Influence of Shading on Cooling Energy Demand

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Abstract. The article presents an analysis of the building cooling load taking into account the variability of the factors affecting the size of the heat gains. In order to minimize the demand for cooling, the effect of shading elements installed on the outside on the windows and its effect on size of the cooling capacity of air conditioning system for the building has been estimated. Multivariate building cooling load calculations to determine the size of the reduction in cooling demand has derived. Determination of heat gain from the sun is laborious, but gives a result which reflects the influence of the surface transparent partitions, devices used as sunscreen and its location on the building envelope in relation to the world, as well as to the internal heat gains has great attention in obtained calculation. In this study, included in the balance sheet of solar heat gains are defined in three different shading of windows. Calculating the total demand cooling is made for variants assuming 0% shading baffles transparent, 50% shading baffles transparent external shutters at an angle of 45°, 100% shading baffles transparent hours 12 from the N and E and from 12 from the S and W of the outer slat blinds. The calculation of the average hourly cooling load was taken into account the option assuming the hypothetical possibility of default by up to 10% of the time assumed the cooling season temperatures in the rooms. To reduce the consumption of electricity energy in the cooling system of the smallest variant identified the need for the power supply for the operation of the cooling system. Also assessed the financial benefits of the temporary default of comfort.

1. Introduction

Each building requires energy to operate properly. Depending on the intended use of the building, its cubic capacity and building structure, the required energy is different with regard to its quantity and quality. In almost all buildings, electric energy and thermal energy in winter in the Polish climate are necessary. Currently, internal air cooling is used quite frequently, especially in public utilities and storehouses. To determine the energy consumption of a building, there is an obligation to obtain Energy Performance Certificates for existing buildings, e.g. for the purpose of their rental, and Energy Pattern Certificates for new buildings. A demand for thermal or cooling energy is determined on the basis of a heat balance [1]. However, a heat balance made to determine the demand for thermal energy is different from a heat balance for the demand for cooling energy in such a way that the former covers heat losses and the latter - heat gains. In connection with a more and wider application of air cooling in buildings, more and more cooling devices and cooling techniques have been developed, which use e.g. natural resources [2]. To meet requirements, each cooling system should be designed on the basis of precise and individual calculations of the heat balance of the examined building. The way how the air should be treated and exchanged depends on the intended use of the building, its location, spatial arrangement and
on individual requirements of the investor. A building structure and the cubic capacity of air-conditioned rooms have a significant influence on the type and size of devices used [3, 4]. Additionally, it is very important for the designed system to fulfil all cooling requirements and also to take into account electric energy consumption and, thus, operating costs of the system.

2. Factors affecting a cooling load of the building

An essential factor which significantly affects a cooling load of the building is the geographical situation of the building and its orientation with regard to cardinal directions. For the demonstration building, calculations of its cooling load were made, depending on different orientations of the building with the same location. The analyzed building used for catering and storing purposes - an inn, is situated in the south-eastern part of Poland in the Lublin Province, in the small village of Urszulin, in a municipal, unindustrialized area. The building consists of the following rooms:

- three rooms for consumption which are open 24 hours,
- kitchen with a clean preparation room and a washing annex,
- dish-washing room,
- vegetable and egg preparation room,
- store for meat, vegetables, drinks and dishes,
- waste room.

The orientation of the building is determined by deviation of the axis of the external walls from north by 16 ° towards east. External partitions of rooms situated from the north are exposed to sun rays to the smallest degree. From the north (NNE to be more precise), the designed building is partially adjacent to an existing building. External walls of rooms situated from the south are exposed to solar radiation to the greatest extent, thus, they significantly contribute to the increase of heat balance in those rooms.

Another significant factor which has as influence on heat gains in the building is shading and shading devices [5,6]. Solar radiation which reaches the earth is partially absorbed in the atmosphere by water vapour, carbon dioxide and ozone. Dust and mist hanging in the air also significantly affect the intensity of solar radiation. Their influence is particularly visible in cities and industrialized areas where density of solar radiation is smaller compared to rural areas. The intensity of solar radiation depends also on the distance sun rays cover in the atmosphere, which has an influence on the variation of the intensity of solar radiation in daily and yearly cycles [7]. Direct radiation depends on the location of the Sun relative to the building and the angle of incidence on external partitions (figure 1).

Figure 1. Location and direction of incidence of solar radiation in specific seasons of the year and hours
Diffuse radiation is radiation which reaches the surface of partitions as already diffuse in the atmosphere by molecules of atmospheric gases, water drops and dust. Falling e.g. on earth, a water surface or nearby building walls, solar radiation reflects from them and falls on the examined partitions as reflected radiation [8]. Reflected radiation is usually extremely small compared to direct or diffuse radiation. However, it may not be passed over in the event of radiation reflected from a water surface [9,10]. Heat gains from insolation create a stream of heat penetrating into rooms through external transparent and intransparent partitions. If the examined building is extended (L-shape) or if its structure contains loggias, balconies or windows recessed into the facade, then not the whole window glass surface is exposed to direct solar radiation. Also, nearby obstacles which are on the way of direct radiation, e.g. trees and buildings, have an influence on window shading (figure 2). Window shading decreases heat gains from insolation, which translates into smaller values of rooms' heat balance. The influence of shading on heat gains from insolation depends on the orientation of windows relative to cardinal directions and, thus, for example, window shading from the south has the greatest negative influence on the heat balance of rooms. The area of window shading caused by structural elements which stick out, just like in the case of recessing the window into the facade, or by balconies depends on the length of side and upper projections.

![Figure 2. Influence of structural elements and the building location on shading of partitions.](image)
a) balcony, b) recess into the façade, c) neighbouring building, d) natural elements (tree)

Table 1 shows approximate percentages of solar radiation reduction depending on shading elements which have been installed on external and internal sides. Because external shading elements protect against solar radiation more effectively than internal shading elements, they are applied more frequently on facades in forms of permanent or moving, horizontal or vertical blades. They protect against penetration of direct solar radiation but they let in radiation reflected in periods of intensified solar radiation at noon (figure 3). Thanks to that, natural room lightening is used with simultaneous limitation of heat gains from insolation [11].
Table 1. Hourly heat gains in specific periods of the year

| Type of external shading element | Heat gain reduction | Type of internal shading element | Heat gain reduction |
|----------------------------------|---------------------|----------------------------------|---------------------|
| blinds, opening angle 45°        | 15%                 | blinds, opening angle 45°        | 70%                 |
| awning fabric vented from the top and sides | 30%*                | light curtains, cotton fabric    | 50%                 |
| awning fabric, enclosed top and sides | 40%*                | plastic film:                    |                     |
|                                   |                     | - absorbing                      | 70%                 |
|                                   |                     | - reflective                      | 50%                 |
| blinds between the panes, opening angle 45° | 50%                 |                                  |                     |

The use of horizontal blinds on the windows on the outside reduces heat gain from sunlight during the hours in which it reaches the maximum value, i.e. between approx. 12 to 16 hour.

Figure 3. Influence of external permanent horizontal blades on room insolation.

At this time, blinds block the direct radiation, but reflected radiation freely passes into the room to provide adequate illumination of the interior space. This solution is very common in public buildings, due to the possibility of a significant reduction in cooling energy required for air conditioning of the building.

3. Analysis of required cooling power

In the analyzed building, double-glaze PVC windows have been fixed with a glass thickness of 5 mm, operation time of air-conditioning system: 16 h/day. The computing temperature in rooms was assumed at 20 °C. External temperatures were assumed on the basis of average hourly external air temperatures for the small town in Lublin Providence, calculated as an average in the examined month from information for the years 1971-2000 provided at the website of the Institute of Metrology and Hydrology in Warsaw (table 2).

To determine the minimum power of cooling unit, 3 calculation variants are taken into account:

Variant I. Calculation of the total demand for coolness for:
   a) 0% shading of transparent partitions,
   b) 50% shading of transparent partitions using external blinds at the angle of 45°,
c) 100% shading of transparent partitions till 12 from N and E and from 12 from S and W using external strip blinds.

Table 2. List of hourly temperature for specific periods in the year in degree of Celsius

| Month    | 8   | 10  | 12  | 14  | 16  | 18  | 20  |
|----------|-----|-----|-----|-----|-----|-----|-----|
| April    | 10.3| 13.2| 16.5| 19.0| 19.0| 17.7| 15.0|
| May      | 15.8| 18.7| 22.0| 24.5| 24.5| 23.2| 20.5|
| June     | 19.0| 21.9| 25.2| 27.7| 27.7| 26.4| 23.7|
| July     | 20.8| 23.7| 27.0| 29.5| 29.5| 28.2| 25.5|
| August   | 20.8| 23.7| 27.0| 29.5| 29.5| 28.2| 25.5|
| September| 17.4| 20.3| 23.6| 26.1| 26.1| 24.8| 22.1|

Variant II. Calculation of the total demand for coolness:

d) assuming a building rotation by 90° from north to east,
e) assuming a building rotation by 180° from north to south,
f) assuming a building rotation by 270° from north to west.

Variant III. Calculation of an average hourly cooling load like for Variant Ia, but:
a) for external temperatures occurring for 97% of the cooling season,
b) for external temperatures occurring for 95% of the cooling season,
c) for external temperatures occurring for 90% of the cooling season.

Analyzed building of inn located in Poland, Lublin Providence is presented on figure 4. It’s included in two part, the old and the new one. All calculation is considered the new part of the Inn with windows located on all walls, what is significant for heat gain calculation from solar radiation.

Figure 4. View of analysed building and its orientation

An annual cooling load in the examined buildings as determined on the basis of the methodology according to energy performance of the building based on PN-EN ISO 13790: 2009 Energy performance of buildings. Calculation of energy consumption for heating and ventilation [12] reach 291 754 kWh,
which constitutes a base result for calculations of Variant Ia. An annual cooling load for Variant Ib is 281 902 kWh and for Variant Ic - 289 193 kWh. A percentage of cooling load reduction obtained by adequately selected shading devices were presented in figure 5.

![Figure 5](image.png)

**Figure 5.** An annual reduction of demand for coolness for the building for Variants Ia-c

An assembly of shading devices in this case does not result in significant savings. However, the best variant is an assembly of simple shades on windows at the angle of 45°, which decreases the annual demand for coolness by approx. 4%. The problem may be a disadvantageous arrangement of windows which constitute quite a large surface on the side which is less sunny. Neither does a rotation of the building significantly increase the annual demand for coolness, which was presented in figure 6.

Monthly changes in the demand for coolness are slight and their difference is approx. 3%. Because the largest window area is situated on the shaded side, a rotation of the building caused a high exposure of windows to solar radiation. It means that the location of the building is a well-thought-out decision which has not been left to chance, all other orientations would result in increasing a heat load of the building and almost 5% increase of the annual demand for cooling energy.

![Figure 6](image.png)

**Figure 6.** Daily demand for coolness depending on a variant of building rotation.

When analysing Variant III, in the first place a number of hours with highest external temperatures (starting from the highest ones and calculating towards the lower ones) which constitute a total of 0, 3, 5 and 10%, respectively, of the whole cooling season should be established and for what external temperatures a specific situation will occur. It will allow to determine for what period in the season it is possible not to keep assumed parameters of the air in the room. Whether the decreased cooling power may reduce thermal comfort for a given period in the cooling season will depend only on the user. The computing hourly demand for coolness for the building was established to be 144.9 kW. Table 3 presents external temperature values, the number of hours in which they occur and percentages of the periods in which such temperatures occur with higher temperatures in the whole season. The 10 % of the period in which temperatures occur is when the external temperature is 26°C. It is possible to reduce the hourly demand for the power of chiller almost three times when Variant IIIc is chosen, i.e. the operational time of the system is shortened and the assumed temperature of the internal air is kept up to 90%; however,
in the season that does not result in such sensational gains from savings of the system operation, mainly due to major operational time (more than 2/3) of devices with lower temperatures compared to 30-26°C.

Table 3. Percentage of the time period in which specific temperatures occur in the cooling period with higher temperatures for selected providence.

| Number of hours | Temperature, ºC | Percentage of occurrences in all cooling period, approx. | Hourly cooling demand, kW |
|-----------------|-----------------|----------------------------------------------------------|--------------------------|
| 4               | 31              |                                                          |                          |
| 5               | 30              |                                                          |                          |
| 12              | 29              |                                                          |                          |
| 25              | 28              | 3 %                                                      | 135.0                    |
| 42              | 27              | 5 %                                                      | 93.3                     |
| 61              | 26              | 10 %                                                     | 55.4                     |
| 90              | 25              |                                                          |                          |
| 88              | 24              |                                                          |                          |
| 121             | 23              |                                                          |                          |
| 131             | 22              |                                                          |                          |
| 135             | 21              |                                                          |                          |
| Σ 714           |                 |                                                          |                          |

The greatest reduction of the hourly demand for coolness in the examined building and powers necessary for devices and investment costs compared to a cooling load calculated on the basis of average hourly monthly temperatures for the small town of Lublin Providence is in the cooling load established on the basis of a temperature which constitutes 10% of higher temperatures than the cooling point temperature, Variant IIIc and it is 61.8% - figure 7.

Figure 7. Hourly cooling load for examined variants of reducing thermal comfort

Reduction of requirements and assumptions of the outside air temperature down to 26ºC allows for significant savings on power needed to cooling of the building. The inevitable cost of such action is comfort decreasing during 42 hours of the entire cooling season. This disadvantage can be eliminated by the use of shading elements in the form of horizontal blinds mounted on the outside of the windows.

4. Conclusions

The decision on whether rooms should be air-conditioned depends on needs and the intended use of given rooms. A choice of a proper variant of air-conditioning system requires an analysis of advantages and disadvantages of particular types of the system, its solutions and equipment used. Features such as: achieving the set aim of the system, operational reliability as well as investment and operational costs require comparison of many variants. When choosing a type of air-conditioner, its influence on environment while its operation and utilization of its specific elements are very important as well.
Operational costs of air-conditioning system depend mainly on the amount and quality of conditioned air and set parameters of air treatment. Energy-saving of an air-conditioning system may be achieved mainly by air-conditioning of separate parts of the building and not all the rooms. Achieving the upper limit of tolerance of temperatures in rooms has an economic influence on operation of air-conditioning system, e.g. while cooling. It is possible to lower operational costs of the air-conditioner by limiting its operation at night and by using natural (night) cooling of rooms. A cooling load of rooms depends on thermal gains in the summer season. Thermal gains from humans, lightening, food or devices do not depend on external conditions and it is not possible to affect their volume. However, it is possible to affect heat gains from insolation through external partitions. Heat gains through external transparent partitions may be limited by using external or internal shading devices. After the conducted analysis of the influence of shading devices on heat gains from insolation, it turns out that the most efficient way is to apply shading devices in a form of external blinds which are 50% closed. That causes a perceptible reduction of the cooling load in the season compared to the situation in which we resign from shading elements. In the analysis of the influence of building rotation to cardinal directions, insignificantly small differences of heat gains were observed in this case. Above all, external temperatures affect heat gains in the building in summer. In the calculations of the thermal balance of the building, mainly external temperature values included in standard PN-B-03420 Computing parameters of external air [1] are applied. After calculations made in several variants on the basis of temperatures taken from metrological data for the town in Lublin Providence, it was concluded that the temperature in the period of the cooling season decreased by 10, 5 or 3%, respectively, compared to the total length of the season may be assumed when calculating the building thermal balance. A reduction of the power of devices and investment outlays may be reduced almost by 60% compared to the volume calculated on the basis of maximum hourly computing temperatures assumed when designing that kind of systems.

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