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October 2006

Nordic Thermal Mass – Effect on Energy and Indoor Climate

Report 184

Table of contents

Foreword

The importance of the thermal performance of buildings has increased due to e.g. the implementation of the Energy Performance Directive of Buildings. In this context energy certification systems of buildings will also require the calculation of energy consumption of buildings in future. The fact that the thermal mass of buildings decreases total energy consumption, is well known, but the amount of this effect depends on many assumptions and values used in the calculations. During this project it has been collected the best available Nordic knowledge around the table to develop a Nordic consensus about the questions studied.

It's important that we have in Nordic countries enough knowledge to be in the forefront in order to get our views included in the European standardisation. The thermal mass of buildings has a clearly positive effect on energy consumption and indoor climate. However, the buildings have to be designed cleverly to be capable to utilise possibilities for smaller energy consumption and better indoor climate.

This project was a co-operation project with research institutes of Nordic countries. There were used six different energy calculation software's, whose results were compared with each other and with one program based on the European standard EN 13790, *Thermal performance of buildings - Calculation of energy use for space heating and cooling*. The main author of the report and the collector of the results was Timo Kalema from Tampere University of Technology.

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1. Introduction

The role of buildings' energy analysis using calculations is coming more important. The energy performance directive of buildings (EPDB) demands that the energy efficiency (e.g. energy consumption/floor area) must be calculated in the design phase. EPDB also demands the use of an energy certificate for buildings, when they are sold or rented. This certificate is based for new buildings on calculations. On the other hand, the improvement of the level of thermal insulation, the increasing use of electricity and the use of big window areas on south facades can cause very high interior temperatures, if no cooling or extra ventilation are used. For these reasons cooling energy and interior temperatures must be analysed also in Nordic climate in certain cases.

There are energy calculation programs based on different methods and level of complexity. The simplest ones are so called energy balance programs, which calculate the monthly energy balances for a fixed interior set-point temperature. They are suited for the calculation of the heating energy as well as cooling energy. The most important of these is ISO DIS 13790, *Thermal Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling.* It has an official role in Europe, because it is mentioned in the EPDB and many European countries use it in their national energy performance calculation methods.

There has been much discussion and it has been made many studies concerning the effect of thermal mass on energy consumption and the validity of ISO DIS 13790 in the calculation of energy consumption. For the effect of thermal mass on heating energy values from approximately 0 to 10 % have been obtained. In the cooling energy the effect of thermal mass is clearly higher. On the other hand it has been questioned generally the ability of ISO DIS 13790 to calculate the energy consumption in Nordic climate and especially its two parameters a_0 and $\tau_{0,}$ which are used to calculate the utilisation factor of ISO DIS 13790.

Because of the importance to get reliably research results on the effects of thermal mass on the energy consumption and the importance of ISO DIS 13790 in Europe it was wanted to make a joint Nordic research on the effects of thermal mass as well as the validity of ISO DIS 13790. The purpose was to find a Nordic consensus on these two main questions. In addition to this some sensitivity analysis on the effects of climate, thermal insulation level of the envelope, windows' size and orientation and the tightness of the building were performed.

There have been made earlier many studies, which show that various energy analysis programs and their users can get very different results even for a simple building. The reasons for the differences can depend e.g. from the different modelling assumptions, different interpretations of the reality and simplifications and errors involved in all programs. Therefore, in the energy analysis of buildings many analysis methods should be used at the same time and the input data should be described so detailed, that there would not be too many possibilities for misinterpretations.

In this study the energy calculations were made for a single-family house and an apartment building, which fulfil the present Finnish building regulations. The buildings were extremely detailed described and the physical reality was partly simplified in order to allow all methods to calculate at the same level of complexity. The weather data of Helsinki was mainly used in calculations.

The following six simulation programs were used: Consolis Energy/Sweden, IDA/ICE Sweden/Finnish user, SciaQPro, Norway, TASE/Finland, VIP/ Sweden and VTT House Model/Finland. The validity of ISO DIS 13790 was evaluated by analysing its utilisation factor and by using in the energy analysis maxit energy program, which is based on the European standard EN 832, which is the predecessor if ISO DIS 13790.

2. Utilisation factor

2.1 Definition

The calculation of heating energy is based in the monthly energy balance methods, such as ISO DIS 13790, *Energy Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling* on a fixed interior (set-point) temperature. However, when the internal and solar heat gains exceed the steady-state heat loss, the interior temperature raises increasing heat losses. This increase cannot be taken into account in the energy balance methods as increased heat losses, because the interior temperature is fixed.

When the heat loss (*total heat transfer according to ISO DIS 13790)* for the heating mode $Q_{L,H}$ is calculated using a fixed interior temperature, the total heat sources $Q_{G,H}$ must be reduced in order to obtain a right value for the net heating energy Q_{NH}. This reduction is made using the gain utilisation factor for heating $\eta_{G,H}$ of Eq. 2.1, which is also the definition of the gain utilisation factor:

$$Q_{NH} = Q_{L,H} - \eta_{G,H} Q_{G,H} \qquad (2.1)$$

$Q_{L,H}$ is total heat loss (heat transfer) including thermal conduction, infiltration and that part of mechanical ventilation, which is heated in the calculation zone

$\eta_{G,H}$ gain utilisation factor for heating

The total heat loss is the sum of transmission (Q_T) and ventilation heat losses (Q_V)

$$Q_{L,H} = Q_T + Q_V \qquad (2.2)$$

The total heat sources *($Q_{G,H}$)* consist from the internal heat sources (such as lighting and heat from appliances and persons, *$Q_{i,H}$)* and from the solar heat sources *($Q_{S,H}$)*, which mainly consists from the solar radiation transmitted trough windows

$$Q_{G,H} = Q_{i,H} + Q_{S,H} \qquad (2.3)$$

The utilisation factor is calculated using simulation models, which calculate at the same time the heating energy and the interior temperature. The utilisation factor is usually a monthly one, but it can be also presented for the heating season. The net energy use for cooling can be calculated analogously with the utilisation factor for heat losses ($\eta_{L,C}$).

The utilisation factor is this not a physical parameter, but a correlation coefficient, which can be obtained using building simulation models. The reliability of the utilisation factor depends therefore on the quality of the simulation models used and the consistent use of input data and operational strategy. E.g. the cooling strategy used in simulations affects the energy use for space heating. Therefore, when estimating the reliability of utilisation factors, the methods by which they have been obtained should be known.

The monthly gain utilisation factor for heating is calculated from two simulations and from Eq. 2.4:

$$\eta_{G,H} = \frac{Q_{Lsim1} - Q_{Hsim2}}{Q_{G,H}} \qquad (2.4)$$

where

Q_{Lsim1} is monthly heat loss from a first simulation calculated at fixed interior temperature 21 ^{o}C (both the heating and cooling set points are 21^{o}C). If the calculation model does not directly give heat loss it can be obtained indirectly from the building's energy balance: $Q_{Lsim1} = Q_{Hsim1} + Q_{G,H}$. This heat loss corresponds that of the energy balance method.

Q_{Hsim2} monthly heating energy from a second simulation with real set-point temperatures (e.g. 21 ^{o}C for heating and 25 ^{o}C for cooling)

$Q_{G,H}$ monthly total energy of heat sources (same in both simulations)

The utilisation factor is presented as a function of the gain/loss ratio

$$\gamma_H = \frac{Q_{G,H}}{Q_{L,H}} \qquad (2.5)$$

In order to get a good fit for the utilisation factor curve (e.g. Fig. 2.1) many (γ_H, $\eta_{G,H}$) points must be calculated.

2.2 Correlation equations

The standard proposal *ISO DIS 13790* gives for the gain utilisation factor equations 2.6 and 2.7. The last mentioned equation is for the special case when the gain/loss ratio is exactly 1:

$$\text{if } \gamma_H \neq 1: \ \eta_{G,H} = \frac{1 - {\gamma_H}^{a_H}}{1 - {\gamma_H}^{a_H + 1}} \qquad (2.6)$$

$$\text{if } \gamma_H = 1: \ \eta_{G,H} = \frac{a_H}{a_H + 1} \qquad (2.7)$$

The dimensionless parameter a_H is

$$a_H = a_{0,H} + \frac{\tau_H}{\tau_{0,H}} \qquad (2.8)$$

where

$a_{0,H}$ is a parameter, which is $a_{0,H}$ = 1,0 for continuously heated buildings and for monthly calculations

$\tau_{0,H}$ a reference time constant, which is $\tau_{0,H}$ = 15 h for continuously heated buildings and for monthly calculations

The time constant of the building or its zone is

$$\tau_H = \frac{C_m}{H_{L,H}} \qquad (2.9)$$

C_m is the internal heat capacity of the building or its zone
$H_{L,H}$ heat loss coefficient of the building or its zone for the heating mode

The physical interpretation for C_m is a single thermal capacity at the surface of the construction that gives the same turnover of heat during a daily variation of the internal temperature as the real construction. This can be calculated exactly with analytical methods, but ISO DIS 13790 also gives approximate methods for calculating the internal heat capacity. The thermal capacity of the construction taken into account is limited to 0,10 m from the surface or to the first insulation layer.

Thus when calculating the net heating energy using a monthly energy balance method the parameters $a_{0,H}$ and $\tau_{0,H}$ are correlation coefficients based on simulation results from a large number of simulations with varying preconditions such as building parameters and climates. Recently a number of publications have questioned the generality of the chosen parameters from given examples. More often it is obvious that the preconditions in these studies are not consistent with the basis of the standard. One of the central issues of this study is to evaluate the possible range and validity of the above mentioned values $a_{0,H}$ = 1,0 and $\tau_{0,H}$ = 15 h by carrying out numerous simulations that are consistent with the original preconditions used as a basis for ISO DIS 13790 .

Equations 2.6 and 2.7 can also be presented using Figure 2.1.

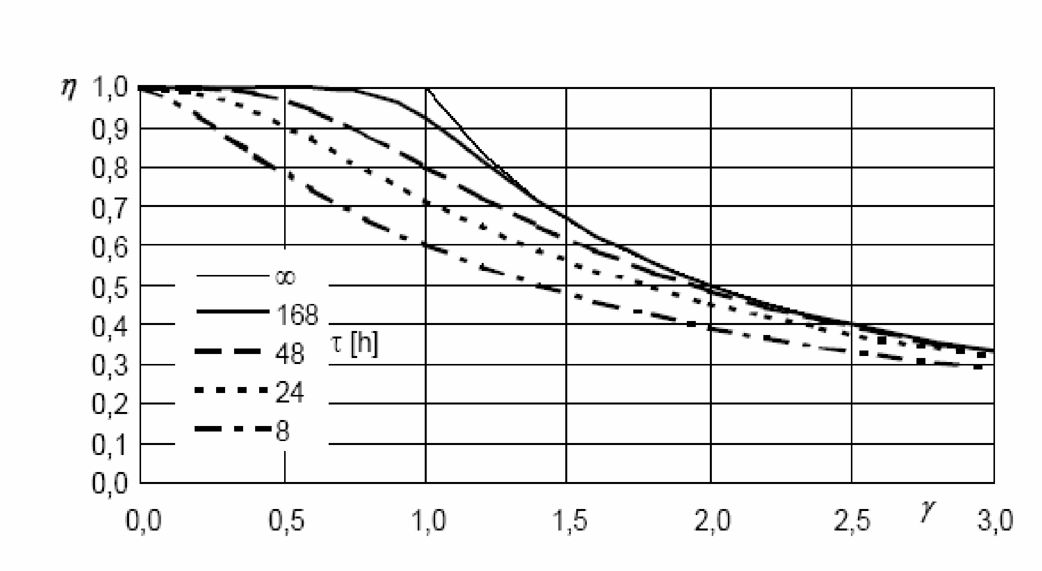

Figure 2.1. Gain utilisation factor according to ISO DIS 13790 for continuous heated buildings and for the monthly calculation method.

H.A.L. van Dijk & C.A.M. Arkesteijn report as the result of the PASSYS project some gain utilisation factors. From the equations they have studied the best fit for net heating energy seems to be obtainable with the following simple equation for the utilisation factor:

$$\eta_{G,H} = 1 - e^{\frac{-K}{\gamma_H - D}} \qquad (2.10)$$

where the parameters K and D for two building types are presented in Table 2.1

Table 2.1. Parameters K and D for Eq. 2.10 /Dijk & Arkesteijn/. Continuous heating.

Building type	***K***	***D***
Masonry type	1,35	0,27
Wooden frame type	1,19	0,00

3. Single family house used in calculations

3.1 General information on the single-family house

The building is a ridge roofed single-family house having alternatively four structures; the extra light, the light, the semi-weight and the massive ones. Their thermal capacities per floor area are 50, 190, 470 and 610 kJ/Km^2, respectively. The extra-light and the light buildings have a parquet flooring and the semi-weight and the heavy buildings have a ceramic tile flooring.

The original layout of the house is shown in Figure 3.1. Its two-zone and single-zone simplifications for calculations are presented in Figures 3.2 and 3.3. The overall internal dimensions of the building are 18,6*8,7*2,5 m. The building is located so that its living room is facing to the south and the kitchen to the north. The latitude and longitude of the house are 60,22° and 25,00° respectively. The house is inhabited by a four-person family, 2 adults and 2 children, which is taken into account in the internal heat gains. Tables 3.1 and 3.2 present the measurements for the two-zone building.

Table 3.1. Measurements according to the overall internal dimensions, when the building is divided into two zones.

Building volume	405 m^3
Floor area	162 m^2
Room height	2,5 m

Table 3.2. Areas of exterior walls and doors as well as windows in various directions for the two-zone building.

Direction of compass	**Exterior walls** *m^2*	**Windows** *m^2*	**Doors** *m^2*
North	36,06	8,44	2,0
West	20,09	1,66	-
South	36,12	8,38	2,0
East	21,50	0,25	-
Total	**113,77**	**18,73**	**4,0**

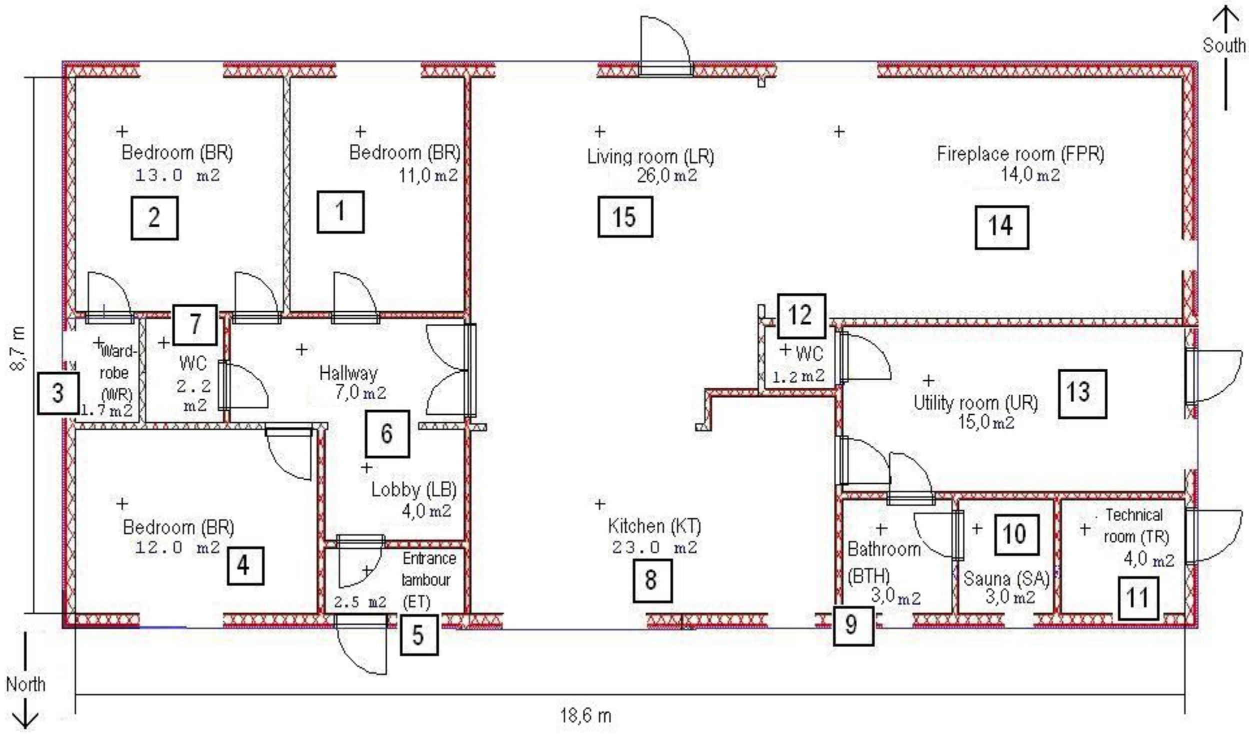

Figure 3.1. The original layout of the small house and the numbering of the rooms.

3.2 Structures

The single-family house has the following four alternative building structures:

- Extra light-weight structures, thermal capacity/floor area 50 kJ/ Km^2
- Light-weight wooden structures, thermal capacity/floor area 190 kJ/Km^2
- Semi-weight masonry structures, thermal capacity/floor area 470 kJ/Km^2
- Massive concrete structures , thermal capacity/floor area 610 kJ/Km^2

The U-values of different exterior walls, roofs and floors are exactly the same respectively and they are slightly lower than the demands of Finnish building regulations (RakMK D3).

All structures are presented in Tables 3.3 – 3.6 in which the layers are given from the outside to the inside.

The U-value of the windows and the exterior doors is 1,40 W/m^2K in all buildings. Total solar transmission coefficient (g) is 0,64 for perpendicular radiation. The coefficient 0,9 is used to take into account the angle dependence for the average radiation, if this is not taken into account in a more accurate way in the calculation model. The average value of the frame factor is 0,20.

In calculations base floors are dealt as exterior walls, which are restricted to open-air.

When making calculation with the maxit energy program the thickness of the insulation layers may be altered so that the correct U-values are obtained. This is due to the fact, that the values of thermal conductivity can not be changed in maxit energy. The foundation depth in calculations is 0,4 m (maxit energy).

Extra light-weight structures

Table 3.3. Extra light-weight structures. The U-values of exterior structures include a thermal resistance of 0,20 m^2K/W for interior and exterior surfaces.

	Structures	D *mm*	λ $\frac{W}{Km}$	ρ $\frac{kg}{m^3}$	c $\frac{J}{kgK}$	R $\frac{Km^2}{W}$	U $\frac{W}{Km^2}$
Exterior wall, EW1	Exterior covering (wooden board) Air gap Wind shield board (RKL-EJ) Support structure 50x150x600 Mineral wool insulation (KL 35) Moisture barrier Interior covering (gypsum board)	28 22 25 150 13	0,14 0,031 0,047 0,23	460 320 15 800	1360 840 840 840	 0,17	0,22
Roof, RF1	Sheet metal Ventilation space Mineral wool insulation (KL 35) Roof truss (tie) 48x300x1200 Air gap Interior covering panel	 300 22 12	 0,041 0,23	 15 500	 840 1500	 0,17	0,13
Base floor, BF3	Polystyrene Woodchip board Surface material -parquet	250 25 15	0,035 0,13 0,14	20 600 460	1210 1380 1360		Struc-ture only: 0,13
Insulated separating wall, SW1 *Basic structure*	Gypsum board Mineral wool insulation (KL 37) Gypsum board	10 100 10	0,23 0,037 0,23	800 15 800	840 840 840		
Uninsu-lated separating wall, SW2 *An altern-ative*	Gypsum board Air gap Gypsum board	10 10	0,23 0,23	800 800	840 840	 0,17	

In basic calculations it is used the insulated separating wall.

Light-weight structures

Table 3.4. Light-weight structures. The U-values of exterior structures include a thermal resistance of 0,20 m^2K/W for interior and exterior surfaces.

	Structures	**D** mm	**λ** $\frac{W}{Km}$	**ρ** $\frac{kg}{m^3}$	**c** $\frac{J}{kgK}$	**R** $\frac{Km^2}{W}$	**U** $\frac{W}{Km^2}$
Exterior wall, EW1	Exterior covering (wooden board) Air gap Wind shield board (RKL-EJ) Support structure 50x150x 600 Mineral wool insulation (KL 35) Moisture barrier Interior covering (gypsum board)	28 22 25 150 13	0,14 0,031 0,047 0,23	460 320 15 800	1360 840 840 840	 0,17	0,22
Roof, RF1	Sheet metal Ventilation space Mineral wool insulation (KL 35) Roof truss (tie) 48x300x1200 Air gap Interior covering panel	 300 22 12	 0,041 0,23	 15 500	 840 1500	 0,17	0,13
Base floor, BF1	Foundation soil Condensed gravel Polystyrene Reinforced concrete Surface material -parquet	- - 250 80 15	 0,034 1,7 0,14	 20 2400 460	 1210 840 1360		Struc-ture only: 0,13
Insulated separating wall, SW1 *Basic structure*	Gypsum board Mineral wool insulation (KL 37) Gypsum board	10 100 10	0,23 0,037 0,23	800 15 800	840 840 840		
Uninsulated separating wall, SW2 *An alternative*	Gypsum board Air gap Gypsum board	10 10	0,23 0,23	800 800	840 840	 0,17	

In basic calculations it is used the insulated separating wall.

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Semi-weight structures

Table 3.5. Semi-weight structures. The U-values of exterior structures include a thermal resistance of 0,20 m^2K/W for interior and exterior surfaces.

	Structures	**D** mm	**λ** $\frac{W}{Km}$	**ρ** $\frac{kg}{m^3}$	**c** $\frac{J}{kgK}$	**R** $\frac{Km^2}{W}$	**U** $\frac{W}{Km^2}$
Exterior wall, EW2	Block structure 100mm Insulation layer 140 mm (EPS) Block structure 100mm	100 140 100	0,21 0,0405 0,21	700 25 700	840 1200 840		0,22
Roof, RF2	Insulation layer (KL-35 mineral wool) Cored slab (P 27) - concrete - air gap - concrete	250 79 79	0,034 1,7 1,7	15 2400 2400	840 840 840	0,10	0,13
Base floor, BF1	Foundation soil Condensed gravel Polystyrene Reinforced concrete Surface material -clinker	- - 250 80 15	 0,034 1,7 0,70	 20 2400 1700	 1210 840 920		Structure only: 0,13
Separating wall, SW3	Brick structure (CSU)	85	0,95	1900	840		

Massive structures

Table 3.6. Massive structures. The U-values of exterior structures include a thermal resistance of 0,20 m^2K/W for interior and exterior surfaces.

	Structures	**D** mm	**λ** $\frac{W}{Km}$	**ρ** $\frac{kg}{m^3}$	**c** $\frac{J}{kgK}$	**R** $\frac{Km^2}{W}$	**U** $\frac{W}{Km^2}$
Exterior wall, gable, EW3	Exterior concrete Mineral wool insulation (OL-E) Interior concrete	70 160 80	1,7 0,037 1,7	2400 15 2400	840 840 840		0,22
Exterior wall, facade, EW4	Exterior concrete 70mm Mineral wool insulation (OL-E) Interior concrete 120mm	70 160 120	1,7 0,037 1,7	2400 15 2400	840 840 840		0,22
Roof, RF1	Mineral wool insulation (KL-35) Cored slab (P 27) - concrete - air gap - concrete	250 79 79	0,034 1,7 1,7	15 2400 2400	840 840 840	0,10	0,13
Base floor, BF2	Foundation soil Insulation layer (EPS 60S) Cored slab (P 27) - concrete - air gap - concrete Surface material - clinker	- 270 79 79 15	 0,037 1,7 1,7 0,70	 20 2400 2400 1700	 1210 840 840 920	0,10	Structure only: 0,13
Separating wall, SW3	Brick structure (CSU)	85	0,95	1900	840		

3.3 Simplified floor plans and surfaces

Two different simplified floor plans have been used in calculations. In *Case 1* the building is divided into two zones using a separating wall in the east-west direction. In this case the living room and the kitchen form the zone 1 and all other rooms the zone 2. In *Case 2* there is only one big zone which contains all rooms.

3.3.1 Case 1, a two-zone building having a separating wall in east-west direction

The simplified two-zone building having a separating wall in east-west direction is presented in Figure 3.2 and in Table 3.7. The area of the fictive interior walls (Table 3.7) is the area of the separating walls in the original layout (Figure 3.1) excluding the separating wall in case 1 (Figure 3.2). The fictive interior wall must be modelled in such a way each model makes is possible.

Thermal capacities and the corresponding time constants of the four different construction types in zone 1 of Case 1 are shown in Table 3.8.

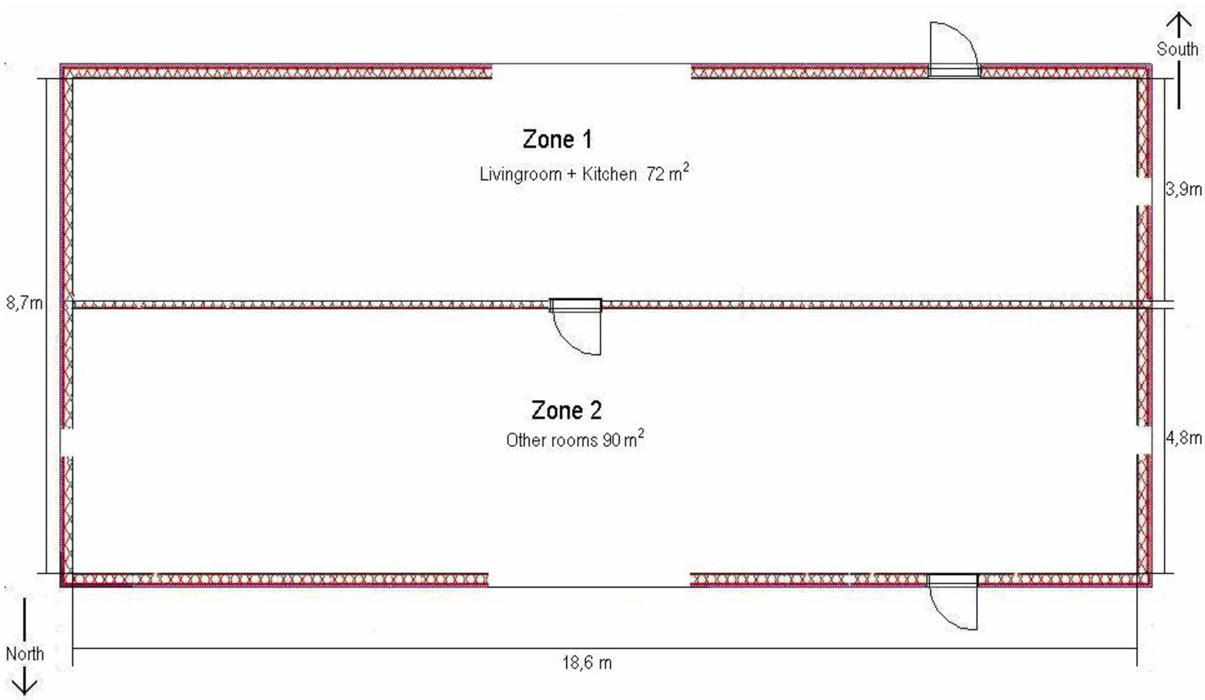

Figure 3.2. Case 1, a two-zone building having a separating wall in east-west direction.

Table 3.7. Surface areas for the two-zone building (Case 1).

Zone 1 / Case 1

Direction of compass	**Exterior walls** *m²*	**Windows** *m²*	**Doors** *m²*	**Separating wall** *m²*	**Base floor** *m²*	**Fictive interior walls** *m²*
South	36,12	8,38	2,0	-	-	-
West	9,05	0,7	-	-	-	-
East	9,75	-	-	-	-	-
North	-	-	2,0	44,5	-	-
Total	**54,92**	**9,08**	**4,0**	**44,5**	**72**	**31,6**

Zone 2 / Case 1

Direction of compass	**Exterior walls** *m²*	**Windows** *m²*	**Doors** *m²*	**Separating wall** *m²*	**Base floor** *m²*	**Fictive interior walls** *m²*
South	-	-	2,0	44,5	-	-
West	11,04	0,96	-	-	-	-
East	11,75	0,25	-	-	-	-
North	36,06	8,44	2,0	-	-	-
Total	**58,85**	**9,65**	**4,0**	**44,5**	**90**	**39,6**

Table 3.8 a. Thermal capacities of the four constructions for zone 1/ Case 1.

Extra light-weight structures

Zone 1	**Effective thermal capacity**		**Time constant** *h*
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	
Exterior walls	0,48		
Roof	0,65		
Base Floor			
- with parquet	2,17		
Separating wall	0,30		
Total	**3,59**	**50**	**17**

Table 3.8 b. Thermal capacities of the four constructions for zone 1/ Case 1.

Light-weight structures

Zone 1	Effective thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	0,48		
Roof	0,65		
Base floor			
- with parquet	12,29		
Separating wall	0,30		
Total	**13,72**	**190**	**65**

Semi-weight structures

Zone 1	Effective thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	3,23		
Roof	14,52		
Base floor			
- with clinker	13,30		
Separating wall	3,02		
Total	**34,07**	**473**	**160**

Massive-structures

Zone 1	Effective thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	10,31		
Roof	14,52		
Base Floor			
- with clinker	16,20		
Separating wall	3,02		
Total	**44,05**	**612**	**208**

3.3.2 Case 2, a single-zone building

The simplified building having a single-zone is presented in Figure 3.3 and in Table 3.9. The area of fictive interior walls is the area of separating walls in original layout (Figure 3.1). The thermal capacities of different building types and their time constants for Case 2 are shown in Table 3.10.

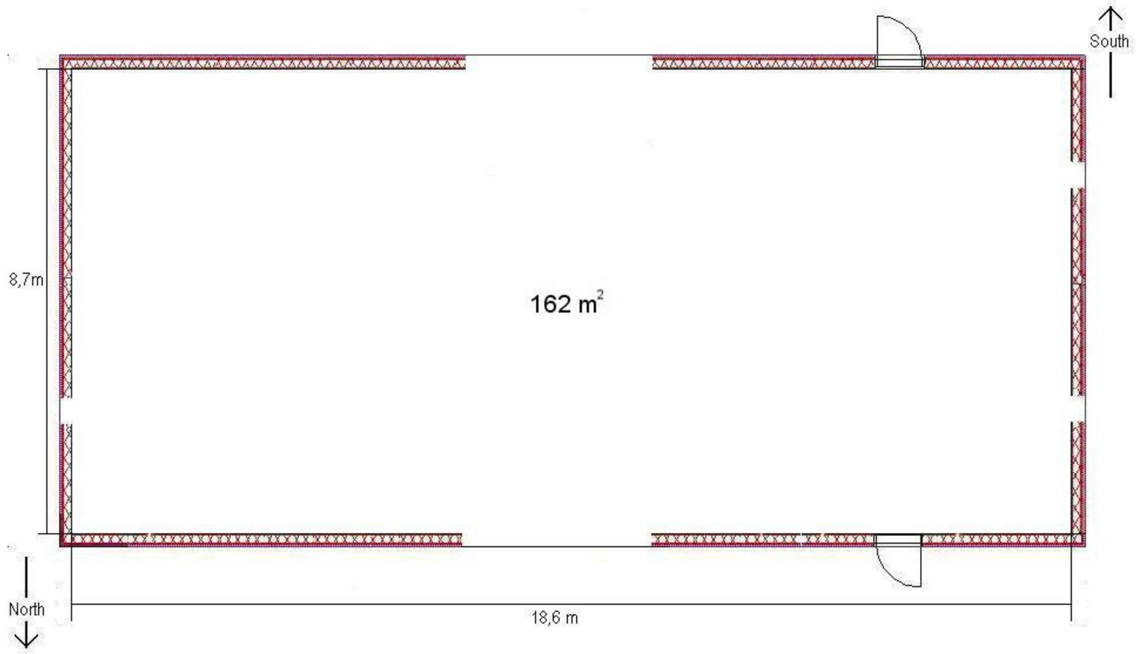

Figure 3.3. Case 2, Single-zone building having no separating wall.

Table 3.9. Surface areas for Case 2.

Direction of compass	**Exterior walls** *m²*	**Windows** *m²*	**Doors** *m²*	**Base floor** *m²*	**Fictive interior walls** *m²*
South	36,12	8,38	2,0	-	-
West	20,09	1,66	-	-	-
East	21,50	0,25	-	-	-
North	36,06	8,44	2,0	-	-
Total	**113,77**	**18,73**	**4,0**	**162**	**115,7**

Table 3.10.a. Thermal capacities of various structures for of Case 2.

Extra light-weight structures

Case 2	**Effective thermal capacity**		**Time constant**
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	0,99		
Roof	1,46		
Base Floor			
- with parquet	4,87		
Total			
- with parquet	**7,33**	**45**	**15**

Light-weight structures

Case 2	**Effective thermal capacity**		**Time constant**
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	0,99		
Roof	1,46		
Base floor			
- with parquet	27,65		
Total			
- with parquet	**30,10**	**186**	**64**

Semi-weight structures

Case 2	**Effective thermal capacity**		**Time constant**
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	6,69		
Roof	32,66		
Base floor			
- with clinker	29,93		
Total			
- with clinker	**69,28**	**428**	**147**

Table 3.10.b. Thermal capacities of various structures for of Case 2.

Massive structures

Case 2	Effective thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	21,26		
Roof	32,66		
Base Floor			
- with clinker	36,46		
Total			
- with clinker	**90,38**	**558**	**191**

3.4 Mechanical ventilation

The single-family house is equipped with a balanced mechanical supply and exhaust ventilation system that uses heat recovery from the exhaust air. The mechanical ventilation air flow rate (exterior air) during the heating season is 65 dm³/s. The heat recovery from the exhaust air has an efficiency of 50 %. The ventilation machine is equipped with a supply air heating (electric radiator) and the temperature of supply air during the heating season is +18 °C (if this information is needed in the calculation).

In the simplified two-zone building it is assumed that there is no ventilation between the zones. For the two-zone building (Case 1) the ventilation air flow rates are 28,9 dm³/s for zone 1 and 36,1 dm³/s for zone 2. For the single-zone building (Case 2) the air flow rate is 65 dm³/s.

In case that there is mechanical cooling the mechanical supply ventilation air flow rate can be increased for cooling purposes to the value 250 dm³/s (if this information is needed in the calculation)

3.5 Air infiltration

The air tightness value of the exterior envelope is n_{50} = 1,0 1/h. This corresponds a tight building envelope, that has a specific infiltration rate of 0,4 dm³/sm² calculated per exterior wall and roof area. The average infiltration rate expressed as an air change rate is 0,05 1/h (= n_{50}/20).

In basic calculations the infiltration is not taking into account. Thus the building is assumed to be absolutely tight.

4. Apartment building used in calculations

4.1 General description of the apartment house

The apartment building used in calculations is the same as the one of the REL project. Figure 4.1 presents its façade and Figure 4.2 the floor plan for floors 2 – 4 having only apartments. The first floor includes also garages and office rooms, but it is not studied in this work. Two simplified flats, a single-zone and a two-zone one, are used for modelling of the apartment house.

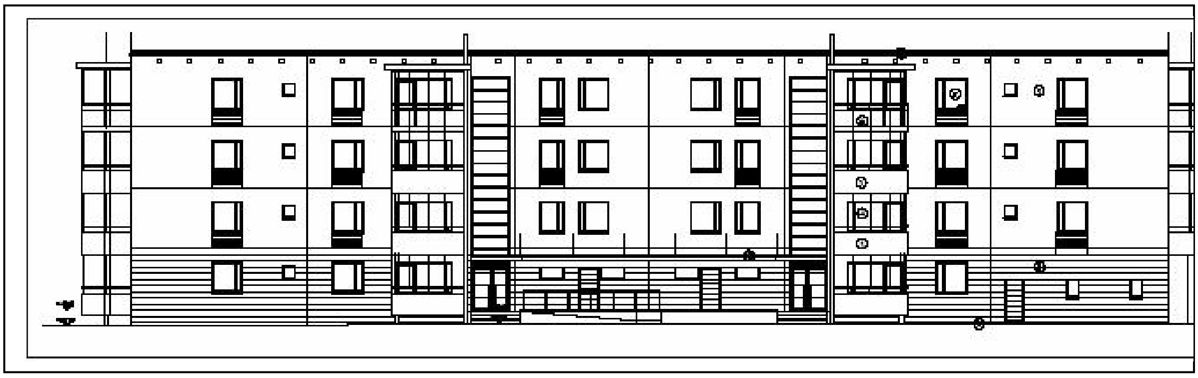

Figure 4.1. Façade of the apartment building.

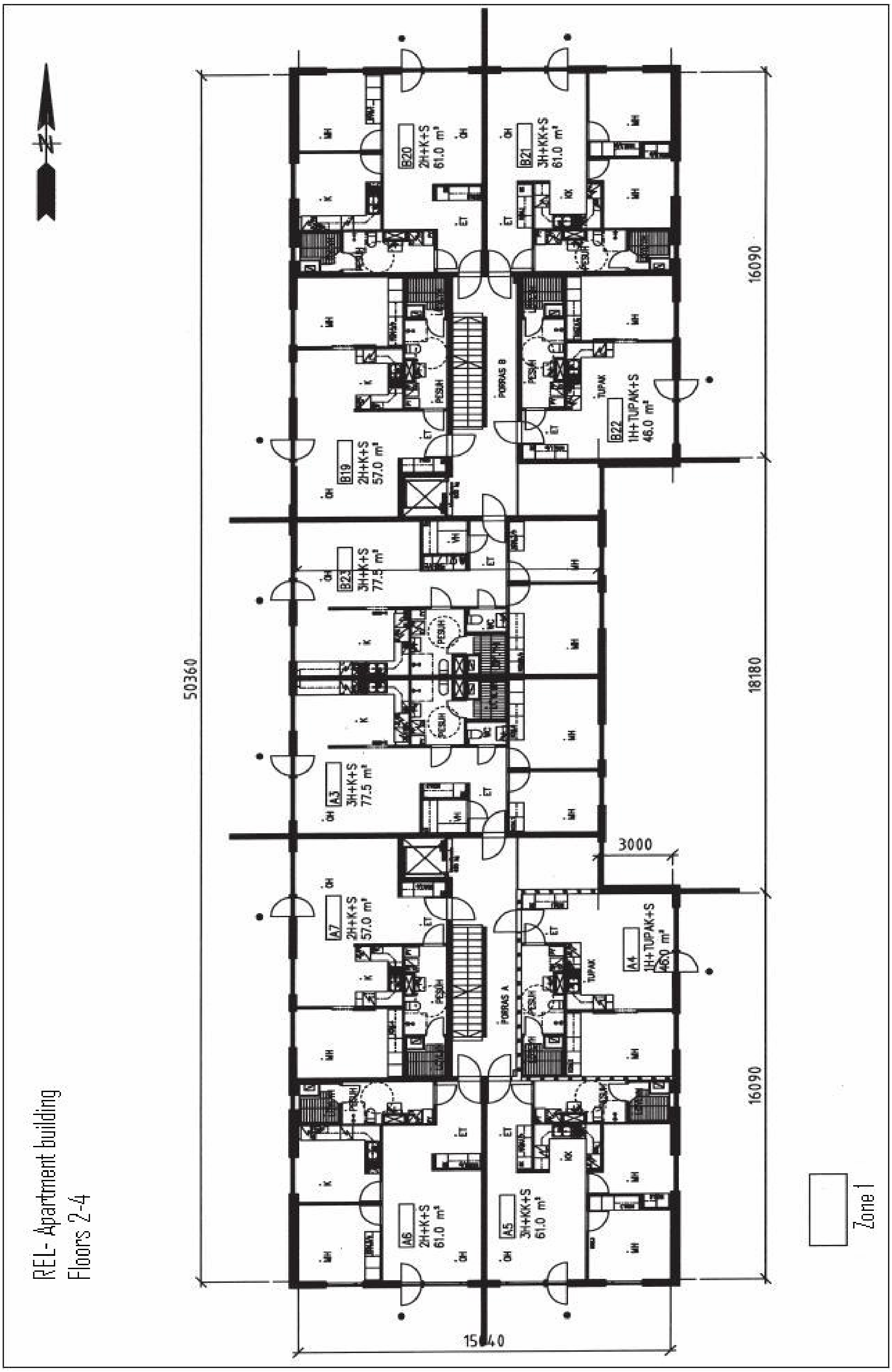

Figure 4.2. Floor plans for apartment floors 2 – 4.

4.2 Structures of the apartment house

4.2.1 Exterior envelope

A light-weight and a massive building have been studied. Tables 4.1 and 4.2 show the wall structures given from the outside to the inside for the apartment zone (the third floor) and the corresponding U-values.

The U-values of different exterior walls are exactly the same respectively and are slightly lower than the demands of Finnish building regulations (RakMK C3).

The U-value of the windows and the exterior doors is 1,40 W/m^{2}K in all cases. Total solar transmission coefficient (g) is 0,64 for perpendicular radiation. The coefficient 0,9 is used to take into account the angle dependence for the average radiation, if this is not taken into account in a more accurate way in the calculation model. The average value of the frame factor of windows is 0,20. The balcony doors don't have a glazing.

4.2.2 Light-weight structures

Table 4.1 presents the light-weight structures used for the apartment building. The same separating walls are inside the flat and between the flats.

Table 4.1. Light-weight structures. The U-values of exterior structures include a thermal resistance of 0,20 m^{2}K/W for interior and exterior surfaces.

	Structures	**D** mm	**λ** $\frac{W}{Km}$	**ρ** $\frac{kg}{m^3}$	**c** $\frac{J}{kgK}$	**R** $\frac{Km^2}{W}$	**U** $\frac{W}{Km^2}$
Exterior wall, EW1,	Wind shield board	9	0,031	320	840		0,23
	Mineral wool	200	0,053	15	840		
	Sheet metal	0,7					
	Gypsum board	13	0,23	800	840		
Separating walls, SW1	2 x Gypsum board	26	0,23	800	840		
	Mineral wool	100	0,037	15	840		
	2 x Gypsum board	26	0,23	800	840		
Intermediate floor, IF1	Surface covering - parquet	15	0,14	460	1360		
	2 x Gypsum board	26	0,23	800	840		
	Mineral wool	100	0,037	15	840		
	Gypsum board	13	0,23	800	840		

4.2.3 Massive structures

Table 4.2 presents the massive structures used. The same separating walls are inside the flat and between the flats.

Table 4.2. Massive structures. The U-values of exterior structures include a thermal resistance of 0,20 m^2K/W for interior and exterior surfaces.

	Structures	**D** mm	**λ** $\frac{W}{Km}$	**ρ** $\frac{kg}{m^3}$	**c** $\frac{J}{kgK}$	**R** $\frac{Km^2}{W}$	**U** $\frac{W}{Km^2}$
Exterior wall, EW2	Exterior concrete	70	1,7	2400	840		0,23
	Mineral wool	150	0,037	15	840		
	Interior concrete		1,7	2400	840		
	Surface covering	80					
Separating walls, SW1	Surface covering						
	Concrete	180	1,7	2400	840		
	Surface covering						
Interme-diate floor, IF1	Surface covering						
	- clinker	20	0,70	1700	920		
	Covering (screed)	20	1,2	2000	840		
	Cored slab						
	- concrete	106	1,7	2400	840		
	- air gap					0,3	
	- concrete	106	1,7	2400	840		

4.3 Simplified floor plans and surfaces

Chapters 4.2.1 and 4.2.2 show two simplified floor plans for calculations. The first one is a double-zone floor plan having windows towards east and towards west. The second floor plan is a single-zone case having windows towards west. In both cases the balcony is facing towards west. The windows on each exterior surface are lumped together.

4.3.1 Case 1, a two-zone flat

The apartment with three rooms and a kitchen is described with the floor plan of Figure 4.3. The façade towards the west does not include a wall area. It consists of the window and the balcony door, which cover the whole façade. The separating wall inside the flat is in north-south direction. The internal dimensions and surface areas are shown in Tables 4.3 and 4.4. The area of fictive interior walls in Table 4.4 is the area of separating walls inside the flat (thus not the interior walls between the flats) in the original layout (Figure 4.2) excluding the area of the separating wall between zones 1 and 2 in Figure 4.3 (Case 1).

The thermal capacities and the time constants for two different structures of Case 1 are shown in Table 4.5

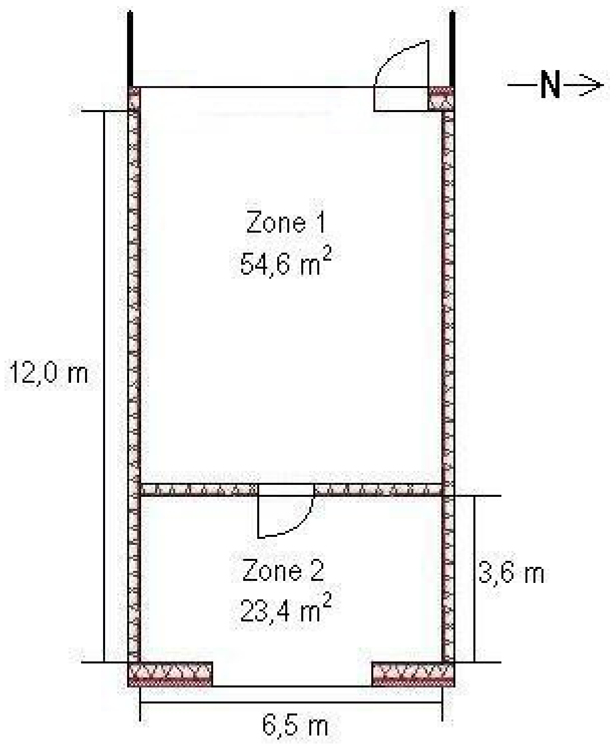

Figure 4.3. Case 1, a simplification of the apartment with three rooms and a kitchen with a separating wall inside the flat in north-south direction.

Table 4.3. Internal dimensions for Case 1.

Volume	218 m^3
Floor area	78 m^2
Room height	2,8 *m*

Table 4.4. Surface areas for Case 1.

Areas of zone 1 (Case 1).

Direction of compass	**Exterior walls** m^2	**Windows** m^2	**Doors** m^2	**Separating wall** m^2	**Intermediate floor and roof** m^2	**Fictive interior walls** m^2
North				23,5		
East*			2,0	16,2		
South				23,5		
West		16,2	2,0			
Total		**16,2**	**4,0**	**63,2**	**54,6**	**46**

* Interior wall inside the flat

Areas of zone 2 (Case 1).

Direction of compass	**Exterior walls** m^2	**Windows** m^2	**Doors** m^2	**Separating wall** m^2	**Intermediate floor and roof** m^2	**Fictive interior walls** m^2
North				10,1		
East	15,2	3,0				
South				10,1		
West*			2,0	16,2		
Total	**15,2**	**3,0**	**2,0**	**36,4**	**23,4**	**10**

* Interior wall inside the flat

Table 4.5. Thermal capacities of Case 1.

Light-weight structures, Case 1:

Zone 1	**Thermal capacity**		**Time constant**
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	0,13		
Intermediate floor + roof			
- with parquet	3,02		
Separating wall	1,17		
Total:			
- with parquet	**4,33**	**55**	**17**

Massive structures, Case 1:

Zone 1	**Thermal capacity**		**Time constant**
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	2,45		
Intermediate floor + roof			
- with ceramic tiles	77,11		
Separating wall	24,39		
Total:			
- with ceramic tiles	**103,95**	**1333**	**408**

4.3.2 Case 2, a single-zone flat

The apartment with two rooms and a kitchen is simplified into a one-roomed plan shown in Figure 4.4. The internal dimensions and surface areas are shown in Tables 4.6 and 4.7. The area of the fictive interior walls is the area of separating walls in the original layout (Figure 4.2) inside the flat. The thermal capacities and the time constants of the two different construction types of Case 2 are shown in Table 4.8.

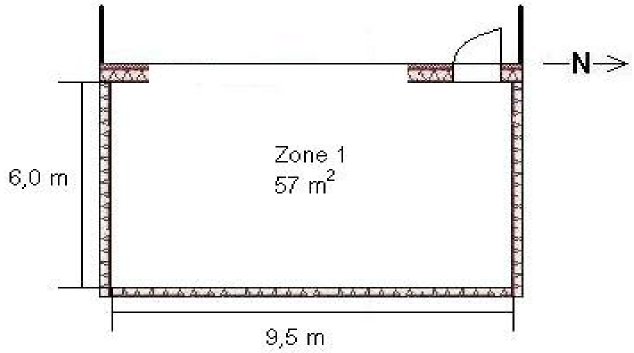

Figure 4.4. Case 2, an apartment consisting of two rooms and a kitchen simplified into one zone.

Table 4.6. Internal dimensions for Case 2.

Volume	160 m^3
Floor area	57 m^2
Room height	2,8 *m*

Table 4 7. Surface areas for Case 2.

Direction of compass	**Exterior walls** m^2	**Windows** m^2	**Exterior doors** m^2	**Separating wall** m^2	**Intermediate floor and roof** m^2	**Fictive interior walls** m^2
North				16,8		
East				26,6		
South				16,8		
West	12,6	12,0	2,0			
Total	**12,6**	**12,0**	**2,0**	**60,2**	**57**	**35**

Table 4.8. Thermal capacities of Case 2.

Light-weight structures, Case 2:

Zone 1	Thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	0,11		
Intermediate floor + roof			
- with parquet	2,21		
Separating wall	1,05		
Total			
- with parquet	**3,37**	**59**	**18**

Massive structures, Case 2:

Zone 1	Thermal capacity		Time constant
	Absolute *MJ/K*	**Per floor area** *kJ/m²K*	*h*
Exterior walls	2,03		
Intermediate floor + roof			
- with clinker	56,35		
Separating wall	21,85		
Total			
- with clinker	**80,23**	**1407**	**444**

4.4. Mechanical ventilation

The building is equipped with a balanced mechanical supply and exhaust ventilation system that uses heat recovery from the exhaust air. The heat recovery from the exhaust air has an efficiency of 30 %. The air change rate for the exterior air is 0,75 1/h. The corresponding air flow rates for the two cases are shown in Table 4.9. It is assumed that there is no ventilation between the zones.

Table 4.9. Exterior air flow rates for Case 1 and Case 2.

Air flow rate		
Case 1		**Case 2**
Zone 1	**Zone 2**	**Zone 1**
dm³/s	*dm³/s*	*dm³/s*
32	14	33

4.5 Air infiltration

In the basic calculations the infiltration is not taking into account. Thus the building is assumed to be absolutely tight. The effect of buildings’ tightness is taken into account in the sensitivity analysis.

5. General input data for both building types

5.1. Indoor climate

The set point temperature for heating is 21 °C and that for mechanical cooling, when it is used, is 25 °C.

5.2 Internal heat gains

The internal heat gains of the building are 5 W/m^2 calculated per floor area on the average. They are 50 % convective and 50 % radiative. Their daily profile as an effect/floor-area is shown in Table 5.1.

Table 5.1. Internal heat load profile.

Hour	**Internal heat gains** *W/m^2*		**Hour**	**Internal heat gains** *W/m^2*
1	3,38		13	3,38
2	3,38		14	3,38
3	3,38		15	3,38
4	3,38		16	3,38
5	3,38		17	5,07
6	3,38		18	8,45
7	8,45		19	11,83
8	8,45		20	5,07
9	3,38		21	5,07
10	3,38		22	5,07
11	3,38		23	3,38
12	11,83		24	3,38

5.3 Shading

The permanent horizon angle (α) in all directions is 5° (Figure 5.1).

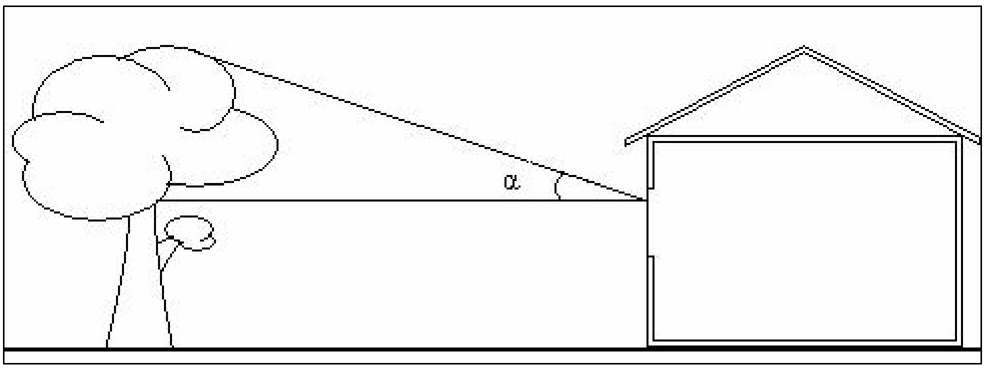

Figure 5.1. Shading angle in all directions.

5.4 Weather data

The weather data used is from the synthetic weather data generator Meteonorm for Helsinki. The weather parameters used are the exterior temperature and the total and diffuse radiation onto a horizontal plane (Table 5.2).

Table 5.2. Monthly exterior temperature and solar radiation onto horizontal surface. Meteonorm for Helsinki.

Month	**Exterior temperature**	**Solar radiation on horizontal surface**		
		Direct	**Diffuse**	**Total**
	^oC	*kWh/m^2*	*kWh/m^2*	*kWh/m^2*
1	-6,4	1,8	5,8	7,6
2	-7,0	9,8	14,9	24,7
3	-2,3	26,7	36,9	63,6
4	3,3	49,8	58,2	108,0
5	10,3	89,6	75,3	164,9
6	14,0	102,5	80,6	183,1
7	16,9	91,5	79,9	171,4
8	15,2	58,3	67,4	125,7
9	9,7	28,2	41,7	69,9
10	4,9	13,2	19,2	32,4
11	-0,1	1,9	6,9	8,8
12	-4,5	0,6	3,8	4,4
Year	**4,6**	**474,1**	**490,7**	**964,8**

5.5 Other input data

Solar radiation onto exterior surfaces is taken into account only for windows and the long-wave radiation is not taking into account at all on external surfaces. Reflective solar radiation from the ground is calculated using the total horizontal radiation and the value 0,3 for the albedo (reflection coefficient). Other initial data, which may be needed in simulations, are shown in Table 5.3.

Table 5.3. Other initial data for the single-family house calculations.

	Heat transfer coefficient		**Reflection coefficient of internal surface**
	Convection *W/Km^2*	**Radiation** *W/Km^2*	
Floor	0,5	5,3	0,5
Wall / Ceiling	2,0	5,3	0,5
Window	3,0	5,3	
Absorption coefficient of external surfaces is 0,0			

6. General information on calculations

The single-family house as well as the apartment building are exactly specified in chapters 3 - 5. In energy calculations made in practice the designer has to evaluate the dimensions and the technical details (e.g. U-values, internal heat gains, solar transmission properties of windows, absorptance of surfaces etc) from various documents. Therefore in practical calculations each calculator has his/her own interpretation for the reality. In this study this interpretation was for all calculators the same.

A short description of the energy calculation programs used is given in Appendix B. The programs were dynamic simulation programs having different level of complexity with the exception of maxit energy, which is a program based on the monthly method of EN 832 (the predecessor of ISO DIS 13790). Dynamic simulation programs calculate at the same time the interior temperature and the heating and cooling energy. maxit energy calculates only heating energy based on a constant interior temperature. The method of ISO DIS 13790 allows also the calculation of cooling energy based on a constant cooling set-point temperature, but this property is not included in maxit energy. Table 6.1 presents the programs used and their users. Each organization/user used only one program.

Because maxit energy does not calculate cooling energy for its cooling energy has been used a fixed value (- 2kWh/m^2/a) in the heating energy / cooling energy plots (e.g. Figure 6.1). This negative value naturally has no physical meaning.

Four construction types, which all have exactly the same U-values for the exterior envelope, have been used for the single-family house:

- Extra-light (ExL)
- Light (Lig)
- Semi-weight (SWe) and
- Massive (Mas)

For the apartment building there were two construction alternatives (the light and the massive one) having also exactly the same U-values. The U-values were approximately according to the present Finnish Building Regulations.

Both the single-family house and the apartment building were modelled as a single-zone building or as a single-zone flat (SgZo) as well as a two-zone building or as a two-zone flat (Zo1+2).

The central issue of this study is to evaluate the effect of thermal mass (exactly spoken the effect of thermal heat capacity) on the heating and cooling energy but also to calculate indoor temperatures, when no cooling is used. These results are presented in Chapters 7.2 and 8.1 for the single-family house and for the apartment building respectively.

The other point concerning the thermal mass and the time-constant was to evaluate if the correlation equations for the utilisation factor of ISO DIS 13790 are correct enough or should they be somehow modified. This issue is handled in Chapters 7.3 and 8.2.

Table 6.1. Energy calculation programs and their users in this study.

Program	User/Country	Description of program
Consolis Energy	KTH, Sweden	Two-zone model, simplified thermal dynamics
Ida Climate and Energy	Ax-Consulting Oy, Finland	Thermal, multi-zone simulation model
SciaQPro	Sintef , Norway	Thermal, multi-zone simulation model
Tase	TUT, Finland	Thermal, multi-zone simulation model
VIP	Cementa AB, Sweden	Simplified dynamic method, single-zone model*
VTT House Model	VTT, Finland	Thermal, multi-zone simulation model
maxit energy	maxit Oy Ab,Finland Control Engineering Ab, Sweden	Monthly energy balance method according to EN 832 Single-zone calculation

* A recent version of VIP gives the possibility for multi-zone modelling.

In addition to the basic calculations, whose purpose was to find out the effect of thermal mass on energy consumption and on the utilisation factor for exactly defined cases, various sensitivity analysis were performed. These included e.g. the effects of following issues on the energy consumption:

- Size, solar transmission and orientation of windows
- Level of thermal insulation of building's envelope
- Tightness of building's envelope
- Climate
- Set-point of interior temperatures
- Time-constant
- Split of heating effect on convection and radiation

These results are presented in Chapters 7.4 and 8.3 and the definitions of the abbreviation used (e.g. Mas, SgZo) in Appendix A.

7. Results on the single-family house

7.1 General view on the results of single-family house calculations

The simulation models used in this study (Appendix B) are based on various theories and solution techniques. Even the input data used was described extremely detailed all models could not use these modelling assumptions. Therefore, there is a significant spread in the calculation results of heating and cooling energy (Figure 7.1). This figure presents the distribution obtained when various users model an exactly specified single-family house either as a single-zone (SgZo) or a two-zone (Zo1+2) case and using the extra-light (ExL) and the massive (Mas) constructions. For the VTT House Model also a multi-zone model (15 zones) is used in calculations. The calculated net heating energy varies from 58 – 76 kWh/m^2/a and the net cooling energy from 3 – 20 kWh/m^2/a (Figure 7.1).

E.g. the following reasons cause differences in calculation results:

- The reflected solar radiation was modelled with snow cover during winter time (VTT)
- The long-wave emission from exterior surfaces was not neglected (VTT)
- Internal heat gains were not split into convection and radiation (VTT)
- The efficiency of the heat recovery system was calculated in real time, i.e. the efficiency was changing a bit as it does in reality when temperatures change (VTT)
- The multi-zone modelling clearly increases the spread of calculation results compared with the single-zone or double-zone modelling. This is because in the description phase it was decided that all internal doors were ideally tight, thus an air leakage was not possible (VTT).

The relative difference between the greatest and smallest heating energy calculated is approximately 30 % and that for the cooling energy 85 %, when the effect of thermal mass is neglected. The maximum absolute difference in both the heating energy and in the cooling energy is approximately17 kWh/m^2/a.

When only the extra-light and the massive buildings are compared with each other (as it shall), the absolute accuracy of calculating both the heating energy and the cooling energy is 10 – 16 kWh/m^2/a. In heating energy this means a relative error of approximately 20 % and in cooling energy a relative error of 75 % (Table 7.1).

Thus the heating energy can be calculated in an accuracy of 20 %, but there are great uncertainties in the calculation of cooling energy (75 %). However, the absolute uncertainty in both calculations seems to be approximately the same.

For all cases the greatest values of the heating and cooling energy are obtained with the multi-zone model of VTT House Model. Obviously one reason for this is that the internal heat loads in the description of the multi-zone model were different from those in the two zone model (not only the profile but also the average values). The average internal gains were 6 W/m^2 in the multi-zone model and 5 W/m^2 in the single-zone and in the double-zone models. Thus, the higher values in heating and cooling energy for the VTT House Model were partly due to different internal gains and partly due to the fact, that in the multi-zone model all internal doors were air-tightly closed. E.g. in the spring time some rooms of the building need cooling due to solar and internal gains while other rooms need heating. The results calculated with the two-zone model of VTT House Model were close to the results of other programs.

Table 7.1. Maximum differences in calculation results.

Thermal mass	**Energy**	**Energy**		**Difference between max and min energy**		**Programs****	
		Max.	**Min.**	**Absolute**	**Relative***	**Max**	**Min**
		kWh/m²/a		*kWh/m²/a*	*%*		
Mas	Heating	70,2	58,3	11,9	17	VTT	IDA, VIP
Mas	Cooling	13,6	3,1	10,5	77	VTT	IDA, TASE
ExL	Heating	76,4	59,9	16,5	22	VTT	IDA, VIP
ExL	Cooling	19,9	5,9	14,0	70	VTT	IDA, TASE

* Calculated from the greater energy
** With the accuracy of 1 $kWh/m^2/a$
*** The results of maxit energy are calculated using the original parameters of the utilisation factor of EN 13790.

The heating energy of the two-zone building is greater than that of the single-zone building in all calculations excluding the cases SCIAQ-ExL, SCIAQ-Mas and IDA-Mas. The cooling energy of the two-zone building is greater than that of the single-zone building in all calculations with the exception of case SCIAQ-Mas in which the cooling energy of the single-zone case is greater than that of the two-zone case. Theoretically the right result is that both the heating energy and the cooling energy are smaller for the single-zone building because the perfect heat transfer inside the single-zone equals heat and cooling demands compared with the two-zone model, in which the interior wall slows down heat transfer between the zones. The effect of zoning is approximately 1 $kWh/m^2/a$ in the heating and cooling energy of the extra-light building, but very small for the massive building. The conclusion from this could be that the single-zone modelling is good enough for a single-family house with a normal window configuration.

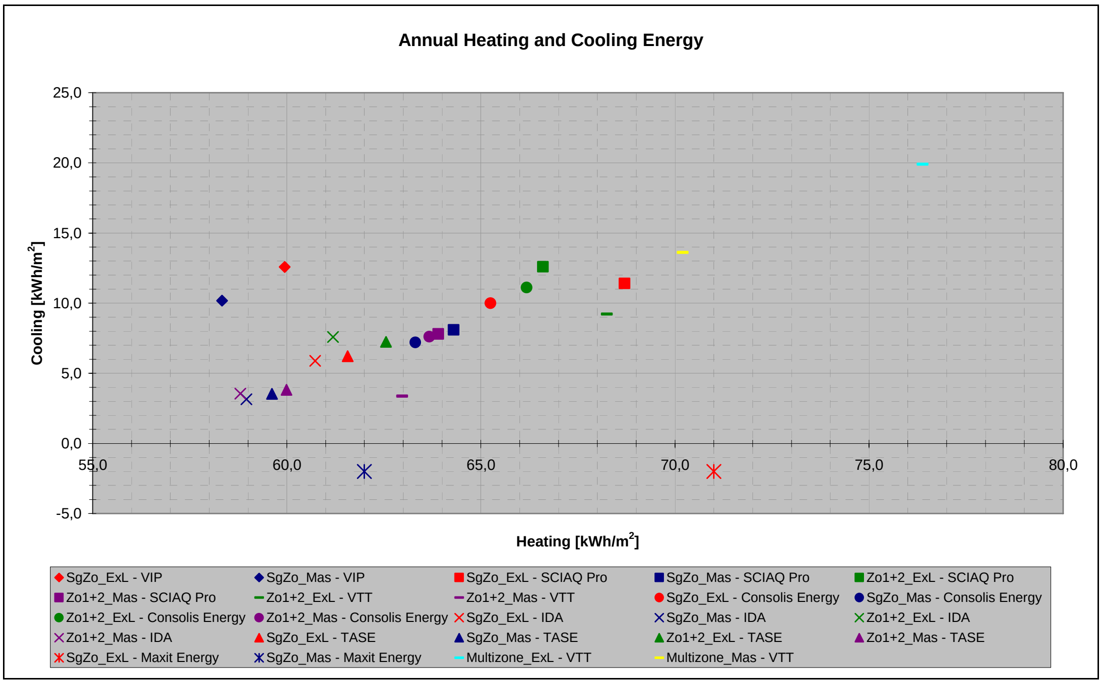

Figure 7.1. Annual heating and cooling energy for the single-family house. maxit energy calculates only the heating energy. Therefore for its cooling energy is set a negative value.

Total heat sources (other energy but heating) are composed of solar and internal heat sources. In this study only the solar energy transmitted trough windows was taken into account. The absorption of solar energy on exterior walls was neglected. Heat losses are composed of ventilation and conduction. The internal heat sources were exactly specified and therefore these were the same in all models. The solar sources are calculated by each program with its own methods from the hourly values of direct and diffuse solar radiation onto a horizontal surface. The total heat sources seem to be approximately the same for all programs but IDA, for which the total sources are approximately 3 kWh/m^2/a smaller than for the other programs (Figure 7.2). Because the internal heat sources are approximately 44 kWh/m^2/a (5 W/m^2) the difference in the solar heat sources is approximately 10 % (3 kWh/m^2/a / 30 kWh/m^2/a) between IDA and the other programs.

The maximum difference in heat losses between various programs is approximately 10 %. VTT House Model gives the highest losses and VIP, SciaQPro and maxit energy the lowest (Figure 7.2).

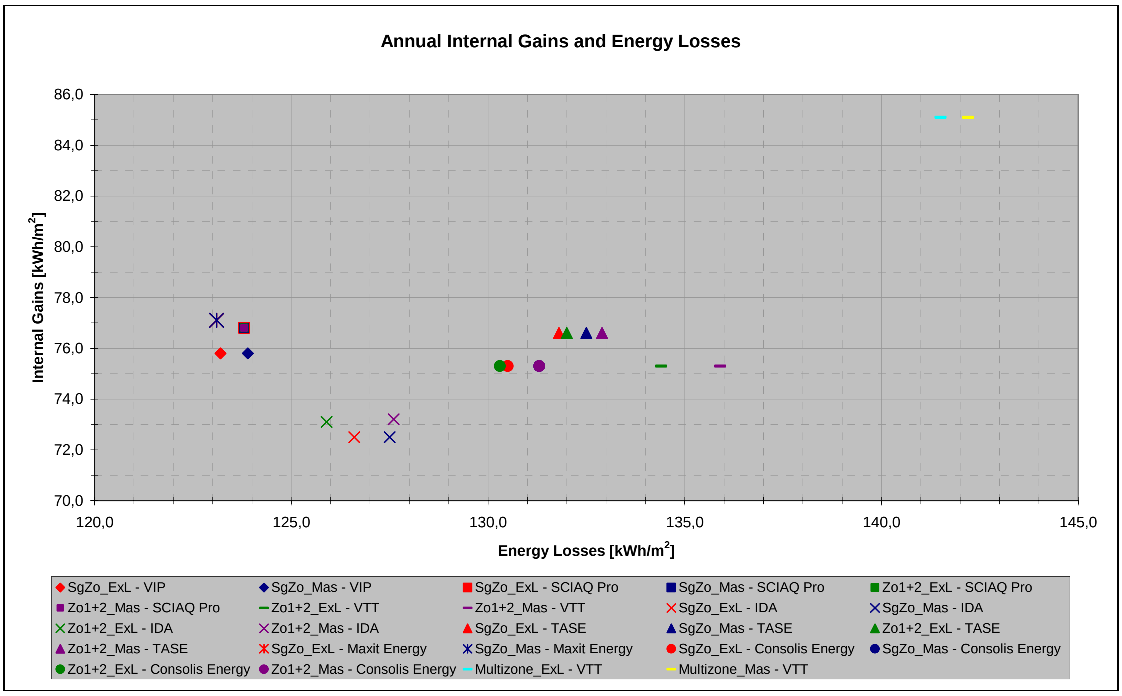

Figure 7.2. Annual total heat sources and losses.

In energy calculations it is very important that the annual and monthly energy balances are correct. This means that the energy input must be exactly the same as the energy loss for the period considered. The annual energy balances for all programs but SciaQPro are very accurate (Figures 7.3). For SciaQPro the energy loss is calculated using the set-point interior temperature, not the calculated one, which causes a too low energy loss. This reason also causes the fact, that the magnitude of gains and losses in the energy balance is lower for maxit energy than for other programs on the average.

From the results of TASE it has also been possible to extract the division of energy input into net heating and solar and internal sources and the energy loss into conduction through the components of the envelope and into ventilation. This division was not possible to extract from the results of all programs (Figure 7.3).

Figures 7.4 and 7.5 show the annual heating energy for the single-zone and the two-zone buildings for a case, where there is no cooling, respectively. The interior temperature is thus allowed rise freely in summer and other occasions, when the gain/loss ratio is high. One reason for the relatively small effect of thermal mass is the small window area (12 % from the floor area). With a greater window area also the effect of thermal mass is greater.

The annual heating energy calculated by maxit energy is presented in Figure 7.4 for a comparison, even if the calculation of energy use is based on a constant set-point interior temperature. This figure also shows the problems of the standard ISO DIS 13790 (EN 832) when calculating extra-light buildings with very low time-constants.

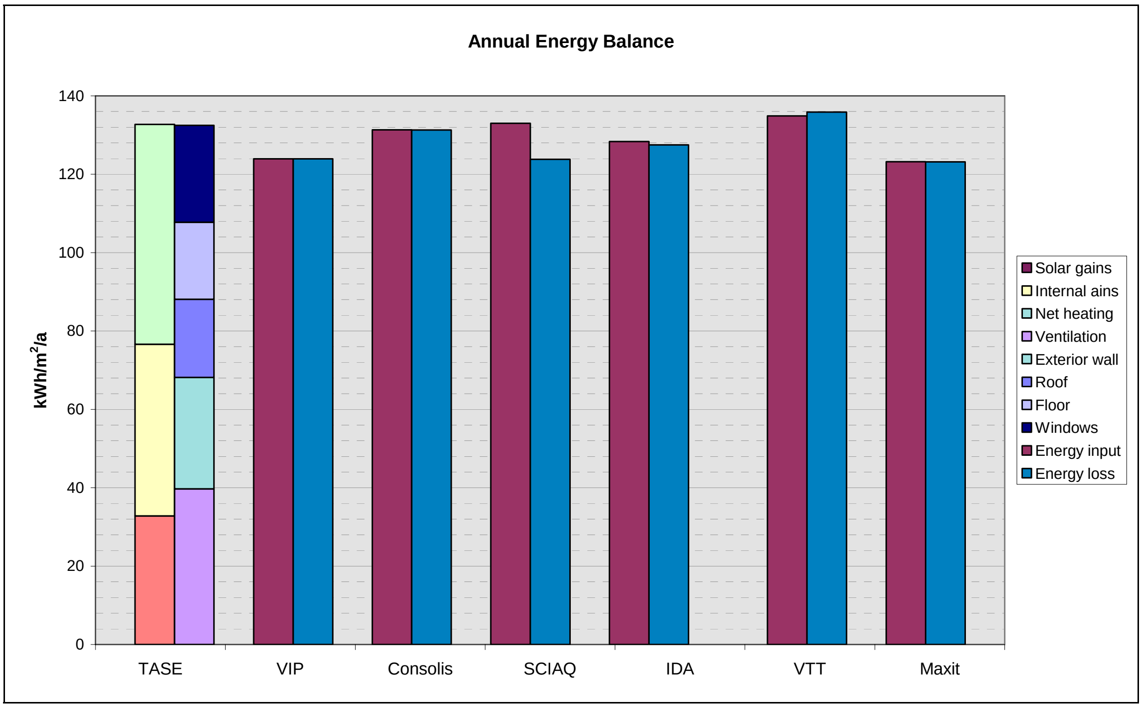

Figure 7.3. Annual energy balances of the programs used. 2-zone models for all programs except VIP and maxit energy.

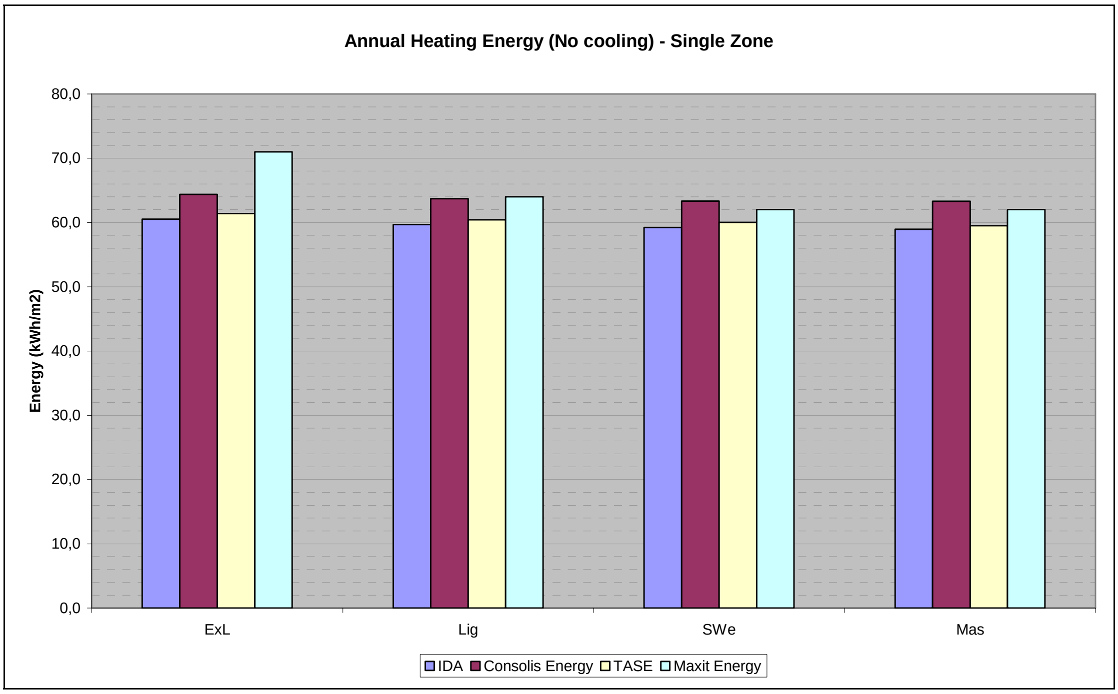

Figure 7.4. Annual heating energy for the single-zone building, when there is no cooling. maxit energy uses a constant set-point interior temperature.

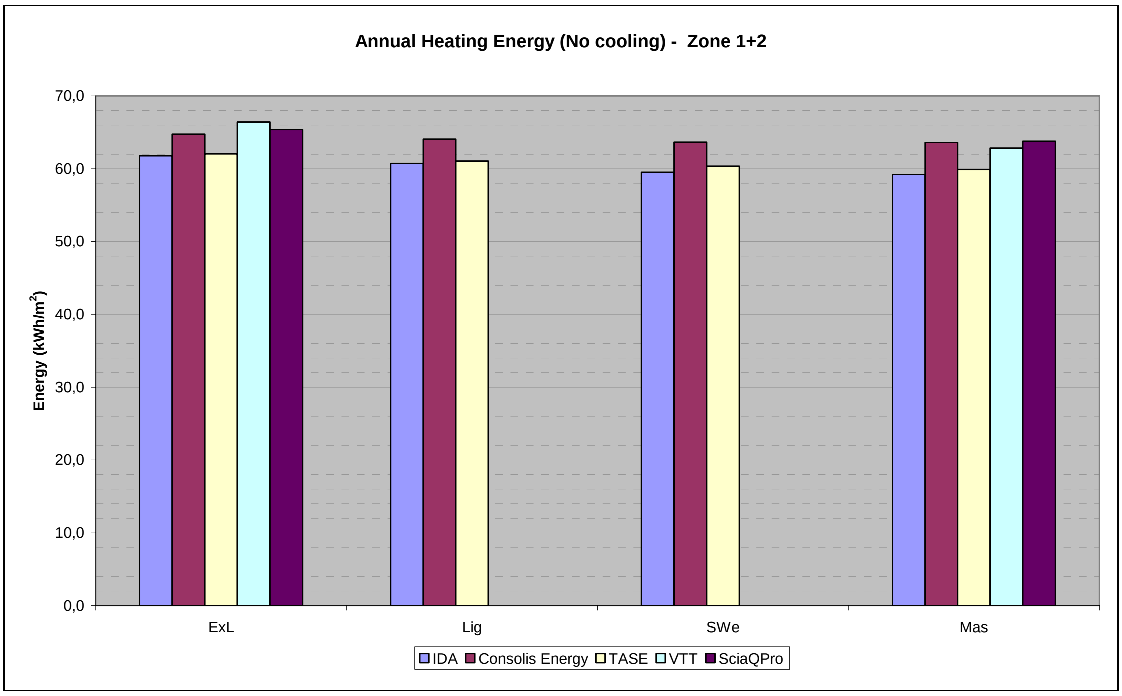

Figure 7.5. Annual heating energy for the two-zone building, when there is no cooling.

7.2 Effect of thermal mass (heat capacity) on energy and indoor climate

The effect of thermal mass is approximately 4 % on the annual heating energy and 40 % on the cooling energy, when the massive and the extra-light small houses are compared for a case having a relatively small window area (12 % from the floor area) (Figure 7.6). VTT House Model gives clearly the highest effect on thermal mass both in heating energy and in cooling energy. This partly is due to the detailed zoning (15 zones) used in the model, but there are probably other reasons too. maxit energy gives for the effect of thermal mass on heating energy 13 %, when the massive and the extra-light buildings are compared. The big effect is due to the problem in the utilisation factor of the extra-light building.

The effect of thermal mass on heating and cooling energy strongly depends on the window area. The basic window area of this study was quite small. The effect of thermal mass clearly increases, when the window size increases. When the effect of thermal mass is about 4 % in the heating energy for the small basic window size, this effect is approximately 10 % for the window size of 20 % from the floor area and 15 % for the window size of 45 % of floor area. This is handled more detailed in Chapter 7.4.1.

The effect of thermal mass on heating energy increases approximately 1 % when a two-zone model is used instead of the single-zone model. In the cooling energy the effect of zoning is approximately 10 %.

The effect of thermal mass is greatest when the thermal capacity is increased from the level of the extra-light building (50 MJ/m^2K) to the level of the light building (190 MJ/m^2K), which has a concrete floor. When the window size is great (20 % from the floor area) the increase of thermal mass can reduce the heating energy up to 10 % (Figure 7.7). The results of Figure 7.7 are not quite comparable, because in the calculations of TASE and maxit energy the window size is increased only on the south façade, but in those of Consolis Energy proportionally on all exterior walls.

The simulation programs used give approximately the same effect for the thermal mass. maxit energy (EN 832) gives a clearly higher effect, which is due to the erroneous utilisation factor of EN 832 for the extra-light building (Figures 7.8 and 7.9).

When cooling is used the interior temperatures are between 21 – 25 ^{o}C. The duration curve of Figure 7.10 gives the relative time of the year, when the interior air temperature exceeds the value presented in figure. The air temperature is always (100 %) higher than the heating set-point temperature 21 ^{o}C and never (0 %) greater then the cooling set-point temperature 25 ^{o}C. The air temperature is 20 – 30 % from the total time (year, 8760 h) at the cooling set-point temperature depending on the thermal mass and the window size. Both the basic window area (12 % from the floor area) and a greater window area (20 % from the floor area) have been used in these calculations. The increase of the window size raises the level of indoor temperatures in well-insulated buildings.

When the cooling set-point air temperature is 25 ^{o}C, the air temperature is usually this 25 ^{o}C during daytime in summer. In the evening the building starts to cool, which happens more rapidly in the extra-light building than in the massive one. Therefore the air temperatures are slightly lower in the extra-light building, when cooling is used. However, it must be remembered, that these interior temperatures are obtained in the massive building with a clearly smaller cooling energy consumption than in the extra-light building. Also it must be remembered, that the temperatures of Figure 7.10 are air temperatures and not comfort temperatures, which include also the effects of interior surface temperatures.

When cooling or extra ventilation are not used the interior temperatures rise very high (Figure 7.11). For the basic window size (12 % from the floor area) the interior temperature exceeds 30 ^{o}C about 400 h in the massive single-family house and about 800 h in the extra-light house. When the window size is 20 % from the floor area, the temperature 30 ^{o}C is exceeded about 1700 h during the year. For the greater window area the effect of thermal mass can bee seen in temperatures above 32 ^{o}C. Thus, in order to get realistic temperatures in simulations of well-insulated buildings either mechanical cooling or extra ventilation must be used.

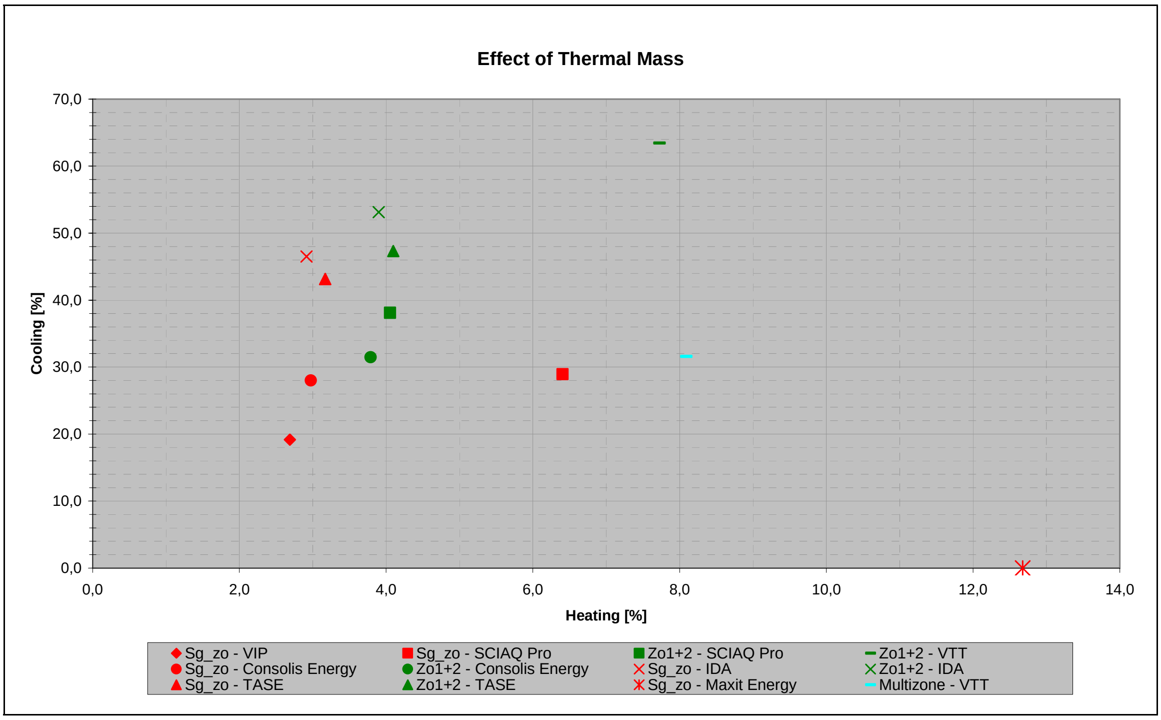

Figure 7.6. Effect of thermal mass on heating and cooling energy. x- and y-axis present the relative differences in heating and cooling energy between the extra-light and massive single-family houses respectively.

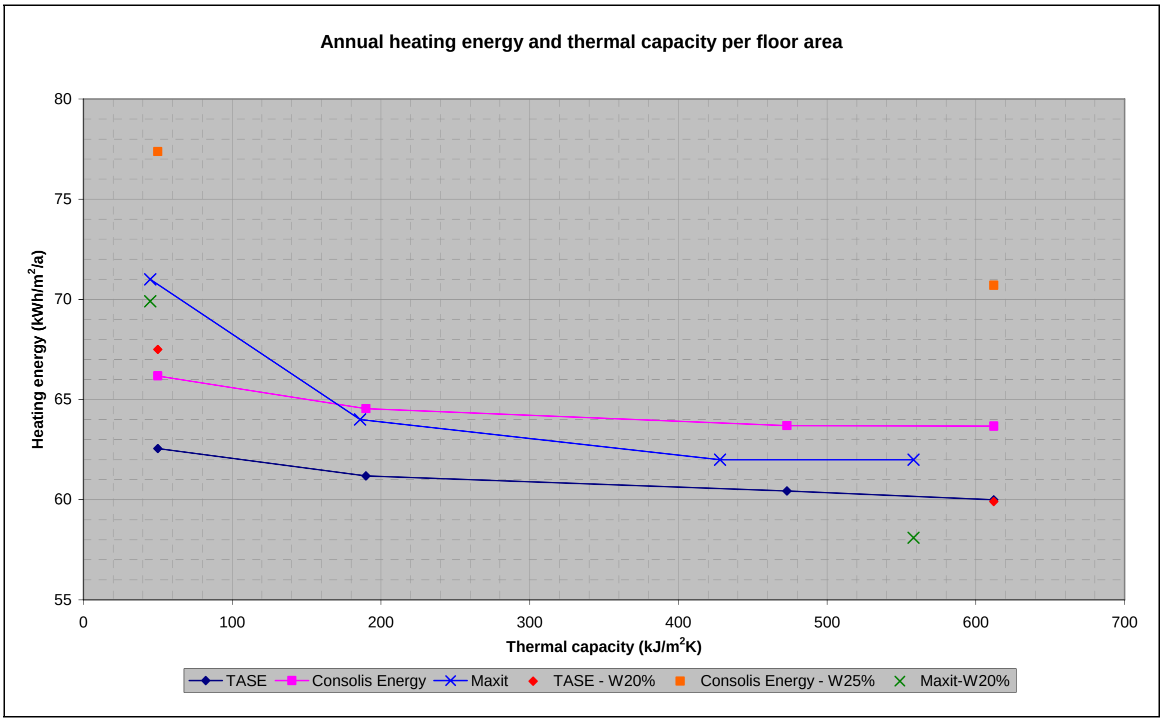

Figure 7.7. Effect of thermal mass (capacity) and window size/floor-area (W = 12 % (basic case), W = 20 % and W = 25 %) on heating energy.

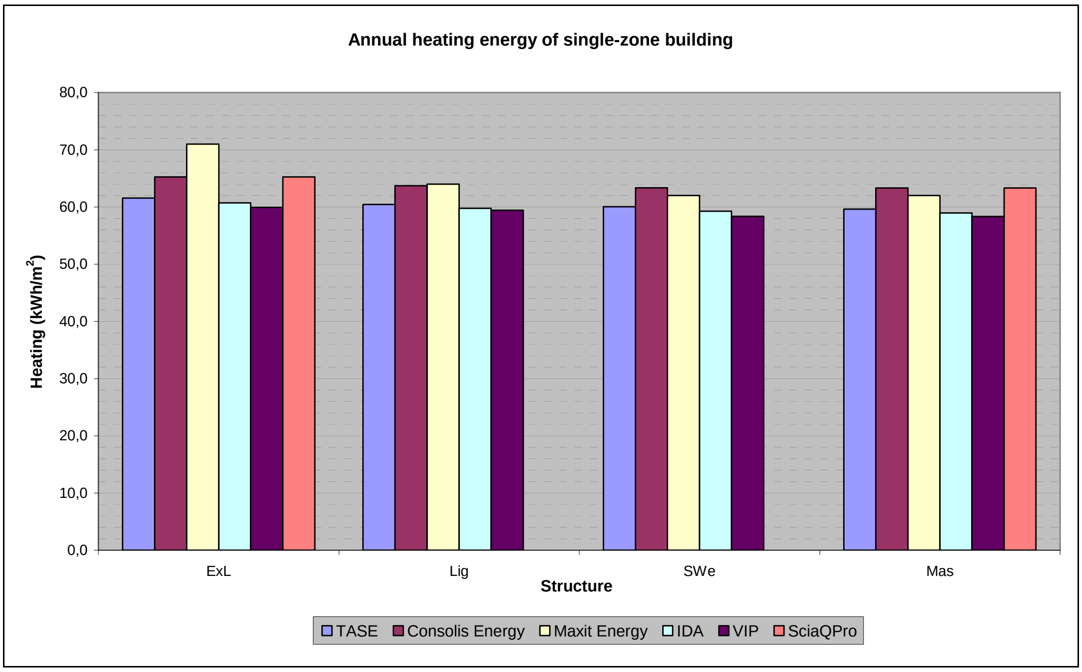

Figure 7.8. Effect of thermal mass on heating energy calculated with four simulation programs and one energy balance method (maxit energy). Single-zone building.

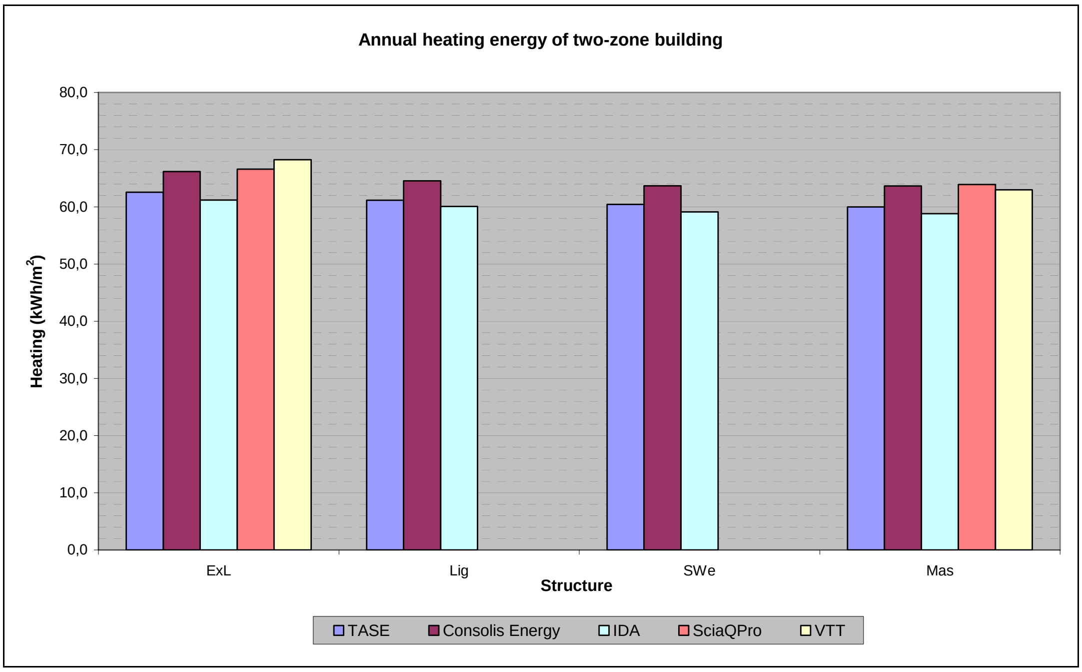

Figure 7.9. Effect of thermal mass on heating energy calculated with five simulation programs. Two-zone building.

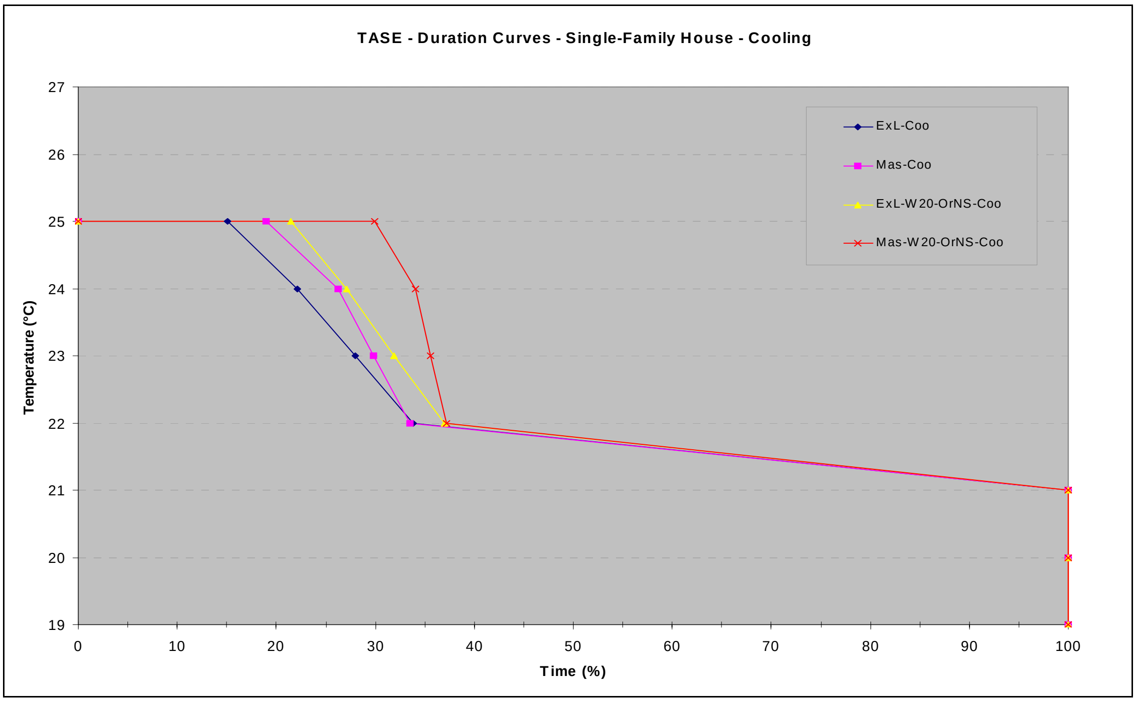

Figure 7.10. Duration curves of indoor temperature with mechanical cooling for the whole year (100 % corresponds 8760 h). TASE, single-family, single-zone building. Window area 12 % or 20 % from the floor area.

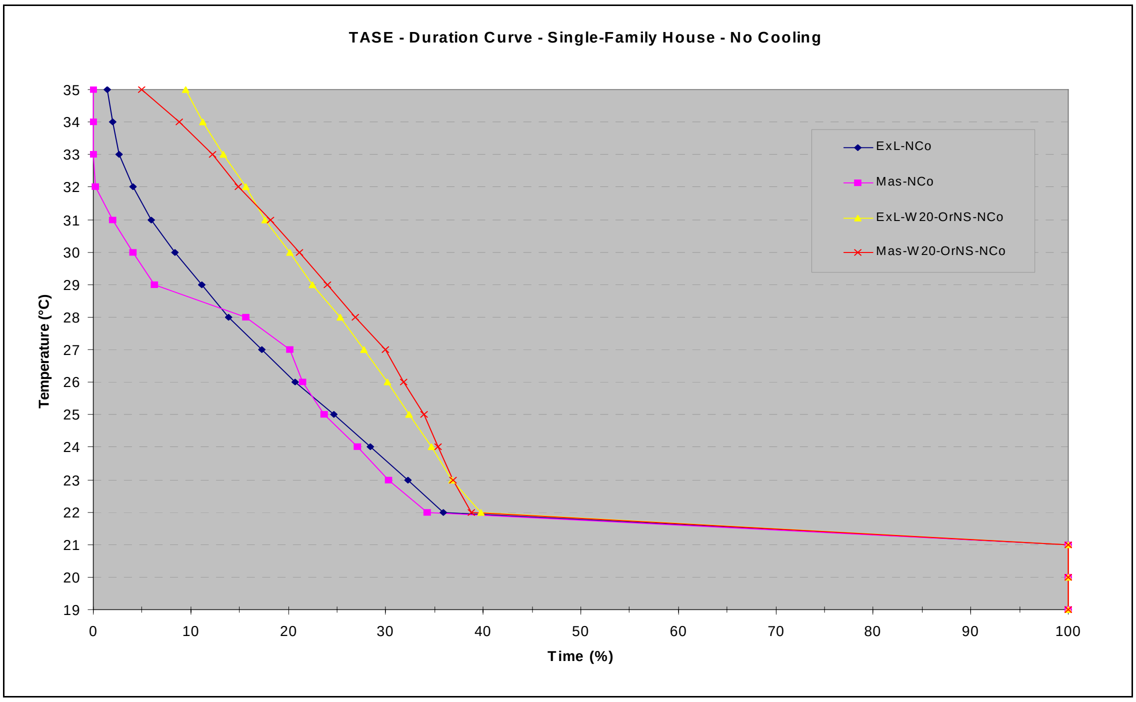

Figure 7.11. Duration curves of indoor temperature without mechanical cooling for the whole year (100 % corresponds 8760 h). TASE, single-family, single-zone building. Window area 12 % or 20 % from the floor area.

7.3 Utilisation factor for the single-family house

The utilisation factors are constructed from monthly calculation results according to Chapter 2.1. They have been calculated using four simulation programs (TASE, Consolis Energy, VIP and VTT House Model). Each point of the curves corresponds to one monthly result. The points with a low gain/loss ratio present winter months and correspondingly the points with a high gain/loss ratio spring and summer months. The extra-light building had no massive surfaces and its time constant was 15 – 17 h depending whether single-zone or double-zone modelling was used. The time constant of the massive building was correspondingly 190 – 208 h.

The values for the utilisation factor obtained from simulations are compared with the values of ISO DIS 13790 (Eq. 2.6) and those created in the PASSYS project (Eq. 2.10). For Eq. 2.6 together with its basic parameters ($a_0 = 1$ and $\tau_0 = 15$ h) other parameters have been studied in order to find a good fit with the utilisation factors obtained from simulations. Also for Eq. 2.10 other parameters than the original ones (K=1,35 or 1,19 and D=0,27 or 0,00) have been studied. The PASSYS utilisation curve is presented as an IEA curve in Figures 7.16 – 7.19 due to the publishing forum (an IEA report).

TASE, VIP and Consolis Energy give very similar utilisation factors for the extra-light, the light and the heavy single-zone, single-family house (Figures 7.12 - 7.13). VTT House Model gives a slightly higher spread for the utilisation factor (Figures 7.14 and 7.15) both when using the two-zone and multi-zone models.

The original parameters of ISO DIS 13790 give a good fit for the utilisation factor of the light and the massive house, but quite a poor fit for the extra-light building, especially when the gain/loss ratio is less than 3 (Figures 7.16 - 7.18). The utilisation factor of PASSYS (Eq. 2.10) with its original parameters clearly gives a poorer fit for the utilisation factor of the light and the massive buildings than those of ISO DIS 13790.

It is possible to find for Eqs. 2.6 and 2.10 parameters which give a good fit with the simulation results also for the utilisation factor of the extra-light building (Figure 7.19). The parameters $a_0 = 3{,}1$ and $\tau_0 = 15$ h and K = 1,02 and D = 0,43 seem to give a good fit. However, these are just two examples of parameters, which give a good fit for the utilisation factor. Many other well-suiting parameters could be found as well.

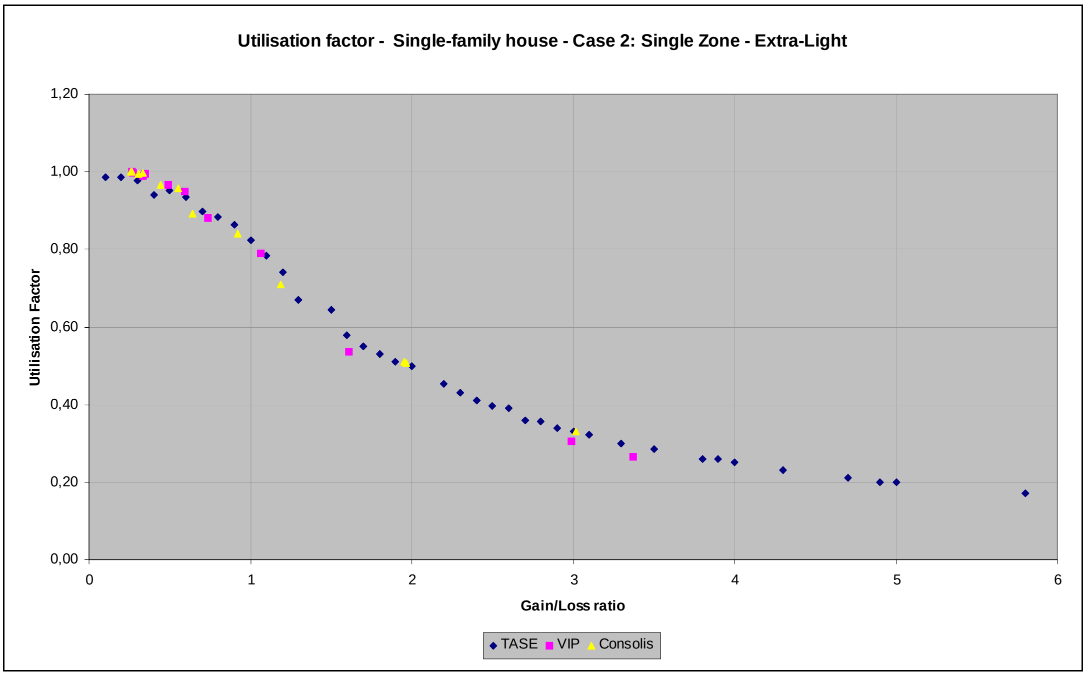

Figure 7.12. Utilisation factor for the extra-light single-zone, single-family house according to TASE, VIP and Consolis Energy.

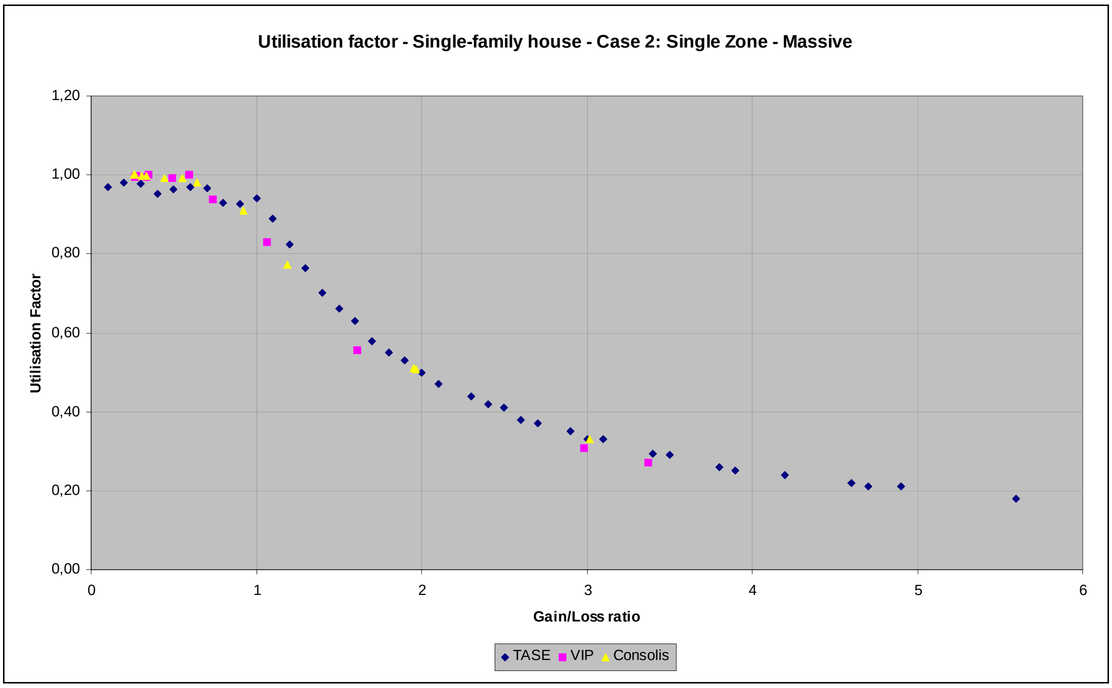

Figure 7.13. Utilisation factor for the massive single-zone, single-family house according to TASE, VIP and Consolis Energy.

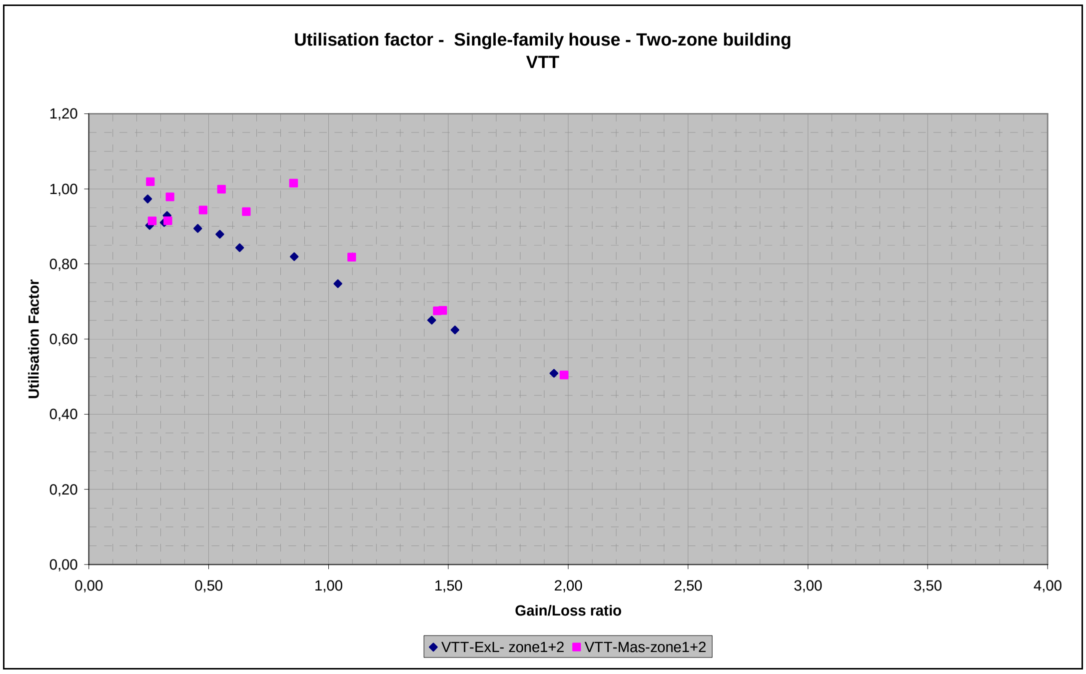

Figure 7.14. Utilisation factor for the extra-light and the massive two-zone, single-family house according to VTT House Model.

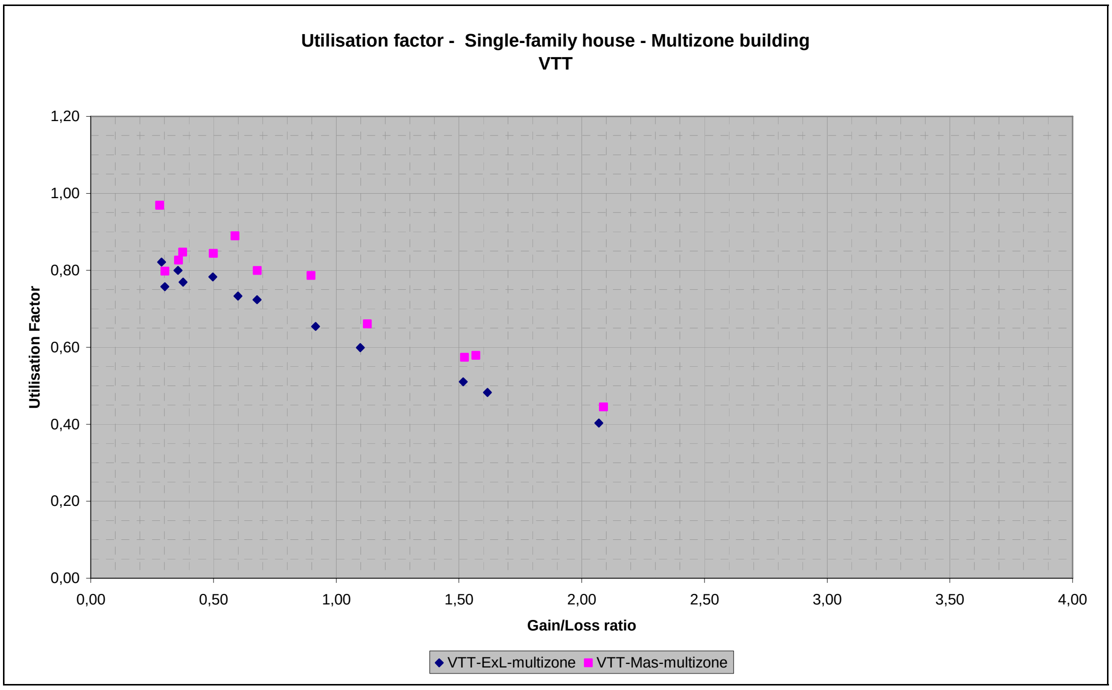

Figure 7.15. Utilisation factor for the extra-light and the massive multizone (15 zones), single-family house according to VTT House Model.

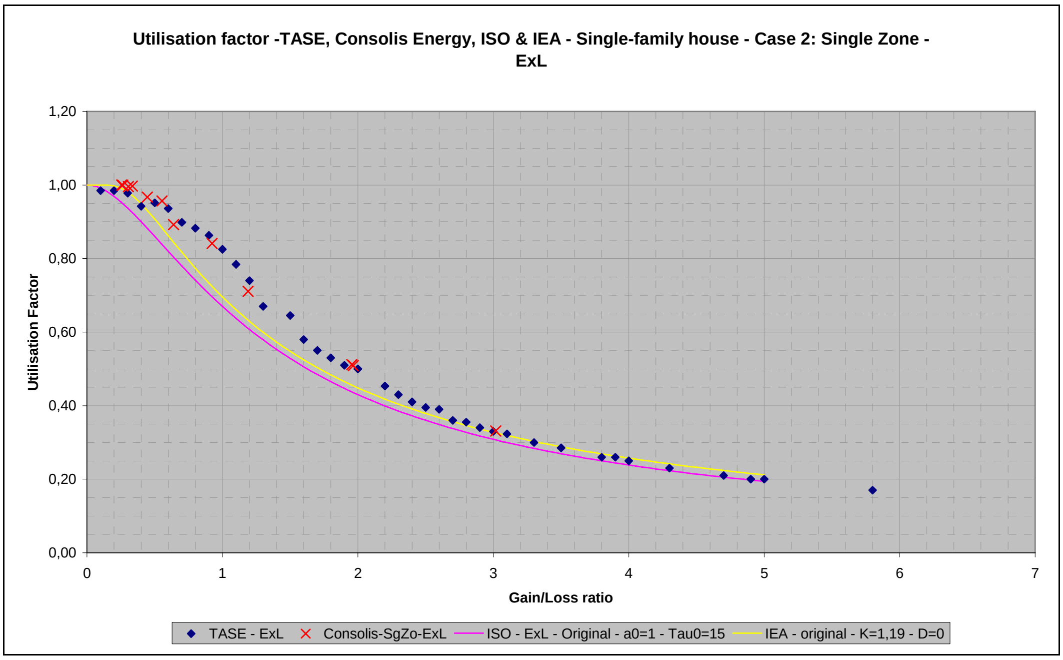

Figure 7.16. Utilisation factor for the extra-light single-family house according to TASE, Consolis Energy, ISO DIS 13790 and PASSYS. Original parameters of ISO DIS 13 790 and PASSYS.

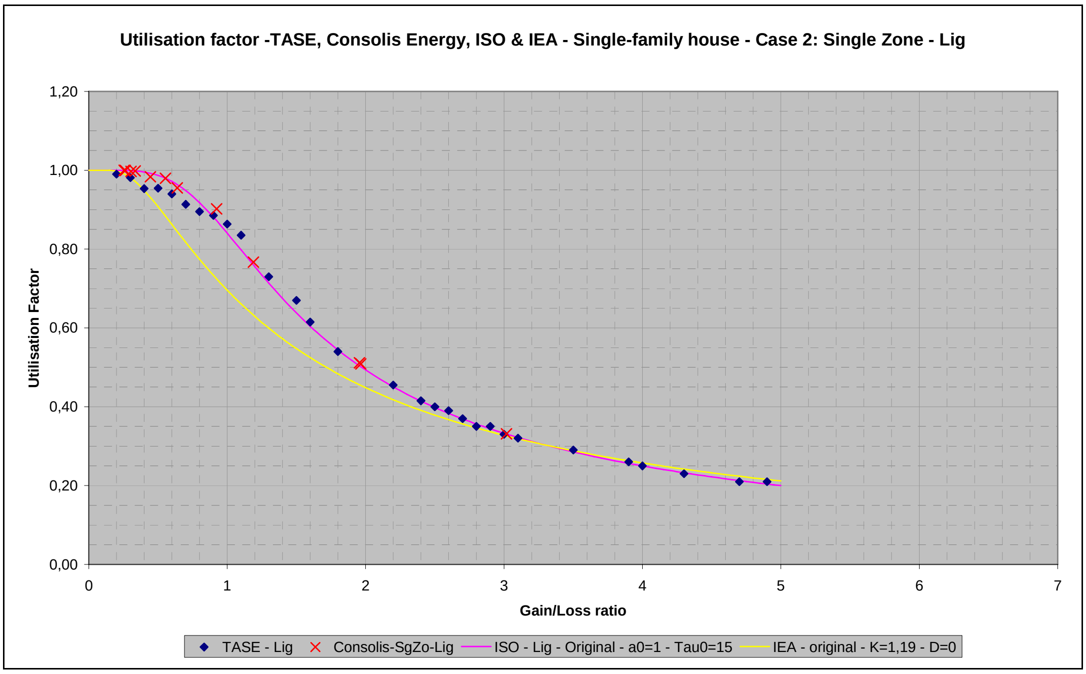

Figure 7.17. Utilisation factor for the light single-family house according to TASE, Consolis Energy, ISO DIS 13790 and PASSYS. Original parameters of ISO DIS 13 790 and PASSYS.

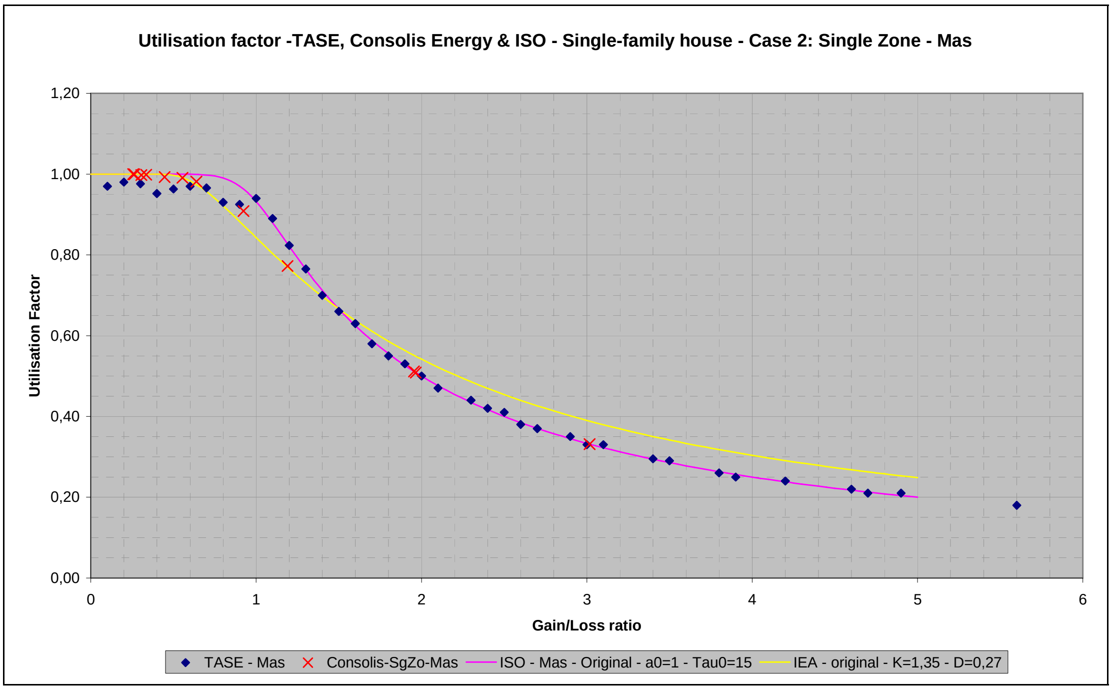

Figure 7.18. Utilisation factor for the massive single-family house according to TASE, Consolis Energy, ISO DIS 13790 and PASSYS. Original parameters of ISO DIS 13790 and PASSYS.

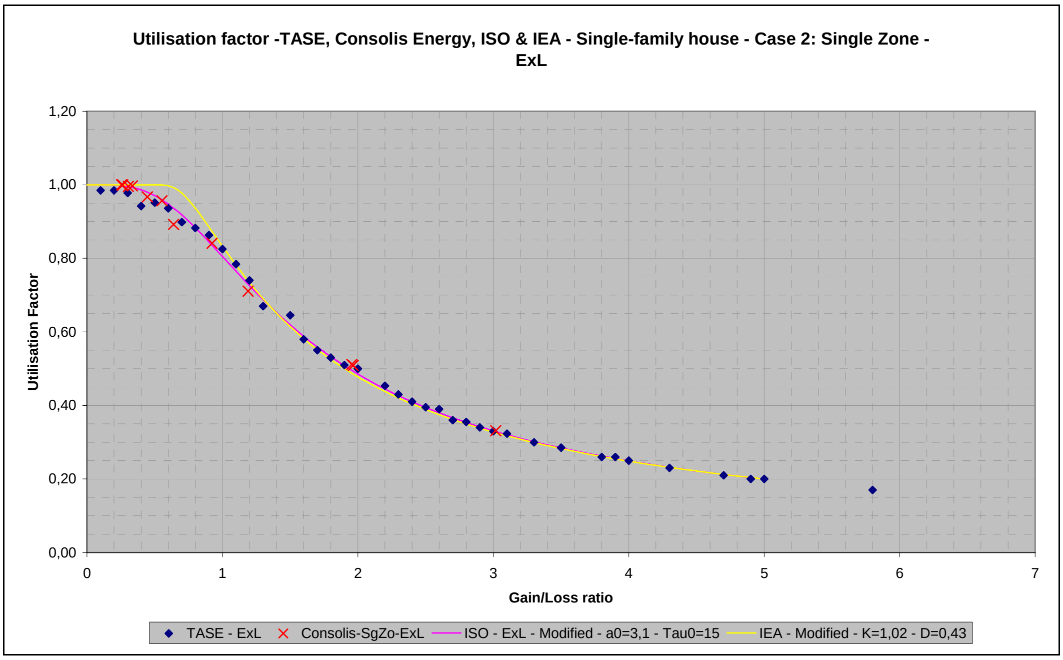

Figure 7.19. Utilisation factor for the extra-light, single-zone, single-family house according to TASE, Consolis Energy, ISO DIS 13790 and PASSYS. Modified parameters of ISO DIS 13 790 and PASSYS.

7.4 Sensitivity analysis of some factors affecting the energy consumption

7.4.1 Orientation of exterior walls and size of windows

The effect of windows' size and orientation on the energy consumption was studied with TASE, Consolis Energy, SciaQpro and maxit energy. In the basic case of calculations the size of windows is small, 12 % from the floor area. In the sensitivity studies of TASE and maxit energy the area of windows is increased to 15 % and 20 % from the floor area. In SciaQPro the window area is increased to 17 % from the floor area. In the sensitivity analysis of Consolis Energy the increased area of windows is 17 %, 25 %, 35 % and 45 % from the floor area. In the calculations of TASE, SciaQPro and maxit energy the window area is increased only on the main façade (south or after a clockwise rotation west), but in the calculations of Consolis Energy also on other exterior walls.

These calculations were made with the double-zone model for other programs, but maxit energy, which uses the single-zone model.

In the studies of the windows' orientation the building is rotated 90 degrees clockwise. Thus the main façade, which originally was facing towards south and which had the greatest window area, was facing after the rotation towards west. The change in the windows' orientation is presented by the symbol Or NS, which means that the windows are after the rotation in north – south direction and that the greatest window area is facing towards west. The window area/floor area is presented by the notation W 20, if e.g. the relative window area is 20 %.

When the window area is increased noticeably from the basic level (12 % from the floor area) to 45 % from the floor area, heating energy increases by about 30 kWh/m^2/a (50 %) in the extra-light building and 20 kWh/m^2/a (30 %) in the massive building (Figure 7.20). The increase of cooling energy is noticeable, approximately 60 kWh/m^2/a in the extra-light building and 50 kWh/m^2/a in the massive building.

When the window area is increased only moderately from the basic level 12 % to 20 % from the floor area, heating energy of the massive building decreases slightly or remains approximately constant. In the extra-light building this increase of windows' size increases heating energy slightly, by 1,5 – 5 kWh/m^2/a (Figure 7.21).

The effect of thermal mass clearly increases, when the relative window size increases. When the effect of thermal mass is about 3 – 4 % in heating energy for the small basic window size (12 % from the floor area), this effect is approximately 10 % for the window size of 20 % and 16 % for the window size of 45 % (Figures 7.21 and 7.22). The absolute differences in the heating energy between the extra-light and the massive buildings increase from approximately 3 kWh/m^2/a to13 kWh/m^2/a and from when the relative window size is increased from its basic level 12 % to 45 % from the floor area. In the cooling energy the corresponding increase is from 3,5 kWh/m^2/a to 15 kWh/m^2/a.

The effect of building's façade's orientation is quite small in the heating energy, when the window size is 12 % from floor area. The heating energy of the extra-light building is increasing by 1 % and that of the massive building by 3 % when the orientation of the building is rotated 90 ^{o} clockwise, thus the orientation of the main façade is rotated from south to west. If the window area is 20 % from the floor area, the same rotation increases heating energy by 3 % and 11 % in the extra-light and in the massive buildings respectively. These numbers show, that the massive constructions can utilise the solar radiation coming from the big south-facing windows better than the extra-light constructions.

The cooling energy of the extra-light and the massive buildings increase only slightly, by 1,5 kWh/m^2/a, by rotating the façade towards west with the original window area. When the window size great (20 % from the floor area) the west-facing main façade does not affect the cooling energy of the massive building, but slightly decreases the cooling energy in the extra-light building (Figure 7.20 and 7.22).

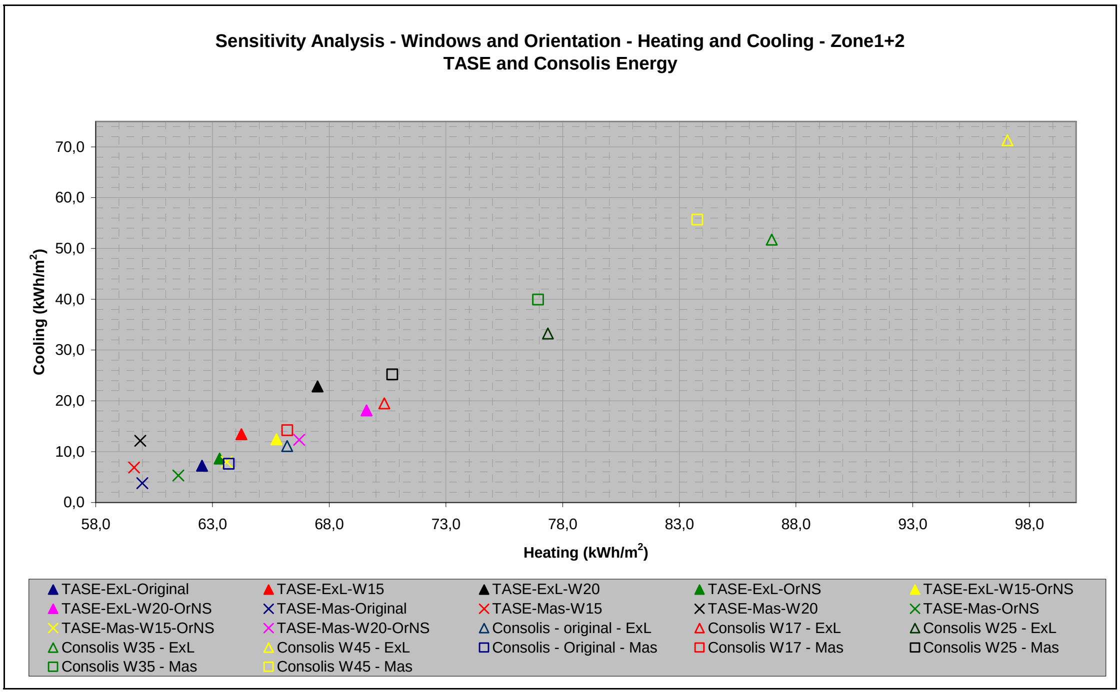

Figure 7.20. Effect of windows' orientation and size on the relative difference between the heating and cooling energy of the extra-light and the massive buildings. Double-zone building.

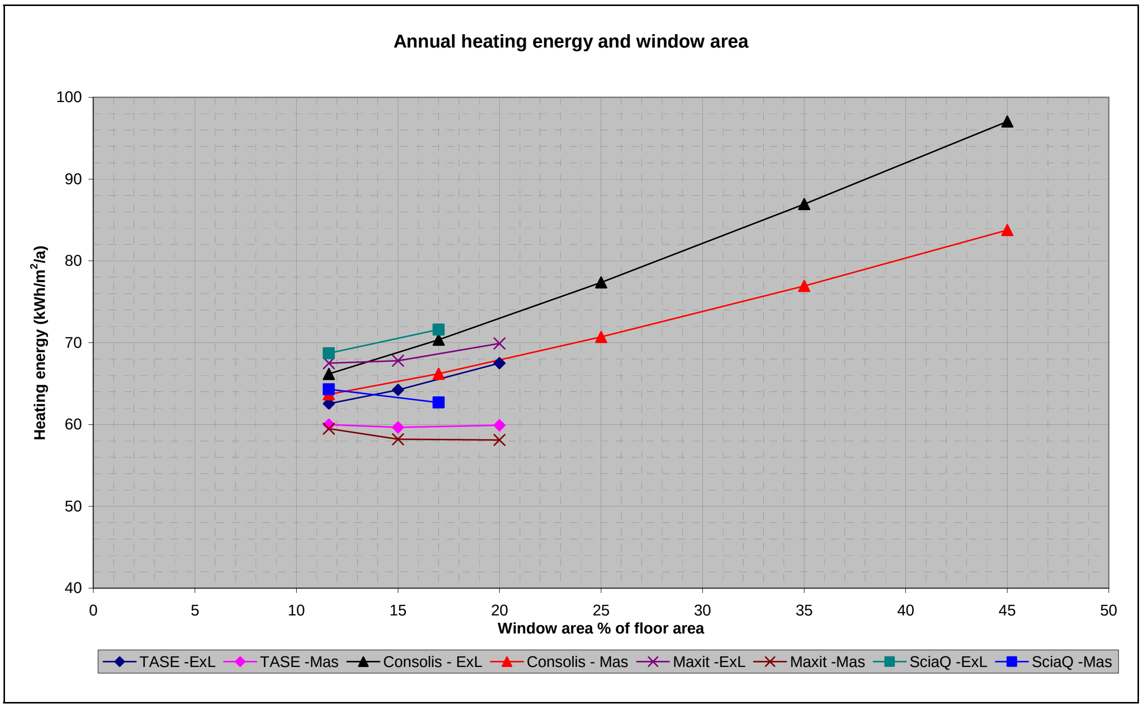

Figure 7.21. Effect of relative window area on the heating energy. Double-zone building.

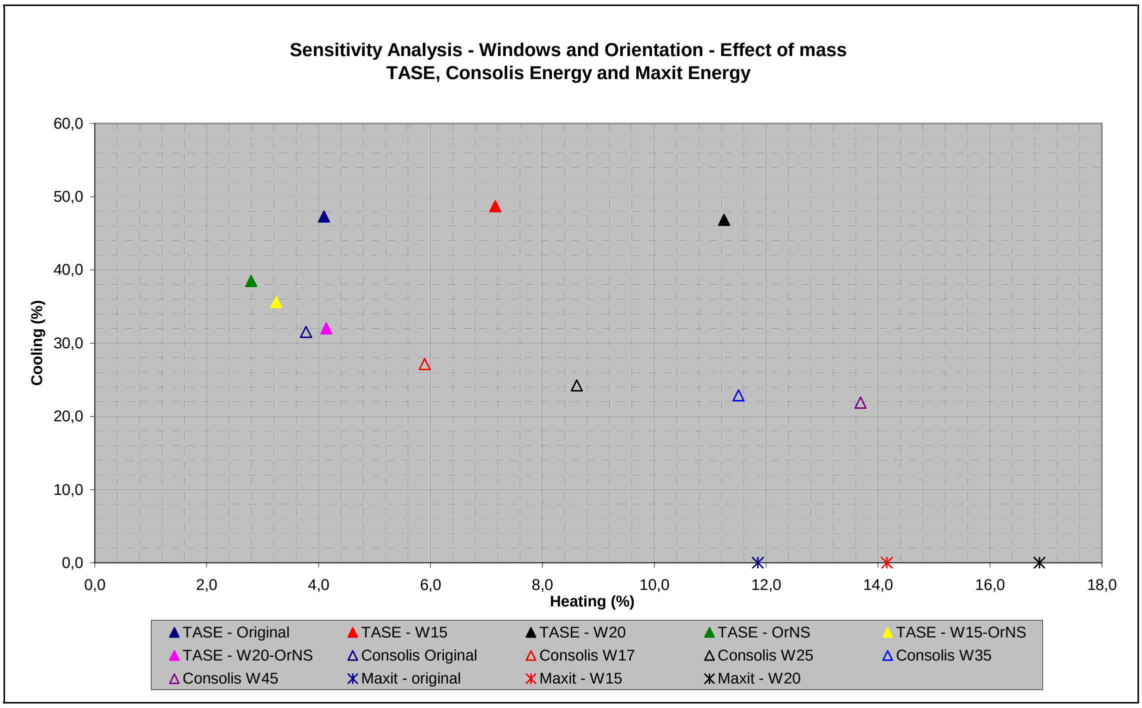

Figure 7.22. Effect of windows' orientation and size on the relative difference between the heating and the cooling energy of the extra-light and the massive buildings. The energy consumption of the massive building is lower. Single-zone building in maxit energy, in others double-zone building.

7.4.2 Thermal insulation and solar transmittance of windows

The effect of thermal insulation of the building's envelope and the effect of g-values of windows (solar transmittance) on the heating and cooling energy is studied using VTT's House Model. There are three cases in the sensitivity studies of the thermal insulation: original, increased and reduced insulation (Table 7.2). The window area in these studies is the basic one (12 % from the floor area). The g-values of windows varied from 0,14 to 0,64, which is the basic value.

Table 7.2. The U-values of the exterior envelope.

Wall / window	**U-value**		
	Original	**Increased insulation**	**Reduced insulation**
	W/m²K	*W/m²K*	*W/m²K*
Exterior walls	0,22	0,10	0,33
Base floor	0,13	0,10	0,19
Roof	0,13	0,10	0,30
Windows	1,4	1,0	2,6

When using the increased insulation level heating energy decreases by about 20 kWh/m^2/a (30%). However, at the same time the cooling energy increases by about 5 kWh/m^2/a (Figure 7.23). If the reduced insulation level is used heating energy increases by 50 kWh/m^2/a, but at the same the cooling energy decreases (Figure 7.23).

Heating energy increases and cooling energy decreases, when the g-value of windows decreases (Figure 7.23). In the massive building heating energy increases by 20 % and in the extra-light building 12 %, when g-value decreases from the basic value 0,64 to the value 0,14. When g-value is 0,14 then cooling energy in the massive building is zero and in the extra-light building 3 kWh/m^2/a.

The relative effect of thermal mass on heating energy decreases when the windows' g-value or the level of thermal insulation of the envelope decrease (Figure 7.24). When g-value is 0,24, heating energy of the massive and the extra-light buildings are almost equal. However, there is clear difference (5 kWh/m^2/a) in the cooling energy.

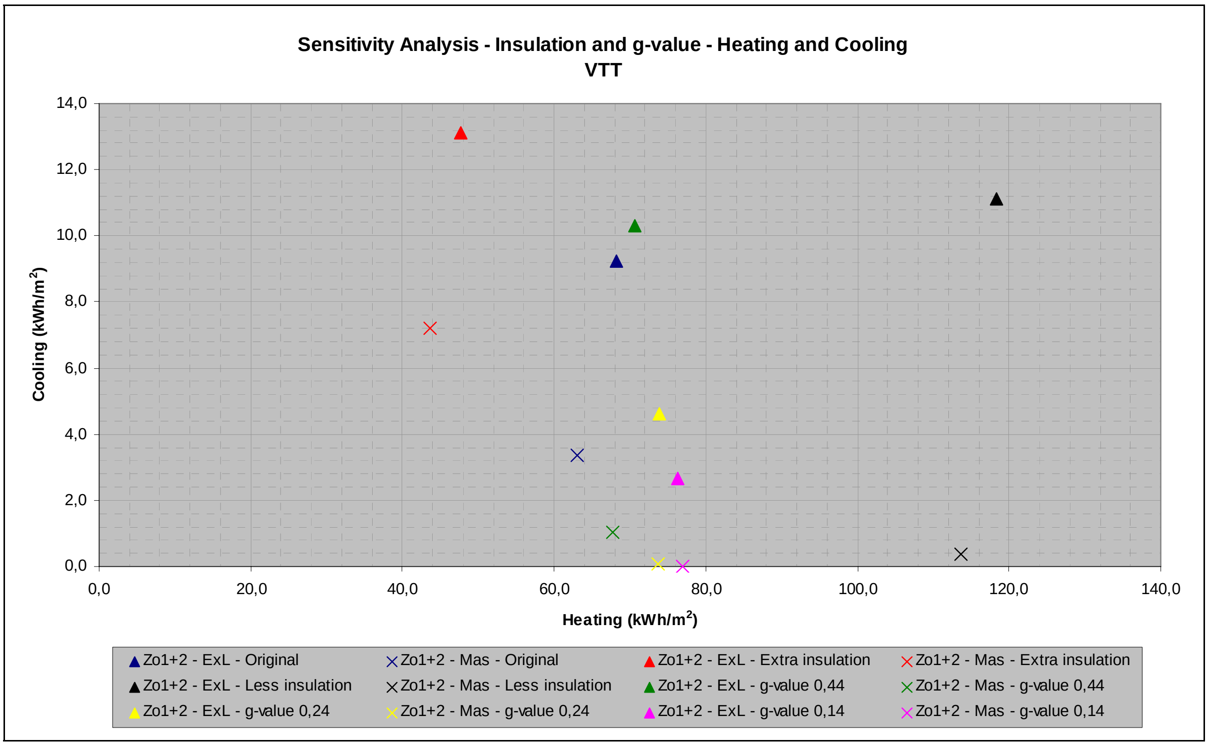

Figure 7.23. Effect of thermal insulation and windows' g-value on the heating and cooling energy.

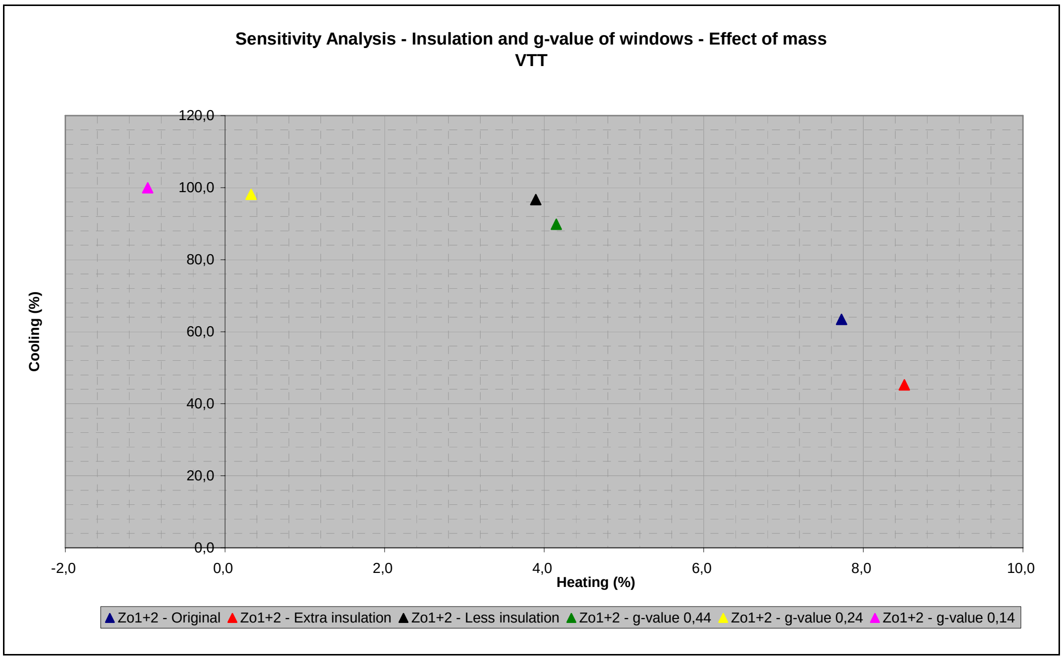

Figure 7.24. .Effect of windows' g-value and thermal insulation level of the envelope on the difference between the heating and cooling energy of the extra-light and the massive buildings.

The relative significance of the thermal mass on heating energy increases, when the insulation level of the exterior envelope improves. The relative difference in heating energy between the extra-light and the massive single-family houses approximately doubles from 4 % to 8 %, when the average U-value of the exterior envelope decreases from 0,36 W/Km^2 to 0,14 W/Km^2 (Figure 7.25). Both the 8 % difference between the energy consumptions of the extra-light and the massive, well-insulated buildings and the corresponding 4 % difference in the poorly insulated buildings correspond to an energy consumption of 5 kWh/m^2/a. The percentage numbers show higher differences in the well-insulated buildings, because they have lower energy consumptions.

7.4.3 Tightness of the envelope

The big effect of the tightness of the building's envelope on heating energy can bee seen from Figure 7.26. The calculations were done by VIP. In the basic calculation the building was absolutely tight. For the untight case the specific infiltration rate was 1,2 dm^3/sm^2, which corresponds the value n_{50} = 3 1/h of the pressure test (pressure difference in the envelope 50 Pa).

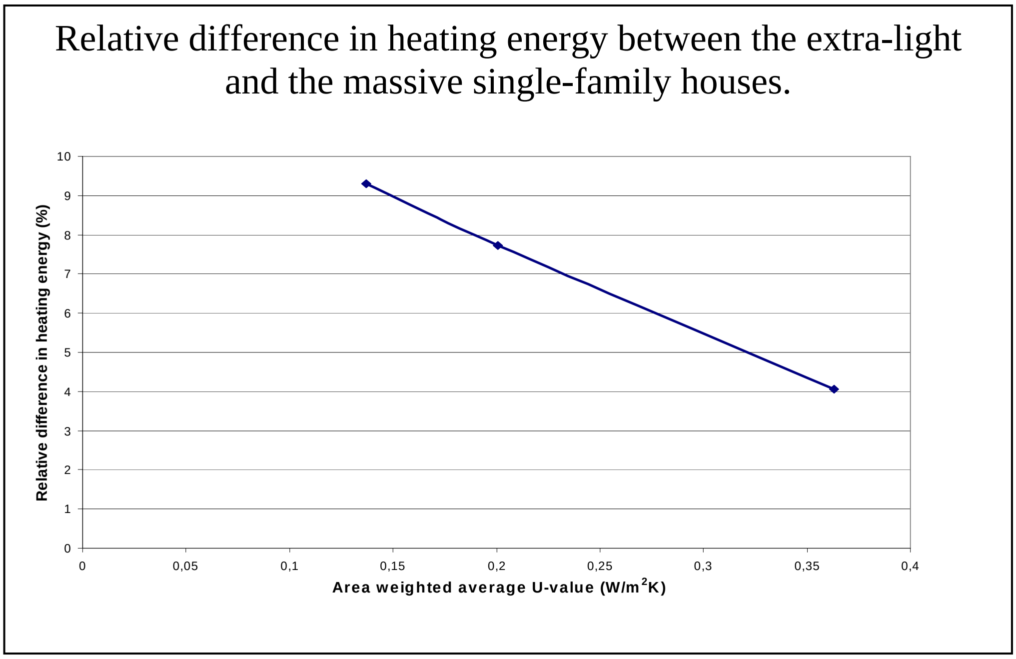

Figure 7.25. Effect of the average U-value of the exterior envelope and the thermal mass on heating energy. Results calculated with the VTT House Model.

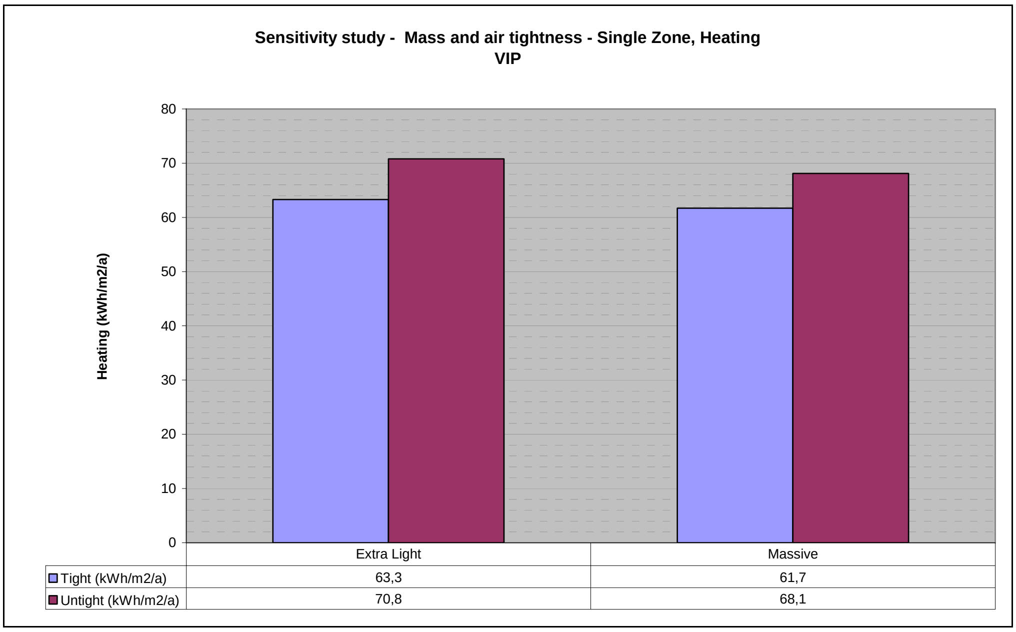

Figure 7.26. Effect of air-tightness of the building's envelope on heating energy. Results calculated by VIP.

7.4.4 Climate

Sensitivity studies concerning the climate were done by VIP. It has been compared energy consumptions obtained with the basic weather data of Helsinki (Table 5.2) with those of Malmö, Oslo, Stockholm and Luleå. In addition there were two different weather data for Stockholm; Meteonorm (Sto met) and Stockholm year 1971 (Sto 71). In Malmö, Stockholm and Oslo heating energy is 35 %, 20 % and 10 % smaller than in Helsinki respectively. There is no effect, which weather data for Stockholm is used. In Luleå heating energy is 30 % greater than in Helsinki. Cooling energy is approximately the same in all locations (Figure 7.27).

Weather data of Helsinki is used in the basic calculations. Swedish and Finnish versions of maxit energy have also been used for studying the effect of thermal mass and weather data on heating energy. In these calculations Finnish weather data of Helsinki, Oulu and Sodankylä and correspondingly Swedish weather data for Lund, Stockholm and Umeå were used.

The effect of thermal mass on heating energy depends greatly on the weather data used. On the other hand its effect on cooling energy is almost constant. The effect of thermal mass on heating energy is greatest (approximately 6 %) for Malmö and lowest (2 %) for Luleå (Figure 7.28), when the extra-light and the massive constructions are compared with each other. However, VIP gives a clearly smaller effect for the thermal mass than maxit energy.

maxit energy gives for the effect of thermal mass for Swedish weather data 10 – 20 %, when the extra-light and the massive constructions are compared and 3 – 4 % when the light and the massive constructions are compared (Table 7.3). The effect of thermal mass is greatest in South-Sweden. For the Finnish weather data there is a 9 – 14 % difference between the energy consumptions of the extra-light and the massive buildings, but no practical difference between the energy consumptions of the light and the massive buildings for the three Finnish weather data (Table 7.4).

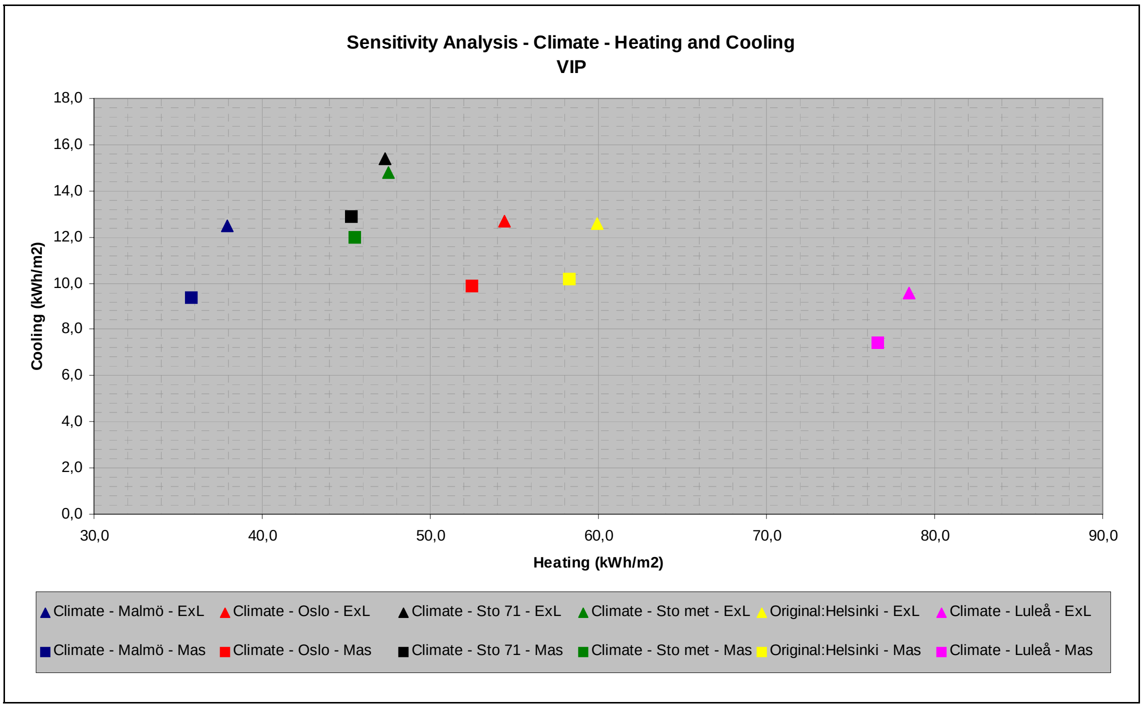

Figure 7.27. Effect of weather data on heating and cooling energy.

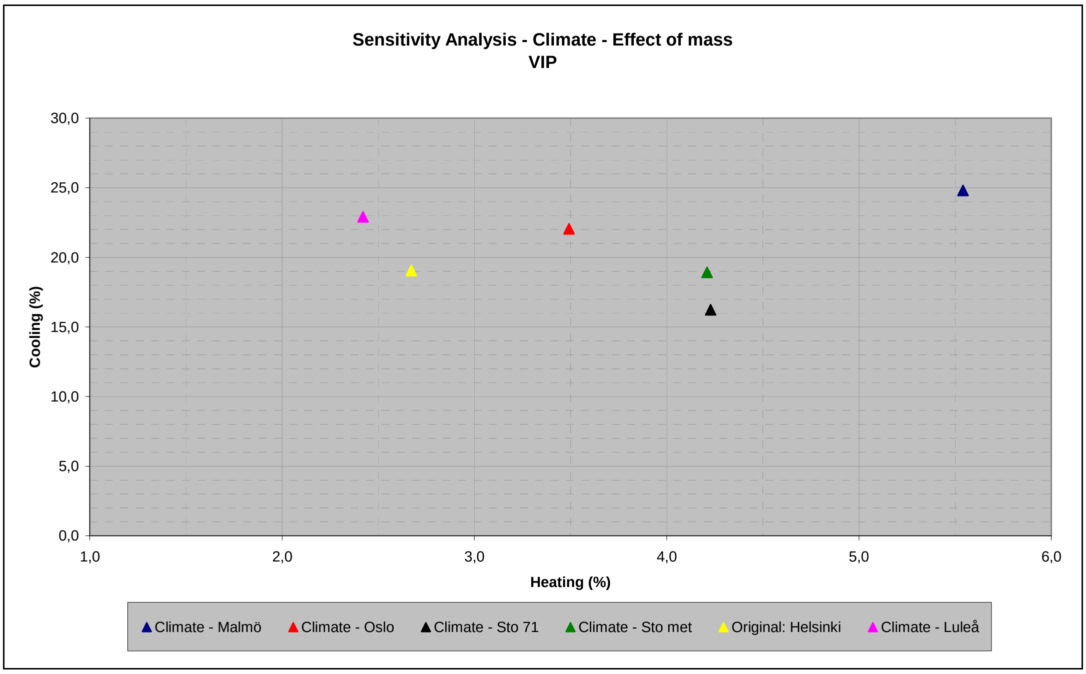

Figure 7.28. Effect of weather data on the effect of thermal mass.

Table 7.3. Effect of thermal mass and weather data on heating energy. maxit energy / Sweden.

	Heating energy *[kWh/m²/a]*		
Construction	**Lund**	**Stockholm**	**Umeå**
Extra light	50,9	59,5	84,1
Light	43,5	52,5	76,5
Semi	41,9	50,9	74,7
Massive	41,7	50,7	74,5
	Relative difference between structures		
ExL/Mas	1,22	1,17	1,13
Lig/Mas	1,04	1,03	1,03

Table 7.4. Effect of thermal mass and weather data on heating energy. maxit energy / Finland.

	Heating energy *[kWh/m²/a]*		
Construction	**Helsinki**	**Oulu**	**Sodankylä**
Extra light	67,5	91,0	109,8
Light	59,6	82,6	100,6
Massive	59,5	82,6	100,7
	Relative difference between structures		
ExL/Mas	1,14	1,10	1,09
Lig/Mas	1,00	1,00	1,00

7.4.5 Indoor temperature set-points

It has been studied by VIP, what is the effect of indoor temperature set-point temperatures on heating and cooling energy. In all cases the heating set-point temperature is 21°C. There are five different values for the cooling set-point temperature: 21, 23, 25, 27, 29 °C. In basic calculations the indoor temperature set-point temperatures are 21 and 25°C. The heating energy remains almost constant when the cooling set-point temperature is changed to 23, 27 or 29 °C. When the cooling set-point temperature is 21 °C (the same as the heating set-point temperature), the heating energy increases by 10 % (6 kWh/m^2/a) in the extra-light building and 7 % (4 kWh/m^2/a) in the massive building (Figure 7.29).

The effect of cooling set-point temperature is much greater on the cooling energy than in the heating energy. If the indoor temperature is constant 21 °C, the cooling energy of the extra-light building increases by approximately 150 % (from 13 kWh/m^2/a to 31 kWh/m^2/a in the extra-light building and from 10 kWh/m^2/a to 27 kWh/m^2/a in the massive building).

The relative effect of a more narrow temperature set-point band clearly increases the relative effect of thermal mass on heating energy, but reduces its relative effect on cooling energy (Figure 7.30).

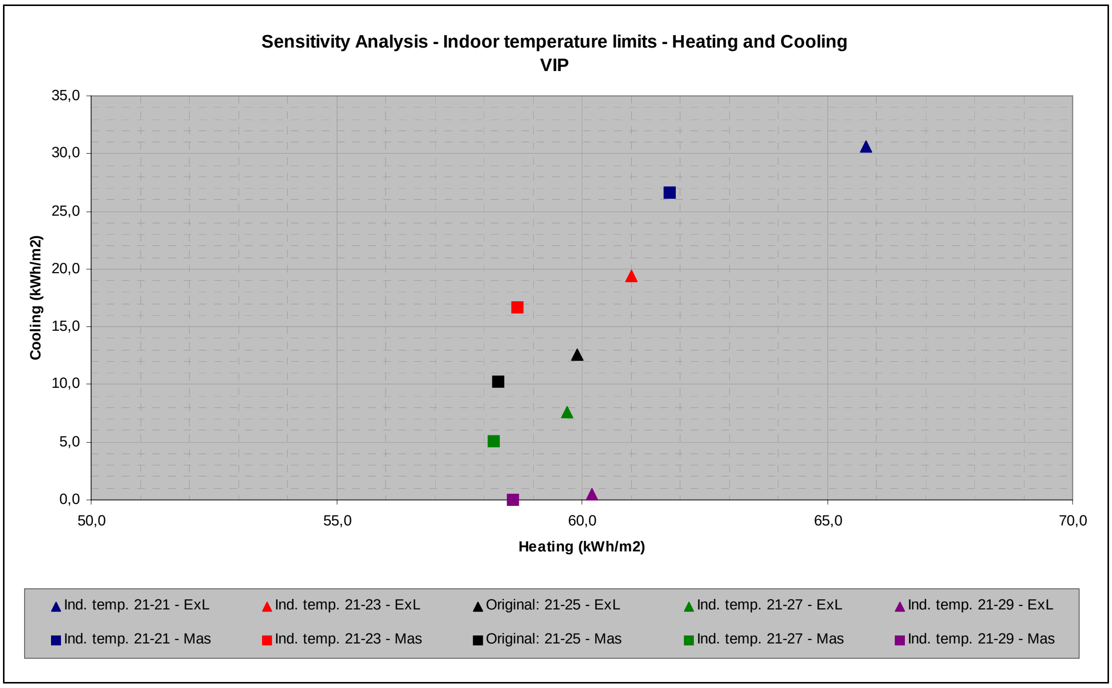

Figure 7.29. Effect of cooling set-point temperature on heating and cooling energy.

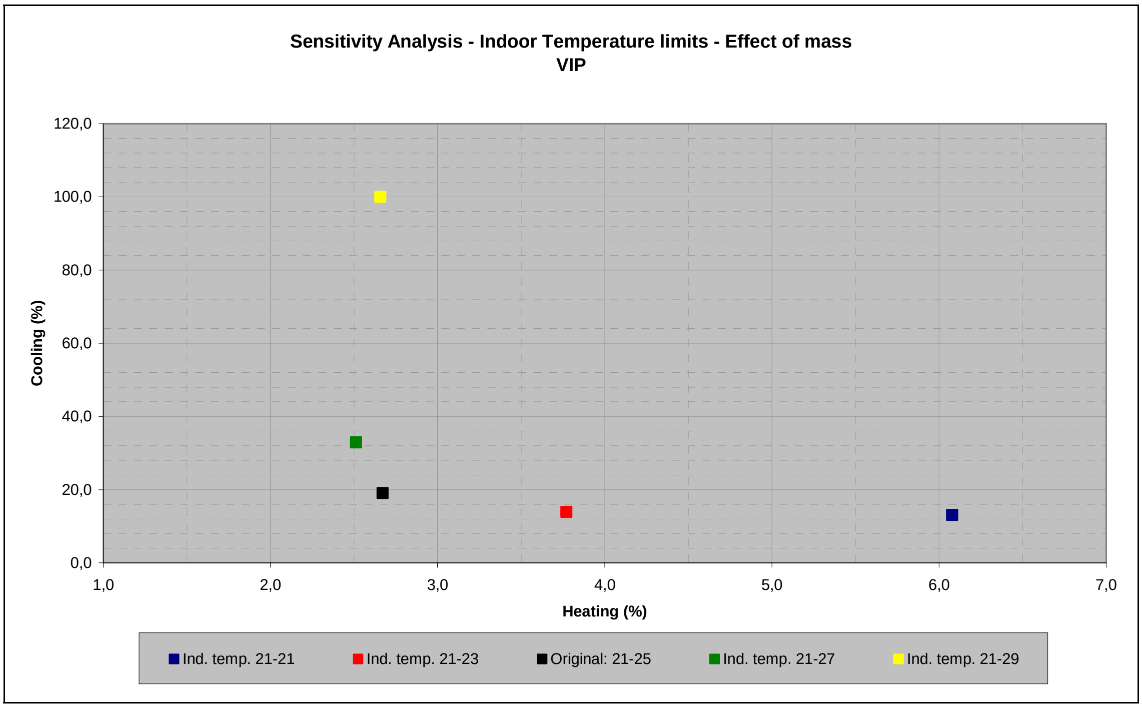

Figure 7.30. Effect of cooling set-point temperature on the relative effect of thermal mass on heating and cooling energy. The heating and the cooling energy of the massive building are smaller.

7.4.6 Distribution of internal sources and the method to control heating

In the basic case of calculations the distribution of internal heat sources is 50% radiative and 50% convective. The area of windows is the original one (12 %) or 25 % from the floor area (W 25). In a sensitivity study made by Consolis Energy the division of internal heat sources is changed to the following:

- 0 % convective and 100 % radiative (0/100),
- 20 % convective and 80 % radiative (20/80),
- 80 % convective and 20 % radiative (80/20) as well as
- 100 % convective and 0 % radiative (100/0).

The way to distribute internal sources into convection and radiation has a very little effect on the heating and cooling energy (Figure 7.31)

The heating and cooling effect can be controlled by air temperature, by radiative temperature or by a proper combination of these. In this context it is used the term *temperature control method* for this. In the sensitivity studies made by Consolis Energy the following cases have been studies:

- 0/100, the temperature of the zone is controlled by surface temperatures
- 20/80, the temperature of the zone is controlled by an effective temperature consisting 20 % from the air temperature and 80 % from the surface temperatures
- 50/50, the temperature of the zone is controlled by an effective temperature consisting 50 % from the air temperature and 50 % from the surface temperatures
- 80/20, the temperature of the zone is controlled by an effective temperature consisting 80 % from the air temperature and 20 % from the surface temperature
- 100/0, the temperature of the zone is controlled by air temperature.

Changes in the temperature control method have no practical effect on the heating and cooling energy. The maximum change is about 1 $kWh/m^2/a$ in heating and cooling energy compared with the basic case (Figure 7.32). Observe that these results are valid for energy use on an annual basis and can not be projected to the calculation of indoor climate under shorter periods.

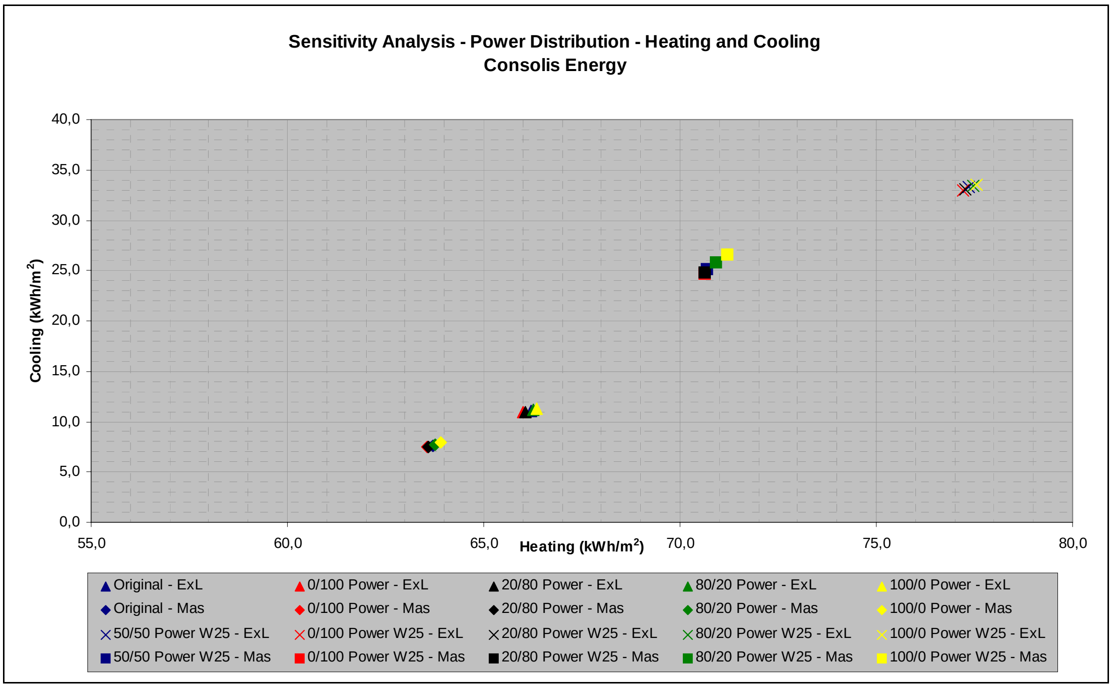

Figure 7.31. Effect of the share of radiation and convection in the internal gains on the heating and cooling energy.

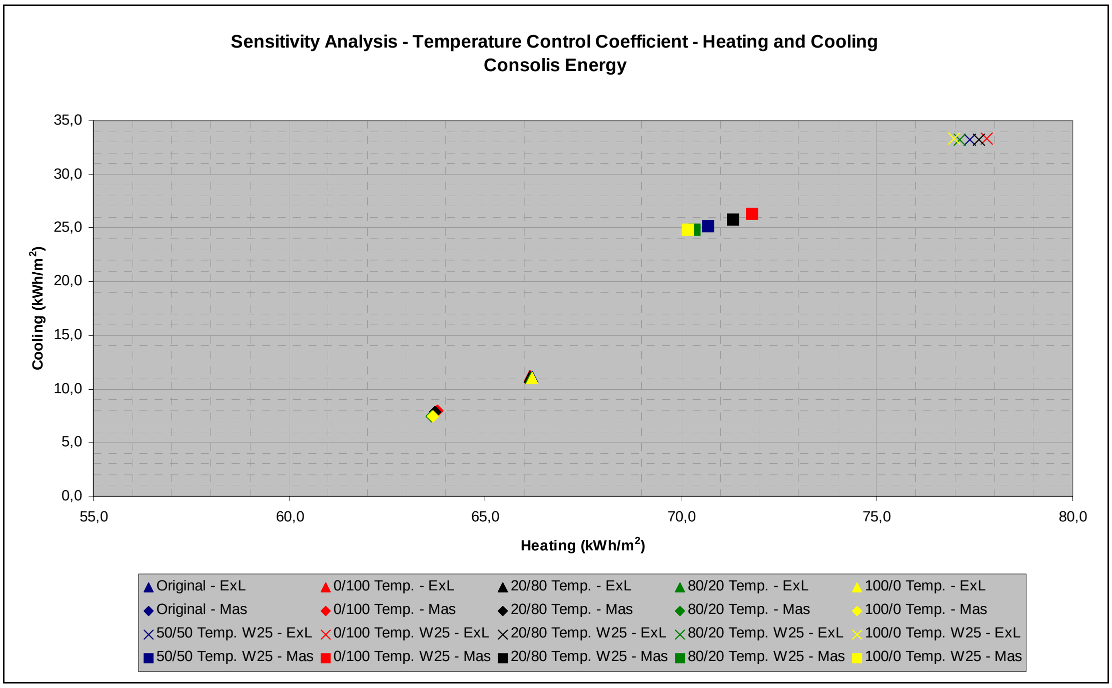

Figure 7.32. Effect of temperature control method on heating and cooling energy.

7.4.7 Effect of time-constant

There is only a small change in the heating and cooling energy, if the time-constant of the building is between 70-210 h. The heating and cooling energy start to grow rapidly, when time-constant is getting smaller than 70 h (Figures 7.33 and 7.34). The time constants of Figures 7.33 and 7.34 include the extra-light (ExL), light (Lig), semi-weight (SWe) and massive (Mas) structures. These simulations are done by Consolis Energy.

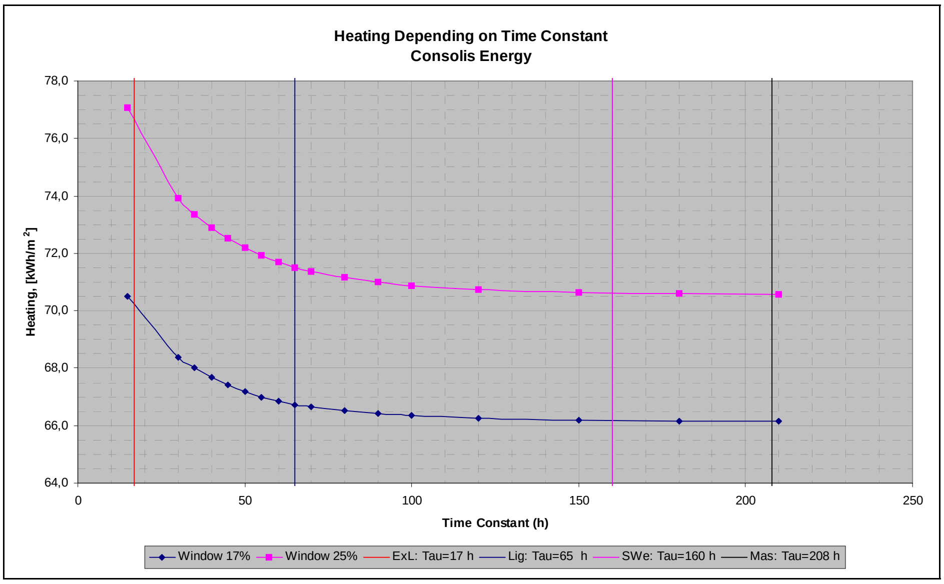

Figure 7.33. Effect of time-constant on heating energy.

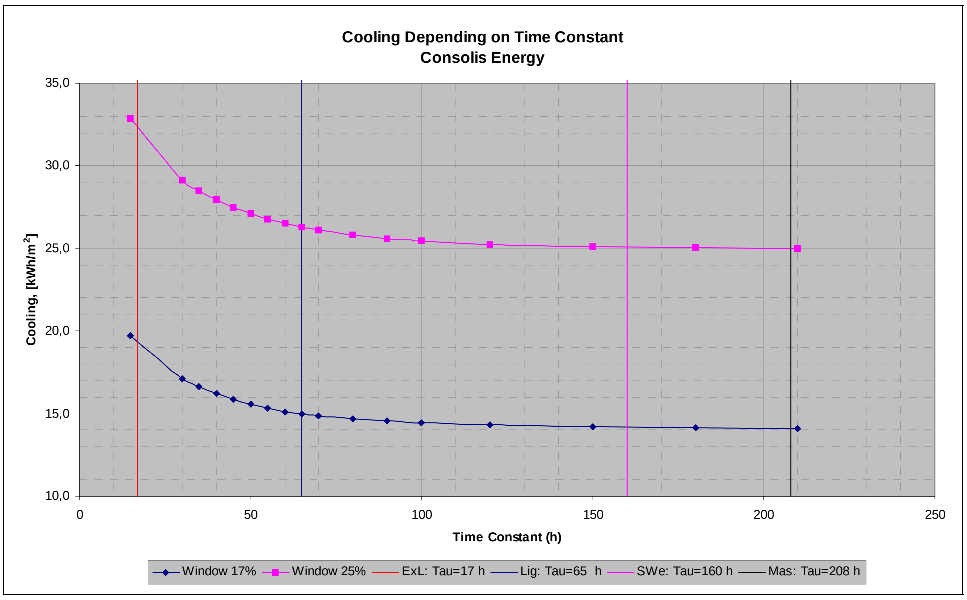

Figure 7.34. Effect of time-constant on cooling energy.

8. Results on the apartment house

8.1 Effect of thermal mass (heat capacity) on energy and indoor climate

Annual heating and cooling energy of the light and the massive apartment building were calculated by TASE, VIP, SciaQPro and Consolis Energy. For the double-zone case 1 (DbZo1+2) TASE, SciaQPro and Consolis Energy were used and for the single-zone case 2 (SgZo) also VIP was used. Compared with the single-family house the cooling energy of the apartment house is noticeable, about 50 % from that of the heating energy. Both the heating and cooling energy show a spread from about 55 to 65 kWh/m^2/a and 15 to 50 kWh/m^2/a for the light and the massive constructions and for the single-zone and double-zone cases respectively (Figure 8.1).

The effect of thermal mass on heating energy is 2 – 5 kWh/m^2/a and that on cooling energy 5 - 10 kWh/m^2/a depending on whether single-zone or double-zone modelling is used and which calculation model is used. Relatively the effect of thermal mass is 3 – 7 % on heating energy and 10 - 20 % on cooling energy (Figure 8.2).

Total heat sources include solar and internal heat sources. Ventilation and thermal conduction constitute the energy losses. Differences in internal gains are caused by differences in solar sources. In all calculations the internal heat sources are 43,8 kWh/m^2/a (5 W/m^2). The single-zone case of VIP seems to give the lowest heat losses and that of TASE the lowest total internal heat sources. The maximum difference between various models in heat losses and in total heat sources is 15 – 20 % (Figure 8.3).

The interior temperatures rise high in a well-insulated apartment building, when only basic ventilation and no cooling are used. The interior temperature exceeds in the single-zone case 25 ^{o}C about 35 % (3000 h) from the length of the whole year (Figure 8.4). Figure 8.5 presents the interior temperatures, when cooling is used. The interior temperatures are very similar also for the case, in which the apartment house was modelled as a double-zone.

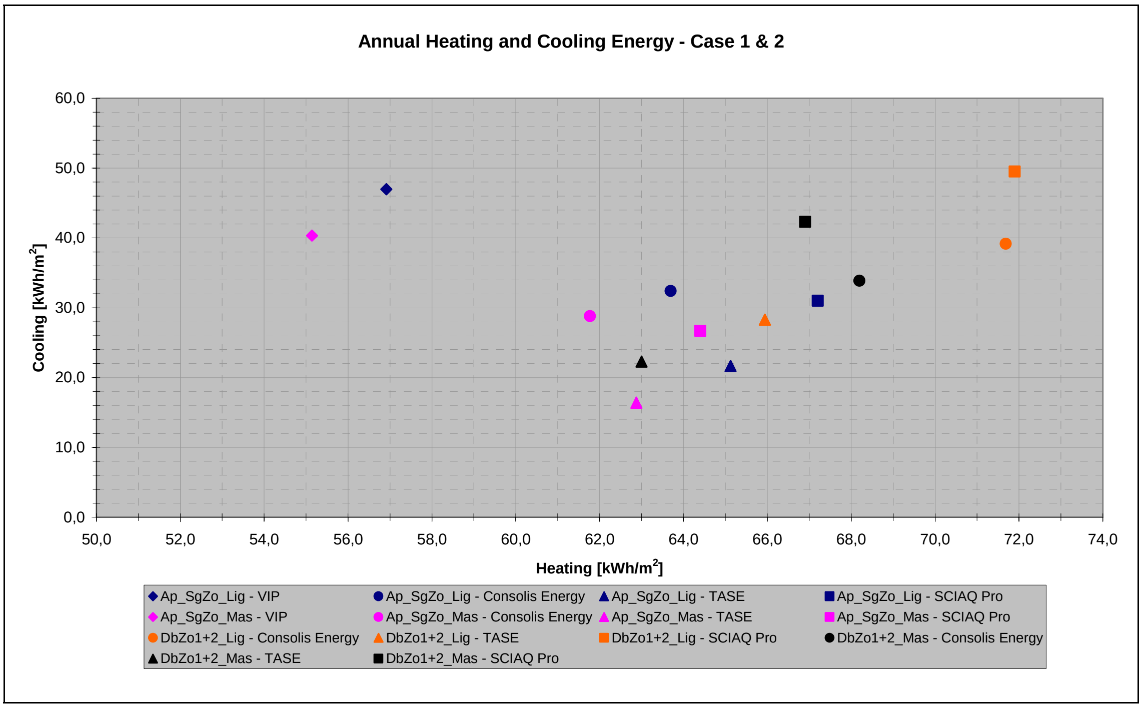

Figure 8.1. Annual heating and cooling energy for the apartment building. Single-zone and double-zone cases.

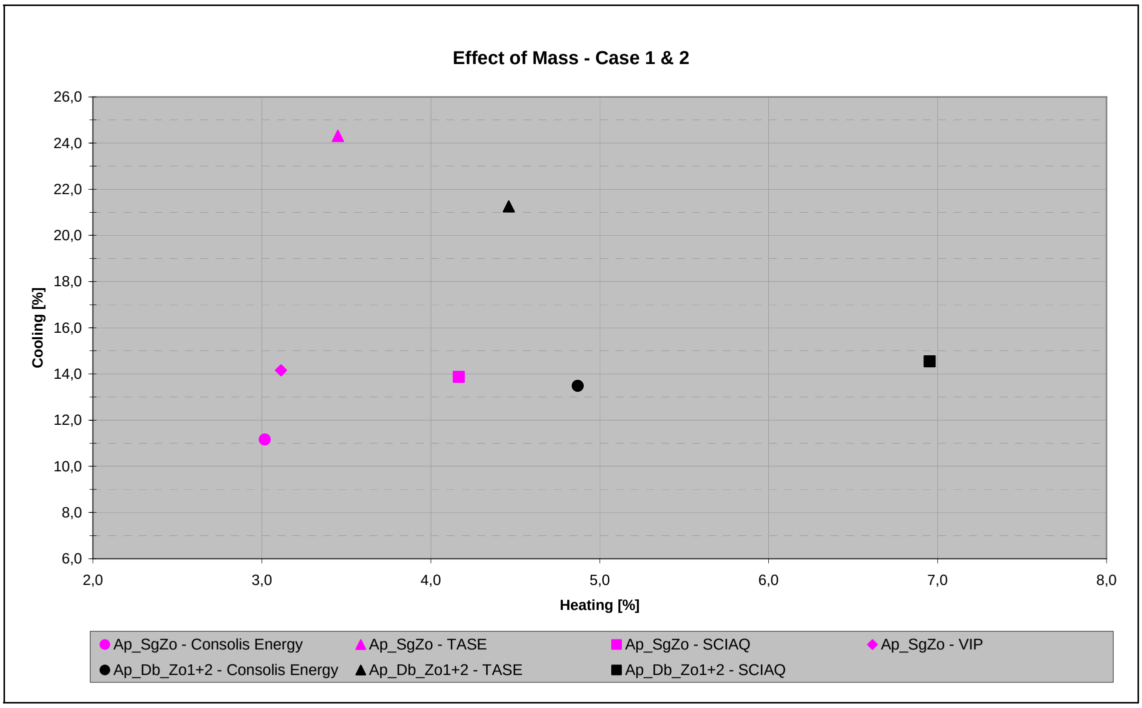

Figure 8.2. Effect of thermal mass on heating and cooling energy. Single-zone and double-zone cases.

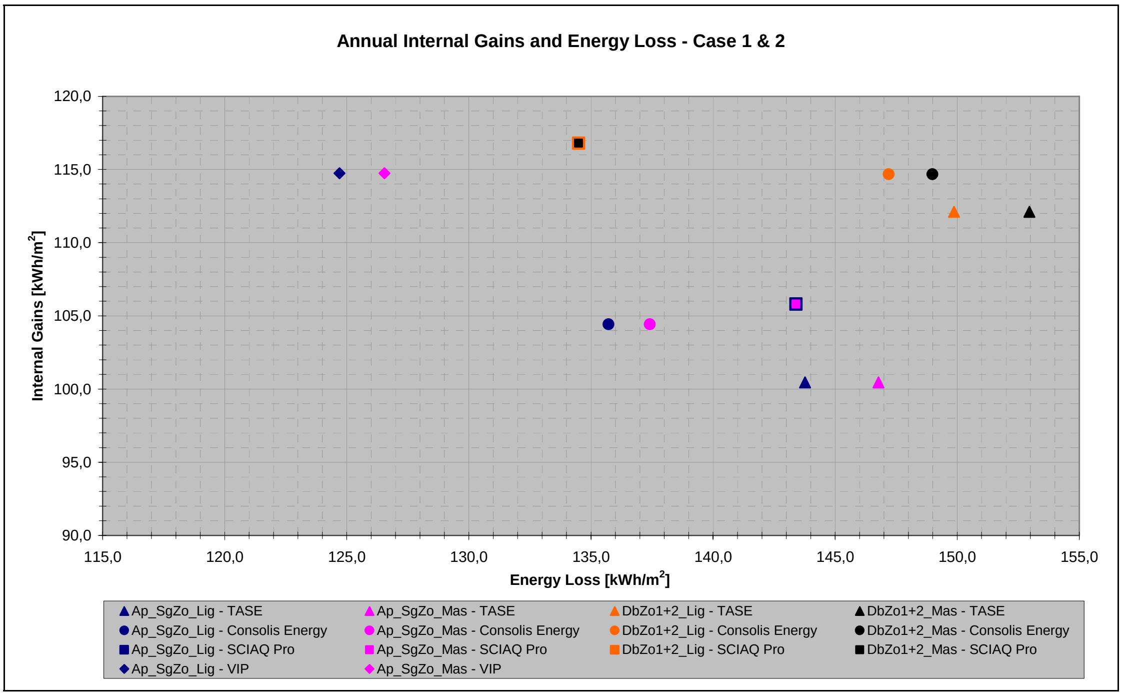

Figure 8.3. Total heat sources and energy losses. Single-zone and double-zone cases.

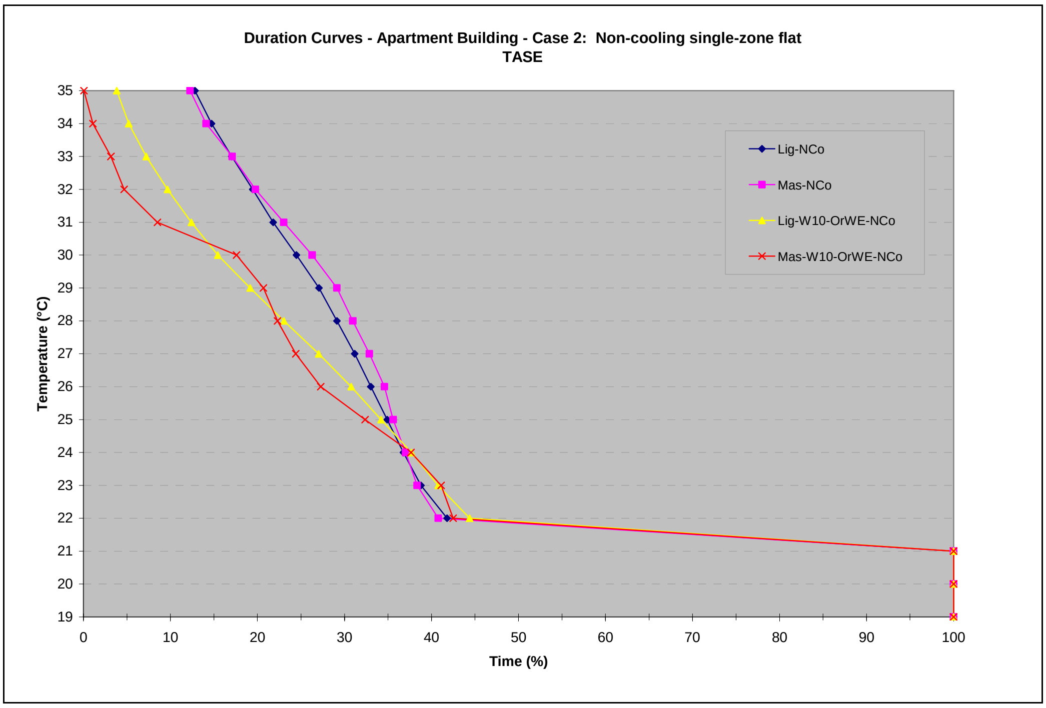

Figure 8.4. Duration curve of interior temperature for the single-zone flat without cooling.

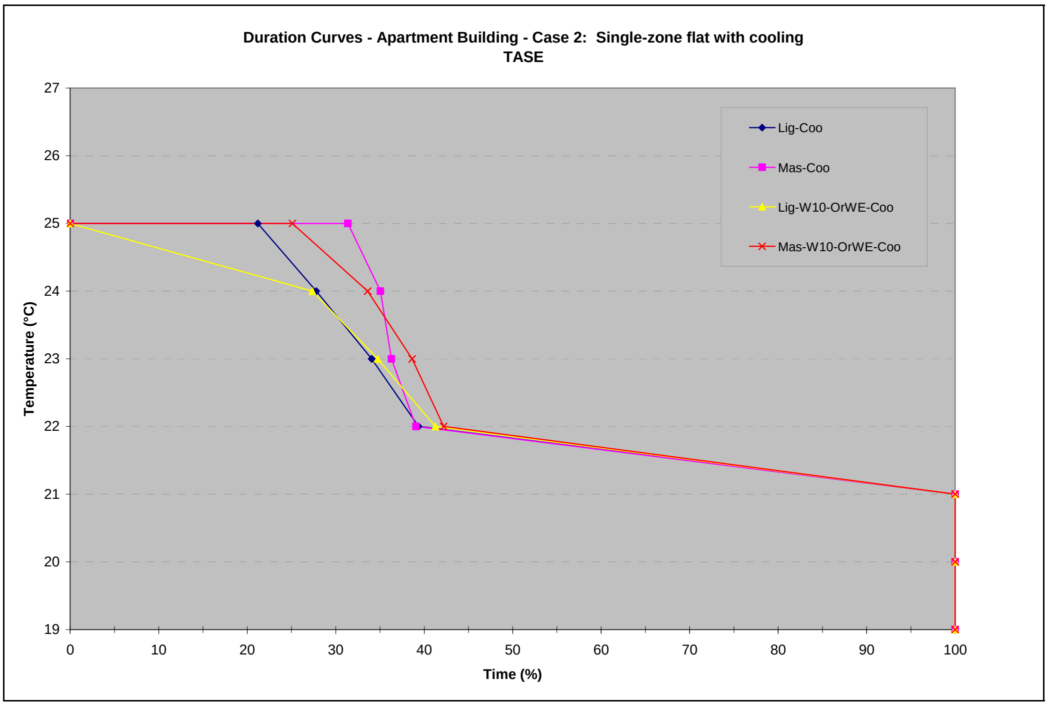

Figure 8.5. Duration curve of interior temperature for the single-zone flat with cooling.

8.2 Utilisation factor

The basic parameters of utilisation factor of ISO DIS 13 790 (a_0 = 1 and τ_0 = 15 h) give a good fit for the utilisation factor of the massive building (time constant 408 h) both for the single-zone and the double-zone cases. However, the basic parameters give a poor fit for the utilisation factor of the light building, which had no massive surfaces at all and the time constant was very low (17 - 18 h). When the parameter a_0 is changed to 2,9 – 3,0, a good fit is also obtained for the light apartment building (Figures 8.6 - 8.9). This result is valid both for the single-zone and the double-zone cases.

The relative heat losses in the apartment building are smaller than in the single-family house. This is one reason for the fact, that the scatter of the calculated points for the utilisation factor of the apartment building is greater than that of the single-family house.

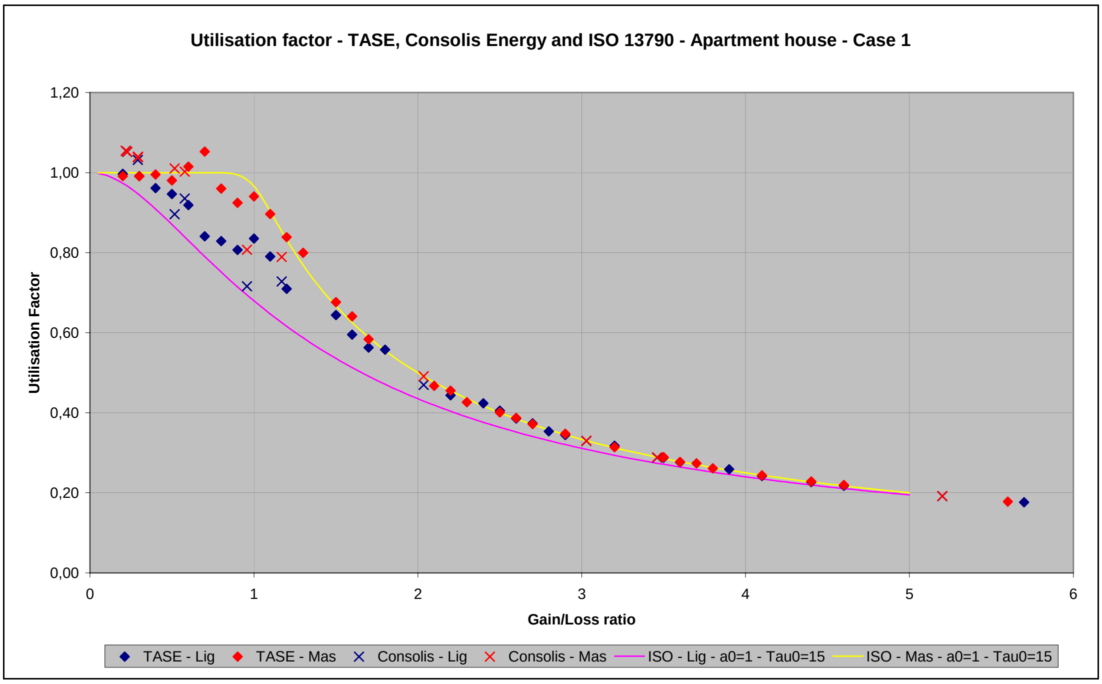

Figure 8.6. Utilisation factor for the apartment building. Case 1 (DbZo1+2). TASE, Consolis Energy and the basic parameters of ISO DIS 13790.

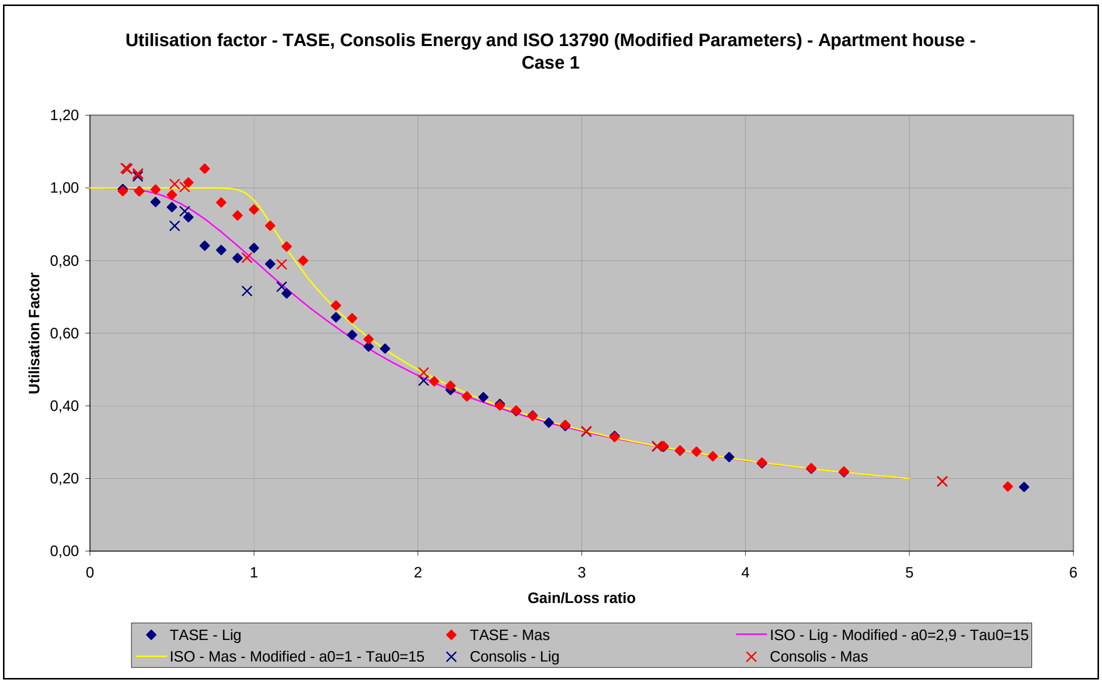

Figure 8.7. Utilisation factor for the apartment building. Case 1 (DbZo1+2). TASE, Consolis Energy and the modified parameters of ISO DIS 13790.

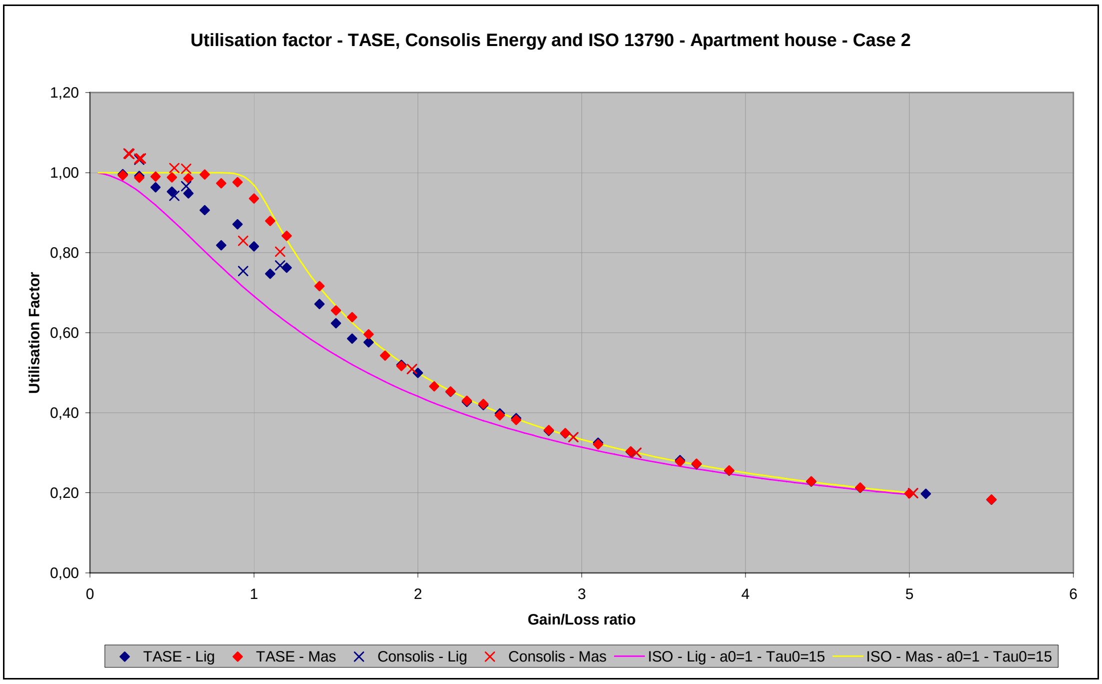

Figure 8.8. Utilisation factor for the apartment building. Case 2 (SgZo). TASE, Consolis Energy and the basic parameters of ISO DIS 13790.

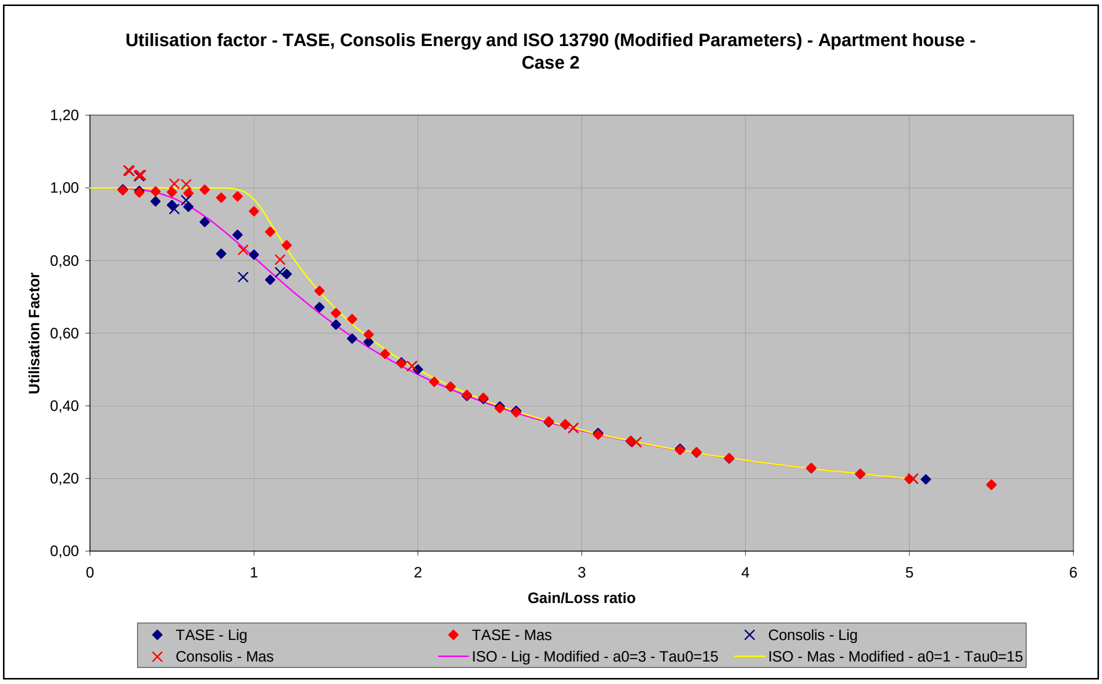

Figure 8.9. Utilisation factor for the apartment building. Case 2 (SgZo). TASE, Consolis Energy and the modified parameters of ISO DIS 13790.

8.3 Sensitivity analysis of some factors affecting the energy consumption

8.3.1 Orientation and size of windows

It has been studied what are effects of building's orientation and window area together with the effects of thermal mass on heating and cooling energy. These calculations were made with TASE. The window area/floor area was decreased from its original value, which was 25 % for the double-zone Case 1 and 21 % for the single-zone Case 2, to 10 % and to 15 % . In the orientation study the building is rotated 90 degrees counter clockwise. The facades, which originally were facing towards west and east, are after the rotating facing towards south and north.

The change in the windows' orientation is presented by the symbol Or WE, which means that the windows are after the rotation in west – east direction and that the greatest window area is facing to south. The ratio window area/floor area is presented by the notation W 20, if e.g. the relative window area is 20 %.

Both the decrease of windows' size as well as the rotation of the main façade from west to south decrease heating energy for the double-zone Case 1. When the window area is decreased to10 % from the floor area, heating energy decreases by approximately 10 kWh/m^2/a (15 %) both in the light-weight building and in the massive building compared with the cases of the basic window area.

When the building is rotated by 90 degrees counter clockwise, so that the main façade is towards south, the heating energy decreases by 5 kWh/m^2/a in the light-weight building and by 12 kWh/m^2/a in the massive building. When both the rotation is made and the window area is decreased to10 % from the floor-area, heating energy decreases by 3 – 4 kWh/m^2/a both in the light-weight building and in the massive building (Figure 8.10).

The cooling energy decreases as well when the window area is reduced (Figure 8.10). When the window area decreases to 10 % from the floor area, cooling energy is approximately by 16 kWh/m^2/a (60 %) smaller than in the original case. When the building is rotated counter clockwise but the window size is according to the original case, cooling energy increases by 10 kWh/m^2/a (35 %) in the light-weight building and 3 kWh/m^2/a (10 %) in the massive building (Figure 8.10).

For the single-zone Case 2 heating energy also decreases in all sensitivity cases (Figure 8.11). When the window area is 10 % from the floor-area, heating energy is 10 % smaller than in the basic case. The rotation of building's façade from west towards south decreases heating energy by 8 – 14 kWh/m^2/a (15 - 25 %) in the light and in the massive buildings correspondingly. However, in the same rotation the corresponding cooling energy increases by 12 and 6 kWh/m^2/a. Also here it can be seen, that the massive constructions utilise better the solar radiation trough south facing windows and reduce the cooling demand than the light structures (Figure 8.11)

The effect of thermal mass on heating energy decreases when the size of windows is decreased in both cases modelled. On the other hand in both cases the effect of thermal mass increases noticeably (from the level of 2 – 4 % up to 15 %) when the orientation of building's facades is changed from west-east towards south-north (Figure 8.12).

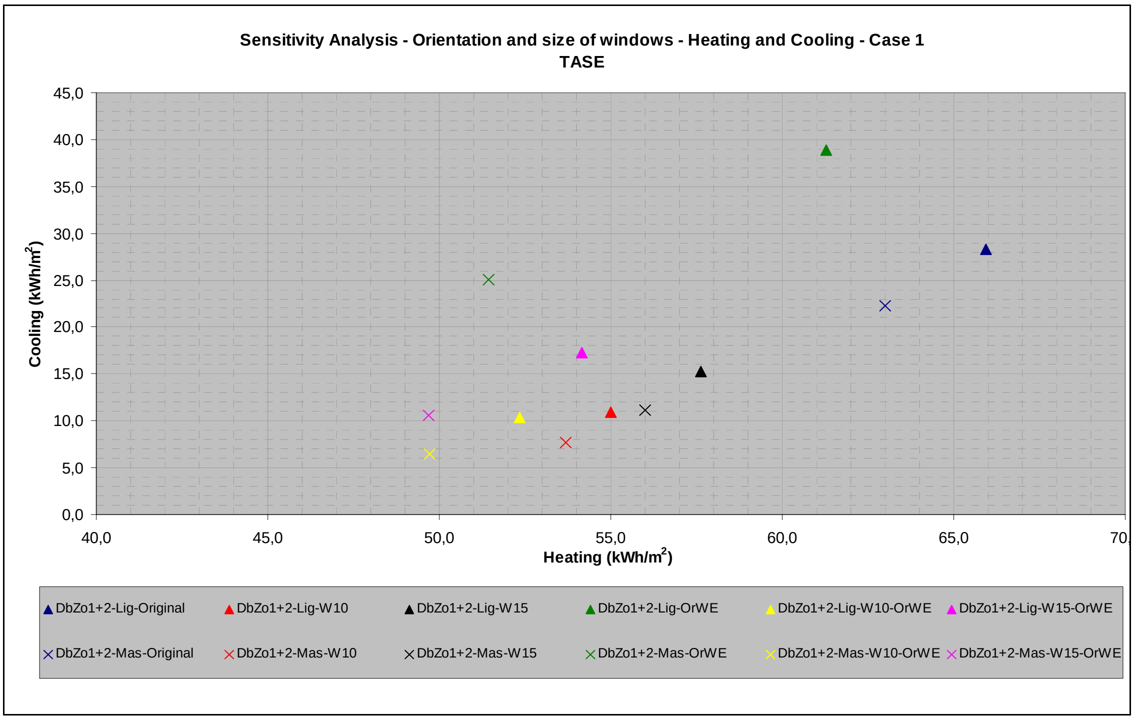

Figure 8.10. Effect of windows' orientation and size on heating and cooling energy. Double-zone Case 1. Results of TASE.

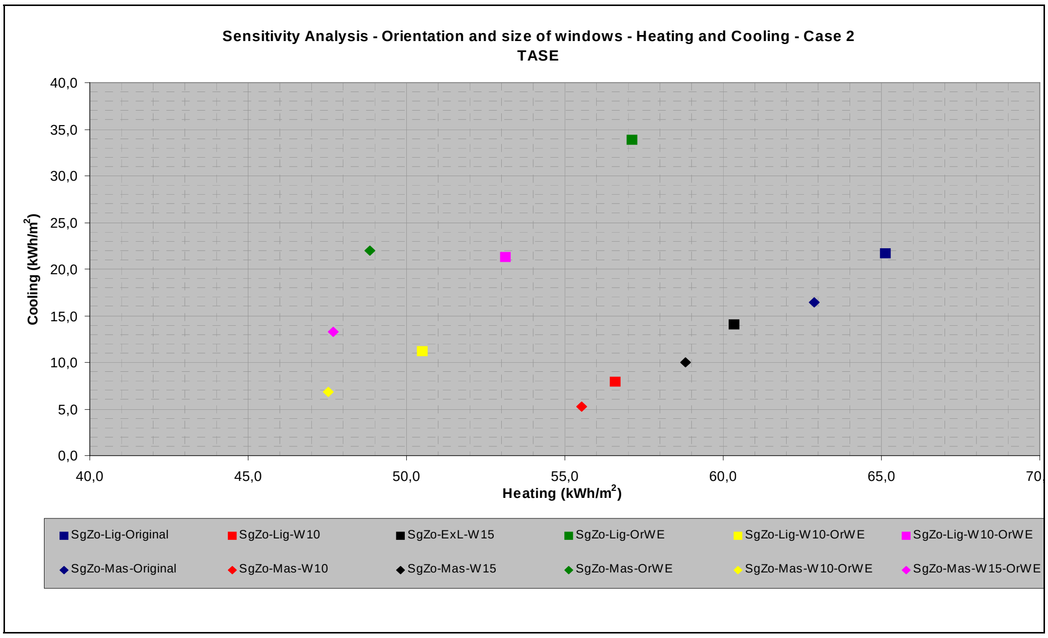

Figure 8.11. Effect of windows' orientation and size on heating and cooling energy. Single-zone Case 2. Results of TASE.

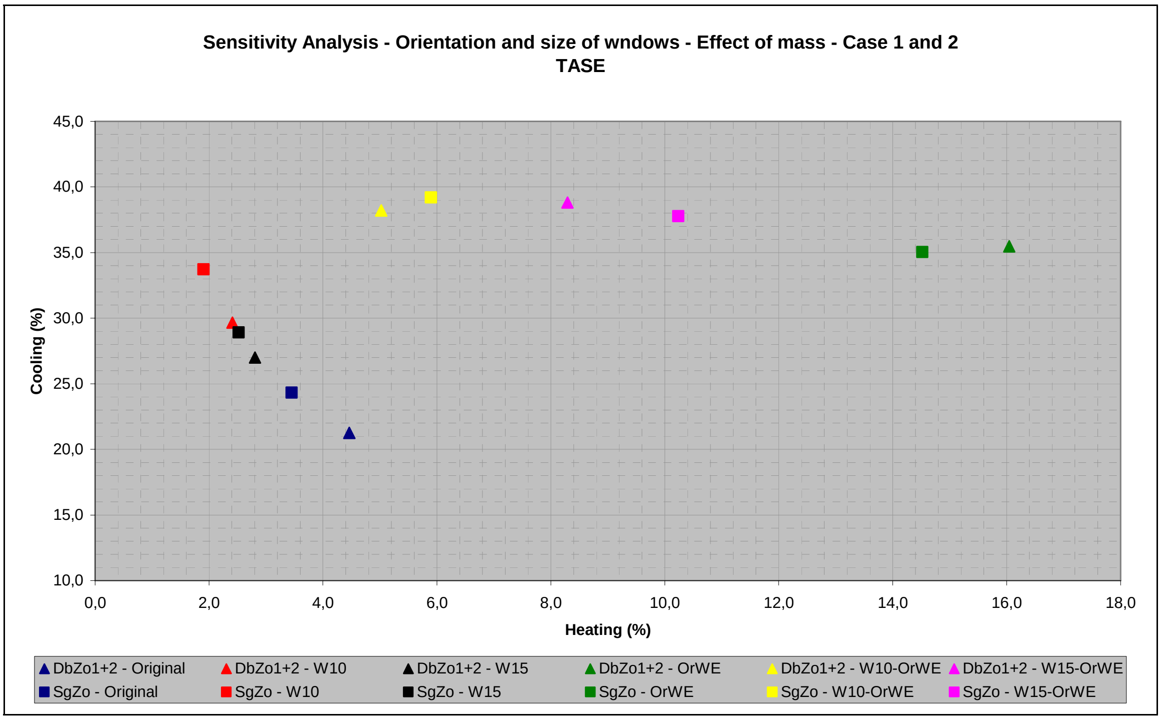

Figure 8.12. Effect of building's thermal mass and windows' size and orientation on heating and cooling energy. Results of TASE.

8.3.2 Climate

The effect of climate has been studied by VIP for Helsinki, Malmö, Oslo, Luleå and Stockholm. It has been used two different weather data for Stockholm; Meteonorm and the year 1971. The basic weather data for calculations is that of Helsinki.

In Malmö the energy consumptions of heating and cooling are 35 % and 15 % smaller than the consumptions in Helsinki respectively. The energy consumptions in Oslo are quite close to the results of Helsinki; in Oslo heating energy is 7 % smaller and cooling energy 2 % smaller than in Helsinki. In Luleå heating energy is 35 % greater than in Helsinki, but cooling energy is very small. For Stockholm both weather data give approximately the same heating energy, but the cooling energy calculated by Meteonorm is 45 % greater than that calculated by the year's 1971 weather data. Both the heating energy and the cooling energy of Stockholm are approximately 15 % smaller than those of Helsinki (Figure 8.13).

The effects of thermal mass on heating energy are close to each others, about 3 – 4 %, with the weather data of Helsinki, Oslo and Stockholm, when the light and the massive buildings are compared. With the weather data of Malmö the effect of thermal mass is approximately 6 % and with those of Luleå approximately 2 % (Figure 8.14).

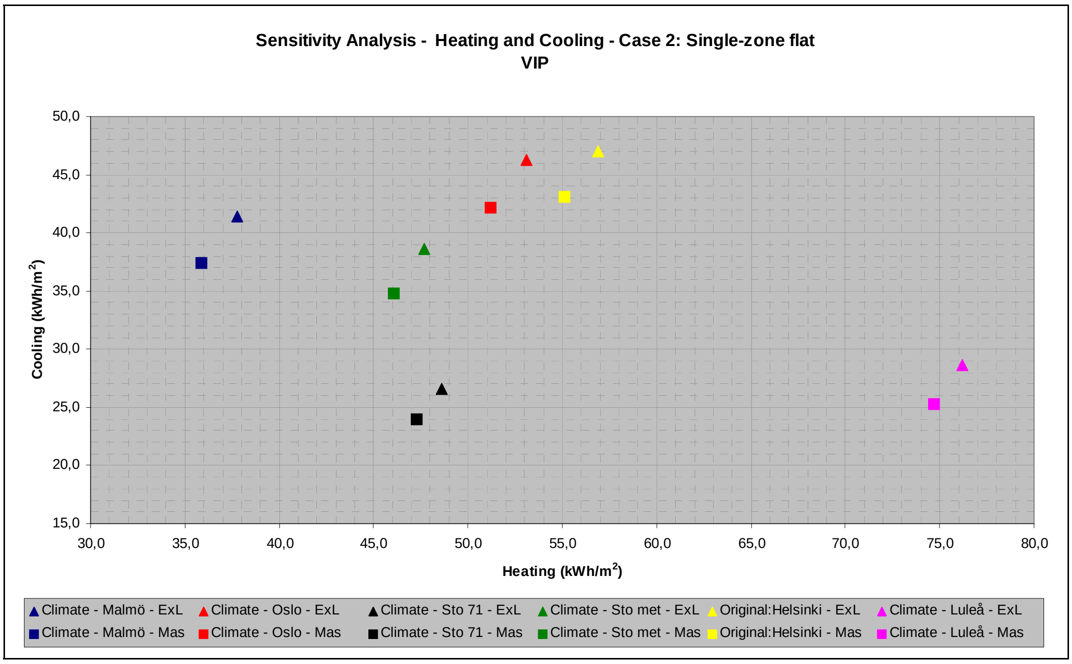

Figure 8.13. Effect of weather data on heating and cooling energy. Calculations made by VIP.

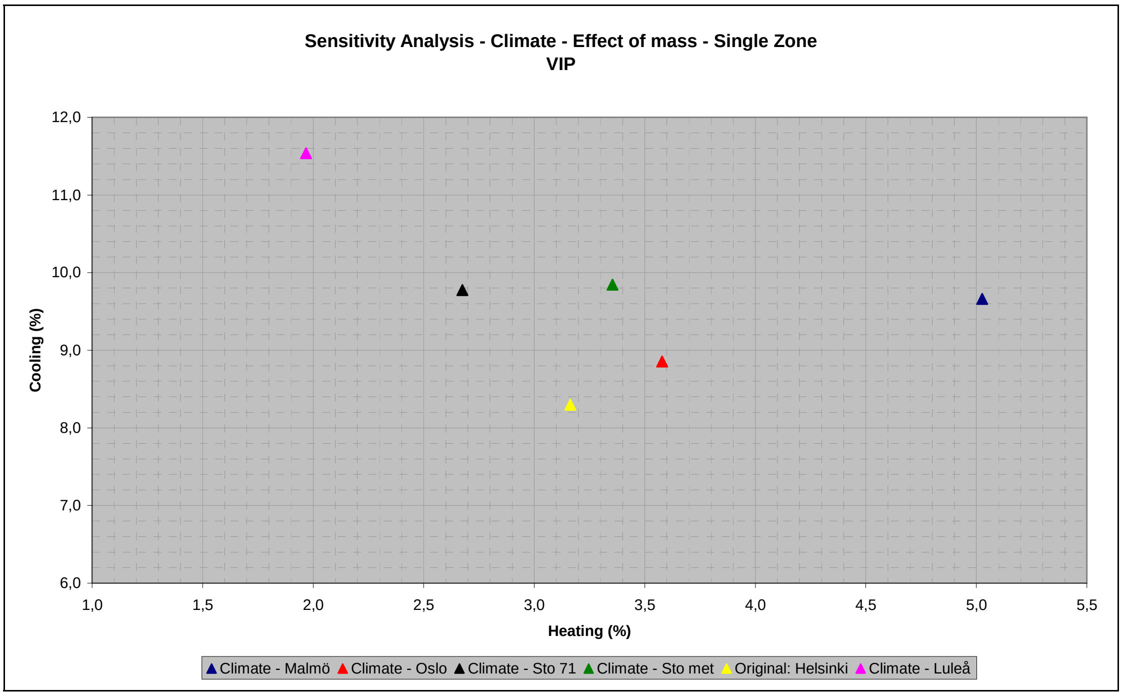

Figure 8.14. Effects of weather data and thermal mass on heating and cooling energy. Calculations made by VIP.

8.3.3 Night ventilation

The thermal mass clearly increases the benefits of night ventilation in reducing the cooling energy. When the night ventilation rate is triple compared with the daytime rate, the cooling energy of the massive apartment building is about one third lower than that of the light building (Figure 8.15).

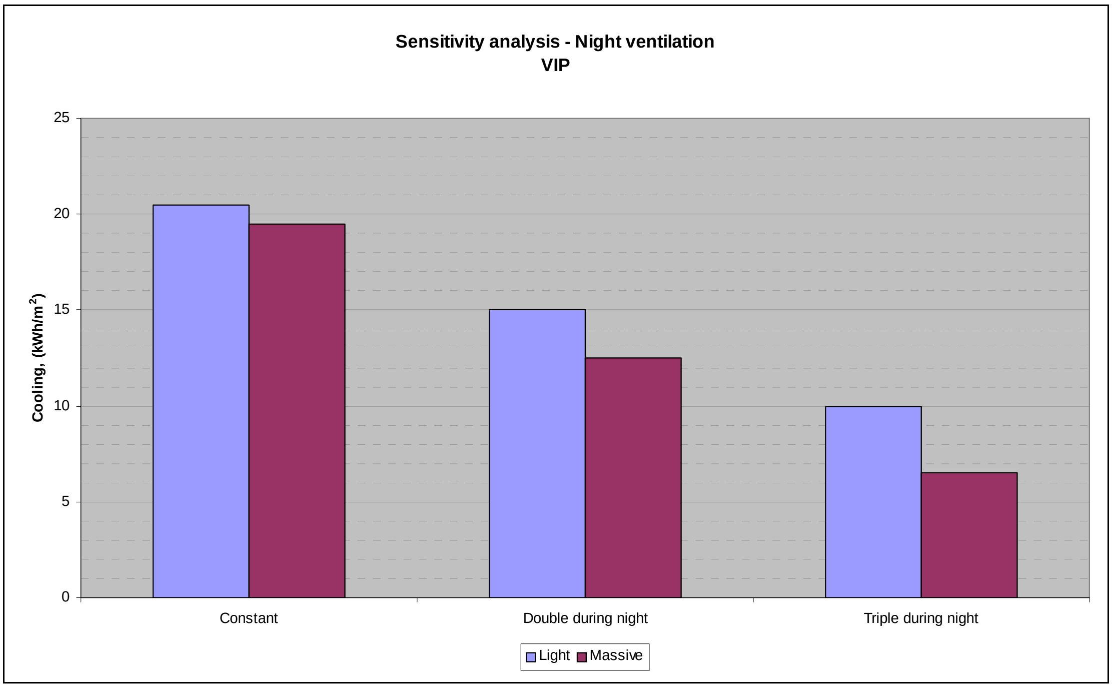

Figure 8.15. Effect of night-ventilation and thermal mass on cooling energy. Calculations made by VIP.

9. Conclusions

Buildings' heating and cooling energy can be calculated by either a monthly energy balance method or a simulation method, in which the time-step of calculations is usually one hour. The simulation methods calculate at the same time the energy consumption and the indoor air and surface temperatures. In the energy balance methods the indoor temperature is the heating or cooling set-point temperature.

The most important of the energy balance methods from the point of view of Nordic countries is *ISO DIS 13790 Thermal Performance of Buildings – Calculation of Energy Use for Heating and Cooling.* It is important, because it has an official role in Europe and it is mentioned e.g. in the Energy Performance Directive of Buildings (EPDB).

This study had three main goals. Firstly it was purpose to make a comprehensive study on the effects of thermal mass on the heating and cooling energy in Nordic climate and for typical, modern Nordic buildings. The effect of thermal mass was analysed using different calculation methods. Because different methods and their users get for the same research problem different results, 6 simulation programs (Consolis Energy, IDA-ICE, SciaQPro, TASE, VIP, VTT House Model) and one standard method, maxit energy, were use. maxit energy is based on the standard *EN 832*, which is the predecessor of *ISO DIS 13790.* Secondly it was purpose to evaluate the reliability of the monthly calculation method *ISO DIS 13790* mentioned above and its parameters for the utilisation factor (a_0, τ_0). The third purpose was to make sensitivity analysis concerning e.g. the effect of the size and the orientation of windows, the tightness and the thermal insulation of the envelope and the weather data on the energy consumption.

Usually differences in input data cause great differences in calculated energy consumptions. In this study these differences were tried to be avoided by describing the buildings calculated as detailed as possible. It was used two various buildings in the calculations; a single-family house and an apartment building. For the single-family house four construction alternatives were studied; extra-light, light, semi-weight and massive. The extra-light building did not have any massive surfaces and in the light building only the floor was massive. For the apartment building two construction alternatives were studied; the light and the massive ones. In both buildings it was used both single-zone and double-zone models. Synthetic Helsinki weather (Meteonorm) was used as the basic data of calculations.

The heating energy/floor-area is approximately from 60 to70 kWh/m^2/a and the cooling energy from 3 to 13 kWh/m^2/a for the extra-light and for the massive single-family houses calculated with the six programs mentioned above. The results of VTT House Model are excluded from these numbers, because it had slightly different input data and modelling assumptions. The difference between the calculated maximum and minimum energy consumptions is absolutely 10 kWh/m^2/a and relatively 15 % in the heating energy and 75 % in the cooling energy (the percentages are calculated using the maximum energy consumptions are the basic). This is important to know, if e.g. a national energy performance criteria is set as a kWh/m^2/a-value and the calculation method is left open. Then it would be in principle possible to get a 15 % improvement in the energy efficiency of heating and a 75 % improvement in the energy efficiency of cooling just by changing the calculation method. Therefore, if for the energy performance criteria is set a value expressed in kWh/m^2/a, the calculation method and certain important input data (e.g. internal sources) must be given.

Various calculation methods give different effects for the thermal mass. For the relatively small basic window area (12 % from the floor area) the effect of thermal mass is approximately 3 – 5 % in heating energy and 30 – 50 % in cooling energy, when the extra-light and the massive single-family houses are compared. When the light single-family house having a concrete floor and a small window size (12 % from the floor area) is compared with the massive single-family house, the effect of thermal mass is clearly smaller, a few percent. On the other hand, when the window size is greater (from 20 to 45 % from the floor area) the difference in heating energy between the extra-light and the massive buildings can rise up to 14 %.

The absolute differences in heating energy as well in cooling energy of the single-family house increase from approximately 2 kWh/m^2/a to 15 kWh/m^2/a, when the relative window size is increased from its basic level to 45 % from the floor area.

The relative effect of thermal mass in heating energy increases from 2 to 6 % when the weather data of South-Sweden (Lund, Malmö) instead that of North-Sweden (Luleå, Umeå) are used in calculations and the extra-light and the massive single-family houses are compared with each other using the calculation results of VIP. However, the absolute difference in heating energy between these two constructions is approximately constant, 2 kWh/m^2/a. The weather data does not affect much on the cooling energy. For all weathers studied the effect of thermal mass is approximately 20 % (2 kWh/m^2/a) in the cooling energy. The effect of thermal mass was also about the same between the extra-light and the massive constructions when different climate data of Sweden and Finland were used in maxit energy.

The conclusions obtained for the single-family house are generally valid also for the apartment building. However, compared with the single-family house the cooling energy of the apartment building is noticeable higher, about 50 % from that of the heating energy. The heating and the cooling energy of the apartment building show a spread from about 55 to 70 kWh/m^2/a and 20 to 50 kWh/m^2/a for the light and the massive constructions and for the single-zone and double-zone cases respectively.

The basic parameters of ISO DIS 13790 for the utilisation factor (a_0=1 and τ_0=15 h) give generally a good fit compared with the utilisation factors calculated with the simulation models in this study. The fit is good with the only exception, that these parameters give a too low utilisation factor for the extra-light single-family house and apartment building having no massive surfaces at all and a time-constant of approximately 20 - 50 h. Because so light buildings are very seldom in practice, it can be concluded that the basic parameters are well-suited also for the Nordic climate and for modern Nordic buildings. The correctness of the utilisation factor means also that ISO DIS 13790 is an accurate energy analysis method.

On the basis of this research we want to present the following conclusions:

1. Calculation methods based on the standard ISO DIS 13790 are accurate enough for calculating the annual heating energy, e.g. in the context of energy design and energy certification. Many times the inaccuracies of the input data and the various ways to

interpret it cause greater affects on results than the simplifications of the calculation method.

2. The basic parameters of the utilisation factor of ISO DIS 13790 (a_0=1 and τ_0=15 h) are correct, when there is at least one massive surface in the building. For an extremely light building having no massive walls (time constant less than 50 h), the above mentioned coefficients give a too low utilisation factor and thus a too high energy consumption.

3. Thermal mass of buildings has many positive effects. It decreases noticeably cooling energy need and decreases heating energy. Especially, benefits can be achieved when the window size is great and the building is well-insulated. The thermal mass can be effectively utilised together with night ventilation to reduce the need for mechanical cooling.

   Usually the thermal mass of buildings also improves the thermal indoor climate, when mechanical cooling is not used. The interior temperatures in massive buildings are lower than those of light buildings in summertime, when mechanical cooling is not used.

   Thus the thermal mass should be a design parameter in national building regulations in order to promote the building owners, designers and constructors to search the most energy efficient solutions leading also into a good indoor climate.

4. The inaccuracy in the calculation of heating energy is 10 – 15 kWh/m^2/a and that in the cooling energy 10 – 30 kWh/m^2/a for the single-family house and the apartment building correspondingly, when the input data of calculations is exactly specified. If the energy consumptions were calculated so, that each calculator draws his/her input data directly from design documents the differences between the results obtained with various programs would be much higher. In addition to these, it must be mentioned that all program users of this study were experienced.

   One conclusion of these numbers is that authorities should be very careful when setting energy performance requirements only on the basis of the calculated energy consumption. If the specific energy consumption is wanted to fix to a certain level, then also the calculation method and the important input data must be fixed, in order to ascertain, that certain energy consumption also corresponds certain level of thermal insulation and efficiency of equipment.

   The calculation method of ISO DIS 13790 gives accurate results compared with those of the 6 simulation programs used in this study. Therefore it should be an allowed method in the energy analysis of buildings.

5. For energy analysis purposes single-zone modelling seems to give results accurate enough compared with the double-zone modelling.

10. Literature

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11. Appendices

A. Symbols for calculation cases

The following specifications are used for identification the calculation cases.

1. Building type

SFa_SgZo	Single family house as a single zone
SFa_Zo1	Zone 1 of single family house
SFa_Zo2	Zone 2 of single family house
SFa_Zo1+2	Zones 1+2 of single family house
Ap_SgZo	Single zone flat (Case 2)
Ap_DbZo1	Zone 1 of the double-roomed flat (Case 1)
Ap_DbZo2	Zone 2 of the double-roomed flat (Case 1)
Ap_DbZo1+2	Zones 1+2 of the double-roomed flat (Case 1)

2. Construction type

ExL	Extra-light
Lig	Light
SWe	Semi-weight
Mas	Massive

3. Use of mechanical cooling

The set point temperature for heating is always 21 ^oC

NCo	No cooling
Coo	Cooling, set point temperature 25 ^oC
CoT	The set point temperatures for heating and cooling are both 21 ^oC,

4. Window area and orientation

W xx	Window area/floor area xx % (e.g. W 20)
Or NS	Windows in north – south direction (facing either to west or to east)
Or WE	Windows in west – east direction (facing either to south or to north)

B. Simulation tools used

B 1. Consolis Energy

Timely resolution and climatic data.

The climate is represented by three typical days for each month. The days have an average temperature which is the average for the month and for the actual location over a period of 30 years as given in climatic handbooks. One day is with clear sky, one with partly cloudy and one with full cloud cover. The temperature variation over the day as a function of the time t in hours is given by a synthetic algorithm based on cloudiness and solar radiation on a horizontal surface. The algorithm for the daily variation of the outdoor temperature, Te, K, is given in Eq. (1).

$$T_e = T_{[illegible]} + (2.4 + 0.0162 \cdot I_{[illegible]}) \cdot \cos\left(\frac{t-15}{24} \cdot 2 \cdot \pi\right) \qquad (1)$$

The temperature for the ground under the floor construction is derived from the monthly heat flow given by EN ISO 13370. This temperature is constant for each month and is specific for each construction. The overall monthly result for heating and cooling loads will then be a weighted average based on the monthly cloudiness data generally available for most locations.

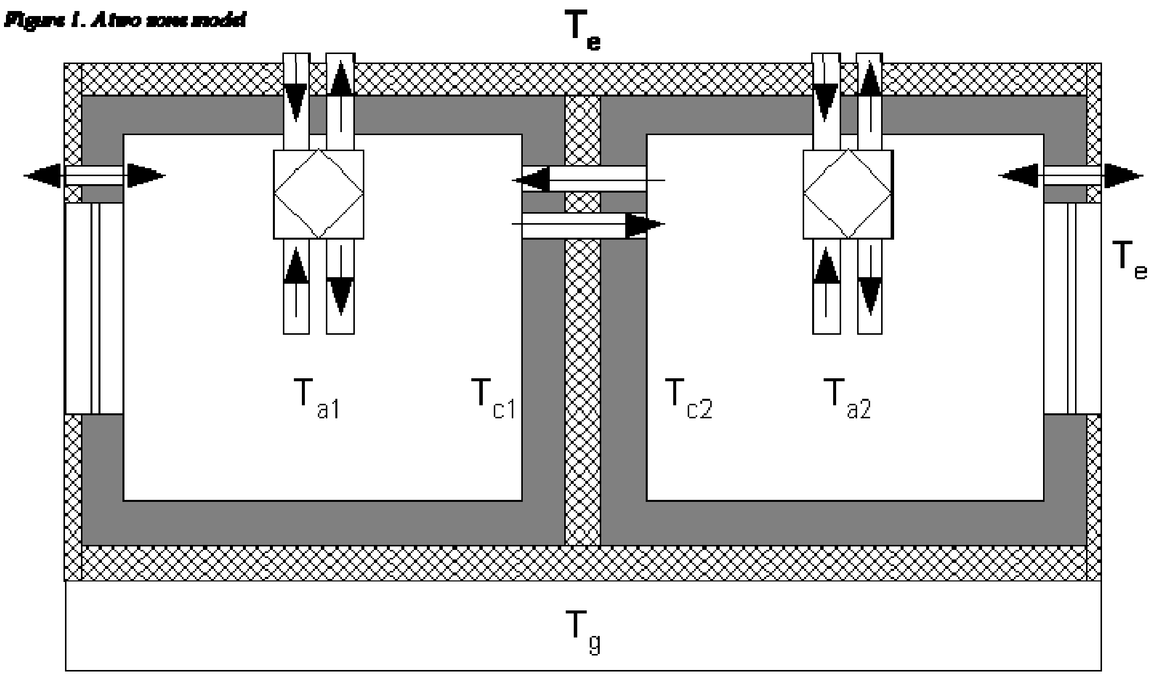

Figure 1. A two-zone model.

The main advantage is that the data set needed for each location is limited to 36 values per month which makes it easily accessible for the user and easy to control. The data will basically be the same as for a normal calculation with EN ISO 13790 so that both methods can be run on the same data set for calibration.

Multiple zones

The model includes two zones. Each zone is characterized by its thermal capacity at the surfaces and heat transfer coefficients between the temperature nodes which are Te the outdoor air temperature, Ta1and Tc1, the air and surface temperatures in zone 1 and Ta2 and Tc2, the air and surface temperatures in zone 2.

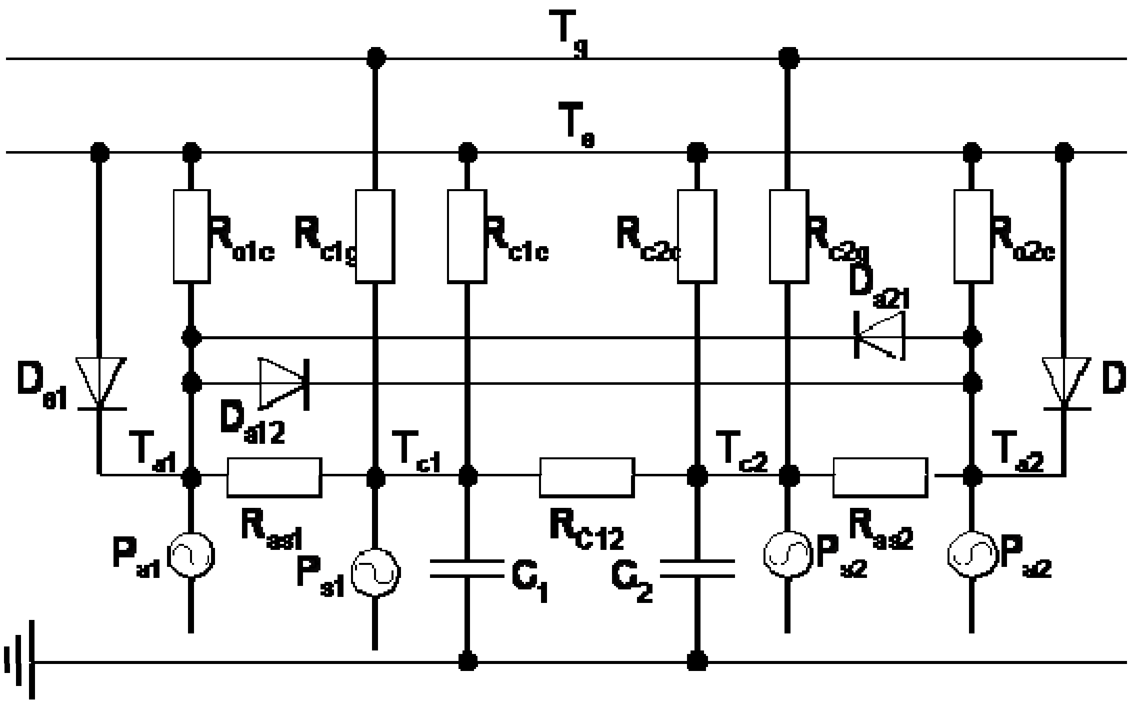

Figure 2. A schematic graph of the thermal model for the two zone conficuration.

Each zone has an equivalent surface heat capacity that takes into account both internal and external surfaces. The air temperature is linked to the exterior temperature via the ventilation, infiltration and window heat transfer, to the air in the other zone via air flows and to the surface in the zone via convective surface heat transfer. The surface temperature is linked to the exterior and ground temperatures via transmission through opaque constructions, to the surface of the other zone via transmission through partitions and to the zone air. Arbitrary fractions of emitted or extracted heat in the zone can be directed towards the surface or the air. Ventilation flows in and out can be varied at will and an air to air heat exchanger function is included.

The model is geometric in a way as the solar radiation through the windows is based on the geometry and orientation of the windows. The most significant simplification is that all the surfaces in a zone have a uniform temperature and thermal capacity. This is justified by the fact that there is about twice as strong coupling by radiation between a surface and other surfaces in a room than by convection to the air.

Thermal inertia and utilisation factor

The thermal inertia of the constructions is for each zone represented by a single capacitance evenly distributed over the inner surfaces. The equivalent capacity for each surface is derived from the analytically calculated heat flow response for a 24 hour temperature variation and simply added for the various surfaces.

In ISO 13790 the single node thermal capacity representation is already used in the calculation of the building time constant. The so called utilisation factor for internal heat loads is based on the load/gain ratio and the time constant. The empirical expressions are based on a fixed maximum indoor temperature for venting and cooling which can not be varied by the user.

Space model and nodal representation

The nodal points for the temperatures and the connecting devices are shown in the system sketch in figure 2. The model has 4 power generators, Pa1 etc., W, that generate heating or cooling at the air and surface nodes for the spaces. The power to each node consist of power for heating or cooling, power from internal loads such as persons or lighting and the power from solar radiation through windows. The model is built up so that each separate power source to the room can be divided between the air and the surfaces by the choice of the user. This gives the possibility to model air heating versus surface heating and its implication on the dynamics and control of indoor temperatures in a simplified way. RC12 is a thermal resistance over the common partitions for the two zones, Ras1 and Ras1 represent the convective heat transfer between the air and the surfaces. RC1e and RC2e represent the heat transfer between the indoor surface through all opaque exterior construction above ground and the ambient outdoor temperature. RC1g and RC2g represent the heat transfer between inner surface and the ground temperature below. Ra1e and Ra2e represent the direct heat transfer between the room air and the exterior ambient temperature that can be considered as steady state. This includes heat transmission flow through windows and doors and may also include bidirectional in- and exfiltration. The heat transfer with directed air flows is symbolized with diodes that transfer heat only in one direction. De1 and De2 are depending on the air flows from the exterior to the air but also on the flow from the air to the exterior together with the air to air heat exchanger efficiency of a possible heat exchanger. A possible air flow between the zones is modelled differently in each direction as Da12 and Da21. This gives a relatively large freedom for the user to lead the air in and out of the zones and between the zones.

Mathematical solution

To calculate the heating and cooling load we need to establish an algorithm that relates the temperatures at the end of a time step to the temperatures at the beginning of the time step. The solution used showed frequent instabilities in the solution with a simple forward difference scheme which were eliminated by switching over to backward differences. The mathematical formulation then becomes implicit and the unknown temperatures of the system have to be expressed as n equation system for each time step or in matrix form.

$$\boldsymbol{HTM} \cdot \boldsymbol{T} = \boldsymbol{B} \qquad (2)$$

In which **HTM** is the heat transfer matrix, **T** is the vector for unknown temperatures and **B** is a vector that consisting of boundary temperatures, supplied power and initial temperatures at the beginning of the time step. Inverting the heat transfer matrix and multiplying on both sides gives:

$$T = HTM^{-1} \cdot B \qquad (3)$$

The boundary temperatures and the supplied power to the nodes can be expressed as constant during the time step or varying linearly during the time step. In the present work the former approach has been chosen. This has to be taken care of in the modelling of the boundary condition, especially the solar gains in order not to create a half an hour time shift in the results.

Since the calculation is based on repeated daily cycles the temperatures at 0 hours are set equal to the temperatures at 24 hours. Due to nonlinearities in the temperature control they solution for the whole day is best reached with iteration.

Temperature control

As input to the model the user can choose a set point temperature for heating and a set point temperature for cooling in each zone. A complication is that when we have introduced the air and surface mass node for each room we have to define the comfort temperature. In the model the default procedure is to define the comfort temperature as the arithmetic mean of the air and surface temperature but the user can decide to weigh them differently. This means that, besides the unknown temperatures for air and the surface mass nodes, we define the comfort temperatures for the different zones, Tz1 and Tz2 where a and b are the weights as

$$T_{z1} = \frac{\alpha \cdot T_{a1} + \beta \cdot T_{s1}}{\alpha + \beta} \qquad (4)$$

and

$$T_{z2} = \frac{\alpha \cdot T_{a2} + \beta \cdot T_{s2}}{\alpha + \beta} \qquad (5)$$

This approach excludes the window surfaces temperature from the weighted comfort temperature. It is not expected that this method will give local operative temperature close to windows etc. For heavily glazed spaces this might become of importance.

For each time step the resulting temperatures are calculated without any supplied heating or cooling. If the temperatures, Tz1 and Tz2, lie between the set point temperatures for heating and cooling no action has to be taken. Else, the supplied power to the temperature nodes has to be calculated simultaneously. By calculating the response of the comfort temperature vector Tz to a unit increase in supplied power for each node, we can we can identify the matrix **HCR** relating changes in comfort temperatures and supplied heating/cooling power in the zones.

$$\Delta T_z = HCR \cdot P_z \qquad (6)$$

and further

$$P_z = HCR^{-1} \cdot \Delta T_z \qquad (7)$$

In this way the power needed to meet a desired temperature changes ΔTz can be explicitly expressed.

Software solutions

The program is written in Microsoft Excel. The special routines that were used included complex number arithmetic, vector and matrix algebra and allowing for circular references to make use of the effective built in iteration processing. The calculation for 2 zones and a whole year is carried out in few seconds.

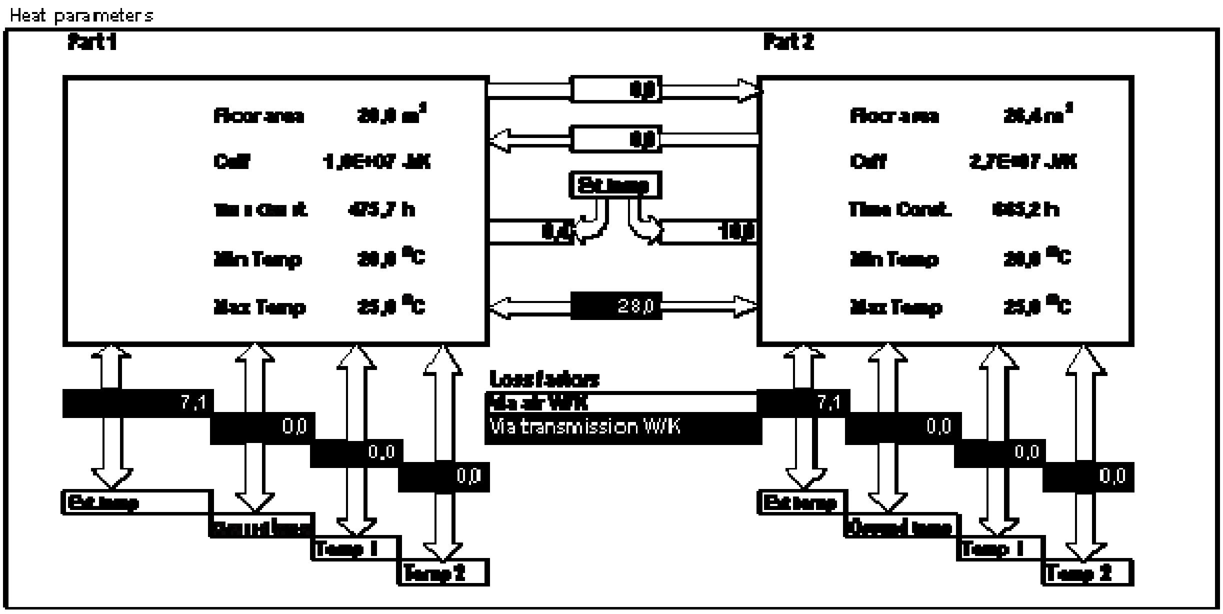

Figure 3. Heat transfer parameters for the given base case, i.e. two adjacent office spaces, part 1 facing south and part 2 facing south. Temp 1 and Temp 2 are optional zones with fixed temperatures. C_{eff} is the total thermal capacity for each zone

B 2. VIP

The commercially available VIP+ (2002) is a dynamic hourly-based programme that manages energy supply from space heating, solar radiation, internal gains (people, appliances), heat recovery from ventilation and energy release by transmission, ventilation, air leaks, hot water production, and cooling. There are two important calculation modules; one to estimate airflows through the ventilation system and air leaks according to Nylund (1980) and one for thermal mass according to Johannesson (1981). There are two important links where the properties connect. One is the internal air pressure model where wind-pressure, thermal uplift, air-leakage and ventilation flows are merged into an 'air-system' which balances in and outflow of air. The other is the temperature of the building frame model where the energy flows of radiation, air flow and transmission are integrated with the balance of added, removed and stored energy.

The programme is based on a one-zone model. A building with thermally separated rooms which have different set point temperatures or different free energy gains can be modelled by first calculating each zone is calculated separately and then clustering the zones by a specific procedure provided in the programme.

The programme has no specific routine to calculate heat-bridges, which instead can be modelled as any other element of the building. This gives good understanding of the impact of the heat-bridges. Indoor temperatures are computed, which allows an assessment of thermal comfort for the specific design alternatives. It should be pointed out that VIP+ primarily is an energy balance programme for the design of the climate shell, and that in general cases, other types of programmes should be used for the thermal comfort related design in general cases. For a normal residential building with limited window areas, no air conditioning and moderate internal gains,
VIP+ is however deemed to be a sufficient tool to predict indoor temperatures. The programme has been in operation since the end of the 1980s with good agreement in comparisons with measurements on real buildings (Öberg, 2002). Currently a user inter-phase addressing also the energy certification procedures of the EPBD is being developed.

Jóhannesson G. (1981). *Active Heat Capacity, Models and parameters for the thermal performance of building*s. PhD thesis. Report TVBH – 1003, Lund Institute of Technology, Sweden

Nylund P-O. (1980). *Infiltration och Ventilation.* (Infiltration and ventilation) Report D22:1980. Swedish Council for Building Research, Stockholm (In Swedish)

Öberg M. (2002). *INTEGRATED LIFE CYCLE DESIGN - Application to Concrete Multi-Dwelling building,* Report TVBM-3103 Division of Building Materials, Lund University. Lund, Sweden pp 59-60.

VIP+ (2002). Computer programme for energy balance calculations. STRUSOFT, Malmö, Sweden.

B 3. VTT House Model

The simulations were made in VTT House Model simulation environment. VTT House Model is a dynamic simulation tool for building simulations. The House Model combines air infiltration and ventilation, as well as heat and moisture transfer processes. A network assumption is adopted for both air flow and thermal simulation. An iterative method is used for air flow simulations and lumped capacitance method for thermal simulation. VTT House Model includes mass balance, momentum and heat balance equations, which makes it possible to take into consideration the interaction between ventilation and heat transfer processes.

VTT House Model can read IFC 2x format which makes it easy to use the architect's drawings as an input data for building shape and form. VTT House Model uses XML-format for the project. The output data is saved as txt-file but can be examined already during the simulation phase with help of several time dependent charts of variables.

Building wizard automatically analyses the zone type and sets typical heat loads, temperature set points and ventilation values. However, these values are easy to change to the project specific ones. Internal heat loads can have different time schedules in each zone. For heating and cooling it is possible to vary the PID-controls set points.

Ventilation device is functioning as a real one, thus, the temperature efficiency is a function of air flow. The curve of temperature efficiency can be defined for each project individually if needed. Also the heat transfer surfaces can be defined very specifically. Ventilation ducts can also be modelled as real ones.

In VTT House Model there are several options for different building structures but also new structures can be added to the library.

Climate file is in TMY2 format. That format is the most common and evaluated climate format. The TMY2 format includes the buildings location and time zone. Solar radiation for outside surfaces is calculated depending on surface direction and angle as well as on sun position. The horizontal solar radiation is given in climate file. The solar radiation penetrating through windows is calculated as diffuse radiation from inside panel of the window to the zone, this is why also the ceiling of the zone can have heat load from radiation. The radiation from surfaces (e.g. from radiator) is calculated with help of view factors.

The detailed description of the program is in *Pekka Tuomaala, 2002, Implementation and evaluation of air flow and heat transfer routines for building simulation tools, VTT Publications 471.*

B 4. maxit energy

General description

maxit energy calculates monthly heating energy for a one zone building according to the European standard EN 832. It is heavily focused on simplicity for the user and the ambition is that even non experts should be able to perform advanced energy calculations. Beyond EN 832 maxit energy also uses several other international standards to calculate key input values to EN 832.

The energy balance calculation from EN 832 includes heating energy, solar radiation, internal heat gains, ventilation heat recovery, transmission losses, ventilation losses and air leakage losses. The balance equation is also affected by a heat gain utilisation factor that is determined by the building time constant and the gain/loss ratio. Other calculation standards used are ISO 13790 for calculating ground losses, ISO 1386 and ISO 6946 for thermal properties of multilayered components and ISO 13789 for total building thermal properties

The use of standardized calculation methods is an important feature of maxit energy. All calculations are performed according to commonly accepted international standards. This makes the calculations reliable, well documented and verified by independent experts.

All calculations of heating energy are made making assumptions of occupant behaviour, air flow rates, weather estimations, etc and those assumptions add a bit of uncertainty. When comparing design changes impact on the heating energy for a certain building the accuracy is very good. It is very easy to change a construction detail and get an accurate figure for the impact on the energy consumption.

The user interface of maxit energy hides much of the input data to the calculation engine. This makes the program less confusing, easy to use and leaves less room for sloppy input. The calculation report on the other hand is more detailed and contains all key values and information about the calculation and the used calculation data.

maxit energy also contains a database with old calculations and predefined input data such as material properties and calculated statistical weather data. The database of material data, predefined constructions etc makes it easy for the user to set up a calculation. It is also easy to store commonly used constructions and to export calculations to file and share these calculations with other maxit energy users.

maxit energy is well suited for everybody needing to make heating energy calculations and especially for normal building constructors and others without expert knowledge of energy calculations. This is achieved by using open and commonly accepted standards, advanced calculations hidden for the user by an easy interface and a comprehensive report that makes the calculations traceable and possible to verify.

Calculations

The energy balance is calculated through the standard EN 832. Several other standards are used to calculate the data required in EN 832 from the data given by the user. The standards are:

EN 832:1998
ISO 13786:1999
ISO 13789:1999
ISO 6946:1996
ISO 13370:1998

EN 832:1998
EN 832 is used to calculate the energy balance.

ISO 13786:1999
ISO 13786 is used to calculate the heat capacity of layered components. The surface resistances used are 0,04 for internal surfaces and 0,13 for surfaces towards the external environment.

ISO 13789:1999
ISO 13789 is used to calculate the total transmission heat loss coefficient from all building components.

ISO 6946:1996
ISO 6946 is used to calculate the u-value of layered components.

ISO 13370:1998
ISO 13370 is used to calculate ground properties.

B 5. TASE

Tase program is a dynamic, multi room model for energy analysis of buildings. The main emphasis in the program is in the modelling of building physics. The HVAC systems are modelled in a quite simplified way.

The TASE program was originally developed at VTT. It was originally a one room model. Later it was changed to a multi room model and it was verified in the Annex 21 of International Energy Agency (IEA).

The time step used in calculations on normally 1 hour, but it is possible to use also other time steps. The energy balance of one room consists from the convective balance of the room air (Equation 1) and from the heat balance of each surface, which is taken into account. When it is needed a surface can be divided into parts. The transient values of heat flux are calculated using the transfer factors (P_i, Q_i, R_i) developed by Mitalas & Arsenault (Equation 2).

In the heat balance of each surface, convection from the room air, thermal radiation between interior surfaces and the short wave radiation from internal gains and from solar radiation through windows are taken into account (Equation 4, Figure 1). The solar radiation transmitted trough a glazing is first supposed to fall on the floor and to reflect from that according to view factors and values of surfaces' reflectance to other surfaces. The solar absorption in exterior walls is also taken into account in the effective exterior temperature $T^*_{o,n}$ (equation 2).

The heat storage effect into room air is:

$$C_R \frac{dT_R}{dt} = \sum_i h_{ci} A_i (T_{i,n} - T_{R,n}) + \sum_i (\dot{C}_i T_{i,n}) - (\sum_i \dot{C}_i) T_{R,n} + \Phi_{1c,n} \qquad (1)$$

The transient conduction heat flux from interior surface to outside is:

$$q_{i,n} = \sum_{j=0}^{N} P_{ij} T_{i,n-j} - \sum_{j=0}^{N} Q_{ij} T^*_{o,n-j} - \sum_{j=1}^{N} R_{ij} q_{i,n-j} \qquad (2)$$

Equation (2) can be simplified into equation (3), where $T_{i,n}$ is the unknown surface temperature of surface i at time point n and the term the $g_{i,n}$ includes known temperatures and values of heat flux:

$$q_{i,n} = f_i T_{i,n} + g_{i,n} \tag{3}$$

$g_{i,n}$ is a function of $T_{i,n-j}$, $q_{i,n-j}$, $T^{*}_{o,n+1-j}$, $j \geq 1$
$T_{i,n}$ the unknown interior surface temperature
f_i a constant (for exterior walls $f_i = P_{io}$)

The heat flux coming into an interior surface is:

$$q_{i,n} = f_i T_{i,n} + g_{i,n} = h_{ci}(T_{R,n} - T_{i,n}) + \tag{4}$$

$$+ h_{r,ij} \sum_j F_{ij}(T_{j,n} - T_{i,n}) + e_i I_{f,n} + q_{lri,n}$$

The heat balance of the room consists from that of the room air and those of the surfaces. It can be presented with a set of linear equations (Equation 5)

$$[\ A\ ]\ \{\ T\ \} = \{\ B\ \} \tag{5}$$

where

[A] is a constant matrix including the e.g. heat transfer coefficients, transfer factors
{ T } a vector including air and surface temperatures
{ B } a vector including the heating or cooling effect needed, internal heat and solar gains as well as the history of surface temperatures and values heat flux.

Equation (5) can be used for calculating the heating or cooling effect, when the set-point temperature is given or for calculating the interior temperature, when a heating or cooling effect is given.

TASE program includes two heating systems, air heating and radiator heating. The mechanical ventilation can include a heat recovery system from exhaust air. In addition a constant infiltration rate can be given. The internal heat gains can have an hourly profile and they can be split into convection and radiation.

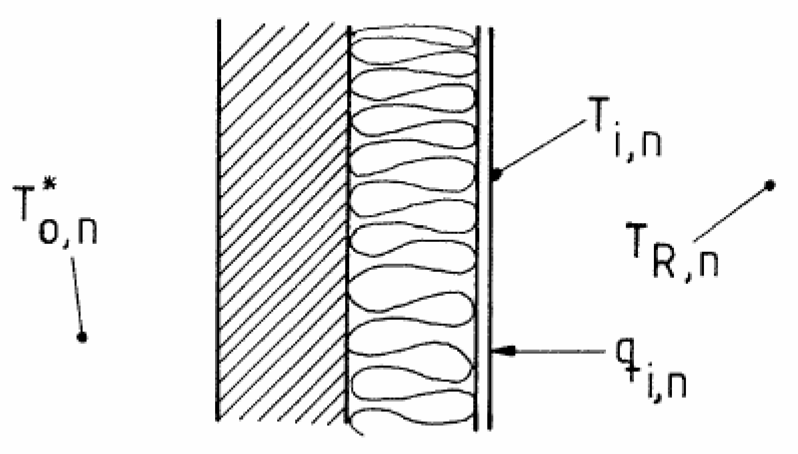

Figure 1. The heat balance of an interior surface.

References

T. Kalema, Thermal Analysis of Buildings – Verification and Further Development of the Program. Tampere University of Technology. Publication 87. Tampere 1992. 185 pp.

A. Aittomäki & T. Kalema, TASE – A Computer Program for Energy Analysis of Buildings. Technical Research Centre of Finland (VTT), Laboratory of Heating and Ventilating, Report, Espoo 1976. (in Finnish).

K. J. Lomas, H. Eppel, C. Martin and D. Bloomfield, Empirical Validation of Thermal Building Simulation Programs Using Test Room Data. Volume 1, Final Report. International Energy Agency, Annex 21 and Task 12. September 1994. 34 pp + Appendices.

G. Mitalas & J. Arsenault, Fortran IV Program to Calculate Z-Transfer Functions for the Calculation of Transient Heat Transfer Trough Walls and Roofs. National Bureau of Standards. Building Science Series 39. Use of Computer for Environmental Engineering Related to Buildings. Washington, DC, 1971, pp. 633 - 668.

B 6. SciaQPro

The aim of SCIAQ Pro is to perform advanced climate simulations in a user-friendly fashion.
SCIAQ is a computer tool for evaluating the indoor climate and energy use in one or several zones in a building. Based on outside climate conditions, the building structure, ventilation system, heating and cooling system, equipment and user habits, SCIAQ computes room temperature, annual and peak heating and cooling loads, air humidity, CO_2 levels, thermal comfort and productivity.

The main thermal simulation model in SCIAQ Pro is based on a 2C-3R[1] electrical analogy wall model. This simplified model is solved analytically within each time step, and all internal and external loads are assumed to be step-functions. The time step can be set between 5 minutes and 1 hour. Heat loss to the ground is calculated according to ISO 13 370. For multi-zone cases, iteration with relaxation is used for solving the zones simultaneously.

A lot of other sub-models for solar radiation, solar shading, components in mechanical ventilation systems, natural ventilation, infiltration, night cooling, thermal comfort, productivity loss, and more are also implemented in SCIAQ Pro.

The thermal model in SCIAQ Pro has been tested against IEA's BESTTEST with good results. It performs well within the range of other international well known buildings energy simulation programs.

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[1] C stands for capacitance and R stands for resistance.

B 7. IDA ICE

3. Basic Principles of IDA and IDA Indoor Climate and Energy

3.1. Introduction

IDA Indoor Climate and Energy (ICE) is a program for study of the indoor climate of individual zones within a building, as well as energy consumption for the entire building. IDA Indoor Climate and Energy is an extension of the general IDA Simulation Environment. This means that the advanced user can, in principle, simulate any system whatsoever with the aid of the general functionality in the IDA environment.

In normal circumstance, the system to be simulated consists of a building with one or more zones and a primary system and one or more air handling systems. Surrounding buildings might shade the building. The air inside the building contains both humidity and carbon dioxide. Weather data is supplied by weather data files, or created for a given 24-hour period. Consideration of wind and temperature driven airflow can be taken. Predefined building components and other parameter objects can be loaded from a database. This can also be used to store personally defined building components.

3.2. The three levels of user interface

The user interface is divided into three different levels, with different support and scope for the user. At the simplest level, called wizard, the user enters input into one or more forms, which are displayed in sequence. The user is then given the opportunity of carrying out a simulation directly, or transferring the data entered to the next level, called the standard level. Chapter 4 covers the most important points for using the IDA Room wizard (Figure 3.1).

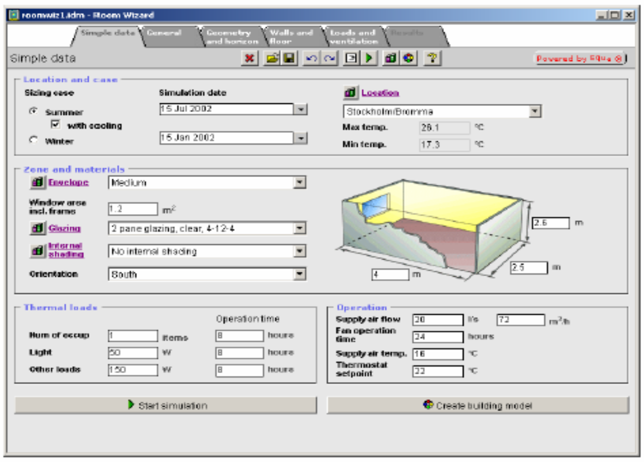

Figure 3.1. One of the tabs of IDA room

At the standard level, the user is given greater freedom to design his building. This level defines geometry, material, controller settings, loads, etc., in a manner that should be easy to handle for the majority of engineers who lack any specific simulation knowledge. Chapter 5 takes the reader through the construction of a system at the standard level (Figure 3.2).

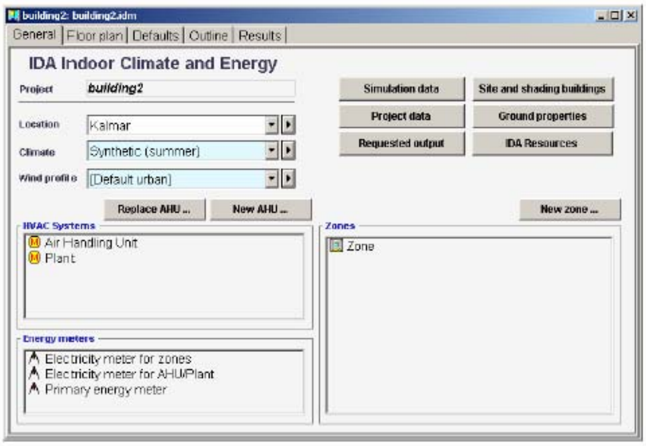

Figure 3.2. Main form for the building at standard level

The simulation model is no longer defined in physical terms at the advanced level, but in the form of connected component models, whose meaning is defined by equations. At this level the connection structure and equation parameters can be freely changed, and the individual time evolution of the variables can be studied. Some of these operations are easy to carry out, e.g., changing a proportional controller with a thermostat. Others are more complicated and require a deeper knowledge of the models' design. All equations, parameters and variables can be examined at this level, but if changes are made in the model at the advanced level, they are not reflected at the standard level. That is to say, changes are in many cases lost if a new model is generated from the standard level. Use of the advanced level is introduced in chapter 8. There are also online help texts in the program for this purpose and several separate reports that are available on the user's web page, which is reached from the Help menu, IDA on the Web, ICE User Support.

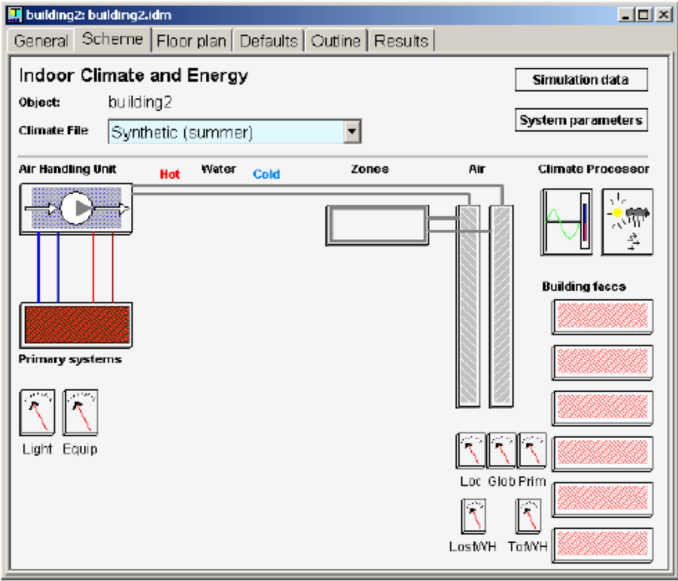

Figure 3.3. Main Form for the building at the advanced level

3.3. Two quick simulations

Before we go on, we will do two simple simulations in IDA Room and at the standard level to assist understanding.

3.3.1. IDA Room

To start IDA Room, first start IDA (double click on the IDA symbol on the Windows' desktop) and then press the IDA Room button in the toolbar. Your web browser is then started (IDA Room works best in Internet Explorer 5.0 or later) and IDA Room is loaded. It is also possible to launch IDA Room directly from the Start menu of Windows: select IDA Software and then IDA Room.

Here, the simplest possible simulation is done by pressing Start simulation in the first tab, Simple data. IDA Room is designed to be usable by clicking and learning, i.e. reading the manual should normally not be needed.

3.3.2. Standard level

It is equally easy to make a first simulation at the standard level. After having started IDA, press the button for a building with a single zone in the toolbar. Then start a simulation, a design summer case, by pressing the green arrow in the toolbar.

In the standard level it is more difficult (and not very efficient) to find one's way around without first reading the manual. Skim through the first chapters of the manual before you start, especially this chapter and Chapter 5.

3.4. Forms, dialogs and status bar

The Windows part of the program (everything but IDA Room) is built up around forms and dialogs. The forms contain no Cancel button, i.e., there is no access to earlier versions of a

C. Results of the single-family house

Table C.1. Results of basic calculations on the single-family house.

Case	Calculation	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	%	%
1 - SFa_Zo1+2 - ExL - Coo	IDA	29,3	43,8	61,2	-7,6	39,9	86,0	3,9	53,1
	SCIAQ Pro	33,0	43,8	66,6	-12,6	35,5	88,3	4,1	38,1
	VTT	31,7	43,6	68,2	-9,2	35,5	98,9	7,7	63,4
	Consolis Energy	31,5	43,8	66,2	-11,1	130,3		3,8	31,5
	TASE	32,9	43,7	62,6	-7,2	39,1	92,9	4,1	47,3
2 - SFa_Zo1+2 -Lig - Coo	IDA	29,3	43,8	60,1	-5,6	40,1	86,7		
	Consolis Energy	31,5	43,8	64,5	-8,9	130,9			
	TASE	32,9	43,7	61,2	-5,5	39,3	93,1		
3 - SFa_Zo1+2 -SWe - Coo	IDA	29,4	43,8	59,1	-3,7	40,3	87,4		
	Consolis Energy	31,5	43,8	63,7	-7,7	131,3			
	TASE	32,9	43,7	60,4	-4,0	39,6	93,6		
4 - SFa_Zo1+2 - Mas - Coo	IDA	29,4	43,8	58,8	-3,6	40,3	87,2		
	SCIAQ Pro	33,0	43,8	63,9	-7,8	35,5	88,3		
	VTT	31,7	43,6	63,0	-3,4	35,8	100,1		
	Consolis Energy	31,5	43,8	63,7	-7,6	131,3			
	TASE	32,9	43,7	60,0	-3,8	39,6	93,3		
5 - SFa_SgZo - ExL - Coo	VIP	32,1	43,7	59,9	-12,6	40,7	82,5	2,7	19,2
	IDA	28,7	43,8	60,7	-5,9	39,9	86,7	2,9	46,5
	SCIAQ Pro	33,0	43,8	68,7	-11,4	35,5	88,3	6,4	28,9
	Consolis Energy	31,5	43,8	65,3	-10,0	130,5		3,0	27,5
	TASE	32,8	43,8	61,6	-6,2	39,3	92,5	3,2	43,1
6 - SFa_SgZo - Lig - Coo	VIP	32,1	43,7	59,5	-11,8	40,8	82,7		
	IDA	28,7	43,8	59,8	-4,4	40,2	86,9		
	Consolis Energy	31,5	43,8	63,7	-7,9	131,1			
	TASE	32,8	43,8	60,4	-4,8	39,4	92,7		
7 - SFa_SgZo - SWe - Coo	VIP	32,1	43,7	58,4	-10,3	41,0	82,9		
	IDA	28,7	43,8	59,3	-3,3	40,3	87,4		
	Consolis Energy	31,5	43,8	63,3	-7,3	131,3			
	TASE	32,8	43,8	60,1	-3,7	39,7	93,1		
8 - SFa_SgZo - Mas - Coo	VIP	32,1	43,7	58,3	-10,2	41,0	82,9		
	IDA	28,7	43,8	59,0	-3,1	40,3	87,1		
	SCIAQ Pro	33,0	43,8	64,3	-8,1	35,5	88,3		
	Consolis Energy	31,5	43,8	63,3	-7,2	131,3			
	TASE	32,8	43,8	59,6	-3,5	39,7	92,8		
9 - SFa_Zo1+2 - ExL - NCo	IDA	29,2	43,8	61,8	0,0	42,8	90,1	4,2	
	VTT	31,6	43,6	66,4	0,0	37,4	104,3	5,4	
	SCIAQ Pro	33,0	43,8	65,4	0,0	35,5	88,3	2,4	
	Consolis Energy	31,5	43,8	64,7		140,0		1,7	
	TASE	32,9	43,7	62,0	0,0	39,5	99,3	3,5	
10 - SFa_Zo1+2 - Lig - NCo	IDA	29,2	43,8	60,7	0,0	42,5	89,8		
	Consolis Energy	31,5	43,8	64,1	0,0	139,3			
	TASE	32,9	43,7	61,1	0,0	39,3	98,5		
11 - SFa_Zo1+2 - SWe - NCo	IDA	29,3	43,8	59,5	0,0	42,1	89,6		
	Consolis Energy	31,5	43,8	63,6	0,0	138,9			
	TASE	32,9	43,7	60,4	0,0	39,0	98,1		
12 - SFa_Zo1+2 - Mas - NCo	IDA	29,3	43,8	59,2	0,0	42,0	89,4		
	VTT	31,6	43,6	62,8	0,0	36,7	102,4		
	SCIAQ Pro	33,0	43,8	63,8	0,0	35,5	88,3		
	Consolis Energy	31,5	43,8	63,6		138,9			
	TASE	32,9	43,7	59,9	0,0	38,9	97,7		
13 - SFa_SgZo - ExL - NCo	IDA	28,6	43,8	60,5	0,0	42,4	90,1	2,6	
	Consolis Energy	31,5	43,8	64,4		139,6		1,7	
	TASE	32,8	43,8	61,4	0,0	39,4	98,3	3,0	
14 - SFa_SgZo - Lig - NCo	IDA	28,6	43,8	59,7	0,0	42,1	89,5		
	Consolis Energy	31,5	43,8	63,7		139,0			
	TASE	32,8	43,8	60,4	0,0	39,2	97,6		
15 - SFa_SgZo - SWe - NCo	IDA	28,6	43,8	59,2	0,0	41,8	89,4		
	Consolis Energy	31,5	43,8	63,3		138,6			
	TASE	32,8	43,8	60,0	0,0	39,0	97,4		
16 - SFa_SgZo - Mas - NCo	IDA	28,6	43,8	58,9	0,0	41,8	89,1		
	Consolis Energy	31,5	43,8	63,3		138,6			
	TASE	32,8	43,8	59,5	0,0	38,9	97,0		
Extra Light Multizone, Coo	VTT	32,5	52,6	76,4	-19,9	37,8	103,7	8,1	31,6
Massive Multizone, Coo	VTT	32,5	52,6	70,2	-13,6	37,9	104,3		
Extra Light Multizone, NCo	VTT	32,5	52,6	67,9	0,0	41,0	112,0	4,4	
Massive Multizone, NCo	VTT	32,5	52,6	65,0	0,0	40,3	110,4		
Extra Light	Maxit Energy	33,3	43,8	71,0		35,3	87,8	12,7	
Massive	Maxit Energy	33,3	43,8	62,0		35,3	87,8		
Massive	ISO 13790	13,8	36,1	57,2		35,1	72	72	

Table C.2. Results of sensitivity analysis of TASE on the single-family house.

TASE - SENSITIVITY ANALYSIS - SINGLE-FAMILY HOUSE									
Building type	Case	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	%	%
SFa_Zo1+2 - ExL - Coo	Original	32,9	43,7	62,6	-7,2	39,1	92,9	4,1	47,3
	W15	45,9	43,7	64,2	-13,4	40,0	100,5	7,2	48,7
	W20	63,4	43,7	67,5	-22,8	40,7	111,1	11,2	46,9
	OrNS	34,3	43,7	63,3	-8,6	39,6	93,2	2,8	38,5
	W15-OrNS	43,4	43,7	65,7	-12,4	40,2	100,3	3,2	35,6
	W20-OrNS	55,6	43,7	69,6	-18,1	40,7	110,1	4,1	32,0
SFa_Zo1+2 - Mas - Coo	Original	32,9	43,7	60,0	-3,8	39,6	93,3		
	W15	45,9	43,7	59,6	-6,9	41,0	101,3		
	W20	63,4	43,7	59,9	-12,1	42,4	112,4		
	OrNS	34,3	43,7	61,5	-5,3	40,6	93,8		
	W15-OrNS	43,4	43,7	63,6	-8,0	41,7	101,0		
	W20-OrNS	55,6	43,7	66,7	-12,3	42,8	110,9		
SFa_SgZo - ExL - Coo	Original	32,8	43,8	61,6	-6,2	39,3	92,5	3,2	43,1
	W15	45,8	43,8	62,3	-10,9	40,5	100,3	5,1	42,9
	W20	63,7	43,8	64,5	-18,7	41,9	111,0	8,3	41,8
	OrNS	34,2	43,8	62,8	-7,9	39,9	92,8	2,4	36,1
	W15-OrNS	43,2	43,8	65,1	-11,5	40,5	99,9	2,8	33,6
	W20-OrNS	55,5	43,8	68,7	-16,7	41,2	109,7	3,5	30,3
SFa_SgZo - Mas - Coo	Original	32,8	43,8	59,6	-3,5	39,7	92,8		
	W15	45,8	43,8	59,1	-6,2	41,4	100,9		
	W20	63,7	43,8	59,1	-10,9	43,4	112,0		
	OrNS	34,2	43,8	61,2	-5,0	40,7	93,3		
	W15-OrNS	43,2	43,8	63,3	-7,6	41,9	100,6		
	W20-OrNS	55,5	43,8	66,3	-11,7	43,2	110,4		

Table C.3. Results of sensitivity analysis of VTT on the single-family house.

VTT - SENSITIVITY ANALYSIS - SINGLE-FAMILY HOUSE									
Building type	Case	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	%	%
SFa_Zo1+2 - ExL	Original	31,7	43,6	68,2	-9,2	35,5	98,9	7,7	63,4
	Extra insulation	32,5	43,6	47,7	-13,1	36,1	73,8	8,5	45,2
	Less insulation	31,8	43,6	118,3	-11,1	33,2	149,5	3,9	96,7
	g-value 0,44	21,5	43,6	70,7	-10,3	33,3	92,3	4,2	89,8
	g-value 0,24	11,3	43,6	73,9	-4,6	33,2	91,1	0,3	98,1
	g-value 0,14	6,2	43,6	76,3	-2,7	33,1	90,4	-1,0	100,0
SFa_Zo1+2 - Mas	Original	31,7	43,6	63,0	-3,4	35,8	100,1		
	Extra insulation	32,5	43,6	43,7	-7,2	36,6	76,0		
	Less insulation	31,7	43,6	113,7	-0,4	34,5	155,5		
	g-value 0,44	21,5	43,6	67,8	-1,0	35,2	97,6		
	g-value 0,24	11,3	43,6	73,7	-0,1	34,5	95,0		
	g-value 0,14	6,2	43,6	77,0	0,0	34,2	93,6		

Table C.4. Results of sensitivity analysis of Consolis Energy on the single-family house.

Building type	Case	Energy input				Energy loss		Effect of mass
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating
		kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	%
SFa_Zo1+2 - ExL - Coo	Original			66,2	-11,1			3,8
	0/100 Power Dist.			66,0	-10,9			3,7
	20/80 Power Dist.			66,1	-11,0			3,7
	80/20 Power Dist.			66,3	-11,2			3,8
	100/0 Power Dist.			66,3	-11,3			3,7
	0/100 Temp. Contr.			66,1	-11,2			3,6
	20/80 Temp. Contr.			66,1	-11,1			3,7
	80/20 Temp. Contr.			66,2	-11,0			3,8
	100/0 Temp. Contr.			66,2	-11,0			3,9
	0/100 Power Dist. W25			77,2	-33,0			8,5
	20/80 Power Dist. W25			77,3	-33,1			8,6
	50/50 Power Dist. W25			77,4	-33,2			8,6
	80/20 Power Dist. W25			77,5	-33,4			8,4
	100/0 Power Dist. W25			77,5	-33,5			8,2
	0/100 Temp. Contr. W25			77,8	-33,3			7,7
	20/80 Temp. Contr. W25			77,6	-33,3			8,1
	50/50 Temp. Contr. W25			77,4	-33,2			8,6
	80/20 Temp. Contr. W25			77,1	-33,2			8,8
	100/0 Temp. Contr. W25			77,0	-33,3			8,8
	Window 17%			70,4	-19,5			5,9
	Window 25%			77,4	-33,2			8,6
	Window 35%			87,0	-51,7			11,5
	Window 45%			97,1	-71,3			13,7
SFa_Zo1+2 - Mas - Coo	Original			63,7	-7,6			
	0/100 Power Dist.			63,6	-7,5			
	20/80 Power Dist.			63,6	-7,5			
	80/20 Power Dist.			63,8	-7,8			
	100/0 Power Dist.			63,9	-7,9			
	0/100 Temp. Contr.			63,8	-8,0			
	20/80 Temp. Contr.			63,7	-7,8			
	80/20 Temp. Contr.			63,6	-7,5			
	100/0 Temp. Contr.			63,7	-7,4			
	0/100 Power Dist. W25			70,6	-24,6			
	20/80 Power Dist. W25			70,6	-24,8			
	50/50 Power Dist. W25			70,7	-25,2			
	80/20 Power Dist. W25			70,9	-25,8			
	100/0 Power Dist. W25			71,2	-26,6			
	0/100 Temp. Contr. W25			71,8	-26,3			
	20/80 Temp. Contr. W25			71,3	-25,8			
	50/50 Temp. Contr. W25			70,7	-25,2			
	80/20 Temp. Contr. W25			70,3	-24,9			
	100/0 Temp. Contr. W25			70,2	-24,8			
	Window 17%			66,2	-14,2			
	Window 25%			70,7	-25,2			
	Window 35%			77,0	-39,9			
	Window 45%			83,8	-55,7			

Table C.5. Results of sensitivity analysis of VIP on the single-family house.

Building type	Case	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	%	%
SFa_SgZo - ExL - Coo	Climate - Malmö			37,9	-12,5			5,5	24,8
	Climate - Oslo			54,4	-12,7			3,5	22,0
	Climate - Sto 71			47,3	-15,4			4,2	16,2
	Climate - Sto met			47,5	-14,8			4,2	18,9
	Original: Helsinki			59,9	-12,6			2,7	19,0
	Climate - Luleå			78,5	-9,6			2,4	22,9
	Ind. temp. 21-21			65,8	-30,6			6,1	13,1
	Ind. temp. 21-23			61,0	-19,4			3,8	13,9
	Original: 21-25			59,9	-12,6			2,7	19,0
	Ind. temp. 21-27			59,7	-7,6			2,5	32,9
	Ind. temp. 21-29			60,2	-0,5			2,7	100,0
SFa_SgZo - Mas - Coo	Climate - Malmö			35,8	-9,4				
	Climate - Oslo			52,5	-9,9				
	Climate - Sto 71			45,3	-12,9				
	Climate - Sto met			45,5	-12,0				
	Original: Helsinki			58,3	-10,2				
	Climate - Luleå			76,6	-7,4				
	Ind. temp. 21-21			61,8	-26,6				
	Ind. temp. 21-23			58,7	-16,7				
	Original: 21-25			58,3	-10,2				
	Ind. temp. 21-27			58,2	-5,1				
	Ind. temp. 21-29			58,6	0,0				

D. Results of the apartment building

Table D1. Calculation results on the apartment building

Building type	Calculation	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	kWh/m²	%	%
41 - Ap_Db_Zo1+2 - Lig - Coo	SCIAQ Pro	73,0	43,8	71,9	-49,5	73,0	61,5	**7,0**	**14,5**
(case1)	Consolis Energy	70,9	43,8	71,7	-39,2	147,2		**4,9**	**13,5**
	TASE	68,3	43,8	65,9	-28,3	80,1	69,7	**4,5**	**21,3**
42 - Ap_Db_Zo1+2 - Mas - Coo	SCIAQ Pro	73,0	43,8	66,9	-42,3	73,0	61,5		
(case1)	Consolis Energy	70,9	43,8	68,2	-33,9	149,0			
	TASE	68,3	43,8	63,0	-22,3	82,8	70,1		
43 - Ap_SgZo - Lig - Coo	VIP	71,0	43,7	56,9	-47,0	62,6	62,1	**3,1**	**14,2**
(case2)	SCIAQ Pro	62,0	43,8	67,2	-31,0	71,7	71,7	**4,2**	**13,9**
	Consolis Energy	60,6	43,8	63,7	-32,4	135,7		**3,0**	**11,2**
	TASE	56,7	43,8	65,1	-21,7	79,6	64,2	**3,4**	**24,3**
44 - Ap_SgZo - Mas - Coo	VIP	71,0	43,7	55,1	-40,3	63,5	63,1		
(case2)	SCIAQ Pro	62,0	43,8	64,4	-26,7	71,7	71,7		
	Consolis Energy	60,6	43,8	61,8	-28,8	137,4			
	TASE	56,7	43,8	62,9	-16,4	82,2	64,6		
45 - Ap_Db_Zo1+2 - Lig - NCo	SCIAQ Pro	73,0	43,8	69,3	0,0	73,0	61,5	**4,3**	
(case1)	Consolis Energy	70,9	43,8	69,4		184,1		**1,8**	
	TASE	68,3	43,8	65,2	0,0	93,0	84,4	**3,5**	
46 - Ap_Db_Zo1+2 - Mas - NCo	SCIAQ Pro	73,0	43,8	66,3	0,0	73,0	61,5		
(case1)	Consolis Energy	70,9	43,8	68,2		182,8			
	TASE	68,3	43,8	62,9	0,0	92,0	83,2		
47 - Ap_SgZo - Lig - NCo	SCIAQ Pro	62,0	43,8	66,0	0,0	71,7	71,7	**3,0**	
(case2)	Consolis Energy	60,6	43,8	62,6		167,0		**1,3**	
	TASE	56,7	43,8	64,6	0,0	89,8	75,1	**2,8**	
48 - Ap_SgZo - Mas - NCo	SCIAQ Pro	62,0	43,8	64,0	0,0	71,7	71,7		
(case2)	Consolis Energy	60,6	43,8	61,8		166,2			
	TASE	56,7	43,8	62,8	0,0	88,8	74,2		

Table D2. Results of sensitivity analysis of TASE on the apartment building.

TASE - SENSITIVITY ANALYSIS - APARTMENT HOUSE									
Building type	Case	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	%	%
Ap_DbZo1+2 - Lig - Coo	Original	68,3	43,8	65,9	-28,3	80,1	69,7	4,5	21,3
	W10	33,5	43,8	55,0	-11,0	78,1	43,2	2,4	29,7
	W15	42,8	43,8	57,6	-15,2	78,9	50,0	2,8	27,0
	OrWE	86,1	43,8	61,3	-38,8	81,3	71,1	16,0	35,5
	W10-OrWE	36,1	43,8	52,3	-10,4	78,5	43,3	5,0	38,2
	W15-OrWE	49,4	43,8	54,2	-17,3	79,6	50,5	8,3	38,8
Ap_DbZo1+2 - Mas - Coo	Original	68,3	43,8	63,0	-22,3	82,8	70,1		
	W10	33,5	43,8	53,7	-7,7	79,8	43,5		
	W15	42,8	43,8	56,0	-11,1	81,1	50,3		
	OrWE	86,1	43,8	51,4	-25,1	84,4	72,0		
	W10-OrWE	36,1	43,8	49,7	-6,4	79,6	43,6		
	W15-OrWE	49,4	43,8	49,7	-10,6	81,4	50,9		
Ap_SgZo -Lig - Coo	Original	56,7	43,8	65,1	-21,7	79,6	64,2	3,4	24,3
	W10	27,3	43,8	56,6	-7,9	77,4	42,3	1,9	33,7
	W15	41,1	43,8	60,3	-14,1	78,6	52,5	2,5	28,9
	OrWE	81,4	43,8	57,1	-33,9	82,2	66,1	14,5	35,0
	W10-OrWE	39,2	43,8	50,5	-11,2	79,2	43,1	5,9	39,2
	W15-OrWE	59,1	43,8	53,1	-21,3	80,9	53,8	10,2	37,8
Ap_SgZo -Mas - Coo	Original	56,7	43,8	62,9	-16,4	82,2	64,6		
	W10	27,3	43,8	55,5	-5,2	78,8	42,5		
	W15	41,1	43,8	58,8	-10,0	80,8	52,8		
	OrWE	81,4	43,8	48,8	-22,0	85,1	66,8		
	W10-OrWE	39,2	43,8	47,5	-6,8	80,3	43,4		
	W15-OrWE	59,1	43,8	47,7	-13,2	83,0	54,3		

Table D3. Results of sensitivity analysis of VIP on the apartment building.

VIP - SENSITIVITY ANALYSIS - APARTMENT BUILDING									
Building type	Case	Energy input				Energy loss		Effect of mass	
		Solar Gain	Internal Gain	Heating	Cooling	Ventilation	Conduction	Heating	Cooling
		kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	%	%
Ap_SgZo - Lig - Coo	Climate - Malmö			37,8	-41,4			5,0	9,7
	Climate - Oslo			53,1	-46,3			3,6	8,9
	Climate - Sto 71			48,6	-26,6			2,7	9,8
	Climate - Sto met			47,7	-38,6			3,4	9,8
	Original: Helsinki			56,9	-47,0			3,2	8,3
	Climate - Luleå			76,2	-28,6			2,0	11,5
Ap_SgZo -Mas - Coo	Climate - Malmö			35,9	-37,4				
	Climate - Oslo			51,2	-42,2				
	Climate - Sto 71			47,3	-24,0				
	Climate - Sto met			46,1	-34,8				
	Original: Helsinki			55,1	-43,1				
	Climate - Luleå			74,7	-25,3				

E. Utilisation factors

E 1. Single-family house

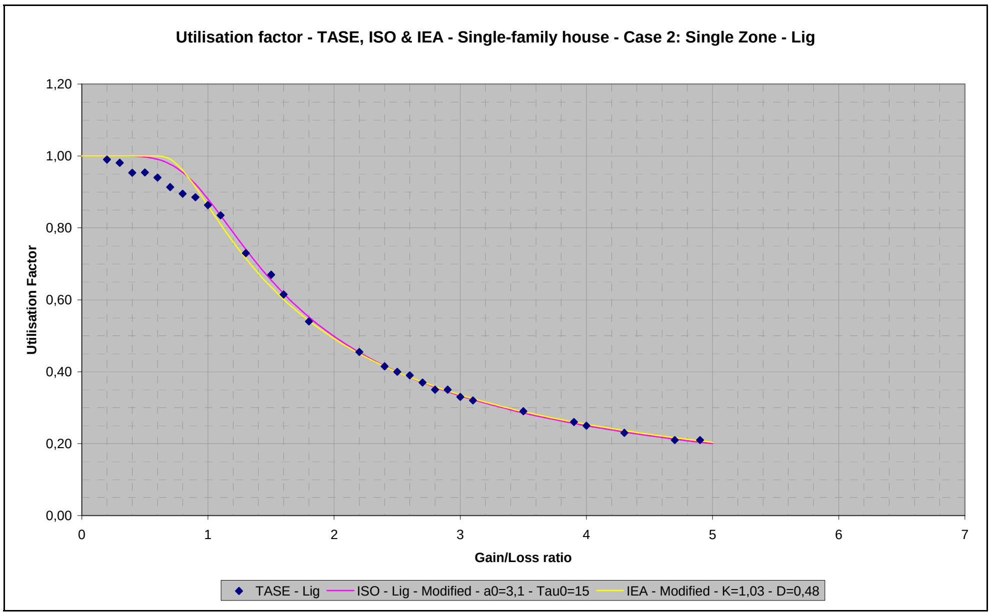

Figure E.1. Utilisation factor for the light single-family, single-zone house. Modified parameters for ISO DIS 13 790; $a_0 = 3{,}1$ and $\tau_0 = 15$ h.

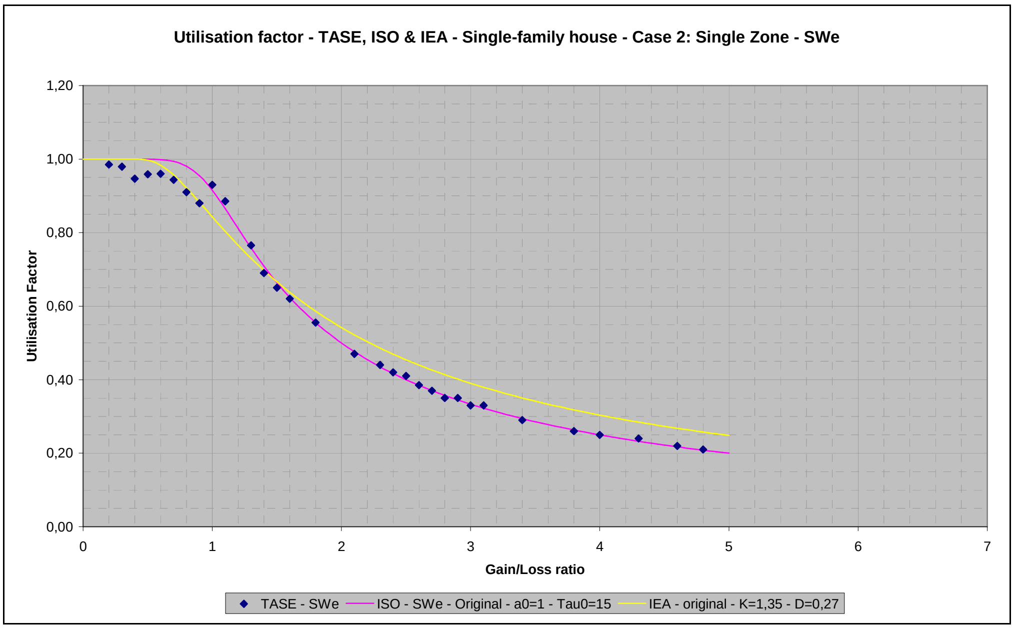

Figure E.2. Utilisation factor for the semi-weight single-family, single-zone house. Original parameters for ISO DIS 13 790; $a_0 = 1{,}0$ and $\tau_0 = 15$ h.

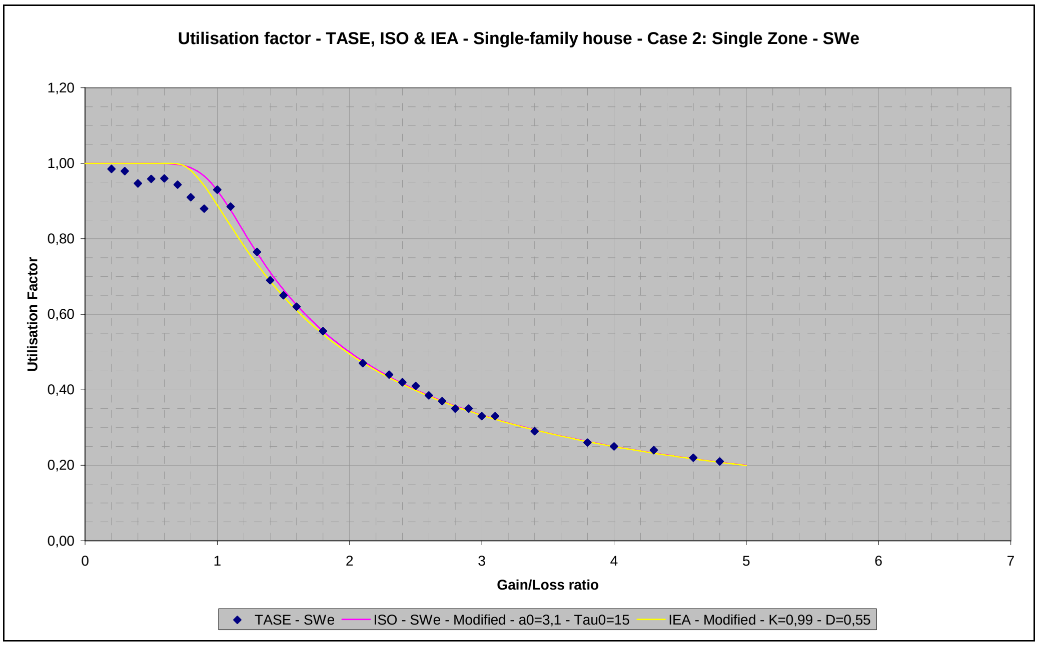

Figure E.3. Utilisation factor for the semi-weight single-family, single-zone house. Modified parameters for ISO DIS 13 790; $a_0 = 3,1$ and $\tau_0 = 15$ h.

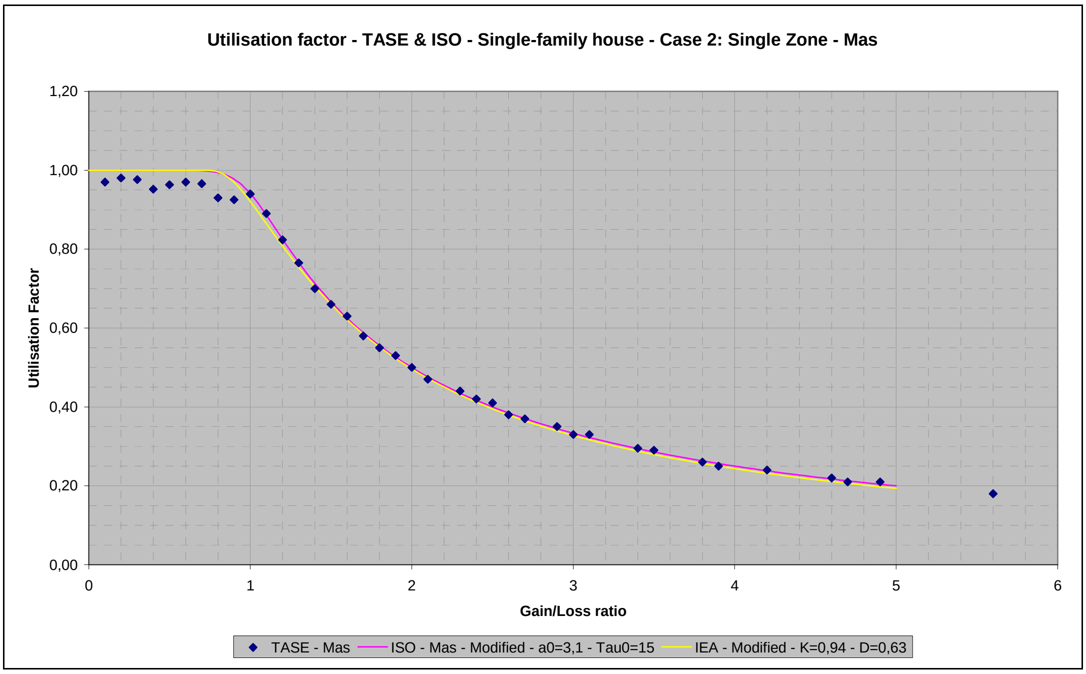

Figure E.4. Utilisation factor for the massive single-family, single-zone house. Modified parameters for ISO DIS 13 790; $a_0 = 3,1$ and $\tau_0 = 15$ h.

E 2. Apartment building

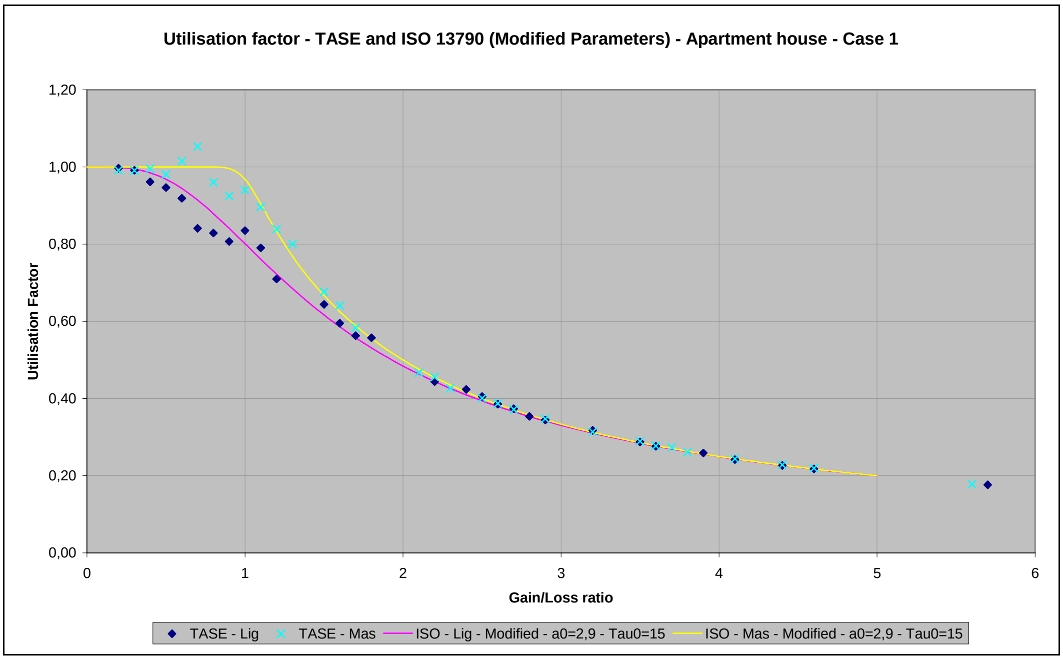

Figure E.5. Utilisation factor for the apartment building having the two-zone flat. Modified parameters for ISO DIS 13 790; $a_0 = 2{,}9$ and $\tau_0 = 15$ h.

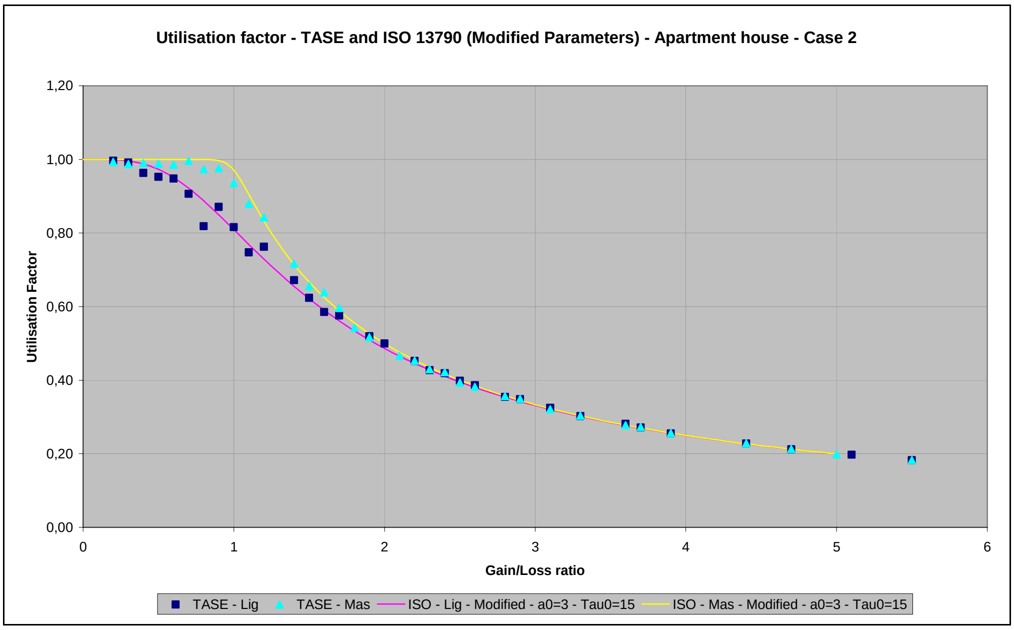

Figure E.6. Utilisation factor for the apartment building having the single-zone flat. Modified parameters for ISO DIS 13 790; $a_0 = 3{,}0$ and $\tau_0 = 15$ h.