Integration of daylighting, lighting control and HVAC system design in Concordia Engineering building

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1. ABSTRACT

This paper discusses major façade design options for the new Faculty of Engineering building at Concordia University in Montreal. The stated approach of the design team was to develop a green building and integrate concepts such as daylighting and natural ventilation. Detailed energy simulations have been performed in order to present recommendations on the choice of façade, glazings, shading devices, lighting control options, and natural ventilation. Integrated thermal studies, a daylighting analysis and impact of the above on HVAC system sizing are also presented.

2. ENERGY ANALYSIS OF FAÇADE DESIGN OPTIONS

2.1 Façade Options

The major objectives of this simulation design study are maximization of daylight utilization, optimal control of solar gains, reduction in electricity consumption for heating, cooling and lighting and also reduction of peak loads, while maintaining good thermal and visual comfort. A typical floor (11^{th}) was selected for energy analysis, to simultaneously select and optimize the fraction of façade area that will be glass and the properties of the curtain wall and the windows. The base type of glazing chosen was clear double-glazed low-e. The thermal resistance of the spandrel (opaque) section of the curtain wall was a minimum of 3 RSI, to meet energy code recommendations for Montreal. Integrated thermal studies were performed for different glazing R-values (0.52, 0.67 and 0.85) and different fractions of glazing area of the façade (1/2, 2/3 and 3/4). As shown in section 2.4, the optimum glass fraction of the façade is two thirds and the optimum window R-value 0.67. Also, by choosing a glazing R-value of at least 0.67, thermal comfort calculations showed that perimeter heating may be eliminated. This results in significant capital cost savings and increases the useable area of the perimeter offices.

2.2 Control of solar gains, shading and daylighting analysis

The building is 16-storeys high and two of its main facades are facing approximately SW and SE respectively. Thus, shading devices must be utilized to control solar gains and prevent from overheating, while at the same time creating a high quality visual environment in the perimeter offices. The shading options considered are: (i) motorized reflective venetian blinds integrated in double-glazed low-e window and controlled by the building automation system (ii) roller blinds with variable transmittance (iii) a translucent glazing unit with honeycomb insulation between glazings (60% transmittance) and (iv) combinations of roller blind in the middle section of the window and motorized venetian blinds or translucent honeycomb glazing in the upper third. Figure 1 illustrates the last option where roller blind is used in the middle third and motorized venetian blind in the top third, together with other concepts investigated for a typical perimeter office, such as photovoltaic panels integrated on the spandrel.

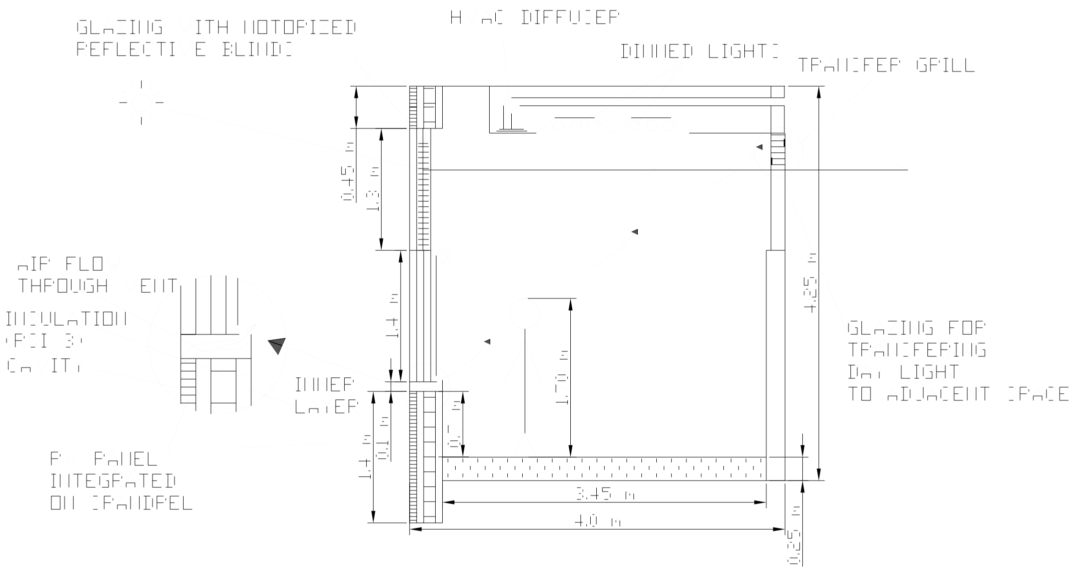

Figure 2. The multifunctional façade with the daylighting and shading design options for typical perimeter office.

The choice of the optimal shading device was based on visual comfort, daylight quality, energy efficiency, thermal comfort, appearance, cost and control aspects. Roller blinds may ensure privacy and can be open during overcast days to allow maximum daylight in the room. On clear days, they may diffuse daylight and their transmittance can be low in the bottom half and higher in its upper part. Motorized venetian blinds block direct sunlight, reduce cooling loads and allow view to the outside. Moreover, they reflect daylight towards the ceiling and improve the daylight uniformity in the room. The honeycomb translucent glazing has good thermal resistance, but it creates glare on clear days and can lead to overheating. A detailed daylighting analysis was carried out to investigate the daylighting performance of each system. Illuminance distributions on the work plane of a typical 4x4x4.25 m high perimeter office on the SW façade were determined for every hour in the year, using each of the shading devices and combinations. Athienitis and Tzempelikos (2002) developed a methodology for optimal operation of the motorized venetian blinds and calculated their transmittance as a function of blind tilt angle, solar incidence angle and sky conditions. Fig.2 shows typical results for the most important cases. A December afternoon was chosen for this graph because this is the worst case in the year; the sun is low and the venetian blinds have to close at a high angle to prevent glare, blocking most of the daylight. The translucent glazing is not included in Fig. 2, because even in this case the illuminance reaches very high values (6000lx). For almost all the other cases, the venetian blinds perform better than the other systems. Comparing all the results, the best solution is the combination of motorized venetian blinds (top half of the window) operated by the building automation system, and a manually controlled roller blind (bottom half of window) as shown in

Figure 1. The venetian blinds block sunlight and improve daylight distribution in the room, while the manually controlled roller blind gives the occupants the choice of changing their visual environment and it provides privacy. Under normal circumstances, the roller blind should be open during overcast days and closed during sunny days. Also, by using this kind of system, the control points are dramatically reduced (1-2 points on each façade), because the venetian blinds operate uniformly on each façade (if there is no shading from adjacent buildings).

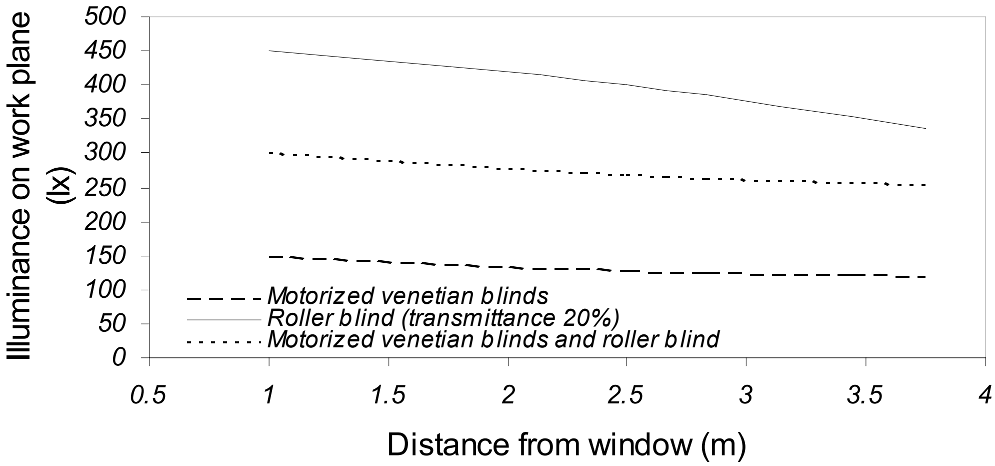

Figure 2. Illuminance distribution on the work plane for different shading devices, December 15th, 3pm, clear day.

The perimeter offices may also be used to illuminate adjacent spaces (corridors) with natural daylight, if back windows (single glazing) are placed on top of the back wall of the office (see Fig. 1). This will reduce electricity consumption for lighting in the corridors (as shown below) and create a pleasant environment during clear days, although corridors are not in the perimeter of the building. Since the illuminance distribution is known in the office, it is possible to find the amount of daylight incident on the back window and transmitted in the corridor, and then compute the illuminance distribution in the corridor. This is shown in Fig. 3 for the case of motorized venetian blinds and a roller blind on the exterior window. It is evident that in this case, the corridors are well illuminated and no artificial lighting is necessary. The corridor is assumed to be 3m wide.

2.3 Electric lighting options and energy savings

The electric lights are to be dimmed to provide adequate illumination on the work plane, when there is insufficient amount of natural daylight (set point is 500lx), so as to reduce electricity consumption. Simulations were performed to estimate the potential benefits of daylight utilization in conjunction with the motorized shading devices and light dimming.

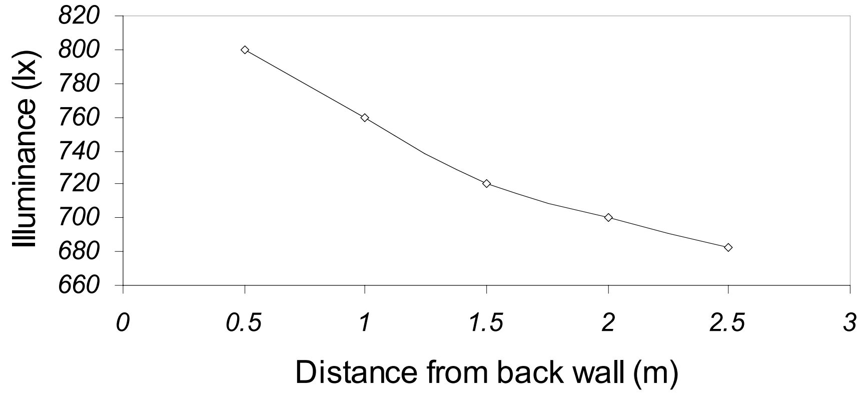

Figure 3. Illuminance in adjacent corridors, July 15th, 1pm, clear day.

For a typical office, three 60W T8 lamps with their 10W ballasts were assumed (12W/m^2 power). Two options were considered for electric lighting control: (i) continuous dimming of all lamps, 0%-100% and (ii) three-level control based on on/off operation of one, two and three lamps. Figure 4 shows the daily electricity consumption for lighting throughout the year for both options.

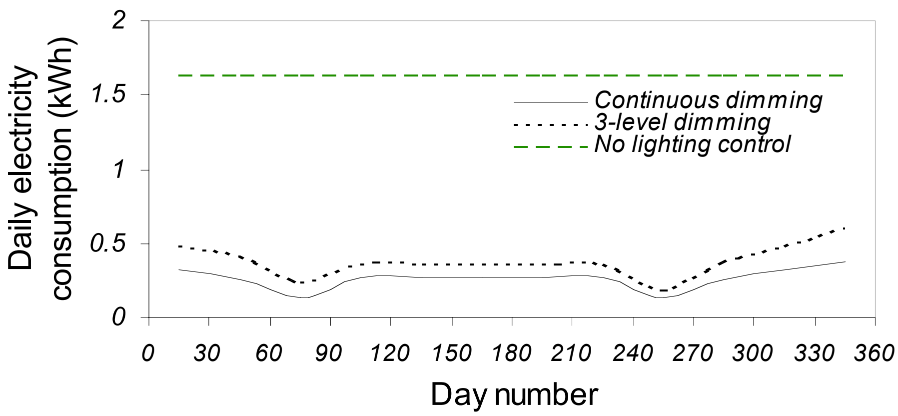

Figure 4. Comparison of electricity consumption with continuous dimming, three-level switching and no lighting control for a typical perimeter office on SW façade.

These calculations were performed for all facades, to estimate the total energy savings due to reduction in electric lighting for the perimeter offices (see Table 1).

Table 1. Yearly electricity savings (kWh) for the whole building perimeter.

Savings from:	Continuous dimming	Three-level control
SW façade	110000	90000
SE façade	61400	50000
NW façade	28200	23000
NE façade	74700	61000
Total in perimeter spaces	274300	224000

The advantages of dimming the lamps continuously are better visual environment and high energy savings (83%). Energy savings with the three-level dimming reach 70%. This option is more cost-effective and it was the one tentatively chosen by the administration.

2.4 Reductions in energy consumption for heating and cooling, and peak loads

Detailed transient thermal studies were performed for heating design days (cold cloudy and sunny) and for cooling design days (hot sunny) using software based on a MathCAD electronic book (Athienitis 1998). Solar gains, conduction gains, lighting and other internal gains are all taken into account and the results are based on detailed transient analysis. It was found that the motorized shading devices reduce dramatically the peak cooling loads and energy consumption. Cooling loads are further reduced because the lights are dimmed. Table 2 shows the impact of different options on peak heating and cooling loads and Table 3 shows the impact of the same parameters on the energy consumption. The heating analysis is for a cold cloudy January day, while the cooling analysis is for a hot sunny summer day.

Table 2. Impact of glazing thermal resistance, shading control and light dimming on heating and cooling peak loads (for perimeter spaces only).

Window R-value (RSI)	Peak heating load (kW)	Peak cooling load-no shading control, no light dimming (kW)	Peak cooling load-no shading control, light dimming (kW)	Peak cooling load-motorized shading devices & light dimming (kW)
0.52	1023	1431	1263	919
0.67	865	1405	1236	892
0.85	632	1386	1217	873

Table 3. Impact of glazing thermal resistance, shading control and light dimming on heating/cooling energy demand (for perimeter spaces only, interior zones not considered).

Window R-value (RSI)	Yearly heating energy demand (MWh)	Yearly cooling energy demand-no shading control, no light dimming (MWh)	Yearly cooling energy demand-no shading control, light dimming (MWh)	Yearly cooling energy demand-motorized shading devices & light dimming (MWh)
0.52	1023	1431	1263	919
0.67	865	1405	1236	892
0.85	632	1386	1217	873

As can be seen, there is no significant reduction in cooling load or energy consumption when window R-value is increased beyond 0.67 RSI, because most of the cooling is due to solar gains, lighting and other internal gains. The major reduction in required cooling capacity is obtained with motorized shading devices. Figure 5 compares the cooling load curves for all three cases during a hot summer day.

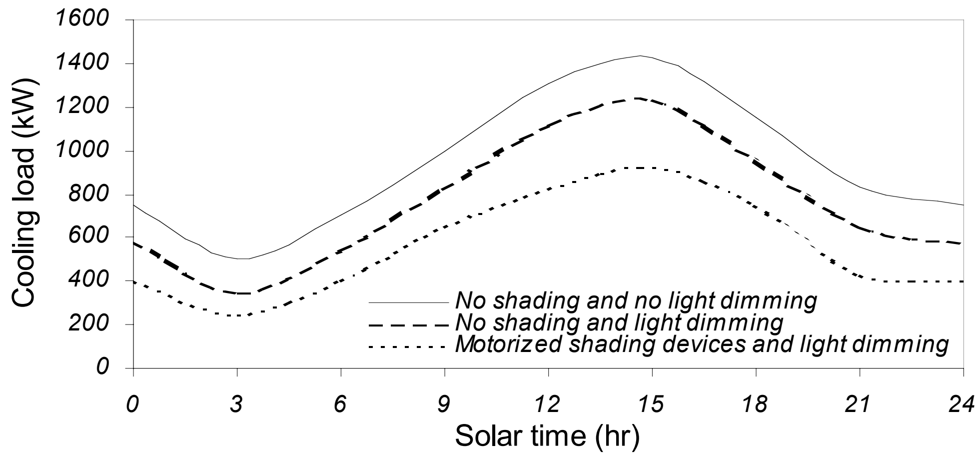

Figure 5. Cooling load during a hot summer day for the different cases of Table 2.

3. CONCLUSION

Major design façade options and associated energy simulation results were presented for the new Concordia University Engineering building. By choosing two thirds of the façade area to be glass with R-value 0.67 RSI, perimeter heating may be eliminated. Maximization of daylight is achieved by selecting clear glass for the facades.

The selection of shading devices and their control is particularly important; thermal and visual comfort, heating and cooling energy consumption are strongly affected by the type and control of the shading device used. The combination of motorized venetian blinds operated by the building automation system with a manually controlled roller blind in the lower portion of the window was an optimal solution; high daylight quality is achieved and peak cooling loads and energy consumption are significantly reduced. Motorized shading devices should be taken into account in sizing the cooling system (600 kW reduction).

Three-level light control in conjunction with the motorized shading devices leads to extra energy savings due to reduction in electricity consumption for lighting (260000 kWh for perimeter offices and adjacent corridors) and also due to reduction in cooling energy demand (170 MWh yearly).

4. REFERENCES

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