INFLUENCE OF SHADING SYSTEMS ON ENERGY PERFORMANCE OF BUILDINGS WITH LARGE GLAZING AREAS

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Abstract. The paper aims at evaluating the energy performance of an average office building characterized by high glazing ratio and various shading degrees. Two hypotheses have been considered and compared: i) the building without shading and ii) the building having a fixed shading system with vertical and horizontal elements. Results show a small increase in heating energy demand of 18.18% because of the blocked heat gains during winter and a significant decrease in cooling energy demand of 80.69%. By using a mobile shading system, the zero energy target can be achieved beginning with the end of March up to the beginning of November (except for one third of July and one third of August).

Keywords: fixed shading, mobile shading, energy efficiency, office buildings, adaptable envelope.

1. Introduction

Sustainable design is becoming more and more complex due to the need to satisfy increasingly severe requirements related to economic, social and environmental performance - where energy efficiency is essential. Buildings should be closely related to the climate context and the envelope as a moderator between the exterior and the indoor environment is a key element for sustainable design.

An important issue in the case of office buildings is the large glazed façade preferred for both, natural lighting and the idea of openness, as well as to convey a message of transparency and democracy. This leads to overheating during summer and significant heat losses during winter, with high energy consumption for cooling and heating [4]. Studies show that air conditioning systems alone consume 10-60% of the total energy demand for these buildings [7], highlighting an important aspect in terms of energy performance, as they offered solutions to a problem that could be avoided by using efficient shading devices.
The evolution and use of shading elements thus derive from the need to reduce the energy demand of a building [2], the shape of the envelope being designed in order to increase the absorption and reflection of solar radiation by active or passive means. The development of technologies for adaptable envelopes, able to change their characteristics according to the variation of the parameters of the outdoor and indoor environment, is an important step towards optimizing the energy performance of buildings and achieving the nZEB goal, taking into account the global warming.

2. Typology and efficiency of shading systems

In order to reach the green building standard, optimal sun protection is essential to decrease the energy demand for cooling and lighting and therefore to minimize the total energy demand. The glazed surface area and the shading system determine the amount of light that enters the interior space, the cooling energy demand being inversely proportional to the need for artificial lighting [5].

Even though in the Northern Hemisphere the maximum intensity of solar radiation is reached on June 21st and the lowest on December 21st, due to thermal mass, the maximum temperatures are recorded in July and August, and the minimum temperatures in January and February. While a fixed shading system is designed taking into account the geometry and intensity of solar radiation, throughout the year, it proves to be inefficient as it provides the same shading degree in April (when heating is necessary) as in September (when cooling is necessary) [6].

Mobile shading devices can therefore reduce the amount of incident radiation on the glazed surface during the warm season when the sun reaches the maximum altitude and also in autumn when temperatures are high [8]. To draw the geometry of a shading system, graphical or analytical methods can be used [6] in order to reduce the cooling energy demand from mid-spring to autumn, depending on local climatic conditions.

Shading systems can be classified into three formal types: horizontal (Fig. 1), vertical (Fig. 2) and combined (Fig. 3), having considerably different impact on the shading degree [10], as demonstrated by the attached shading masks[3].
Fig. 1- Shading masks for horizontal shading systems [1]
Fig. 2 - Shading masks for vertical shading systems [1]

Fig. 3 - Shading masks for combined shading systems [1]
Fig. 4 – Scheme for determining the required degree of shading

Transferred to a solar diagram, the shading criteria define portions of the sky that shading systems must block. The way of determining the required degree of shading is illustrated in Fig. 4. Two solar charts are necessary to illustrate the yearly need for shading due to higher temperatures in the autumn than in the spring.

Unlike fixed shading systems that are designed for shading purposes only, mobile shading systems can also be used to control heat gains, reduce glare and redirect light. Manually operated or mechanized systems offer higher flexibility due to the possibility of retraction or rotation of the elements, which thus meet the conditions of the external environment.

Mobile shading systems have a clear advantage over the fixed ones due to their ability to adapt to a particular climate zone and the requirements of the indoor environment. They can be operated manually or through an automatic system that uses various sensor systems.

3. Case study

In order to determine the contribution of shading systems in optimizing the overall energy efficiency of a building, an office building with large glazing areas on the east, south and west façades was analyzed (Fig. 5) using the PHPP program [12].
Fig. 5 – Office building – current floor and elevation

Two hypotheses have been evaluated:

i. the building without shading system;

ii. the building with a shading system consisting of 2m wide horizontal elements placed at each floor (equivalent to any other horizontal system providing the same shading degree) for the southern façade (Fig. 9) and 1m wide vertical elements placed at 1m from each other (equivalent to any other vertical system providing the same degree of shading) for the eastern and western façades (Fig. 6).

iii. the shading mask diagram depends on the dimensions, shape in plane and section of the shading elements (Fig. 6), as well as on the cardinal orientation. The efficiency of the shading devices in Fig. 6 and 9 is determined by overlapping the shading mask, the solar diagram and the shading requirement for each previously analyzed façade (Fig. 7, 8 and 10).
Fig. 6 – Horizontal view and elevation of the elements for shading on western and eastern glazed areas

Fig. 7 – Western façade – shading mask overlapping the solar diagram with the shading demand

Fig. 8 - Eastern façade – shading mask overlapping the solar diagram with the shading demand
For the analyzed office building the shading system can be improved by using inclined vertical elements for the eastern and western façades, which would determine an asymmetrical shading mask and could meet the need for shading, not fulfilled in this case. For the southern façade, the efficiency of the shading system can be optimized by enlarging the compact horizontal console (Fig.9).

The share of the glazed area exposed to direct radiation and the value of solar radiation at glazing level for each shaded façade are shown in Fig. 11.
Fig. 11 - Percentage of glazed area exposed to direct radiation and the radiation value for: eastern façade with horizontal (a) and vertical (b) shading system; southern façade with horizontal (c) and vertical (d) shading system.
The calculation highlights the increase in heating energy demand from 11 kWh/m²/year to 13 kWh/m²/year (Fig. 12), as the fixed shading elements block the heat gains during winter (chart Fig. 13). The solar energy use increases from 48% in the first case to 52% in the second case, as the presence of shading elements slightly decreases the heat gains during the summer, from 11 kWh/m²/month to 10 kWh/m²/month.
Fig. 14 highlights the decrease of the cooling energy demand from 20.2 kWh/m²/year for the building with no shading, to 3.9 kWh/m²/year for the building with horizontal shading system. There is also a reduction to zero for the cooling energy demand in April and a nearly zero cooling energy demand in May (from 2.3 kWh/m²/month to 0.2 kWh/m²/month) and September (from 1.1 kWh/m²/month to 0.1 kWh/m²/month). For July, the month with the highest cooling energy demand, the reduction is of 66.66% due to the shading system (from 6.9 kWh/m²/month to 2.3 kWh/m²/month).

In order to determine the efficiency of the shading systems in terms of yearly heat gains, cooling energy demand and energy performance, the office building was analyzed with the CASAnova program. Fig. 15 shows the results regarding the zero energy hours (time in which no heating or cooling is required to achieve interior comfort) and the energy demand for heating and cooling, for the building with: a. no shading; b. a shading degree of 50% and c. 100% shading degree.

![Fig. 15 – Zero energy hours and energy demand for heating and cooling, for the building with: a. 0% ; b. 50%; c. 100% shading degree; d. increment of zero energy hours by using mobile shading systems](image)

There is a significant increase in the number of zero energy hours by increasing the shading degree, but also an increase in heating energy demand compared to the
cooling energy demand. There are also differences between the cooling and heating energy demand for the months when the sun trajectory is the same. Therefore in April and September when the sun trajectory is similar, excessive shading leads to the need for heating, while in September shading is necessary in the first part of the month to prevent overheating. The charts show the possibility of reaching the zero energy target in the time lapse beginning with the last third of March and ending with the first third of November, by using a mobile shading system that can adjust the shading degree according to the external conditions, except for one third of July and one third of August when the cooling energy demand cannot be reduced to zero.

Fig. 16 indicates the decrease of the maximum cooling load during summer, from 486.3 kW for the building with no shading to 57.4 kW for a 100% shading degree, representing 88.19% reduction. The maximum specific cooling load decreases from 187.6 W/m² to 22.1 W/m².

Thus, the exceeding heat flow to be removed from the building and the heat gains are decreasing due to the reduction of solar radiation through the glazed surfaces. Only in June, July and August the cooling energy demand cannot be completely reduced by the use of shading systems, as shown by Fig. 17.
The use of fixed shading systems increases the heating energy demand by blocking the solar radiation during the cold periods (Fig. 18).

In case of the office building with no shading, the contribution of solar radiation leads to a reduction in heating energy demand and increase in cooling energy demand (Table 1).
Table 1

| Shading degree | Heating energy demand | [%] | Cooling energy demand | [%] |
|----------------|-----------------------|-----|-----------------------|-----|
| 0%             | 48 kW/m²/year         | 38  | 133.9 kW/m²/year      | 100 |
| 100%           | 127.4 kW/m²/year      | 100 | 2 kW/m²/year          | 1.5 |

Fig. 19 – Usable heat gains for the office building with no shading

Fig. 19 shows the chart of usable heat gains from solar radiation, also highlighting the effectiveness in using mobile shading systems by taking into account the axis of symmetry of the solar trajectory (June 21) and unequal amounts of usable solar energy during the months when the sun trajectory is the same. Capture systems may be incorporated into shading devices in order to exploit unusable solar energy, reducing the total energy consumption of the building from non-renewable resources.

4. Conclusions

The wise choice of the shading system, indispensable for achieving interior comfort in the warm season in buildings with large glazing areas, significantly influences not only the cooling energy demand, but also the heating energy demand. The study carried out on a office building with fixed shading system reveals the following: a significant decrease in cooling energy demand, a slow increase in heating energy demand because of the blocked solar inputs, the potential of a mobile shading system to considerably increment the zero energy hours through adjusting the shading degree and allowing the input of only usable solar energy.

Fixed shading systems were analyzed and evaluated, with their limited performance in terms of meeting the necessary shading degree and the possibility of using solar gains during the cold periods of the year. Although the cooling energy demand decreases through the use of fixed shading systems, the heating energy demand increases.
The mobile shading system, being adjustable, provides the possibility to reach the goal of nearly zero energy demand in the time lapse between the end of March and the beginning of November.

The paper highlights the efficiency of a mobile shading system that can be adapted monthly, compared to a fixed one, on the one hand by avoiding the symmetry of the January-June and July-December periods, and on the other hand, by the possibility of using solar radiation during the cold season and also to block it in the warm season.

A shading system self-adjusting on a daily basis would be more efficient, as it avoids the daily symmetrical values of the shading degree determined by the symmetrical trajectory of the sun (as shown in the shading diagrams). It also offers the possibility to increase the shading degree during the afternoon and to adapt itself to daily outdoor conditions (for example, in a cloudy summer day the shade should not be as high as in a sunny day).

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