

# THE EFFECT OF GLAZING TYPE AND SIZE ON ANNUAL HEATING AND COOLING DEMAND FOR SWEDISH OFFICES

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## ABSTRACT

Even in heating-dominated climates, cooling is often needed in offices due to high internal loads. Energy-efficient window design should limit both cooling and heating demands and allow daylight to replace artificial lighting. In order to determine optimal design for office windows for Swedish climates, a parametric study of heating and cooling demand was performed. In addition, the effect of a daylight-linked lighting control system was investigated. The daylight savings were calculated with ADELIN 2.0, while the thermal simulations were performed with DEROB-LTH. The studied windows included clear and low-e glazing with U-values ranging from 1 to 3 W/m<sup>2</sup>K. The sensitivity to window size and orientation, internal load, wall insulation, and ventilation was also studied. Preliminary results show that superinsulated windows ( $U \leq 1$  W/m<sup>2</sup>K) outperform all other glazing types. For south orientation, the superwindow is even a net energy saver. Its cooling demand was the second lowest amongst glazing types tested. The differences in cooling demand were, however, small. A comparison with different climates in Sweden revealed substantial differences in heating demands, while cooling demands were similar. However, the study indicates that the cooling season is shorter in northern compared to southern Sweden leading to higher peak loads. The study shows that cooling demands can mainly be reduced by: increasing the ventilation rate, reducing the window size or the internal load, or by dimming the electric lighting in response to daylight. Windows oriented towards north also yields significantly lower cooling demands. The heating demand can be reduced by using highly insulating windows and walls, increasing the internal load, and by decreasing the window size. The lowest total energy use (heating, cooling and electricity) is achieved by small superwindows with low internal loads.

## 1. INTRODUCTION

Modern Swedish office buildings have much lower heating demands compared to older ones (before 1980) due to a successive modification of the building code. The code deals primarily with space heating. Consequently, electricity use has not decreased in modern offices, but has rather increased [1]. High internal loads from equipment and lighting combined with solar radiation, makes it at times necessary to remove excess heat. Air-conditioning has normally not been used in offices, but is now becoming more and more common even in the Swedish heating-dominated climate.

The trend has thus been to increase the insulation thickness, use better windows and improve the air-tightness of buildings. Better windows has meant using more panes, for example, the triple pane windows has been "standard" since the end of the 1970s. More recent trends, but still not so widely spread, are the use of low-e coatings and low-conductive gas fills. Since the beginning of the 1970s, Swedish total window U-values have dropped from around 3 to between 2 and 1 W/m<sup>2</sup>K, the lower value found among the best performing windows on today's market.

Daylight utilisation i. e. control of the electric lighting in relation to available daylight has often been mentioned as one option to reduce the lighting electricity use [2, 3], and also to reduce cooling loads. Highly insulating windows lead however to windows with lower visual transmittance, which, in turn, may reduce the potential of daylight utilisation. These windows may also affect the way daylight and rooms are perceived [4].

There exist many studies on the impact of windows on heating and cooling demand. Most of them are however

just calculations of a single building. One attempt to make a more systematic analysis was made by Johnson et al. [5]. Low-e coatings were however not part of this study, nor was this made for Swedish climates. Another study by Sullivan et al. [6], which included several high performance windows, stressed the importance of window solar transmittance for cooling demand and the combination of U-value and solar transmittance for heating demand.

## 2. METHODS

### 2.1 Description of the base case

In order to systematically study the effects of both glazing type and size, a single-person office module was chosen as a representative of commercial office design. The office had two windows in the south facade, the lower edge of the glazing was located 1 m above the floor, see Fig. 1. The glazing size and the thermal conductance of the wall, glazing and frame was chosen according to common Swedish building practise. The window was triple-glazed with clear glass (Table 2). A free horizon and no external shading was assumed throughout this study. All other surfaces (ceiling, floor, internal walls) were modelled as adiabatic (no net heat transfer).

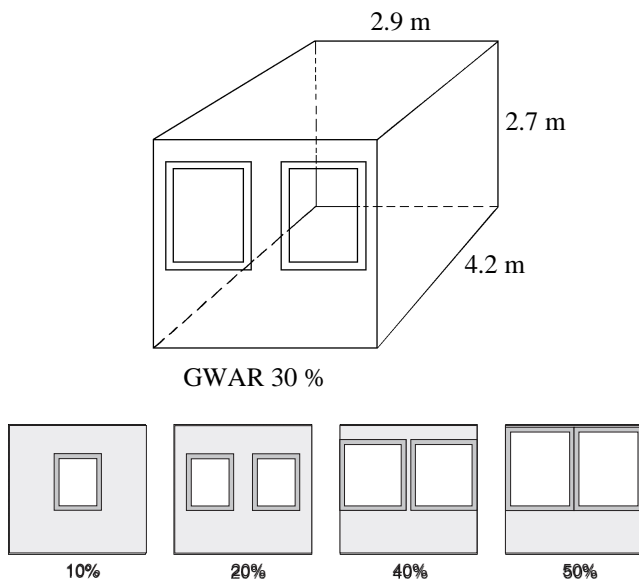


Fig. 1 The geometry of the base case with a Glazing-to-Wall Area Ratio (GWAR) 30 % (above) and wall view of other window sizes as seen from the inside (below).

Annual heating and cooling demand was calculated in DEROB-LTH, a dynamic building energy analysis program, originally from Austin, Texas [7], but continuously improved at the dept. for Building Science in Lund. It currently runs on a PC in the windows environment [8]. The calculations were performed with an improved window module [9], which treats the window in generally the same way as the WINDOW program [10].

At first no effects of daylight savings were considered. The internal heat load was held constant at 330 W during working hours (Mon-Fri between 8-17), except for at 12 (lunch), where it was 290 W. At night it was zero. The internal heat load comprised of three parts: equipment e.g. a computer with monitor (120 W); energy-efficient lighting (120 W) and one person (90 W). The lighting corresponds to an efficient installation with a lighting power density of 10 W/m<sup>2</sup> [11].

The climate file was Lund 1988 (lat. 55.72°N), which had an average outdoor temperature of 8.2°C. A constant ventilation rate of 10 l/s was used, which is close to the recommended minimum ventilation rate for hygienic reasons<sup>a</sup> [12]. No heat recovery of exhaust air was assumed. Infiltration was 0.1 ach. The thermostat settings for heating were 20°C (8-17), with a night setback to 18°C. For cooling the settings were 24°C (8-17), with a night setback to 28°C. Other assumptions are shown in Table 1.

Table 1 Additional assumptions regarding the base case.

Exterior wall U-value	0.18 W/m <sup>2</sup> ,K
Exterior wall	wood studs w. mineral wool
Interior walls	26 mm gypsum board on studs
Interior floor and ceiling	200 mm concrete
Interior absorptances: Ceiling/Walls/Floor	0.2/0.3/0.7
Ground reflectivity	30 %

### 2.2. Limitations of the study

Since daylight utilisation was one of the major interests of this study, only windows with relatively high visual transmittance were included. Visual quality aspects, such as glare, daylight and room perception, and visual interest, were excluded from the study. The calculated heating and cooling demands are the sum of the heating and cooling loads in the room itself, they do not refer to the energy that is delivered to the building. Further, the electricity use only refers to lighting and equipment in the room.

### 2.3. Parameters varied

The sensitivity to the following factors were studied: glazing size, type, and orientation; daylight utilisation; internal load; ventilation rate; wall insulation; and climate. The new glazing areas correspond to Glazing-to-Wall Area Ratios (GWAR) of 10, 20, 40, and 50 % (Figs. 1 & 2).

Three other window types were also studied: Double clear glazing, triple glazing with one silver-based low-e coating, and a triple glazed superinsulated window with two low-e coatings and krypton gas fillings, see Table 2. The window types were chosen as a representative selection of available windows on today's market and windows in the existing

<sup>a</sup> The recommended minimum outdoor air flow is 7 l/s, person plus 0.35 l/s, m<sup>2</sup> floor area.

building stock. All windows (except the smallest one) were modelled as two separate windows with a 100 mm wide frame/sash around. The frame U-values were derived from typical Swedish total window U-values ( $U_{tot}$ ) [13]. Further, the centre-of-glass U-values were applied to the whole glazing area.

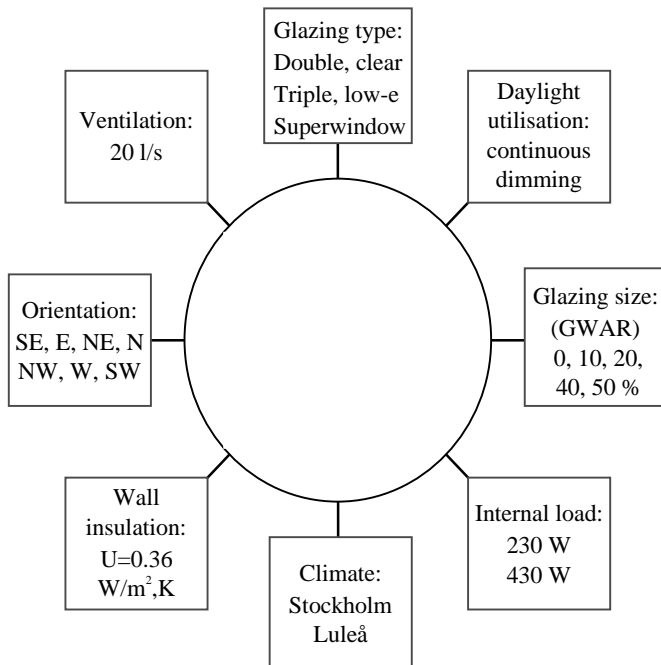


Fig. 2 Schematic overview of parametric study.

Table 2 Fenestration parameters. U-values (at  $-5/+25^{\circ}\text{C}$ , 5 m/s) for the total window are denoted  $U_{tot}$ , for the centre-of-glass  $U_{cog}$ , and for the frame/sash  $U_f$ . SHGC is the solar heat gain coefficient, and  $T_{vis}$  is the visual transmittance at near normal incidence.

Glazing design	$U_{tot}$	$U_{cog}$	$U_f$	SHGC	$T_{vis}$
	<- - (W/m <sup>2</sup> ,K) - ->			<- - (%) - ->	
Double, clear	2.65	2.86	2.16	75	80
Triple, clear	1.97	1.89	2.16	66	72
Triple, low-e	1.57	1.33	2.16	57	69
Superwindow	0.97	0.67	1.70	50	66

The effect of window orientation was studied by turning the office model one revolution in 45 degree increments, starting with south orientation in the base case. Further, the sensitivity to the internal load was studied by varying the load during working hours with  $\pm 100$  W. The lower value (230 W) could be realistic if the efficiency of the equipment was improved, e.g. with flat screens instead of monitors. The higher value (430 W) is not unrealistic for older offices with less efficient lighting installations.

To study the effects of daylight utilisation, i.e. of a daylight-linked lighting control system, lighting calculations were performed using SUPERLITE and SUPERLINK in

the ADELIN 2.0 program [14]. The light control strategy chosen was continuous dimming since this has previously been shown to produce the largest daylight savings [2, 3]. The desired lighting level was set to 500 lux in the mid-point of the room at desk level. SUPERLINK produces an output file with hourly power needs for the lighting. These values were added to hourly equipment and person loads to produce a new internal load file for DEROB. The drawback of this is that there is no interaction between the lighting and thermal simulations. Shading devices can therefore not be activated when solar gain is excessive or when glare becomes intolerable. The electric lighting savings as well as the solar gains described below are therefore optimistic estimates.

In the public debate it has been mentioned that Swedish offices should be less insulated in order to reduce cooling loads. Therefore, the U-value of the exterior wall was for one case doubled to  $0.36 \text{ W/m}^2\text{K}$ . In another case the ventilation rate was doubled to 20 l/s. This rate is used as guideline with respect to smoking and computers [12]. Finally, two other geographic locations were studied, namely Luleå (lat.  $65.55^{\circ}\text{N}$ ), and Stockholm (lat.  $59.35^{\circ}\text{N}$ ). In 1988, they had average outdoor temperatures of  $2.6^{\circ}\text{C}$  and  $6.5^{\circ}\text{C}$  respectively.

### 3. RESULTS

#### 3.1. Base case

The annual energy demand for the base case (Lund, GWAR 30 %, triple, clear glazing) was  $68 \text{ kWh/m}^2\text{,year}$  for heating and  $22 \text{ kWh/m}^2\text{,year}$  for cooling, in total  $90 \text{ kWh/m}^2\text{,year}$ . The heating season starts approximately in October and lasts until April, while the cooling season begins in May and ends in September, see Fig. 3. The electricity use for lighting and equipment was  $46 \text{ kWh/m}^2\text{,year}$ .

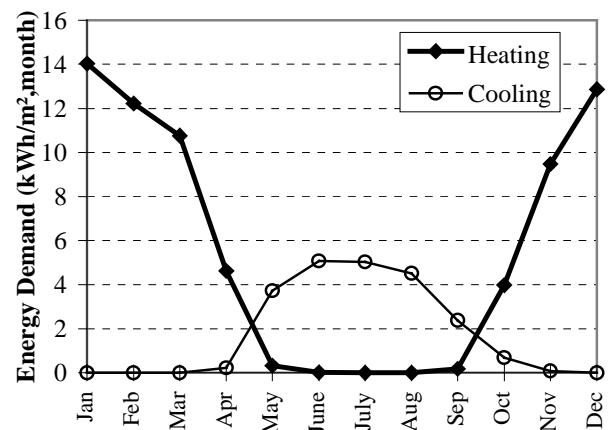


Fig. 3 The monthly heating and cooling demand ( $\text{kWh/m}^2\text{,month}$ ) of the base case.

### 3.2. Glazing size and type

The effect of changing the window size is relatively large for the cooling demand, while the heating demand is much less affected, see Fig. 4. The cooling demand increases somewhat faster than linearly with the glazing area. A GWAR of 40 % instead of 30 % increases the cooling demand by 8 kWh/m<sup>2</sup>,year, while it decreases by 8 kWh/m<sup>2</sup>,year for a GWAR of 20 %.

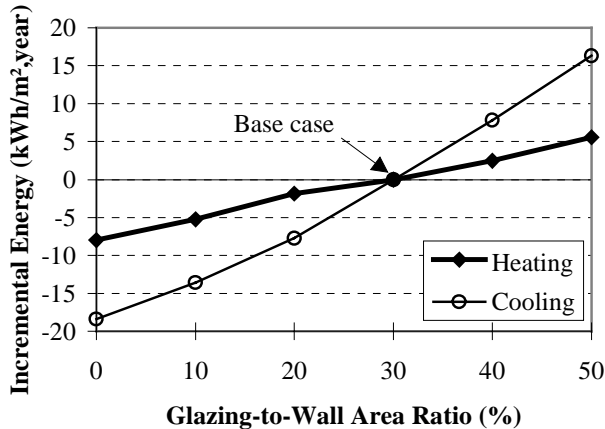


Fig. 4 Incremental energy demand (kWh/m<sup>2</sup>,year) as a function of glazing size.

The incremental heating and cooling demands for various glazing combinations are plotted against total window U-values in Fig. 5. As expected, the double-pane window performs worse than the triple-pane ones. Compared to the base case, both heating and cooling demands are higher: +10 kWh/m<sup>2</sup>,year and +2 kWh/m<sup>2</sup>,year resp. Consequently, the triple-pane window with one low-e coating performs better. Its heating demand is 5 kWh/m<sup>2</sup>,year lower and the cooling demand is 1 kWh/m<sup>2</sup>,year lower compared to the base case. Finally, the superwindow has a heating demand that is 15 kWh/m<sup>2</sup>,year lower and a cooling demand that is less than 1 kWh/m<sup>2</sup>,year lower than the triple, clear window. The heating demand for the superwindow is even lower than having no window at all, which means that the window is a net energy saver for south orientation. At the same time the cooling demand is slightly higher than for the triple, low-e window even if the solar transmittance is the lowest in the group. This shows that, during the cooling season, the balance between solar gains and thermal losses is slightly in favour for the triple, low-e window.

The heating demand shows an almost linear relationship with the U-value. This suggests that the difference in solar transmittance among the glazing types in this study have little or no influence. This is contradictory to what Sullivan et al. concluded for residential buildings in north American climates [6]. They said that both window U-value and solar transmittance was important for the heating performance.

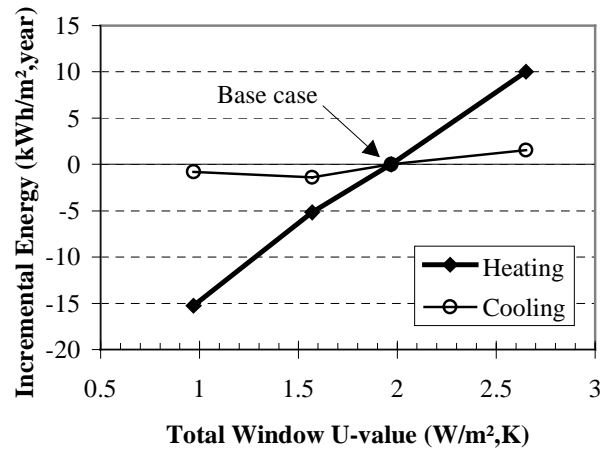


Fig. 5 Incremental energy demand (kWh/m<sup>2</sup>,year) as a function of total window U-value.

### 3.3. Orientation

The effect of window orientation is shown in Fig. 6. Naturally, north orientation has the highest heating demand (+21 kWh/m<sup>2</sup>,year) and the lowest cooling demand (-12 kWh/m<sup>2</sup>,year). East and west orientations show similar behaviour, although the cooling demand is slightly higher for east. In general, the cooling demand for both east and west is similar to south while the heating demand is significantly higher. North-east, north-west etc. orientations generally fall between the main orientations. The largest cooling demand occur for south-east orientation, plus 2 kWh/m<sup>2</sup>,year compared to south.

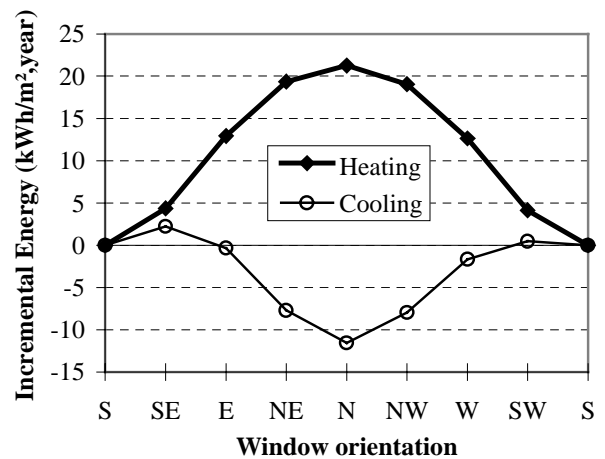


Fig. 6 Incremental energy demand (kWh/m<sup>2</sup>,year) as a function of window orientation.

### 3.4. Daylight utilisation, wall insulation and internal load

The parameters daylight utilisation, wall insulation and internal load were varied individually and the results are summarised in Fig. 7. The effect of daylight utilisation is a reduction of the cooling demand with 6 kWh/m<sup>2</sup>,year, while the heating demand increases by merely 4

kWh/m<sup>2</sup>,year compared to the base case. The electric lighting savings are approx. 10 kWh/m<sup>2</sup>,year (working Mon-Fri, 8-17) or a reduction of 47 % of annual use without dimming.

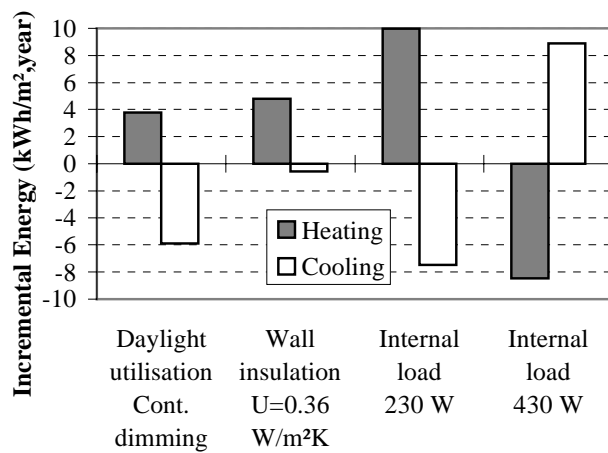


Fig. 7 Incremental energy demand (kWh/m<sup>2</sup>,year) for daylight utilisation, decreased wall insulation and for various internal loads respectively.

When the wall U-value is doubled to 0.36 W/m<sup>2</sup>,K the heating demand increases slightly (+5 kWh/m<sup>2</sup>,year), while the cooling demand is only reduced by 0.6 kWh/m<sup>2</sup>,year. Why the cooling demand does not decrease more is explained by the short time overlap between the heating and the cooling season, compare Fig. 3: in April and Oct. there is a small heating demand, but the cooling demand is almost zero. In May and Sept. the opposite is observed.

With an internal load of 230 W, the heating demand increases by 10 kWh/m<sup>2</sup>,year, while the cooling demand reduces by 7 kWh/m<sup>2</sup>,year. For an internal load of 430 W the heating demand instead decreases by 8 kWh/m<sup>2</sup>,year, while the cooling demand increases by 9 kWh/m<sup>2</sup>,year. Both incremental heating and cooling demand relationships are linear.

### 3.5. Climate and Ventilation

The climate has a large effect on mainly heating demands, see Fig. 8. For Luleå, the heating demand is doubled (+72 kWh/m<sup>2</sup>,year), and for Stockholm it is increased by 24 kWh/m<sup>2</sup>,year compared to Lund. The cooling demand is however the same for both Luleå and Lund, while it is slightly higher for Stockholm (+24 kWh/m<sup>2</sup>,year). Since the cooling season is shorter in Luleå than in Lund, peak power demands are, perhaps surprisingly, higher in Luleå.

Of all parameters tested, a doubling of the ventilation rate to 20 l/s shows the largest effect on the heating demand: It more than doubles (+80 kWh/m<sup>2</sup>,year), while the cooling demand decreases by 11 kWh/m<sup>2</sup>,year. (Fig. 8).

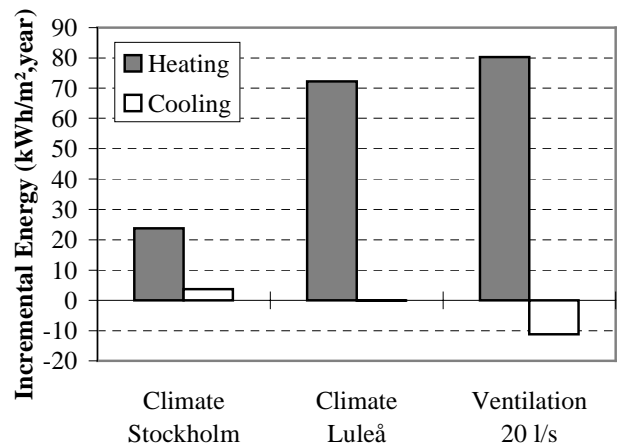


Fig. 8 Incremental energy demand (kWh/m<sup>2</sup>,year) for the Stockholm and Luleå climates and for an increased ventilation (Lund) respectively.

If we combine all results to get a hint about the best versus the worst design options, i.e. those that yield the lowest and highest total energy use (including electricity for lighting and equipment), and verify them by DEROB-simulations the following results are reached: (We keep the Lund climate, and don't consider a case without a window): Best design: base case plus GWAR 10%, internal load 230 W and superwindow. The demand for heating, cooling and electricity then becomes 58, 8 and 27 kWh/m<sup>2</sup>,year resp. Worst design: base case plus GWAR 50%, double pane window, 430 W internal load, east orientation with demands for heating, cooling and electricity equal to 185, 30, and 66 kWh/m<sup>2</sup>,year resp.

## 4. DISCUSSION

By varying one parameter at a time it is possible to see which one is the most important in reducing heating and cooling demands. The calculated differences between one case and the base case depend of course on how much the parameter is changed. Therefore, the steps should be realistic, which is also true for the parameter settings in the base case. It is difficult to establish what a realistic base case is, since most buildings are unique, and trends also vary over time. An attempt was however made to model a typical one-person office room which corresponds to current Swedish building practices and to find realistic steps for the parameters that were varied.

## 5. CONCLUSIONS

For the cooling demand, the following parameters show a large influence (in descending order): glazing size, window orientation, ventilation rate, internal load, and daylight utilisation. The heating demand is mainly affected by: ventilation rate, climate, orientation, and glazing type.

In search for the most promising energy-efficient technologies we firstly look for those that show simultaneous reductions in heating and cooling demand, and secondly those that reduce cooling demands significantly without causing large increases in heating demands. Among technologies identified in the first group are windows with very low U-values, especially the superwindow. For south orientation, the reduction in heating demand is even larger than having an unglazed wall, which means that the window actually gains energy over the year. At the same time the cooling demand is slightly lower than for a triple-glazed window. To limit the window size is also very important since the cooling demand depend strongly on the size. For all windows except the superwindow, both heating and cooling demands decrease with a decreased window size. In the second group, only daylight utilisation show some promise to reduce cooling loads, with only moderate increases in heating loads.

The orientation has quite a large effect on both heating and cooling, but this is only an alternative for new construction. And even then, the lot itself or a city plan may put restrictions on the building's design with regards to orientation. As little as the orientation can be changed for an existing building, as little is it possible to change the climate. However, the study reveals large differences in heating demands between southern and northern Sweden. This only emphasises the importance of well-insulated walls and windows for cold climates.

Increased ventilation has a large potential to reduce the cooling demand, but at the expense of a dramatically increased heating demand. There are a number of solutions to this, e.g. heat recovery of exhaust air, and variable ventilation rates depending on the cooling demand.

When the internal load is changed, both heating and cooling demands are changed by similar amounts. In percent however, cooling is affected more than heating. This points at the importance of keeping the internal load as low as possible. As this load arises from mainly artificial lighting and equipment it leads to electricity use, which cannot be replaced by another energy source.

Finally it can be concluded that it is not good to reduce the wall insulation in order to reduce cooling loads. Since the cooling demand occur when the temperature difference between inside and outside is low, the main effect will be that heating demands are increased, while the cooling demands are almost unaffected.

## REFERENCES

[1] Bygghälsöversynsgruppen. (1995). *Energiboken. Kunskapsläge och forskningsfront*. (The energy book. State of knowledge and research). (in Swedish). (Report T21:1995). Stockholm, Sweden: Bygghälsöversynsgruppen.

- [2] Christoffersen, J. (1995). *Daylight Utilization in Office Buildings*. (Rep. SBI 258). Danish Building Research Inst.
- [3] Szerman, (1994). *Auswirkung der Tageslichtnutzung auf das energetische Verhalten von Bürogebäuden*. (The Effect of Daylight Utilisation on the Energetic Performance of Office Buildings). (In German). Stuttgart, Germany: Universität Stuttgart, Konstruktive Bauphysik.
- [4] Bülow-Hübe, H. (1995). Subjective reactions to daylight in rooms: Effect of using low-emittance coatings on windows. *Lighting Res. Technol.* **27**(1) 37-44.
- [5] Johnson, R, Sullivan, S., Selkowitz, S., Nozaki, S, Conner, C. & Arasteh, D. (1984). Glazing Energy Performance and Design Optimization with Daylighting. *Energy and Buildings*. **6**(4) 305-317.
- [6] Sullivan, R., Beck, F., Arasteh, D., & Selkowitz, W. (1995). *Energy Performance of Evacuated Glazings in Residential Buildings*. (Report LBL-37130). Berkeley, CA: Lawrence Berkeley Laboratory.
- [7] Arumi-Noé, F., & Wysocki, M. (1979). *The DEROB System Volume I, User's Manual for the DEROB System*. Austin, Texas, USA: Numerical Simulation Laboratory, School of Architecture, University of Texas.
- [8] Kvist, Hasse (1995). *DEROB-LTH for Windows. User Manual*. (Report TABK--95/7019). Lund, Sweden: Lund Institute of Technology, Department of Building Science.
- [9] Källblad, Kurt (1997). *Thermal Model of Windows in DEROB-LTH*. (Interim report, March 1997). Lund, Sweden: Lund Inst. of Technology, Dept. of Building Science.
- [10] Arasteh, D., Reilly, S., & Rubin, M. (1989). A Versatile Procedure for Calculating Heat Transfer Through Windows. *ASHRAE Trans.* Vol. 95. Pt. 2.
- [11] NUTEK (1994, Ver. 2). *Office Lighting. 34 Examples of Good and Energy-Efficient Office Lighting*. Swedish National Board for Industrial and Technical Development, Department of Energy Efficiency.
- [12] AFS 1993:5 (1993). *Ventilation och luftkvalitet. Arbetskyddsstyrelsens författningssamling*. (Ventilation and Air Quality). (in Swedish). Solna, Sweden: Ordinance of The National Board of Occupational Safety and Health.
- [13] Elitfönster. (1996). *U-värde katalog*. (Catalogue of U-values) (In Swedish).
- [14] Erhorn, H. & Stoffel, J. (eds.) (1996). *ADELIN 2.0. Advanced Daylighting and Electric Lighting Integrated New Environment*. Documentation of the Software package ADELIN, Version 2.0 (9 volumes). IEA Solar Heating and Cooling Program, Task 12: Solar Building Energy Analysis Tools.