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by

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Contents

1. INTRODUCTION

This report is part of the work performed under the project “Multifunktionelle betonkonstruktioner til renovering og nybyg (EUDP projekt)”. The main purpose of this task is to develop a calculation tool that takes into consideration night-time ventilation in the program Be10.

Therefore this report will focus on three main aspects:

- Assess the robustness of the monthly calculation method by varying the input parameters (Part 3)
- Better take into consideration the thermal mass in the actual tool by updating the utilisation factors used for the calculation of cooling and heating (Part 3)
- Find a method to evaluate night-time ventilation in the monthly calculation (Part 4)

2. ENERGY DEMAND OF BUILDINGS: MONTHLY CALCULATION METHOD

2.1 UTILISATION FACTORS

In order to satisfy the requirements of the EPBD (Energy Performance of Buildings Directive), national calculation methods have been developed to calculate the heating and cooling need of buildings, and most of them are based on a quasi-steady-state method, using monthly calculation. The dynamic effects are therefore taken into consideration by introducing correlation factors (1):

2.1.1 Heating case

For heating, a *gain* utilisation factors is defined: $\eta_{H,gn}$. Only part of the internal and solar heat gains is utilized to decrease the energy need for heating, the rest leading to an undesired increase of the internal temperature above the set-point.

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn}\, Q_{H,gn}$$

With $Q_{H,nd}$ total energy need for the heating mode (MJ)
$Q_{H,ht}$ total heat transfer for the heating mode (MJ)
$Q_{H,gn}$ total heat gains for the heating mode (MJ)

$$\begin{cases} \eta_{H,gn} = \dfrac{1-\gamma_H{}^{a_H}}{1-\gamma_H{}^{a_H+1}} & if\ \gamma_H > 0\ and\ \gamma_H \neq 1 \\ \eta_{H,gn} = \dfrac{a_H}{a_H+1} & if\ \ \gamma_H = 1 \\ \eta_{H,gn} = \dfrac{1}{\gamma_H} & if\ \ \gamma_H < 0 \end{cases}$$

$$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}}$$

$$a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$$

Where

$\eta_{H,gn}$ utilitization factor for the heating mode (-)
γ_H relative heat gain for the heating mode (-)
a_H numerical parameter for the heating mode (-)
$a_{H,0}$ numerical parameter of reference for the heating mode (-)
τ building time constant (h)
$\tau_{H,0}$ building reference time constant for the heating mode (h)

The gain utilisation factor is a measure of the amount of overheating:

- o $\eta_{H,gn} = 1$: no overheating
- o $\eta_{H,gn} = 0$: only overheating

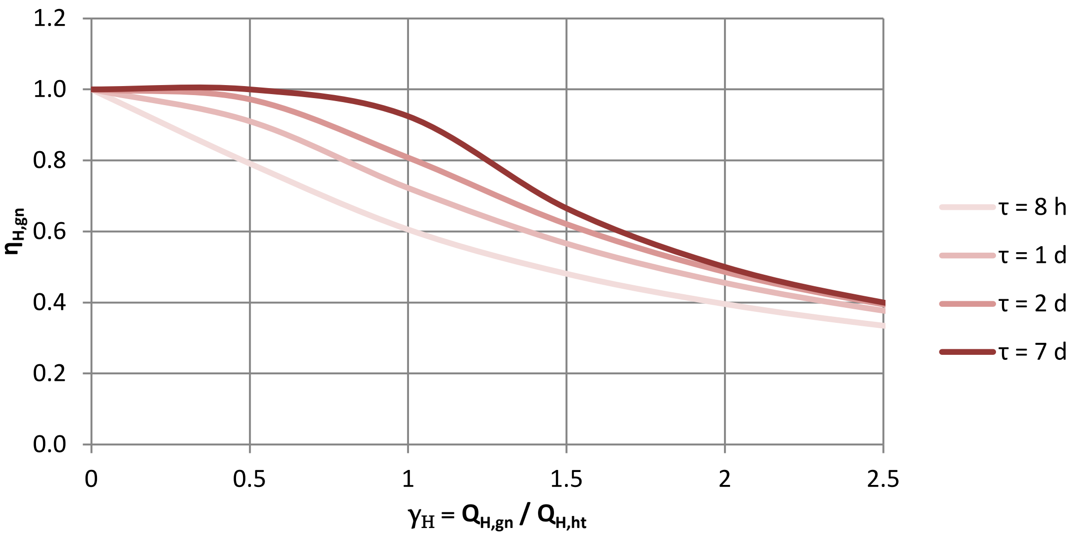


Figure 1: illustration of gain utilisation factor for heating mode

2.1.2 Cooling case

For cooling, a *loss* utilisation factors is defined: $\eta_{C,ls}$. Only part of the transmission and ventilation heat transfer is utilized to decrease the energy need for cooling, the rest leading to an undesired decrease of the internal temperature below the set-point (during night for example).

$$Q_{C,nd} = Q_{C,gn} - \eta_{C,ls}\, Q_{C,ht}$$

With $Q_{C,nd}$ total energy need for the cooling mode (MJ)
$Q_{C,ht}$ total heat transfer for the cooling mode (MJ)
$Q_{C,gn}$ total heat gains for the cooling mode (MJ)

$$\begin{cases} \eta_{C,ls} = \dfrac{1-\gamma_C{}^{-a_C}}{1-\gamma_C{}^{-(a_C+1)}} & if\ \gamma_C > 0\ and\ \gamma_C \neq 1 \\ \eta_{C,ls} = \dfrac{a_C}{a_C+1} & if\ \ \gamma_c = 1 \\ \eta_{C,ls} = 1 & if\ \ \gamma_C < 0 \end{cases}$$

$$\gamma_C = \frac{Q_{C,gn}}{Q_{C,ht}}$$

$$a_C = a_{C,0} + \frac{\tau}{\tau_{C,0}}$$

And similarly to the heating

$\eta_{C,gn}$ utilisation factor for the cooling mode (-)
γ_C relative heat gain for the cooling mode (-)
a_C numerical parameter for the cooling mode (-)
$a_{C,0}$ numerical parameter of reference for the cooling mode (-)
τ building time constant (h)
$\tau_{C,0}$ building reference time constant for the cooling mode (h)

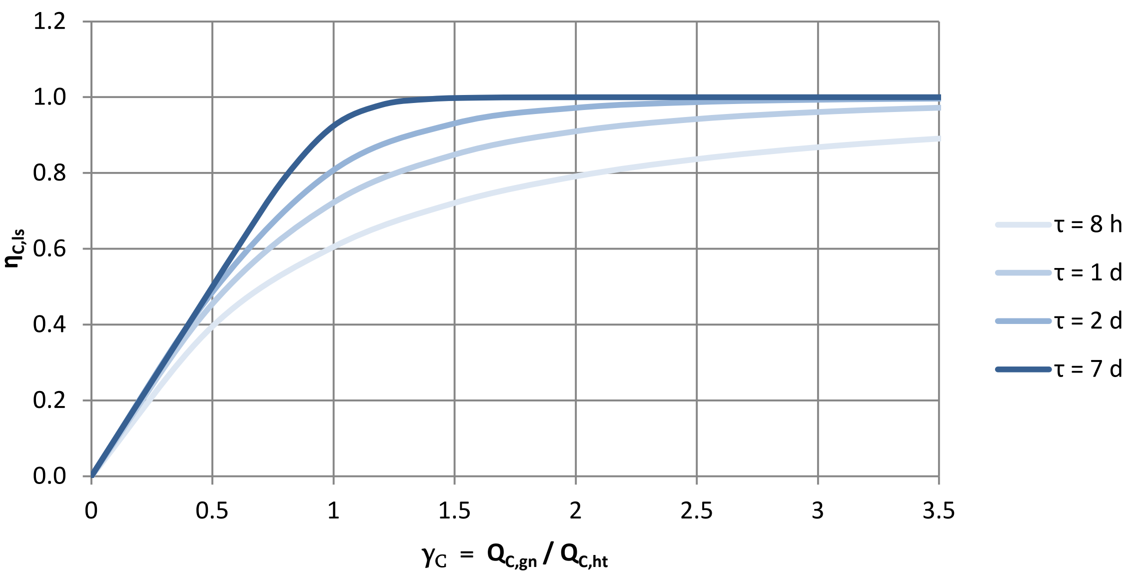


Figure 2: illustration of loss utilisation factor for cooling mode

2.1.3 Definition of the reference parameters a_0 and τ_0

Values proposed in the European standard EN ISO 13790:

	EN ISO 13790			
	Heating		Cooling	
	Residential	Others	Residential	Others
Reference time constant τ_0 (h)	15	15	15	15
Numerical parameter of reference a_0 (-)	1	1	1	1

Values used in Denmark:

	Denmark			
	Heating		Cooling	
	Residential	Others	Residential	Others
Reference time constant τ_0 (h)	15	70	83	83
Numerical parameter of reference a_0 (-)	1	0.8	1.83	1.83

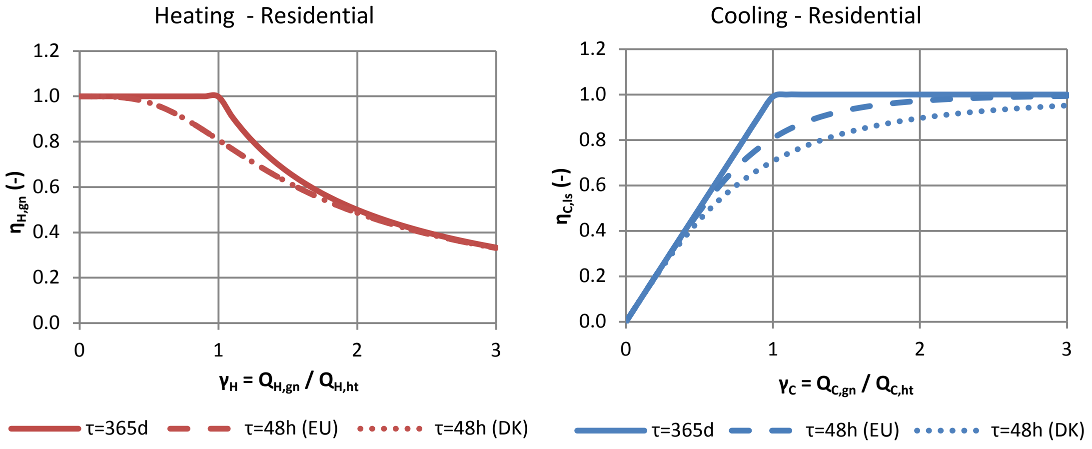


Figure 3: Curves of utilisation factors – Residential buildings

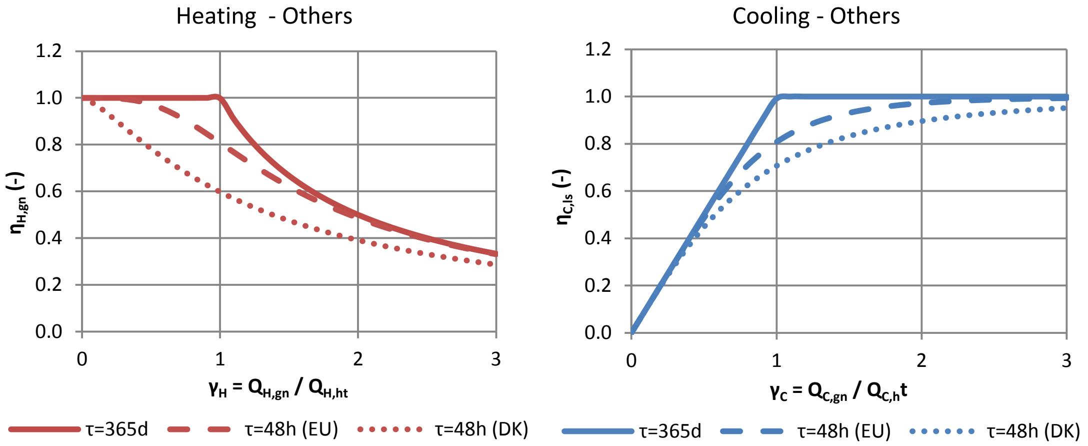


Figure 4: Curves of utilisation factors – Others buildings

2.2 BUILDING TIME CONSTANT

The time constant of the building zone τ characterizes the internal thermal inertia of the conditioned zone. It is a function of the thermal mass of the building zone, and also of the heat losses of the zone.

$$\tau = \frac{C_m \,/\, 3600}{H_{tr} + H_{vent}} \qquad (h)$$

With C_m internal heat capacity (J/K)
H_{tr} overall heat transfer coefficient by transmission (W/K)
H_{vent} overall heat transfer coefficient by ventilation (W/K)

2.3 THERMAL MASS

The internal heat capacity of the building zone C_m is calculated by summing up the heat capacities of all the building elements in direct thermal contact with the internal air of the zone under consideration:

$$C_m = \sum_j \kappa_j \, A_j \qquad (J/K)$$

With κ_j internal heat capacity per area of the building element j (J/m^2.K), determined in accordance with ISO 13786:2007 (detailed method)
A_j area of the element j (m^2)

Typical values for building heat capacity (2):

		C_m (Wh/K·m$^2_{external}$)
Extra Light	light walls, floors, ceilings of such skeleton with slabs or boards, with no heavy parts	40
Medium light	individual heavier elements such as concrete deck with a wooden floor or porous concrete	80
Medium heavy	more heavy elements such as concrete slab with tile and brick or tile and concrete	120
Extra heavy	heavy walls, floors and ceilings of concrete, brick and tile	160

An Excel spreadsheet has been developed to calculate the heat capacity κ_j of different construction types. One side of the construction is subjected to a sinusoidal variation of temperature during one day: this period corresponds to daily meteorological variations and temperature setback in buildings. The penetration depth and the activated thermal mass are then calculated. Surface resistances are not taken into consideration in this calculation method.
This calculation tool has been validated by comparing the results obtained from the spreadsheet with the results from the corresponding literature:

- example given in Annex D of the standard ISO 13786:2008 (3)
- five examples given in Di Perna et al. (4): “Influence of the thermal inertia of the building envelope on summertime comfort in buildings with high internal heat loads”.

2.4 HEAT LOSSES

The total monthly heat losses of the building Q_{ht} are equal to the sum of the heat transfer by transmission and by ventilation:

$$Q_{ht} = Q_{tr} + Q_{vent} = (H_{tr} + H_{vent})\left(\theta_{int,set\ point} - \theta_{ext}\right) t \qquad (MJ)$$

With Q_{tr} total heat transfer by transmission (MJ)
Q_{vent} total heat transfer by ventilation (MJ)
H_{tr} heat transfer coefficient by transmission (W/K)
H_{vent} heat transfer coefficient by ventilation (W/K)
$\theta_{int,set\ point}$ set-point temperature of the building zone (°C)
θ_{ext} external temperature (°C)
t period of time (Ms)

Basic expression for the overall transmission heat transfer coefficient H_{trans} :

$$H_{trans} = \sum_i A_i\, U_i$$

With A_i internal area of element i of the building envelope (m^2)
U_i thermal transmittance of element i of the building envelope ($W/m^2 \cdot K$), surface resistance included

According to DS 418 (5)

	Upward	Vertical	Downward
$R_{si}\ (m^2.K/W)$	0.10	0.13	0.17
$R_{se}\ (m^2.K/W)$	0.04		

Basic expression for the overall ventilation heat transfer coefficient H_{vent} :

$$H_{vent} = \rho_{air}\, C_{air}\, f_{vent,t}\, q_{vent}$$

With $\rho_{air}\, C_{air}$ heat capacity of air per volume (≈ 1200 $J/m^3 \cdot K$)
$f_{vent,t}$ time fraction of operation of the air flow, calculated as the fraction of the number of hours per week (-), and not per day[1]
q_{vent} airflow rate (m^3/s)

[1] Calculation method in Be10 (Danish Building regulation) based on hours per week, and not hours per day. If the daily time fraction is chosen instead of the weekly, the calculated energy consumption will then be the same if the building is used 5 or 7 days a week (which is not the case in reality).

2.5 HEAT GAINS

The total monthly heat gains of the building Q_{gn} are equal to the sum of the internal and solar heat gains:

$$Q_{gn} = Q_{int} + Q_{sol} \qquad (MJ)$$

With Q_{int} internal heat gains (MJ)
Q_{sol} solar heat gains (MJ)

It has to be noticed that the name "heat gains" might be misunderstood because this term regroups all heat transfers that are not dependent on the internal temperature. It can therefore correspond to a "heat loss" (thermal radiation to the sky is included in these "heat gains").

Basic expression for the heat gains from internal heat sources Q_{int} :

$$Q_{int} = \sum_i f_{int,t,i} \Phi_i \; t \qquad (MJ)$$

With Φ_i heat flow rate from the internal heat source i (W)
$f_{int,t,i}$ time fraction of operation of the internal heat load, calculated as the fraction of the number of hours per week (-) and not per day

Basic expression for the heat gains from solar sources Q_{sol} (without external obstacle):

$$Q_{sol} = F_{shading}\, F_w\, \alpha_{gl}\; g_{glazing}\, A_w\; I_{sol}\; t \qquad (MJ)$$

With $F_{shading}$ shading reduction factor for movable shading provisions (-)
F_w correction factor for non-scattering glazing (usually 0.9)
α_{gl} weighting factor, representative of the position of the window, climate and season (-)
$g_{glazing}$ solar energy transmittance for solar radiation (-)
A_w overall projected area of the glazed element (m^2)
I_{sol} solar irradiance, mean energy of the solar irradiation over the time step of the calculation, per square meter of collecting area of surface, with a given orientation and tilt angle (W/m^2)

3. Utilisation factors: development and validation of the calculation method

3.1 Building studied

3.1.1 Model structure in BSim

The model is an office building, consisting of 6 floors. Each floor has 4 rooms (offices).

The 4*6 thermal zones are oriented differently towards the north, east, south and west, and they are all connected to a “connecting room” in the middle of the building

Small rooms are also defined below and above each thermal zone. These small rooms below and above the thermal zone have the same temperature than the considered thermal zone. The external walls are the walls including windows, while the other walls are defined as internal walls.
Therefore the heat flux on all surfaces of the thermal zones equal to zero, except for the external walls.

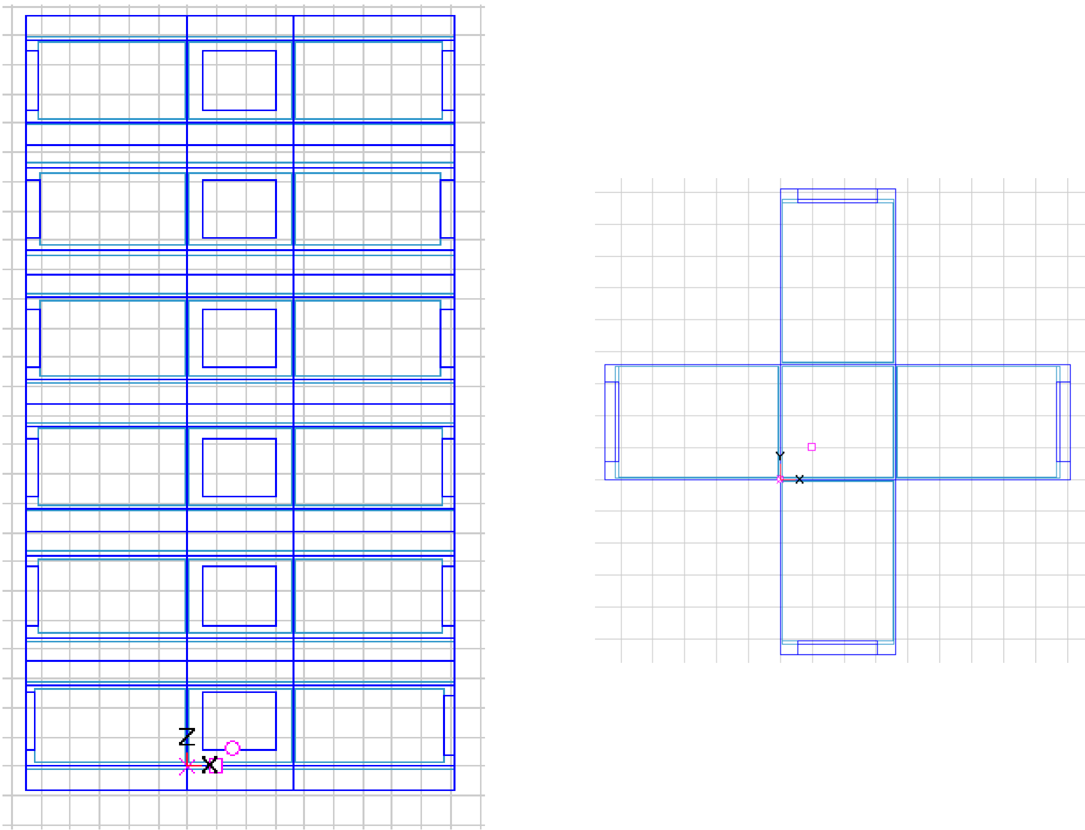


Figure 5: Front view of building (on the left) - Top view building (on the right)

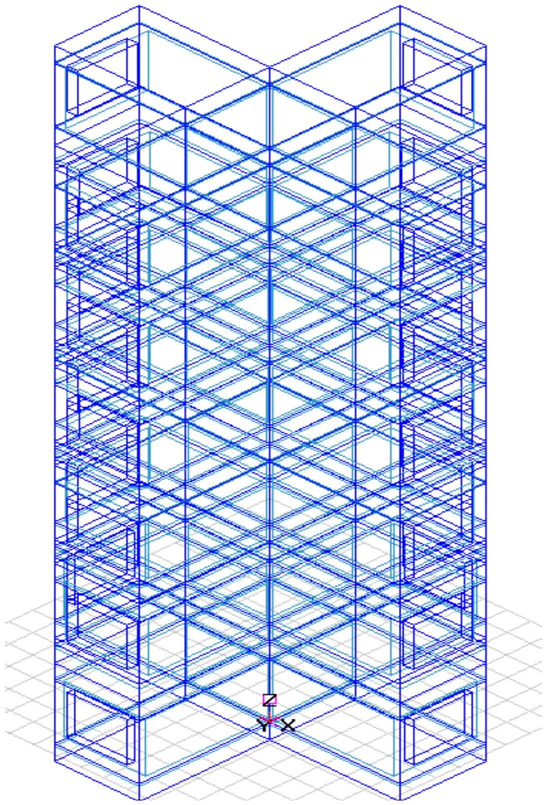


Figure 6: Three dimensional view of the entire building

3.1.2 Geometry of model (surface / volume)

All the rooms have the same external dimension (5,5 m x 3,6 m x 2,8 m height).

The four thermal zones of each floor have all the same internal dimensions (around 5 m x 3,5 m x 2,55 m height, exact dimensions depending on the type of construction). Each thermal zone has one window with the dimensions of (2 m x 2,5 m). The percentage of glazed area compared to the externals walls area is around 55 %.

3.1.3 Building orientation

The buildings model is built in a way to obtain the four different orientations at the same time, by facing the thermal zones towards the North, East, South and West respectively.

The solar distributions over the different surfaces of the room are defined in the following table:

Room element	Solar distribution (%)
To the floor	45,8
To the air	16,7
To the walls	25
To the ceiling	12,5

3.1.4 Building structure

The structural parts of the building are defined according to the minimum requirements of the Danish building regulations 2010 and also for the Low Energy Class 2 (according to the Danish building regulations proposed for 2015).

This is obtained by using the minimum requirements for the Danish building regulations BR10 for the first three lower floors and using higher requirements corresponding to the Low Energy Class 2 for 2015 in the other three upper floors, as illustrated in *Figure 7*.

Referring to the simulation results of energy consumption for the initial case in Denmark, the heating and cooling consumption for each thermal zone is summarized separately for each floor, as also presented in *Figure 7*.

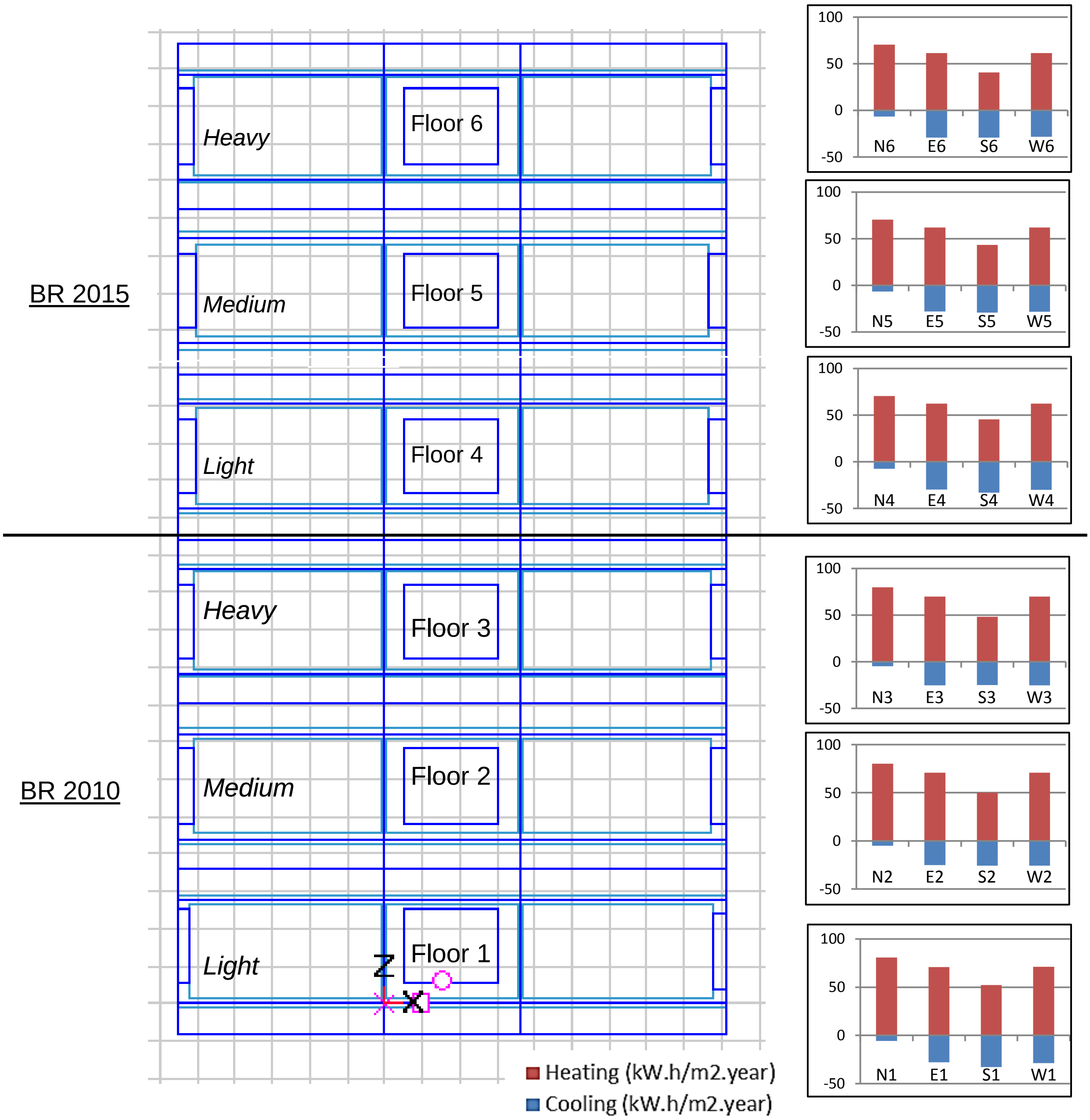


Figure 7: Overview of the modelled building with a summary of the heating and cooling consumption for all thermal zones in each floor

BR 2010 (lower floors)

The specifications of the different constructional parts for the first three lower floors and according to BR 2010 are included in the following tables.

External walls

Constructional part	Materials	U-value (W/m^{2}K)	ρ (kg/m³)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Internal plastering, 13 mm	0.18	900	0.25	1000
(3 rd floor)	Medium density concrete, 120 mm		2200	1.65	1000
	Isolation, 200 mm		25	0.038	1030
	Bricks, 102 mm		1700	0.77	800
2. Medium	Internal plastering, 13 mm	0.17	900	0.25	1000
(2 nd floor)	Inner bricks 108 mm		1700	0.56	800
	Insulation, 200 mm		25	0.038	1030
	Outer bricks 108 mm		1700	0.77	800
3. Light	Gypsumboards, 13 mm	0.19	900	0.25	1000
(1 st floor)	Insulation, 200 mm		25	0.04	1030
	Outer bricks, 108 mm		1700	0.77	800

Intermediate floors

Constructional part	Materials	U-value (W/m^{2}K)	ρ (kg/m³)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Concrete screed, 15 mm	2.36	1200	1.15	1000
(3 rd floor)	Concrete medium density, 150 mm		2200	1.65	1000
	Plasterboard 12,5 mm		900	0.25	1000
2. Medium	Concrete screed, 15 mm	0.18	1200	1.15	1000
(2 nd floor)	Concrete medium density, 75 mm		2200	1.7	1000
	Insulation, 200 mm		25	0.04	1030
	Plasterboard 12,5 mm		900	0.25	1000
3. Light	Tiles, 25 mm	0.31	400	0.07	1500
(1 st floor)	Concrete screed, 15 mm		1200	1.15	1000
	Insulation, 100 mm		25	0.04	1030
	Concrete, 100 mm		2400	2	1000

Internal walls

Constructional part	Materials	U-value (W/m^{2}K)	ρ (kg/m^3)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Gypsumboard, 13mm	6.08	900	0.25	1000
(3 rd floor)	Light weight concrete, 100 mm		2200	1.65	1000
	Gypsumboard, 13mm		900	0.25	1000
2. Medium	Gypsumboard, 13mm	6.08	900	0.25	1000
(2 nd floor)	Light weight concrete, 100 mm		2200	1.65	1000
	Gypsumboard, 13mm		900	0.25	1000
3. Light	Gypsumboard, 13mm	0.48	900	0.25	1000
(1 st floor)	Insulation, 75 mm		25	0.038	1030
	Gypsumboard, 13mm		900	0.25	1000

Windows

A U-value of 1,3 W/m^2.K is used in the simulations for the windows of the first three lower floors. The heat transmittance factor for the glazing is 0,59.

BR 2015 (upper floors)

The specifications of the different constructional parts for the last three upper floors and according to BR 2015 are included in the following tables.

External walls

Constructional part	Materials	U-value (W/m²K)	ρ (kg/m³)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Internal plastering, 13 mm	0.16	900	0.25	1000
(6 th floor)	Medium density concrete, 100 mm		2200	1.65	1000
	Isolation, 220 mm		25	0.038	1030
	Bricks, 102 mm		1700	0.77	800
2. Medium	Internal plastering, 13 mm	0.15	900	0.25	1000
(5 th floor)	Inner bricks 108 mm		1700	0.56	800
	Insulation, 250 mm		25	0.04	1030
	Outer bricks 108 mm		1700	0.77	800
3. Light	Gypsumboards, 13 mm	0.11	900	0.25	1000
(4 th floor)	Insulation, 350 mm		25	0.04	1030
	Outer bricks, 108 mm		1700	0.77	800

Intermediate floors

Constructional part	Materials	U-value (W/m²K)	ρ (kg/m³)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Concrete screed, 15 mm	2.50	1200	1.15	1000
(6 th floor)	Concrete medium density, 110 mm		2200	1.65	1000
	Plasterboard 12,5 mm		900	0.25	1000
2. Medium	Concrete screed, 15 mm	0.15	1200	1.15	1000
(5 th floor)	Concrete medium density, 70 mm		2200	1.7	1000
	Insulation, 250 mm		25	0.04	1030
	Plasterboard 12,5 mm		900	0.25	1000
3. Light	Tiles, 25 mm	0.23	400	0.07	1500
(4 th floor)	Concrete screed, 15 mm		1200	1.15	1000
	Insulation, 150 mm		25	0.04	1030
	Concrete, 85 mm		1800	2	1000

Internal walls

Constructional part	Materials	U-value (W/m²K)	ρ (kg/m³)	λ (W/m.K)	c (J/kg.K)
1. Heavy	Gypsumboard, 13mm	6.31	900	0.25	1000
(6 th floor)	Light weight concrete, 90 mm		2200	1.65	1000
	Gypsumboard, 13mm		900	0.25	1000
2. Medium	Gypsumboard, 13mm	7.12	900	0.25	1000
(5 th floor)	Light weight concrete, 60 mm		2200	1.65	1000
	Gypsumboard, 13mm		900	0.25	1000
3. Light	Gypsumboard, 13mm	0.48	900	0.25	1000
(4 th floor)	Insulation, 75 mm		25	0.038	1030
	Gypsumboard, 13mm		900	0.25	1000

Windows

A U-value of 0,9 W/m^2.K is used in the simulations for the windows of the last upper three floors. The heat transmittance factor for the glazing is 0,59.

3.1.5 Thermal mass of materials for the different constructional parts

Different thermal masses are used for the various constructional parts of the model in order to study the variations of heating and cooling requirements. The lighter materials are used for the lower floors, while they get heavier in the upper floors.

The thermal mass is calculated with reference to EN ISO 13786 (3).

The insulation materials of the different constructional parts are firstly chosen in reference to the regulations of 2010 and then according to the Low Energy Class 2, which corresponds to the proposed building regulations for 2015. This is summarized as shown in the following tables:

BR 2010 (lower floors)

Thermal mass (kJ/m².K)	Heavy +	Medium +	Light +
External wall	154	98	15
Internal wall	108	108	13
Floor	198	173	28
Ceiling	119	15	228
Window	8	8	8
Total thermal mass ($Wh/K{\cdot}m^2_{floor\ internal}$)	161	116	80

BR 2015 (upper floors)

Thermal mass (kJ/m².K)	Heavy	Medium	Light
External wall	150	98	15
Internal wall	101	75	13
Floor	165	166	28
Ceiling	91	15	153
Window	11	11	11
Total thermal mass ($Wh/K{\cdot}m^2_{floor\ internal}$)	140	96	59

3.1.6 Systems

In this part, the different systems used in the BSim simulations are defined as presented in the following tables:

System	Value	Time
Heating Max power Part to air	 ∞ 1	 Always
Cooling Max power Part to air	 ∞ 1	 Always
Equipment (People + Equipment + Lighting) Part to air	 Variable 1	 Variable
Ventilation Supply and return (m^3/s) Pressure rise, Input (Pa) Pressure rise, output (Pa) Total efficiency Part to air	 Variable 0 0 1 0	 Variable

3.1.7 Validation of the model developed in BSim

In order to validate the results of simulations and to ensure that the buildings elements, materials and systems are applied correctly in all simulations, the model of the building is firstly simulated by applying solar blinds to the windows in order to check the heating and cooling consumptions of all thermal zones.
From the results of simulations without any solar radiation, it was observed that the heating and cooling requirements were approximately the same for all the thermal zones of one floor. This means that the construction and systems definitions are correct.

The heating and cooling requirements for the first three floors and in all orientations (in case using blinds for the windows) are summarized in the following table:

		Min	Mean	Max	Δ Mean (%)
Floor 1	qCooling(N1)kW	-0.307	-0.001	0	-42.9
	qCooling(E1)kW	-0.317	-0.002	0	14.3
	qCooling(S1)kW	-0.318	-0.002	0	14.3
	qCooling(W1)kW	-0.313	-0.002	0	14.3
	qHeating(N1)kW	0	0.041	0.423	0.6
	qHeating(E1)kW	0	0.041	0.423	0.6
	qHeating(S1)kW	0	0.04	0.421	-1.8
	qHeating(W1)kW	0	0.041	0.423	0.6
Floor 2	qCooling(N2)kW	-0.277	-0.001	0	0.0
	qCooling(E2)kW	-0.284	-0.001	0	0.0
	qCooling(S2)kW	-0.284	-0.001	0	0.0
	qCooling(W2)kW	-0.286	-0.001	0	0.0
	qHeating(N2)kW	0	0.04	0.428	0.6
	qHeating(E2)kW	0	0.04	0.427	0.6
	qHeating(S2)kW	0	0.039	0.424	-1.9
	qHeating(W2)kW	0	0.04	0.427	0.6
Floor 3	qCooling(N3)kW	-0.256	-0.001	0	0.0
	qCooling(E3)kW	-0.269	-0.001	0	0.0
	qCooling(S3)kW	-0.269	-0.001	0	0.0
	qCooling(W3)kW	-0.271	-0.001	0	0.0
	qHeating(N3)kW	0	0.041	0.437	0.6
	qHeating(E3)kW	0	0.041	0.436	0.6
	qHeating(S3)kW	0	0.04	0.433	-1.8
	qHeating(W3)kW	0	0.041	0.436	0.6

While for the last three upper floors, the cooling and heating requirements (when using blinds) are summarized in the following table:

		Min	Mean	Max	Δ Mean (%)
Floor 4	qCooling(N4)kW	-0.314	-0.001	0	0.0
	qCooling(E4)kW	-0.319	-0.001	0	0.0
	qCooling(S4)kW	-0.317	-0.001	0	0.0
	qCooling(W4)kW	-0.315	-0.001	0	0.0
	qHeating(N4)kW	0	0.136	0.587	0.2
	qHeating(E4)kW	0	0.136	0.587	0.2
	qHeating(S4)kW	0	0.135	0.587	-0.6
	qHeating(W4)kW	0	0.136	0.587	0.2
Floor 5	qCooling(N5)kW	-0.312	-0.001	0	0.0
	qCooling(E5)kW	-0.317	-0.001	0	0.0
	qCooling(S5)kW	-0.315	-0.001	0	0.0
	qCooling(W5)kW	-0.316	-0.001	0	0.0
	qHeating(N5)kW	0	0.136	0.59	0.2
	qHeating(E5)kW	0	0.136	0.589	0.2
	qHeating(S5)kW	0	0.135	0.589	-0.6
	qHeating(W5)kW	0	0.136	0.589	0.2
Floor 6	qCooling(N6)kW	-0.241	0	0	0.0
	qCooling(E6)kW	-0.261	0	0	0.0
	qCooling(S6)kW	-0.256	0	0	0.0
	qCooling(W6)kW	-0.258	0	0	0.0
	qHeating(N6)kW	0	0.137	0.594	0.7
	qHeating(E6)kW	0	0.136	0.594	0.0
	qHeating(S6)kW	0	0.135	0.593	-0.7
	qHeating(W6)kW	0	0.136	0.594	0.0

3.2 CALCULATION METHOD

3.2.1 Introduction

The calculation method used in Be10 is a semi-static calculation, which evaluates the heating and cooling needs on a monthly based and using utilisation factors to simulate the effect of thermal mass. Therefore there are many differences between a dynamic and the semi-static calculation and differences can be expected between the two methods.

The calculation procedures are not the same:

- the conduction is calculated dynamically in the energy simulation program
- the convective and radiative heat transfer coefficient are constant in semi-static calculation
- the solar radiation is usually higher in the monthly calculation

There are also differences occurring when intermittency is applied to some systems:

- ventilation, which occurs during daytime, is using warmer air than ventilation occurring all day long (in average value).

<u>About the relative error of the method:</u>
In the standard EN 13790 (1), the test case developed in EN 15265 is analysed for different climates: Paris (France) and two more extreme European climates Stockholm (Sweden) and Rome (Italy). The error due to the method is then reported on an annual basis:

Deviation (root mean square for 8 cases)	Paris	Rome	Stockholm
Heating	10 %	3 %	8 %
Cooling	6 %	8 %	7 %

Figure 8: Error of the monthly calculation for different climate on annual basis

The differences are given as the difference in calculated monthly energy needs for respectively heating and cooling, expressed as a percentage of the annual energy needs for heating plus cooling. It is clear that this may give too optimistic a view in some cases, but otherwise we would need to show all the detailed results in its detailed context. For instance: a relative difference of, say, 30 % in energy need for cooling has no real meaning if the absolute level of cooling is negligible compared to the energy need for heating.

It can be observed that the accuracy of the method is depending on the type of climate. The accuracy of this method is around 8%.

3.2.2 Presentation of the method

The calculation method used in this report is based on an article from Corrado and Fabrizio (6). This method is based on 5 different simulations, described below:

		Simulations name	Equations
Single set-point $Q_{gn} = 0$	**Heating set-point: 20°C**	(sim. 1/20)	$Q_{H,ht} = Q_{H,nd}^{(sim.1/20)} - Q_{C,nd}^{(sim.1/20)}$
	Cooling set-point: 26°C	(sim. 1/26)	$Q_{C,ht} = Q_{H,nd}^{(sim.1/26)} - Q_{C,nd}^{(sim.1/26)}$
Single set-point	**Heating set-point: 20°C**	(sim. 2/20)	$Q_{H,gn} = Q_{H,ht} - \left(Q_{H,nd}^{(sim.2/20)} - Q_{C,nd}^{(sim.2/20)}\right)$
	Cooling set-point: 26°C	(sim. 2/26)	$Q_{C,gn} = Q_{C,ht} - \left(Q_{H,nd}^{(sim.2/26)} - Q_{C,nd}^{(sim.2/26)}\right)$
Dual set-point	**20-26°C**	(sim. 3)	$Q_{H,nd} = Q_{H,nd}^{(sim.3)}$ $Q_{C,nd} = Q_{C,nd}^{(sim.3)}$

Therefore: $\eta_{H,gn} = \frac{Q_{H,ht} - Q_{H,nd}}{Q_{H,gn}}$ and $\eta_{C,ls} = \frac{Q_{C,ht} - Q_{C,nd}}{Q_{C,gn}}$

<u>Explanations about the calculation method:</u>

- Simulation 1/20 (no heat gains):

$$Q_{H,nd}^{20°C} = Q_{H,nd}^{(sim.1/20)} - \underbrace{Q_{C,nd}^{(sim.1/20)}} = Q_{H,ht}^{20°C} - \cancel{\eta_{H,gn}^{20°C}\, Q_{H,gn}^{20°C}} = Q_{H,ht}^{20°C} = Q_{H,ht}$$

in order to remove the heating part due
to the forced cooling at 20°C
(in reality, this part leads to overheating)

- Simulation 1/26 (no heat gains): similar analysis

- Simulation 2/20:

$$Q_{H,nd}^{20°C} = Q_{H,nd}^{(sim.2/20)} - Q_{C,nd}^{(sim.2/20)} = Q_{H,ht}^{20°C} - \underbrace{\eta_{H,gn}^{20°C}}_{\substack{=1 \\ \textit{because there is no overheating,} \\ \textit{so no non-utilized heat gains}}} Q_{H,gn}^{20°C} = Q_{H,ht}^{20°C} - Q_{H,gn}^{20°C}$$

$$Q_{H,gn}^{20°C} = Q_{H,gn} = \underbrace{Q_{H,ht}^{20°C}}_{= Q_{H,ht}} - \left(Q_{H,nd}^{(sim.2/20)} - Q_{C,nd}^{(sim.2/20)}\right)$$

- Simulation 2/26: similar analysis

3.2.3 Analysis of the results from BSim

In order to get the reference time constant τ_0 and the parameter of reference a_0, the following calculations are performed:

1) Step 1: Perform the simulations
For each simulation case (i.e. same internal heat loads, ventilation strategies…), 5 simulations are performed according to the calculation method presented before. The heating and cooling consumption of each room is obtained.
Different validation steps are performed while analysing the results, in order to check the quality of simulations. For each room and each simulation, the following parameters are checked:
    - the length of the simulated period
    - the aspect of each room
    - the operative temperature, in order to ensure the proper set-point (tolerance of ± 0.01 K)
    - the intensity and time schedule of internal heat loads (that have to be equal to zero in some simulations)
    - the time schedule of ventilation
    - the intensity solar radiation (that has to be equal to zero in some simulations)

2) Step 2: Calculation of the parameters for each rooms
For each room (4 x number of floors), the parameters $\eta_{H,gn}$, γ_H , $\eta_{C,ls}$ and γ_C are calculated on a monthly base.

3) Step 3: Find the right set of data to evaluate a_H and a_C
As each floor of the studied building has the same time constant τ (i.e. same thermal mass C_m and same heat transfer coefficient $H_{tr} + H_{vent}$ [2]), the results of each floor can be grouped.
Nevertheless it is not accurate enough to realize a curve fitting on this set of 48 values (12 months * 4 rooms), the range is not always wide enough. The curve fitting is extremely sensitive to the input data, one should make sure that they are in the correct range and of good quality.

[2] The calculation method of $H_{tr} + H_{vent}$ (and therefore τ) has been validated using the program Be10, which is used in Denmark to validate the energy consumption of buildings.

Therefore the results of 2 different simulations, with different internal heat loads, are also grouped. The necessity of this additional simulation is proven in Annex 2. A curve fitting is realized on these 96 data points (12 months * 4 rooms * 2 internal loads) in order to obtain the parameter a_H. The values $\eta_{H,gn} = f(\gamma_H)$ and $\eta_{C,ls} = f(\gamma_C)$ are plotted for each set of data and the parameters are evaluated using the following equations:

$$\eta_{H,gn} = \frac{1-\gamma_H{}^{a_H}}{1-\gamma_H{}^{a_H+1}} \qquad \text{for heating}$$

$$\eta_{C,ls} = \frac{1-\gamma_C{}^{-a_C}}{1-\gamma_C{}^{-(a_C+1)}} \qquad \text{for cooling}$$

The curve fitting gives more weight to the lowest values in the transition part (weight of 3, instead of 1 for other values) in order to avoid an overestimation of the utilisation of thermal mass and provide safer results (cf. Annex 2).

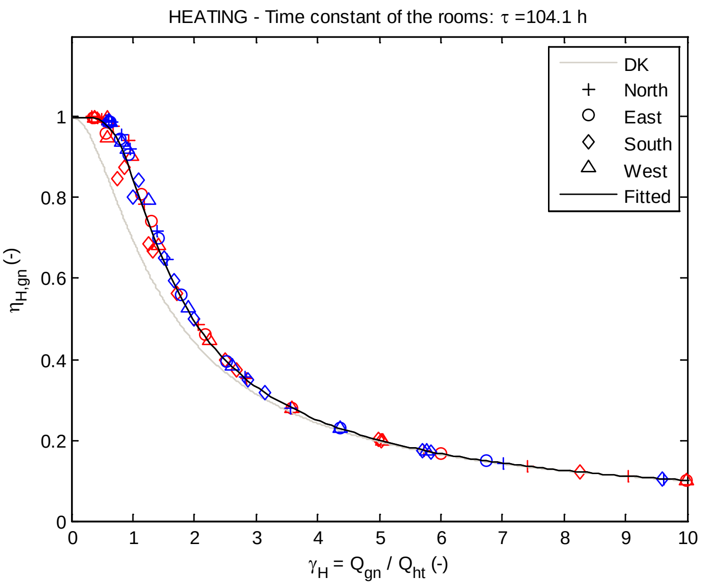


Figure 9: Curves of the utilisation factor for the 4 rooms located at the first floor (τ = 104 h) and two levels of internal heat loads (red markers 10 W/m² - blue markers 20 W/m²) - Heating case

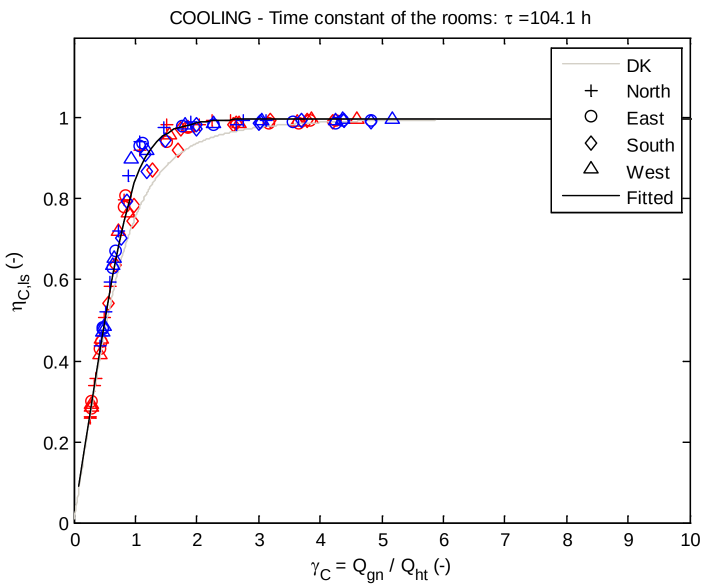


Figure 10: Curves of the utilisation factor for the 4 rooms located at the first floor (τ = 104 h) and two levels of internal heat loads (red markers 10 W/m² - blue markers 20 W/m²) - Cooling case

4) Step 4: obtain the values of a_0 and τ_0
For each floor and each couple of simulations, two sets of parameters (a_H ; τ_H) and (a_C ; τ_C) are obtained. Therefore the values $a_H = f(\tau_H)$ and $a_C = f(\tau_C)$ can be derived and the parameters τ_0 and a_0 can be found by identification:

$$a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}} \qquad \text{for heating}$$

$$a_C = a_{C,0} + \frac{\tau}{\tau_{C,0}} \qquad \text{for cooling}$$

The values obtained are then compared with the values proposed in standards.

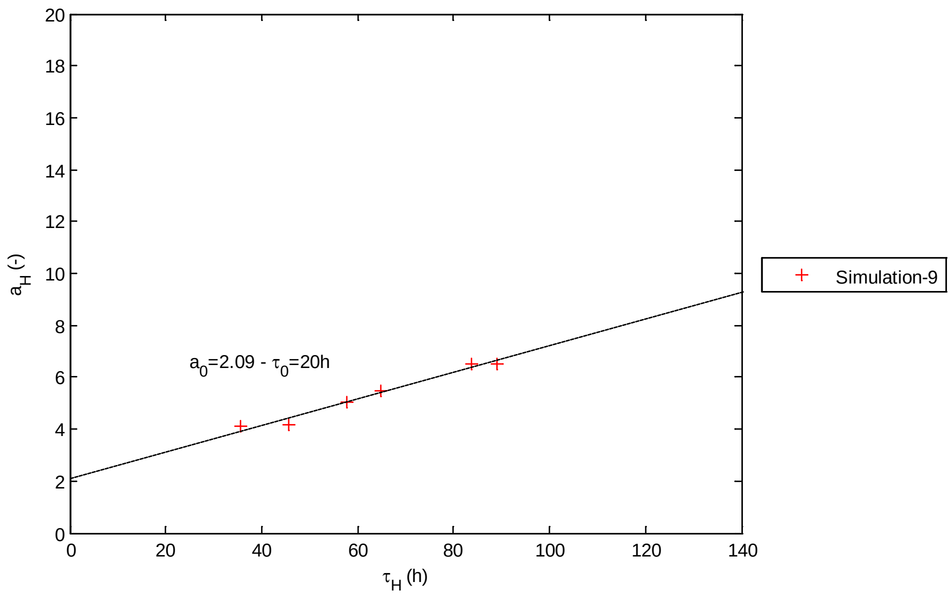


Figure 11: Results from all simulations - Heating case

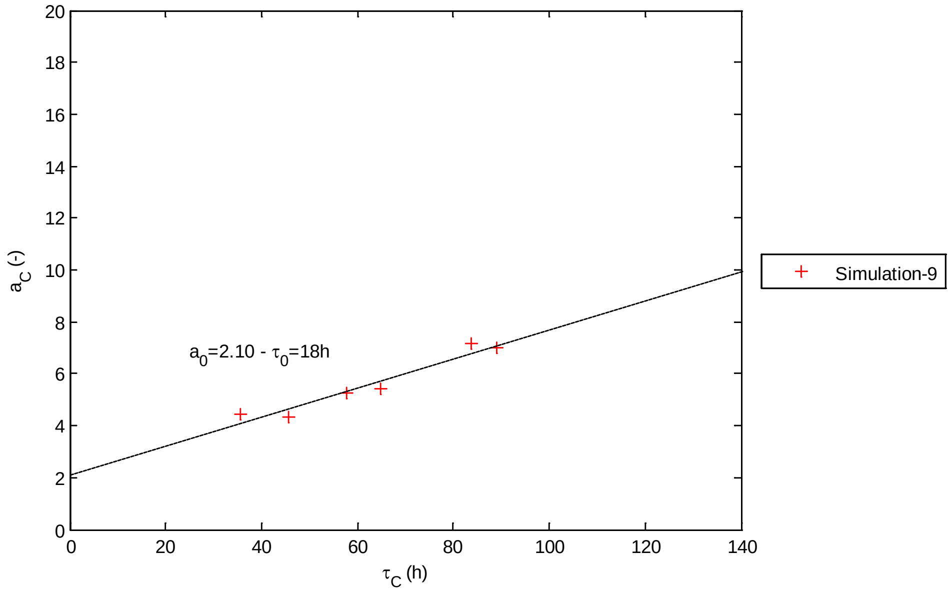


Figure 12: Results from all simulations - Cooling case

3.2.4 Verification of the calculation method

Corresponding standards:
DS-EN ISO 13790 - Calculation of energy use for space heating and cooling
DS-EN ISO 15265 - Energy performance of buildings - Calculation of energy needs for space heating and cooling

Weather data: Trappes (France)

Characteristics of the simulation:

Heat transfer coefficients (radiative and convective)	Constant
Heating and Cooling	Always
Systems:	
Internal heat loads	≈ 9,1 W/m² ext (180 W) - Always
Ventilation	≈1.3 ACH (20 L/s) - Always

Results: Curves obtained to determine the national parameters τ_0 and a_0

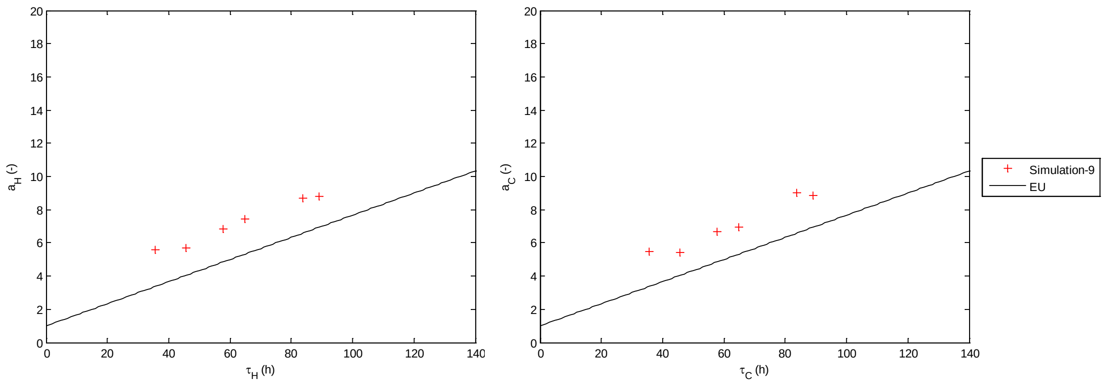


Figure 13: Results with a normal fitting (on the left, heating case – on the right, cooling case)

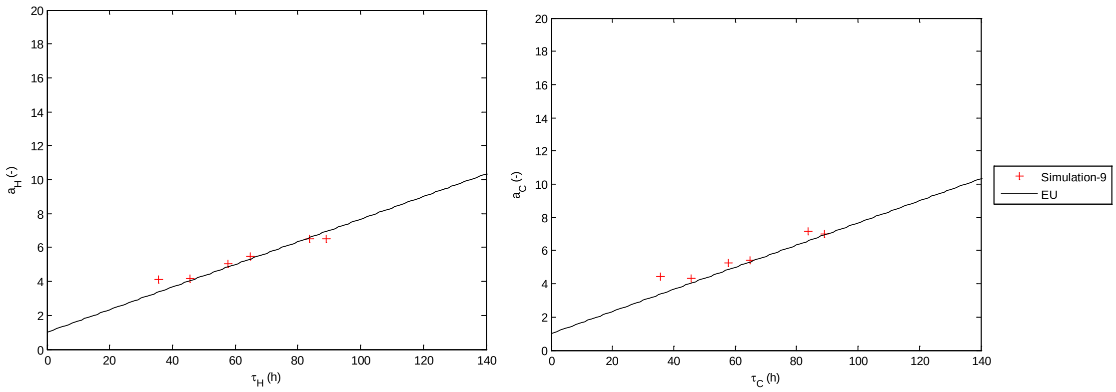


Figure 14: Results with an improved fitting (on the left, heating case – on the right, cooling case)

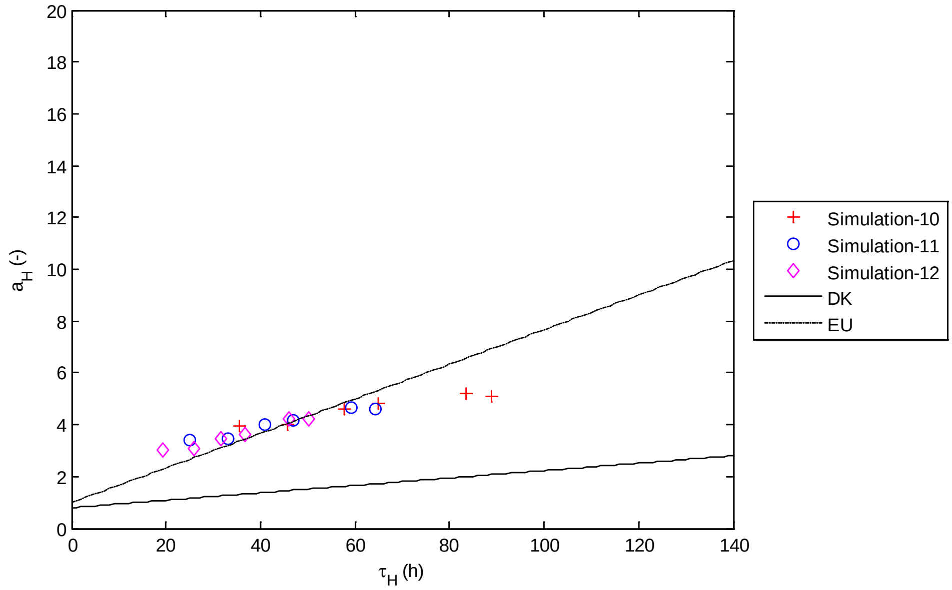
From these results, it can be seen that the calculation method and model developed in this report show good agreement with the standardized data.

3.3 Robustness of the calculation method

3.3.1 Influence of the ventilation

<u>Influence of the level of ventilation losses:</u>

	Description	Schedule	Level
010	Initial case in Denmark: ▪ g=0.59 ▪ ≈ 9,1 W/m²$_{ext}$ (180 W) always	Always	low ≈1.3ACH (20 L/s)
011	Alternative ventilation	Always	medium ≈2ACH (30 L/s)
012	Alternative ventilation	Always	high ≈2.6ACH (40 L/s)



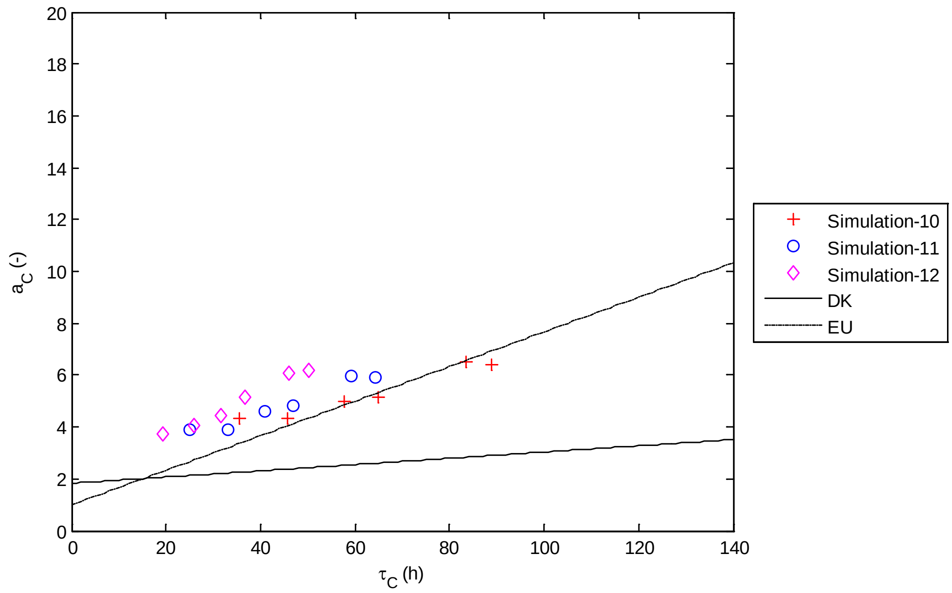
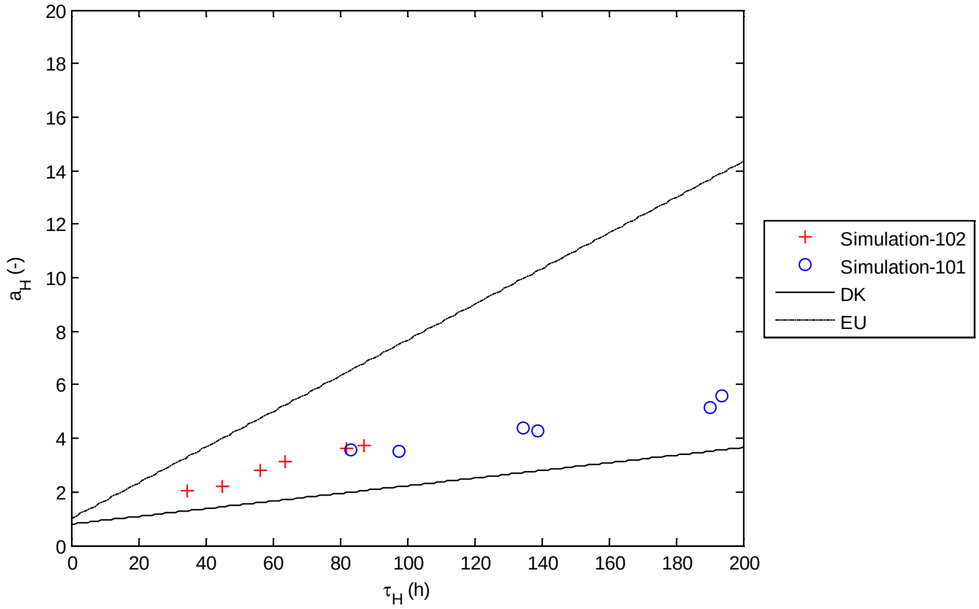


Figure 15: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different ventilation rates)

Influence of the ventilation schedules:

	Description	Schedule	Level
102	Case in Denmark: ▪ g=0.59 ▪ ≈ 9,1 W/m²$_{ext}$ office hours	Always (24h)	Low ≈1,5 ACH (23 L/s)
101	Alternative ventilation	Office hours (8h-17h)	Low ≈1,5 ACH (23 L/s)



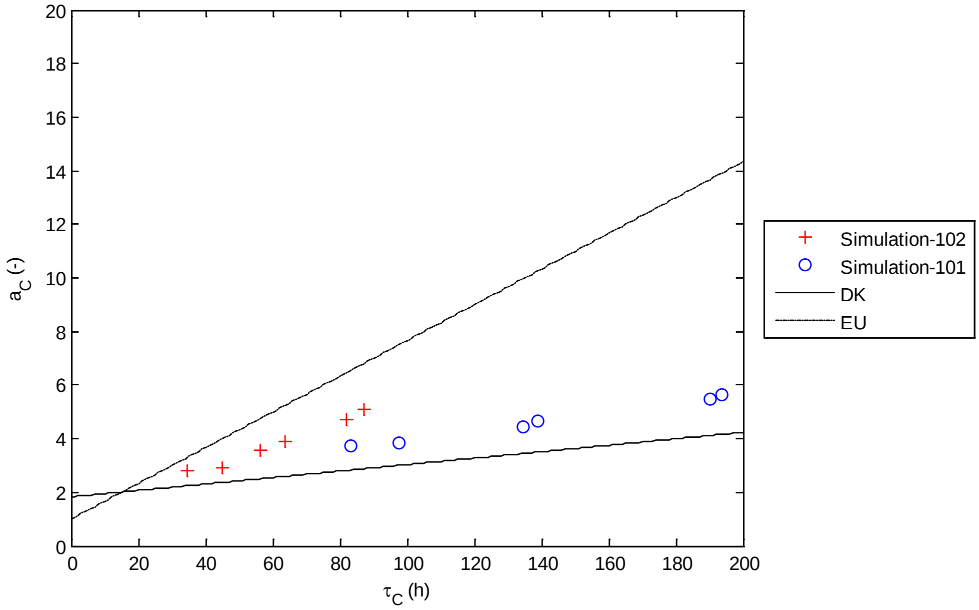


Figure 16: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different ventilation schedules)

About a ventilation system with heat recovery:

It has not been possible to get an accurate comparison between the standards values and the simulations. The definition of the efficiency of the heat recovery is not the same in the standards and in BSim:

$$\eta_{standards} = \frac{\theta_{inlet} - \theta_{ext}}{\theta_{set\,point} - \theta_{ext}} \qquad \& \qquad \eta_{BSim} = \frac{\theta_{inlet} - \theta_{ext}}{\theta_{outlet} - \theta_{exhaust}}$$

A conversion between these two parameters has been attempted, but without success (the conversion factor was not a constant value).

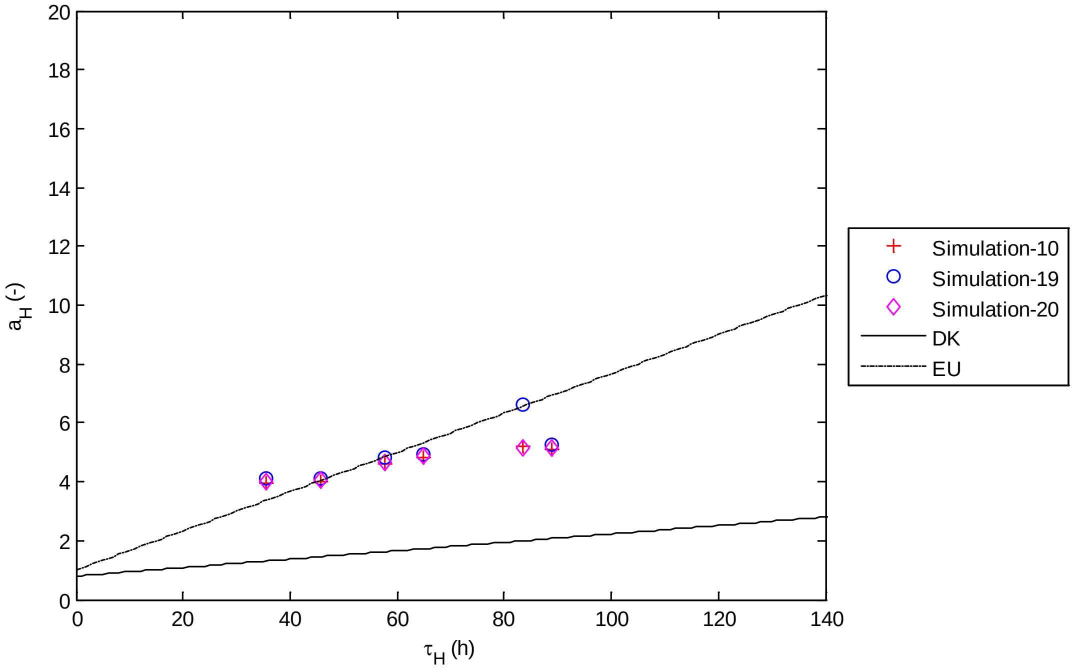
⇒ The air change rate has a low influence on the reference parameters, but the schedule plays a more important role. It can be noticed that the ventilation schedule has a larger effect on the cooling consumption than on the heating consumption.

The reason, why the reference parameters are highly influenced by the schedule, is that the calculation method is using an average outdoor temperature over the month, without taking into consideration day/night variations.

3.3.2 Influence of the internal heat loads

<u>Influence of the "part to air":</u>

	Schedule	Level	Part to air
010	24h	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1
019	24h	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	0.5
020	24h	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	0



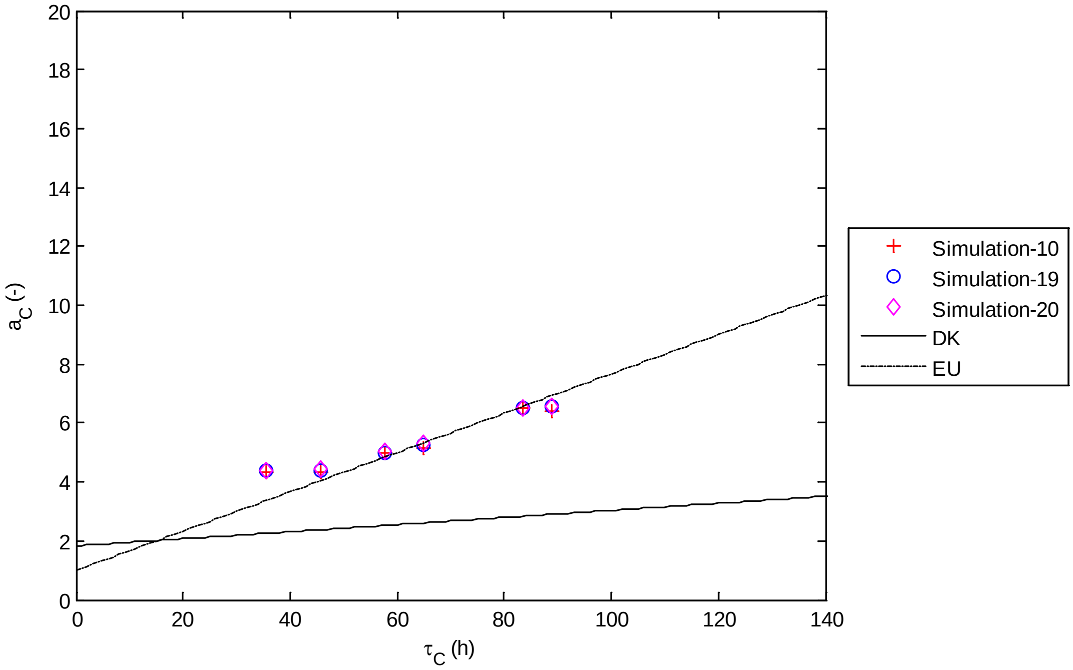


Figure 17: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different part to air for the internal heat loads)

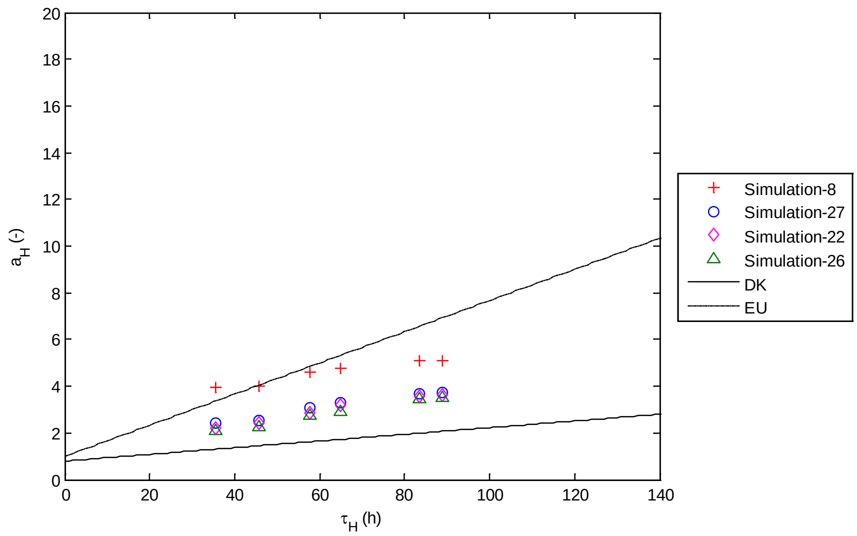
Influence of the time schedule:

When a system is not running continuously, an adjustment factor is defined in the monthly calculation order to decrease the heat losses or heat gains. This factor averages the value over the entire week:

$$f_{adjust,t} = \frac{nb.\ of\ active\ hours\ per\ day \cdot nb.\ of\ active\ days\ per\ week}{24 \cdot 7}$$

In the following cases, a non-continuous ventilation system and non-continuous internal heat loads have been set, so that it corresponds to normal office hours (from 8am to 5pm, everyday). The weather data corresponds to Trappes (France).

	Schedule	Level	Part to air
008	24h	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1
027	12h (7h-19h)	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1
022	9h office hours (8h-17h)	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1
026	6h (9h-15h)	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1



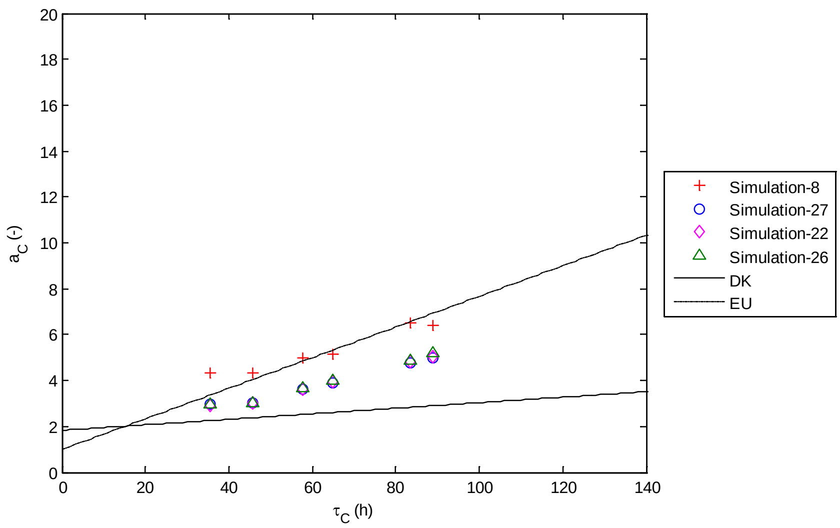


Figure 18: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different internal heat loads schedules)

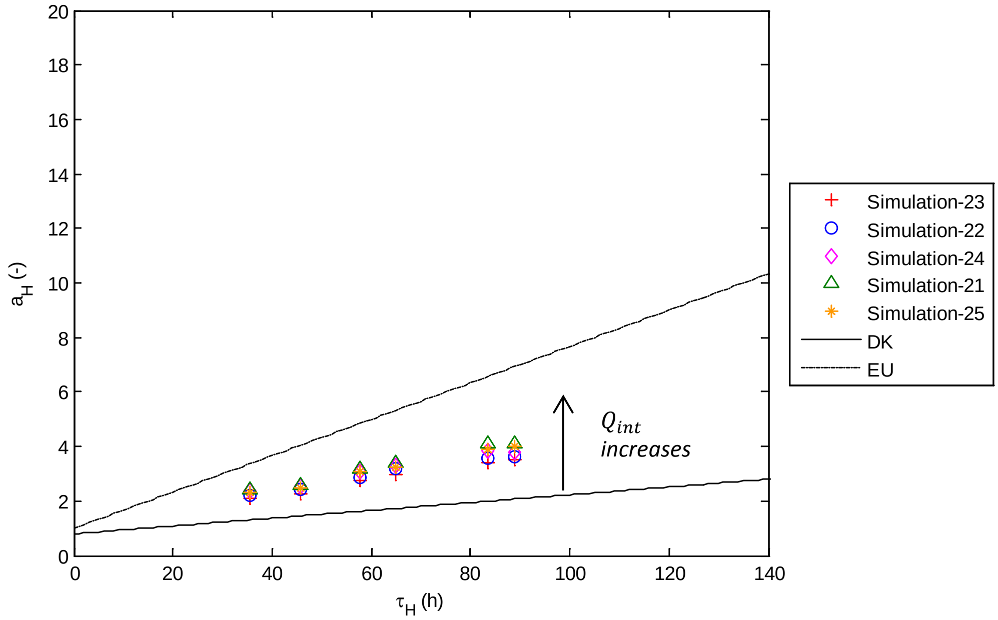
When defining office hours for internal heat loads, differences in the reference parameters appear compared to a constant profile of internal heat load. In fact, averaging the internal heat loads over one day (method used in the standards) does not give the same results than having a non-continuous heat loads:

- During the winter season, there is no internal hat loads during night-time, so when they would have been the most useful. Therefore daytime internal heat loads decrease the utilisation factors and increase the heating consumption.

- During the summer season, internal heat loads occur at the same time than the solar radiation. They are increasing the cooling consumption and can lead to overheating, which will then decrease the utilisation factor.

Influence of the levels of internal heat loads:

	Schedule	Level	Part to air
023	Office hours (8h-17h)	Low ≈ 4,6 W/m^2 $_{ext}$ (90 W)	1
022	Office hours (8h-17h)	Medium ≈ 9,1 W/m² $_{ext}$ (180 W)	1
024	Office hours (8h-17h)	Medium ≈ 18,2 W/m² $_{ext}$ (360 W)	1
021	Office hours (8h-17h)	High ≈ 27,3 W/m^2 $_{ext}$ (540 W)	1
025	Office hours (8h-17h)	High+ ≈ 46 W/m^2 $_{ext}$ (900 W)	1



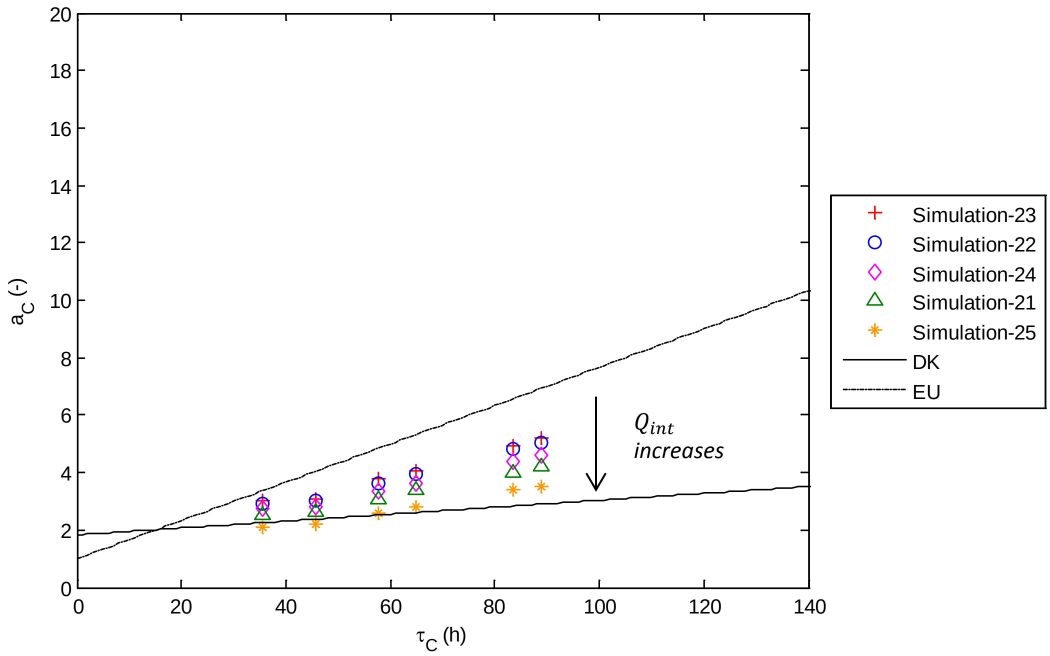


Figure 19: Comparison between the reference parameters proposed in standards and the values obtained from simulations (internal heat loads from 8am till 5pm)

It seems that the reference parameters for cooling depend on the level of internal heat loads. Nevertheless the fitting is not really accurate in the cooling case. In fact γ_C does not cover all the range of relative heat gains: there is not always enough gain to cover the heat losses. This explains why the uncertainty range on a_C is wider than in the heating case.

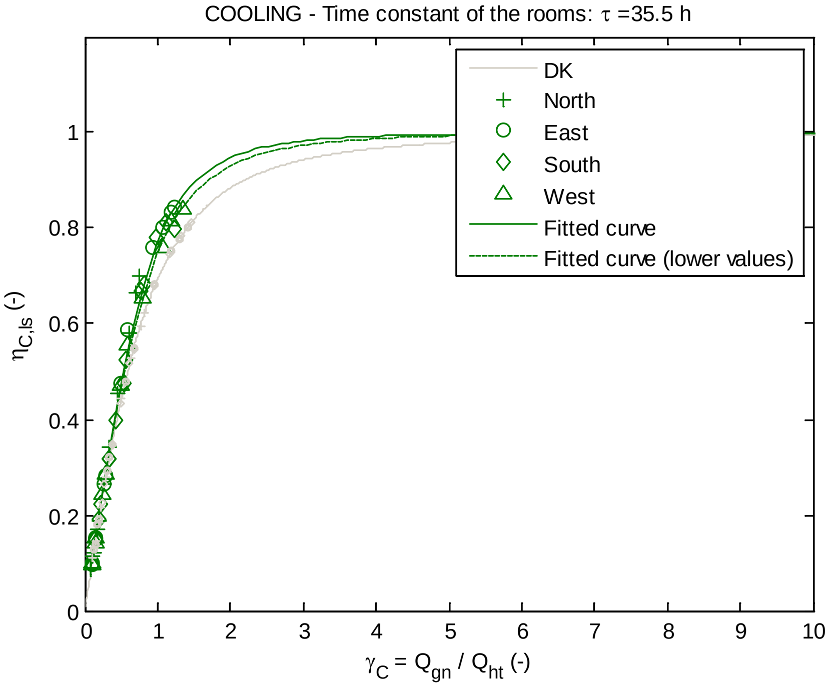


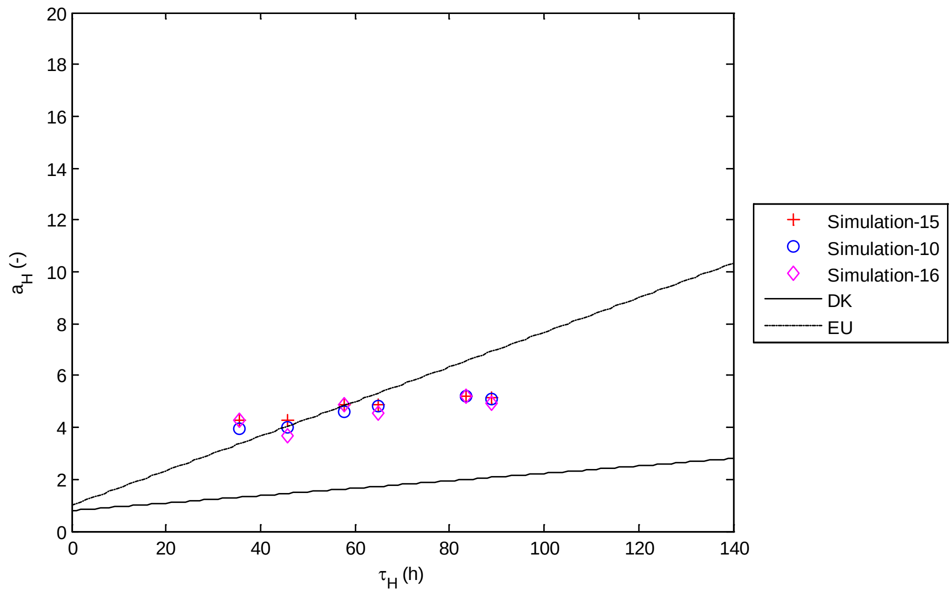
Figure 20: Curves of the utilisation factor for the 4 rooms located at the 4th floor (τ = 35.5h) - Cooling case
Internal heat loads of ≈9,1 W/m²$_{ext}$ during working hours

⇒ The reference parameters defined in the standards have to be defined carefully when internal heat loads occurs only during daytime, so that there is no overestimation of the utilisation of thermal mass. Nevertheless no precise definition of daytime needs to be given as the method is not dependent on the exact schedule.
No dependency on the level of internal heat load and the part to air has been observed.

3.3.3 Influence of the solar heat gains

Influence of the g-values:

	Description	g-value	Windows area (% of the external wall)
015	Alternative solar heat gains	low (g=0.5)	55 %
010	Define the initial case in Denmark: ▪ ≈ 9,1 W/m²$_{ext}$ (180 W) ▪ ≈1.3ACH (20 L/s)	Medium (g=0.59)	55 %
016	Alternative solar heat gains	high (g=0.7)	55 %



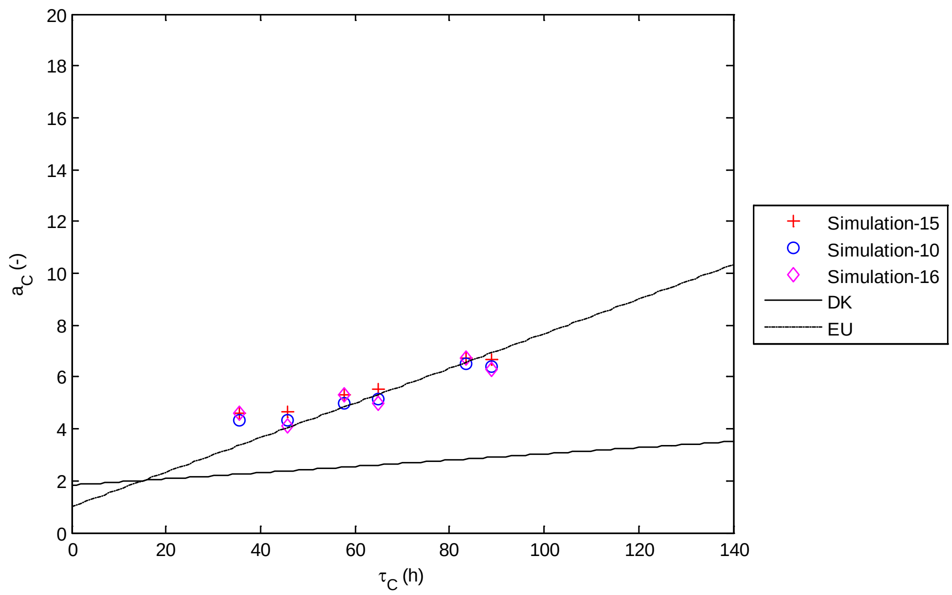
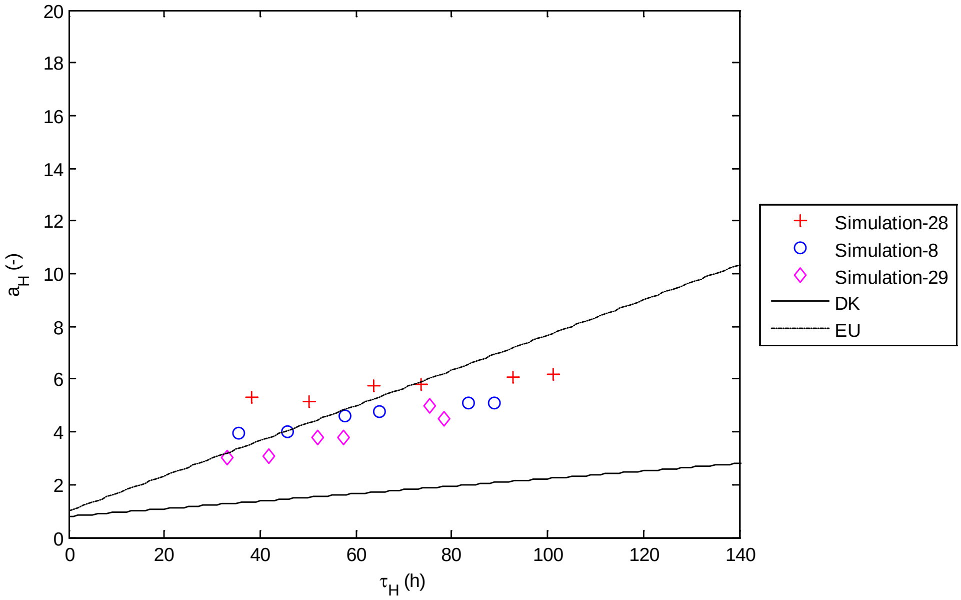


Figure 21: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (g-values of windows)

Influence of the windows area:

By modifying the window area, we increase the influence of the outdoor conditions on the indoor climate.

	g-value	Windows area (% of the external wall)	ξ Ratio of the windows area to the floor area (external)
28	0.59	28 %	0,13
8	0.59	55 %	0,25
29	0.59	84 %	0,38



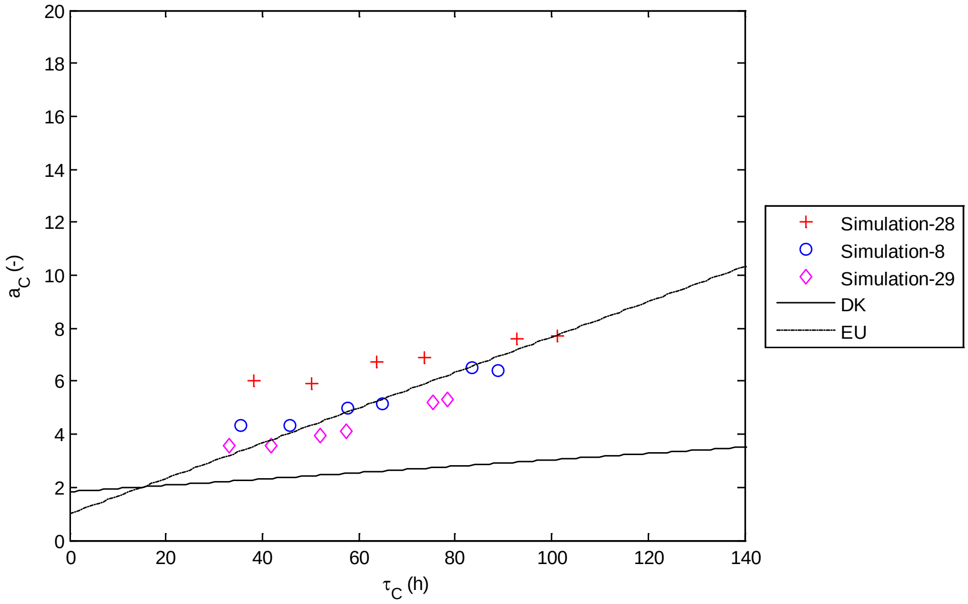


Figure 22: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different windows area)

⇒ The reference parameters defined in the standards is influenced by the window area, but not by the g-value of the glazing.

3.3.4 Dynamic calculation of the convective and radiative heat transfer

010	Constant heat transfer coefficient
018	Dynamic calculation of radiation and convection

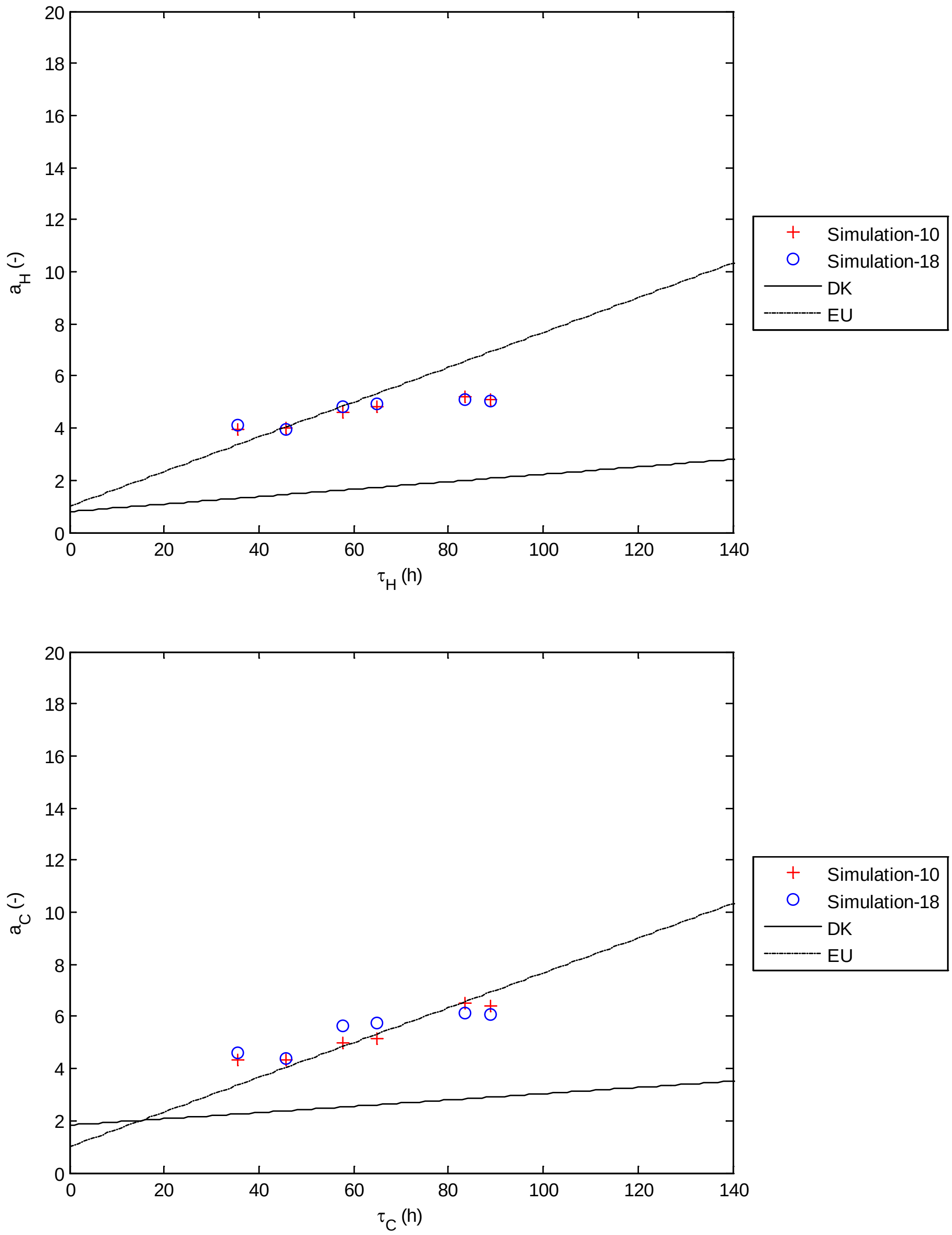


Figure 23: Comparison between the reference parameters proposed in the standards and the values obtained from simulations (different calculations of the radiative and convective transfer)

⇒ The reference parameters defined in the standards is slightly influenced by definition of radiation and convection.

3.4 CONCLUSION ABOUT THE MONTHLY CALCULATION METHOD

In this part, the influence of different parameters on the reference values (a_0 and τ_0) has been studied by mean of computer simulations using the software BSim. The following conclusions can be drawn out of the results:

- The transmission losses have almost no influence on these reference parameters. In fact no difference between the rooms corresponding to BR10 and the ones corresponding to BR15 can be observed.
- The ventilation losses, and especially the ventilation schedule, have an influence on the reference parameters.
- The schedule of internal heat gains has a high influence on the results; this parameter will therefore have to be defined accurately.
- Changing the g-value of the glazing will not influence the results, but changing the window size will have an effect because the room will be more or less influenced by the outdoor climate.

The parameters, which seem to be the most important, are the schedules of ventilation and internal heat loads. It has to be chosen carefully, so that it fits well with the real occupancy of the building. It might otherwise lead to an overestimation of the utilisation factor. This is particularly true for internal heat loads: if the calculation method assumes internal heat loads all day long whereas there is nothing during night-time in the real building, it will give lower heating consumption than what could be expected. In fact, internal heat loads are the most useful during night-time, when the heat losses are high and there is no solar heat gain.
This dependency on the schedule explains why different reference parameters have been set for office buildings and for residential buildings.

When comparing the reference parameters for Denmark to the ones proposed in the standard, it can be observed that the European values will lead to an underestimation of the heating and cooling consumption for office buildings. This is due to different schedules that have been used to set these parameters.

⇒ The calculation method proposed in the European Standard has proven its robustness and it ability to predict the right energy consumption. Nevertheless there might be a need to custom these values for Danish conditions, and introduce more parameters (e.g. ventilation, internal heat loads, window area) in the formula used to calculate the reference values. That what will be discussed in the next part, which is focused on the case of an office building in Denmark…

3.5 PROPOSAL FOR NEW REFERENCE PARAMETERS IN DENMARK

Reminder: values used in Denmark for non-residential buildings

	Denmark - Others	
	Heating	Cooling
Reference time constant τ_0 (h)	70	83
Numerical parameter of reference a_0 (-)	0.8	1.83

The values used nowadays in Denmark come from the project PASSYS, started in 1985. During this project, some experimental measurements have been performed in Denmark on the PASLINK test facility. The results of these experiments have been then used to calculate the reference parameters in Denmark.

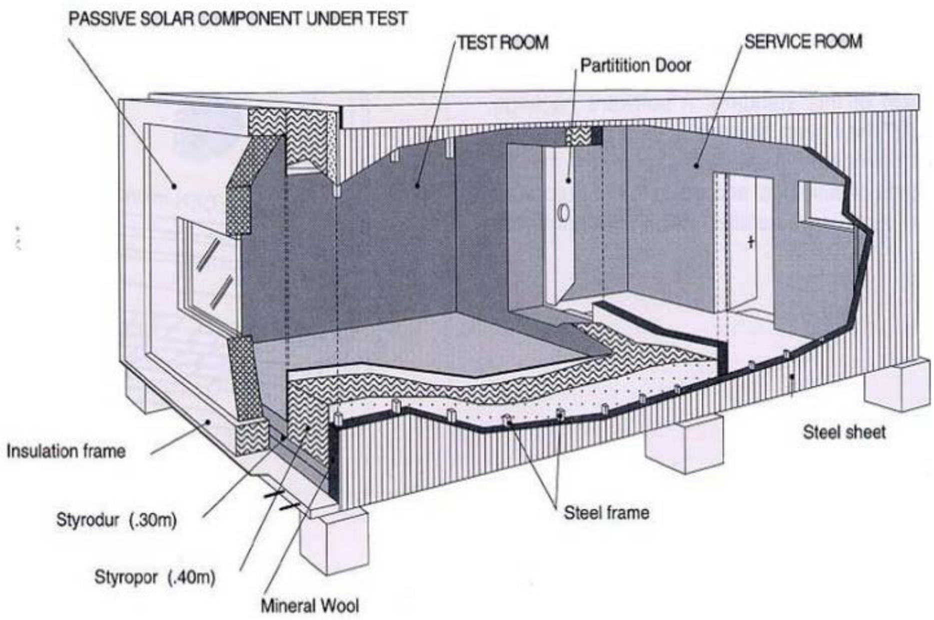


Figure 24: View of the PASLINK test facility

In order to validate these parameters, several simulations have been performed in the conditions of a Danish office building. Therefore the schedules are set to fit with office hours, as well as the level of internal heat loads and ventilation.
The model used is the same than the one described in part 3.1. It is simulated with no infiltration, and a g-value of 0.59 for windows.

Different formulas are then proposed and tested for the Danish reference values, taking into consideration the influence of several parameters:

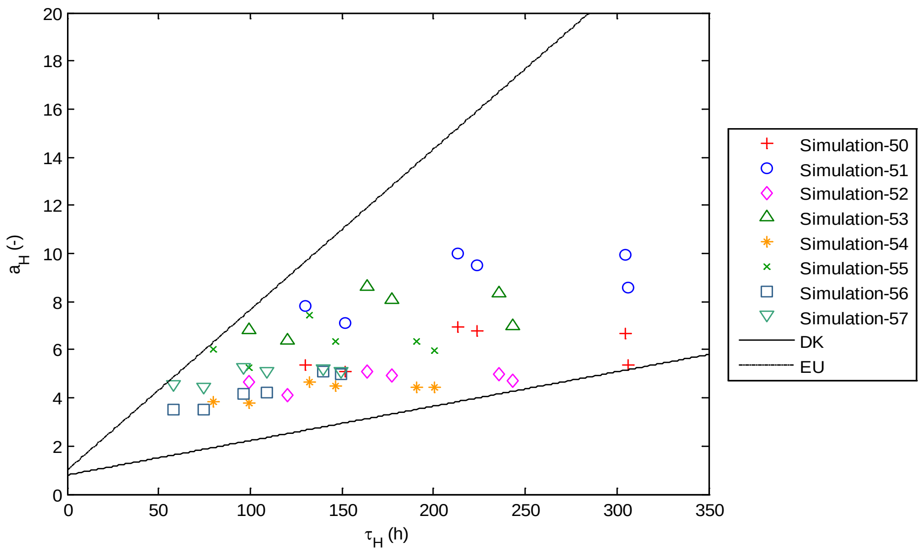
- τ the building time constant (h)
- ξ the ratio of the windows area to the floor area (external) (-). The ratio of the windows area to envelope area has been also tested by Corrado (6), but it did not show better fitting.

The formulas have been developed assuming that these parameters are independent of each other, and using the least square method.

3.5.1 Results from the dynamic simulations

<u>Test case:</u> Windows 28% of the façade area (14% of the floor area)

	Ventilation		Internal heat loads	
	Properties	Level	Properties	Level
050	Office hours (Mon-Fri / 9h-17h) No heat recovery	≈ 1 ACH (15.4 L/s)	Office hours (Mon-Fri / 9h-17h) Part to air = 1	≈ 9,1 W/m^2 (180 W)
052		≈ 1,5 ACH (23 L/s)		
054		≈ 2 ACH (30.8 L/s)		
056		≈ 3 ACH (46 L/s)		
051		≈ 1 ACH (15.4 L/s)		≈ 18,2 W/m² ext (360 W)
053		≈ 1,5 ACH (23 L/s)		
055		≈ 2 ACH (30.8 L/s)		
057		≈ 3 ACH (46 L/s)		



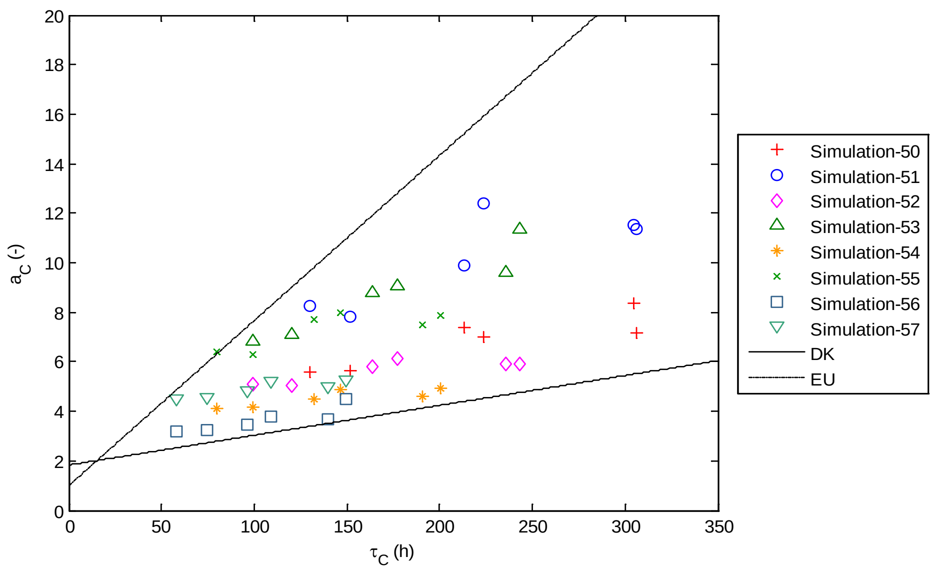


Figure 25: Comparison between the reference parameters proposed in the standards and the values obtained from simulations with the reference office (low window area)

<u>Test case:</u> Windows 55% of the façade area (28% of the floor area)

	Ventilation		Internal heat loads	
	Properties	Level	Properties	Level
040	Office hours (Mon-Fri / 9h-17h) No heat recovery	≈ 1 ACH (15.4 L/s)	Office hours (Mon-Fri / 9h-17h) Part to air = 1	≈ 9,1 W/m^2 (180 W)
042		≈ 1,5 ACH (23 L/s)		
044		≈ 2 ACH (30.8 L/s)		
046		≈ 3 ACH (46 L/s)		
041		≈ 1 ACH (15.4 L/s)		≈ 18,2 W/m² ext (360 W)
043		≈ 1,5 ACH (23 L/s)		
045		≈ 2 ACH (30.8 L/s)		
047		≈ 3 ACH (46 L/s)		

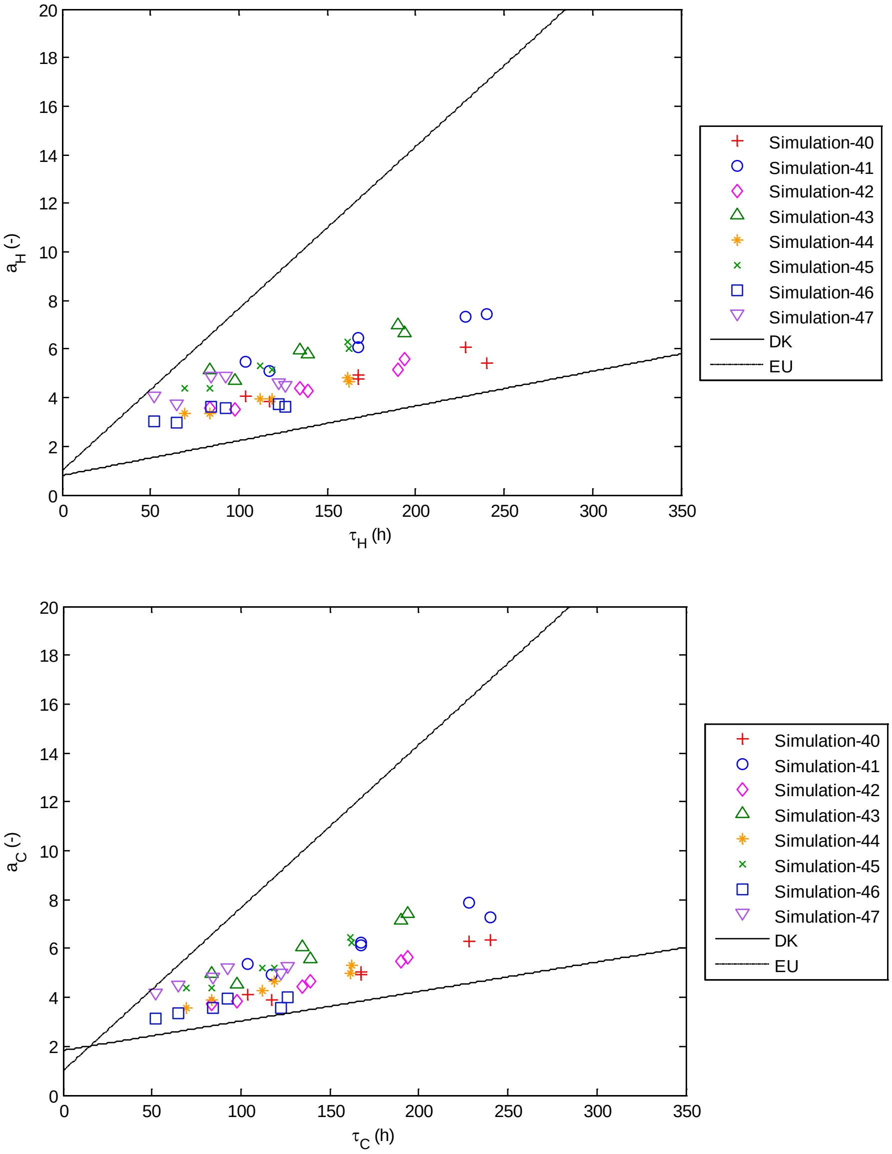
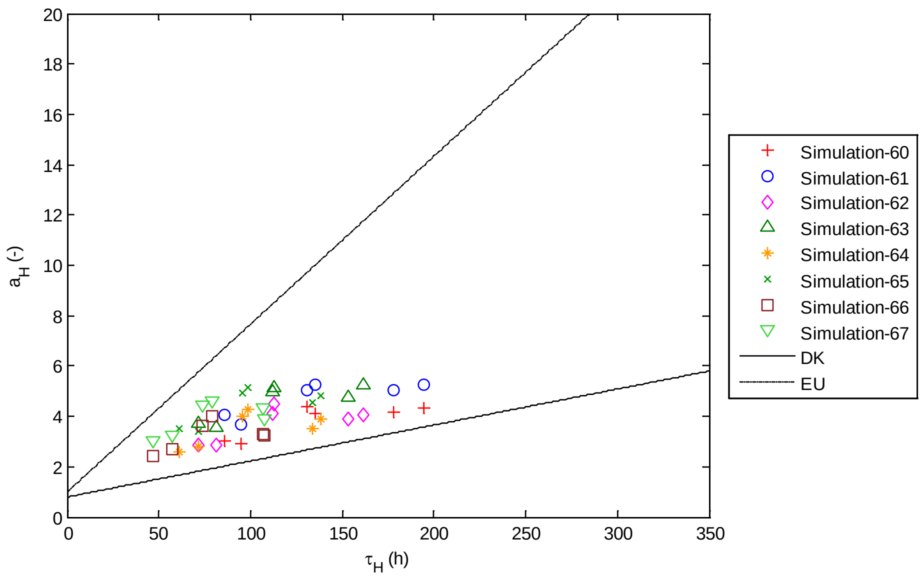


Figure 26: Comparison between the reference parameters proposed in the standards and the values obtained from simulations with the reference office (medium window area)

<u>Test case:</u> Windows 84% of the façade area (43% of the floor area)

	Ventilation		Internal heat loads	
	Properties	Level	Properties	Level
060	Office hours (Mon-Fri / 9h-17h) No heat recovery	≈ 1 ACH (15.4 L/s)	Office hours (Mon-Fri / 9h-17h) Part to air = 1	≈ 9,1 W/m^2 (180 W)
062		≈ 1,5 ACH (23 L/s)		
064		≈ 2 ACH (30.8 L/s)		
066		≈ 3 ACH (46 L/s)		
061		≈ 1 ACH (15.4 L/s)		≈ 18,2 W/m² ext (360 W)
063		≈ 1,5 ACH (23 L/s)		
065		≈ 2 ACH (30.8 L/s)		
067		≈ 3 ACH (46 L/s)		



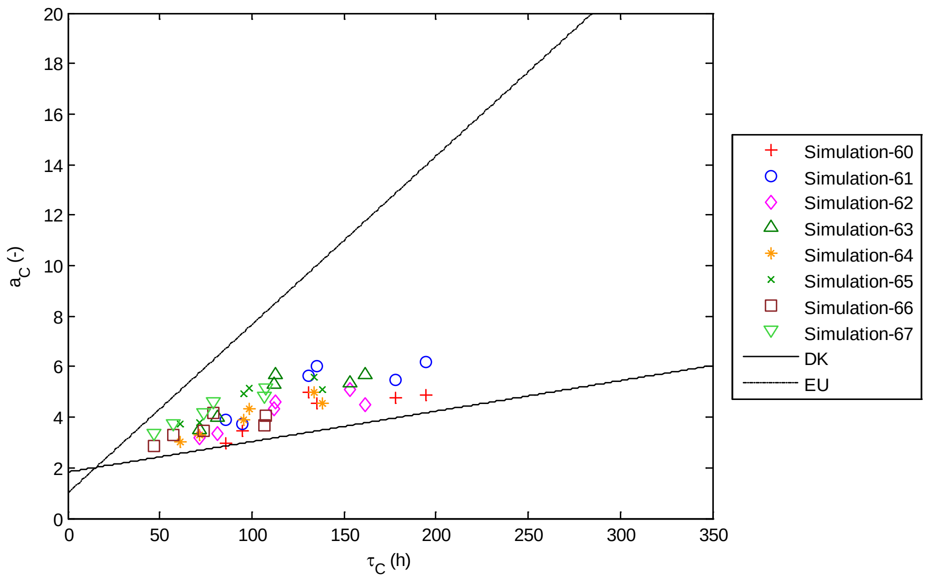


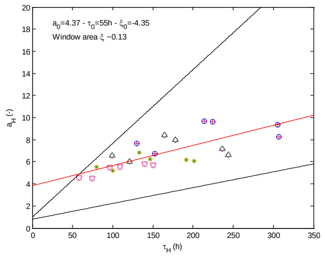
Figure 27: Comparison between the reference parameters proposed in the standards and the values obtained from simulations with the reference office (large window area)

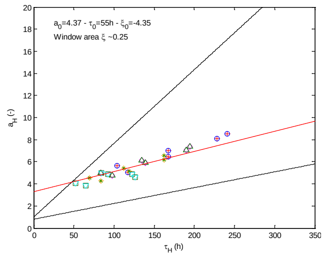
⇒ Proposal Heating:

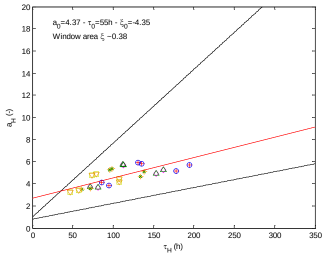
<table>
<tr><th></th><th>Equations & Graphs</th></tr>
<tr><td>Proposal 1 $(\xi\ ;\tau)$</td><td>

- τ_0 not fixed

$$a_H = 4.37 - 4.35\,\xi + \frac{\tau}{55} \qquad (R^2 = 0.76)$$



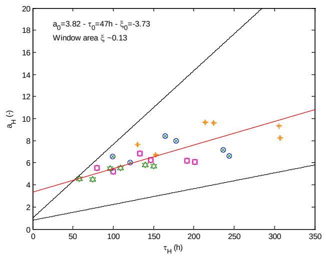


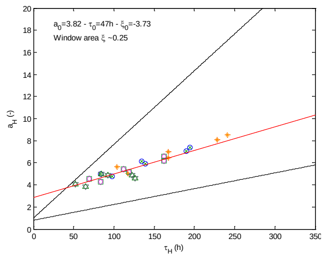


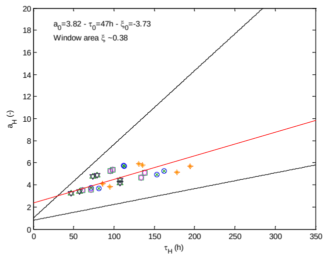
</td></tr>
<tr><td>Proposal 1bis $(\xi\ ;\tau)$</td><td>

- τ_0 fixed according to proposal 2

$$a_H = 3.82 - 3.73\,\xi + \frac{\tau}{47} \qquad (R^2 = 0.75)$$







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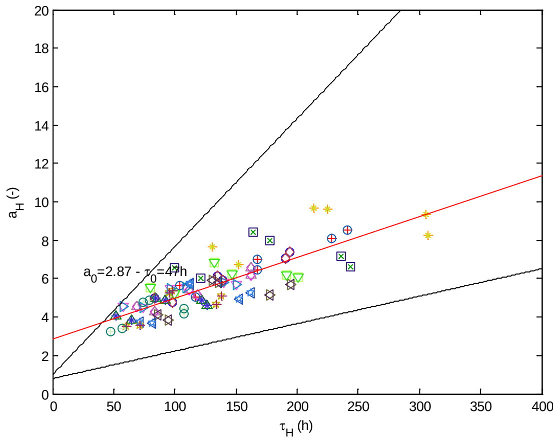
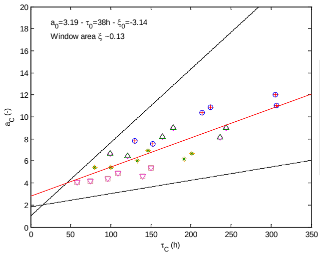
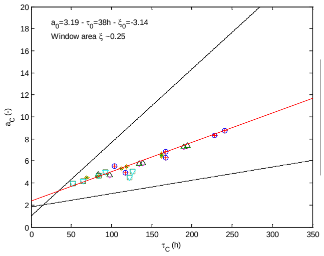
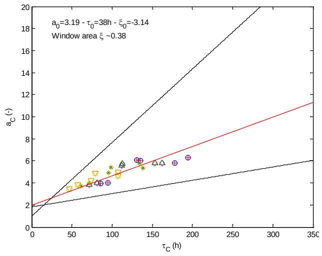
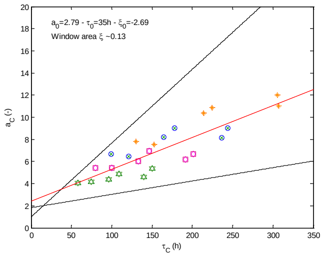
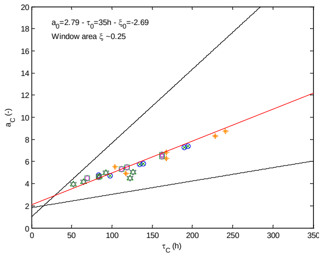
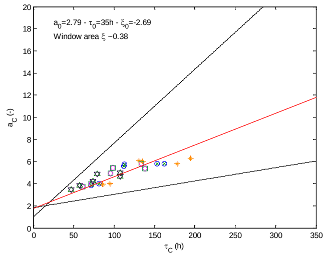
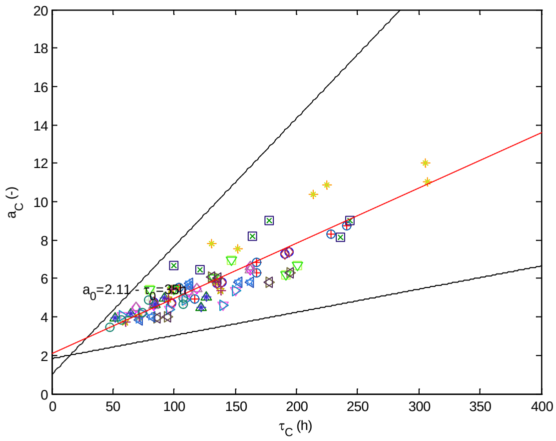
<tr><td>Proposal 2 (τ)</td><td>

$$a_H = 2.87 + \frac{\tau}{47} \qquad (R^2 = 0.68)$$



</td></tr>
</table>

⇒ Proposal Cooling:

	Equations & Graphs
Proposal 1 $(\xi\ ;\ \tau)$	▪ τ_0 not fixed $$a_C = 3.19 - 3.14\,\xi + \frac{\tau}{38} \qquad (R^2 = 0.83)$$   
Proposal 1bis $(\xi\ ;\ \tau)$	▪ τ_0 fixed according to proposal 2 $$a_H = 2.79 - 2.69\,\xi + \frac{\tau}{35} \qquad (R^2 = 0.83)$$   
Proposal 2 (τ)	$$a_C = 2.11 + \frac{\tau}{35} \qquad (R^2 = 0.80)$$ 

⇒ The results proposed here are valid in the range of this study, i.e.:

- thermal mass ϵ [59 ; 161] Wh/K·m²$_{\text{floor internal}}$
- building time constant ϵ [50 ; 300] h
- internal heat loads ϵ [9 ; 18] W/m²
- ratio of the windows area to the floor area ϵ [0.13 ; 0.38]

Equations have been developed for the heating and cooling cases, trying different relationship with τ and ξ. The quality of the fitting with the simulations has been tested using the coefficient of determination R^2 and the proposal 1 fits the best because taking into account more parameters. The proposed relations will give a lower heating and cooling consumption than the actual parameters, but higher dependency on the thermal mass.

Below can be found a comparison between the actual reference values, and the ones calculated through simulations (proposal 2).

	Heating		Cooling	
	Actual parameters	From simulations	Actual parameters	From simulations
Reference time constant τ_0 (h)	70	47	83	35
Numerical parameter of reference a_0 (-)	0.8	2.87	1.83	2.11

Comparison with relations found in other countries:

- ITALY: Corrado et al. (6) developed a correlation for the cooling case depending on the window area:

$$a_C = 8.1 - 13\,\xi + \frac{\tau}{17}$$

  There is a stronger dependence on the window area than for Denmark. This might be due to the higher solar radiation.

- FINLAND: Jolikisalo et al. (7) tested the European values ($a_0 = 1$ and $\tau_0 = 15$) and another set of values ($a_0 = 2$ and $\tau_0 = 15$), but in both cases the “heat demand was strongly underestimated, especially with the typical Finnish internal heat gains”.

- NORWAY: values from NS03031-07 (Calculation of energy performance of buildings - method and data)

$$a_H = 1 + \frac{\tau}{16} \qquad\qquad a_C = 1 + \frac{\tau}{15}$$

3.5.2 Effect of new coefficients on the total energy consumption

In order to test the effect of the new correlations, the case of a real office building (single floor) has been modelled. It corresponds of the reference case used in the Danish regulation (8), with some minor modifications. Therefore the results of the Be10 model (monthly calculation) and the BSim model (dynamic simulation) can be compared.

Characteristics of the building:

- External area: 650.2 m^2
- Internal area: 631 m^2
- Internal height: 2.8 m
- Windows: 145.2 m^2, with U_g = 1.2 $W/m^2.K$ and g = 0.63
- Ventilation: 1.2 $L/s/m^2$ = 1.6 ACH (heat recovery η=0.8)
- Infiltration: 0.13 $L/s/m^2$ = 0.17 ACH during working hours, 0.09 $L/s/m^2$ = 0.12 ACH outside
- Building occupied from 8am to 5pm, from Monday till Friday (45h per week)
- Continuous control of the lighting level according daylight

Some simplifications performed on the model have been made in order to avoid calculation errors, which are not due to utilisation factors. Therefore the solar shadings have been deactivated (only the shading due to the wall thickness is taken into account), and the linear heat losses of the building have been ignored in both models.

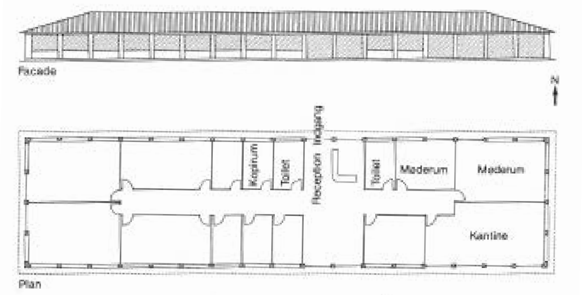


Figure 28: Sketch of the building

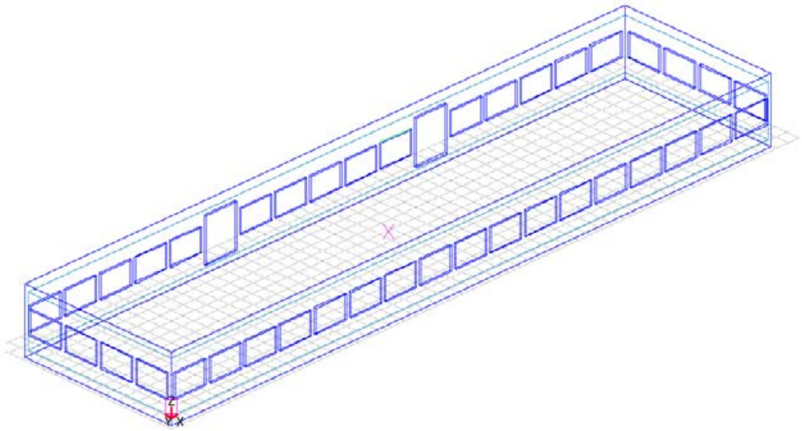


Figure 29: BSim model of the building (one thermal zone for the entire building)

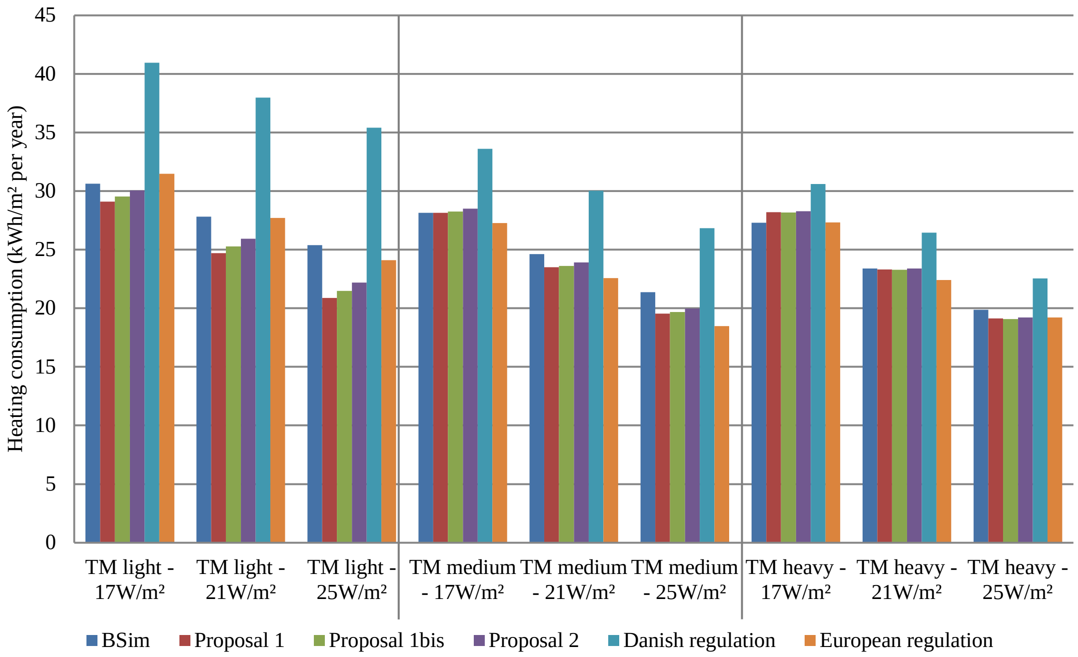
Even if the two models (Be10 and BSim) have similar characteristics, some differences still exist due to the simplifications that have to be made in the monthly calculation:

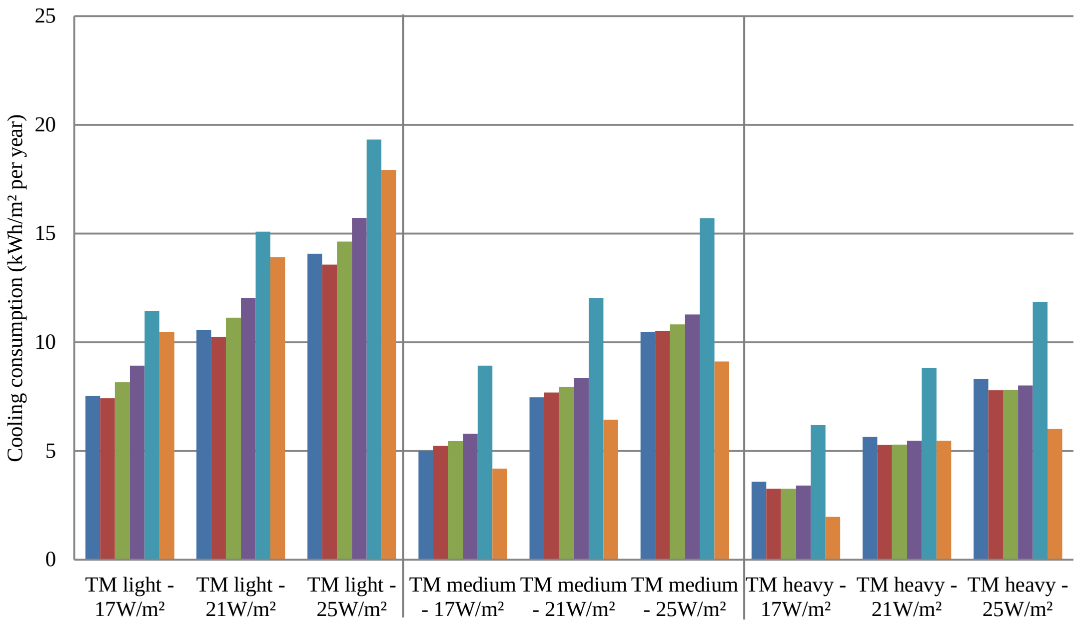
- Simulation of heat recovery are slightly different (especially the bypass during summer)
- The ground temperature is not modelled the same way (sinusoid vs. b-value)

- Automatic control of lighting, which is more advanced in BSim
- Solar loads in the building are calculated differently

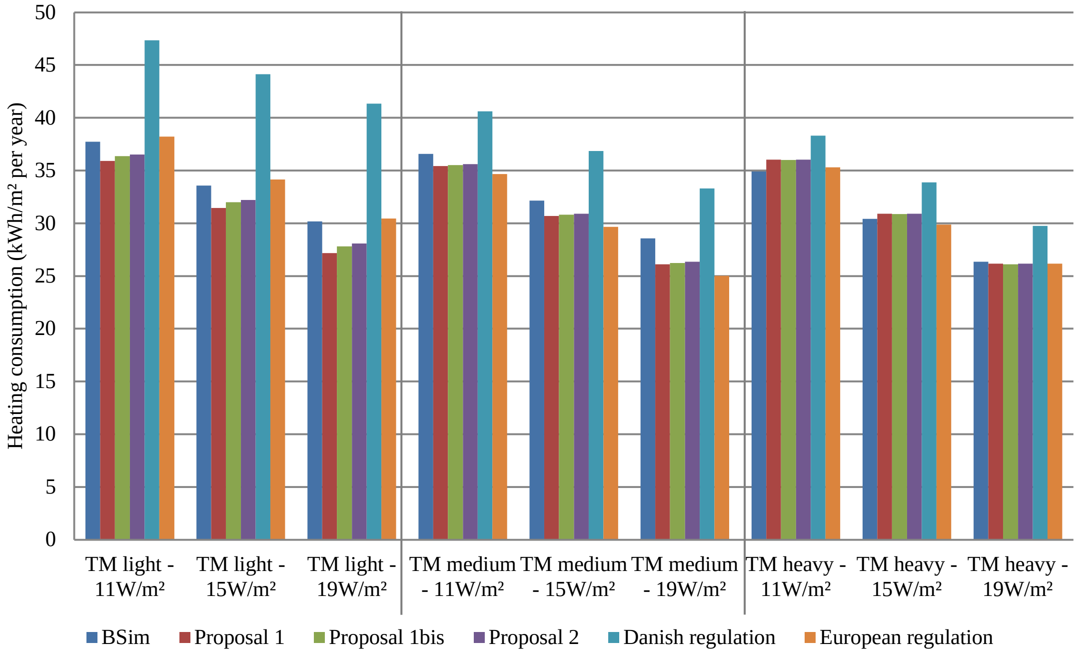
The initial model has been modified, in order to have a wider range of results. Different thermal mass (TM) and different range of internal heat gains have been tested. Proposals 1, 1bis and 2 correspond to the correlations proposed in part 3.5.1.

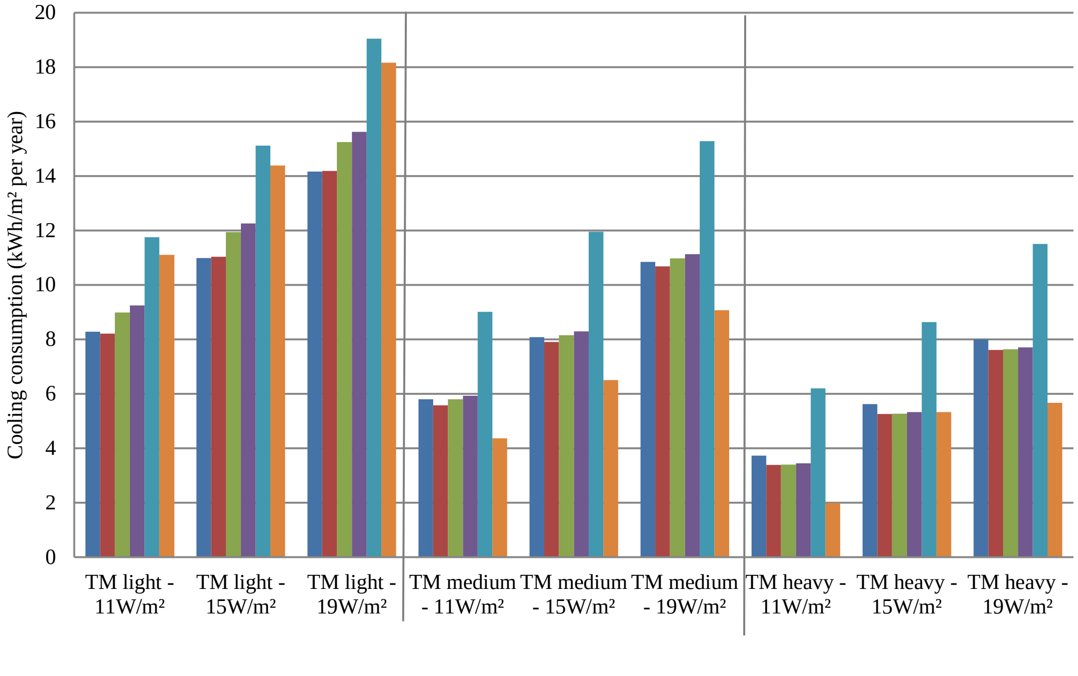
<u>Results for ξ =0.16:</u>
TM light: 20 Wh/K.m² - TM medium: 73 Wh/K.m² - TM heavy: 146 Wh/K.m²



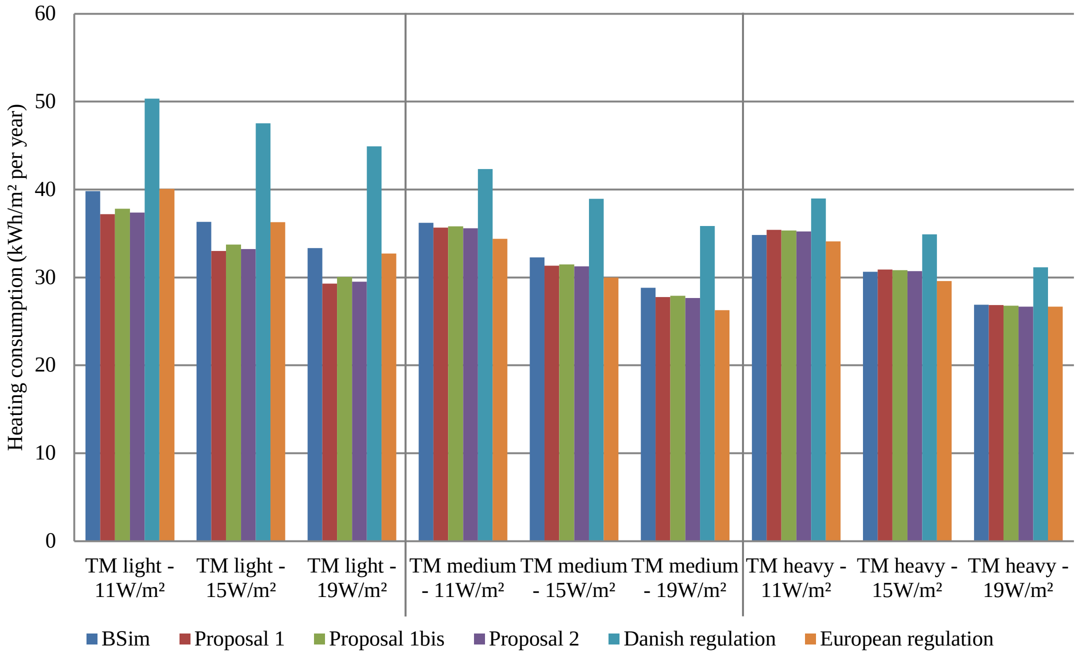


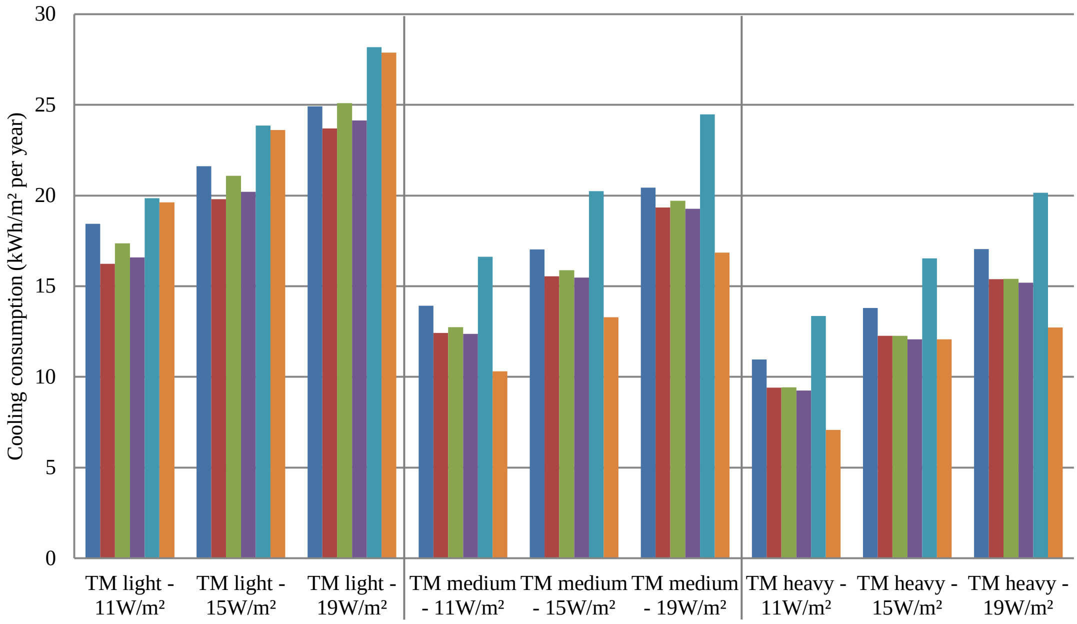
Results for ξ =0.22:
TM light: 20 Wh/K.m^2 - TM medium: 73 Wh/K.m^2 - TM heavy: 142 Wh/K.m^2





Results for ξ =0.31:
TM light: 20 Wh/K.m^2 - TM medium: 73 Wh/K.m^2 - TM heavy: 146 Wh/K.m^2





<u>Summary of the results:</u> accuracy calculated according to (1), with reference uncertainty given in 3.2.1

- Heating case:

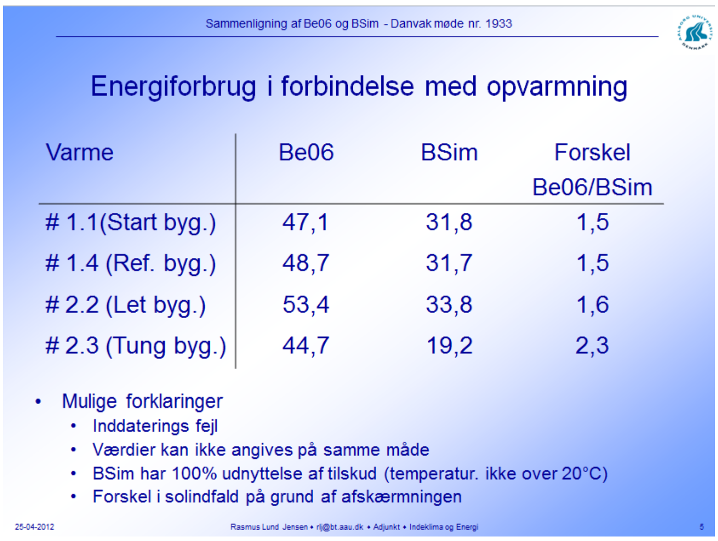
	Window area			Mean value
	Low	Medium	High	
Proposal 1	5.5%	4.1%	3.5%	4.5%
Proposal 1bis	4.8%	3.5%	2.8%	3.8%
Proposal 2	**3.8%**	**3.3%**	**3.4%**	**3.5%**
Danish regulation	19.0%	15.9%	14.5%	16.6%
European regulation	4.2%	4.0%	2.8%	3.8%

- Cooling case:

	Window area			Mean value
	Low	Medium	High	
Proposal 1	1.0%	0.6%	3.1%	1.9%
Proposal 1bis	**1.4%**	**1.3%**	**2.5%**	**1.8%**
Proposal 2	2.7%	1.7%	3.2%	2.6%
Danish regulation	12.4%	9.2%	5.8%	9.5%
European regulation	6.3%	5.7%	6.6%	6.2%

From these simulations, it can be observed that:

- The current reference parameters used in the Danish building regulation are overestimating the heating and cooling consumption. Similar behaviour was pointed out by R.L Jensen (9):



- For the very light buildings (20 Wh/K.m^2), the proposed methods are giving large error most of the time. This can be explained by the range of development of the new correlations, which does not correspond (valid from 59 Wh/K·m²). Nevertheless it has been decided to keep these results to show the robustness of the calculation method.

- When the glazing area is large, the different methods fail to predict the correct cooling consumption. Large errors can be observed.

As it could be expected, the integration of the windows area in the calculation method does improve much the accuracy for the heating case. Therefore proposal 2 should be used for the heating calculation.
For the cooling calculation, the windows area plays a more important role and proposal 1bis should be used.

3.5.3 Final proposal

Actual values used in Denmark for non-residential buildings

	Denmark - Others	
	Heating	Cooling
Reference time constant τ_0 (h)	70	83
Numerical parameter of reference a_0 (-)	0.8	1.83

Proposal:

	Denmark - Others	
	Heating	Cooling
Reference time constant τ_0 (h)	47	35
Numerical parameter of reference a_0 (-)	2.87	2.79
Reference ratio of windows area to the floor area (external) ξ_0 (-)	-	2.69

$$a = a_0 - \xi \cdot \xi_0 + \frac{\tau}{\tau_0}$$

The range of validity of these parameters is given in 3.5.1 and should cover most of the building types. The accuracy of the calculation method with these new parameters is estimated to be around 5% on annual basis.

Remark on the reference parameters for residential buildings:

	Denmark			
	Heating		Cooling	
	Residential	Others	Residential	Others
Reference time constant τ_0 (h)	15	70	83	83
Numerical parameter of reference a_0 (-)	1	0.8	1.83	1.83

From these simulations, it can be observed that it is unlikely that the cooling consumption of residential buildings is well-calculated with the actual coefficients. In fact the coefficients used nowadays are the same than for office buildings, whereas the schedules of occupation are different. And it has been observed that the schedule was playing an important role in the definition of the reference parameters.

4. NIGHT-TIME VENTILATION

In many buildings, night-time ventilation is used instead of air conditioning to achieve thermal comfort during the summer season. The building structure is cooled down overnight with relatively cold outdoor air, in order to provide a heat sink during the occupied period of the next day by making use of the exposed thermal mass.

The objective of this part is to find a method to evaluate night-time ventilation in the monthly calculation method. As it has been observed in Part 3, the calculation method is highly sensitive on the schedules of ventilation and internal heat load. Night-time ventilation is a highly dynamic phenomenon because its efficiency will depend on how much heat can be stored during the day, but also how much heat can be released during the night. This interdependence day/night is the challenge of the calculation method.

In addition to increasing the ventilation losses, night-time ventilation decreases the building time constant due to larger heat transfer coefficient by ventilation. It also leads to a decrease of the utilisation factor. Two existing calculation methods will be presented and two new methods will be developed and tested. Only the cooling season is studied.

4.1 CALCULATION METHODS

	Principle	Calculation
Without correction	*Considering NTV as a regular ventilation heat loss (fixed operation time)*	*Traditional:* $H_{vent} = \rho_{air}\, C_{air}\, f_{vent,t}\, q_{vent}$
Method Breesch	*Correction factor on the ventilation losses (without assuming the operation time) by Breesch* (10)	$H_{vent,extra} = \rho_{air}\, C_{air}\, C_{ve,eff,extra}\, f_{ve,t,extra}\, q_{ve,extra}$
Method 1 (C_{ve})	*Correction factor on the ventilation losses (fixed operation time)*	$H_{vent,extra} = \rho_{air}\, C_{air}\, C_{ve,eff,extra}\, f_{ve,t,extra}\, q_{ve,extra}$
Method 2 (C_γ)	*Correction factor on the ratio gains/losses (fixed operation time)*	$\eta_{C,ls} = \dfrac{1-(C_\gamma\,\gamma_C)^{-a_C}}{1-(C_\gamma\,\gamma_C)^{-(a_C+1)}}$

Method Breesch and Method 1 correspond to the methods proposed in the standard EN ISO 13790 (1).

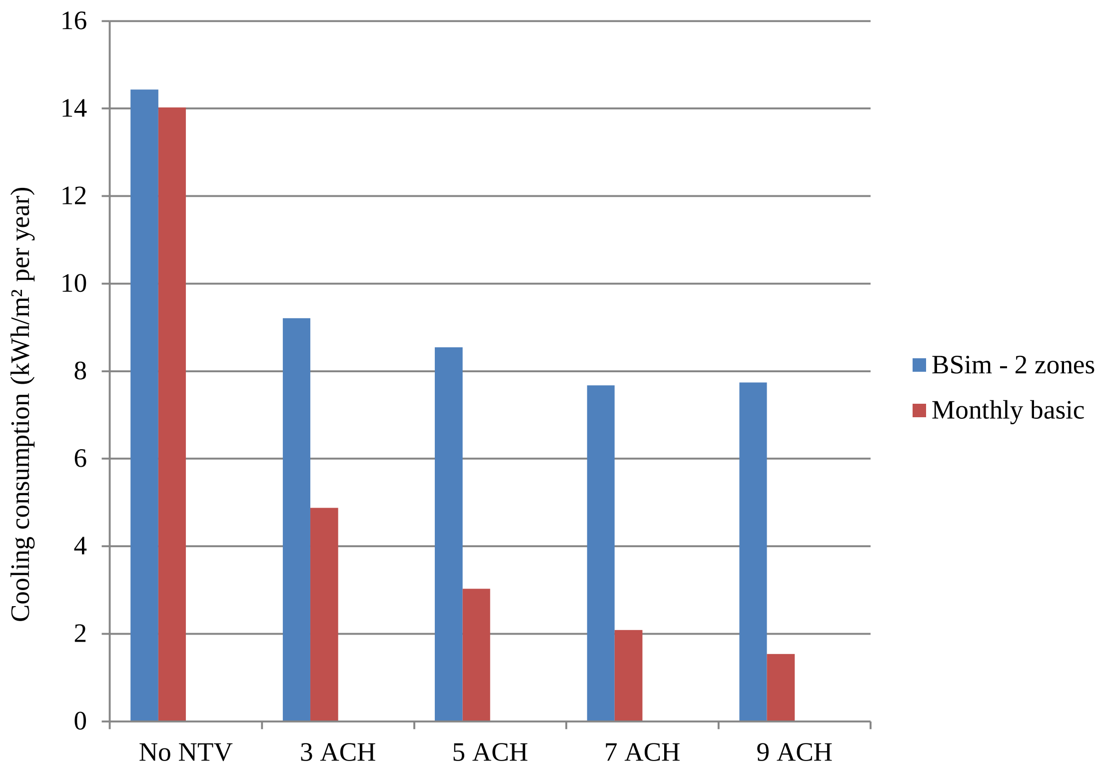
4.1.1 Without correction – Considering NTV as a regular ventilation heat loss

In a first part, we will consider night-time ventilation as a regular ventilation heat loss, therefore calculating the overall ventilation heat transfer coefficient H_{vent} with the following expression:

$$H_{vent} = \rho_{air} \, C_{air} \, f_{vent,t} \, q_{vent}$$

With $\rho_{air} \, C_{air}$ heat capacity of air per volume (≈ 1200 J/m^3·K)
$f_{vent,t}$ time fraction of operation of the air flow, calculated as the fraction of the number of hours per week (~~and not per day~~) (-)
q_{vent} airflow rate (m^3/s)

The graph below presents the comparison of the cooling consumption predicted by thermal dynamic simulation (BSim) and by the actual calculation method (when no correction is applied). It can be observed that the actual calculation method overestimates the effect of night-time ventilation, under-predicting the cooling consumption. Therefore there is a need for correction coefficients.



4.1.2 Method Breesch – Correction factor on the ventilation losses (without assuming the operation time)

In this part, the results from Breesch et al. (9) are presented. They investigated an "assessment method of mechanical night cooling for calculating the cooling demand of non-residential buildings". They performed testing on "small and large office building and a school building" in order to find correlations for $C_{ve,eff,extra}$ and $f_{ve,t,extra}$.

$$H_{vent,extra} = \rho_{air}\ C_{air}\ b_{ve,extra}\ C_{ve,eff,extra}\ f_{ve,t,extra}\ \ q_{ve,extra}$$

"Night cooling is only activated between 22h and 6h when the zone temperature exceeds the external temperature and the indoor temperature of the preceding day exceeded 23°C. A minimum zone set point is specified to prevent overcooling, i.e. a minimum ceiling temperature of 22°C." For activating night-time ventilation, the temperature difference between outdoor and indoor must be at least 2°C

"Three airflow rates for mechanical night cooling are studied as a function of the hygienic airflow rate: $V_{night,mech,seci} = 1.0\ V_{supply,seci,j}$, $3.0\ V_{supply,seci,j}$ or $6.0\ V_{supply,seci,j}$."

<u>Monthly calculation method proposed:</u>

"The internal heat gains are scaled eight times in steps of 12.5%, going from 12.5% to 100% of the default load". The results are presented only as a function of the monthly losses to gains ratio $\lambda_{seci,m}$ (-), as the relationship with the ACH is weaker than the spreading rate of the test cases.

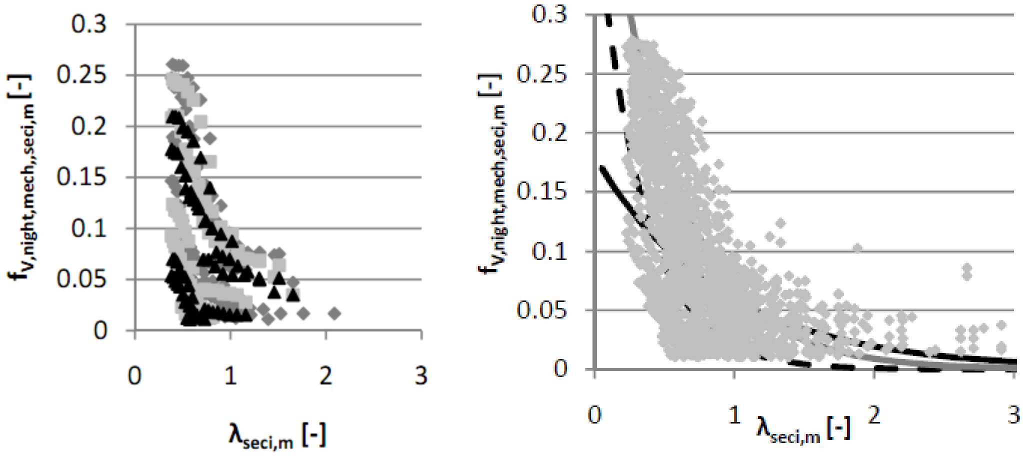


Figure 30: time fraction of operation of mechanical night cooling in the small office building (left) and the 3 cases (right)

All the results are presented on Figure 30; it is therefore difficult to distinguish the effect of thermal mass. But a large spreading rate can be seen as well for the small office building alone (left figure).

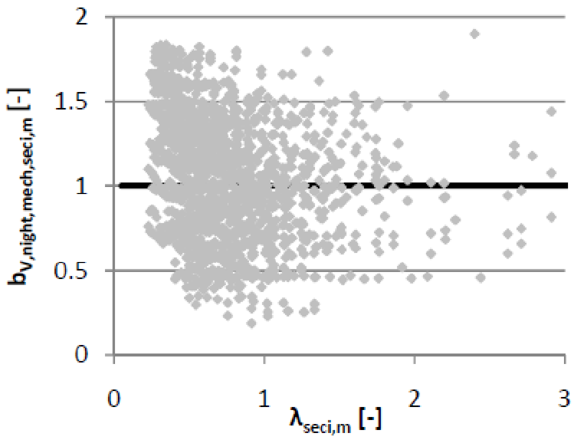


Figure 31: Temperature adjustment factor of mechanical night cooling in the 3 cases

They concluded that "Light structures, i.e. D_j=55kJ/(m².K) and D_j=180kJ/(m².K), have an adjustment factor for dynamic effects $C_{V,night,mech}$ (-) of approximately 0.7. Otherwise, this adjustment factor can be assumed to be 1."

<u>Comparison Method proposed / Dynamic simulation:</u>

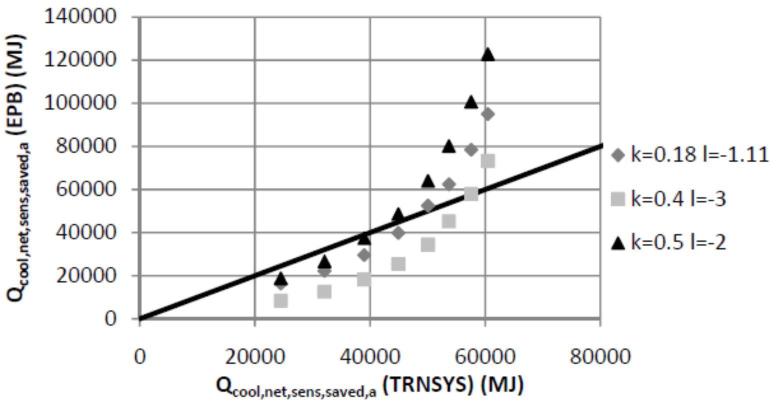


Figure 32: Comparison of saved cooling demand by night cooling (EPB-TRNSYS) for various regression coefficients in small office building

⇒ They came to the conclusion that "comparing the new calculation method to dynamic simulation results of the same buildings shows a non-linear and uncertain correspondence. The dynamic effects, which are essential for night cooling, are insufficiently considered in the new assessment method as described in EN 13790."

4.1.3 Method 1 – Correction factor on the ventilation losses (fixed operation time)

In the standard EN 13790 (1), the extra volumetric flow rate, $H_{vent,extra}$, into the conditioned space for night-time ventilation is defined as follows. The amount of ventilation losses is corrected with an adjustment factor C_{ve}, larger than zero.

$$H_{vent,extra} = \rho_{air}\, C_{air}\, b_{ve,extra}\, C_{ve,eff,extra}\, f_{ve,t,extra}\;\; q_{ve,extra}$$

With $C_{ve,eff,extra}$ an adjustment factor for dynamic (inertia) effects and effectiveness; unless otherwise specified at national level the value is $C_{ve,eff,extra} = 1$

$f_{ve,t,extra}$ the time fraction of operation of the night-time ventilation, calculated as the fraction of the number of hours per week (~~and not per day~~) of operation (full time: $f_{ve,t,extra} = 1$)

$q_{ve,extra}$ the extra air flow rate into the conditioned space due to night-time ventilation, expressed in cubic metres per second, with given time fraction of operation.

For the monthly methods, the value for the associated temperature adjustment factor, $b_{ve,extra}$, can be used to adjust for the temperature difference during time of operation compared to a 24h temperature difference. The value is $b_{ve,extra} = 1$, unless otherwise specified at national level (we will use the default value in this report).

$C_{ve} = 1$ indicates that all the excess heat can be stored and then discharged totally by the ventilation system. It has to be noticed that this parameter can be higher than one: referring to the heat balance, it could indicate that the ventilation system and the thermal storage are more efficient than physically possible; but it is not true, as the building time constant and also $\eta_{C,ls}$ are decreasing with values of C_{ve} larger than one.

4.1.4 Method 2 – Correction factor on the ratio gains/losses (fixed operation time)

In Method 2, the adjustment factor is applied directly on the ratio of gains to losses. The justification for testing this method is the correlation between the effectiveness of night-time ventilation and the ratio of gains to losses. In fact the efficiency of night-time ventilation does not depend only on the ability of the ventilation system to remove heat, but also on the ability of the building to store heat during the day. The ventilation losses are calculated assuming $C_{ve} = 1$ and the relative heat gains are defined as follows:

$$\eta_{C,ls} = \frac{1 - \left(C_{\gamma}\, \gamma_C\right)^{-a_C}}{1 - \left(C_{\gamma}\, \gamma_C\right)^{-(a_C+1)}}$$

Where $\gamma_C = \frac{Q_{C,gn}}{Q_{C,ht}}$

This adjustment factor should be higher than zero, indicating than only part of the gains can be stored in the thermal mass during day-time, or only part of the heat can be discharged from the thermal mass during night-time.

4.2 CALCULATION OF THE ADJUSTMENT FACTORS FROM THE SIMULATIONS

The technique chosen for determining the adjustment coefficients is based on the method proposed by Corrado et al. (2007). They detailed a calculation method to derive the reference parameters $a_{C,0}$ and $\tau_{C,0}$ from dynamic simulations.

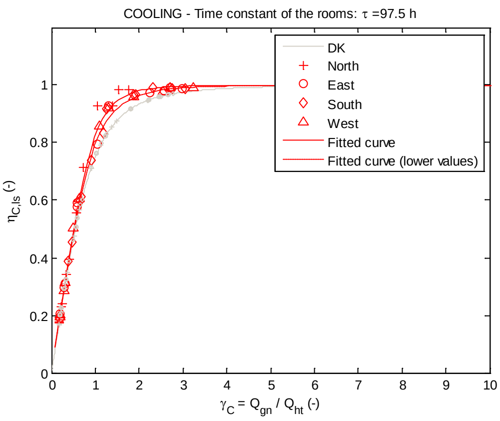
From each simulation case, the parameters $Q_{C,ht}$, $Q_{C,gn}$, $\eta_{C,ls}$ and γ_C can be extracted for the 12 months by performing three dynamic simulations:

- a first simulation with no gains (solar and internal) and a fixed set-point of 26°C is executed to obtain $Q_{C,ht}$
- $Q_{C,gn}$ is derived from a second simulation with a fixed set-point of 26°C
- $\eta_{C,ls}$ is finally obtained from the third simulation, with the operative temperature kept within the range of 20 to 26°C

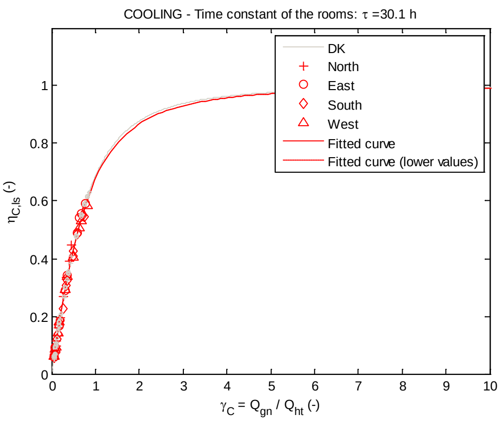
4.2.1 Disadvantages of deriving the correlations from the utilisation factors

When working with NTV, the ratio γ_C is becoming relatively small, making the derivation of the reference parameters more uncertain.

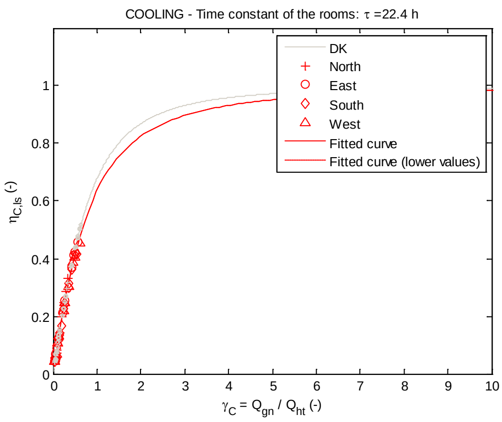
<u>Internal heat loads of 9 W/m^2</u>
Below can be found the curve for the determining the utilisation factor for different intensity of night time-ventilation:



0 ACH

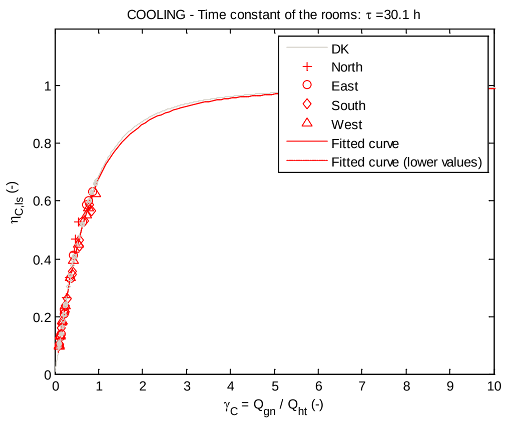


4 ACH

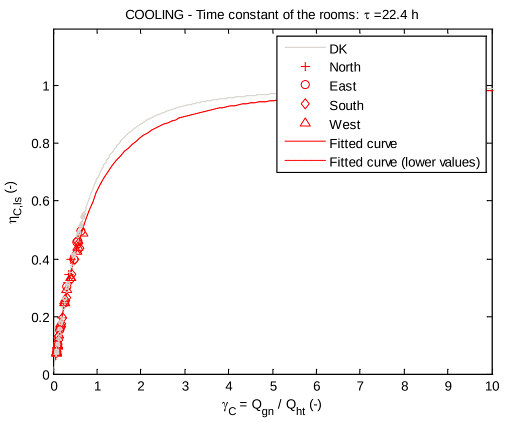


6 ACH

Internal heat loads of 18 W/m²



4 ACH



6 ACH

These results point out the uncertainty on the utilisation factors for high air change rates. It is therefore more suitable to use another technique.

4.2.2 Inverse method

The method that has been used for this report is named "inverse method", meaning that the cooling consumption is not directly used to derive the correction coefficients. Theoretical values of cooling consumption are derived for different values of correction coefficients, and the most suitable value is selected by minimising the error with the cooling consumption obtained from simulation.

Method 1

The adjustment factor C_{ve} can be calculated for each simulation case through an iterative process. The parameters $Q_{C,nd}$ and $Q_{C,gn}$ are obtained from the dynamic simulations. $\eta_{C,ls}$ and $Q_{C,ht}$ are derived theoretically for different values of C_{ve}.

$$H_{vent} = \rho_{air}\, C_{air}\left(f_{vent,t}\, q_{vent} + C_{ve,eff,extra}\, f_{ve,t,extra}\ \ q_{ve,extra}\right)$$

$$\tau = \frac{C_m \,/\, 3600}{H_{tr} + \rho_{air}\, C_{air}\left(f_{vent,t}\, q_{vent} + C_{ve,eff,extra}\, f_{ve,t,extra}\ \ q_{ve,extra}\right)}$$

Finally the correct value of C_{ve} is selected by minimising the error between the annual calculated cooling consumption and the value obtained through the dynamic simulation (over the four rooms facing the four different orientations).

Method 2

A similar iterative process is performed to obtain the value of C_γ. In this case, all the parameters except a_C are derived from the dynamic simulations.

$$\eta_{C,ls} = \frac{1 - \left(C_\gamma\, \gamma_C\right)^{-a_C}}{1 - \left(C_\gamma\, \gamma_C\right)^{-(a_C+1)}}$$

4.3 SIMULATIONS PARAMETERS

4.3.1 General parameters

The cooling set-point is set to 26°C and an operative temperature down to 20°C is allowed during night-time. The level and schedule for the internal heat loads and the ventilation system (during daytime) are described in the table below. The schedule corresponds to typical office hours. The air change rate of the ventilation system has been chosen according to EN ISO 15251, for a low polluting building and a ratio of occupancy of 0.1 person/m^2.

	Schedule	Level
Internal heat loads	Working days (8am – 5pm)	10.3 $W/m^2_{internal}$ or 20.6 $W/m^2_{internal}$
Ventilation	Working days (8am – 5pm)	≈ 1,85 ACH (23 L/s)

Others:

- Window: area 55% of the façade – g-value 0.59
- Longwave radiation
- Convection coefficient: dynamic (ASHRAE)

4.3.2 Night-time ventilation

During nights of working days, the ventilation system is activated for a maximum period of 8 hours up to 15 hours depending on the simulations (table below). When the temperature in the building drops below the heating set-point (20°C), the night ventilation stops. There is no preheating of the outdoor air and the air change rate varies from 4 up to 7.5 ACH.

	Time start	Latest stopping time
8 hours	9pm	5am
12 hours	6pm	6am
15 hours	5pm	8am

The level of NTV is defined as the time of use and the air change rate of NTV. If internal heat loads are high, NTV should be applied for a long time and at high air change rate. Nevertheless these parameters should be realistic, and not lead to an “undercooling” of the building.

Therefore a simulation with the correct parameters (e.g. level of internal heat loads and time of operation of NTV) is performed over the entire building.
The right air change rate is selected in order to reach the maximum length of operation of night-time ventilation during the months of July or August in the room facing the south, but not during the other months. This means that NTV has been designed correctly to achieve thermal comfort during summer, without under- or oversizing.

Example of simulations performed in order to select the correct ACH depending on the air change rate of NTV and the level of internal heat loads:

Table 1: operation hours of NTV in the south facing room during all months for different air change rates of night time ventilation (15h running) and different internal heat loads

Internal heat loads (W)	180			360		
Air change rate	1.5 ACH	3 ACH	6 ACH	1.5 ACH	3 ACH	6 ACH
Month						
1	0	0	0	78	34	19
2	39	17	11	125	67	39
3	123	66	31	235	122	57
4	273	174	95	312	229	116
5	**330**	287	177	**330**	321	222
6	**330**	326	249	**330**	**330**	289
7	**330**	**330**	268	**330**	**330**	297
8	**330**	**330**	284	**330**	**330**	320
9	**330**	259	150	**330**	315	207
10	201	109	58	305	185	112
11	62	31	16	193	98	46
12	7	4	1	115	56	32

The maximum time of operation for the months of July and August is 15h * 22 days = 330 hours. Therefore the air change rate of NTV should be equal to 3-4 ACH when the time of running of NTV is 15 hours.

Drawback of this method: as it can be seen on the table below, the need of NTV is not the same in the entire building; it depends much on the thermal mass and aspect. Nevertheless defining a specific schedule for each room is time-consuming…

Table 2: operation hours of NTV for floors 4, 5 and 6 and for all room orientations, during all months (15h NTV, 4ACH, internal heat loads 180 W)

	Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Floor 6	N6	0	3	27	78	165	260	278	280	142	54	20	3
	E6	1	11	69	136	266	305	304	329	226	87	31	6
	S6	32	57	82	136	226	278	292	333	248	145	85	34
	W6	1	12	48	132	230	299	301	329	215	89	29	6
Floor 5	N5	0	3	31	66	158	237	257	249	131	50	18	3
	E5	2	12	50	102	195	258	268	285	176	74	31	6
	S5	19	31	52	89	157	225	250	269	167	90	55	28
	W5	2	9	41	96	173	248	267	276	163	70	30	5
Floor 4	N4	1	5	30	50	116	185	207	195	96	42	23	7
	E4	3	14	41	75	152	210	221	230	122	54	28	8
	S4	13	24	40	62	116	176	197	206	116	62	40	15
	W4	3	14	34	77	140	208	222	219	121	54	24	10

4.3.3 List of simulations

Different cases have been tested, in order to test the quality of the proposed methods. In total, 288 different cases have been simulated.

	Office hours (Mon-Fri / 8h-17h)	Night Time Ventilation		
		Days	Time	Level
123	≈ 1,5 ACH (23 L/s) ≈ 9,1 W/m^2$_{ext}$ (180 W)			0 ACH
115		Mon-Fri	8-hours running (21h-5h)	≈ 5 ACH (76 L/s)
116		Mon-Fri	8-hours running (21h-5h)	≈ 6 ACH (92 L/s)
113		Mon-Fri	12-hours running (18h-6h)	≈ 4 ACH (61 L/s)
114		Mon-Fri	12-hours running (18h-6h)	≈ 5 ACH (76 L/s)
111		Mon-Fri	15-hours running (17h-8h)	≈ 3 ACH (46 L/s)
112		Mon-Fri	15-hours running (18h-6h)	≈ 4 ACH (61 L/s)
123	≈ 1,5 ACH (23 L/s) ≈ 18,2 W/m^2$_{ext}$ (360 W)			0 ACH
121		Mon-Fri	8-hours running (21h-5h)	≈ 5 ACH (76 L/s)
122		Mon-Fri	8-hours running (21h-5h)	≈ 6 ACH (92 L/s)
119		Mon-Fri	12-hours running (18h-6h)	≈ 4 ACH (61 L/s)
120		Mon-Fri	12-hours running (18h-6h)	≈ 5 ACH (76 L/s)
117		Mon-Fri	15-hours running (17h-8h)	≈ 3 ACH (46 L/s)
118		Mon-Fri	15-hours running (18h-6h)	≈ 4 ACH (61 L/s)

4.3.4 Effect of night-time ventilation on the cooling consumption

The cooling need for the South facing rooms is presented in the figure below. The cooling need is greatly reduced by using night-time ventilation. It can also be observed that the higher the thermal mass, the more efficient night-time ventilation.

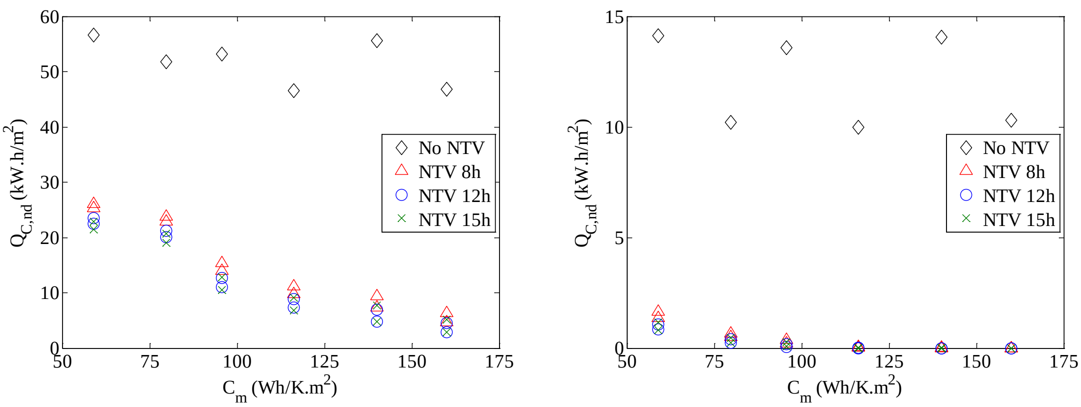


Figure 33: Yearly cooling need in the rooms facing South (on the left) and North (on the right)
Heat loads = 10.3 W/m²

4.4 SIMULATION RESULTS

4.4.1 Results with Method 1 (C_{ve})

From the 288 simulations performed, the adjustment coefficients C_{ve} have been derived. The values obtained have been correlated to different parameters, such as the thermal mass, the air change rate, the number of operating hours of night-time ventilation, the level of internal heat load, and the daily asymmetry in the heat gains-losses. From all these parameters, it has been observed that the thermal mass of the room has the largest influence on the value of C_{ve}. Therefore, all the results will be presented as a function of the thermal mass.

From the figures below, it can be observed that there is a strong correlation between the adjustment coefficients C_{ve} and the thermal mass. The higher the thermal mass, the higher the value of C_{ve}. This can be explained by a better use of the thermal mass to store heat during the day, and release it during the night. For very light buildings (lower than 80 Wh/K.m²), the value of C_{ve} is not decreasing anymore, suggesting a threshold. Different colours and markers have been set according to the maximum time of operation and the air change rate of night-time ventilation. A correlation can be observed with the duration of night-time ventilation: the longer the period of operation, the higher the value of C_{ve}. In fact, operating night-time ventilation for a longer period allows a deeper activation of the thermal mass of the building (except if the thermal mass has already been fully discharged).

The two figures below present the results for two levels of internal heat loads. The adjustment coefficient is not influenced by the amount of heat accumulated in the room.

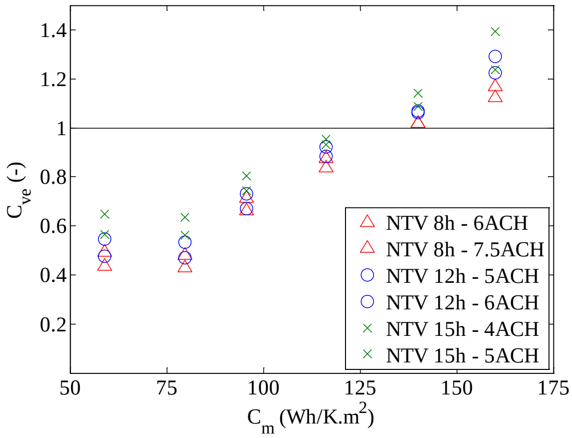


Figure 34: Adjustment coefficient C_{ve} as a function of the room thermal mass (heat loads = 10.3 W/m²)

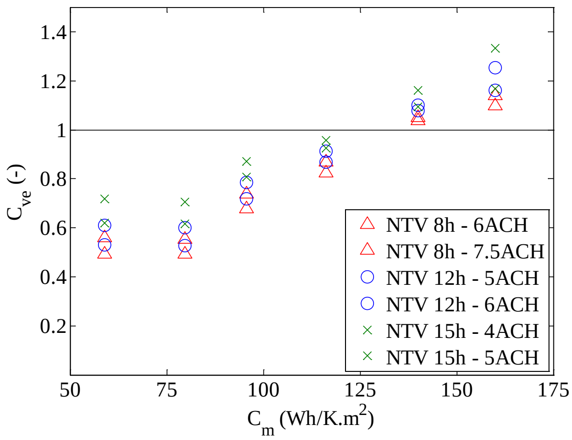


Figure 35: Adjustment coefficient C_{ve} as a function of the room thermal mass (heat loads = 20.6 W/m²)

From the previous observations, it can be concluded that the adjustment coefficient C_{ve} depends mainly on the thermal mass of the room, but also on the maximum operating time of night-time ventilation. Therefore a correlation has been developed based on these parameters:

$$C_{ve} = max\begin{pmatrix}-0.251 + 0.008\, C_m + 0.016\, max\, hrs_{NTV} \\ 0.55\end{pmatrix}$$

A minimum threshold value has been set in order to avoid too large errors for buildings with low thermal mass. Comparing the derived values of C_{ve} to the one obtained with the previous equation, a mean deviation of 6.1 % on C_{ve} has been observed.

In order to evaluate the improvement achieved with the use of customized values of C_{ve}, the annual cooling consumption obtained with $C_{ve} = 1$ and with the derived equation have been compared to the values obtained from dynamic simulations. The error is expressed a percentage of the total energy consumption, as performed in EN ISO 13790. In this standard, deviations up to 10 % have been observed.

As expected, the default value $C_{ve} = 1$ underestimates the cooling consumption due to an overestimation of the efficiency of the storage and the night cooling. The use of a customised value of C_{ve} improves the accuracy of the calculation method: the uncertainty is lowered down to 4.5%. The largest error is observed in the case of buildings with low thermal mass.

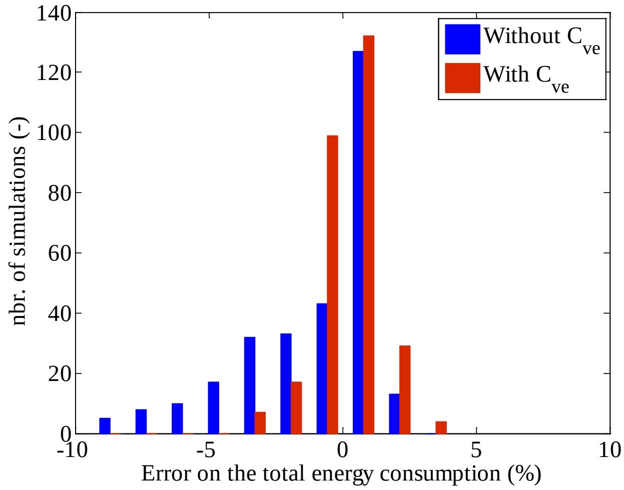


Figure 36: Comparison of the error on the total energy consumption with and without C_{ve}

4.4.2 Results with Method 2 (C_γ)

The method used for analysing the results with the correction factor C_γ is similar to the one described in the previous section. In this case, a strong correlation between thermal mass and adjustment factor has also been observed. But the threshold, which has been observed in the case of C_{ve}, is not so distinct in this case. Similarly to method 1, there is also a dependence between the maximum operating time of night-time ventilation and the value of C_γ.

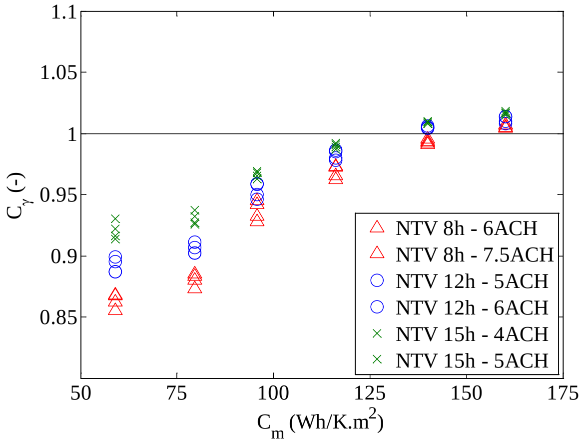


Figure 37: Adjustment coefficient C_γ as a function of the room thermal mass (all simulations)

Therefore, another correlation has been developed between C_γ and these parameters:

$$C_\gamma = 0.7666 + 0.0013\, C_m + 0.0044\, max\ hrs_{NTV}$$

Comparing the derived values of C_γ to the one obtained with the derived equation, a mean deviation of 1.2 % on C_γ has been observed. This value is lower than the one obained for C_{ve}, but it does not mean that the method is more accurate, as the variation range of C_γ is smaller.

The figure below compares the accuracy of the original calculation method, to the one using the parameter C_γ. Even though the new calculation method slightly underestimates the performance of night-time ventilation, a large improvement of the accuracy can be observed.

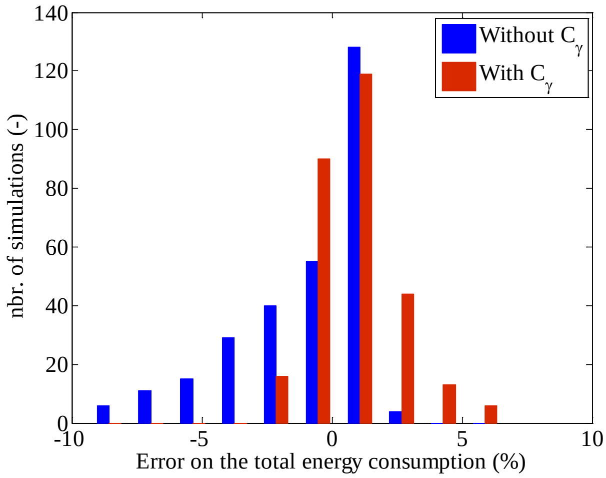


Figure 38: Comparison of the error on the total energy consumption with and without C_γ

4.5 VALIDATION

Validation case:

In order to test the effect of the new correlations, the case of a real office building (single floor) has been modelled. It corresponds of the reference case used in part 3.5.2.

The following characteristics have been changed compared to the model presented before:

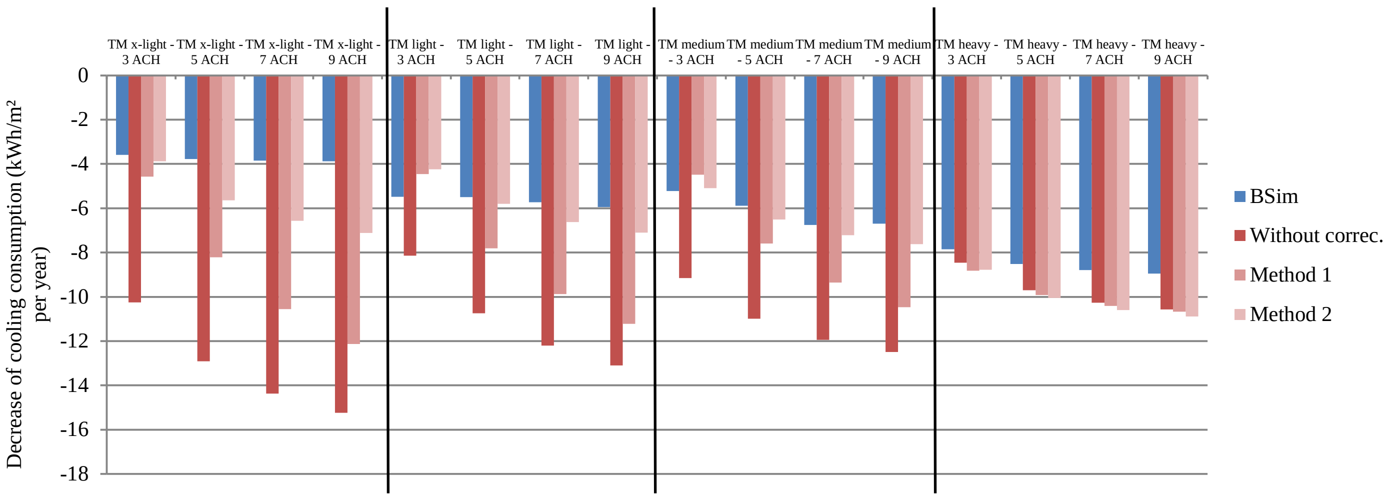
- Internal heat loads: ≈ 21 W/m² during working hours
- building separated in 2 thermal zones, one corresponding to the North façade and another one corresponding to the South façade

Settings for night-time ventilation:

- Maximum time of operation: 12h
- Minimum temperature allowed in the building: 20.1°C
- No pre-heating of air
- No heat emitted by the fans

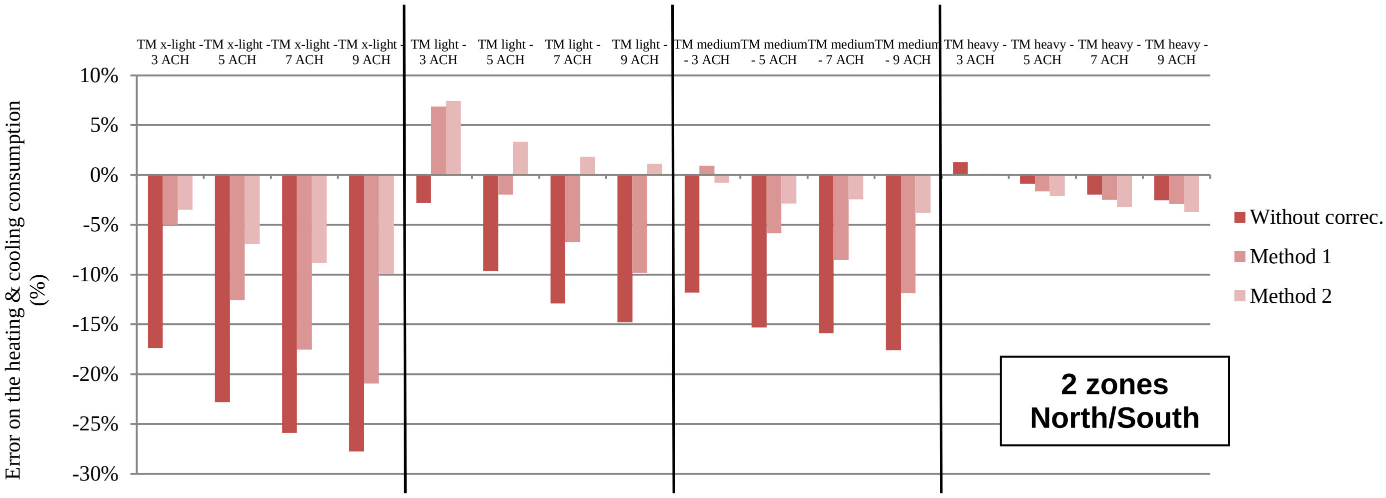
Decrease of the cooling consumption due to NTV:

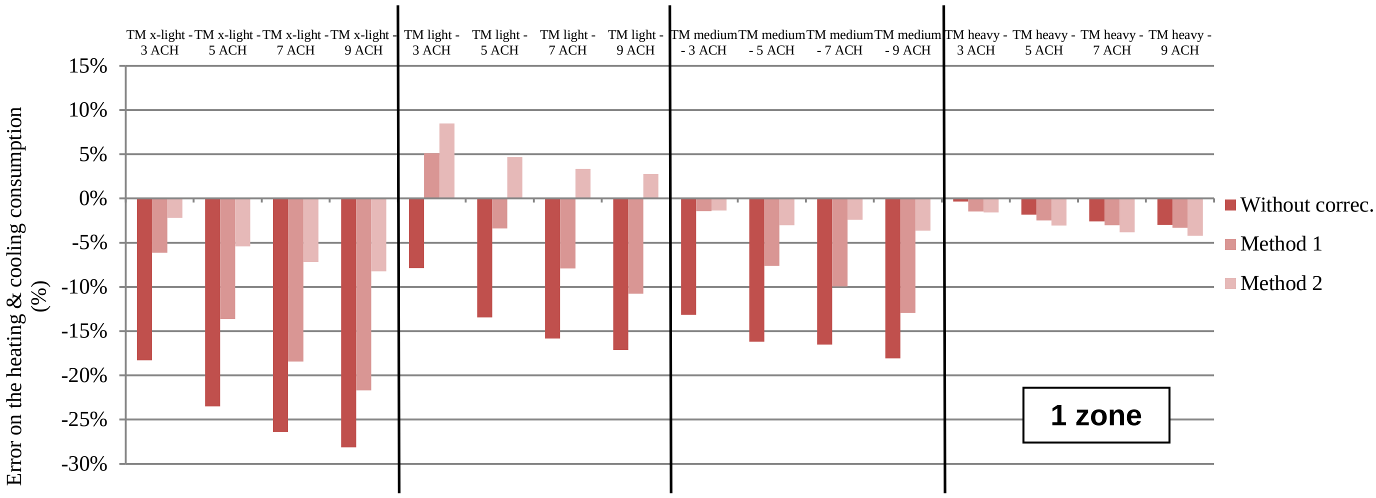
TM x-light: 21 Wh/K.m^2 - TM light: 43 Wh/K.m^2 - TM medium: 75 Wh/K.m^2 - TM heavy: 144 Wh/K.m^2



<u>Total error on the Heating & Cooling consumption:</u>

The heating consumption is assumed to be calculated without error, in order to highlight the effect of the new correlations.





<u>Analysis:</u>

- As expected, when no correction coefficients are applied, the efficiency of night-time ventilation will be overestimated
- When the building thermal mass is extremely light (i.e. 21 Wh/K.m^2), all methods overestimate the efficiency of night-time ventilation. This can be explained by the fact that correlations have been developed for buildings over 50 Wh/K.m^2, which corresponds to most of the building stock. Setting a lower value for the coefficients could be a solution to improve the accuracy of Method 2.
- Method 2 could be a suitable method to model night-time ventilation in the monthly calculation method, as the uncertainty is less than 5 % for most of the cases. It behaves better than Method 1, which is too much dependant on the air change rate of NTV.

- One attracting characteristic of Method 2 is that the results are accurate enough when modelling a building as a single zone. It can therefore save a lot of computational time. It has to be noticed that the mono-zone modelling with BSim will not give results accurate enough.
- The maximum value of the correction coefficient for Method 2 could be set equal to 1, as it seems that it slightly overestimates the efficiency of NTV for heavy buildings.

4.6 CONCLUSION

The possibility of modelling night-time ventilation in the quasi-steady state method (also named monthly calculation method) has been studied by mean of dynamic simulations. The case of a typical office room located in Denmark has been simulated under different conditions. The thermal mass, the level of insulation, the orientation, the internal heat loads and also the duration and the air change rate of night-time ventilation have been varied resulting in a total of 288 simulations.
The dynamic effects have a strong influence on the efficiency of night-time ventilation. The decrease of the cooling consumption depends on the ability of the building to store heat during the day, but also on the efficiency of the ventilation system to remove this heat during night. This interdependence day/night is the main issue when defining a calculation method.

Two different calculation methods have been tested: one corrects the convective heat transfer by ventilation using the factor C_{ve}, and the other one introduces an adjustment factor C_γ on the relative heat gains. For both methods, the derived correction factors are highly dependent on the thermal mass of the building. An influence of the maximum period of activation of night-time ventilation has also been observed. Correlations have been developed for C_{ve} and C_γ for buildings having a thermal mass between 50 up to 175 Wh/K.m². The increase of accuracy has been assessed by comparing the annual cooling and heating consumption obtained with and without adjustment factor. The use of such coefficients improves the accuracy of the calculation method, lowering the uncertainty from around 10 % down to 5%. The first method proposed (C_{ve}) showed a slightly better accuracy, but is quite dependant on the threshold set. The second method has a better accuracy for low thermal mass buildings, and is easier to apply.

In order to further validate the methods and assess the most suitable model, simulations on a whole building with different shape and windows size have been performed. Method 2 showed a better accuracy than Method 1: the maximum error on the cooling and heating consumption was below 5 %, except for extremely light buildings. It has also been observed that the accuracy of the model developed was not sensitive to the zoning of the building, which is an important feature of the monthly calculation method (robustness).
Therefore the adjustment factor C_γ seems to be a good solution for modelling night-time ventilation. This adjustment factor is probably climate-dependant, i.e. not applicable to climate with a different Climatic Cooling Potential (CCP). The use of a pre-heating system or a different minimum temperature (20°C in this case) might also influence the accuracy of the correlation developed.

$$\mathrm{C}_\gamma = min\begin{pmatrix} 0.7666 + 0.0013\, C_m + 0.0044\, max\, hrs_{NTV} \\ 1 \end{pmatrix}$$

Summary

The main purpose of this report was to develop a calculation tool that takes into consideration night-time ventilation in the program Be10.

In a first part, the robustness of the monthly calculation has been assessed by varying the ratio of gains/losses and comparing the results from BSim with the results of the monthly calculation. It has been observed that the schedules of ventilation and internal heat loads play an important role in the accuracy of the calculation method.

In a second part, the effect of thermal mass on the energy consumption has been better taken into consideration for the Danish conditions, by updating the utilisation factors used for the calculation of cooling and heating. The following proposal has been made, based on the results of simulations of a typical office building located in Denmark:

	Denmark - Others	
	Heating	Cooling
Reference time constant τ_0 (h)	47	35
Numerical parameter of reference a_0 (-)	2.87	2.79
Reference ratio of windows area to the floor area (external) ξ_0 (-)	-	2.69

$$a = a_0 - \xi \cdot \xi_0 + \frac{\tau}{\tau_0}$$

For the cooling case, a new parameter ξ_0 has been introduced: it is the reference ratio of windows area to the floor area. The accuracy of the calculation method with these new parameters is estimated to be around 5% on annual basis.

Finally four different methods for evaluating night-time ventilation in the monthly calculation have been evaluated. Out of these four calculation methods, one has shown a good potential for modelling night-time ventilation: The adjustment factor is applied directly on the ratio of gains to losses and the ventilation losses are calculated assuming $C_{ve} = 1$. The loss utilisation factor is defined as follows:

$$\eta_{C,ls} = \frac{1 - (C_\gamma \, \gamma_C)^{-a_C}}{1 - (C_\gamma \, \gamma_C)^{-(a_C+1)}}$$

$$C_\gamma = min\begin{pmatrix} 0.7666 + 0.0013\, C_m + 0.0044\, max\, hrs_{NTV} \\ 1 \end{pmatrix}$$

In the validation case, the accuracy of this calculation method has been evaluated to ± 5%, which is in line with the accuracy of the global calculation method.

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Appendix

1. Structure of the Matlab program

Room numbering

			N	E	S	W
		TM 120	021	022	023	024
	BR15	TM 90	017	018	019	020
		TM 60	013	014	015	016
		TM 120	009	010	011	012
	BR10	TM 90	005	006	007	008
		TM 60	001	002	003	004

INPUT FILES

Simul_w.m	Date						
	Heating_SP	Heating_t_start	Heating_t_end	Heating_d_start	Heating_d_end		
	Cooling_SP	Cooling_t_start	Cooling_t_end	Cooling_d_start	Cooling_d_end		
	Ventil_ACR	Ventil_hr_h	Ventil_hr_c	Ventil_t_start	Ventil_t_end	Ventil_d_start	Ventil_d_end
	Loads_q	Loads_t_start	Loads_t_end	Loads_d_start	Loads_d_end		
	Solar_g						
	NTV_ACR	NTV_t_start	NTV_t_end	NTV_d_start	NTV_d_end		
	Comments						

BSim_w_dualSP.txt	**B1**	Bsim text file	
BSim_w_heatingSP.txt	**B2**	GENERAL	Year Month Day Hour
BSim_w_coolingSP.txt	**B3**	VALUES (for each room)	GrossSun(qHeating(qCooling(` qTransmis qVentilat(qEquipme qSunRad(TZ)kW
BSim_w_heatingSP_NoGain.txt	**B4**	CHECK (for each room)	Nbr of hou GrossSun(Top qEquipment(TZ)kW qSunRad(TZ)kW
BSim_w_coolingSP_NoGain.txt	**B5**		

! on the window

CONTENT (197 columns) Year Month Day Hour $\underbrace{\text{qCooling(` qHeating( qEquipme qTransmis qVentilat( qSunRad(` GrossSun(Top}}_{\text{x 24 rooms (from 001 to 024)}}$ ExtTmp

COMMON DEFINITIONS

Input_rooms.m from room 001 to room 024, define:

Aspect	Internal dimensions	Floor area	Volume	Window area	External wall area
Building regulation					
U window	U external wall				

Input_TM.m Thermal mass of each element and rooms

Input_weather.m Solar radiation for the 4 aspects: I_sol_N I_sol_E I_sol_S I_sol_W
Monthly Temp ext
Monthly time (sec)

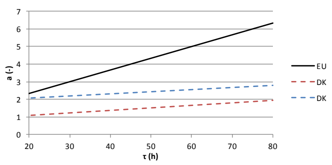
Input_util_factor.m

DK

	Heating		Cooling	
	Residenti:	Others	Residenti:	Others
Reference time constant depending on the country τ0 (h)	15	70	83	83
Numerical parameter of reference a0 (-)	1	0.8	1.83	1.83

EU

	Heating		Cooling	
	Residenti:	Others	Residenti:	Others
Reference time constant depending on the country τ0 (h)	15	15	15	15
Numerical parameter of reference a0 (-)	1	1	1	1



MONTHLY

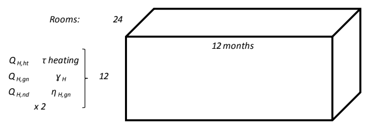
Monthly_Util_factor_room.m input: room nbr
type of calc (DK,EU)
simulation case w

output monthly: heating: H_{tr} $Q_{H,tr}$ H_{vent} $Q_{H,ve}$ $Q_{H,ht}$
$Q_{H,sol}$ $Q_{H,int}$ H_{int} $Q_{H,gn}$
$Q_{H,nd}$
τ heating $a_{H,red}$ γ_H $\eta_{H,gn}$

cooling: same parameters

Monthly_Util_factor_allRooms.m input: simulation case w
type of calc (DK,EU)

calculation for all rooms of the simulation
create Monthly_Simul_w.mat



BSIM

readBSim.m convert text files into .mat files

BSim_Util_factor_room.m input: for the 5 simulations (matrix 8760*5)
Top_x ventil_x
heating_x GrossSun_x
cooling_x Solar_x
trans_x Equip_x

check validity simulation: length of the simulation
operative temperature (+/- 0.01K max)
internal heat loads (value or 0, profile)
solar radiation (5% difference on the mean solar radiation depending on aspect or 0) - Gross Sun > qSunRad

output monthly: heating: $Q_{H,ht}$ $Q_{H,gn}$ $Q_{H,nd}$
*a_h** γ_H $\eta_{H,gn}$

cooling: $Q_{C,ht}$ $Q_{C,gn}$ $Q_{C,nd}$
*a_c** γ_C $\eta_{C,gn}$

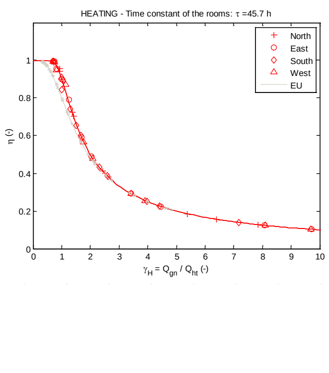
* 1st column: normal fitting - 2nd fitting: security fitting, south rooms - 3rd fitting: security, lower values
obtained from the fitting curve, same value for the 4 aspects

BSim_Util_factor_allRooms.m input: simulation case w

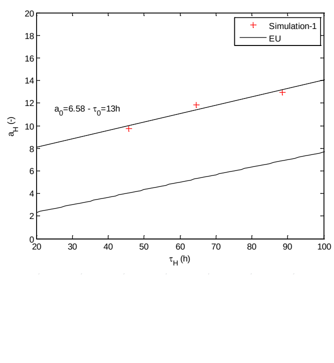
calculation for all rooms of the simulation
create Bsim_Simul_w.mat (same than Monthly_Simul_w.mat, except that τ replaced by a)

OUTPUT

Plot_Eta_Gamma_Bsim_Monthly.m
Output: For each floor, and for cooling-heating, plot η=f(γ)



Plot_a_To_BSim.m
Output: For all the experiments, and for cooling-heating, plot a=f(τ)

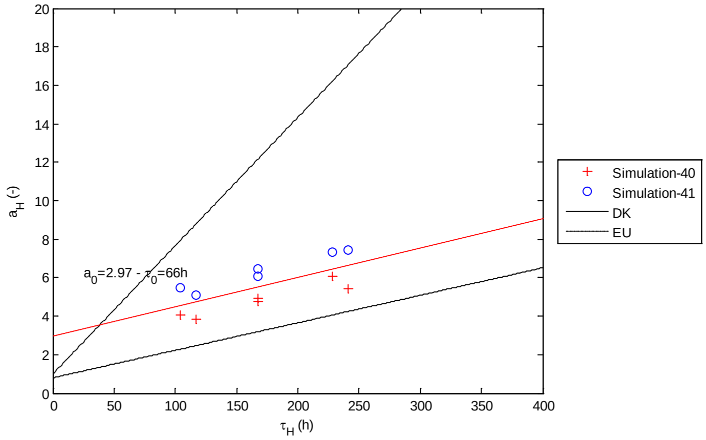


2. Validation of the calculation method

About the necessity of grouping 2 levels of internal heat loads:

- Example 1:

  The initial fitting does not gather the 2 simulations (internal heat loads of 10 W/m² for one simulation, and 20 W/m² for the other one). It seems that there is a dependence on the level of internal heat loads.



But when comparing the curves of $\eta_{H,gn} = f(\gamma_H)$ and $\eta_{C,ls} = f(\gamma_C)$, no difference can be observed between the two sets of data:

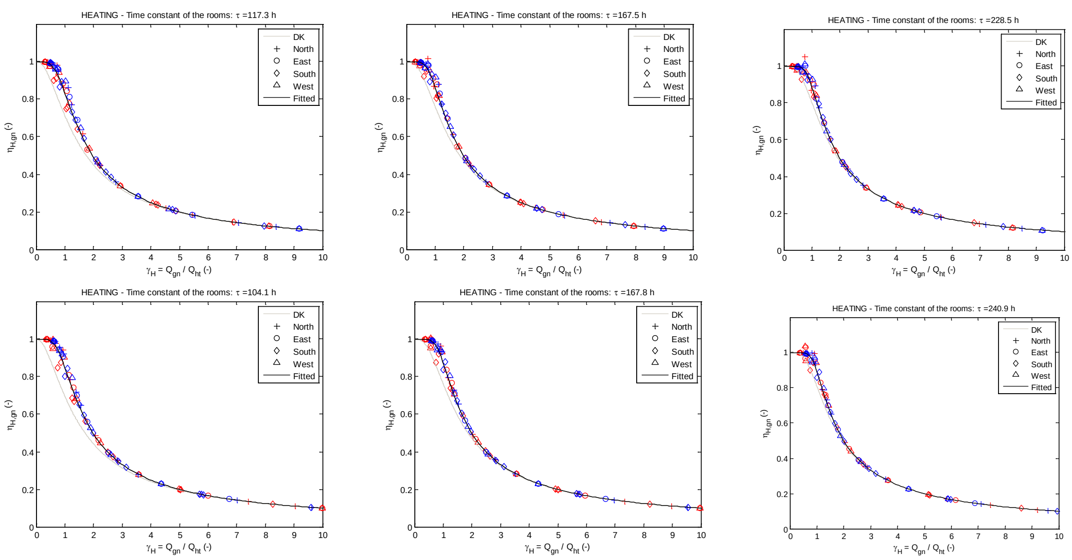


Figure 39: Curves of the utilisation factor for the six floors and two levels of internal heat loads (red markers 10 W/m² - blue markers 20 W/m²) - Heating case

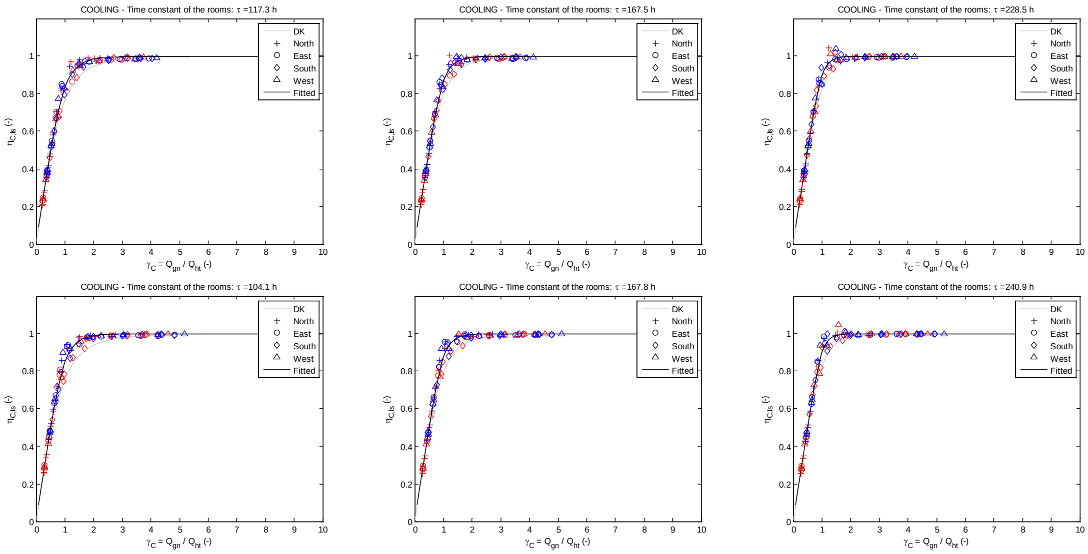
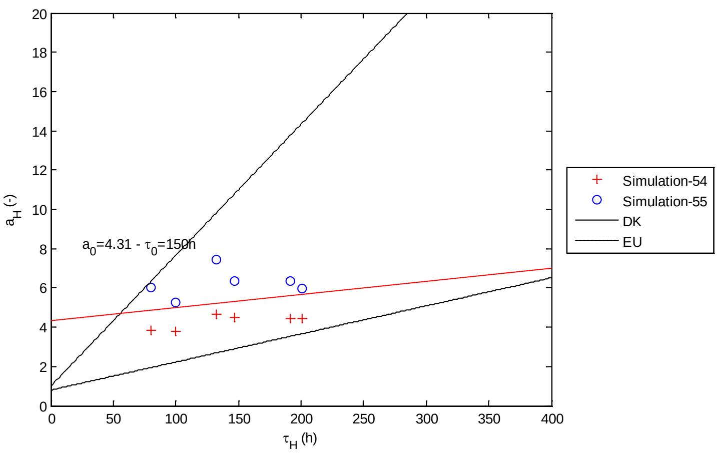
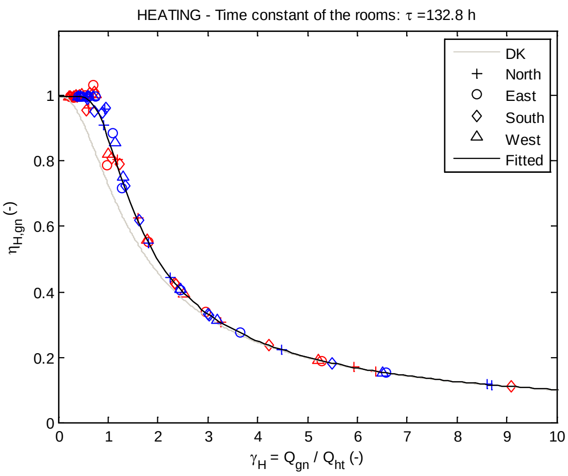


Figure 40: Curves of the utilisation factor for the six floors and two levels of internal heat loads (red markers 10 W/m² - blue markers 20 W/m²)   -   Cooling case

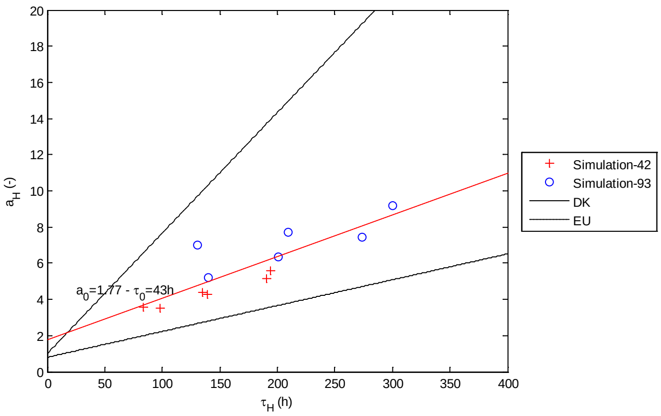
- o <u>Example 2:</u>
  The same comments can be done on this curve (smaller windows):



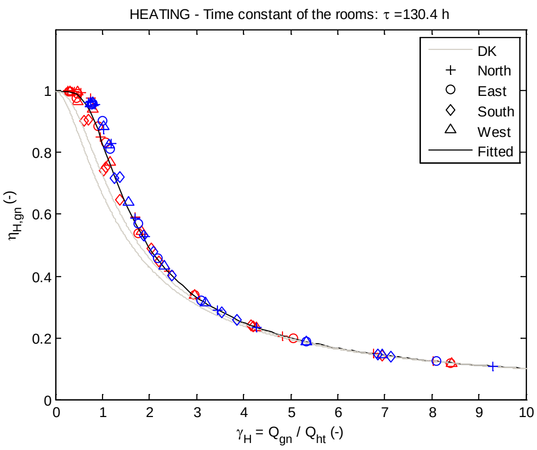
And here are the two curves $\eta_{H,gn} = f(\gamma_H)$:



o <u>Example 3:</u>
The same comments can be done on this set of data (ventilation with heat recovery):



And here are the two curves $\eta_{H,gn} = f(\gamma_H)$:



Why realizing a "safe" curve fitting?

When having a closer look to the results, it can be seen that a normal fitting does not give appropriate results. There are two main reasons for it:

- a normal fitting will lead to an overestimation of the utilisation factor in 50% of the case, as it corresponds to an average value
- the overestimation occurs mainly for rooms, which are receiving high solar heat loads (e.g, the south facing rooms). Therefore a small overestimation in the utilisation factor will automatically leads to a high error in the calculation of the heating and cooling consumption

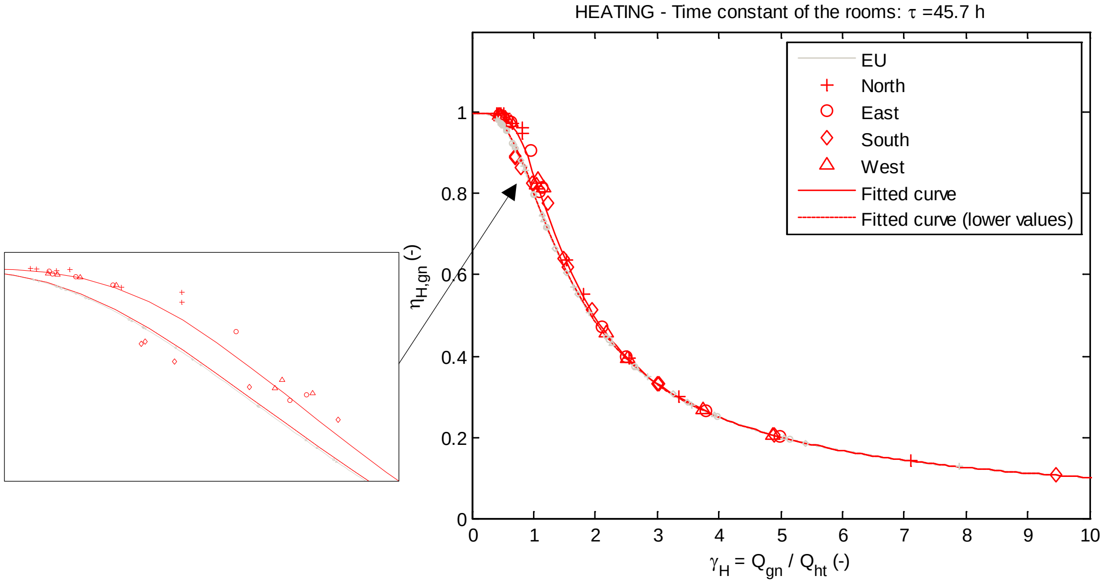


Figure 41: Utilisation factor for heating – comparison of the results from dynamic simulation, with the theoretical results (from the monthly calculation)

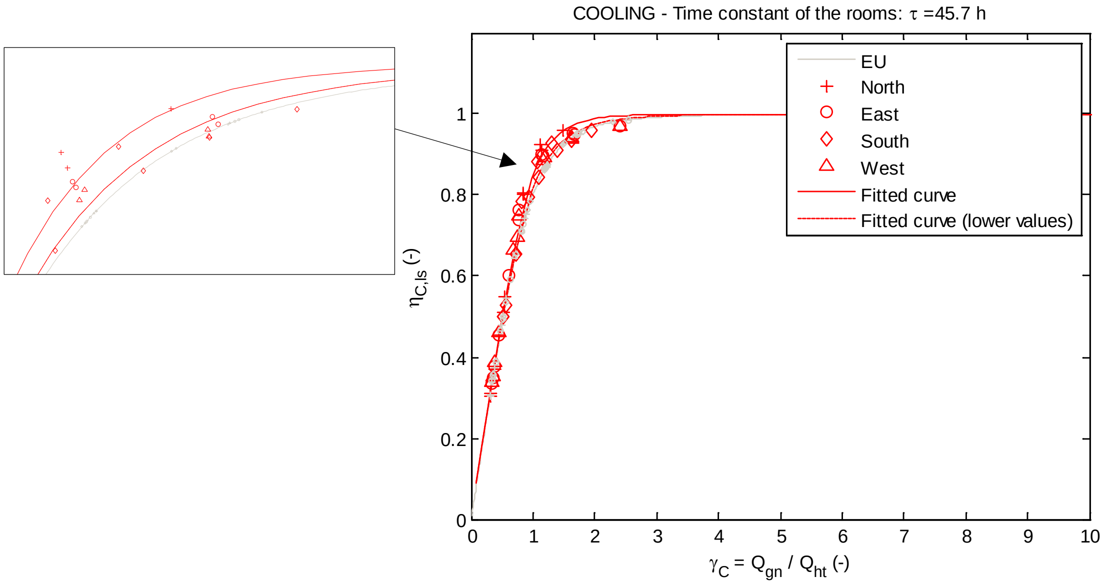


Figure 42: Utilisation factor for cooling – comparison of the results from dynamic simulation, with the theoretical results (from the monthly calculation)

Therefore an improved fitting has been performed on the results. This new fitting gives more weight to the lowest values in the transition part (weight of 3, instead of 1 for other values), and therefore avoids overestimation of the utilisation of thermal mass.

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