Building Simulation 2009

Eleventh International IBPSA Conference
Glasgow, Scotland
July 27-30, 2009

ACTIVE SOLAR SHADING

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ABSTRACT

Solar shading can be used to decrease the cooling power demand and cooling energy use but that also reduces the possible benefit for heating with the incoming solar radiation when there is a heating need. The apparent solution is to shade when there is a cooling need and allow solar gains when there is a heating need. This paper presents energy use simulations on such a system set up in a theoretical office cell and a theoretical apartment in southern Sweden showing remarkable decrease in energy use for heating and cooling, or too high over indoor temperatures.

INTRODUCTION

As a part of decreasing the energy use, and thus carbon dioxide emissions within the European Union, focus has increased on low energy buildings. Buildings are commonly fitted with windows to enable a view out and, during parts of the day, let light in. The windows of a building are generally known to increase the use of energy. Usually, it is not a cooling need, and the window acts as a piece of wall with insufficient insulation most of the year. When there is solar radiation, it acts as a heat gain, usually increasing both annual heating and cooling (Hellström, 2008).

Analogously, in dwellings, where it is uncommon to cool the apartments, windows can lead to increased heating demand due to high thermal transmittance and a lot of hours and degree hours of too warm indoor climate (Bagge et al., 2006; Bagge, 2007).

If it is assumed that a certain window area is the case, due to for example architectural reasons, it is not an option to change the window area to decrease the energy use. Fixed, constant, solar shading can be used to decrease the cooling power demand and cooling energy use but that also reduces the possible benefit for heating with the solar gain when there is a heating need.

There are systems that control the solar shading based on measured solar radiation for example against a certain façade of a building. When there is too much solar radiation, the windows are shaded. The risk is still that heat that could be beneficial is kept out from the room.

The apparent solution would be to use a controllable solar shading and shade when there is a cooling need and allow solar gains when there is a heating need. To do this in practice, there is need for an output telling if there is a heating need or not, and a controllable solar shading system. This paper presents energy use simulations on such a system set up for a theoretical office cell and for a theoretical apartment in southern Sweden.

Objectives

A typical office cell was simulated regarding heating and cooling use for the room, and an apartment was simulated regarding heating use and over temperatures with different strategies of solar shading on the windows, amongst them active solar shading, which means that the windows are shaded from incoming solar radiation when there is a cooling need in the room. A number of parameters were changed to allow for an overview of the potential of active solar shading.

Limitations

The amount of windows was assumed to be given. Only shortwave solar radiation coming into the room was modeled. Window airing was not considered in the simulation model. Windows were also assumed to be used in one direction only. The internal heat loads were assumed to be constant and not in relation to the incoming light. Measurements of the proposed system are not presented in this paper.

METHOD

Commercial commonly used energy simulation softwares have not been found to handle active solar shading. Therefore, code was developed to implement this strategy. The different tested strategies were to

- ‘Nev’ – never use solar shading
- ‘Alw’ – always use solar shading to a ratio of 0.1 of the window solar gain coefficient
- ‘Lim’ – shade at an optimal level of outdoor shortwave solar radiation normal to the simulated window to a ratio of 0.1 of the window solar gain coefficient to give the lowest sum of heating and cooling annual energy use in the office case.

- 'Dem' – shade when there is a cooling need in the room to a ratio of 0.1 of the window solar gain coefficient. When this shading would change the power balance of the room between heating and cooling need, the shading was continuously set to a room temperature in the middle between the maximum and minimum desired room temperatures.

The ratio, 0.1, between the incoming solar radiation that heats the room in the most shaded state and the incoming solar radiation without shading was set to be reasonably low. 0.1 is a reasonable value for a motorized screen (PARASOL, 2008).

Tested rooms

The test buildings used in the simulation were a theoretical building office cell and an apartment respectively which default configurations were supposed to be representative for buildings in Sweden built according to the Swedish building regulations (The National Board of Housing Building and Planning, 2008). Table 1 presents the input data of the two buildings.

Table 1
The building data of the two simulated buildings.

Quantity	Cell office	Apartment
Floor area, heated area/m²	12	64
Transmission area/floor area	1.45	1.12
Window area/m²	4	9.6
Window normal direction	south	south
Solar gain coefficient	0.7	0.7
Load at presence incl persons/W	340	320
Ventilation airflow rate/(l/s)	10	30
Supply air temperature/°C	18	18
Desired max room temperature/°C	24	24
Min room temperature/°C	22	22
Max cooling power/W	1000	0
Heat storage capacity/(J/(m²·K))	20000	20000
Area of heat capacitor/m²	24	64
Transmission area/m²	17.4	71.7
Thermal transmittance/(W/(m²·K))	0.5	0.4
Actual leakage/(l/(s·m² wall)	0.04	0.04
Specific fan power/(kW/(m³/s))	2	2
Temperature eff. of heat recovery/%	80	80
Occupancy from day schedule/%	60	100

The occupancy in the office cell were spread out over the working day, between 8 and 18 to be 60%, four days a week to represent vacations. Outside these times, the load was assumed to be 0. For the apartment, the occupancy was assumed to be constant, and so was the load.. The default theoretical buildings were located in Malmö, southern Sweden, lat N55.6º.

Simulation tool

The developed code to simulate the energy use was based on the power balance shown in Figure 1 (Johansson, 2005). ROOM is the simulated zone. P_{trans} is the transmitted heat, P_{cap} is the heat from the first order heat capacitor inside the insulation with the temperature t_{cap}, P_{solar} is incoming shortwave solar radiation that heats the room and P_{vent} is the power needed to change the temperature of the supply air, t_{sa}, to the temperature of the exhaust air, t_{ex}. It is assumed that the room temperature, t_{room}, is the same as the exhaust temperature.

The air handling unit was assumed to use a heat recovery with a constant temperature efficiency of 80%, but never lower outgoing air temperature than 0°C. Leakage air was assumed to have a constant airflow rate, $q_{leak,}$ of 5% of the airflow rate at 50 Pa pressure difference, which is reasonable for a supply and exhaust ventilation system with under balance to prevent over pressure (Johansson, 2008; Torssell, 2005). P_{int} refers to the load from people and electricity that was assumed to heat the indoors.

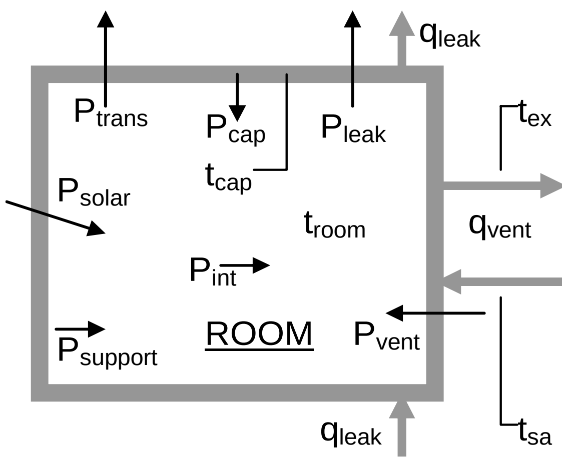

Figure 1 Power balance used in the simulation tool for the buildings. The air handling unit is not shown. Quantities are given in the text.

$P_{support}$ is the energy needed to keep the room in balance at the desired t_{room}. In the apartment, it was assumed that there was no cooling system, $P_{support}$ could not be negative then. In that case, the code solved for the t_{room} at balance. Outdoor climate data was obtained from the computer program Meteonorm (Meteotest, 2003) which simulates outdoor climate data for the entire world.

Simulations

Simulations of annual space heating and space cooling were made with parametric variations on

- the ratio between the solar heat gain in the shaded state and the solar heat gain in the non shaded state for the office building.
- solar radiation limit against the wall to find out the optimal level for the case with a certain solar radiation limit for the office cell.

By help of these two parameters, the optimal level of limit of solar radiation against the wall for lowest sum of annual heating and cooling was found to be 300 W/m². Furthermore, studied parameters for the office cell included

- average thermal transmittance
- window's solar heat gain coefficient
- thermal storage capacity
- internal heat load at presence
- outdoor annual average temperature
- maximum desired indoor temperature
- window normal direction
- occupancy pattern. 1: no occupancy, 2:the default schedule and occupancy, 3:always

Table 2 gives the outdoor climates tested.

Table 2
Simulated outdoor climates and their annual average temperatures. Malmö outdoor climate was the default for the simulations.

Location	Annual average outdoor temperature/°C	Lat/°
Karasjok, Norway	-2.52	N69.4
Umeå, Sweden	3.67	N63.8
Malmö, Sweden	8.01	N55.6
Paris, France	10.9	N48.9
Los Angeles, US	18.1	N34.1

For the apartment, analysed parameters were

- average thermal transmittance
- window area. In this case, the avergae thermal transmittance was not changed.

RESULT

Table 3 gives the result of the simulated energy use for the default theoretical office building, including fan electricity, air heating and air cooling. Further on, only room heating and room cooling are presented. The needed cooling power for the room without solar shading is close to 3 kW for the 12 m². The abbreviations of the solar shading strategies are given in the Method section. 'H' means heating energy in the room, 'C' cooling energy in the room and 'S' the sum of these. In some figures, cooling is not given to avoid too many curves in the graphs. In these cases, the cooling energy is the sum minus the heating energy. Figure 2 gives the annual energy use for varying levels of solar shading. 0.1 was chosen for the further simulations.

Table 3
Simulated energy use for the office building for the different cases of solar shading strategies.

Energy use/	Room cooling<1000W				No cooling limit			
(kWh/(m²·year)	Nev	Alw	Lim	Dem	Nev	Alw	Lim	Dem
Room heating	78.0	101	83.7	79.1	78.0	101	83.7	79.1
Room cooling	106	4.2	6.7	4.8	114	4.2	6.7	4.8
Fan electricity	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
Air heating	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.2
Air cooling	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Sum	202	123	108	101	210	123	108	101

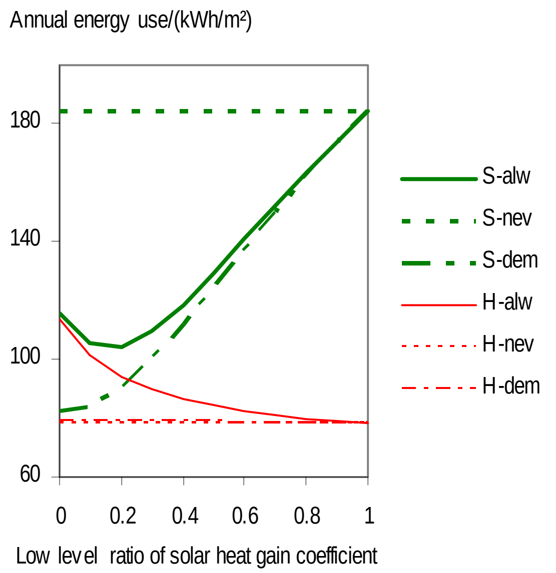

Figure 2 The ratio between the solar heat gain in the shaded state and the solar heat gain in the non shaded state for the office building.

Figure 3 presents the result from varying levels of the limit where the solar shading is on or off in the 'Lim' case of solar shading strategy. For the rest of the parametric study, the optimal limit of 300 W was chosen. Figures 4 through 11 show the results of the parametric variations, still for the office cell. The scale on the y-axis is not the same and does usually not start at zero.

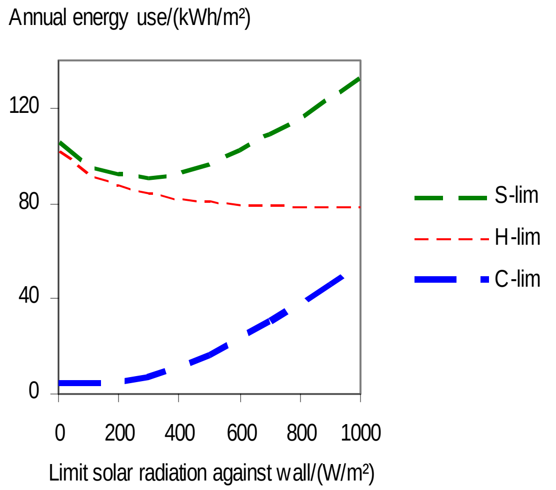

Figure 3 Limit of incoming solar radiation against the wall when the state of the solar shading was changed in the 'Lim' case for the office building. 300 W gives a minimal sum of heating and cooling energy use.

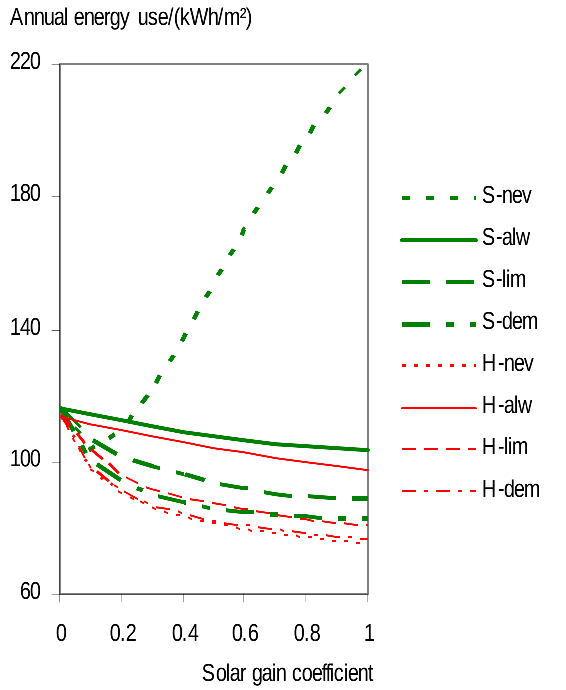

Figure 5 The solar heat gain coefficient of the window was 0.7 in the default case. It was assumed in the model that the solar heat gain coefficient included a possible shading effect from the sourrounding.

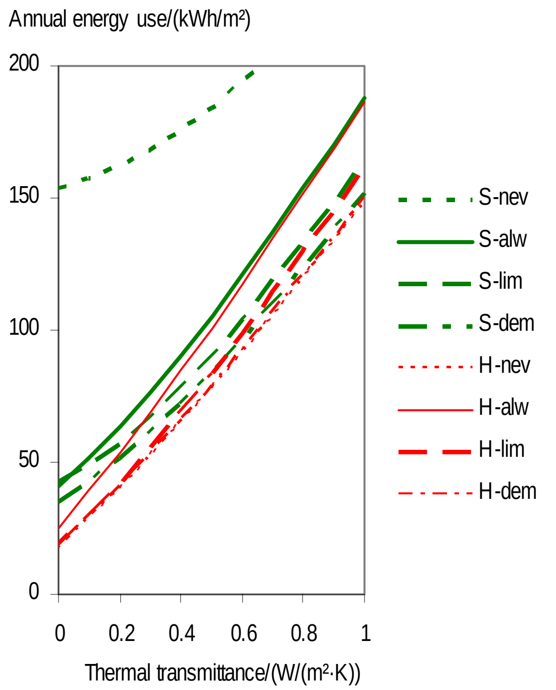

Figure 4 The average thermal transmittance was varied for the office building. At zero, the energy use depends on heating supply air and leakage air.

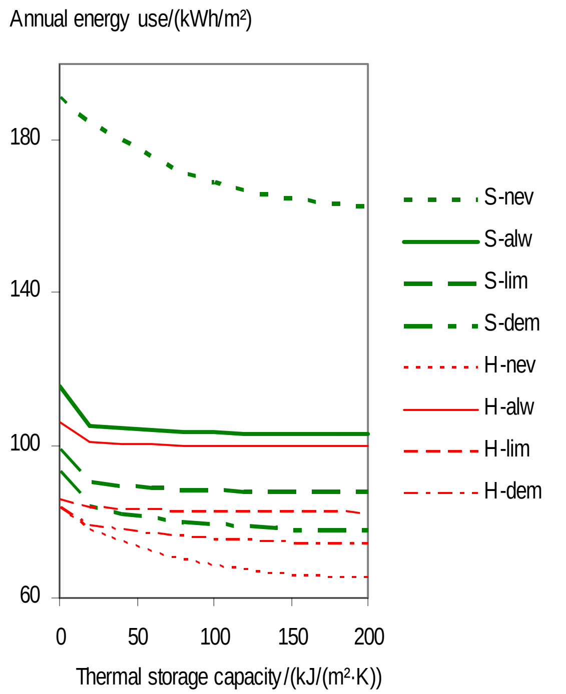

Figure 6 The thermal storage capacity of a m² of thermally active indoor material was varied.

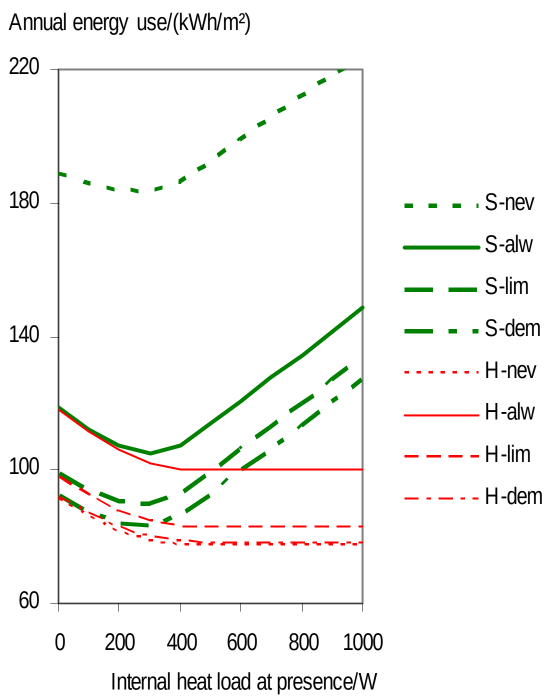

Figure 7 The internal heat load at presence was varied. At absence, it was zero all the time. The default, 340 W, is close to the optimal level regarding the sum of the heating and cooling energy use.

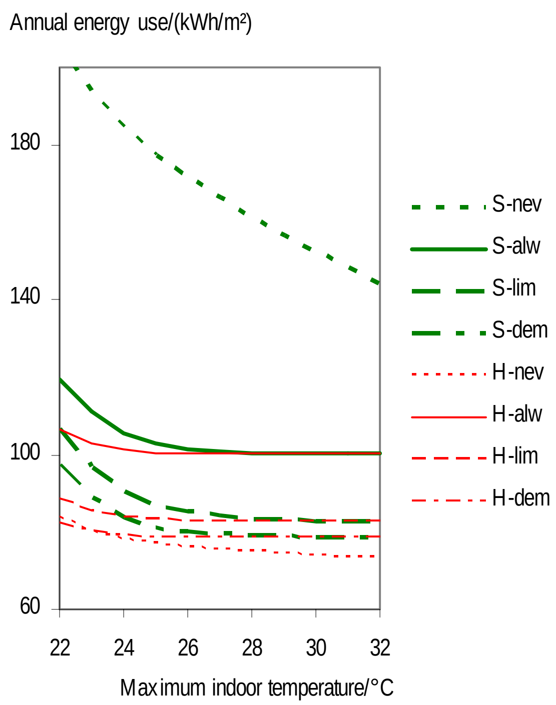

Figure 9 A maximum indoor desired temperature of 22°C is the same as the minimum indoor temperature which disables the heat storage. At approximately 28°C, there was no cooling need.

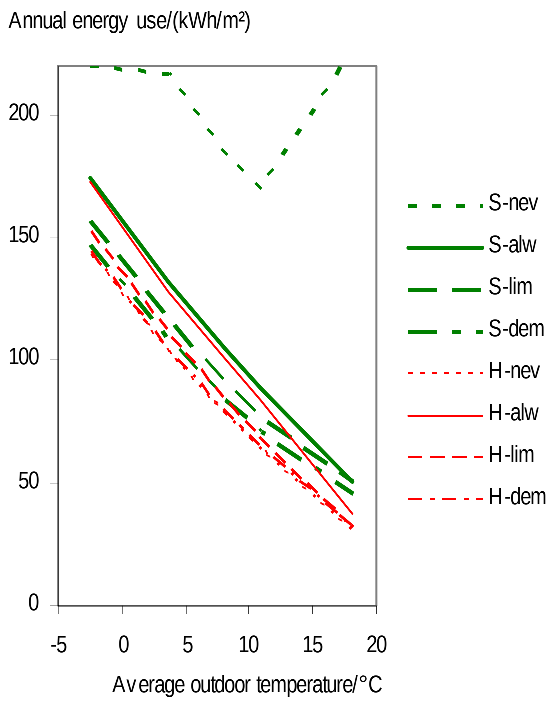

Figure 8 The annual average outdoor temperature of a typical year was varied through simulations based on the outdoor climates in Table 2.

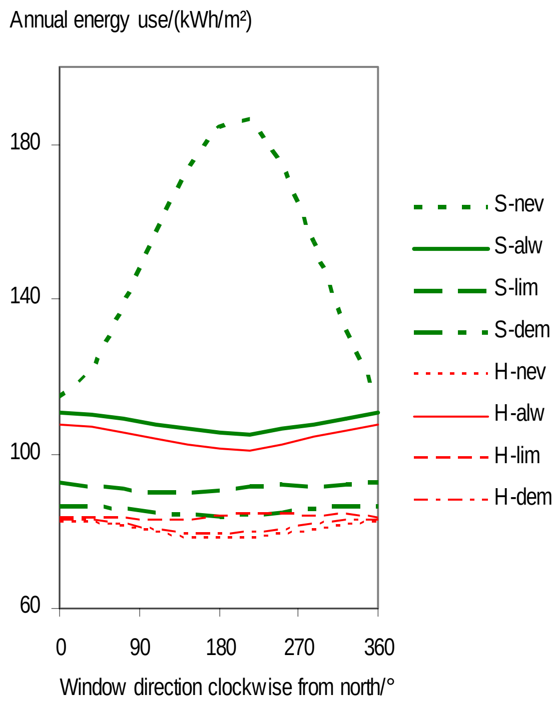

Figure 10 Window normal direction was varied from the default which was 180°, south. 0° and 360° are the same direction, north.

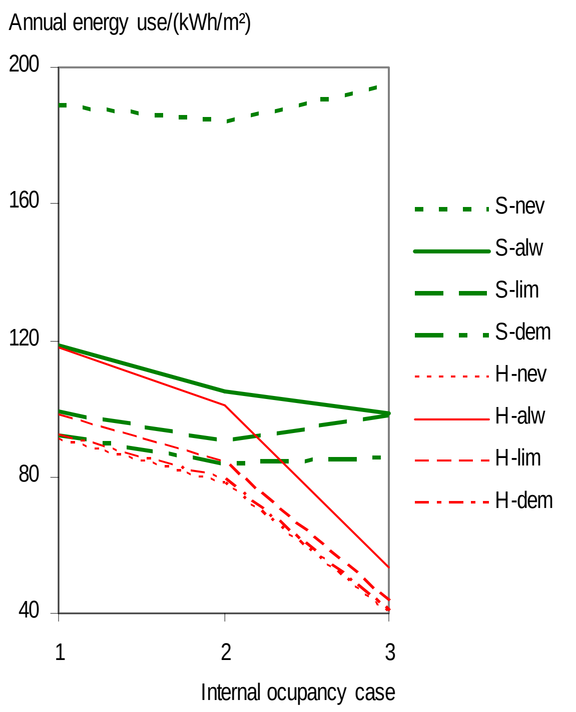

Figure 11 Internal occupancy cases are numbered 1, no occupancy at all, 2, default occupancy, 60% between 08 and 18 4 days a week, and 3, occupancy all the year.

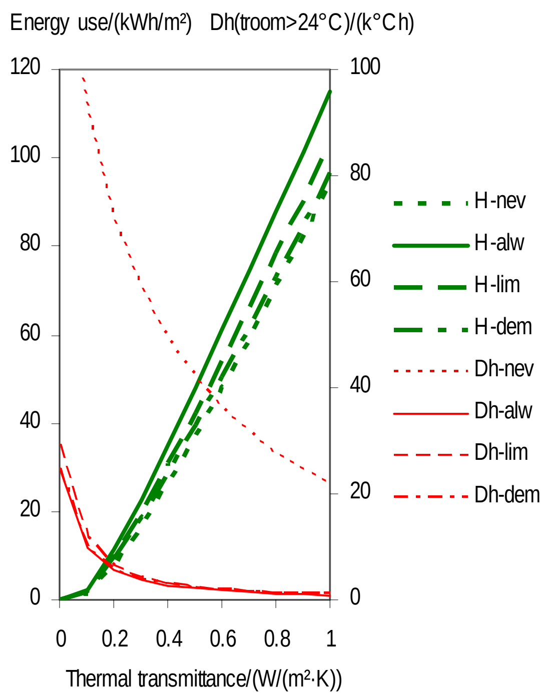

Figure 13 The average thermal transmittance was varied for in the apartment simulation. The right y-axis shows the number of degree hours, Dh over 24°C.

Figure 12 gives the accumulated temperatures for the apartment. The desired temperature in the case of demand controlled, continous, active solar shading, 23°C is visible. Figures 13 and 14 shows the result from the apartment simulations.

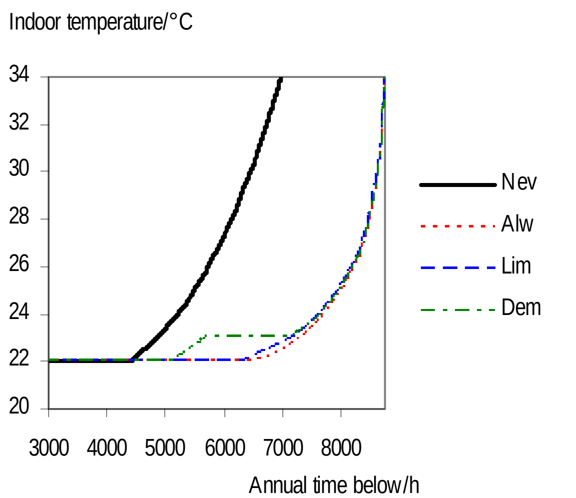

Figure 12 The permanence of indoor temperatures for the apartment for the different solar shading strategies. In the apartment simulation, there was no cooling power available.

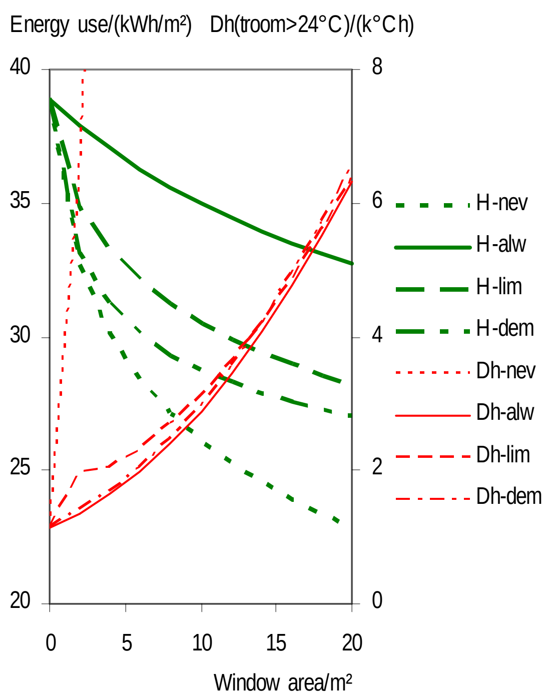

Figure 14 The window area was varied for the apartment. The average thermal transmittance was kept constant.

DISCUSSION AND CONCLUSIONS

Different solar shading strategies result in different energy use, and particularly use of heating and cooling energy, in a room. In the case of no solar shading, an increased solar heat gain coefficient or window area results in higher energy use as in Figure 5. Figure 14 shows the opposite, but for that parameter, the thermal transmittance was kept constant for the purpose of the parametric study, which is not the realistic case where the thermal transmittance seems to have been ten times higher for windows than for walls during the latest 50 years.

Comparisons between the 'Nev' strategy with no solar shading and the other strategies show a remarkable difference, according to Table 3, but in a real case no one would choose a solar heat gain coefficient of 0.7 with such an amount of windows as in the examples. On the other hand, with solar shading, it is of interest to receive as much heat as possible when desired, so for the 'Dem' case with active solar shading based on the demand of heating or cooling, it would be reasonable to choose a low thermal transmittance window in combination with a rather high solar heat gain coefficient.

By the help of Figure 2, and a reasonable solar heat gain coefficient of, for example, 0.35, the sum of heating and cooling is found to be 129 kWh/(m²·year). If a window with low solar heat gain coefficient is taken, for example 0.2, it will be 110 kWh/(m²·year). This could reasonably be compared with the other strategies in Table 3 for the office case. It is 105 kWh/(m²·year) for the 'Alw' strategy with shading all the time, 90.4 kWh/(m²·year) for the 'Lim' strategy based on a solar radiation limit on the outside of the window, and 84 kWh/(m²·year) for the demand controlled active solar shading. A decrease of (129 - 84) kWh/(m²·year) = 45 kWh/(m²·year) would then be possible, or (110 – 84) kWh/(m²·year) = 26 kWh/(m²·year) if compared with a, more expensive, window system with a low solar heat gain coefficient.

The same can be argued regarding the apartment example, but instead of increased energy use due to increased cooling, the number of degree hours with too high indoor temperatures increases.

The air heating varies slightly between the cases due to different indoor and following exhaust temperatures in the heat recovery. The air heating or air cooling is not included in the results except for Table 3.

The limit controlled solar shading need a motorized shading system, and a sensor system on the outside of each façade to measure incoming solar radiation. The demand controlled solar shading system needs an output from the room indoor temperature control system instead of sensors. This output exists in proper indoor climate systems, which means that the demand controlled solar shading should be cheaper to implement than the limit controlled solar shading.

The examples have rather high window area only directed towards south, and, usually, buildings have windows in different directions. Therefore the saving would be reduced. On the other hand, if a house has windows on for example the south and north facades, it would be reasonable to only use solar shading on the south façade, and the cost of installing it would be half. The economics of solar shading systems is not the issue of this paper, but with an assumed saving of 25 kWh/(m²·year), a constant energy price of 0.1 €/kWh, a discount interest of zero representing an energy real price increase of the same amount as the real rate of interest, and the exemplified office room size of 12 m², life cycle economics gives a possible saving over 15 years of 450 €/room.

Here, no attention is taken to the fact that motorized solar shading can be used for other reasons and therefore the costs should be allocated on more than the energy saving. On the other hand, in practice, maybe the occupant wants to be able to override the system and by that the saving can be lower.

Other influencing factors on the possible savings and calculations are the efficiencies of the energy supply, which is usually called coefficient of performance, COP, for the chiller. In the calculations they were assumed to be 1 to show the need of the room. The power demand was not calculated in this study. Regarding the heating supply, it is reasonable that it will not be lower due to solar shading strategies since the peak is during the dark period of year and day. A lower power demand on the chiller would decrease the cost of the chiller. Johansson (2005) found the cost of a typical chiller to a constant plus 0.28 €/W installed power. If a COP of 3 is assumed, this means 0.093 €/W room power. Table 3 indicates that a room cooling power in this situation can be 1000 W even if it was far from enough to give the desired room temperatures. If it is assumed that it would be enough with 400 W with demand controlled solar shading, the difference 600 W costs 56 €/room which is not negligible. Then, the total saving could be in the magnitude of 500 €/room over 15 years, which may be in the magnitude of what a demand controlled solar shading system costs per room. There will also be a difference in the cost of the windows since the windows with low solar heat gains coefficient that are needed in the case without solar shading are more expensive than the ones that are of interest to let heat in when needed.

Regarding the apartment, the main issue is not the total energy as long as the window area is kept constant. The best solar shading strategy to decrease the energy use is to always let the solar gain enter. The issue is to avoid too high indoor temperatures and by that, discomfort, and in turn, the occupant's need for mechanical cooling systems that would increase the energy use in the dwelling sector. The simulation model did not allow for airing which gives some unreasonably high indoor temperatures that were not realistic for the case without solar shading.

Some conclusions are that the optimal thermal transmittance for both the office cell and the apartment was zero from an energy use perspective. High thermal storage capacity decrease the possible saving due to transfer of solar heat gain from day to night. Figure 7 shows that the actual internal heat load of 340 W in the office cell is close to optimal for all strategies.

Non modeled benefits with demand controlled solar shading could be to control for lower outgoing long wave radiation during nights, and use the solar shading to decrease the risk of outside condensation in the morning. A test facility was set up in an office cell where motorized outside solar shading screens were controlled by the heating demand output of the room indoor temperature control. The results from this are not the focus of this paper, but generally, the system worked. Future research could include a model for the needed lighting level in the room as well as a model for occupant's overriding the system.

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