AALBORG UNIVERSITY
DENMARK

RENOVATION STRATEGY OF TYPICAL DANISH SINGLE-FAMILY HOUSE FOR OPTIMIZATION OF ENERGY FLEXIBILITY

Building Energy Design
Fourth Semester Master Thesis

AALBORG UNIVERSITET
STUDENTERRAPPORT

Department of Civil Engineering
Building Energy Design
Thomas Manns Vej 23
DK - 9220 Aalborg Øst
Tlf. 99 40 93 09

Title: Renovation strategy of typical Danish single-family house for optimization of energy flexibility

Thesis subject: Energy Flexibility of Buildings

Semester: Fourth Semester

Project period: September 2018 - January 2019

ECTS: 30

Supervisors: Anna Joanna Marszal-Pomianowska, Hicham Johra

Nadin Hisham Sharif

Laia-Tuixent Morgo Monne

Una Polonanova

Pages: 115
Appendix: 8 pcs

Synopsis:

Denmark's future plan for 2050 is to become 100% independent of fossil fuels. The fluctuating patterns of renewable sources, like wind and solar, will demand flexible systems to address the stability of the grid.
Buildings have the potential of storing the heat within their thermal mass and use it when energy shifting is needed, due to energy price, production or high demand.
This study is taking the renovation process of a typical Danish single-family house as a case study. The goal of the renovation will be ensuring the correlation between energy flexibility and energy efficiency to define renovation strategies that facilitates secure network operation. This means that the focus will be on how much and when the building consumes energy. With proper control strategies the building has the ability to shift a part of its energy consumption from high to low demand periods.
It was discovered, that energy efficiency and flexibility are affected by building thermal resistance more than its effective thermal inertia.

Abstract

This work is about renovation strategies for a typical Danish single family house with a focus on energy efficiency and energy flexibility. The potential of increasing the energy efficiency and flexibility provided to the energy grid through specific building component combinations are investigated. Heating cut-off periods are applied to a building simulation model with different renovation components and packages. Building energy flexibility and efficiency are evaluated with respect to comfort preservation and heating power peak shifting.

Within this study, the largest impact on energy efficiency and flexibility seems to be from thermal transmittance of the building envelope. However, effective thermal inertia affects energy flexibility only if the thermal resistance of the envelope is sufficient.

Preface

This Master Thesis has been written from September 2018 to January 2019 at the faculty of Engineering and Science at Aalborg University during the 4th semester of the Building Energy Design program.

The objective of this research is to investigate energy flexibility and energy efficiency potential in different renovation strategies of a typical Danish single family house. Renovation strategies and prices are based on technical report "Development of Energy Renovation Packages for Danish Residential Single Family House".

A special gratitude goes to our supervisors Anna Joanna Marszal-Pomianowska and Hicham Johra, each of whom has provided patient advice and guidance throughout the research process. Moreover we would like to thank Evangelia Loukou for her support and input, as well as Mingzhe Liu for his assistance.

Nomenclature

Symbol	**Unit**	**Description**
$HVAC$	-	Heating Ventilation and Cooling
DHW	-	Domestic Hot Water
$U - value$	$\frac{\mathrm{W}}{\mathrm{m^2K}}$	Heat transmission coefficient
LCC	-	Life Cycle Cost
DH	-	District Heating
SBi	-	Statens Bygge Institut
$DGNB$	-	The German Sustainable Building Council
RES	-	Renevable Energy Sources
DSM	-	Demand Side Management
R	$\frac{\mathrm{m^2.K}}{\mathrm{W}}$	Building Thermal Resistance
τ	s	Time Constant
ppl		Number of People
$k_{m.internal}$	$\frac{\mathrm{J}}{\mathrm{m^2.K}}$	Building Effective Thermal Inertia
NPV	DKK	Net Present Value
24/7	-	Twenty-four hours a day, seven days a week; all the time
$P - value$	-	The probability of getting a result at least as extreme as the one that was actually observed

Contents

List of Tables

List of Figures

1 | Introduction

1.1 Project Background

Energy demand must be decreased by 41% by 2050 compared to peaks in years 2005 and 2006, while renewable energy sources (RES) in gross final energy consumption should represent 75% and there should be at least 97% RES in electricity consumption. The largest share for electricity production is expected to be from wind power [1]. Already in 2015, more than 40% of the Danish electricity consumption was wind power based. By 2020 wind power share will grow to 50% [2]. Fluctuating patterns of renewable sources, like wind and solar, require a flexible system to address the stability of the grid. There is a need for flexibility in the power system, for example, flexible generation, storage and demand management strategies [1].

Buildings can offer different storage potential in either their structure or in hot water tanks, batteries, etc. [3]. A large part of the energy demand of buildings may be shifted in time, which can significantly contribute in increasing flexibility of the demand in the energy system [4].

Almost half of all energy in Denmark is consumed by buildings. Two-thirds of this energy is used in residential buildings [5]. Privately owned single-family houses account for approximately 60% of the heated residential floor area [6]. This means that single family houses consumption accounts for almost 20% of total space heating energy need in Denmark.

Renovation of buildings has a relevant importance since they are expected to represent 75% of buildings in 2050 [4]. Nowadays, renovation processes are focused into minimizing the overall energy consumption of the building. Strategies such as reducing heat losses to impact the final heating demand or improving the efficiency of the systems are the most common measures to fulfill the energy frame stated in the building regulations.

There have been studies about separate building component or parameter influence on energy flexibility and direct connection with energy efficiency, for example H. Johra, P. Heiselberg and J. Le Dréau has investigated the influence of envelope, structural thermal mass and indoor content of the building heating energy flexibility [7]. The research of T. Moffiet, D. Alterman, S. Hands, K. Colyvas, A. Page and B. Moghtaderi stated that building indoor air sensitivity to outdoor temperature change lowers the energy flexibility potential of the building structure. Building insulation plays an important role in increasing cut off period for energy consumption peak load shifting, as well as decreases heating demand [8].

The design of buildings was researched as a tool for retaining heat by adapting changes in heating schedule, thus providing energy flexibility to the heating network [9]. It was concluded that the temperature drop after a cut-off was mostly due to the heat losses through building envelope, where the two main factors were the external walls insulation followed by windows U-value.

The study about potential of structural thermal mass for demand-side management in dwellings has found that the floor heating system is more beneficial for the peak shifting in comparison with radiators [3]. It also states that improving the insulation level reduces the peaks in the electricity load and that the heavy-weight building shows higher potential for demand side management

(DSM) compared to the light-weight cases.

The study about energy flexibility of residential buildings concluded, that for poorly insulated buildings, a large amount of energy need can be modulated for short periods of time (2.5 h) and long periods of activation (over 6 h) should be avoided to maintain comfortable indoor conditions [10].

Wind power production in Denmark can often have low production periods for more than 2.5 hours or even days [11], thus it is of great importance to investigate modulation periods of buildings potentially undergoing renovation and increase their energy flexibility according to the electricity grid needs.

Since building envelope, insulation level, external building component thermal properties and boundary condition, such as building orientation, impact building energy efficiency and flexibility potential and since these building parameters can be completely or partly changed within a renovation process [3] [4] [8] [10], this Master Thesis research focus is finding the optimal renovation strategies concerning energy efficiency and flexibility.

1.2 Problem Statement

The problem statement of this master thesis and the main research questions are:

Which is the optimal renovation strategy that can optimize both the energy efficiency and flexibility of a typical Danish single family house?

Since the study case takes the renovation process packages of a typical Danish single family houses including only construction, the following sub-questions will be part of the research:

- 1: To which extend a typical renovation strategy contributes to energy flexibility?
- 2: What influence has each component of renovation packages?

The flexibility performance will be simulated using building energy software DesignBuilder. The results will be examined and a flexibility factor will be determined and compared according to the methodology.

2 | Methodology

The study case selected for the present master thesis was based on the technical report “Development of energy renovation packages for Danish residential single family houses” elaborated for the department of Civil Engineering at Aalborg University as part of Horizon 2020 EU project REFURB [12]. The technical report assesses methodology and presents 5 cost-efficient renovation packages on a representative case of the single family house sector. The methodology was based on theoretical energy saving calculations performed in B15 software tool together with a cost–efficiency analysis.

2.1 Building Study Cases

The investigated building represents the case of a typical Danish single family house from the period of 1960-1976. Building is within the category of Danish houses with the highest possibility for improvement (energy class from G to C) [12]. Renovation strategy impact on building energy flexibility was evaluated according to the proposed components and packages for the typical Danish single family house, further referred as "Reference Case". Analyzing each building component of the renovation packages, allows to understand energy flexibility potential for each component, as well as the energy flexibility potential of components combinations.

2.2 Limitations

2.2.1 Limitations of Thermal Comfort

According to ISO 15241, Category II is sufficient for thermal comfort in new buildings and renovations, thus other thermal comfort categories are not considered in this report.

Table 2.1: Recommended design values of the indoor temperature

Type of building or space	Category	Temperature range for heating, ^{o}C, Clothing ~1,0 clo	Temperature range for cooling, ^{o}C, Clothing ~0,5 clo
Residential buildings, living spaces (bedroom’s living rooms etc.), Sedentary activity ~1,2 met	I	21.0-25.0	23.5-25.5
	II	20.0-25.0	23.0-26.0
	III	18.0-25.0	22.0-27.0

2.2.2 Limitations of Used HVAC Systems

This report does not investigate HVAC systems influence on energy flexibility and focuses only on building construction, considering short term heat storage in thermal mass during heating season. Mechanical ventilation, heating system (heating source, emitters, etc) and cooling systems are not included in any of renovation packages and are not separately simulated.

2.2.3 Limitations due to The Simulating Tool

Renovation packages used for this research included separately foundation improvements and external wall improvements, but due to DesignBuilder limitations, it has been chosen to have external wall and foundation improvement as one building component. The control strategy set point modulation is limited to only two set points (main set-point and set-back) beside the cut-off.

2.3 Parameter Variation

Two main parameters were considered to evaluate the flexibility potential: renovated components with their combination into renovation packages and the impact of the weather conditions.

2.3.1 Renovated Components and Renovation Packages

In total, nine model building components and five renovation packages were evaluated. The presented parameters were not evaluated by a single value-range variation (e.g. wall insulation thickness variation), however, focus was on the overall component characteristics.

Renovated Components

Table 2.2 presents the investigated building components in comparison with the Reference Case. Additionally, new wall typologies were included and used to analyze the effect of the thermal mass. This was conducted by adding an internal massive layer on the external heavy walls, 1cm of mortar, 1cm of cement and 5 cm of cement. Moisture calculation for these walls was made and no risk of condensation was found in the construction, see Appendix F.1. The components are sorted and ranked from high to low percentage of envelope area with an overview of their thickness and thermal transmittance before and after being renovated. External walls and crawl floor have the largest U-value improvement with different thicknesses. Detailed layer composition and thermal characteristics can be found in chapter 3.3. Detailed constructions of the building with different renovated components are shown in Appendix A.2. The orange band in the table represents the increase in layer thickness, meaning that full length of the band corresponds to double thickness.

Table 2.2: Characteristics of the renovated components

N° Case	Component	Envelope Area [%]	Existing Thickness [m]	Renovated Thickness [m]	Existing U-value [W/m²K]	New U-value [W/m²K]
1	Wall Type 1	33,11	0,29	0,33	0,42	0,16
2	Wall Type 2			0,45		0,16
3	Wall Type 3			0,42		0,16
4	1cm Mortar			0,30		0,42
	1cm Cement			0,30		0,42
	5cm Cement			0,34		0,41
5	Semi exposed floor	21,21	0,15	0,17	0,54	0,23
6	Crowl floor	21,00	0,35	0,70	0,38	0,11
7	Roof	20,61	0,28	0,43	0,22	0,12
8	Windows	5,27	(-)	(-)	2,80	1,20
9	Light wall	0,74	0,17	0,38	0,38	0,15

Renovation Packages

Table 2.3 presents the 5 renovation packages. The range can be interpreted from the lowest to the highest ratio of the renovated envelope, where Package 4 and 5 represent a 100% envelope renovation. The difference between these two packages is the wall type. Package 3 with 80% of renovated envelope does not include the semi-exposed floor renovation. Package 2 includes renovated external wall, which accounts for a 75% of the existing envelope. Package 1 is the least renovated one, where solely the roof is the only renovated element in contact with the outdoor weather condition variations. Detailed constructions of the building with different renovated packages are shown in Appendix A.3.

Table 2.3: Components of the renovation packages

Building component	**Package 1**	**Package 2**	**Package 3**	**Package 4**	**Package 5**
Wall type 1		+			
Wall type 2			+	+	
Wall type 3					+
Windows			+	+	+
Light wall		+	+	+	+
Roof	+	+	+	+	+
Semi exposed floor				+	+
Crawl floor	+	+	+	+	+
Building envelope renovation amount [%]	54	75	80	100	100

2.3.2 Weather Conditions

To assess the influence of the weather conditions on time constant, five representative climate scenarios were chosen for the heating season (1^{st} of November to 30^{th} of April) [13]. The dates and characteristics of their variables are shown in table 2.4.

Table 2.4: Climate variables of the chosen days

Date	**8^{th} Jan.**	**15^{th} Jan.**	**22^{nd} Jan.**	**30^{th} Jan.**	**1^{st} Dec.**
Outdoor temperature [^{o}C]	2.08	1.66	-3.28	1.9	-4.7
Wind speed [m/s]	9.53	10.15	8.14	5.43	5.06
Wind direction	NW	SW	NE	SE	NE
Solar radiation [kWh/m^2]	0.32	1.85	2.68	0.33	0.83

Since the critical room is oriented towards south-west, data from wind is included to provide better analysis of the results.

2.4 Efficiency and flexibility Assessment Indicators

2.4.1 Efficiency Assessment

The energy need for space heating (further referred as energy consumption) of the building, with different renovated components and renovation packages, was simulated for the heating season with the dynamic building simulation software. Energy consumption includes the energy need for room heating and the electricity use for the operation of the heating system. Results were evaluated and compared to Reference Case, in order to see the energy consumption reduction.

2.4.2 Flexibility Assessment

Flexibility assessment was done at the room level, where the living room was chosen as the critical room where the occupants spend most of the time, and consequently the comfort conditions are especially valuable to be kept. The room has south-west orientation and the larges glazing-to-wall ratio (0.45), comparing to other rooms. Flexibility was assessed by:

- Internal daily areal heat capacity, further referred to as effective thermal inertia.
- Weather impact on time constant.

Effective Thermal Inertia

As the thermal capacity of building components have an influence on the dynamics of heat transfer processes through the envelope and on the building ability to store and discharge heat [14], the effective thermal inertia was calculated by MATLAB, using a code designed according to the matrix method described in EN ISO 13786 [15]. MATLAB calculation was conducted on the building with different renovated components and renovation packages, to define the renovation impact on the theoretical time constant.

Theoretical Time Constant

The known concept of time constant τ is characterizing a system response to a step input, where it represents the time that system needs to reach 63% of the total response after it stabilizes [16]. Time constant can be calculated according to the following equation:

$$\tau = R \cdot K_{m.internal} \tag{2.1}$$

Where:

τ - building time constant [S]

R - building thermal resistance [m^2.K/W]

$K_{m.internal}$ - building effective thermal inertia [J/m^2.K] [17]

Numerical Time Constant

The procedure comprises a cut-off on the heating system schedule to measured variations on the operative temperature. A cut-off was applied from 7:00 until midnight after a normal operation of the heating system. The continuous heating schedule is a daily program 24h/7 with an operative set point temperature of 22^{o}C. The selected cut-off strategy was chosen to match with the morning peak demand in electricity grid and evaluate the power peak shaving potential.

Numerical time constant determines the time during which the building can keep comfortable operative temperature after turning off the heating system. Simulated time constant in this study represents the calculated time between cut-off in the heating system and temperature drop from 22^oC to 20^oC, where the heating season comfort band was taken into account.

Table C.1 in Appendix C.1 shows the difference between the numerical and theoretical time constants for the Reference Case.

This report analyzes the Numerical time constant (further referred as time constant), not theoretical time constant.

2.5 Package Selection: Sensitivity and Economical Analysis

The first part was defining the optimal typical renovation package for further analysis. It was based on energy flexibility and efficiency assessment. Further, suggested packages were developed according to separate building component performance, sensitivity analysis and initial investment.

2.5.1 Sensitivity Analysis

The one-way analysis of variance (Anova) was used to determine whether there were any statistically significant differences between the means of three or more independent groups [18]. Anova analysis showed which renovated building components has no significant difference compared to Reference Case, in terms of energy consumption and energy flexibility. Those components were not chosen to be analyzed further. This method was also used to compare renovation packages to Reference Case, as well to compare renovation packages between themselves. Sensitivity analysis was used to determine on which component combination the control strategy analysis will be applied.

2.5.2 Economical Analysis

When the renovated components showed insignificant difference between their effect on energy efficiency and flexibility, their initial investments represented the deciding factor in choosing the components of the suggested renovation packages. The initial investments of renovated component were taken as price per m^2 [12], while packages initial investments were calculated by summing up their components initial investments.

Time constants and net present values were calculated for the suggested packages, to decide which package represents the optimum renovation package regarding investment, energy efficiency and energy flexibility. Net present values (NPV) were calculated by conducting a simple life cycle cost analysis (LCC), taking into consideration the initial investments and the operation energy consumption cost along 30 years analysis period [19]. The electricity prices was calculated as 2,29 DKK/kWh, with 4,7% as an annual price increase [20].

2.5.3 Control Strategies

Two main types of heating control strategy, were applied on the optimal renovation package. Analyzed control strategies are compatible with electricity grid demand. They both consist in variation of the heating system activation time:

- Simple cut-off.
- Pre-heating before the cut-off.

Figure 2.1 shows examples of the analyzed control strategies set point modulation, where the temperature set point at 0 ^{o}C represents the heating cut-off, not the simulated indoor temperature during that period. Electricity grid high demand period [11], was considered as the period when the consumption is above the yearly average working hours consumption (8:00 - 17:00).

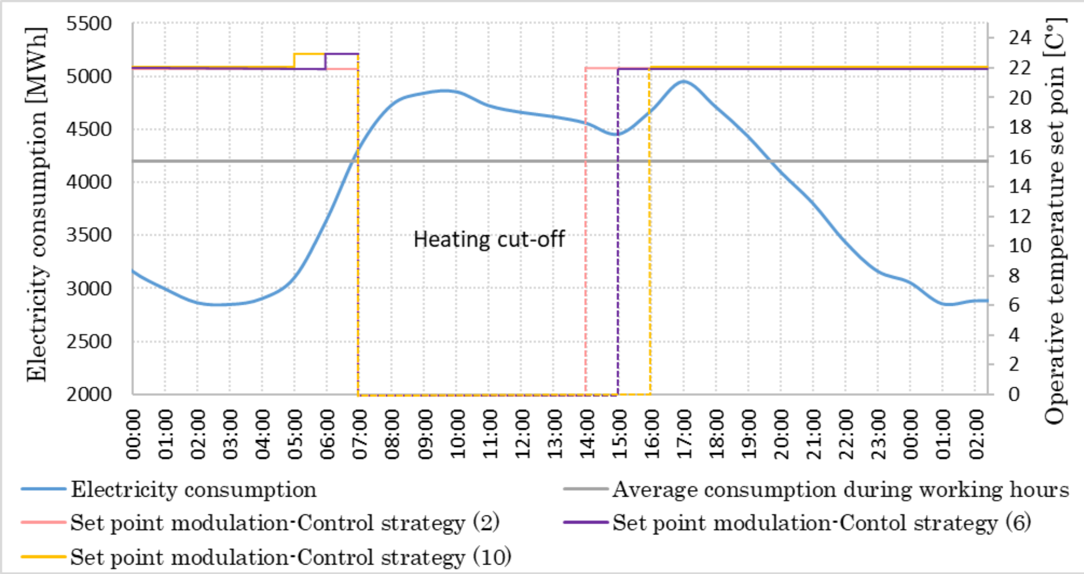

Figure 2.1: Heating set point modulation in control strategies 2,6,10 and Electricity grid consumption on 3/1/2017

The cut-off was applied at 7:00, since it is the beginning of the electricity grid high demand period. It was also found that the optimal package time constant in the coldest day is almost 1 hour, as shown in figure 5.1. Which means that the operative temperature can be kept above 20^{o}C until 8:00, when the occupants leave the building. Defining the duration of the cut off period depend on the operative temperature at 17:00, when occupants get back home. Three cut-off periods were analyzed, cutting the heating until 14:00, 15:00 and 16:00. Pre-heating activation periods of 1 and 2 hours were analyzed, see the analyzed control strategies in table 2.5.

Table 2.5: Analyzed control strategies

No.	Control strategy
1	Heating 24/7
2	Cutting off the heating 07:00 - 14:00
3	Cutting off the heating 07:00 - 15:00
4	Cutting off the heating 07:00 - 16:00
5	1 h preheating & cutting off 07:00 - 14:00
6	1 h preheating & cutting off 07:00 - 15:00
7	1 h preheating & cutting off 07:00 - 16:00
8	2 h preheating & cutting off 07:00 - 14:00
9	2 h preheating & cutting off 07:00 - 15:00
10	2 h preheating & cutting off 07:00 - 16:00

Control strategies were evaluated based on three main indicators:

- Number of occupied hours outside category II thermal comfort band, as shown in table 2.1, This number should not exceed 3% of the total occupied hours, as stated in DS EN 15251 Annex G [21].
- The total saved energy during the heating season. This value was found by calculating the difference between the energy saved during the heating system cut-off period (A) and the rebound energy need after the cut-off period (B), that are shown in figure 2.2.
- The flexibility factor, which is calculated as shown in equation 2.2 [22]. The flexibility factor ranges between -1 and 1, where the positive values mean that the heating energy used during the low demand period is higher than the energy used during the high demand period [22].

$$F = \frac{\sum q_{heating,LowDemand} - \sum q_{heating,HighDemand}}{\sum q_{heating,LowDemand} + \sum q_{heating,HighDemand}} \tag{2.2}$$

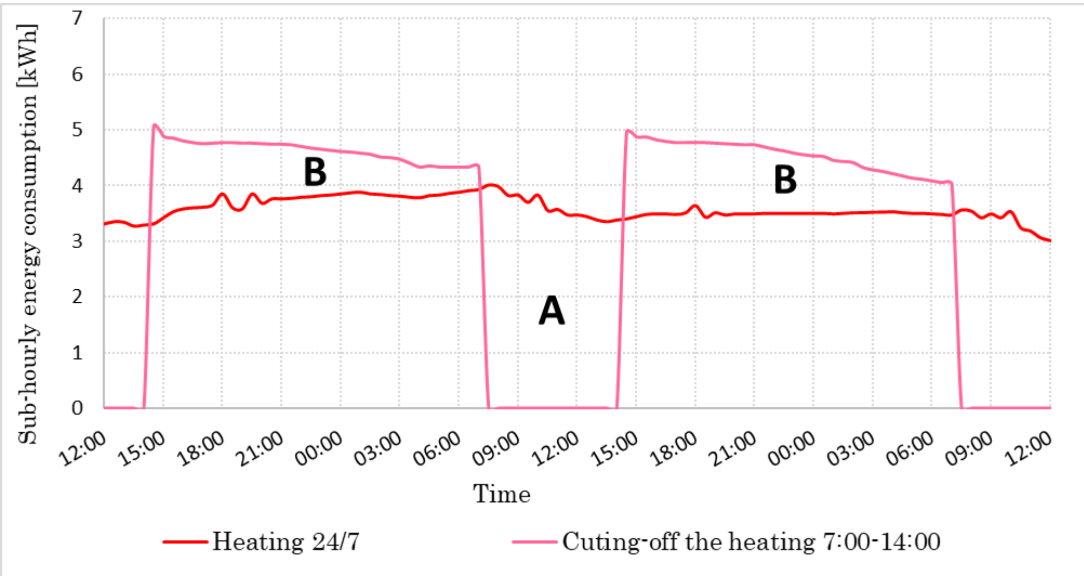

Figure 2.2: Example of the saved and boosted energy consumption - with control strategy number 2

3 | Model Description

3.1 Used Software

This study was based on a set of models created on the building performance simulation software DesignBuilder.

3.2 Geometry

The investigated building, that was built in 1973, was modelled as two separate blocks,the heated ground floor block with a total area of 136 m^2 and the unheated crawl space block. The ground floor has 3 sleeping rooms, office, living room, kitchen, entrance, bathroom, toilet, corridor and laundry room. The floor plan was simplified in DesignBuilder, where toilet and bathroom were considered as one zone and master bedroom was combined with the office as one zone. The internal partitions between the combined rooms were replaced with an internal thermal mass that has the same construction and surface area.

The model orientation and geometry are shown in figure 3.1. Where the shown rooms represent the 9 analyzed thermal zones.

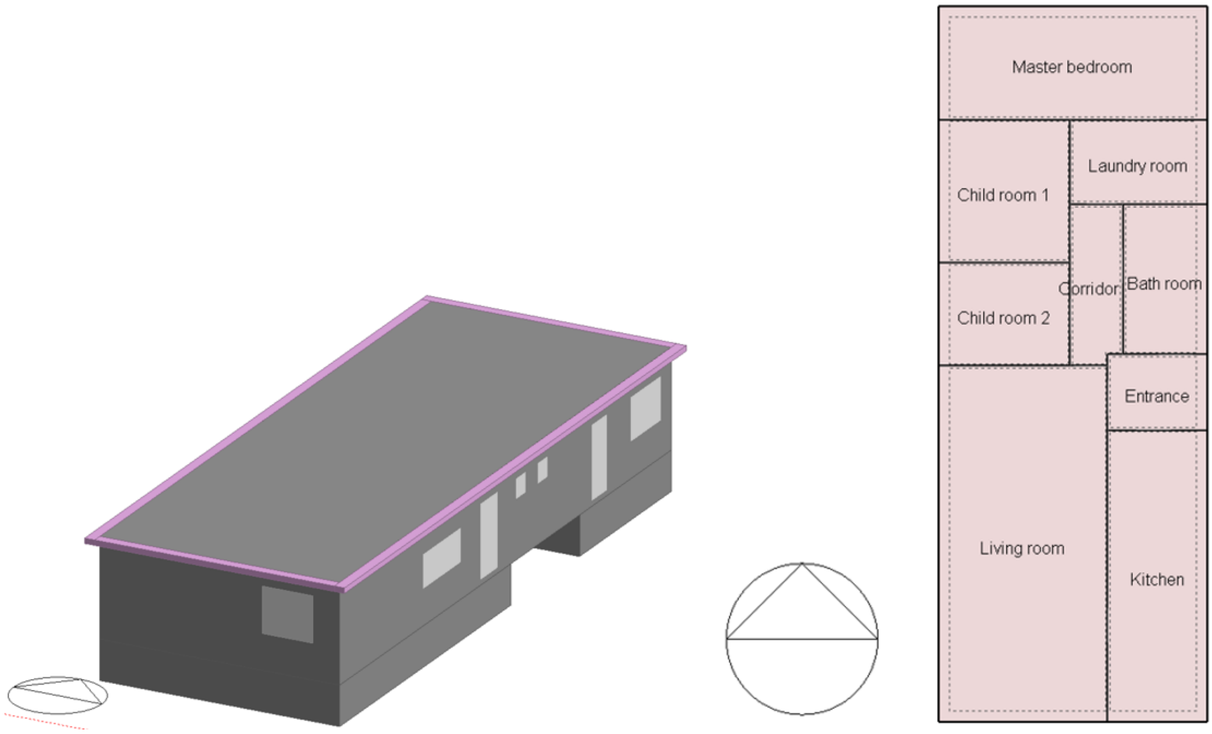

Figure 3.1: Single family house floor plan - Design builder

Regarding the infiltration, DesignBuilder has crack templates that range from Very Poor to

Excellent. Each crack template has different flow rate for each component. See the chosen crack templates for each renovated component and renovation packages in table 3.1.

Table 3.1: The crack template used in simulations in DesignBuilder

Poor	**Medium**	**Good**	**Excellent**
Reference Case	Roof	Wall 1	Package 3
Crawl floor	Semi exposed floor	Wall 2	Package 4
Light wall	Package 1	Wall 3	Package 5
	1 cm mortar	Windows	
	1 cm cement	Package 2	
	5 cm cement		

3.3 Building Materials

The reference case roof consists of wooden rafters with mineral wool insulation between rafters, plaster boards as internal finishing and eternit as external finishing. External walls consists of load-bearing layer of gas concrete, mineral-wool insulation and brick facade, external light weight wall is a wooden carcass with mineral-wool insulation, hardboard outer layer and plasterboard inner layer. Reference case has light weight concrete internal walls and concrete foundation. There is a crawl space under wooden floors in all spaces except bathroom and toilet, where concrete floor with tiles is used with integrated floor heating. Crawl floor consists of gravel, aerated concrete slab, wooden frame with mineral-wool in-between and flooring blocks. Windows are with double glazing and wooden frame. Construction details are shown in table 3.2. Reference Case total U-value is 0,563 [W/m^2.K]

Table 3.2: Reference Case component layers, U-values and areas

Building component	U-value [W/m^2.K]	Area [m^2]	Total thickness [m]	Detailed layers (from outer layer)
External walls	0.421	119.52	0.288	Brick Mineral wool Concrete
External light walls	0.38	4	0.171	Hardboard Bridged inner embrane 2x plaster board
Roof	0.215	116.12	0.28	Zinc plate Bridged mineral wool between wood Hardboard (high density) 2x plaster board
Semi exposed floor	0.535	108.74	0.15	Bridged mineral wool between wood Wooden flooring
Bathroom floor	1.832	7.38	0.196	Gravel Concrete (high density) Vapor membrane Mortar Brick tiles
Windows	2.8	29.7	0.022	Double glazing
Foundation	0.593	67.02	0.288	Concrete
Crawl floor	0.38	110.96	0.35	Gravel Aerated concrete slab Bridged mineral wool between wood Flooring block

The Reference Case detailed construction template with components layers, thickness, density, heat capacity and heat loss through components can be seen in appendix A.1 in table A.1. Figure A.1 shows the components share of the total envelope area and calculated transmission heat losses through the envelope.

3.4 Systems

The Building has two types of heat emitters - floor heating in the bathroom and toilet, and radiators in all other rooms except the corridor. Both of them are modeled in the simulation tool as water-based systems with variable flows between 0-130 l/h with a continuous heating program. The heat it is supplied by a condensing oil boiler as stated in the reference case. The design temperatures for radiators for supply and return 70^{o}C - 40^{o}C respectively and 30^{o}C for the floor the heating system. The heating set-point is chosen to be set at 22^{o}C for the normal operation schedule.

According to the existing case, the house is not provided with mechanical ventilation or a cooling system, though there is natural ventilation in the summer season with a ventilation rate of 1.2 l/s per m^2. Natural ventilation during the heating season corresponds to the air-tightness of the building, with a infiltration rate of 0.32 l/s per m^2 [12]. Designbuilder uses this infiltration rate in heating design (steady state) calculation, while the dynamic simulation is based on the crack template. Domestic hot water production is not taken into account for model simplification purpose.

3.5 Weather Data and Internal Gains

All simulations have been done under the same outdoor conditions. The weather file used is the standard EnergyPlus weather data for Copenhagen from the year 2015. For energy consumption simulations, the entire heating season was considered, from 1^{st} of November1^{st} to the 30^{th} of April. For time constant, the following representative days: 1^{st} of December and 08^{th}, 15^{th}, 22^{th}, 30^{th} of January.

Regarding occupancy and internal gains a typical family case of 4 members was modeled with defined schedule for working days and weekends for each thermal zone with defined densities, seen in Appendix A.4. Overall, during the working days, occupants are not present in the house from 8:00 to 17:00 and from 14:00 to 17:00 during the weekend. Internal gains from lighting and equipment were neglected in order to adjust the initial boundary conditions as similar as the reference study case for energy use comparison. Same condition was applied for the simulation in order to minimize the impact of internal gains and have a better comprehension of the results.

3.6 Simulation Parameters

Heating season energy consumption was simulated with 2 steps per hour, while for the time constant simulation, the accuracy was increased up to 6 steps per hours. Simulations were conducted with minimum 12 warm-up days before the heating cut-off.

4 Study of Typical Renovation Cases

4.1 Simulation Results

4.1.1 Building Components

In figure 4.1, results for the energy saving potential and time constant of each renovated component are presented. Energy consumption was simulated for the entire heating season, while their time constants were simulated for the five representative chosen dates. See detailed table B.1 in Appendix B.1.

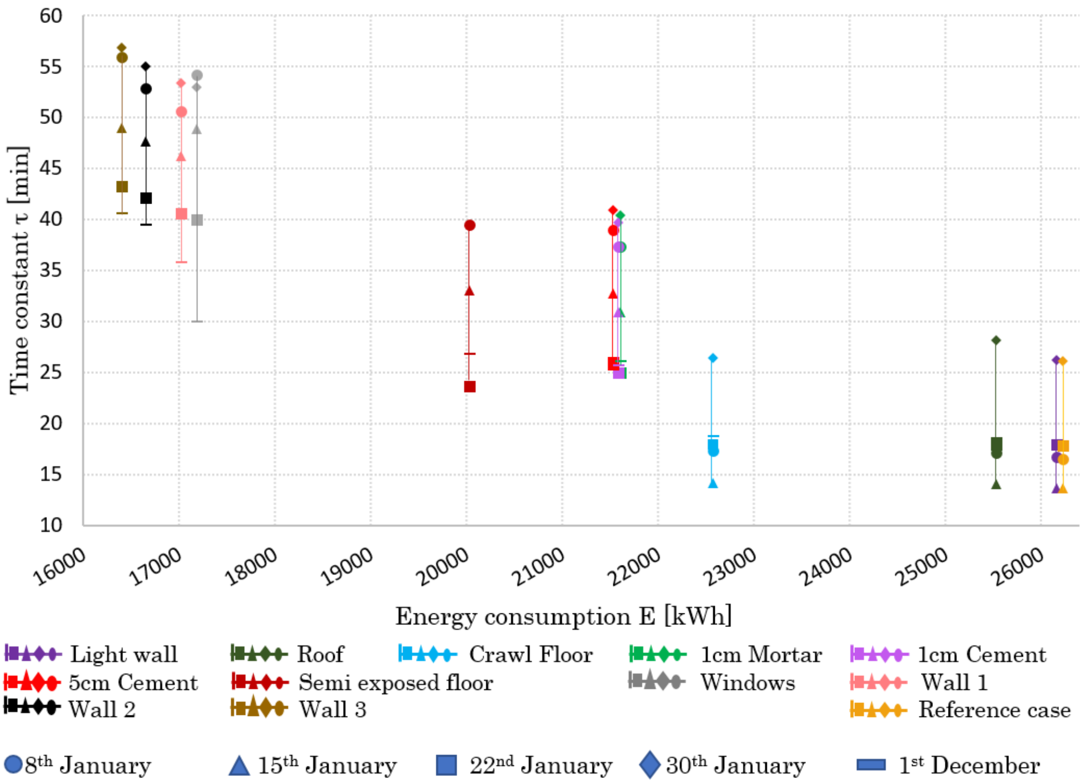

Figure 4.1: Time constant and energy consumption for the renovated components

The results shows three main categories for time constant:

- Roof, crawl floor and light wall provide low increase of time constant during the cut-off. Time constant increase in the coldest day ranges between 0 - 0.8 min. Energy consumption savings in this category are 71.2 and 700 kWh (0.64 - 6.3 kWh/m^2) for light wall and roof respectively, while crawl floor provides higher savings with 3657 kWh (32.9 kWh/m^2).
- Adding internal massive layer of cement or mortar and semi-exposed floor, where the thermal capacity or insulation thickness were improved respectively, provide average

increase of time constant during the heating cut-off. Time constant increase in the coldest day ranges between 7.8 - 8.9 min. Energy consumption savings in this category range between 4618 and 6200 kWh (41.6 - 55.8 kWh/m^2).

- Windows and wall types that tackle directly building's external facade, provide the best increase of time constant during the heating cut-off. Time constant increase in the coldest day ranges between 12.3 - 22.7 min. Energy consumption savings in this category range between 9039 and 9821 kWh (81.4 - 88.5 kWh/m^2). Windows with 5% of the envelope area, are able to offer high savings and long time constant.

4.1.2 Renovation Packages

Figure 4.2, shows the simulated results of renovation packages concerning energy consumption and time constant, where Package 4 obtains the best values for both indicators, where the time constant in the coldest day was increased by 53.8 min and the energy consumption was reduced by 16775 kWh (151.1 kWh/m^2). The highest improvements were obtained in packages 3, 4 and 5, where the external walls and windows are renovated. Package 2, where the external walls are renovated, shows a big improvement in comparison with Package 1. See detailed table B.2 in Appendix B.1.

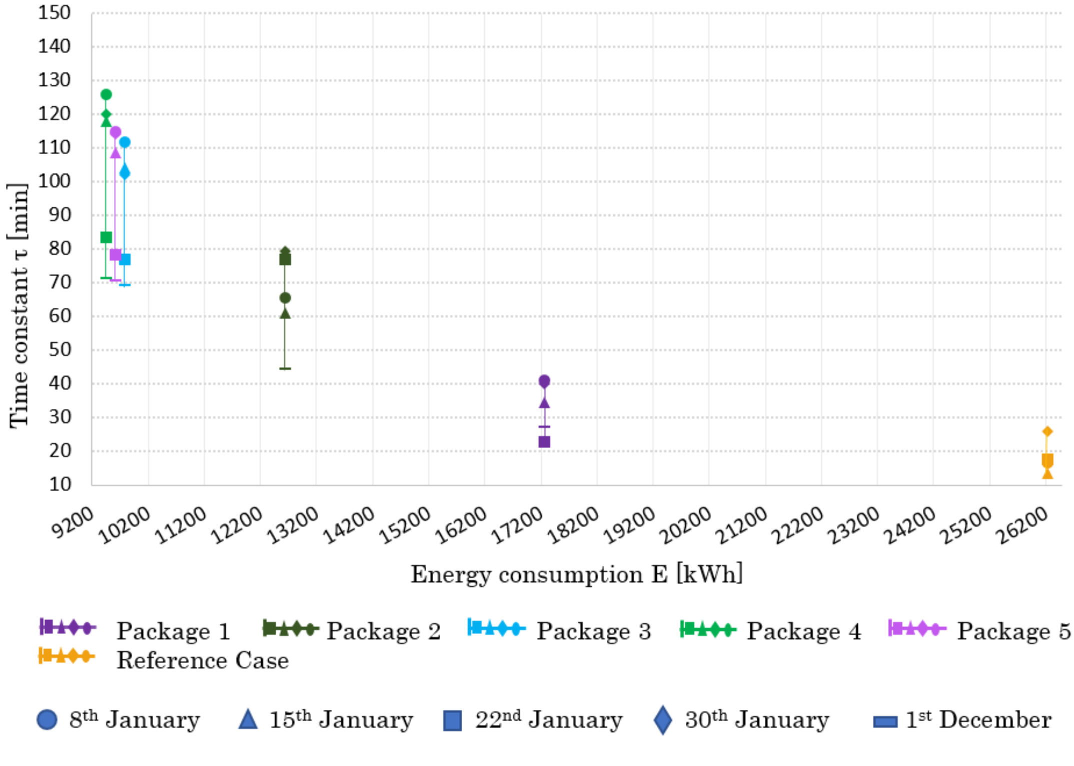

Figure 4.2: Time constant and energy consumption for the renovated Packages

4.2 Analysis of Energy Efficiency

4.2.1 Building Components

The heat balance for the entire heating season of the typical renovation is presented in figure 4.3. Heat balance of gains and losses was extracted from DesignBuilder. Detailed values can be found in figure B.3 and table B.4 in Appendix B.2.

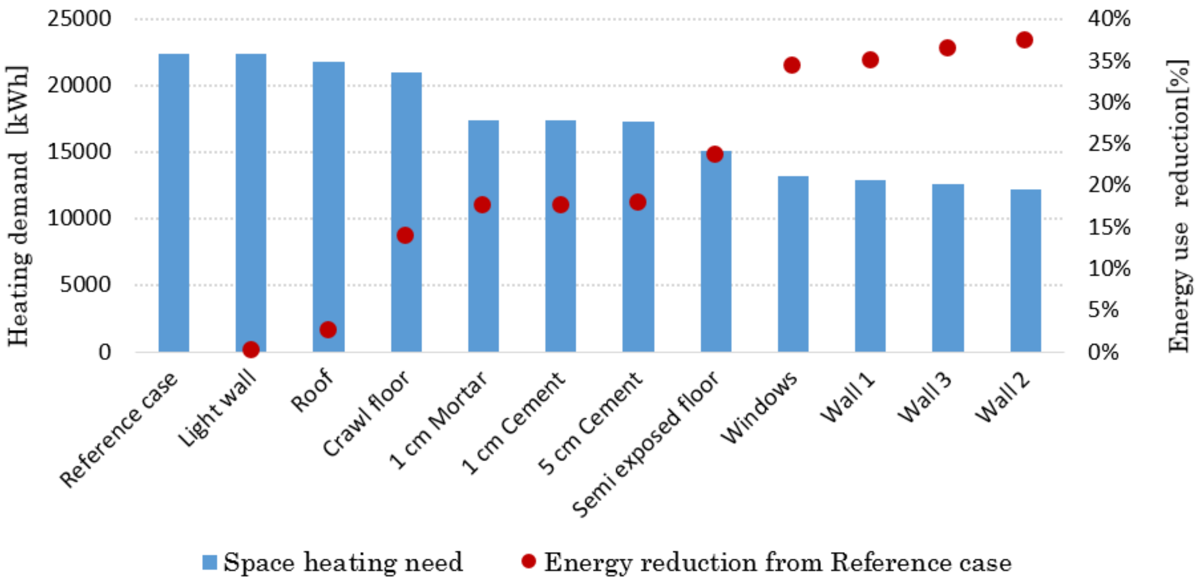

Figure 4.3: Comparison between building heat demand and energy saving for the renovated components

Figure 4.3 shows that renovating the light wall, that is only 4 m^2, does not have notable impact in reducing the energy consumption. Roof, which represents 21% of the envelope area, only slightly reduces the energy consumption, as it has the least improved U-value. Semi exposed floor and crawl floor have highly improved U-value, reducing the consumption by 14 and 26,7 kWh respectively. However, crawl floor is not in direct connection with the heated space or weather conditions, that is why it has lower consumption reduction. Additional internal massive layer (1 and 5 cm cement and 1 cm mortar) reduces the energy consumption, though these renovated components did not improve the external walls U-value (from 0.421 to 0.419 and 0.409 $W/m^2.K$), but they improved the building air tightness. This led to reduced energy consumption up to 17.9%.

Improving the thermal resistance of the external facade elements shows to be the most effective measure for energy efficiency. Windows, which U-Value is reduced from 2.8 to 1.2 $W/m^2.K$, achieves 34.5% energy savings. This is the highest saving per m^2, as windows represent 5.27% of total envelope area . The last investigated building components were the three types of walls with similar U-value of 0.16 [$W/m^2.k$]. From them, wall type 2 showed the highest consumption reduction, as it has the highest insulation thickness, with the highest internal surface temperature. The analyzed wall types temperature profiles can be found in figures B.2, B.3, B.4 and B.5 in appendix B.3

4.2.2 Renovation Packages

As shown in figure 4.4, Package 1 has the lowest savings of energy consumption, since it contains renovated building components that have the least impact on energy consumption reduction. The combination of renovated roof and crawl floor together with additionally renovated foundation, provides energy consumption savings of 34,2 %.

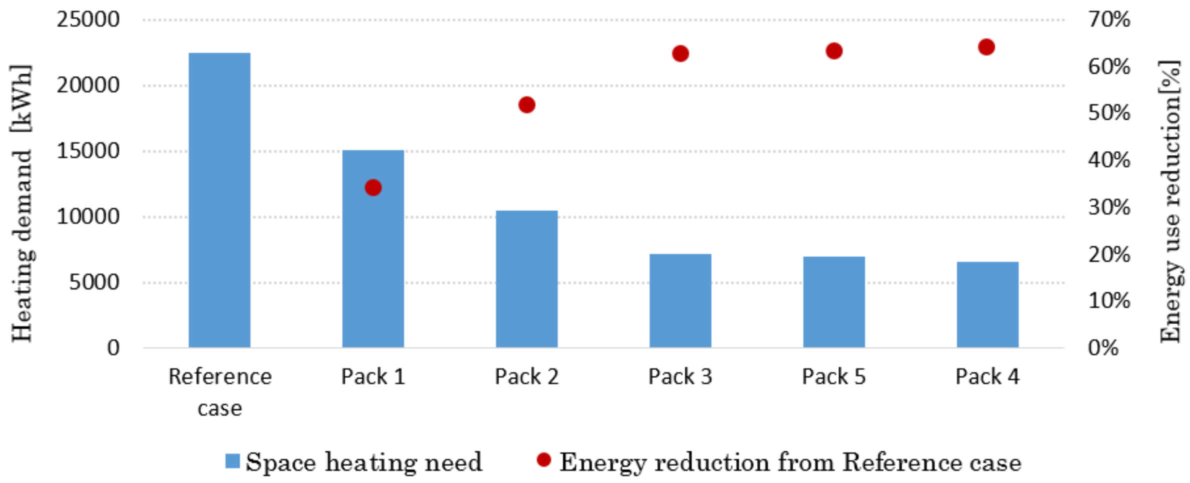

Figure 4.4: Comparison between building heat demand and energy saving for the renovated packages

When combining components with high impact on energy consumption reduction - walls, windows and semi-exposed floor, as it is in Package 4, the reduction escalates up to 65 %.

It can be concluded that the renovated components with the highest improved U-value and direct connection with heated space, have the highest energy consumption reduction.

4.3 Analysis of Energy Flexibility

4.3.1 Weather Impact on Time Constant

In figure 4.1, Reference Case, light wall, roof and crawl floor have the lowest time constant on 15^{th} of January, the windiest chosen date. Since they have a poor and medium crack templates with high infiltration rates, they are the most affected by wind, thus giving lower time constant.

For components and packages where the air-tightness was greatly improved by applying good and excellent crack templates, outdoor temperature variations had the main impact. In these cases, the smallest time constant is on dates with the lowest outdoor temperature (1^{th} of December and 22^{th} of January). Weather data variations for the chosen days under the cut-off period are shown in figure 4.5.

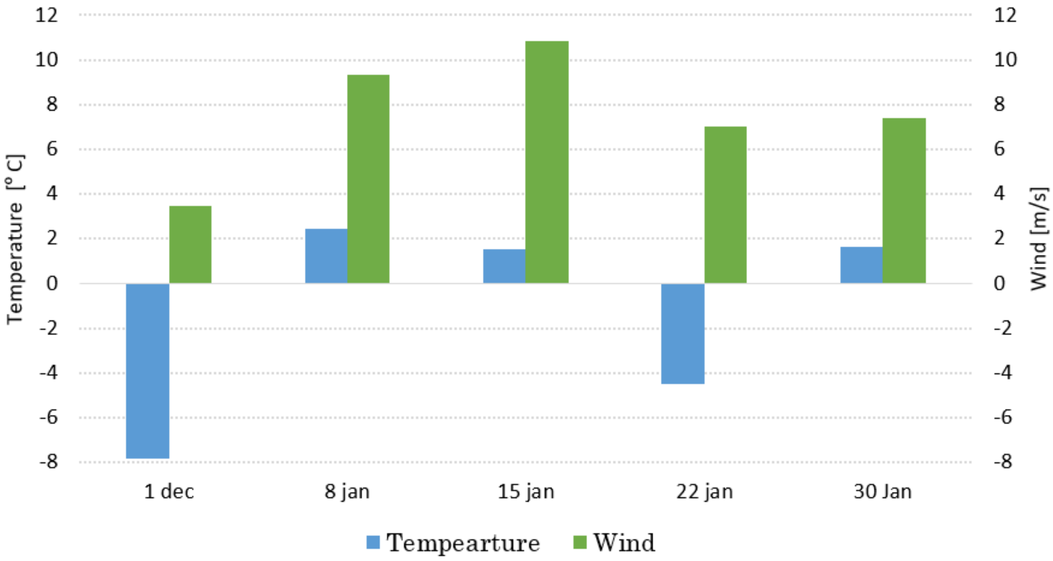

Figure 4.5: Outdoor conditions of the chosen days

4.3.2 Thermal Resistance and Effective Thermal Inertia Calculation

The building total thermal resistance and effective thermal inertia were calculated for the building with different renovation components and renovation packages. This process was conducted to obtain a better understanding of the simulation results. Figures 4.6 and 4.7 show the calculated values for renovated components and renovation packages respectively. See calculation tables in figures C.2 and C.3 in Appendix C.2. See also MATLAB detailed calculations in Appendix C.3.

By comparing figure 4.1 and figure 4.6, it is shown that the renovated components with high time constant, which are wall types and semi exposed floor, are having highest thermal resistances. However these components do not have the highest effective thermal inertia. Crawl floor, light wall and roof, which do not significantly increase the Reference Case thermal resistance, do not significantly increase its time constant either. When the building effective thermal inertia was enlarged by adding 1 cm and 5 cm cement or 1 cm mortar to external wall, its thermal resistance was not improved, though its time constant was increased.

The same result can be obtained by comparing figure 4.2 and figure 4.7, where package 4 increases the time constant the most, because it has the highest thermal resistance not the highest effective thermal inertia.

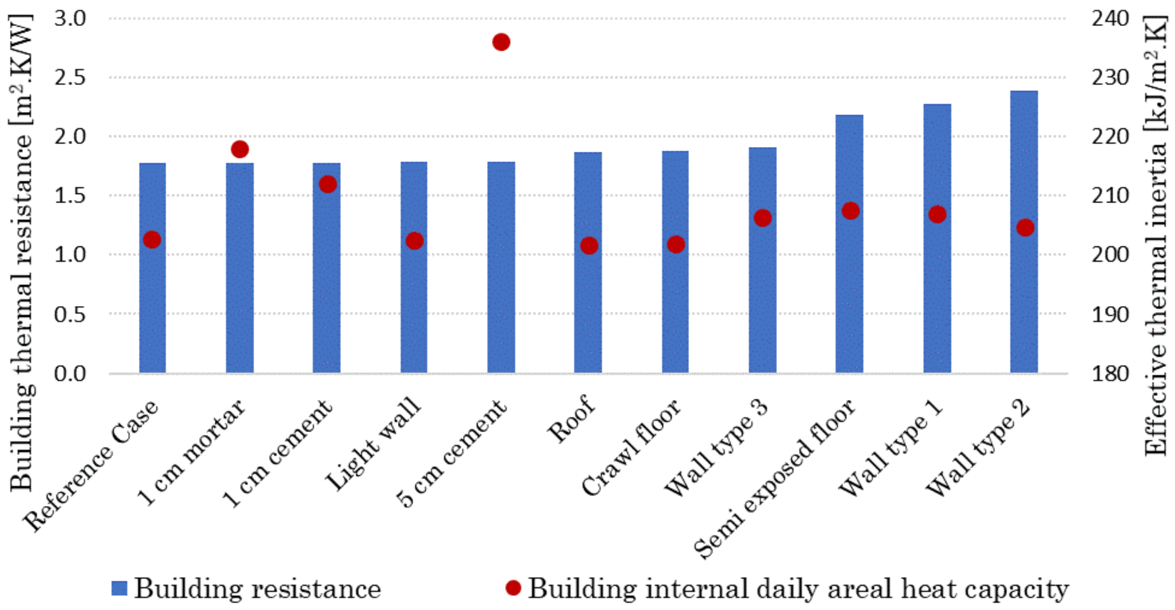

Figure 4.6: Comparison between buildings thermal resistances and effective thermal inertia with different renovated components

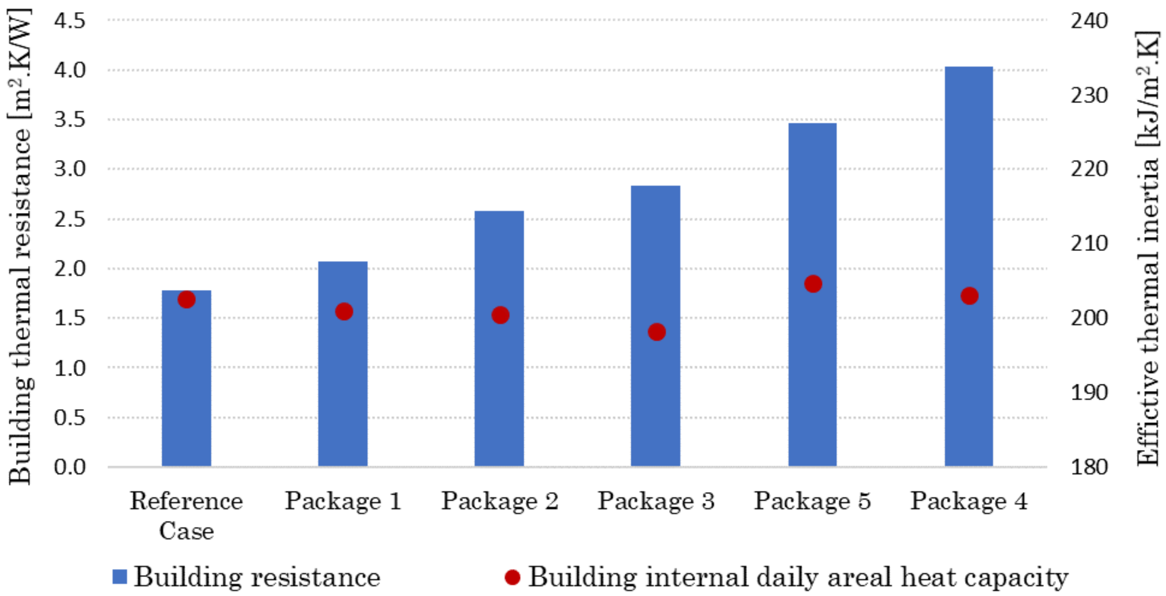

Figure 4.7: Comparison between buildings thermal resistances and effective thermal inertia with different renovation packages

A further analysis was conducted for the suggested renovation on external heavy walls separately, as they represent the building components that significantly affect the energy efficiency and flexibility, as shown in figures A.1 and 4.1.

Table 4.1 shows MATLAB calculation results, where two daily areal heat capacities are shown and they are not equal to each other, as they are related with two different wall surfaces (internal and external surfaces) [14]. The internal areal heat capacity is the one that represents the effective thermal inertia, which is compared between wall types, as it is the one that is connected to the internal space.

Table 4.1: MATLAB calculation of walls heat capacities

External walls	Internal daily areal heat capacity [kJ/m^2.K]	External daily areal heat capacity [kJ/m^2.K]	Total daily areal heat capacity [kJ/m^2.K]	Maximum areal heat capacity [kJ/m^2.K]	Total/ maximum capacity percentage [%]	Wall total thickness [m]
Reference Case	29938	111770	141708	226770	62	0.29
Wall type 1	29485	38213	67698	97496	69	0.33
Wall type 2	27322	5016	32338	231620	14	0.45
Wall type 3	28852	110550	139402	238410	58	0.42
Reference Case with additional 1 cm cement	39093	111650	150743	242390	62	0.30
Reference Case with additional 5 cm cement	62393	110690	173083	304890	57	0.34
Reference Case with additional 1 cm mortar	44974	111590	156564	251850	62	0.30

It can be seen that Reference wall and wall types 1-2-3 have almost the same effective thermal inertia, as it depends on the thickness of the internal massive layer [14], which is the same for all of them (aerated concrete). The small differences can be explained by wall total thicknesses. For example, the reference wall has the largest effective thermal inertia, because it has the lowest thickness and the thinnest insulation, meaning that the temperature variation on one side of the wall might also influences the other side of the wall. Other walls have higher insulation thickness, which decouples the external surfaces from each other.

Walls with different internal massive layer, 1-5 cm cement and 1cm mortar have significantly higher effective thermal inertia.

As a conclusion, the renovated components and renovation packages that have the highest time constant were the ones with improved thermal resistances. Though when the building thermal inertia was increased by adding internal massive layer, its time constant was increased. The impact of combination between improved thermal resistance and increased thermal capacity is further analyzed in Suggested Renovation Packages.

4.4 Sensitivity Analysis

4.4.1 Building components

Each renovated building component results for monthly energy consumption during heating season and time constant has been compared to Reference Case and analyzed with one-way Anova test.

The significance level alpha was chosen as 0.05. If P-value in Anova test is less than 0.05, it means that there is a significant difference between the analyzed data. If P-value is more than 0.05, then there is no significant difference. Significant difference between the groups, which are compared to each other, was referred as True, insignificant different between the groups is referred as False. Results of Anova analysis is shown in table 4.2.

Table 4.2: Anova analysis summary for building component comparison with Reference Case

Building component	**Renovation**		**Renovation**		**Significant difference in energy consumption**	**Significant difference in time constant**
	Average Monthly Consumption (January, December) [kWh]	**Average time constant [min]**	**Average Monthly Consumption (January, December) [kWh]**	**Average time constant [min]**		
Wall type 1	3365.1	45.3	5279.0	18.4	**TRUE**	**TRUE**
Wall type 2	3243.6	49.1	5279.0	18.4	**TRUE**	**TRUE**
Wall type 3	3285.0	44.3	5279.0	18.4	**TRUE**	**TRUE**
Roof	5150.6	19.3	5279.0	18.4	**FALSE**	**FALSE**
Crawl floor	4612.9	18.9	5279.0	18.4	**FALSE**	**FALSE**
Semi exposed floor	4010.5	32.5	5279.0	18.4	**TRUE**	**TRUE**
Light wall	5265.4	18.5	5279.0	18.4	**FALSE**	**FALSE**
1cm Cement	4296.0	31.1	5279.0	18.4	**TRUE**	**TRUE**
5cm Cement	4286.6	33.0	5279.0	18.4	**TRUE**	**TRUE**
Window	3379.9	45.3	5279.0	18.4	**TRUE**	**TRUE**

For Wall Type 1, Wall Type 2, Wall Type 3, Windows, Semi-exposed Floor and additional 5 cm thermal mass on external walls in comparison with Reference Case, the Anova test results stated that the mean values of 5 different points are equal. Because the p-value is less than the alpha, it was concluded, that there is a significant difference.

For Roof, Crawl Floor and External Light Wall in comparison with Reference Case, Anova test results showed that the p-value is larger than alpha, meaning that significant difference does not exists.

In comparison between different wall types, no significant difference in energy consumption and time constant was found, see table 4.3.

Full Anova analysis results are shown in Appendix D

Table 4.3: Anova analysis summary for Wall Type 1, Wall Type 2 and Wall Type 3

Comparison between wall types	Average Monthly Consumption (January, Dcember) [kWh]	Average comfort period after cut-off [min]	Significant difference in comfort period	Significant difference in consumption
Wall type 1	3365.1	45.3	FALSE	FALSE
Wall type 2	3243.6	49.1		
Wall type 3	3285.0	44.3		

4.4.2 Renovation Packages

Each renovation package results for monthly consumption during heating season and time constant has been compared to Reference Case and analyzed with one-way Anova test.

The p-value in all renovation package comparisons to the Reference Case is less than alpha value, which means, that there is significant difference. Table 4.4 shows the results of these comparisons.

Table 4.4: Anova analysis summary for renovation package comparison with Reference Case

Renovation Package	Renovation		Referance case		Significant difference in comfort period	Significant difference in consumption
	Average Monthly Consumption (January, December) [kWh]	Average comfort period after cut-off [min]	Average Monthly Consumption (January, December) [kWh]	Average comfort period after cut-off [min]		
Package 1	3447.7	33.2	5279.0	18.4	TRUE	TRUE
Package 2	2567.2	59.7	5279.0	18.4	TRUE	TRUE
Package 3	2000.7	92.8	5279.0	18.4	TRUE	TRUE
Package 4	1902.7	102.4	5279.0	18.4	TRUE	TRUE
Package 5	1941.0	96.2	5279.0	18.4	TRUE	TRUE

Further tests indicated that there is no significant difference between package 3, 4 and 5, considering time constant. Regarding energy consumption, significant difference was not found between packages 3 and 5. These results are shown in Appendix D in table D.2.

4.5 Initial Investment Analysis

Figures 4.8 and 4.9 show the initial investments of renovated components and renovation packages respectively. Figure 4.9 shows that renovation packages 3, 4 and 5 have the highest initial investment, as they have more renovated components than packages 1 and 2, see table 2.3. Package 4 is the most expensive package with two expensive components - wall type 2 and crawl floor, as shown in figure 4.8. Wall type 1 has the lowest initial investment among wall types, see figure 4.8. See appendix E to find the detailed initial investments of all renovated components and renovation packages.

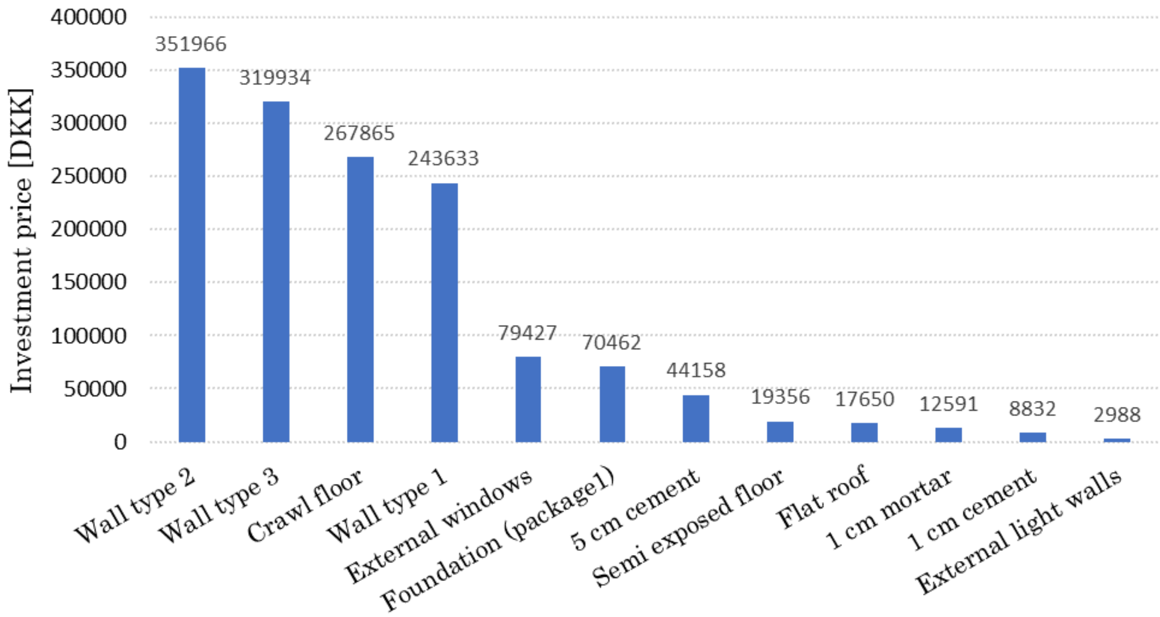

Figure 4.8: Prices of renovated component

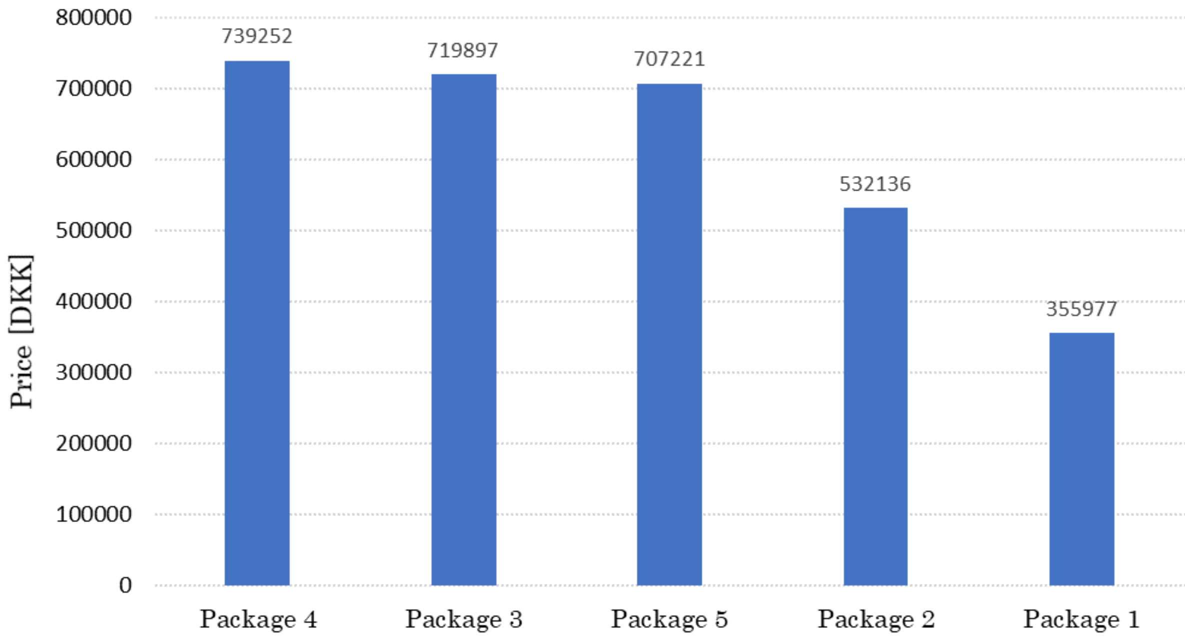

Figure 4.9: Prices of typical renovation packages

4.6 Sub-conclusion

Building energy efficiency analysis, energy flexibility analysis, initial investment analysis and result comparison with Anova test, led to a conclusion, that Package 4 has the best results for energy efficiency and energy flexibility. Even though the initial investment for Package 4 is the highest, the difference between packages 3 and 4 is only 2.6% and between packages 4 and 5 the initial investment difference is only 4.3%. It is concluded, that Package 4 has good potential for further renovation strategy development. Building components of Package 4 have been evaluated and combined with other components, in order to make additional renovation packages that are cost and energy efficient and flexible at the same time.

5 Study of Suggested Renovation Cases

5.1 Suggested Renovation Packages Description

Improvements were applied on package 4, forming new suggested renovation packages 6, 7, 8, 9, 10 and 11.

Table 5.1 shows the renovated components of each suggested renovation package.

Semi exposed floor, windows and doors were renovated in all suggested packages, because their impacts on energy efficiency and flexibility are significant. Light wall was renovated in all suggested packages, because it represents only 4 m^2 and is relatively cheap to renovate, as well as, the technical solutions for external wall renovations requires light wall renovation. Crawl floor was excluded, as it is expensive to renovate and it gives insignificant improvement to energy efficiency and flexibility. Roof was renovated in all suggested packages, because, based on the simulation of heat balance, roof and partitions are the two main components that discharge heat during the heating cut off periods, as shown in table B.5 and figure B.1 in Appendix B.2. Wall type 2 was replaced with wall types 1 and 3 in packages 7 and 11 respectively, as wall type 2 is the most expensive wall and the difference between the three walls impacts on energy efficiency and flexibility is insignificant. 1 cm and 5 cm cement or 1 cm mortar were added on the internal side of the cheapest wall (wall type 1) in the suggested packages 8, 9 and 10 respectively, as they are relatively cheap to add and they increase the calculated effective thermal inertia, as shown in figure 4.6.

Table 5.1: Suggested packages components

Building components	**Package 6**	**Package 7**	**Package 8**	**Package 9**	**Package 10**	**Package 11**
Wall type 1		+	+	+	+	
Wall type 2	+					
Wall type 3						+
Windows	+	+	+	+	+	+
Light wall	+	+	+	+	+	+
Roof	+	+	+	+	+	+
Semi exposed floor	+	+	+	+	+	+
Crawl floor						
1 cm cement			+			
5 cm cement				+		
1 cm mortar					+	

5.2 Simulation Results

Figure 5.1 shows the results of time constants and net present values of all typical and suggested renovation packages. Package 4, that represented the best typical renovation package regarding time constant and yearly energy needed for heating, is not the best regarding the net present value. As shown in figure 5.1, regarding both time constant and net present value, packages 1 and 2 have the highest net present values and the lowest time constants. While package 7 represents the best package, regarding the net present value. In term of time constant, packages (from 3 to 11) have time constant that range between between 60-70 min in the coldest analyzed day (1^{st} December) and between 100-130 min in the warmest analyzed day (8^{th} January). To decide which package represents the optimum package, Anova analysis was conducted.

In Appendix F, see table F.1 to find the time constants and net present values results. To find the LCC analysis, see figure F.1.

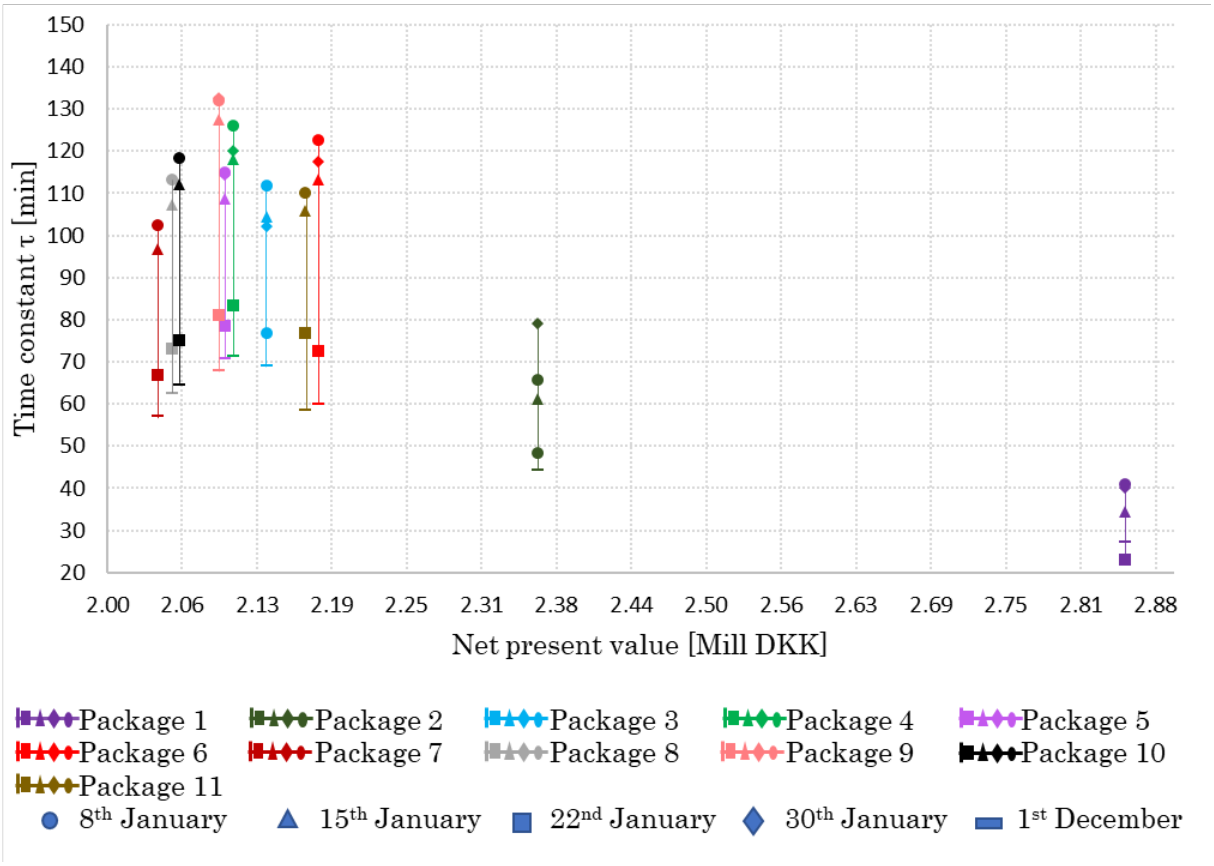

Figure 5.1: Typical and suggested packages results of time constants and net present values

5.3 Sensitivity Analysis

Since it was not found any significant difference in time constant between packages 3, 4 and 5, they were compared to all suggested packages. According to Anova analysis results, packages 3, 4, 5, 6, 7, 8, 9, 10 and 11 have no significant difference. Detailed Anova analysis results can be seen in Appendix D.

Table 5.2: Anova analysis comparison between renovation packages

Time constant	**1-Dec**	**8-Jan**	**15-Jan**	**22-Jan**	**30-Jan**	**Significant difference**
Component	**[min]**	**[min]**	**[min]**	**[min]**	**[min]**	
Package 3	69.2	111.7	104.3	76.9	102.1	**FALSE**
Package 4	71.7	126.0	118.0	83.3	113.2	
Package 5	70.6	115.0	108.8	78.5	108.1	
Package 6	60.0	113.3	72.5	117.5	122.5	
Package 7	57.2	96.7	66.9	102.5	102.5	
Package 8	62.5	107.1	73	113.3	113.3	
Package 9	68.0	127.5	81.1	132.5	132	
Package 10	64.5	112	75	118.3	118.3	
Package 11	58.8	105.7	76.9	110.0	110	

5.4 Sub-conclusion

Since Anova analysis showed no significant difference in time constant between all packages starting from Package 3 to Package 11, then NPV does matter for choosing the final package for control strategy analysis. Package 9 has the largest time constant, while Package 7 has the lowest NPV. Difference in NPV between Packages 7 and 9 is 51501 DKK. The control strategies were applied for Package 7, because of the lowest NPV. Applying the control strategy based on NPV was due to two main reasons:

- Anova analysis showed no significant difference in time constant between Package 7 and Package 9.
- The difference in time constant between Package 7 and Package 9 is only 10 minutes in the coldest day, while the chosen control strategies were made with hourly time interval.

6 | Control Strategies

Figure 6.1 shows the saved energy and the calculated flexibility factor of all analyzed control strategies, that were applied on package 7 during the heating season. All the strategies are acceptable regarding the number of occupied hours outside the thermal comfort band, as they represent less than 3% of total occupied hours, see table G.1, in Appendix G. As shown in figure 6.1, all control strategies have positive flexibility factors, but not all of them save energy in comparison with the continuous heating. Control strategies 6, 8, 9 and 10 increase the flexibility factor, but they increase the energy consumption as well. Control strategies 4, 7 and 10 have almost the same flexibility factors of 0.37 and 0.38, but control strategy number 4 save energy, while number 7 and 10 do not.

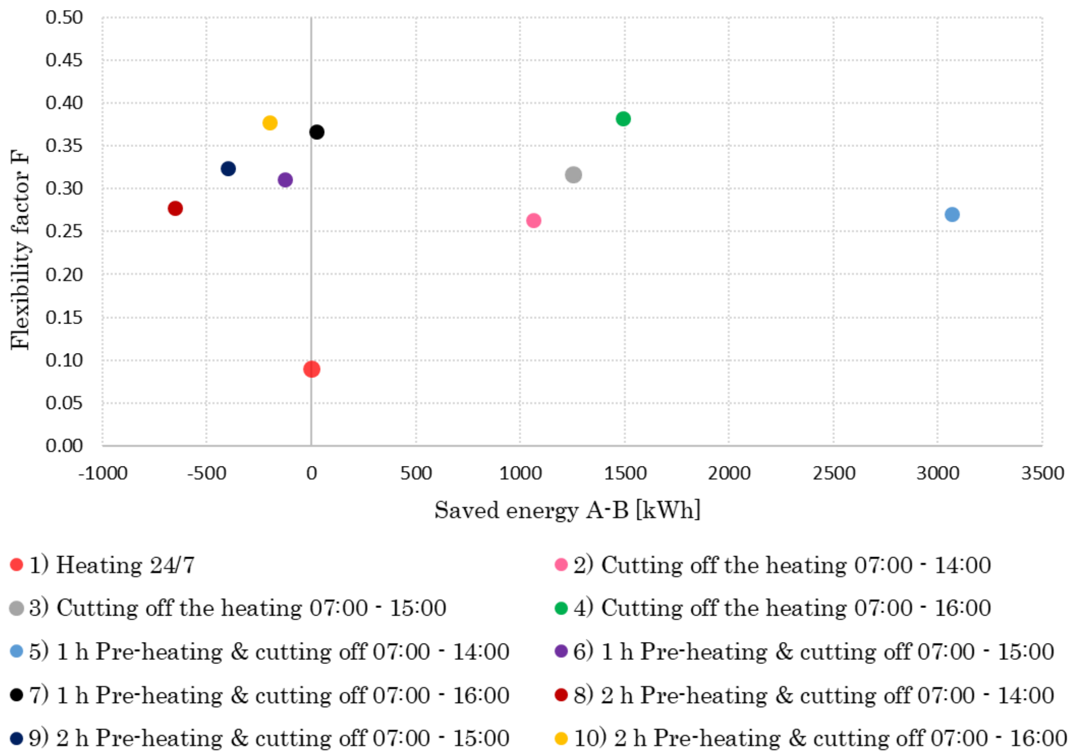

Figure 6.1: Saved energy and flexibility factor of all analyzed control strategies

Choosing between the different control strategies depends on electricity prices. As shown in figure 6.2, for the grid interest, the three strategies provide almost the same flexibility, where the shifted energy will be consumed in the evening, to heat the building after the cut-off period, with control strategy 4. While with control strategies 7 and 10, energy will be consumed in both morning to preheat and evening to heat the building before and after the cut-off periods respectively. For the consumer interest, electricity prices define which control strategy saves more money. If electricity is more expensive during the morning then control strategy number 4 is more beneficial, while if prices are higher in the evening then strategies 7 and 10 are preferable.

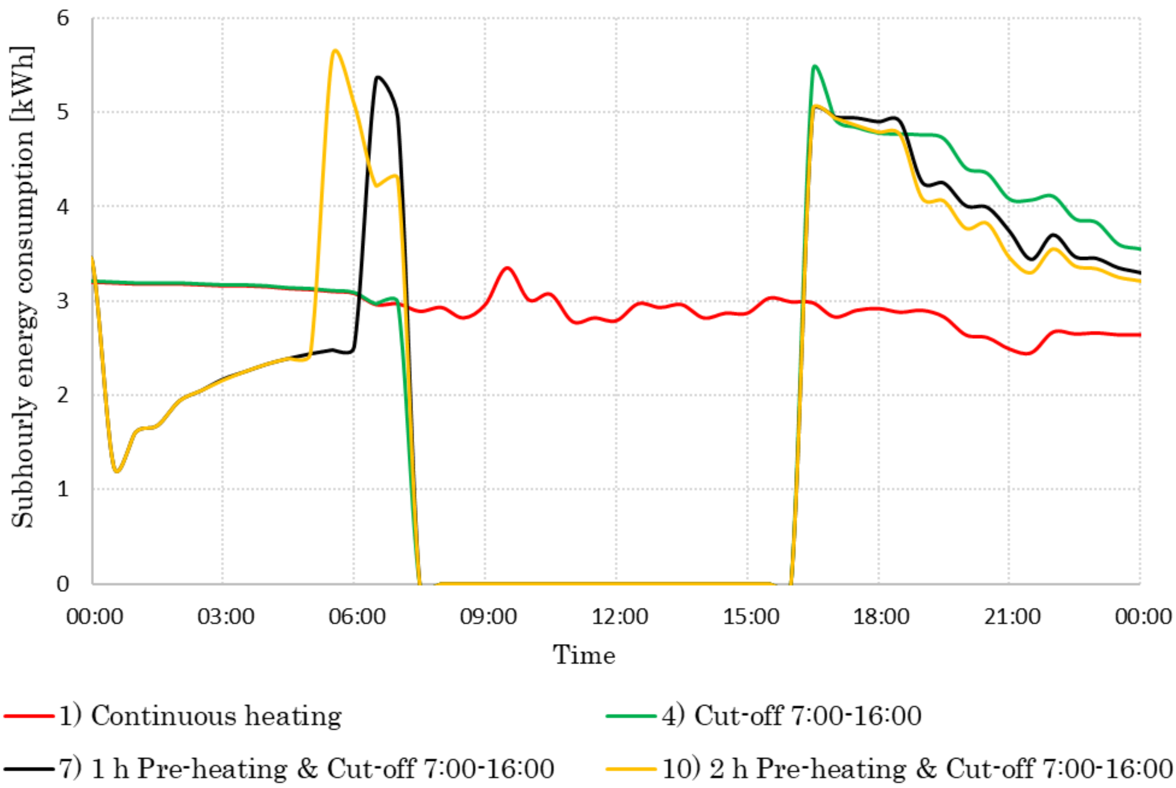

Figure 6.2: Energy consumption with different control strategies

7 | Conclusion

This study was about analyzing the impact of a typical Danish single family house renovation on both energy efficiency and flexibility. Non-renovated single family house from 70's was chosen to be the reference case. The simulated space heating demand during the heating season was 26227.16 kWh (236.3 kWh/m^2), the time constant for energy flexibility during the coldest day was 17.9 min. Typical renovation packages decreased the space heating need by 34.2% and 63.96% for Package 1 (light renovation) and Package 4 (integral renovation) respectively, while single building component renovation reduced the space heating up to 34,47% and 37,45%, for renovated windows and wall type 2 respectively. The results showed that changing one building component from the external facade, like windows or the external walls, reduces the energy need more than choosing renovation Package 1. The same result was observed for energy flexibility where the building component renovation increased the time constant in the coldest chosen day to 40.6 min with wall type 2, while renovation packages increased the time constant to 40 min and 132 min with Package 1 and Package 9 respectively.

The placement of the renovated components showed an important impact on energy efficiency and flexibility, where the components that have the highest energy savings and longest time constant are the ones that tackle the building's external facade and are in contact with the heated space. External walls and windows improve the energy efficiency and flexibility the most, followed by the semi exposed floor. Roof did not show noticeable savings, simply because its U-value was not greatly improved. Windows showed significant improvement for energy consumption and time constant even with low share of the building envelope (5%).

Since the building time constant is affected by the thermal resistance and effective thermal inertia, this study attempted to define which of them is the key factor. It was found that both efficiency and flexibility are affected by building thermal resistance more than its effective thermal inertia. Increasing the effective thermal inertia, by adding massive internal layer on the external walls, improved the building efficiency and flexibility, but the improvement was mostly due to the reduced infiltration. This result was demonstrated by comparing Package 7, that have wall type 1, with packages 8, 9 and 10 that have the same wall type, combined with different additional massive internal layers. The comparison showed that packages 8, 9 and 10 have insignificantly increased time constant and have higher energy consumption. Though, the compared energy consumption between these packages was simulated with continuous heating, meaning that the ability of the added massive layer, in packages 8, 9 and 10, to discharge heat during the cut-off periods was not activated. To evaluate the impact of the internal massive layer that was added on external walls of some of the suggested packages, LCC analysis was conducted to compare packages 7 and 9 under heating cut-off 7:00 – 16:00 instead of continuous heating. LCC analysis shows that the break-even point is after 12 years and the savings that Package 9 provides is 146050 [DKK], see figure F.2 and table F.2.

The optimal package (Package 7), that was chosen in terms of NPV, reduced the Reference Case consumption by 55.72% and increased its time constant in the coldest day by 39.3 min. All control strategies that were analyzed on Package 7 heating system, include a cut-off during the electricity grid high demand period. Applying the cut-off between 07:00 - 16:00 during the heating season, could increase the heating system flexibility factor from 0.09 under continuous operation up to 0.39. Electricity grid benefits from reduced energy consumption and the improved time constant that are combined with a proper control strategy, as this will shift the energy consumption from high to low demand periods.

It was found that renovating the building components that tackles the external facade (windows and external walls) are the ones that reduces the heat loss the most, by means of improved U-value and air-tightness. Overall, the report proves that the building envelope thermal resistance has a great importance for both energy efficiency and flexibility, since it conserves the heat indoors. Increasing the building thermal mass have low initial investment, though it increases the building heat storage capacity, thus its flexibility. Similar conclusions were drawn in other researches, thus emphasizing the firmness of the obtained results in this study case.

It is known that investing in renovation strategies that optimize the energy efficiency is long term beneficial. This study demonstrates that investing in measures to improve building flexibility will increase the economical benefits for both the owner and the grid.

Even though there are already studies about energy flexibility, the topic is promising and more research can be done in terms of utilization of energy flexibility. Since all energy grids in Denmark are undergoing great change to reach the goal of 100 % independence of fossil fuels, investigating the impact of single family houses flexibility, that account for 60% of the heated residential floor area in Denmark, on different energy grids has a great importance.

8 | Future Works

- Control strategy: Analyzing more control strategy possibilities would help in increasing the heating system flexibility factor. Additionally, heating system control strategy could be designed in response to electricity prices signal instead of electricity demand signal.
- Effective thermal inertia: The additional massive layer could be applied on the roof and internal partitions, as they represents the components that discharged the heat the most during the cut-off period. The continuous heating that was applied on simulation models with different renovated components and renovation packages to compare the energy consumption, could be replaced by a cut-off control strategy during the entire heating season, which would utilize the full effect of the effective thermal inertia in storing and discharging heat.
- Weather impact: More knowledge can be gained evaluating the impact of different weather climates on building flexibility.
- Building systems: Analyzing the impact of renovating the building systems on energy efficiency and flexibility, such as changing the heating system emitters or applying a ventilation system.

Bibliography

[1] Communication From The Commission To The European Parliament; The Council; The European Economic, Social Committee, and The Committee Of The Regions. Energy roadmap 2050, Brussels, 15 December 2011.

[2] Danish Energy Agency. The danish energy model, 2015.

[3] G. Reynders; T. Nuytten and D. Saelens. Potential of structural thermal mass for demand-side management in dwellings. *Building and Environment*, 64:187–199, June 2013.

[4] Søren Østergaard Jensen; Anna Marszal-Pomianowska; Roberto Lollini; Wilmer Pasut; Armin Knotzer; Peter Engelmann; Anne Stafford and Glenn Reynders. Iea ebc annex 67 energy flexible buildings. *Energy and buildings*, 155:25–34, November 2017.

[5] Nordic Energy Research. Denmark: Danish energy used mostly in buildings. http://www.nordicenergy.org/figure/energy-consumption-by-sector/danish-energy-used-mostly-in-buildings/, 2013.

[6] Kragh J. and Wittchen K. B. Development of two danish building typologies for residential buildings. *Energy and buildings*, 68, Part A:79–86, January 2014.

[7] Hicham Johra; Per Heiselberg and Jérôme Le Dréau. Influence of envelope, structural thermal mass and indoor content on the building heating energy flexibility. *Energy and Buildings*, 183:325–339, 15 January 2019.

[8] Trevor Moffiet; Dariusz Alterman; Stuart Hands; Kim Colyvas; Adrian Page and Behdad Moghtaderi. A statistical study on the combined effects of wall thermal mass and thermal resistance on internal air temperatures. 2015.

[9] Sarran Lucile; Kyriaki Foteinaki; Panagiota Gianniou and Carsten Rode. Impact of building design parameters on thermal energy flexibility in a low-energy building, 2017.

[10] Jérôme Le Dréau and Per Heiselberg. Energy flexibility of residential buildings using short term heat storage in the thermal mass. *Energy*, 111:991–1002, September 2016.

[11] Nord Pool. Historical market data. https://www.nordpoolgroup.com/historical-market-data/, 2018.

[12] Michal Pomianowski; Yovko Ivanov Antonov and Per Heiselberg. Development of energy renovation packages for danish residential single family houses - “parcel houses”, May 2018.

[13] Dgnb system denmark, dansk bæredygtighedscertificering, 2016.

[14] Elśbieta Kossecka. The effect of structure and thickness on periodic thermal capacity of building components. Technical report, 2007.

[15] Iso 13786:2007: Thermal performance of building components, dynamic thermal characteristics, calculation methods, December 2007.

[16] Mingzhe Liu. Control and analysis of building energy systems - dynamic modelling (cabes 4). Technical report, 2018.

[17] Johan Hedbrant. On the thermal inertia and time constant of single-family houses, 2001.

[18] One way anova. https://statistics.laerd.com/statistical-guides/one-way-anova-statistical-guide.php.

[19] Anna Marszal Pomianowska. Environmental assessment methods and life cycle cost analysis = economic sustainability, 2018.

[20] El priser privatbolig. https://www.vivaenergi.dk/El priser og afgifter, August 2016.

[21] Input-parametre til indeklimaet ved design og bestemmelse af bygningers energimæssige ydeevne vedrørende indendørs luftkvalitet, termisk miljø, belysning og akustik., 2007.

[22] Jérôme Le Dréau. Demand side management of the heating need in residential buildings, 2001.

A Model

A.1 Reference Case Construction Analysis

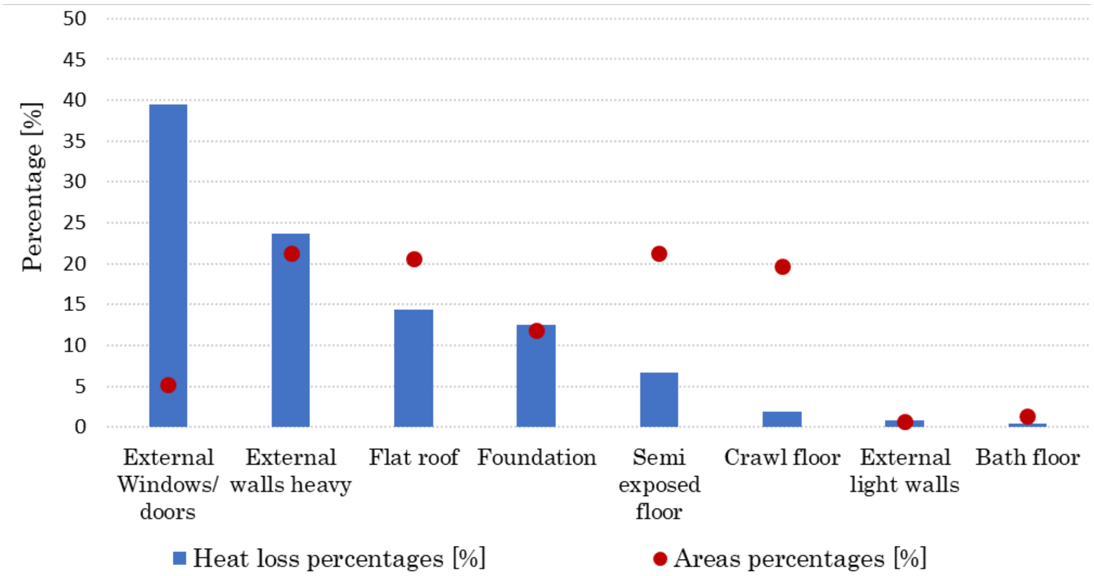

Figure A.1: Components share of the total envelope area and transmission heat losses through the envelope

Table A.1: Building construction template, Reference Case

Reference Case	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920	840	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140	840	1.49			
				Concrete	0.11	0.19	480	840	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900	2000	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140	840	1.67			
				Wood	10%		650	2120				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800	896	0.10			
				plaster board	0.025	0.25	2800	896	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200	380	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140	840	3.37			
				Wood	10%		650	2120				
				Hard board (high density)	0.02	1.34	1010	1340	0.01			
				Plaster board	0.025	0.17	2800	896	0.15			
				Plaster board	0.025	0.17	2800	896	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140	840	0.84	1.196	90.92	454.59
				wood	10%		650	2120				
				Timber flooring	0.02	0.14	650	1200	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840	840	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400	1000	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890	880	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480	840	1.52	2.146	31.24	843.35
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840	840	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500	840	0.50			
				neniral wool between wood	0.045	0.049	140	840	0.92			
				Wood	10%		2800	896	0.00			
				Flooring Blocks	0.02	0.14	650	1200	0.14			

A.2 Renovated Building Components

Table A.2: Characteristics of the renovated windows

Direction	**Placement**	**U_w [W/m^2.K]**	**G_w**	**E_{ref} [kWh/m^2/year]**
South	Kitchen	1.291	0.536	-11.5027
East	Kitchen	1.068	0.410	-16.0426
East	Toilet	0.973	0.378	-13.7112
East	Bath	0.973	0.378	-13.7112
East	Master bedroom	1.064	0.410	-15.7106
West	Living window	1.266	0.536	-9.20657
West	Living door	1.294	0.536	-11.7258
West	Living window	1.288	0.536	-11.2148
West	Child room 2 window	1.301	0.536	-12.4149
West	Child room 1 window	1.290	0.536	-11.408
West	Master bedroom	1.290	0.536	-11.4073

Table A.3: Building construction template with renovated crawl floor

Construction template - Crawl floor	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m^2.K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920.00	840.00	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.203	1.82	58.09
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001	0.17	650.00	2120.00	0.01			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polysterene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480.00	840.00	1.52	2.146	31.24	843.35
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded polysterene	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.4: Building construction template with renovated roof

Construction template - Roof	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920.00	840.00	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480.00	840.00	1.52	2.146	31.24	843.35
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				meniral wool between wood	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.5: Building construction template with renovated semi exposed floor

Construction template - Semi exposed floor	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity Λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920.00	840.00	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.233	108.74	0.25	Mineral wool	0.02	0.038	140.00	710.00	0.53	3.418	31.812	159.059
				Bridged meniral wool	0.13	0.0512	140.00	710.00	2.54			
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480.00	840.00	1.52	2.146	31.24	843.35
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.6: Building construction template with renovated external heavy walls - wall type 1

Construction template - Wall type 1	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.16	119.52	0.33	Brick tiles	0.02	0.8	1890.00	880.00	0.03	6.253	19.11	611.61
				Insulation	0.2	0.0365	140.00	710.00	5.48			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	(0,13 m)	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.4	67.024	0.33	Fiber/cement board	0.02	0.25	1400.00	840.00	0.08	2.959	22.650	724.799
				XPS extruded polysteren	0.022	0.03	35.00	1400.00	0.73			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.7: Building construction template with renovated external heavy walls - wall type 2

Construction template - Wall type 2	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m^2.K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.159	119.52	0.448	Fiber board	0.01	0.06	300.00	1000.00	0.17	6.305	18.96	606.61
				Mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Brick	0.108	0.72	1920.00	840.00	0.15			
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.155	67.024	0.448	Fiber/cement board	0.02	0.25	1400.00	840.00	0.08	6.892	9.724	311.176
				XPS extruded polysteren	0.14	0.03	35.00	1400.00	4.67			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.8: Building construction template with renovated external heavy walls - wall type 3

Construction template - Wall type 3	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.162	119.52	0.418	Brick	0.108	0.72	1920.00	840.00	0.15	6.162	19.40	620.67
				Insulation	0.2	0.038	140.00	710.00	5.26			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.418	Concrete	0.418	0.19	480.00	840.00	2.20	1.686	39.745	1271.847
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.884	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.9: Building construction template with renovated Light wall

Construction template - Light wall	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m^2.K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920.00	840.00	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.152	4	0.321	Hardboard	0.02	0.13	900.00	2000.00	0.15	7.197	0.56	17.78
				imneral wool	0.15	0.03	140.00	710.00	5.00			
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200.00	380.00	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840.00	840.00	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400.00	1000.00	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890.00	880.00	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480.00	840.00	1.52	2.146	31.24	843.35
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840.00	840.00	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				meniral wool between wood	0.045	0.049	140.00	840.00	0.92			
				Wood	10%		2800.00	896.00	0.00			
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.10: Building construction template with addition of 1 cm cement on the internal side of external walls

Construction template - 1 cm cement	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m^2.K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.298	Brick	0.108	0.72	1920	840	0.15	2.402	49.75	1592.14
				Insulation	0.07	0.047	140	840	1.49			
				Concrete	0.11	0.19	480	840	0.58			
				1cm cement	0.01	0.72	1860	840	0.01			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900	2000	0.15	2.197	1.82	58.25
				Bridged ineral wool	0.1	0.05975	140	840	1.67			
				Wood	10%		650	2120				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800	896	0.10			
				plaster board	0.025	0.25	2800	896	0.10			
Flat roof	0.215	116.12	0.28	Zink	0.01	110	7200	380	0.00	3.822	30.38	972.27
				Bridged mineral wool	0.2	0.0593	140	840	3.37			
				Wood	10%		650	2120				
				Hard board (high density)	0.02	1.34	1010	1340	0.01			
				Plaster board	0.025	0.17	2800	896	0.15			
				Plaster board	0.025	0.17	2800	896	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140	840	0.84	1.196	90.92	454.59
				wood	10%		650	2120				
				Timber flooring	0.02	0.14	650	1200	0.14			
Bath floor	1.832	7.38	0.196	Gravel	0.075	0.36	1840	840	0.21	1.996	3.70	36.97
				Concrete (high density)	0.08	2	2400	1000	0.04			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1890	880	0.03			
External doors	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows - 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.288	Concrete	0.288	0.19	480	840	1.52	2.146	31.24	843.35
Crawl floor	0.38	110.96	0.35	Gravel	0.2	0.36	1840	840	0.56	4.287	25.88	129.42
				Aerated concrete slab	0.08	0.16	500	840	0.50			
				meniral wool between wood	0.045	0.049	140	840	0.92			
				Wood	10%		2800	896	0.00			
				Flooring Blocks	0.02	0.14	650	1200	0.14			

Table A.11: Building construction template with addition of 5 cm cement on the internal side of external walls

Construction template - 5 cm cement	U-value [w/m².k]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity ʎ [w/(m.k)]	Density ρ [kg/m³]	Capacity c [J/(kg.k)]	Detailed Thermal resistance per component [m².k/w]	Thermal resistance per component [m2.k/w]	Specific transmittion heat loss per component [w/k]	Transmittion heat loss [w]
External walls heavy	0,421	119,52	0,338	Brick	0,108	0,72	1920	840	0,15	2,458	48,63	1556,15
				Insulation	0,07	0,047	140	840	1,49			
				Concrete	0,11	0,19	480	840	0,58			
				5 cm cement	0,05	0,72	1860	840	0,07			
External light walls	0,38	4	0,171	Hardboard	0,02	0,13	900	2000	0,15	2,197	1,82	58,25
				Bridged ineral wool	0,1	0,05975	140	840	1,67			
				Wood	10%		650	2120				
				Vapor membrane	0,001				0,00			
				plaster board	0,025	0,25	2800	896	0,10			
				plaster board	0,025	0,25	2800	896	0,10			
Flat roof	0,215	116,12	0,28	Zink	0,01	110	7200	380	0,00	3,822	30,38	972,27
				Bridged mineral wool	0,2	0,0593	140	840	3,37			
				Wood	10%		650	2120				
				Hard board (high density)	0,02	1,34	1010	1340	0,01			
				Plaster board	0,025	0,17	2800	896	0,15			
				Plaster board	0,025	0,17	2800	896	0,15			
Semi exposed floor	0,535	108,74	0,15	Bridged meniral wool	0,05	0,0593	140	840	0,84	1,196	90,92	454,59
				wood	10%		650	2120				
				Timber flooring	0,02	0,14	650	1200	0,14			
Bath floor	1,832	7,38	0,196	Gravel	0,075	0,36	1840	840	0,21	1,996	3,70	36,97
				Concrete (high density)	0,08	2	2400	1000	0,04			
				Vapor membrane	0,001				0,00			
				Mortar	0,02	0,38	1120	840	0,05			
				Brick tiles	0,02	0,8	1890	880	0,03			
External doors	2,836	4,36	0,042		0,042	0,8	2579	792	0,05	0,353	12,36	395,68
Windows -2,8	2,8	24,62	0,022		0,022	0,8	2579	792	0,03	0,357	68,94	2205,95
Windows - 2,9	2,9	0,72	0,022		0,022	0,8	2579	792	0,03	0,345	2,09	66,82
Foundation	0,593	67,024	0,288	Concrete	0,288	0,19	480	840	1,52	2,146	31,24	843,35
Crawl floor	0,38	110,96	0,35	Gravel	0,2	0,36	1840	840	0,56	4,287	25,88	129,42
				Aerated concrete slab	0,08	0,16	500	840	0,50			
				meniral wool between wood	0,045	0,049	140	840	0,92			
				Wood	10%		2800	896	0,00			
				Flooring Blocks	0,02	0,14	650	1200	0,14			

Table A.12: Building construction template with addition of 1 cm mortar on the internal side of external walls

Construction template - 1 Cm mortar	U-value [w/m².k]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [w/(m.k)]	Density ρ [kg/m³]	Capacity c [J/(kg.k)]	Detailed Thermal resistance per component [m².k/w]	Thermal resistance per component [m2.k/w]	Specific transmittion heat loss per component [w/k]	Transmittion heat loss [w]
External walls heavy	0,421	119,52	0,298	Brick	0,108	0,72	1920	840	0,15	2,400	49,81	1593,82
				Insulation	0,07	0,047	140	840	1,49			
				Concrete	0,11	0,19	480	840	0,58			
				1 cm mortar	0,01	0,88	2800	896	0,01			
External light walls	0,38	4	0,171	Hardboard	0,02	0,13	900	2000	0,15	2,197	1,82	58,25
				Bridged ineral wool	0,1	0,05975	140	840	1,67			
				Wood	10%		650	2120				
				Vapor membrane	0,001				0,00			
				plaster board	0,025	0,25	2800	896	0,10			
				plaster board	0,025	0,25	2800	896	0,10			
Flat roof	0,215	116,12	0,28	Zink	0,01	110	7200	380	0,00	3,822	30,38	972,27
				Bridged mineral wool	0,2	0,0593	140	840	3,37			
				Wood	10%		650	2120				
				Hard board (high density)	0,02	1,34	1010	1340	0,01			
				Plaster board	0,025	0,17	2800	896	0,15			
				Plaster board	0,025	0,17	2800	896	0,15			
Semi exposed floor	0,535	108,74	0,15	Bridged meniral wool	0,05	0,0593	140	840	0,84	1,196	90,92	454,59
				wood	10%		650	2120				
				Timber flooring	0,02	0,14	650	1200	0,14			
Bath floor	1,832	7,38	0,196	Gravel	0,075	0,36	1840	840	0,21	1,996	3,70	36,97
				Concrete (high density)	0,08	2	2400	1000	0,04			
				Vapor membrane	0,001				0,00			
				Mortar	0,02	0,38	1120	840	0,05			
				Brick tiles	0,02	0,8	1890	880	0,03			
External doors	2,836	4,36	0,042		0,042	0,8	2579	792	0,05	0,353	12,36	395,68
Windows -2,8	2,8	24,62	0,022		0,022	0,8	2579	792	0,03	0,357	68,94	2205,95
Windows - 2,9	2,9	0,72	0,022		0,022	0,8	2579	792	0,03	0,345	2,09	66,82
Foundation	0,593	67,024	0,288	Concrete	0,288	0,19	480	840	1,52	2,146	31,24	843,35
Crawl floor	0,38	110,96	0,35	Gravel	0,2	0,36	1840	840	0,56	4,287	25,88	129,42
				Aerated concrete slab	0,08	0,16	500	840	0,50			
				meniral wool between wood	0,045	0,049	140	840	0,92			
				Wood	10%		2800	896	0,00			
				Flooring Blocks	0,02	0,14	650	1200	0,14			

A.3 Renovation Packages

Table A.13: Building construction template with renovation package 1

Construction template - Package 1	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component [m².K/W]	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.421	119.52	0.288	Brick	0.108	0.72	1920.00	840.00	0.15	2.388	50.04	1601.40
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.38	4	0.171	Hardboard	0.02	0.13	900.00	2000.00	0.15	2.203	1.82	58.09
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001	0.17	650.00	2120.00	0.01			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Bridged ineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged ineral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polystyrene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.593	67.024	0.3488	Fiber cement coard	0.01	0.25	1400	840	0.04	3.88	17.28	466.51
				XPS Extruded polystyrene	0.0508	0.03	35.00	1400.00	1.69			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.14: Building construction template with renovation package 2

Construction template Package 2	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.16	119.52	0.33	Brick tiles	0.02	0.8	1890.00	880.00	0.03	6.253	19.11	611.61
				Insulation	0.2	0.0365	140.00	710.00	5.48			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.152	4	0.321	Hardboard	0.02	0.13	900.00	2000.00	0.15	7.197	0.56	17.78
				imneral wool	0.15	0.03	140.00	710.00	5.00			
				ted ineral wool between v	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				ed mineral wool between	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	ed meniral wool between	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polystyrene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External	2.836	4.36	0.042		0.042	0.8	2579	792	0.05	0.353	12.36	395.68
Windows -2,8	2.8	24.62	0.022		0.022	0.8	2579	792	0.03	0.357	68.94	2205.95
Windows- 2,9	2.9	0.72	0.022		0.022	0.8	2579	792	0.03	0.345	2.09	66.82
Foundation	0.4	67.024	0.33	Fiber/cement board	0.02	0.25	1400.00	840.00	0.08	2.959	22.650	724.799
				XPS extruded polysteren	0.022	0.03	35.00	1400.00	0.73			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded polystyrene	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				eniral wool between woo	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.15: Building construction template with renovation package 3

Construction template - Package 3	U-value [W/m^2.K]	Areas [m^2]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m^3]	Capacity c [J/kg.K]	Detailed Thermal resistance per component	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.159	119.52	0.448	Fiber board	0.01	0.06	300.00	1000.00	0.17	6.305	18.96	606.61
				Mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Brick	0.108	0.72	1920.00	840.00	0.15			
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.152	4	0.321	Hardboard	0.02	0.13	900.00	2000.00	0.15	7.197	0.56	17.78
				imneral wool	0.15	0.03	140.00	710.00	5.00			
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Bridged ineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.535	108.74	0.15	Bridged meniral wool	0.05	0.0593	140.00	840.00	0.84	1.196	90.92	454.59
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polystyrene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External	2.836	4.36	0.042		0.06	0.8	2579	792	0.08	0.353	12.36	395.68
Windows	1.2	24.62	0.022		0.022	0.8	2579	792	0.03	0.833	29.54	945.41
Windows	0.97	0.72	0.022		0.022	0.8	2579	792	0.03	1.031	0.70	22.35
Foundation	0.593	67.024	0.3488	Fiber cement coard	0.01	0.25	1400	840	0.04	3.88	17.28	466.51
				XPS Extruded polystyrene	0.0508	0.03	35.00	1400.00	1.69			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded polystyrene	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.16: Building construction template with renovation package 4

Construction template - Package 4	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.159	119.52	0.448	Fiber board	0.01	0.06	300.00	1000.00	0.17	6.305	18.96	606.61
				Mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Brick	0.108	0.72	1920.00	840.00	0.15			
				Insulation	0.07	0.047	140.00	840.00	1.49			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.152	4	0.321	Hardboard	0.02	0.13	900.00	2000.00	0.15	7.197	0.56	17.78
				imneral wool	0.15	0.03	140.00	710.00	5.00			
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Bridged ineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high density)	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.233	108.74	0.25	Mineral wool	0.02	0.038	140.00	710.00	0.53	3.418	31.812	159.059
				Bridged ineral wool	0.13	0.0512	140.00	710.00	2.54			
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polystyrene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External	2.836	4.36	0.042		0.06	0.8	2579	792	0.08	0.353	12.36	395.68
Windows	1.2	24.62	0.022		0.022	0.8	2579	792	0.03	0.833	29.54	945.41
Windows	0.97	0.72	0.022		0.022	0.8	2579	792	0.03	1.031	0.70	22.35
Foundation	0.593	67.024	0.3488	Fiber cement coard	0.01	0.25	1400	840	0.04	3.88	17.28	466.51
				XPS Extruded polystyrene	0.0508	0.03	35.00	1400.00	1.69			
				Concrete	0.288	0.19	480.00	840.00	1.52			
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded polystyrene	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

Table A.17: Building construction template with renovation package 5

Construction template - Package 5	U-value [W/m².K]	Areas [m²]	Total thickness [m]	Detailed layers	Detailed thicknesses [m]	Thermal conductivity λ [W/m.K]	Density ρ [kg/m³]	Capacity c [J/kg.K]	Detailed Thermal resistance per component	Thermal resistance per component [m2.K/W]	Specific transmittion heat loss per component [W/K]	Transmittion heat loss [W]
External walls heavy	0.162	119.52	0.418	Brick	0.108	0.72	1920.00	840.00	0.15	6.162	19.40	620.67
				Insulation	0.2	0.038	140.00	710.00	5.26			
				Concrete	0.11	0.19	480.00	840.00	0.58			
External light walls	0.152	4	0.321	Hardboard	0.02	0.13	900.00	2000.00	0.15	7.197	0.56	17.78
				imneral wool	0.15	0.03	140.00	710.00	5.00			
				Bridged ineral wool	0.1	0.05975	140.00	840.00	1.67			
				Wood	10%		650.00	2120.00				
				Vapor membrane	0.001				0.00			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
				plaster board	0.025	0.25	2800.00	896.00	0.10			
Flat roof	0.119	116.12	0.43	Zink	0.01	110	7200.00	380.00	0.00	7.572	15.34	490.75
				New mineral wool	0.15	0.04	12.00	1030.00	3.75			
				Bridged mineral wool	0.2	0.0593	140.00	840.00	3.37			
				Wood	10%		650.00	2120.00				
				Hard board (high	0.02	1.34	1010.00	1340.00	0.01			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
				Plaster board	0.025	0.17	2800.00	896.00	0.15			
Semi exposed floor	0.233	108.74	0.25	Mineral wool	0.02	0.038	140.00	710.00	0.53	3.418	31.812	159.059
				Bridged meniral wool	0.13	0.0512	140.00	710.00	2.54			
				wood	10%		650.00	2120.00				
				Timber flooring	0.02	0.14	650.00	1200.00	0.14			
Bath floor	0.103	7.38	0.771	Gravel	0.4	0.36	1840.00	840.00	1.11	2.986	2.47	24.71
				XPS Extruded polystyrene	0.25	2	2400.00	1000.00	0.13			
				Concrete (high density)	0.08	0.38	1120.00	840.00	0.00			
				Vapor membrane	0.001				0.00			
				Mortar	0.02	0.38	1120	840	0.05			
				Brick tiles	0.02	0.8	1860.00	880.00	0.03			
External	2.836	4.36	0.042		0.06	0.8	2579	792	0.08	0.353	12.36	395.68
Windows	1.2	24.62	0.022		0.022	0.8	2579	792	0.03	0.833	29.54	945.41
Windows	0.97	0.72	0.022		0.022	0.8	2579	792	0.03	1.031	0.70	22.35
Foundation	0.593	67.024	0.418	Concrete	0.418	0.19	480.00	840.00	2.20	1.686	39.745	1271.847
Crawl floor	0.109	110.96	0.601	Gravel	0.2	0.36	1840.00	840.00	0.56	10.537	10.53	52.65
				EPS Expanded	0.25	0.04	15.00	1400.00	6.25			
				Aerated concrete slab	0.08	0.16	500.00	840.00	0.50			
				Vapor membrane	0.001				0.00			
				Bridged meniral wool	0.045	0.049	140.00	840.00	0.92			
				wood	10%		2800.00	896.00				
				Flooring Blocks	0.02	0.14	650.00	1200.00	0.14			

A.4 Occupancy Schedules

Working days	Total				Living room				Master bedroom				Child room 1				Child room 2				Kitchen				Bathroom			
time\ppl	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
23:00				4						2			1				1											
22:00				4						2			1				1											
21:00				4		2							1				1											
20:00				4			3																		1			
19:30				4			3																		1			
19:00				4				4																				
18:30				4				4																				
18:00				4			3														1							
17:30				4			3														1							
17:00				4			3														1							
16:00																												
15:00																												
14:00																												
13:00																												
12:00																												
11:00																												
10:00																												
9:30																												
9:00																												
8:30																												
8:00																												
7:30			3			2																			1			
7:00			3			2																			1			
6:00				4									1				1				1				1			
5:00				4						2			1				1											
4:00				4						2			1				1											
3:00				4						2			1				1											
2:00				4						2			1				1											
1:00				4						2			1				1											
0:00				4						2			1				1											

Table A.18: Occupancy schedule for working days

Weekend	Total				Living room				Master bedroom				Child room 1				Child room 2				Kitchen				Bathroom			
time\ppl	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
23:00				4						2			1				1											
22:00				4						2			1				1											
21:00				4		2							1				1											
20:00				4			3																		1			
19:30				4			3																		1			
19:00				4			3																		1			
18:30				4				4																				
18:00				4				4																				
17:30				4		2																2						
17:00				4				4																				
16:00																												
15:00																												
14:00																												
13:00				4				4																				
12:00				4				4																				
11:00		2				2																						
10:00		2				2																						
9:30				4			3																		1			
9:00				4				4																				
8:30				4					1				1				1				1							
8:00				4						2			1				1											
7:30				4						2			1				1											
7:00				4						2			1				1											
6:00				4						2			1				1											
5:00				4						2			1				1											
4:00				4						2			1				1											
3:00				4						2			1				1											
2:00				4						2			1				1											
1:00				4						2			1				1											
0:00				4						2			1				1											

Table A.19: Occupancy schedule for weekends

B Typical renovation

B.1 Main results

Table B.1: Energy consumption and time constant of the renovated components

Renovated building components	Time constant [min]					Monthly energy consumption [kWh]		Heating season energy consumption [kWh]
	8^{th} Jan.	**15^{th} Jan.**	**22^{nd} Jan.**	**30^{th} Jan.**	**1^{th} Dec.**	**Jaunuary**	**December**	**1^{st} Nov. to 30^{st} Apr.**
Reference Case	16.5	13.6	17.8	26.1	17.9	5467.1	5091.0	26227.16
Light wall	16.7	13.6	17.9	26.2	17.9	5453.3	5077.4	26155.89
Roof	17.1	14.1	18.6	28.1	18.6	5342.4	4958.9	25526.27
Crawl floor	17.3	14.2	17.9	26.4	18.7	4778.3	4447.5	22569.76
1cm mortar	37.3	30.9	25.0	40.4	26.1	4376.8	4225.3	21608.80
1cm cement	37.3	30.9	25.0	39.7	25.7	4371.8	4220.2	21586.92
5cm Cement	39.0	32.7	25.8	41.0	26.4	4361.6	4211.6	21529.93
Semi exposed floor	39.5	33	23.6	39.4	26.8	4084.2	3936.8	20028.34
Window	54.20	48.9	40.0	53.0	30.2	3401.2	3358.6	17187.43
Wall type 1	50.60	46.2	40.6	53.3	35.8	3389.5	3340.7	17024.99
Wall type 3	52.90	47.6	42.10	39.5	39.5	3313.2	3256.9	16646.70
Wall type 2	55.90	49.0	43.3	56.8	40.6	3260.8	3226.3	16405.39

Table B.2: Energy consumption and time constant of the renovation packages

Renovated building components	Time constant [min]					Monthly energy consumption [kWh]		Heating season energy consumption [kWh]
	8^{th} Jan.	**15^{th} Jan.**	**22^{nd} Jan.**	**30^{th} Jan.**	**1^{th} Dec.**	**Jaunuary**	**December**	**1^{st} Nov. to 30^{st} Apr.**
Reference Case	16.5	13.6	17.8	26.1	17.9	5467.1	5091.0	26227.16
Package 1	41.0	34.5	23.0	40.0	27.4	3507.7	3387.7	17252.97
Package 2	65.6	61.1	48.3	79.2	44.4	2583.9	2550.4	12637.50
Package 11	110	106	77	110	59	2365	2347	11939.91
Package 6	122.5	113.3	72.5	117.5	60	2324	2317	11792.83
Package 9	132	127.5	81.1	132.5	68	2311	2296	11664.79
Package 10	118.3	112	75	118.3	64.6	2312	2297	11656.77
Package 8	113.3	107.1	73	113.3	62.5	2308	2292	11638.22
Package 7	102.5	96.7	67	102.5	57.2	2304	2288	11613.99
Package 3	111.7	104.3	76.9	102.1	69.2	1980.5	2020.8	9777.30
Package 5	115.0	108.8	78.5	108.1	70.6	1941	1941	9623.19
Package 4	126.0	118.0	83.3	120	71.7	1897	1909	9452.25

B.2 Heat Balance

Table B.3: Detailed heat balance

	Transmission loss heated zone [kWh]					Ventilation loss [kWh]		Gains [kWh]		Transmission loss un-heated zone [kWh]		Q. Loss (T) [kWh]	Q. Loss (V) [kWh]	Total Loss (T+V) [kWh]	Q. Gains (Internal+ solar) [kWh]	Total Heat demand [kWh]
	Glazing	External Wall	Semi exposed Floor	Partitions	Roof	Int. Natural vent.	Infiltration	Occupancy	Solar Gains	Foundation Walls	Crawl Floor					
Reference case	-4818.52	-4080.95	-2162.29	-55.15	-2307.32	-570.01	-9046.19	820.68	1562.04	-777.98	-988.52	-15190.72	-9616.21	-24806.92	2382.72	-22424.20
Light wall	-4818.25	-4080.83	-2161.94	-55.78	-2307.44	-571.84	-9041.24	820.68	1562.04	-778.56	-989.25	-15192.05	-9613.08	-24805.13	2382.72	-22422.41
Roof	-4825.11	-4352.82	-2144.03	-48.42	-1283.14	-543.93	-9166.03	820.68	1569.32	-793.37	-1008.06	-14454.95	-9709.96	-24164.91	2390.00	-21774.91
Crawl floor	-4827.35	-4096.03	-1851.67	-67.83	-2313.11	-487.65	-8469.27	820.68	1562.04	-978.12	-343.60	-14477.71	-8956.91	-23434.63	2382.72	-21051.90
1 cm mortar	-4792.95	-4021.90	-2178.47	-43.81	-2286.75	-316.91	-4539.70	820.68	1562.04	-727.93	-925.15	-14976.96	-4856.61	-19833.57	2382.72	-17450.85
1 cm cement	-4791.59	-4015.19	-2178.95	-43.68	-2287.28	-317.76	-4542.97	820.68	1562.04	-728.37	-925.72	-14970.78	-4860.73	-19831.51	2382.72	-17448.79
5 cm cement	-4790.01	-3931.54	-2178.40	-44.30	-2286.26	-314.66	-4539.42	820.68	1562.04	-727.37	-924.45	-14882.33	-4854.08	-19736.41	2382.72	-17353.69
Semi exposed floor	-4804.74	-4079.87	-1222.60	-30.86	-2289.52	-326.01	-3939.17	820.68	1561.87	-352.26	-468.17	-13248.00	-4265.18	-17513.18	2382.55	-15130.63
Pack 1	-4816.60	-4199.05	-1597.41	-51.48	-1277.19	-252.51	-4360.90	820.68	1569.32	-548.72	-391.40	-12881.86	-4613.40	-17495.26	2390.00	-15105.26
Windows	-2418.20	-4027.89	-2209.60	-40.26	-2267.61	-162.06	-2671.59	820.68	1339.50	-695.61	-883.38	-12542.55	-2833.65	-15376.20	2160.18	-13216.01
Wall 1	-4782.28	-1623.29	-2133.32	-40.93	-2317.10	-171.62	-2631.94	820.68	1515.36	-523.97	-1000.33	-12421.23	-2803.55	-15224.78	2336.04	-12888.74
Wall 3	-4765.44	-1676.29	-2234.71	-33.37	-2395.36	-196.00	-1967.17	820.68	1424.17	-546.60	-1016.00	-12667.77	-2163.17	-14830.95	2244.85	-12586.10
Wall 2	-4761.69	-1541.37	-2078.39	-32.17	-2423.51	-190.54	-1965.84	820.68	1395.12	-231.64	-1183.55	-12252.31	-2156.37	-14408.68	2215.80	-12192.88
Pack 2	-4800.64	-1734.89	-1762.88	-42.93	-1293.49	-134.76	-1967.71	798.67	1522.11	-687.52	-362.58	-10684.92	-2102.47	-12787.39	2320.79	-10466.60
Pack 11	-2416.10	-1813.12	-1298.83	-51.94	-1385.85	-98.85	-1776.96	820.68	1426.16	-253.37	-478.17	-7697.38	-1875.81	-9573.19	2246.84	-7326.35
Pack 6	-2413.54	-1681.48	-1272.02	-51.84	-1401.10	-99.53	-1825.37	820.68	1396.83	-111.14	-565.82	-7496.93	-1924.90	-9421.84	2217.51	-7204.32
Pack 9	-2409.04	-1757.62	-1311.66	-27.99	-1393.95	-20.76	-1764.58	820.68	1387.27	-235.68	-461.76	-7597.70	-1785.34	-9383.04	2207.95	-7175.09
Pack 10	-2410.39	-1757.49	-1312.66	-28.14	-1395.11	-20.63	-1761.85	820.68	1387.11	-235.97	-462.30	-7602.06	-1782.48	-9384.54	2207.79	-7176.75
Pack 8	-2410.99	-1754.29	-1300.01	-28.14	-1395.30	-21.06	-1767.71	820.68	1387.27	-248.00	-485.95	-7622.68	-1788.77	-9411.45	2207.95	-7203.50
Pack 7	-2412.81	-1750.33	-1314.13	-28.24	-1396.37	-21.11	-1758.79	820.68	1401.70	-236.39	-463.12	-7601.39	-1779.90	-9381.29	2222.38	-7158.91
Pack 3	-2417.96	-1646.40	-1537.55	-47.33	-1352.16	-67.86	-1787.12	820.68	1397.02	-153.11	-362.58	-7517.09	-1854.99	-9372.08	2217.70	-7154.38
Pack 5	-2422.87	-1810.79	-1181.97	-43.65	-1337.60	-73.71	-1795.03	820.68	1426.23	-365.98	-190.61	-7353.47	-1868.74	-9222.21	2246.91	-6975.30
Pack 4	-2421.19	-1659.55	-1099.30	-42.91	-1353.69	-70.14	-1788.15	820.68	1396.87	-170.11	-243.98	-6990.71	-1858.29	-8849.00	2217.55	-6631.45

Table B.4: Total consumption and energy reduction percentages

Building components and packages	**Total energy consumption [kWh]**	**Total energy consumption [kWh/m^2]**	**Energy consumption reduction [%]**
Reference case	26227.16	236.28	0.00 %
Light wall	26155.89	235.64	0.27 %
Roof	25526.27	229.97	2.67 %
Crawl floor	22569.76	203.33	13.95 %
1 cm mortar	21608.80	194.67	17.61 %
1 cm cement	21586.92	194.48	17.69 %
5 cm cement	21529.93	193.96	17.91 %
Semi exposed floor	20028.34	180.44	23.64 %
Package 1	17252.97	155.43	34.22 %
Windows	17187.43	154.84	34.47 %
Wall type 1	17024.99	153.38	35.09 %
Wall type 3	16646.70	149.97	36.53 %
Wall type 2	16405.39	147.80	37.45 %
Package 2	12637.50	113.85	51.82 %
Package 11	11939.91	107.57	54.48 %
Package 6	11792.83	106.24	55.04 %
Package 9	11664.79	105.09	55.52 %
Package 10	11656.77	105.02	55.55 %
Package 8	11638.22	104.85	55.63 %
Package 7	11613.99	104.63	55.72 %
Package 3	9777.30	88.08	62.72 %
Package 5	9623.19	86.70	63.31 %
Package 4	9452.25	85.16	63.96 %

Table B.5: Heat balance during cut-off from the thermal mass components

Renovated building components	**Delivered heat to building components [kWh] 07:00-12:00**			
	Semi exposed floor	**Internal walls**	**Roof**	**External walls**
Reference Case	2794.28	17155.51	33489.33	-7824.91
Light wall	2719.32	17101.11	33294.56	-7881.85
Roof	1847.77	17161.49	38793.87	-9526.21
Semi exposed floor	2716.04	161.35.83	27907.22	-8418.20
Crawl floor	4577.28	16575.29	31582.59	-8418.20
1 cm mortar	-525.92	15723.85	26610.49	-3899.85
1 cm cement	-204.17	15911.62	27413.29	-5638.50
5 cm cement	-1773.60	14879.25	23495.61	3146.36
Wall type 2	-1715.42	14320.74	20652.48	2880.20
Wall type 3	-2720.46	14756.18	21092.35	1783.47
Wall type 1	-2359.82	15038.68	20718.97	2031.22
Windows	-2986.25	13962.87	21162.35	-10992.54

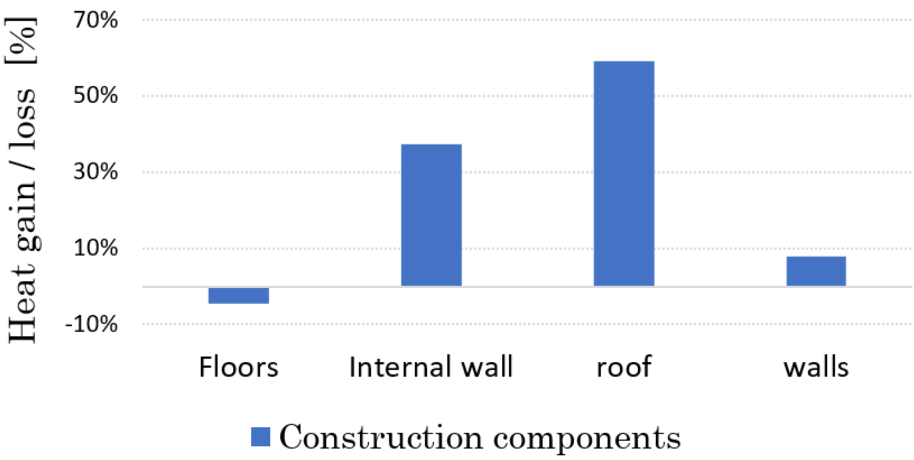

Figure B.1: Components heat discharged during cut-off period

B.3 Walls Temperature Profiles

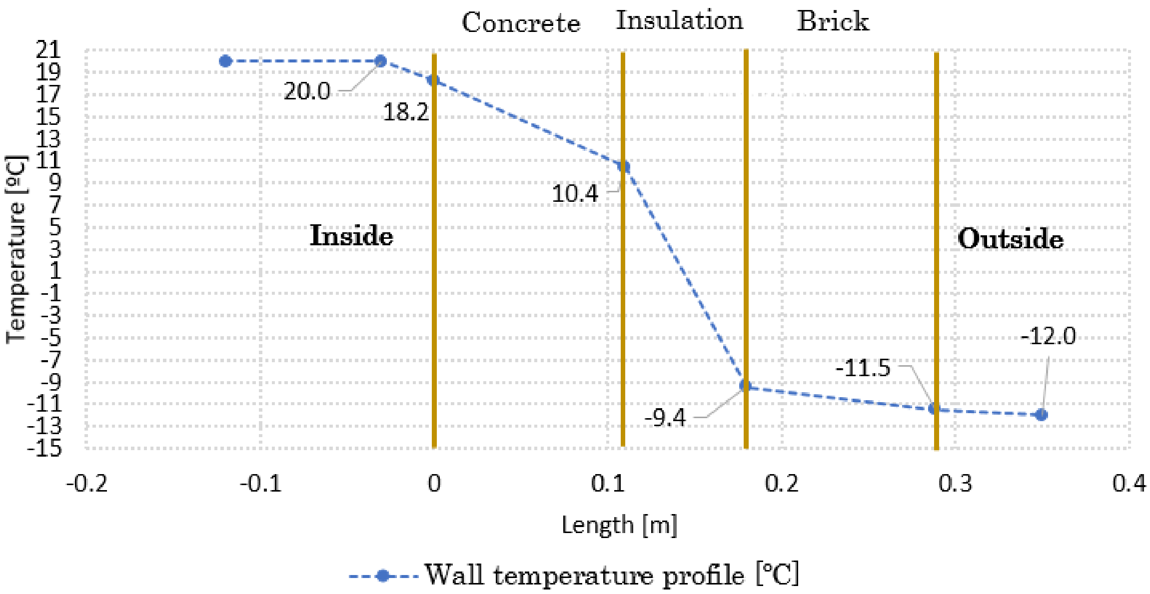

Figure B.2: Temperature profile from Reference Case wall type

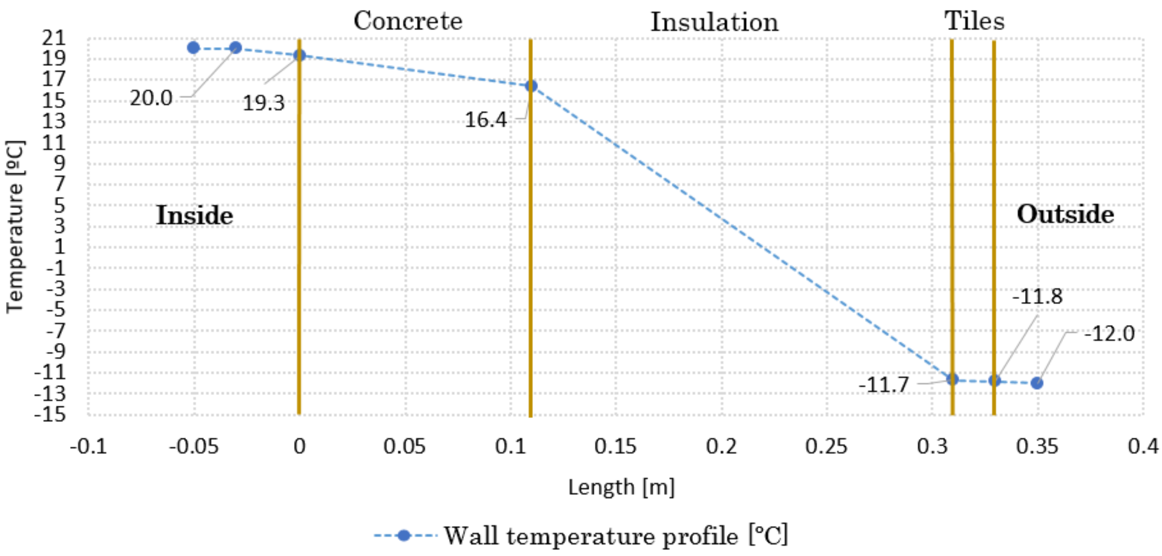

Figure B.3: Temperature profile from Wall type 1

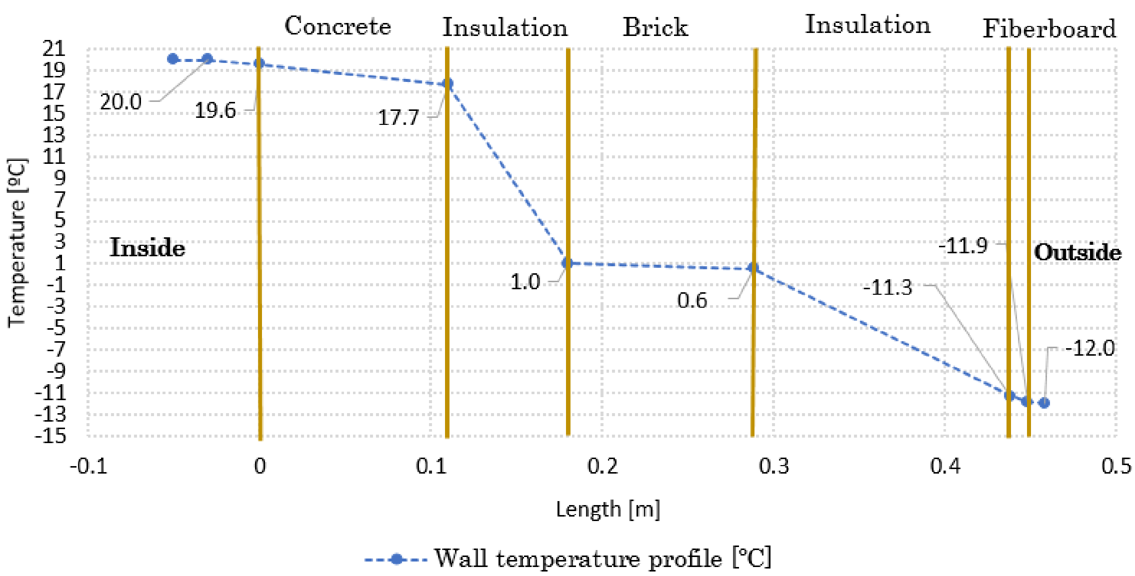

Figure B.4: Temperature profile from Wall type 2

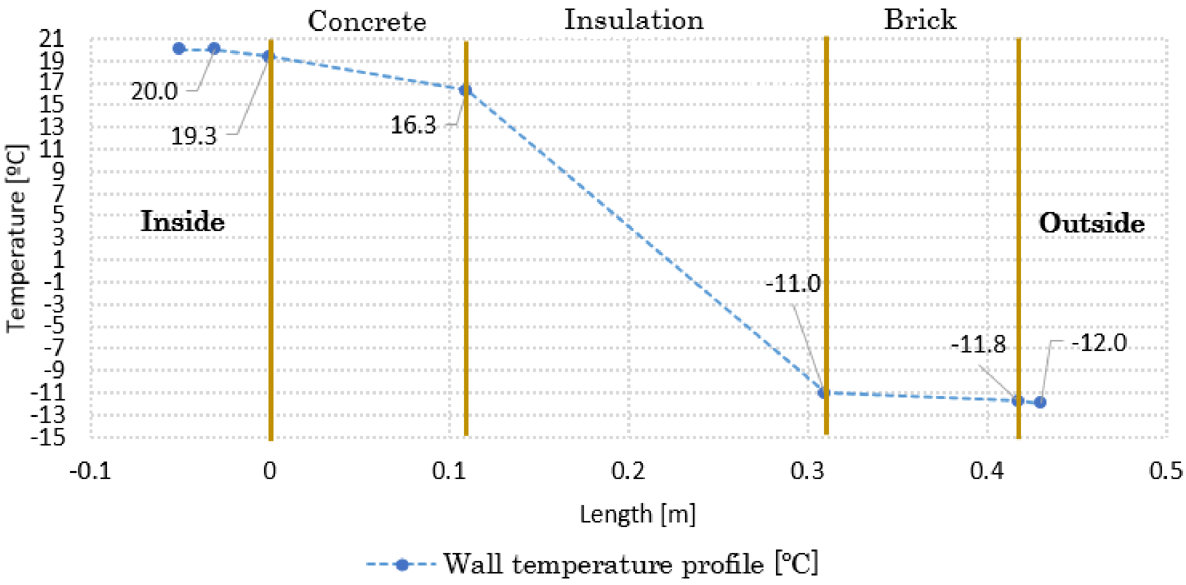

Figure B.5: Temperature profile from Wall type 3

C | MATLAB

C.1 Theoretical and Numerical time constant

Table C.1: Theoretical VS Numerical time constant

	Building thermal resistance [m^2.K/W]	Internal daily areal heat capacity ($k_{m.internal}$) [kJ/m^2.K]	Theoretical time constant (R.$k_{m.internal}$) [min]	Numerical time constant 1^{st} Dec [min]
Reference Case	1.775	203	5993	17.9

C.2 Effictive Thermal Inertia

Table C.2: Building thermal characteristics with different renovated components

Renovated components	**Building U-value [W/m^2.K]**	**Building resistance [m^2.K/W]**	**Building internal daily areal heat capacity [kJ/m^2.K]**	**Building maximum areal heat capacity [kJ/m^2.K]**	**Theoretical time constant [min]**
Reference Case	0.563	1.775	203	827	5993
Crawl floor	0.534	1.873	202	925	6303
Roof	0.537	1.864	202	828	6263
Semi exposed floor	0.458	2.182	207	836	7544
Wall type 1	0.441	2.269	207	706	7829
Wall type 2	0.420	2.381	205	841	8128
Wall type 3	0.524	1.908	206	847	6564
Light wall	0.561	1.782	202	842	6015
Suggested renovation building components (reference external wall with additional layer of cement or mortar on the internal side of wall)					
1 cm cement	0.563	1.777	212	842	6277
5 cm cement	0.561	1.783	236	905	7013
1 cm mortar	0.563	1.777	218	852	6456

Table C.3: Building thermal characteristics with different renovation packages

Renovated components	**Building U-value [W/m^2.K]**	**Building resistance [m^2.K/W]**	**Building internal daily areal heat capacity [kJ/m^2.K]**	**Building maximum areal heat capacity [kJ/m^2.K]**	**Theoretical time constant [min]**
Reference Case	0.563	1.775	203	827	5993
Package 1	0.482	2.073	201	927	6944
Package 2	0.389	2.574	200	813	8598
Package 3	0.353	2.836	198	947	9370
Package 4	0.248	4.038	203	956	13672
Package 5	0.288	3.468	205	963	11835

C.3 Detailed calculations

Table C.4: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, reference case

Reference Case	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	202.54	826.63
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.5: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, reference case

Crawl floor	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	201.88	925.18
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

Table C.6: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated roof

Roof	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	202.62	828.48
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.7: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated Semi exposed floor

Semi exposed floor	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	207.49	835.66
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	19643	7936	27579	30510	90		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.8: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated wall type 1

Wall type 1	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	207.02	706.38
Heavy walls type 1	119.52	29485	38213	67698	97496	69		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.9: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated wall type 2

Wall type 2	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	204.80	840.51
Heavy walls type 2	119.52	27322	5016	32338	231620	14		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.10: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated wall type 3

Wall type 3	**Area [m^2]**	**Internal daily areal heat capacity per component [J/m^2.K]**	**External daily areal heat capacity per component [J/m^2.K]**	**Total daily areal heat capacity per component [J/m^2.K]**	**Maximum areal heat capacity per component [J/m^2.K]**	**Total/ maximum capacity ratio [%]**	**Building internal daily areal heat capacity [kJ/m^2.K]**	**Building maximum daily areal heat capacity [kJ/m^2.K]**
Partition	282.852	38691	38691	77382	80000	97	206.37	847.30
Heavy walls type 3	119.52	28852	110550	139402	238410	58		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.11: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, renovated light wall

Light wall	**Area [m^2]**	**Internal daily areal heat capacity per component [J/m^2.K]**	**External daily areal heat capacity per component [J/m^2.K]**	**Total daily areal heat capacity per component [J/m^2.K]**	**Maximum areal heat capacity per component [J/m^2.K]**	**Total/ maximum capacity ratio [%]**	**Building internal daily areal heat capacity [kJ/m^2.K]**	**Building maximum daily areal heat capacity [kJ/m^2.K]**
Partition	282.852	38691	38691	77382	80000	97	202.48	841.54
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	59341	37408	96749	188110	51		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.12: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, adding 1 cm cement on the internal side of heavy external walls

1 cm cement on internal side of heavy wall	**Area [m^2]**	**Internal daily areal heat capacity per component [J/m^2.K]**	**External daily areal heat capacity per component [J/m^2.K]**	**Total daily areal heat capacity per component [J/m^2.K]**	**Maximum areal heat capacity per component [J/m^2.K]**	**Total/ maximum capacity ratio [%]**	**Building internal daily areal heat capacity [kJ/m^2.K]**	**Building maximum daily areal heat capacity [kJ/m^2.K]**
Partition	282.852	38691	38691	77382	80000	97	211.96	842.25
1 cm cement on internal side of heavy wall	119.52	39093	111650	150743	242390	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.13: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, adding 5 cm cement on the internal side of heavy external walls

5 cm cement on internal side of heavy wall	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	235.94	904.75
5 cm cement on internal side of heavy wall	119.52	62393	110690	173083	304890	57		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.14: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, adding 1 cm mortar on the internal side of heavy external walls

1 cm mortar on internal side of heavy wall	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	218.01	851.71
1 cm mortar on internal side of heavy wall	119.52	44974	111590	156564	251850	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	57500	34581	92081	203388	45		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	55094	9232	64326	36000	18		
Doors	4.36	24848	58613	83461	85788	97		

Table C.15: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, Renovation package 1

Renovation Package 1	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	200.96	927.04
Heavy walls	119.52	29938	111770	141708	226770	62		
Light walls	4	60921	39483	100404	173200	58		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

Table C.16: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, Renovation package 2

Renovation Package 2	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	200.44	812.67
Heavy walls type 1	119.52	29485	38213	67698	97496	69		
Light walls	4	59341	37408	96749	188110	51		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

Table C.17: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, Renovation package 3

Renovation Package 3	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	198.21	946.80
Heavy walls type 2	119.52	27322	5016	32338	231620	14		
Light walls	4	59341	37408	96749	188110	51		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	14356	6604	20960	21480	98		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

Table C.18: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, Renovation package 4

Renovation Package 4	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	203.16	955.83
Heavy walls type 2	119.52	27322	5016	32338	231620	14		
Light walls	4	59341	37408	96749	188110	51		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	19643	7936	27579	30510	90		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

Table C.19: MATLAB calculation of internal daily areal heat capacity and maximum areal heat capacity, Renovation package 5

Renovation Package 5	Area [m^2]	Internal daily areal heat capacity per component [J/m^2.K]	External daily areal heat capacity per component [J/m^2.K]	Total daily areal heat capacity per component [J/m^2.K]	Maximum areal heat capacity per component [J/m^2.K]	Total/ maximum capacity ratio [%]	Building internal daily areal heat capacity [kJ/m^2.K]	Building maximum daily areal heat capacity [kJ/m^2.K]
Partition	282.852	38691	38691	77382	80000	97	204.74	962.62
Heavy walls type 3	119.52	28852	110550	139402	238410	58		
Light walls	4	59341	37408	96749	188110	51		
Roof	116.12	56579	28542	85121	205242	41		
Semi exposed floor	108.74	19643	7936	27579	30510	90		
Bathroom floor	7.38	44750	8515.5	53265.5	134558	40		
Doors	4.36	24848	58613	83461	85788	97		

D | Anova analysis

The one-way ANOVA compares the means between the groups and determines whether any of those means are statistically significantly different from each other. Alpha level (significance level) is typically chosen to be 0,05. The p-value is the probability of obtaining a result as extreme as, or more extreme than, the result actually obtained when the null hypothesis is true. If p-value is larger than alpha value 0,05, there is no significant difference between compared groups [18].

Table D.1: Anova analysis summary for renovation packages

Component/ Renovation Package	**Renovation**		**Referance case**		**Significant difference in comfort period**	**Significant difference in consumption**
	Average Monthly Consumption (January, December) [kWh]	**Average comfort period after cut-off [min]**	**Average Monthly Consumption (January, December) [kWh]**	**Average comfort period after cut-off [min]**		
Package 1	3447.7	33.2	5279.0	18.4	TRUE	TRUE
Package 2	2567.2	59.7	5279.0	18.4	TRUE	TRUE
Package 3	2000.6	92.8	5279.0	18.4	TRUE	TRUE
Package 4	1916.1	102.4	5279.0	18.4	TRUE	TRUE
Package 5	1947.9	96.2	5279.0	18.4	TRUE	TRUE

Table D.2: Anova analysis comparison between renovation packages

Renovation packages	**Average Monthly Consumption (January, December) [kWh]**	**Average comfort period after cut-off [min]**	**Significant difference in consumption**	**Significant difference in comfort period**
Package 1	3447.7	33.2	TRUE	TRUE
Package 2	2567.2	59.7		
Package 3	2000.7	92.8		
Package 4	1902.7	102.4		
Package 5	1941.0	96.2		
Renovation packages				
Package 2	2567.2	59.7	TRUE	TRUE
Package 3	2000.7	92.8		
Package 4	1902.7	102.4		
Package 5	1941.0	96.2		
Renovation packages				
Package 3	2000.7	92.8	TRUE	FALSE
Package 4	1902.7	102.4		
Package 5	1941.0	96.2		
Renovation packages				
Package 4	1902.7	102.4	TRUE	FALSE
Package 5	1941.0	96.2		
Renovation packages				
Package 3	2000.7	92.8	FALSE	FALSE
Package 5	1941.0	96.2		

Table D.3: Anova analysis - consumption comparisonn between Reference Case and Package 1

Consumption	**December**	**January**				
Package	**[kWh]**	**[kWh]**				
Reference case	5091.0	5467.1				
Package 1	3387.7	3507.7				
Anova: Single Factor						
SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Reference case	2	10558.08	5279.04	70718.08		
Package 1	2	6895.3	3447.65	7200		
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	3353989.3	1	3353989	86.09014	0.011417	18.51282
Within Groups	77918.083	2	38959.04			
Total	3431907.4	3				
Significant difference	TRUE					

Table D.4: Anova analysis - consumption comparison between Package 1, Package 2, Package 3, Package 4 and Package 5

Consumption	**December**	**January**
Package	**[kWh]**	**[kWh]**
Package 1	3387.7	3507.7
Package 2	2550.4	2583.9
Package 3	1980.6	1990.6
Package 4	1896.8	1908.7
Package 5	1940.9	1941.2

Anova: Single Factor

SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 1	2	6895.3	3447.65	7200
Package 2	2	5134.4	2567.2	560.1
Package 3	2	3971.6	1985.6	50.5
Package 4	2	3805.5	1902.7	70.0
Package 5	2	3882.0	1941.0	0.03

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	3500687.3	4	875171.8	555.2677	8.36E-07	5.192168
Within Groups	7880.6299	5	1576.126			
Total	3508568	9				
Significant difference	TRUE					

Table D.5: Anova analysis - consumption comparison between Package 2, Package 3, Package 4 and Package 5

Consumption	**December**	**January**
Package	**[kWh]**	**[kWh]**
Package 2	2550.4	2583.9
Package 3	1980.6	1990.6
Package 4	1896.8	1908.7
Package 5	1940.9	1941.2

Anova: Single Factor

SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 2	2	5134.4	2567.2	560.1
Package 3	2	3971.6	1985.6	50.5
Package 4	2	3805.5	1902.7	70.0
Package 5	2	3882.0	1941.0	0.03

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	591061.26	3	197020.4	1157.871	2.48E-06	6.591382
Within Groups	680.62995	4	170.1575			
Total	591741.89	7				
Significant difference	TRUE					

Table D.6: Anova analysis - consumption comparison - Package 3, Package 4 and Package 5

Consumption	**December**	**January**
Package	**[kWh]**	**[kWh]**
Package 3	1980.6	1990.6
Package 4	1896.8	1908.7
Package 5	1940.9	1941.2

Anova: Single Factor
SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 3	2	3971.6	1985.6	50.5
Package 4	2	3805.5	1902.7	70.0
Package 5	2	3882.0	1941.0	0.03

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	6875.5699	2	3437.785	85.58126	0.002261	9.552094
Within Groups	120.5095	3	40.16983			
Total	6996.0794	5				

Significant difference TRUE

Table D.7: Anova analysis - consumption comparison between Package 4 and Package 5

Consumption	**December**	**January**
Package	**[kWh]**	**[kWh]**
Package 4	1896.8	1908.7
Package 5	1940.9	1941.2

Anova: Single Factor
SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 4	2	3805.5	1902.7	70.0
Package 5	2	3882.0	1941.0	0.03

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	1465.7412	1	1465.741	41.87339	0.023059	18.51282
Within Groups	70.00825	2	35.00413			
Total	1535.7495	3				

Significant difference TRUE

Table D.8: Anova analysis - consumption comparison between packages 6, 7, 8, 9, 10 and 11

Consumption	December	January
Package	**[kWh]**	**[kWh]**
Package 6	2659.3	2634.5
Package 7	2303.5	2287.6
Package 8	2308.3	2292.4
Package 9	2311.1	2296.0
Package 10	2312.4	2296.7
Package 11	2364.5	2346.8

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Package 6	2	5293.76	2646.88	306.0338
Package 7	2	4591.18	2295.59	126.405
Package 8	2	4600.73	2300.365	125.9285
Package 9	2	4607.15	2303.575	113.5525
Package 10	2	4609.16	2304.58	123.245
Package 11	2	4711.33	2355.665	157.5313

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	191832.57	5	38366.51	241.6291	7.88E-07	4.387374
Within Groups	952.69595	6	158.7827			
Total	192785.26	11				

Significant difference TRUE

Table D.9: Anova analysis - consumption comparison between packages 7, 8, 9, 10 and 11

Consumption	December	January
Package	**[kWh]**	**[kWh]**
Package 7	2303.5	2287.6
Package 8	2308.3	2292.4
Package 9	2311.1	2296.0
Package 10	2312.4	2296.7
Package 11	2364.5	2346.8

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Package 7	2	4591.18	2295.59	126.405
Package 8	2	4600.73	2300.365	125.9285
Package 9	2	4607.15	2303.575	113.5525
Package 10	2	4609.16	2304.58	123.245
Package 11	2	4711.33	2355.665	157.5313

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4874.6409	4	1218.66	9.422696	0.015056	5.192168
Within Groups	646.66215	5	129.3324			
Total	5521.3031	9				

Significant difference TRUE

Table D.10: Anova analysis - consumption comparison between packages 7, 8, 9 and 10

Consumption	**December**	**January**
Package	**[kWh]**	**[kWh]**
Package 7	2303.5	2287.6
Package 8	2308.3	2292.4
Package 9	2311.1	2296.0
Package 10	2312.4	2296.7

Anova: Single Factor
SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 7	2	4591.18	2295.59	126.405
Package 8	2	4600.73	2300.365	125.9285
Package 9	2	4607.15	2303.575	113.5525
Package 10	2	4609.16	2304.58	123.245

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	98.23065	3	32.74355	0.267769	0.846174	6.591382
Within Groups	489.1309	4	122.2827			
Total	587.36155	7				

Significant difference FALSE

Table D.11: Anova analysis - consumption comparison between building components

Consumption	**December**	**January**
Component	**[kWh]**	**[kWh]**
Reference case	5091.0	5467.1
Wall type 1	3340.7	3389.53
Wall type 2	3226.3	3260.84
Wall type 3	3256.9	3313.17
Window	3358.6	3401.22
Roof	4958.9	5342.4
Crawl floor	4447.5	4778.3
Semi exposed floor	3936.8	4084.2
External light wall	5077.4	5453.3
1cm Cement	4220.2	4371.8
5cm Cement	4211.6	4361.6

Anova: Single Factor
SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Reference case	2	10558.1	5279.0	70718.1
Wall type 1	2	6730.2	3365.1	1193.2
Wall type 2	2	6487.1	3243.6	596.5
Wall type 3	2	6570.0	3285.0	1585.4
Window	2	6759.9	3379.9	906.5
Roof	2	10301.3	5150.6	73547.6
Crawl floor	2	9225.8	4612.9	54707.7
Semi exposed floor	2	8021.0	4010.5	10873.7
External light wall	2	10530.7	5265.4	70665.4
1cm Cement	2	8592.1	4296.0	11489.8
5cm Cement	2	8573.2	4286.6	11253.0

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	13095237	10	1309524	46.83912	1.46E-07	2.853625
Within Groups	307536.9	11	27957.9			
Total	13402774	21				

Significant difference TRUE

Table D.12: Anova analysis - consumption comparison between building components

Consumption Component	December [kWh]	January [kWh]
Reference case	5091.0	5467.1
External light wall	5077.4	5453.3
Roof	4958.9	5342.4
Crawl floor	4447.5	4778.3
1cm Cement	4220.2	4371.8
5cm Cement	4211.6	4361.6

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Reference case	2	10558.08	5279.04	70718.08
External light wall	2	10530.74	5265.37	70665.44
Roof	2	10301.27	5150.635	73547.63
Crawl floor	2	9225.78	4612.89	54707.7
1cm Cement	2	8592.05	4296.025	11489.76
5cm Cement	2	8573.18	4286.59	11253

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2240435	5	448087.1	9.195251	0.008815	4.387374
Within Groups	292381.6	6	48730.27			
Total	2532817	11				

Significant difference TRUE

Table D.13: Anova analysis - consumption comparison between building components

Consumption Component	December [kWh]	January [kWh]
Reference case	5091.0	5467.1
External light wall	5077.4	5453.3
Roof	4958.9	5342.4
Crawl floor	4447.5	4778.3
1cm Cement	4220.2	4371.8

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Reference case	2	10558.08	5279.04	70718.08
External light wall	2	10530.74	5265.37	70665.44
Roof	2	10301.27	5150.635	73547.63
Crawl floor	2	9225.78	4612.89	54707.7
1cm Cement	2	8592.05	4296.025	11489.76

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1570082	4	392520.4	6.981154	0.028043	5.192168
Within Groups	281128.6	5	56225.72			
Total	1851210	9				

Significant difference TRUE

Table D.14: Anova analysis - consumption comparison between building components

Consumption	December	January
Component	**[kWh]**	**[kWh]**
Reference case	5091.0	5467.1
External light wall	5077.4	5453.3
Roof	4958.9	5342.4
Crawl floor	4447.5	4778.3

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Reference case	2	10558.08	5279.04	70718.08
External light wall	2	10530.74	5265.37	70665.44
Roof	2	10301.27	5150.635	73547.63
Crawl floor	2	9225.78	4612.89	54707.7

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	594247.2	3	198082.4	2.938485	0.162381	6.591382
Within Groups	269638.9	4	67409.71			
Total	863886.1	7				

Significant difference FALSE

Table D.15: Anova analysis - Time constant comparison between renovation packages

Time constant	1-Dec	8-Jan	15-Jan	22-Jan	30-Jan
Component	**[min]**	**[min]**	**[min]**	**[min]**	**[min]**
Reference case	17.9	16.5	13.6	17.8	26.1
Package 1	27.4	41.0	34.5	23.0	40.0

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Reference case	5	91.88	18.376	21.64188
Package 1	5	165.93	33.186	61.46268

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	548.3403	1	548.3403	13.19639	0.006659	5.317655
Within Groups	332.4182	8	41.55228			
Total	880.7585	9				

Significant difference TRUE

Table D.16: Anova analysis - Time constant comparison between renovation packages

Time constant	1-Dec	8-Jan	15-Jan	22-Jan	30-Jan
Component	**[min]**	**[min]**	**[min]**	**[min]**	**[min]**
Package 3	69.2	111.7	104.3	76.9	102.1
Package 4	71.7	126.0	118.0	83.3	113.2
Package 5	70.6	115.0	108.8	78.5	108.1

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Package 3	5	464.22	92.844	346.1917
Package 4	5	512.21	102.442	556.1168
Package 5	5	481.02	96.204	406.1095

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	237.2064	2	118.6032	0.271939	0.766473	3.885294
Within Groups	5233.672	12	436.1393			
Total	5470.878	14				
Significant difference	FALSE					

Table D.17: Anova analysis - Time constant comparison between renovation packages

Time constant	1-Dec	8-Jan	15-Jan	22-Jan	30-Jan
Component	**[min]**	**[min]**	**[min]**	**[min]**	**[min]**
Package 3	69.2	111.7	104.3	76.9	102.1
Package 4	71.7	126.0	118.0	83.3	113.2
Package 5	70.6	115.0	108.8	78.5	108.1
Package 6	60.0	113.3	72.5	117.5	122.5
Package 7	57.2	96.7	66.9	102.5	102.5
Package 8	62.5	107.1	73	113.3	113.3
Package 9	68.0	127.5	81.1	132.5	132
Package 10	64.5	112	75	118.3	118.3
Package 11	58.8	105.7	76.9	110.0	110

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Package 3	5	464.22	92.844	346.1917
Package 4	5	512.21	102.442	556.1168
Package 5	5	481.02	96.204	406.1095
Package 6	5	485.8333	97.16667	826.5972
Package 7	5	425.812	85.16239	461.7148
Package 8	5	469.3095	93.8619	588.3612
Package 9	5	541.1111	108.2222	969.8164
Package 10	5	488.2121	97.64242	667.614
Package 11	5	461.3874	92.27747	542.1432

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1702.279	8	212.7849	0.356977	0.936173	2.208518
Within Groups	21458.66	36	596.0739			
Total	23160.94	44				
Significant difference	FALSE					

Table D.18: Anova analysis - Time constant comparison between renovation packages

Time constant	**1-Dec**	**8-Jan**	**15-Jan**	**22-Jan**	**30-Jan**
Component	**[min]**	**[min]**	**[min]**	**[min]**	**[min]**
Package 3	69.2	111.7	104.3	76.9	102.1
Package 4	71.7	126.0	118.0	83.3	113.2
Package 5	70.6	115.0	108.8	78.5	108.1
Package 6	60.0	113.3	72.5	117.5	122.5
Package 7	57.2	96.7	66.9	102.5	102.5
Package 8	62.5	107.1	73	113.3	113.3
Package 9	68.0	127.5	81.1	132.5	132
Package 10	64.5	112	75	118.3	118.3
Package 11	58.8	105.7	76.9	110.0	110

Anova: Single Factor

SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Package 3	5	464.22	92.844	346.1917
Package 4	5	512.21	102.442	556.1168
Package 5	5	481.02	96.204	406.1095
Package 6	5	485.8333	97.16667	826.5972
Package 7	5	425.812	85.16239	461.7148
Package 8	5	469.3095	93.8619	588.3612
Package 9	5	541.1111	108.2222	969.8164
Package 10	5	488.2121	97.64242	667.614
Package 11	5	461.3874	92.27747	542.1432

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	1702.279	8	212.7849	0.356977	0.936173	2.208518
Within Groups	21458.66	36	596.0739			
Total	23160.94	44				

Significant difference FALSE

E Initial Investments

Table E.1: Initial investments of renovated components

No.	Renovation building component	Price [DKK]
1	Wall type 1	243633
2	Wall type 2	351966
3	Wall type 3	319934
4	External light wall	2988
5	Flat roof	17650
6	Semi exposed floor	19356
7	External windows/ doors	79427
8	Crawl floor	267865
9	Foundation (Package 1)	70462
Suggested renovation building components (reference external wall with additional internal layer of cement or mortar)		
10	1 cm cement	8832
11	5 cm cement	44158
12	1 cm mortar	12591

Table E.2: Initial investments of renovation packages

No.	Renovation packages	Price [DKK]
1	Package 1	355977
2	Package 2	532136
3	Package 3	719897
4	Package 4	739252
5	Package 5	707221
Suggested packages		
6	Package 6	471387
7	Package 7	363054
8	Package 8	371886
9	Package 9	407212
10	Package 10	375645
11	Package 11	439356

Table E.3: Calculation of the initial investment of renovated crawl floor

Demolition of existing floor (hand work - not reinforced concrete)		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	401	47454.34
Removing existing insulation (50 mm)		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	81.00	9585.54
Hand excavation of 60 cm for new insulation and lecca capillary breaking layer		
Volume [m^3]	Price/m^3 [DKK]	Total Price [DKK]
71.00	550.00	39052.20
New capillary breaking layer 300 mm		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	192	22721.28
New insulation EPS 80,200 mm		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	213.00	25206.42
New concrete casting 80 mm		
Volume [m^3]	Price/m^3 [DKK]	Total Price [DKK]
9.47	2419.00	22901.16
New vapor barrier on the ground		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	14.00	1656.76
New 50 mm mineral wool insulation between battens		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	81	9585.54
New 47x50 mm battens on the concrete		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	81.00	9585.54
Premium wooden floors		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
118.34	677.00	80116.18
Crawl floor total price [DKK]		
267864.96		

Table E.4: Calculation of the initial investment of renovated roof

Air and moisture tightening with vapor membrane		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
116.12	28.00	3251.36
Additional roof insulation mineral wool (150mm)		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
116.12	124.00	14398.88
Roof total price [DKK]		
17650.24		

Table E.5: Calculation of the initial investment of renovated semi exposed floor

Insulation of semi exposed floor (150 mm)		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
108.74	178.00	19355.72
Semi exposed floor total price [DKK]		
19355.72		

Table E.6: Calculation of the initial investment of renovated foundation of wall type 1

Hand digging around perimeter					
Perimeter [m]	Width [m]	Depth [m]	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.3	0.042	1.35	4.123332	2021	8333.253972
Excavator digging around perimeter					
Perimeter [m]	Width [m]	Layers	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.3	0.042	1.35	16.493328	592	9764.050176
Insulation around foundation with 22 mm XPS					
Perimeter [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.3	1.35	70.605	66.54	4698.06	
Fiber cement board					
length [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.3	1.35	70.605	466	32901.93	
Wall type 1 foundation - Total price [DKK]					
55697.29					

Table E.7: Calculation of the initial investment of renovated wall type 1

External brick work demolition		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	72.42	8655.64
Prefabricate 150 mm mineral wool and brick tiles		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	1000.00	119520.00
Installation of prefabricated 150 mm mineral wool and brick tiles		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	500.00	59760.00
Wall type 1 foundation - Total price [DKK]		
55697.29		
Wall type 1 total price [DKK]		
243632.93		

Table E.8: Calculation of the initial investment of renovated foundation of wall type 2

Hand digging around perimeter					
Perimeter [m]	Width [m]	Depth [m]	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.16	1.35	5.79	2021.00	11700.80
Excavator digging around perimeter					
Perimeter [m]	Width [m]	Layers	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.16	1.35	23.16	592.00	13709.80
Insulation around foundation with 22 mm XPS					
Perimeter [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.30	1.35	70.61	563.60	39793.19	
Fiber cement board					
length [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.30	1.35	70.61	466.00	32901.93	
Wall type 1 foundation - Total price [DKK]					
98105.72					

Table E.9: Calculation of the initial investment of renovated wall type 2

Rockwool REDart facade insulation 150 mm		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	1658.00	198164.16
Fibre cement board		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	466.00	55696.32
Wall type 1 foundation total price [DKK]		
98105.72		
Wall type 2 total price [DKK]		
351966.20		

Table E.10: Calculation of the initial investment of renovated foundation of wall type 3

Hand digging around perimeter					
Perimeter [m]	Width [m]	Depth [m]	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.13	1.35	5.37	2021.00	10844.65
Excavator digging around perimeter					
Perimeter [m]	Width [m]	Layers	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.13	1.35	21.46	592.00	12706.64
Lecca block					
Perimeter [m]	Width [m]	Layers	Area [m^2]	Price /m^2 [DKK]	Total price
52.30	1.02	1.00	[DKK]	1176.00	62734.90
Mpa foundation under lecca blocks (without reinforcement)					
length [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.30	0.33	17.26	2371.00	40921.09	
Wall type 3 foundation - Total price [DKK]					
127207.27					

Table E.11: Calculation of the initial investment of renovated wall type 3

External brick work demolition		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	72.42	8655.64
New mineral wool insulation (200 mm)		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	199.09	23795.24
New brick facade		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
119.52	1341.00	160276.32
Wall type 1 foundation total price [DKK]		
127207.3		
Wall type 3 total price [DKK]		
319934.50		

Table E.12: Calculation of the initial investment of renovated light wall

Wooden facade disassembly		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
4.00	95	380.00
New mineral wool insulation 150 mm		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
4.00	186.00	744.00
Establishment of new facade - fiber facade plates		
Area [m^2]	Price/m^2 [DKK]	Total Price [DKK]
4.00	466.00	1864.00
Wall type 2 total price [DKK]		
2988.00		

Table E.13: Calculation of the initial investment of cement and mortar applying on the internal face of external walls

Materials prices					
	Density [kg/m^3]	Volume [m^3]	Weight [kg]	Price per kg [DKK]	Materials price [DKK]
1 cm cement	1860	1.235	2297	3.238	7439
5 cm cement	1860	6.176	11487	3.238	37196
1 cm mortar	2800	1.235	3459	3.238	11199
Installing price					
	Working hours	Hourly rate [DKK]			
1 cm cement	11	124			
5 cm cement	56	124			
1 cm mortar	11	124			
Total price [DKK]					
1 cm cement	8832				
5 cm cement	44158				
1 cm mortar	12591				

Table E.14: Calculation of the initial investment of package 1 foundation

Hand digging around perimeter					
Perimeter [m]	Width [m]	Depth [m]	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.06	1.35	4.39	2021.00	8869.78
Excavator digging around perimeter					
Perimeter [m]	Width [m]	Layers	Volume [m^3]	Price /m^3 [DKK]	Total price [DKK]
52.30	0.61	1.35	48.46	592.00	28690.26
Insulation around foundation with 50 mm XPS					
Perimeter [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price	
52.30	1.35	70.61	195.38	13794.62	
Fiber cement board					
length [m]	Width [m]	Area [m^2]	Price /m^2 [DKK]	Total price [DKK]	
52.30	1.35	70.61	466.00	32901.93	
Package 1 foundation - Total price [DKK]					
70461.97					

F | Suggested Renovation Packages

Table F.1: Comparison between packages time constants, yearly energy consumption and net present values

Renovation packages	Time constant [min]					NPV [mill DKK]	Yearly energy consumption [kWh]
	8^{th} Jan.	**15^{th} Jan.**	**22^{nd} Jan.**	**30^{th} Jan.**	**1^{th} Dec.**		
Package 1	41.0	34.5	23.0	40.0	27.4	2.85	17253
Package 2	65.6	61.1	48.3	79.2	44.4	2.36	12638
Package 3	111.7	104.3	76.9	102.1	69.2	2.13	9777
Package 4	126.0	118.0	83.3	113.2	71.7	2.11	9452
Package 5	115.0	108.8	78.5	108.1	70.6	2.10	9623
Package 6	113.3	72.5	117.5	60.0	122.5	2.18	11793
Package 7	96.7	66.9	102.5	57.2	102.5	2.04	11614
Package 8	107.1	73	113.3	62.5	113.3	2.05	11638
Package 9	127.5	81.1	132.5	68.0	132	2.09	11665
Package 10	112	75	118.3	64.5	118.3	2.06	11657
Package 11	105.7	76.9	110.0	58.8	110	2.17	11940

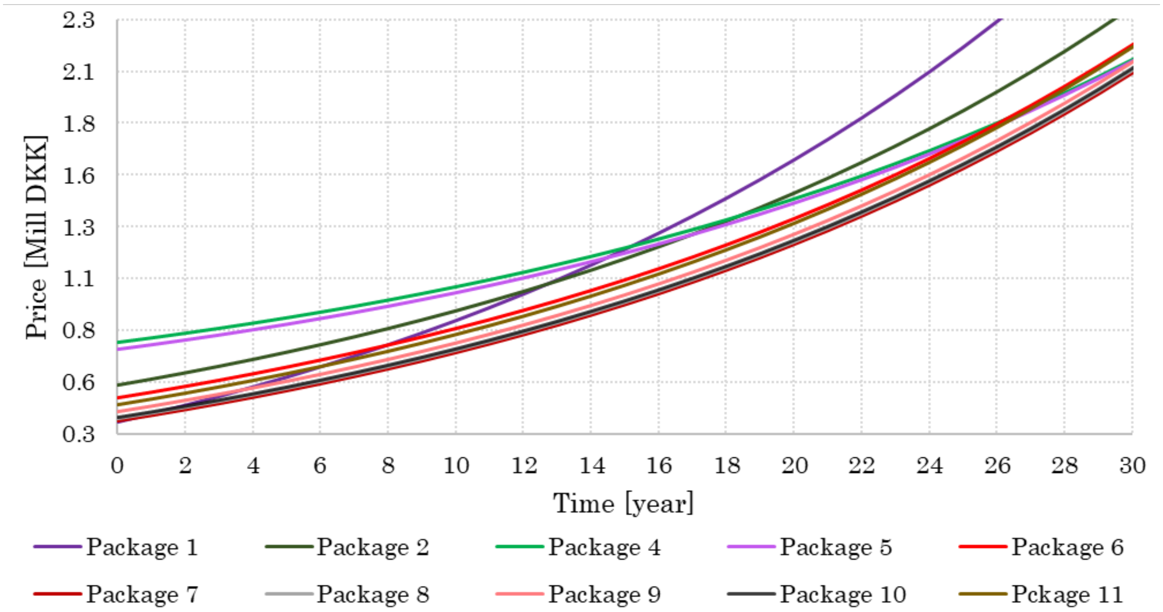

Figure F.1: Life cycle cost analysis of typical and suggested renovation packages

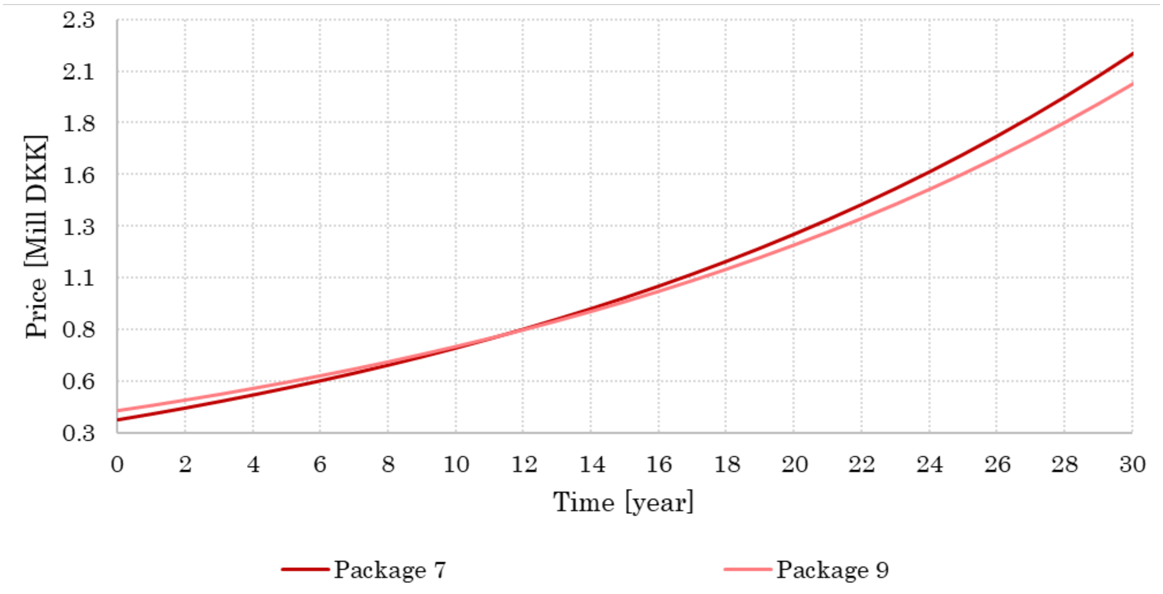

Figure F.2: Life cycle cost analysis of packages 7 and 9 with heating cut-off 7:00 - 16:00

Table F.2: Comparison between Package 7 and Package 9 with heating cut-off 7:00 - 16:00

	Package 7	**Package 9**
Initial investment [DKK]	363054	407212
Energy consumption [kWh]	12246	10931
NPV [DKK]	2133028	1986978

F.1 Moisture Calculation

Table F.3: Moisture transfer calculation in the construction for additional 5 cm layer of cement on the internal side of the load bearing wall

Wall type 1 + 5 cm concrete	**Temperature profile**				
	Thickness	**Thermal conductivity**	**Thermal resistance**	**Temperature gradient**	**Temperature**
Calculation	d	λ	$R = \frac{e}{\lambda}$	$\Delta\theta = \frac{R_1}{\sum R_1(t_i - t_u)}$	θ
Unit	[m]	[W/m·K]	[m^2·K/W]	[^{o}C]	[^{o}C]
Internal temperature					20
Internal resistance			0.250	1.55	18.45
Brick tile	0.020	0.800	0.025	0.15	18.30
Mineralwool	0.200	0.048	4.211	26.04	-7.74
Concrete	0.110	0.190	0.579	3.58	-11.32
Cement	0.050	0.720	0.069	0.43	-11.75
Extenal resistance			0.040	0.25	-12.00
Extenal temperature					-12
Assembly thickness (m) =	0.33	$\sum$ R =	5.173918129		

Table F.4: Moisture transfer calculation in the construction for additional 5 cm layer of cement on the internal side of the load bearing wall

Wall type 1 + 5 cm concrete	**Vapor pressure**								
	Saturated vapor pressure	**Vapor permeability**	**Vapour resistance**	**Vapour partial pressure drop**	**Diffusion resistance**	**Vapor partial pressure**	**Relative air humidity**	**Min. accept. vapor pressure**	**Min. accept. surf. temp [^{o}C]**
Calculation	$P_{dm} = f(localtemp.)$	δ	$\delta = d/\delta$	ΔP	$d = d/d$	P	$RF = P/P_{dm}$		
Unit	[GPa]	[kg/msPa]	[m^2sPa/kg]	[Pa]	[m^2sPa/kg]	[Pa]	[%]		
Internal temperature	2343.96		0			1171.98	0.5		
Internal resistance	2124.800712		0			1171.98	0.551571728		
Brick tile	2103.868681	2.45E-12	4.9E-14	-1.329422019	10.2040816	1170.650578	0.556427589		13.65823264
Mineralwool	337.7315256	1.575E-10	3.15E-11	-854.6284406	26.7335004	316.0221374	0.935719983		
Concrete	236.0855122	2.53E-11	2.783E-12	-75.50574445	22.8832952	240.5163929	1.018768118		
Cement	224.0171753	2.53E-11	1.265E-12	-34.32079293	2.7448397	206.1956	0.920445496		Accepted
External resistance	217.048		0			206.1956	0.95	1562.64	
External temperature	217.048		0			206.1956	0.95		
Assembly		$\sum M_d$ =	3.5597E-11		62.5657169				

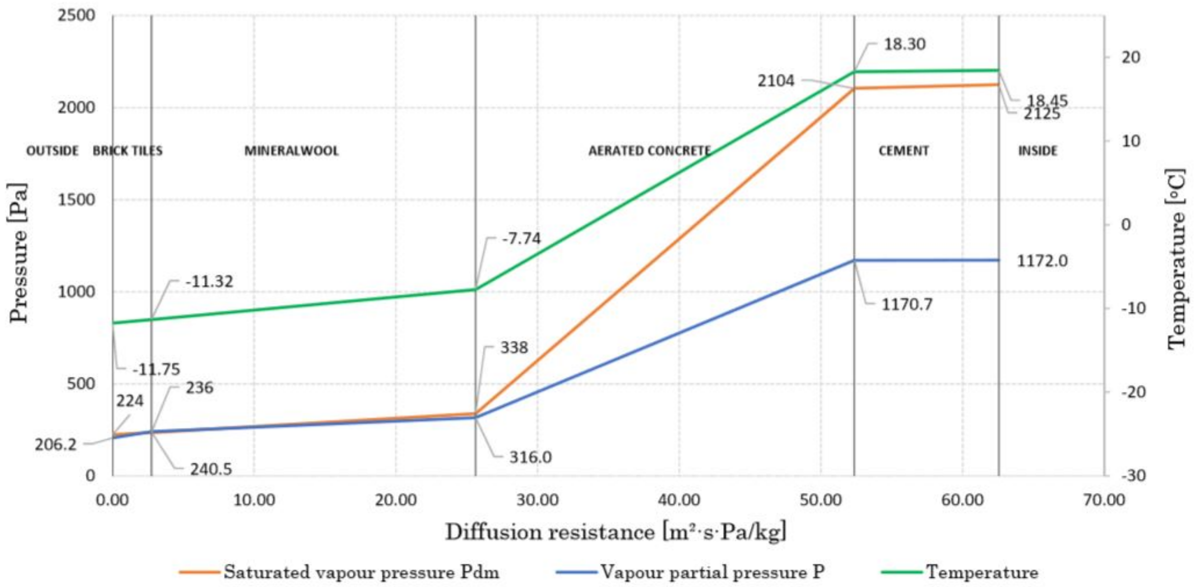

Figure F.3: Moisture transfer through the construction for additional 5 cm layer of cement on the internal side of the load bearing wall

G | Control Strategies

Table G.1: Comparison between control strategies comfort hours, saved energy and flexibility factors

Control strategy	**Energy saving A [kWh]**	**Energy boosting B [kWh]**	**Total saving A-B [kWh]**	**Hours below 20°C [%]**	$\sum$**q**$_{heating}$ **need (Total) [kWh]**	$\sum$**q**$_{heating}$ **need (low demand) [kWh]**	$\sum$**q**$_{heating}$ **need (High demand) [kWh]**	**Flexibility factor**
Heating 24/7	0	0	0	0.39	23124	12550	10574	0.09
Cutting off the heating 07:00 - 14:00	4373	-3328	1044	0.41	22079	14027	8052	0.27
Cutting off the heating 07:00 - 15:00	4906	-3674	1232	0.39	21891	14528	7363	0.33
Cutting off the heating 07:00 - 16:00	5472	-4003	1469	0.64	21654	15102	6552	0.39
1 h Pre-heating & cutting off 07:00 - 14:00	4574	-6385	-1812	0.72	24935	15429	9506	0.24
1 h Pre-heating & cutting off 07:00 - 15:00	5212	-5100	112	0.61	23011	15032	7979	0.31
1 h Pre-heating & cutting off 07:00 - 16:00	5761	-5481	280	0.90	22843	15602	7241	0.37
2 h Pre-heating & cutting off 07:00 - 14:00	4651	-5136	-486	0.57	23609	15019	8590	0.27
2 h Pre-heating & cutting off 07:00 - 15:00	5168	-5502	-335	0.38	23458	15494	7964	0.32
2 h Pre-heating & cutting off 07:00 - 16:00	5739	-5785	-46	0.68	23169	15978	7191	0.38