ENERGY SAVING AND CO_2 REDUCTION POTENTIAL FROM SOLAR SHADING SYSTEMS AND SHUTTERS IN THE EU-25

(ESCORP-EU25)

A scientific study about the effects of solar shading on energy use and comfort.
Reducing the use of fossil energy means reducing carbon emissions in the atmosphere and reducing our dependence on imported sources of energy.
Passive cooling – as opposed to artificial cooling with electric energy – is a responsible and smart way to deal with overheating in summer.
Solar shading is a large part of the answer.

A RESEARCH PROJECT COMMISSIONED BY ES-SO, THE EUROPEAN SOLAR SHADING ORGANIZATION

Introduction

Everybody has heard about the EU targets under the Kyoto Protocol and the need to reduce the emission levels of greenhouse gases. Also, almost everybody in the EU has experienced the heat waves of 2006 -- so close to those of 2003 -- and has wondered whether the climate change is finally becoming a palpable reality. Shouldn't we be worried?

Climate change and the corresponding need to reduce fossil fuel use have been making headlines for years now. Heat waves are countered with massive purchases of air conditioners, with an equally massive increase of the use of electricity as a logical consequence. But where will the growth of electricity be coming from? Shouldn't we care?

The EU authorities have understood that energy efficiency – using energy more intelligently – is a source of great savings. Absorbing a staggering 40% of the total energy use, the building sector cannot be left alone. In fact, it is the biggest single energy user, larger than industry and even transport. Shouldn't we act?

Among the strategic objectives of the EU, security of energy supply, economic growth and more qualified jobs rank very high. Security of energy supply is enhanced, of course, by energy efficiency. But . . . . did we tap all available sources of energy efficiency? Of course, we did not! In the building practice, we have come to rely more and more on installations to provide comfort, heat and fresh air. The traditional 'intuitive' building methods, where a relative degree of comfort was a logical consequence of common sense building practices, has made way to an almost unlimited confidence in the merits of 'installations', that will blow, heat, cool, humidify and dry. At the expense of considerable energy use, robust investments and often underestimated maintenance cost and trouble.

When it comes to summer comfort, blowing in cold air through ducts and pipes, to compensate for the unlimited entry of solar heat, is not always the smartest solution. Solar shading is probably the most underestimated and misunderstood source of passive cooling. 'Passive cooling' means cooling without the use of extra energy. Free, no cost. 'Solar shading' is a term that refers to a great number of products. Each of us is familiar with some of them: roller shutters, curtains, maybe venetian blinds. But there is so much more, especially for the outside of the building. Stopping the heat from the sun from entering the house or the building, obviously, is better that letting it in and then cooling it down to comfort levels, at the expense of extra energy.

ES-SO, the umbrella organization of the European solar shading industry with members from twelve EU countries, has commissioned a reputable engineering company, specialized in building simulations, to calculate what the effect would be if solar shading would be applied more systematically. Would we make a contribution toward the Kyoto targets? Would it be noticeable in the energy balance? Would it make a dent in the imported oil consumption of the EU? In short, would it make a difference for the EU policy objectives?

It would. This report will explain. Enjoy reading it and let us know if we can help you.

ES-SO – 2006
Dick Dolmans

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PHYSIBEL REPORT 2005_09A_ES-SO

Title .... ENERGY SAVING AND CO_2 REDUCTION POTENTIAL
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Date ....December 2005

INTRODUCTION

Solar blinds and shutters contribute to reduce the energy demand of buildings in 2 ways:

- In wintertime, due to a supplementary thermal resistance in closed position, they reduce the heating energy demand.
- In summertime, by avoiding superfluous solar heat gains, they reduce the cooling energy demand.

The energy demand reduction and the corresponding CO_2 reduction are quantified using so-called building simulations, i.e. numerical simulations of the heat transfer in buildings under real climate conditions using real user profiles. The simulations are in line with European and ISO standards.
A lot of parameters affect the thermal behaviour of a building: the climate, the façade, roof and floor building up, its orientation, its use, and much more. The simulations are done for a set of representative combinations of the parameters, allowing predicting the energy demand reduction from solar blinds and shutters for the EU building stock.

BUILDING SIMULATION PARAMETERS

Each building is unique in respect of its thermal and energy behaviour because of the large amount of parameters affecting its thermal behaviour. However, looking to the effect of solar blinds and shutters on the energy demand of buildings, some parameters are more important and some less important. In the building simulations, fixed values are taken for the less important parameters, while for 7 important parameters representative values are selected, as described below.

1) A room with dimensions 5 m x 5 m x 3 m is considered.
   2 building envelope types are considered (Figure 1):
   B1: 1 external façade, 3 internal walls, an internal floor and an internal ceiling
   B2: 2 external façades, 2 internal walls, an internal floor, half an external roof and half an internal ceiling.
   The first situation is representative for a room in an apartment block, or for an office room in large building, while the second one is representative for a office in a building with a weak compactness but also for a room in a stand-alone house.
   The thermal inertia of the room is considered as being medium assuming perforated brickwork in walls and floors. The configuration of all walls and floors is given in Figure 2.
   The window opening in each external façade is 4.5 m^2 (18 % of the floor area).

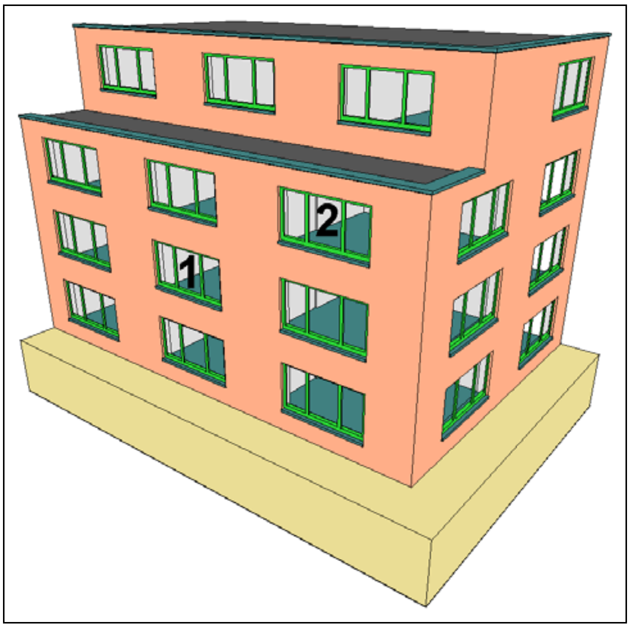

Figure 1. Building envelope types 1 and 2.

cavity_wall_1.CWT

side1 => side2

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	side 1 ε1ir [-]	side 1 ρ1s [-]	side 1 α1s [-]	side 2 ε2ir [-]	side 2 ρ2s [-]	side 2 α2s [-]
1	brickwork_1800	NORMAL		0.09	0.900	0.100	1800	850	-	-	0	0.90	0.40	0.60	0.00	0.00	1.00
2	insulation	NORMAL		0.06	0.035	1.714	40	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
3	brickwork_1200	NORMAL		0.14	0.450	0.311	1200	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
4	gypsum layer	NORMAL		0.015	0.500	0.030	1300	850	-	-	0	0.00	0.00	1.00	0.90	0.70	0.30

dtot=0.305 m, Rtot=2.155 m²K/W with [h1=25.0 W/m²K, h2=7.7 W/m²K] U=0.43 W/m²K , g=0.00

half_wall_1.CWT

side1 => side2

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	side 1 ε1ir [-]	side 1 ρ1s [-]	side 1 α1s [-]	side 2 ε2ir [-]	side 2 ρ2s [-]	side 2 α2s [-]
1	gypsum layer	NORMAL		0.015	0.500	0.030	1300	850	-	-	0	0.90	0.70	0.30	0.00	0.00	1.00
2	brickwork_1200	NORMAL		0.07	0.450	0.156	1200	850	-	-	0	0.00	0.00	1.00	0.90	0.00	1.00

dtot=0.085 m, Rtot=0.186 m²K/W with [h1=25.0 W/m²K, h2=7.7 W/m²K] U=2.81 W/m²K , g=0.00

flat_roof_1.CWT

side1 => side2

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	side 1 ε1ir [-]	side 1 ρ1s [-]	side 1 α1s [-]	side 2 ε2ir [-]	side 2 ρ2s [-]	side 2 α2s [-]
1	bitumen	NORMAL		0.015	0.200	0.075	1000	1700	-	-	0	0.90	0.10	0.90	0.00	0.00	1.00
2	insulation	NORMAL		0.06	0.035	1.714	40	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
3	concrete_1600	NORMAL		0.05	0.850	0.059	1600	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
4	vaults	NORMAL		0.14	0.450	0.311	1200	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
5	gypsum_layer	NORMAL		0.015	0.500	0.030	1300	850	-	-	0	0.00	0.00	1.00	0.90	0.70	0.30

dtot=0.280 m, Rtot=2.189 m²K/W with [h1=25.0 W/m²K, h2=7.7 W/m²K] U=0.42 W/m²K , g=0.00

half_floor_1.CWT

side1 => side2

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	side 1 ε1ir [-]	side 1 ρ1s [-]	side 1 α1s [-]	side 2 ε2ir [-]	side 2 ρ2s [-]	side 2 α2s [-]
1	hard limestone	NORMAL		0.015	2.100	0.007	2350	840	-	-	0	0.90	0.40	0.60	0.00	0.00	1.00
2	concrete_1600	NORMAL		0.05	0.850	0.059	1600	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
3	vaults	NORMAL		0.04	0.450	0.089	1200	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00

dtot=0.105 m, Rtot=0.155 m²K/W with [h1=25.0 W/m²K, h2=7.7 W/m²K] U=3.08 W/m²K , g=0.00

half_ceiling_1.CWT

side1 => side2

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	side 1 ε1ir [-]	side 1 ρ1s [-]	side 1 α1s [-]	side 2 ε2ir [-]	side 2 ρ2s [-]	side 2 α2s [-]
1	vaults	NORMAL		0.1	0.450	0.222	1200	850	-	-	0	0.00	0.00	1.00	0.00	0.00	1.00
2	gypsum_layer	NORMAL		0.015	0.500	0.030	1300	850	-	-	0	0.00	0.00	1.00	0.90	0.70	0.30

dtot=0.115 m, Rtot=0.252 m²K/W with [h1=25.0 W/m²K, h2=7.7 W/m²K] U=2.37 W/m²K , g=0.00

Figure 2. Wall and floor configuration and material properties.

2) 2 orientations are considered:
   SW: South-West for the 1st external façade, North-West for the 2nd external façade.
   NE: North-East for the 1st external façade, South-East for the 2nd external façade.

3) 2 user profiles are considered:
   U1: thermal comfort requirement and 5 W/m² internal gains from 08:00h to 22:00h 7 days a week,
   U2: thermal comfort requirement and 25 W/m² internal gains from 09:00h to 18:00h 5 days a week.
   The first user profile is representative for a residential situation, the second for an office.
   The thermal comfort control system used is described further.

4) 2 types of windows (frame + glazing) are considered (cf. Table 1):
   W1: window with thermal transmittance U = 2.6 W/m^{2}K and solar factor g = 0.63,
   W2: window with thermal transmittance U = 1.8 W/m^{2}K and solar factor g = 0.63.
   The first situation is representative for a renovation of a building with existing double glazed windows in good condition. The second situation is representative for of new windows in new or existing buildings.

5) 2 types of window protection systems are considered:
   BH: with high air permeability,
   BL: with low air permeability.
   The degree of permeability is defined in EN ISO 10077-1 (cf. Figure 3). This standard defines 5 air permeability classes (very high, high, average, low, very low).
   A roller blind is an example of a high air permeability system.
   A (tight) roller shutter is an example of a low air permeability system.
   Therefore, the term ‘blind’ will be used to refer to a high air permeability system, while the term ‘shutter’ will refer to a low air permeability system.
6) 2 blind or shutter positions are considered:
   BE: external position,
   BI: internal position.
   The internal position for a high air permeability system (shutter) can be associated with the use of curtains.

Table 1 shows the thermal transmittance U and the solar factor g of the windows with and without both blinds and shutters and for both positions. These values are derived from the material properties listed according to EN 673, EN 410 and EN ISO 10077-1.

Transparent wall file name	**thermal transmittance U** **[W/m2K]**	**solar factor g** **[-]**	layer	thickness [m]	thermal conductivity [W/mK]	thermal resistance [m2K/W]	density [kg/m3]	specific heat [J/kgK]	side 1 longwave emissivity [-]	side 2 longwave emissivity [-]	solar transmission factor [-]	side 1 solar reflection factor	side 2 solar reflection factor
Window_U2p6_g63_int_lowpb_up.CWT	**2.60**	**0.63**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U2p6_g63_int_lowpb_down.CWT	**1.64**	**0.28**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
			cavity R 0.14	0.1		0.14	1.2	1005					
			blind R 0.08	0.02	0.25	0.08	500	1470	0.9	0.9	0.001	0.5	0.499
Window_U2p6_g63_int_highp_up.CWT	**2.60**	**0.63**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U2p6_g63_int_highp_down.CWT	**2.07**	**0.31**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
			cavity R 0.09	0.05		0.09	1.2	1005					
			blind R 0.01	0.001	0.2	0.01	500	1470	0.9	0.9	0.1	0.5	0.499
Window_U2p6_g63_ext_lowpb_up.CWT	**2.60**	**0.63**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U2p6_g63_ext_lowpb_down.CWT	**1.64**	**0.07**	blind R 0.08	0.02	0.25	0.08	500	1470	0.9	0.9	0.001	0.5	0.499
			cavity R 0.14	0.1		0.14	1.2	1005					
			eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U2p6_g63_ext_highp_up.CWT	**2.60**	**0.63**	eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U2p6_g63_ext_highp_down.CWT	**2.07**	**0.11**	blind R 0.01	0.001	0.2	0.01	500	1470	0.9	0.9	0.1	0.5	0.499
			cavity R 0.09	0.05		0.09	1.2	1005					
			eq. U=2.6 g=0.63	0.008	0.0372	0.22	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_int_lowpb_up.CWT	**1.80**	**0.63**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_int_lowpb_down.CWT	**1.28**	**0.31**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
			cavity R 0.14	0.1		0.14	1.2	1005					
			blind R 0.08	0.02	0.25	0.08	500	1470	0.9	0.9	0.001	0.5	0.499
Window_U1p8_g63_int_highp_up.CWT	**1.80**	**0.63**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_int_highp_down.CWT	**1.53**	**0.34**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
			cavity R 0.09	0.05		0.09	1.2	1005					
			blind R 0.01	0.001	0.2	0.01	500	1470	0.9	0.9	0.1	0.5	0.499
Window_U1p8_g63_ext_lowpb_up.CWT	**1.80**	**0.63**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_ext_lowpb_down.CWT	**1.28**	**0.05**	blind R 0.08	0.02	0.25	0.08	500	1470	0.9	0.9	0.001	0.5	0.499
			cavity R 0.14	0.1		0.14	1.2	1005					
			eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_ext_highp_up.CWT	**1.80**	**0.63**	eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32
Window_U1p8_g63_ext_highp_down.CWT	**1.53**	**0.10**	blind R 0.01	0.001	0.2	0.01	500	1470	0.9	0.9	0.1	0.5	0.499
			cavity R 0.09	0.05		0.09	1.2	1005					
			eq. U=1.8 g=0.63	0.008	0.0207	0.39	2500	850	0.837	0.837	0.6	0.32	0.32

Table 1. Data for transparent walls without and with blinds and shutters, at external or internal position.

5.3 Windows with closed shutters

A shutter on the outside of a window introduces an additional thermal resistance, resulting from both the air layer enclosed between the shutter and the window, and the shutter itself (see figure 7). The thermal transmittance of a window with closed shutters, U_{WS}, is given by:

$$U_{WS} = \frac{1}{1/U_W + \Delta R} \qquad (7)$$

where

U_w is the thermal transmittance of the window;

ΔR is the additional thermal resistance due to the air layer enclosed between the shutter and the window and the closed shutter itself (see figure 7).

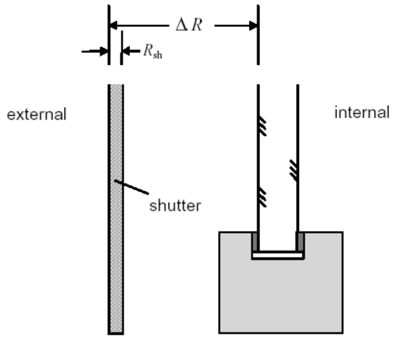

Figure 7 - Window with external shutter

The additional thermal resistance for five categories of shutter air permeability is given in the following expressions:

– shutters with very high air permeability:

ΔR = 0,08 m²·K/W (8)

– shutters with high air permeability:

$\Delta R = 0{,}25\ R_{sh} + 0{,}09$ m²·K/W (9)

– shutters with an average air permeability (for example solid wing shutters, wooden venetian shutters with solid overlapping slats, roller shutters made of wood, plastic or metal, with connecting slats):

$\Delta R = 0{,}55\ R_{sh} + 0{,}11$ m²·K/W (10)

– shutters with low air permeability:

$\Delta R = 0{,}80\ R_{sh} + 0{,}14$ m²·K/W (11)

– tight shutters:

$\Delta R = 0{,}95\ R_{sh} + 0{,}17$ m²·K/W (12)

where R_{sh} is the thermal resistance of the shutter itself.

The above equations are valid for $R_{sh} < 0{,}3$ m²·K/W. If no measured or calculated values for R_{sh} are available, the typical values given in annexes G and H can be used. For external or internal blinds use equations (8) to (12) with $R_{sh} = 0$.

Figure 3. EN ISO 10077-1: additional thermal resistance caused by shutters.

7) 4 climates are considered: Brussels (BRU), Budapest (BUD), Rome (ROM) and Stockholm (STO). The climatic data consist of hourly values of temperature and global and diffuse horizontal solar radiation during a so-called reference year. Figure 4 and Figure 5 contain the weekly mean values of temperature and global horizontal radiation. Plotting the weekly mean values instead of the hourly values used in the simulations allows a more clear comparison between the 4 climates.
The Brussels climate is representative for a moderate sea climate. The Budapest climate is similar in wintertime but warmer and sunnier in summertime. Compared to Brussels, Stockholm has colder winters and more sunny summers. The Rome climate is warmer and sunnier than the other ones.

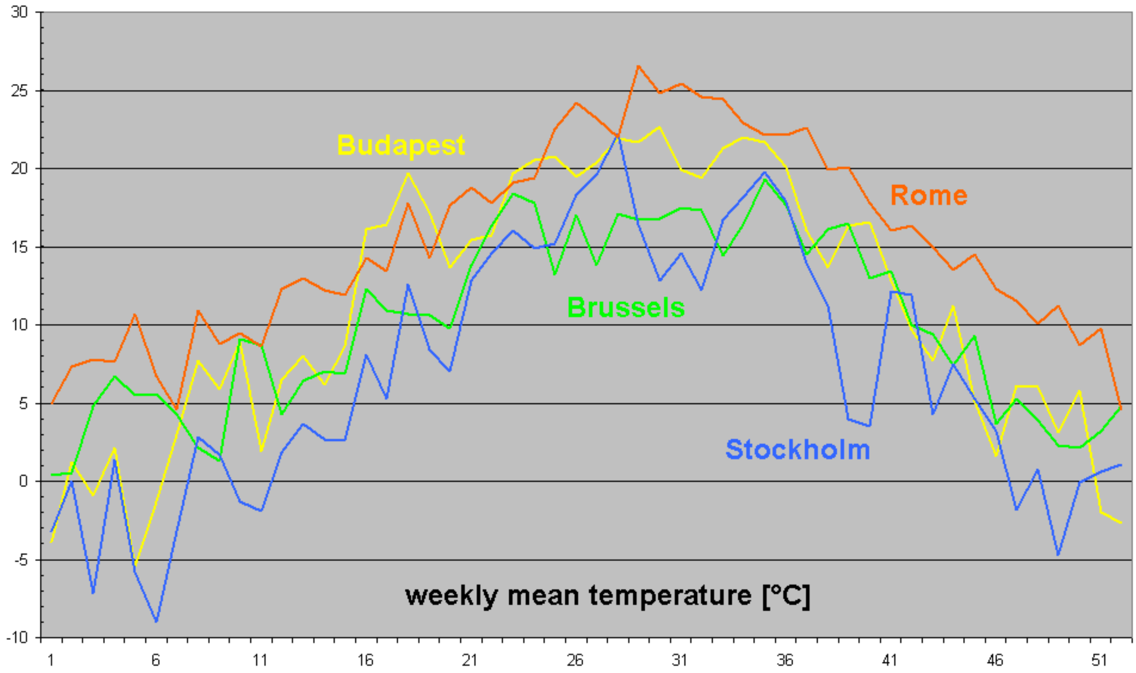

Figure 4. Weekly mean temperature for Brussels, Budapest, Rome and Stockholm.

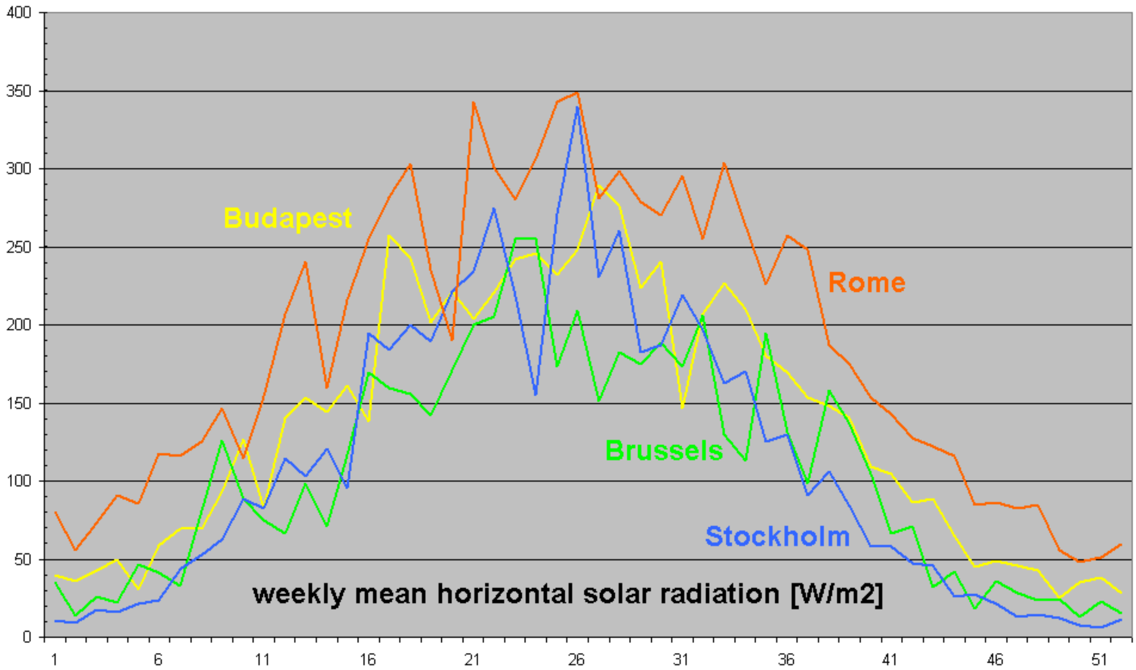

Figure 5. Weekly mean horizontal global solar radiation for Brussels, Budapest, Rome and Stockholm.

Temperature control.
An important issue in building simulation is the temperature control. It concerns the measures required for attempting realizing thermal comfort. These measures can be heating, cooling, ventilation and closing or opening blinds or shutters. In the performed building simulations the following control settings are applied:

- Heating, user profile 1 (residential): target temperature of 20 °C from 08:00h until 22:00h 7 days a week and of 10 °C outside that period.
  Heating, user profile 2 (office): target temperature is 20 °C from 09:00h until 18:00h 5 days a week and of 10 °C outside that period (Figure 6).
- Cooling, user profile 1 (residential): target temperature of 24 °C from 08:00h until 22:00h 7 days a week and of 30 °C outside that period.
  Cooling, user profile 2 (office): target temperature of 24 °C from 09:00h until 18:00h 5 days a week and of 30 °C outside that period (Figure 6).
- Cooling, both user profiles:
  If the indoor temperature is higher than 26 °C and the outdoor temperature is 3 °C lower than the indoor temperature, an extra ventilation of 75 m^3/h (1 room volume per hour) is applied. This avoids active cooling during the mid-season.
- Blinds and shutters, used to reduce heating energy demand:
  - Shutters (low air permeability) are closed from sunset until sunrise.
  - Blinds (high air permeability) are always open during the night. Indeed high air permeability systems such as roller blinds are usually not closed during the night (although it would result in some heating energy demand).
- Blinds and shutters, used to reduce cooling energy demand and to improve summer thermal comfort: Blinds and shutters are closed if the total solar radiation striking the window exceeds 150 W/m^2 and if the indoor temperature is higher than 22 °C. This so-called "intelligent control" allows solar heat gains the heating energy demand during the heating season.

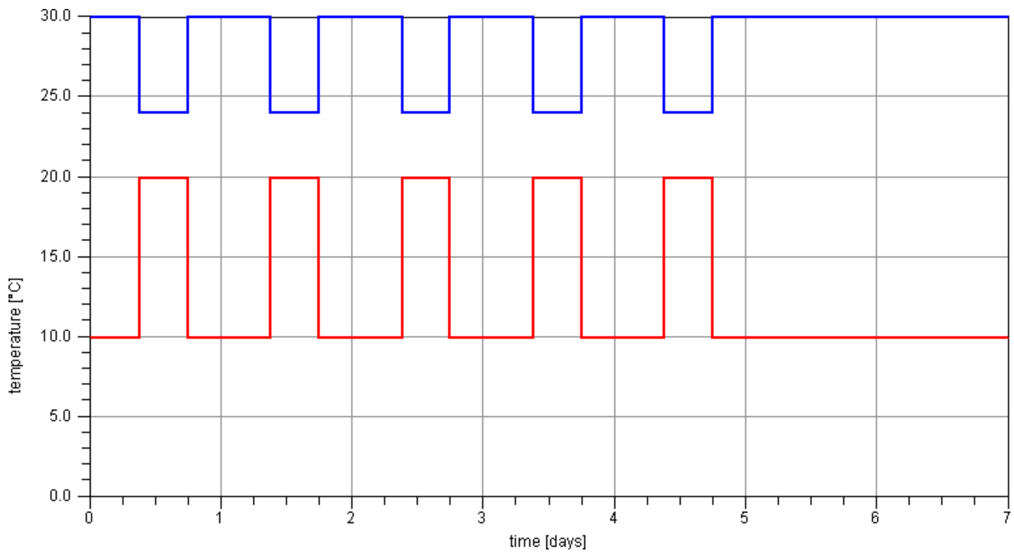

Figure 6. Target temperature for heating and cooling for user profile 2 (office).

Simulation principles.
The simulations are performed using the Physibel program CAPSOL. The principles of this building simulation tool are explained in the CAPSOL manual (Physibel, 2002). The program CAPSOL is validated according to the international standard ISO/FDIS 13791 "Thermal performance of buildings – Calculation of internal temperatures of a room in summer without mechanical cooling – General criteria and validation procedures".

SELECTION OF 24 CASES

The variable parameters mentioned allow a total of 2 x 2 x 2 x 2 x 2 x 2 x 4 = 256 possible combinations. Table 2 shows these combinations. The abbreviations used in the table are explained in the previous section. From these combinations 24 cases were selected in such a way that the results allow to compare the effect of all parameters on the energy demand for heating and cooling. For each case 2 building simulations are done, the first without blinds or shutters, the second with the controlled blinds or shutters.

Building type	Mean Orientation	User Profile	Window type	Blind type	Blind position	CLimate	Simulation done
B1	SW	U1	W1	BH	BE	BRU	11
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	01
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	13
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	12
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
		U2	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	09
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	21
						STO	22
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	

Building type	Mean Orientation	User Profile	Window type	Blind type	Blind position	CLimate	Simulation done
B1	NE	U1	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	07
						BUD	
						ROM	08
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
		U2	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	23
						STO	24
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	

Building type	Mean Orientation	User Profile	Window type	Blind type	Blind position	CLimate	Simulation done
B2	SW	U1	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	02
						BUD	03
						ROM	04
						STO	05
					BI	BRU	15
						BUD	16
						ROM	17
						STO	18
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	14
						BUD	
						ROM	
						STO	
		U2	W1	BH	BE	BRU	20
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	10
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	

Building type	Mean Orientation	User Profile	Window type	Blind type	Blind position	CLimate	Simulation done
B2	NE	U1	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	06
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	19
						BUD	
						ROM	
						STO	
		U2	W1	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
			W2	BH	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	
				BL	BE	BRU	
						BUD	
						ROM	
						STO	
					BI	BRU	
						BUD	
						ROM	
						STO	

Table 2.
Overview of 256 parameter combinations and of the selected 24 simulation cases.

BUILDING SIMULATION RESULTS AND DISCUSSION

The building simulation results in the indoor air and comfort temperature course during the year, and in the energy demand for heating and cooling.
The temperature course is reported only for the first case in order to illustrate the operation of the building simulation program used. Figure 7, Figure 9 and Figure 10 show the outdoor air temperature, the indoor comfort temperature, the indoor air temperature and the solar radiation striking the window, respectively during one year, a winter week and a summer week. The figures show clearly the heating and cooling control and the effect of the solar radiation on the indoor comfort and air temperature and on the heating and cooling control.
Also the monthly heating and cooling energy demand is shown for only one case: Figure 8 shows the demands for case 3, both without and with shutters . It concerns blinds with a low air permeability and the graph shows clear the reduction of both the heating and cooling demand.

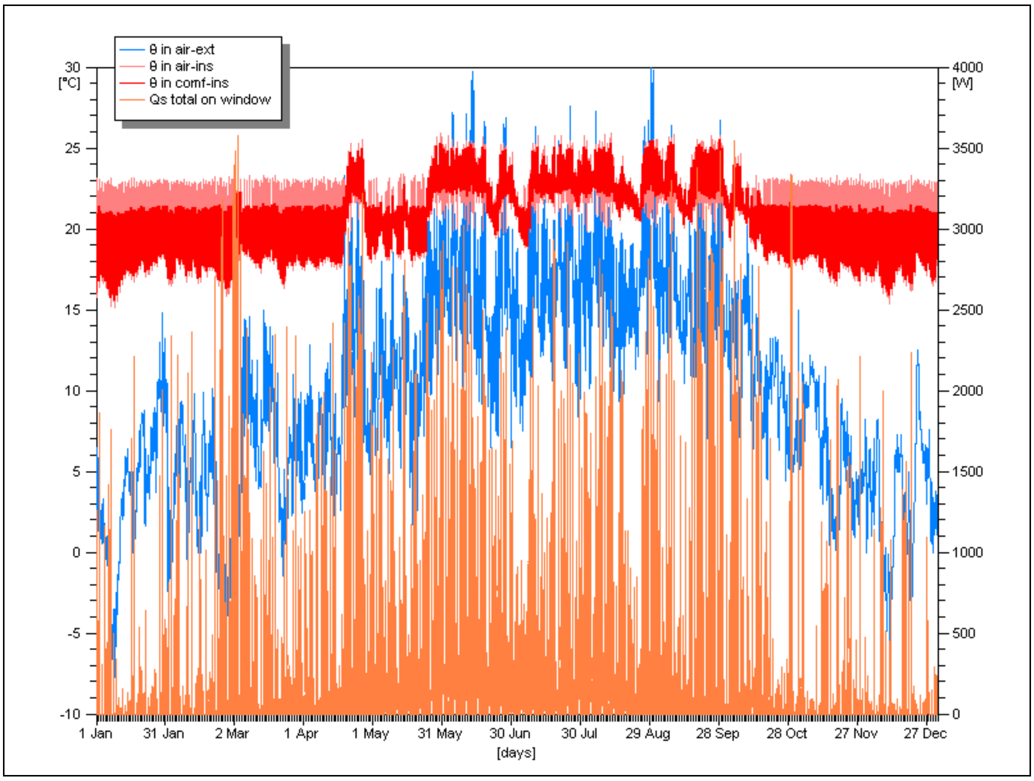

Figure 7. Indoor and outdoor temperature and solar radiation striking the window during 1 year.

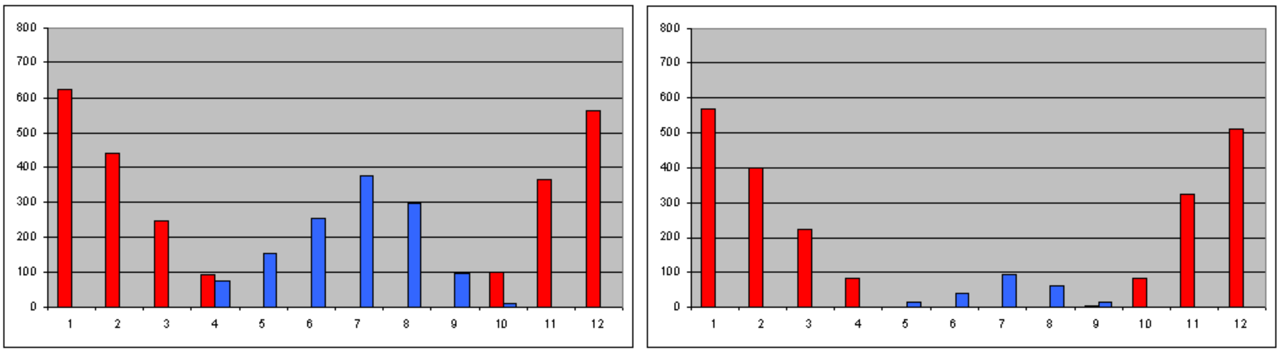

Figure 8. Monthly heating and cooling demand in kWh for case 3,
without shutters (left) and with shutters (right).

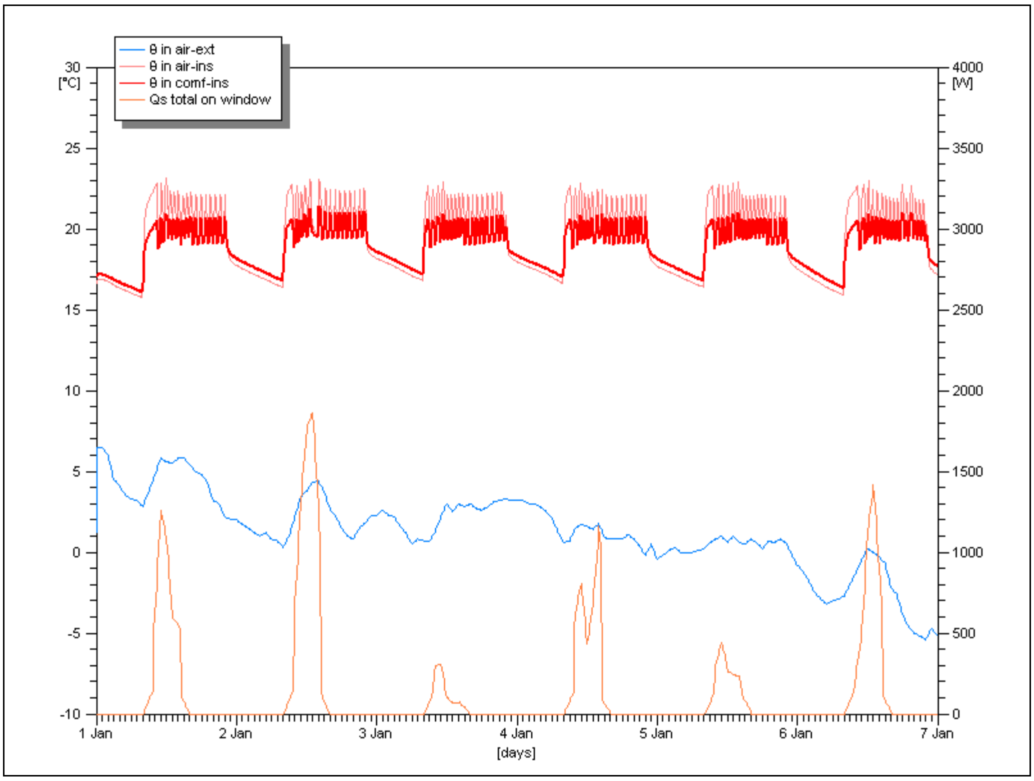

Figure 9. Indoor comfort temperature (dark red line), indoor air temperature (light red line), outdoor temperature and solar radiation striking the window during a winter week.

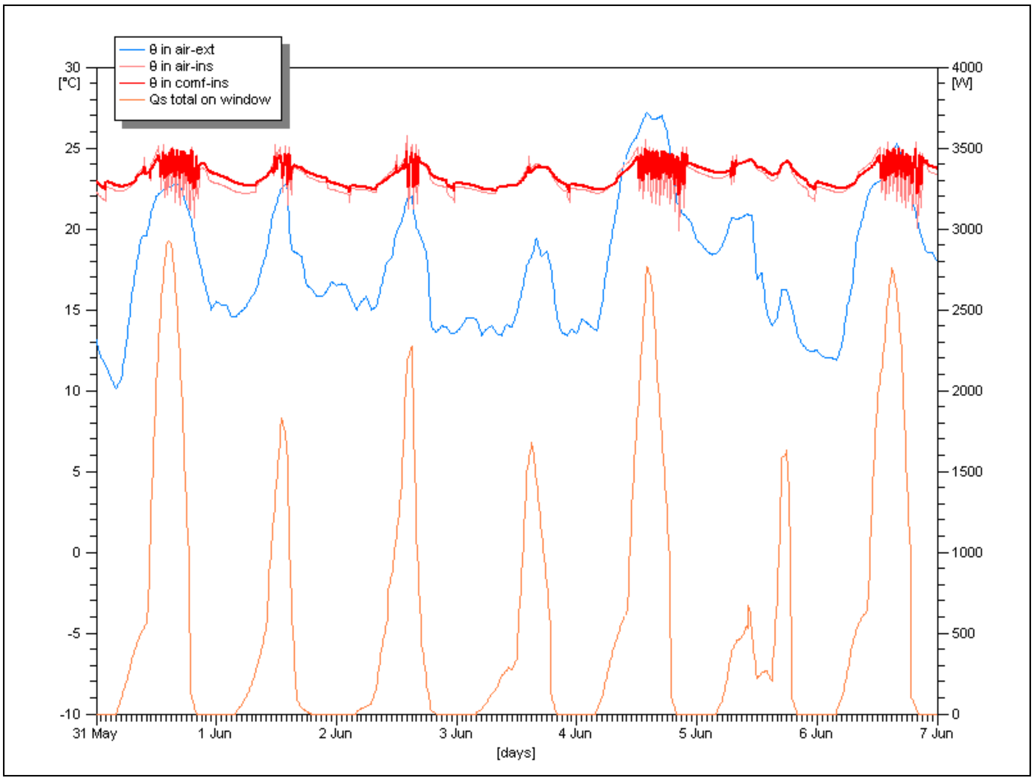

Figure 10. Indoor comfort temperature (dark red line), indoor air temperature (light red line), outdoor temperature and solar radiation striking the window during a summer week.

Table 3 contains the yearly energy demand for heating and cooling for all 24 cases. The abbreviations used in the table are explained a previous section.
Both for heating and cooling the following quantities are listed:

- the energy demand without blinds or shutters [kWh/a]
- the energy demand with controlled blinds or shutters [kWh/a]
- the difference between the two demands [kWh/a]
- the difference between the two demands as a percentage of the demand without blinds or shutters [%]
- the difference between the two demands pro m^2 of the room floor (25 m^2) [kWh/m^2a].

Simulation	Building type	Mean Orientation	User Profile	Window type	Blind type	Blind position	CLimate	Heating energy demand without blinds [kWh/year]	Heating energy demand with blinds [kWh/year]	Heating energy demand difference [kWh/year]	Heating energy demand difference [%]	Heating energy demand difference [kWh/m2.year]	Cooling energy demand without blinds [kWh/year]	Cooling energy demand with blinds [kWh/year]	Cooling energy demand difference [kWh/year]	Cooling energy demand difference [%]	Cooling energy demand difference [kWh/m2.year]
1	B1	SW	U1	W1	BL	BE	BRU	1401	1256	-146	-10	**-6**	220	7	-214	-97	**-9**
2	B2	SW	U1	W1	BL	BE	BRU	2522	2257	-265	-10	**-11**	421	24	-397	-94	**-16**
3	B2	SW	U1	W1	BL	BE	BUD	2428	2190	-238	-10	**-10**	1259	225	-1033	-82	**-41**
4	B2	SW	U1	W1	BL	BE	ROM	854	717	-138	-16	**-6**	1663	630	-1033	-62	**-41**
5	B2	SW	U1	W1	BL	BE	STO	3754	3426	-328	-9	**-13**	704	79	-624	-89	**-25**
6	B2	NE	U1	W1	BL	BE	BRU	2519	2244	-275	-11	**-11**	393	30	-363	-92	**-15**
7	B1	NE	U1	W1	BL	BE	BRU	1683	1521	-161	-10	**-6**	61	11	-50	-82	**-2**
8	B1	NE	U1	W1	BL	BE	ROM	742	647	-95	-13	**-4**	889	317	-571	-64	**-23**
9	B1	SW	U2	W1	BL	BE	BRU	726	638	-88	-12	**-4**	483	145	-338	-70	**-14**
10	B2	SW	U2	W1	BL	BE	BRU	1418	1280	-138	-10	**-6**	601	198	-403	-67	**-16**
11	B1	SW	U1	W1	BH	BE	BRU	1402	1409	8	1	**0**	221	12	-208	-94	**-8**
12	B1	SW	U1	W2	BL	BE	BRU	1176	1101	-76	-6	**-3**	244	7	-237	-97	**-9**
13	B1	SW	U1	W2	BH	BE	BRU	1176	1140	-37	-3	**-1**	244	12	-232	-95	**-9**
14	B2	SW	U1	W2	BL	BI	BRU	2118	1962	-156	-7	**-6**	464	217	-246	-53	**-10**
15	B2	SW	U1	W1	BL	BI	BRU	2535	2262	-273	-11	**-11**	412	164	-248	-60	**-10**
16	B2	SW	U1	W1	BL	BI	BUD	2406	2152	-253	-11	**-10**	1244	645	-600	-48	**-24**
17	B2	SW	U1	W1	BL	BI	ROM	860	714	-146	-17	**-6**	1645	1036	-610	-37	**-24**
18	B2	SW	U1	W1	BL	BI	STO	3814	3456	-358	-9	**-14**	699	321	-378	-54	**-15**
19	B2	NE	U1	W2	BL	BI	BRU	2119	1957	-162	-8	**-6**	441	177	-265	-60	**-11**
20	B2	SW	U2	W1	BH	BE	BRU	1419	1437	19	1	**1**	603	237	-366	-61	**-15**
21	B1	SW	U2	W2	BH	BI	ROM	82	90	7	9	**0**	1428	1091	-337	-24	**-13**
22	B1	SW	U2	W2	BH	BI	STO	1126	1139	13	1	**1**	640	412	-228	-36	**-9**
23	B1	NE	U2	W2	BH	BI	ROM	247	247	0	0	**0**	1231	984	-246	-20	**-10**
24	B1	NE	U2	W2	BH	BI	STO	1410	1410	0	0	**0**	303	254	-49	-16	**-2**

Table 3. Yearly energy demand for heating and cooling for the 24 cases.

Figure 11 shows the yearly energy demand for heating for all cases with and without blinds or shutters. Figure 12 shows the yearly energy demand for cooling for all cases with and without blinds or shutters.

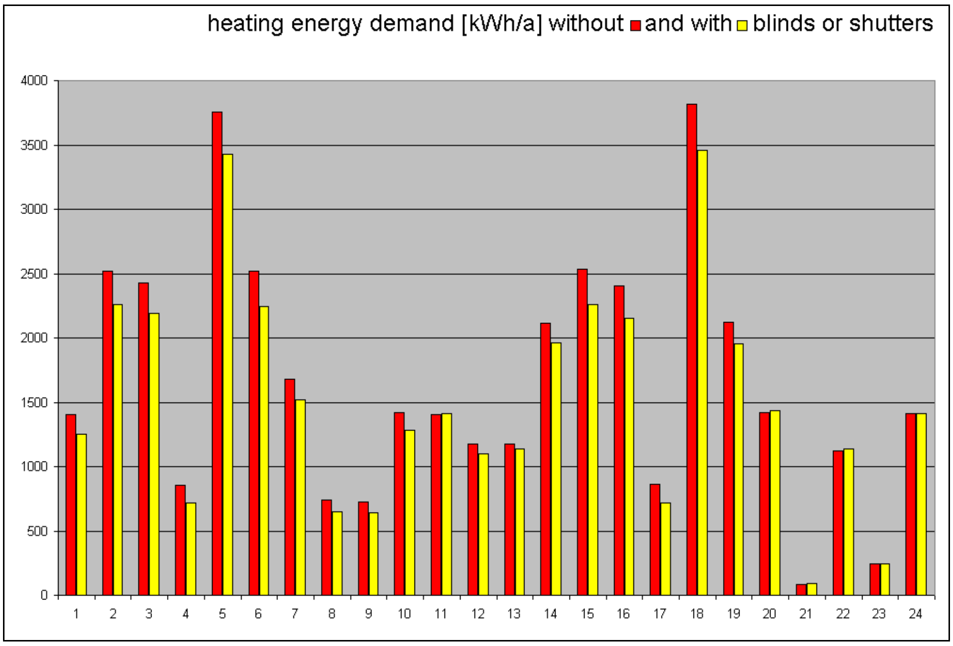

Figure 11.

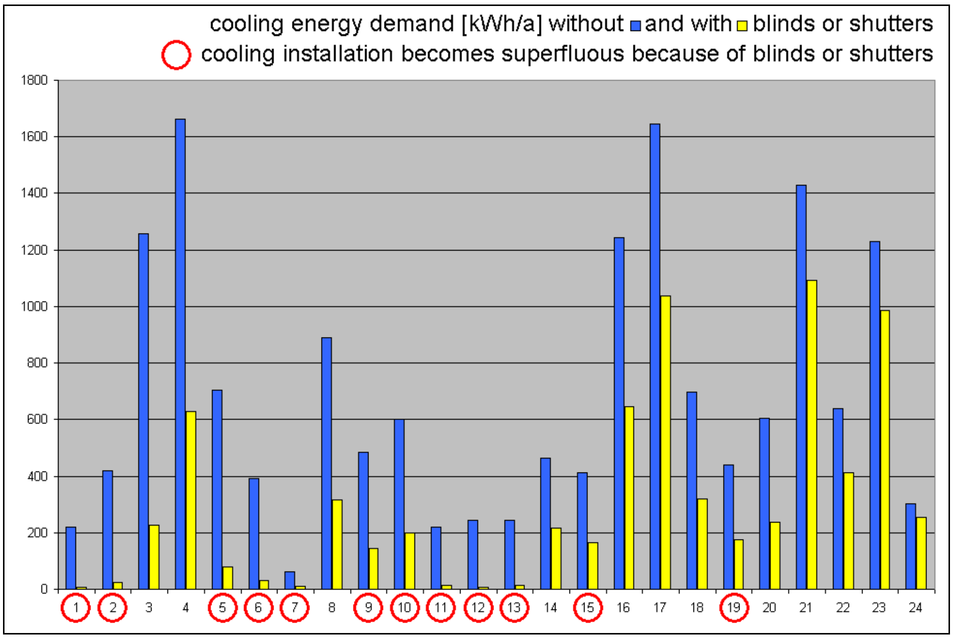

Figure 12.

Figure 12 shows that the application of blinds or shutters results for 12 of the 24 cases in a very small energy demand for cooling (less than 200 kWh/a). With such a small demand it is unlikely that an active cooling system will be installed. A first important conclusion is:

Blinds and shutters can make an active cooling system superfluous. ***(Conclusion A)***

Figure 13 shows the difference in energy demand for heating and cooling per m^2 room [kWh/m^2a] for the 24 cases.
Figure 14 shows the difference in energy demand for heating and cooling as a percentage of the demand without blinds or shutters [%].
Figure 13 and Figure 14 will be used further in other formats (enhancing several cases) allowing more precise conclusions.

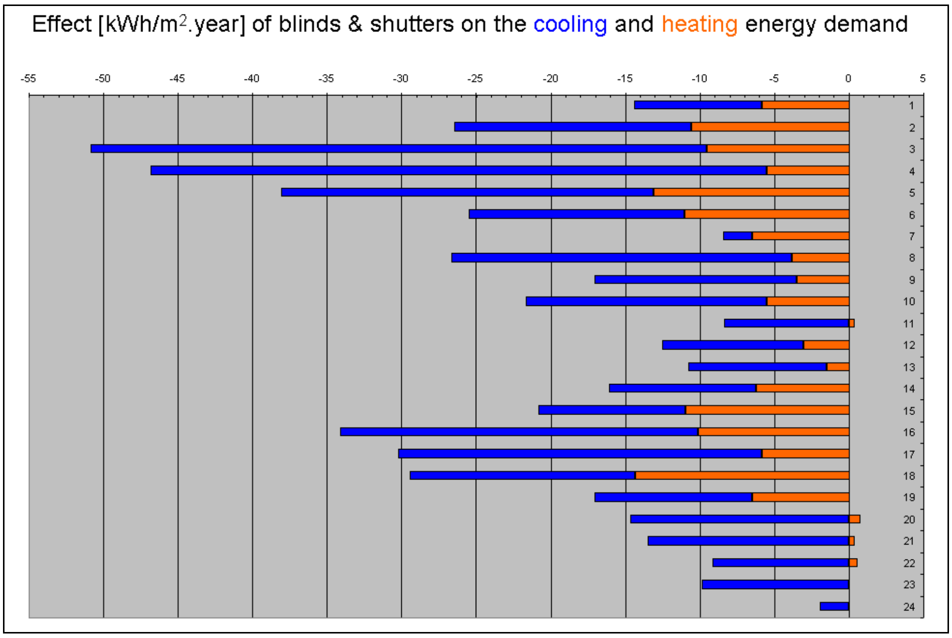

Figure 13.

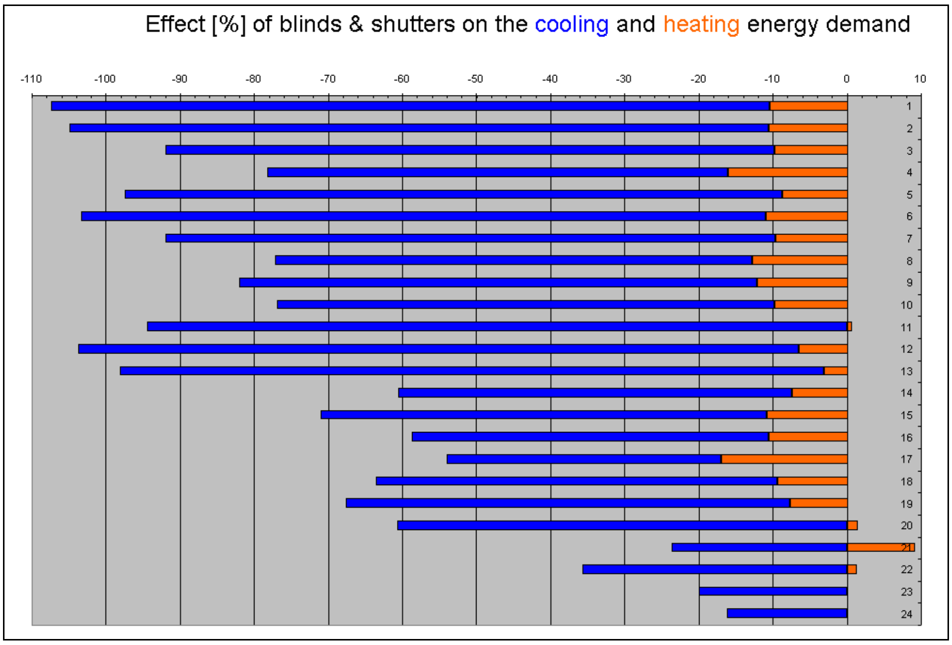

Figure 14.

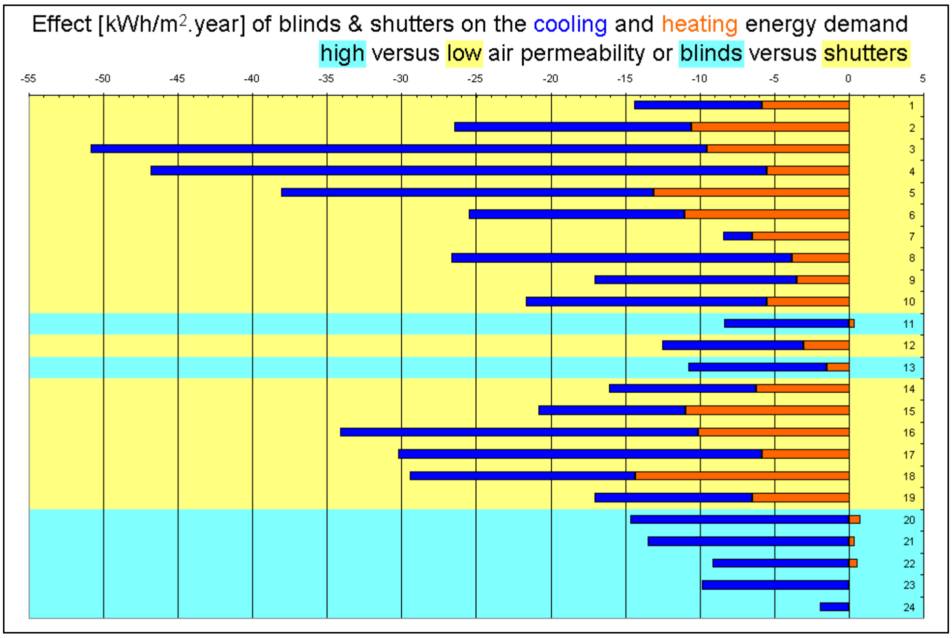

Figure 15.

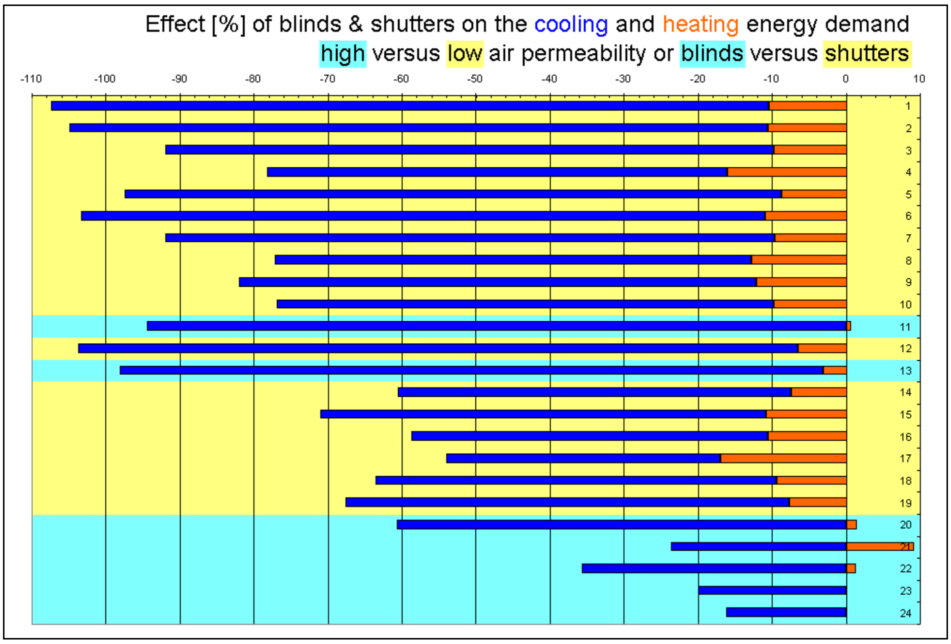

Figure 16.

Figure 15 and Figure 16 show that shutters contribute substantially to a decrease of the energy demand for heating. The order of magnitude is 10 %. Blinds do not, but this is obvious: they are not intended for this purpose (cf. section on 'temperature control' above).
Conclusion:

Shutters can contribute to a decrease of the heating energy demand of about 10 %. (Conclusion B)

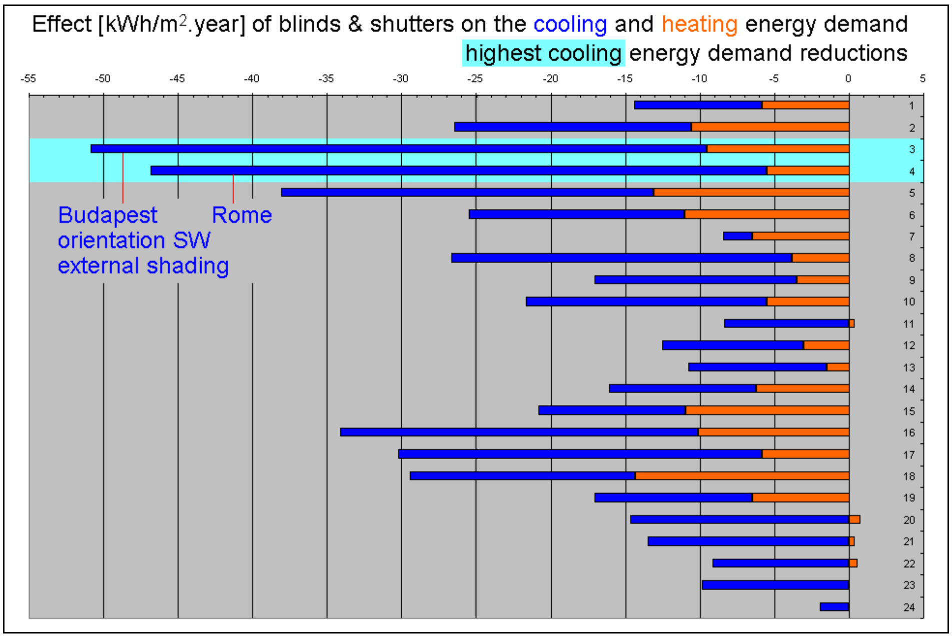

Figure 17.

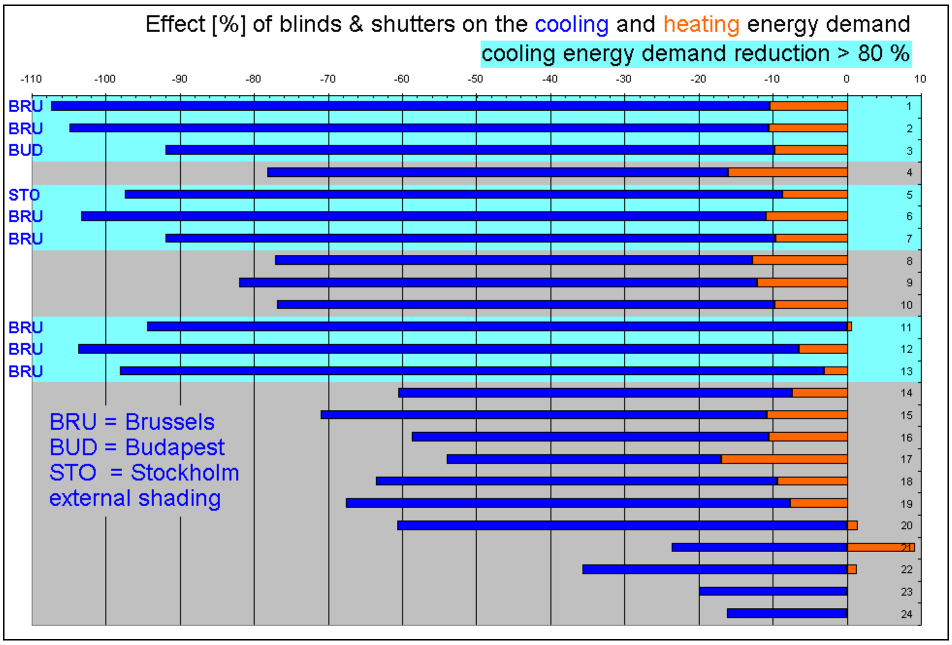

Figure 18.

Figure 17 shows that the highest decrease of cooling energy demand is obtained the southwest orientation in Rome and Budapest using an external shading device. A decrease of about 40 kWh/m^{2}a can be realised. Figure 18 shows that the relative decrease of cooling energy demand is higher than 80 % for Brussels, Budapest and Stockholm. Conclusion:

Blinds and shutters can contribute to a substantial decrease of the cooling energy demand, up to about 40 kWh/m^2 for southern and eastern regions. Relatively spoken, blinds and shutters have the highest effect on the cooling energy demand in western, northern and eastern regions.

(Conclusion C)

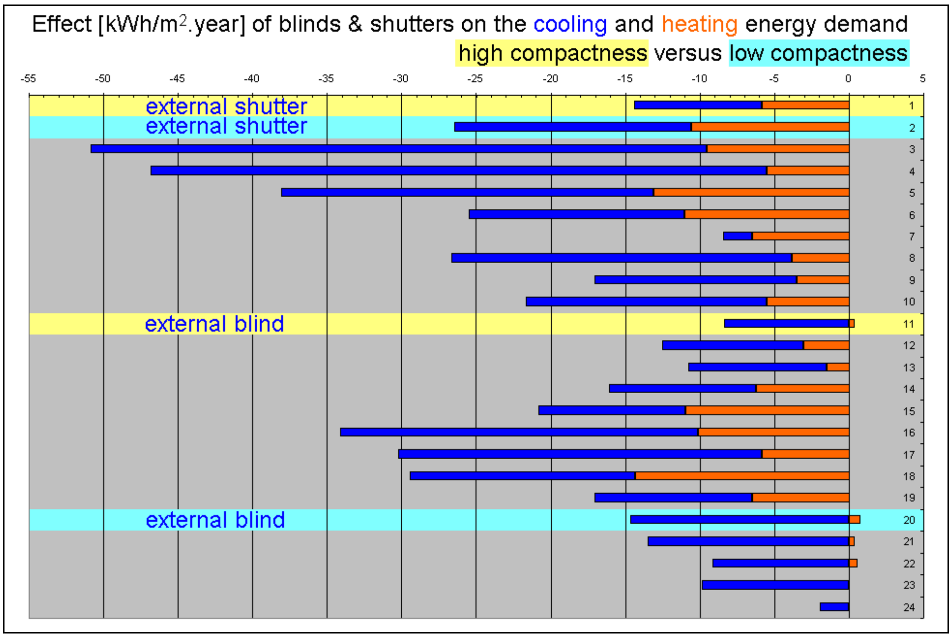

Figure 19.

Figure 19 shows that the effect of blinds and shutters is more important in buildings with low compactness. Because of the higher window area, both the heat losses and heat gains become higher, and therefore the protection measures become more effective. Conclusion:

The effect of blinds and shutters increases with decreasing compactness of the rooms. (Conclusion D)

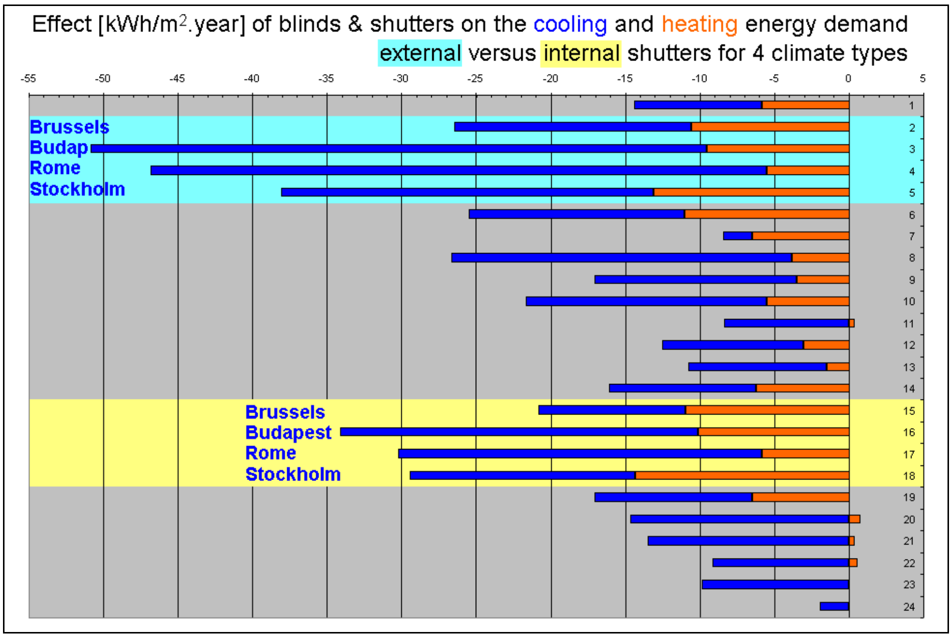

Figure 20.

Figure 20 shows that external and internal shutters have about the same effect on the decrease of the heating energy demand. External blinds and shutters have a much better performance concerning the decrease of the cooling energy demand. In southern (Rome) and eastern (Budapest) regions the effect is the highest, but also in northern (Stockholm) regions the decrease of cooling energy demand is considerable. Conclusion:

External and internal shutters have the same effect on the heating energy demand. External blinds or shutters are more effective to decrease the cooling energy demand. (Conclusion E)

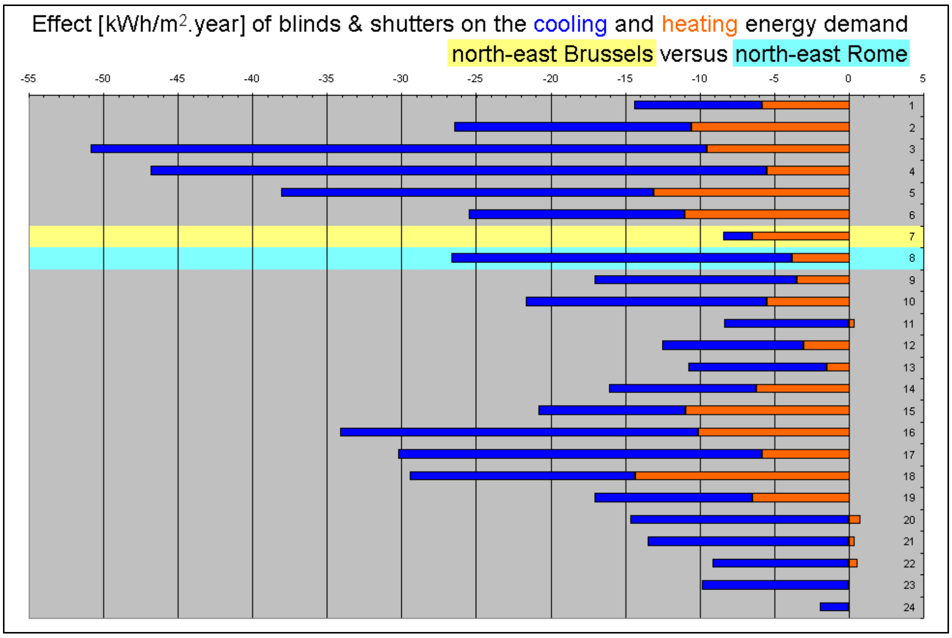

Figure 21.

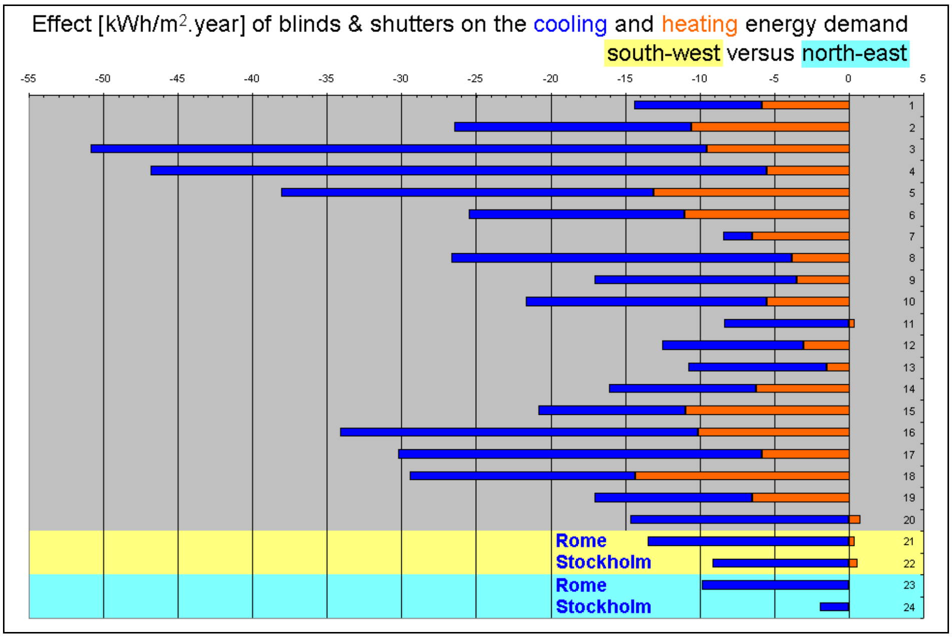

Figure 22.

Figure 21 and Figure 22 show that the effect of blinds and shutters on the cooling energy demand remains important for north-west orientations in sunny regions. Conclusion:

The effect of blinds and shutters on the cooling energy demand remains important for northern orientations in sunny regions. ***(Conclusion F)***

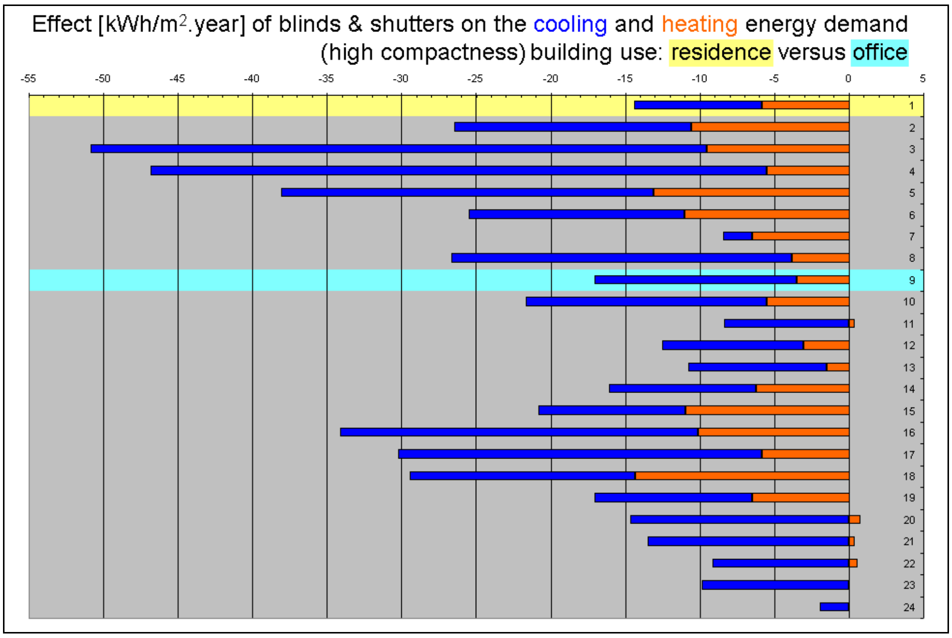

Figure 23.

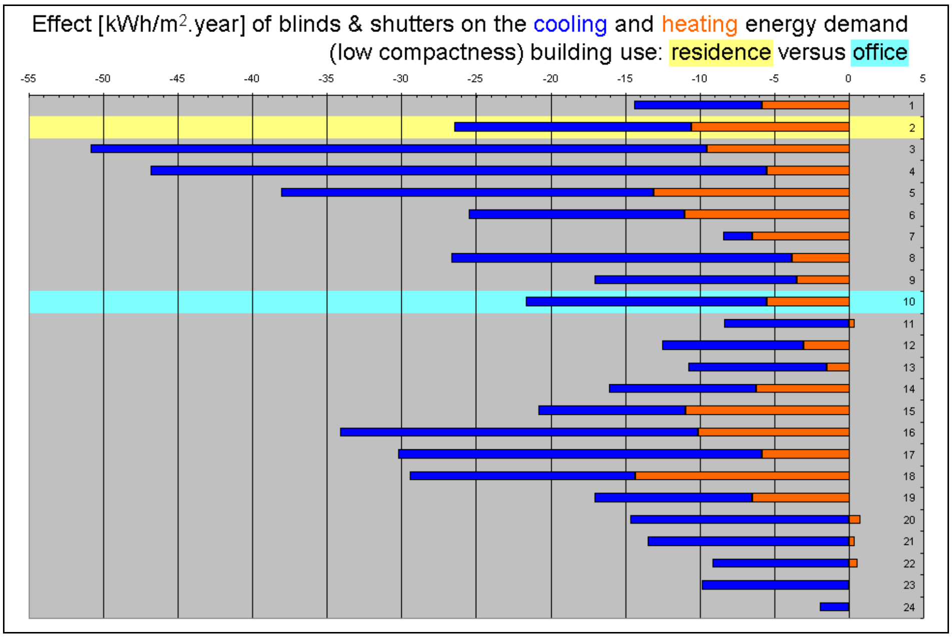

Figure 24.

Figure 23 and Figure 24 shows that the effect of shutters on the heating energy demand is higher in residential buildings. Residential buildings are longer heated and in the offices more free gains occur. The effect of blinds and shutters on the cooling energy demand is about the same for both user profiles. In an office the requested comfort duration is shorter, but the cooling needs to remove also the higher free gains. Conclusion:

The effect of shutters on the heating energy demand is more important in residential buildings.
(Conclusion G)

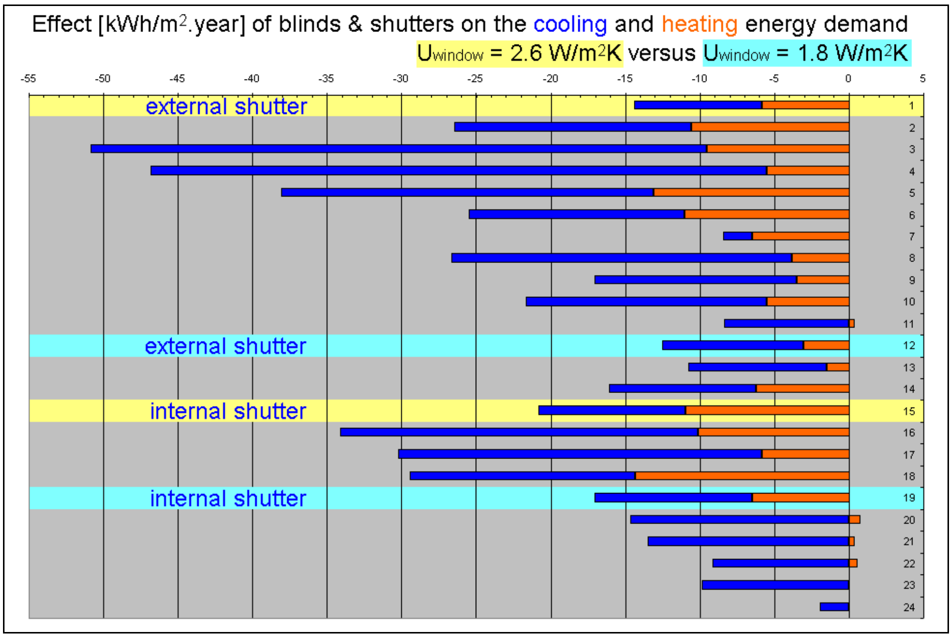

Figure 25.

Figure 25 shows that a lower window thermal transmittance decreases the effect of shutters on the heating energy demand. The effect of blinds and shutters on the cooling energy demand seems practically not affected by the window thermal transmittance. Conclusion:

The thermal transmittance of the window affects the effect of shutters on the heating energy demand but not on cooling energy demand. (Conclusion H)

FEASIBLE ENERGY DEMAND REDUCTION FROM BLINDS AND SHUTTERS

Figure 26 shows the feasible energy demand reductions for both heating and cooling in kWh/m^2.a for the 4 climate types considered. The figures are derived from the simulations for the 24 cases.

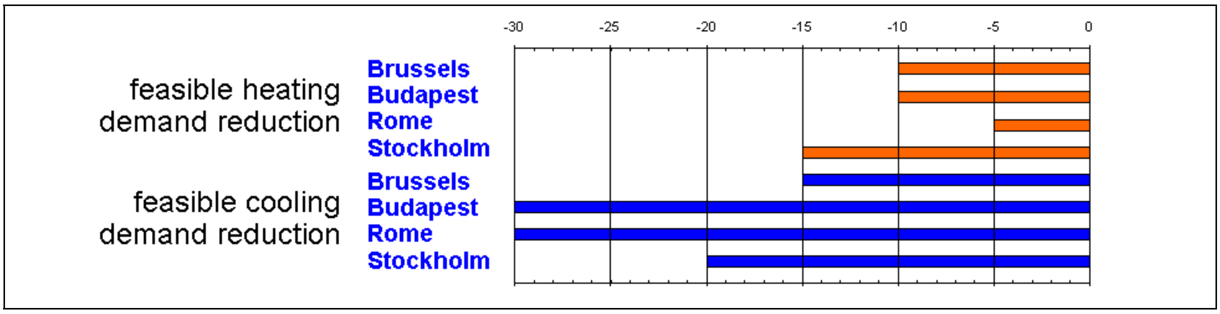

Figure 26.

In Table 4 these energy demands reductions per m^2 floor area are extrapolated for all residential and office buildings in the EU as follows.
4 climate regions are considered: west (Belgium, Denmark, France, Germany, Ireland, Luxembourg, The Netherlands, United Kingdom), east (Austria, Czech Republic, Hungary, Poland, Slovak Republic, Slovenia), south (Cyprus, Greece, Italy, Malta, Portugal, Spain) and North (Estonia, Finland, Latvia, Lithuania, Sweden).

climate type	number of habitants	floor area per habitant	floor area	blind or shutter applicability factor	applicable floor area		Mtoe - MWh conversion factor
	person x 10^6	m2/person	m2 x10^6		m2 x10^6		Mwh/Mtoe
west	236.4	54.8	12955	0.5	6477		1.16E+07
east	74.6	50.0	3730	0.5	1865		
south	120.5	52.7	6350	0.5	3175		
north	21.2	57.7	1223	0.5	612		

climate type	feasible heating demand reduction	heating system efficiency	feasible (fuel eq.) energy demand reduction	average CO2 emission factor	applicable floor area	feasible heating CO2 emission reduction	feasible heating Mtoe reduction
	kWh/m2.a	-	kWh/m2.a	kg/kWh	m2 x10^6	Mt/a	Mtoe/a
west	10	0.8	12.5	0.229	6477	19	7.0
east	10	0.8	12.5	0.229	1865	5	2.0
south	5	0.8	6.3	0.202	3175	4	1.7
north	15	0.8	18.8	0.245	612	3	1.0
						31	**12**

climate type	feasible cooling demand reduction	cooling system efficiency	feasible (fuel eq.) energy demand reduction	average CO2 emission factor	applicable floor area	feasible cooling CO2 emission reduction	feasible cooling Mtoe reduction
	kWh/m2.a	-	kWh/m2.a	kg/kWh	m2 x10^6	Mt/a	Mtoe/a
west	15	0.71	21.0	0.229	6477	31	11.7
east	30	0.71	42.0	0.229	1865	18	6.7
south	30	0.71	42.0	0.202	3175	27	11.5
north	20	0.71	28.0	0.245	612	4	1.5
						80	**31**

Table 4. feasible energy demand reduction, CO_2 emission reduction and Mtoe reduction from blinds and shutters in the EU.

The number of habitants for each region (source: http://www.eu2004.ie) multiplied by the floor area per habitant (source: Cost-Effective Climate Protection in the EU Building Stock, Report established by Ecofys for Eurima, 02/2005) and multiplied by a 'blind or shutter applicability factor' gives the total applicable floor area. The 'blind or shutter applicability factor' (value 0.5) takes into account that blinds or shutters are not always of interest, for example in case of a naturally shaded situation (trees around the building, narrow streets) or in case of weakly heated or weakly cooled rooms. The factor takes also into account that a part of the existing buildings have already blinds or shutters.
The feasible fuel equivalent energy demand reduction is calculated from the heating and cooling demand reduction divided by the system efficiency. For heat production a system efficiency of 0.8 is considered. For cool production a system efficiency of 0.71 is considered based on a coefficient of performance COP=2 and a electricity-fuel conversion factor of 2.8.
Multiplying the feasible fuel equivalent energy demand reduction with the average CO_2 emission factor (values from Ecofys report mentioned) and with the applicable floor area leads to feasible CO_2 emission reduction for both heating and cooling.
Dividing the product of the feasible fuel equivalent energy demand reduction and the applicable floor area by the Mtoe-MWh conversion factor leads to the feasible Mtoe (millions tonnes of oil equivalent) reduction for both heating and cooling.

Solar shading and shutters have a feasible CO_2 reduction of 31 Mt/a through a heating energy demand reduction.
Blinds or shutters have a feasible CO_2 reduction of 80 Mt/a through a cooling energy demand reduction. These figures do not take into account that a considerable amount of buildings when equipped with blinds or shutters do not need the investment in an active cooling system, which is an extra advantage.