Building Energy Flexibility: A Sensitivity Analysis and Key Performance Indicator Comparison

Master's Thesis Report

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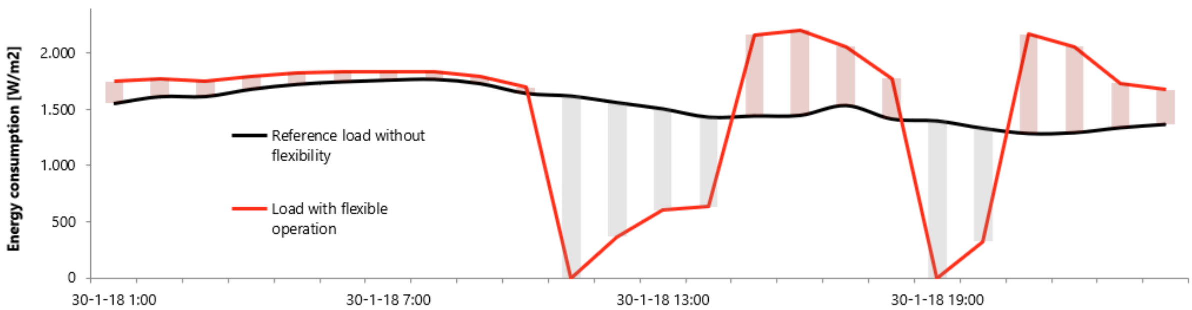

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Synopsis:

This study aims analyze the impact of insulation level, thermal mass, type of heating system, control strategy, outdoor temperature, solar radiation and type of building (office or single family house), on the flexibility function and the two key performance indicators developed by IEA EBC Annex 67. Raw data from 6 case studies is used assess the impact of the parameters in an ANOVA test. As a result of the analysis, the parameters are ranked according to their influence. In general, insulation level and thermal mass were found to have the largest influence.

There are numerous key performance indicators developed to assess building energy flexibility. In this study, 11 key performance indicators are analyzed, categorized and compared to the key performance indicators developed by IEA EBC Annex 67. It was found that 8 of the 11 analyzed key performance indicators are comparable to the ones by IEA EBC Annex 67.

Preface and Acknowledgements

This Master Thesis has been written at the faculty of Engineering and Science at Aalborg University during the 4^{th} semester of the Building Energy Design program. The time period has been from 3^{th} of September 2018 to 10^{th} of January 2019.

Building energy flexibility was a topic that immediately got my interest, and moreover, how buildings can be a part of reducing the need for fossil fuels. Through a literature review, it was found that the influence of different parameters on the buildings energy flexibility ability was yet not known, and that there is no exact definition nor quantification methodology for building energy flexibility. Therefore, with guidance and advises from the supervisors, Anna Marszal-pomianowska and Hicham Johra, it was decided to investigate the influence of insulation level, thermal mass, type of heating system, outdoor temperature and solar radiation on the buildings energy flexibility ability. Further it was decided to compare numerous key performance indicators to two key performance indicators developed by IEA EBC Annex 67.
The thesis builds on raw data from simulations, gathered from 6 study cases that have assessed building energy flexibility, as well as key performance indicators from 11 studies.

A special gratitude goes to my supervisors Anna Marszal-Pomianowska and Hicham Johra for their guidance, innovative ideas and their helpfulness throughout the semester. Moreover I would like to thank Tobias Wiess, Evangelia Loukou, Anna Marszal-Pomianowska, Hicham Johra, Jérôme Le Dréau and Mingzhe Liu for sharing their raw data. I would also like to thank Søren Østergaard Jensen for commenting on the work.

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Abstract

This thesis has two objectives, the first is to analyze the impact of insulation level, thermal mass, type of heating system, control strategy, outdoor temperature, solar radiation and type of building (office or single family house), on the flexibility function and the two key performance indicators developed by IEA EBC Annex 67. This sensitivity analysis is based on raw data from 6 case studies, and to assess the influence of the different parameters, ANOVA tests are used. The results are then ranked according to their influence on the different flexibility characteristics and key performance indicators. Furthermore, another sensitivity analysis is performed to more specifically analyze the impact of insulation level, thermal mass, heating system and control strategy on the flexibility characteristics.
The results showed that insulation level has the largest influence on all the flexibility characteristics and key performance indicators, except the total time of increased energy demand. Thermal mass is also found to have a significant influence on the flexibility characteristics, especially on low insulated buildings.
The validity of the sensitivity analysis results on the total time of increase/decrease energy demand are questionable. Based on analysis and result from other studies, the ranking order should be different. Insulation level and thermal mass should be the parameters that have the largest influence.
The results also showed that only insulation level has an influence on the cost/savings. This can be more related to the decrease of energy consumption from a low insulated to a high insulated building.

The second objective of this thesis is so analyze and compare different key performance indicators to the ones developed by IEA EBC Annex 67. For comparison, a graph with results from both the respective and key performance indicators developed by IEA EBC Annex 67 is used. In total, 11 key performance indicators were analyzed, and it was found that they can be categorized into four categories.
The comparison showed that 8 of the 11 analyzed key performance indicators were either comparable to shifted flexible load or efficiency of flexible operation, or, if only considering the KPIs that can assess the flexibility potential on a yearly basis, 8 of the 9 analyzed key performance indicators were comparable to the IEA EBC Annex 67 key performance indicators. The shifting efficiency was not comparable to the IEA EBC Annex 67 key performance indicators, in fact it was found that with increasing shifted flexible load potential, the shifting efficiency was decreasing. This can be due to the rebound effect, where a larger loss of energy requires a higher amount of energy to reach the same state.

Nomenclature of Symbols and Acronyms

Symbol	Unit	Description
A	W/m^2	Total amount of decreased energy demand
B	W/m^2	Total amount of increased energy demand
T	h	Total time of increased energy demand
β	h	Total time of decreased energy demand
Δ	W/m^2	Maximum change in demand
τ	h	Time from signal to action
α	h	Period from start to max response
S_{flex}	%	Shifted flexible load
E_{flex}	%	Efficiency of flexible operation
Q_{ref}	W	Reference energy consumption
Q_{flex}	W	Flexible energy consumption
C	unit/kWh	Cost function
Q_{low}	W	Energy consumption during low price periods
Q_{high}	W	Energy consumption during high price periods
$U - value$	$\frac{W}{m^2K}$	Heat transmission coefficient
RES	-	Renewable energy source
RE	-	Renewable energy
$HVAC$	-	Heating Ventilation and Cooling
IEA	-	International Energy Agency
EBC	-	Energy in Building and Communities program
$DSMS$	-	Demand side management strategies
KPI	-	Key performance indicator
UFH	-	Under floor heating
FF	-	Flexibility function
FC	-	Flexibility characteristic
CS	-	Case study
OAT	-	One at a time
$4K$	-	±2K set-point modulation
$3K$	-	2K upward and 1K downward set-point modulation
$2K$	-	±1K set-point modulation
$1K$	-	1K upward and 0,5K downward set-point modulation
$BR15$	-	Bygningsreglementet 2015
TES	-	Thermal energy storage
$ANOVA$	-	Analysis of variance

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1 Introduction

Increasing global energy demand and a reduction in available fossil fuels, leads to a high interest in renewable energy sources (RES) [1]. The drawback of RES is that the production is intermittent, difficult to modulate and can affect the stability of the energy system if it accounts for a high percentage of the total generation [1] [2] [3]. According to the Danish Climate Policy Plan, all energy supply shall be covered by RES by 2050, with a intermediate goal in 2035, that all heating and electricity supply shall be 100% covered by RES [4].

With RES as the main supplier, a transition from generation on demand to consumption on demand is necessary. Since buildings account for approximately 40% of the annual energy use worldwide, building energy flexibility could play a significant role of providing a safe and efficient operation of the future energy system. Buildings are therefore seen as an important part in the future energy system, that can provide flexibility by several means e.g. utilization of thermal mass, modulation of plug-loads, and use of electric vehicles [1] [5] [6] [7] [8] [9] [10] [11].

1.1 Building Energy Flexibility

When talking about building energy flexibility, there are two main approaches; thermal energy storage (TES) and appliance operation shifting [12]. Appliance shifting operation is considering the electrical appliances in an household such as; dish washer, tumble dryer, washing machine. These appliances are highly depended on the user behavior and difficult to assess. A description of appliance shifting operation is given in appendix A.4. TES on the other hand, as the name indicates, is more depended on the building characteristics and can be more accurately assessed and quantified. This study only focuses on TES flexibility.
Energy flexibility of a building is often defined as *"The ability to manage its demand and generation according to the local climate conditions, user needs and grid requirements without jeopardizing indoor comfort and technical requirements of the building and heating, ventilation and cooling (HVAC) systems"* [13]. There is however no agreement on the exact definition [14]. With no exact definition, there is no uniform understanding, and without an uniform understanding, numerous definitions and quantification methodologies are developed in parallel [8].

The International Energy Agency (IEA) Energy in Buildings and Communities program (EBC) Annex 67: "Energy Flexible Buildings" started in 2015 as a corporation between 16 countries with the aim "*to increase the knowledge on and demonstrate what the Energy Flexibility buildings can provide for the energy grids, and to identify critical aspects and possible solutions to manage Energy Flexibility* [13]. IEA EBC Annex 67 is aiming to tackle the above-mentioned problems [3].

Demand side management strategies (DSMS) is one way to apply energy flexibility. It helps to reduce the mismatch between the energy demand and the energy production [15]. This can be done by peak shaving and load shifting, as seen in figure 1.1. Load shifting means accumulating or over-consume energy when there is an overproduction on the energy grid, and conserve energy when the production is too low. Peak shaving, in contrast, includes using electricity consuming equipment at different times, than during the peak period.

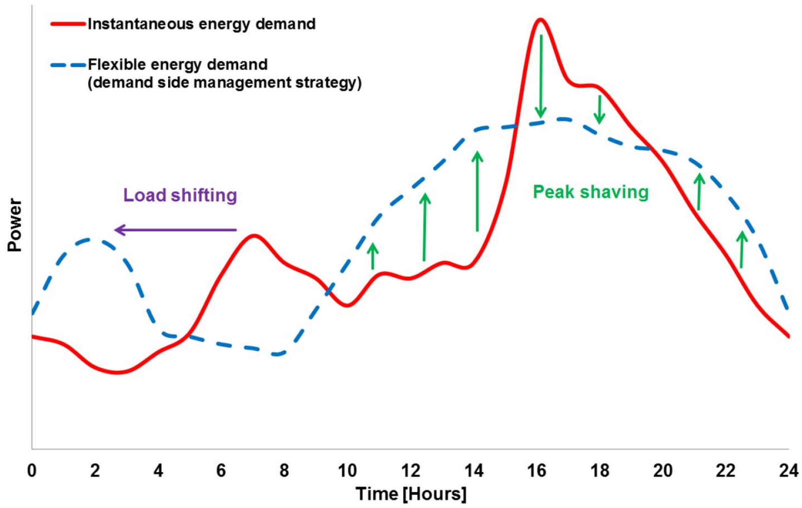


Figure 1.1: Shows demand side strategy with peak shaving and load shifting. Source: Hicham Johra (2018) [14]

As mentioned, there are numerous quantification methodologies which have been developed. Several researchers aim to review and explain the different methodologies [8] [12] [16].

According to an extensive literature review done by IEA EBC Annex 67, there are in general three different aspects when assessing energy flexibility [13]:

Capacity : How much energy that can be shifted over time
Temporal aspects : Duration of the load shift
Cost : Potential cost or energy savings

The buildings ability to provide energy flexibility is influenced by several factors [17]:

- Physical characteristics such as insulation, thermal mass and architectural layout.
- Technologies such as HVAC and energy storage systems
- Control systems that enable the possibility to respond to external signals, such as electrical price or CO_2 intensity of energy production
- Occupant behavior and comfort requirements

Energy flexibility of a building is not a constant nor a fixed value, but varies according to factors such as: RES availability, energy prices, internal/solar gains and user behavior [13]. The aim or end-goal of building energy flexibility is to allow integration of a larger share of RES. For that purpose, the buildings should be able to accumulate energy when there is over production of renewable energy (RE), and reduce energy consumption when the RE production is low [15]. The focus of energy flexibility can be on different objectives, i.e minimize energy costs, maximize use of RES or minimize CO_2 emissions [18].

Studies show that the flexibility potential mainly depends on the insulation level, where a higher insulation level, results in higher flexibility potential [3] [19]. A study performed by Le Dréau and Heiselberg [20] showed that a large amount of thermal energy can be shifted over a short period of time for a low insulated building, while a high insulated building can shift a smaller quantity for a longer period. Moreover, the study showed that the type of heating system has a significant influence on the flexibility potential. A radiator heating system has a quick activation of the indoor air, and the heat storage in heavy buildings is limited. The under floor heating (UFH) directly activates the high thermal capacity of the floor elements, which improves the effective heat storage in the building [20].

1.1.1 Assessment Method

As previously mentioned, there are several quantification methodologies developed and used by different researchers. Hereafter the focus will be on the key performance indicators (KPIs), some researchers use numerous KPIs to quantify the energy flexibility potential.
IEA EBC annex 67 have developed an evaluation tool to assess and quantify energy flexibility. The tool calculates the flexibility function (FF) and the flexibility characteristics (FCs) of the building, as well as two KPIs.

Flexibility Function

Junker et al. [18] proposed a dynamic function to characterize the flexibility potential of a building, called the flexibility function. The FF consists of different FCs, which are seen in figure 1.2. Figure 1.2 shows that during a penalty signal, the heating is turned off, when the heating system is turned off, the accumulated heat will be released, which corresponds to the value A. The more heat energy that is accumulated, the longer the building can retain a comfortable temperature. When the temperature reaches the lower limit for the comfort level, the heating system will be activated again. This results in an increase of the heating energy in order to bring the building to the original state, which is the value B.

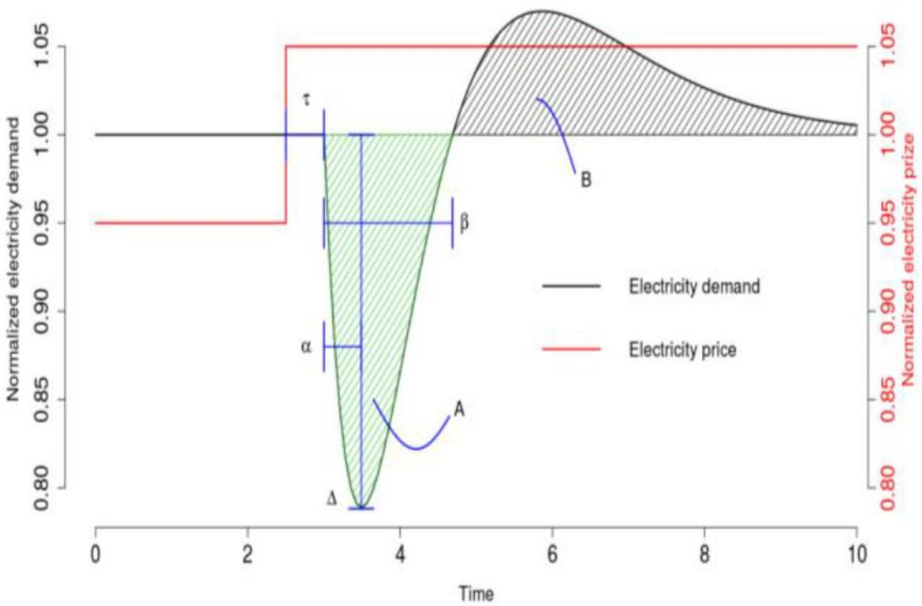
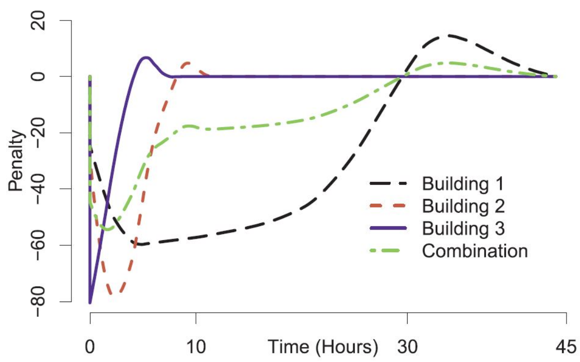


Figure 1.2: Shows the flexibility function. Source: Junker et al. (2018) [18]

Where [18]:

τ is the time from the signal is submitted to an action starts.
α is the period from start of the response to the max response
Δ is the maximum change in demand following the penalty change.
β is the time of decreased energy demand
A is the total amount of decreased energy demand
B is the total amount of increased energy demand
T is the total time of increased energy demand (Not shown in the figure)

Junker et al. [18] analyzed the flexibility potential of 3 different buildings with different flexibility functions in 3 types of RES dominated energy grids. The 3 various RES energy grids are: a wind dominated, solar dominated and hydro power dominated. Figure 1.3 (left) shows the flexibility functions for the 3 different buildings, and as seen, building 1 is able to move a large amount of energy, while building 3 only can move a small amount, but building 3 responds faster. Building 2 is in the middle. The FCs can be used to describe how feasible control strategies can be constructed. As seen in figure 1.3 (right) building 1, has greater flexibility potential for a wind dominated system, whereas if the solar panels are the main RES, building 2 has the highest flexibility potential. With hydro power as the main RES, building 3, a fast responding building, has the largest flexibility potential [18].



	Wind [%]	Solar [%]	Ramp [%]
Building 1	35,1	7,2	18,9
Building 2	10,3	24	37,5
Building 3	4,9	11,1	71
Combination	16,8	14,1	42,5

Figure 1.3: Shows the flexibility function for 3 types of buildings (left) and the calculated flexibility potential for the 3 types of building depending on 3 types of penalty signal (right). Source: Junker et al. [18]

Key Performance Indicators

IEA EBC Annex 67 have developed two KPIs to quantify energy flexibility, namely efficiency of flexible operation E_{flex} [%] and shifted flexible load S_{flex} [%]. The KPIs by Annex 67 have different focus areas. Shifted flexible load focuses on the load shifting ability, while efficiency of flexible operation focuses on the related costs/savings. Hereafter, S_{flex} will be referred to as KPI1 and E_{flex} will be referred to as KPI2. KPI1 is calculated according to equation 1.1, and KPI2 is calculated according to equation 1.2.

$$KPI1 = \frac{\sum_{i=1}^{n} max(Q_{ref,i} - Q_{flex,i}, 0)}{\sum_{i=1}^{n} Q_{ref,i}} \tag{1.1}$$

$$KPI2 = \frac{\sum_{i=1}^{n} C_i \cdot (Q_{ref,i} - Q_{flex,i})}{\sum_{i=1}^{n} C_i \cdot Qref,i} \tag{1.2}$$

Additionally to the two KPIs developed by Annex 67 there are numerous KPIs developed with the aim to quantify building energy flexibility. A research based on 11 studies, showed that several of the studies use the same KPIs, and some use more than 1 KPI to assess flexibility. Table 1.1 shows the KPIs with equations.

Table 1.1: Summary of the analyzed KPIs

Reference	KPIs	Equation
Jorha et al. [3]	Ability to shift energy use from high price periods to low price periods	$F = \left[\left(1 - \frac{\%High}{\%High_{ref}}\right) + \left(1 - \frac{\%Medium}{\%Medium_{ref}}\right)\right] \cdot \frac{100}{2}$
Jerome Le Dréau [21]	Ability to shift energy use from high price periods to low price periods	$F = \frac{\sum q_{heatingneed(low)} - \sum q_{heatingneed(high)}}{\sum q_{heatingneed(low)} + \sum q_{heatingneed(high)}}$
Liu and Heiselberg [22]	(i) Ability to shift energy use from high price periods to low price periods (ii) Power adjustment ability (iii) Economic benefit	$F = \frac{\int_{low} q_{heating+cooling} dt - \int_{high} q_{heating+cooling} dt}{\int_{low} q_{heating+cooling} dt + \int_{high} q_{heating+cooling} dt}$ $P_{difference} = P_{flexibility} - P_{reference}$ $C = \int (Q \cdot P_{el}) dt$
Loukou et al. [23]	(i) Ability to shift energy use from high price periods to low price periods (ii) Power adjustment ability (iii) Economic benefit	$F = \left[\left(1 - \frac{\%High}{\%High_{ref}}\right) + \left(1 - \frac{\%Medium}{\%Medium_{ref}}\right)\right] \cdot \frac{100}{2}$ $P_{difference} = P_{flexibility} - P_{reference}$ $C = \int (Q \cdot P_{el}) dt$
Marszal-Pomianowska et al. [9]	Ability to shift energy use from high price periods to low price periods	NA
Reynders et al. [24]	(i)Storage capacity (ii)Power adjustment ability (iii) Storage efficiency	$C_{ADR} = \int_0^{ADR} (Q_{ADR} - Q_{ref}) dt$ $Q_\delta = Q_{ADR} - Q_{ref}$ $\eta_{ADR} = 1 - \frac{\int_0^{\inf} (Q_{ADR} - Q_{ref} dt}{\int_0^{ADR} (Q_{ADR} - Q_{ref} dt}$
Pean et al. [25]	(i)Storage capacity (ii) Storage efficiency	$C_{ADR} = \int_0^{ADR} (Q_{ADR} - Q_{ref}) dt$ $\eta_{ADR} = 1 - \frac{\int_0^{\inf} (Q_{ADR} - Q_{ref} dt}{\int_0^{ADR} (Q_{ADR} - Q_{ref} dt}$
Foteinaki et al. [26]	(i)Time above comfort limit (ii) Effect of flexible operation	$Ind1 = min\{t \vert T_{op}(t) \geq 20^oC\}$ $Ind2 = \frac{P_{maxdaily}}{P_{continious}}$
Weiss et al. [27]	(i)Time above comfort limit	$\Delta t = min\{t \vert T_{op}(t) \geq 20^oC\}$
Heiselberg and Le Dreau [20]	(i) Shifting efficiency	$\eta_{shifting} = \frac{-\Delta Q_{discharged}}{\Delta Q_{charged}}$ $FF = \frac{\int_{low} Q_{heating} dt - \int_{high} q_{heating} dt}{\int_{low} Q_{heating} dt + \int_{high} q_{heating} dt}$
Junker et al. [18]	Saved cost	$FI = 1 - \frac{c^1}{c^0}$

As observed in table 1.1, different researchers use different symbols for the same parameter, and some of the KPIs are closely related. It can also be observed that not all researchers use the same assumptions when assessing the energy flexibility. Some use the total energy consumption, while others use the consumption used for heating only. The KPIs are further discussed and categorized in section 2.3.

1.2 Delimitation's

As the evaluation tool from IEA EBC Annex 67 does not calculate α and τ, they are excluded from the sensitivity analysis in this study. The sensitivity analysis on the FCs is based on 7 days data. The data from 23^{th} to 30^{th} of January is chosen. Concerning the values of KPI1 and KPI2, an evaluation period of 1 year is chosen. KPI1 and KPI2 can be used for short period analysis as well, but to give an overall indication of the flexibility potential and efficiency of flexible operation, 1 year is chosen. As the KPIs are analyzed on a yearly basis, outdoor temperature and solar radiation are excluded from these sensitivity analysis.

Only KPIs considering the TES are analyzed and compared with the reference KPIs in this study. KPIs related to appliance shifting operation are not considered, as influence of appliance shifting operation is highly depended on the user behavior and the raw data from the case studies is based on energy consumption used for heating and cooling.

1.3 Problem Statement and Research Questions

The flexibility function for a building can be calculated, but the influence of different parameters on the flexibility function is yet not known. By knowing the influence of different parameters, it is possible to design a building according to the desired flexibility function.

Many methodologies have been developed in parallel and with no exact definition and no specific quantification methodology, there is yet not any clear method how to assess building energy flexibility. IEA EBC Annex 67 have developed two KPIs to assess energy flexibility. Can the two KPIs be related the other developed KPIs?

The research questions are:

1. Which parameters, such as insulation level, thermal mass, control strategy, type of heating system, type of building, outdoor temperature and solar radiation, have the largest influence on the flexibility function?
2. Is there a relation between the analyzed KPIs and the KPIs developed by IEA EBC Annex 67?

2 | Methodology

2.1 Analysis of Case Studies

In this study, raw data from six case studies (CS), will be used to analyze the impact of the parameters mentioned below, on the FCs, KPI1 and KPI2, in a sensitivity analysis. All CS are based on simulations, and what is meant by raw data is: the energy consumption of a reference case, the energy consumption of a flexible case, and the cost function.
The chosen parameters to be analyzed are:

- Insulation level
- Thermal mass
- Solar radiation
- Outdoor temperature
- Control strategies
- Type of heating system
- Type of building

Table 2.1 shows the CS analyzed in this study. Hereafter the CS letter will be used when referring to a CS. It should be noted that several CS may use the same KPI, and therefore the CS letter and KPI number should not be mixed.

Table 2.1: A list of the case studies used in this thesis

CS	Author	Type of building	Parameter Variabilities	use of reference case / cost function	Available raw data	Location
A	Loukou et al. [23]	Office building	3	yes / yes	1 year	Denmark
B	Johra et al. [3]	Single family house	12	yes / yes	1 month	Denmark
C	Jerome Le Dreau [21]	Single family house	2	yes / yes	1 year	France
D	Marszal-pominawska et al. [9]	Single family house	12	yes / yes	1 year	Denmark
E	Liu and Heiselberg [22].	Office building	4	yes / yes	1 year	Denmark
F	Weiss et al. [27]	Single family house	1	yes / yes	1 year	Austria

In table 2.1 it is seen that some CS have analyzed up to 12 variabilities of the above-mentioned parameters available, to assess the influence on the FCs, KPI1 and KPI2.
Concerning the variabilities, they are divided and arranged as follows:

The control strategies are divided into 4 categories, namely 4K, 3K, 2K and 1K. 4K refers to a ±2K set-point modulation, 3K refers to 2K upward + 1 K downward set-point modulation, 2K refers to a ±1K set-point modulation and 1K refers to a 1K downward + 0,5K upward set-point modulation.

The insulation level is divided into two categories: low and high. According to BR15, the total demand for offices, schools and institutions should not exceed 41 kWh/m^2 + 1000 kWh per year divided by the heated floor area [28]. Assuming the building is located in Denmark, a temperature difference of 32K is used, which leads to a heat loss of 1,28 kWh/m$^2 \cdot K$. Based on this value, a U-value below 1,28 kWh/m$^2 \cdot K$ is considered as high insulation level, whereas a U-value above 1,28 kWh/m$^2 \cdot K$ is considered as a low insulation level.

The thermal mass is divided into three categories: low, medium and high. Similar to Johra et al. [3], a thermal inertia between 30 to 50 Wh/K·m^2 is a light-weight structure house and is therefore considered low. A thermal inertia between 50 to 70 Wh/k·m^2 is considered medium, and above 70 Wh/k·m^2 is considered high.

The type of heating systems is divided into three categories: Radiator, under floor heating (UFH) and Lindab Solus system. Lindab Solus system is a two-pipe water system which uses high temperature cooling and low temperature heating [23].

Solar radiation and outdoor temperature are from the weather files used in the CS.

Based on these different parameter variabilities the CS are arranged as seen in table 2.2. A1, A2, B1, B2 and so on are referring to the CS variabilities. The full table of the CS variabilities is shown in appendix A.1.

Table 2.2: Shows an example of how the case studies variabilities are arranged

CS	U-value [W/m^{2}K]	Insulation level	cm [kWh/m^{2}K]	Thermal mass	Control strategy	Heating system	Type of building
A1	1,1	high	100	high	4K	Radiator	Office
A2	1,1	high	100	high	4K	Under floor heating	Office
B1	1,7	low	30	low	4K	Radiator	Single family house
B2	0,6	high	30	low	4K	Under floor heating	Single family house
C1	1,7	low	49	low	4K	Radiator	Single family house
C2	0,78	high	48	low	4K	Radiator	Single family house

2.2 Sensitivity Analysis

In this study, sensitivity analysis is used to analyze the influence of the parameters seen in table 2.2 on the FCs, KPI1 and KPI2. A sensitivity analysis determines the contribution of the variables to the total performance on the design, which then makes it possible to identify which design parameters have the largest influence [29].
The approach to the sensitivity analysis in this study is the Morris method which is a specialized randomized One-At-a-Time (OAT) design, and is a reliable technique to identify and rank important variables [30]. The assumption is that only one or the same variability will be changed, and when only changing one or the same variability, the variable that causes the largest variation, is the most important [30].

Two types of sensitivity analysis are performed in this study. The first aims to rank the parameters according to their influence on the FCs, KPI1 and KPI2. The second aims to more specifically analyze the impact of insulation level, thermal mass, heating system and control strategy on the FCs.

Both sensitivity analysis are based on ANOVA (Analysis of Variance) tests. *ANOVA is used when comparing the means of two or more than two groups by looking at how different they are* *from each other* [31].

There are mainly two purposes of the data analysis in a multi-group situation, they are [31]:

1. To analyze if the group means are (significantly) different
2. Quantify the groups and their potential differences.

The approach of the sensitivity analysis when ranking the parameters according to their influence, is based on all CS, and is similar to Johra et al. [3], where the effect level of the parameters will be assessed by using ANOVA tests on linear regression models.
In this study, multiple linear regression model is used. A multiple linear regression model is when the outcome of a model is influenced by several independent variables. The sensitivity analysis performed in this study, analyses the influence of the different parameters on the FCs, KPI1 and KPI2. They are denoted Y_i in equation 2.1. $X_1 + X_2 + ...X_3$ are considered independent variables. These are: insulation level, thermal mass, control strategy, type of heating system, type of building, outdoor temperature and solar radiation. When choosing the parameters for sensitivity analysis, collinearity has to be avoided. This means that there should not be a correlation between the independent variables. For example including location and outdoor temperature or type of building and size of building.

$$Y_i = lm(X_1 + X_2 + ... + X_7) \tag{2.1}$$

The sensitivity analysis on the FCs is based on data from 7 days. The data is chosen from 23^{th} January to 30^{th} January. KPI1 and KPI2 are calculated based on one year of data. As the KPIs are calculated as a yearly value, the solar radiation and outdoor temperature are excluded from these sensitivity analyses.
The sensitivity analysis on the KPIs is based on 33 values, whereas on the FCs, it is based on 231 values.

The sensitivity analysis analyzing the specific influence of insulation level, thermal mass, heating system and control strategy is based on raw data from CS B and CS D. In this case, a one-way ANOVA is used. 7 values for each FC and each variability is calculated, and analyzed towards 7 values calculated where one variability is changed. Lets say 7 values for A are calculated in B1, and compared with 7 values calculated for A in B2. This way, the impact of the changed variability can be assessed.

In this study the F-value is used to rank the design parameters according to the influence. The larger the F-value, the larger impact a parameter has on the assessed characteristic. The F-value is further described in appendix B.1.

2.3 Key Performance Indicators Comparison

As mentioned in section 1.1, there are several KPIs developed, and used by different researchers to assess energy flexibility. When analyzing the KPIs used in the 11 studies, it was found that researchers use different symbols for the same parameter. For example are L, Q and P used for energy consumption. For simplification, Q is used for energy consumption in this study.

As observed in table 1.1, the outcome of the different KPIs differs from one another. In some cases, the outcome is a percentage value, whereas in some cases the outcome is just a number. In order to be able to compare the KPIs, the outcome has to be in the same format. As KPI1 and KPI2 are in %, the other KPIs have to be modified into % as well. The KPI concerning the time constant of the building is not possible to convent to a percentage value, therefore this KPI is excluded from the comparison.
The storage capacity and storage efficiency focus on short period analysis. Concerning the storage capacity, if a long period, say a year, is analyzed, the result is the same as for power adjustment ability. As mentioned in the delimitation's, the KPIs are analyzed on a yearly basis, therefore are these KPIs excluded from the comparison.

In general, the KPIs can be grouped into 4 categories as seen in table 2.3. The outcome of "Ability to shift energy use from high price periods to low price periods" is a percentage value, and therefore no modifications are necessary.
KPI4 is the power adjustment ability, and as seen in table 1.1, the outcome has to be modified into a percentage value. This KPI can be modified to the equation seen in table 2.3. Comparing KPI4 and KPI1, the main difference is that the numerators are switched and KPI1 only takes the numerator into consideration when the values are positive.
Concerning the economic benefit, the KPI from Junker et al. [18] can be used, and as the outcome is a percentage value no modifications are necessary.
The KPIs are further explained in appendix A.3.

Table 2.3: Summary of analyzed and KPIs

KPI #	KPI	Equation	Reference
1	Shifted flexible load	$KPI1 = \frac{\sum_{i=1}^{n} max(Q_{ref,i} - Q_{flex,i}, 0)}{\sum_{i=1}^{n} Q_{ref,i}}$	Annex 67
2	Efficiency of flexible operation	$KPI2 = \frac{\sum_{i=1}^{n} C_i \cdot (Q_{ref,i} - Q_{flex,i})}{\sum_{i=1}^{n} C_i \cdot Qref,i}$	Annex 67
3	Ability to shift energy use from low to low price periods	$KPI3 = \frac{\sum Q_{low} - \sum Q_{high}}{\sum Q_{low} + \sum Q_{high}}$	[3] [21] [22] [9] [23] [20]
4	Power adjustment ability	$KPI4 = \frac{\sum Q_{flex} - \sum Q_{ref}}{\sum Q_{flex}}$	[23] [22] [24] [**?**]
5	Economic benefit	$KPI5 = 1 - \frac{C \cdot Q_{flex}}{C \cdot Q_{ref}}$	[23] [22] [18]
6	Shifting efficiency	$KPI6 = \frac{-\sum Q_{discharged}}{\sum Q_{charged}}$	[20]

where:

$\mathbf{Q}_{ref}$ Reference load without flexibility [kW/m^2]

$\mathbf{Q}_{flex}$ Load with flexible operation [kW/m^2]
$\mathbf{C}$ Cost function [units/kWh, eg. gCO$_2$/kWh, £/kWh, PE/kWh]
$\mathbf{Q}_{discharge}$ Energy decrease during flexible operation
$\mathbf{Q}_{charge}$ Energy increase during flexible operation
$\mathbf{Q}_{low}$ Energy consumption during low price periods
$\mathbf{Q}_{high}$ Energy consumption during high price periods

As seen in the equations, all analyzed KPIs use the consumption difference, either between flexible and reference operation, or during high or low price periods. Only KPI2 and KPI5 take the cost function into consideration.

KPI3 is calculated with raw data from CS B, whereas KPI4, KPI5 and KPI6 are based on raw data from CS A, C, D and E. A graph is used to compare the KPIs with the KPIs developed by IEA EBC Annex 67, where it should be possible to visually analyze if the KPIs are correlated to KPI1, KPI2 or not correlated at all.

3 Results And Analysis

In this chapter, the results of the sensitivity analysis and KPI comparison are analyzed and discussed.

3.1 Sensitivity Analysis

The aim of the first sensitivity analysis is to rank parameters such as insulation level, thermal mass, outdoor temperature, solar radiation, type of heating system, control strategy and type of building (office or single family house) according to their influence on the FCs, KPI1 and KPI2. The aim of the second sensitivity analysis is to analyze more specifically how parameters such as control strategy, insulation level, type of heating system and thermal mass affect the FCs. The two sensitivity analysis will be analyzed separately.

3.1.1 Significance Ranking

This sensitivity analysis is based on raw data from all CS. The numbers in table 3.1 indicates the ranking position of each parameter with 1 being the one with the most significant influence. The aim of table 3.1 is to provide a list of which parameters to focus on, depending on which FCs or KPIs are of greatest interest.

A summary of the results is shown in table 3.1. The data used for the sensitivity analysis on the FCs and reference KPIs is seen in appendix B.2, and the sensitivity analysis is seen in appendix B.3.

Table 3.1: Summary of sensitivity analysis results ranked

	A	**B**	**Δ**	**T**	β	**KPI1**	**KPI2**
Insulation level	1	1	1	3	1	1	1
Thermal mass	2	2	2	7	6	2	4
Heating system	5	5	3	1	5	3	2
Control strategy	4	4	5	2	4	4	5
Type of building	3	3	4	4	7	5	3
Outdoor temperature	6	6	6	5	3		
Solar radiation	7	7	7	6	2		

All FCs and KPIs will be analyzed separately in the following subsections.

A and B

The sensitivity analysis showed that solar radiation was the only parameter with no significant impact on the A and B value. This may be due to the period of analysis. If the analysis were conducted over a longer period, the result could be different.

As seen in table 3.1, the insulation level has the greatest influence. As stated by Johra et al. [3] and Le Dréau and Heiselberg [20], a low insulated building can move a large amount of energy

over a short period of time, whereas a high insulated building can move a lower amount of energy over a longer period of time. This is also observed in appendix B.2, where the calculated values for A and B, are a lot higher for low insulated building than for high insulated buildings. As A and B is the amount of energy that can be moved, insulation level is expected to have the largest influence.
Thermal mass is ranked 2^{nd}, but according to the calculated F-values, as seen in appendix B, thermal mass has almost the same influence as insulation level on the A value. The thermal mass increases the time constant of the building, and especially on low insulated buildings, the thermal mass has a significant influence on the time constant. A large time constant increases the A value by being able to maintain a comfortable temperature for a longer period, and the B value by the time it takes to store the energy and the possible amount of accumulated energy.
Ranked 3^{rd} is the type of building. In this study, type of building also reflects the size of the buildings, where an office building is larger than a single family house. As the energy consumption of a building also depends on the size of a building, it makes sense that larger buildings are able to shift more energy.
4^{th} is the control strategy. A control strategy with a low set-point modulation, say 1K, affects the A and B values by reducing the time of increased/decrease energy demand, due to the thermal comfort requirements. On the other hand, a large set-point modulation allows a larger temperature drop/increase, and thereby the and A and B values are increased.
The heating system is ranked 5^{th} and influences A and B as described in the introduction. A radiator heating system increases the indoor temperature faster than a UFH system, but the UFH system improves the effective heat storage in the building. If the indoor temperature increases faster, the temperature limit is reached faster, and thereby B and A values would become smaller than for a UFH system.
The impact of outdoor temperature in ranked 6^{th}. A higher outdoor temperature leads to lower transmission losses, and with lower transmission losses, the A value does not decrease as fast if the outdoor temperature would be lower.

Δ value

According to the F-values calculated in the sensitivity analysis as seen in appendix B.3, solar radiation is the only parameter with no significant influence. The reason can be the same as for the A and B value, which was due to the period of the analysis.
Insulation level has the greatest influence on the Δ value. Considering the Δ value as the maximum change in energy demand, it makes sense that a low insulated building, with a high energy demand can change its demand the most. On the other hand, a high insulated building is limited due to the low energy consumption of the building.
Thermal mass is also an important focus area if there is an interest in changing Δ. If an on/off controller would be used to control the heating system, and the heating system was turned off for a longer period, say 1 week, the thermal mass would not have an influence on the Δ value. But due to the fact that the cost function is controlling the heating system, the heating system could be turned on and off several times during the day, and thereby a high thermal mass decreases the Δ value.
The heating system, control strategy and type of building have approximately the same F-value but are ranked according to table 3.1. A radiator heating system, increases the indoor temperature faster than a UFH system. And with a high thermal mass, the UFH system activates more efficiently the thermal mass, and thereby the indoor temperature decreases slower. With the

cost function as heating system controller, the temperature may not reach the lowest allowable temperature.

β and T

β is the time of decreased energy demand, whereas T is the time of increase energy demand. Interestingly the F-values from the sensitivity analysis showed that thermal mass, outdoor temperature temperature and solar radiation have no influence on the β value, whereas only solar radiation and insulation level have an influence on T. According to other studies [3] [19] [20], insulation level and thermal mass increase the time constant of a building. And especially in a low insulated building, the thermal mass has a significant impact on the time constant. The thermal mass should therefore have an larger influence on T and β. The control strategy should influence the T and β where a larger set-point modulation would increase the characteristics. Concerning the type of heating system, a UFH system should increase the T and β values.
The validity of the sensitivity analysis on T and β can therefore be questioned.

KPI1

KPI1 is referring to the buildings energy shifting ability. Comparing the results obtained in the sensitivity analysis to results from Johra et al. [3], the same ranking order is observed. A high insulated building is able the maintain a comfortable temperature over a long period of time, and this increases the energy shifting potential of a building. Johra et al. [3] showed that thermal mass has a significant influence on low insulated buildings, but not on highly insulated buildings. The study also showed that the impact of thermal mass stagnates with a thermal inertia above 80 Wh/m^{2}K. This is also seen in the calculated KPI1 values seen in appendix B.2, where the KPI1 value increases more from low to middle thermal mass, then from middle to high thermal mass. This can be due to the dynamic control of the heating system, where time constant for a high insulated building with middle thermal mass could be long enough to maintain a comfortable temperature until the heating system in turned on again. Assuming that the heating system would be off for a week, the thermal mass would also have a influence on high insulated buildings. Control strategy can influence KPI1, where the higher the set-point modulation, the higher shifted flexible load potential. A control strategy with $\pm$2K temperature modulation, allows the heating system to be turned off for a longer period than a control strategy with $\pm$0,5K.

KPI2

The ranking order differs from KPI1 to KPI2. According to the F-values calculated in the sensitivity analysis, only insulation level has a significant influence on KPI2. This is however more related to the energy consumption of the building. Where, of course, a high insulated building has a significant lower energy consumption than a low insulated building.

3.1.2 Impact of Parameters

CS B and CS D have as mentioned before, been used to assess the influence of certain parameters of the FCs. In CS D the focus is on different control strategies, whereas in CS B the focus is on insulation level, thermal mass and heating system.
The aim is to analyze more specifically how the parameters affect the FCs, KPI1 and KPI2.

Influence of control strategy

When analyzing the impact of the different control strategies, a reference case with no control strategy is used. The three analyzed control strategies are described section 2.1 and further in appendix A.2. The control strategies are denoted the same way as in section 2.1. Additionally, R is for radiator, U is for under floor heating. The control strategies are hereafter referred to as 2KR, 3KR 4KR, 2KU, 3KU and 4KU.

The results are shown graphically in appendix B.4. The results showed that in general, in a low insulated house, the 4KR and 4KU have the largest influence on the A, B and Δ. In a high insulated house, 4KU and 4KR have the largest influence, but the difference from 2K to 3K is insignificant.
It should be assumed that a larger set-point modulation would result in larger T and β values, but the result showed no clear improvement from 2K control strategy to 4K. Considering the results obtained by the sensitivity analysis of significance ranking, the T and β value were questionable. The same can be said about the T and β results in this sensitivity analysis.

Figure 3.1 shows the flexibility function for the high insulated house with control strategy 2KR and 4KR on the 30^{th} of January. It should be noted that the flexibility function is dynamic, and is therefore varying from one day to another. As seen, the Δ value is higher for 4KR, since a larger set-point modulation is allowed. During some periods the A and B values are larger for 2KR than 4KR. This is due to the dynamic control of the heating system, which does not always utilize the full potential of a ±2K set-point modulation. In general, a larger set-point modulation allows larger values for A and B. The flexibility function for a high insulated building with 2KU and 4KU is shown in appendix B.4.

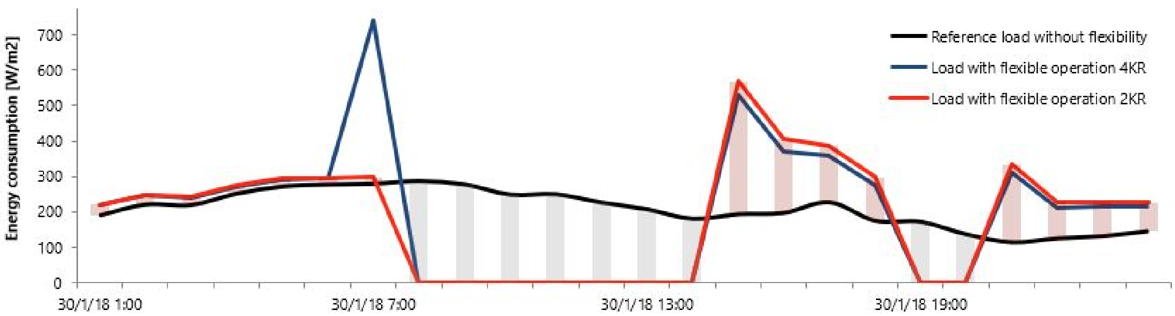


Figure 3.1: Shows a high insulated building from case study D's flexibility function on the 30^{th} of January with control strategy 2KR and 4KR

Influence of insulation level, thermal mass and type of heating system

To analyze the impact of insulation level, thermal mass and heating system, raw data from CS B is used.

As only one parameter will be changed at the time, the influence of the type of heating system was analyzed in 6 different cases. Two categories of building envelope performance: high or low, and 3 classes thermal inertia: low, middle or heavy. The result is shown in a histogram in appendix B.4 figure B.6. The result of the sensitivity analysis showed that the type of heating system only has an influence on low insulated buildings with middle or heavy weight structure,

especially on the Δ value. In a highly insulated building, the heating system does not have any significant impact on any of the FCs.
A high insulated building has a large time constant, and considering a dynamic heating control system, the temperature drop between the heating system is set to increase or decrease is limited. Whereas in a low insulated building, the time constant is significantly lower, and with a low time constant the differences between the types of heating systems becomes visible. As mentioned before, radiators heat the room more quickly than UFH. Concerning the A and B value, a fast reacting heating system decreases the A and B values, whereas a UFH system utilizes the thermal storage more efficiently, and thereby increases the A and B values.

When analyzing the impact of thermal mass, low thermal mass was chosen as the reference case, and then compared to increasing values of thermal mass. The result of the sensitivity analysis is shown in figure 3.2. As seen, an increase of thermal mass only has an influence on low insulated buildings, and especially on A, B and Δ. Figure 3.2 also shows a larger influence on the UFH system than with radiator heating system. As stated by Le Dréau and Heiselberg [20] and Johra et al. [3], the under floor heating allows a larger heat storage capacity, and activates the thermal mass more efficiently. It can also be observed that an increase from 30 kWh/m^{2}K 55 kWh/m^{2}K almost has the same impact as an increase from 30kWh/m^{2}K to 98 kWh/m^{2}K. This is also concluded by Johra et al. [3], where the impact of thermal mass stagnates at approximately 80 kWh/m^{2}K. The influence of thermal mass on the A, B and Δ values has been analyzed earlier in this study.

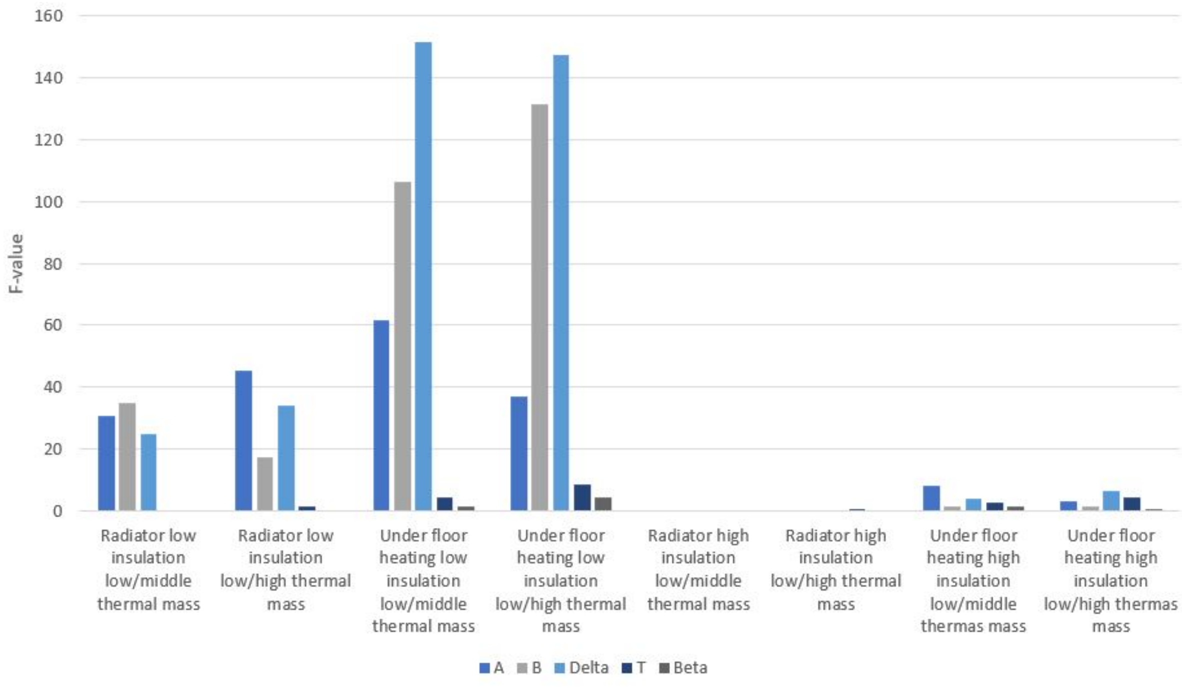


Figure 3.2: Results from sensitivity analysis of thermal mass

To analyze the impact of insulation level, the heating system and thermal mass are kept constant, so the only changed parameter is the insulation level: from 1,7 W/m^{2}K to 0,78 W/m^{2}K. This results in 6 different cases, since there are two types of heating systems and 3 classes of thermal mass. The result is shown in figure 3.3. When analyzing the impact of insulation level, the sensitivity analysis showed that insulation level has significant impact on the A, B and Δ values.

In general it can be seen that the difference on the A, B and Δ value is greatest with middle thermal mass.
When improving the insulation level, the energy consumption decreases. Therefore a high insulation level influence A, B and Δ values significantly. As stated by other studies, insulation level is of greatest importance when increasing the flexibility potential of a building [3] [20].

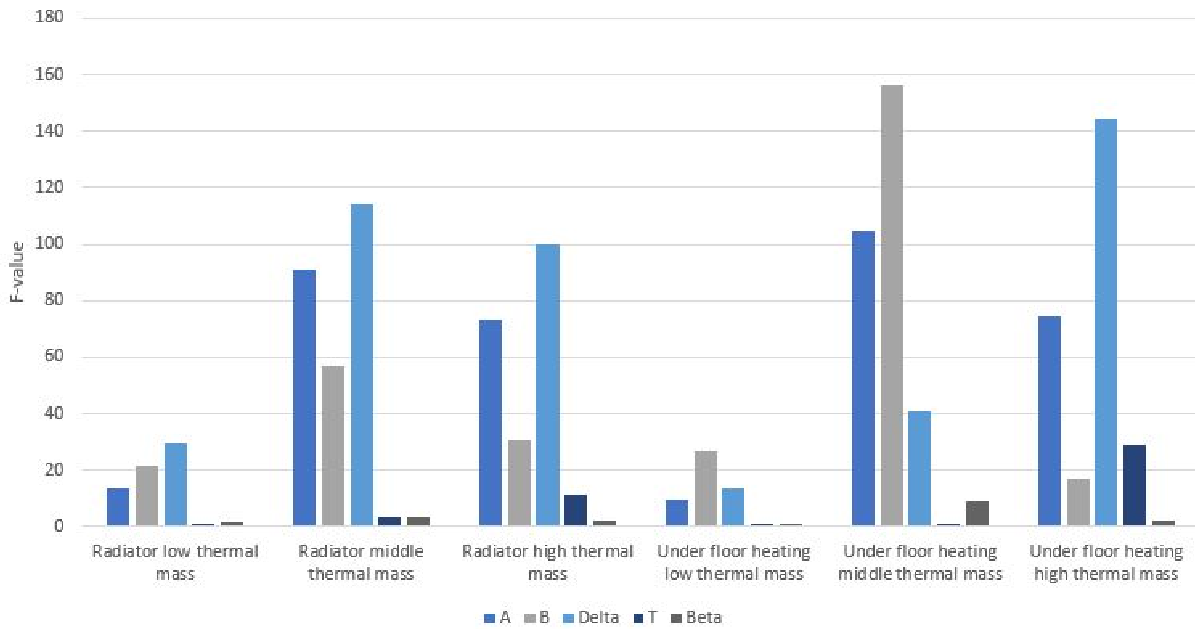


Figure 3.3: Results from sensitivity analysis of insulation level

Figure 3.4 shows impact of thermal mass and heating system on the flexibility function on the 30^{th} of January for a low insulated building. As observed, radiator heating system in a heavy building (Green line) does not utilize the thermal mass as efficient as UFH (light blue line). This is observed by the fluctuating control of the heating system. In general, a building with high thermal mass has larger A and B values than a building with low thermal mass. As mentioned, the flexibility function is dynamic, and no conclusions can be based on a flexibility function from one day.

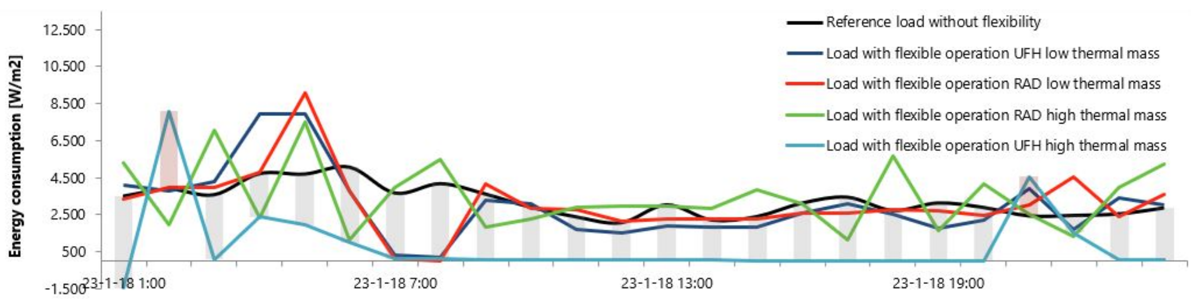


Figure 3.4: Shows the flexibility function on the 30^{th} of January for a low insulated building from CS B with low and high thermal mass and radiator and UFH system.

3.2 Key Performance Indicators Comparison

In this section KPI3, KPI4, KPI5 and KPI6 will be compared to the reference KPI1 and KPI2 to assess correlations.

KPI3

Raw data from CS B is used when comparing KPI3 with the reference KPIs. The reason is that CS B has 12 different variabilities for assessing the KPIs.
The comparison is shown in figure 3.5, where it can be deduced that KPI1 and the KPI3 are correlated, whereas there is no correlation between KPI3 and KPI2.

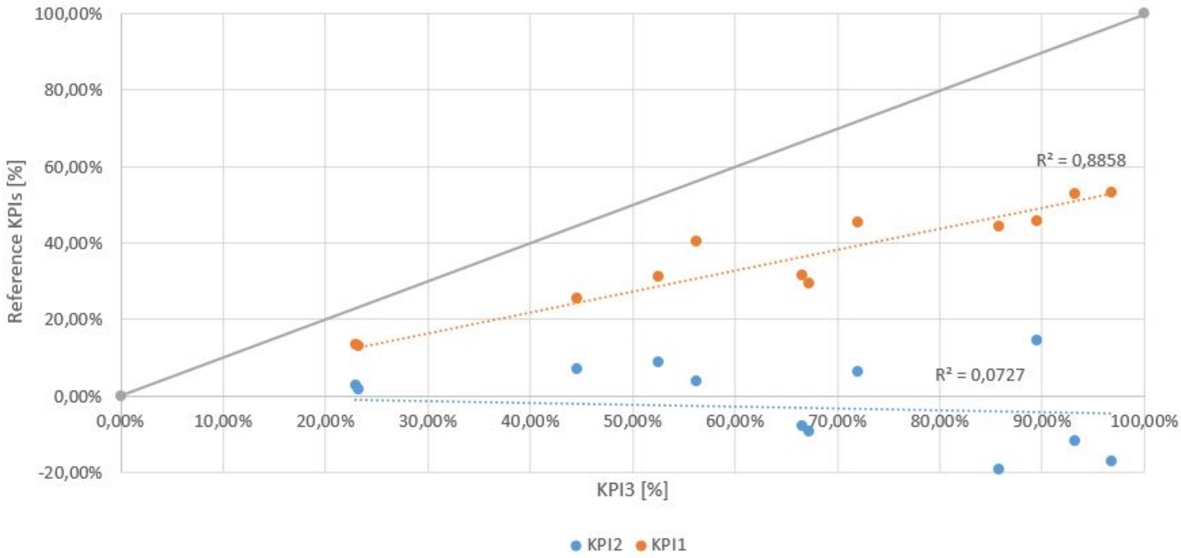


Figure 3.5: Comparison: KPI3 / Reference KPIs

The focus area of KPI3 is the ability to shift energy from high price periods to low price periods. The more energy that can be shifted results in a higher flexibility potential. The same is valid in KPI1, but instead of shifting to low price periods, the focus is on the consumption difference from a reference case to a flexible case. The lower the energy consumption during flexible operation, the higher a flexibility potential the building has.

KPI4

As stated in section 2.3, KPI4 and KPI1 are similar. Figure 3.6 shows the comparison between KPI4 and the reference KPIs. As the figure indicates, there is a correlation between KPI4 and KPI1, whereas there is no correlation between KPI4 and KPI2.
This was also expected based on the equations. As expected, KPI1 reached slightly higher values than KPI4. The reason is that in KPI1 the values where the reference consumption minus flexibility consumption is negative are excluded.

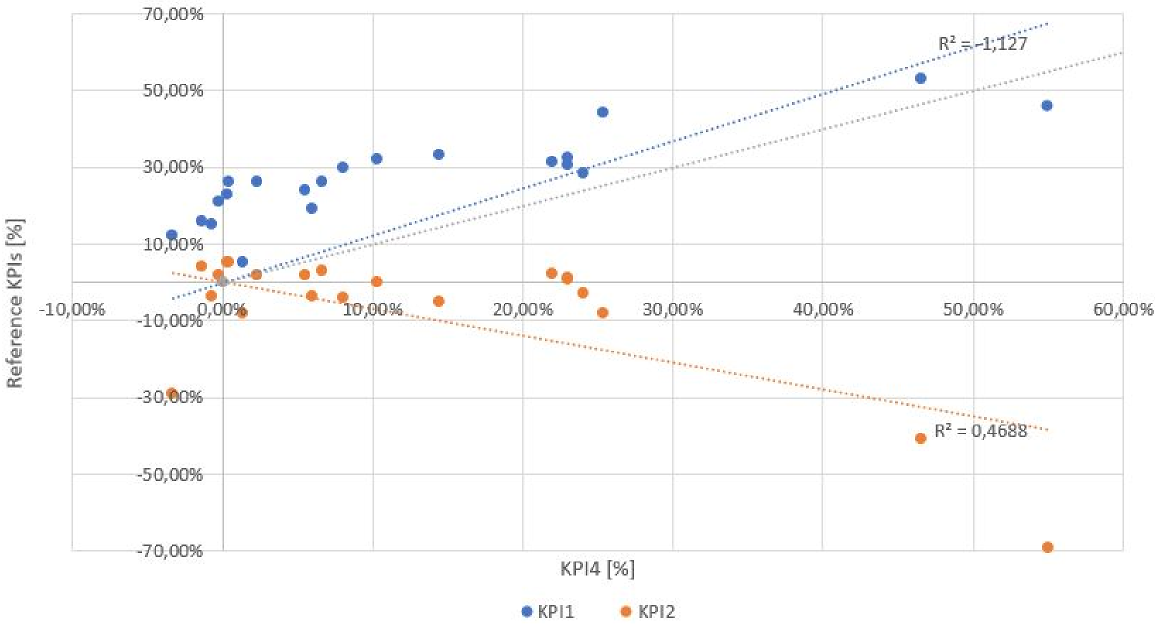


Figure 3.6: Comparison: KPI4 / Reference KPIs

KPI5

KPI5 and KPI2 are the only KPIs who take the cost function into account. These KPIs should give an indication of the possible savings/costs. The result of the comparison is shown in figure 3.7. It can be deduced that KPI5 and KPI2 are related.

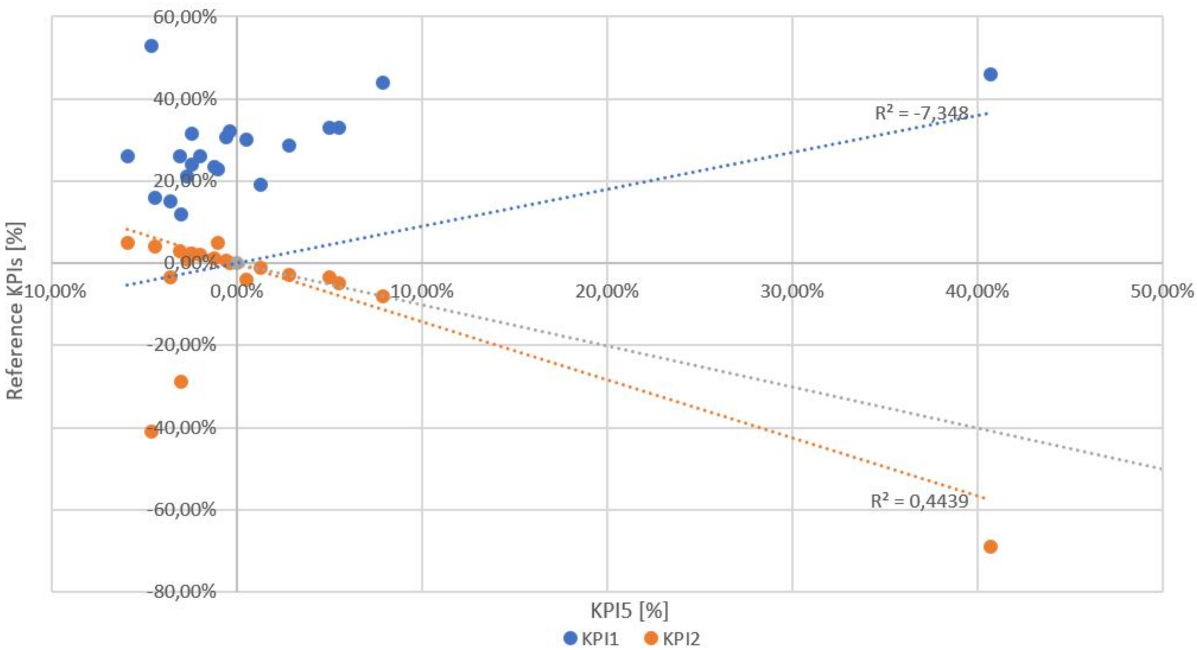


Figure 3.7: Comparison: KPI5 / Reference KPIs

KPI6

KPI6 is concerns the shifting efficiency. The shifting efficiency depends on how much energy is used during discharging and how much is used during charging. The building is discharging when the flexible load is higher than the reference load, and charging if the reference load is higher than the flexible load.

As seen in figure 3.8 there is no correlation between KPI6 and KPI1 nor KPI2. If the trend-line is not attached to (0,0) there is observed an negative correlation. Which means increasing values of shifted flexible load, leads to lower values of shifting efficiency. This could indicate that the more energy that is shifted, the less efficient the shifting is.

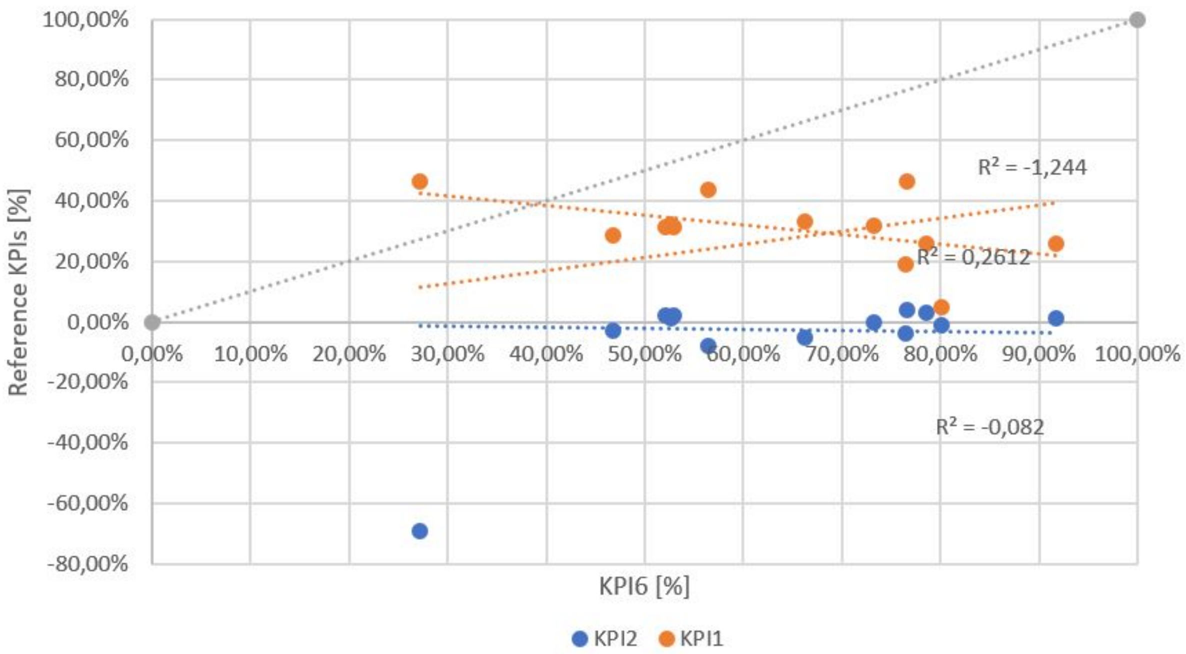


Figure 3.8: Comparison: KPI6 / Reference KPIs

3.2.1 Analysis

Table 3.2 shows the result of the comparison. As seen, 2 of the 4 analyzed KPIs are correlated to KPI1, which is shifted flexible load, whereas only 1 is correlated to KPI2, which is the efficiency of flexible operation. The only KPI that is not correlated to either KPI1 nor KPI2 is KPI6. The shifting ability and shifting efficiency are not necessarily correlated. In fact, Le Dréau and Heiselberg [20] showed that increasing hours of activation reduces the shifting efficiency. On Figure 3.8 is a trend-line added which is not assumed to start from (0,0), and as seen, the trend-line has an opposite correlation. Where the higher the flexibility potential, the lower the shifting efficiency. The reason can be the rebound effect, where the more energy that is released during flexible operation, the more energy is needs to be accumulated to reach the same state.

The literature review done in this study confirms the three main aspects found by IEA EBC Annex 67 [13] when assessing building energy flexibility.
As observed in table 2.3, some studies use more than 1 KPI to assess the flexibility potential.

Table 3.2: Summary of KPI comparison

	Load shifting	**Cost savings**
KPI3	x	
KPI4	x	
KPI5		x
KPI6		

It can be deduced that 8 of the 11 analyzed studies use entirely or partly a KPI correlated to shifted load operation. On the other hand, 3 studies use entirely or partly a KPI correlated to the efficiency of flexible operation, or savings/costs. The time constant and storage capacity are not compared in this study, but analyzing these KPIs, it can be assumed that they are correlated to the energy shifting ability of a building.
Based on the literature research and KPI comparison it can be deduced that the energy shifting ability is the most used methodology to assess energy flexibility. As 8 of the 11 analyzed KPIs can be related to the reference KPIs, the IEA EBC Annex 67 KPIs are representing the majority, and only considering KPIs that are assessed on a yearly basis, the reference KPIs represent 8 of the 9 analyzed KPIs.

4 Conclusion

Having a better understanding of how different parameters affect the energy flexibility ability of a building, the possibility to design efficient systems useful to help managing the energy grid increases. This study aims to provide a ranked list of focus areas for the different flexibility characteristics, where it then should be possible to improve the flexibility characteristics that are of greatest interest. Combining the results obtained in this study and the results obtained by Junker at al. [18], should give an indication of which parameters to focus on in order to get the most suitable flexibility function depending on the renewable energy system.
In general, insulation level has the greatest impact on all flexibility characteristics and key performance indicators developed by IEA EBC Annex 67. A high insulation level decreases energy consumption and thereby also the amount of energy that can be released. It also decreases the maximum change in demand. The sensitivity analysis showed that high thermal mass only has an influence on low insulated buildings, where it increases the amount of energy that can be released/accumulated, but decreases maximum change in demand. The reason that the maximum change in demand decreases, is the temperature does not reach the lower comfortable temperature limit with a dynamic heating control. It was also found that type of heating system also only has an influence on low insulted buildings. A radiator heats the room more quickly than the UFH, but the UFH more efficiently utilizes the thermal storage in the floor.
The sensitivity analysis results on the total time of increased and decreased energy demand are questionable, since other studies, and analysis of the flexibility function showed different results.

This study also aims to compare different key performance indicators to the two key performance indicators developed by IEA EBC Annex 67. The comparison showed that all the analyzed KPIs except KPI6 were either comparable to KPI1 or KPI2, and only considering the KPIs that can assess flexibility on a yearly basis, 8 of 9 were found comparable. KPI6 is considering the shifting efficiency, and with increasing values of shifting ability, decreasing values of shifting efficiency were reached. It can be due to the rebound effect, where the larger the amount of energy that is released, an even larger amount has to be accumulated to reach the same state. In general, the results obtained by the comparison leads to the conclusion that all the analyzed KPIs are basically trying to answer the same question, but with different methods. In can be concluded that the IEA EBC Annex 67 KPIs are representing the majority of the analyzed KPIs.

5 | Future Work

As observed in the sensitivity analysis concerning the influence of different parameters, the same parameters have vastly different influence on low and high insulated buildings. This raises a question whether the significance ranking is different for a low and a high insulated building. By analyzing this, a more precise focus area would be provided depending on the type of building.

In this study, the influence of type of building, hereby meant office or single family houses, was analyzed. Based on the data used in this study, the offices are approximately 2900m^2 whereas the single family houses vary in sizes. A more precise analysis could have been reached if the size of the building was analyzed instead of the type of building.

As stated by Liu and heiselberg [22] and as seen in the KPI2 values calculated in appendix B.2, it can be deduced that savings are not guaranteed by applying flexibility. With no economic benefit it can be difficult to encourage tenants or house owners to consider a flexible operation [18] [22]. The result of the sensitivity analysis showed that none of the analyzed parameters except for insulation level had any influence on KPI2. Other parameters such as cost function, electricity price, taxes would be more interesting to analyze.

All analyzed KPIs are related to thermal energy storage. Thereby no KPI considering appliance operation shifted is compared to the reference KPIs. If the two KPIs developed by IEA EBC Annex 67 aim to quantify the general building energy flexibility of a building, a comparison between appliance operation shifting and Annex 67 KPIs needs to be performed and analyzed.

In this study, the validity of the sensitivity analysis on the total time of increase/decrease energy demand is questionable. It could be interesting to analyze more data points to see if the same results are obtained or more reliable results.

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A Appendix A

A.1 Study Cases variabilities Summary

CS	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	thermal_mass	Control_strategy	Heating_system	Type_of_building
A1	1,1	high	100	high	4K	Radiator	Office building
A2	1,1	high	100	high	4K	under floor heating	Office building
A3	1,1	high	100	high	4K	Lindab	Office building
B1	1,7	low	30	low	4K	Radiator	Single family house
B2	0,78	high	30	low	4K	Radiator	Single family house
B3	1,7	low	55	medium	4K	Radiator	Single family house
B4	0,78	high	55	medium	4K	Radiator	Single family house
B5	1,7	low	98	high	4K	Radiator	Single family house
B6	0,78	high	98	high	4K	Radiator	Single family house
B7	1,7	low	30	low	4K	under floor heating	Single family house
B8	0,78	high	30	low	4K	under floor heating	Single family house
B9	1,7	low	55	medium	4K	under floor heating	Single family house
B10	0,78	high	55	medium	4K	under floor heating	Single family house
B11	1,7	low	98	high	4K	under floor heating	Single family house
B12	0,78	high	98	high	4K	under floor heating	Single family house
C1	1,6	low	49	low	4K	Radiator	Single family house
C2	0,6	high	48	low	4K	under floor heating	Single family house
D1	0,6	high	54	medium	2K	Radiator	Single family house
D2	0,6	high	54	medium	3K	Radiator	Single family house
D3	0,6	high	54	medium	4K	Radiator	Single family house
D4	0,6	high	54	medium	2K	under floor heating	Single family house
D5	0,6	high	54	medium	3K	under floor heating	Single family house
D6	0,6	high	54	medium	4K	under floor heating	Single family house
D7	1,7	low	44	low	2K	Radiator	Single family house
D8	1,7	low	44	low	3K	Radiator	Single family house
D9	1,7	low	44	low	4K	Radiator	Single family house
D10	1,7	low	44	low	2K	under floor heating	Single family house
D11	1,7	low	44	low	3K	under floor heating	Single family house
D12	1,7	low	44	low	4K	under floor heating	Single family house
E1	1,1	high	100	high	1K	Radiator	Office building
E2	1,1	high	100	high	1K	Radiator	Office building
E3	1,1	high	100	high	1K	Radiator	Office building
E4	1,1	high	100	high	1K	Radiator	Office building
F1	0,6	high	75	high	2K	Radiator	Single family house

Figure A.1: Summary of case studies with variabilities

A.2 Control Strategies used in Case Study D

The following text is extracted from Marszal-Pomianowska et al. [9].

Based on these rules, different scenarios of activation's have been defined. For the 80s house:
- Reference scenario, with a constant set-point of 22°C,
- Flex scenario # 1 (4 hrs conservation): the set-point is decreased by 2 K in periods with high prices, but for a maximum period of 4 hours. This modulation can be repeated over the day after a waiting period of 4 hours.
- Flex scenario # 2 (4 hrs storage and conservation): the set-point is decreased by 2 K in periods with high prices or increased by 2 K in periods with low prices, but for a maximum period of 4

hours. These modulations can be repeated over the day after a waiting period of 4 hours.
- Flex scenario # 3 (6 hrs storage and conservation): similar to Scenario # 2, but with 6 hrs.

For the passive house:
- Reference scenario, with a constant set-point of 22°C
- Flex scenario # 1 (12 hrs conservation): the set-point is decreased by 2 K in periods with high prices, but for a maximum period of 12 hours. This modulation can be repeated over the day after a waiting period of 12 hours.
- Flex scenario # 2 (24 hrs conservation): similar to Scenario # 1, but with 24 hrs.
- Flex scenario # 3 (24 hrs conservation / 1 hr storage): the set-point is decreased by 2 K in periods with high prices, but for a maximum period of 24 hours. This modulation can be repeated over the day after a waiting period of 24 hours. Moreover, the set-point can also be increased by 2 K in periods with low prices, but for a maximum period of 1 hour. This modulation can be repeated over the day after a waiting period of 1 hour.

A.3 Key Performance Indicators Description

A.3.1 KPI3

KPI3 uses a concept for thermal energy storage by set-point modulations, where the set-point indicates whether the heating, ventilation and cooling (HVAC) system is charging or discharging [20]. When the set-point is increased by 2K, the system is charging, and energy is being stored, this is called upward modulation. Whereas discharging is when the set-point is decreased by 2K, and energy is being released. This is called downward modulation. Whether the system is in upward or downward modulation is determined by a prize signal. The price signal is divided into three categories; Low, medium and high prize. The low prize is when the price is lower than the first quartile, whereas the high prize is when the price is higher than the third quartile. The prize signal is used as an indicator of the availability of electricity [20]. As seen in figure A.2, the aim is to shift the heating use from high to low price periods, and thereby use the electricity when it is available [14].

The energy flexibility index will then be calculated based on the buildings ability to shift the energy use from high to low prize periods [20]. The flexibility index is calculated as stated in equation A.1 [14] or equation A.2 [21]:

$$F = \left[\left(1 - \frac{\%High}{\%High_{ref}}\right) + \left(1 - \frac{\%Medium}{\%Medium_{ref}}\right)\right] \cdot \frac{100}{2} \tag{A.1}$$

$$FlexibilityFactor = \frac{\sum q_{heatingneed(low)} - \sum q_{heatingneed(high)}}{\sum q_{heatingneed(low)} + \sum q_{heatingneed(high)}} \tag{A.2}$$

Where $\%High$ and $\%Medium$ are the percentages of thermal energy used during high and medium prize with set-point modulation controlled by prize in activated. $\%High_{ref}$ and $\%Medium_{ref}$ are the percentages of thermal energy used without using heating storage strategy

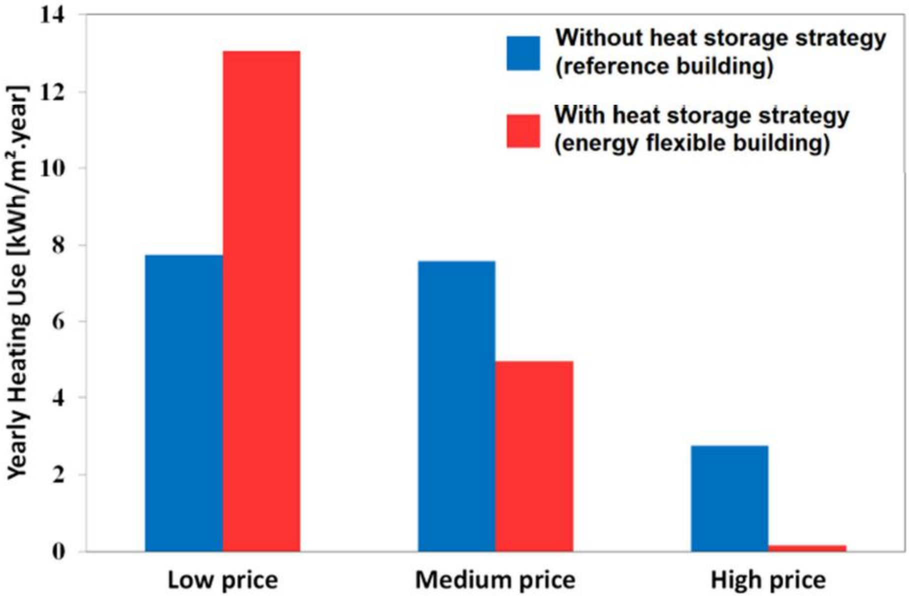

Figure A.2: Shows how heat storage strategy shifts the use from high to low prize periods. Source: Johra et al. (2018) [3]

[14]. As it can be seen from the equation, if the energy use using heat storage strategy and without are the same, the flexibility index will be zero. Whereas if the energy used using heat storage strategy is higher than the reference, the flexibility index will be negative. If all the energy used during high periods shifts to low prize periods, the flexibility factor will be 50%, and if all the energy used during high and medium prize shifts to low prize, the flexibility factor will be 100%, which is the maximum value [14].

As the KPI3 indicates, the energy flexibility is defined as the ability to minimize the heating use during high price periods and maximize it during low price periods [14]. This definition focuses on the load shifting ability.

The main difference between equation A.1 and A.2 is that A.1 analyzes the difference from a reference case, and the flexible case, whereas as A.2 the consumption from the reference case is not needed, but calculates how much of the total power is used during low price periods.
Both equations result is positive if the use of power is higher during low price periods, and negative if the use of power is higher during high price periods.

A.3.2 KPI4

KPI4 quantifies the the power difference between the flexible and reference operation. Case A and E use equation A.3 to calculate the power adjustment ability, whereas [24] and [?] use equation A.4. As seen the equations are very similar, equation A.4 assumes an active demand response, whereas equation A.3 just assumes an flexible operation.

$$PowerDifference = PowerFlexibility - PowerReference \tag{A.3}$$

$$Q_\delta = Q_{ADR} - Q_{Ref} \tag{A.4}$$

Due to the form of results achieved by using equation A.3 and A.4 it is not possible compare KPI4 with the reference KPIs.
In order to be able to compare the result obtained by equation A.3 with the reference KPIs, the equation has to be modified, so the outcome is a percentage value. This is done by summing the power during the flexibility case, and summing the use during reference case and divide with the sum of power used during reference. This is seen in equation A.5.

$$KPI4 = \frac{\sum PowerFlexibility - \sum PowerReference}{\sum PowerFlexibility} \tag{A.5}$$

Comparing equation A.5 and equation 1.1 the main difference is that 1.1 only takes the numerator into consideration when ref-flex is positive.

A.3.3 KPI5

KPI5 is also used by case A and E and as the name "Economic benefit" indicates, this KPI gives an indication of possible economic savings. Economic savings is an important metric for the end users. Savings are expected by the house owners or tenants [22].

It can be assumed that economic benefit metric would correlate to the efficiency of flexible operation, since both take are related to the costs of flexible operation.

The economic benefit is evaluated as the used hourly energy consumption (Q) times the electrical price (P_{EL}). Where C is the yearly cost for heating and cooling. The economic benefit is expressed mathematically in equation A.6.

$$C = \int (Q \cdot P_{EL}) dt \tag{A.6}$$

Equation A.6 calculates the yearly costs for heating and cooling, whereas Annex67 efficiency of flexible operation shown in equation 1.2 calculates the percentage of economic savings during the assessed period.

Junker et al. [18] use a similar KPI, which is a combination of both the penalty signal and the buildings flexibility function. If the penalty signal is real time electricity cost, then the KPI shows the actual savings.
This KPI is expressed mathematically in equation A.7, where C^0 is the penalty signal times consumption for a penalty ignorant system (reference case), and C^1 is the penalty signal times consumption for a penalty-aware system (flexible case). The equations for C^0 and C^1 are shown in equation A.8 and A.9.

$$KPI5 = 1 - \frac{C^1}{C^0} \tag{A.7}$$

$$C^0 = \sum_{t=0}^{N} \lambda_t \cdot u_t^0 \tag{A.8}$$

$$C^1 = \sum_{t=0}^{N} \lambda_t \cdot u_t^1 \tag{A.9}$$

where: λ is the penalty signal/cost function and u_t is the energy consumption.

The economic benefit calculated in A.6 is just a value, and can therefore not be compared to the reference KPIs. In order compare the result equation A.7 will be used as KPI5.

A.3.4 KPI6

KPI #6 depends on set-point modulation, where *during part of the modulation, the energy use decreases compared to the reference case, this amount of energy is named the discharged heat* ($\Delta Q_{HeatDischarged}$, *see equation A.10). During another part of the modulation, the energy use increases compared to the reference case; this quantity is named the charged heat* ($\Delta Q_{HeatCharged}$, *see equation A.11)* [20]. The ratio of these terms corresponds to the shifting efficiency ($\eta_{shifting}$), see equation A.12.

$$\Delta Q_{heatdischarged} = \int_0^{\inf} {}_{heating}(\Delta q_{heating} < 0)dt \tag{A.10}$$

$$\Delta Q_{heatdischarged} = \int_0^{\inf} {}_{heating}(\Delta q_{heating} > 0)dt \tag{A.11}$$

The outcome of equation A.12 is lower than 1 in case of heat storage, and higher than 1 in case of heat conservation, where the energy use decreases from the reference case.

$$FI\#6 = \frac{-\Delta Q_{HeatDischarged}}{\Delta Q_{HeatCharged}} \tag{A.12}$$

A.4 Appliance Shifting Operation

Appliance flexibility can be divided into two categories: Postponable and buffered. Postponable appliances are flexible because of the possibility to shift the energy use to latter times, within a time frame defined by the user. Whereas buffered appliances are appliances which have a buffer where energy can be stored or buffered [11]. Postponable appliances such as washing machines, tumble dryers, dish washers and postponable appliances such as domestic hot water (DHW) buffers and electric vehicles can contribute to the energy flexibility of a residential building by modifying the consumption pattern. In order for the consumption changes to be acceptable, the correct function of the appliances and the comfort level for the used should not be impacted [11]. The consumption pattern could be modified according to real time price level [32]. This could be done by information and communication technology (ICT) which enables the consumers to monitor and control the demand automatically [32].

Electric vehicles (EV) can be used both for storing electricity, and the use it at latter times, but also to shift the charging time. In order to use a EV for storing electricity, it is necessary to define the time the EV can be used as a battery, and at what time it should be fully loaded.

B | Appendix B

B.1 ANOVA Description

Figure B.1 illustrates the concept for the one-way ANOVA. There is an overall mean across all the groups ($\hat{\mu}$) and each group (treatment) has its own mean value ($\hat{\mu_i}$). $\hat{\alpha_i}$ denotes the difference between each group mean.

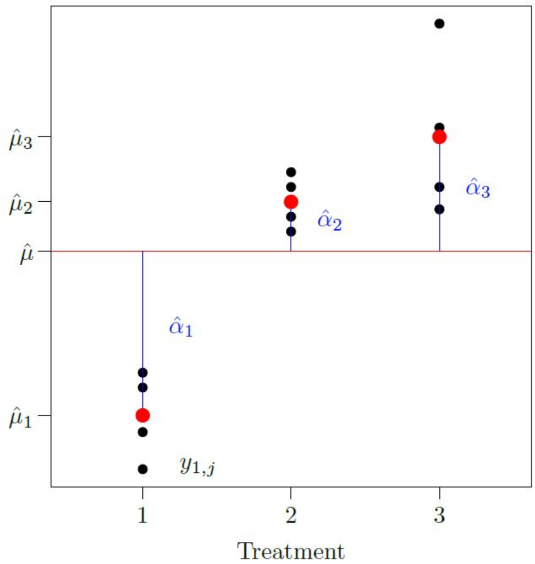

Figure B.1: Conceptual plot for the one-way ANOVA problem. Source: Brockhoss et al. (2018) [24]

In this study, the F-value is used so assess the ranking order according to the influence.
The F-value can simply be descried as the ratio between the "between group variance" and the "within group variance". This is mathematically expressed in equation B.1. By looking at this equation, is it visible that a large variance between the groups and a small variance within the group equals a large F-value. In this context, an example could be if a value of A is small in one case, and large in another case, the between variance becomes large. On the other hand, if the variance within the case A values is small, the within variance is small. This leads so a high F-value, or in other words, that there is a difference between the groups. A small F-value indicates that there is no significant difference between the groups.

$$F = \frac{betweenvariance}{withinvariance} \tag{B.1}$$

In this study, R is used to perform the sensitivity analysis and calculate the F-values. In Table B.1 is an overview of how the ANOVA is working.

SS(Tr) is the group mean differences. SSE expresses the average variability within each group, as each individual observation is compared with the mean of the group is belongs to [31].

B.2 Sensitivity Analysis Data

Results of study used for sensitivity analysis for flexibility characteristic A

A	U-value [W/m2K]	Insulation_level	Cm [kWh/m2K]	Thermal_mass	Control_strategy	Heating_system	Day	utdoor_temperatu	Solar_radiation	Type_of_building	location
-9,84	1,1	high	100	high	4K	Radiator	0	-0,632	11,96	Office	Denmark
-19,34	1,1	high	100	high	4K	Radiator	1	0,617	12,07	Office	Denmark
-4,99	1,1	high	100	high	4K	Radiator	2	0,235	30,72	Office	Denmark
-14,65	1,1	high	100	high	4K	Radiator	3	1,143	12,66	Office	Denmark
-19,62	1,1	high	100	high	4K	Radiator	4	1,193	20,19	Office	Denmark
-38,72	1,1	high	100	high	4K	Radiator	5	1,445	13,4	Office	Denmark
-11,91	1,1	high	100	high	4K	Radiator	6	1,97	13,86	Office	Denmark
-14,84	1,1	high	100	high	4K	Radiator	7	1,661	14,21	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	0	-0,632	11,96	Office	Denmark
-63,51	1,1	high	100	high	4K	under floor heating	1	0,617	12,07	Office	Denmark
-20,39	1,1	high	100	high	4K	under floor heating	2	0,235	30,72	Office	Denmark
-2,84	1,1	high	100	high	4K	under floor heating	3	1,143	12,66	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	4	1,193	20,19	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	5	1,445	13,4	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	6	1,97	13,86	Office	Denmark
-52,6	1,1	high	100	high	4K	under floor heating	7	1,661	14,21	Office	Denmark
-71,99	1,6	low	49	low	4K	Radiator	0	3,74	480	SFH	France
-37,04	1,6	low	49	low	4K	Radiator	1	0,08	500	SFH	France
-36,22	1,6	low	49	low	4K	Radiator	2	-3,46	450	SFH	France
-26,88	1,6	low	49	low	4K	Radiator	3	-2,52	700	SFH	France
-37,32	1,6	low	49	low	4K	Radiator	4	-0,02	3400	SFH	France
-37,92	1,6	low	49	low	4K	Radiator	5	-0,75	700	SFH	France
-72,96	1,6	low	49	low	4K	Radiator	6	0	3500	SFH	France
-37,17	1,6	low	49	low	4K	Radiator	7	-0,45	4000	SFH	France
-800,56	0,6	high	48	low	4K	under floor heating	0	3,74	480	SFH	France
-786,51	0,6	high	48	low	4K	under floor heating	1	0,08	500	SFH	France
-794,87	0,6	high	48	low	4K	under floor heating	2	-3,46	450	SFH	France
-783,21	0,6	high	48	low	4K	under floor heating	3	-2,52	700	SFH	France
-795,24	0,6	high	48	low	4K	under floor heating	4	-0,02	3400	SFH	France
-797,06	0,6	high	48	low	4K	under floor heating	5	-0,75	700	SFH	France
-797,74	0,6	high	48	low	4K	under floor heating	6	0	3500	SFH	France
-796,66	0,6	high	48	low	4K	under floor heating	7	-0,45	4000	SFH	France
-11,6	0,6	high	75	high	2K	Radiator	0	-1,8	700	SFH	Austria
-16,6	0,6	high	75	high	2K	Radiator	1	-1,81	760	SFH	Austria
-9,53	0,6	high	75	high	2K	Radiator	2	-2,65	3900	SFH	Austria
-7,64	0,6	high	75	high	2K	Radiator	3	-2,55	650	SFH	Austria
-9,15	0,6	high	75	high	2K	Radiator	4	-0,95	2000	SFH	Austria
-9,86	0,6	high	75	high	2K	Radiator	5	-4,3	4100	SFH	Austria
-7,88	0,6	high	75	high	2K	Radiator	6	-4,24	4000	SFH	Austria
-8,62	0,6	high	75	high	2K	Radiator	7	-5,91	4050	SFH	Austria
-1362	1,7	high	44	medium	2K	Radiator	0	-3,32	22,62	SFH	Denmark
-41,2	1,7	high	44	medium	2K	Radiator	1	-4,9	35,58	SFH	Denmark
-0,1	1,7	high	44	medium	2K	Radiator	2	-8,54	28,46	SFH	Denmark
-3924,6	1,7	high	44	medium	2K	Radiator	3	-0,75	10,25	SFH	Denmark
-6010,3	1,7	high	44	medium	2K	Radiator	4	0,32	25,1	SFH	Denmark
-5054,8	1,7	high	44	medium	2K	Radiator	5	-3,33	23,63	SFH	Denmark
-4756	1,7	high	44	medium	2K	Radiator	6	-2	26,26	SFH	Denmark
-5438,2	1,7	high	44	medium	2K	Radiator	7	-5,25	21,38	SFH	Denmark
-4082,4	1,7	high	44	medium	3K	Radiator	0	-3,32	22,62	SFH	Denmark
-4052,9	1,7	high	44	medium	3K	Radiator	1	-4,9	35,58	SFH	Denmark
-4167,1	1,7	high	44	medium	3K	Radiator	2	-8,54	28,46	SFH	Denmark
-5957,9	1,7	high	44	medium	3K	Radiator	3	-0,75	10,25	SFH	Denmark
-7366,2	1,7	high	44	medium	3K	Radiator	4	0,32	25,1	SFH	Denmark
-6249,2	1,7	high	44	medium	3K	Radiator	5	-3,33	23,63	SFH	Denmark
-4393,4	1,7	high	44	medium	3K	Radiator	6	-2	26,26	SFH	Denmark
-6636,3	1,7	high	44	medium	3K	Radiator	7	-5,25	21,38	SFH	Denmark
-5833,4	1,7	high	44	medium	4K	Radiator	0	-3,32	22,62	SFH	Denmark
-6051,5	1,7	high	44	medium	4K	Radiator	1	-4,9	35,58	SFH	Denmark
-6279,1	1,7	high	44	medium	4K	Radiator	2	-8,54	28,46	SFH	Denmark
-7544,6	1,7	high	44	medium	4K	Radiator	3	-0,75	10,25	SFH	Denmark
-8132,2	1,7	high	44	medium	4K	Radiator	4	0,32	25,1	SFH	Denmark
-7018	1,7	high	44	medium	4K	Radiator	5	-3,33	23,63	SFH	Denmark
-4156,6	1,7	high	44	medium	4K	Radiator	6	-2	26,26	SFH	Denmark
-7117	1,7	high	44	medium	4K	Radiator	7	-5,25	21,38	SFH	Denmark
-2004	1,7	high	44	medium	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
-1387,4	1,7	high	44	medium	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
-609,6	1,7	high	44	medium	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
-3575	1,7	high	44	medium	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
-4937	1,7	high	44	medium	2K	under floor heating	4	0,32	25,1	SFH	Denmark
-3813,7	1,7	high	44	medium	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
-4231,5	1,7	high	44	medium	2K	under floor heating	6	-2	26,26	SFH	Denmark
-3579,3	1,7	high	44	medium	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
-3294,5	1,7	high	44	medium	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
-3537,7	1,7	high	44	medium	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
-3233,3	1,7	high	44	medium	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
-4771,5	1,7	high	44	medium	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
-5283,2	1,7	high	44	medium	3K	under floor heating	4	0,32	25,1	SFH	Denmark

-4175,7	1,7	high	44	medium	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
-4295,2	1,7	high	44	medium	3K	under floor heating	6	-2	26,26	SFH	Denmark
-4519,5	1,7	high	44	medium	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
-3969,3	1,7	high	44	medium	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
-5435,9	1,7	high	44	medium	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
-5145,9	1,7	high	44	medium	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
-5064,1	1,7	high	44	medium	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
-5727,8	1,7	high	44	medium	4K	under floor heating	4	0,32	25,1	SFH	Denmark
-5616,8	1,7	high	44	medium	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
-4042,2	1,7	high	44	medium	4K	under floor heating	6	-2	26,26	SFH	Denmark
-4571,8	1,7	high	44	medium	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
-195,7	0,6	low	54	low	2K	Radiator	0	-3,32	22,62	SFH	Denmark
-31,2	0,6	low	54	low	2K	Radiator	1	-4,9	35,58	SFH	Denmark
-5,4	0,6	low	54	low	2K	Radiator	2	-8,54	28,46	SFH	Denmark
-515,2	0,6	low	54	low	2K	Radiator	3	-0,75	10,25	SFH	Denmark
-1206,5	0,6	low	54	low	2K	Radiator	4	0,32	25,1	SFH	Denmark
-939,1	0,6	low	54	low	2K	Radiator	5	-3,33	23,63	SFH	Denmark
-865	0,6	low	54	low	2K	Radiator	6	-2	26,26	SFH	Denmark
-1458,1	0,6	low	54	low	2K	Radiator	7	-5,25	21,38	SFH	Denmark
-195,5	0,6	low	54	low	3K	Radiator	0	-3,32	22,62	SFH	Denmark
-30,7	0,6	low	54	low	3K	Radiator	1	-4,9	35,58	SFH	Denmark
-5	0,6	low	54	low	3K	Radiator	2	-8,54	28,46	SFH	Denmark
-514,7	0,6	low	54	low	3K	Radiator	3	-0,75	10,25	SFH	Denmark
-1206	0,6	low	54	low	3K	Radiator	4	0,32	25,1	SFH	Denmark
-937,5	0,6	low	54	low	3K	Radiator	5	-3,33	23,63	SFH	Denmark
-864,3	0,6	low	54	low	3K	Radiator	6	-2	26,26	SFH	Denmark
-1457,7	0,6	low	54	low	3K	Radiator	7	-5,25	21,38	SFH	Denmark
-594,2	0,6	low	54	low	4K	Radiator	0	-3,32	22,62	SFH	Denmark
-611,1	0,6	low	54	low	4K	Radiator	1	-4,9	35,58	SFH	Denmark
-614,3	0,6	low	54	low	4K	Radiator	2	-8,54	28,46	SFH	Denmark
-822,5	0,6	low	54	low	4K	Radiator	3	-0,75	10,25	SFH	Denmark
-1379,5	0,6	low	54	low	4K	Radiator	4	0,32	25,1	SFH	Denmark
-1417,4	0,6	low	54	low	4K	Radiator	5	-3,33	23,63	SFH	Denmark
-733,7	0,6	low	54	low	4K	Radiator	6	-2	26,26	SFH	Denmark
-1711,5	0,6	low	54	low	4K	Radiator	7	-5,25	21,38	SFH	Denmark
-168,3	0,6	low	54	low	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
-22,1	0,6	low	54	low	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
-31	0,6	low	54	low	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
-347	0,6	low	54	low	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
-735,8	0,6	low	54	low	2K	under floor heating	4	0,32	25,1	SFH	Denmark
-292,6	0,6	low	54	low	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
-420	0,6	low	54	low	2K	under floor heating	6	-2	26,26	SFH	Denmark
-723,8	0,6	low	54	low	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
-172,6	0,6	low	54	low	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
-9	0,6	low	54	low	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
-11,4	0,6	low	54	low	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
-343,2	0,6	low	54	low	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
-735,9	0,6	low	54	low	3K	under floor heating	4	0,32	25,1	SFH	Denmark
-278,2	0,6	low	54	low	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
-421,3	0,6	low	54	low	3K	under floor heating	6	-2	26,26	SFH	Denmark
-722,1	0,6	low	54	low	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
-335	0,6	low	54	low	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
-347,8	0,6	low	54	low	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
-410,4	0,6	low	54	low	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
-449	0,6	low	54	low	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
-688,2	0,6	low	54	low	4K	under floor heating	4	0,32	25,1	SFH	Denmark
-342,3	0,6	low	54	low	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
-418,8	0,6	low	54	low	4K	under floor heating	6	-2	26,26	SFH	Denmark
-726,9	0,6	low	54	low	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
-2,05	1,1	high	100	high	1K	Convective	0	-4	11,96	Office	Denmark
-20,09	1,1	high	100	high	1K	Convective	1	-4	12,07	Office	Denmark
-5,69	1,1	high	100	high	1K	Convective	2	-4	30,72	Office	Denmark
-2,86	1,1	high	100	high	1K	Convective	3	-4	12,66	Office	Denmark
-1,07	1,1	high	100	high	1K	Convective	4	-4	20,19	Office	Denmark
-7,71	1,1	high	100	high	1K	Convective	5	-4	13,4	Office	Denmark
-15,82	1,1	high	100	high	1K	Convective	6	-4	13,86	Office	Denmark
-2,09	1,1	high	100	high	1K	Convective	7	-4	14,21	Office	Denmark
-2,08	1,1	high	100	high	1K	Convective	0	-1	11,96	Office	Denmark
-20,11	1,1	high	100	high	1K	Convective	1	-1	12,07	Office	Denmark
-5,59	1,1	high	100	high	1K	Convective	2	-1	30,72	Office	Denmark
-2,84	1,1	high	100	high	1K	Convective	3	-1	12,66	Office	Denmark
-0,99	1,1	high	100	high	1K	Convective	4	-1	20,19	Office	Denmark
-8,49	1,1	high	100	high	1K	Convective	5	-1	13,4	Office	Denmark
-15,49	1,1	high	100	high	1K	Convective	6	-1	13,86	Office	Denmark
-12,55	1,1	high	100	high	1K	Convective	7	-1	14,21	Office	Denmark
-1,99	1,1	high	100	high	1K	Convective	0	2	11,96	Office	Denmark
-20	1,1	high	100	high	1K	Convective	1	2	12,07	Office	Denmark
-5,53	1,1	high	100	high	1K	Convective	2	2	30,72	Office	Denmark
-2,79	1,1	high	100	high	1K	Convective	3	2	12,66	Office	Denmark
-0,94	1,1	high	100	high	1K	Convective	4	2	20,19	Office	Denmark

-8,44	1,1	high	100	high	1K	Convective	5	2	13,4	Office	Denmark
-15,45	1,1	high	100	high	1K	Convective	6	2	13,86	Office	Denmark
-12,52	1,1	high	100	high	1K	Convective	7	2	14,21	Office	Denmark
-1,81	1,1	high	100	high	1K	Convective	0	5	11,96	Office	Denmark
-19,92	1,1	high	100	high	1K	Convective	1	5	12,07	Office	Denmark
-5,49	1,1	high	100	high	1K	Convective	2	5	30,72	Office	Denmark
-2,75	1,1	high	100	high	1K	Convective	3	5	12,66	Office	Denmark
-0,9	1,1	high	100	high	1K	Convective	4	5	20,19	Office	Denmark
-8,4	1,1	high	100	high	1K	Convective	5	5	13,4	Office	Denmark
-15,41	1,1	high	100	high	1K	Convective	6	5	13,86	Office	Denmark
-30,76	1,1	high	100	high	1K	Convective	7	5	14,21	Office	Denmark
-20284	1,7	low	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
-13901	1,7	low	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
-13529,99	1,7	low	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
-14097,67	1,7	low	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
-12987,64	1,7	low	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
-11567,21	1,7	low	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-2757,5	1,7	low	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-7325,63	1,7	low	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
-30448,83	1,7	low	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-13356,11	1,7	low	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-11982,62	1,7	low	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-18076,66	1,7	low	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-13290,1	1,7	low	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-9697,5	1,7	low	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-3540	1,7	low	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-10338,7	1,7	low	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-25894,96	1,7	low	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
-26146,87	1,7	low	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
-22457,1	1,7	low	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
-28747,06	1,7	low	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
-31512,45	1,7	low	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
-34218,89	1,7	low	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-16590,68	1,7	low	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-31938,8	1,7	low	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
-54389,54	1,7	low	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-57638,89	1,7	low	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-33368,66	1,7	low	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-42548,35	1,7	low	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-40335,15	1,7	low	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-62986,49	1,7	low	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-54016,52	1,7	low	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-61230,55	1,7	low	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-47518,15	1,7	low	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
-16033,92	1,7	low	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
-39729,66	1,7	low	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
-53252,75	1,7	low	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
-50341,28	1,7	low	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
-41770,01	1,7	low	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-50844,2	1,7	low	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-43290,1	1,7	low	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
-42585,45	1,7	low	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-30852,04	1,7	low	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-43900,47	1,7	low	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-30502,56	1,7	low	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-39572,84	1,7	low	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-54005,64	1,7	low	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-41988,9	1,7	low	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-64648,7	1,7	low	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-8100,03	0,78	high	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
-3931,93	0,78	high	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
-2176,96	0,78	high	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
-4680	0,78	high	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
-5401,66	0,78	high	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
-5625,84	0,78	high	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-2779,13	0,78	high	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-6295,07	0,78	high	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
-9176,23	0,78	high	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-4095,9	0,78	high	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-2111,52	0,78	high	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-4263,1	0,78	high	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-5025,45	0,78	high	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-5709,71	0,78	high	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-3985,23	0,78	high	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-5531,56	0,78	high	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-9392,61	0,78	high	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
-5825,17	0,78	high	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
-3048,71	0,78	high	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
-4780,06	0,78	high	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
-7809,81	0,78	high	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark

-7989,34	0,78	high	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-907,39	0,78	high	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-5708,9	0,78	high	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
-11174,49	0,78	high	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-11766,25	0,78	high	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-12026,34	0,78	high	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-9759,67	0,78	high	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-10307,67	0,78	high	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-10535,65	0,78	high	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
0	0,78	high	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-10110,44	0,78	high	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-10778,46	0,78	high	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
-6267,07	0,78	high	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
-3752,29	0,78	high	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
-5490,4	0,78	high	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
-7593,04	0,78	high	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
-7958,06	0,78	high	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
0	0,78	high	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-3856,38	0,78	high	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
-8229,2	0,78	high	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-9724,55	0,78	high	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-7151,41	0,78	high	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-8118,49	0,78	high	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-9756,07	0,78	high	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-10186,48	0,78	high	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
0	0,78	high	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-6179,33	0,78	high	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark

Results of study used for sensitivity analysis for flexibility characteristic B

B	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	Thermal_mass	Control_strategy	Heating_system	Day	Outdoor_temperature [°C]	Solar_radiation [W/m2]	Type_of_building	location
29,47	1,1	high	100	high	4K	Radiator	0	-0,632	11,96	Office	Denmark
0,43	1,1	high	100	high	4K	Radiator	1	0,617	12,07	Office	Denmark
0	1,1	high	100	high	4K	Radiator	2	0,235	30,72	Office	Denmark
6,7	1,1	high	100	high	4K	Radiator	3	1,143	12,66	Office	Denmark
18,03	1,1	high	100	high	4K	Radiator	4	1,193	20,19	Office	Denmark
3,17	1,1	high	100	high	4K	Radiator	5	1,445	13,4	Office	Denmark
21,52	1,1	high	100	high	4K	Radiator	6	1,97	13,86	Office	Denmark
36,84	1,1	high	100	high	4K	Radiator	7	1,661	14,21	Office	Denmark
54,31	1,1	high	100	high	4K	under floor heating	0	-0,632	11,96	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	1	0,617	12,07	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	2	0,235	30,72	Office	Denmark
0,66	1,1	high	100	high	4K	under floor heating	3	1,143	12,66	Office	Denmark
16,78	1,1	high	100	high	4K	under floor heating	4	1,193	20,19	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	5	1,445	13,4	Office	Denmark
16,35	1,1	high	100	high	4K	under floor heating	6	1,97	13,86	Office	Denmark
51,6	1,1	high	100	high	4K	under floor heating	7	1,661	14,21	Office	Denmark
58,41	1,6	low	49	low	4K	Radiator	0	3,74	480	SFH	France
30,94	1,6	low	49	low	4K	Radiator	1	0,08	500	SFH	France
28,92	1,6	low	49	low	4K	Radiator	2	-3,46	450	SFH	France
21,14	1,6	low	49	low	4K	Radiator	3	-2,52	700	SFH	France
31,27	1,6	low	49	low	4K	Radiator	4	-0,02	3400	SFH	France
31,8	1,6	low	49	low	4K	Radiator	5	-0,75	700	SFH	France
58,04	1,6	low	49	low	4K	Radiator	6	0	3500	SFH	France
30,94	1,6	low	49	low	4K	Radiator	7	-0,45	4000	SFH	France
687	0,6	high	48	low	4K	under floor heating	0	3,74	480	SFH	France
706,26	0,6	high	48	low	4K	under floor heating	1	0,08	500	SFH	France
703,85	0,6	high	48	low	4K	under floor heating	2	-3,46	450	SFH	France
698,69	0,6	high	48	low	4K	under floor heating	3	-2,52	700	SFH	France
703,29	0,6	high	48	low	4K	under floor heating	4	-0,02	3400	SFH	France
704,11	0,6	high	48	low	4K	under floor heating	5	-0,75	700	SFH	France
705,37	0,6	high	48	low	4K	under floor heating	6	0	3500	SFH	France
709,91	0,6	high	48	low	4K	under floor heating	7	-0,45	4000	SFH	France
10,53	0,6	high	75	high	2K	Radiator	0	-1,8	700	SFH	Austria
4,96	0,6	high	75	high	2K	Radiator	1	-1,81	760	SFH	Austria
6,8	0,6	high	75	high	2K	Radiator	2	-2,65	3900	SFH	Austria
8,11	0,6	high	75	high	2K	Radiator	3	-2,55	650	SFH	Austria
7,74	0,6	high	75	high	2K	Radiator	4	-0,95	2000	SFH	Austria
8,34	0,6	high	75	high	2K	Radiator	5	-4,3	4100	SFH	Austria
13,34	0,6	high	75	high	2K	Radiator	6	-4,24	4000	SFH	Austria
15,96	0,6	high	75	high	2K	Radiator	7	-5,91	4050	SFH	Austria
192,4	0,6	high	54	medium	2K	Radiator	0	-3,32	22,62	SFH	Denmark
0	0,6	high	54	medium	2K	Radiator	1	-4,9	35,58	SFH	Denmark
0,6	0,6	high	54	medium	2K	Radiator	2	-8,54	28,46	SFH	Denmark
849,3	0,6	high	54	medium	2K	Radiator	3	-0,75	10,25	SFH	Denmark
1348,3	0,6	high	54	medium	2K	Radiator	4	0,32	25,1	SFH	Denmark
799,2	0,6	high	54	medium	2K	Radiator	5	-3,33	23,63	SFH	Denmark
855,2	0,6	high	54	medium	2K	Radiator	6	-2	26,26	SFH	Denmark
1979,9	0,6	high	54	medium	2K	Radiator	7	-5,25	21,38	SFH	Denmark
192,4	0,6	high	54	medium	3K	Radiator	0	-3,32	22,62	SFH	Denmark
0	0,6	high	54	medium	3K	Radiator	1	-4,9	35,58	SFH	Denmark
0,3	0,6	high	54	medium	3K	Radiator	2	-8,54	28,46	SFH	Denmark
849,3	0,6	high	54	medium	3K	Radiator	3	-0,75	10,25	SFH	Denmark
1348,3	0,6	high	54	medium	3K	Radiator	4	0,32	25,1	SFH	Denmark
799,2	0,6	high	54	medium	3K	Radiator	5	-3,33	23,63	SFH	Denmark
855,2	0,6	high	54	medium	3K	Radiator	6	-2	26,26	SFH	Denmark
1979,9	0,6	high	54	medium	3K	Radiator	7	-5,25	21,38	SFH	Denmark
390,7	0,6	high	54	medium	4K	Radiator	0	-3,32	22,62	SFH	Denmark
233,5	0,6	high	54	medium	4K	Radiator	1	-4,9	35,58	SFH	Denmark
321,7	0,6	high	54	medium	4K	Radiator	2	-8,54	28,46	SFH	Denmark
1027,6	0,6	high	54	medium	4K	Radiator	3	-0,75	10,25	SFH	Denmark
1342,3	0,6	high	54	medium	4K	Radiator	4	0,32	25,1	SFH	Denmark
879,9	0,6	high	54	medium	4K	Radiator	5	-3,33	23,63	SFH	Denmark
855,2	0,6	high	54	medium	4K	Radiator	6	-2	26,26	SFH	Denmark
1979,9	0,6	high	54	medium	4K	Radiator	7	-5,25	21,38	SFH	Denmark
167	0,6	high	54	medium	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
19,4	0,6	high	54	medium	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
19,6	0,6	high	54	medium	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
318,1	0,6	high	54	medium	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
716,4	0,6	high	54	medium	2K	under floor heating	4	0,32	25,1	SFH	Denmark
315,3	0,6	high	54	medium	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
428,3	0,6	high	54	medium	2K	under floor heating	6	-2	26,26	SFH	Denmark
661,3	0,6	high	54	medium	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
174,7	0,6	high	54	medium	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
7,9	0,6	high	54	medium	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
11,1	0,6	high	54	medium	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
307,1	0,6	high	54	medium	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
725,4	0,6	high	54	medium	3K	under floor heating	4	0,32	25,1	SFH	Denmark
298	0,6	high	54	medium	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
426,8	0,6	high	54	medium	3K	under floor heating	6	-2	26,26	SFH	Denmark
661	0,6	high	54	medium	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
329,5	0,6	high	54	medium	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
23,3	0,6	high	54	medium	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
415,8	0,6	high	54	medium	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
504,3	0,6	high	54	medium	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
670	0,6	high	54	medium	4K	under floor heating	4	0,32	25,1	SFH	Denmark
328,3	0,6	high	54	medium	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
429,7	0,6	high	54	medium	4K	under floor heating	6	-2	26,26	SFH	Denmark
658,5	0,6	high	54	medium	4K	under floor heating	7	-5,25	21,38	SFH	Denmark

1369,1	1,7	low	44	low	2K	Radiator	0	-3,32	22,62	SFH	Denmark
1,2	1,7	low	44	low	2K	Radiator	1	-4,9	35,58	SFH	Denmark
23,3	1,7	low	44	low	2K	Radiator	2	-8,54	28,46	SFH	Denmark
5950,2	1,7	low	44	low	2K	Radiator	3	-0,75	10,25	SFH	Denmark
7024,3	1,7	low	44	low	2K	Radiator	4	0,32	25,1	SFH	Denmark
5311	1,7	low	44	low	2K	Radiator	5	-3,33	23,63	SFH	Denmark
5523,4	1,7	low	44	low	2K	Radiator	6	-2	26,26	SFH	Denmark
6908	1,7	low	44	low	2K	Radiator	7	-5,25	21,38	SFH	Denmark
1369,1	1,7	low	44	low	3K	Radiator	0	-3,32	22,62	SFH	Denmark
2213,4	1,7	low	44	low	3K	Radiator	1	-4,9	35,58	SFH	Denmark
2999,4	1,7	low	44	low	3K	Radiator	2	-8,54	28,46	SFH	Denmark
5950,2	1,7	low	44	low	3K	Radiator	3	-0,75	10,25	SFH	Denmark
7024,3	1,7	low	44	low	3K	Radiator	4	0,32	25,1	SFH	Denmark
5311	1,7	low	44	low	3K	Radiator	5	-3,33	23,63	SFH	Denmark
5523,4	1,7	low	44	low	3K	Radiator	6	-2	26,26	SFH	Denmark
6908,6	1,7	low	44	low	3K	Radiator	7	-5,25	21,38	SFH	Denmark
4337,7	1,7	low	44	low	4K	Radiator	0	-3,32	22,62	SFH	Denmark
2976,8	1,7	low	44	low	4K	Radiator	1	-4,9	35,58	SFH	Denmark
4118,3	1,7	low	44	low	4K	Radiator	2	-8,54	28,46	SFH	Denmark
8797,6	1,7	low	44	low	4K	Radiator	3	-0,75	10,25	SFH	Denmark
8147,4	1,7	low	44	low	4K	Radiator	4	0,32	25,1	SFH	Denmark
6135,4	1,7	low	44	low	4K	Radiator	5	-3,33	23,63	SFH	Denmark
5558,4	1,7	low	44	low	4K	Radiator	6	-2	26,26	SFH	Denmark
9386,1	1,7	low	44	low	4K	Radiator	7	-5,25	21,38	SFH	Denmark
2017	1,7	low	44	low	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
1232,5	1,7	low	44	low	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
826,3	1,7	low	44	low	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
3435,2	1,7	low	44	low	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
4911,2	1,7	low	44	low	2K	under floor heating	4	0,32	25,1	SFH	Denmark
3947,2	1,7	low	44	low	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
4530,2	1,7	low	44	low	2K	under floor heating	6	-2	26,26	SFH	Denmark
4075,7	1,7	low	44	low	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
2749,7	1,7	low	44	low	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
2598,6	1,7	low	44	low	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
2806,5	1,7	low	44	low	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
4164	1,7	low	44	low	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
4873,6	1,7	low	44	low	3K	under floor heating	4	0,32	25,1	SFH	Denmark
3782,7	1,7	low	44	low	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
5610,8	1,7	low	44	low	3K	under floor heating	6	-2	26,26	SFH	Denmark
4616,4	1,7	low	44	low	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
3067,4	1,7	low	44	low	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
3160,5	1,7	low	44	low	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
4130,9	1,7	low	44	low	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
4211,2	1,7	low	44	low	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
4746	1,7	low	44	low	4K	under floor heating	4	0,32	25,1	SFH	Denmark
3688,9	1,7	low	44	low	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
4418,9	1,7	low	44	low	4K	under floor heating	6	-2	26,26	SFH	Denmark
5582,3	1,7	low	44	low	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
24,45	1,1	high	100	high	1K	Convective	0	-4	11,96	Office	Denmark
0	1,1	high	100	high	1K	Convective	1	-4	12,07	Office	Denmark
0	1,1	high	100	high	1K	Convective	2	-4	30,72	Office	Denmark
0	1,1	high	100	high	1K	Convective	3	-4	12,66	Office	Denmark
1,08	1,1	high	100	high	1K	Convective	4	-4	20,19	Office	Denmark
0	1,1	high	100	high	1K	Convective	5	-4	13,4	Office	Denmark
4,08	1,1	high	100	high	1K	Convective	6	-4	13,86	Office	Denmark
26,64	1,1	high	100	high	1K	Convective	7	-4	14,21	Office	Denmark
24,38	1,1	high	100	high	1K	Convective	0	-1	11,96	Office	Denmark
0	1,1	high	100	high	1K	Convective	1	-1	12,07	Office	Denmark
0	1,1	high	100	high	1K	Convective	2	-1	30,72	Office	Denmark
0	1,1	high	100	high	1K	Convective	3	-1	12,66	Office	Denmark
1,08	1,1	high	100	high	1K	Convective	4	-1	20,19	Office	Denmark
0	1,1	high	100	high	1K	Convective	5	-1	13,4	Office	Denmark
4,08	1,1	high	100	high	1K	Convective	6	-1	13,86	Office	Denmark
30,72	1,1	high	100	high	1K	Convective	7	-1	14,21	Office	Denmark
24,49	1,1	high	100	high	1K	Convective	0	2	11,96	Office	Denmark
0	1,1	high	100	high	1K	Convective	1	2	12,07	Office	Denmark
0	1,1	high	100	high	1K	Convective	2	2	30,72	Office	Denmark
0	1,1	high	100	high	1K	Convective	3	2	12,66	Office	Denmark
1,08	1,1	high	100	high	1K	Convective	4	2	20,19	Office	Denmark
0	1,1	high	100	high	1K	Convective	5	2	13,4	Office	Denmark
4,08	1,1	high	100	high	1K	Convective	6	2	13,86	Office	Denmark
30,74	1,1	high	100	high	1K	Convective	7	2	14,21	Office	Denmark
24,61	1,1	high	100	high	1K	Convective	0	5	11,96	Office	Denmark
0	1,1	high	100	high	1K	Convective	1	5	12,07	Office	Denmark
0	1,1	high	100	high	1K	Convective	2	5	30,72	Office	Denmark
0	1,1	high	100	high	1K	Convective	3	5	12,66	Office	Denmark
1,08	1,1	high	100	high	1K	Convective	4	5	20,19	Office	Denmark
0	1,1	high	100	high	1K	Convective	5	5	13,4	Office	Denmark
4,08	1,1	high	100	high	1K	Convective	6	5	13,86	Office	Denmark
30,76	1,1	high	100	high	1K	Convective	7	5	14,21	Office	Denmark
13625	1,7	low	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
4050,53	1,7	low	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
14116,77	1,7	low	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
14725,65	1,7	low	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
12699,29	1,7	low	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
14682,78	1,7	low	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
11061,7	1,7	low	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
15876,86	1,7	low	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
11639,48	1,7	low	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
6515,5	1,7	low	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark

10930,34	1,7	low	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
19629,8	1,7	low	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
19282,99	1,7	low	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
20515,33	1,7	low	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
14630,5	1,7	low	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
16497,96	1,7	low	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
31475,58	1,7	low	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
13203,25	1,7	low	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
38997,9	1,7	low	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
31539,9	1,7	low	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
44679,9	1,7	low	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
38689,75	1,7	low	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
35098,24	1,7	low	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
41809,86	1,7	low	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
46343,13	1,7	low	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
45272,15	1,7	low	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
58857,71	1,7	low	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
54909,52	1,7	low	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
52219,29	1,7	low	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
73723,11	1,7	low	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
57368,77	1,7	low	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
45183,93	1,7	low	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
38474,17	1,7	low	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
55350,92	1,7	low	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
23659,58	1,7	low	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
20934,43	1,7	low	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
21251,37	1,7	low	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
37245,87	1,7	low	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
20167,8	1,7	low	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
40684,03	1,7	low	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
55454,1	1,7	low	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
36555,72	1,7	low	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
66971,1	1,7	low	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
58346,5	1,7	low	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
64057,06	1,7	low	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
59286,35	1,7	low	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
62904,52	1,7	low	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
61461,76	1,7	low	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark
6486,46	0,78	high	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
1583,89	0,78	high	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
5501,27	0,78	high	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
5175,45	0,78	high	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
5675,96	0,78	high	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
7927,29	0,78	high	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
6891,52	0,78	high	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
6282,51	0,78	high	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
6623,02	0,78	high	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
1147,09	0,78	high	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
3248	0,78	high	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
5091,64	0,78	high	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
5535,1	0,78	high	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
6306,06	0,78	high	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
7214,12	0,78	high	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
5921,52	0,78	high	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
8857,33	0,78	high	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
1061,14	0,78	high	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
4048,37	0,78	high	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
4175,51	0,78	high	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
2805,32	0,78	high	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
5689,13	0,78	high	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
15191,9	0,78	high	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
5883,3	0,78	high	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
13111,63	0,78	high	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
10068,72	0,78	high	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
5571,32	0,78	high	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
114411,12	0,78	high	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
3516,42	0,78	high	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
6195,97	0,78	high	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
13632,72	0,78	high	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
7009,84	0,78	high	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
8805,45	0,78	high	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
941,18	0,78	high	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
4247,65	0,78	high	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
5124,45	0,78	high	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
3204,5	0,78	high	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
3434,06	0,78	high	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
13888,9	0,78	high	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
8414,19	0,78	high	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
10490,2	0,78	high	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
4817,31	0,78	high	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
6758,25	0,78	high	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
6029,07	0,78	high	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
4217,51	0,78	high	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
4409,05	0,78	high	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
13126,93	0,78	high	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
82270,52	0,78	high	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark

Results of study used for sensitivity analysis for flexibility characteristic Beta

Beta	U-value [w/m2K]	Insulation_level	cm [kWh/m2K]	Thermal_mass	Control_strategy	Heating_system	Day	Outdoor_temperature [°C]	Solar_radiation [W/m2]	Type_of_building	location
15	1,1	high	100	high	4K	Radiator	0	-0,632	11,96	Office	Denmark
2	1,1	high	100	high	4K	Radiator	1	0,617	12,07	Office	Denmark
1	1,1	high	100	high	4K	Radiator	2	0,235	30,72	Office	Denmark
15	1,1	high	100	high	4K	Radiator	3	1,143	12,66	Office	Denmark
13	1,1	high	100	high	4K	Radiator	4	1,193	20,19	Office	Denmark
13	1,1	high	100	high	4K	Radiator	5	1,445	13,4	Office	Denmark
18	1,1	high	100	high	4K	Radiator	6	1,97	13,86	Office	Denmark
14	1,1	high	100	high	4K	Radiator	7	1,661	14,21	Office	Denmark
19	1,1	high	100	high	4K	under floor heating	0	-0,632	11,96	Office	Denmark
1	1,1	high	100	high	4K	under floor heating	1	0,617	12,07	Office	Denmark
1	1,1	high	100	high	4K	under floor heating	2	0,235	30,72	Office	Denmark
2	1,1	high	100	high	4K	under floor heating	3	1,143	12,66	Office	Denmark
10	1,1	high	100	high	4K	under floor heating	4	1,193	20,19	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	5	1,445	13,4	Office	Denmark
20	1,1	high	100	high	4K	under floor heating	6	1,97	13,86	Office	Denmark
14	1,1	high	100	high	4K	under floor heating	7	1,661	14,21	Office	Denmark
4,25	1,6	low	49	low	4K	Radiator	0	3,74	480	SFH	France
13,5	1,6	low	49	low	4K	Radiator	1	0,08	500	SFH	France
13,5	1,6	low	49	low	4K	Radiator	2	-3,46	450	SFH	France
14,3	1,6	low	49	low	4K	Radiator	3	-2,52	700	SFH	France
12,2	1,6	low	49	low	4K	Radiator	4	-0,02	3400	SFH	France
11,45	1,6	low	49	low	4K	Radiator	5	-0,75	700	SFH	France
2,2	1,6	low	49	low	4K	Radiator	6	0	3500	SFH	France
13,5	1,6	low	49	low	4K	Radiator	7	-0,45	4000	SFH	France
16,9	0,6	high	48	low	4K	under floor heating	0	3,74	480	SFH	France
16,9	0,6	high	48	low	4K	under floor heating	1	0,08	500	SFH	France
16,9	0,6	high	48	low	4K	under floor heating	2	-3,46	450	SFH	France
4,9	0,6	high	48	low	4K	under floor heating	3	-2,52	700	SFH	France
4,9	0,6	high	48	low	4K	under floor heating	4	-0,02	3400	SFH	France
4,9	0,6	high	48	low	4K	under floor heating	5	-0,75	700	SFH	France
4,9	0,6	high	48	low	4K	under floor heating	6	0	3500	SFH	France
4,9	0,6	high	48	low	4K	under floor heating	7	-0,45	4000	SFH	France
13	0,6	high	75	high	2K	Radiator	0	-1,8	700	SFH	Austria
7	0,6	high	75	high	2K	Radiator	1	-1,81	760	SFH	Austria
11	0,6	high	75	high	2K	Radiator	2	-2,65	3900	SFH	Austria
13	0,6	high	75	high	2K	Radiator	3	-2,55	650	SFH	Austria
12	0,6	high	75	high	2K	Radiator	4	-0,95	2000	SFH	Austria
12	0,6	high	75	high	2K	Radiator	5	-4,3	4100	SFH	Austria
16	0,6	high	75	high	2K	Radiator	6	-4,24	4000	SFH	Austria
17	0,6	high	75	high	2K	Radiator	7	-5,91	4050	SFH	Austria
2	0,6	high	54	medium	2K	Radiator	0	-3,32	22,62	SFH	Denmark
1	0,6	high	54	medium	2K	Radiator	1	-4,9	35,58	SFH	Denmark
1	0,6	high	54	medium	2K	Radiator	2	-8,54	28,46	SFH	Denmark
6	0,6	high	54	medium	2K	Radiator	3	-0,75	10,25	SFH	Denmark
7	0,6	high	54	medium	2K	Radiator	4	0,32	25,1	SFH	Denmark
5	0,6	high	54	medium	2K	Radiator	5	-3,33	23,63	SFH	Denmark
5	0,6	high	54	medium	2K	Radiator	6	-2	26,26	SFH	Denmark
10	0,6	high	54	medium	2K	Radiator	7	-5,25	21,38	SFH	Denmark
2	0,6	high	54	medium	3K	Radiator	0	-3,32	22,62	SFH	Denmark
1	0,6	high	54	medium	3K	Radiator	1	-4,9	35,58	SFH	Denmark
1	0,6	high	54	medium	3K	Radiator	2	-8,54	28,46	SFH	Denmark
6	0,6	high	54	medium	3K	Radiator	3	-0,75	10,25	SFH	Denmark
7	0,6	high	54	medium	3K	Radiator	4	0,32	25,1	SFH	Denmark
5	0,6	high	54	medium	3K	Radiator	5	-3,33	23,63	SFH	Denmark
5	0,6	high	54	medium	3K	Radiator	6	-2	26,26	SFH	Denmark
10	0,6	high	54	medium	3K	Radiator	7	-5,25	21,38	SFH	Denmark
20	0,6	high	54	medium	4K	Radiator	0	-3,32	22,62	SFH	Denmark
20	0,6	high	54	medium	4K	Radiator	1	-4,9	35,58	SFH	Denmark
23	0,6	high	54	medium	4K	Radiator	2	-8,54	28,46	SFH	Denmark
13	0,6	high	54	medium	4K	Radiator	3	-0,75	10,25	SFH	Denmark
7	0,6	high	54	medium	4K	Radiator	4	0,32	25,1	SFH	Denmark
8	0,6	high	54	medium	4K	Radiator	5	-3,33	23,63	SFH	Denmark
5	0,6	high	54	medium	4K	Radiator	6	-2	26,26	SFH	Denmark
10	0,6	high	54	medium	4K	Radiator	7	-5,25	21,38	SFH	Denmark
8	0,6	high	54	medium	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
6	0,6	high	54	medium	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
5	0,6	high	54	medium	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
10	0,6	high	54	medium	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
13	0,6	high	54	medium	2K	under floor heating	4	0,32	25,1	SFH	Denmark
11	0,6	high	54	medium	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
8	0,6	high	54	medium	2K	under floor heating	6	-2	26,26	SFH	Denmark
6	0,6	high	54	medium	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
9	0,6	high	54	medium	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
5	0,6	high	54	medium	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
5	0,6	high	54	medium	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
10	0,6	high	54	medium	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
13	0,6	high	54	medium	3K	under floor heating	4	0,32	25,1	SFH	Denmark
9	0,6	high	54	medium	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
10	0,6	high	54	medium	3K	under floor heating	6	-2	26,26	SFH	Denmark
6	0,6	high	54	medium	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
10	0,6	high	54	medium	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
6	0,6	high	54	medium	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
12	0,6	high	54	medium	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
11	0,6	high	54	medium	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
12	0,6	high	54	medium	4K	under floor heating	4	0,32	25,1	SFH	Denmark

11	0,6	high	54	medium	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
8	0,6	high	54	medium	4K	under floor heating	6	-2	26,26	SFH	Denmark
6	0,6	high	54	medium	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
2	1,7	low	44	low	2K	Radiator	0	-3,32	22,62	SFH	Denmark
1	1,7	low	44	low	2K	Radiator	1	-4,9	35,58	SFH	Denmark
1	1,7	low	44	low	2K	Radiator	2	-8,54	28,46	SFH	Denmark
6	1,7	low	44	low	2K	Radiator	3	-0,75	10,25	SFH	Denmark
7	1,7	low	44	low	2K	Radiator	4	0,32	25,1	SFH	Denmark
5	1,7	low	44	low	2K	Radiator	5	-3,33	23,63	SFH	Denmark
5	1,7	low	44	low	2K	Radiator	6	-2	26,26	SFH	Denmark
7	1,7	low	44	low	2K	Radiator	7	-5,25	21,38	SFH	Denmark
19	1,7	low	44	low	3K	Radiator	0	-3,32	22,62	SFH	Denmark
15	1,7	low	44	low	3K	Radiator	1	-4,9	35,58	SFH	Denmark
20	1,7	low	44	low	3K	Radiator	2	-8,54	28,46	SFH	Denmark
14	1,7	low	44	low	3K	Radiator	3	-0,75	10,25	SFH	Denmark
7	1,7	low	44	low	3K	Radiator	4	0,32	25,1	SFH	Denmark
6	1,7	low	44	low	3K	Radiator	5	-3,33	23,63	SFH	Denmark
5	1,7	low	44	low	3K	Radiator	6	-2	26,26	SFH	Denmark
10	1,7	low	44	low	3K	Radiator	7	-5,25	21,38	SFH	Denmark
17	1,7	low	44	low	4K	Radiator	0	-3,32	22,62	SFH	Denmark
18	1,7	low	44	low	4K	Radiator	1	-4,9	35,58	SFH	Denmark
18	1,7	low	44	low	4K	Radiator	2	-8,54	28,46	SFH	Denmark
14	1,7	low	44	low	4K	Radiator	3	-0,75	10,25	SFH	Denmark
7	1,7	low	44	low	4K	Radiator	4	0,32	25,1	SFH	Denmark
12	1,7	low	44	low	4K	Radiator	5	-3,33	23,63	SFH	Denmark
5	1,7	low	44	low	4K	Radiator	6	-2	26,26	SFH	Denmark
19	1,7	low	44	low	4K	Radiator	7	-5,25	21,38	SFH	Denmark
12	1,7	low	44	low	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
11	1,7	low	44	low	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
13	1,7	low	44	low	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
12	1,7	low	44	low	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
12	1,7	low	44	low	2K	under floor heating	4	0,32	25,1	SFH	Denmark
13	1,7	low	44	low	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
11	1,7	low	44	low	2K	under floor heating	6	-2	26,26	SFH	Denmark
10	1,7	low	44	low	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
11	1,7	low	44	low	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
11	1,7	low	44	low	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
13	1,7	low	44	low	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
10	1,7	low	44	low	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
11	1,7	low	44	low	3K	under floor heating	4	0,32	25,1	SFH	Denmark
10	1,7	low	44	low	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
11	1,7	low	44	low	3K	under floor heating	6	-2	26,26	SFH	Denmark
9	1,7	low	44	low	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
13	1,7	low	44	low	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
10	1,7	low	44	low	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
13	1,7	low	44	low	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
11	1,7	low	44	low	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
1	1,7	low	44	low	4K	under floor heating	4	0,32	25,1	SFH	Denmark
10	1,7	low	44	low	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
13	1,7	low	44	low	4K	under floor heating	6	-2	26,26	SFH	Denmark
10	0,6	low	44	low	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
11	1,1	high	100	high	1K	Convective	0	-4	11,96	Office	Denmark
1	1,1	high	100	high	1K	Convective	1	-4	12,07	Office	Denmark
1	1,1	high	100	high	1K	Convective	2	-4	30,72	Office	Denmark
1	1,1	high	100	high	1K	Convective	3	-4	12,66	Office	Denmark
3	1,1	high	100	high	1K	Convective	4	-4	20,19	Office	Denmark
1	1,1	high	100	high	1K	Convective	5	-4	13,4	Office	Denmark
6	1,1	high	100	high	1K	Convective	6	-4	13,86	Office	Denmark
14	1,1	high	100	high	1K	Convective	7	-4	14,21	Office	Denmark
11	1,1	high	100	high	1K	Convective	0	-1	11,96	Office	Denmark
1	1,1	high	100	high	1K	Convective	1	-1	12,07	Office	Denmark
1	1,1	high	100	high	1K	Convective	2	-1	30,72	Office	Denmark
1	1,1	high	100	high	1K	Convective	3	-1	12,66	Office	Denmark
3	1,1	high	100	high	1K	Convective	4	-1	20,19	Office	Denmark
1	1,1	high	100	high	1K	Convective	5	-1	13,4	Office	Denmark
6	1,1	high	100	high	1K	Convective	6	-1	13,86	Office	Denmark
14	1,1	high	100	high	1K	Convective	7	-1	14,21	Office	Denmark
11	1,1	high	100	high	1K	Convective	0	2	11,96	Office	Denmark
1	1,1	high	100	high	1K	Convective	1	2	12,07	Office	Denmark
1	1,1	high	100	high	1K	Convective	2	2	30,72	Office	Denmark
1	1,1	high	100	high	1K	Convective	3	2	12,66	Office	Denmark
3	1,1	high	100	high	1K	Convective	4	2	20,19	Office	Denmark
1	1,1	high	100	high	1K	Convective	5	2	13,4	Office	Denmark
6	1,1	high	100	high	1K	Convective	6	2	13,86	Office	Denmark
14	1,1	high	100	high	1K	Convective	7	2	14,21	Office	Denmark
11	1,1	high	100	high	1K	Convective	0	5	11,96	Office	Denmark
1	1,1	high	100	high	1K	Convective	1	5	12,07	Office	Denmark
1	1,1	high	100	high	1K	Convective	2	5	30,72	Office	Denmark
1	1,1	high	100	high	1K	Convective	3	5	12,66	Office	Denmark
3	1,1	high	100	high	1K	Convective	4	5	20,19	Office	Denmark
1	1,1	high	100	high	1K	Convective	5	5	13,4	Office	Denmark
6	1,1	high	100	high	1K	Convective	6	5	13,86	Office	Denmark
14	1,1	high	100	high	1K	Convective	7	5	14,21	Office	Denmark
8	1,7	low	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
4	1,7	low	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
11	1,7	low	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
11	1,7	low	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark

13	1,7	low	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
10	1,7	low	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
16	1,7	low	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
18	1,7	low	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
5	1,7	low	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
7	1,7	low	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
10	1,7	low	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
14	1,7	low	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
15	1,7	low	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
16	1,7	low	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
17	1,7	low	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
17	1,7	low	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
13	1,7	low	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
5	1,7	low	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
13	1,7	low	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
12	1,7	low	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
14	1,7	low	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
12	1,7	low	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
15	1,7	low	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
16	1,7	low	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
15	1,7	low	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
13	1,7	low	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
19	1,7	low	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
18	1,7	low	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
16	1,7	low	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
18	1,7	low	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
17	1,7	low	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
17	1,7	low	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
12	1,7	low	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
16	1,7	low	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
11	1,7	low	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
7	1,7	low	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
8	1,7	low	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
11	1,7	low	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
7	1,7	low	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
9	1,7	low	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
15	1,7	low	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
16	1,7	low	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
19	1,7	low	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
20	1,7	low	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
20	1,7	low	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
18	1,7	low	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
18	1,7	low	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
18	1,7	low	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark
10	0,78	high	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
6	0,78	high	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
17	0,78	high	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
19	0,78	high	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
15	0,78	high	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
16	0,78	high	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
14	0,78	high	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
17	0,78	high	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
13	0,78	high	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
6	0,78	high	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
17	0,78	high	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
17	0,78	high	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
14	0,78	high	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
17	0,78	high	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
17	0,78	high	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
17	0,78	high	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
14	0,78	high	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
6	0,78	high	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
16	0,78	high	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
15	0,78	high	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
21	0,78	high	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
21	0,78	high	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
22	0,78	high	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
16	0,78	high	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
13	0,78	high	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
11	0,78	high	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
11	0,78	high	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
8	0,78	high	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
11	0,78	high	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
15	0,78	high	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
19	0,78	high	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
12	0,78	high	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
14	0,78	high	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
6	0,78	high	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
16	0,78	high	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
19	0,78	high	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
21	0,78	high	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
21	0,78	high	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
0	0,78	high	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
22	0,78	high	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
16	0,78	high	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
10	0,78	high	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
16	0,78	high	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark

18	0,78	high	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
16	0,78	high	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
14	0,78	high	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
21	0,78	high	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
17	0,78	high	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark

Results of study for sensitivity analysis for flexibility characteristic Delta

Delta	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	Thermal_mass	Control_strategy	Heating_system	Day	Outdoor_temperature [°C]	Solar_radiation [W/m2]	Type_of_building	location
-2,07	1,1	high	100	high	4K	Radiator	0	-0,632	11,96	Office	Denmark
-1,73	1,1	high	100	high	4K	Radiator	1	0,617	12,07	Office	Denmark
-0,64	1,1	high	100	high	4K	Radiator	2	0,235	30,72	Office	Denmark
-8,46	1,1	high	100	high	4K	Radiator	3	1,143	12,66	Office	Denmark
-3,84	1,1	high	100	high	4K	Radiator	4	1,193	20,19	Office	Denmark
-6,29	1,1	high	100	high	4K	Radiator	5	1,445	13,4	Office	Denmark
-2,38	1,1	high	100	high	4K	Radiator	6	1,97	13,86	Office	Denmark
-4,42	1,1	high	100	high	4K	Radiator	7	1,661	14,21	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	0	-0,632	11,96	Office	Denmark
-0,92	1,1	high	100	high	4K	under floor heating	1	0,617	12,07	Office	Denmark
-3,54	1,1	high	100	high	4K	under floor heating	2	0,235	30,72	Office	Denmark
-1,08	1,1	high	100	high	4K	under floor heating	3	1,143	12,66	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	4	1,193	20,19	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	5	1,445	13,4	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	6	1,97	13,86	Office	Denmark
-13,62	1,1	high	100	high	4K	under floor heating	7	1,661	14,21	Office	Denmark
-41,8	1,6	low	49	low	4K	Radiator	0	3,74	480	SFH	France
-32,8	1,6	low	49	low	4K	Radiator	1	0,08	500	SFH	France
-29,6	1,6	low	49	low	4K	Radiator	2	-3,46	450	SFH	France
-42,5	1,6	low	49	low	4K	Radiator	3	-2,52	700	SFH	France
-28,9	1,6	low	49	low	4K	Radiator	4	-0,02	3400	SFH	France
-31,7	1,6	low	49	low	4K	Radiator	5	-0,75	700	SFH	France
-41,8	1,6	low	49	low	4K	Radiator	6	0	3500	SFH	France
-33,4	1,6	low	49	low	4K	Radiator	7	-0,45	4000	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	0	3,74	480	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	1	0,08	500	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	2	-3,46	450	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	3	-2,52	700	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	4	-0,02	3400	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	5	-0,75	700	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	6	0	3500	SFH	France
-20,8	0,6	high	48	low	4K	under floor heating	7	-0,45	4000	SFH	France
-1,4	0,6	high	75	high	2K	Radiator	0	-1,8	700	SFH	Austria
-1,59	0,6	high	75	high	2K	Radiator	1	-1,81	760	SFH	Austria
-0,96	0,6	high	75	high	2K	Radiator	2	-2,65	3900	SFH	Austria
-0,98	0,6	high	75	high	2K	Radiator	3	-2,55	650	SFH	Austria
-1,1	0,6	high	75	high	2K	Radiator	4	-0,95	2000	SFH	Austria
-1,09	0,6	high	75	high	2K	Radiator	5	-4,3	4100	SFH	Austria
-1,29	0,6	high	75	high	2K	Radiator	6	-4,24	4000	SFH	Austria
-1,68	0,6	high	75	high	2K	Radiator	7	-5,91	4050	SFH	Austria
-85	0,6	high	54	medium	2K	Radiator	0	-3,32	22,62	SFH	Denmark
-2,6	0,6	high	54	medium	2K	Radiator	1	-4,9	35,58	SFH	Denmark
-0,5	0,6	high	54	medium	2K	Radiator	2	-8,54	28,46	SFH	Denmark
-143,1	0,6	high	54	medium	2K	Radiator	3	-0,75	10,25	SFH	Denmark
-275,8	0,6	high	54	medium	2K	Radiator	4	0,32	25,1	SFH	Denmark
-191,1	0,6	high	54	medium	2K	Radiator	5	-3,33	23,63	SFH	Denmark
-186,2	0,6	high	54	medium	2K	Radiator	6	-2	26,26	SFH	Denmark
-375,4	0,6	high	54	medium	2K	Radiator	7	-5,25	21,38	SFH	Denmark
-85,1	0,6	high	54	medium	3K	Radiator	0	-3,32	22,62	SFH	Denmark
-2,6	0,6	high	54	medium	3K	Radiator	1	-4,9	35,58	SFH	Denmark
-0,5	0,6	high	54	medium	3K	Radiator	2	-8,54	28,46	SFH	Denmark
-143	0,6	high	54	medium	3K	Radiator	3	-0,75	10,25	SFH	Denmark
-275,7	0,6	high	54	medium	3K	Radiator	4	0,32	25,1	SFH	Denmark
-191	0,6	high	54	medium	3K	Radiator	5	-3,33	23,63	SFH	Denmark
-186,2	0,6	high	54	medium	3K	Radiator	6	-2	26,26	SFH	Denmark
-375,3	0,6	high	54	medium	3K	Radiator	7	-5,25	21,38	SFH	Denmark
-554,5	0,6	high	54	medium	4K	Radiator	0	-3,32	22,62	SFH	Denmark
-611,1	0,6	high	54	medium	4K	Radiator	1	-4,9	35,58	SFH	Denmark
-614,3	0,6	high	54	medium	4K	Radiator	2	-8,54	28,46	SFH	Denmark
-515,6	0,6	high	54	medium	4K	Radiator	3	-0,75	10,25	SFH	Denmark
-491,1	0,6	high	54	medium	4K	Radiator	4	0,32	25,1	SFH	Denmark
-567,9	0,6	high	54	medium	4K	Radiator	5	-3,33	23,63	SFH	Denmark
-177	0,6	high	54	medium	4K	Radiator	6	-2	26,26	SFH	Denmark
-460,2	0,6	high	54	medium	4K	Radiator	7	-5,25	21,38	SFH	Denmark
-115,6	0,6	high	54	medium	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
-6,9	0,6	high	54	medium	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
-8,9	0,6	high	54	medium	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
-184,8	0,6	high	54	medium	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
-356,8	0,6	high	54	medium	2K	under floor heating	4	0,32	25,1	SFH	Denmark
-176,9	0,6	high	54	medium	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
-210	0,6	high	54	medium	2K	under floor heating	6	-2	26,26	SFH	Denmark
-192,9	0,6	high	54	medium	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
-117,3	0,6	high	54	medium	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
-1,6	0,6	high	54	medium	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
-5,6	0,6	high	54	medium	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
-186,8	0,6	high	54	medium	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
-356,9	0,6	high	54	medium	3K	under floor heating	4	0,32	25,1	SFH	Denmark
-170,8	0,6	high	54	medium	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
-206,4	0,6	high	54	medium	3K	under floor heating	6	-2	26,26	SFH	Denmark
-192,7	0,6	high	54	medium	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
-215,4	0,6	high	54	medium	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
-340,5	0,6	high	54	medium	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
-329,5	0,6	high	54	medium	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
-139	0,6	high	54	medium	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
-289,9	0,6	high	54	medium	4K	under floor heating	4	0,32	25,1	SFH	Denmark
-116,6	0,6	high	54	medium	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
-217,8	0,6	high	54	medium	4K	under floor heating	6	-2	26,26	SFH	Denmark
-157,1	0,6	high	54	medium	4K	under floor heating	7	-5,25	21,38	SFH	Denmark

-825,9	1,7	low	44	low	2K	Radiator	0	-3,32	22,62	SFH	Denmark
-7,5	1,7	low	44	low	2K	Radiator	1	-4,9	35,58	SFH	Denmark
-0,1	1,7	low	44	low	2K	Radiator	2	-8,54	28,46	SFH	Denmark
-962,7	1,7	low	44	low	2K	Radiator	3	-0,75	10,25	SFH	Denmark
-792,7	1,7	low	44	low	2K	Radiator	4	0,32	25,1	SFH	Denmark
-871,2	1,7	low	44	low	2K	Radiator	5	-3,33	23,63	SFH	Denmark
-763,4	1,7	low	44	low	2K	Radiator	6	-2	26,26	SFH	Denmark
-885	1,7	low	44	low	2K	Radiator	7	-5,25	21,38	SFH	Denmark
-880,3	1,7	low	44	low	3K	Radiator	0	-3,32	22,62	SFH	Denmark
-1065,2	1,7	low	44	low	3K	Radiator	1	-4,9	35,58	SFH	Denmark
-1072,8	1,7	low	44	low	3K	Radiator	2	-8,54	28,46	SFH	Denmark
-965,9	1,7	low	44	low	3K	Radiator	3	-0,75	10,25	SFH	Denmark
-795,4	1,7	low	44	low	3K	Radiator	4	0,32	25,1	SFH	Denmark
-876,2	1,7	low	44	low	3K	Radiator	5	-3,33	23,63	SFH	Denmark
-764,4	1,7	low	44	low	3K	Radiator	6	-2	26,26	SFH	Denmark
-886,3	1,7	low	44	low	3K	Radiator	7	-5,25	21,38	SFH	Denmark
-959,5	1,7	low	44	low	4K	Radiator	0	-3,32	22,62	SFH	Denmark
-110,6	1,7	low	44	low	4K	Radiator	1	-4,9	35,58	SFH	Denmark
-1088,4	1,7	low	44	low	4K	Radiator	2	-8,54	28,46	SFH	Denmark
-967,9	1,7	low	44	low	4K	Radiator	3	-0,75	10,25	SFH	Denmark
-803,5	1,7	low	44	low	4K	Radiator	4	0,32	25,1	SFH	Denmark
-875,8	1,7	low	44	low	4K	Radiator	5	-3,33	23,63	SFH	Denmark
-769,9	1,7	low	44	low	4K	Radiator	6	-2	26,26	SFH	Denmark
-886,1	1,7	low	44	low	4K	Radiator	7	-5,25	21,38	SFH	Denmark
-781,8	1,7	low	44	low	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
-275,9	1,7	low	44	low	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
-117,3	1,7	low	44	low	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
-1006,9	1,7	low	44	low	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
-982,5	1,7	low	44	low	2K	under floor heating	4	0,32	25,1	SFH	Denmark
-583,8	1,7	low	44	low	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
-1023	1,7	low	44	low	2K	under floor heating	6	-2	26,26	SFH	Denmark
-1047	1,7	low	44	low	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
-686,2	1,7	low	44	low	3K	under floor heating	0	-3,32	22,62	SFH	Denmark
-1244,8	1,7	low	44	low	3K	under floor heating	1	-4,9	35,58	SFH	Denmark
-1060,1	1,7	low	44	low	3K	under floor heating	2	-8,54	28,46	SFH	Denmark
-816	1,7	low	44	low	3K	under floor heating	3	-0,75	10,25	SFH	Denmark
-981,1	1,7	low	44	low	3K	under floor heating	4	0,32	25,1	SFH	Denmark
-519	1,7	low	44	low	3K	under floor heating	5	-3,33	23,63	SFH	Denmark
-1025,9	1,7	low	44	low	3K	under floor heating	6	-2	26,26	SFH	Denmark
-1054,1	1,7	low	44	low	3K	under floor heating	7	-5,25	21,38	SFH	Denmark
-765,1	1,7	low	44	low	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
-1281,3	1,7	low	44	low	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
-1297,5	1,7	low	44	low	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
-685	1,7	low	44	low	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
-979,3	1,7	low	44	low	4K	under floor heating	4	0,32	25,1	SFH	Denmark
-534,1	1,7	low	44	low	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
-1023,9	1,7	low	44	low	4K	under floor heating	6	-2	26,26	SFH	Denmark
-1050,4	1,7	low	44	low	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
-0,83	1,1	high	100	high	1K	Convective	0	-4	11,96	Office	Denmark
-2,54	1,1	high	100	high	1K	Convective	1	-4	12,07	Office	Denmark
-0,88	1,1	high	100	high	1K	Convective	2	-4	30,72	Office	Denmark
-1,18	1,1	high	100	high	1K	Convective	3	-4	12,66	Office	Denmark
-0,63	1,1	high	100	high	1K	Convective	4	-4	20,19	Office	Denmark
-2,57	1,1	high	100	high	1K	Convective	5	-4	13,4	Office	Denmark
-2,67	1,1	high	100	high	1K	Convective	6	-4	13,86	Office	Denmark
-0,58	1,1	high	100	high	1K	Convective	7	-4	14,21	Office	Denmark
-0,84	1,1	high	100	high	1K	Convective	0	-1	11,96	Office	Denmark
-2,64	1,1	high	100	high	1K	Convective	1	-1	12,07	Office	Denmark
-0,88	1,1	high	100	high	1K	Convective	2	-1	30,72	Office	Denmark
-1,18	1,1	high	100	high	1K	Convective	3	-1	12,66	Office	Denmark
-0,5	1,1	high	100	high	1K	Convective	4	-1	20,19	Office	Denmark
-2,49	1,1	high	100	high	1K	Convective	5	-1	13,4	Office	Denmark
-2,61	1,1	high	100	high	1K	Convective	6	-1	13,86	Office	Denmark
-2,9	1,1	high	100	high	1K	Convective	7	-1	14,21	Office	Denmark
-0,81	1,1	high	100	high	1K	Convective	0	2	11,96	Office	Denmark
-2,64	1,1	high	100	high	1K	Convective	1	2	12,07	Office	Denmark
-0,87	1,1	high	100	high	1K	Convective	2	2	30,72	Office	Denmark
-1,17	1,1	high	100	high	1K	Convective	3	2	12,66	Office	Denmark
-0,5	1,1	high	100	high	1K	Convective	4	2	20,19	Office	Denmark
-2,48	1,1	high	100	high	1K	Convective	5	2	13,4	Office	Denmark
-2,6	1,1	high	100	high	1K	Convective	6	2	13,86	Office	Denmark
-2,9	1,1	high	100	high	1K	Convective	7	2	14,21	Office	Denmark
-0,78	1,1	high	100	high	1K	Convective	0	5	11,96	Office	Denmark
-2,64	1,1	high	100	high	1K	Convective	1	5	12,07	Office	Denmark
-0,86	1,1	high	100	high	1K	Convective	2	5	30,72	Office	Denmark
-1,16	1,1	high	100	high	1K	Convective	3	5	12,66	Office	Denmark
-0,49	1,1	high	100	high	1K	Convective	4	5	20,19	Office	Denmark
-2,47	1,1	high	100	high	1K	Convective	5	5	13,4	Office	Denmark
-2,59	1,1	high	100	high	1K	Convective	6	5	13,86	Office	Denmark
-2,89	1,1	high	100	high	1K	Convective	7	5	14,21	Office	Denmark
-4491,04	1,7	low	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
-3654,84	1,7	low	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
-4813,33	1,7	low	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
-4493,33	1,7	low	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
-3857,77	1,7	low	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
-4685,45	1,7	low	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-2194,15	1,7	low	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-4684,02	1,7	low	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
-4339,13	1,7	low	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-3053,53	1,7	low	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark

-2163,8	1,7	low	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-4100,46	1,7	low	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-4692,7	1,7	low	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-4586,05	1,7	low	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-1414,97	1,7	low	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-3255,76	1,7	low	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-5938,58	1,7	low	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
-5935,69	1,7	low	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
-6371,5	1,7	low	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
-4826,77	1,7	low	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
-5576,4	1,7	low	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
-6097,88	1,7	low	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-6144,66	1,7	low	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-6610,57	1,7	low	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
-13287,7	1,7	low	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-15570,57	1,7	low	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-14039,18	1,7	low	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-17909,54	1,7	low	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-12973,41	1,7	low	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-15148,42	1,7	low	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-19294,01	1,7	low	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-19483,02	1,7	low	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-7193,94	1,7	low	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
-5901,03	1,7	low	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
-6632,59	1,7	low	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
-8976,63	1,7	low	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
-7468,06	1,7	low	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
-6547,52	1,7	low	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-6788	1,7	low	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-5693,99	1,7	low	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
-18039,75	1,7	low	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-12845,25	1,7	low	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-16206,38	1,7	low	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-15318,99	1,7	low	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-18715,8	1,7	low	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-18524,55	1,7	low	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-22379,98	1,7	low	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-21616,85	1,7	low	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-2702,93	0,78	high	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
-986,52	0,78	high	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
-606,23	0,78	high	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
-2158,82	0,78	high	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
-1637,58	0,78	high	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
-2190,16	0,78	high	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-2707,63	0,78	high	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-2061,18	0,78	high	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
-2299,81	0,78	high	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-563,37	0,78	high	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-571,81	0,78	high	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-1676,36	0,78	high	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-1573,5	0,78	high	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-1758,52	0,78	high	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-2680,63	0,78	high	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-1806,07	0,78	high	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-2814,35	0,78	high	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
-792,45	0,78	high	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
-880,08	0,78	high	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
-1895,93	0,78	high	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
-2720,86	0,78	high	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
-2800,76	0,78	high	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-574,46	0,78	high	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-2009,12	0,78	high	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
-4389,89	0,78	high	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-2542,07	0,78	high	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-2742,11	0,78	high	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-3791,26	0,78	high	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-4311,86	0,78	high	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-5672,61	0,78	high	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-1,5	0,78	high	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
14363,02	0,78	high	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
-2576,37	0,78	high	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
-841,47	0,78	high	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
-782,91	0,78	high	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
-1516,65	0,78	high	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
-2929,68	0,78	high	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
-2820,87	0,78	high	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
-69,5	0,78	high	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
-1932,73	0,78	high	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
-3886,09	0,78	high	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
-3227,85	0,78	high	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
-1949,4	0,78	high	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
-3523,26	0,78	high	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
-4247,86	0,78	high	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
-4578,5	0,78	high	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
-1,74	0,78	high	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
-3571,67	0,78	high	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark

Results of study for sensitivity analysis for flexibility characteristic T

T	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	Thermal_mass	Control_strategy	Heating_system	Day	Outdoor_temperature [°C]	Solar_radiation [W/m2]	Type_of_building	location
7	1,1	high	100	high	4K	Radiator	0	-0,632	11,96	Office	Denmark
17	1,1	high	100	high	4K	Radiator	1	0,617	12,07	Office	Denmark
17	1,1	high	100	high	4K	Radiator	2	0,235	30,72	Office	Denmark
2	1,1	high	100	high	4K	Radiator	3	1,143	12,66	Office	Denmark
6	1,1	high	100	high	4K	Radiator	4	1,193	20,19	Office	Denmark
9	1,1	high	100	high	4K	Radiator	5	1,445	13,4	Office	Denmark
6	1,1	high	100	high	4K	Radiator	6	1,97	13,86	Office	Denmark
5	1,1	high	100	high	4K	Radiator	7	1,661	14,21	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	0	-0,632	11,96	Office	Denmark
9	1,1	high	100	high	4K	under floor heating	1	0,617	12,07	Office	Denmark
9	1,1	high	100	high	4K	under floor heating	2	0,235	30,72	Office	Denmark
8	1,1	high	100	high	4K	under floor heating	3	1,143	12,66	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	4	1,193	20,19	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	5	1,445	13,4	Office	Denmark
0	1,1	high	100	high	4K	under floor heating	6	1,97	13,86	Office	Denmark
5	1,1	high	100	high	4K	under floor heating	7	1,661	14,21	Office	Denmark
4	1,6	low	49	low	4K	Radiator	0	3,74	480	SFH	France
2	1,6	low	49	low	4K	Radiator	1	0,08	500	SFH	France
2	1,6	low	49	low	4K	Radiator	2	-3,46	450	SFH	France
2	1,6	low	49	low	4K	Radiator	3	-2,52	700	SFH	France
2	1,6	low	49	low	4K	Radiator	4	-0,02	3400	SFH	France
2	1,6	low	49	low	4K	Radiator	5	-0,75	700	SFH	France
4	1,6	low	49	low	4K	Radiator	6	0	3500	SFH	France
2	1,6	low	49	low	4K	Radiator	7	-0,45	4000	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	0	3,74	480	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	1	0,08	500	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	2	-3,46	450	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	3	-2,52	700	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	4	-0,02	3400	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	5	-0,75	700	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	6	0	3500	SFH	France
0,2	0,6	high	48	low	4K	under floor heating	7	-0,45	4000	SFH	France
10	0,6	high	75	high	2K	Radiator	0	-1,8	700	SFH	Austria
16	0,6	high	75	high	2K	Radiator	1	-1,81	760	SFH	Austria
12	0,6	high	75	high	2K	Radiator	2	-2,65	3900	SFH	Austria
10	0,6	high	75	high	2K	Radiator	3	-2,55	650	SFH	Austria
11	0,6	high	75	high	2K	Radiator	4	-0,95	2000	SFH	Austria
11	0,6	high	75	high	2K	Radiator	5	-4,3	4100	SFH	Austria
7	0,6	high	75	high	2K	Radiator	6	-4,24	4000	SFH	Austria
6	0,6	high	75	high	2K	Radiator	7	-5,91	4050	SFH	Austria
15	1,7	high	44	medium	2K	Radiator	0	-3,32	22,62	SFH	Denmark
8	1,7	high	44	medium	2K	Radiator	1	-4,9	35,58	SFH	Denmark
0	1,7	high	44	medium	2K	Radiator	2	-8,54	28,46	SFH	Denmark
10	1,7	high	44	medium	2K	Radiator	3	-0,75	10,25	SFH	Denmark
17	1,7	high	44	medium	2K	Radiator	4	0,32	25,1	SFH	Denmark
19	1,7	high	44	medium	2K	Radiator	5	-3,33	23,63	SFH	Denmark
19	1,7	high	44	medium	2K	Radiator	6	-2	26,26	SFH	Denmark
14	1,7	high	44	medium	2K	Radiator	7	-5,25	21,38	SFH	Denmark
15	1,7	high	44	medium	2K+1K	Radiator	0	-3,32	22,62	SFH	Denmark
8	1,7	high	44	medium	2K+1K	Radiator	1	-4,9	35,58	SFH	Denmark
0	1,7	high	44	medium	2K+1K	Radiator	2	-8,54	28,46	SFH	Denmark
10	1,7	high	44	medium	2K+1K	Radiator	3	-0,75	10,25	SFH	Denmark
17	1,7	high	44	medium	2K+1K	Radiator	4	0,32	25,1	SFH	Denmark
19	1,7	high	44	medium	2K+1K	Radiator	5	-3,33	23,63	SFH	Denmark
19	1,7	high	44	medium	2K+1K	Radiator	6	-2	26,26	SFH	Denmark
14	1,7	high	44	medium	2K+1K	Radiator	7	-5,25	21,38	SFH	Denmark
2	1,7	high	44	medium	4K	Radiator	0	-3,32	22,62	SFH	Denmark
1	1,7	high	44	medium	4K	Radiator	1	-4,9	35,58	SFH	Denmark
1	1,7	high	44	medium	4K	Radiator	2	-8,54	28,46	SFH	Denmark
9	1,7	high	44	medium	4K	Radiator	3	-0,75	10,25	SFH	Denmark
17	1,7	high	44	medium	4K	Radiator	4	0,32	25,1	SFH	Denmark
15	1,7	high	44	medium	4K	Radiator	5	-3,33	23,63	SFH	Denmark
19	1,7	high	44	medium	4K	Radiator	6	-2	26,26	SFH	Denmark
14	1,7	high	44	medium	4K	Radiator	7	-5,25	21,38	SFH	Denmark
5	1,7	high	44	medium	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
6	1,7	high	44	medium	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
5	1,7	high	44	medium	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
7	1,7	high	44	medium	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
9	1,7	high	44	medium	2K	under floor heating	4	0,32	25,1	SFH	Denmark
6	1,7	high	44	medium	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
9	1,7	high	44	medium	2K	under floor heating	6	-2	26,26	SFH	Denmark
9	1,7	high	44	medium	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
5	1,7	high	44	medium	2K+1K	under floor heating	0	-3,32	22,62	SFH	Denmark
5	1,7	high	44	medium	2K+1K	under floor heating	1	-4,9	35,58	SFH	Denmark
4	1,7	high	44	medium	2K+1K	under floor heating	2	-8,54	28,46	SFH	Denmark
7	1,7	high	44	medium	2K+1K	under floor heating	3	-0,75	10,25	SFH	Denmark
9	1,7	high	44	medium	2K+1K	under floor heating	4	0,32	25,1	SFH	Denmark
5	1,7	high	44	medium	2K+1K	under floor heating	5	-3,33	23,63	SFH	Denmark
9	1,7	high	44	medium	2K+1K	under floor heating	6	-2	26,26	SFH	Denmark
10	1,7	high	44	medium	2K+1K	under floor heating	7	-5,25	21,38	SFH	Denmark
6	1,7	high	44	medium	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
3	1,7	high	44	medium	4K	under floor heating	1	-4,9	35,58	SFH	Denmark

7	1,7	high	44	medium	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
11	1,7	high	44	medium	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
9	1,7	high	44	medium	4K	under floor heating	4	0,32	25,1	SFH	Denmark
9	1,7	high	44	medium	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
8	1,7	high	44	medium	4K	under floor heating	6	-2	26,26	SFH	Denmark
11	1,7	high	44	medium	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
12	0,6	low	54	low	2K	Radiator	0	-3,32	22,62	SFH	Denmark
0	0,6	low	54	low	2K	Radiator	1	-4,9	35,58	SFH	Denmark
0	0,6	low	54	low	2K	Radiator	2	-8,54	28,46	SFH	Denmark
10	0,6	low	54	low	2K	Radiator	3	-0,75	10,25	SFH	Denmark
17	0,6	low	54	low	2K	Radiator	4	0,32	25,1	SFH	Denmark
19	0,6	low	54	low	2K	Radiator	5	-3,33	23,63	SFH	Denmark
19	0,6	low	54	low	2K	Radiator	6	-2	26,26	SFH	Denmark
17	0,6	low	54	low	2K	Radiator	7	-5,25	21,38	SFH	Denmark
5	0,6	low	54	low	2K+1K	Radiator	0	-3,32	22,62	SFH	Denmark
4	0,6	low	54	low	2K+1K	Radiator	1	-4,9	35,58	SFH	Denmark
4	0,6	low	54	low	2K+1K	Radiator	2	-8,54	28,46	SFH	Denmark
9	0,6	low	54	low	2K+1K	Radiator	3	-0,75	10,25	SFH	Denmark
17	0,6	low	54	low	2K+1K	Radiator	4	0,32	25,1	SFH	Denmark
18	0,6	low	54	low	2K+1K	Radiator	5	-3,33	23,63	SFH	Denmark
19	0,6	low	54	low	2K+1K	Radiator	6	-2	26,26	SFH	Denmark
14	0,6	low	54	low	2K+1K	Radiator	7	-5,25	21,38	SFH	Denmark
7	0,6	low	54	low	4K	Radiator	0	-3,32	22,62	SFH	Denmark
6	0,6	low	54	low	4K	Radiator	1	-4,9	35,58	SFH	Denmark
6	0,6	low	54	low	4K	Radiator	2	-8,54	28,46	SFH	Denmark
10	0,6	low	54	low	4K	Radiator	3	-0,75	10,25	SFH	Denmark
17	0,6	low	54	low	4K	Radiator	4	0,32	25,1	SFH	Denmark
12	0,6	low	54	low	4K	Radiator	5	-3,33	23,63	SFH	Denmark
19	0,6	low	54	low	4K	Radiator	6	-2	26,26	SFH	Denmark
14	0,6	low	54	low	4K	Radiator	7	-5,25	21,38	SFH	Denmark
11	0,6	low	54	low	2K	under floor heating	0	-3,32	22,62	SFH	Denmark
11	0,6	low	54	low	2K	under floor heating	1	-4,9	35,58	SFH	Denmark
10	0,6	low	54	low	2K	under floor heating	2	-8,54	28,46	SFH	Denmark
12	0,6	low	54	low	2K	under floor heating	3	-0,75	10,25	SFH	Denmark
12	0,6	low	54	low	2K	under floor heating	4	0,32	25,1	SFH	Denmark
10	0,6	low	54	low	2K	under floor heating	5	-3,33	23,63	SFH	Denmark
12	0,6	low	54	low	2K	under floor heating	6	-2	26,26	SFH	Denmark
12	0,6	low	54	low	2K	under floor heating	7	-5,25	21,38	SFH	Denmark
13	0,6	low	54	low	2K+1K	under floor heating	0	-3,32	22,62	SFH	Denmark
10	0,6	low	54	low	2K+1K	under floor heating	1	-4,9	35,58	SFH	Denmark
10	0,6	low	54	low	2K+1K	under floor heating	2	-8,54	28,46	SFH	Denmark
14	0,6	low	54	low	2K+1K	under floor heating	3	-0,75	10,25	SFH	Denmark
12	0,6	low	54	low	2K+1K	under floor heating	4	0,32	25,1	SFH	Denmark
14	0,6	low	54	low	2K+1K	under floor heating	5	-3,33	23,63	SFH	Denmark
13	0,6	low	54	low	2K+1K	under floor heating	6	-2	26,26	SFH	Denmark
15	0,6	low	54	low	2K+1K	under floor heating	7	-5,25	21,38	SFH	Denmark
10	0,6	low	54	low	4K	under floor heating	0	-3,32	22,62	SFH	Denmark
14	0,6	low	54	low	4K	under floor heating	1	-4,9	35,58	SFH	Denmark
11	0,6	low	54	low	4K	under floor heating	2	-8,54	28,46	SFH	Denmark
13	0,6	low	54	low	4K	under floor heating	3	-0,75	10,25	SFH	Denmark
14	0,6	low	54	low	4K	under floor heating	4	0,32	25,1	SFH	Denmark
14	0,6	low	54	low	4K	under floor heating	5	-3,33	23,63	SFH	Denmark
11	0,6	low	54	low	4K	under floor heating	6	-2	26,26	SFH	Denmark
12	0,6	low	54	low	4K	under floor heating	7	-5,25	21,38	SFH	Denmark
3	1,1	high	100	high	1K-0,5K	Convective	0	-4	11,96	Office	Denmark
14	1,1	high	100	high	1K-0,5K	Convective	1	-4	12,07	Office	Denmark
9	1,1	high	100	high	1K-0,5K	Convective	2	-4	30,72	Office	Denmark
7	1,1	high	100	high	1K-0,5K	Convective	3	-4	12,66	Office	Denmark
8	1,1	high	100	high	1K-0,5K	Convective	4	-4	20,19	Office	Denmark
4	1,1	high	100	high	1K-0,5K	Convective	5	-4	13,4	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	6	-4	13,86	Office	Denmark
4	1,1	high	100	high	1K-0,5K	Convective	7	-4	14,21	Office	Denmark
3	1,1	high	100	high	1K-0,5K	Convective	0	-1	11,96	Office	Denmark
14	1,1	high	100	high	1K-0,5K	Convective	1	-1	12,07	Office	Denmark
9	1,1	high	100	high	1K-0,5K	Convective	2	-1	30,72	Office	Denmark
7	1,1	high	100	high	1K-0,5K	Convective	3	-1	12,66	Office	Denmark
8	1,1	high	100	high	1K-0,5K	Convective	4	-1	20,19	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	5	-1	13,4	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	6	-1	13,86	Office	Denmark
5	1,1	high	100	high	1K-0,5K	Convective	7	-1	14,21	Office	Denmark
3	1,1	high	100	high	1K-0,5K	Convective	0	2	11,96	Office	Denmark
4	1,1	high	100	high	1K-0,5K	Convective	1	2	12,07	Office	Denmark
9	1,1	high	100	high	1K-0,5K	Convective	2	2	30,72	Office	Denmark
7	1,1	high	100	high	1K-0,5K	Convective	3	2	12,66	Office	Denmark
8	1,1	high	100	high	1K-0,5K	Convective	4	2	20,19	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	5	2	13,4	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	6	2	13,86	Office	Denmark
5	1,1	high	100	high	1K-0,5K	Convective	7	2	14,21	Office	Denmark
3	1,1	high	100	high	1K-0,5K	Convective	0	5	11,96	Office	Denmark
14	1,1	high	100	high	1K-0,5K	Convective	1	5	12,07	Office	Denmark
9	1,1	high	100	high	1K-0,5K	Convective	2	5	30,72	Office	Denmark
7	1,1	high	100	high	1K-0,5K	Convective	3	5	12,66	Office	Denmark
8	1,1	high	100	high	1K-0,5K	Convective	4	5	20,19	Office	Denmark
6	1,1	high	100	high	1K-0,5K	Convective	5	5	13,4	Office	Denmark

6	1,1	high	100	high	1K-0,5K	Convective	6	5	13,86	Office	Denmark
5	1,1	high	100	high	1K-0,5K	Convective	7	5	14,21	Office	Denmark
16	1,7	low	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
20	1,7	low	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
12	1,7	low	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
13	1,7	low	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
9	1,7	low	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
11	1,7	low	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
4	1,7	low	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
6	1,7	low	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
19	1,7	low	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
16	1,7	low	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
13	1,7	low	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
10	1,7	low	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
8	1,7	low	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
8	1,7	low	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
7	1,7	low	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
7	1,7	low	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
10	1,7	low	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
18	1,7	low	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
11	1,7	low	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
10	1,7	low	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
10	1,7	low	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
12	1,7	low	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
9	1,7	low	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
8	1,7	low	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
9	1,7	low	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
11	1,7	low	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
5	1,7	low	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
6	1,7	low	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
7	1,7	low	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
6	1,7	low	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
7	1,7	low	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
7	1,7	low	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
12	1,7	low	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
8	1,7	low	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark
13	1,7	low	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
17	1,7	low	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
16	1,7	low	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
13	1,7	low	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
17	1,7	low	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
15	1,7	low	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
9	1,7	low	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
8	1,7	low	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
5	1,7	low	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
4	1,7	low	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
4	1,7	low	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
6	1,7	low	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
6	1,7	low	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
6	1,7	low	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark
13	0,78	high	30	low	4K	Radiator	0	2,45	9,875	SFH	Denmark
18	0,78	high	30	low	4K	Radiator	1	2,75	13,308	SFH	Denmark
7	0,78	high	30	low	4K	Radiator	2	1,43	9,75	SFH	Denmark
4	0,78	high	30	low	4K	Radiator	3	1,07	14,29	SFH	Denmark
7	0,78	high	30	low	4K	Radiator	4	0,17	20,63	SFH	Denmark
7	0,78	high	30	low	4K	Radiator	5	-2,71	19,96	SFH	Denmark
6	0,78	high	30	low	4K	Radiator	6	-1,65	6,46	SFH	Denmark
6	0,78	high	30	low	4K	Radiator	7	0,52	25,63	SFH	Denmark
11	0,78	high	30	low	4K	under floor heating	0	2,45	9,875	SFH	Denmark
18	0,78	high	30	low	4K	under floor heating	1	2,75	13,308	SFH	Denmark
7	0,78	high	30	low	4K	under floor heating	2	1,43	9,75	SFH	Denmark
6	0,78	high	30	low	4K	under floor heating	3	1,07	14,29	SFH	Denmark
8	0,78	high	30	low	4K	under floor heating	4	0,17	20,63	SFH	Denmark
7	0,78	high	30	low	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
7	0,78	high	30	low	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
7	0,78	high	30	low	4K	under floor heating	7	0,52	25,63	SFH	Denmark
10	0,78	high	55	medium	4K	Radiator	0	2,45	9,875	SFH	Denmark
18	0,78	high	55	medium	4K	Radiator	1	2,75	13,308	SFH	Denmark
8	0,78	high	55	medium	4K	Radiator	2	1,43	9,75	SFH	Denmark
5	0,78	high	55	medium	4K	Radiator	3	1,07	14,29	SFH	Denmark
3	0,78	high	55	medium	4K	Radiator	4	0,17	20,63	SFH	Denmark
3	0,78	high	55	medium	4K	Radiator	5	-2,71	19,96	SFH	Denmark
2	0,78	high	55	medium	4K	Radiator	6	-1,65	6,46	SFH	Denmark
8	0,78	high	55	medium	4K	Radiator	7	0,52	25,63	SFH	Denmark
7	0,78	high	55	medium	4K	under floor heating	0	2,45	9,875	SFH	Denmark
11	0,78	high	55	medium	4K	under floor heating	1	2,75	13,308	SFH	Denmark
9	0,78	high	55	medium	4K	under floor heating	2	1,43	9,75	SFH	Denmark
7	0,78	high	55	medium	4K	under floor heating	3	1,07	14,29	SFH	Denmark
6	0,78	high	55	medium	4K	under floor heating	4	0,17	20,63	SFH	Denmark
3	0,78	high	55	medium	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
0	0,78	high	55	medium	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
3	0,78	high	55	medium	4K	under floor heating	7	0,52	25,63	SFH	Denmark
10	0,78	high	98	high	4K	Radiator	0	2,45	9,875	SFH	Denmark
18	0,78	high	98	high	4K	Radiator	1	2,75	13,308	SFH	Denmark

8	0,78	high	98	high	4K	Radiator	2	1,43	9,75	SFH	Denmark
5	0,78	high	98	high	4K	Radiator	3	1,07	14,29	SFH	Denmark
3	0,78	high	98	high	4K	Radiator	4	0,17	20,63	SFH	Denmark
3	0,78	high	98	high	4K	Radiator	5	-2,71	19,96	SFH	Denmark
0	0,78	high	98	high	4K	Radiator	6	-1,65	6,46	SFH	Denmark
2	0,78	high	98	high	4K	Radiator	7	0,52	25,63	SFH	Denmark
7	0,78	high	98	high	4K	under floor heating	0	2,45	9,875	SFH	Denmark
11	0,78	high	98	high	4K	under floor heating	1	2,75	13,308	SFH	Denmark
8	0,78	high	98	high	4K	under floor heating	2	1,43	9,75	SFH	Denmark
4	0,78	high	98	high	4K	under floor heating	3	1,07	14,29	SFH	Denmark
4	0,78	high	98	high	4K	under floor heating	4	0,17	20,63	SFH	Denmark
4	0,78	high	98	high	4K	under floor heating	5	-2,71	19,96	SFH	Denmark
0	0,78	high	98	high	4K	under floor heating	6	-1,65	6,46	SFH	Denmark
2	0,78	high	98	high	4K	under floor heating	7	0,52	25,63	SFH	Denmark

Results of study used for sensitivity analysis for KPI1

Sflex	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	thermal_mass	Control_strategy	Heating_system	Type_of_building
53	1,1	high	100	high	4K	Radiator	Office building
44	1,1	high	100	high	4K	under floor heating	Office building
0,5	1,7	low	30	low	4K	Radiator	Single family house
19	0,78	high	30	low	4K	Radiator	Single family house
33	1,7	low	55	medium	4K	Radiator	Single family house
23	0,78	high	55	medium	4K	Radiator	Single family house
26	1,7	low	98	high	4K	Radiator	Single family house
33	0,78	high	98	high	4K	Radiator	Single family house
12	1,7	low	30	low	4K	under floor heating	Single family house
15	0,78	high	30	low	4K	under floor heating	Single family house
26	1,7	low	55	medium	4K	under floor heating	Single family house
16	0,78	high	55	medium	4K	under floor heating	Single family house
24	1,7	low	98	high	4K	under floor heating	Single family house
26	0,78	high	98	high	4K	under floor heating	Single family house
21	1,6	low	49	low	4K	Radiator	Single family house
30	0,6	high	48	low	4K	under floor heating	Single family house
32	0,6	high	54	medium	2K	Radiator	Single family house
28,3	0,6	high	54	medium	3K	Radiator	Single family house
30,7	0,6	high	54	medium	4K	Radiator	Single family house
32,3	0,6	high	54	medium	2K	under floor heating	Single family house
31,4	0,6	high	54	medium	3K	under floor heating	Single family house
13,47	0,6	high	54	medium	4K	under floor heating	Single family house
31,46	1,7	low	44	low	2K	Radiator	Single family house
25,32	1,7	low	44	low	3K	Radiator	Single family house
44,43	1,7	low	44	low	4K	Radiator	Single family house
30,98	1,7	low	44	low	2K	under floor heating	Single family house
45,85	1,7	low	44	low	3K	under floor heating	Single family house
13,03	1,7	low	44	low	4K	under floor heating	Single family house
29,2	1,1	high	100	high	1K	Radiator	Office building
40,41	1,1	high	100	high	1K	Radiator	Office building
52,72	1,1	high	100	high	1K	Radiator	Office building
45,52	1,1	high	100	high	1K	Radiator	Office building
53,03	0,6	high	75	high	2K	Radiator	Single family house

Results of study used for sensitivity analysis for KPI2

Eflex	U-value [W/m2K]	Insulation_level	cm [kWh/m2K]	thermal_mass	Control_strategy	Heating_system	Type_of_building
-41	1,1	high	100	high	4K	Radiator	Office building
-0,08	1,1	high	100	high	4K	under floor heating	Office building
0,03	1,7	low	30	low	4K	Radiator	Single family house
-0,08	0,78	high	30	low	4K	Radiator	Single family house
0,07	1,7	low	55	medium	4K	Radiator	Single family house
-0,19	0,78	high	55	medium	4K	Radiator	Single family house
0,09	1,7	low	98	high	4K	Radiator	Single family house
0,14	0,78	high	98	high	4K	Radiator	Single family house
0,02	1,7	low	30	low	4K	under floor heating	Single family house
-0,10	0,78	high	30	low	4K	under floor heating	Single family house
0,04	1,7	low	55	medium	4K	under floor heating	Single family house
-0,12	0,78	high	55	medium	4K	under floor heating	Single family house
0,06	1,7	low	98	high	4K	under floor heating	Single family house
-0,17	0,78	high	98	high	4K	under floor heating	Single family house
0,03	1,6	low	49	low	4K	Radiator	Single family house
0,19	0,6	high	48	low	4K	under floor heating	Single family house
0,05	0,6	high	54	medium	2K	Radiator	Single family house
0,05	0,6	high	54	medium	3K	Radiator	Single family house
-0,05	0,6	high	54	medium	4K	Radiator	Single family house
-0,29	0,6	high	54	medium	2K	under floor heating	Single family house
-0,035	0,6	high	54	medium	3K	under floor heating	Single family house
0,02	0,6	high	54	medium	4K	under floor heating	Single family house
0,04	1,7	low	44	low	2K	Radiator	Single family house
0,02	1,7	low	44	low	3K	Radiator	Single family house
0,03	1,7	low	44	low	4K	Radiator	Single family house
0,02	1,7	low	44	low	2K	under floor heating	Single family house
0,04	1,7	low	44	low	3K	under floor heating	Single family house
0	1,7	low	44	low	4K	under floor heating	Single family house
-0,029	1,1	high	100	high	1K	Radiator	Office building
0,006	1,1	high	100	high	1K	Radiator	Office building
0,012	1,1	high	100	high	1K	Radiator	Office building
0,023	1,1	high	100	high	1K	Radiator	Office building
0	0,6	high	75	high	2K	Radiator	Single family house

B.3 Sensitivity Analysis

B.3.1 Flexibility Characteristics

Influence of Building Parameters on Flexibility Characteristics

The ANOVA method is used on the FC results data to assess which building parameter such as Insulation level, thermal mass, heating system, type of building, control strategy, outdoor temperature and solar radiation have the largest influence on the FC's.

Flexibility characteristic A:

Data results are shown in appendix: ANOVA

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building + Outdoor_temperature + Solar_radiation
, data=data_results)

Analysis of Variance Table

Response: A
                     Df     Sum Sq    Mean Sq  F value    Pr(>F)    
Insulation_level      1 8.4621e+09 8462145265 138.4992 < 2.2e-16 ***
Thermal_mass          2 1.6560e+10 8280238909 135.5220 < 2.2e-16 ***
Heating_system        2 2.2320e+09 1116008458  18.2656 3.893e-08 ***
Control_strategy      2 4.0139e+09 2006954135  32.8477 2.078e-13 ***
Type_of_building      1 2.2668e+09 2266773308  37.1001 4.150e-09 ***
Outdoor_temperature   1 8.2586e+08  825856315  13.5167 0.0002887 ***
Solar_radiation       1 4.2502e+07   42502386   0.6956 0.4050418    
Residuals           253 1.5458e+10   61098864                       
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the solar radiation

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building + Outdoor_temperature, data=data_result
s)

Analysis of Variance Table

Response: A
                     Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level      1 8.4621e+09 8462145265 138.665 < 2.2e-16 ***
Thermal_mass          2 1.6560e+10 8280238909 135.685 < 2.2e-16 ***
Heating_system        2 2.2320e+09 1116008458  18.288 3.803e-08 ***
Control_strategy      2 4.0139e+09 2006954135  32.887 1.990e-13 ***
Type_of_building      1 2.2668e+09 2266773308  37.145 4.049e-09 ***
Outdoor_temperature   1 8.2586e+08  825856315  13.533 0.0002862 ***
Residuals           254 1.5501e+10   61025650                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the Outdoor temperature

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building, data=data_results)

Analysis of Variance Table

Response: A
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 8.4621e+09 8462145265 132.169 < 2.2e-16 ***
Thermal_mass       2 1.6560e+10 8280238909 129.328 < 2.2e-16 ***
Heating_system     2 2.2320e+09 1116008458  17.431 8.027e-08 ***
Control_strategy   2 4.0139e+09 2006954135  31.346 6.729e-13 ***
Type_of_building   1 2.2668e+09 2266773308  35.404 8.805e-09 ***
Residuals        255 1.6326e+10   64024986                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We remove the least significant parameter being the heating system

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass + Control_strategy
+ Type_of_building, data=data_results)
Analysis of Variance Table

Response: A
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 8.4621e+09 8462145265 127.033 < 2.2e-16 ***
Thermal_mass       2 1.6560e+10 8280238909 124.302 < 2.2e-16 ***
Control_strategy   3 5.5760e+09 1858679567  27.902 1.207e-15 ***
Type_of_building   1 2.2099e+09 2209912997  33.175 2.407e-08 ***
Residuals        256 1.7053e+10   66613743                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We remove the least significant parameter being the control strategy

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass + Type_of_building
, data=data_results)
Analysis of Variance Table

Response: A
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 8.4621e+09 8462145265  99.820 < 2.2e-16 ***
Thermal_mass       2 1.6560e+10 8280238909  97.675 < 2.2e-16 ***
Type_of_building   1 2.8827e+09 2882692849  34.005 1.632e-08 ***
Residuals        259 2.1956e+10   84773656                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We remove the least significant parameter being the type of building

```
flexibility_lm <- lm(A ~ Insulation_level + Thermal_mass, data=data_results
)

Analysis of Variance Table

Response: A
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 8.4621e+09 8462145265  88.576 < 2.2e-16 ***
Thermal_mass       2 1.6560e+10 8280238909  86.672 < 2.2e-16 ***
Residuals        260 2.4839e+10   95534884                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusion:

The influence of the different building parameters on the flexibility characteristic A is ranked in the following table with the most significant parameter (lowest p-value and highest F-value) on the top.

Significance Ranking	Building parameter	F-value	p-value
1	Insulation level	88.576	2,20E-16
2	Thermal mass	86,672	2,20E-16
3	Type of building	34,005	1,63E-08
4	Control strategy	27,902	1,21E-12
5	Heating system	17,431	8,03E-05
6	Outdoor temperature	13,533	2,86E-04
7	Solar radiation	0,6956	4,05E-01

Flexibility characteristic B:

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building + Outdoor_temperature + Solar_radiation
, data=data_results)
Analysis of Variance Table

Response: B
                     Df     Sum Sq    Mean Sq  F value    Pr(>F)
Insulation_level      1 1.3495e+10 1.3495e+10 105.5890 < 2.2e-16 ***
Thermal_mass          2 1.6869e+10 8.4346e+09  65.9947 < 2.2e-16 ***
Heating_system        2 4.6028e+09 2.3014e+09  18.0068 4.882e-08 ***
Control_strategy      2 5.3373e+09 2.6686e+09  20.8800 4.045e-09 ***
Type_of_building      1 2.9349e+09 2.9349e+09  22.9631 2.818e-06 ***
Outdoor_temperature   1 9.4248e+08 9.4248e+08   7.3742  0.007073 **
Solar_radiation       1 9.4638e+07 9.4638e+07   0.7405  0.390325
Residuals           253 3.2335e+10 1.2781e+08
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the solar radiation

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building + Outdoor_temperature, data=data_result
s)
Analysis of Variance Table

Response: B
                     Df     Sum Sq    Mean Sq  F value    Pr(>F)
Insulation_level      1 1.3495e+10 1.3495e+10 105.6970 < 2.2e-16 ***
Thermal_mass          2 1.6869e+10 8.4346e+09  66.0622 < 2.2e-16 ***
Heating_system        2 4.6028e+09 2.3014e+09  18.0252 4.784e-08 ***
Control_strategy      2 5.3373e+09 2.6686e+09  20.9014 3.950e-09 ***
Type_of_building      1 2.9349e+09 2.9349e+09  22.9866 2.781e-06 ***
Outdoor_temperature   1 9.4248e+08 9.4248e+08   7.3817  0.007042 **
Residuals           254 3.2430e+10 1.2768e+08
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the outdoor temperature

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building, data=data_results)
Analysis of Variance Table

Response: B
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 1.3495e+10 1.3495e+10 103.116 < 2.2e-16 ***
Thermal_mass       2 1.6869e+10 8.4346e+09  64.449 < 2.2e-16 ***
Heating_system     2 4.6028e+09 2.3014e+09  17.585 7.009e-08 ***
Control_strategy   2 5.3373e+09 2.6686e+09  20.391 6.095e-09 ***
Type_of_building   1 2.9349e+09 2.9349e+09  22.425 3.628e-06 ***
Residuals        255 3.3373e+10 1.3087e+08                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the heating system

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass + Control_strategy
+ Type_of_building, data=data_results)
Analysis of Variance Table

Response: B
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 1.3495e+10 1.3495e+10  96.187 < 2.2e-16 ***
Thermal_mass       2 1.6869e+10 8.4346e+09  60.118 < 2.2e-16 ***
Control_strategy   3 7.5172e+09 2.5057e+09  17.860 1.479e-10 ***
Type_of_building   1 2.8133e+09 2.8133e+09  20.052 1.136e-05 ***
Residuals        256 3.5917e+10 1.4030e+08                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the control strategy

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass + Type_of_building
, data=data_results)
Analysis of Variance Table

Response: B
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 1.3495e+10 1.3495e+10  82.055 < 2.2e-16 ***
Thermal_mass       2 1.6869e+10 8.4346e+09  51.286 < 2.2e-16 ***
Type_of_building   1 3.6513e+09 3.6513e+09  22.201  4.01e-06 ***
Residuals        259 4.2596e+10 1.6446e+08                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the type of building

```
flexibility_lm <- lm(B ~ Insulation_level + Thermal_mass, data=data_results
)
Analysis of Variance Table

Response: B
                  Df     Sum Sq    Mean Sq F value    Pr(>F)    
Insulation_level   1 1.3495e+10 1.3495e+10  75.869 3.598e-16 ***
Thermal_mass       2 1.6869e+10 8.4346e+09  47.419 < 2.2e-16 ***
Residuals        260 4.6247e+10 1.7787e+08                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Conclusion:

The influence of the different building parameters on the flexibility characteristic B is ranked in the following table with the most significant parameter (lowest p-value and highest F-value) on the top.

Significance Ranking	Building parameter	F-value	p-value
1	Insulation level	76	3,60E-16
2	Thermal mass	47,419	2,20E-16
3	Type of building	22,052	1,14E-05
4	Control strategy	17,86	1,47E-10
5	Heating system	17,585	7,01E-08
6	Outdoor temperature	7,3817	7,04E-03
7	Solar radiation	0,7405	3,90E-01

Flexibility characteristic Delta:

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass + Heating_syst
em + Control_strategy + Type_of_building + Outdoor_temperature + Solar_radi
ation, data=data_results)
```

```
 Analysis of Variance Table

Response: Delta
                     Df     Sum Sq   Mean Sq  F value    Pr(>F)    
Insulation_level      1  973893476 973893476 124.1062 < 2.2e-16 ***
Thermal_mass          2 1088634220 544317110  69.3640 < 2.2e-16 ***
Heating_system        2  359401204 179700602  22.8998 7.231e-10 ***
Control_strategy      2  297474606 148737303  18.9540 2.136e-08 ***
Type_of_building      1  198832981 198832981  25.3379 9.143e-07 ***
Outdoor_temperature   1   48315072  48315072   6.1569   0.01374 *  
Solar_radiation       1    6362002   6362002   0.8107   0.36876    
Residuals           253 1985356433   7847259                       
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the solar radiation

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass + Heating_syst
em + Control_strategy + Type_of_building + Outdoor_temperature, data=data_r
esults)
```

```
Analysis of Variance Table

Response: Delta
                     Df     Sum Sq   Mean Sq  F value    Pr(>F)    
Insulation_level      1  973893476 973893476 124.1988 < 2.2e-16 ***
Thermal_mass          2 1088634220 544317110  69.4157 < 2.2e-16 ***
Heating_system        2  359401204 179700602  22.9169 7.080e-10 ***
Control_strategy      2  297474606 148737303  18.9682 2.100e-08 ***
Type_of_building      1  198832981 198832981  25.3568 9.041e-07 ***
Outdoor_temperature   1   48315072  48315072   6.1615    0.0137 *  
Residuals           254 1991718435   7841411                       
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the outdoor temperature

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass + Heating_syst
em + Control_strategy + Type_of_building, data=data_results)

Analysis of Variance Table

Response: Delta
                  Df     Sum Sq   Mean Sq F value    Pr(>F)    
Insulation_level   1  973893476 973893476 121.735 < 2.2e-16 ***
Thermal_mass       2 1088634220 544317110  68.038 < 2.2e-16 ***
Heating_system     2  359401204 179700602  22.462 1.035e-09 ***
Control_strategy   2  297474606 148737303  18.592 2.902e-08 ***
Type_of_building   1  198832981 198832981  24.854 1.144e-06 ***
Residuals        255 2040033507   8000131                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the control strategy

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass + Heating_syst
em + Type_of_building, data=data_results)

nalysis of Variance Table

Response: Delta
                  Df     Sum Sq   Mean Sq F value    Pr(>F)    
Insulation_level   1  973893476 973893476 104.874 < 2.2e-16 ***
Thermal_mass       2 1088634220 544317110  58.615 < 2.2e-16 ***
Heating_system     2  359401204 179700602  19.351 1.485e-08 ***
Type_of_building   1  149745142 149745142  16.125 7.787e-05 ***
Residuals        257 2386595953   9286366                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the type of building

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass + Heating_syst
em, data=data_results)

Analysis of Variance Table

Response: Delta
                  Df     Sum Sq   Mean Sq F value    Pr(>F)    
Insulation_level   1  973893476 973893476  99.066 < 2.2e-16 ***
Thermal_mass       2 1088634220 544317110  55.369 < 2.2e-16 ***
Heating_system     2  359401204 179700602  18.279 3.765e-08 ***
Residuals        258 2536341095   9830779                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the heating system

```
flexibility_lm <- lm(Delta ~ Insulation_level + Thermal_mass, data=data_res
ults)
Analysis of Variance Table

Response: Delta
                  Df     Sum Sq   Mean Sq F value    Pr(>F)    
Insulation_level   1  973893476 973893476  87.443 < 2.2e-16 ***
Thermal_mass       2 1088634220 544317110  48.873 < 2.2e-16 ***
Residuals        260 2895742299  11137470                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Conclusion:

The influence of the different building parameters on the flexibility characteristic Delta is ranked in the following table with the most significant parameter (lowest p-value and highest F-value) on the top.

Significance Ranking	Building parameter	F-value	p-value
1	Insulation level	87	2,20E-16
2	Thermal mass	48,873	2,20E-16
3	Heating system	18,279	3,76E-08
4	type of building	16,125	7,79E-05
5	control strategy	18,529	2,10E-08
6	Outdoor temperature	6,1615	1,37E-02
7	Solar radiation	0,8107	3,69E-01

Flexibility characteristic T:

```
flexibility_lm <- lm(T ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Type_of_building + Outdoor_temperature + Solar_radiation
, data=data_results)
```

```
nalysis of Variance Table

Response: T
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  507.5  507.52 25.8251 7.270e-07 ***
Thermal_mass          2   83.5   41.74  2.1238 0.1217054    
Heating_system        2  309.2  154.60  7.8668 0.0004848 ***
Control_strategy      2  309.9  154.94  7.8844 0.0004768 ***
Type_of_building      1    0.3    0.26  0.0132 0.9087092    
Outdoor_temperature   1  357.5  357.46 18.1893 2.827e-05 ***
Solar_radiation       1  262.4  262.43 13.3536 0.0003136 ***
Residuals           253 4972.0   19.65                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the type of building

```
flexibility_lm <- lm(T ~ Insulation_level + Thermal_mass + Heating_system +
Control_strategy + Outdoor_temperature + Solar_radiation, data=data_results
)
```

```
Analysis of Variance Table

Response: T
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  507.5  507.52 25.8435 7.190e-07 ***
Thermal_mass          2   83.5   41.74  2.1253 0.1215164    
Heating_system        2  309.2  154.60  7.8724 0.0004818 ***
Control_strategy      2  309.9  154.94  7.8900 0.0004739 ***
Outdoor_temperature   1  355.8  355.82 18.1189 2.922e-05 ***
Solar_radiation       1  248.2  248.22 12.6396 0.0004503 ***
Residuals           254 4988.1   19.64                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the Thermal mass

```
flexibility_lm <- lm(T ~ Insulation_level + Heating_system + Control_strate
gy + Outdoor_temperature + Solar_radiation, data=data_results)

Analysis of Variance Table

Response: T
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  507.5  507.52 25.9173 6.911e-07 ***
Heating_system        2  313.6  156.80  8.0073 0.0004236 ***
Control_strategy      2  358.5  179.27  9.1549 0.0001445 ***
Outdoor_temperature   1  322.0  322.02 16.4447 6.653e-05 ***
Solar_radiation       1  287.5  287.47 14.6804 0.0001603 ***
Residuals           256 5013.0   19.58                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the heating system

```
flexibility_lm <- lm(T ~ Insulation_level + Control_strategy + Outdoor_temp
erature + Solar_radiation, data=data_results)
Analysis of Variance Table

Response: T
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  507.5  507.52 24.4840 1.356e-06 ***
Control_strategy      3  406.0  135.33  6.5284 0.0002852 ***
Outdoor_temperature   1  325.5  325.49 15.7026 9.608e-05 ***
Solar_radiation       1  236.0  235.98 11.3842 0.0008551 ***
Residuals           257 5327.2   20.73                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the Control strategy

```
flexibility_lm <- lm(T ~ Insulation_level + Outdoor_temperature + Solar_rad
iation, data=data_results)
Analysis of Variance Table

Response: T
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  507.5  507.52 21.6945 5.106e-06 ***
Outdoor_temperature   1   39.8   39.81  1.7016  0.193239    
Solar_radiation       1  172.5  172.50  7.3736  0.007062 ** 
Residuals           260 6082.4   23.39                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the outdoor temperature

```
flexibility_lm <- lm(T ~ Insulation_level+ Solar_radiation, data=data_resul
ts)
Analysis of Variance Table

Response: T
                  Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level   1  507.5  507.52 21.6719 5.153e-06 ***
Solar_radiation    1  182.5  182.52  7.7939   0.00563 ** 
Residuals        261 6112.2   23.42                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Conclusion:

The influence of the different building parameters on the flexibility characteristic T is ranked in the following table with the most significant parameter (lowest p-value and highest F-value) on the top

Significance Ranking	Building parameter	F-value	p-value
1	Insulation level	22	5,15E-06
2	Solar radiation	7,939	5,63E-03
3	Outdoor temperature	1,7016	1,93E-01
4	control strategy	6,5284	2,85E-04
5	heating system	8,0073	4,24E-04
6	Thermal mass	2,1254	1,22E-01
7	Type of building	0,0132	9,08E-01

Flexibility characteristic Beta:

```
flexibility_lm <- lm(Beta ~ Insulation_level + Thermal_mass + Heating_syste
m + Control_strategy + Type_of_building + Outdoor_temperature + Solar_radia
tion, data=data_results)

Analysis of Variance Table

Response: Beta
                     Df Sum Sq Mean Sq F value    Pr(>F)
Insulation_level      1  244.6  244.59 10.1220 0.0016481 **
Thermal_mass          2   16.9    8.46  0.3503 0.7048438
Heating_system        2 1316.1  658.03 27.2316 1.945e-11 ***
Control_strategy      2  731.8  365.91 15.1425 6.144e-07 ***
Type_of_building      1  301.7  301.73 12.4866 0.0004871 ***
Outdoor_temperature   1   31.6   31.64  1.3095 0.2535634
Solar_radiation       1   29.0   29.04  1.2017 0.2740343
Residuals           253 6113.6   24.16
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We remove the least significant parameter being the thermal mass

```
lexibility_lm <- lm(Beta ~ Insulation_level + Heating_system + Control_stra
tegy + Type_of_building + Outdoor_temperature + Solar_radiation, data=data_
results)
Analysis of Variance Table

Response: Beta
                     Df Sum Sq Mean Sq F value    Pr(>F)
Insulation_level      1  244.6  244.59  9.7280  0.002023 **
Heating_system        2 1109.2  554.62 22.0589 1.459e-09 ***
Control_strategy      2  870.1  435.04 17.3026 8.986e-08 ***
Type_of_building      1  132.6  132.59  5.2734  0.022465 *
Outdoor_temperature   1   10.5   10.51  0.4181  0.518459
Solar_radiation       1    6.9    6.92  0.2753  0.600224
Residuals           255 6411.4   25.14
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We remove the least significant parameter being the solar radiation

```
flexibility_lm <- lm(Beta ~ Insulation_level + Heating_system + Control_str
ategy + Type_of_building + Outdoor_temperature, data=data_results)
Analysis of Variance Table

Response: Beta
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level      1  244.6  244.59  9.7557  0.001993 ** 
Heating_system        2 1109.2  554.62 22.1215 1.375e-09 ***
Control_strategy      2  870.1  435.04 17.3518 8.572e-08 ***
Type_of_building      1  132.6  132.59  5.2884  0.022273 *  
Outdoor_temperature   1   10.5   10.51  0.4193  0.517864    
Residuals           256 6418.3   25.07                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the outdoor temperature

```
flexibility_lm <- lm(Beta ~ Insulation_level + Heating_system + Control_str
ategy + Type_of_building, data=data_results)
Analysis of Variance Table

Response: Beta
                  Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level   1  244.6  244.59  9.7777   0.00197 ** 
Heating_system     2 1109.2  554.62 22.1716 1.309e-09 ***
Control_strategy   2  870.1  435.04 17.3911 8.248e-08 ***
Type_of_building   1  132.6  132.59  5.3004   0.02212 *  
Residuals        257 6428.9   25.02                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the type of building

```
flexibility_lm <- lm(Beta ~ Insulation_level + Heating_system + Control_str
ategy, data=data_results)
Analysis of Variance Table

Response: Beta
                  Df Sum Sq Mean Sq F value    Pr(>F)    
Insulation_level   1  244.6  244.59  9.6174  0.002141 ** 
Heating_system     2 1109.2  554.62 21.8081 1.775e-09 ***
Control_strategy   2  870.1  435.04 17.1059 1.057e-07 ***
Residuals        258 6561.4   25.43                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

We remove the least significant parameter being the insulation level

```
flexibility_lm <- lm(Beta ~ + Heating_system + Control_strategy, data=data_
results)

Analysis of Variance Table

Response: Beta
                  Df Sum Sq Mean Sq F value    Pr(>F)    
Heating_system     2 1324.8  662.40  26.045 4.937e-11 ***
Control_strategy   2  873.6  436.79  17.175 9.906e-08 ***
Residuals        259 6587.0   25.43                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Conclusion:

The influence of the different building parameters on the flexibility characteristic Beta is ranked in the following table with the most significant parameter (lowest p-value and highest F-value) on the top

Significance Ranking	Building parameter	F-value	p-value
1	Heating system	26	4,94E-11
2	control strategy	17,175	9,91E-08
3	Insulation level	9,6174	2,14E-03
4	type of building	5,3004	2,21E-02
5	Outdoor temperature	0,4193	5,16E-01
6	Solar radiation	0,2753	6,00E-01
7	Thermal mass	0,3503	7,05E-01

Result of ANOVA with colors.

	A	B	Delta	Beta	T	Sflex	Eflex
Insulation level	1	1	1	3	1	1	1
Thermal mass	2	2	2	7	6	2	4
heating system	5	5	3	1	5	3	2
control strategy	4	4	5	2	4	4	5
Type of building	3	3	4	4	7	5	3
Outdoor temperature	6	6	6	5	3		
Solar radiation	7	7	7	6	2		

Table B.1: Overview of ANOVA test. Source: Brockhoss et al. (2018) [25]

Source of variation	**Degrees of freedom**	**Sums of squares**	**Mean sum of squares**	**Test-statistic F**	**p-value**
Treatment	k-1	SS(Tr)	MS(Tr)=$\frac{SS(Tr)}{k-1}$	$F_{obs}=\frac{MS(Tr)}{MSE}$	$P(F>F_{obs})$
Residual	n-k	SSE	MSE=$\frac{SSE}{n-k}$		
Total	n-1	SST			

B.3.2 Shifted Flexible Load

Table B.2: SA for shifted flexible load with all building parameters included

Significance ranking	**Building parameter**	**F-value**
1	Insulation level	10,1
2	Thermal mass	7,5
3	Heating system	3,9
4	Control strategy	1,5
5	Type of building	0,1

Removing the least significant parameter being the type of building.

Table B.3: SA for shifted flexible load with all building parameters included - With type of building removed

Significance ranking	**Building parameter**	**F-value**
1	Insulation level	10,5
2	Thermal mass	7,8
3	Heating system	4,1
4	Control strategy	1,6

Removing the least significant parameter being the control strategy.

Table B.4: SA for shifted flexible load with all building parameters included - With type of building and control strategy removed

Significance ranking	**Building parameter**	**F-value**
1	Insulation level	10,1
2	Thermal mass	7,5
3	Heating system	3,9

B.3.3 Efficiency of flexible operation

Significance ranking	Building parameter	F-value
1	Insulation level	7,6
2	Type of building	7,2
3	Heating system	1,7
4	Thermal mass	0,3
5	Control strategy	0,2

Removing the least significant parameter being the control strategy.

Significance ranking	Building parameter	F-value
1	Insulation level	8,1
2	Type of building	7,6
3	Heating system	1,8
4	Thermal mass	0,3

Removing the least significant parameter being the thermal mass.

Significance ranking	Building parameter	F-value
1	Insulation level	8,1
2	Heating system	5,2
3	Type of building	0,2

Removing the least significant parameter being the type of building.

Significance ranking	Building parameter	F-value
1	Insulation level	6,8
2	Heating system	1,4

B.4 Sensitivity Analysis Results

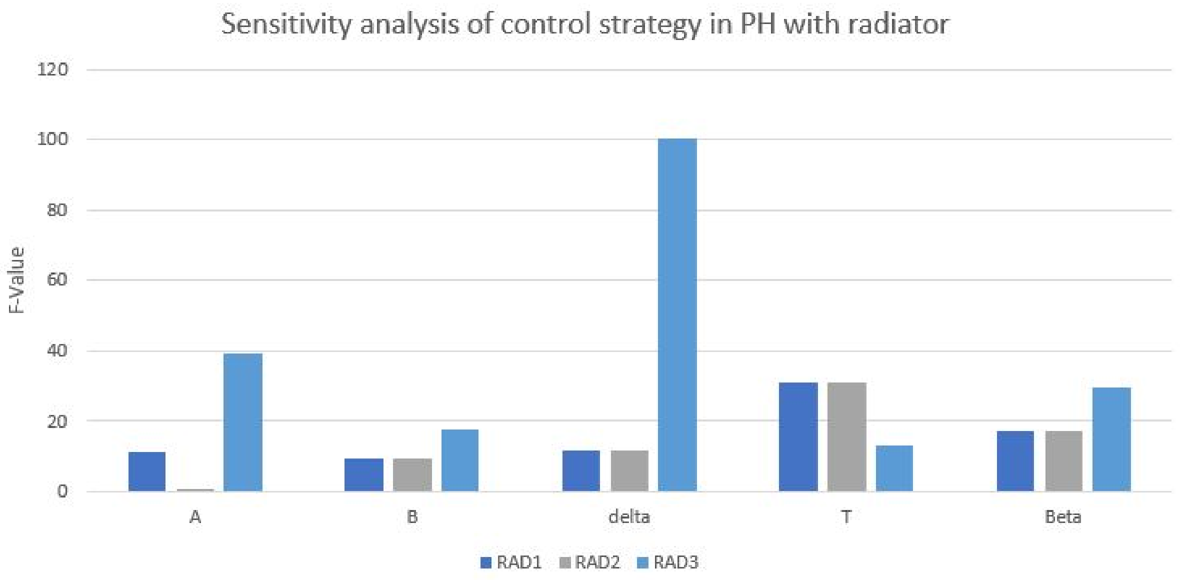

Figure B.2: Results from sensitivity analysis based on case study D, in a passive house with radiator heating system

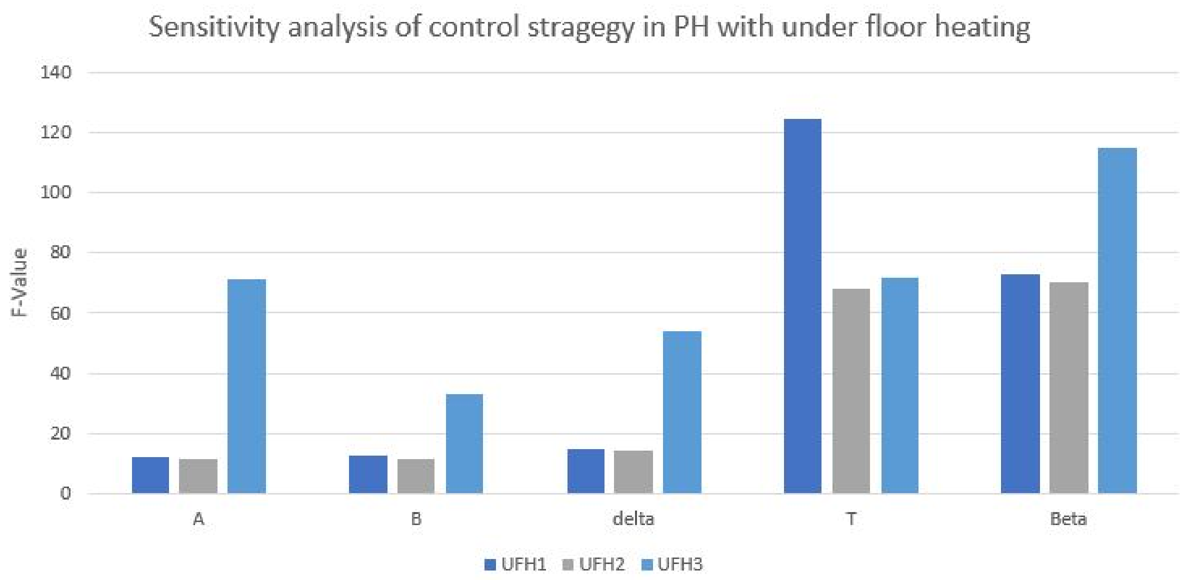

Figure B.3: Results from sensitivity analysis based on case study D, in a passive house with under floor heating

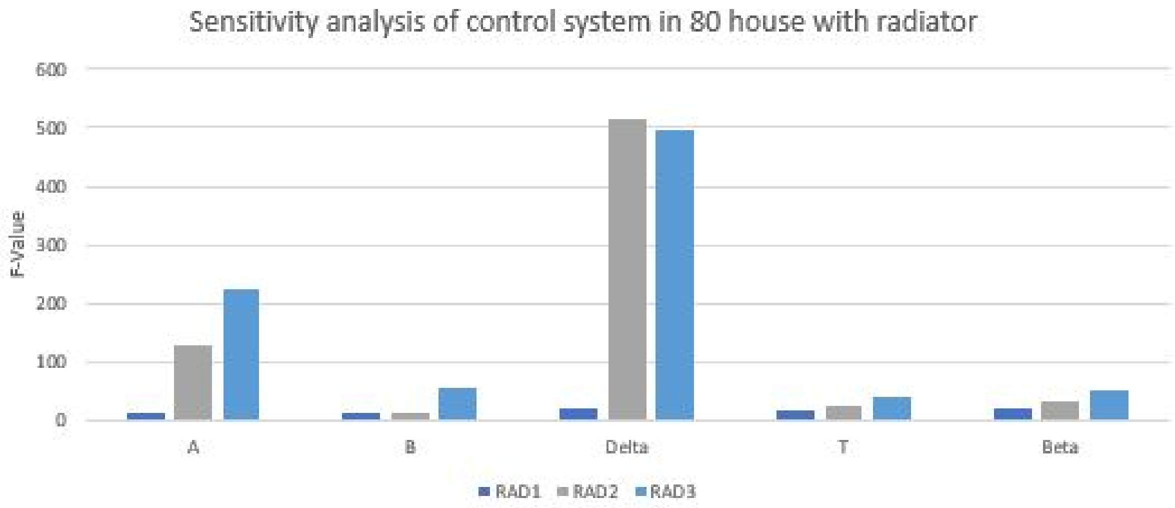

Figure B.4: Results from sensitivity analysis based on case study D, in a house from 80's with radiator heating system

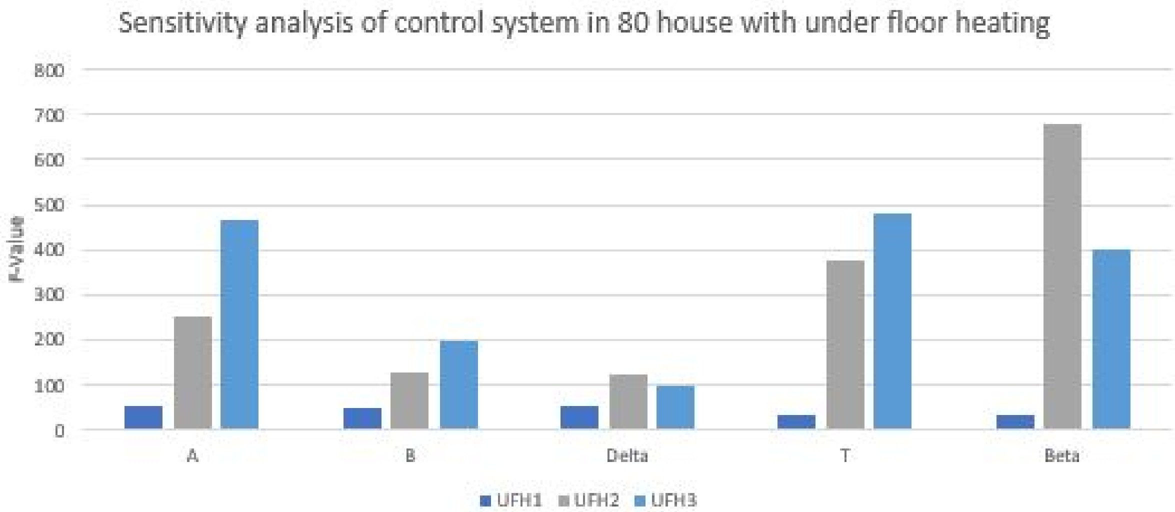

Figure B.5: Results from sensitivity analysis based on case study D, in a house from 80's with under floor heating

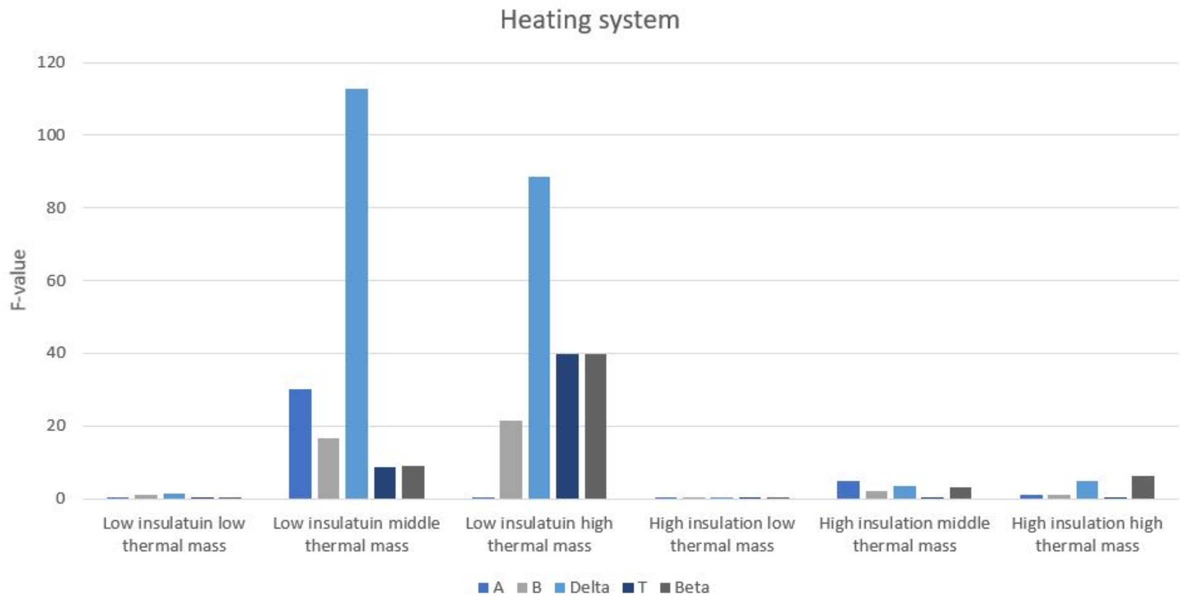

Figure B.6: Results from sensitivity analysis based on case study B, and type of heating system

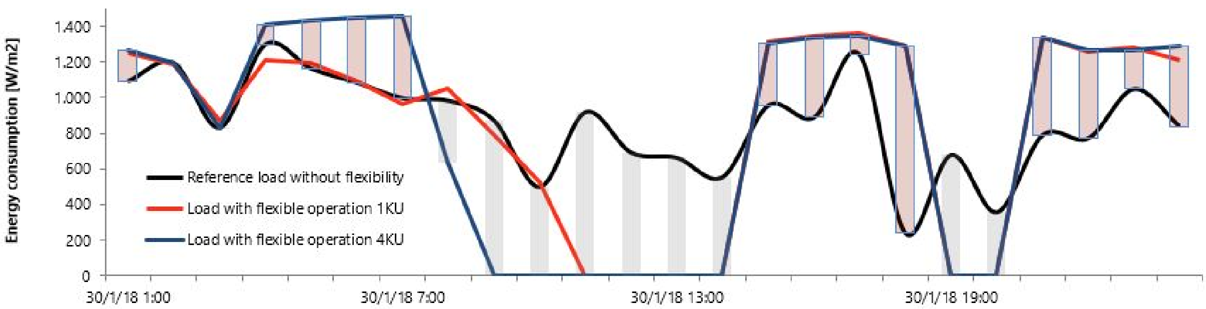

Figure B.7: Shows a high insulated building from CS D's flexibility function on the 30^{th} of January with control strategy 1KU and 4KU

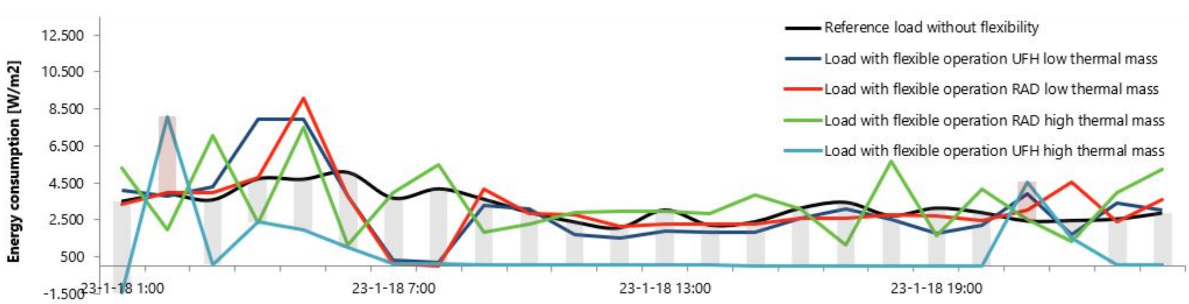

Figure B.8: Shows the flexibility function on the 30^{th} of January for a low insulated building from CS B with low and high thermal mass and radiator and UFH system.

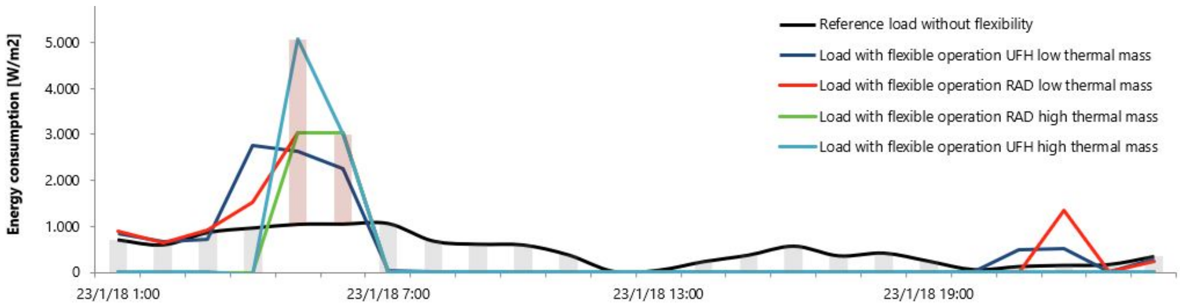

Figure B.9: Shows the flexibility function on the 30^{th} of January for a high insulated building from CS B with low and high thermal mass and radiator and UFH system.