THE EFFECT OF WINDOW POSITION AND WINDOW SIZE ON THE ENERGY DEMAND FOR HEATING, COOLING AND ELECTRIC LIGHTING

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ABSTRACT

The amount of sunlight and daylight through the façade is a key factor in new façade design. Designing a new façade, based on the idea that a façade should be able to function and perform mostly autonomously (i.e. requiring as little input such as warm/cold water, air and electricity from the building as possible), the amount of sunlight and daylight through the façade influences the yearly energy demand for heating, cooling and electric lighting.

In this paper it is shown that it is possible to calculate the yearly energy demand for heating, cooling and electric lighting as a function of window position, window size and window shape for an office environment in the Netherlands. This result should enable the design of improved autonomous facades for office buildings.

KEYWORDS

Daylighting, Facade, Total energy demand.

INTRODUCTION

The amount of solar irradiation entering a building through a facade largely determines the energy demand for heating and cooling in a building. The amount of solar irradiation can be divided into visible light and heat, in this paper called daylight and sunlight. The effect of sunlight on the energy demand for heating and cooling is extensively investigated by others.

In the last decades, however, the energy demand for heating decreased due to better insulation values of facades. The heat generated by electric lighting is now no longer negligible but comparable to the energy demand for heating. When calculating the total energy demand of a building it is therefore necessary to incorporate the energy demand for lighting into the total energy demand of a building.

The size of the window not only determines the total energy demand of a building directly through the availability of sunlight, but also indirectly through the availability of daylight. As an extra complication, the amount of electric lighting indirectly influences the total energy demand for heating, cooling and lighting due to the heat production of the electric lighting.

The electric lighting demand is not only influenced by the size of the window. The window position and the window shape influence the illuminances in a room. In this way the window position and the window size determine the electric lighting demand.

In this paper, it will be shown that it is possible to calculate the yearly energy demand for heating and cooling as a function of window position, window size and window shape for an office environment in the Netherlands.

This result will in future be used to design improved new facades for office buildings as for example described by Hasselaar (2006). He is designing new facades based on the idea that a façade should be able to function and perform mostly autonomously, requiring as little input (e.g. warm/cold water, air, electricity) from the building as possible. His aim can only be realised when the influence of window position, window size and window shape can be taken into account in determining the autonomy of a façade.

SIMULATION METHOD

Using the Radiance-based daylighting simulation tool DAYSIM, as described by Bourgeois, Reinhart en Macdonald (2006, Anon) , simulations are performed that calculate the amount of light (illuminance level) anywhere in a room on an hourly basis using an annual climate file for the building that includes hourly data of direct and diffuse irradiances. This computer program makes it possible to accurately calculate the illuminance level on any position inside a room as a function of the outside availability of diffuse and direct sunlight. This in itself is not so remarkable, but this program can perform this task for hourly sunlight data for a year (i.e. 24*365 illuminance calculations) within a reasonable timeframe (less than a day).

The amount of additional electric lighting, which is necessary to obtain the required daylight performance (= 500 lux), can then be calculated on an hourly basis for a known electric lighting configuration.

Decreasing the total energy demand for heating, cooling and electric lighting requires a controllable electric lighting set-up. A dimmable electric lighting device which reacts on the amount of daylight will have a larger electrical energy saving effect than a simple on/off switch. The control of the electric lighting set-up (sensors, dimmers, automatic blinds, etc.) influences the energy demand for electric lighting. In the most ideal case, the amount of electric lighting is automatically controlled by sensors in a user friendly way. Practice has shown that user unfriendly systems, which are boycotted by the users, usually increase the energy demand for electric lighting.

Semi-automatical electric lighting systems give the user influence over his lighting wishes. This makes the user a large factor in the calculation of the amount of electric lighting over a year. This influence was investigated by Reinhart (2004). He developed a user behaviour control model called Lightswitch. The model can be used to quantify the energy saving potential of automated lighting controls, e.g. of an occupancy sensor over a standard on/off wall switch. This model combines annual illuminance profiles and occupancy profiles with behavioural patterns that are based on field studies in buildings throughout the Western world. Besides the input quantities as the description of the lighting control system (manual wall switch, occupancy sensor, dimmer,...), blind control manual, automated) and the type of occupant (energy-conscious/active or passive) can be taken into account. For example, the model predicts when users will lower window blinds in response to glare, or when they will switch on the electric lighting.

The total energy demand for heating, cooling and electric lighting in this paper is calculated for three different user and blind profiles. This has been done with the above described Lightswitch model which is incorporated into the Daysim program. The total energy demand is calculated with the dynamical thermal program Capsol (Anon A) which simulates the total yearly energy demand for lighting, heating and cooling together using Daysim output. It is, however, not necessary to use the program Capsol. Koti and Addison (2007) have shown that combining Daysim with DOE-2 is also a good possibility.

REFERENCE MODEL

The reference model consists of an office room of 3.6 x 5.4 x 3.0 m^3, situated in the city of Groningen in the North of the Netherlands. The external wall consists of a south facing glass window (the window frame is not taken into account) with the reference size of 3.6 x 1.2 m2 in the middle of the façade made of double glazing with an LTA of 77%, a g value of 62% and a U-value of 1.47 W/m2K. The rest of the façade consists of an insulated wall with concrete on the inside with an R-value of 3 m^{2}K/W. The indoor walls are made of gypsum plates and insulation, the floor and ceiling are made of concrete. The light refection parameters are 0.2 for the floor, 0.65 for the walls and 0.85 for the ceiling.

The office is occupied by two persons (80 W p.p.), each using a computer of 120 W. The installed lighting power density is 10 W /m2, which amounts tot a total power density of 194.4 W for the 19.44 m^2 floor surface of the office. The standby power is 3.0 W and the ballast loss factor is 20%.

The work plane is situated 1.2 meters from the window at a height of 0.8 m and at 1.8 meters from the two side walls. The minimum required illuminance level at the work plane is 500 lux.

For the energy calculations a distinction is made between the summer and the winter situation. In winter, the office is ventilated with 117 m^3/h during office hours (8.00 -17.00 h) and 58 m^3/h at nights and weekends. Heating is applied with a power of 1500 W in order to obtain 21 +/- 1 °C during office hours and 15 +/- 1 °C at night and in weekends.

In the summer, the office is ventilated with 175 m^3/h during office hours and 117 m^3/h at nights and weekends. Cooling is applied with a power of 2000 W in order to obtain temperatures of 23 +/- 1 °C during office hours. Outside office hours the temperature is allowed to reach 30 °C.

SIMULATION PARAMETERS

The Radiance calculation parameters are as follows:
5 ambient bounces, 1000 ambient divisions, 20 ambient super samples, an ambient resolution of 300, an ambient accuracy of 0.1, a limit reflection of 6, a specular threshold of 0.15, a specular jitter of 1, a limit weight of 0.004, a direct jitter of 0, a direct sampling of 0.2, 2 direct relays and a direct preset density of 512.

The Daysim calculations are performed for a working day of 08.00 till 17.00 hour with lunch and intermediate breaks and daylight savings time. Use is made of hourly data from the energy plus database.

In this model DAYSIM uses a simplified model to consider the effect of a generic Venetian blinds system on the annual daylight availability: Daysim uses the basic Radiance scene to calculate indoor illuminances when the blinds are retracted. During times of the year when the blinds are lowered due to direct glare (>50 W/m2 at the workplace), Daysim simply assumes that a generic blind system blocks all direct sunlight and transmits 25 % of all diffuse daylight. The minimum illuminance level is 500 lux.

For the energy calculations, all walls not directly connected to the outdoor air are assumed to have adiabatic boundaries. The energy calculations are performed with 5 minute time steps and with the same climate file as the Daysim calculations. Internal heat production is taken from the Daysim results where the occupancy data against time is converted into internal heat production against time by first multiplying the occupancy data with 400 W (for persons and computers) and then adding the electric lighting load from Daysim to this value. Blind use in the energy calculation is also taken from the blind use data against time calculated with Daysim.

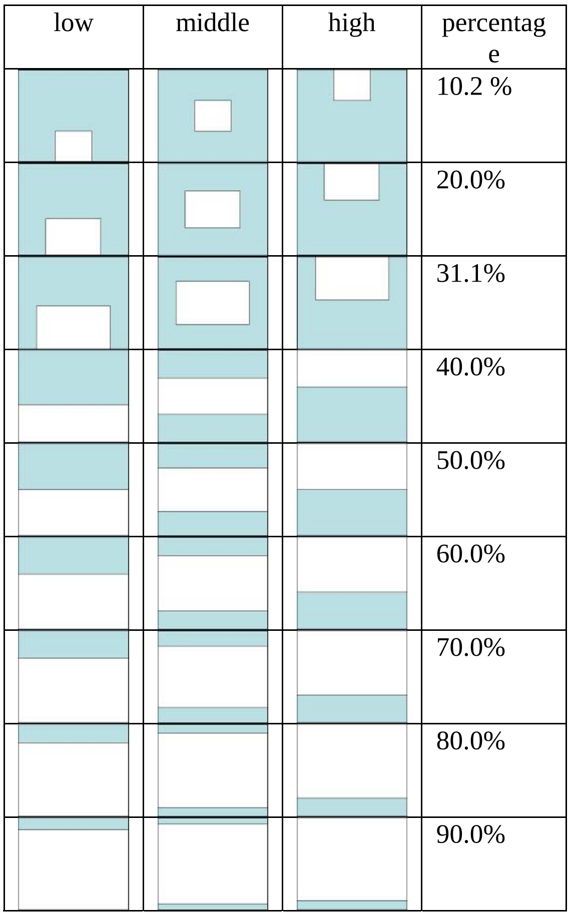


Figure 1: low, medium and high window positions for all window areas

The influence of window size and window position is investigated with nine different window sizes from 10 to 90 % of the façade area and with three window positions: low, medium and high. The low window position means that the window starts at the bottom of the façade, the high window position means that the window ends at the top op the façade and the medium window means that the window is situated exactly at the middle of the façade, see figure 1. In table 1 the window measures corresponding to the different window sizes are shown.

As is demonstrated by others (Bourgeois, Reinhart and Macdonald, 2006), the user and the lighting system play an important role in the energy demand for daylighting. Therefore three different combinations of user type and daylighting system are investigated. The first variant is the active user (daylight and blind use) combined with an automated daylighting system. The blind control is automatic and the lighting control is a combination of a switch-off occupancy and dimming system with an occupancy sensor delay time of 5s. The second variant is a passive user (daylight and blind use) combined with the same automated daylighting system. The third, and worst case scenario, is a passive user (daylight and blind use) combined with a manual blind use and a manual on/off switch at the door.

Table 1 Description of the window sizes

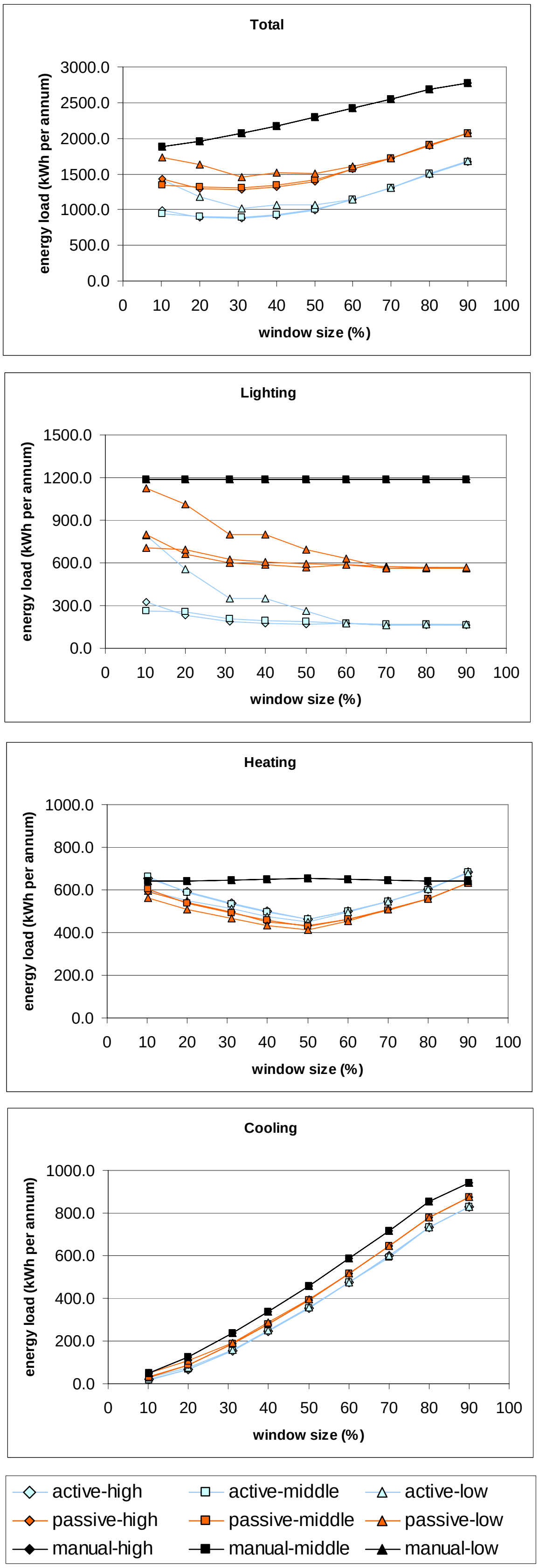
WIDTH	LENGTH	PERCENTAGE
1.1 m	1.0 m	**10.2%**
1.2 m	1.8 m	**20.0%**
1.4 m	2.4 m	**31.1%**
1.2 m	3.6 m	**40.0%**
1.5 m	3.6 m	**50.0%**
1.8 m	3.6 m	**60.0%**
2.1 m	3.6 m	**70.0%**
2.4 m	3.6 m	**80.0%**
2.7 m	3.6 m	**90.0%**

RESULTS

The results of the calculations are shown in figures 2, 3, 4 and 5. The figures show the annual primary energy loads for heating, cooling and electric lighting as a function of the window size (x-axis). For very user type and daylighting system combination (active, passive and manual) the energy load is displayed for the different window positions as a function of the window size.

The annual energy loads calculated with the energy simulation program Capsol are converted into primary energy loads with a distribution and transportation loss of 0.39 % for lighting. A loss of 10 % for heating is coupled with a heat recovery of 50 % to obtain a total energy distribution and trans-portation 'loss' of 180%. For electric cooling a COP factor of 4 is assumed and a distribution and trans-portation loss of 0.39 % for electricity, obtaining a 'loss' of 156 %.

When the window position is considered, the window position does have a significant effect on the primary energy demand for lighting when there is an active or passive user and daylighting system control.


Total

Lighting

Heating

Cooling

Figure 2 Energy load per annum for the total energy demand, lighting, heating and cooling demand for different user profiles (active, passive and manual) and three different window positions as a function of the transparent window ratio.

A lower window is disadvantageous when the primary energy demand for lighting is considered. A lower window, however, is a little advantageous when the primary energy load for heating is considered, especially for small window sizes. Due to the good insulation of the façade, however, a lower window is also disadvantageous when the total primary energy demand is considered, see figure 2. A low window position will probably not have a pleasant view either.

Surprisingly enough, the highest window position does not perform much better than the medium window position. This is probably because the workplace position is situated relatively close to the window (at 1.2 m from the window) whereas a higher window is more advantageous for positions far from the window.

From figure 2 it can be concluded that an optimal window size for this office simulation is around 30 % of the façade area, where the window is positioned in the top half of the facade. A window size of 20 to 40 % is also very acceptable. For larger window sizes, starting at 50 %, the advantage of a larger glass area on the lighting load is negligible. As a larger window area increases the cooling load significantly, the net primary energy load increases for larger window sizes.

From a technical point of view, from figure 2 it can be concluded that the ideal façade and room combination should have an automated lighting and blind control and a window size of around 30 % of the façade area. For this sample office this would then lead to an overall energy load of 1400 kWh per year.

Considering figure 2 from a more social-economical point of view, implementing an automated lighting and blind control system with a user behaviour campaign, might also lead to an overall energy load of 1400 W for window sizes of 10-80 %.

DISCUSSION

Among the other variables that are not varied but do have an influence on the energy load are the U-value of the façade wall, the amount of ventilation, the size of the room, and the room ratio (width vs. length vs. height), the refection factors of the walls, the solar admittance of the window pane, the orientation of the office and the position of the working place.

Blind control is the weak point in this study. From the calculations it appeared that it was not necessary to close the blinds as the value of 50 W/m2 at the workplace was not reached under the automatic blind control setting. However, the total amount of solar irradiation reaching the office space for larger window sizes is so large that a blind closing system based on thermal considerations should be considered for future calculations.

CONCLUSIONS

It is possible to calculate the yearly energy demand for heating and cooling as a function of window position, window size and window shape for an office environment in the Netherlands. Example calcu-lations showed that the total primary energy demand for electric lighting is a significant part of the total primary energy demand for heating, cooling and electric lighting. The future design of an improved autonomous façade for office buildings should therefore carefully consider the influence of the window size, window position and window shape on the total primary energy demand of an autonomous façade.

Above calculations also showed that not only the technical specifications of a façade influence the total primary energy demand for heating, cooling and electric lighting. The lighting and blind control strategy and the user behaviour may be just as important in decreasing the total primary energy demand.

Regardless of the façade, electric lighting should be avoided. The decrease in heating load due to excess electric lighting is smaller than the excess lighting energy load leading to a larger total energy load. Likewise, extra electric lighting leads to higher cooling loads and thus to a higher total energy load. This effect has also been observed by Bourgeois et al. (Bourgeois, Reinhart, Macdonald , 2006) .

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