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Energy and Buildings 40 (2008) 1161–1170
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

Energy simulations for glazed office buildings in Sweden

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Received 19 September 2006; received in revised form 8 October 2007; accepted 9 October 2007

Abstract

Highly glazed buildings are designed by architects to be airy, light and transparent with more access to daylight. Their energy efficiency, however, has become questioned. Therefore, energy simulations of single skin office buildings in Sweden were carried out, using a dynamic energy simulation tool. In order to study the impact of glass on the energy use during the occupation stage, office building alternatives with 30, 60 and 100% window to external wall area were studied. Other varied parameters were the building's orientation, the plan type (open and cell plan offices), the control set points and the façade elements (type and size of windows, type and position of shading devices, etc.). The main conclusion is that careful design is needed to ensure low energy use and good thermal comfort, especially for highly glazed office buildings. Careful design of glazed office buildings has to be based on detailed thermal simulations. Especially in fully glazed buildings (in which the façade is more "sensitive" to climatic conditions), proper combination of control set points, glazing and solar shading are crucial for the energy performance.

A sensitivity analysis of single skin glazed office buildings was one of the main aims of the study. Although it was concluded that highly glazed single skin buildings are likely to consume more energy during the occupation stage, after studying the impact of shadings, window types, etc., the increase was lowered to 15% (100% glazed alternative compared to a typical reference building with 30% window to external wall area) maintaining at the same time an acceptable level of thermal comfort.

Keywords: Glazed office buildings; Energy simulations; Energy use

1. Introduction

Modern office buildings have high energy savings potential. During the nineties many office buildings with single and double skin glass façades were built. Highly glazed single skin office buildings are designed by architects to be airy, light and transparent with more access to daylight but their energy efficiency has become more and more questioned, as there is risk of a high cooling and heating demand.

Today there is a lack of knowledge regarding the overall performance of highly glazed office buildings for Nordic conditions. Therefore, a project was initiated, at the division of Energy and Building Design, Department of Architecture and Built Environment at Lund University, in order to gain knowledge of possibilities and limitations with glazed office buildings in Nordic climates as to energy use and indoor climate. A detailed background and outline of the project is given in an introductory report [1]. The project means further development of calculation methods and analysis tools, improvement of analysis methodology, calculation of LCC, compilation of advice and guidelines for the construction of glazed offices and strengthening the competence on resource efficient advanced buildings in Sweden.

It is claimed that the energy use for different highly glazed buildings may vary more than for buildings with traditional façades since the glazed alternatives are particularly sensitive to the outdoor conditions [2]. The building's shape, site and location, orientation and occupancy are likely to be crucial for its performance.

For this study the starting point was a reference building; a typical Swedish office building of the late 1990s located in Gothenburg. The first part of this project has meant defining this building and fit with different single skin glazed alternatives, choosing simulation tools and carrying out energy simulations for these building alternatives [3]. Energy use and thermal comfort were studied. In this paper the energy use results are presented and discussed.

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0378-7788/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.enbuild.2007.10.011

2. Methods

A virtual reference building was created, representing Swedish office buildings built in the late nineties [4,5], as to design and energy performance. For this building a parametric study of energy use was carried out, where in the simulations the building construction, HVAC system and control system was described in great detail. The building's orientation, plan type, control set points, façade elements (window type and area, shading devices, etc.) were changed while other parameters such as the building's shape, the occupants' activity and schedules, etc. were kept the same. Parametric studies were carried out regarding the energy use during the occupation stage of the building.

Additionally, the concept of acceptable thermal comfort level was introduced in order to evaluate the overall building performance. Therefore, a minimum level of 90% of the working hours with Predicted Percentage of Dissatisfied (PPD) [6] occupants less than 15% was set as a limit for the accepted building alternatives. The PPD levels were calculated by the simulation tool IDA ICE 3.0 (see below) on a zone (occupant) level and by a developed MS Excel post-processor on a building level.

The simulation tool used was IDA ICE 3.0, a dynamic energy simulation tool, used by consultants and researchers in Sweden, Finland and Switzerland [7,8] for advanced energy and indoor climate analysis. Thermal comfort was simulated at building level and zone level, while energy use was calculated only at building level. Validation tests have shown the program to give reasonable results and to be applicable to detailed buildings physics and HVAC simulations [9,10].

3. Description of the building model

3.1. Description of the reference building

The reference building was a six storey high building as shown in Fig. 1. The height of the building was 21 m. The floor area of the building was 6177 m^2. The room height was 2.7 m and the distance between floors was 3.5 m. The two long façades are identical as are the two short ones.

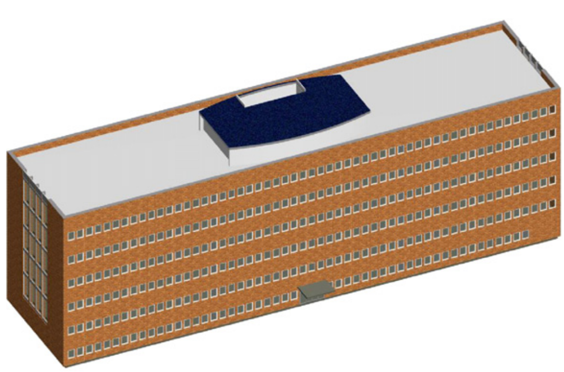

Fig. 1. View of the glazed reference building, where the glazed area is 30% of the façade area.

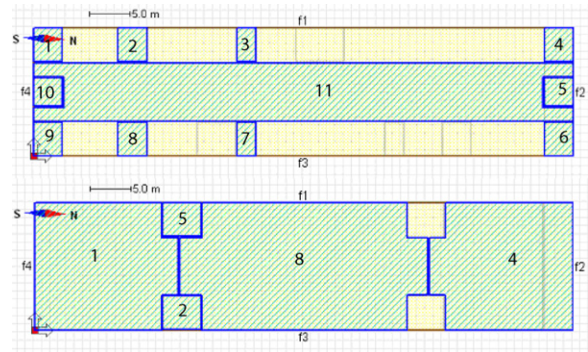

Fig. 2. View of cell and open plan type (IDA input).

Two plan types were assumed for the simulations; cell and open plan. The different zones inserted in IDA are shown in Fig. 2. A large number of zones were used in the model, although reduced compared with the number of rooms to avoid excessive simulation time. The main reason for this was to enable to study thermal comfort in individual zones, but also that more detailed input lead to more accurate energy simulations.

In order to calculate the total building performance, each zone type was multiplied with the number of the identical ones. Since no shading from neighbouring buildings was considered, the multiplication is fairly reasonable; the ground and top floor, however, were simulated separately since the boundary conditions (floor and ceiling correspondently) differ from the intermediate ones. Finally, all internal building elements (walls, floors, ceilings, etc.) are assumed adiabatic (no heat exchange between zones is considered). The repetition of each zone in every floor is presented in Table 1. The thermal transmittance of the building elements is shown in Table 2.

The glass area of the simulated building alternatives was varied (30, 60 and 100% of the façade area). For the 30% glazed alternatives a triple clear pane window with venetian blinds in between the panes was assumed. However, for the 60 and 100% ones, several alternatives were generated as shown in Table 3 and further explained in Section 4.

The effective U-values and g-values are calculated with the shading devices on (100%) when the incident light exceeded 100 W/m^2. However, for the seventh alternative (fixed external louvers) the shading devices were assumed on during all year round.

Table 1
Zone description

Zone number	Zone type	Zone repetition
1, 4, 6, 9 (cell)	Corner office rooms	1 (each floor)
2, 8 (cell)	Double office rooms	7 (each floor)
3, 7 (cell)	Single office rooms	14 (each floor)
5, 10 (cell)	Meeting rooms	1 (each floor)
11 (cell)	Corridor	1 (each floor)
1, 4 (open)	Corner zones	1 (each floor)
8 (open)	Intermediate zone	1 (each floor)
2, 5 (open)	Meeting rooms	2 (each floor)

Table 2
Thermal transmittance of building elements

Building element	U-Value (W/m^2 K)
External wall (long façade)	0.32
External wall (short façade)	0.25
Internal walls	0.62
Roof (above 6th floor)	0.18
Ground floor	0.32
Intermediate floors	1.74

The thermal transmittance of the frame was 2.3 W/m^2 K when triple clear glazing was used (30% glazed alternative and the first of the 60 and 100%), otherwise it was 1.6 W/m^2 K.

3.2. Occupancy

For the reference building it was assumed that 80% of the (theoretical) occupants were present in the rooms during working hours. The occupants' presence was from 08:00 to 12:00 h and 13:00 to 17:00 h for the offices and from 10:00 to 12:00 h and 13:00 to 15:00 h for the meeting rooms every workday. The occupancy was reduced during Christmas (50%) and summer vacations (50% during June and August and 75% during July). The activity level was assumed 1 met (108 W/occupant) for occupants sitting and reading. Finally the occupant's clothing was assumed to be 1 clo (trousers, long-sleeve shirt, long-sleeve sweater, T-shirt) during winter and 0.6 clo (trousers, long-sleeve shirt) during summer.

The total number of occupants differed for the open and cell plan type. For the cell type the "theoretical" number of occupants was 454 and the "practical" one (80% occupancy for the offices and 40% for the meeting rooms) was 319. For the open plan type, an increase of 20% was assumed for the office space, while the density of the meeting rooms was kept the same. This gives a total "theoretical" number of occupants of 590 and a "practical" one of 395. The open plan had more meeting rooms than the cell type. The occupant's density for the cell type plan was 17 m^2/occupant and for the open plan type 13.8 m^2/occupant.

3.3. Lights and equipment

For the lights of the cell type layout, energy efficient lighting (fluorescent tubes with HF fittings) was assumed, i.e. installed power of 12 W/m^2 for the offices and the meeting rooms and desired illuminance at the desk 500 lux. For the corridors and the rest of the spaces an installed power of 6 W/m^2 and desired illuminance 250 lux was assumed. However, for the open plan the installed power of 12 W/m^2 was assumed for all the working space. The luminous efficacy of the lights was set to 41.7 lm/W.

For the cell type office building, the corner offices (one occupant) were equipped with one PC (125 W), one printer (30 W) and one fax (30 W). The double and single offices were equipped only with PCs (two and one, respectively). No electrical equipment was assumed for the meeting rooms. Four copiers (500 W) four printers and two faxes were placed in each corridor for general use. The annual energy use of equipment for the cell type office building was 22 kWh/m^2. For each floor of the open plan office building it was assumed that there is one PC (30 W) per occupant, while the printers (8 units of 30 W and 4 units of 50 W), the faxes (8 units of 30 W) and the copiers (4 units of 500 W) were mainly used by everybody. No equipment was assumed for the meeting rooms. The annual energy use of equipment for the open plan office building was 21 kWh/m^2.

The schedule assumed for the use of the lights and equipment was from 08:00 to 12:00 h (80%), from 12:00 to 13:00 h (15%) and from 13:00 to 17:00 h (80%) for a typical workday. During the Christmas vacations and July 50% of the typical use was assumed and during June and August 75%. During the weekends no use of lights or equipment was assumed. Due to equipment in stand-by mode, however, 15% of the load was assumed for the non-working hours.

3.4. HVAC

For the cell type, it was assumed that the air was supplied in the offices and extracted from the corridors. For the offices a CAV control supplied air with 10 l/s for each person. For the meeting rooms a VAV CO_2 control was assumed. For the open plan the air was supplied and extracted from the office space (since there is no separation between offices and corridors). The supply air for each person was 7 l/s for the office space (CAV control) and a VAV CO_2 control was assumed for the meeting rooms.

The infiltration rate including some window airing was 0.1 ach for both plan types. The heat recovery efficiency was set to 60%. The central Air Handling Unit (AHU) was on from 06:00 till 20:00 h during weekdays and from 8:00 till 17:00 h during weekends for both plan types. The supply temperature of the AHU is shown in Fig. 3.

Table 3
Glazing and frame properties for glazed alternatives

Building alternative	$U_{glazing}$ (W/m^2 K)	$g_{glazing}$	$U_{effective}$ (W/m^2 K)	$g_{effective}$	Shading type	U_{frame} (W/M^2 K)
1	1.85	0.69	1.65	0.30	Intermediate venetian	2.3
2	1.14	0.58	1.08	0.22	Intermediate venetian	1.6
3	1.14	0.35	1.07	0.28	Internal venetian	1.6
4	1.11	0.22	1.04	0.22	Internal venetian	1.6
5	1.14	0.58	1.08	0.47	Internal venetian	1.6
6	1.14	0.35	0.92	0.19	Internal screens	1.6
7	1.14	0.35	1.14	0.2	Fixed external louvers	1.6

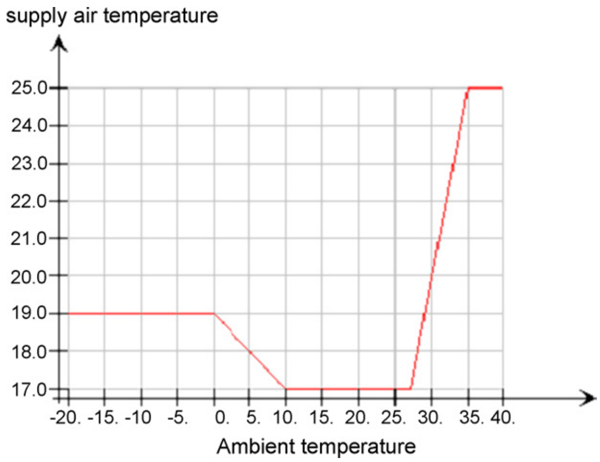

Fig. 3. Supply temperature of the AHU (IDA input).

The presented energy demand for heating is the gross energy demand. Since district heating was assumed the boiler efficiency was chosen as almost 100%, i.e. the gross and net energy demand are almost the same. For the cooling demand the energy use refers to the delivered energy in the zones (as if district cooling). The efficiency of the fans was set to 70%.

3.5. Control set points

Three control set points [11] for the indoor temperature were chosen for the simulations of the reference building, as shown in Table 4. The normal control set point was defined as the standard (reference) case, since the lower and upper temperature limit reflect the Swedish practice in modern offices. However, the two other control set points can provide useful information concerning the influence on energy use, perception of thermal comfort and the occupants' productivity. For the water radiators a proportional control was used and for the cooling beams a PI control.

The artificial light provided at the workplace was changed in parallel with the three control set points. For the strict control it was assumed that the lights were switched on when the occupants were present, regardless of the amount of daylight inside the offices (which is not unusual in existing offices). However, for the normal and poor control set points, a set point of 500 and 300 lux correspondingly was set at the workplace. The main reason that these set points were assumed was to calculate the savings in electricity for artificial lighting in the building.

Table 4
Control set points for the glazed alternatives

Control set point	Minimum operative temperature (°C)	Maximum operative temperature (°C)	Daylight at desk (lux)
Poor	21	26.0	Set points
Normal	22	24.5	Set points
Strict	22	23.0	Schedule

4. Generation of building alternatives

For the 30% glazed building, 18 alternatives were simulated. Although the building construction was kept the same, three orientations (short façade facing the NS, the EW and 45°), three control set points (strict, normal and poor) and two plan types (cell and open) were changed in order to study their influence on the building's performance.

For the 60 and 100% glazed alternatives seven different window constructions (commercially available) were suggested and for each construction different alternatives were generated, as shown in Table 3. The rest of the building construction was kept the same (as for the 30% glazed alternative). Each one of them was simulated for a cell and open plan type office building and for strict, normal and poor control set point. In total 84 alternatives were simulated. A brief description of the generated alternatives follows.

The first building alternative works like a "bridge" between the 30 and 60% glazed buildings. The $U_{glazing}$ and U_{frame} values were kept the same (triple clear pane window) in order to study the impact of larger glazing area on the energy use. The number and type of panes, the type and positioning of shading devices, etc., were also the same as the 30% glazed building.

In the second building alternative the type of window was changed (lower $U_{glazing}$ and U_{frame} values) in order to get a more realistic solution for a glazed building. The new glazing was a triple pane (2 + 1). The type and position of the shading devices stayed the same.

In the third alternative the triple glazing unit was replaced by a double glazing with the same U-value. The total solar transmittance (g-value) was however decreased to 0.35 from 0.58. The intermediate venetian blinds were replaced by internal ones in order to study the influence of the shading devices' on the potential overheating (the properties of the blinds remained the same). This window type was chosen as a typical alternative used for a 60% glazed building.

In the forth alternative the U-value of the window remained the same, while the total solar transmittance (g-value) decreased to 0.28 in order to investigate its impact on the cooling demand. In the fifth alternative the U-value of the window was kept the same, while the total solar transmittance (g-value) increased to 0.58. The number of panes, the position and type of shading devices remained the same. These two cases were selected in order to further investigate the influence of g-value on the heating and cooling demand. Additionally, since the glazing and frame properties were the same as in the second alternative, it was possible to investigate the influence of the position of the shading devices on the energy use and thermal comfort.

In the sixth alternative venetian blinds were replaced by internal screens. The window construction was identical with the third alternative, since this was considered to be the more often used window type. With this alternative it was possible to study the influence of different types of shading devices on the energy use and indoor environment.

In the last alternative the internal screens are replaced by fixed external louvers. The window construction was again identical with the third alternative.

5. Results and discussion

Due to the large amount of simulated building alternatives, only some representative alternatives are presented regarding the total energy use (Section 5.1). In the next two sections (Sections 5.2 and 5.3), most of the simulated alternatives are compared in order to study the influence of the parameters on the energy use during the occupation stage.

The parametric studies were carried out at a building and at a zone level. The energy use for heating, cooling, lighting, pumps and fans was examined. Due to the different control set points applied for the different building alternatives the parametric studies were carried out in two ways:

- Comparison of the alternatives with the same control set points in order to investigate the influence of orientation, façade construction and plan type on the energy use.
- Cross comparison of the alternatives with different set points (assuming the same orientation, façade construction and plan type for the different building alternatives) in order to investigate the influence of set points on the energy use. For this cross comparison, and in order to ensure good overall building performance, the concept of acceptable thermal comfort level is introduced. Therefore, a minimum level of 90% of the working hours with Predicted Percentage of Dissatisfied occupants less than 15% was set as a limit for the accepted building alternatives.

5.1. Total energy use

The energy use for the 30% glazed building alternatives is shown in Table 5. Where C, O: cell or open plan type; NS, NS 45, EW: short façade facing the North-South, North-South 45° or East-West orientation); strict, normal, poor: the control set points.

As shown in Table 5, the influence of orientation on the 30% glazed building's energy use is small (see also Section 6.2 for alternatives with the same control set points). For this reason the orientation was not varied for all the highly glazed alternatives and was just briefly studied.

The first 60% glazed alternative was chosen only for a cross comparison with the 30% glazed building. As expected, the total energy use increases dramatically (from 123 to 151 kWh/m^2 a), when the window to external wall area increases (Table 6). The alternative with 100% window to external wall area results in an even higher energy use (177 kWh/m^2 a as shown in Table 7).

Table 5
Energy use for 30% glazed alternatives

30% glazed alternatives	Space heating (kWh/m^2 a)	Cooling (kWh/m^2 a)	Total (kWh/m^2 a)
C-NS-normal	52.2	11.5	123.4
C-NS45-strict	56.0	20.2	136.2
C-NS45-normal	52.1	11.0	122.8
C-NS45-poor	47.1	6.6	113.3
C-EW-normal	52.3	10.3	122.3
O-NS45-normal	44.6	17.3	126.8

Table 6
Energy use for 60% glazed alternatives

60% glazed alternatives.	Space heating (kWh/m^2 a)	Cooling (kWh/m^2 a)	Total (kWh/m^2 a)
C-NS45-nor (1)	72.3	20.3	151.4
C-NS45-nor (2)	49.6	24.4	133.2
C-NS45-nor (3)	53.9	18.0	131.4
O-NS45-nor (3)	46.3	22.2	133.3
C-NS45-nor (4)	55.5	13.4	128.5
C-NS45-nor (5)	48.5	35.8	143.5
C-NS45-nor (6)	53.5	18.2	131.2
C-NS45-nor (7)	58.9	7.2	125.9

If the thermal transmittance of the window is decreased by lowering the thermal transmittance of the frame and replacing the triple clear pane with a triple-glazed window with low-E coating (internal pane) and argon (between the two inner panes) for the 60% glazed alternative (second glazing alternative), then the total energy use is decreased by 18.2 kWh/m^2 a.

By decreasing the *g*-value in the third alternative and replacing the intermediate blinds by internal ones, the total energy use drops only 1.8 kWh/m^2 a. In this case the *g* effective is slightly higher but the *g*-value (when shading is not applied) is much lower. So the saving are mostly due to the periods that shading is off. Further decrease of the total solar transmittance (fourth alternative) causes similar results (total decrease of 2.9 kWh/m^2 a compared with the third alternative).

If the total solar transmittance is increased (still using internal blinds) in the fifth alternative, keeping the rest of the parameters the same, the total energy use increases 12.1 kWh/m^2 a. The only difference between the second and fifth alternative is the position of the venetian blinds. When the venetian blinds are placed internally in the fifth alternative, the dramatic increase in cooling load results in an increase of the total energy use.

The intermediate blinds give an effective *g*-value of 0.22 while the internal ones (fifth alternative) give a *g*-value of 0.47. By replacing the internal blinds alternative by internal screens (sixth alternative), the effective *g*-value slightly decreases. This results in similar total energy demand.

Finally in the seventh alternative, the internal blinds of the third alternative were replaced by external fixed horizontal louvers. In this case the *g*-value was calculated using the Parasol software [12] for each month and a monthly average *g*-value was inserted in IDA. The total energy use in this case is the lowest of the seven alternatives. However, since the

Table 7
Energy use for 100% glazed alternatives

100% glazed alternatives	Space heating (kWh/m^2 a)	Cooling (kWh/m^2 a)	Total (kWh/m^2 a)
C-NS45-nor (1)	91.7	30.3	176.8
C-NS45-nor (2)	59.3	37.1	151.7
C-NS45-nor (3)	65.4	26.7	147.9
O-NS45-nor (3)	57.6	29.6	152.0
C-NS45-nor (4)	67.6	19.4	143.0

properties of the shading devices (g-values) were calculated in a different way for the seventh alternative the choice of the most energy efficient alternative was among the first six ones and therefore the forth alternative was picked out as the most energy efficient one.

The third alternative was chosen as a common case in real buildings for comparisons of the plan types (C-NS45-nor (3), O-NS45-nor (3)). As for the 30% glazed alternatives, the heating demand of the cell type is higher than for the open plan while the cooling demand is lower. The total energy use of the open plan type is 4 kWh/m^2 a higher than the one of the cell type.

From the 100% glazed alternatives only the 4 first cases (4 cell and one open plan) are presented (Table 7). The impact of different glazing for the 100% glazed alternative is similar to the 60% ones. For example, the (total) energy saving when replacing the triple clear pane (first alternative) of the 60% glazed building with the one of the second alternative (lower U- and g-values) in Table 6 is 18 kWh/m^2 a. The same change for the 100% glazed building in Table 7 gives a difference of the total energy demand of 25 kWh/m^2 a.

A cross comparison of the 30% (alternative 1), 60% (alternative 4) and 100% (alternative 4) glazed buildings shows that the total energy use of the 60% glazed alternative is similar with the 30% one. However, the 100% glazed building alternative uses 18% more energy.

5.2. Energy use for alternatives with the same control set points

5.2.1. Plan type

Mainly due to higher internal loads and a different ventilation strategy (mostly lower ventilation rates), the open plan type tends to be warmer than the cell type. Thus, the cooling demand increases while the space heating demand decreases, especially for the strict heating and cooling set points. The difference between the total energy use for the two plan types is rather small and similar for all the building alternatives.

For the reference building (30% window area to external wall area) the energy use for heating the cell type office building (with normal set points) is 14% (7.5 kWh/m^2 a) higher than for the open plan one as shown in Fig. 4. For the 60 and 100% glazed alternatives with the same window type (triple clear pane) the increase is reduced to 11% or 7.6 and 9.9 kWh/m^2 a correspondingly (since the effect of glazing area is more important, the effect of plan type decreases). On the contrary, the cooling demand of the open plan type is much higher for the 30% glazed alternative (57% or 6.3 kWh/m^2 a), while for the 60 and 100% glazed ones the cooling demand of the open plan type increases by 28% (5.8 kWh/m^2 a) and 20% (6 kWh/m^2 a), respectively (the effect of glazing area is much more important than the heating demand, therefore the decrease of difference between the glazing alternatives is larger). In any case, the impact of plan type is reduced for highly glazed alternatives (the large window area of the 100% glazed alternatives combined with the high thermal transmittance of the windows reduce the impact of plan type on the cooling demand as shown in Fig. 4). The higher glass area leads to a (small) decrease in the energy use for lighting. The higher energy use of the open plan type than the cell type (see Fig. 4) can be explained by the need for proper lighting of the whole building (for the open plan type), since all of it is used as working area (for the corridor of the cell type half the lighting power is required).

The impact of plan type on heating and cooling demand is quite similar regardless of the window type (see Fig. 4). Generally, the impact of plan type on the cooling demand tends to increase for the alternatives with lower g and $g_{effective}$ values (e.g. the seventh one with the fixed external louvers).

Finally, there is a 24% higher energy demand for the operation and cooling of the server rooms (regardless of the set point) for the open plan due to the increased number of occupants. The energy use for operation and cooling of the server rooms was assumed to be 175 kWh/a per occupant for the server rooms and 87.5 kWh/a per occupant for cooling [13].

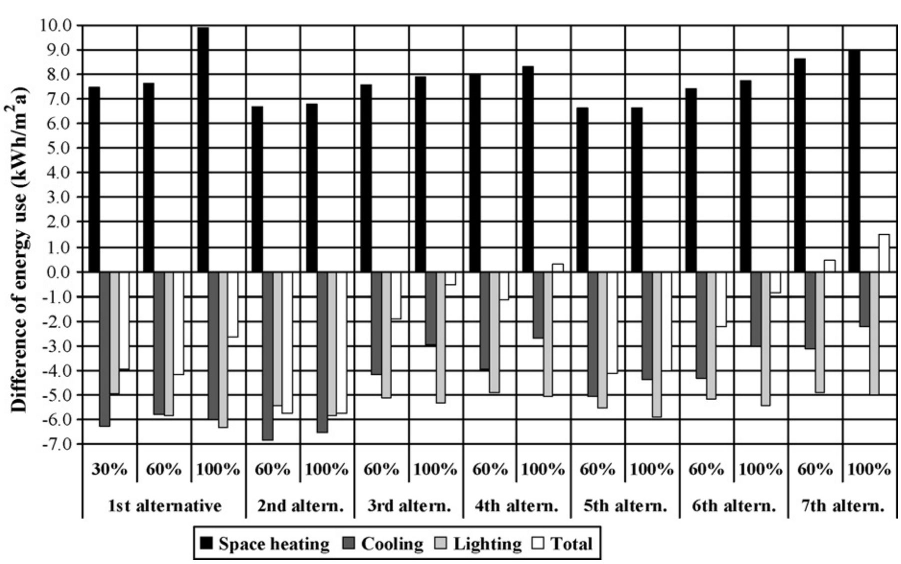

Fig. 4. Impact of the plan type on the energy use of the glazed alternatives. Difference of energy use between cell and open plan layouts for normal control set points.

5.2.2. Orientation

On a building level the orientation does not have much effect on the energy use, mainly due to the fact that the two short façades and the two long façades are identical. The stricter the control set points, the smaller the differences are in energy use for different orientations. The influence of the plan type on the energy use is still rather small (when comparing the C-NS45-nor and O-NS45-nor). The energy use is slightly higher for the open plan type. Due to the small impact of the orientation on the total energy use, no further study has been made on a building level. There would likely have been an influence of orientation, if the façades had been different.

5.2.3. Façade construction

In order to study the impact of glass area on the energy use, 60 and 100% glazed alternatives with triple clear glazing (as in the reference building) were generated. (In reality windows used for highly glazed alternatives typically have lower thermal and solar transmittance.)

A cross comparison diagram of energy use of the 30, 60 and 100% glazed alternatives (cell type) with strict and normal set points is presented in Fig. 5. The increase in the total energy use for the 60% glazed building is 23% regardless of the set point (compared with the reference building). The increase for the 100% glazed alternatives is 45% for the strict and 47% for the normal set points. Both the heating and cooling demand increase in the highly glazed building alternatives as shown in Fig. 5. The increase in cooling demand of the 100% glazed building is very high (112% for the strict and 177% for the normal set points).

One of the main arguments for using increased glazed areas in buildings is the provision of better indoor environment due to daylight. However, the increased window area does not necessarily lead to a reduction in energy use for lighting the building properly (see Fig. 6).

A cross comparison of the 60 and 100% glazed alternatives with different windows and shading devices, shows that the difference in the total energy use (compared with the reference building) is reduced when the thermal transmittance and the total solar transmittance decrease.

In order to show the impact of the windows and shading devices on the energy use, the seven 100% glazed alternatives with normal set points (cell type plan) are compared (see Fig. 6). A decrease in the thermal transmittance of the window (alternatives 2–7) results in a reduction in the energy use for heating and a smaller increase in cooling demand (comparison of alternatives 1 and 2). The alternatives (second and fifth) with high total solar transmittance values (0.58) have also a slightly lower heating demand (compared with the third one with $g = 0.35$), while the one (forth) with lower g-values (0.27) has slightly higher heating demand. The effect on cooling demand is the opposite; lower g-values give lower cooling demand.

The position of shading devices and the influence on the energy use was also studied. Intermediate blinds result in lower $g_{\text{effective}}$ values and thus lower energy use for cooling than internal ones. When the second and fifth alternatives (same window and shading devices properties) are compared, it is obvious that the cooling demand increases dramatically (37%) when the blinds are placed inside. The heating demand is almost the same (slightly higher in the second alternative), since the blinds were used mostly during the warm periods.

When fixed external louvers are applied (seventh alternative) the cooling demand is reduced dramatically while the heating demand is increased, due to reduced solar gains most of the year. The cooling demand of the seventh alternative is lower because the shading is applied always. The third and sixth alternatives have almost the same g effective. The different types of internal shading (blinds in the third and screens in the sixth) do not influence the energy use much.

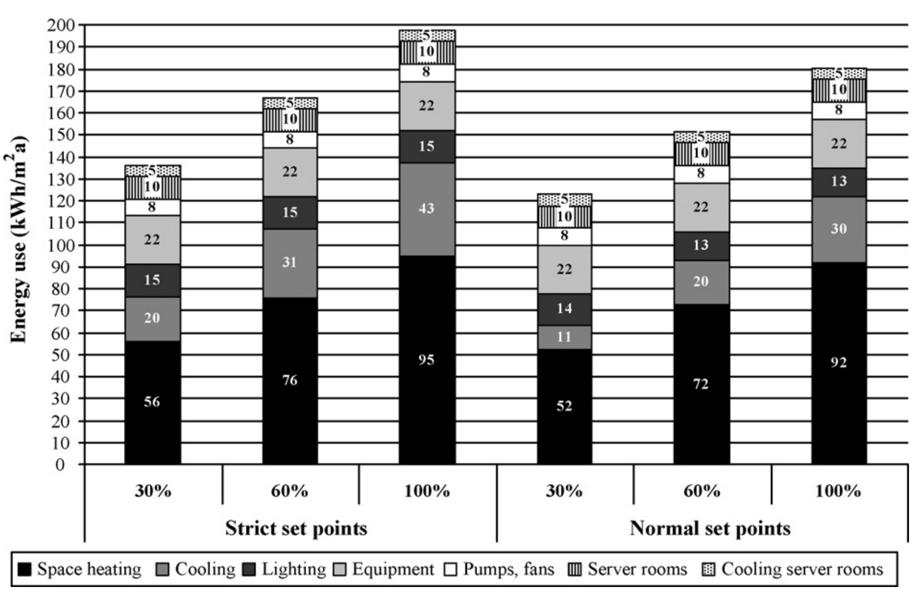

Fig. 5. Energy use of the 30, 60 and 100% glazed alternatives (cell type, triple clear glazing) with strict and normal set points.

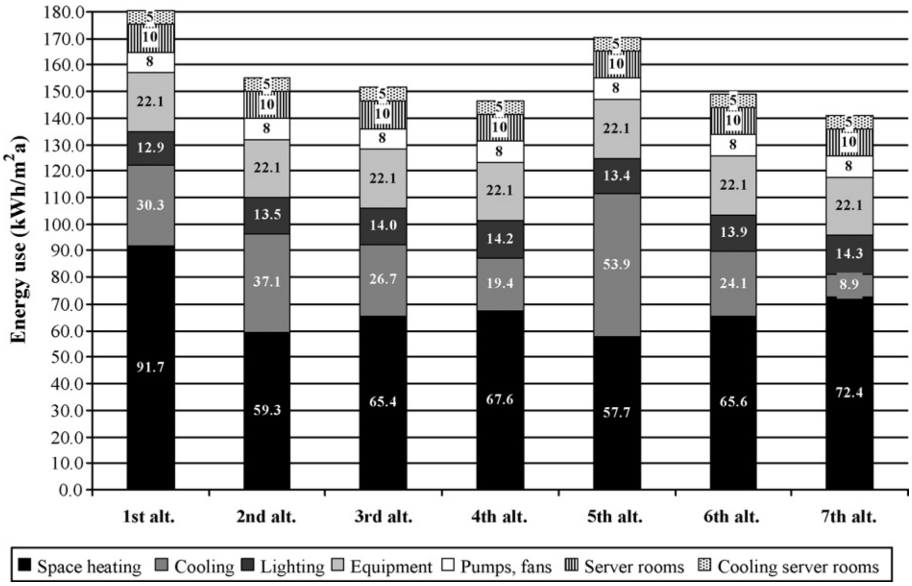

Fig. 6. Impact of window types and shading devices on the energy use for 100% glazing and normal set points.

5.3. *Energy use for alternatives with different control set points*

A cross comparison of the impact of set points on the energy use for the 30, 60 and 100% glazed alternatives with triple clear glazing is shown in Fig. 7. For the cell type reference building the energy use for heating decreases by 7% for the normal control set point and by 16% for the poor set point (compared with the strict one). For the open plan type the heating demand decreases even more, by up to 11 and 24%. Although the minimum temperature limit is the same for the strict and normal control set points (22 °C), the strict set points reduce the possibility of storing heat (thermal mass), thus increasing the heating demand. For a larger window area (60% alternatives) the difference drops to 5 and 7% for the cell type and to 14 and 19% for the open plan type. As the window area increases even more the impact of set points decreases even more as shown in Fig. 7.

For the normal control set points the maximum allowed temperature is 24.5 °C while for the strict and poor set points it is 23 and 26 °C respectively. The cooling demand for the normal (compared with the strict) set point is 45% lower for the cell and 39% lower for the open plan type. The decrease for the poor type is as much as 65 and 64% respectively.

The decreased impact of the set point on the heating demand is similar to the decreased impact on the cooling demand as the window area increases to 60 and 100%. The impact of the set point on lighting the cell type offices properly increases

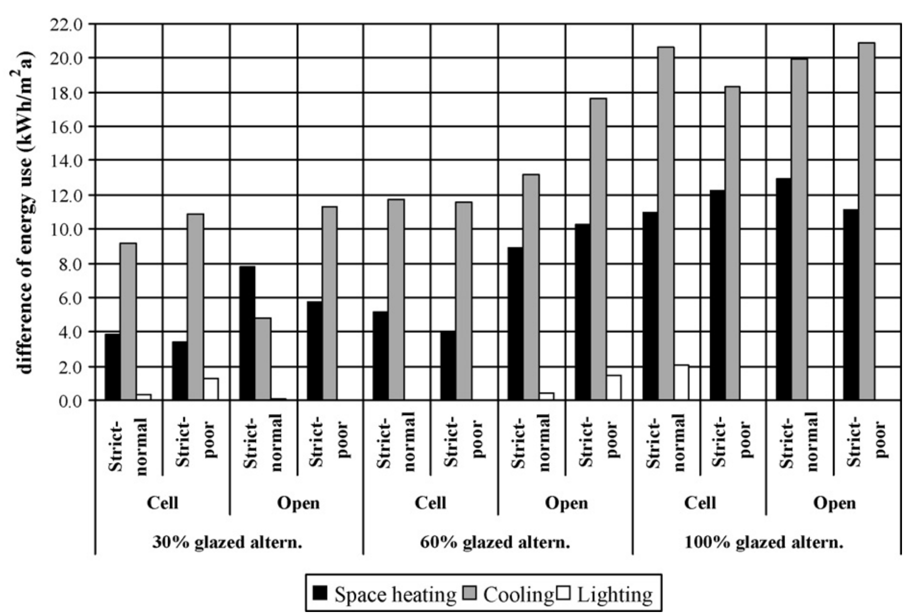

Fig. 7. Impact of set points on the energy use for the 30, 60 and 100% glazed alternatives with triple clear glazing.

somewhat as the window area increases, due to the provision of daylight.

Similar is the tendency for the alternatives 2–7 for the 60 and 100% glazed buildings. However, not all the alternatives fulfil the requirement of a minimum level of 90% of the working hours with PPD less than 15%. The alternatives that do not fulfil this requirement are the ones with poor control set points and the highly glazed alternatives with triple clear pane. Therefore, when considering the overall building performance, the energy efficient alternatives should be the ones with minimum energy demand and at the same time the ones that fulfil certain thermal comfort requirements.

6. Conclusions

The energy efficiency of a building highly depends on the façade construction. Highly glazed buildings should be studied very carefully during the design stage since different types of constructions have a large impact on the energy efficiency compared to 30% or even to 60% window to wall area alternatives. The main aim when designing glazed office buildings should be to avoid a high cooling demand since this was often shown to ensure a low overall energy use. Low thermal transmittance values can also be crucial to ensure reasonable heating demand and low energy use.

The main conclusions from this study are:

- At a building level, the influence of the orientation on the energy use was rather small, mainly due to the fact that the two long façades and the two short façades were identical.
- Increased window area does not necessarily mean reduced electricity use for lighting. The use of electricity for lighting for the studied alternatives was 15 kWh/m^2 a (approximately 10% of the total energy use). Glare problems that can be caused by the large amount of daylight entering a highly glazed working space often reduce the quality of visual comfort. Thus, shading devices are used more frequently in highly glazed buildings often maintaining the same levels of the daylight used in a building with a conventional façade. This is especially true for traditional solar shading and control.
- The further to the inside the shading is placed, the poorer it reduces solar gains and thereby the higher the cooling demand is.
- Low thermal transmittance of windows is a good choice since it decreases the heating demand, while the cooling demand is not influenced much.
- Low g and $g_{\text{effective}}$ values of windows have a great impact on the cooling demand. Externally placed shading devices are an efficient way of reducing cooling demand.
- The higher internal loads of the open plan type result in higher cooling and lower heating demand than for the cell type.
- The impact of indoor temperature set points on the energy use for heating and cooling decreases as the window area increases. On the other hand, the larger window areas increase the impact of light set points on the energy use for lighting.
- When the window area increases, the impact of the plan type (open or cell) on the energy use for heating, cooling and lighting is higher for the alternatives with wider range of allowed air temperatures (i.e. poor set points).
- High solar transmittance windows increase the impact of the set points on the heating demand, while the ones with lower solar transmission increase the impact of the set points on the cooling demand.

Office buildings with fully glazed façades are likely to have a higher energy use for heating and cooling than buildings with conventional façades (e.g. 30% window to external wall area). The difference in total energy use, however (60 and 100% glazed studied building alternatives) is reduced when the thermal transmittance and the total solar transmittance (g and $g_{\text{effective}}$ value) are reduced. Using commercially available window types for the simulations, the most energy efficient 100% glazed alternative results in ‘‘only’’ 15% higher total energy use compared with the reference building.

To add a second façade to the single skin highly glazed buildings could solve some of the problems with the single skin façade. In the next phase of the project the analyses will, therefore, be expanded to glazed office building with double skin façades and will also include advanced simulations of daylight. A recently developed double skin façade module for IDA will be used and improved upon.

Acknowledgements

The ‘‘Glazed Office Buildings’’ project was mainly funded by the Swedish Energy Agency, but also by SBUF, SKANSKA and by WSP.

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