
Study of Parameters and Criteria Influencing the Choice of Glazing in Office Buildings in Belgium

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ABSTRACT

The choice of glazing is a critical stage in the design of a building. Very often, architects select the glazing at the end of the project, taking into account only aesthetic aspects and building first costs. They are unaware that an unwise choice could involve problems in comfort or require excessive energy consumption in order to reach acceptable comfort levels.

This paper shows that the choice of glazing must form an integral part of the design of the building and depends on a certain number of parameters.

This study is based on a great number of thermal and lighting simulations. These simulations were carried out by coupling two programs—ADELINE and TRNSYS. It covers office buildings and shows us the following:

- *In order to select a type of glazing, it is necessary to know various parameters relating to the building or the room studied. We should also know up to what point these parameters have an impact on glazing selection.*
- *We see that it is essential to study the aspects of lighting in parallel with the aspects of thermal comfort (winter and summer). This paper shows how the integration of lighting criteria can weigh in the choice of glazing.*
- *When analyzing the simulation results, one must determine which are the glazing selection criteria. For example, these criteria can be of environmental, energetic, or economic nature. In this paper, we also study how the choice of the criteria of analysis can influence the choice of glazing.*

INTRODUCTION

Fenestration has always played an important role in architecture in every culture, time, or place. Before the advent of glazing, the role of window openings was relatively simple (view to the outside, daylighting penetration, and ventilation), but it changed dramatically thereafter.

Nowadays, the use of glazing improves the thermal, the visual, and the acoustic comfort inside buildings. It can also play a role of security, intimacy, decoration, or view from the inside to the outside as well as the opposite (for a shop window, for example).

The market and the research sector now offer a growing number of new materials, and the future will confirm this tendency. Although architects are confronted with a vast

choice of possibilities, their criteria in selecting glazing often remains limited to first-cost concerns and architectural appearance.

Architects should be helped in the choice of the optimal glazing in each particular case so that they can benefit from the latest advances coming from the glazing industry.

The objective of the work presented in this paper was the determination of the parameters that could influence the choice of glazing in office buildings.

The three glazing energy performance criteria that affect this study are the visible transmittance, the heat transfer coefficient, and the solar heat gain coefficient. Any change in one of these parameters induces a change in visual and thermal comfort, directly or indirectly. The consequences of such a change are not so easy to evaluate.

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For example, increasing the daylight availability in a room by increasing the window visible transmittance not only reduces artificial lighting consumption but also the internal lighting loads and, thus, the cooling loads. However, the admission of too much daylight can introduce solar heat gains that can increase cooling loads associated with the window unless the architect makes a thoughtful choice.

There is an optimum cooling, heating, and lighting energy balance that can only be reached by an integrated approach combining daylight and thermal aspects. Ideally, glazing should be selected according to this combination. However, this can be difficult in practice as many office buildings are built on a speculative basis, so the tenants are not known. Even where the initial tenants are known, these may change after several years.

In this study, we have tried to simulate a typical Belgian office building in order to find what parameters should be studied when choosing glazings and what criteria can influence the choice of glazing in office buildings.

HYPOTHESIS AND MODEL DESCRIPTION

Model Geometry

Calculations were performed for room widths of 2.7 m, 3.6 m, 4.5 m, and 5.4 m and a constant depth and height of 5.4 m and 3 m, respectively. Nine window configurations were tested for each of the four room widths (Figure 1). For the four room widths, the S_{window}/S_{floor} ratio is constant for any given window configuration. Rooms are assumed to be on the second floor of a three-story building, surrounded by other rooms, with only one exterior wall surface (Figure 2).

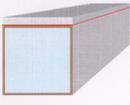
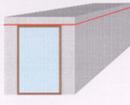
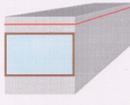
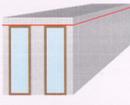
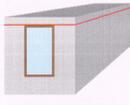
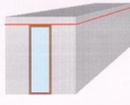
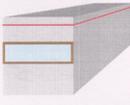
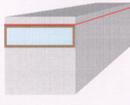
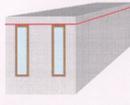
<p>C1</p> <p>Swin./Sfloor = 50 % Swin./Swall = 90 %</p> 	<p>C2</p> <p>Swin./Sfloor = 32 % Swin./Swall = 57 %</p> 	<p>C3</p> <p>Swin./Sfloor = 32 % Swin./Swall = 57 %</p> 
<p>C4</p> <p>Swin./Sfloor = 32 % Swin./Swall = 57 %</p> 	<p>C5</p> <p>Swin./Sfloor = 16 % Swin./Swall = 28.5 %</p> 	<p>C6</p> <p>Swin./Sfloor = 16 % Swin./Swall = 28.5 %</p> 
<p>C7</p> <p>Swin./Sfloor = 16 % Swin./Swall = 28.5 %</p> 	<p>C8</p> <p>Swin./Sfloor = 16 % Swin./Swall = 28.5 %</p> 	<p>C9</p> <p>Swin./Sfloor = 16 % Swin./Swall = 28.5 %</p> 

Figure 1 Proposed window configurations.

Building Construction Aspects

The modeled building is supposed to represent a new office building in Belgium. The facade insulation is, thus, 50 mm thick and the assembly has an overall U-factor, including thermal bridges of 0.66 W/m²·K (0.116 Btu/h·ft²·°F) for the lightweight wall and 0.57 W/m²·K (0.101 Btu/h·ft²·°F) for the heavyweight wall.

We modeled two different buildings in terms of thermal mass.

1. The first building is a lightweight construction, with almost no accessible internal mass (25% of the total thermal mass is accessible),
2. The second construction is heavier, with accessible thermal mass (69% of the total thermal mass is accessible).

This distinction was made in order to show architects the impact of thermal mass on consumption and on thermal comfort.

Internal Loads

1. *Lighting.* The lighting loads are calculated hourly by Superlink: the outputs of Superlink are used as TRNSYS inputs.
2. *Office devices.* According to a Belgian project report (Architecture et Climat 1998) and a Holland publication (Stichting bouwresearch 1994), we chose to test three different solutions.
 - Weak internal loads: one PC (115 W) per person,
 - Mean internal loads: one PC per person + desk printer (45 W) per room,
 - High internal loads: one PC per person + laserjet printer (100 W) per room.
3. *Metabolism.* We made the assumption that one office occupant produces 80 W/h of heating. The number of occupants per room is represented in Figure 3.

Wall Reflection Coefficients

We tested three different cases corresponding to very clear, average, and dark rooms. Three different ensembles of reflection coefficients for the floor/walls/ceiling are, respec-

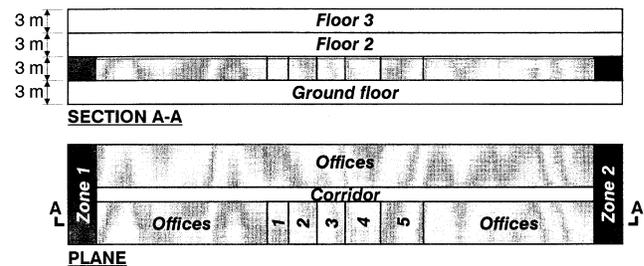


Figure 2 Whole office building section and plane.

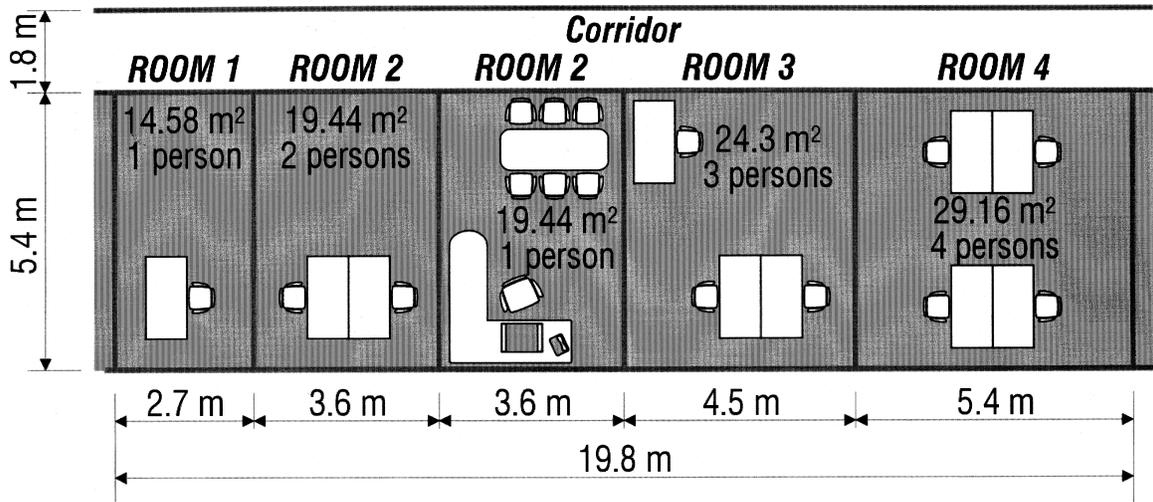


Figure 3 Description of the tested rooms.

tively, 35%/70%/75% (combination r1), 20%/50%/60% (combination r2), and 10%/25%/40% (combination r3).

Orientation

The calculation was performed for the four cardinal orientations—north, south, east, and west.

Room Occupation Schedule

The building is occupied from 8:00 a.m. to 6:00 p.m., but we consider that between 8:00 a.m. and 9:00 a.m. and between 5:00 p.m. and 6:00 p.m., not everyone is present and the lighting is only on in 75% of the office rooms.

Climate

The simulations were done with climatic data of Uccle (Belgium 50°47' North, 4°21' East, altitude: 100 m). The heating degree-days on base 18°C are 3004 and the heating period (in days) is 365 (Dogniaux 1978). The total annual insolation duration is 1555 hours. This number can be divided from October to March (471 hours) and from April to September (1084 hours).

Glazings

Nine glazing types were analyzed. Their main physical characteristics are summarized in Table 1.

Artificial Lighting System

A high-performance artificial lighting system is used. It consists of TL5 tubes placed in a high-efficiency lighting device (installed lighting power = 8 W/m²). We should note that Superlink does not take into account either the lighting device efficiency or its lighting luminous distribution. These factors should then be integrated in the chosen lamp luminous efficiency description. According to the Belgian standard NBN L13-006 (Institut Belge de Normalisation 1992), the

TABLE 1
Glazing Thermal and Luminous Characteristics

	Overall window values (80% of glazing and 20% of frame)			
	U-Factor		Visible transmittance VT (%)	Solar heat gain coefficient SHGC (%)
	U (W/m ² ·K)	U (Btu/h·ft ² ·°F)		
g1	2.6	0.46	81	75
g2	2.5	0.44	45	47
g3	2.2	0.39	7	12
g4	1.5	0.26	49	36
g5	1.5	0.26	61	42
g6	1.5	0.26	65	37
g7	1.5	0.26	75	54
g8	1.5	0.26	70	38
g9	0.9	0.16	69	70

chosen design illuminance level is 500 lux for reading and writing work. The lighting simulations were performed making the assumption that the lighting sensor is placed in the center of the room, 80 cm from the floor. The lighting management system is a continuous dimming system. The minimum fraction of power to which the lighting system can be reduced is 3% of the system's total power.

Strategies

Two different strategies were followed.

1. The HVAC system was simulated to maintain the internal temperature between 21°C and 25°C and the relative humidity between 40% and 60% during occupation time.
2. The HVAC system was simulated to maintain the internal temperature above 21°C and the relative humidity above

TABLE 2
Primary Energy Conversion Factors

		Mean building efficiency	Conversion factor	Primary energy (kWh)
Cooling	Electricity	2.5	2.8	1.1
	Electricity	0.9	2.8	3.1
Heating	Gas	0.7	1	1.4
	Fuel	0.66	1	1.5
Lighting	Electricity	0.9	2.8	3.1

40% during occupation time. There is thus no cooling system, but a night ventilation strategy is set up in case of overheating in summer.

The day ventilation rate is set in order to answer the Belgium standard concerning the hygienic air rate supply.

When there is no cooling system, the program calculates the heating, lighting, and humidification consumption and the yearly number of overheating hours (above 25.5°C and 28°C). According to the Holland standard (Stichting bouwresearch 1994), the number of hours above 25.5°C during working hours cannot exceed 100 and the number above 28°C (during working hours) cannot exceed 20. There is no calculation including day natural ventilation.

THE PARAMETERS INFLUENCING THE GLAZING CHOICE

Building Global Consumption Evaluation

Our main objective was the study of the lighting management effect according to daylight availability on total consumption. We thus made a link between the daylighting simulation program Superlink and the multizone dynamic thermal program TRNSYS. The hourly artificial consumption, calculated by Superlink, representing the lighting internal loads, is then entered into TRNSYS. The latter program then calculates the sensible and latent energy needs for a whole year.

The electrical consumption figures for office equipment and pumps are not integrated in the results presented here.

Energy Need Conversion into Primary Energy

It is wrong to simply add together the net energy needs as calculated by Superlink (lighting) with results from TRNSYS (heating, cooling, humidification, dehumidification).

We decided to work in terms of primary energy.

The conversion factors used are summarized in Table 2. These data come from the Belgian electricity producer.

Thousands of simulations were done. The aim of this paper is not to present all of the results but to show, through several examples, the main conclusions of the study.

Facade Configuration

Effect of Window Position and Area on Lighting Energy Consumption. It is clear that the window position has an influence on the daylighting distribution and then on the artificial lighting consumption.

The classification is the same in every case (whatever the room width and the wall reflection coefficients and the orientation). In order from lowest to highest consumption, ranking is as follows: c1-c3-c2-c4-c8-c5-c7-c9-c6. One can remark that there are diminishing returns with increasing visible transmittance. This can be observed by the curves' slope changes in Figure 4 that shows the annual lighting consumption for the four oriented rooms, with r1 wall reflection coefficients combination. The returns coming from the increase of window area varies according to the glazing visible transmittance. For example, increasing the fenestration area from 16% (c7) to 32% (c3) can reduce the lighting consumption by 12% for a glazing of 20% visible transmittance or by 36% for a 81% visible transmittance glazing.

Effect of Window Position and Area on Total Energy Consumption. In Belgium, any increase of the window area/floor area ratio induces an increase of the total primary energy consumption except for few cases (north orientation, for glazing having a high SHGC/VT ratio). This is shown in Figure 5 for room n°1 for mean internal loads in the case of wall reflection combination r2 for a lightweight building.

Orientation

For many researchers, it is clear that room orientation has an impact on visual and thermal comfort and consumption. However, despite the fact that glazing having different physical properties can have the same visual aspect, few architects choose different glazing in the same building.

Figure 6 shows the results in the case of configuration c3, room n°1 for mean internal loads in the case of wall reflection combination r2 for a lightweight building.

In this case, this looks like a very small difference. It appears that the designer can choose from a range of options without bad results. For example, in this case, the best glazing for a north orientation is different from the best glazing for the other orientations. Architects should thus chose g7 for the north oriented room and g8 for other rooms. However, if they absolutely want to have the same glazing regardless of the room orientation, they could choose g8. There will be almost no consumption difference.

In some cases, the difference also appears for east and west orientations.

Internal Loads

The internal load can have an influence on the choice of glazing. For example, Figure 7 shows the results for the configuration c3, for the room number 1, in the case of the strategy number 1 and the r2 wall reflection coefficient combination.

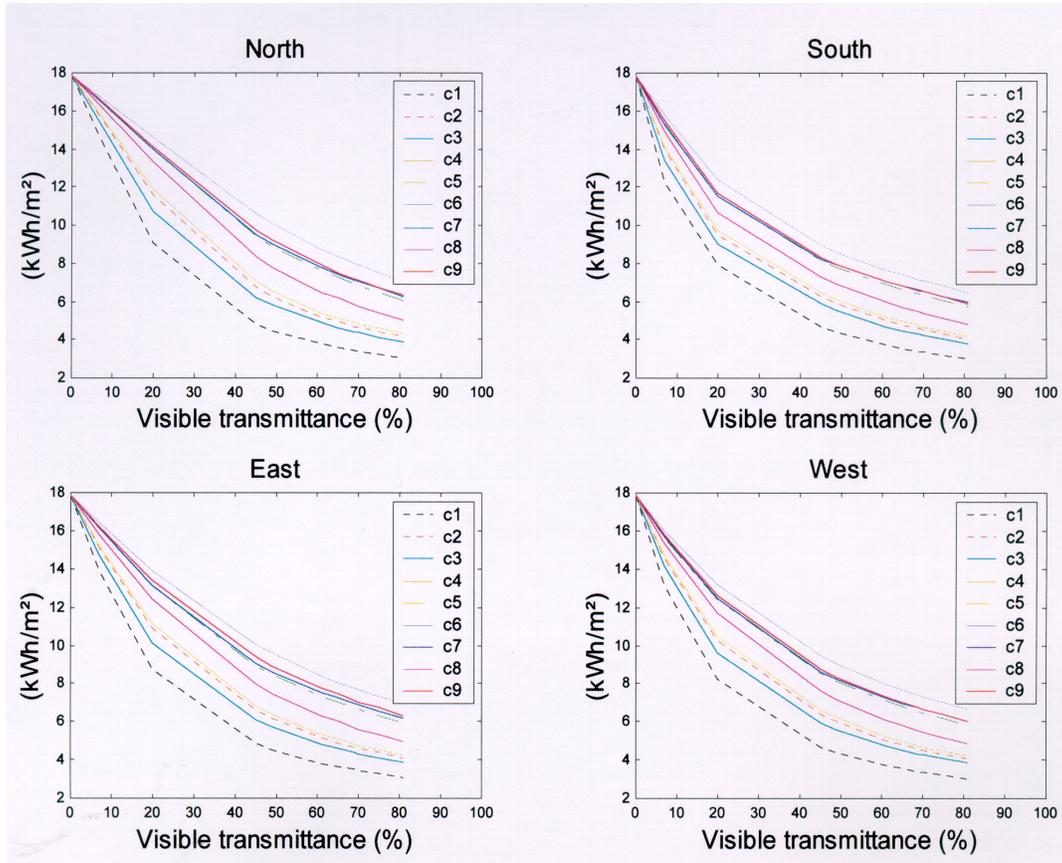


Figure 4 Annual lighting consumption for each configuration as a function of the glazing visible transmittance.

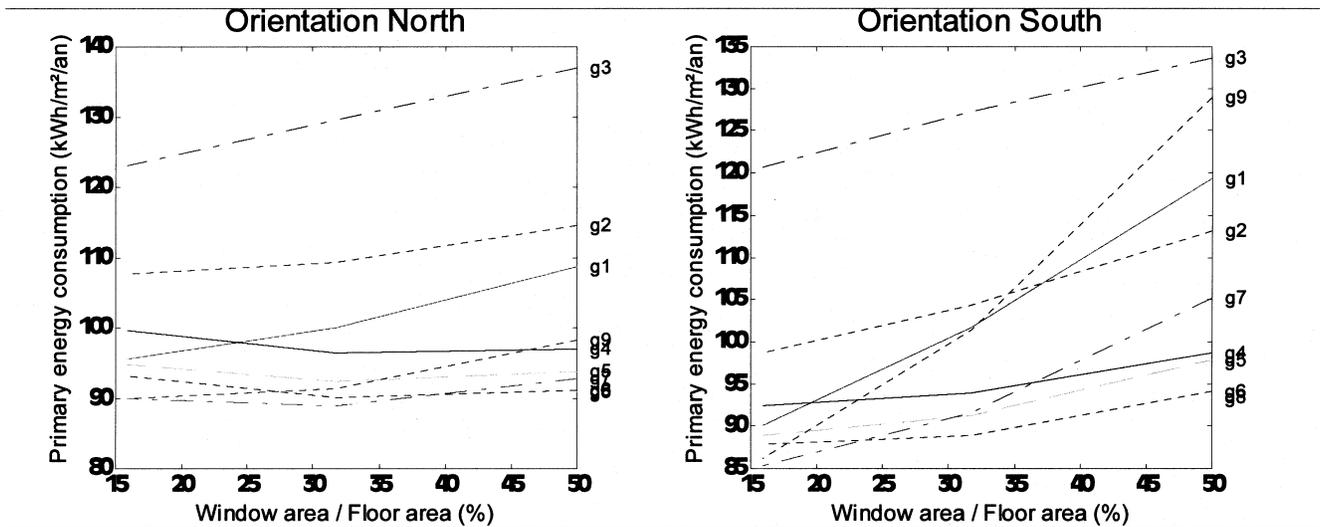


Figure 5 Primary energy consumption as a function of the window area/floor area ratio.

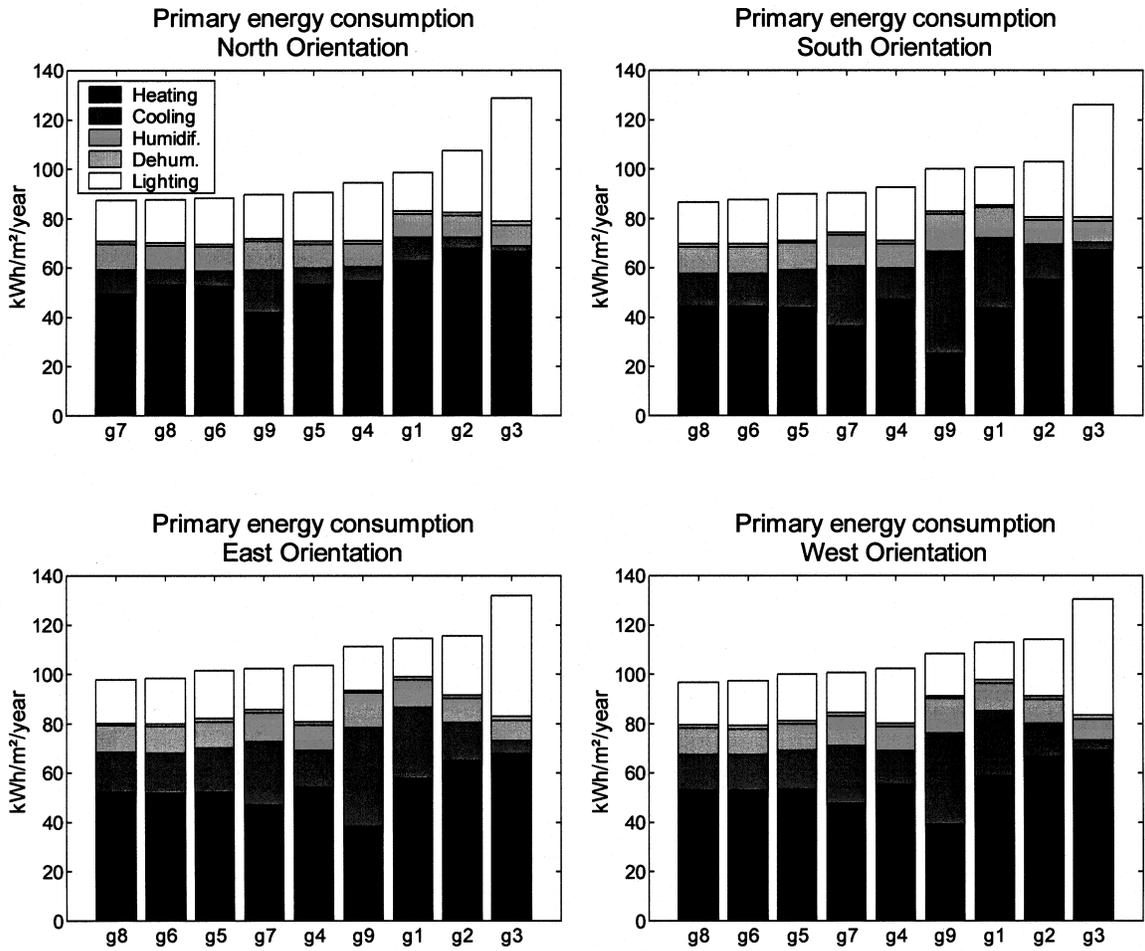


Figure 6 Influence of the facade orientation on the glazing choice.

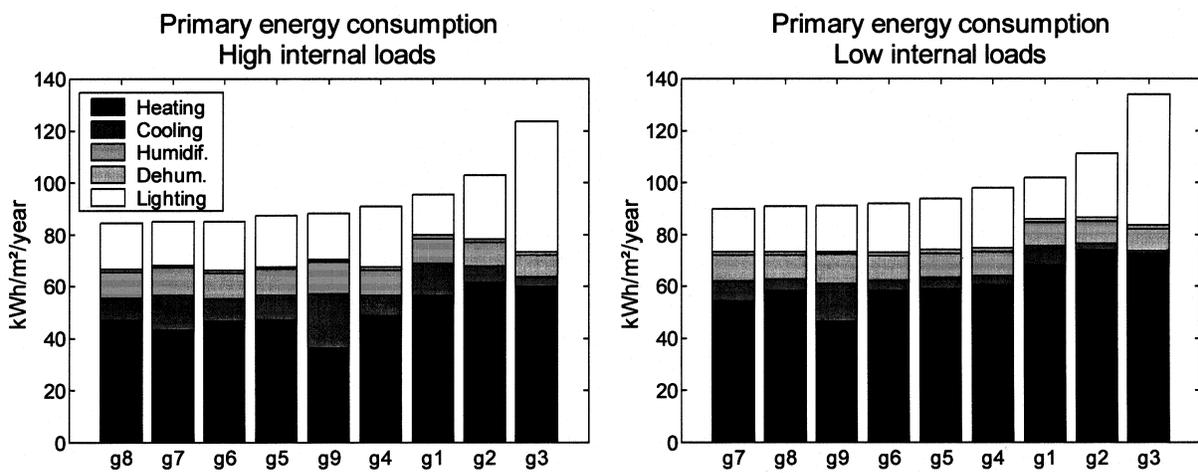


Figure 7 Influence of the internal load on the glazing choice (with a cooling system).

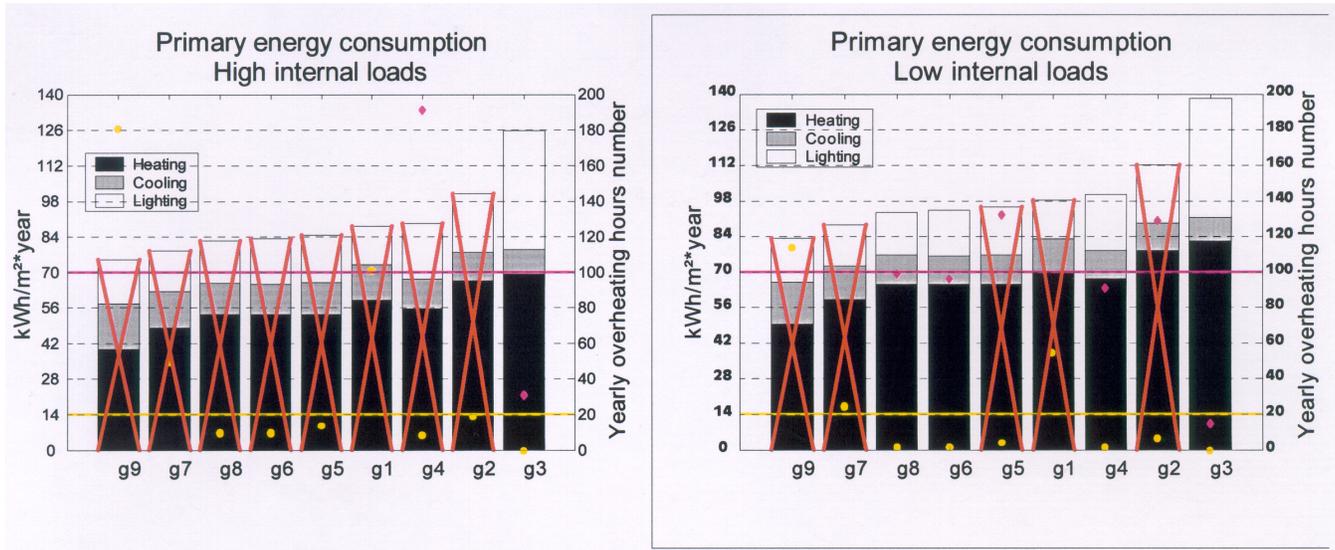


Figure 8 Influence of the internal loads on the glazing choice (without cooling system).

The glazing number nine, which is ranked third in the case of low internal loads, falls to fifth in the case of high internal loads. The difference between the five first glazings does not exceed 10%, but the classification can change when the internal loads increase or decrease.

The internal load influence is greater when there is no cooling system. For example, for a lightweight building, in the case of strategy number 2, significant differences can appear depending on the glazing choice. Figure 8 shows the case of a west-oriented room, for configuration c3 and wall reflection coefficient combination r2. Glazings that do not respect the limit number of overheating hours, in the case of the strategies studied here, are shown crossed out. The clear round dots represent the yearly number of overheating hours above 28°C and the diamond-shaped dots represent the yearly number of overheating hours above 25.5°C.

In the case of high internal loads, the only acceptable glazing is number 3 even though, in the case of low internal loads, numbers 8 and 6 could be chosen.

In conclusion, the internal load quantity should influence the choice of glazing, especially when there is no cooling system. Remember, however, when doing the analysis, to use internal loads that include diversity of operation and the fact that computers and other electronic equipment goes into a power-off, energy-saving mode when not in use. The analysis should be based on the average load, not the peak installed equipment capacity.

Wall Reflection Coefficients

Table 3 presents, for glazing number 5, the global room consumption difference coming from modifications to wall, floor, and ceiling reflection coefficients.

Light-colored internal surfaces are always helpful for lighting and particularly in terms of lighting distribution in the

TABLE 3
Influence of the Surface Reflection Coefficients on Global Room Consumption

(r3 - r1)/r3 office 1	g5			
	North	South	East	West
c1	7%	6%	6%	5%
c2	9%	8%	8%	7%
c3	8%	7%	7%	7%
c4	10%	8%	9%	8%
c5	9%	7%	9%	7%
c6	11%	8%	10%	9%
c7	9%	7%	8%	7%
c8	9%	6%	8%	7%
c9	10%	7%	9%	8%

room. The mean value of savings is 8%. They can even reach 10% of the global building consumption.

The results show us that changing from dark walls to light-colored walls has more influence on consumption in rooms with average daylighting, either because of a low-glazing visible transmittance coefficient, or in the case of a small or badly positioned window.

These figures are related to the case of low internal loads. In case of high internal loads, the figures are a little bit higher.

Thermal Mass

First Strategy (Cooling System). The analysis of all the results shows that it is not possible to conclude anything regarding the influence of thermal mass when there is a cooling system; in fact, the thermal mass can have positive or negative influence on the total building energy consumption. The

thermal mass effect depends on the facade configuration, the glazing type, the room width, and, in some cases, the orientation. In buildings that are not naturally cooled, the thermal mass has to be studied accurately.

Second Strategy (Natural Nighttime Ventilation). The building having a high quantity of thermal mass will always engender fewer overheating hours than the lightweight building, whatever the other characteristics. It is thus really important to have as much accessible thermal mass as possible in order to reduce the overheating hours in the building.

It should be noted that not all the simulated glazings make it possible to respect the overheating hours number recommended by the Holland standard.

Moreover, this analysis shows us that it is much more difficult to set up night natural ventilation in a lightweight building. For this type of building, the prediction of night temperature evolution is more difficult and it is not easy to calculate the external ventilation airflow in order not to have to heat the building at the end of the night.

In conclusion, in Belgium, when deciding to set up nighttime summer ventilation, it is better to design a heavy building with a maximum of accessible thermal mass.

Another conclusion of this study is that the amount of thermal mass and the type of glazing should be chosen according to the cooling strategy that will be set up in the building.

IMPORTANCE OF LIGHTING INTEGRATION

If we do not take into account the artificial lighting consumption, we run the risk of favoring a glazing having good thermal properties but bad visual properties. This can easily be shown by an example.

Figure 9 shows the same case (configuration c3, high internal loads, r2, room 2, and strategy number 1) with or without taking into account the lighting consumption. This

extreme case shows that if we do not take into account the lighting consumption, the worst glazing (VT=7%) (Figure 9a) can become the best (Figure 9b) and the overall energy consumption is significantly increased.

It is thus absolutely necessary to take into account the combination of the visible and thermal glazing features in order to not favor one of these aspects to the prejudice of the other.

INFLUENCE OF THE EFFICIENCY FACTORS

Until now, we have considered that the heating system was a gas system.

The following example shows us that the choice of the type of system can influence the choice of glazing. Figure 10 shows the same case (configuration c3, high internal loads, r2, room 2, and strategy number 1) fitted with a gas heating system (Figure 10a) or with an electric heating system (Figure 10b).

Glazing type number 7, which was ranked fourth when heating with gas, becomes the first when heating with electricity. The reason is that electric heating is very energy demanding, so glazing having a low heating demand is thus favored.

It is clear that the system efficiency influences the results, as well as the national energy factor conversion.

It is important to choose these factors accurately—the accuracy of the thermal and visual calculations can be lost if these factors are not chosen carefully.

GLAZING SELECTION CRITERIA

Until now, we have mostly spoken in terms of primary energy. However, the architect's or the building owner's criterion is often cost. If we chose the criterion "cost" instead of the criterion "primary energy," the glazing ranks could change. At present, in Belgium, the primary energy costs for one kWh of

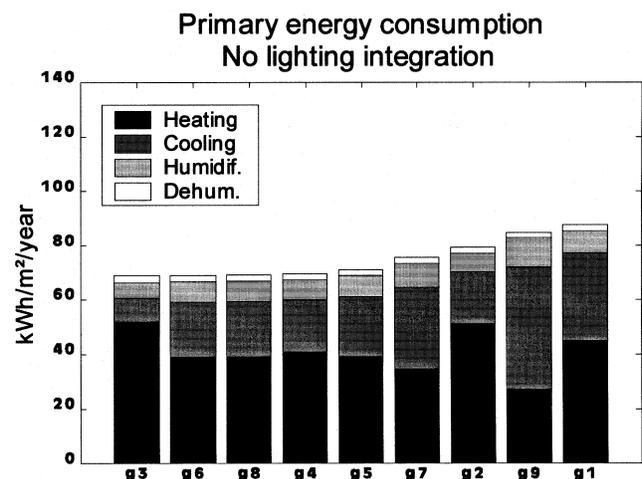
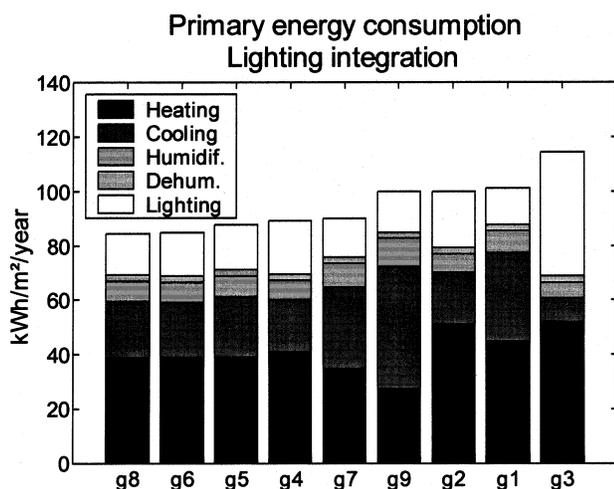


Figure 9 Importance of lighting integration.

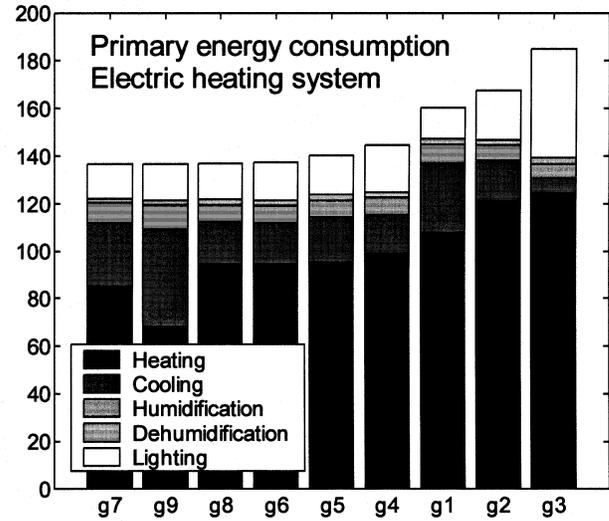
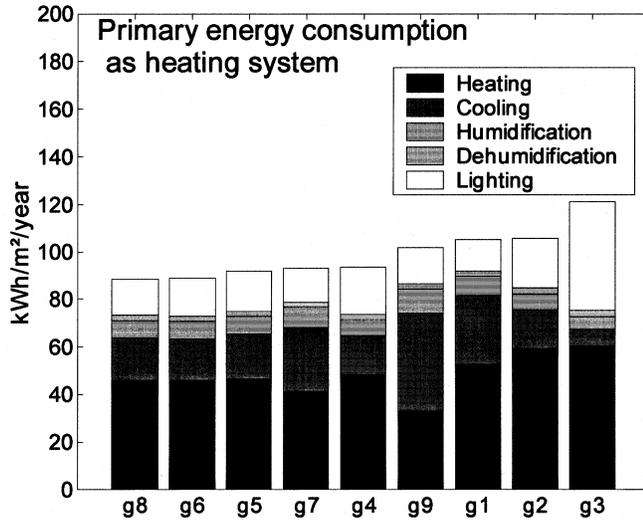


Figure 10 Heating system influence on the choice of glazing.

TABLE 4
Comparison of Selection Criteria for the Choice of Glazing: Situation at Present

	Primary energy (kWh)	Cost (Euro)	Cost/primary energy (Euro/kWh)
Cooling	1.1	0.04	0.0364
Electricity	3.1	0.11	0.0355
Heating Gas	1.4	0.03	0.0214
Fuel	1.5	0.05	0.0333
Lighting	3.1	0.1	0.0323

TABLE 5
Comparison of Selection Criteria for the Choice of Glazing: Future Situation

	Primary energy (kWh)	Cost (Euro)	Cost/primary energy (Euro/kWh)
Cooling	0.72	0.04	0.056
Electricity	2	0.11	0.055
Heating Gas	1.4	0.03	0.021
Fuel	1.5	0.05	0.033
Lighting	2	0.1	0.050

primary energy are rather similar for heating, cooling, and lighting (see Table 4, last column).

Glazing ranks are thus similar if the choice criterion is cost or primary energy. However, energy prices are fluctuating significantly at the moment, and these changes could lead to a difference in the glazing classification if the choice criterion is cost instead of primary energy consumption.

Another change could come from the change in the primary energy conversion factor. For example, the Belgian electric utility company would like to improve its power plant efficiency and would like to attain a conversion factor of 1.8 in the future (instead of 2.8). If we suppose that the energy cost would not change, Table 4 would become identical to Table 5.

Cooling and lighting demand would weigh more heavily than heating demand (whether using gas or fuel) and glazing inducing low cooling and lighting demand could present better results in terms of costs than in terms of primary energy consumption.

When studying environmental aspects through toxic gas emissions (CO_2 , NO_x , SO_2), one remarks that the gas emission for glazing production is marginal with regard to gas emis-

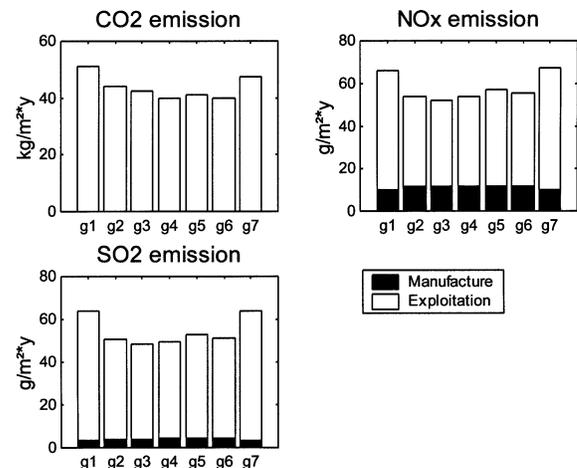


Figure 11 Toxic gas emissions for several glazings.

sions during the building's life. Figure 11 shows the results for one particular case, for seven of the chosen glazing types (data for glazing numbers 8 and 9 were unfortunately not available).

Higher gas emission is thus linked to the building's energy consumption. The glazing that favors less energy consumption also favors less toxic emissions.

DISCUSSION

Our results suggest the potential for significant savings in artificial lighting (see Figure 4). We should compare these results with real measured values. It has not been done for Belgium. In the literature, we find little information on this subject. Opdal (1995) has compared measured and calculated values and has found that calculations were about 30% higher than measurements. Reinhart (2000) affirms that the yearly sky combination realized by Superlink underestimates the inside illuminance and, therefore, the possibilities of lighting energy savings. It is planned to compare the calculation values to real Belgian measurements.

The study presented here has two other limitations.

1. No solar shading devices were considered even though internal shading devices are used in almost every office building and external shading devices are used on some office buildings (their effectiveness varying by orientations). This work will be done in the coming months. For this future work, different possibilities could be studied:
 - For internal shades, assuming that blinds are partially closed when light exceeds a fixed quantity.
 - For external shading: (1) simple overhang for the four orientations, (2) light shelves for the four orientations, (3) fins (side shading) for the four orientations.
2. No external obstructions were considered.

CONCLUSION

This study teaches us first that the choice of glazing can have a significant impact on energy consumption.

Second, fenestration systems with glazings g8, g7, and g6 result in the lowest energy consumption for the building configurations studied.

Third, the optimum fenestration system varies by building configuration and by orientation within that building.

This study shows that many parameters can influence the choice of glazing: (1) facade configuration, (2) orientation, (3) internal loads, (4) wall reflection coefficients, (5) thermal mass, (6) heating and cooling system energy source and efficiency, (7) type of strategy, and (8) consideration of daylighting potential.

The choice criterion is also an important aspect that could influence the choice of glazing.

With regard to this last point, it is interesting to remember that an architect only interested by the consumption cost will choose different glazing than an architect more sensitive to sustainable development and, thus, to primary energy aspects. One other important conclusion of this study is that the toxic gas emission linked to the glazing production is marginal

compared with the production linked to the glazing life cycle. It is thus important to concentrate on energy waste reduction during the building life.

The reader should remember that these results apply to a typical Belgian office building and cannot be applied in countries with very different climates or other building types (schools, apartments, etc.). However, there is every likelihood that these parameters have an influence on the choice of glazing in many other climates and for other types of buildings.

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