Cooling Demand in Commercial Buildings -The Influence of Daylight Window Design

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Abstrac t- The objective of the paper is to show how window design could influence the peak cooling load, daylight availability and direct sun penetration for a south facing office room in North European circumstances latitude about 59 ~ 60°. A daylight window is compared with an ordinary window to find out the design consequence differences. Both size and cost of the HVAC system needed to avoid unacceptably high room temperatures in office buildings depend on the peak load. In office rooms with windows this peak load is usually decided by the solar irradiation. Therewith the architectural design is decisive for the HVAC solutions needed. The Seattle Daylighting Lab heliodon table has been used to analyze daylight window potential in North European circumstances in decreasing the peak cooling load and glare from direct sun by blocking the direct solar rays from entering the room.

Finally, outgoing from simulations, daylight and solar tests, the possible combination of window glass share and solar factor for fulfilling the requirements for the highest accepted dimensioning cooling load and lowest accepted daylight level for daylight window compared to ordinary window are presented.

Keywords - Commercial buildings, building design, window share, solar factor, cooling load, daylight factor, daylight window.

I. INTRODUCTION

Many studies have indicated that well daylit buildings increase human performance, because people enjoy such spaces and will stay a little longer and return more frequently [3],[4], [12], [13], [14]. Daylight brings warmth and sparkle to architecture, but it may also cause extreme discomfort for building occupants and excessive energy and retrofit costs for building owners when its potential is misused [1],[9],[11].

A study based on both simulations and measurements in new or newly renovated office buildings in operation was carried out in summer 2004 in the North European city Tallinn, Estonia, latitude 59.1°[2]. It was found that in 70% of the office rooms studied, the installed cooling capacity exceeded 100 W/m² being as high as 250 W/m² in one south facing room. The same study revealed that a south facing facade has the highest required cooling capacity in North European circumstances, latitudes about 60° [2].

II. BACKGROUND

When the heat from the solar irradiation, people, office equipment and lighting exceeds the heat loss at the highest accepted room temperature, there will be a heat surplus that has to be removed. In rooms next to the exterior wall it is often solar irradiation that accounts for the greater part of the heat surplus [5].

Solar protection factor g or shading coefficient is the ratio of solar heat gain through a glazing to the solar heat gain through a single clear glass. The smaller the number, the better the glazing is at preventing solar gain, but poorer to let the natural daylight inside the room [8].

Daylight factor is the ratio that describes the outside illuminance over the inside illuminance, expressed in percent [10].

$$DF = 100 \times (E_{in} / E_{ext}) \tag{1}$$

Where,

DF is the daylight factor, Ein Inside illuminance at a fixed point, Eext Outside horizontal illuminance under an overcast (CIA sky) [10].

In North European circumstances latitude about $59 \sim 60^{\circ}$ spaces with average daylight factor of 2 give us a feeling of daylit. If the difference between the highest and lowest daylight factor in a space exceeds about 20 it might respond to too large contrast and risk of glare [10].

Figure 1 presents the office room layout for which the cooling capacity and daylight study is based.



Figure 1 Office room layout studied in further simulations and measurements [2].

In office room simulations the following values were used. U-values: Facade wall 0.27 W/(m^{2-} K); Window 1.6 W/(m^{2-} K); Roof 0.15 W/(m^{2-} K). Installed lighting power 10 W/ m^{2} , office equipment 10 W/ m^{2} , and people 6 W/ m^{2} . It is presupposed that that room temperature is not allowed to exceed + 25 °C during more than 80 working hours per year[2].

III. COOLING DEMAND

The study on dimensioning cooling load influenced of the shape of the room, the window orientation, the window size and the solar factor for ordinary window is given by H.Voll [2]. and not presented in this paper in more detailed. Only the results needed to make the following simulation discussion for the reader easier to understand are presented in figure 2.

Figure 2 shows the possible combination of glass share and solar factor for fulfilling the cooling load requirements 100 W/m², left figure and/or 75 W/m², right figure for south and north orientations. If the requirement is to be fulfilled, the window glass share and actual solar factor must lay within the marked areas.



Figure 2 Possible window glass share and solar factor combination for fulfilling the requirement: highest accepted dimensioning cooling load 100 W/m^2 or 75 W/m². Rooms facing south and north are presented. If the marked area is exceeded cooling requirement would become above presented values.

IV. TESTS AT THE SEATTLE DAYLIGHTING LAB

Daylight tests were conducted at Seattles Daylighting Lab. During the first step a scale model of the office room was built. The model was built in scale 1:10 of the original size, with interchangeable parts to test multiple floor and facade alternatives. Four different facade layouts with 15%, 30%, 50% and 80% of window (glass) area were built. To study the daylight window effectiveness in north European circumstances latitude about 60°, a daylight window for both room types was designed and tested parallel with the ordinary window.

A daylight window is basically the exterior overhang and interior lightshelf design for the window, see figure 3.



Figure 3 Starting from left: The daylight window in general, example of the daylight window model tested in Seattles daylighting laboratory [7].

The width of the exterior overhang (nr 3 on figure 3) and interior lightshelf (nr 4 on figure 3) is normally equal with the width of the daylight and view window (nr 5 and 6 on figure 3). The length of the exterior overhang is normally equal to the height of the view window height. The length of the interior lightshelf is normally equal to the height of the daylight window share [7].

- 1. Daylight Window: High performance glazing- Low solar factor 0.4 or less. For tests described in this paper the solar factor was taken 0.2 throughout the tests.
- 2. View Window: solar factor 0.74 or lower. For tests described in this paper the view window was tested with solar factors 0.4; 0.6 and 0.74.
- 3. Exterior Overhang: Can be almost any material depending on the architectural vocabulary and/or location of the building (snowy or not snowy climates). Common material choices include Panel Systems, Metal Grate, Tempered Translucent Glass, Polycarbonates.
- 4. Interior Lightshelf: Often made of painted plywood, gypsum board, perforated metal, translucent glass. It is crucial that the top surface be matt finish white. A light colour bottom surface will help decrease contrast between the lightshelf and the window.

- 5. Louver Blind: Horizontal adjustable louver blinds are very common. They range between very inexpensive standard aluminium louvers, to highly engineered specialty louver systems.
- 6. Roll-Down Fabric Shade: Aluminium roller housings for the roll-down shades are standard from several manufacturers. The fabric can be dark colours vinyl, or woven fiberglass fabric- which offers more flexibility with surface colour differentiation, and creates less volatile organic compound off-gassing than vinyl [7].

The Daylighting Lab in Seattle has a mirror-box overcast sky and Heliodon sun simulator table.

The mirror-box overcast sky conforms to the "International Overcast Sky". The shadowless artificial overcast sky condition created in mirror-box is a test condition defined by the international commission of illumination (CIA) [10]. The shadowless sky is generally three times brighter at the zenith (directly overhead) than it is at the horizon. The mirror-box in the Seattle Daylighting Lab has two switch settings December noon and September noon. Figure 4 illustrates the outside and inside view of the mirror-box artificial sky used in Seattle for daylight tests.



Figure 4 Pictures from left: Mirror box overcast sky picture from outside [7], overcast sky interior view, the author of the article testing the models.

Six photocells were used to measure the percentage of available daylight. One "control cell" was placed on top of the model oriented towards zenith to measure the amount of available daylight. Inside the model, five photocells were placed on working zone height (0.85 m original scale [6]) to measure the amount of light reaching the interior. The photocells inside the room were replaced parallel with the window facade. For each window glass shares, 50 daylight factor readings were measured. The interior readings were then divided by the value of the exterior reading, directly giving the Daylight Factor (percentage of outdoor illumination indoors). The light flux metering equipment measuring the daylight factor is shown in figure 5.



Figure 5 Flux metering equipment measuring the daylight factor [7].

The heliodon table shown in figure 6 seek to examine shading devices that eliminate direct sun from areas where visual tasks are critical. The heliodon table is comprised of a tilting/rotating table (the earth) and a stationary 1000 watt

theatrical light source (the sun). By filming the room interior, the heliodon table tests were used to examine how the direct rays of the sun interact with different facade design.



Figure 6 Pictures from left: Heliodon table in general, heliodon table in use for testing [6].

V RESULTS

Daylight factor measurement results for an ordinary window and for a daylight window, expressed as DW, are presented in table 2. The first number in the table shows the highest measured daylight factor in the room and the second the lowest. The word "Dark" in the table indicates that the room has its lowest daylight factor below 2. The word "Glare" indicates that the difference between the highest and lowest daylight factor in the room exceeds 20 and there might be a risk of glare in the room. The solar factor for daylight window upper part is constantly 0.2. In the table 2 only solar factor values for the view window part are shown.

Table 2 Overcast study results for September. Presented are daylight factor values for ordinary window and for a daylight window (DW) different facade sizes and solar factors.

Window solar	DF, window	DF, window	DF, window	DF, window
factor g	15%	30%	50%	80%
g = 0.2	Dark	Dark	Dark	7-2
g = 0.4	Dark	Dark	13-2	15-4
g = 0.6	Dark	17-2	19-3	Glare
g = 0.74	18-2	22-2	Glare	Glare
$\mathbf{DW} \mathbf{g} = 0.4$	Dark	Dark	3-2	5-3
DW g = 0.6	Dark	Dark	4-3	8-4
DW $g = 0.74$	Dark	5-2	5-3	9-5

According to daylight factor measurement results presented in table 2 the daylight window compared to the ordinary window spreads the daylight inside the room more equally. Daylight window helps to smooth out the interior daylight distribution. There is no risk of glare due to high contrast in office room work zone even when large window glass shares per facade are used. Table 2 can be illustrated in accordance with figure 7. Figure 7 shows the results for ordinary window and daylight window for fulfilling the requirement: the daylight factor should be higher than 2 and the difference between the lowest and highest daylight factor must not exceed 20. If the requirement is to be fulfilled, the window glass share and solar factor combination must lay within the marked areas.



Figure 7 Possible window glass share and solar factor combination for fulfilling the requirement: daylight factor should be higher than 2 and the difference between the lowest and highest daylight factor must not exceed 20. If the requirements are to be fulfilled, combination must lay within the marked areas.

Figure 8 combines the cooling demand results from figure 2 and the daylight study results from figure 7 and shows the possible combination of ordinary window glass share and solar factor for office room that fulfil both the requirements: the dimensioning cooling load should not exceeds 100 W/m^2 or 75 W/m², the daylight factors should be higher than 2 and the difference between the highest and lowest daylight factor in the room should not exceed 20. If smaller window glass

shares than presented in figure 8 are to be used the daylight factor in the room would become below 2. Daylight factor below 2 however would require electrical light to be switched on to have enough light in the room. If larger glass shares are to be used, that would mean heat loads above 100 W/m² or 75 W/m², and/or possibly potential risk of glare in the room due to large light contrast.



Figure 8 Possible window glass share and solar factor combination for fulfilling the requirements: highest accepted dimensioning cooling load 100 W/m², left figure and 75 W/m² on right figure, lowest accepted daylight factor level 2 and the difference between the highest and lowest daylight factor less than 20. Rooms facing south and north are presented. If the requirements are to be fulfilled, the window share and solar factor combination must lay within the marked areas.

As can be seen from figure 8 south facade compared to north facade has much less of combinations of glass shares and solar factors that could fulfil the design requirements with the highest accepted cooling load 100 W/m^2 . In case the highest

accepted design cooling load for south facing room is 75 W/m^2 , design requirements for daylight cannot be fulfilled. Obviously if solar heat gain during the summer months could be decreased, that would decrease the peak cooling load in the

room and make it easier to design good daylight conditions for south facade orientations. One way of decreasing solar heat gain could be by using a daylight window. The idea of study daylight window for north European conditions is to find out if that type of window construction for south orientation might block the direct heat gain from the sun during the summertime, reduce cooling peak load and glare. Figures 9 and 10 show the heliodon direct sun test results. The figures show the movement of direct sun pattern inside the south facing office room through the year. Figure 9 illustrates the direct sun pattern movement inside the room on clear sky conditions at 12.00 PM at different months of the year for an ordinary window. Figure 10 illustrates the same things for a daylight window.



Figure 9 The direct sun pattern in south facing office room at 12.00 PM in different months of the year with an ordinary window. Window is on the left side.



Figure 10 The direct sun pattern in south facing office room at 12.00 PM in different months of the year with a daylight window. Window is on the left side.

<u>Ordinary window</u>: On clear sky conditions on midday the solar radiation would probably have following consequences: risk of overheating the office room, risk of glare caused by too much sun light inside the room.

<u>Daylight window</u>: As can be seen from figure 9 a daylight window blocks the direct solar radiation entering the office room from the middle of April until the middle of August. During this period there is no risk of glare by the solar radiation.

Figure 11 shows the possible direct sun pattern movement inside the office room through one day on June 21 during the ordinary office work hours from 08.00 AM to 05.00 PM. In figure 9 the direct solar radiation for east orientation starts at 08.00 AM and ends about 11.45 AM. The figure shows that

for the east orientation daylight window could block direct solar radiation from 09.00 AM to 11.45 AM. After 11.45 AM the risk of glare for east orientation ends.

During the ordinary office work hours the south orientation is influenced by direct solar radiation for the longest hours of all the orientations. As can be seen from figure the risk of glare for ordinary south facing window occurs about from 09.00 AM and is not over than before about 4.00 PM. The risk of glare for a south facing orientation due to direct solar radiation during the middle of April until the middle of August could be completely eliminated if a daylight window would be used. The risk of glare for a west orientation starts approximately about at 1.00 PM and for office workers ends with the end of the office workers work day. Daylight window could block the direct solar radiation entering the room from 1.00PM to 4.00 PM.





Heliodon tests indicate that on clear sky conditions the south facing facade orientation is influenced the most hours per day by direct solar radiation. The study showed that for an ordinary window type the critical time is about around 09.00 AM - 4.00 PM depending on the time of the year. That time also indicates to the potential risk of glare inside the room. However, the risk of glare for south orientation could be completely eliminated from the middle of April until the middle of August from 09.00 AM - 4.00 PM with the use of a daylight window.

Figure 12 shows the possible combination of daylight window glass share and solar factor for an office room that fulfil all the requirements: the dimensioning heat load should not exceeds 100 W/m^2 or 75 W/m², the daylight factors should be higher than 2 but the difference between the highest and lowest daylight factor in the room should not exceed 20. If smaller window glass shares than presented in figure 12 are to be used the daylight factor in the room would become below 2. A daylight factor below 2 would require electrical light to be switched on to have enough light in the room. If larger glass shares are to be used, that would mean cooling loads above

100 W/m² or 75 W/m². As the solar factor for daylight window upper part was constantly 0.2 only the solar factor

values for view window are shown in figure.



Figure 12 Possible daylight window glass share and solar factors combinations for fulfilling the requirements: maximum cooling load 100 W/m², figure on the left and 75 W/m² on right figure, lowest accepted daylight factor level 2 and the difference between the highest and lowest daylight factor less than 20. Results for room facing south are presented. If the requirements are to be fulfilled, the window share and solar factors combination must lay within the marked areas.

The following comparison for ordinary and daylight window is based on cooling requirement 100 W/m^2 .

<u>Ordinary window</u>: Based on figure 8 the following conclusions could be made: If window with the moderate of the applied solar factor g = 0.4 is installed, it is possible to use glass area of only in between 40-50%. If solar factor g = 0.6 is installed, it is possible to use glass share of only in between 30-35%.

VI CONCLUSIONS

Daylight availability tests by using Seattle daylighting laboratory artificial overcast mirror-box were accomplished. In these tests a daylight window was compared with the ordinary window. The results indicate that the daylight window spreads the daylight inside the room more equally. Daylight window helps to smooth out the interior daylight distribution. There is also no risk of glare due to high contrast in office room work zone height even when large window glass shares per facade are used.

Solar tests at Seattles daylighting laboratories heliodon table indicate that daylight window blocks the direct sun from solar radiation entering the office room through window from the middle of April until the middle of August from 09.00 AM to 4.00 PM.

<u>Daylight window</u>: As can be seen from figure 12 if window with the moderate of the applied solar factor g = 0.4 for view window is installed, it is possible to use glass area in between 50-95%. If solar factor g = 0.6 for view window is installed, it is possible to use glass share in between 35-65%.

Even when using daylight window, south orientation requires cooling capacity above 75 W/m^2 for good daylight conditions.

Finally the combination between the possible daylight window glass shares and solar factor for office room that fulfil requirements: the dimensioning cooling load should not exceeds 100 W/m² or 75 W/m², the daylight factors should be higher than 2 but the difference between the highest and lowest daylight factor should not exceed 20 were presented. The results show that if the dimensioning cooling load should not exceeds 100 W/m² the ordinary window with the moderate of the applied solar factor g = 0.4 allows glass area of only in between 40-50% then daylight window would allow glass area 50-90% per facade to fulfil the required assumptions.

The simulations also reviled that in North European circumstances, latitude about 59 ~ 60° in order to fulfil good daylight requirements for the south orientations the cooling capacity above 75 W/m² even when using daylight window is required.

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