

# CHALMERS



## Uncertainties in energy calculations and their effect upon the results of theoretical specific energy usage

*Master of Science Thesis in the Master's Programme Structural Engineering and  
Building Performance Design*

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CHALMERS UNIVERSITY OF TECHNOLOGY  
Göteborg, Sweden 2010  
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The reference object used in this report, located in Öjersjö Sweden. Photo: Martin Jansson 2010-07-23

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## ABSTRACT

In Sweden forty percent of the total energy usage is connected to the building sector. Decreasing the energy usage in this sector is therefore essential with regards to the greenhouse emissions. A number of rules have been formulated by the Swedish National Board of Housing, Building and Planning (Boverket) to govern the amount of energy that is used for heating, cooling and running buildings. The rules set limitations for the amount of energy used for running buildings, and require that in situ measurements are done within two years after the building has been taken in use to verify that the limits are not exceeded. These regulations raise higher demands for accurate predictions of the energy usage in buildings. A poor prediction would result in large deviation in comparison to the measured value and therefore demand a higher safety margin in the theoretical analysis. The purpose of this master's thesis has been to examine the calculation procedure used in energy analysis in order to estimate the size of the uncertainties concerning specific energy usage. Moreover, the parameters that mostly affect the analysis can be identified and thus clarified where in the calculation process the emphasis must be to provide a more precise result. This was done by going through the calculation procedure step by step and in each part looking at the options available and then analysing the differences between them. The on-going analysis was continuously compared to a residential building, which was provided by NCC Teknik. A literature review has been conducted to clarify the structure of the parameters. The calculation software used were IDA Indoor Climate and Energy 4.0 and VIP-Energy 1.0.

The results show that the deviations in calculated specific energy usage can, depending on the software used in the analysis, reach the magnitude of 30 %. This size of deviation is possible but unlikely to achieve and can be lowered by changing the procedure used, with the means to decrease the likeliness for assumptions made by the single designing engineer. According to our findings, the parameters with the potential to cause the largest deviations are the climate files used, the setting of the indoor temperature and the choice of horizon angle which affects the shading of a building.

Key words: energy use, specific energy usage, thermal bridges, deviations, energy analysis, analysis procedure, building energy analysis software

Osäkerheter i energiberäkningar och deras inverkan på det beräknade resultatet av teoretisk specifik energianvändning

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## SAMMANFATTNING

I Sverige kan fyrtio procent av den totala energianvändningen kopplas till byggsektorn. Att minska energianvändningen i denna sektor är därför viktigt med anledning av utsläppen av växthusgaser. Ett antal regler har formulerats av Boverket för att styra den mängd energi som används för uppvärmning, kylning och drift av byggnader. Reglerna sätter gränser för hur mycket energi som får användas för att hålla en byggnad i drift, och kräver att in situ-mätningar utförs inom två år efter det att byggnaden har tagits i bruk. Detta för att kontrollera att gränsvärdena inte överskrids. Dessa föreskrifter ökar kraven på korrekta prognoser för energianvändningen i byggnader. En bristfällig förutsägelse resulterar i stor avvikelse i förhållande till det uppmätta värdet och därmed sätts krav på en större säkerhetsmarginal i den teoretiska analysen. Syftet med detta arbete är att undersöka det beräkningsförfarande som används i energianalyser för att uppskatta storleken på osäkerheten i den beräknade specifika energiförbrukningen. Syftet innefattar också att identifiera de parametrar som påverkar avvikelsen mest, för att kunna klargöra var i analysprocessen tyngdpunkten måste ligga för att ge ett mer exakt resultat. Detta genomförs genom att gå igenom det förfarande som används vid energianalyser steg för steg och i varje del titta på de alternativ som finns tillhanda, för att kunna klargöra skillnaderna mellan dem. Den pågående analysen kommer kontinuerligt att jämföras med en referensbyggnad, ett tvåfamiljshus som tillhandahålls av NCC Teknik. En litteraturstudie kommer att genomföras för att klargöra uppbyggnaden av parametrarna. Programvara som används är IDA Indoor Climate and Energy 4.0 och VIP-Energy 1.0.

Resultaten visar att avvikelserna i beräknade specifika energianvändningen kan, beroende på den programvara som används för analysen, nå upp till storleksordningen 30 %. Denna storlek på avvikelser är möjlig men inte trolig att uppnå, och kan sänkas genom förändringar i förfarandet, med syftet att minska utrymmet för bedömningar baserade på antaganden gjorda av den enskilda energianalyseraren. De parametrar som har potential att orsaka de största avvikelserna är de klimatfiler som används i programvaran, kravet på minsta inomhustemperatur samt fastställandet av horisontvinkeln, vilken påverkar skuggningen av en byggnad.

Nyckelord: energianvändning, specifik energianvändning, köldbryggor, avvikelser, energianalys, analysförfarande, energiberäkningsprogram

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## Preface

This master's thesis, performed as a part of the Msc programme Structural Engineering and Building Performance design has been conducted at NCC Teknik in Göteborg from March to September 2010.

This project has been carried out after an initiative from Martin Sandberg, NCC Teknik, Göteborg. The company's supervisor of this project has been Christian Johansson. Angela Sasic Kalagasidis at the Department of Civil and Environmental Engineering, Chalmers University of Technology has also been supervising the work.

We would like to thank these people along with the staff at NCC Teknik, Göteborg who have been supportive during the work.

We would also like to express our appreciation to the companies EQUA Simulation AB and StruSoft AB who have provided us with licences for the software IDA Indoor Climate and Energy 4.0 and VIP-Energy 1.0.

Göteborg September 2010

Anders Ljungberg

Martin Jansson

# Notations

## Roman letters

$A$	Area
$A_{temp}$	The floor area inside the building's envelope intended to be heated above 10°C
$c$	Specific heat capacity
$c_{eq}$	Equivalent specific heat capacity
$h_{eq}$	Equivalent height
$K$	Thermal conductance
$L$	Length
$R_{se}$	External thermal surface resistance
$R_{si}$	Internal thermal surface resistance
$R_u$	Thermal resistance for cold attic
$t$	Thickness
$U$	Thermal transmittance
$U_m$	Mean value of the thermal transmittance
$\dot{V}$	Air flow rate

## Greek letters

$\alpha_h$	Horizon angle
$\alpha_{sol}$	Absorptivity for solar radiation
$\varepsilon$	Emissivity of radiation
$\eta_{fan}$	Fan efficiency, the ratio between power transferred to the airflow and the power used by the fan
$\lambda$	Thermal conductivity
$\lambda_{eq}$	Equivalent thermal conductivity
$\rho$	Density

$\rho_{eq}$	Equivalent density
$\tau$	Solar transmittance
$\Psi$	Linear heat transfer coefficient

### **Abbreviations and acronyms**

<i>BBR</i>	Set of rules for building in Sweden. Swedish National Board of Housing, Building and Planning
<i>DHW</i>	Domestic hot water
<i>NCC</i>	Swedish construction company
<i>SFP</i>	Specific fan power
<i>SHGC</i>	Solar heat gain coefficient

# 1 Introduction

## 1.1 Background

With increasing knowledge of the connections between the global warming and the emissions of greenhouse gases, the need for taking measurements towards reducing these emissions is a reality. The European Union has put up as a goal to lower the emissions of the greenhouse gases globally by twenty percent until 2020 and by fifty percent until 2050 in comparison to 1990 years' emissions (EUR-Lex, 2007). In Sweden forty percent of the total energy usage is connected to the building sector (Statens energimyndighet, 2006). Decreasing the energy usage in this sector is therefore essential with regards to the greenhouse emissions. A number of rules have been formulated by the Swedish National Board of Housing, Building and Planning (Boverket), henceforth referred as BBR, to govern the amount of energy that is used for heating and running buildings. The rules set limitations for the amount of energy used for running buildings. They also require that in situ measurements are done within two years after the building has been taken in use to verify that the limits are not exceeded.

These regulations raise higher demands for accurate predictions of the energy usage in buildings. A poor prediction would result in large deviation in comparison to the measured value and therefore demand a higher safety margin in the theoretical analysis.

The rules issued set demands on the final outcome but do not specify any procedures for performing calculations. This leaves room for the single energy analyst to decide how the analysis should be performed. Different choices and approaches during an energy analysis will thus lead to a theoretical distribution of the calculated result. If these fluctuations can be reduced, the need for safety margins will be reduced. This may ultimately result in using e.g. less insulation with regard to the pre-determined energy requirements and thus a cost saving. A more accurate prediction of how the energy usage varies with the choice of materials and design solutions will also lead to the comparison between different solutions being fair and that the choice of solutions is done on a sound basis.

## 1.2 Purpose

The purpose of this master's thesis is to examine the calculation procedure used in energy analysis in order to estimate the size of the uncertainties concerning specific energy usage. Moreover, the parameters that mostly affect the analysis can be identified and thus clarify where in the calculation process the emphasis must be to provide a more precise result.

## 1.3 Method

During the review of the calculation methodology applied when analysing the theoretical specific energy usage, a residential building containing two apartments had been used. During the work, the influential parameters of the analysis were identified and their importance for the outcome clarified. This has been done by going through the calculation procedure step by step and in each part looking at the options available

and then analysing the differences between them. The on-going analysis was continuously compared to the residential building, which was provided by NCC Teknik. A literature review has been conducted to clarify the structure of the parameters. The calculation software used were IDA Indoor Climate and Energy 4.0 and VIP-Energy 1.0.

## **1.4 Limitations**

The scope of this master's thesis concerns the analysis of the theoretical specific energy usage calculated in the design stage of buildings.

## 2 Updating energy calculation standards

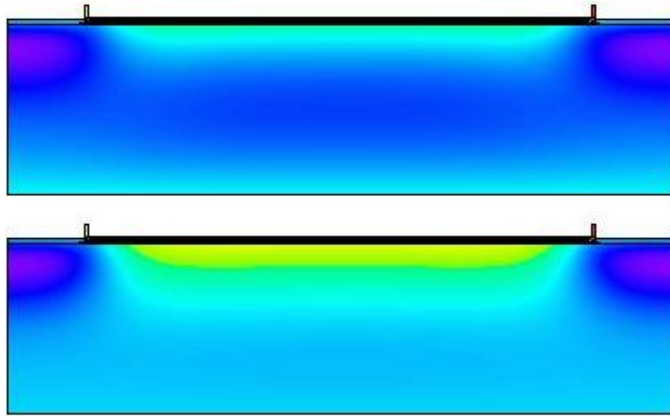
The heating methods used in Sweden in recent years have reflected the availability and prices of the energy forms that have existed. After the oil crisis in the 70's a conversion from the use of oil as a heat source to primarily direct electricity started. Later, after the referendum concerning the Swedish nuclear power in 1980 (Sundström, 1997) the use of electricity for heating the houses was restricted.

The rules concerning energy issues related to buildings have been, as mentioned previously, set up in BBR. This is an administrative authority that is responsible for not only energy issues but also other regulations concerning the built environment. The rules drawn up after the oil crisis in the 70's were set to reduce the energy use. These resulted in demands for limiting the window area and individual building component's insulating capacity (Elmroth, 2009). The rules provided some opportunity to redistribute transmission losses and this redistribution calculation came to be reshaped and finally developed into what is now an average heat transfer coefficient,  $U_m$ , calculated for the whole building.

With greater understanding of energy usage's effect upon the environment, newer rules have been drafted in BBR as well as by the European Union. The EU has adopted Directive 2002/91/EC that, inter alia, urges member states to set minimum energy performance requirements on new buildings and buildings undergoing major renovation. This directive has been set up in the light of increased greenhouse gas emissions and due to that Europe is increasingly more dependent on energy imports (Summaries of EU legislation, 2007).

Sweden has, as a result, set rules for energy certification of buildings and requirements for measuring the annual energy usage in buildings. The measurements are done in order to control the building's specific energy usage [ $\text{kWh/m}^2\text{yr}$ ]. The specific energy usage is defined as the energy used for heating and cooling a building together with the energy used in the ventilation system and the hot water usage distributed over the heated floor area  $A_{\text{temp}}$ .  $A_{\text{temp}}$  is the floor area inside the building's envelope intended to be heated above  $10\text{ }^\circ\text{C}$  (Boverket, 2008).

This measurement should be performed within 2 years after the building is placed in service and is intended to verify the energy performance of buildings (Building and Planning, 2009; Schulz, 2008). The measurement shall, however, not be performed during the first year the building is used. A recently constructed building contains a high rate of moisture that has to exsiccate and during that period the building uses more energy. Larger buildings will also, over time, develop a thermal pillow in the ground underneath the building. The thermal pillow is developed due to heat losses from the building to the ground. When the thermal pillow is developed the heat losses to the ground will decrease, but the effect from the thermal pillow is small during the first year, see Figure 2.1.



*Figure 2.1 A thermal pillow developed in the ground underneath a building's slab after 1 and 2 years respectively. Simulations made in HEAT2.*

These rules have collectively made it necessary to in a greater extent than before formulating standards for energy calculations.

In 2009 a compilation of user input data for housing developed by the construction and property industry was published, *Brukarindata för energiberäkningar i bostäder* (Svebyprogrammet, 2009), which is a set of user input data for energy calculations in dwellings. This compilation of user input data is financed mainly by SBUF, the Swedish Construction Industry Development Fund, and is a part of a larger project with the purpose to set standards for both energy calculations and verifications of measured values in the buildings when constructed and used. The data has been developed using measurements from both villa areas and multi-dwelling buildings for investigating the use of tap water and household electricity usage and also by conducting surveys with the purpose to investigate airing habits. A standardised user has been developed that has a certain amount of presence in a building as well as habits regarding showering, dishing, doing laundry etc. This standardised user is partially based on old behaviour studies and is in need of an update (Svebyprogrammet, 2009). The University of Linköping has during 2008 conducted an investigation regarding dweller habits, which is to be used as base for updating the standardised user along with projects performed by the Swedish Energy Agency. This new data might also include use behaviour regarding computer usage, TV, etc (Svebyprogrammet, 2009). This compilation of user input data, *Brukarindata för energiberäkningar i bostäder*, will henceforth be referred to as *Svebyprogrammet*.

In addition to this standard, several companies including NCC have developed their own procedures for energy calculations. The methods used today still contain many different approaches. It is these procedures this work aims to investigate and test in order to see how they affect the expected outcome in terms of specific energy usage.



### 3 The reference object

In order to perform the investigation a reference object is required. The reference object is provided by NCC Teknik and is the base of the investigation. Changes that the parametric study provides will appear as a percentage difference between the modified object and reference object in the form of specific energy usage. The reference object, a semi-detached house, is located in Öjersjö about 8 km east of Göteborg (see Figure 3.1) and consists of two apartments each divided into two floors and a storage room respectively. The building is positioned so that the living room and patio doors face south, so also the majority of window area.

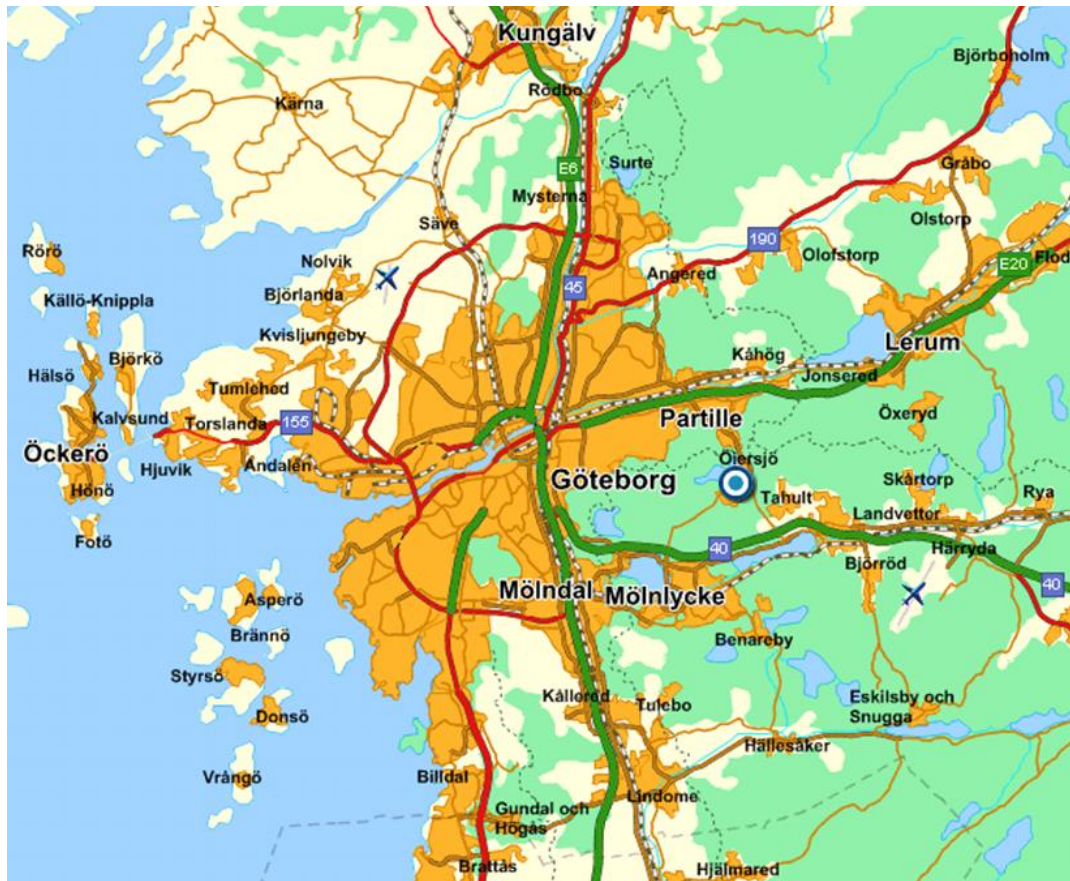


Figure 3.1 Map showing the geographical position of Öjersjö. (Hittapunkt.se AB, 2010)

The apartments are laterally transposed and each have a floor area of  $133.4 \text{ m}^2$ ,  $71.1 \text{ m}^2$  in floor 1,  $62.3 \text{ m}^2$  in floor 2 and storage of  $5.2 \text{ m}^2$ . The storage is placed in the lowest part of Figure 3.2. The building is founded on a drainage layer on top of bedrock. A picture of the building can be found on the front page.

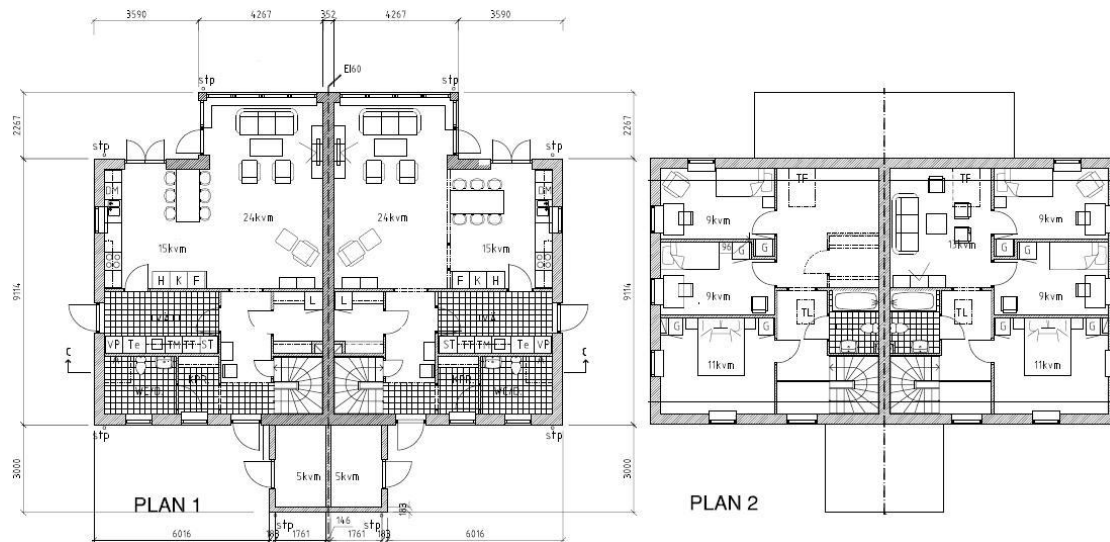


Figure 3.2 Floor plans of reference object. (Wahlström & Steijner arkitekter AB, 2007)

Temperature requirements are 21 °C for the apartments and 10 °C for the storage. Since the specific energy usage is calculated using the heated floor area  $A_{temp}$  and the temperature in the storage area does not exceed 10 °C, the storage area is not included.  $A_{temp}$  thus becomes 266.8 m<sup>2</sup> (Boverket, 2008).

## 4 The software used in the analysis

In order to perform the parametric study the reference object has to be created in software capable to execute energy calculations. Two different software will be used for the parametric study, IDA Indoor Climate and Energy 4.0, henceforth referred to as IDA ICE, made by EQUA Simulation AB and VIP-Energy 1.0, henceforth referred to as VIP-E, made by StruSoft AB.

IDA ICE is used for calculating the energy usage as well as thermal indoor climate for buildings by using a dynamic multi-zone simulation.

IDA ICE uses a geometrically model of a building in 3-dimensions. The model has a compass which can be rotated to choose the cardinal directions. Also, nearby buildings and other objects which shadow the building can be constructed. Walls, roof, doors and slab are described having both heat capacity and thermal conductivity. Windows can be placed geometrically in the exterior walls and are described having a U-value, solar heat gain coefficient (SHGC), solar transmittance ( $\tau$ ), internal and external emissivity ( $\epsilon$ ) and a frame percentage.

Once a geometrical model is created the house can be divided into different zones. The zones allow different temperature set-points, internal loads and different airflows, all with time-schedules, so that the buildings different demands can be taken into account.

The indoor climate and thereby the needed energy to heat the building, due to the requirements set, is affected by outdoor climate, as well as the geographical position of the building, the indoor heat loads and need for ventilation. To simulate a building's energy need IDA ICE uses climate files from different locations that can be chosen by the user. This climate data consists of:

- Dry bulb temperature
- Relative humidity of air
- Wind direction
- Wind speed
- Direct solar radiation
- Diffuse radiation

Added to this information is the location of the collected climate data expressed in longitudinal and latitudinal direction, together with the height above the sea. The time step used in the climate data is one hour.

VIP-E is used for calculating the energy usage and indoor temperature for buildings. When modelling a building in VIP-E, construction areas with different cardinal directions are used. It is the choice of cardinal directions of each area that describe how the building is rotated geographically. In order to consider nearby buildings and other object that may shadow the model, horizon lines are specified around the building. The areas are defined as different construction parts such as walls, roof and slab. They are described having both heat capacity and thermal conductivity. Doors are having a U-value, and so do windows along with the SHGC,  $\tau$  and a frame rate percentage.

To take care of the building's demands of different temperature set-points and internal loads, several zones may be needed. Zones are created using different files, one for

each zone, which are connected together by defining the construction area between them.

In order to predict the indoor temperature and the energy need, statistic weather data from different locations is used. This data includes:

- Dry bulb temperature
- Relative humidity of air
- Wind speed
- Solar radiation
- Longitudinal and latitudinal direction

Some weather data also includes measured wind direction. When the wind direction is not measured VIP-E use the wind speed together with a manually chosen locked wind direction. The time step used in this climate data is one hour.

Some calculations have to be made throughout the procedure of the thesis and they are conducted in the mathematical calculation tool Mathcad produced by Parametric Technology Corporation.

Area-measurements done in the reference building have been made using the software AutoCAD created by Autodesk and also using Adobe Acrobat 8 Professional created by Adobe Systems Inc.

The thermal bridges in the reference building have been analysed using the software HEAT2 created by Blocon. HEAT2 is software used for analysing two-dimensional steady-state and transient heat transfer.

## 5 Modelling the reference object

Once the reference object is selected it has to be transformed into a model that can be used and analysed in the mentioned software. The following sections will describe how the reference building is adapted and modelled in IDA ICE and VIP-E.

### 5.1 Geometry

The reference object's geometry, including pitched roof has to be adapted to the two software used and some simplifications are needed to implement for the simulation to work smoothly.

#### 5.1.1 Equivalent building height

The building is constructed using a pitched roof, which is more time-consuming to construct than a flat roof in IDA ICE. The reference building is therefore modelled as a box using a flat roof. In order to do that an equivalent height  $h_{eq,b}$  [m] has to be calculated. This is done by setting the envelope area equal for the two cases. The measurements have been made in the software AutoCAD using the inner walls dimensions. The storage and part of the first floor going outside of the main construction have been disregarded when summing up this area see, Figure 5.1.

The calculation to get  $h_{eq,b}$  is done by using equal envelope area, see Figure 5.1. The same procedure is used when calculating the equivalent height  $h_{eq,s}$  [m] for the storage. The equivalent height could also be calculated using the inner volume of the building. When choosing whether to use the envelope area or the inner volume of the building for calculating the equivalent height the different effects of the alternatives have to be weighed against each other. The envelope area has a huge effect upon the heat loss and heat gain of the building. The inner volume is connected to certain needs and demands for ventilation, but these demands are often expressed in terms of litres per square meter [ $l/m^2$ ] which is not affected when changing the inner volume. Therefore the envelope area is used when calculating the equivalent height.

VIP-E uses the exterior envelope areas and these areas are measured in AutoCAD. The equivalent height is used in VIP-E as well. The building areas used for creating the reference object in VIP-E are calculated using the exterior measures of the building. To get the proper building height the roof thickness of 0.483 m is therefore added.

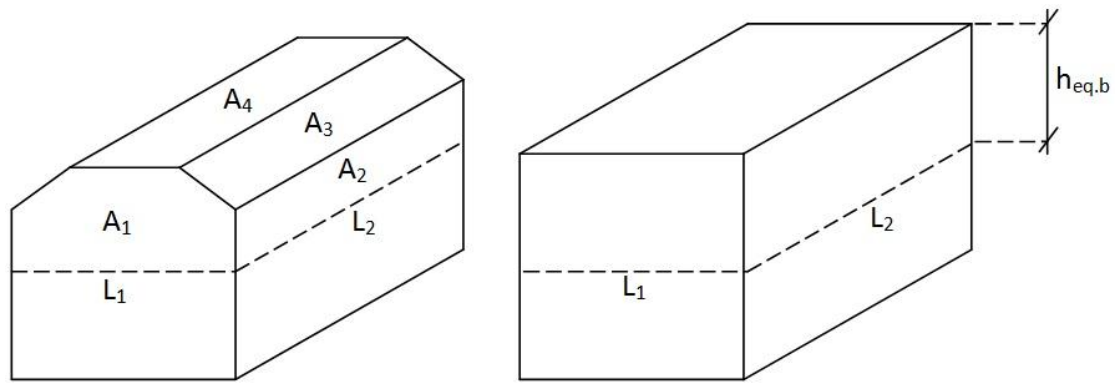


Figure 5.1 Describing the equivalent height  $h_{eq,b}$  [m] for the reference object.

The calculations for  $h_{eq,b}$  (the equivalent building's second floor height) and  $h_{eq,s}$  (the equivalent storage height) are shown in Annex A: Calculation of reference object and the result is:

$$h_{eq,b} = 1.827 \text{ m} \quad (5.1)$$

$$h_{eq,s} = 2.603 \text{ m} \quad (5.2)$$

Adding the thickness of the roof gives the equivalent second floor height used for creating the reference object in VIP-E:

$$h_{eq,v.b} = 2.31 \text{ m} \quad (5.3)$$

### 5.1.2 Envelope area and geometry

IDA ICE and VIP-E work in different ways regarding the geometry of a building. In VIP-E the exterior areas for all the different building parts, (e.g. roof, walls, windows), in every cardinal direction is set by the software user. In IDA ICE the geometry is handled in a 2-axis coordinate system and then heights are added to the coordinate system, thereby creating a 3D-model of the building. In order to get the right dimensions and orientation of windows and doors, and the areas of the different building parts into the software, measurements have been made in AutoCAD to gather all relevant information. The symmetry between the two apartments give that every wall appears two times with one laterally transposed the other. The geometry and summation of areas used in VIP –E and IDA ICE can be seen in Annex B: Geometry and areas of the reference object

The reference building has three different types of windows installed. One operable window; one type that is fixed and finally one glass door with the same properties as a window. The total window perimeter of the reference building is measured in AutoCAD and then three different types of windows are used in order to affirm the real frame percentage. The windows data used to establish the real frame rate is obtained from Elitfönster AB (2010). The frames used in these windows have the frame width of 100 mm when used in the operable windows and the glass doors and a width of 50 mm when used on the fixed windows. Of all the windows in the building, including the glass doors, 20 are assumed to be operable. Using these figures together with the total window area the frame rate is calculated. The result is:

$$A_{tot.frame}/A_{tot.window} = 25.4 \% \quad (5.4)$$

The portion of frame area in the windows is calculated in Annex A: Calculation of reference object. This frame rate is used in both VIP-E and IDA ICE.

## 5.2 Heat loads and losses

A buildings need of heating is affected of both internal and external loads along with the demands set on the indoor climate. When modelling the reference building the new standards in Svebyprogrammet (2009) have been used along with rules concerning minimum ventilation (Enberg, 2006), standards formulated by NCC Teknik that are adapted to rules set in BBR and the Swedish Standard Institute.

Moreover, when simulating the reference building in IDA ICE climate data from Säve, Göteborg 1977 is used in order to calculate the needed energy to heat the building. VIP-E uses a synthesis of climate data gathered in 1993-2003 (Structural Design Software, 2009). When simulating the reference object climate data from Göteborg is used.

The reference object consists of two apartments each containing two floors. In VIP-E two zones are used to construct the reference building; the residential part of the building and the storage. The areas gathered in Annex B: Geometry and areas of the reference object are used to define the two zones. In IDA ICE each apartment is divided into four different zones (see Figure 5.2). The building is positioned with the front doors towards north. The zones are divided by internal walls and a joist internal floor and is analysed separately in the simulation.

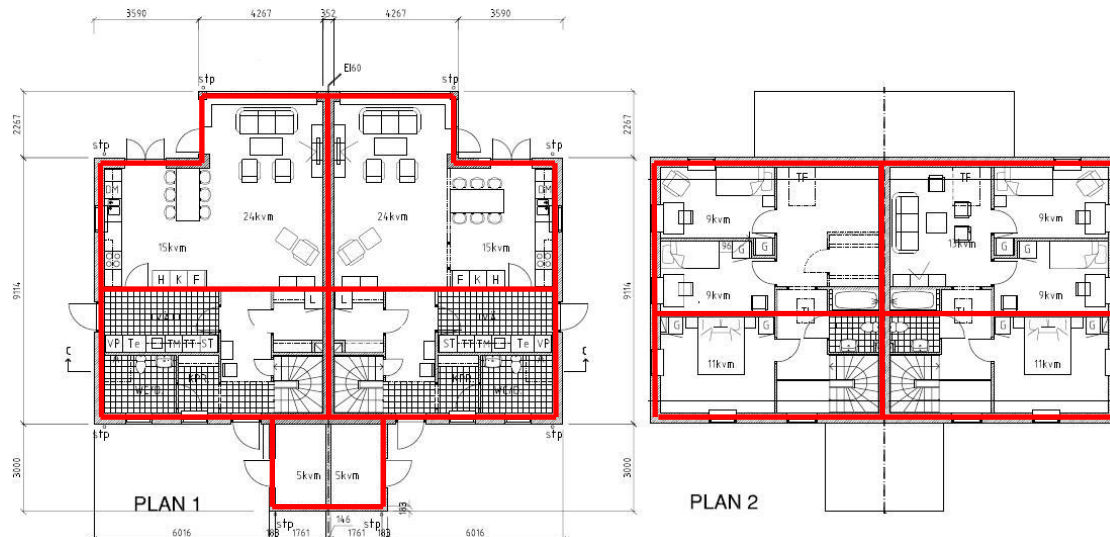


Figure 5.2 Dividing the reference object into climate zones in IDA ICE.

The zones allow different temperatures, internal loads and ventilation rates to be set in the building. By using zones, different temperatures within the building caused by the outdoor climate and the indoor prerequisites, can occur during a simulation. The temperature in the building might therefore reach more extreme values than when using one zone.

The following sections describe how the different indoor parameters are calculated in order to be used in the simulation of the reference object.

### 5.2.1 Ventilation

The needed ventilation rate is calculated as a summation of the demands regarding exhaust and supply air (Enberg, H. 2006). The calculation is shown in Annex A: Calculation of reference object.

Table 5.1 Data for summation of supply air needed for one apartment.

General regulation for dwelling houses	0.35 l/(s × m <sup>2</sup> )
Extra demand for bedroom	4 l/(s × person)
Number of people in apartment	4 persons
Floor area, one apartment excl. storage	A <sub>temp</sub> = 133.42 m <sup>2</sup>

The summation of the supply air needed for both apartments becomes:

$$\dot{V}_{supply} = 125.4 \text{ l/s} \quad (5.5)$$

Table 5.2 Data for summation of exhaust air needed for one apartment.

Kitchen	10 l/s
Bathroom with operable window	10 l/s
Bathroom without operable window	15 l/s
Wash-house	10 l/s

The summation of the exhaust air needed for both apartments becomes:

$$\dot{V}_{exhaust} = 90 \text{ l/s} \quad (5.6)$$

The building is equipped with an mechanical exhaust air system with heat recovery connected to the hot tap water and using passive supply air through vents. The designing air exchange rate is the supply air and can be seen above. This is the minimum flow rate and in accordance with NCC Teknik the design value is raised to:

$$\dot{V} = 150 \text{ l/s} \quad (5.7)$$

or

$$\dot{V} = 0.562 \text{ l/(s × m}^2\text{)} \quad (5.8)$$



This is done to provide the installers of the ventilation system with a safety margin and still ensure minimum demand for air exchange rate. The value in equation 5.8 is used in IDA ICE and VIP-E.

In order to model the exhaust air handling unit in the two software the default air handling unit (exhaust-supply) is changed by adjusting the pressure rise over the fans so that the SFP-value becomes  $1.0 \text{ kW}/(\text{m}^3\text{s})$  (demand for an exhaust air system with heat recovery according to Boverket, 2008). All other units in the ventilation system as heaters etc. are turned off. The supply air flow rate is decreased with 10 % in comparison with the exhaust air flow rate in order to ensure underpressure. Otherwise the cold supply air will expand due to temperature increase inside the building causing overpressure. The fan energy efficiency  $\eta_{\text{fan}}$ , electricity to air, is set to 0.6 according to NCC, 2010.

### 5.2.2 Infiltration and airing

Infiltration caused by wind or differences in air pressure can arise due to leakage in the climate shell. There are no quantitative demands for buildings larger than  $100 \text{ m}^2$  ( $A_{\text{Temp}}$ ). Instead, according to Boverket (2008), the building envelope has to be tight enough to ensure fulfilment of the requirements of the building's specific energy usage and installed electric output used for heating. NCC (2009) recommends an air infiltration flow rate of  $0.6 \text{ l}/(\text{m}^2\text{s})$  at a pressure difference of 50 Pa between indoor and outdoor climate to be used as designing value. This is done in VIP-E. In addition a template value of  $4 \text{ kWh}/(\text{m}^2\text{yr})$  should be added to the result to make up for used heating energy caused by airing. This is done in the reference object in both software. The air infiltration flow rate shall be divided by 40 when used as a fixed infiltration in an exhaust air system which is done in IDA ICE. This is done to obtain a value of current air leakage during normal use of the building. When used in an exhaust-supply air ventilation system the air infiltration flow rate shall be divided by 20 due to the same reason (Elmroth, 2009).

### 5.2.3 Occupants

The number of occupants in a building containing five rooms and kitchen is set to 3.51 and each occupant emits a heat effect of 80 W. The occupants are present in the building 14 hours per day (Svebyprogrammet, 2009). The occupants are distributed evenly in the building using the heated area  $A_{\text{temp}}$ . The result is:

$$0.02631 \text{ occupants}/\text{m}^2 \quad (5.9)$$

Since the occupants are present only 14 hours per day their presence is distributed evenly over one day as 58% of their total number. The calculations are shown in Annex A: Calculation of reference object.

### 5.2.4 Equipment

Energy used in a household for domestic purposes such as electricity used for running e.g. refrigerators, stoves and lighting is not included when calculating the specific energy usage. However a certain amount of this energy can be included in the internal heat loads, thereby reducing the need for heating. According to Svebyprogrammet

(2009) the template value to be used when calculating this heat gain is an energy usage of 30 kWh/m<sup>2</sup> (A<sub>Temp</sub>) and year. Of this energy usage 70% is assumed to assimilate as an internal heat gain. The calculation is shown in Annex A: Calculation of reference object. This results in an internal heat gain of:

$$2.396 \text{ W/m}^2 \quad (5.10)$$

### 5.2.5 Hot water usage

A great part of the energy used in a domestic building is for the heating of DHW. The DHW usage depends on the amount of users and their habits along with the types of armatures being used and the time it takes for the hot water to reach the water faucet. Therefore a value with a certain safety margin has to be used when calculating the effect upon the specific energy usage with regards taken to this energy.

Svebyprogrammet (2009) recommends a template value of 25 kWh/m<sup>2</sup> (A<sub>Temp</sub>) and year and asserts that 20% of this energy can be accounted for as an internal heating source, but mentions that further investigation of this percentage is needed. This 20% is not used in the reference building in accordance with NCC (2009).

## 5.3 Thermal transmittance and heat capacity

The indoor climate in buildings highly relates to the building's envelope and therefore material properties of the construction have a big impact upon the energy usage in buildings. Heat can be stored in the building's envelope, a property that is related to the used material's density  $\rho$  [kg/m<sup>3</sup>] and specific heat capacity  $c$  [J/(kgK)]. When differences in temperature occur between the indoor and outdoor climate, heat is transmitted through the envelope. The heat transfer is affected by the thickness  $t$  [m] of the envelope and the thermal conductivity  $\lambda$  [W/(mK)] of the materials used. A thicker construction and using materials with high heat capacity and low thermal conductivity leads to a decrease in heat transfer. Combining the thermal conductivity and the thickness will give the thermal transmittance of the concerned construction part:

$$U = \frac{\lambda}{t} \left[ \frac{W}{m^2K} \right] \quad (5.11)$$

In order to get the right U-value (thermal transmittance) and heat capacity in the software each layer in all constructions has to be defined using thickness  $t$ , thermal conductivity  $\lambda$ , density  $\rho$  and the specific heat capacity  $c$ . For some layers e.g. insulation with wooden joists equivalent values for  $\lambda$ ,  $\rho$  and  $c$  has to be used. Both software automatically set the internal and external thermal surface resistance  $R_{si}$  and  $R_{se}$  to 0.13 m<sup>2</sup>K/W and 0.04 m<sup>2</sup>K/W respectively. VIP-E use an absorptivity for solar radiation  $\alpha_{sol}$  [-] which depends upon the colour of the surface the shortwave radiation hits. Dark surfaces can have  $\alpha_{sol}$  of 0.9 and light surfaces  $\alpha_{sol}$  of 0.5 (Pettersson, 2004). All construction parts except for the windows and doors in VIP-E are set to have  $\alpha_{sol}$  of 0.7 according to NCC, 2010.

References for all material data can be found in Annex C: References for material data.

### 5.3.1 Walls

For exterior walls with an air gap ambient climate is assumed in the gap due to the air layers being well-ventilated i.e. the air gap and the outer layers are disregarded (Swedish standards institute, 2008).

#### 5.3.1.1 Exterior wall

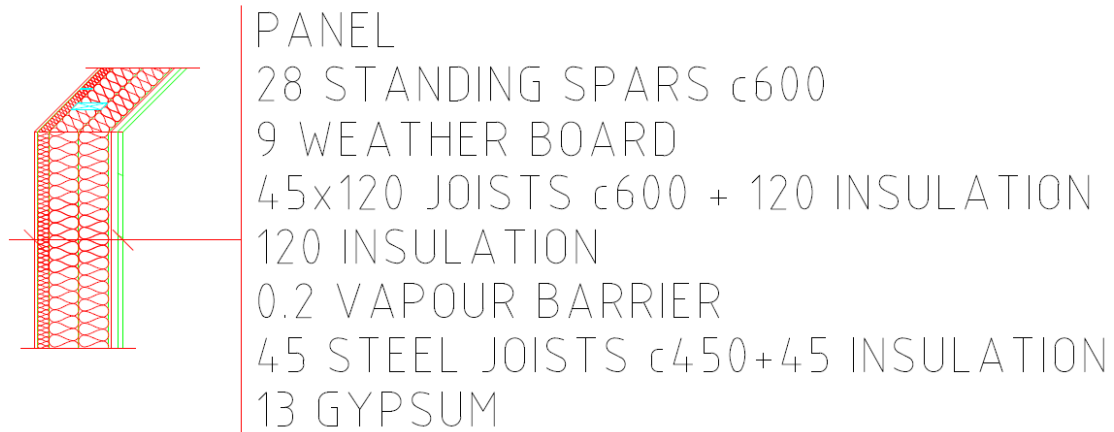


Figure 5.3 Construction of exterior wall.

The construction of the exterior wall is shown in Figure 5.3. The panel, standing spars and the air gap are disregarded due to the air gap being well-ventilated. For the insulation layers with steel joists and wooden joists equivalent values for  $\lambda$ ,  $\rho$  and  $c$  has to be calculated. This is done by weighting the material properties for one c-distance, in this case 450 mm and 600 mm respectively.

Table 5.3 Material properties.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
Insulation	0.036	20	750
Wood	0.14	500	1500
Steel	60	7800	500
Gypsum	0.22	850	800
Weather board	0.22	800	800

The weighting of the two layers is done in the software Mathcad (Annex A: Calculation of reference object) and the results are shown in Table 5.4.

Table 5.4 Equivalent material properties for the exterior wall.

	$\lambda_{eq}$ [W/(mK)]	$\rho_{eq}$ [kg/m <sup>3</sup> ]	$c_{eq}$ [J/(kgK)]
Insulation + wooden joists c600	0.044	56	806.25
Insulation + steel joists c450	0.111	29.7	749.69

### 5.3.1.2 Interior wall between apartments

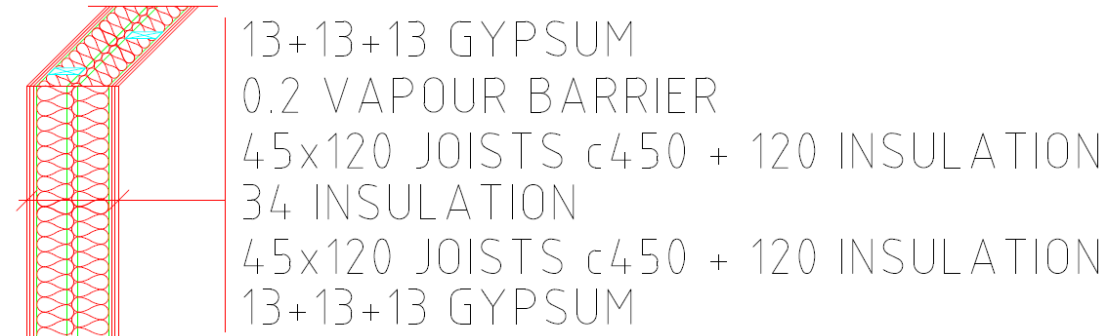


Figure 5.4 Construction of interior wall between apartments.

The construction of the interior wall between the apartments is shown in Figure 5.4. For the insulation layers with wooden joists equivalent values for  $\lambda$ ,  $\rho$  and  $c$  has to be calculated. This is done by weighting the material properties for one c-distance, in this case 450 mm for both layers. The material properties are shown in Table 5.3. The weighting of the two layers is done in the software Mathcad (Annex A: Calculation of reference object) and the results are shown in Table 5.5.

Table 5.5 Equivalent material properties for the interior wall between apartments.

	$\lambda_{eq}$ [W/(mK)]	$\rho_{eq}$ [kg/m <sup>3</sup> ]	$c_{eq}$ [J/(kgK)]
Insulation + wooden joists c450	0.046	68	825

### 5.3.1.3 Interior wall



Figure 5.5 Construction of interior wall.

The construction of the interior wall is shown in Figure 5.5. The wooden joists are disregarded because the construction part's small influence upon the final calculated

result due to no temperature difference over the wall. The air gap is treated according to Swedish standards institute (2008), see Table 5.6. Material properties for the gypsum board are shown in Table 5.3.

Table 5.6 Material properties for a 70 mm air gap.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
70 mm air gap	0.39	1.2	1000

### 5.3.1.4 Exterior wall for storage

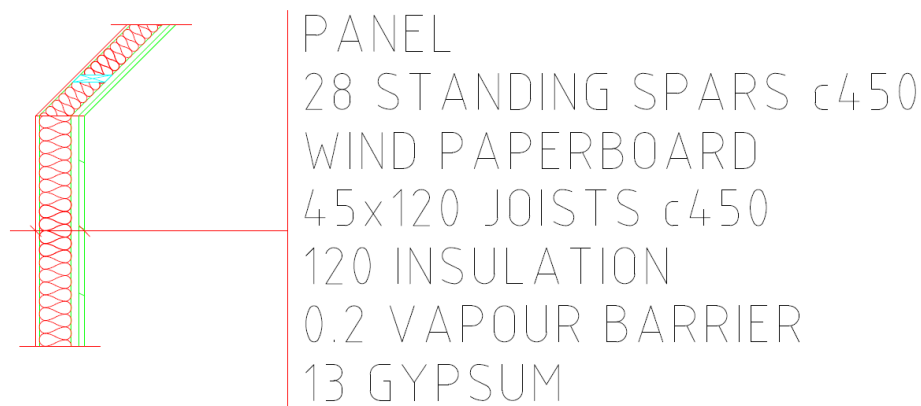


Figure 5.6 Construction of exterior wall for storage.

The construction of the exterior wall for the storage is shown in Figure 5.6. The panel, standing spars and the air gap are disregarded due to the air gap being well-ventilated. The wind paperboard is also disregarded due to no thermal insulation capacity. For the insulation layers with wooden joists equivalent values for  $\lambda$ ,  $\rho$  and  $c$  has to be calculated. This is done by weighting the material properties for one c-distance, in this case 450 mm for both layers, see Table 5.5. Material properties for the gypsum board are shown in Table 5.3.

### 5.3.2 Windows and doors

A window's ability to let in solar radiation can help reduce energy used for heating. Solar radiation can pass through a window as both direct or diffuse radiation, diffuse radiation being the radiation that is reflected on the surroundings (ground, sky, etc.) and then hitting the window. Only a fraction of the sunlight that hits a window passes straight through. The rest of the radiation is either reflected or absorbed by the window and then transferred to the building in the form of convection or long-wave radiation. The solar heat gain coefficient, called SHGC or  $g$ , [-] includes both the radiation absorbed by the window and the radiation that passes through and becomes heat. Radiation reflected on the surface is excluded. The windows used in the reference object in IDA ICE and VIP-E have a SHGC-value of 0.67.

The solar transmittance, sometimes referred to as  $T$  or  $\tau$  [-], is the proportion of radiation directly entering the building through the window. In the reference object the solar transmittance is set to 0.58. The solar heat gain and the solar transmittance are affected by the solar radiation incident angle and the software take this into

account. Both software use a frame rate which reduces the direct radiation. The frame rate is described in Section 5.1.2. The U-value of the windows is set to 1.1 W/m<sup>2</sup>K.

In IDA ICE the outer and inner emissivity of the windows also has to be defined. Emissivity defines a material's ability to emit energy by radiation, and is expressed as a ratio between the specific material and a black body. A black body has the emissivity  $\varepsilon$  of 1, and any other material has  $\varepsilon < 1$ . The emissivity is used for calculating the long wave radiation exchange between surfaces. The windows used in the reference object have an emissivity of 0.837. (Hagentoft 2001 & Petersson 2004)

The doors in the reference object are modelled as two types. Three of the five doors used for one apartment including storage are modelled using a U-value of 1 W/m<sup>2</sup>K. The two remaining doors are modelled using the same material properties as the windows. The properties of the windows are compiled in Table 5.7.

Table 5.7 Window material properties

SHGC [-]	$\tau$ [-]	$\varepsilon$ [-]	$U$ [W/m <sup>2</sup> K]
0.67	0.58	0.837	1.1

SHGC and  $\tau$  in Table 5.7 are later to be changed due to shading of the windows. This procedure along with the values that are finally used when modelling the reference object is explained in Section 5.5.

### 5.3.3 Roof

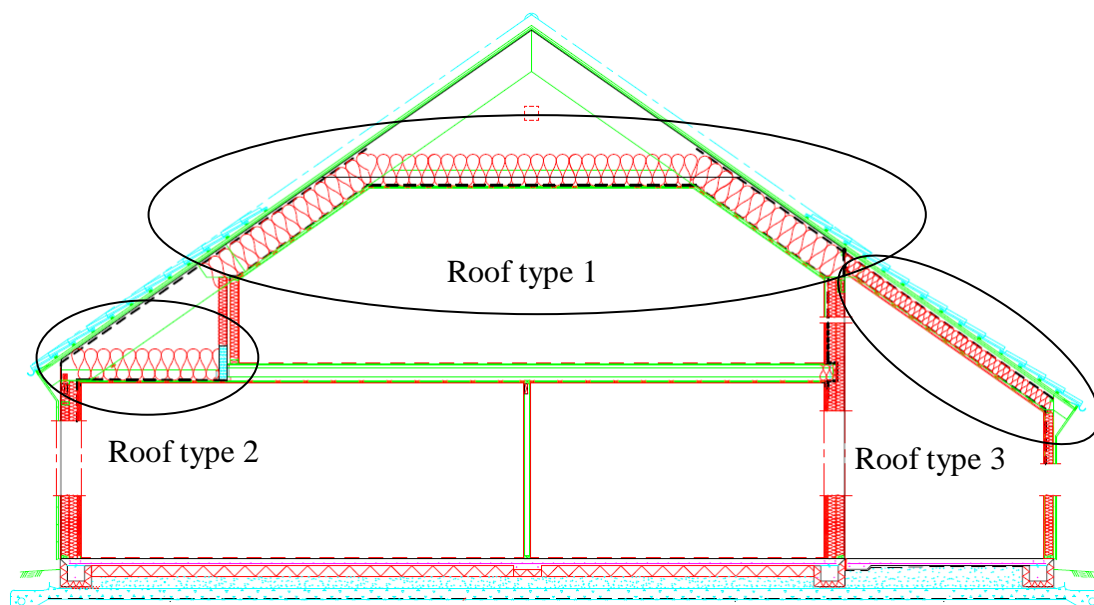


Figure 5.7 Construction of exterior roof.

The actual design of the exterior roof of the reference object involves a few different types of construction as can be seen in Figure 5.7. Roof type 1 is constructed using a 470 mm insulation layer. Above the middle part of roof type 1 there is an attic. Roof type 2 is insulated using a 400 mm insulation layer. The storage roof, roof type 3, is constructed using a 200 mm insulation layer. In all insulation layers there are roof

trusses with a cc-distance of 1200 mm which results in having equivalent values for  $\lambda$ ,  $\rho$  and  $c$ .

The actual exterior roof is constructed using tiles, wind stopper and a board with air gaps. According to Swedish standards institute (2008) a roof structure consisting of a flat insulated ceiling and a pitched roof lined with boards and felt may be regarded as a thermally homogenous layer with a thermal resistance of:

$$R_u = 0.3 \frac{m^2 K}{W} \quad (5.12)$$

This thermal resistance is included in the roof type 2 but disregarded in roof type 1 since only parts of that roof include an attic and adding the resistance  $R_u$  will only affect the insulation capacity a small amount in comparison to the 470 mm insulation.

The roof can be regarded as provided with a well-ventilated air layer, and therefore the air gap and the layers between the air gap and the external environment shall be disregarded when calculating the thermal resistance of the building component (Swedish standards institute, 2008).

The roof is modelled with an insulation layer with roof trusses and a gypsum board beneath. The equivalent values for  $\lambda$ ,  $\rho$  and  $c$  are shown in Table 5.8 and calculated in Annex A: Calculation of reference object. These values are valid for all roof types in Figure 5.7. Material properties for the gypsum board are shown in Table 5.3.

Table 5.8 Equivalent material properties for the roof.

	$\lambda_{eq}$ [W/(mK)]	$\rho_{eq}$ [kg/m <sup>3</sup> ]	$c_{eq}$ [J/(kgK)]
Insulation + roof trusses c1200	0.046	44.738	826.25

### 5.3.4 Floor

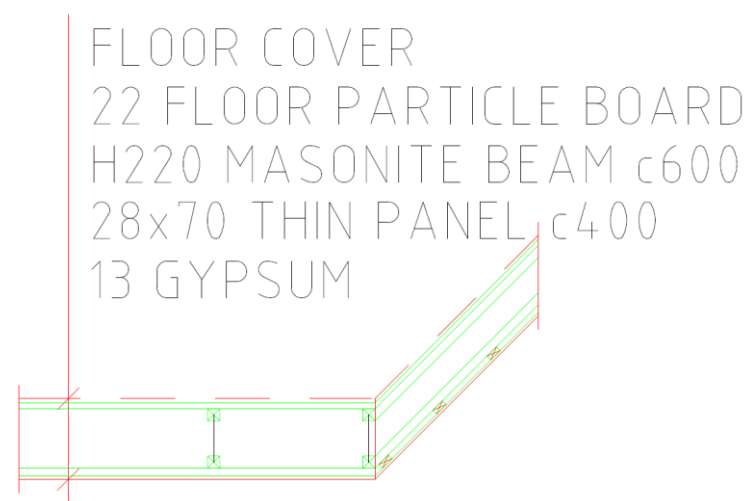


Figure 5.8 Construction of the floor.

The construction of the internal floor is shown in Figure 5.8. The masonite beams and the layer with thin panel are disregarded because the construction part's small

influence upon the final calculated result due to no temperature difference over the floor structure. The air gap in between the masonite beams is treated according to Swedish standards institute (2008). Material properties for the air gap and the particle board are shown in Table 5.9 and material properties for the gypsum board are shown in Table 5.3.

Table 5.9 Material properties for floor cover, 220 mm air gap and particle board.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
Floor cover	0.18	1100	920
220 mm air gap	1.375	1.2	1000
Particle board	0.14	600	-

### 5.3.5 Slab and ground

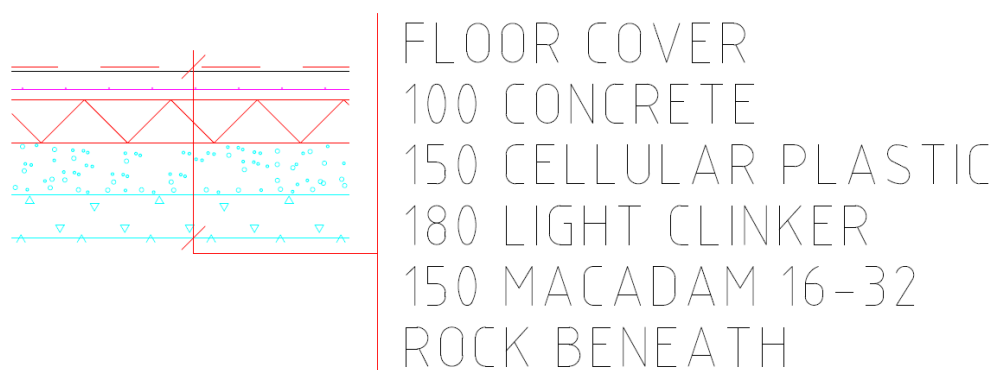


Figure 5.9 Construction of the exterior slab.

The construction of the external slab on the ground and the materials in the ground are shown in Figure 5.9. In IDA ICE the bottom layer of the ground is automatically set to 0.5 m depth by the software regardless of chosen depth. The material sequence and properties are shown in Table 5.10 except for the floor cover which is shown in Table 5.9.

In VIP-E a number of different ground materials can be chosen. The reference object is simulated using rock as ground with  $\lambda$ -value according to Table 5.10. The ground material alternatives are predefined and cannot be changed, thus the ground properties in VIP-E do not include macadam and light clinker.



Table 5.10 Material properties for the slab and the ground.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
Concrete	1.7	2300	880
Cellular plastic	0.037	20	-
Light clinker	0.13	330	900
Macadam	2	770	-
Rock	3.5	2500	800

## 5.4 Thermal bridges

A thermal bridge is a local difference in a homogenous building envelope which leads to increasing heat flow. Thermal bridges normally occur around connections between different building parts such as a window and a wall or a slab and a wall (Pettersson, 2004). In order to more precisely predict the insulation capability of a building envelope the thermal bridges have to be taken into consideration. That can be done in different ways. One way is to reduce the total insulation capacity of the building envelope by increasing the thermal transmittance  $U$  [W/(m<sup>2</sup>K)] for all or some parts of the building a certain amount and thereby enclose the thermal bridges. However to ascertain a more exact calculation of the influence of thermal bridges, each type of thermal bridge that might occur has to be investigated. For the reference building in Öjersjö a couple of different thermal bridges have been analysed.

The thermal bridges that are used when modelling the reference building are calculated in the software HEAT2. Each thermal bridge is calculated by first modelling the construction's part of interest including the thermal bridge and then excluding the thermal bridge. The difference between the two results is then considered to be the influence of the thermal bridge. The final result is given as a linear heat transfer coefficient  $\Psi$  [W/(mK)]. These heat transfer coefficients are calculated for the connections between

- External wall - Internal slab
- External wall – Internal wall
- External wall -External wall
- External windows perimeter
- External doors perimeter
- Roof- External walls
- External slab - External wall

Figure 5.10 shows the difference with and without the thermal bridge when modelling the connection between the external slab and the external walls in HEAT2.

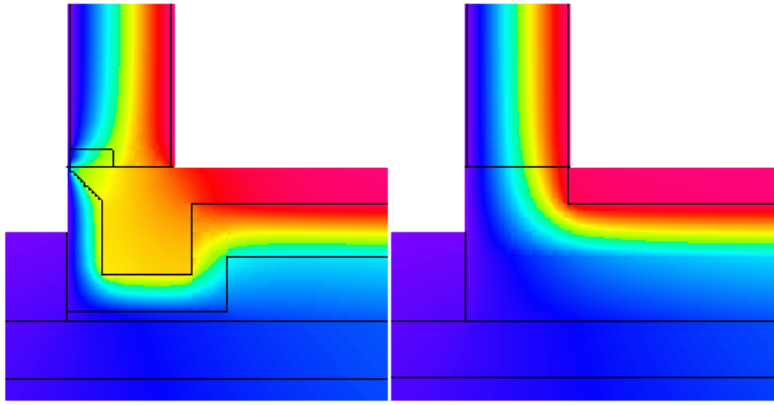


Figure 5.10 Thermal bridge for the connection external wall – external slab.

When analysing the thermal bridges in HEAT2 the indoor temperature is set to 21 °C and the ambient temperature including the ground temperature is set to 8 °C. In order to create a one-dimensional heat flow around the thermal bridge, the created model uses a ground depth and width of at least 8 meters to get below the periodic temperature penetration depth caused by the outdoor climate. The construction is elongated in each direction to assure that the heat flow is not affected by the boundary conditions used in the simulation in HEAT2.

The reference building in the software IDA ICE is constructed using two different internal wall types. One wall type is used to separate the apartments, and one wall type is used to create zones inside the building. The first wall mentioned will work as a thermal bridge since it affects the structure of the exterior wall. The second wall type is not to be regarded as a thermal bridge since this wall construction does not penetrate the exterior wall. IDA ICE will regard this wall type as a thermal bridge by default. To get around that the lengths of the thermal bridges constituted by the walls are summed up and then the percentage of the interior walls are subtracted from the linear heat transfer coefficient  $\Psi$  used for the connection between external walls and internal walls. As a result the calculated heat transfer coefficient shall therefore be multiplied with the factor 0.4156 before used in IDA ICE. All calculations can be seen in Annex A: Calculation of reference object.

The connections between walls and windows, and walls and doors are assumed to cause the same thermal bridge and the same values are therefore used in these connections. The final result of the calculated thermal bridges follows in Table 5.11 and these values are used in IDA ICE.

Table 5.11 Linear heat transfer coefficients for thermal bridges.

	$\Psi$ [W/(mK)]
External wall - Internal slab	0.0058
External wall – Internal wall	0.00233 <sup>1)</sup> 0.005606 <sup>2)</sup>
External wall - External wall	0.001
External windows and door perimeter	0.0364
Roof - External walls	0.0125
External slab - External walls	0.196

<sup>1)</sup> Value used in IDA ICE.

<sup>2)</sup> Value used in VIP-E.

In order to transfer the calculated thermal bridges from HEAT2 to VIP-E the length of each type of thermal bridge is multiplied with the linear heat transfer coefficient  $\Psi$  of that very thermal bridge. This results in a thermal conductance  $K$  [W/K] representing each thermal bridge in construction.

These thermal conductances are then summoned together resulting in one total thermal conductance representing all thermal bridges in the building. The value is divided with the envelope area of the reference building giving a U-value of 0.04444 W/(m<sup>2</sup>K). This U-value is then used as an extra thermal conductance in the construction parts in VIP-E when constructing the reference object.

## 5.5 Shading

The shading of a building has a big impact upon the energy used for heating and cooling the building. Shading can be either external, e.g. surrounding buildings or window recess, or internal as e.g. blinds. The shading is also dependent upon the solar incident angle and building habitants; their use of e.g. blinds during the day will affect the solar radiation into the building. It is of importance not to overestimate the internal heat gain caused by the solar radiation in buildings with no cooling demand, but also difficult to set up standards that can be used generally when calculating the shading of a building. Svebyprogrammet uses two screening factors for reducing the internal solar radiation heat gain; one represents the behaviour controlled shading and one represents the fixed shading. These screening factors are multiplied into a total screening factor which then is used to reduce the solar radiation heat gain. The screening factors can be seen in Table 5.12.

Table 5.12 Screening factors (Svebyprogrammet, 2009).

Fixed screening	Behaviour controlled screening	Total screening
0.71	0.71	0.5

This total screening factor is multiplied with the solar heat gain coefficient and the solar transmittance of the windows used in the reference object. The new values are shown in Table 5.13.

Table 5.13 Window properties used in reference object

SHGC [-]	$\tau$ [-]	$\varepsilon$ [-]	U [W/m <sup>2</sup> K]
0.335	0.29	0.837	1.1

In VIP-E a horizon angle  $\alpha_h$  has to be defined. The horizon angle is measured from half the building's height to the top of the surrounding horizon line, see Figure 2.1 This angle is usually set to a value of 15-30° according to NCC (2010) and has to be not less than 5°. In the reference object the horizon angle is set to 5°. This is done since the total screening factor of 0.5 is used to decrease the solar radiation heat gain through the building's windows, and this factor includes external shading.

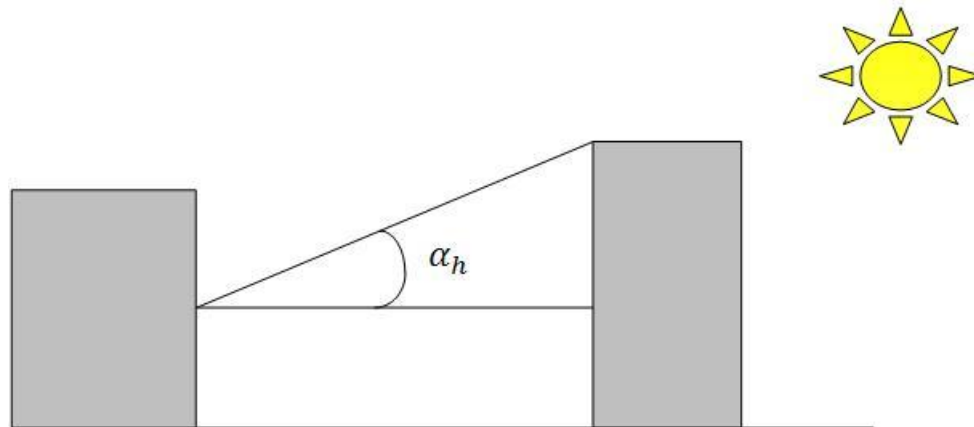


Figure 5.11 The horizon angle  $\alpha_h$ .

## 5.6 Location and climate

Both software used in the analysis use different climate data files. In VIP-E the location of the simulated building is included and represented in the climate data file in terms of longitude and latitude. The air pressure due to the height above sea level has to be set separate.

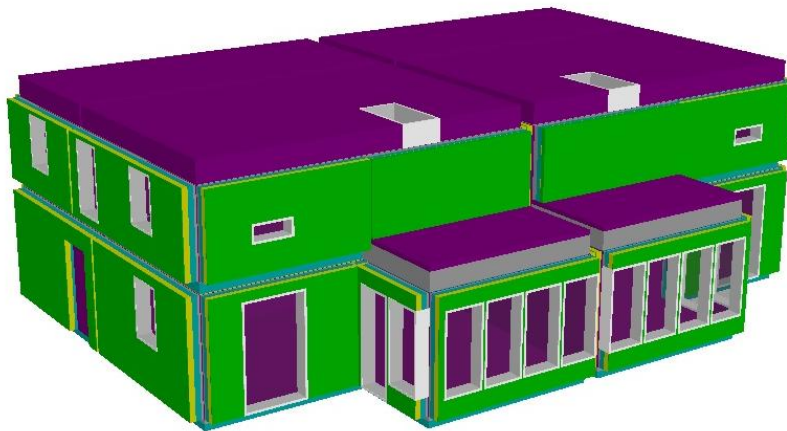
In IDA ICE the location is chosen separately and thereby setting longitude, latitude and height above sea level. This means that in theory it is possible to combine climate data from one location with the geographical position from another location. By using the geographical position the solar incident angle can be calculated. The location is set to Göteborg in VIP-E and Säve in IDA ICE.

VIP-E's climate file for Göteborg does not include wind direction, but this can be chosen manually in the software as a locked wind direction (Structural Design Software, 2009). The locked wind direction in VIP-E is set to west for the reference object.

The height above the sea level affects the density of the air, and thereby its ability to transport heat. The height above the sea level is not known for the reference building in Öjersjö, but the location data in IDA ICE sets a value of 53 m. for Säve. This height is transformed into an air pressure that is used in VIP-E. This is done by assuming that the air pressure is 100 kPa at the sea level and decreases with 0.1 kPa every 8 metres above the sea level. This sets the air pressure to 99.3 kPa at the height of 53 m (Structural Design Software, 2009).

The indoor temperature is set to 21 °C. This temperature is to be used in small houses, but when analysing multi-dwelling buildings an indoor temperature of 22 °C should be used (NCC, 2009). The definition of a small house is, according to the Swedish real estate law, a building that is set up to accommodation for one or two families (FSF 1979:1152). Svebyprogrammet assert that all domestic buildings, except retirement homes, should be analysed using 21 °C. There are no demands set upon the indoor relative humidity.

VIP-E uses a value for solar reflection on the ground [%] to express the amount of solar radiation that is reflected on the ground to the building. This value is normally between 20-50 % (Structural Design Software, 2009) and in the reference building the value is set to 35 %.



*Figure 5.12 The reference object in IDA ICE seen from south west.*

## 6 The search for uncertainties

Certain standards have been formulated the last few years to be used when analysing the energy usage in buildings. The calculations and proceedings used for retrieving the specific energy usage in buildings are however not entirely declared in these regulations, and leaves choices open for the single designing engineer. The different ways of procedure regard aspects such as the choice of a certain heat transfer coefficient or what type of software to use in the analysis. In order to identify what parameters to be analysed a list of parameters is elaborated. These parameters are cross-checked with NCC's procedure for calculating the specific energy usage. As the procedure used by NCC for calculating the specific energy usage involves either the use of IDA ICE or VIP-E the parameters are then checked a second time in order to see how they can be changed in these software.

There are a huge number of parameters that affect a specific energy usage calculation. The purpose of this thesis is not to analyse all aspects, but focuses on the ones that supposedly affect the energy analysis the most when using the analysis procedure set up by NCC. This means that if a parameter is not used in the analysis it does not imply that the parameter is of any lower importance than the others, but the procedure used by NCC does not admits a great span of options for changing the parameter.

The parameter that is to be investigated is changed in the reference building. The new calculated specific energy usage is compared to the one calculated for the reference building before the change. Finally the deviation is calculated as a percentage. The parameters and the changes are described in the following sections.

During the simulation the changes in energy usage caused by heating is logged as well. This is done since the specific energy usage includes tap water usage and this parameter is not changed. By then adding the energy used for heating tap water with the energy used for heating the building, the percental change in energy usage will then appear smaller than what it actually is. Each simulation is dedicated a code that can be seen in the sections that follows.

### 6.1 The parameters

The following sections present the parameters used in the analysis. The parameters are described along with the changes that are to be done. IDA ICE and VIP-E are programmed in different ways and therefore use different input data. Some parameters are therefore only possible to change in one of the two software and some are handled using different types of data input. This is considered individually for each parameter and described in the following sections. Lastly the changes of the parameter are assigned codes that are used in the compilation of the result in Chapter 7. The first number in the code represents the software used. 1 stands for IDA ICE and 2 for VIP-E. The rest of the code represents the parameter changed, and to make it easier to study the result in Chapter 7 a short description will follow in the presentation there as well.

#### 6.1.1 Frame percentage of total window area

As a default in IDA ICE the frame percentage of the total windows area is set to 10% and in VIP-E 20 %. Since the procedure allows this default value to be unchanged,

simulations are done using these values. This will not change the U-value of the window since the frame and the glass has the same U-value, but will affect the heat load due to solar radiation. NCC normally calculate the frame rate individually for each building that is to be analysed but recommends a frame rate of 25 % to be used as an average value in rough estimations. Therefore this value is used in a simulation in VIP-E. The frame rate used in the reference object is 25.4 %.

Codes: *1F%W10; 2F%W20; 2F%W25*

### **6.1.2 Climate and location data**

As mentioned in Section 5.6 climate data from several locations can be used when analysing a building. The locations are however naturally limited, and it is up to the software user to choose which location that best describes the location of the building of interest. The location of the reference building simulated in IDA ICE is set to Säve in Göteborg. In VIP-E climate data from Göteborg is used. Then simulations using other climate data and locations are done in order to compare the differences in result. The chosen places are Stockholm, Kalmar, Landvetter and Malmö for IDA ICE, and using VIP-E Stockholm and Kalmar. Note that in VIP-E the location is automatically set when choosing the climate data. It is not possible to choose the location manually as in IDA ICE.

Codes: *1LocSthlm; 1LocKalmar; 1LocMalmo; 1LocLandv; 1ClKalmar; 1ClLandv; 1ClSthlm; 2ClSthlm; 2ClKalmar*

### **6.1.3 Ideal heater**

IDA ICE uses an ideal heater to provide heat in the building. Each climate zone in the reference building modelled in IDA ICE has a heater with an effect of 3 kW. The effect from the ideal heater is instant and exact and meets the zone's need for heating in each specific moment. The software uses the heater to measure the need for heating. Since the reference building in IDA ICE contains nine different climate zones, the model uses nine ideal heaters. One simulation is done setting the effect of the ideal heaters to 6 kW and one simulation with an effect of 1 kW per heater to see whether the energy usage is affected. This analysis is not related to NCCs energy calculation procedure but will, in case of a big difference in result, have to be investigated further. VIP-E only limits the heating if the user of the software decides to do so and therefore no simulation will be done to investigate that further.

Codes: *1Heat6k; 1Heat1k*

### **6.1.4 Infiltration**

In IDA ICE the infiltration can be dealt with by either using a fixed infiltration flow rate or using a wind driven air flow. The model of the reference building uses fixed infiltration with the infiltration factor provided by NCCs leaflet of 0.6 l/(m<sup>2</sup>s) divided by 40 (see Section 5.2.2). Simulations are then done after changing the infiltration to wind driven flow with openings in internal walls. According to IDA ICE openings must be used when simulations are done using wind driven air flow and therefore a simulation is done without openings as well, since that could be something that is easily overlooked. Simulations are also done using fixed flow where the infiltration of

0.6 l/(m<sup>2</sup>s) is divided by 20. This is done because when analysing a balanced supply and exhaust air ventilation system the infiltration factor should be divided by 20. No simulation is done using VIP-E since it only uses wind driven air flow in the reference object. The effect on the energy usage when changing the wind properties is tested in Section 6.1.18.

Codes: *1Op; 1Wd0.6Op; 1Wd0.6NOp; 1Ffdiv25; 1Ffdiv20*

### **6.1.5 Airing**

To compensate for an extra energy usage due to airing 4 kWh/(m<sup>2</sup>year) is added to the final specific energy usage in the reference object. This extra energy usage can also, according to Svebyprogrammet, be taken into account by either adding 0.5 l/(m<sup>2</sup>s) to the infiltration flow rate or by adding 2.3 l/s and apartment to the ventilation flow rate. This is done in simulations in both IDA ICE and VIP-E.

Codes: *1Air2.3; 1AirLeak0.5; 2Air2.3; 2AirLeak0.5*

### **6.1.6 Sun screening**

The sun has a great impact upon the indoor climate due to the radiation through the windows in a building. The radiation can, as mentioned earlier, be in direct or diffuse form, diffuse being the sun radiation reflecting on the surrounding environment into the building. In order to take sun screening into account, a sun screening coefficient of 0.5 [-] is multiplied with the solar heat gain coefficient SHGC, and the solar transmittance  $\tau$  (see Section 5.3.2). As an alternative to the sun screening coefficient blinds can be used in both software. The blinds work by using a multiplier for SHGC of 0.39 which can be used according to Svebyprogrammet, 2009. The blinds also use a multiplier for  $\tau$  of 0.12 and for the U-value of 0.87. When using blinds in the simulations the external shading still has to be regarded. This is done by using a sun screening coefficient of 0.71 according to Svebyprogrammet, 2009. The blinds are drawn when the solar radiation reaches 100 W/m<sup>2</sup>. This is a default value in IDA ICE and used in both software to simulate the same type of activation of blinds.

Codes: *1Blinds; 2Blinds*

### **6.1.7 Ground properties**

The procedures used by NCC do not get in to specifics regarding the choice of ground properties. In IDA ICE one simulation is done using the default ground properties. This default ground type consists of 100 mm insulation followed by 1 m of soil. One simulation is done using a soil layer of 5 m followed by 0.5 m rock, and one simulation using only 0.5 m rock. In VIP-E rock is used in the reference object, and two simulations are done using clay and then silt.

Codes: *1GrDefault; 1GrDiffIay; 1GrRock; 2GrClay; 2GrSilt*

### **6.1.8 Manually measured floor area**

The different areas of a building; floor areas, wall areas etc. can be retrieved in different ways. One way is to conduct the measurement electronically by using



software such as Adobe Reader or AutoCAD. Another way is to measure manually using a printed drawing. The floor area used when simulating the reference object is measured in AutoCAD. To investigate the difference in final calculated result of specific energy usage the drawing is converted into PDF-format and then printed in A3 format. This drawing is then used when measuring the floor area of the building. The floor area in the reference object is 277.17 m<sup>2</sup>, and measuring manually the area becomes 273.74 m<sup>2</sup>. The measured area is used in both IDA ICE and VIP-E.

Codes: 1ManFloorAr; 2ManFloorAr

### 6.1.9 Manually measured building height

The building height is measured using the same procedure as when the manually measured floor area is simulated. The floor height in the reference object is 4.61 m in IDA ICE. This height is changed to 4.51 m and then simulated. VIP-E uses the exterior measures, and therefore the thickness of the roof is added, setting the old building height to 5.09 m and the new height to 4.99 m. Simulations are then done in both IDA ICE and VIP-E.

Codes: 1ManZ; 2ManZ

### 6.1.10 Changing the material properties to default values

When creating the reference object in both IDA ICE and VIP-E the material properties have been gathered from different sources, see Annex C: References for material data. Both software have predefined material properties for the materials used in the reference object, and using this data will be less time consuming when creating a model than manually set the properties. Therefore this pre-set data is used in simulations in both software.

Table 6.1 Pre-set material properties. First figure in each cell retrieved from IDA ICE and second figure retrieved from VIP-E.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
Insulation	0.036/0.036	20/50	750/840
Wooden joist c600 mm <sup>1)</sup>	-/0.041	-/55	-/845
Wooden joist c450 mm <sup>1)</sup>	-/0.041	-/55	-/845
Wooden joist c1200 mm <sup>1)</sup>	-/0.0403	-/68	-/900
Steel joist c700 mm <sup>2)</sup>	-/0.09	-/112	-/900
Gypsum	0.22/0.22	970/900	1090/1100
Weather board	0.22/0.22	970/900	1090/1100
70 mm air gap <sup>3)</sup>	0.39/-	1.2/-	1006/-

Floor cover <sup>3)</sup>	0.18/-	1100/-	920/-
220 mm air gap <sup>4)</sup>	1.375/1.375	1.2/1.2	1006/1006
Particle board	0.14/0.14	500/600	2300/2300
Concrete	1.7/1.7	2300/2300	880/800
Cellular plastic	0.036/0.036	32/25	750/1400

- 1) Equivalent material; a combination of wood joist and insulation. In IDA ICE insulation is used.
- 2) Equivalent material; a combination of steel joist and insulation. In IDA ICE insulation is used.
- 3) Do not exist as default value in VIP-E.
- 4) Do not exist in any of the software used. The values set in the reference object used instead.

Codes: *1MatDefault*; *2MatDefault*

### 6.1.11 Pitched roof

Due to simplicity the reference object is built up as a box in IDA ICE. VIP-E uses areas instead of 3-D modelling and therefore a pitched roof is as easy to create as a flat roof. In order to make the reference object equal in both software, flat roof is used in VIP-E as well. When creating the reference object in VIP-E the areas are worked out using the equivalent height (see Section 5.1.1), and when creating the building with a pitched roof the areas are summoned up in AutoCAD. It is possible to create a pitched roof in IDA ICE as well, and one simulation is done in both software using pitched roof.

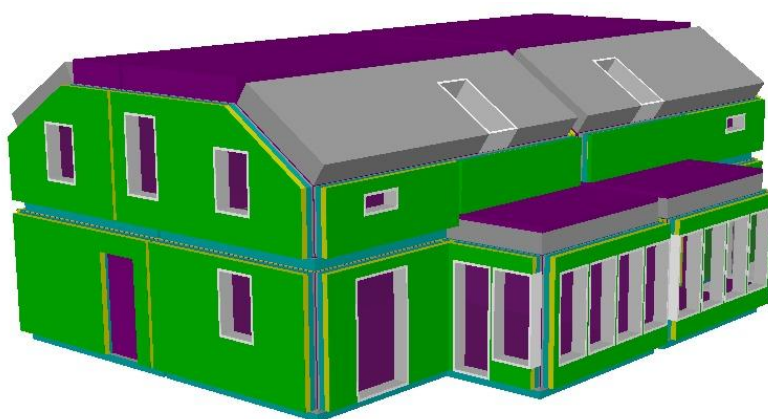


Figure 6.1 Model in IDA ICE using pitched roof.

Codes: *1PitchedR*; *2PitchedR*

### **6.1.12 Start-up date**

A simulation of the building used in this study spans over one year. The simulated year starts January 1<sup>st</sup> and ends December 31<sup>st</sup>. In order not to use more energy than actually needed IDA ICE uses one day for setting the inner climate and the heat stored in the construction. This day is run in a loop until a steady state is reached, and then the actual simulation starts. The date of the day is possible to choose, so that although the simulation starts in January, any day during the year can be used. The reference object is set to use January 1<sup>st</sup>, but simulation is made using July 1<sup>st</sup> in order to see whether there is any difference in energy usage. This option does not exist in VIP-E.

Code: *1Start0701*

### **6.1.13 Changing the air pressure**

As mentioned in Section 5.6 the height above the sea level affects the air's ability to transport due to differences in density. The default setting of air pressure is 100 kPa in VIP-E. This setting is used in one simulation. In IDA ICE the height above the sea level is set automatically when setting the location and therefore no simulation is done using that software.

Code: *2AirPress*

### **6.1.14 Horizon angle**

Since a screening factor is used (see Section 5.5) when constructing the reference object in VIP-E, the horizon angle is set to 5° originally. But in the procedure used by NCC (2010) it is claimed that a horizon angle between 15-30° normally should be used. 5° is the smallest angle allowed to use according to this procedure. Two simulations are done in VIP-E using 15° and 30°.

Codes: *2HorizAng15; 2HorizAng30*

### **6.1.15 Solar reflection on ground**

The amount of solar radiation reflected on the ground is in Section 5.6 set to 35 % for the reference object when simulated in VIP-E. The value is normally between 20-50 % (StruSoft AB, 2009) and these limit values are used in two simulations in VIP-E.

Codes: *2SunRefl20; 2SunRefl50*

### **6.1.16 Indoor temperature**

The indoor temperature used in the reference object is 21°C (see Section 5.6). If the building had been adapted to 3 families instead of 2, NCC (2009) suggests that the indoor temperature is set to 22°C. Simulations are therefore done in both software using 22°C.

Codes: *1Temp22; 2Temp22*

### 6.1.17 Using equivalent window area

The window area used when creating the reference object is, as mentioned in Section 5.1.2 measured in AutoCAD. In IDA ICE the windows are handled individually, and a less time-consuming way of setting up a building is to use an equivalent window area. This will handle the solar radiation in the same way as when using the actual windows, but decrease the window perimeter, and thereby also the thermal bridges.

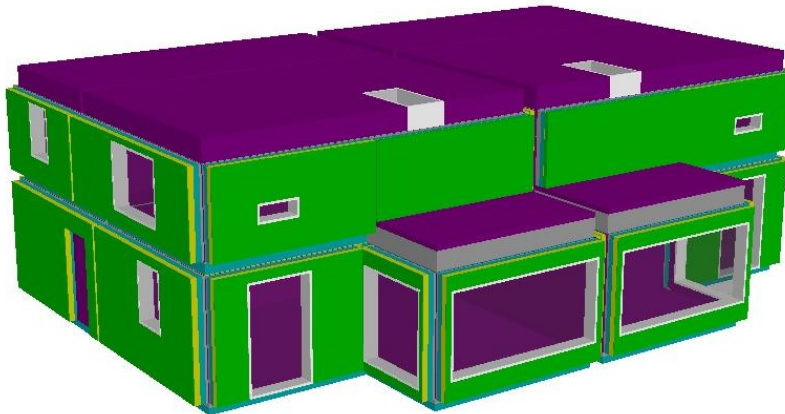


Figure 6.2 Equivalent window area used in IDA ICE, compare with Figure 5.12.

VIP-E uses a summation of areas and so the windows cannot be treated individually and no simulation is done using that software.

Code: *1Win1A*

### 6.1.18 Changing the wind

The wind affects the air infiltration through the building envelope and is only of interest when a wind driven air flow is chosen in IDA ICE, not when using fixed infiltration during simulation (EQUA Simulation AB, 2009). IDA ICE uses 3 types of wind profiles; urban, suburban and open country. These wind profiles set a percentage of the wind speed from the actual climate file that is to be used.

The reference object in IDA ICE is set using the suburban wind profile. One simulation is done using open country, which will increase the wind speed in the simulation.

In VIP-E the percentage of wind speed retrieved from the climate file is set to 70%. In order to do the same analysis in this software this percentage is raised to 95%. This is equal to constructing a relatively well wind exposed building according to NCC (2010). The reference object is set with a locked wind direction as mentioned in Section 5.6. This wind direction is changed from west to south west and then simulated.

Codes: *1WindOC; 2WindOC; 2WindDirSW*

### **6.1.19 Changing the zones**

One of the largest differences when setting up reference object in the two software used is the number of zones created. While nine zones have been set up to create the reference object in IDA ICE, only two zones have been used in VIP-E. The reason is mainly due to the way changes are performed in the different software. In IDA ICE the building used in a simulation is saved as a single file, and changes that are performed are valid for every zone in the building if the software user wishes. In VIP-E all zones are saved individually as separate files. By choosing to create the reference object using nine different zone, all the zone-files would have to be changed and saved for every parameter that is to be analysed. This would be a time-consuming work and increase the risk of some mistake slipping through when changing a parameter before performing a simulation. When using the software in an ordinary energy usage analysis, these zones are only set up one time and therefore a software user should not refrain from using VIP-E due to that reason.

There is no recommendation regarding how many zones to use in a simulation, and so the numbers of zones are changed in two simulations. In IDA ICE the nine zones are reduced to two zones; one for the storage, and one for each floor in the main part of the building. In VIP-E the number of zones are increased to three zones, divided into the storage and one zone used for each apartment.

Codes: *1Zone3*; *2Zone3*

## 6.1.20 Thermal bridges

In the reference building the thermal bridges are calculated using HEAT2, the procedure is described in Section 5.4. In IDA ICE they are specified as in Figure 6.3 with one  $\Psi$ -value [W/(mK)] for each type of connection.

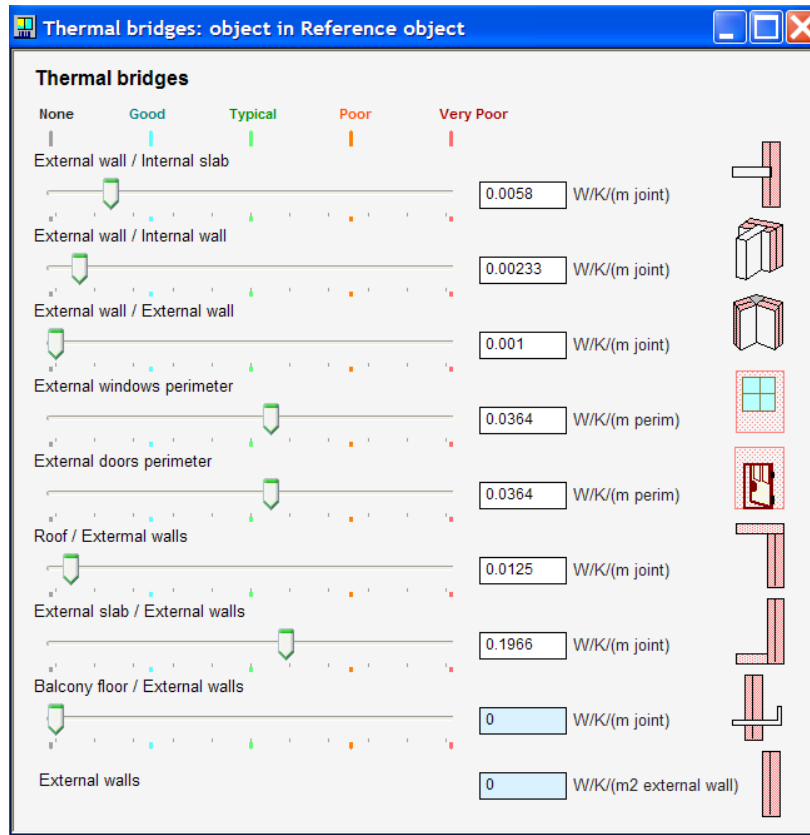


Figure 6.3 Thermal bridges set in IDA ICE.

In VIP-E the thermal bridges are chosen to be specified as an addition to the U-value for envelope construction parts. The total value of the thermal bridges in both IDA ICE and VIP-E is 18.4 W/K. Due to the analysis of each thermal bridge being time-consuming template values may be used. These template values can be formulated as an increase in percent of the  $U_m$ -value without any thermal bridges.

Aagard & Johansson (2006) state that thermal bridges result in an increase of the  $U_m$ -value of approximately 10 %. NCC (2009) uses an increase of 15 %. One simulation using 10 % thermal bridges and one using 15 % for are done in both IDA ICE and VIP-E. Simulations are also done using no thermal bridges. This is done in order to see the difference in specific energy usage caused by the thermal bridges in the reference object.

Codes: 1ThBr10%; 1ThBr15%; 2ThBr10%; 2ThBr15%; 1ThBr0; 2ThBr0

## 6.2 Simulating worst case scenario

The parametric study described in Section 6.1 results in a deviation in the specific energy usage caused by changing the parameters one by one. A simulation of a building in order to investigate its energy usage does however involve more than one parameter being changed due to assumptions made by the single analysing engineer.

The procedure used for energy analysis set up by NCC Teknik and the procedure in Svebyprogrammet allow many of these parameters to be set according to choices made by the single software user. Therefore it is of importance to see how the final result, in specific energy usage, can differ depending on the combination of these assumptions and choices.

As of today there is no way to predict and summon these types of deviations in results, which occur due to the assumptions and choices made during an energy analysis. Different choices are more or less likely to occur, and the changes in the parameters affect the final outcome in specific energy usage in different ways. Hence a complete summation of the percental deviation in specific energy usage caused by a series of parameter changes usage might not describe the possible outcome that well.

One way of trying to identify the possible order of magnitude of these deviations in the final result, presented in specific energy usage, is to combine the parameters that affect the specific energy usage in the same direction and can be combined according to the procedures used by NCC.

Two simulations are made in each software using these combinations of parameters; one simulation when combining the parameters that decrease the specific energy usage, and one simulation when combining the parameters that increase the specific energy usage. These parameters are identified in the simulations where the parameters are changed individually. These two final results, presented in specific energy usage, are then compared with the reference object and a possible total deviation can be identified.

The parameters used in the simulations can be seen in Table 6.2. In these simulations different input data is used in the different software as described in 6.1. Therefore these simulations do not use the same combination of parameters.

Some parameters give the same type of deviation but are still not combined in these two simulations. As an example increasing the horizon angle to 15° or 30° respectively resulted in an increase in specific energy usage. But these are still not combined since they cannot be used at the same time in a simulation. Other parameters that affect the deviations in the individual tests are left out because NCC's procedure and Svebyprogrammet does not recommend using them. Climate data retrieved from Stockholm was not used in these two simulations, despite that this would affect the outcome more than using the climate data from Landvetter. That alternative should never been considered when analysing a building situated on the Swedish west coast.

In this section the parameters tested in Chapter 6 are tabled and organized depending on the way they affect the specific energy usage. For the simulations named 1MaxEnergy and 2MaxEnergy, listed in Table 6.2, parameters that raise the specific energy usage are combined into a likely scenario to give an upper limit of the deviation. Conversely, the simulations 1MinEnergy and 2MinEnergy give a lower limit of the deviation.

Table 6.2 The parameters used in combinations.

IDA ICE simulations		VIP-E simulations	
<b>1MaxEnergy</b>	<b>1MinEnergy</b>	<b>2MaxEnergy</b>	<b>2MinEnergy</b>
<i>1ClLandv</i>	<i>1Blinds</i>	<i>2AirPress</i>	<i>2Blinds</i>
<i>1Ffdiv20</i>	<i>1F%W10</i>	<i>2HorizAng30</i>	<i>2F%W25</i>
<i>1GrRock</i>	<i>1GrDiffLay</i>	<i>2PitchedR</i>	<i>2GrClay</i>
<i>1Temp22</i>	<i>1LocLandv</i>	<i>2SunRef120</i>	<i>2ManFloorAr</i>
<i>1ThBr15%</i>	<i>1ManFloorAr</i>	<i>2Temp22</i>	<i>2ManZ</i>
<i>1WindOC</i>	<i>1ManZ</i>	<i>2ThBr15%</i>	<i>2MatDefault</i>
	<i>1MatDefault</i>	<i>2WindOC</i>	<i>2SunRef150</i>
	<i>1PitchedR</i>		<i>2ThBr10%</i>
	<i>1Start0701</i>		<i>2WindDirSW</i>
	<i>1ThBr10%</i>		<i>2Zone3</i>
	<i>1Wd0.6NOp</i>		
	<i>1Win1A</i>		
	<i>1Zone3</i>		

Codes: *1MaxEnergy*; *1MinEnergy*; *2MaxEnergy*; *2MinEnergy*

### 6.3 Comparing software

This thesis uses two different software to investigate deviations in the calculated specific energy usage. These two software, IDA ICE and VIP-E, were chosen as they are to be used in accordance with the procedure for specific energy usage calculations at NCC Teknik. In addition to these software, there are a number of other software available for calculating energy usage in buildings. It is therefore important to stress that the final outcome of the analysis will differ not only due to the parameters mentioned above, but also depend upon the selection of software. To ensure that the energy calculation program provides reliable results, there are a number of tests available. One of these tests, called Building Energy Simulation Test or BESTEST, was developed by the International Energy Agency (IEA) in 1995. This test is commonly used for validating and testing building energy analysis software. It is based on standard cases that specify climate and geographical conditions as well as geometric data and material data which to be used when validating a software. The



reference building used in this test is a small box-like building 2.7 m high, 8 m wide and 6 m long. It has two windows facing south (Henninger & Witte, 2003). See Figure 6.4. Parts of the geometry and material data are then changed during different simulations in order to retrieve different data that is to be used in a comparison to other software.

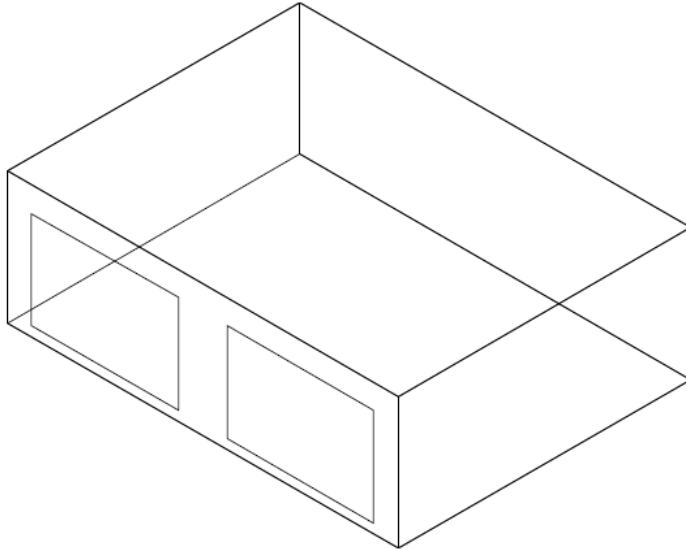


Figure 6.4 Base cases 600 and 900. (Henninger & Witte, 2003)

These standard cases have been calculated in a number of selected energy calculation software and the results have been compiled to serve as a basis for the evaluation of building energy analysis software. The ranges in results between the different reference programs provide a qualitative lower and upper limit. A calculated result produced by the software being evaluated should preferably be within these limits. There are no exact requirements defined in terms of kWh or indoor temperatures a software should produce in comparison to the reference software results. A final result outside the expected range is not necessarily wrong, but a deviation of that magnitude suggests that the calculation may need to be reviewed and the source of the deviation in result investigated (Judkoff & Neymark 1995, p. 2-147).

IDA ICE and VIP-E are compared with each other and also with the reference software used in BESTEST. The result is presented in Section 7.2. The comparison will use cases with both high and low mass buildings, named case 600 and 900 respectively. In some of the cases thermal demands are set in the building with lower and upper limits of 20-27 °C. In these cases the annual heating and cooling is measured and compared.

Other cases are free-floating, i.e. using no temperature demands. The free-floating cases are named 600ff and 900ff. In these cases the indoor temperature is measured and compared between the software used. There are more cases formulated in BESTEST but they are not used in this thesis. The main aim of this comparison is to emphasize the difference between the software used. The information and data regarding BESTEST is retrieved from International Energy Agency Building Energy Simulation Test (IEA BESTEST) and Diagnostic Method (Judkoff & Neymark, 1995). Data used to test VIP-E have been provided by StruSoft AB and the results from BESTEST simulation using IDA ICE have been provided by EQUA Simulation AB.

## 7 Results

### 7.1 Results of parametric study

Several parameters are investigated to see how they affect the specific energy usage. It is the changes in specific energy usage that is of actual interest, since the regulations set by the Swedish National Board of Housing, Building and Planning are expressed in demands upon specific energy usage. The energy used for heating the building has also been logged during the simulations since it is almost exclusively the energy used for heating that is changed during the parametric study. These changes are declared in Annex D: Analysing parameters.

Due to the differences in requirement of input data between the two software, all parameters could not be investigated in both IDA ICE and VIP-E. Therefore the results are presented separately in Section 7.1.1 and Section 7.1.2. The parameters that were possible to change in the both software are then compared in Section 7.1.3.

As described in Section 6.2 some of the parameters used in the analysis are combined in two simulations in each software. This is done in order to reach the largest deviations that are likely to occur using the procedure according to NCC (2009). The results are presented in Section 7.1.4.

Every section that follows presents the result in a chart and is followed by descriptions of the parameters used together with the percental deviation in specific energy usage in comparison to the reference object. These descriptions follow every chart, and this is done to facilitate the reader's interpretation of the results. All results are presented in Annex D: Analysing parameters.

#### 7.1.1 Parameters investigated individually using IDA ICE

The following section presents the results collected from simulations done after changing the parameters individually in IDA ICE. Changing the parameters results in either an increase or a decrease in the energy usage. This change is calculated as a percental deviation in specific energy usage from the reference object, and presented in the two following charts. Figure 7.1 presents all parameter changes that gave an increase in the specific energy usage when changed. Figure 7.2 shows the parameter changes resulting in a decrease in specific energy usage. The codes in the charts are described in the tables below the figures.

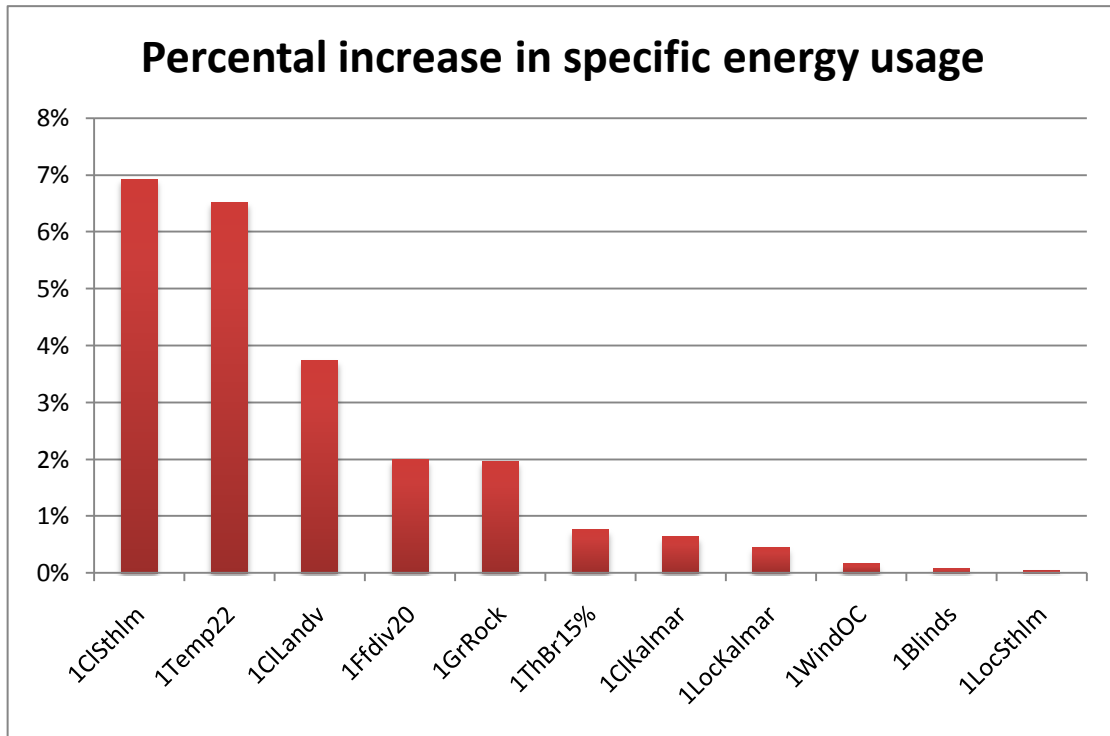


Figure 7.1 Parametric changes resulting in an increase in specific energy usage.

Table 7.1 The percental deviation and description of the parameters presented in Figure 7.1.

Code	[%]	Description
1ClSthlm	6.9	Climate data changed from Säve to Stockholm.
1Temp22	6.5	Indoor set-point temperature increased from 21°C to 22°C.
1ClLandv	3.7	Climate data changed from Säve to Landvetter.
1Ffdiv20	2.0	Infiltration changed from 0.015 l/(m <sup>2</sup> s) to 0.03 l/(m <sup>2</sup> s).
1GrRock	2.0	Changed the ground properties to 0.5 m rock.
1ThBr15%	0.8	Thermal bridges set to 15 % of mean UA-value.
1ClKalmar	0.6	Climate data changed from Säve to Kalmar.
1LocKalmar	0.5	Location changed from Säve to Kalmar.
1WindOC	0.2	Wind profile changed from suburban to open country.
1Blinds	0.1	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
1LocSthlm	0.0	Location changed from Säve to Stockholm.

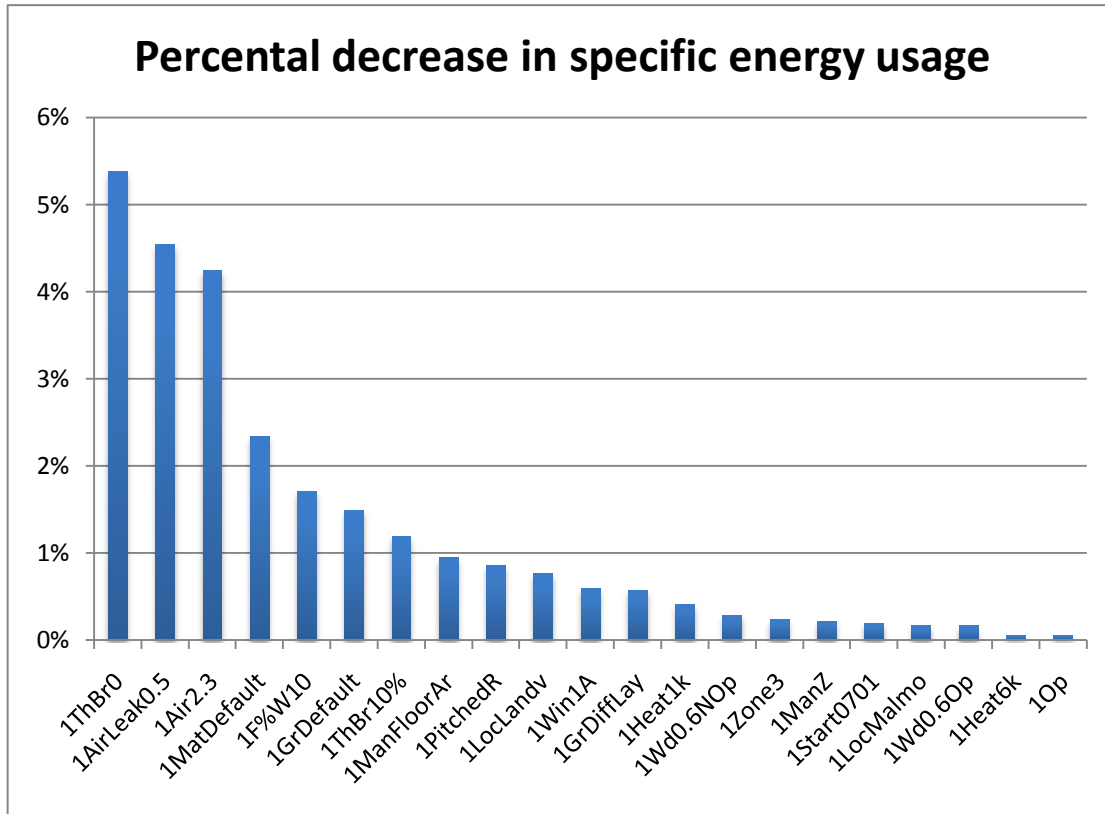


Figure 7.2 Parametric changes resulting in a decrease in specific energy usage.

Table 7.2 The percental deviation and description of the parameters presented in Figure 7.2.

Code	[%]	Description
1ThBr0	-5.4	Thermal bridges set to 0.
1AirLeak0.5	-4.5	Adding 0.5 l/(m <sup>2</sup> s) to air leakage instead of 4 kWh/(m <sup>2</sup> yr) heat losses due to airing.
1Air2.3	-4.2	Airing changed from 4 kWh/(m <sup>2</sup> yr) to extra ventilation of 2.3 l/s and apartment.
1MatDefault	-2.3	Changed material properties to software default materials.
1F%W10	-1.7	Frame percentage of total window area decreased from 25.4 % to 10 %.
1GrDefault	-1.5	Changed ground properties to software default.
1ThBr10%	-1.2	Thermal bridges set to 10 % of mean UA-value.
1ManFloorAr	-0.9	Floor area changed according to manual measurements.

1PitchedR	-0.9	Roof type changed from flat to pitched.
1LocLandv	-0.8	Location changed from Säve to Landvetter.
1Win1A	-0.6	Windows are merged together, total window area being unchanged.
1GrDiffLay	-0.6	Changed the ground properties to 5 m default soil followed by 0.5 m rock.
1Heat1k	-0.4	Maximum heating effect limit set to 1000 W instead of 3000 W in each zone.
1Wd0.6NOp	-0.3	Infiltration changed from fixed to wind driven without openings.
1Zone3	-0.2	Number of zones decreased from 9 to 3.
1ManZ	-0.2	Building height changed according to manual measurement.
1Start0701	-0.2	Start-up date changed from 1/1 to 1/7.
1LocMalmo	-0.2	Location changed from Säve to Malmö.
1Wd0.6Op	-0.2	Infiltration changed from fixed to wind driven with openings in internal walls.
1Heat6k	-0,1	Maximum heating effect limit set to 6000 W instead of 3000 W in each zone.
1Op	-0.1	Openings added when using fixed infiltration.

### 7.1.2 Parameters investigated individually using VIP-E

This section presents the results collected from simulations done after changing the parameters individually in VIP-E. Changing the parameters results either in an increase or a decrease in the energy usage. This change is calculated as a percental deviation in specific energy usage from the reference object, and presented in the two following charts. Figure 7.3 presents all parameter changes that gave an increase in the specific energy usage when changed. Figure 7.4 shows the parameter changes resulting in a decrease in specific energy usage. The codes in the charts are described in the tables below the figures.

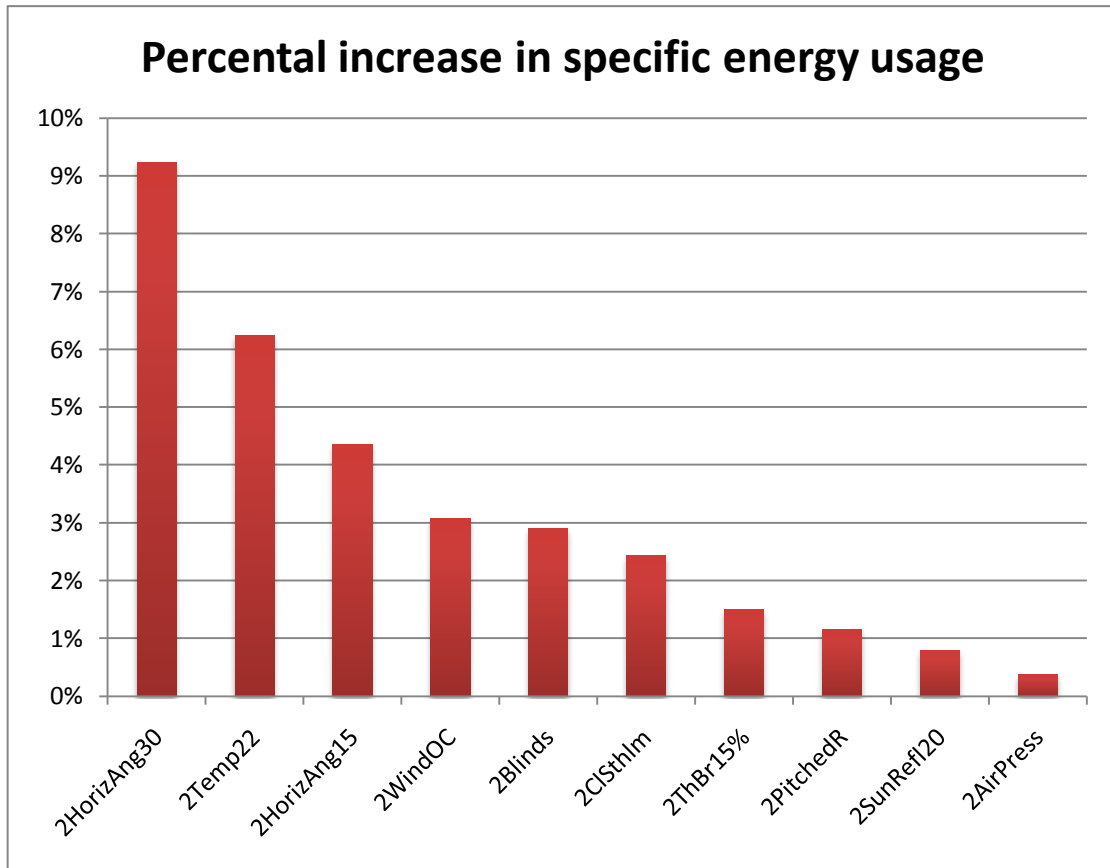


Figure 7.3 Parametric changes resulting in an increase in specific energy usage.

Table 7.3 The percental deviation and description of the parameters presented in Figure 7.3.

Code	[%]	Description
2HorizAng30	9.2	Changing the horizon angle from 5° to 30°.
2Temp22	6.3	Indoor set-point temperature increased from 21°C to 22°C.
2HorizAng15	4.4	Changing the horizon angle from 5° to 15°.
2WindOC	3.1	Wind profile changed from 70 % of wind speed in climate file to 95 %.
2Blinds	2.9	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
2ClSthlm	2.4	Climate data changed from Göteborg to Stockholm.
2ThBr15%	1.5	Thermal bridges set to 15 % of U <sub>m</sub> -value.
2PitchedR	1.2	Using actual measurements from AutoCAD.

2SunRef120	0.8	Changing the solar reflection on ground from 35 % to 20 %.
2AirPress	0.4	Changing air pressure due to height above sea level from 99.3 kPa to default 100 kPa.

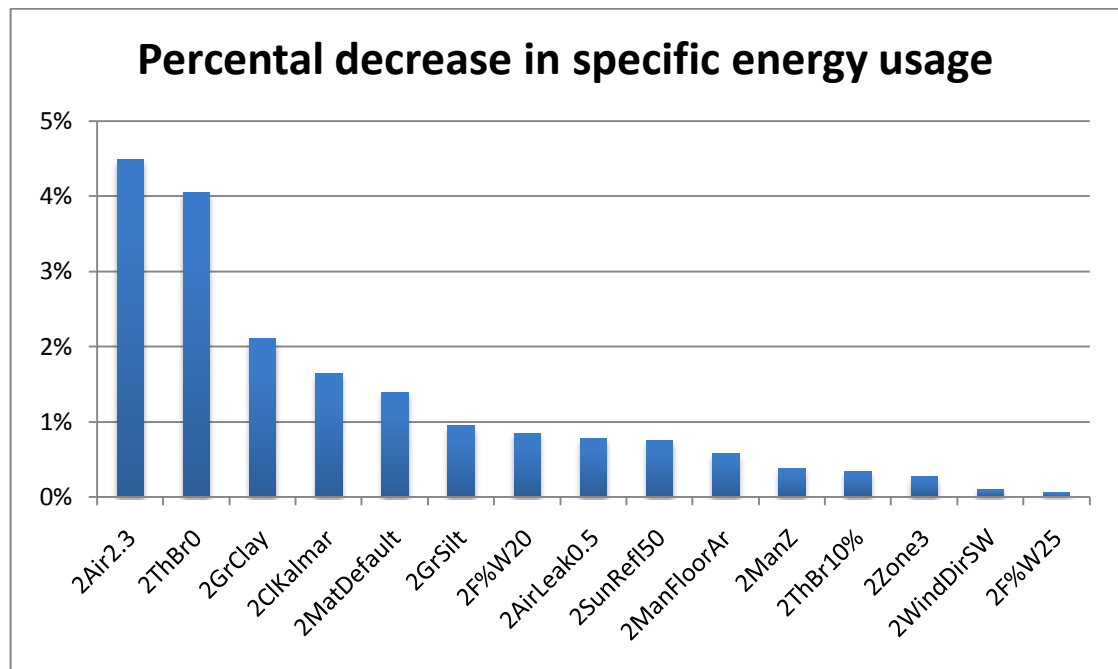


Figure 7.4 Parametric changes resulting in a decrease in specific energy usage.

Table 7.4 The percental deviation and description of the parameters presented in Figure 7.4.

Code	[%]	Description
2Air2.3	-4.5	Airing changed from 4 kWh/(m <sup>2</sup> yr) to extra ventilation of 2.3 l/s and apartment.
2ThBr0	-4.0	Thermal bridges set to 0.
2GrClay	-2.1	Changing ground properties from rock to clay.
2ClKalmar	-1.6	Climate data changed from Göteborg to Kalmar.
2MatDefault	-1.4	Changed material properties to software default materials.
2GrSilt	-0.9	Changing ground properties from rock to silt.
2F% W20	-0.8	Frame percentage of total window area decreased from 25.4 % to 20 %.
2AirLeak0.5	-0.8	Adding 0.5 l/(m <sup>2</sup> s) to air leakage instead of 4 kWh/(m <sup>2</sup> yr)

		heat losses due to airing.
2SunRefl50	-0.8	Changing the solar reflection on ground from 35 % to 50 %.
2ManFloorAr	-0.6	Floor area changed according to manual measurements.
2ManZ	-0.4	Building height changed according to manual measurement.
2ThBr10%	-0.3	Thermal bridges set to 10 % of $U_m$ -value.
2Zone3	-0.3	Number of zones increased from 2 to 3.
2WindDirSW	-0.1	Changing the locked wind direction from west to southwest.
2F% W25	-0.1	Frame percentage of total window area decreased from 25.4 % to 25 %.

### 7.1.3 Difference in results between the software

The reference object has been created in both IDA ICE and VIP-E with the intention that the simulations are based on equal conditions, i.e. using the same material properties, set-point temperatures, internal heat loads etc. The result from the simulations done to analyse the reference object in IDA ICE and VIP-E are presented in Table 7.5. It should be noted that although the results of the two simulations are close to being equal, that does not prove that the two software work in the same way. This is a single comparison, the two software uses different climate data and are programmed in different ways. A more standardized comparison is done using BESTEST, see Section 6.3, and the result is shown in Section 7.2.

Table 7.5 *Calculated specific energy usage in the reference object when simulated in IDA ICE and VIP-E.*

	Specific energy usage [kWh/m <sup>2</sup> yr]	Difference in result [%]
<b>IDA ICE</b>	64.22	0.25
<b>VIP-E</b>	64.38	

Many of the parameters used in this study can only be changed in one of the two software used. Some of the parameters are however possible to change in both software, and these are presented separately in Figure 7.5. The presentation is done in the same way as in previous sections in Chapter 7, using the percental deviation in specific energy usage in relation to the reference object.



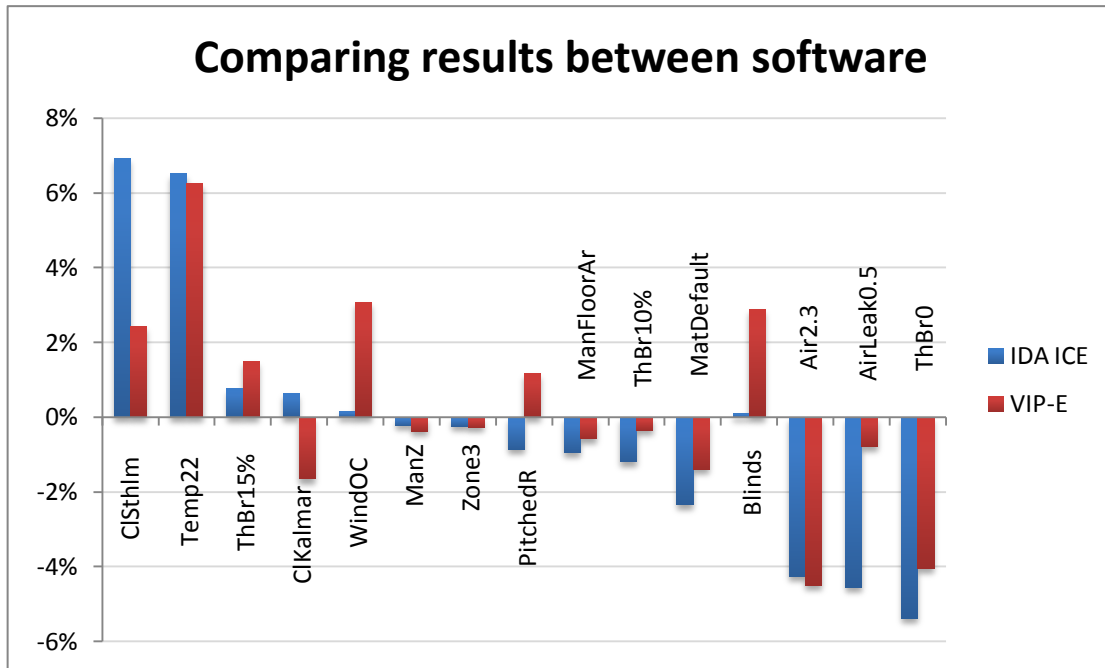


Figure 7.5 Showing the differences in results when changing the same parameters in the two software used.

Table 7.6 The percental deviation and description of the parameters presented in Figure 7.5.

Code	IDA ICE [%]	VIP-E [%]	Description
ClSthlm	6.9	2.4	Climate data changed from Göteborg to Stockholm.
Temp22	6.5	6.3	Indoor set-point temperature increased from 21°C to 22°C.
ThBr15%	0.8	1.5	Thermal bridges set to 15 % of $U_m$ -value.
ClKalmar	0.6	-1.6	Climate data changed from Göteborg to Kalmar.
WindOC	0.2	3.1	Wind profile changed from suburban to open country.
ManZ	-0.2	-0.4	Building height changed according to manual measurement.
Zone3	-0.2	-0.3	Number of zones decreased from 9 to 3.
PitchedR	-0.9	1.2	Roof type changed from flat to pitched.

ManFloorAr	-0.9	-0.6	Floor area changed according to manual measurements.
ThBr10%	-1.2	-0.3	Thermal bridges set to 10 % of Um-value.
MatDefault	-2.3	-1.4	Changed material properties to software default materials.
Blinds	0.1	2.9	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
Air2.3	-4.2	-4.5	Airing changed from 4 kWh/(m <sup>2</sup> yr) to extra ventilation of 2.3 l/s and apartment.
AirLeak0.5	-4.5	-0.8	Adding 0.5 l/(m <sup>2</sup> s) to air leakage instead of 4 kWh/(m <sup>2</sup> yr) heat losses due to airing.
ThBr0	-5.4	-4.0	Thermal bridges set to 0.

#### 7.1.4 Combining parameters into worst case scenarios

The results from the simulations described in Section 6.2 are presented in this section. It should be emphasized that the combinations of parameters used in these simulations are not claimed to be the worst combinations possible in terms of largest possible deviations in relation to the reference object. A software user can make mistakes or use input data that most likely leads to even larger deviations. However these simulations are meant to show deviations that occur due to choices plausible to occur.

The combination of parameters that are likely to affect the deviation in largest way possible, according to the individual parameter tests, results in four simulations. The results from these simulations are presented in Figure 7.6. The result is given in percental deviation in specific energy usage in comparison to the reference object.

The simulations are named:

- 1MaxEnergy – Parameters combined in IDA ICE resulting in an increase in specific energy usage.
- 1MinEnergy – Parameters combined in IDA ICE resulting in a decrease in specific energy usage.
- 2MaxEnergy – Parameters combined in VIP-E resulting in an increase in specific energy usage.
- 2MinEnergy – Parameters combined in VIP-E resulting in a decrease in specific energy usage.

The combined parameters are described in Table 7.7 - Table 7.10 where also the individual parameter deviations are tabled as a percentage. Note that these percentages are not used in Figure 7.6. The reason they are tabled is that they will be summoned and this summation will be compared to the percental deviation that is produced by the simulations listed above.

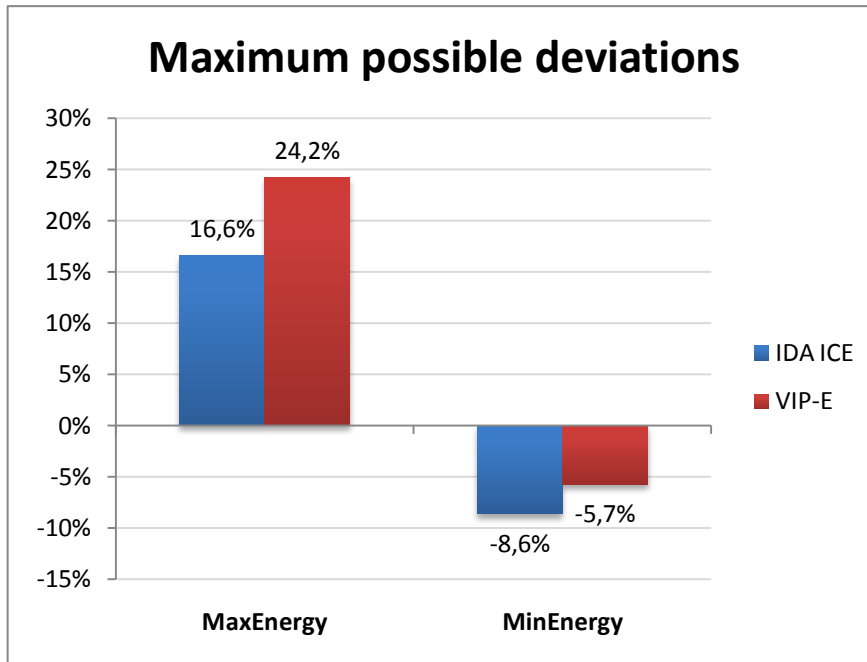


Figure 7.6 The parameters combined into largest possible percental deviation in specific energy usage in comparison to the reference object.

Table 7.7 Parameters combined in IDA ICE that increases specific energy usage. Simulation code: 1MaxEnergy.

Code	[%]	Description
1Blinds	0.1	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
1Cllandv	3.7	Climate data changed from Säve to Landvetter.
1Ffdiv20	2.0	Infiltration changed from 0.015 l/(m <sup>2</sup> s) to 0.03 l/(m <sup>2</sup> s).
1GrRock	2.0	Changed the ground properties to 0.5 m rock.
1Temp22	6.5	Indoor set-point temperature increased from 21°C to 22°C.
1ThBr15%	0.8	Thermal bridges set to 15 % of mean UA-value.
1WindOC	0.2	Wind profile changed from suburban to open country.

Table 7.8 Parameters combined in IDA ICE that decreases specific energy usage. Simulation code: 1MinEnergy.

Code	[%]	Description
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1F% W10	-1.7	Frame percentage of total window area decreased from 25.4 % to 10 %.
1GrDiffLay	-0.6	Changed the ground properties to 5 m default soil followed by 0.5 m rock.
1LocLandv	-0.8	Location changed from Säve to Landvetter.
1ManFloorAr	-0.9	Floor area changed according to manual measurements.
1ManZ	-0.2	Building height changed according to manual measurement.
1MatDefault	-2.3	Changed material properties to software default materials.
1PitchedR	-0.9	Roof type changed from flat to pitched.
1Start0701	-0.2	Start-up date changed from 1/1 to 1/7.
1ThBr10%	-1.2	Thermal bridges set to 10 % of mean UA-value.
1Wd0.6NOp	-0.3	Infiltration changed from fixed to wind driven without openings.
1Win1A	-0.6	Windows are merged together, total window area being unchanged.
1Zone3	-0.2	Number of zones decreased from 9 to 3.

Table 7.9 Parameters combined in VIP-E that increases specific energy usage. Simulation code: 2MaxEnergy.

Code	[%]	Description
2AirPress	0.4	Changing air pressure due to height above sea level from 99.3 kPa to default 100 kPa.
2Blinds	2.9	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
2HorizAng30	9.2	Changing the horizon angle from 5° to 30°.
2PitchedR	1.2	Using actual measurements from AutoCAD.
2SunRef120	0.8	Changing the solar reflection on ground from 35 % to 20 %.
2Temp22	6.3	Indoor set-point temperature increased from 21°C to 22°C.
2ThBr15%	1.5	Thermal bridges set to 15 % of U <sub>m</sub> -value.

2WindOC	3.1	Wind profile changed from 70 % of wind speed in climate file to 95 %.
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Table 7.10 Parameters combined in VIP-E that decreases specific energy usage. Simulation code: 2MinEnergy.

Code	[%]	Description
2F% W25	-0.1	Frame percentage of total window area decreased from 25.4 % to 25 %.
2GrClay	-2.1	Changing ground properties from rock to clay.
2ManFloorAr	-0.6	Floor area changed according to manual measurements.
2ManZ	-0.4	Building height changed according to manual measurement.
2MatDefault	-1.4	Changed material properties to software default materials.
2SunRef150	-0.8	Changing the solar reflection on ground from 35 % to 50 %.
2ThBr10%	-0.3	Thermal bridges set to 10 % of $U_m$ -value.
2WindDirSW	-0.1	Changing the locked wind direction from west to southwest.
2Zone3	-0.3	Number of zones increased from 2 to 3.

The percental deviations produced by changing the parameters individually cannot be summoned together in order to find the largest plausible deviations produces when combining the parameters. Combining parameters in order to see the total effect upon the specific energy usage is however time consuming. Summing up the result produced by changing the parameters individually is not the same as combining changed parameters. But if a summation presents a result that is close to the result from the combined parameter simulations, a summation can be used to approximate the effect of combining parameters.

In Figure 7.7 the percental deviation in specific energy usage from the four simulations are presented. The summations of the percental deviations from the parameters used in the simulations are also presented in the figure so that the results can be compared.

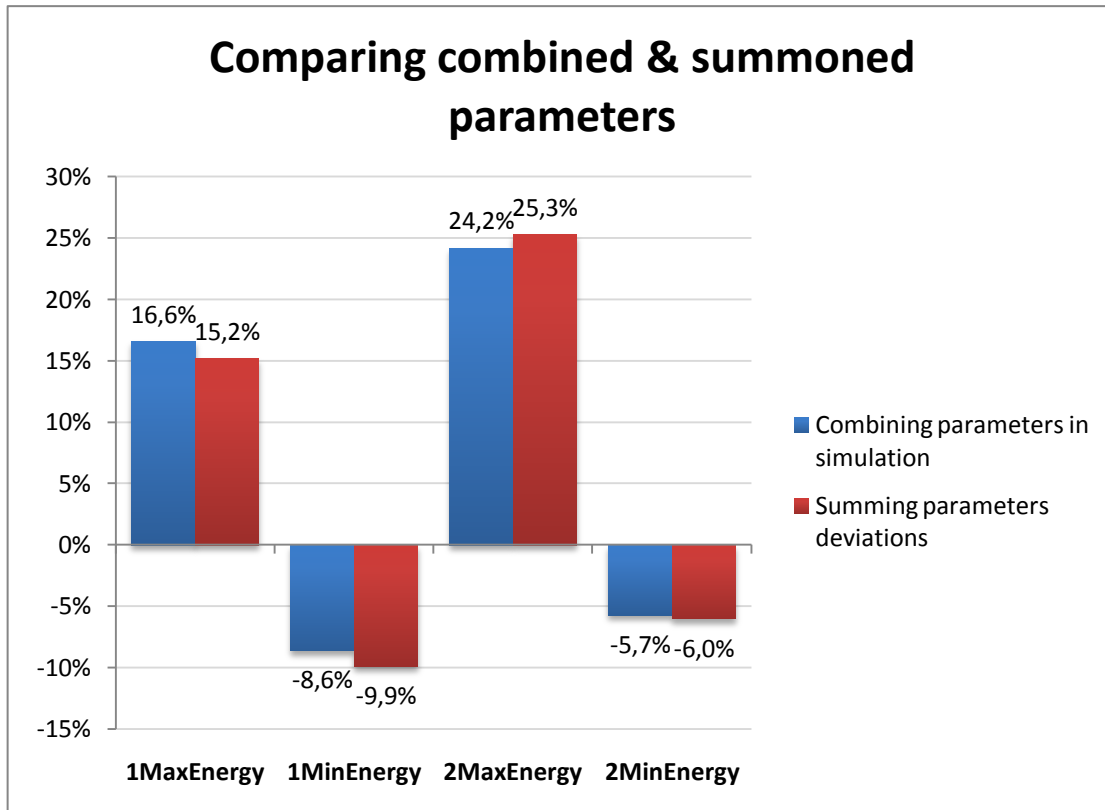


Figure 7.7 Showing the results in percental deviation in specific energy usage when combining parameter changes in simulations (blue bars) and the summation of deviations gathered from parameters tested individually (red bars).

## 7.2 Comparing the software using BESTEST

To compare IDA ICE and VIP-E in a more precise way a validation test called BESTEST is used. The test specifies the geometry of a simple building along with material and climate data, to ensure that the same input data is used in all software that are to be validated using this test.

BESTEST includes several types of tests, called cases. Four of these cases are chosen to compare IDA ICE and VIP-E. The four cases are:

- Case 600 – Low mass building
- Case 600ff – Low mass building with free float temperatures
- Case 900 – High mass building
- Case 900ff – High mass building with free float temperatures

Case 600 and case 900 are used to calculate the annual energy used to heat and cool the building while case 600ff and case 900ff are used to calculate the indoor temperature without any temperature set-points indoors. The cases are further described in Section 6.3. The following pages show the results from simulations when using these cases together with results from using other building energy analysis software.

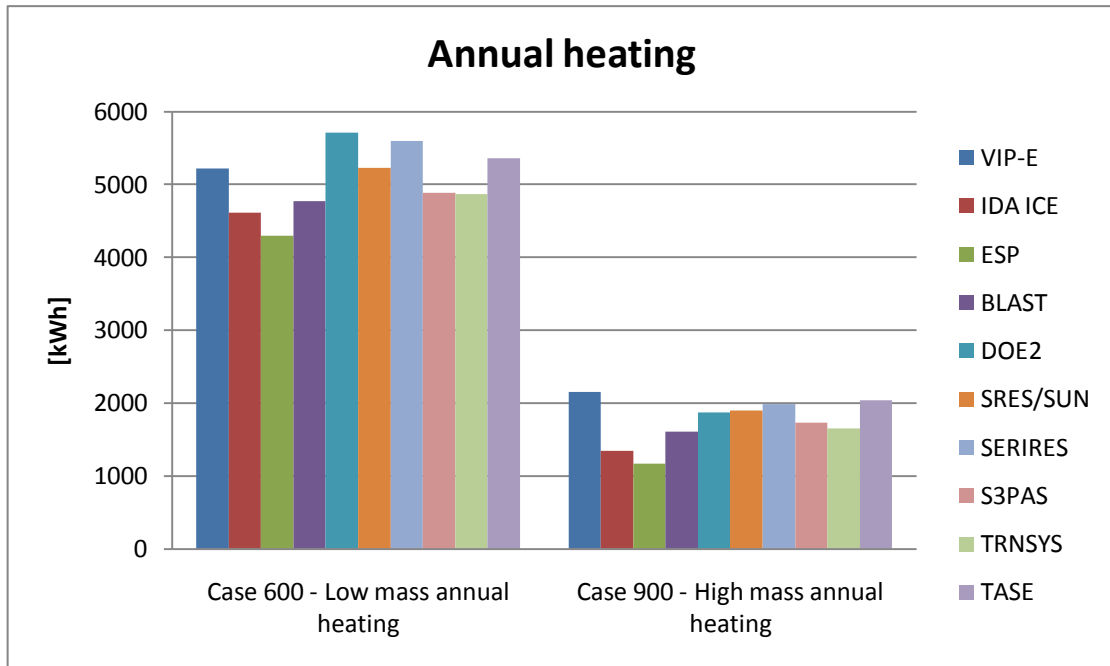


Figure 7.8 Annual heating from simulations made using case 600 and case 900.

Table 7.11 Annual heating.

Case 600 - Low mass annual heating		Case 900 - High mass annual heating	
Software	[kWh]	Software	[kWh]
<b>VIP-E</b>	5216	<b>VIP-E</b>	2150
<b>IDA ICE</b>	4614	<b>IDA ICE</b>	1348

Table 7.12 Difference in energy used for heating between VIP-E and IDA ICE, in percentage.

Case 600 - Low mass annual heating	Case 900 - High mass annual heating
11.5 %	37.3 %

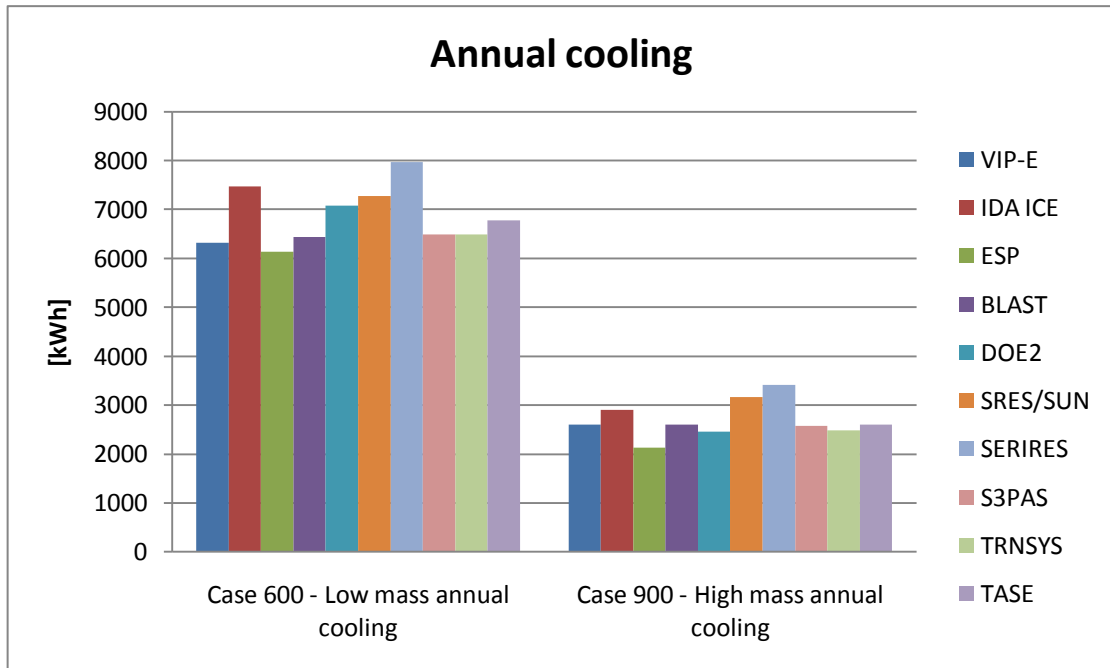


Figure 7.9 Annual cooling from simulations made using case 600 and case 900.

Table 7.13 Annual cooling.

Case 600 - Low mass annual cooling		Case 900 - High mass annual cooling	
Software	[kWh]	Software	[kWh]
<b>VIP-E</b>	6322	<b>VIP-E</b>	2599
<b>IDA ICE</b>	7467	<b>IDA ICE</b>	2906

Table 7.14 Difference in energy used for cooling between VIP-E and IDA ICE, in percentage.

Case 600 - Low mass annual cooling	Case 900 - High mass annual cooling
15.3 %	10.6 %



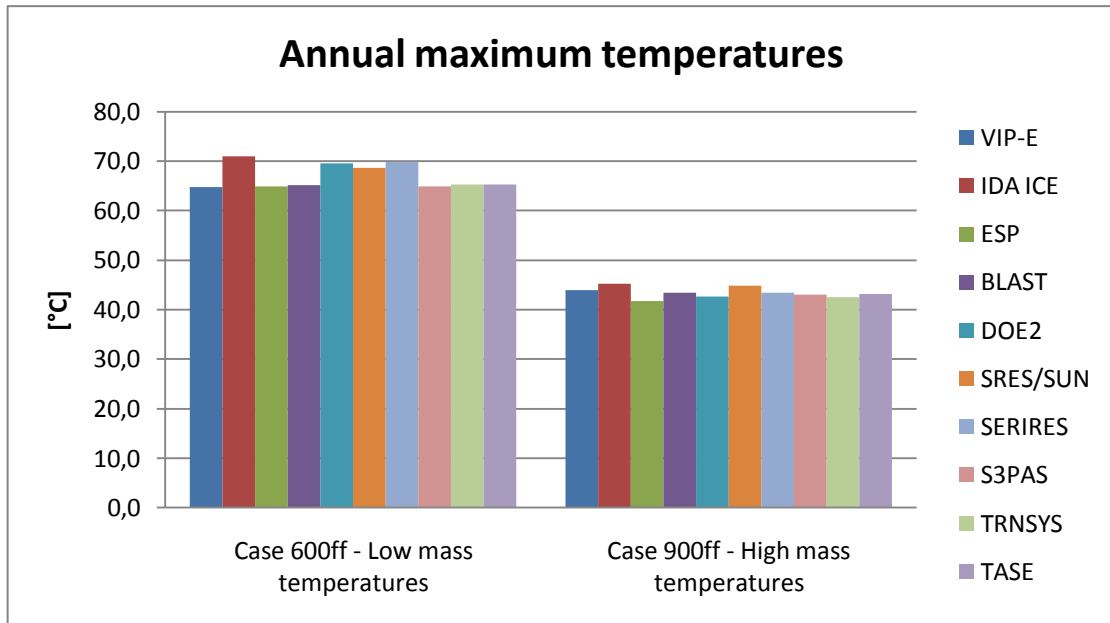


Figure 7.10 Annual maximum indoor temperatures from simulations made using case 600ff and case 900ff.

Table 7.15 Annual maximum indoor temperatures.

Case 600ff - Low mass temperatures		Case 900ff - High mass temperatures	
Software	Max [°C]	Software	Max [°C]
<b>VIP-E</b>	64.7	<b>VIP-E</b>	44.0
<b>IDA ICE</b>	71.0	<b>IDA ICE</b>	45.3

Table 7.16 Difference in maximum indoor temperature between VIP-E and IDA ICE, in percentage.

Case 600ff - Low mass temperatures	Case 900ff - High mass temperatures
8.8 %	2.9 %

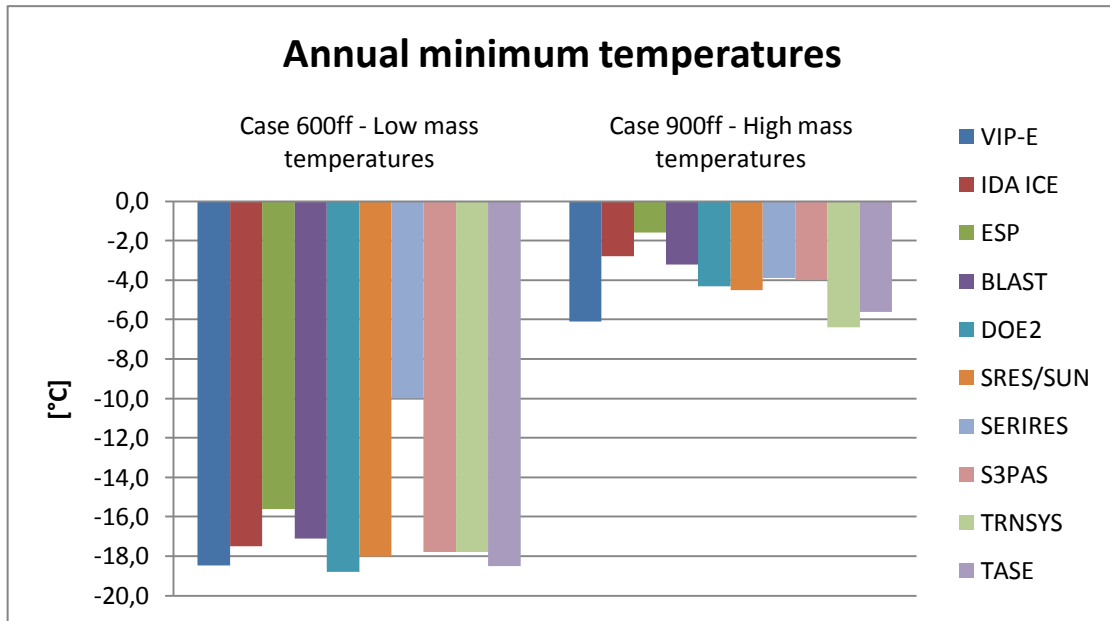


Figure 7.11 Annual minimum indoor temperatures from simulations made using case 600ff and case 900ff.

Table 7.17 Annual minimum indoor temperatures.

Case 600ff - Low mass temperatures		Case 900ff - High mass temperatures	
Software	Min [°C]	Software	Min [°C]
<b>VIP-E</b>	-18.5	<b>VIP-E</b>	-6.1
<b>IDA ICE</b>	-17.5	<b>IDA ICE</b>	-2.8

Table 7.18 Difference in minimum indoor temperature between VIP-E and IDA ICE, in percentage.

Case 600ff - Low mass temperatures	Case 900ff - High mass temperatures
5.3 %	54.2 %

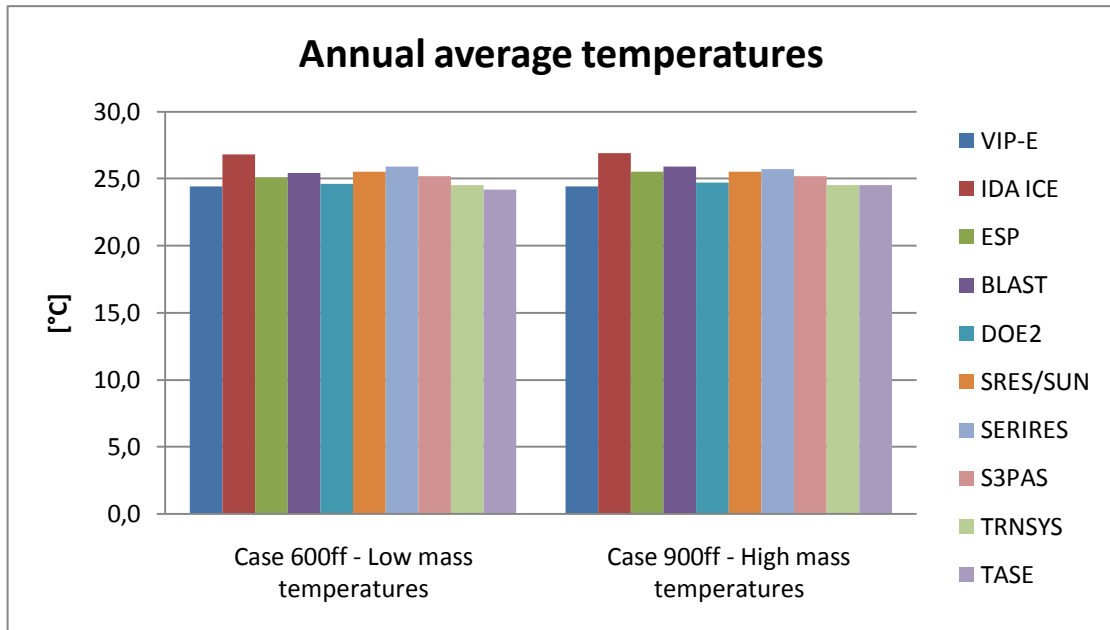


Figure 7.12 Annual average indoor temperatures from simulations made using case 600ff and case 900ff.

Table 7.19 Annual average indoor temperatures.

Case 600ff - Low mass temperatures		Case 900ff - High mass temperatures	
Software	Average [°C]	Software	Average [°C]
<b>VIP-E</b>	24.4	<b>VIP-E</b>	24.4
<b>IDA ICE</b>	26.8	<b>IDA ICE</b>	26.9

Table 7.20 Difference in average indoor temperature for VIP-E and IDA ICE, in percentage.

Case 600ff - Low mass temperatures	Case 900ff - High mass temperatures
8.9 %	9.2 %

## 8 Discussion

The analysis done in this work aims to investigate the theoretical deviations that occur in specific energy usage due to parameter changes. This is done as a part of a bigger task; to, as in a precise matter as possible, be able to predict the actual energy usage in buildings. Not only can deviations in energy usage occur depending on different choices made throughout the analysis procedure, differences also occur between this calculated value and the measured value. To use the outcome of this analysis in order to decrease the theoretically calculated deviations is only one step; the procedure used in the energy analysis also has to be adapted to reality. The only way to do this is by comparing the forecasted results with the actual building's energy usage. This work has only just started. Some buildings energy usages have already been compared, with interesting results. In the master's thesis Energy performance in multi-family dwellings, Eliasson & Lindström (2009) investigated why the forecasted energy usage differed from the measured value in four buildings associated with HSB, a Swedish organisation with housing co-operatives. For these buildings the largest measured energy used for heating was 112 % greater than the forecasted value. Without knowing anything of the procedure used when analysing these buildings, it should be said that even when using a procedure completely cleared from choices made by the single designing engineer, this procedure still has to be calibrated with reality. That means that parameters set in a calculation standard procedure have to be reviewed continuously and compared to analysed buildings where the actual energy usage has been measured.

### 8.1 Individual simulations

An energy analysis with the intent to calculate the specific energy usage of a building involves a huge number of parameters that affects the final result in different ways. These parameters are of course not independent of each other but might either result in a bigger or smaller final result than the summation of their effect as single parameters. To obtain an understanding of to what extent the different parameters affect the final outcome it is however necessary to look at them one by one. This is done in the simulations where the parameters have been changed individually.

These simulations were done to see the magnitude of their impact on the calculated specific energy usage.

#### 8.1.1 The effect of climate and location

One of the parameters affecting the final result the most is the choice of climate file to use, especially in IDA ICE. As an example the Stockholm climate data increases the specific energy usage with 6.9 % in comparison to the reference object in IDA ICE. In VIP-E this increase is 2.4 %.

The difference in results is partially due to the way the different software are programmed, but the main reason the difference occur is probably because of the different climate data used. IDA ICE uses climate data from 1977 while VIP-E uses a synthesis of climate data collected from 1993 to 2003. A synthesis of different years will dampen extreme conditions that can occur during certain parts of a single year.

This could explain why IDA-ICE climate files result in larger deviations in the calculated result than VIP-E's climate files.

In IDA ICE the climate file used was changed from Säve, used in the reference object, to Landvetter. These two locations are situated only 25 km from each other. Despite of their geographical closeness to each other the outcome of result differed with an increase in specific energy usage of 3.7 %. These results show that the choice of climate file used in a simulation has to be well considered. A way of getting around this issue is to specify which climate data to use in which locations of the country. Either a map can be worked out in advance, or this map can be worked out along with buildings in new locations being analysed. The locations set in the simulations do not affect the calculated result as much as the climate files. The location chosen should be as geographically close to the building analysed as possible.

### 8.1.2 Three ways of dealing with airing

The energy loss caused by airing is hard to predict due to the tenants habits. Svebyprogrammet (2009) provides three ways of dealing with this energy loss. The energy loss can be expressed as an increase in air leakage per envelope area and second by  $0.5 \text{ l}/(\text{m}^2\text{s})$ ; an increase in ventilation rate per  $A_{\text{temp}}$  by  $2.3 \text{ l}/\text{m}^2$  and apartment, or by adding  $4 \text{ kWh}$  per  $A_{\text{temp}}$  and year to the energy usage. The last option is the one recommended by Svebyprogrammet and this option is also the one used by NCC, and therefore also used in the reference object. All three alternatives are used in simulations, to see how they affect the calculated result. The simulations show that the addition of  $4 \text{ kWh}/(\text{m}^2\text{yr})$  to the energy usage is the alternative that produces the highest energy usage, thereby presenting a result on the safe side. Although Svebyprogrammet stresses that the variations and the uncertainties associated with airing are big, this is a parameter that does not lead to any theoretical deviations as long as this single figure is always used.

### 8.1.3 Considering shading

The way the shading of a building is handled differs between the software. In IDA ICE external shading caused by the surrounding environment such as buildings can be set. VIP-E allows the software user to set the horizon angle. Both software also allows different types of blinds to be used in simulations. In Svebyprogrammet (2009) different ways of shading windows using e.g. curtains or blinds are listed, but a standard solution is provided that summons the external shading and the behaviour controlled shading. This summation results in a sun screening coefficient of 0.5 [-] that is to be multiplied with the solar heat gain coefficient SHGC, and the solar transmittance  $\tau$ . This is done in the reference object.

Simulations are done in both software using blinds activated by solar radiation above  $100 \text{ W}/\text{m}^2$  instead of using the sun screening coefficient. When the blinds are used in simulations, a sun screening coefficient of 0.71 according to Svebyprogrammet is used to take the external shading into consideration. These simulations lead to an increase in the energy usage of 0.1 % in IDA ICE and 2.9 % in VIP-E. The result from the simulation in IDA ICE is almost equal to the result retrieved from using the sun screening coefficient of 0.5.

The simulation made in VIP-E points towards something else; using the standard sun screening coefficient of 0.5 could actually underestimate the actual energy usage. In VIP-E there is however one more parameter that has a huge impact on the calculated energy usage; the horizon angle. Svebyprogrammet uses two sun screening coefficients, one representing the external shading and one representing the internal shading. They both have the value of 0.71 and are multiplied into the total coefficient of 0.5. In IDA ICE these figures includes the horizon angle, but in VIP-E the horizon angle is set separately. So when using the standard sun screening coefficient of 0.5 in VIP-E, the horizon angle is actually taken into consideration two times, with an increased heating as result.

This leads to the question of how to deal with the horizon angle. The simulations show that this parameter is, besides the set-point temperature, the parameter that results in the largest deviations in the entire simulation series made in VIP-E. The procedure used by NCC stresses that the angle under normal conditions should be set to between 15° - 30°, but that the angle should not be set below 5°. In the reference object the horizon angle is set to 5°. Depending on how this parameter is set, using this procedure, the result can differ up to 9.2 % according to the simulations. This raises questions whether the horizon angle and the sun screening coefficient should be combined in simulations. Regardless of the outcome of that decision, the horizon angle is a parameter that really has to be taken into consideration before the value is set.

#### **8.1.4 Indoor temperature**

The set-point temperature is, not surprisingly, a parameter that has a great influence on the calculated specific energy usage. While NCC (2009) recommends that 21°C is used in all small houses, and 22°C in multi-dwelling buildings, Svebyprogrammet suggest that 21°C is used in all buildings but retirement homes, where 22°C should be used. Increasing the set-point temperature with one degree increases the specific energy usage 6.5 % in IDA ICE and 6.3 % in VIP-E. This is a big deviation from the reference object, but if the procedure established by either NCC or Svebyprogrammet is used, the only way this parameter could be set incorrect, is if the software user does not know what differs a small house from a multi-dwelling building.

#### **8.1.5 The procedure of measuring**

Two parameters that were expected to have a huge impact on the calculated specific energy usage were the floor area and the building height when measured manually. The area was measured in AutoCAD when used in the reference object, and then the drawing was printed as an A3-format, and measured manually. All simulations resulted in a decrease in specific energy usage of less than 1 % using these manually measurements. But when comparing these decreases in energy usage to the changes made as a difference in percentage, it is actually somewhat clear that bigger deviations should not be expected. The change in floor area that arose due to the different measurements procedures was only 1.2 % and the difference in building height around 2 % in both software.

This moves focus away from the unexpected small difference in energy usage to the way the manual measurements have been carried out. Could it have been, that since

we knew that the manual produced measures were to be used in the analysis, too much effort were put into performing them more exact than someone else would have done? To answer that question it should be mentioned that the reference object has been analysed before using the software Enorm produced by EQUA Simulation AB. Not wanting to be influenced by that analysis we have tried not to look closer into it. But when it came to the measurement of the floor area, it turned out that the analysis in Enorm had been performed using manually measured areas. So firstly, we measured the area by hand. And secondly, we compared our result of the measurement with the one used in Enorm in order to make sure that our fault was bigger than that one. This should prove that there are other parameters that should be of a greater concern than the way the area is retrieved. Note that a larger building could be affected in other ways, and that deviations still occur. Hence, measurements should be performed in AutoCAD, to ensure deviations are avoided when setting these parameters.

### **8.1.6 The thermal bridges**

In the reference object the thermal bridges have been analysed individually. This is a time consuming task and therefore seldom done. Instead NCC (2009) recommends that the thermal bridges are dealt with by increasing the  $U_m$ -value with 15 %. This is done in simulations in both software. 10 % is also added to the  $U_m$ -value in two simulations with the purpose to see whether that gets closer to the result retrieved from when simulating the reference object. The result shows that using the additional 15 % in the  $U_m$ -value increases the specific energy usage by 1.5 % in IDA ICE and 0.8 % in VIP-E. When using 10 % the specific energy usage decreases with less than 1 % in both software. This shows that if a default value is to be used, 15 % is on the safe side, and actually fairly close to analysing the thermal bridges individually.

According to the simulations done the thermal bridges in the reference object are equal to adding about 12 % to the  $U_m$ -value. The effect on the specific energy usage is about 5 % in both software. This difference can be explained by the fact that thermal bridges only increase the energy used for heating due to transmission losses.

### **8.1.7 Choosing wind profile**

The wind profile sets a percentage of the wind speed in the climate file that is used in a simulation. For the reference object a suburban wind profile is used in IDA ICE and in VIP-E the percentage is set to 70 % which is equal to a partially wind protected location. Simulations are performed using an increased wind speed by choosing open country in IDA ICE and setting the percentage to 95 % in VIP-E. This change results in an increase of 0.2 % in specific energy usage in IDA Ice and 3.1 % in VIP-E. There are no regulations documented in NCC's procedure of how to set this parameter. In IDA ICE the effect on the calculated result can be overseen, but the effect in VIP-E is quite large. To draw conclusions based on these simulations are difficult, and setting up a standard that decreases the possible deviations seems hard to do. This is a parameter that has to be carefully considered in every single building energy analysis.

### **8.1.8 Setting the material properties**

A big effort was put into setting the material properties in the reference object. For those construction parts that are assembled using different materials, equivalent material properties have been calculated. The compilations of material data can be seen in Section 5.3.

This is however not entirely necessary, since both software have default materials with predefined properties that can be used. Using these properties saves time, but that has to be put in relation to the possible deviation in specific energy usage. VIP-E is provided with some default equivalent material properties, and these are used where possible in the building. IDA ICE has no equivalent materials as default and in this simulation only standard materials are used. These simulations result in a decrease in specific energy usage by 1.4 % in VIP-E and 2.3 % in IDA ICE. The difference in result can partially be explained by the difference in default material properties. VIP-E has equivalent materials as default, and using these properties will increase the energy usage in comparison to the default materials used in IDA ICE.

The material data used in the reference object is gathered from different sources, and it should be said that the material properties in the software are just as likely to be correct as the ones we have compiled. Should material data be possible to retrieve from the manufacturer, this is the data that is preferred. This is not always possible since some simulations are performed before the choices of which materials to use have been made. The comparison shows that using equivalent material properties should be used. If the details regarding the use of equivalent materials are not known, an approximation can still be done. As an example, an exterior wall insulated with mineral wool will most certainly include wooden joist.

### **8.1.9 The choice of ground properties**

The reference building is founded on bedrock. In IDA ICE drainage material is added straight below the slab insulation above the bedrock. This ground property was not possible to choose in VIP-E, and therefore disregarded. The ground properties may not always be known, and therefore simulations are performed to analyse the deviations that might occur depending on the choice of ground. The simulations results in deviations of up to 2 %. Both software give the highest specific energy usage when using only bedrock, without drainage layer. Should the ground properties be known, those properties are of course the ones to use. But if the properties are not known and bedrock could be positioned some smaller distance below the building, then the properties for rock should be used in order to produce a result that does not underestimate the energy usage.

### **8.1.10 Windows**

Simulations are done when both adjusting the frame rate as well as using an equivalent area for all windows. The frame rate is set in both software. The reference object has windows with a frame rate of 25.4 %. NCC (2010) suggests that the frame rate is set to 25 % in rough estimations when the actual frame rate is not calculated. In IDA ICE the default frame rate is 10 % and in VIP-E 20 %. These three values are used in simulations. All simulations produce a lower specific energy usage than the one in the reference object. The reason is that the frame and the rest of the window are



set using the same U-value. When decreasing the frame rate the U-value stays the same, but the building gains more heating energy due to the solar radiation. According to our estimation of the window frame rate in Section 5.1.2, the suggestion in NCC's procedure to use a frame rate of 25 % is correct. A proper way of using the correct frame rate would be to perform a calculation as done when setting up the reference object. The main importance regarding this parameter lies in not using the default values set in the software.

One simulation was also performed in IDA ICE where the windows were merged together to as few as possible. This is done since placing the windows one by one in a model is time consuming. When doing this the perimeter of the windows is affected. This perimeter is used when the effect of the thermal bridges is simulated. The same window area and frame rate as in the reference object is used. The simulation resulted in a decrease in specific energy usage of 0.6 %. This way of creating a model does not affect the result as much as many other parameters and can be used with one exception. In IDA ICE the operative temperatures are possible to calculate, and if this is ever to be done, the windows have to be set one by one. The operative temperature takes into account both the room temperature as well as the surrounding surface temperatures (Petersson, 2004). Therefore the operative temperature in front of a window with an area equivalent to all windows in a certain cardinal direction will be more extreme than if the actual windows are used.

### **8.1.11 Modelling the roof**

Of simplicity reasons the roof modelled in IDA ICE is flat. The roof in VIP-E can easily be pitched but since the aim is to compare differences in the simulations between the two software, this roof is also flattened. In one simulation in each software the roof is pitched, and the difference in result compared. In IDA ICE the specific energy usage decreased by 0.9 %, while in VIP-E an increase occurred of 1.2 %. So these simulations diverged and that is an interesting result. The pitched roof in IDA ICE is created using the interior measurements, as opposed to VIP-E, where the exterior area is used. So when modelling the roof in IDA ICE the roof is partially pitched with the top still set as flat, since these are the interior geometry, see Figure 6.1. The top part of the roof is only considered in terms of a thermal resistance.

When setting the pitched roof area in VIP-E the external area is measured in AutoCAD. In the drawings used in AutoCAD the roof is angled from the base of the roof and all the way to the ridge. Therefore a larger roof area is used in VIP-E than in IDA ICE, which leads to larger transmission losses. This partially explains the difference in results. If the same geometry were to be used there would still be a difference in result, since the exterior area still would be larger than the interior area. The conclusion is that a flat roof can be used in IDA ICE, since an equivalent height of a building is relatively easily calculated, and the specific energy usage increases with less than one percent in comparison to when pitched roof is used. In VIP-E it is more complicated to use an equivalent height than to use the actual exterior areas, since they are easily set in the software, and also easily measured in AutoCAD.

### 8.1.12 The parameters not mentioned above

Some of the parameters used in the simulations are not commented above. These are all, except for one, parameters that did not cause any deviations in specific energy usage of more than one percent each. These parameters are discussed in this section.

The exception is the simulation done where the infiltration is changed from 0.015 l/(m<sup>2</sup>s) to 0.03 l/(m<sup>2</sup>s), code 1Ffdiv20. The simulation resulted in an increase in specific energy usage by 2 %. This should only occur due to a mistake in input data; the air infiltration flow rate shall be divided by 40 (which corresponds to 0.015 l/(m<sup>2</sup>s) in the reference object) when used as a fixed infiltration in an exhaust air system. Not divided by 20 as done in this simulation (Elmroth, 2009).

The infiltration is also changed in two other simulations in IDA ICE. All three simulations resulted in a small decrease in specific energy usage with less than one percent. According to NCC (2009) the infiltration should be set as fixed and the deviations that occur due to these simulations are therefore not an issue.

In a simulation performed in each software the number of zones used in the building was changed to three. This decreased the specific energy usage by 0.2 to 0.3 %. This shows that dividing small houses into different zones is probably over-elaborating a simulation of this building size. No conclusion can be drawn from these simulations of the need of using zones in larger buildings, but most certainly using zones will affect the outcome more, with increasing building size.

The last simulations to discuss are software-related. In IDA ICE simulations where performed to see the difference in energy usage when changing the effect of the ideal heaters, see Section 6.1.3. The result showed a small decrease in specific energy usage of less than one percent. The ideal heater is only used to fulfil the need for heating, and the effect set should fulfil that demand in order to produce a reliable result. A designing engineer who uses IDA ICE should bear in mind that when once having created a zone with an ideal heater, the set effect on the ideal heater does not always change if the size of the zone is changed. This could end up showing a result in specific energy usage lower than it should actually be, since the temperature demands are not fulfilled.

One simulation was also done when using a summer day for pre-heating the building before running a simulation, see Section 6.1.12. The simulation shows a decrease in specific energy usage of 0.2 %. The correct day to use when pre-heating the building should be the first day that is used in the simulation time period.

In VIP-E two simulations are done when changing maximum and minimum recommended values for solar reflection on the ground according to StruSoft AB (2009). Using the maximum value, 50%, the specific energy usage decreased with 0.8 %, and when using the minimum value of 20 % the specific energy usage increased with 0.8 %. These are no extreme deviations, but the designing engineer still have to consider the surrounding of the building. Asphalt have a solar radiation absorptivity factor  $\alpha_{sol}$  [-] of 0.93 that can be compared to e.g. concrete with  $\alpha_{sol}$  between 0.6 – 0.7 (Pettersson, 2004). This can result in a larger deviation than in the performed simulations. In northern parts of Sweden, where the ground is covered with snow during parts of the year, this also will affect the solar reflection on the ground although the light hours during a day are few during the winter.

The air pressure was changed from 99.3 kPa used in the reference object to the default value of 100 kPa. This increased the specific energy usage by 0.4 %. The value valid

for the specific height above sea level related to the simulated building is the one to use when setting this parameter.

Lastly, the wind direction was changed from west to south-west in a simulation which resulted in a decrease of 0.1 %, showing no urgent need of a standard procedure of how to handle this parameter.

## 8.2 Combining parameters in software

The simulations using combinations of parameters described in Section 6.2 provided different deviations in the two software. In general the combination of parameters in VIP-E resulted in a higher energy usage than the combinations of parameters in IDA ICE. The biggest difference between the software appeared when the parameters that increased the specific energy usage were combined. IDA ICE showed an increase in specific energy usage of 16.6 % and VIP-E produced an increase of 24.2 %. According to conclusions made in Section 8.1.3, this large difference in result might be related to the horizon angle. Further discussion regarding this matter will follow. The simulations performed to test the lower limit of deviation provided a decrease in specific energy usage of 8.6 % in IDA ICE and 5.7 % in VIP-E.

Using these percentages caused by combining parameters in simulations, a largest possible theoretical deviation can be retrieved for both software. These largest possible deviations are found by adding the absolute values of the percentages retrieved from both software. So by adding 16.6 % and 8.6 % as a result for largest possible deviation in IDA ICE the sum is 25.2 %. Adding the same values retrieved from VIP-E result in a largest possible deviation of 29.9 %. So, are these values possible to add? Yes, they are and the explanation follows. The reference object could, when simulated, have resulted in a specific energy usage that landed anywhere between the highest and the lowest calculated specific energy usage, which is calculated when combining the parameters. Suppose that the result of simulating the reference object in IDA ICE would have provided the same result as the 1MinEnergy-simulation. Then every single change of parameters, according to the procedures used, would result in an increase in specific energy usage. At this state, following the used procedures, no further decrease in specific energy usage is possible. If all parameters are changed into worst case increase for this analysed building, this will result in a specific energy usage corresponding to 1MaxEnergy. Thus, the increase in specific energy usage is equal to adding the percentages of the deviations in simulation 1MaxEnergy and 1MinEnergy according to what has been done above, and the increase becomes 25.2 %, see Figure 8.1.

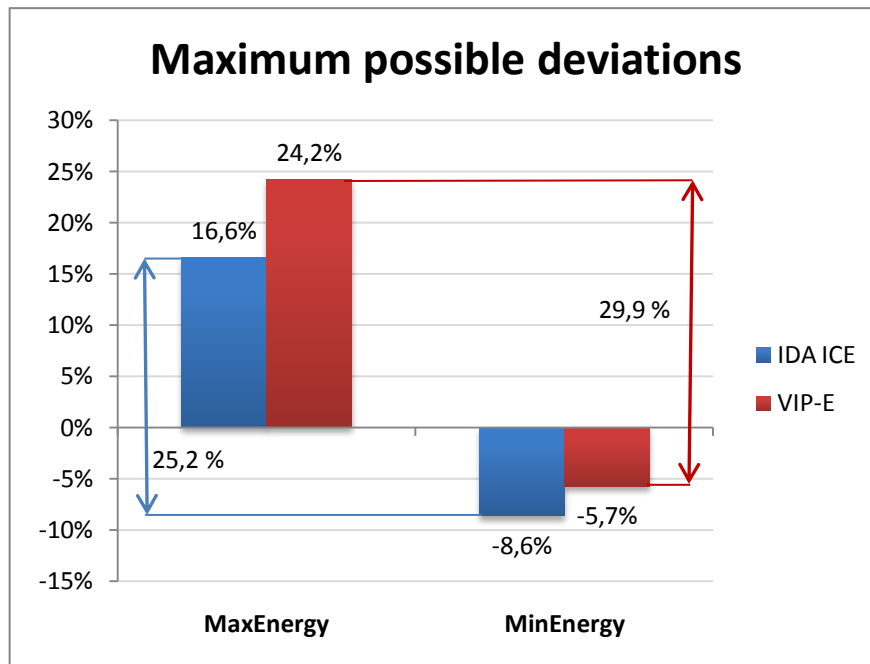


Figure 8.1 Showing the largest possible deviations in IDA ICE and VIP-E.

So, when having calculated the specific energy usage of a building there is no way of predicting the possible deviation in terms of upper and lower limits in percentages, as e.g.  $\pm 20\%$ , but only refer to the sum of these percentages as absolute values.

These possible deviations are large, but it should be stressed that they are the result of combining the most extreme values allowed according to the procedure used and using assumptions that ensure large deviations. Combinations like this are most likely seldom done when analysing buildings specific energy usage.

The percental changes in specific energy usage retrieved from testing the parameters individually are also compiled in Section 7.1.4. This is done to see whether the sum of the individually tested parameters in any way can be compared to the simulations performed when combining the parameters. The result is interesting; in none of the four simulations does the percental change in specific energy usage differ more than 1.4 % from the sum of the same parameters. This implies that changing one parameter in a certain simulation will affect the result, presented in specific energy usage, in the same order of magnitude as the deviations seen in the simulations using the individually tested parameters. This is an approximate method of evaluating the effects of parameters in simulations.

It should be noted that all deviations (presented as percentages of the change in specific energy usage) retrieved from the individually tested parameters simulations cannot without reflection be subtracted from result produced by the simulations done where the parameters were combined. This should be avoided since some of the parameters have a big influence on each other; changing e.g. both the use of blinds and the horizon angle in VIP-E will produce different result than the sum of the percental deviations retrieved from these individually tested parameters.

According to this conclusion, when comparing the results in the two simulations that increased the specific energy usage, a large part of the difference can be related to the horizon angle. And using the same conclusion, the raised set-point temperature from 21° C to 22° C in the simulations has had a big impact on the result.

This section has so far put the attention towards two main points:

- I. The largest plausible deviations in specific energy usage caused by combining parameters into worst case scenarios.
- II. Summing the results from the individually tested parameters are almost equal to the deviations of combining them in simulations.

As previously discussed the simulations performed when combining the parameters resulted in quite large deviations. The combinations of parameters are subjectively chosen and meant to produce the largest deviations that are possible to occur when using the procedure used by NCC and Svebyprogrammet. Even if these parameters are allowed to be set as done in the simulations, it is not very likely these combinations are used. At least some of the parameters will most certainly be set differently and thereby produce a result that is not this extreme.

But even so, it is desirable to make sure that simulations cannot produce as large deviations as these depending on choices made by a single software user. Therefore standards are needed, and by using standards that provide less room for assumptions, these large deviations can be avoided.

The two main points mentioned should be used to decrease the possibility of large deviations in building energy analysis. The list of individually simulated parameters can be used to see what parameters to put the main focus on. If point II. above is presumed correct, the percental deviation (in specific energy usage) caused by a change of a certain parameter can be subtracted from the sum of percental deviations in specific energy usage, to appreciate how much smaller the possible deviation could be by ruling out the possibility of changing this parameter.

The question is which parameters to focus on first and which ones can be overseen when trying to decrease the largest possible deviations. One way of rating the parameters is using the results from the simulations where the parameters were tested individually. In these results a tolerance level can be set. Suppose this tolerance level is set to 2 %, see Figure 8.2. Then all parameters that cause a percental deviation in specific energy usage, increase or decrease, of more than 2 % should be studied closer, with the objective to reduce the possibility to vary them.

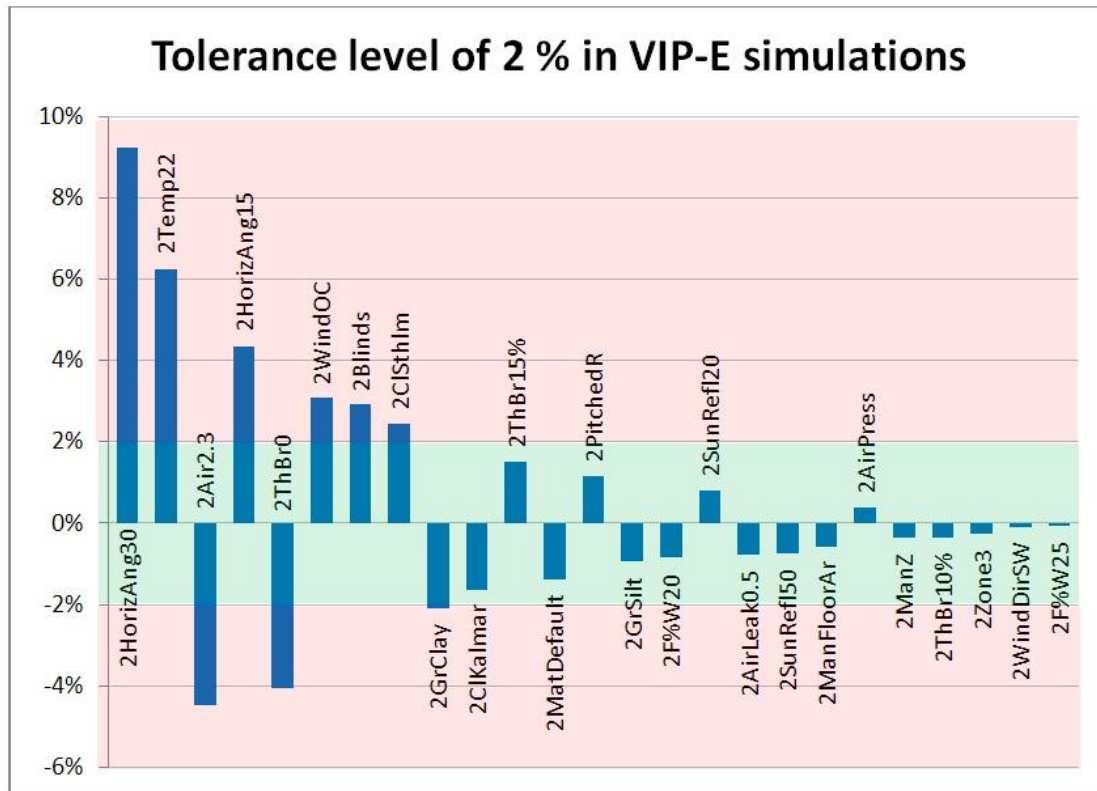


Figure 8.2 Example showing the use of a tolerance level of 2 %.

This tolerance level is not only to be used when rating the parameters used in these simulations. A procedure elaborated to be used when performing building energy analysis always has to be changed and updated. New ways of performing energy analysis and changes in software will affect the use and influence of parameters, and even add new ones. By testing a parameter in a reference object its impact on the simulation result can be established. The tolerance level shows whether the specific parameter will have to be reviewed further or whether it just has a minor impact on the final calculated specific energy usage. Many parameters causing deviations that exceed the tolerance level cannot be completely locked in an energy analysis procedure. For some of these parameters the alternatives can be restricted. If that is impossible to do, they have to be taken into great concern before being set in a simulation.

### 8.3 Software comparison

There are other factors that affect an energy analysis than the settings of certain parameters. A major factor is the choice of software. When simulating the reference object in VIP-E and IDA ICE the difference in result was surprisingly low; 0.25 % differed in specific energy usage between the two software. In Section 7.1.3 the software were compared to each other by changing the same parameters in both software equally. The difference in result, presented in Figure 7.5 shows that although the final result was almost the same for the reference object, the settings of the parameters affect the final calculated result differently in the different software. The similarity in the specific energy usage shown when analysing the reference object seems to be somewhat of a coincidence.

This comparison is not entirely correct to draw any further conclusions from, other than that the different software work in different ways. A more precise way of comparing building energy analysis software is to use BESTEST, described in Section 6.3. The result is presented in Section 7.2. BESTEST main purpose is to validate a building energy analysis software and also to identify the sources of larger deviations in the software. In this thesis the main purpose of using BESTEST is merely to emphasize that different software produce different result, and energy analysis result shall never be compared to each other. And although the results of the BESTEST simulations showed a huge variation in the result, the combination of parameters can still end up showing a very similar result between different software, as seen when simulating the reference object.

## 9 Conclusions

Comparing the results retrieved from the simulations when combining the tested parameters to the sum of the deviations in percentage showed that these two results were in the same order of magnitude. Therefore, the results compiled from the simulations done when testing each parameter individually can be used to identify the parameters that affect the energy usage mostly. Furthermore, the percental deviations in specific energy usage retrieved from the simulations performed when testing the parameters individually can be subtracted from the sum of the same percental deviations to approximate how much the possible deviation could decrease by ruling out the possibility of changing a certain parameter.

After changes have been conducted in a building energy analysis procedure these changes shall be evaluated again using the same building energy analysis software, and using the combinations of the parameters as described in Section 6.2 in order to evaluate the new largest possible deviations.

The results show that the deviations in calculated specific energy usage can, depending on the software used in the analysis, reach the magnitude of 30 %. This size of deviation is possible but unlikely to achieve and can be lowered by changing the procedure used, with the means to decrease the room for assumptions made by the single designing engineer.

A tolerance level described in Section 8.2 should be set in order to, as a first step, estimate which parameters to evaluate further and treat with special concern in a building energy analysis procedure. This tolerance level should be used continuously to evaluate new parameters as well as parameters whose effects on the specific energy usage are to be changed due to different procedures or changes in building energy analysis software used.

Several conclusions are drawn in Chapter 8; some of them are mentioned here:

- A national map should be used showing what climate data to be used where. When new buildings in the same region are analysed the same climate data should be used. This map can either be worked out in advance, or along with buildings in new locations being analysed.
- Since different climate data is used in different software there is a need of standardized climate data that can be used in all building energy analysis software.
- When blinds are used in simulations, a sun screening coefficient of 0.71 according to Svebyprogrammet is to be used to take the external shading into consideration.
- The horizon angle has proven to have a big impact on the calculated specific energy usage. The use of this parameter and combining it with a sun screening coefficient or blinds should be well taken into consideration.
- The manual measurements did not affect the result in specific energy usage as much as first expected, but measurement should however be performed in AutoCAD, to ensure deviations are avoided when setting these parameters.
- Increasing the  $U_m$ -value of 15 % in order to take the effect of thermal bridges into consideration in an analysis is setting the marginal on the safe side, and the result in the analysis is close to the result when analysing the thermal bridges individually.



Finally, to use the outcome of this analysis in order to decrease the theoretically calculated deviations is only one step; the procedure used in the energy analysis also has to be adapted to reality. There is only one way to do this, namely comparing the forecasted results with the actual building's energy usage.

## 10 Continued work

During this work a number of ideas have emerged that could be used as continuous studies. All of them are related to our work and has arisen due to discussions regarding the subject in this thesis.

This work inflicts the use of a reference building, which has been a dual family dwelling. How the settings of the parameters affect a larger building, such as a multi-family dwelling or an office building, where the demands involve not only a minimum temperature, but also involve cooling, remains to be seen.

Comparing the calculated specific energy usage towards the actual usage in buildings is still in an initial phase. Interesting studies can most certainly be done in this field, and then used to modify the procedures used when performing building energy analysis.

Windows is an interesting subject that we unfortunately did not have enough time to look further into. The U-value of window often gets a lot of attention, but other factors related to windows that also affect the energy usage are the solar heat coefficient  $g$ , the solar transmittance  $\tau$  and the emissivity  $\epsilon$ . An interesting subject would be to study simulations over a year to investigate how different combinations of these parameters affect the specific energy usage in buildings, both with and without a cooling demand.

When setting the internal heat loads we did not find any relevant effects [W] to use for describing the equipment in the building. Although the effect used by electric devices can be found, these effects are not the heating effect of the device. Svebyprogrammet has defined some template values, but these values could be specified further and complemented with more values. If using the actual heating effect and combining this effect with user behaviour this would result in more precise predictions of internal heat loads and thereby also a better prediction of the specific energy usage.

The simulations done using BESTEST resulted in large differences in energy usage between the high mass and the low mass building. The differences are of a magnitude that arises questions regarding how to use different building materials in the most energy efficient way. These tests indicate that using high mass materials such as concrete can reduce the specific energy usage substantially. This is a subject that needs to be further investigated using Swedish climate data and combining different building materials.

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## 12 Annex A: Calculation of reference object

### 12.1 Geometry

#### 12.1.1 Equivalent building height for the storage

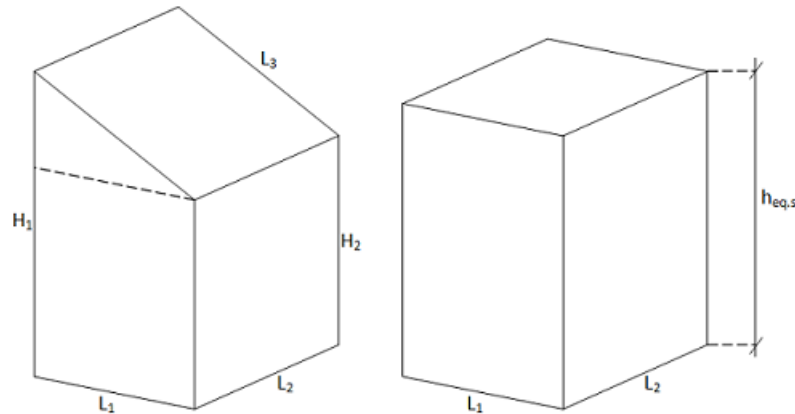


Figure 12.1 Storage with pitched roof transformed into a box with equivalent height.

Measurements from AutoCAD for the storage with pitched roof:

$$L_1 := 2.817 \text{ m}$$

$$L_2 := 3.668 \text{ m}$$

$$L_3 := 3.43892 \text{ m}$$

$$H_1 := 3.73314 \text{ m}$$

$$H_2 := 1.76066 \text{ m}$$

The total area becomes:

$$A_{\text{tot}} := 2 \cdot L_1 \cdot H_2 + L_2 \cdot H_2 + L_3 \cdot L_2 + 2 \cdot \frac{(H_1 - H_2) \cdot L_1}{2} = 34.548 \text{ m}^2$$

The equivalent height of the storage can be calculated as:

$$h_{\text{eq},s} := \frac{A_{\text{tot}} - L_1 \cdot L_2}{2 \cdot L_1 + L_2} = 2.603 \text{ m}$$

### 12.1.2 Equivalent building height for the building

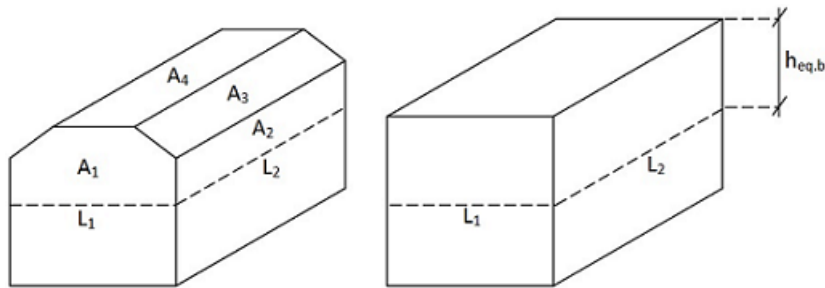


Figure 12.2 Building with pitched roof transformed into a box with equivalent height

Measurements from AutoCAD for the building with pitched roof:

$$L_1 := 8.4\text{m}$$

$$L_2 := 15.352\text{m}$$

$$A_1 := 18.59\text{m}^2$$

$$A_2 := 1.2\text{m} \cdot L_2$$

$$A_3 := 2.27\text{m} \cdot L_2$$

$$A_4 := 4.69\text{m} \cdot L_2$$

The total area becomes:

$$A_{\text{tot}} := 2 \cdot A_1 + 2 \cdot A_2 + 2 \cdot A_3 + A_4 = 215.724\text{m}^2$$

The equivalent height of the building can be calculated as:

$$h_{\text{eq,b}} := \frac{A_{\text{tot}} - L_1 \cdot L_2}{2 \cdot (L_1 + L_2)} = 1.827\text{m}$$

## 12.2 Windows and doors

Calculation of frame percentage of the total window area:

Table 12.1 Windows frame widths.

Frame width for operable windows	$d_o := 100\text{mm}$
Frame width for fixed windows	$d_f := 50\text{mm}$

Table 12.2 Window types 1-4.

Window type 1	Window type 2	Window type 3	Window type 4
$h_1 := 1600\text{mm}$	$h_2 := 1500\text{mm}$	$h_3 := 1300\text{mm}$	$h_4 := 2300\text{mm}$
$w_1 := 910\text{mm}$	$w_2 := 1010\text{mm}$	$w_3 := 910\text{mm}$	$w_4 := 1410\text{mm}$
$n_1 := 8$	$n_2 := 2$	$n_3 := 2$	$n_4 := 2$
Operable	Operable	Operable	Operable

Table 12.3 Window types 5-8.

Window type 5	Window type 6	Window type 7	Window type 8
$h_5 := 1800\text{mm}$	$h_6 := 2200\text{mm}$	$h_7 := 400\text{mm}$	$h_8 := 1200\text{mm}$
$w_5 := 910\text{mm}$	$w_6 := 910\text{mm}$	$w_7 := 910\text{mm}$	$w_8 := 910\text{mm}$
$n_5 := 10$	$n_6 := 2$	$n_7 := 4$	$n_8 := 4$
Fixed	Operable	Fixed	Operable

Total window area:

$$A_{\text{tot.window}} := h_1 \cdot w_1 \cdot n_1 + h_2 \cdot w_2 \cdot n_2 + h_3 \cdot w_3 \cdot n_3 + h_4 \cdot w_4 \cdot n_4 \dots = 49.738 \text{ m}^2$$

$$+ h_5 \cdot w_5 \cdot n_5 + h_6 \cdot w_6 \cdot n_6 + h_7 \cdot w_7 \cdot n_7 + h_8 \cdot w_8 \cdot n_8$$

Total frame area:

$$A_{\text{tot.frame}} := 2 \left[ h_1 + \left| w_1 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_1 + 2 \left[ h_2 + \left| w_2 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_2 \dots = 12.614 \text{ m}^2$$

$$+ 2 \left[ h_3 + \left| w_3 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_3 + 2 \left[ h_4 + \left| w_4 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_4 \dots$$

$$+ 2 \left[ h_5 + \left| w_5 - 2 \cdot d_f \right| \right] \cdot d_f \cdot n_5 + 2 \left[ h_6 + \left| w_6 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_6 \dots$$

$$+ 2 \left[ h_7 + \left| w_7 - 2 \cdot d_f \right| \right] \cdot d_f \cdot n_7 + 2 \left[ h_8 + \left| w_8 - 2 \cdot d_o \right| \right] \cdot d_o \cdot n_8$$

Window frame percentage of the total window area:

$$\frac{A_{\text{tot.frame}}}{A_{\text{tot.window}}} = 25.361 \%$$

## 12.3 Zone parameters

### 12.3.1 Ventilation

Needed supply air for one apartment:

$$V_{\text{supply}} := 0.35 \frac{1}{\text{s}\cdot\text{m}^2} + \frac{\left(4 \cdot \text{persons} \frac{1}{\text{s}\cdot\text{persons}}\right)}{133.42 \text{m}^2} = 0.47 \cdot \frac{1}{\text{s}\cdot\text{m}^2}$$

Needed exhaust air for one apartment:

$$V_{\text{exhaust}} := \frac{10 \frac{1}{\text{s}} + 10 \frac{1}{\text{s}} + 15 \frac{1}{\text{s}} + 10 \frac{1}{\text{s}}}{133.42 \text{m}^2} = 0.337 \cdot \frac{1}{\text{s}\cdot\text{m}^2}$$

Area for two apartments:

$$A := 266.84 \text{m}^2$$

Needed supply air for both apartments in [l/s]:

$$V_{\text{supply}} := V_{\text{supply}} A = 125.394 \cdot \frac{1}{\text{s}}$$

Needed exhaust air for both apartments in [l/s]:

$$V_{\text{exhaust}} := V_{\text{exhaust}} A = 90 \cdot \frac{1}{\text{s}}$$

The greatest flow of the supply and exhaust air flow:

$$V_{\text{tot}} := \max\{V_{\text{supply}} V_{\text{exhaust}}\} = 125.394 \cdot \frac{1}{\text{s}}$$

Round up in agreement with NCC Teknik to:

$$V_{\text{tot}} := 150 \frac{1}{\text{s}}$$

This gives:

$$V_{\text{exhaust}} := \frac{V_{\text{tot}}}{A} = 0.562 \cdot \frac{1}{\text{s}\cdot\text{m}^2}$$

10 % decrease of the supply air to ensure underpressure:

$$V_{\text{supply}} := V_{\text{exhaust}}^{90\%} = 0.506 \cdot \frac{1}{\text{s}\cdot\text{m}^2}$$

### 12.3.2 Airing

Template value for extra heating caused by airing:

$$q_{\text{airing}} := 4 \cdot \frac{\text{kW}\cdot\text{hr}}{\text{m}^2 \cdot \text{yr}}$$

$A_{\text{temp}}$  of one apartment:

$$A_{\text{temp}} := 133.42 \text{m}^2$$

The template value for extra heating caused by airing translated into [W] becomes:

$$q_{\text{airing}} \cdot 2 \cdot A_{\text{temp}} = 121.764 \text{ W}$$



### 12.3.3 Infiltration

Template value for infiltration at 50 Pa:

$$0.6 \frac{1}{\text{s} \cdot \text{m}^2}$$

Translated to be used as a fixed infiltration instead of a wind driven:

$$0.6 \frac{1}{\text{s} \cdot \text{m}^2} \cdot \frac{1}{40} = 0.015 \cdot \frac{1}{\text{s} \cdot \text{m}^2}$$

### 12.3.4 Occupants

$A_{\text{temp}}$  of one apartment:

$$A_{\text{temp}} := 133.42 \text{m}^2$$

Number of occupants:

$$n_{\text{occupants}} := 3.51 \text{persons}$$

Number of occupants per square meter:

$$\frac{n_{\text{occupants}}}{A_{\text{temp}}} = 0.026 \cdot \frac{\text{persons}}{\text{m}^2}$$

Occupant presence per day:

$$h_{\text{present}} := 14 \text{hr}$$

Evenly distributed over 24 hours:

$$\frac{h_{\text{present}}}{24 \text{hr}} = 0.583$$

### 12.3.5 Equipment

Template value for household electricity:

$$Q_{\text{equipment}} := 30 \frac{\text{kW} \cdot \text{hr}}{\text{m}^2 \cdot \text{yr}}$$

70% is assumed to assimilate as an internal heat gain:

$$x := 70\%$$

$$Q_{\text{equipment}} := x \cdot Q_{\text{equipment}} = 21 \cdot \frac{\text{kW} \cdot \text{hr}}{\text{m}^2 \cdot \text{yr}}$$

Translated into  $[\text{W}/\text{m}^2]$ :

$$Q_{\text{equipment}} = 2.396 \cdot \frac{\text{W}}{\text{m}^2}$$

### 12.3.6 Tap water usage

Template value for tap water usage:

$$q_{\text{tapwater}} := 25 \frac{\text{kW}\cdot\text{hr}}{\text{m}^2\cdot\text{yr}}$$

Area for the whole storage:

$$A_{\text{storage}} := 10.33 \text{ m}^2$$

Area for one apartment:

$$A_{\text{temp}} = 133.42 \text{ m}^2$$

Total area of the two apartments and the storage:

$$A_{\text{tot}} := A_{\text{storage}} + 2 \cdot A_{\text{temp}} = 277.17 \text{ m}^2$$

The template value is adapted for use in the software IDA ICE. The template value should not include the storage area which by default is included in the software.

$$q_{\text{tapwater.IDA}} := q_{\text{tapwater}} \left( \frac{2 \cdot A_{\text{temp}}}{A_{\text{tot}}} \right) = 24.068 \frac{\text{kW}\cdot\text{hr}}{\text{m}^2\cdot\text{yr}}$$

## 12.4 Thermal transmittance and heat capacity

Table 12.4 Material properties for insulation, wood and steel.

$\lambda_{\text{ins}} := 0.036 \frac{\text{W}}{\text{m}\cdot\text{K}}$	$\rho_{\text{ins}} := 20 \frac{\text{kg}}{\text{m}^3}$	$c_{\text{ins}} := 750 \frac{\text{J}}{\text{kg}\cdot\text{K}}$
$\lambda_{\text{wood}} := 0.14 \frac{\text{W}}{\text{m}\cdot\text{K}}$	$\rho_{\text{wood}} := 500 \frac{\text{kg}}{\text{m}^3}$	$c_{\text{wood}} := 1500 \frac{\text{J}}{\text{kg}\cdot\text{K}}$
$\lambda_{\text{steel}} := 60 \frac{\text{W}}{\text{m}\cdot\text{K}}$	$\rho_{\text{steel}} := 7800 \frac{\text{kg}}{\text{m}^3}$	$c_{\text{steel}} := 500 \frac{\text{J}}{\text{kg}\cdot\text{K}}$

### 12.4.1 Walls

#### 12.4.1.1 Exterior wall

c-distance between the wooden joists in the 120 mm insulation layer:

$$c_{\text{ins\_wood}} := 0.6 \text{ m}$$

Thickness of the joists:

$$d_{\text{wood}} := 0.045 \text{ m}$$

The width of the insulation between the wooden joists in the 120 mm insulation layer:

$$d_{\text{ins120}} := c_{\text{ins\_wood}} - d_{\text{wood}} = 0.555 \text{ m}$$

Equivalent material properties for 120 mm insulation and wooden joists with c-distance of 0.6 m:

$$\lambda_{eq120} := \frac{\lambda_{ins} \cdot d_{ins120} + \lambda_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 0.044 \cdot \frac{W}{m \cdot K}$$

$$\rho_{eq120} := \frac{\rho_{ins} \cdot d_{ins120} + \rho_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 56 \frac{kg}{m^3}$$

$$c_{eq120} := \frac{c_{ins} \cdot d_{ins120} + c_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 806.25 \frac{m \cdot s}{kg} \cdot \frac{W}{m \cdot K}$$

c-distance between the steel joists in the 45 mm insulation layer:

$$c_{ins\_steel} := 0.45 \text{ m}$$

Thickness of the steel joists:

$$d_{steel} := 0.56 \text{ mm}$$

The width of the insulation between the steel joists in the 45 mm insulation layer:

$$d_{ins45} := c_{ins\_steel} - d_{steel} = 0.449 \text{ m}$$

Equivalent material properties for 45 mm insulation and steel joists with c-distance of 0.45 m:

$$\lambda_{eq120} := \frac{\lambda_{ins} \cdot d_{ins120} + \lambda_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 0.044 \cdot \frac{W}{m \cdot K}$$

$$\rho_{eq120} := \frac{\rho_{ins} \cdot d_{ins120} + \rho_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 56 \frac{kg}{m^3}$$

$$c_{eq120} := \frac{c_{ins} \cdot d_{ins120} + c_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 806.25 \frac{m \cdot s}{kg} \cdot \frac{W}{m \cdot K}$$

#### 12.4.1.2 Interior wall between apartments

c-distance between the wooden joists in the 120 mm insulation layer:

$$c_{ins\_wood} := 0.45 \text{ m}$$

Thickness of the wooden joists:

$$d_{wood} := 0.045 \text{ m}$$

The width of the insulation between the wooden joists in the 120 mm insulation layer:

$$d_{ins120} := c_{ins\_wood} - d_{wood} = 0.405 \text{ m}$$

Equivalent material properties for 120 mm insulation and wooden joists with c-distance of 0.45 m:

$$\lambda_{eq120} := \frac{\lambda_{ins} \cdot d_{ins120} + \lambda_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 0.046 \cdot \frac{W}{m \cdot K}$$

$$\rho_{eq120} := \frac{\rho_{ins} \cdot d_{ins120} + \rho_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 68 \frac{\text{kg}}{\text{m}^3}$$

$$c_{eq120} := \frac{c_{ins} \cdot d_{ins120} + c_{wood} \cdot d_{wood}}{c_{ins\_wood}} = 825 \frac{\text{m} \cdot \text{s}}{\text{kg}} \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

### 12.4.1.3 Interior wall

In the software a thermal resistance R has to be described using a thickness d and a thermal conductivity  $\lambda$ . The resistance for 70 mm air gap:

$$R_{70\text{mm\_air\_gap}} := 0.18 \frac{\text{m}^2 \cdot \text{K}}{\text{W}}$$

Thickness of the air gap:

$$d_{70\text{mm\_air\_gap}} := 70\text{mm}$$

Transformation of the thermal resistance R into a thermal conductivity  $\lambda$ :

$$\lambda_{70\text{mm\_air\_gap}} := \frac{d_{70\text{mm\_air\_gap}}}{R_{70\text{mm\_air\_gap}}} = 0.389 \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

### 12.4.1.4 Roof

c-distance between the wooden joists (roof trusses) in the roof insulation layer:

$$c_{ins\_wood\_roof} := 1.2\text{m}$$

Thickness of the wooden joists:

$$d_{wood\_roof} := 0.045\text{m}$$

The width of the insulation between the wooden joists (roof trusses) in the roof insulation layer:

$$d_{ins\_roof} := c_{ins\_wood\_roof} - d_{wood\_roof} = 1.155\text{m}$$

Table 12.5 Material properties for roof insulation.

$\lambda_{ins\_roof} := 0.042 \frac{\text{W}}{\text{m} \cdot \text{K}}$	$\rho_{ins\_roof} := 27 \frac{\text{kg}}{\text{m}^3}$	$c_{ins\_roof} := 800 \frac{\text{J}}{\text{kg} \cdot \text{K}}$
---	---	--

Equivalent material properties for roof insulation and roof trusses with c-distance of 1.2 m:

$$\lambda_{eq\_roof} := \frac{\lambda_{ins\_roof} \cdot d_{ins\_roof} + \lambda_{wood} \cdot d_{wood\_roof}}{c_{ins\_wood\_roof}} = 0.046 \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

$$\rho_{eq\_roof} := \frac{\rho_{ins\_roof} \cdot d_{ins\_roof} + \rho_{wood} \cdot d_{wood\_roof}}{c_{ins\_wood\_roof}} = 44.738 \frac{\text{kg}}{\text{m}^3}$$

$$c_{eq\_roof} := \frac{c_{ins\_roof} \cdot d_{ins\_roof} + c_{wood} \cdot d_{wood\_roof}}{c_{ins\_wood\_roof}} = 826.25 \frac{\text{m} \cdot \text{s}}{\text{kg}} \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

### 12.4.1.5 Floor

In the software a thermal resistance R has to be described using a thickness d and a thermal conductivity  $\lambda$ . The resistance for 220 mm air gap:

$$R_{220\text{mm\_air\_gap}} := 0.16 \frac{\text{m}^2 \cdot \text{K}}{\text{W}}$$

Thickness of the air gap:

$$d_{220\text{mm\_air\_gap}} := 220\text{mm}$$

Transformation of the thermal resistance R into a thermal conductivity  $\lambda$ :

$$\lambda_{220\text{mm\_air\_gap}} := \frac{d_{70\text{mm\_air\_gap}}}{R_{70\text{mm\_air\_gap}}} = 0.389 \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

## 12.5 Thermal bridges

The subscript 1 means that the value is valid with thermal bridge. The subscript 2 means that the value is valid without thermal bridge. These values are results from HEAT2 simulations as the pictures illustrates.

The difference in temperature over the thermal bridge in all calculations:

$$\Delta T := 13\text{K}$$

$\Psi$  is the linear heat transfer coefficient for the thermal bridge in  $[\text{W}/(\text{m} \cdot \text{K})]$ .

### 12.5.1 External wall – internal floor

The thermal bridge in the connection between the external wall and the internal floor is developed due to the wooden joists that are situated at the end of the internal floor.

Heat flow through the construction with thermal bridge:

$$q_1 := 3.7843 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 3.7089 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 5.8 \times 10^{-3} \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

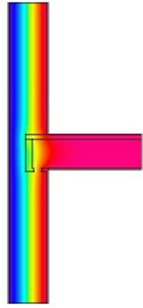


Figure 12.3 Temperature distribution in construction with thermal bridge.



Figure 12.4 Temperature distribution in construction without thermal bridge.

### 12.5.2 External wall – internal wall

The thermal bridge in the connection between the external wall and the internal wall is developed due to the wooden joists that are situated at the end of the internal wall.

Heat flow through the construction with thermal bridge:

$$q_1 := 3.8623 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 3.7895 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 5.6 \times 10^{-3} \frac{\text{W}}{\text{m} \cdot \text{K}}$$

Scale factor due to internal walls which should not be included because of no thoroughgoing construction (this is only valid for IDA ICE):

$$x := 0.4156$$

The new thermal bridge's linear heat transfer coefficient valid for IDA ICE becomes:

$$\Psi := x \cdot \Psi = 2.327 \times 10^{-3} \frac{\text{W}}{\text{m} \cdot \text{K}}$$

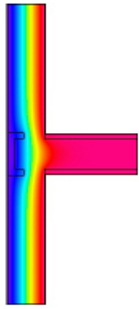


Figure 12.5 Temperature distribution in construction with thermal bridge.



Figure 12.6 Temperature distribution in construction without thermal bridge.

### 12.5.3 External wall – external wall

The thermal bridge in the connection of two external walls (corner of the house) is developed due to the extra wooden joists needed in the connection and due to the warm perimeter being of shorter length than the cold perimeter.

Heat flow through the construction with thermal bridge:

$$q_1 := 3.3618 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 3.3488 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 10 \times 10^{-4} \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

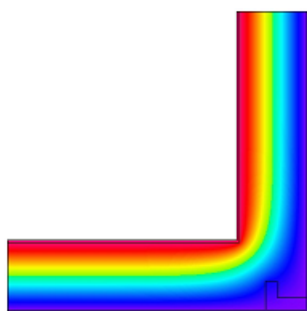


Figure 12.7 Temperature distribution in construction with thermal bridge.

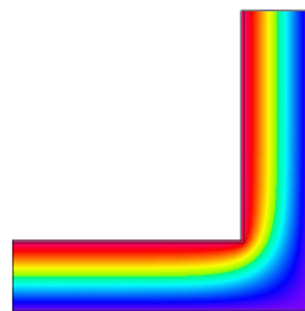


Figure 12.8 Temperature distribution in construction without thermal bridge.

### 12.5.4 External wall – windows/doors

The thermal bridge developed in connection between external walls and windows/doors arises from the frames used to fasten these construction parts.

Heat flow through the construction with thermal bridge:

$$q_1 := 2.093 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 1.6198 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 0.036 \cdot \frac{\text{W}}{\text{m}\cdot\text{K}}$$



Figure 12.9 Temperature distribution in construction with thermal bridge.



Figure 12.10 Temperature distribution in construction without thermal bridge.

### 12.5.5 External wall – roof

The thermal bridge in the connection between the external wall and the roof is developed due to the wooden joists that are situated at the top of the external wall and due to the warm perimeter being of shorter length than the cold perimeter.

Heat flow through the construction with thermal bridge:

$$q_1 := 3.3553 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 3.1928 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 0.013 \cdot \frac{\text{W}}{\text{m}\cdot\text{K}}$$



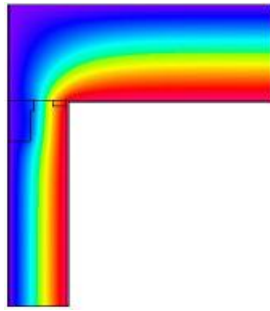


Figure 12.11 Temperature distribution in construction with thermal bridge.

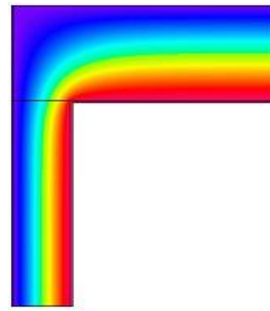


Figure 12.12 Temperature distribution in construction without thermal bridge.

### 12.5.6 External wall – slab

The thermal bridge in the connection between the external wall and the slab is developed due to the edge beam in the slab going along the edge of the house and due to extra wooden joists needed in the external wall.

Heat flow through the construction with thermal bridge:

$$q_1 := 10.9031 \frac{\text{W}}{\text{m}}$$

Heat flow through the construction without thermal bridge:

$$q_2 := 8.3473 \frac{\text{W}}{\text{m}}$$

The thermal bridge's linear heat transfer coefficient becomes:

$$\Psi := \frac{q_1 - q_2}{\Delta T} = 0.197 \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$$

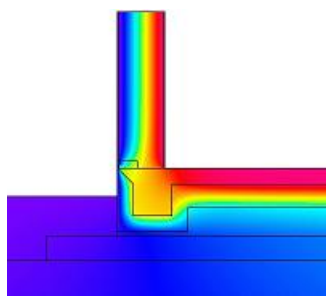


Figure 12.13 Temperature distribution in construction with thermal bridge.

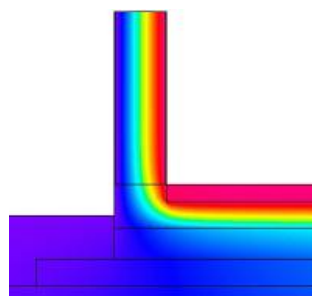


Figure 12.14 Temperature distribution in construction without thermal bridge.

## 13 Annex B: Geometry and areas of the reference object

All walls (Figure 13.2 to Figure 13.13) are seen from the inside. The geometry is used in IDA ICE when constructing the reference object.

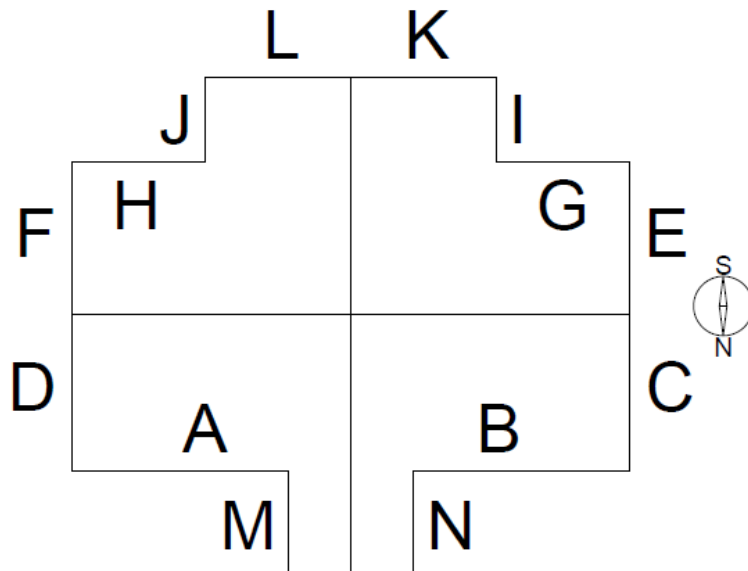


Figure 13.1 Plan view for first floor. Walls defined with letters.

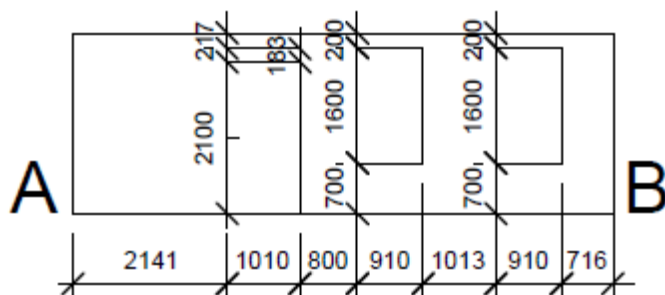


Figure 13.2 Windows and door in wall A and B [mm].

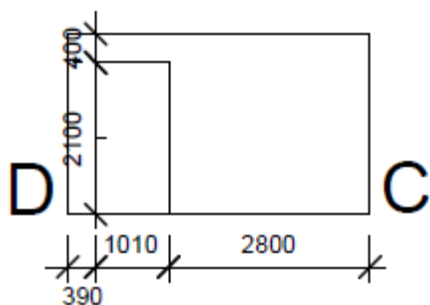


Figure 13.3 Door in wall C and D [mm].

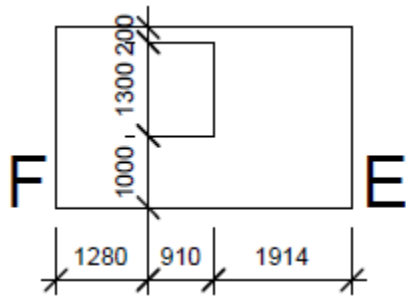


Figure 13.4 Window in wall E and F [mm].

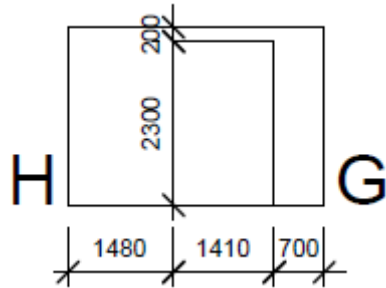


Figure 13.5 Terrace door in wall G and H [mm].

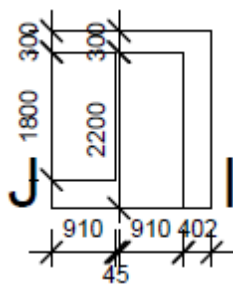


Figure 13.6 Window and terrace door in wall I and J [mm].

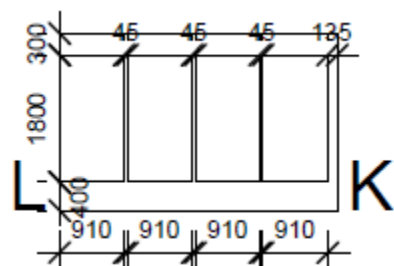


Figure 13.7 Windows in wall K and L [mm].

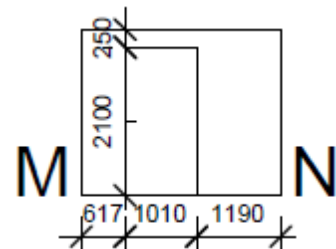


Figure 13.8 Door in wall M and N [mm].

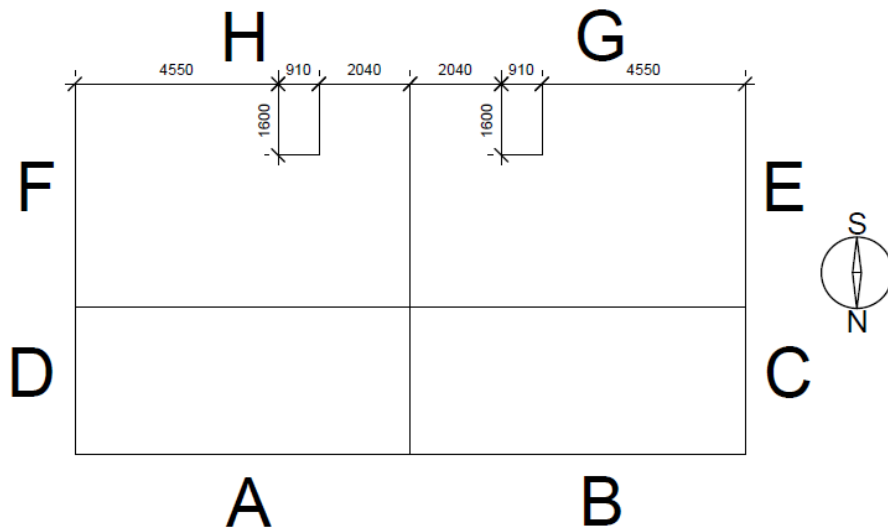


Figure 13.9 Plan view for second floor with roof windows. Walls defined with letters [mm].

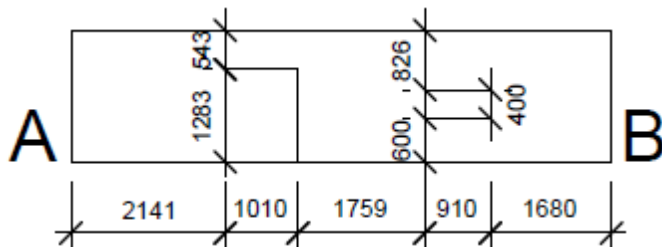


Figure 13.10 Windows in wall A and B [mm].

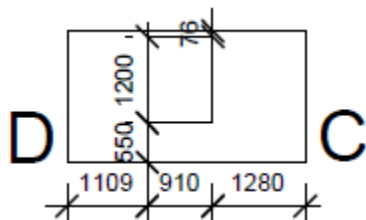


Figure 13.11 Window in wall C and D [mm].

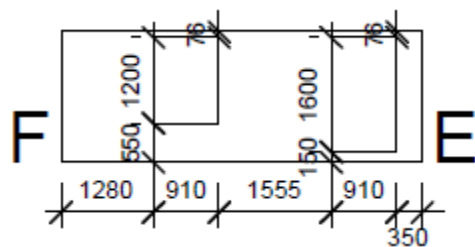


Figure 13.12 Windows in wall E and F [mm].

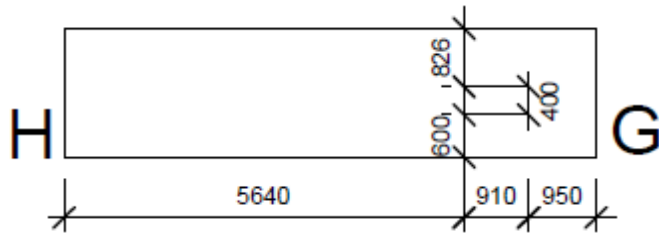


Figure 13.13 Window in wall G and H [mm].

In VIP-E buildings are defined as having areas facing cardinal directions. A compilation of areas to describe the reference object is done in Table 13.1.

Table 13.1 Compilation of areas used to create the reference building in VIP-E.

Outer geometry [m]	Height	Width faces South & North		Width faces East & West
Living room	3,013	8,886		2,267
Building	5,092	16,066		9,114
Storage	2,813	4,034		3,000
Building [m <sup>2</sup> ]	Total area	Window area	Door area	Wall area
South	81,808	20,32	0	61,488
West (main)	46,408	4,82	2,12	39,468
West (living room)	6,830	3,64	0	3,190
East (main)	53,239	8,46	2,12	42,659
East (living room)	6,830	3,64	0	3,190
North	70,460	9,6	4,24	56,620
Living room roof	20,145	0	0	20,145
Main roof	146,426	2,92	0	143,506
Slab	166,570	0	0	166,570
Storage [m <sup>2</sup> ]	Total area	Window area	Door area	Wall area
South	0	0	0	0
West	8,439	0	2,12	6,319
East	8,439	0	2,12	6,319
North	11,348	0	0	11,348
Roof	12,102	0	0	12,102
Slab	12,102	0	0	12,102

## 14 Annex C: References for material data

Table 14.1 References for material data.

	$\lambda$ [W/(mK)]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/(kgK)]
Insulation	0.036 [3]	20 [3]	750 [3]
Wood	0.14 [2]	500 [2]	1500 [2]
Steel	60 [1]	7800 [1]	500 [1]
Gypsum	0.22 [1]	850 [1] <sup>1)</sup>	800 [1]
Weather board	0.22 [1] <sup>2)</sup>	800 [4]	800 [1] <sup>2)</sup>
70 mm air gap	0.39 [5]	1.2 [2]	1000 [2]
Floor cover	0.18 [3]	1100 [3]	920 [3]
220 mm air gap	1.375 [5]	1.2 [2]	1000 [2]
Particle board	0.14 [2]	600 [2]	-
Concrete	1.7 [3]	2300 [3]	880 [3]
Cellular plastic	0.037 [6]	20 [6]	-
Light clinker	0.13 [2]	330 [2]	900 [7]
Macadam	2 [1]	1625 [1] <sup>3)</sup>	-
Rock	3.5 [3]	2500 [3]	800 [3]

<sup>1)</sup> Mean value of 900 kg/m<sup>3</sup> and 800 kg/m<sup>3</sup>.

<sup>2)</sup> Assumed gypsum properties.

<sup>3)</sup> Assumed 35% porosity and homogenous rock.

[1] Hagentoft, C-E (2001). *Introduction to Building Physic*. Lund: Studentlitteratur.

[2] Petersson, B-Å (2004). *Tillämpad byggnadsfysik*. Lund: Studentlitteratur.

[3] EQUA Simulation AB (2009 [1]). *IDA ICE* Software.

[4] Knauf Danogips (2008). Read 2010-04-28. Available: [http://byggsystem.knaufdanogips.se/products/boards/glasmat\\_gypsum/weather\\_board/technical\\_facts\\_weather.html](http://byggsystem.knaufdanogips.se/products/boards/glasmat_gypsum/weather_board/technical_facts_weather.html)

[5] Swedish standards institute (2008): *SS-EN ISO 6946:2007*. Stockholm.

[6] Sundolitt ab (2004) Read 2010-04-28. Available: <http://www.sundolitt.se/default.asp?menu=161>

[7] Saint-Gobain Byggprodukter AB, Weber (2008). *Leca Lättklinker Egenskapsredovisning*. PDF format. Read 2010-04-28. Available: <[http://se.maxit-cms.com/media/22/pdf/leca/lattklinker/leca\\_lattklinker\\_egenskr.pdf](http://se.maxit-cms.com/media/22/pdf/leca/lattklinker/leca_lattklinker_egenskr.pdf)>

# 15 Annex D: Analysing parameters

## 15.1 Results from parametric study in IDA ICE

Green cells marked in Table *Parametric study – IDA ICE* below represents the parameters combined into simulation 1MaxEnergy. These marked percentages are also summoned together and the result shown below 1MaxEnergy, marked green.

Blue cells marked in Table *Parametric study – IDA ICE* below represents the parameters combined into simulation 1MinEnergy. These marked percentages are also summoned together and the result shown below 1MinEnergy, marked blue.

Specific energy usage for reference object 17137 [kWh/year] 64,22 [kwh/m <sup>2</sup> year]	A <sub>temp</sub> for both apartments 266,84 m <sup>2</sup>	Heating energy for reference object 12821 [kWh/year]
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### Parametric study - IDA ICE

Report code	Unit	Parameters		Specific energy usage			Energy for heating	
		Original	Changes to	Changes to		Change in %	Changes to	Change in %
				[kWh/year]	[kwh/m <sup>2</sup> year]			
1CISthlm	[-]	Gbg	Sthlm	18324	68,67	6,9%	14009	9,3%
1Temp22	[°C]	21	22	18254	68,41	6,5%	13939	8,7%
1ThBr0	[W/K]	18,4	0,0	16216	60,77	-5,4%	11901	-7,2%
1AirLeak0.5	[l/m <sup>2</sup> s]	0,6	1,1	16359	61,31	-4,5%	12043	-6,1%
1Air2.3	[-]	Energy	Flow	16409	61,49	-4,2%	12055	-6,0%
1CLandv	[-]	Gbg	Landv	17779	66,63	3,7%	13464	5,0%
1MatDefault	[-]	Real	Default	16736	62,72	-2,3%	12421	-3,1%
1Ffdiv20	[l/m <sup>2</sup> s]	0,015	0,030	17481	65,51	2,0%	13166	2,7%
1GrRock	[-]	3 layers	Only rock	17474	65,48	2,0%	13159	2,6%
1F%W10	[%]	25,4%	10,0%	16844	63,12	-1,7%	12529	-2,3%
1GrDefault	[-]	Real	Default	16881	63,26	-1,5%	12566	-2,0%
1ThBr10%	[W/K],[%]	18,4	10%	16933	63,46	-1,2%	12617	-1,6%
1ManFloorAr	[m <sup>2</sup> ]	277,17	273,74	16975	64,33	-0,9%	12709	-0,9%
1PitchedR	[-]	Flat	Pitched	16991	63,67	-0,9%	12676	-1,1%
1LocLandv	[-]	Gbg	Landv	17006	63,73	-0,8%	12691	-1,0%
1ThBr15%	[W/K],[%]	18,4	15%	17268	64,71	0,8%	12952	1,0%
1CKalmar	[-]	Gbg	Kalmar	17247	64,63	0,6%	12932	0,9%
1Win1A	[n-win]	36	20	17036	63,84	-0,6%	12721	-0,8%
1GrDiffLay	[-]	3 layers	2 layers	17039	63,85	-0,6%	12724	-0,8%
1LocKalmar	[-]	Gbg	Kalmar	17215	64,51	0,5%	12900	0,6%
1Heat1k	[W]	3000	1000	17066	63,96	-0,4%	12751	-0,5%
1Wd0.6NOp	[-]	Fixed	Wind 0,6	17089	64,04	-0,3%	12774	-0,4%
1Zone3	[n-zone]	9	3	17097	64,07	-0,2%	12782	-0,3%
1ManZ	[m]	4,61	4,51	17100	64,08	-0,2%	12785	-0,3%
1Start0701	[-]	1/1	1/7	17104	64,10	-0,2%	12789	-0,2%
1LocMalmo	[-]	Gbg	Malmo	17108	64,11	-0,2%	12793	-0,2%
1Wd0.6Op	[-]	Fixed	Wind 0,6	17109	64,12	-0,2%	12794	-0,2%
1WindOC	[-]	Suburb	Open	17165	64,33	0,2%	12850	0,2%
1Blinds	[-]	0,5*g&T	Blinds	17150	64,27	0,1%	12835	0,1%
1Heat6k	[W]	3000	6000	17127	64,18	-0,1%	12812	-0,1%
1Op	[-]	No open.	Openings	17127	64,18	-0,1%	12812	-0,1%
1LocSthlm	[-]	Gbg	Sthlm	17144	64,25	0,0%	12829	0,1%

### Combination of possible choices that will raise the energy usage

1MaxEnergy	19982	74,88	16,6%	15666	22,2%
Summation of the parameters individually used in simulations			15,2%		

### Combination of possible choices that will lower the energy usage

1MinEnergy	15660	57,38	-8,6%	11250	-12,3%
Summation of the parameters individually used in simulations			-9,9%		

Table 15.1 Description of report codes used in the parametric study in IDA ICE.

1CISthlm	Climate data changed from Göteborg to Stockholm.
1Temp22	Indoor set-point temperature increased from 21°C to 22°C.
1ThBr0	Thermal bridges set to 0.
1AirLeak0.5	Adding 0.5 l/(m <sup>2</sup> s) to air leakage instead of 4 kWh/(m <sup>2</sup> yr) heat losses due to airing.
1Air2.3	Airing changed from 4 kWh/(m <sup>2</sup> yr) to extra ventilation of 2.3 l/s and apartment.



1CILandv	Climate data changed from Göteborg to Landvetter.
1MatDefault	Changed material properties to software default materials.
1Ffdiv20	Infiltration changed from 0.015 l/(m <sup>2</sup> s) to 0.03 l/(m <sup>2</sup> s).
1GrRock	Changed the ground properties to 0.5 m rock.
1F%W10	Frame percentage of total window area decreased from 25.4 % to 10 %.
1GrDefault	Changed ground properties to software default.
1ThBr10%	Thermal bridges set to 10 % of mean UA-value.
1ManFloorAr	Floor area changed according to manual measurements.
1PitchedR	Roof type changed from flat to pitched.
1LocLandv	Location changed from Göteborg to Landvetter.
1ThBr15%	Thermal bridges set to 15 % of mean UA-value.
1CIKalmar	Climate data changed from Göteborg to Kalmar.
1Win1A	Windows are merged together, total window area being unchanged.
1GrDiffLay	Changed the ground properties to 5 m default soil followed by 0.5 m rock.
1LocKalmar	Location changed from Göteborg to Kalmar.
1Heat1k	Maximum heating effect limit set to 1000 W instead of 3000 W in each zone.
1Wd0.6NOp	Infiltration changed from fixed to wind driven without openings.
1Zone3	Number of zones decreased from 9 to 3.
1ManZ	Building height changed according to manual measurement.
1Start0701	Start-up date changed from 1/1 to 1/7.
1LocMalmo	Location changed from Göteborg to Malmö.
1Wd0.6Op	Infiltration changed from fixed to wind driven with openings in internal walls.
1WindOC	Wind profile changed from suburban to open country.
1Blinds	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
1Heat6k	Maximum heating effect limit set to 6000 W instead of 3000 W in each zone.
1Op	Openings added when using fixed infiltration.
1LocSthlm	Location changed from Göteborg to Stockholm.
1MaxEnergy	Combination of possible choices that will raise the energy usage.
1MinEnergy	Combination of possible choices that will lower the energy usage.

## 15.2 Results from parametric study in VIP-E

Green cells marked in Table *Parametric study – VIP-E* below represents the parameters combined into simulation 2MaxEnergy. These marked percentages are also summoned together and the result shown below 2MaxEnergy, marked green.

Blue cells marked in Table *Parametric study – VIP-E* below represents the parameters combined into simulation 2MinEnergy. These marked percentages are also summoned together and the result shown below 2MinEnergy, marked blue.

Specific energy usage for reference object				A <sub>temp</sub> for both apartments		Heating energy for reference object			
17179 [kWh/year]				266,84 m <sup>2</sup>		12869 [kWh/year]			
64,38 [kWh/m <sup>2</sup> year]									
Parametric study - VIP-E									
Report code	Unit	Parameters		Specific energy usage			Energy for heating		
		Original	Changes to	Changes to		Change in %	Changes to	Change in %	
				[kWh/year]	[kWh/m <sup>2</sup> year]				[kWh/year]
2HorizAng30	[deg]	5	30	18767	70,33	9,2%	14456	12,3%	
2Temp22	[°C]	21	22	18253	68,41	6,3%	13943	8,3%	
2Air2.3	[-]	Energy	Flow	16409	61,49	-4,5%	12059	-6,3%	
2HorizAng15	[deg]	5	15	17927	67,18	4,4%	13617	5,8%	
2ThBr0	[W/K]	18,4	0	16484	61,78	-4,0%	12173	-5,4%	
2WindOC	[%]	70%	95%	17707	66,36	3,1%	13397	4,1%	
2Blinds	[-]	0,5*g&T	Blinds	17679	66,25	2,9%	13369	3,9%	
2ClSthlm	[-]	Gbg	Sthlm	17597	65,95	2,4%	13286	3,2%	
2GrClay	[-]	Rock	Clay	16818	63,03	-2,1%	12507	-2,8%	
2ClKalmar	[-]	Gbg	Kalmar	16896	63,32	-1,6%	12585	-2,2%	
2ThBr15%	[W/K],[%]	18,4	15%	17438	65,35	1,5%	13127	2,0%	
2MatDefault	[-]	Real	Default	16941	63,49	-1,4%	12631	-1,8%	
2PitchedR	[-]	Flat	Pitched	17379	65,13	1,2%	13069	1,6%	
2GrSilt	[-]	Rock	Silt	17016	63,77	-0,9%	12705	-1,3%	
2F%W20	[%]	25,4%	20,0%	17034	63,84	-0,8%	12723	-1,1%	
2SunRefI20	[%]	35%	20%	17316	64,89	0,8%	13005	1,1%	
2AirLeak0.5	[l/m <sup>2</sup> s]	0,6	1,1	17046	63,88	-0,8%	12736	-1,0%	
2SunRefI50	[%]	35%	50%	17050	63,90	-0,8%	12740	-1,0%	
2ManFloorAr	[m <sup>2</sup> ]	277,17	273,74	17081	64,01	-0,6%	12818	-0,4%	
2AirPress	[kPa]	99,3375	100	17244	64,62	0,4%	12934	0,5%	
2ManZ	[m]	5,09	4,99	17115	64,14	-0,4%	12804	-0,5%	
2ThBr10%	[W/K],[%]	18,4	10%	17120	64,16	-0,3%	12809	-0,5%	
2Zone3	[n-zone]	2	3	17133	64,21	-0,3%	12822	-0,4%	
2WindDirSW	[-]	South	SouthWest	17161	64,31	-0,1%	12850	-0,1%	
2F%W25	[%]	25,4%	25,0%	17169	64,34	-0,1%	12858	-0,1%	
<b>Combination of possible choices that will raise the energy usage</b>									
2MaxEnergy				21329	79,93	24,2%	17019	32,2%	
Summation of the parameters individually used in simulations						25,3%			
<b>Combination of possible choices that will lower the energy usage</b>									
2MinEnergy				16208	61,42	-5,7%	11945	-7,2%	
Summation of the parameters individually used in simulations						-6,0%			

Table 15.2 Description of report codes used in the parametric study in VIP-E.

2HorizAng30	Changing the horizon angle from 5° to 30°.
2Temp22	Indoor set-point temperature increased from 21°C to 22°C.
2Air2.3	Airing changed from 4 kWh/(m <sup>2</sup> yr) to extra ventilation of 2.3 l/s and apartment.
2HorizAng15	Changing the horizon angle from 5° to 15°.
2ThBr0	Thermal bridges set to 0.
2WindOC	Wind profile changed from 70 % of wind speed in climate file to 95 %.
2Blinds	Sun screen coefficient of 0.71 and blinds drawn: solar radiation >100 W/m <sup>2</sup> .
2ClSthlm	Climate data changed from Göteborg to Stockholm.
2GrClay	Changing ground properties from rock to clay.
2ClKalmar	Climate data changed from Göteborg to Kalmar.
2ThBr15%	Thermal bridges set to 15 % of U <sub>m</sub> -value.

2MatDefault	Changed material properties to software default materials.
2PitchedR	Using actual measurements from AutoCAD.
2GrSilt	Changing ground properties from rock to silt.
2F%W20	Frame percentage of total window area decreased from 25.4 % to 20 %.
2SunRefl20	Changing the solar reflection on ground from 35 % to 20 %.
2AirLeak0.5	Adding 0.5 l/(m <sup>2</sup> s) to air leakage instead of 4 kWh/(m <sup>2</sup> yr) heat losses due to airing.
2SunRefl50	Changing the solar reflection on ground from 35 % to 50 %.
2ManFloorAr	Floor area changed according to manual measurements.
2AirPress	Changing air pressure due to height above sea level from 99.3 kPa to default 100 kPa.
2ManZ	Building height changed according to manual measurement.
2ThBr10%	Thermal bridges set to 10 % of U <sub>m</sub> -value.
2Zone3	Number of zones increased from 2 to 3.
2WindDirSW	Changing the locked wind direction from west to southwest.
2F%W25	Frame percentage of total window area decreased from 25.4 % to 25 %.
2MaxEnergy	Combination of possible choices that will raise the energy usage.
2MinEnergy	Combination of possible choices that will lower the energy usage.