-to-Water heat pump for very cold outdoor conditions to support heat generation.	**COP:** 1,0	Attic
After Renovation	Cooling	Direct Cooling system. Only active if excessive ventilation (natural) cannot reduce indoor air temperatures effectively.	**COP:** 12,0	Zone Specific
After Renovation	Ventilation	Mechanical supply and extraction with heat recovery. Demand controlled ventilation system. Extraction in wet spaces supply in primary spaces. Excessive natural ventilation during summer period. Heat recovery and mechanical supply bypassed.	**Heat Recovery:** 80%	Attic & Wet & Primary Spaces
After Renovation	Ventilation Piping	Single zone extraction and supply pipes 10 cm diameters. Main extraction & supply pipes 16 cm diameter	-	Between floor slab & ceiling
After Renovation	Energy Generation	East facing roof 18,4 m^2 photovoltaic (9 panels at 45°), West facing roof 6,7 m^2 photovoltaic (3 panels at 45°)	19.7% Solar Efficiency	Applied over pitched Roofs

Table 9-1: Building services upgrade in refurbishment-1 strategy to achieve zero energy building

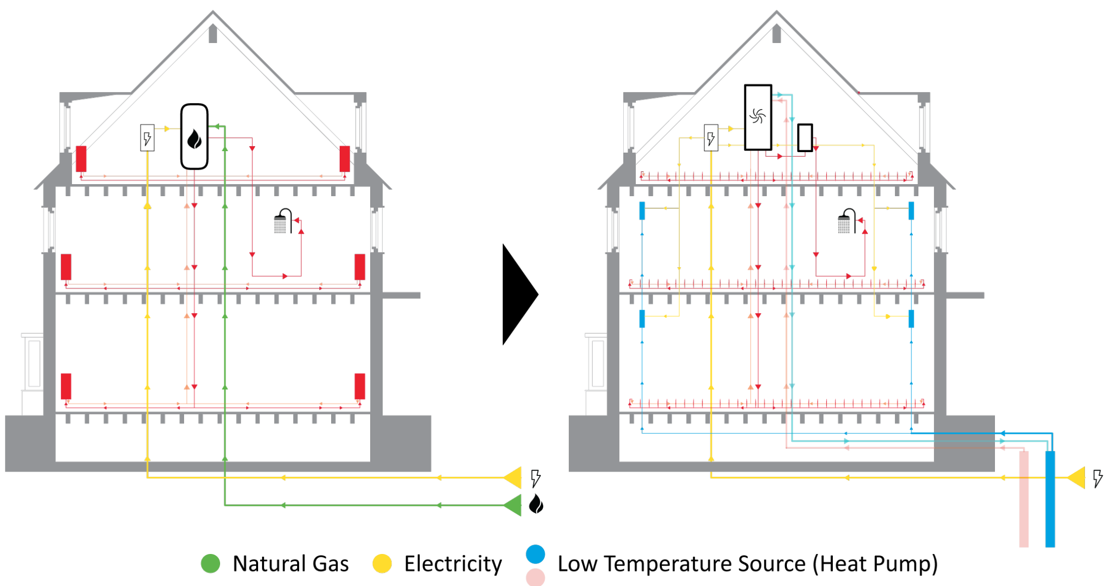
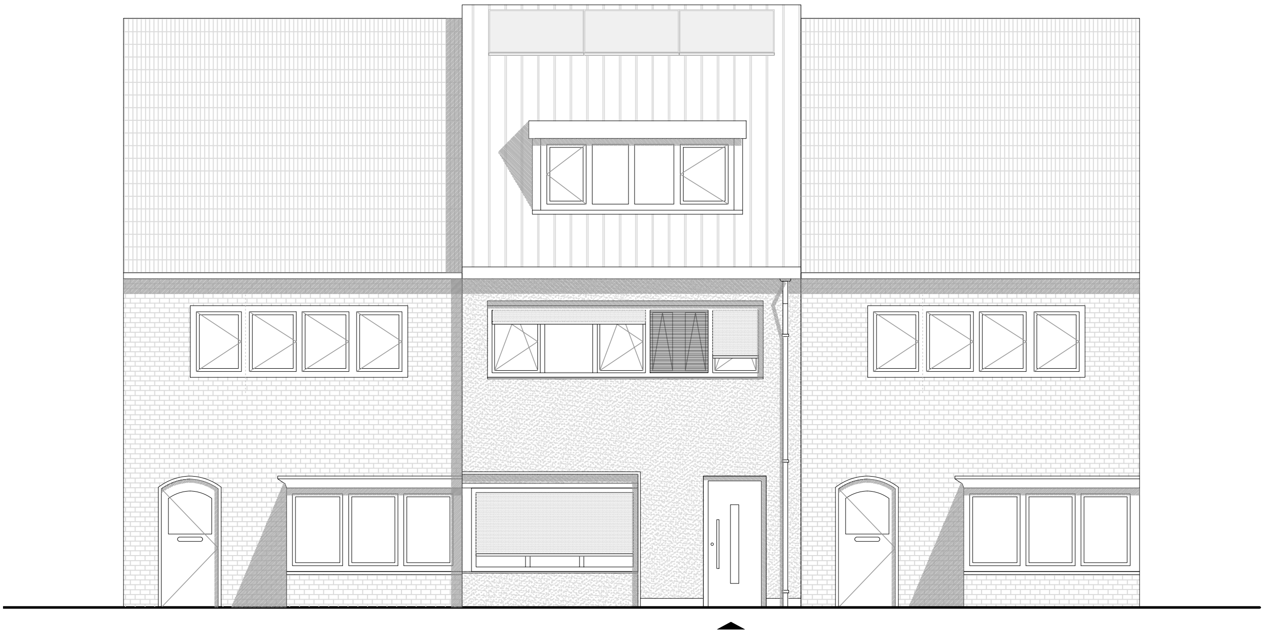


Figure 9-9: Building services diagram for existing condition and after renovation.

Building Elevation & Visualization

Building elevation and visualizations are to illustrate how Hospeslaan24 dwelling would look after all the refurbishment measures have been executed to achieve annual Zero Energy Balance. Elevation of the building is given in *figure 9-10* and Renders regarding refurbished state of the building are in *figure 9-11.*

Refurbishment-2 | West Elevation



Refurbishment-2 | East Elevation

Figure 9-10: Building elevations given with before and after look to illustrate the change on the building envelope after refurbishment

Figure 9-11: Visualization of the refurbished state following refurbishment-2 strategy measures.

9.3 Final Design Conclusion

Refurbishment measures applied in both strategies to achieve zero energy balance in the building create diversity in the possible applications for reducing energy consumption and optimizing comfort in the building. These refurbishment measures could be used individually or with combination from both strategies to successfully reduce energy consumption, generate necessary energy and provide comfort for the users of the dwelling.

It is necessary to highlight different applications of measures for envelope renovation, ventilation and heating distribution in refurbishment-1 and refurbishment-2. These measures have their advantages and disadvantages regarding application, flexibility, performance, impact on energy consumption reduction and scale of intervention along with impact on residents. Comparison, advantages and disadvantages of different components used in both refurbishment strategies are given in *table 9-6.*

		Advantages	Disadvantages
REF-1	External Wall	Application of insulation measures is fast with cavity filling and doesn't require intensive work or workforce. No additional equipment is necessary. Exterior insulation reduces thermal bridge risk on the building skin. People can still use the building while construction is underway.	Application of the refurbishment strategy depends on how clean the cavity is; otherwise external wall thickness increases to achieve desired R-value. Less flexibility on external rendering applications. Harder to achieve low airtightness values for reduced energy consumption.
	Roof	Easy installation of insulation and finishing components. No requirement to access roof from outside. Insulation is positioned from the attic. Roof structure is not altered. Insulation is applied from inside not to offset the thickness of the roof over the dormers to reduce visual comfort. If applied outside dormers require to be shifted upwards.	No added value to the building besides better insulation. No upgrade on already outdated roofing materials. Possible problems of thermal bridges. If the roof components are damaged its hard to apply the refurbishment from inside.
	Dormers	Dormers are not upgraded to increase the intensity of the work on the roof structure. It is necessary to access roof for dormer refurbishment.	Limited insulation on dormers will decrease the potential of roof insulation.
	Ventilation System	Natural inlet through openings and mechanical extraction through wet spaces reduce additional costs for piping, machinery and labor while delivering necessary conditions.	Only applicable in primary spaces if users trigger ventilation. System only reaches wet spaces for extraction. Heat recovery is not efficient for natural inlet systems. Piping application is necessary regardless of the number of reached spaces.
	Heating Distribution	Radiators are replaced with low surface temperature alternatives, possible to integrate to existing hot water circulation infrastructure. Very limited work need and quick application. Compared to under floor heating.	Heavily relies upon high-insulated building skin and demand-controlled ventilation for reduced space exposure to outdoor conditions. If exposure is constant and for an extend of time, heating affectivity of the system is hindered. It is possible that heating system could be insufficient during very cold outdoor conditions, if natural ventilation is present.
REF-2	External Wall	Replacement of a section of the existing wall structure with prefabricated panels to reduce on-site work. Very quick application of prefabricated panels. Reduced junction points on the building skin. Possibility of reaching lower levels of infiltration rate. Flexible application for envelope finishes & renders. Easier to avoid thermal bridge in the building.	Requires machinery for positioning panels. High workload even though application is quick due to prefabricated panels. Strategy requires people to leave the premises due to changes on the openings sizes, removal of building envelope. Prefabrication of the envelope panels require precise calibration and off-site construction. Hard to avoid mistakes on-site.
	Roof	Roof is totally removed and replaced with prefabricated construction. Prefabrication reduces junction points. Better and precise connection with façade edge. No reliance to outdated roofing material, brand new look on the roof and flexible on finishing options. Application of the panel is easy and saves time due to off-site construction.	Total removal of existing roof structure besides rafters and edge pieces. Additional structural backing such as edge bracing or glulam beams may be required to support existing structure for the total weight of the roof. Roof is exposed to outdoor conditions for a certain period due to removal of outer skin.
	Dormers	In built to the roof structure with prefabricated panels. Insulated to required values. Application is the same with roof.	Disadvantages in roof apply for dormers.
	Ventilation System	Demand controlled ventilation with mechanical supply and extraction in primary and wet spaces. Preheated air condition the space during occupancy, energy consumption is further reduced to almost eliminated exposure to outside conditions. Heat recovery is highly effective due to limited changes in indoor temperatures.	Application requires floating ceilings for piping application. All spaces must be reached with pipes to provide ventilation. Higher costs due to heat recovery application and higher handling capacity. Possibility of system upgrade with humidification dehumidification for further improved comfort conditions.
	Heating Distribution	Under floor heating is integrated for low temperature heating provision. Lowered space heating consumption due to high insulation, low infiltration and minimized outside exposure.	Major change in interior floors. Requires time for application and spaces become disused during changes. All floors must be changed.

Table 9-6: A comparison of measures applied differently under different refurbishment strategies for delivering the similar conditions.

Differences of applications have created variety on possible measures for refurbishment. Different application on the building envelope aims to deliver same thermal performances with different executions. When compared building envelope changes for refurbishment-2 provide better performance with the cost on people leaving the house for the refurbishment work. While refurbishment-1 applications do not fall short than refurbishment-2 thermal performance wise, certain components are not being replaced, renders the potential of envelope refurbishment.

To successfully and precisely refurbish the building envelope refurbishment-2 applications are preferable over refurbishment-1 considering the potential of reducing infiltration rate even further with higher possibility on architectural rendering on exterior wall.

Ventilation in both strategies is using mechanical components for extraction however they differ on the supply of primary spaces in the building. Natural ventilation is increasing the exposure of space to outdoor conditions, while mechanical system provides minimized effect from it. Piping infrastructure for total centralized mechanical ventilation system is rigorous work compared to partial upgrade on only wet spaces.

However heat recovery is very effective when used in mechanical supply/extraction system for preconditioning the intake air with exhaust air. Within a natural ventilation system, heat recovery cannot be utilized for any sort of preconditioning resulting in waste. Regarding the energy consumption mechanical supply and extraction is a viable choice for the ventilation systems in the building. However necessity of installing piping is a major shortcoming for refurbishment projects due to limited space, time constraints and interior work.

Heating distribution upgrades are essential on reduction of used energy for space conditioning. Both refurbishment strategies are utilizing low temperature emitters however applications of the components differ majorly. Within refurbishment-1 only high temperature radiators are replaced with low surface temperature radiators, changes in the piping are applicable if necessary but easy to execute. However for refurbishment-2 under floor heating upgrades all the floors with additional layering in addition to extra insulation levels below every floor space to keep the heat flow in one direction. Application of under floor heating for refurbishment is costly for time as well as for intervention scale due to alteration of almost all floor surface area and living spaces.

10. Conclusions & Recommendations & Reflection

Final conclusions will be given as a summary of the conclusion steps previously descried under every step for refurbishment. Regarding these conclusions recommendations will be given for further research and improvement in the approach to problem as well as the execution of the step along with simulation methods.

10.1 Conclusions

For the general conclusion of the report main research question will be answered. The answer of the main question will be derived from the extensive conclusions made from every step of research made for refurbishment, comfort optimization and energy generation. The main research question is:

What are possible refurbishment solutions for a cluster of Dutch row houses in Haarlem, Ramplaankwartier built before 1945 to achieve annual energy neutrality including energy generation and energy exchange within the selected cluster?

Several factors influence as refurbishment solution for creating an energy efficient terraced house with annual and daily energy neutrality. Within the research five major factors have been taken into account. These factors are:

- Building Envelope and the refurbishment strategy impact on space heating and cooling.
- Comfort Optimization of the dwelling.
- Building Installations and their affectivity on operational energy consumption
- On site energy generation impact on creating energy balance
- Application to cluster level

Building Envelope & Refurbishment Strategy

Envelope refurbishment strategies for a terraced house are numerous and must be selected according to time, user and applicability constraints. In order to highlight differences two strategies are selected to describe the potentials in both approaches. Strategies have been selected to apply are based on the scale of intervention, user delay and the applicability.

One of the strategies has been to totally refurbish a terraced house to extensively carry construction work where users are forced to leave the building. Other strategy is to apply what is possible regarding the condition of the envelope component without any disturbance on the users and extensive construction work.

Building envelope is upgrade in three steps these steps are; building skin insulation and façade upgrade, glazing change and window upgrade and infiltration rate optimization. Every upgrade had followed their specific criteria's.

Insulation and façade upgrade had been executed differently for both of the refurbishments due to different strategies. However both of the building envelopes are upgraded to R_c 6,0 for roof, R_c 4,5 for walls and R_c 3,5 for ground floor with the exception of refurbishment-1 dormers are not upgraded. The resulting energy performances after insulation and the envelope upgrade are 24% reduction for refurbishment-1 and 25% reduction for refurbishment-2. It is possible to upgrade the envelope beyond given figures, however upgrade above given figures does not result in desired effect and the affectivity of insulation amount on energy consumption reduces beyond given figures.

Windows of both refurbishment strategies are upgraded with the same approach. Different glazing options are used for different orientations to emphasize on passive solar gain in space to reduce space heating. Triple glazing (0,9 U-window) on west orientation and double glazing (1,1 U-window) is selected as the optimal condition resulting in 38% space heating reduction in refurbishment-1 and 38.9% in refurbishment-2.

Infiltration rate of both refurbishments are reduced accordingly the scale of intervention allowed in both approaches. Refurbishment-1 infiltration rate is reduced to 2,95 AC/H@50pa, which is the limit for natural ventilation air supply in a building and refurbishment-2 is reduced to 0,74 AC/H@50pa where mechanical ventilation is a necessity and it is the lowest level accepted by the Dutch regulations.

The application of infiltration rate is majorly dependent on the execution quality of the building details, how clearly possible cracks or junctions are sealed of and how simplified building details are. With the upgraded infiltration rates applied space heating energy consumption for refurbishment-1 reduced by 58% and for refurbishment-2 by 68%.

With the application of building envelope measures for both refurbishment strategies regarding the necessary criteria's for every step, energy consumption for space is reduced by 80% for refurbishment-1 and by 86% for refurbishment-2

Building envelope refurbishment is effective on reducing energy consumption for space heating throughout the year along with regulating indoor air temperatures, decreasing the fluctuations. However increased insulation is also keeping the heat inside the building in summer conditions resulting in heightened overheating in space.

Comfort Optimization

Comfort optimization applications differ for both of the refurbishment strategies. Sleeping -2 is optimized for refurbishment-1 and refurbishment-2 and the strategy in optimization is used for other zones in the building.

Refurbishment-1 is using natural supply and mechanical extraction from wet spaces. Due to natural ventilation usage a steady heating temperature for providing the necessary indoor air temperature has not been possible. During the very cold periods 06-09/01 zone exposure to unconditioned air supply, results in very low indoor air temperatures, to balance the problem heating temperatures had to be increased up to 23,5 ° C when necessary.

On the other hand for a typical winter week optimal thermal conditions can be provided with 20 ° C of heating provision. Therefore periods with high temperature provision are highlighted to balance the energy consumption for space heating between comfort requirements and non-excessive provision to reduce consumption.

Refurbishment-2 ventilation system is based on mechanical supply and extraction for the winter season. With preconditioned air provision to the space and upgraded building skin it is possible to stabilize the indoor air temperatures unless the space is overheated. Therefore single heating temperature is enough to condition the spaces when mechanical supply is active.

Measures included for optimization of the cooling season are the same for both refurbishments with different simulation inputs. Operable exterior roller shades are sued as an effective block against passive solar gain during summer season. Extensive cooling is applied with natural ventilation to utilize the colder air in space to cool down the building during day and night. Effectively with the combination of excessive ventilation and exterior solar shading overheating hours have reduced below 100 for the whole season and resulting overheating hours are periods with very high outside temperatures.

Thermal optimization of both refurbishments contributed to the calibration of energy consumption for space conditioning. Refurbishment-1 annual space heating energy has reduced by 14% and for refurbishment-2 by 17%.

Building Services

Even though mechanical ventilation is applied under comfort requirements of the component is included under building services. Mechanical supply and extraction gives way to usage of heat recovery. With 80% heat recovery application to optimized comfort condition of refurbishment-2 energy consumption for space heating reduces by 70% to 722,6 kWh of delivered natural gas.

With the application of different building services (SUI Options 1a, 1c, 2) for space heating, DHW and cooling purposes energy total operational primary energy consumption in the building reduces by 6% minimum and 9% maximum for refurbishment-2. For refurbishment-1 application of the same systems result in 14% minimum and 22% maximum reduction on total operational primary energy consumption. Changes in percentages are related to the efficiency of the systems used and total consumption is converted to electricity after the application of new building services. Highest energy reduction is observed and SUI option-2 system of ground source heat pump with low temperature collective source and direct cooling is selected as the best option.

Differences between the resulting efficiencies of the same building services are due to use of Heat recovery in refurbishment-2. 80% heat recovery system is reducing the energy consumption space heating to almost possible lowest that applied building services systems cannot reflect an efficient improvement. Changes in percentages are related to the efficiency of the systems used and total consumption is converted to electricity after the application of new building services.

Energy Generation & Cluster Application

Photovoltaic options are selected for on-site energy generation due to all electric building systems, balance over primary energy, and conversional penalties for electricity space availability, individual investment possibility and simple application. These panels are located on the roof of the refurbished buildings to output the operational energy in the building. Building is connected to grid for the exchange of annual energy balance.

14 panels are required and they generate 8187,0 kWh of primary energy to offset total operational energy of refurbishment-2. Due to restricted space 11 panels were used on east facing roof and 3 on west facing roof.

For refurbishment-1 due to higher operational energy and lesser roof space of refurbishment strategy difference total of 15 photovoltaic panels are used with these panels 8541,4 kWh of primary energy is generated annually to create the balance of import, export energy. Among these panels 9 of them positioned on east and 6 of them positioned on west.

With the application of photovoltaic options refurbishment-1 becomes 101% Zero Energy Building and refurbishment-2 105%. Differences between the percentages are caused by the surplus in the energy generation system.

When the refurbishment strategies are applied to the adjacent middle section row houses, application of the cluster system reduces the amount of photovoltaic panels to offset the operational energy of two of the dwellings. Increased roof surface with and possible utilization of blind spots of the roof due to individual usage is bypassed with grouped approach to maximize the potential of east facing roof surface to generate energy with the same photovoltaic options used in individual balance.

With the application of grouped approach, energy surplus in refurbishment-2 is reduced along with the percentage of ZEB to 101%. 25 PV panels are used for the energy balance over annual period for refurbishment-2, which is two panels shorter than what is required for individual application for both of the buildings.

Application to refurbishment-1 strategy results in the same reduction on PV panels and both the building get 101% ZEB for annual balance. Cluster approach reduces the peak loads in the electricity system for relieving the stress of electric load on the national grid. It may seem as two building peak loads are not relevant of an electric load overload or to trigger the necessity of an upgrade however if the majority of the buildings are renovated with individual approaches it would require to upgrade the grid along with the infrastructure of energy delivery.

Measures for reaching annual zero energy that has been used for the case study designs under two different refurbishment strategies offer variable options for the set target. Different application methods, systems, ventilation strategies give chance for the users to make a decision over their preferences as well as to see the advantages, disadvantages in each system elaborated throughout the case study design.

Variable options of renovation in both refurbishments are possible to be applied as individual measures or they could be combined to reach zero energy balance in the building. Two different refurbishment strategies give the flexibility and the option for comparison between applications.

10.2 Recommendations

Infiltration level reached with the validation process is possible to have in buildings especially built before 1945 however the value of 16 AC/H@50pa is still quite high for the building. It is important to see the real life infiltration value of the case study building in order to precisely build the base of the simulation model for extremely accurate calculations within climate simulations. In order to obtain true value, it is possible to conduct blower door test in the dwelling.

Scheduling in the building regarding space usage, heating provision and ventilation could have different application due to different usage of rooms in the building. Schedules used in simulations are in built in DesignBuilder as default for using specifically in dwelling simulations, however they are always subject to change and it is possible to create a new or modify a schedule for better reflection on user patterns. It is important to be familiar with the usual pattern of the people utilizing the spaces in the building.

Envelope refurbishment measures are variable within the research and they still could be quantified, however among the elaborated strategies it is viable to utilize the envelope upgrade system in refurbishment-2 to achieve better levels of infiltration level, renovate the building envelope totally for a better look and condition on the building components which would increase the land value of the building along with energy performance. Flexibility of the building envelope gives all sorts of possibilities for a façade finishing in the building suitable for a dwelling.

Important to use additional insulation or airtightness foil in the envelope refurbishment designs for very vulnerable points such as window wall connections, air inlets-outlets of the ventilation system to increase the R_c value of weak points of the building envelope. Differences between the theoretical value accepted in DesignBuilder simulations and real-life applications should be highly regarded for achieving the desired envelope thermal resistances therefore drawn details are the envelope are representing the actual condition of the building envelopes state if to be refurbished.

Ventilation system is an essential part of comfort provision during summer season due to overheating in the building. High insulation rate and very low infiltration rate results in long periods of overheating even though outside conditions are between comfort levels. Therefore renovation requires the measures for shading and extensive ventilation to cool the building down during summer period.

Within certain periods ventilation is not avoidable even though outdoor conditions are very high due to occupancy in building spaces. For periods with temperatures above comfort level, cooling is introduced in the building however it is also possible to withstand the warmth instead of using cooling considering that the period of overheating is limited with passive applications.

Application for the energy balance for offsetting the operational energy in the building is more effective in cluster approach with reduced surpluses and peak loads as well as photovoltaic panels. Individual application increases the amount of PV's resulting in higher costs for reaching zero energy balance for the year.

It is essential to renovate buildings at the same time to offer accurate reflection in the simulations, if buildings are renovated separately within the same row, weak spots of the adjacent buildings will result in heat losses and undesirable results after refurbishment work, which could affect the comfort levels in the building resulting in uncomfortable conditions during occupancy.

10.3 Future Research

Within the case study design only two different refurbishment strategies are taken into account for increasing possible applications regarding applicable measures in the building. Increasing the refurbishment measures for achieving zero energy balance in buildings is possible for the future research to deliver larger quantity of options with different applications.

Building services in the case study have been simplified for easy calculation with DesignBuilder software. However the software offers a wide range of building services applications under detailed HVAC, which would increase the accuracy of calculations for heating & cooling, DHW and ventilation applications. It is possible to use detailed HVAC as a future research step for the refurbishment building to highlight the impact of HVAC systems to the building energy consumption as well for sizing the components.

Research for achieving daily energy balance in the building could be considered with photovoltaic applications to take on the challenge of energy mismatch of generation and consumption in the buildings. Utilization of batteries or thermal storage for the balance and integration of the systems to individual building or a cluster of buildings could be a next step for achieving total zero energy balance for the building, which would result in autonomous dwellings.

Renewable energy options in the research could be quantified to wind turbine, wood pellets from sustainable forests or any sort of renewable energy source for individual or collective application. Usage of energy and the generation could be integrated for the building to achieve autonomous ZEBs within the vicinity where collective application of generation is distributed to buildings regarding their energy demand. Therefore achieving higher level of integration of individual buildings with their surroundings resulting in zero energy clusters, where energy generation and exchange is possible.

10.4 Reflection

Integration to Personal Interest and Relevance

Sustainability technologies and zero energy in buildings focus has been my personal interest for a long period. Within the graduation topic I have been able to combine my interest with the research topics to deliver an adequate approach to creating a Zero Energy Building cluster with effective technologies on energy consumption and generation. It must be stated that zero energy refurbishments must be integrated with the indoor comfort conditions for delivering user satisfaction. Therefore comfort in space is added in the graduation research to deliver a complete improved conditions package.

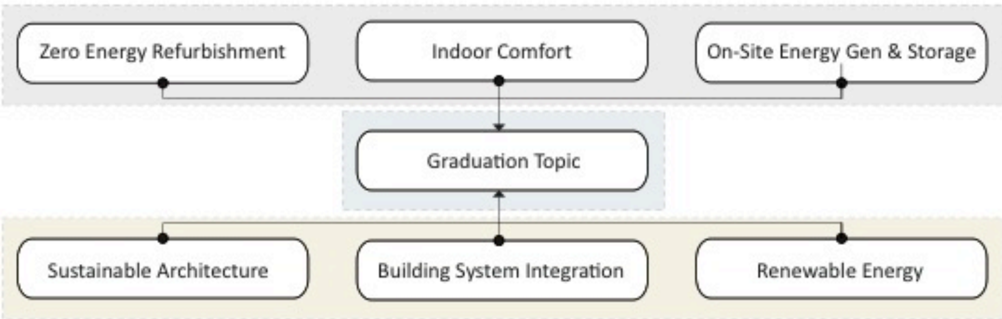


Figure 10-0: Integration of personal interest and research focuses

The graduation topic can be acknowledged as a necessity for Europe and the Netherlands as we are facing fossil resources depletion and global warming threat. The set target by the Netherlands for 2050 to completely transform all the building stock into energy neutral buildings is a bold challenge and the graduation topic integrates with the national aim as it is focusing on the refurbishment of an existing building cluster in Ramplaankwartier, Haarlem under SUI (smart urban isles) project.

Approach, Research and Design

The research is structured with the framework given in *figure 1-1* in chapter *1.3 Research Methodology.* Division of the graduation into four sub topics has increased the effective progression and the coherence between introduction, literature study, case study design and the conclusions. First two sections of graduation process were done before the P2, to clarify the follow up steps of case study design. The envelope refurbishment strategies were derived from the conclusions in literature research.

Within literature study; certain boundary conditions, criteria's are defined and possible refurbishment measures are gathered along with background research on row-houses refurbishment cases in the Netherlands to highlight real-time applications and measures for refurbishment. During the case study design additional frameworks are added for different application and refurbishment measures to clarify, enhance and strengthen the connection between boundary conditions, simulations and conclusions in each step.

The fractionized approach for refurbishing made it possible to give enough attention to every subject to improve energy performance and the comfort conditions in both of the refurbishments.

The architectural design variations within the research haven't been the primary objective, however it has been taken into account not to provide irrelevant end product architecture wise. It is always possible to increase the variations of the façade appearance for refurbished row houses, thou appearance of the envelope hasn't been stated as a research objective nor it has been included as a research question.

Product

Large portion of the research has been simulation for every input thought for as a design data and the conclusions derived from the end results of simulations. The approach has made it possible to increase the control over inputs and the driven conclusions from the steps, where the conclusions from each step formed the final design of the Zero Energy Building cluster.

Conclusions have been generated regarding the criteria's defined for each step and assessed within simulations in DesignBuilder software for energy consumption reduction, human comfort in closed spaces. Energy generation inputs were calculated over excel and to increase the accuracy of the calculations data from DesignBuilder is used for certain variables. Inputs for every step were quantified to highlight the possible result for different applications on the state of the building as well on human comfort. Among the simulations inputs suitable with defined criteria's and arguments are selected to form the final design of the buildings.

Assessment of different building services options has been simplified to reduce complexity on the process. Simulation inputs have been extensive and out of context if detailed HVAC is to be used for building services due to requirement of total control over every component regarding connections, efficiencies, heating loops and provisions.

Less emphasis was put on an energy neutral building cluster formation rather than individual condition of the building due to low numbers of the similar typologies of case study building in the vicinity. Due to time planning as well as the energy type of the building services in use only one type of energy generation system is used to offset the energy consumption in the cluster. It would be interesting to see options with higher integration and varieties for the energy generation part of the process.

Time Planning

Time planning given in figure… hasn't been altered since and after P2 due to flexible research focus. Most time consuming section has been the integration of inputs into simulations and how could they be shaped in the software along with the calibration and optimization of comfort in space. Zone based comfort optimization has taken a bit more time than expected due to extensive calibration requirements per zone for both of the refurbishments, where different strategies of ventilation are followed.

Initially it was expected to work longer on the energy generation and its integration to available space. However due to constraints in the number of the buildings and the followed generation strategy, it has been shortened. Thou the time lost during comfort optimization have been compensated in energy balance portion of the research.

Ideally it is important to focus on the conclusions from the calculations conducted and not on the detailing of the envelope components or sizing of the elements used in the simulations. However the focus on sizing and detailing of components have helped to create a healthy and relevant design and it will be included in the report after P4.

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12. Appendix

Appendix A: Zone Based Schedules for Occupancy & Space Conditioning

Schedules of zones in Hospeslaan 24 are given regarding their occupancy and space conditioning for providing living conditions. Heating, cooling, fresh air provision or air extraction is given based on corresponding space density during the period. Seasonal provisions only change for heating and cooling, DesignBuilder automatically sizes the building systems for thermal conditioning for summer season if heating or cooling is required. During winter period heating is available 24/7 however provision has to match with the space occupancy.

SLAAPKAMER-1 (PRIMARY SPACES)

PRIMARY SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Air Supply Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Heating & Cooling Provision Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,25	0,75

SLAAPKAMER-2

PRIMARY SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Air Supply Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Heating & Cooling Provision Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,25	0,75

SLAAPKAMER-3

PRIMARY SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Air Supply Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
	Heating & Cooling Provision Schedule	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,25	0,75

EETKAMER

CONNECTED SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Air Supply Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Heating & Cooling Provision Schedule	0	0	0	0	0	0,25	0,25	1	1	0,25	0	0	0	0	0	0	0	0,25	0,5	1	1	0,3	0	0

WOONKAMER

CONNECTED SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,5	0,5	1	1	1	1	0,67	0
	Air Supply Schedule	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,5	0,5	1	1	1	1	0,67	0
	Heating & Cooling Provision Schedule	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,5	0,5	1	1	1	1	0,67	0

TOILET

WET SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Air Supply Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Heating & Cooling Provision Schedule	0	0	0	0	0	0,25	0,25	1	1	0,25	0	0	0	0	0	0	0	0,25	0,5	1	1	0,3	0	0

BADKAMER

WET SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Air Supply Schedule	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
	Heating & Cooling Provision Schedule	0	0	0	0	0	0,25	0,25	1	1	0,25	0	0	0	0	0	0	0	0,25	0,5	1	1	0,3	0	0

KEUKEN

WET SPACES	Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Occupancy Schedule	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0,2	0,2	0,2	0,2	0,2
	Air Supply Schedule	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0,2	0,2	0,2	0,2	0,2
	Heating & Cooling Provision Schedule	0	0	0	0	0	0	0,25	1	1	1	0	0	0	0	0	0	0	0	0,2	0,2	0,2	0,2	0,2	0,2

SEASONAL CONDITIONING (Heating & Cooling)*

ALL SPACES		SLAAPKAMER			EETKAMER					WOONKAMER			TOILET & BADKAMER					KEUKEN				
	Time (conditioning until- XX:00)	09:00	20:00	00:00	04:00	10:00	16:00	22:00	00:00	14:00	23:00	00:00	04:00	10:00	16:00	22:00	00:00	05:00	10:00	17:00	23:00	00:00
	Summer Design Days	1	0,5	1	0,5	1	0,5	1	0,5	0,5	1	0,5	0,5	1	0,5	1	0,5	0,5	1	0,5	1	0,5
	Time (conditioning until- XX:00)	24:00			24:00					24:00			24:00					24:00				
	Winter Design Days	1			1					1			1					1				
	Time (conditioning until- XX:00)	09:00	20:00	00:00	04:00	10:00	16:00	22:00	00:00	14:00	23:00	00:00	04:00	10:00	16:00	22:00	00:00	05:00	10:00	17:00	23:00	00:00
	Holidays	1	0,5	1	0,5	1	0,5	1	0,5	0,5	1	0,5	0,5	1	0,5	1	0,5	0,5	1	0,5	1	0,5

* Given schedules only applicable if the zone occupancy matches the heating period

Figure A-0: Space based scheduling for ventilation, heating & cooling along with seasonal conditioning schedules.

Appendix B: Infiltration Rates of Different Pressures

Example Infiltration rates from NEN-EN 15242:2007- Ventilation for buildings - Calculation methods for the determination of airflow rates in buildings including infiltration.

Table B.1 — examples of leakages characteristics

	leakages level	Q4Pa	m³/h per m² of outer enveloppe (exp n = 0,667) 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

	leakages level	n (vol.h) (exp n=0,667) n4Pa	n10Pa	n50Pa	outer area/vol 1/m
single family	low	0,4	0,8	1,9	0,75
	average	0,8	1,5	3,8	0,75
	high	1,5	2,6	7,5	0,75
multi family ; non residential except industrial	low	0,2	0,4	1,0	0,4
	average	0,4	0,8	2,0	0,4
	high	0,8	1,4	4,0	0,4
industrial	low	0,3	0,6	1,5	0,3
	average	0,6	1,1	3,0	0,3
	high	1,2	2,1	6,0	0,3

	leakages level	Q4Pa	m³/h per m² of floor area (exp n = 0,667) Q10Pa	Q50Pa	outer area / floor area 1/m
single family	low	0,9	1,8	4,5	1,8
	average	1,8	3,6	9,0	1,8
	high	3,6	6,3	18,0	1,8
multi family ; non residential except industrial	low	0,6	1,1	2,8	1,1
	average	1,1	2,2	5,5	1,1
	high	2,2	3,9	11,0	1,1
industrial	low	1,5	3,0	7,5	1,5
	average	3,0	5,3	15,0	1,5
	high	6,0	10,5	30,0	1,5

Figure A-0: Infiltration rate examples from NEN-EN 15242:2007 for different pressure calculation methods. Part-1

	leakages level	m³/h per m² of outer enveloppe (exp n = 0,667) 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

		n (vol.h) (exp n=0.667)			outer
	leakages level	n4Pa	n10Pa	n50Pa	area/vol 1/m
single family	low	0,4	0,8	1,9	0,75
	average	0,8	1,5	3,8	0,75
	high	1,5	2,6	7,5	0,75
multi family ; non residential except industrial	low	0,2	0,4	1,0	0,4
	average	0,4	0,8	2,0	0,4
	high	0,8	1,4	4,0	0,4
industrial	low	0,3	0,6	1,5	0,3
	average	0,6	1,1	3,0	0,3
	high	1,2	2,1	6,0	0,3

			m³/h per m² of floor area (exp n = 0,667)		outer area /
	leakages level	Q4Pa	Q10Pa	Q50Pa	floor area 1/m
single family	low	0,7	1,4	3,4	1,8
	average	1,4	2,7	6,8	1,8
	high	2,7	4,7	13,5	1,8
multi family ; non residential except industrial	low	0,2	0,4	1,1	1,1
	average	0,4	0,9	2,2	1,1
	high	0,9	1,5	4,4	1,1
industrial	low	0,5	0,9	2,3	1,5
	average	0,9	1,6	4,5	1,5
	high	1,8	3,2	9,0	1,5

Figure A-1: Infiltration rate examples from NEN-EN 15242:2007 for different pressure calculation methods. Part- 2

Appendix C: Calculation of Minimum Fresh Air Provision

Calculation of minimum fresh air in space is based on the required minimum supply of air for the number of occupants in space and the air changer per hour as a result of the supplied air. The value obtained by the multiplication of the occupants, minimum fresh air per person divided by the space volume determines the AC/H in the space. When values are converted to DesignBuilder minimum fresh air supply if not converted based on AC/H in space results in higher air supply than required amount for the occupied period. Therefore ventilation is determined according to the following formulas:

$$\frac{Min\ fresh\ air\ (m^3/s)x\ Occupant}{Space\ Volume\ (m^3)} x3600 = AC/H$$

However given minimum fresh air supply per person in chapter *2.4.3 Indoor Air Quality & Ventilation* are based on m^3/h therefore within calculation there is no requirement for multiplication with x3600.

$$\frac{Min\ fresh\ air\ (m^3/h)x\ Occupant}{Space\ Volume\ (m^3)} = AC/H$$

With the above given formula AC/H per hour is calculated regarding the users in space. The value for minimum fresh air in DesignBuilder is adapted according to the AC/H resulting from the formula.

Example Calculation: *Sleeping -2*

$$\frac{25{,}2(m^3/h)x\ 2}{38{,}79(m^3)} = 1{,}30\ AC/H$$

Expected air change in space during occupied hours.

DesignBuilder requires 12,5 L/s to reach 1,37 AC/H for delivering desired conditions in space for air quality.

Refurbishment-1

	Primary Spaces	Min Fresh Air (m3/h) PP	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/s)	Final Averaging AC/H
Natural Ventilation	Slaapkamer-2	25,2	2	38,79	1,30	12,5	1,37
	Slaapkamer-1	25,2	1	31,3	0,81	5,5	0,813
	Slaapkamer-3	25,2	1	12,59	2,00	6,5	2,05
	Woonkamer*	25,2	4	82,9	1,04	2,1	1,1
	Eetkamer*	25,2	4		1,40	4	1,42
	Wet Spaces	Min Extraction (m3/h)	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/sm2)	Final Averaging AC/H
Mech. Extraction	Keuken	72	1	16,3	4,42	3,5	
	Toilet	36	1	2,81	12,81		
	Badkamer	54	1	15,73	3,43	2,5	3,57

Calculation for Connected Spaces

	Connected Spaces	Zone Volume m3	Total Volume m3	Share of Volume	Occupancy Factor
Nat. Vent.	Woonkamer	35,35	82,9	42,64%	2
	Eetkamer	47,65		57,47%	2

Refurbishment-2 (If Natural Vent was Used)

	Primary Spaces	Min Fresh Air (m3/h) PP	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/s)	Final Averaging AC/H
Natural Ventilation	Slaapkamer-2	25,2	2	38,79	1,30	13,5	1,37
	Slaapkamer-1	25,2	1	31,3	0,81	6	0,813
	Slaapkamer-3	25,2	1	12,59	2,00	6,8	2,05
	Woonkamer*	25,2	4	82,9	1,04	2,5	1,1
	Eetkamer*	25,2	4		1,40	4	1,42
	Wet Spaces	Min Extraction (m3/h)	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/sm2)	Final Averaging AC/H
Mech. Extraction	Keuken	72	1	16,3	4,42	3,55	4,47
	Toilet	36	1	2,81	12,81	10,3	13,1
	Badkamer	54	1	15,73	3,43	2,6	3,45

Calculation for Connected Spaces

	Connected Spaces	Zone Volume m3	Total Volume m3	Share of Volume	Occupancy Factor
Nat. Vent.	Woonkamer	35,35	82,9	42,64%	2
	Eetkamer	47,65		57,47%	2

Refurbishment-2

	Primary Spaces	Min Fresh Air (m3/h)	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/sm2)	Final Averaging AC/H
Mechanical Supply	Slaapkamer-2	25,2	2	38,79	1,30	2,5	1,37
	Slaapkamer-1	25,2	1	31,3	0,81	0,6	0,84
	Slaapkamer-3	25,2	1	12,59	2,00	1,525	2,05
	Woonkamer*	25,2	4	82,9	1,04	0,825	1,15
	Eetkamer*	25,2	4		1,40	1,1	1,45
	Wet Spaces	Min Extraction (m3/h)	Occupancy	Zone Volume m3	AC/H	DesignBuilder (L/sm2)	Final Averaging AC/H
Mech. Extraction	Keuken	72	1	16,3	4,42	3,55	4,47
	Toilet	36	1	2,81	12,81	10,3	13,1
	Badkamer	54	1	15,73	3,43	2,6	3,45

Calculation for Connected Spaces

	Connected Spaces	Zone Volume m3	Total Volume m3	Share of Volume	Occupancy Factor
Mech. Supply	Woonkamer	35,35	82,9	42,64%	2
	Eetkamer	47,65		57,47%	2

Figure B-0: Calculated ventilation requirements to deliver desired AC/H and values used in DesignBuilder to deliver similar conditions.

Appendix D: Comfort Optimization Inputs & Results

Comfort optimization of additional zones is given in the following appendices as results only due to already explained state of the applied measures. In addition to comfort optimization, mechanical system calculations are added for describing the user patterns accepted for fresh air provision and foul air extraction along with component sizing measurements.

Appendix D-1: Heating Season

Ref-1- Sleeping 1 Heating

Sleeping 1 Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	5,5 l/s Per person	No restriction	No restriction	Non
Simulation2	20,5° C	0° C	5,5 l/s Per person	No restriction	No restriction	Non
Simulation3	22° C	0° C	5,5 l/s Per person	No restriction	No restriction	Non
Simulation4	20° C	0° C	5,5 l/s Per person	No restriction	No restriction	Non

Table D-0: Simulation inputs for weekly & seasonal optimization in sleeping -1 blue background (coldest week optimization) & orange background (typical winter week inputs)

Simulation-1 represents the state of the Sleeping -1 after passive measures have been applied and minimum amount of air is supplied to the space. Strategy for optimizing the seasonal thermal comfort for Sleeping -1 is adapted from Sleeping -2 with the coldest week and the typical winter week for seasonal simulations. Inputs for the simulation of coldest and the typical week are given in *the table D-0.*

Typical winter week optimization require 20° C as heating temperature in space. Within *figure D-0* heating provision is sufficient to stabilize indoor air temperatures for user comfort during the occupancy. Points where indoor air temperature is falling below required limit are the periods where there is no occupancy or outside dry bulb temperatures have decreased rapidly.

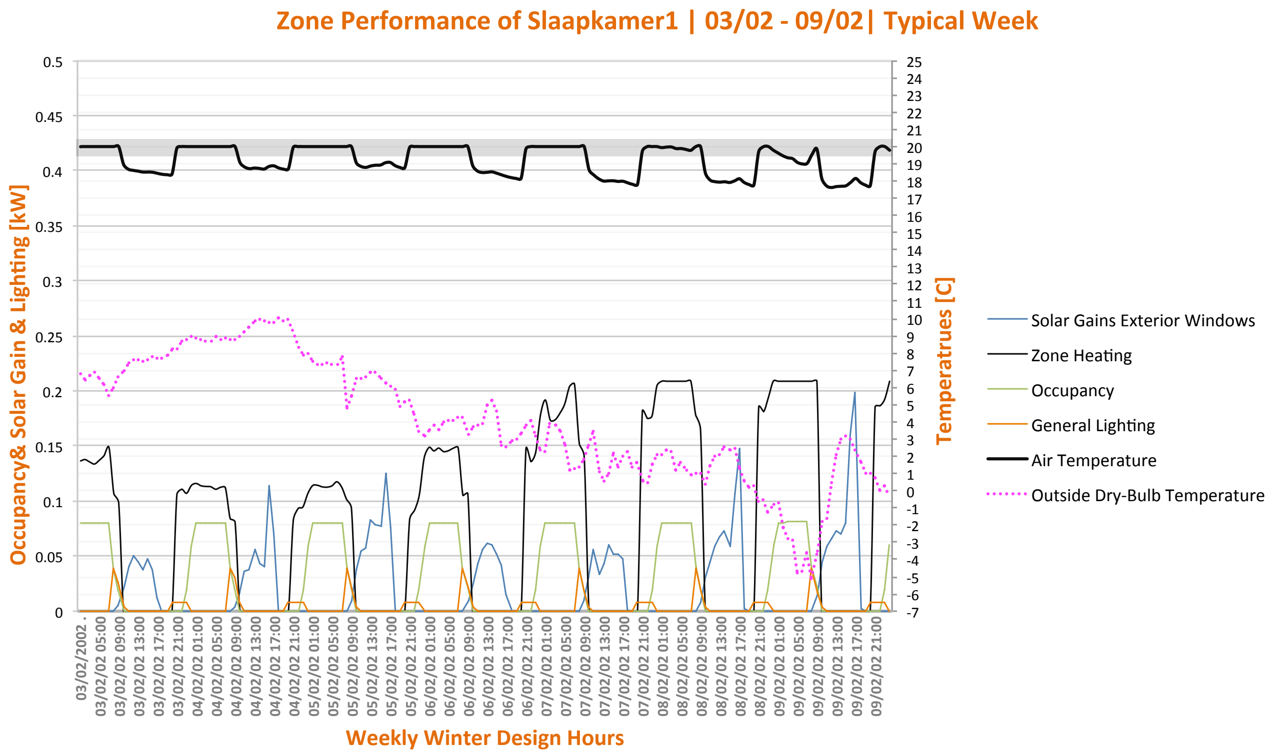

Figure D-0: Typical week performance of sleeping -1

Ref-1- Sleeping 3 Heating

Sleeping 3 Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	0° C	6,5 l/s Per person	No restriction	No restriction	Non
Simulation2	22° C	0° C	6,5 l/s Per person	No restriction	No restriction	Non
Simulation3	23° C	0° C	6,5 l/s Per person	No restriction	No restriction	Non
Simulation3	20,5° C	0° C	6,5 l/s Per person	No restriction	No restriction	Non

Table D-01: Simulation inputs for weekly & seasonal optimization in sleeping -3 blue background (coldest week optimization) & orange background (typical winter week inputs)

Thermal Comfort for winter season in Sleeping -3 is provided with the inputs in simulation-2 and 1. Weekly optimization of the zone is following the same strategy as previous zones and based on using different sets of temperatures depending on cold and very cold outdoor dry-bulb temperature. Simulations are based on the coldest week and a typical winter week. Inputs for simulations are given in *table D-01.*

Air temperature inside the space is stabilized according to the minimum allowed temperatures or slightly above minimum to deliver thermal comfort conditions along with reduced heating energy consumption. Typical week heating temperature is 20,5° C and sufficient to deliver desired conditions. Within *figure D-01* indoor air temperatures are satisfactory with the provided heating temperature to the space.

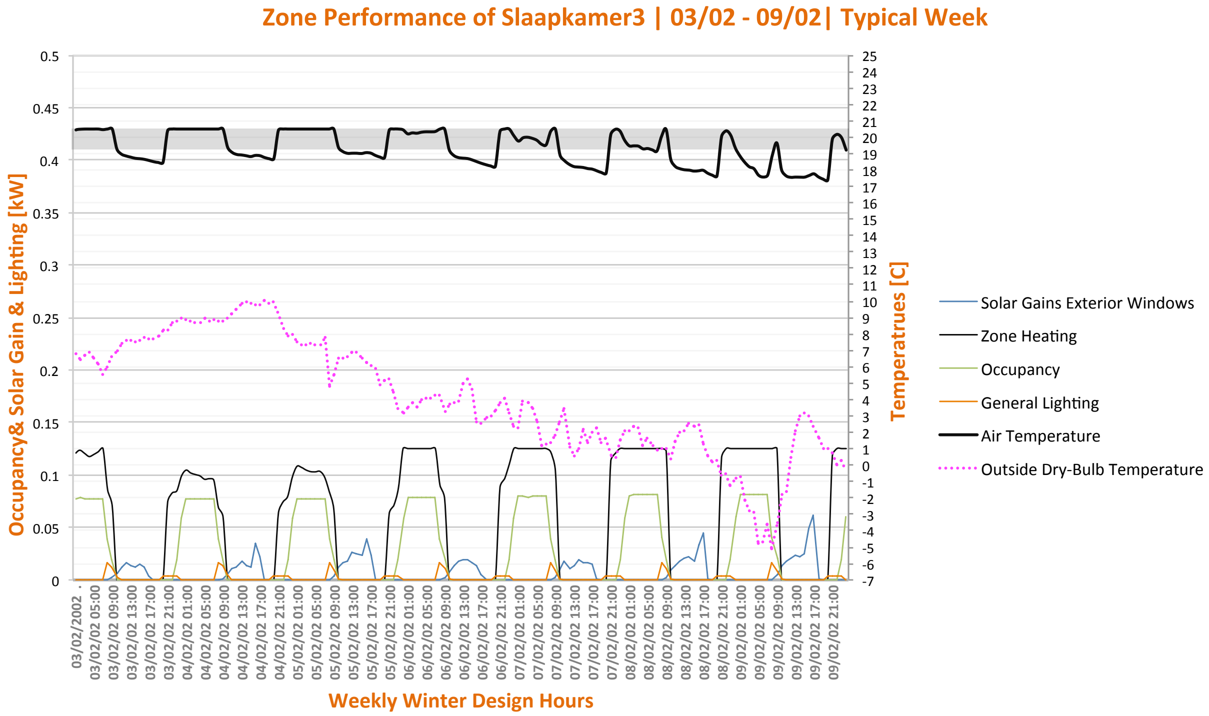

Figure D-01: Typical week thermal performance of sleeping -3

Ref-1- Wet Spaces | Kitchen & Toilet

Both of the zones are ventilated by mechanical extraction therefore not exposed to outdoor conditions. Therefore the indoor air temperature inside the space is balanced accordingly the occupancy in the zone and fixed at 21° C.

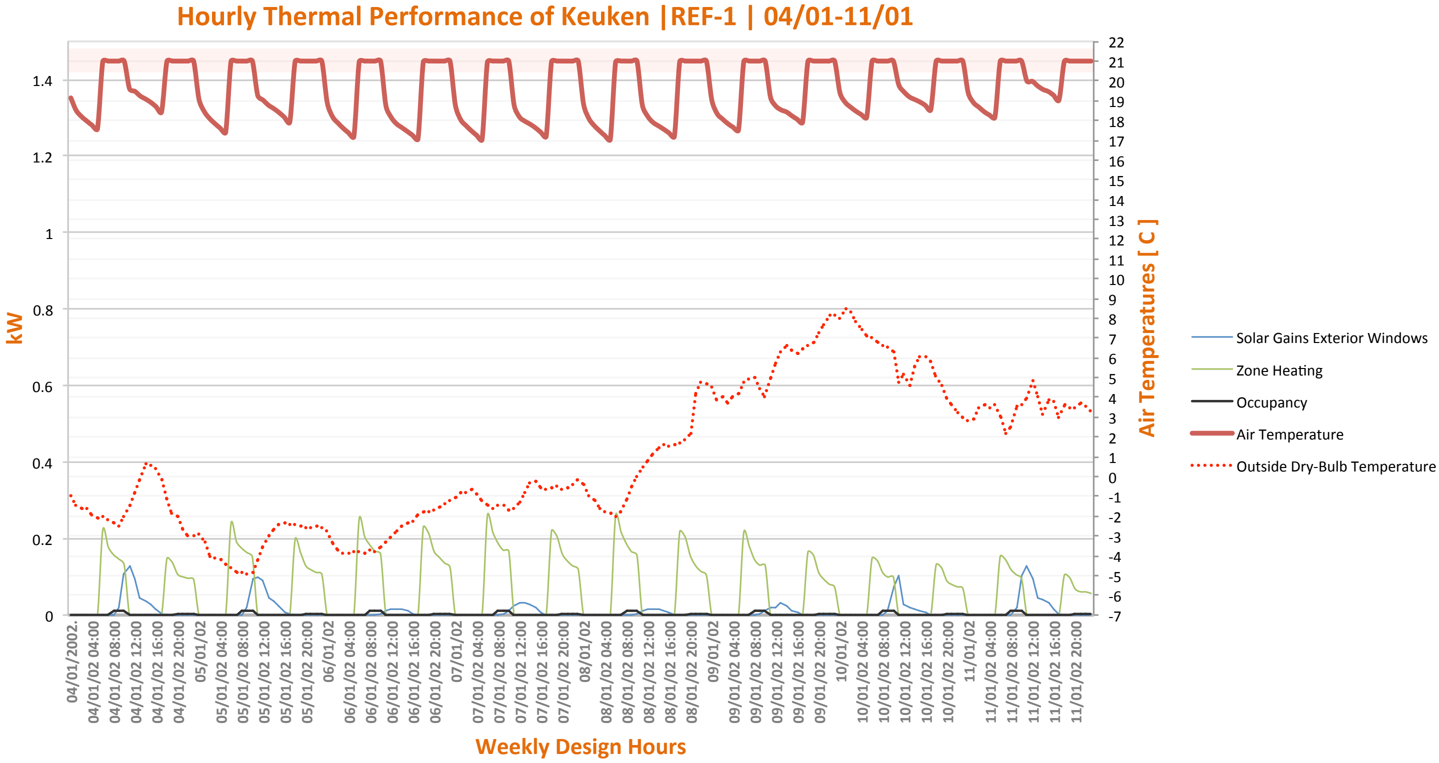

Figure D-02: Weekly thermal conditions in Kitchen.

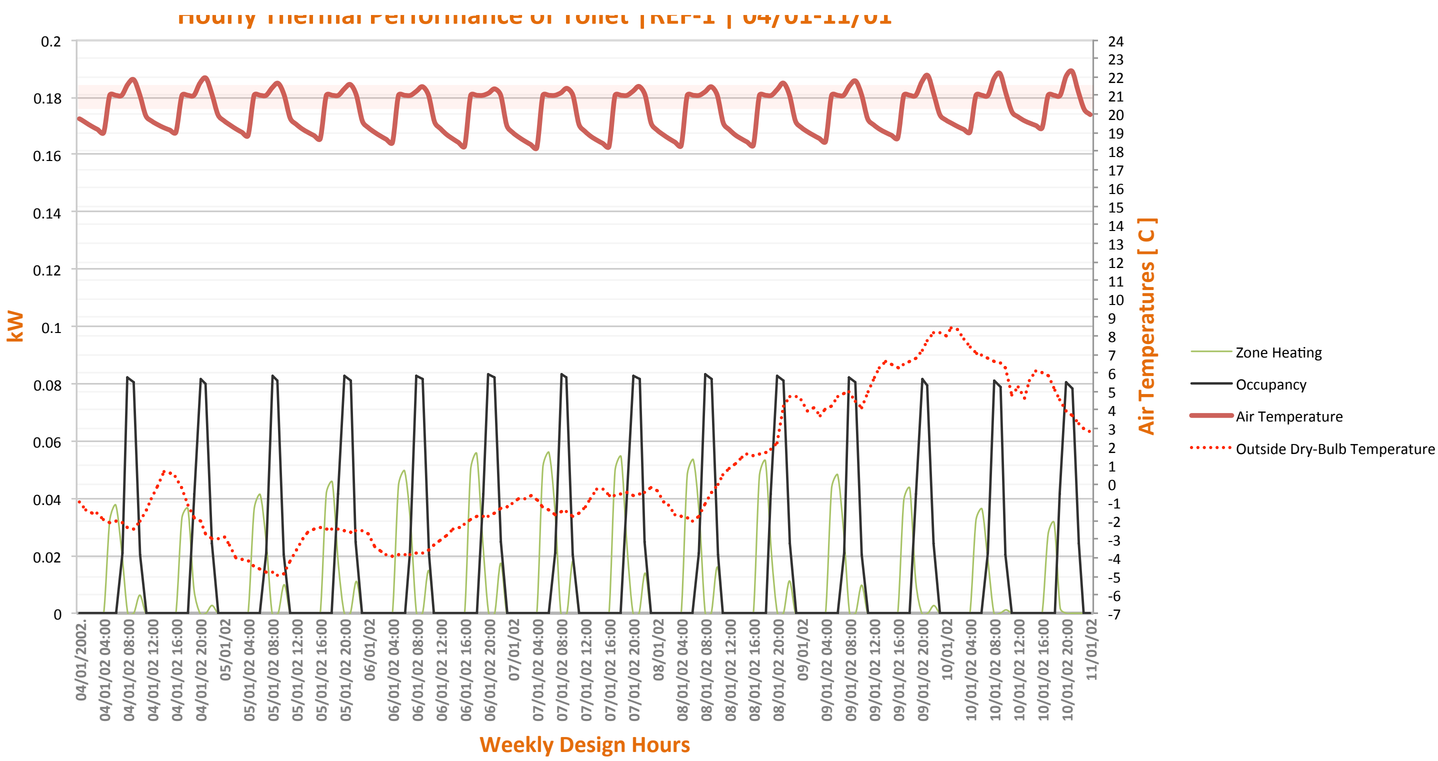

Figure D-03: Weekly Thermal conditions in Toilet

Ref-2- Sleeping 1 Heating

Sleeping 1 Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	6,5 l/s Per person	No restriction	No restriction	Non
Simulation2	23° C	15° C	6,5 l/s Per person	No restriction	No restriction	Non
Simulation3	19,5° C	0° C	No provision	No restriction	No restriction	0,6 l/sm^2

Table D-02: Simulation inputs for comfort optimization in sleeping -1. Highlighted simulation has the selected input for seasonal optimal conditions.

Inputs of simulation-1 and 2 are representing the behavior of different temperatures when natural ventilation is supplying air into the space. Simulation-3 with mechanical ventilation however resulting in stable indoor air temperatures at 19,5° C for the simulation week as well as for the whole season which is in the required range of 19,0-20,0° C. All inputs used for balancing the comfort conditions are given in *table D-02.*

Within *figure D-04* heating intensity for space and the resulting temperatures of the provided heating are given under every simulation step for optimization week. Simulation-3 resulting in low temperature heating provision due to conditioned air supply to space, minimizing the impact of outdoor temperature levels unless the users open a window manually. Therefore simulation-3 inputs are used for the seasonal simulation.

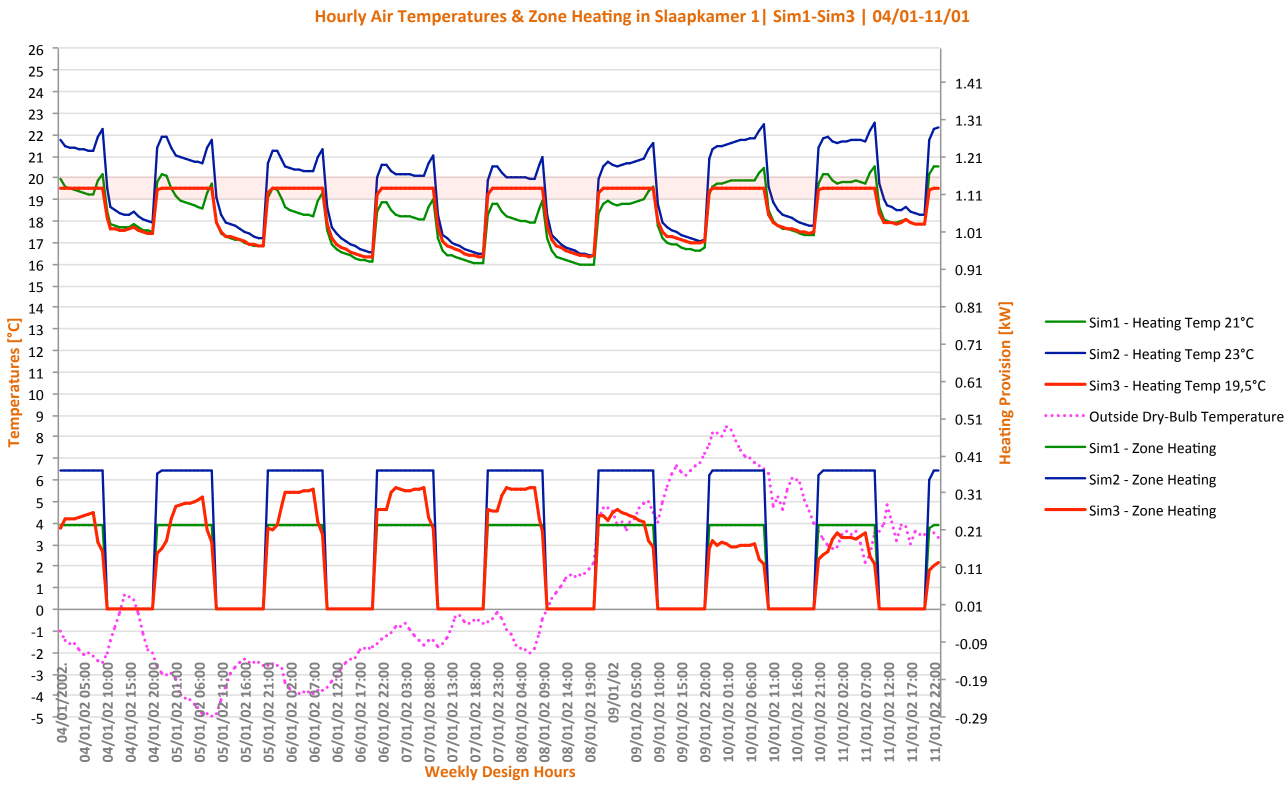

Figure D-04: Thermal performance of sleeping -1 under coldest simulation week.

Ref-2- Sleeping 3 Heating

Sleeping 3 Inputs	Heating Temperature	Set-back Temperature	Minimum Fresh Air (Natural Ventilation)	Minimum Indoor Air Temperature	Minimum Outdoor Air Temperature	Mechanical Ventilation
Simulation1	21° C	15° C	6,8 l/s Per person	No restriction	No restriction	Non
Simulation2	23° C	15° C	6,8 l/s Per person	No restriction	No restriction	Non
Simulation3	19,5° C	0° C	No provision	No restriction	No restriction	1,525 l/sm^2

Table D-03: Simulation inputs for comfort optimization in sleeping -3. Highlighted simulation has the selected input for seasonal optimal conditions.

Sleeping -3 is following the same strategy for Sleeping -1 for seasonal comfort optimization. Simulation-3 inputs are used for stabilizing the air temperature in space by eliminating natural ventilation therefore unconditioned air entry to space. Simulation inputs for sleeping -3 are given in table *D-05.*

Hourly indoor air temperatures in *figure D-05* are the results of all three simulation steps and simulation-3 is giving stable temperature balance within required range with 19,5° C. Utilizing mechanical ventilation is increasing the natural gas consumption compared to simulation-1 by 1,5% however by small fraction of gas consumption increase is providing thermal comfort for winter season.

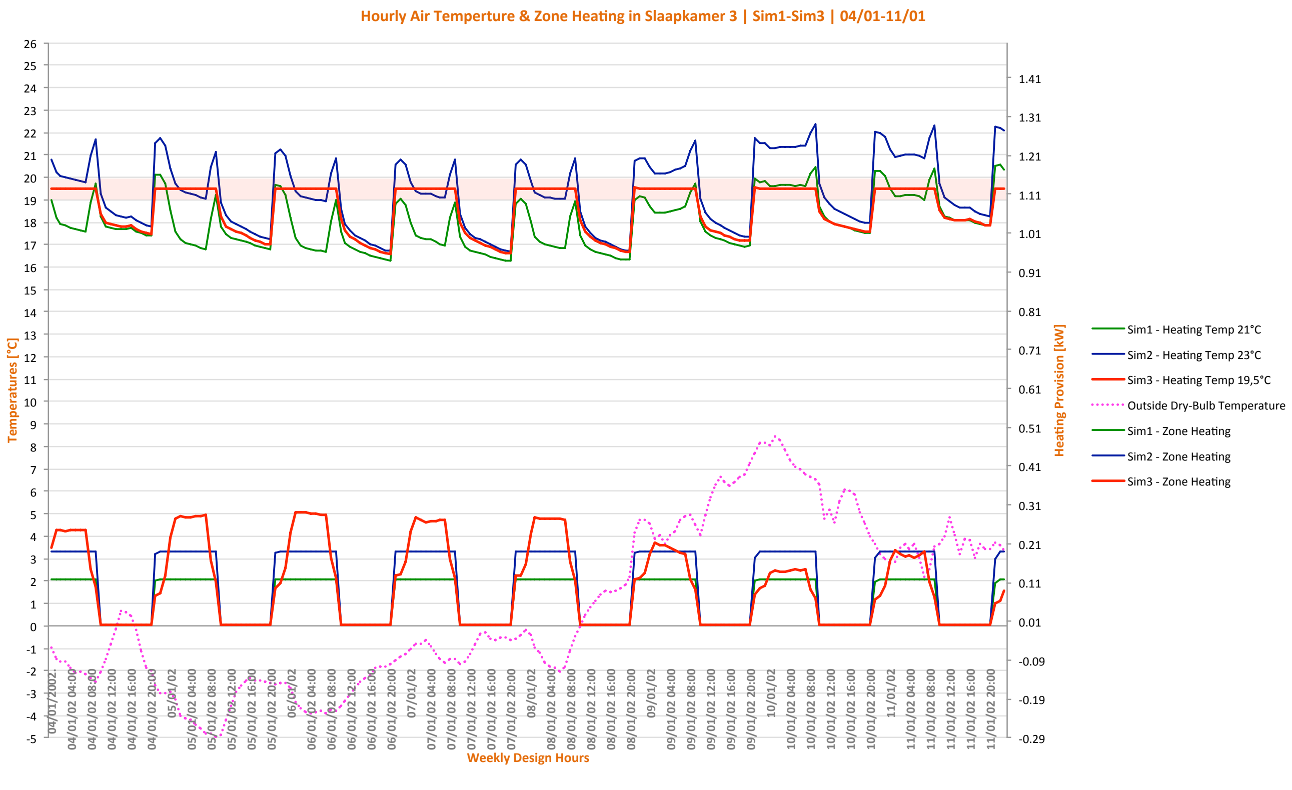

Figure D-05: Thermal performance of sleeping -3 under coldest simulation week.

Ref-2- Wet Spaces | Kitchen & Toilet

Both of the zones are ventilated by mechanical extraction therefore not exposed to outdoor conditions. Therefore the indoor air temperature inside the space is balanced accordingly the occupancy in the zone and fixed at 21° C.

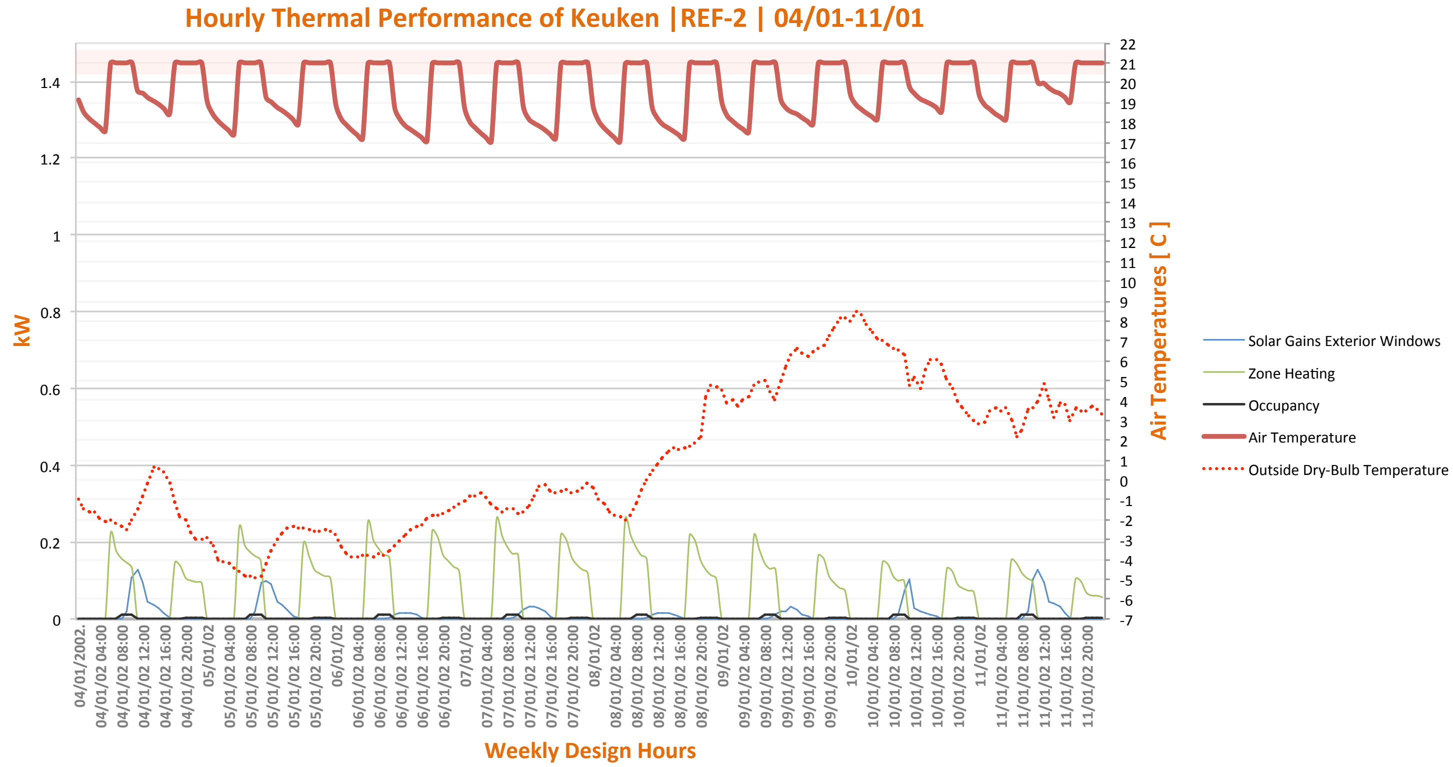

Figure D-06: Thermal conditions in Kitchen after comfort optimization and ventilation measures

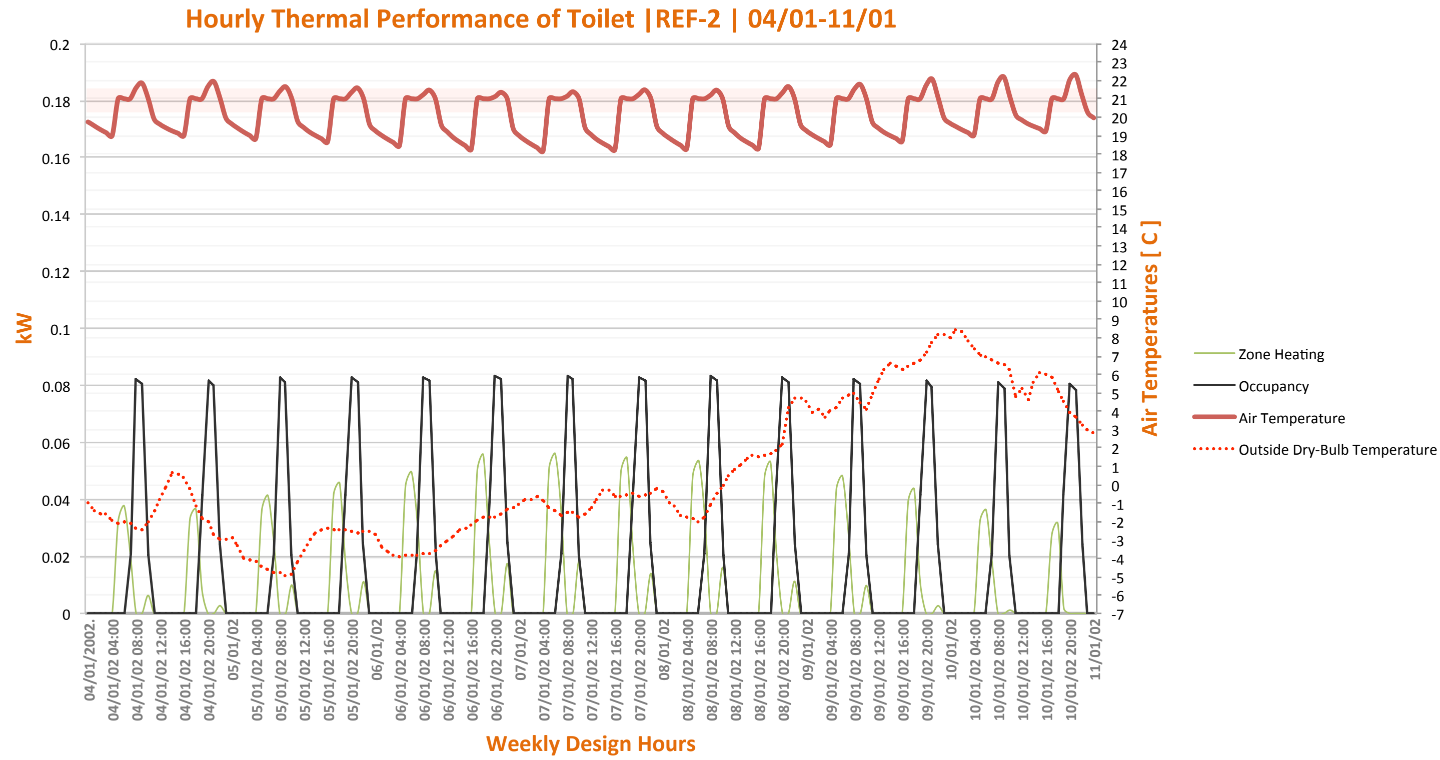

Figure D-07: Thermal conditions in Toilet after comfort optimization and ventilation measures

Appendix D-2: Cooling Season

Ref-2- Sleeping 1 Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	0,6 l/sm^2	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	0,6 l/sm^2	Outside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Natural Ventilation**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation3	Simulation-2 inputs	Standard	6,5 L/s (min rate) per person	On 24/7	21° C	Non
Simulation4	Simulation-2 inputs	0,1 m^2	25 L/s per person	On 24/7	21° C	Non
Simulation5	Simulation-2 inputs	0,3 m^2	60 L/s per person	On 24/7	21° C	Non

Table D-04: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted

Strategy in Sleeping -2 is applied to Sleeping -1 with roller shades positioned outside are used for shading purposes. Inputs per simulation for thermal optimization are given in *table D-21.*

Simulation-5 results in *figure D-08* for the simulation week reflect the optimized air provision into the space for delivering the satisfactory conditions in summer season. Within simulation-5 overheating hours reduce to… 56 hours from 1763 in simulation-1 for the whole season. Throughout the whole summer season, air supply is only excessive as long as indoor temperatures are above 21° C. Additional air supply application would result in increased heating consumption in space and therefore not applied.

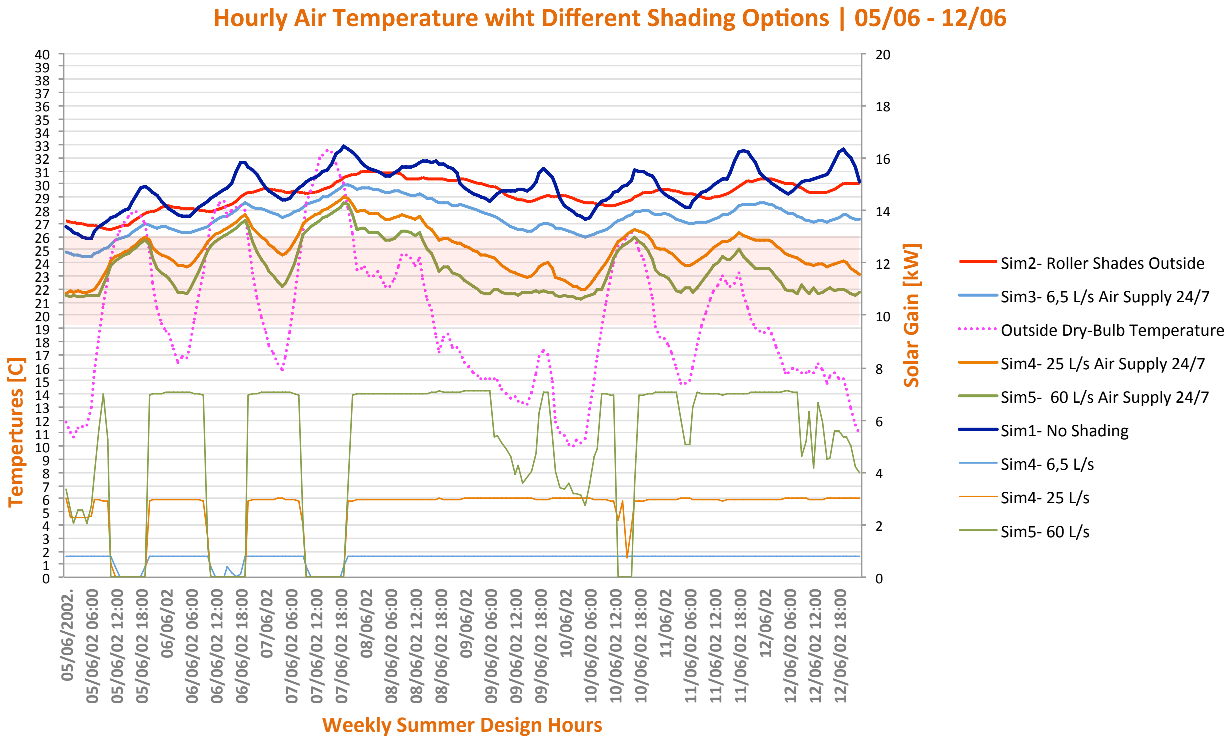

Figure D-08: Indoor air temperatures and AC/H for every simulation step for overheating reduction in sleeping -1

Ref-2- Sleeping 3 Overheating

Sleeping -2 Inputs	Glazing Element	Shading Element	Operable Shading Schedule	Mechanical Ventilation	Operable Shading Positioning	Electricity & Visual Comfort
Simulation1	Rehau Geneo	Non	Non	1,525 l/sm^2	-	-
Simulation2	Rehau Geneo	Roller Shades (Opaque)	On (07:00-20:00) for 6-7-8th Months	1,525 l/sm^2	Outside	-
Sleeping -2 Inputs	**Shading & Glazing Application**	**Ventilation Opening**	**Resulting Air supply in space**	**Air Supply Period**	**Minimum Indoor Air Temperature**	**Minimum Outdoor Air Temperature**
Simulation3	Simulation-2 inputs	Standard	6, 8L/s (min rate) per person	On 24/7	21° C	Non
Simulation4	Simulation-2 inputs	0,3 m^2	33 L/s per person	On 24/7	21° C	Non

Table D-05: Simulation inputs for zone based thermal comfort optimization. Highlighted simulations are the final inputs accepted

Due to small sized opening, solar gain in space is not significant to cause excessive amount of overheating hours in the season. Therefore measures required to optimize the space are equally not excessive as previous optimizations. These inputs are given in *table D-05.*

Within *figure D-08* reflection of all the simulation steps are given in indoor air temperatures for the simulation week. Simulation-4 has the lowest indoor air temperatures due to excessive ventilation during day and nighttime.

With 33 L/s of air supply per person in space for the whole season overheating hours are reduced to 17 hours from 363 hours. 21° C minimum indoor air temperature limit is restricting the constant ventilation during certain times within the season not to trigger or increase additional heating if indoor air temperatures are not excessively high.

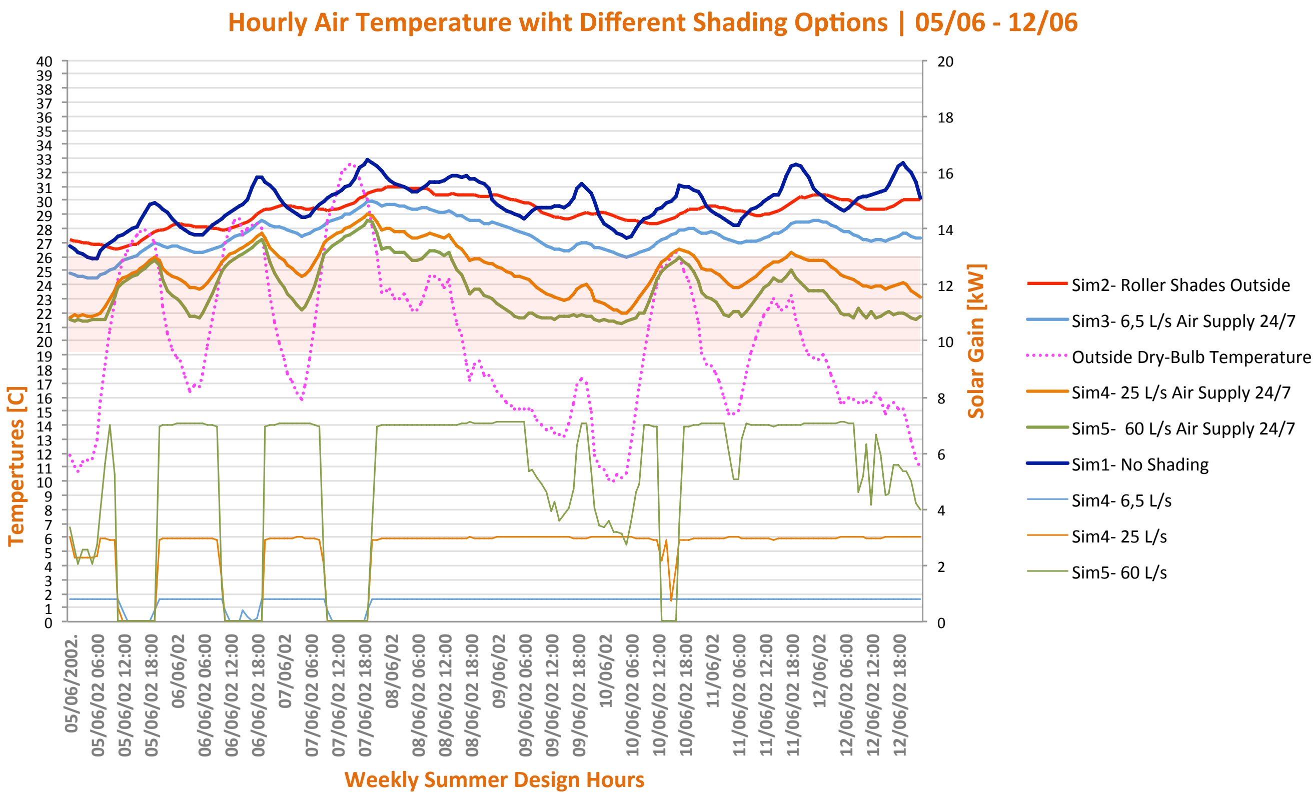

Figure D-08: Indoor air temperature per simulation step with different ventilation rate in sleeping -3

Appendix D-3: Mechanical System & Ducts Sizing

PRIMARY SPACES

SLAAPKAMER-1

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
Air Supply (L/sm2)	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Zone Area m2	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	24,84	24,84	24,84	24,84	24,84	24,84	24,84	12,42	6,21	0	0	0	0	0	0	0	0	0	0	0	0	0	6,21	18,63

SLAAPKAMER-2

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
Air Supply (L/sm2)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone Area m2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2	14,2
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	51,12	51,12	51,12	51,12	51,12	51,12	51,12	25,56	12,78	0	0	0	0	0	0	0	0	0	0	0	0	0	12,78	38,34

SLAAPKAMER-3

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	1	1	1	1	1	1	1	0,5	0,25	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,75
Air Supply (L/sm2)	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525
Zone Area m2	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6	4,6
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	25,25	25,25	25,25	25,25	25,25	25,25	25,25	12,63	6,314	0	0	0	0	0	0	0	0	0	0	0	0	0	6,314	18,94

CONNECTED SPACES

EETKAMER

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Usage Density	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
Supply Density*	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0,5	0,5	1	1	1	1	0,67	0
Air Supply (L/sm2)	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Zone Area m2	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57	16,57
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	0	0	0	0	0	0	16,4	65,62	65,62	16,4	0	0	0	0	0	0	32,81	32,81	65,62	65,62	65,62	65,62	43,96	0

WOONKAMER

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Usage Density	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,5	0,5	1	1	1	1	0,67	0
Supply Density*	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0,5	0,5	1	1	1	1	0,67	0
Air Supply (L/sm2)	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825	0,825
Zone Area m2	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98	12,98
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	0	0	0	0	0	0	9,638	38,55	38,55	9,638	0	0	0	0	0	0	19,28	19,28	38,55	38,55	38,55	38,55	25,83	0

WET SPACES

TOILET

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
Air Extraction (L/sm2)	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3
Zone Area m2	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	0	0	0	0	0	0	9,085	36,34	36,34	9,085	0	0	0	0	0	0	0	0	18,17	36,34	36,34	10,9	0	0

BADKAMER

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	0	0	0	0	0	0	0,25	1	1	0,25	0	0	0	0	0	0	0	0	0,5	1	1	0,3	0	0
Air Extraction (L/sm2)	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6	2,6
Zone Area m2	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76	5,76
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	0	0	0	0	0	0	13,48	53,91	53,91	13,48	0	0	0	0	0	0	0	0	26,96	53,91	53,91	16,17	0	0

KEUKEN

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Density	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0,2	0,2	0,2	0,2	0,2
Air Extraction (L/sm2)	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55	3,55
Zone Area m2	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67	5,67
L/s to m3h rate	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6
Total Air Volume (m3h)	0	0	0	0	0	0	0	72,46	72,46	72,46	0	0	0	0	0	0	0	0	0	14,49	14,49	14,49	14,49	14,49

TOTALS

REF-2 | HOSPESLAAN 24

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Total Air Volume (m3h)	101,2	101,2	101,2	101,2	101,2	101,2	149,8	317,5	292,2	121,1	0	0	0	0	0	0	52,08	52,08	149,3	208,9	208,9	145,7	109,6	90,4
Fresh Air (Primary and Connected)	101,2	101,2	101,2	101,2	101,2	101,2	127,3	154,8	129,5	26,04	0	0	0	0	0	0	52,08	52,08	104,2	104,2	104,2	104,2	95,1	75,91
Extract Air (wet spaces)	0	0	0	0	0	0	22,56	162,7	162,7	95,03	0	0	0	0	0	0	0	0	45,13	104,7	104,7	41,57	14,49	14,49

VENTILATION DUCTS

DUCT SIZING

Main Carriers & End Ducts	Air Flow-m3h (q)	m3h to m3s	Air Speed (v) m/s	Duct Cross Sectio-m2 (A)	Duct Diameter (m)	Effective Diameter (m)
Main Supply Duct	160	0,000277778	1	0,044	0,16	0,16
Slaapkamer-1 Supply Duct	25	0,000277778	0,7	0,010	0,04	0,1
Slaapkamer-2 Supply Duct	52	0,000277778	0,7	0,021	0,07	0,1
Slaapkamer-3 Supply Duct	26	0,000277778	0,7	0,010	0,04	0,1
Main Extract Duct	170	0,000277778	1	0,047	0,17	0,16
Badkamer Extract Duct	55	0,000277778	0,7	0,022	0,08	0,1
Woonkamer Supply Duct	39	0,000277778	0,7	0,015	0,05	0,1
Eetkamer Supply Duct	66	0,000277778	0,7	0,026	0,09	0,1
Keuken Exract Duct	73	0,000277778	0,7	0,029	0,10	0,1
Toilet Exract Duct	37	0,000277778	0,7	0,015	0,05	0,1

Figure D-09: Calculation of airflow volume in every space for sizing mechanical equipment regarding ventilation peak load periods and totals.

** Living Room and Dining Room are connected spaces and the total ventilation of the whole space is distributed to each other regarding their volumes. Therefore their air supply periods have to be identical even though one space is physically not used.*

Appendix E: Conversion of Energy Types and Calculations for Primary Energy

Calculation of total operational energy consumption of the validated model and the stages of refurbished states of both strategies. Primary energy calculations are made according to the conversional rates provided in *chapter 2.3.8 Energy Conversion Rates in the Netherlands.*

VALIDATED MODEL | PRE REFURBISHMENT

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Gas)	Percentage	CP	Primary Energy
01/01/02	3299,589	100%	1	3299,589
01/02/02	2897,045	100%	1	2897,045
01/03/02	2537,841	100%	1	2537,841
01/04/02	1608,19	100%	1	1608,19
01/05/02	689,1248	100%	1	689,1248
01/06/02	325,6043	100%	1	325,6043
01/07/02	110,5327	100%	1	110,5327
01/08/02	170,5139	100%	1	170,5139
01/09/02	520,8744	100%	1	520,8744
01/10/02	1472,137	100%	1	1472,137
01/11/02	2514,809	100%	1	2514,809
01/12/02	3219,914	100%	1	3219,914

DHW

Months	DHW (Gas)	Percentage	CP	Primary Energy
01/01/02	391,6888	100%	1	391,6888
01/02/02	353,7834	100%	1	353,7834
01/03/02	391,6888	100%	1	391,6888
01/04/02	379,0537	100%	1	379,0537
01/05/02	391,6888	100%	1	391,6888
01/06/02	379,0537	100%	1	379,0537
01/07/02	391,6888	100%	1	391,6888
01/08/02	391,6888	100%	1	391,6888
01/09/02	379,0537	100%	1	379,0537
01/10/02	391,6888	100%	1	391,6888
01/11/02	379,0537	100%	1	379,0537
01/12/02	391,6888	100%	1	391,6888

COOLING

Months	Cooling (Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	0	100%	2,48	0
01/06/02	0	100%	2,48	0
01/07/02	0	100%	2,48	0
01/08/02	0	100%	2,48	0
01/09/02	0	100%	2,48	0
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	129,53339	100%	2,48	321,2428072
01/02/02	108,17276	100%	2,48	268,2684448
01/03/02	104,95079	100%	2,48	260,2779592
01/04/02	74,932761	100%	2,48	185,8332473
01/05/02	79,994783	100%	2,48	198,3870618
01/06/02	74,078241	100%	2,48	183,7140377
01/07/02	78,722313	100%	2,48	195,2313362
01/08/02	87,280433	100%	2,48	216,4554738
01/09/02	95,731571	100%	2,48	237,4142961
01/10/02	116,99989	100%	2,48	290,1597272
01/11/02	120,99346	100%	2,48	300,0637808
01/12/02	130,97219	100%	2,48	324,8110312

Primary Energy Consumption

Months	Electricity (Ligthing	Gas (Heating)	Gas (DHW)	Electricity (Cooling)
01/01/02	321,2428072	3299,589	391,6888	0
01/02/02	268,2684448	2897,045	353,7834	0
01/03/02	260,2779592	2537,841	391,6888	0
01/04/02	185,8332473	1608,19	379,0537	0
01/05/02	198,3870618	689,1248	391,6888	0
01/06/02	183,7140377	325,6043	379,0537	0
01/07/02	195,2313362	110,5327	391,6888	0
01/08/02	216,4554738	170,5139	391,6888	0
01/09/02	237,4142961	520,8744	379,0537	0
01/10/02	290,1597272	1472,137	391,6888	0
01/11/02	300,0637808	2514,809	379,0537	0
01/12/02	324,8110312	3219,914	391,6888	0
Annual	2981,859203	19366,1751	4611,8198	0
Absolute To	26959,8541			

Figure E-0: Validated model operational primary energy calculation

AFTER COMFORT OPTIMIZATION | REF-1 |

Energy Conversion & Calculation

	Months	Heating (Gas)	Percentage	CP	Primary Energy
SPACE HEATING	01/01/02	693,73	100%	1	693,73
	01/02/02	556,64	100%	1	556,64
	01/03/02	352,09	100%	1	352,09
	01/04/02	85,53	100%	1	85,53
	01/05/02	92,38196	100%	1	92,38196
	01/06/02	53,56336	100%	1	53,56336
	01/07/02	29,32508	100%	1	29,32508
	01/08/02	30,48344	100%	1	30,48344
	01/09/02	61,64118	100%	1	61,64118
	01/10/02	156,46	100%	1	156,46
	01/11/02	501,96	100%	1	501,96
	01/12/02	717,61	100%	1	717,61
	Months	DHW (Gas)	Percentage	CP	Primary Energy
DHW	01/01/02	391,6888	100%	1	391,6888
	01/02/02	353,7834	100%	1	353,7834
	01/03/02	391,6888	100%	1	391,6888
	01/04/02	379,0537	100%	1	379,0537
	01/05/02	391,6888	100%	1	391,6888
	01/06/02	379,0537	100%	1	379,0537
	01/07/02	391,6888	100%	1	391,6888
	01/08/02	391,6888	100%	1	391,6888
	01/09/02	379,0537	100%	1	379,0537
	01/10/02	391,6888	100%	1	391,6888
	01/11/02	379,0537	100%	1	379,0537
	01/12/02	391,6888	100%	1	391,6888
	Months	Heating (Electricity)	Percentage	CP	Primary Energy
COOLING	01/01/02	0	100%	2,48	0
	01/02/02	0	100%	2,48	0
	01/03/02	0	100%	2,48	0
	01/04/02	0	100%	2,48	0
	01/05/02	1,12	100%	2,48	2,7776
	01/06/02	5,43	100%	2,48	13,4664
	01/07/02	20,21	100%	2,48	50,1208
	01/08/02	17,98	100%	2,48	44,5904
	01/09/02	8,39	100%	2,48	20,8072
	01/10/02	0	100%	2,48	0
	01/11/02	0	100%	2,48	0
	01/12/02	0	100%	2,48	0
	Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
Ligthing	01/01/02	115,773343	100%	2,48	287,1178906
	01/02/02	95,780475	100%	2,48	237,535578
	01/03/02	91,837113	100%	2,48	227,7560402
	01/04/02	74,070561	100%	2,48	183,6949913
	01/05/02	79,717003	100%	2,48	197,6981674
	01/06/02	73,599561	100%	2,48	182,5269113
	01/07/02	78,104423	100%	2,48	193,698969
	01/08/02	86,651963	100%	2,48	214,8968682
	01/09/02	95,344131	100%	2,48	236,4534449
	01/10/02	104,346243	100%	2,48	258,7786826
	01/11/02	107,733081	100%	2,48	267,1780409
	01/12/02	117,254543	100%	2,48	290,7912666

Primary Energy Consumption

Months	Electricity (Ligthing	Gas (Heating)	Gas (DHW)	Electricity (Cooling)
01/01/02	287,1178906	693,73	391,6888	0
01/02/02	237,535578	556,64	353,7834	0
01/03/02	227,7560402	352,09	391,6888	0
01/04/02	183,6949913	85,53	379,0537	0
01/05/02	197,6981674	92,38196	391,6888	2,7776
01/06/02	182,5269113	53,56336	379,0537	13,4664
01/07/02	193,698969	29,32508	391,6888	50,1208
01/08/02	214,8968682	30,48344	391,6888	44,5904
01/09/02	236,4534449	61,64118	379,0537	20,8072
01/10/02	258,7786826	156,46	391,6888	0
01/11/02	267,1780409	501,96	379,0537	0
01/12/02	290,7912666	717,61	391,6888	0
Annual	2778,126851	3331,41502	4611,8198	131,7624
Absolute To	10853,12407			

Figure E-1: Refurbishment-1 operational primary energy calculation post comfort optimization.

REF-2 | 80% HEAT RECOVERY

Energy Conversion & Calculation

	Months	Heating (Gas)	Percentage	CP	Primary Energy
SPACE HEATING	01/01/02	177,64	100%	1	177,64
	01/02/02	91,82	100%	1	91,82
	01/03/02	21,94	100%	1	21,94
	01/04/02	1,22	100%	1	1,22
	01/05/02	67,74	100%	1	67,74
	01/06/02	26,37	100%	1	26,37
	01/07/02	5,14	100%	1	5,14
	01/08/02	9,63	100%	1	9,63
	01/09/02	40,51	100%	1	40,51
	01/10/02	7,53	100%	1	7,53
	01/11/02	87,15	100%	1	87,15
	01/12/02	185,87	100%	1	185,87
	Months	DHW (Gas)	Percentage	CP	Primary Energy
DHW	01/01/02	391,6888	100%	1	391,6888
	01/02/02	353,7834	100%	1	353,7834
	01/03/02	391,6888	100%	1	391,6888
	01/04/02	379,0537	100%	1	379,0537
	01/05/02	391,6888	100%	1	391,6888
	01/06/02	379,0537	100%	1	379,0537
	01/07/02	391,6888	100%	1	391,6888
	01/08/02	391,6888	100%	1	391,6888
	01/09/02	379,0537	100%	1	379,0537
	01/10/02	391,6888	100%	1	391,6888
	01/11/02	379,0537	100%	1	379,0537
	01/12/02	391,6888	100%	1	391,6888
	Months	Heating (Electricity)	Percentage	CP	Primary Energy
COOLING	01/01/02	0	100%	2,48	0
	01/02/02	0	100%	2,48	0
	01/03/02	0	100%	2,48	0
	01/04/02	0	100%	2,48	0
	01/05/02	2,12	100%	2,48	5,2576
	01/06/02	8,09	100%	2,48	20,0632
	01/07/02	34,6	100%	2,48	85,808
	01/08/02	28,22	100%	2,48	69,9856
	01/09/02	10,55	100%	2,48	26,164
	01/10/02	0	100%	2,48	0
	01/11/02	0	100%	2,48	0
	01/12/02	0	100%	2,48	0
	Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
Ligthing	01/01/02	129,53339	100%	2,48	321,2428072
	01/02/02	108,17276	100%	2,48	268,2684448
	01/03/02	104,95079	100%	2,48	260,2779592
	01/04/02	74,932761	100%	2,48	185,8332473
	01/05/02	79,994783	100%	2,48	198,3870618
	01/06/02	74,078241	100%	2,48	183,7140377
	01/07/02	78,722313	100%	2,48	195,2313362
	01/08/02	87,280433	100%	2,48	216,4554738
	01/09/02	95,731571	100%	2,48	237,4142961
	01/10/02	116,99989	100%	2,48	290,1597272
	01/11/02	120,99346	100%	2,48	300,0637808
	01/12/02	130,97219	100%	2,48	324,8110312

Primary Energy Consumption

Months	Electricity (Ligthing	Gas (Heating)	Gas (DHW)	Electricity (Cooling)
01/01/02	321,2428072	177,64	391,6888	0
01/02/02	268,2684448	91,82	353,7834	0
01/03/02	260,2779592	21,94	391,6888	0
01/04/02	185,8332473	1,22	379,0537	0
01/05/02	198,3870618	67,74	391,6888	5,2576
01/06/02	183,7140377	26,37	379,0537	20,0632
01/07/02	195,2313362	5,14	391,6888	85,808
01/08/02	216,4554738	9,63	391,6888	69,9856
01/09/02	237,4142961	40,51	379,0537	26,164
01/10/02	290,1597272	7,53	391,6888	0
01/11/02	300,0637808	87,15	379,0537	0
01/12/02	324,8110312	185,87	391,6888	0
Annual	2981,859203	722,56	4611,8198	207,2784
Absolute To	8523,517403			

Figure E-2: Refurbishment-2 operational primary energy calculation post comfort optimization and Heat Recovery application.

SUI OPTION 1A | REF-1

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	190,2178	90%	2,48	424,5661296	182,8323	10%	2,48	45,3424104
01/02/02	152,6293	90%	2,48	340,6685976	103,6028	10%	2,48	25,6934944
01/03/02	96,54353	90%	2,48	215,485159	27,03289	10%	2,48	6,70415672
01/04/02	23,45372	90%	2,48	52,34870304	2,203607	10%	2,48	0,546494536
01/05/02	18,57577	100%	2,48	46,0679096	-	-	-	0
01/06/02	7,272615	100%	2,48	18,0360852	-	-	-	0
01/07/02	1,411845	100%	2,48	3,5013756	-	-	-	0
01/08/02	2,66284	100%	2,48	6,6038432	-	-	-	0
01/09/02	11,25204	100%	2,48	27,9050592	-	-	-	0
01/10/02	42,90232	90%	2,48	95,75797824	9,821075	10%	2,48	2,4356266
01/11/02	137,6366	90%	2,48	307,2048912	94,85828	10%	2,48	23,52485344
01/12/02	196,7647	90%	2,48	439,1788104	191,1508	10%	2,48	47,4053984

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling (Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	0,2925	100%	2,48	0,7254
01/06/02	1,26	100%	2,48	3,1248
01/07/02	6,10875	100%	2,48	15,1497
01/08/02	22,73625	100%	2,48	56,3859
01/09/02	20,2275	100%	2,48	50,1642
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	115,773343		2,48	287,1178906
01/02/02	95,780475		2,48	237,535578
01/03/02	91,837113		2,48	227,7560402
01/04/02	74,070561		2,48	183,6949913
01/05/02	79,717003		2,48	197,6981674
01/06/02	73,599561		2,48	182,5269113
01/07/02	78,104423		2,48	193,698969
01/08/02	86,651963		2,48	214,8968682
01/09/02	95,344131		2,48	236,4534449
01/10/02	104,346243		2,48	258,7786826
01/11/02	107,733081		2,48	267,1780409
01/12/02	117,254543		2,48	290,7912666

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	287,1178906	469,90854	388,5695	0
01/02/02	237,535578	366,362092	350,9660288	0
01/03/02	227,7560402	222,1893157	388,5695	0
01/04/02	183,6949913	52,89519758	329,812224	0
01/05/02	197,6981674	46,0679096	340,805816	0,7254
01/06/02	182,5269113	18,0360852	329,812224	3,1248
01/07/02	193,698969	3,5013756	340,805816	15,1497
01/08/02	214,8968682	6,6038432	340,805816	56,3859
01/09/02	236,4534449	27,9050592	329,812224	50,1642
01/10/02	258,7786826	98,19360484	388,5695	0
01/11/02	267,1780409	330,7297446	376,0348856	0
01/12/02	290,7912666	486,5842088	388,5695	0
Annual	2778,126851	2128,976976	4293,133034	125,55
Absolute Total	9325,786862			

Figure E-3: Refurbishment-1 operational primary energy calculation for SUI option 1A- all electric system.

SUI OPTION 1C | REF-1

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,1337	90%	2,48	306,0824184	182,8323	10%	2,48	45,3424104
01/02/02	110,0351	90%	2,48	245,5983432	103,6028	10%	2,48	25,6934944
01/03/02	69,60115	90%	2,48	155,3497668	27,03289	10%	2,48	6,70415672
01/04/02	16,9085	90%	2,48	37,739772	2,203607	10%	2,48	0,546494536
01/05/02	18,57577	100%	2,48	46,0679096	-	-	-	0
01/06/02	7,272615	100%	2,48	18,0360852	-	-	-	0
01/07/02	1,411845	100%	2,48	3,5013756	-	-	-	0
01/08/02	2,66284	100%	2,48	6,6038432	-	-	-	0
01/09/02	11,25204	100%	2,48	27,9050592	-	-	-	0
01/10/02	30,92958	90%	2,48	69,03482256	9,821075	10%	2,48	2,4356266
01/11/02	99,22634	90%	2,48	221,4731909	94,85828	10%	2,48	23,52485344
01/12/02	141,8536	90%	2,48	316,6172352	191,1508	10%	2,48	47,4053984

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling(Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	0,0975	100%	2,48	0,2418
01/06/02	0,42	100%	2,48	1,0416
01/07/02	2,03625	100%	2,48	5,0499
01/08/02	7,57875	100%	2,48	18,7953
01/09/02	6,7425	100%	2,48	16,7214
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	115,773343		2,48	287,1178906
01/02/02	95,780475		2,48	237,535578
01/03/02	91,837113		2,48	227,7560402
01/04/02	74,070561		2,48	183,6949913
01/05/02	79,717003		2,48	197,6981674
01/06/02	73,599561		2,48	182,5269113
01/07/02	78,104423		2,48	193,698969
01/08/02	86,651963		2,48	214,8968682
01/09/02	95,344131		2,48	236,4534449
01/10/02	104,346243		2,48	258,7786826
01/11/02	107,733081		2,48	267,1780409
01/12/02	117,254543		2,48	290,7912666

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	287,1178906	351,4248288	388,5695	0
01/02/02	237,535578	271,2918376	350,9660288	0
01/03/02	227,7560402	162,0539235	388,5695	0
01/04/02	183,6949913	38,28626654	329,812224	0
01/05/02	197,6981674	46,0679096	340,805816	0,2418
01/06/02	182,5269113	18,0360852	329,812224	1,0416
01/07/02	193,698969	3,5013756	340,805816	5,0499
01/08/02	214,8968682	6,6038432	340,805816	18,7953
01/09/02	236,4534449	27,9050592	329,812224	16,7214
01/10/02	258,7786826	71,47044916	388,5695	0
01/11/02	267,1780409	244,9980443	376,0348856	0
01/12/02	290,7912666	364,0226336	388,5695	0
Annual	2778,126851	1605,662256	4293,133034	41,85
Absolute Total	8718,772142			

Figure E-4: Refurbishment-1 operational primary energy calculation for SUI option 1C- all electric system.

SUI OPTION 2 | REF-1

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	115,6226	90%	2,48	258,0696432	182,8323	10%	2,48	45,3424104
01/02/02	92,7747	90%	2,48	207,0731304	103,6028	10%	2,48	25,6934944
01/03/02	58,68333	90%	2,48	130,9811926	27,03289	10%	2,48	6,70415672
01/04/02	14,25618	90%	2,48	31,81979376	2,203607	10%	2,48	0
01/05/02	14,14194	100%	2,48	35,0720112	-	-	-	0
01/06/02	8,366617	100%	2,48	20,74921016	-	-	-	0
01/07/02	4,083862	100%	2,48	10,12797776	-	-	-	0
01/08/02	4,569742	100%	2,48	11,33296016	-	-	-	0
01/09/02	10,47695	100%	2,48	25,982836	-	-	-	0
01/10/02	26,07788	90%	2,48	58,20582816	9,821075	10%	2,48	2,4356266
01/11/02	83,66143	90%	2,48	186,7323118	94,85828	10%	2,48	23,52485344
01/12/02	119,6021	90%	2,48	266,9518872	191,1508	10%	2,48	47,4053984

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	100%	2,48	340,850456	329,8552	0%	2,48	0
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling (Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	0,0975	100%	2,48	0,2418
01/06/02	0,42	100%	2,48	1,0416
01/07/02	2,03625	100%	2,48	5,0499
01/08/02	7,57875	100%	2,48	18,7953
01/09/02	6,7425	100%	2,48	16,7214
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	115,773343	100%	2,48	287,1178906
01/02/02	95,780475	100%	2,48	237,535578
01/03/02	91,837113	100%	2,48	227,7560402
01/04/02	74,070561	100%	2,48	183,6949913
01/05/02	79,717003	100%	2,48	197,6981674
01/06/02	73,599561	100%	2,48	182,5269113
01/07/02	78,104423	100%	2,48	193,698969
01/08/02	86,651963	100%	2,48	214,8968682
01/09/02	95,344131	100%	2,48	236,4534449
01/10/02	104,346243	100%	2,48	258,7786826
01/11/02	107,733081	100%	2,48	267,1780409
01/12/02	117,254543	100%	2,48	290,7912666

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	287,1178906	303,4120536	388,5695	0
01/02/02	237,535578	232,7666248	350,9660288	0
01/03/02	227,7560402	137,6853493	388,5695	0
01/04/02	183,6949913	31,81979376	329,812224	0
01/05/02	197,6981674	35,0720112	340,805816	0,2418
01/06/02	182,5269113	20,74921016	329,812224	1,0416
01/07/02	193,698969	10,12797776	340,805816	5,0499
01/08/02	214,8968682	11,33296016	340,805816	18,7953
01/09/02	236,4534449	25,982836	329,812224	16,7214
01/10/02	258,7786826	60,64145476	340,850456	0
01/11/02	267,1780409	210,2571652	376,0348856	0
01/12/02	290,7912666	314,3572856	388,5695	0
Annual	2778,126851	1394,204722	4245,41399	41,85
Absolute Total	8459,595564			

Figure E-5: Refurbishment-1 operational primary energy calculation for SUI option 2- all electric system.

SUI OPTION 1A | REF-2

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	48,7	90%	2,48	108,6984	150,99	10%	2,48	37,44552
01/02/02	25,17	90%	2,48	56,17944	78,05	10%	2,48	19,3564
01/03/02	6,01	90%	2,48	13,41432	18,65	10%	2,48	4,6252
01/04/02	0,335	90%	2,48	0,74772	1,03	10%	-	0
01/05/02	18,57577	100%	2,48	46,0679096	-	-	-	0
01/06/02	7,272615	100%	2,48	18,0360852	-	-	-	0
01/07/02	1,411845	100%	2,48	3,5013756	-	-	-	0
01/08/02	2,66284	100%	2,48	6,6038432	-	-	-	0
01/09/02	11,25204	100%	2,48	27,9050592	-	-	-	0
01/10/02	2,06	90%	2,48	4,59792	6,405	10%	2,48	1,58844
01/11/02	23,89	90%	2,48	53,32248	74,08	10%	2,48	18,37184
01/12/02	50,96	90%	2,48	113,74272	157,99	10%	2,48	39,18152

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	100%	2,48	340,850456	329,8552	0%	2,48	0
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling (Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0,64893	100%	2,48	1,6093464
01/05/02	2,442875	100%	2,48	6,05833
01/06/02	8,70065	100%	2,48	21,577612
01/07/02	38,98751	100%	2,48	96,6890248
01/08/02	31,49046	100%	2,48	78,0963408
01/09/02	11,8473	100%	2,48	29,381304
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	129,53339	100%	2,48	321,2428072
01/02/02	108,17276	100%	2,48	268,2684448
01/03/02	104,95079	100%	2,48	260,2779592
01/04/02	74,932761	100%	2,48	185,8332473
01/05/02	79,994783	100%	2,48	198,3870618
01/06/02	74,078241	100%	2,48	183,7140377
01/07/02	78,722313	100%	2,48	195,2313362
01/08/02	87,280433	100%	2,48	216,4554738
01/09/02	95,731571	100%	2,48	237,4142961
01/10/02	116,99989	100%	2,48	290,1597272
01/11/02	120,99346	100%	2,48	300,0637808
01/12/02	130,97219	100%	2,48	324,8110312

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	321,2428072	146,14392	388,5695	0
01/02/02	268,2684448	75,53584	350,9660288	0
01/03/02	260,2779592	18,03952	388,5695	0
01/04/02	185,8332473	0,74772	329,812224	1,6093464
01/05/02	198,3870618	46,0679096	340,805816	6,05833
01/06/02	183,7140377	18,0360852	329,812224	21,577612
01/07/02	195,2313362	3,5013756	340,805816	96,6890248
01/08/02	216,4554738	6,6038432	340,805816	78,0963408
01/09/02	237,4142961	27,9050592	329,812224	29,381304
01/10/02	290,1597272	6,18636	340,850456	0
01/11/02	300,0637808	71,69432	376,0348856	0
01/12/02	324,8110312	152,92424	388,5695	0
Annual	2981,859203	573,3861928	4245,41399	233,411958
Absolute Total	8034,071345			

Figure E-6: Refurbishment-2 operational primary energy calculation for SUI option 1A- all electric system.

SUI OPTION 1C | REF-2

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	45,44	90%	2,48	101,42208	150,99	10%	2,48	37,44552
01/02/02	24,1	90%	2,48	53,7912	78,05	10%	2,48	19,3564
01/03/02	6,51	90%	2,48	14,53032	18,65	10%	2,48	4,6252
01/04/02	0,559	90%	2,48	1,247688	1,03	10%	-	0
01/05/02	13,39	100%	2,48	33,2072	-	-	-	0
01/06/02	5,24	100%	2,48	12,9952	-	-	-	0
01/07/02	1,01	100%	2,48	2,5048	-	-	-	0
01/08/02	1,91	100%	2,48	4,7368	-	-	-	0
01/09/02	8,11	100%	2,48	20,1128	-	-	-	0
01/10/02	2,35	90%	2,48	5,2452	6,405	10%	2,48	1,58844
01/11/02	22,82	90%	2,48	50,93424	74,08	10%	2,48	18,37184
01/12/02	47,48	90%	2,48	105,97536	157,99	10%	2,48	39,18152

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	100%	2,48	340,850456	329,8552	0%	2,48	0
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling(Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	1,143478	100%	2,48	2,83582544
01/06/02	3,829877	100%	2,48	9,49809496
01/07/02	15,95579	100%	2,48	39,5703592
01/08/02	12,94456	100%	2,48	32,1025088
01/09/02	5,330295	100%	2,48	13,2191316
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	129,53339		2,48	321,2428072
01/02/02	108,17276		2,48	268,2684448
01/03/02	104,95079		2,48	260,2779592
01/04/02	74,932761		2,48	185,8332473
01/05/02	79,994783		2,48	198,3870618
01/06/02	74,078241		2,48	183,7140377
01/07/02	78,722313		2,48	195,2313362
01/08/02	87,280433		2,48	216,4554738
01/09/02	95,731571		2,48	237,4142961
01/10/02	116,99989		2,48	290,1597272
01/11/02	120,99346		2,48	300,0637808
01/12/02	130,97219		2,48	324,8110312

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	321,2428072	138,8676	388,5695	0
01/02/02	268,2684448	73,1476	350,9660288	0
01/03/02	260,2779592	19,15552	388,5695	0
01/04/02	185,8332473	1,247688	329,812224	0
01/05/02	198,3870618	33,2072	340,805816	2,83582544
01/06/02	183,7140377	12,9952	329,812224	9,49809496
01/07/02	195,2313362	2,5048	340,805816	39,5703592
01/08/02	216,4554738	4,7368	340,805816	32,1025088
01/09/02	237,4142961	20,1128	329,812224	13,2191316
01/10/02	290,1597272	6,83364	340,850456	0
01/11/02	300,0637808	69,30608	376,0348856	0
01/12/02	324,8110312	145,15688	388,5695	0
Annual	2981,859203	527,271808	4245,41399	97,22592
Absolute Total	7851,770922			

Figure E-7: Refurbishment-2 operational primary energy calculation for SUI option 1C- all electric system.

SUI OPTION 2 | REF-2

Energy Conversion & Calculation

SPACE HEATING

Months	Heating (Electricity)	Percentage	CP	Primary Energy	Heating (Electricity)	Percentage	CP	Primary Energy
01/01/02	44,88	90%	2,48	100,17216	150,99	10%	2,48	37,44552
01/02/02	22,21	90%	2,48	49,57272	78,05	10%	2,48	19,3564
01/03/02	2,85	90%	2,48	6,3612	18,65	10%	2,48	4,6252
01/04/02	0,2	90%	2,48	0,4464	1,03	10%	2,48	0
01/05/02	8,55	100%	2,48	21,204	-	-	-	0
01/06/02	2,97	100%	2,48	7,3656	-	-	-	0
01/07/02	0,62	100%	2,48	1,5376	-	-	-	0
01/08/02	1,14	100%	2,48	2,8272	-	-	-	0
01/09/02	5,26	100%	2,48	13,0448	-	-	-	0
01/10/02	0,9	90%	2,48	2,0088	6,405	10%	2,48	1,58844
01/11/02	21,17	90%	2,48	47,25144	74,08	10%	2,48	18,37184
01/12/02	47,81	90%	2,48	106,71192	157,99	10%	2,48	39,18152

DHW

Months	DHW (Electricity)	Percentage	CP	Primary Energy	DHW (Electricity)	Percentage	CP	Primary Energy
01/01/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/02/02	124,1391	90%	2,48	277,0784712	297,9337	10%	2,48	73,8875576
01/03/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896
01/04/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/05/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/06/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/07/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/08/02	137,4217	100%	2,48	340,805816	-	-	-	0
01/09/02	132,9888	100%	2,48	329,812224	-	-	-	0
01/10/02	137,4397	100%	2,48	340,850456	329,8552	0%	2,48	0
01/11/02	133,0061	90%	2,48	296,8696152	319,2148	10%	2,48	79,1652704
01/12/02	137,4397	90%	2,48	306,7654104	329,8552	10%	2,48	81,8040896

COOLING

Months	Cooling (Electricity)	Percentage	CP	Primary Energy
01/01/02	0	100%	2,48	0
01/02/02	0	100%	2,48	0
01/03/02	0	100%	2,48	0
01/04/02	0	100%	2,48	0
01/05/02	1,143478	100%	2,48	2,83582544
01/06/02	3,829877	100%	2,48	9,49809496
01/07/02	15,95579	100%	2,48	39,5703592
01/08/02	12,94456	100%	2,48	32,1025088
01/09/02	5,330295	100%	2,48	13,2191316
01/10/02	0	100%	2,48	0
01/11/02	0	100%	2,48	0
01/12/02	0	100%	2,48	0

Ligthing

Months	Ligthing (Electricity)	Percentage	CP	Primary Energy
01/01/02	129,53339	100%	2,48	321,2428072
01/02/02	108,17276	100%	2,48	268,2684448
01/03/02	104,95079	100%	2,48	260,2779592
01/04/02	74,932761	100%	2,48	185,8332473
01/05/02	79,994783	100%	2,48	198,3870618
01/06/02	74,078241	100%	2,48	183,7140377
01/07/02	78,722313	100%	2,48	195,2313362
01/08/02	87,280433	100%	2,48	216,4554738
01/09/02	95,731571	100%	2,48	237,4142961
01/10/02	116,99989	100%	2,48	290,1597272
01/11/02	120,99346	100%	2,48	300,0637808
01/12/02	130,97219	100%	2,48	324,8110312

Primary Energy Consumption

Months	Electricity (Ligthing)	Electricity (Heating)	Electricity (DHW)	Electricity (Cooling)
01/01/02	321,2428072	137,61768	388,5695	0
01/02/02	268,2684448	68,92912	350,9660288	0
01/03/02	260,2779592	10,9864	388,5695	0
01/04/02	185,8332473	0,4464	329,812224	0
01/05/02	198,3870618	21,204	340,805816	2,83582544
01/06/02	183,7140377	7,3656	329,812224	9,49809496
01/07/02	195,2313362	1,5376	340,805816	39,5703592
01/08/02	216,4554738	2,8272	340,805816	32,1025088
01/09/02	237,4142961	13,0448	329,812224	13,2191316
01/10/02	290,1597272	3,59724	340,850456	0
01/11/02	300,0637808	65,62328	376,0348856	0
01/12/02	324,8110312	145,89344	388,5695	0
Annual	2981,859203	479,07276	4245,41399	97,22592
Absolute Total	7803,571874			

Figure E-8: Refurbishment-2 operational primary energy calculation for SUI option 2- all electric system.