The impact of shading on thermal comfort conditions in perimeter zones with glass facades

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ABSTRACT

This paper describes an experimental study of the thermal environment in a highly-glazed perimeter zone of an office building under varying climatic conditions, as well as in a controlled test chamber at the Hydro-Quebec research facilities in Shawinigan (LTE). Glazing and shading temperatures were measured at several points and the thermal environment was measured using an indoor climate analyzer and a thermal comfort meter. The aim of this study is to present measured thermal comfort conditions in perimeter zones and also to develop recommendations for high-performance façades that will permit the decreased use or elimination of perimeter heating as a secondary heating system in office buildings.

1. INTRODUCTION

Occupants situated near windows often experience thermal discomfort. In the winter, window surface temperatures usually fall below indoor air temperature, causing discomfort due to radiant temperature asymmetry and low operative temperature. In the summer, glass temperatures are usually higher than indoor air temperature, causing discomfort due to radiant temperature asymmetry and increased operative temperature. In addition, solar radiation falling directly on the occupant can exacerbate discomfort. Shading devices, which are typically used for visual comfort purposes (glare control), can also be used to improve thermal comfort conditions in perimeter zones.

The building façade is one of the most important elements in the design of any building. Not only does the façade have a significant influence on a building’s appearance, but it also plays a critical role in the building’s energy consumption, comfort conditions, and environmental impact. As the trend towards highly-glazed façades for commercial buildings continues to grow, it is becoming increasingly important to be able to design façades taking into account its influence on all these considerations. Perimeter zones experience the largest fluctuations in temperature and human comfort. While the heating and cooling needs of commercial buildings are provided by forced air HVAC systems, additional radiant and convective perimeter heating systems are usually needed beneath windows to counteract cold interior surfaces and the related downdraft (Carmody, et al., 2004). High-performance windows (low U-factor, low-e coatings, low SHGC) are able to reduce heat losses and gains significantly, and can therefore improve comfort since the interior window surface temperature can be maintained closer to room air temperature. One of the main objectives of this paper is to study whether thermal comfort can be further improved with the use of shading devices. It can be said that the “success” of a building depends on whether a comfortable indoor environment is achieved. Occupants often list thermal comfort as one of the most important requirements of any building. Creating a comfortable indoor environment is also important because occupants will react to any discomfort by taking actions to restore their comfort. Usually these reactions will have an energy cost, such as an occupant opening a window in the winter, when the heating is on, due to overheating (Nicol, Santamouris, 2003).

2. THERMAL COMFORT

Thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ASHRAE 55, 2004). It can be complex to evaluate since there exists large psychological and physiological variations from person to person.


The metabolic rate and clothing insulation are considered personal factors while others are considered environmental factors. The radiant temperature is usually expressed as the mean radiant temperature (MRT), defined as “the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual nonuniform
A window influences thermal comfort in three ways:

• by long-wave radiation between glass surface and interior surfaces in zone;

• by transmitting solar radiation to the interior;

• by creating induced air motion (convective drafts) caused by temperature differences.

Absorbed solar radiation influences the temperature of the glass, which affects the MRT, while transmitted solar radiation falling directly on the occupant can cause discomfort due to radiant temperature asymmetry if it falls directly on the occupant. There have been a limited number of studies into the effect of solar radiation on mean radiant temperature and thermal comfort in the built environment. These studies, however, have not included the effects of shading devices (Le Gennusa et al., 2005).

3. MEASUREMENTS WITH AN EXPERIMENTAL FAÇADE

An experimental setup was established in a perimeter zone with a large glass façade at the Solar & Lighting Laboratory at Concordia University in downtown Montreal. The lab is located on the 16th floor of the unobstructed building and its façade is facing 20º west of south. In the lab, the length of the façade is divided into six different sections (Figure 2). Since each section is equipped with its own individual shading device, the section being studied was isolated with partitions to eliminate the effects of the adjacent sections. Each section is 1.5 m wide, 3.4 m high, and 2.3 m deep. The height of the façade is comprised of a 0.8 m high span-drel, and two sections of 1.3 m high glazing. Perimeter heating under the windows was turned off so as to make it a passive perimeter zone and study free-floating temperatures and resulting comfort conditions. Climatic data were collected every minute from exterior sensors placed outside next to the lab. Incident solar radiation and daylight levels were recorded using a Li-cor LI-200 pyranometer and a LI-210 photometric sensor. The pyranometer has a spectral response from 280-2800 nm and it is pre-calibrated against an Eppley precision spectral pyranometer under natural conditions. It has a linear response up to 3000 W/m², a cosine correction for up to 80º angle of incidence and the absolute error is 3%; the response time is 0.01 ms. Several T-type thermocouples were used to record the exterior air temperature as well as the temperatures of all the interior surfaces (glazing, shading device, floor), in the air gap between the glazing and the shade, and the indoor air temperature (Figure 3).

Indoor environmental conditions were measured using a Brüel & Kjaer Indoor Climate Analyzer Type 1213, a collection of instruments which provides a way to measure individual basic environmental parameters (air velocity, humidity, air temperature, plane radiant temperature in two directions). In addition, a Brüel & Kjaer Thermal Comfort Meter Type 1212 was used for measurement of the operative temperature. This trans-
ducer is able to evaluate the thermal effect that the surrounding objects and surfaces would have on the human body. The transducer’s size has been designed such as to closely match the ratio of radiative heat loss to convective heat loss of a human body. Its ellipsoid shape is determined by the need to obtain the same angle factors to the individual room surfaces as for a human body. The transducer can be set at different angles depending on the posture of the human body in question. For the case of a seated person it is set at a 45° angle. The indoor climate analyzer and thermal comfort meter were placed 1.3 m from the façade at a height of 1.1 m (Figure 3). The air speed remained at approximately 0.1 m/s and the relative humidity remained around 30%.

Two different shading devices were used: a roller shade and a venetian blind. The roller shade is an off-white colour with an average reflectance of 55%, absorptance of 40%, and transmittance of 5%. The venetian blind is aluminum grey, with an average specular reflectance of 5% and average diffuse reflectance equal to 75%. The windows of the façade are double glazed (6mm/12mm air space/6mm) with a low-e coating outside the interior pane and argon filling. The glazing has a total solar transmittance of 36% and a visible transmittance of 69%; the U-value is 1.59 W/m²K and the SHGC is 0.37.

4. RESULTS AND DISCUSSION

The thermal comfort experiments took place between January and March 2007. The objective was to examine thermal comfort conditions near the façade during both sunny and cloudy days, with and without shading. Each graph presented in the following sections shows the variation of weather parameters (outside temperature and solar radiation), surface temperatures (glazing, shade/blind), room air temperature, operative temperature and radiant temperature assymetry (between front-facing the window- and back-facing the room). Table 1 presents a summary of the experimental findings.

4.1 Measurements under clear sky

Figure 4 shows the experimental results for the case with no shading during a cold, sunny day. Although the outside temperature is very low, the interior surface of the glass reaches 30°C around noon. The operative temperature of the space exceeds the upper limit of 25°C during a large part of the day (approx. 11:00am – 3:00pm solar time), reaching a maximum of 31°C (total incident solar radiation is higher than 800 W/m² during that time). The plane radiant temperature in the direction of the façade is greatly influenced by the presence of direct solar radiation, causing radiant temperature asymmetry to exceed 15°C during the same time period (the plane radiant temperature transducer cannot measure temperatures higher than 50°C in any one direction). Room air temperature remained near 25°C from solar noon until 3:00 pm.

When using a roller shade on a sunny day with slightly higher outside temperature, both the shade and the interior surface of the window reached temperatures near 40 °C – the shade surface is slightly hotter than the glazing surface (Figure 5). However, because the shade does not allow direct sunlight to be transmitted inside, conditions remained within the comfort zone for most
of the day (9:30am – 6:00pm) although the operative temperature reached a maximum of 26 °C in the afternoon –which is on the upper limit of the comfort zone. Radiant temperature asymmetry remained at or below about 5 °C, while the room air temperature was between 22-25°C during the day.

With the venetian blind set at a horizontal position on a cold, sunny day (Figure 6), the glazing and blind reached temperatures of 32°C. More importantly, however, is the fact that direct solar radiation is allowed into the space, thereby increasing the radiant temperature asymmetry to a maximum of over 20 °C. The spikes in the radiant temperature asymmetry readings shown in Figure 6 are due to the intermittent shading effect of the individual slats on the radiant temperature asymmetry transducer. The operative temperature remained above the comfort zone from about 11:00am – 5:00pm.

Figure 5 - Results with roller shade- sunny day.

Figure 6 - Results with venetian blind at 0° (horizontal) - sunny day.

Figure 7 - Results with venetian blind at 45° - sunny day.

Tilting the venetian blind to 45° (tilt from horizontal in order to block direct sunlight) has a significant effect on the thermal environment (Figure 7). The venetian blind reaches a maximum temperature of 34°C. From 10:30 am to 6:00 pm, the operative temperature is maintained between 21-27 °C. Radiant temperature asymmetry is kept below 10 °C for almost the entire day, with only a few instances when the direct solar radiation enters the space in the afternoon (low sun angles).

Finally, with the venetian blind closed (tilted to 90°), a vertical barrier between the indoor space and the glazing is created. The blind reaches a maximum temperature of 34°C and the operative temperature is kept between 20-26 °C during the day. The RTA never exceeds 3 °C (Figure 8).

Figure 8 - Results with venetian blind at 90° (closed) – sunny day.

4.2. Measurements under overcast sky

The same experiments were conducted during cold days under cloudy sky, in order to estimate the impact of shading on thermal comfort conditions and temperatures in the absence of direct solar radiation. Nevertheless, because of the high quality glazing, there is no significant radiant temperature asymmetry due to the window surface temperature for any case. Figure 9 presents the results during a cold cloudy day without shading.
For the venetian blind at horizontal position on a cloudy day (Figure 10), the indoor air and blind temperature remained between 17 - 19 °C for the entire day. The blind surface temperature is 7°C higher than the glass temperature on average; the glazing temperature remained between 10 - 13 °C and RTA does not exceed 4°C.

On a cold cloudy day with the venetian blind tilted at 45º (Figure 11), operative and room air temperatures remain at similar levels as with the horizontal blind case. With the blinds fully closed (Figure 12), operative temperature never falls below 20ºC – outside temperature was a little higher in this case. The blind temperature was 5°C higher than the glass temperature, which reached 23°C around noon.

It is interesting to note, as well, that the perimeter baseboard heating use in the room directly beneath the solar laboratory was monitored during the measurement period. This room’s façade has the same orientation and is similarly designed, making use of the same roller shades used in this study. It was shown that on cold, sunny days, when the perimeter zone in the laboratory was maintained in the comfort zone for most of the day, the room directly beneath had the perimeter heating on for over 50% of the day. On cold, cloudy days when the perimeter zone was barely in the lower end of the comfort zone, perimeter heating was shown to have been on for up to 90% of the day.

5. CONCLUSION

This paper summarizes the experimental results of thermal comfort conditions in a highly-glazed perimeter zones with shading devices. In cold and sunny conditions, a roller shade is shown to improve the thermal environment by decreasing RTA due to direct solar radiation and maintaining the operative temperature of the space within the comfort zone for most of the day. Venetian blinds are also able to improve the thermal environment, but this depends on the tilt angle of the slats and solar altitude. With the slats in a horizontal position, for example, discomfort will be experienced due to high operative temperature and RTA. Moving the slats to a tilt of 45º improves thermal comfort by decreasing RTA to below 10°C for most of the day, although allowing a small time with RTA greater than 23°C in the late afternoon. Closing the venetian blinds completely will keep the operative temperature in the comfort zone for most of the day while decreasing RTA for the entire day. These results show that the installed perimeter heating is not needed for almost the entire day on cold and sunny days; the main VAV system in the zone can supply nearly all the required heating.
For cloudy days, the differences in thermal comfort conditions between using a shading device and not using one are less apparent. This is due to the high-performance, double-glazed, low-e glazing used on the façade. Even on very cold, cloudy days, the operative temperature of the perimeter zone never falls below 18°C. Using shading devices on cold, cloudy days does not provide any significant improvement in the thermal environment when high-performance glazing is used. This is important, since most occupants generally choose not to use any shading device on cloudy days in order to maximize view and daylighting without any detrimental effects to visual comfort.

In this experiment, an insulated glazing unit with a low-e coating and argon filling was used. Usually, double-glazed windows with standard low-e coatings are used on glass facades. For similar perimeter zones with standard double-glazed windows, the impact of shading on thermal comfort would be even higher. With the results of these measurements, in contrast with the perimeter heating data collected from a similar space directly beneath the solar laboratory, it can be seen how important it is to take the façade design into consideration, including glazing, shading, and orientation, when devising the heating strategy for perimeter zones and selecting perimeter heating capacity and control options.

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REFERENCES


