Load Reduction Potential by Employing Internal Shading Devices: a Comparative Analysis in Canadian Cold Climate Zones

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Abstract

Windows are the weakest insulating part of a building envelope. Internal shading attachments such as roller shades, cellular shades, and Venetian blinds can improve the thermal performance of windows by altering their thermal transmittance and Solar Heat Gain Coefficient. Most current studies focus on the deployment of shading attachments in cooling-dominated zones, with a view to reducing unwanted solar gains and glare.

In this study, the thermal performance of 4 different internal shading attachments: (1) Blackout Roller Shades, (2) Roller Shades with 3% openness, (3) Roller Shades with 10% openness, and (4) cellular shades were studied for office space in 5 different cold climate zones. It was found that Blackout Roller shades outperform other shading devices in terms of annual cooling load reduction, with a 70% reduction in sensible cooling energy compared to the unshaded condition. On the other hand, cellular shades perform the best in terms of heating load reduction, resulting in a 55% reduction in heating loads compared to unshaded positions. Blackout Roller Shades, Cellular Shades and Roller Shades with 3% openness have similar annual total energy performance.

This study evaluates the thermal characteristics and energy consumption associated with different types of shading devices to inform building design and operation practices that enhance energy efficiency and occupant comfort.

Keywords

Sustainability, Building Energy Efficiency, Automated Shading, EnergyPlus, Energy Savings

Introduction

Windows are the weakest insulating part of a building envelope (Tan et al., 2020). Attachments, such as roller shades, cellular shades, and Venetian blinds, are widely used to avoid excessive heat gain in the cooling season and mitigate heat losses in the heating season. Attachment devices alter the thermal transmittance and Solar Heat Gain Coefficient, which are important properties in heat loss and heat gain, respectively.

An analytical study by Oleskowicz-Popiel and Sobczak (2014) showed that external and internal roller shades could reduce the heating energy by 45% and 33%, respectively, during the nighttime in Central Europe. However, studies have shown that occupants in residential and commercial buildings rarely adjust the position of the shades, making it difficult to take advantage of the benefits of the attachment devices (Firlag et al., 2015). In fact, Firlag et al. (2015) found that there is very little difference between manually operated shades and a window with no shades in terms of annual energy consumption.

Automated control of window attachments emerges as a viable solution to address this challenge and optimize energy performance. It has been widely deployed in Venetian blinds, cellular shades, and roller shades (Nicoletti et al., 2020; Cort et al., 2018; Tzempelikos and Shen, 2013). Tzempelikos and Shen (2013) studied four different control algorithms, focusing on reducing glare and solar radiation in the test space.

While most control strategies for automated shading focus on reducing cooling energy demands due to excessive solar gain, there are few studies that focus on the effect of shading in cold climate zones. Moreover, there are few studies that explicitly compare different types of internal shading devices in terms of their thermal performance.

This study aims to look at the energy performance of 4 different types of internal shading devices: (1) Blackout Roller Shades, (2) Roller Shades with 3% Openness, (3) Roller Shades with 10% openness, and (4) Cellular Shades in a real-time office space building in 5 different climate zones using a preliminary always-shaded control strategy. The annual sensible heating and cooling energy requirement is compared for the different shading devices. Insights into monthly energy loads are also provided.

Methods

To study the influence of different types of shading devices, a CAD model of a room at SUB 6-24 was developed using Sketchup for energy modelling in Energy Plus.

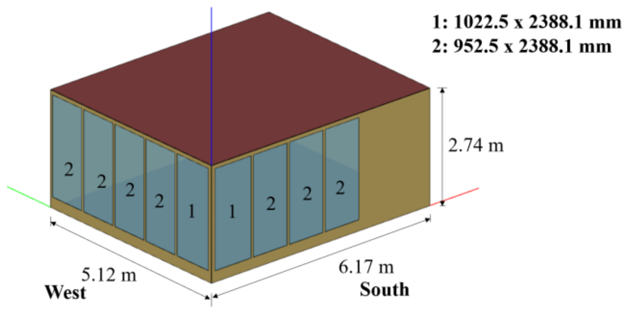

Figure 1: Room Under Study

The room consists of 5 west-facing windows and 4 south-facing windows.

Table 1: Parameters for the EnergyPlus Model

Model Parameter	Description
North Wall, East Wall, Ceiling, and Floor	Default Construction for Particular Climate Zone; Adiabatic
South and West Walls	Default Construction for Particular Climate Zone; Sun and Wind Exposed
Windows	Double Pane Clear Glass (5.7mm panes and 13mm air space between panes); U Value: 2.685 W/m^{2}K SHGC: 0.704
Window Dimensions	952.5 mm x 2388.1 mm (4 windows on west; 3 windows on south) 1022.5mm x 2388.1 mm (1 window on wet, 1 window on south)
Occupancy	Unoccupied

As per Figure 1, the room has the south and west facing portions exposed to the outdoor environment. The north and east walls of the room are connected to other rooms, and have been modelled as adiabatic walls, since this study focuses on the heat gains and losses from the outdoor environment. Similarly, the ceiling and the floor are connected to the 7th and 5th floors respectively, and have also been modelled as adiabatic walls.

Four different types of internal shading devices, Blackout Roller Shades, Roller Shades with 3% openness, Roller Shades with 10% Openness, and Cellular Shades, were studied. Two baseline scenarios were used: the windows were unshaded and fully shaded.

Table 2: Climate Zones of Cities studied

City	Climate Zone (ASHRAE,2019)
Vancouver	Zone 4C (Mixed-Marine)
Toronto	Zone 5A (Cool-Humid)
Quebec City	Zone 6A (Cold-Humid)
Edmonton	Zone 7 (Very Cold)
Yellowknife	Zone 8 (Subarctic)

Further, the simulations were performed in 5 different cities: Edmonton, Vancouver, Toronto, Quebec City, and Yellowknife, which belong to different climate zones, to study the behavior of the window attachments in different environmental conditions.

These cities capture the full range of environmental conditions in Canada, which majorly consists of cities in the Cool and Cold Climate Zones.

Window Model

The window model was created using WINDOW 7.8, which the LBNL developed to model different types of windows with attachments.

Table 3: Window Attachment Information

Window System	Attachment	Package Properties
Double Pane Window with 5.7mm Clear Glass	Internal Roller Shade (Blackout)	Shade-Window Distance: 35 mm Thickness: 0.6 mm U-Value: 1.737 W/m^{2}K SHGC: 0.222
	Internal Roller Shade (3% Openness)	Shade-Window Distance: 35 mm Thickness: 0.5 mm U-Value: 1.435 W/m^{2}K SHGC: 0.257
	Internal Roller Shade (10% Openness)	Shade-Window Distance: 35mm Thickness: 1 mm U-Value: 1.976 W/m^{2}K SHGC: 0.334
	Cellular Shade	Shade-Window Distance: 35 mm Thickness: 20 mm U-Value: 1.301 W/m^{2}K SHGC: 0.291

For the current study, a double-pane clear glass window with 5.7 mm thick panes and a 13mm air gap between the panes was modelled. WINDOW generates a Bi-Directional Distribution Function, which is then exported to EnergyPlus as an IDF File. BSDF files define a specific set of incoming and outgoing angles, providing a comprehensive description of the optical performance of any system, regardless of its complexity. Each layer and the entire system are described using a matrix of incident and outgoing angles.

BSDF files for each of the cases (unshaded and different shades) were created and exported to EnergyPlus, and the simulations were run. All the shades were fixed at a distance of 35 mm, which is the window-shade distance for an internal roller shading system installed in the room.

The openness of shades determines how much light falls on them. Blackout shades completely block any light from passing through them and have lower SHGC values compared to 3% open and 10% open shades. Blackout roller shades also completely block light from infiltrating them and thus are more effective at reducing the cooling energy requirements.

For each of the cases on EnergyPlus 23.2, year-round simulations were run. The thermostat setpoints were based on the actual setpoints used at the office facility.

Table 4: Temperature Setpoints

Setpoint	Temperature
Heating	20℃
Cooling	22℃

For simplicity, in this study, the same setpoints were used in all the climate zones.

Sensible heating and cooling energy are defined as the sensible energy required to raise or lower the space's temperature at that time to the set point temperature. The annual sensible heating and cooling energies were assessed for the shaded condition with different shading attachments and compared with the unshaded condition.

Results and Discussion

Comparison of Performance of Attachment Devices

The simulations were performed for the baseline scenarios: unshaded, and fully shaded position with different shades. The annual total sensible heating and cooling energies were calculated in EnergyPlus.

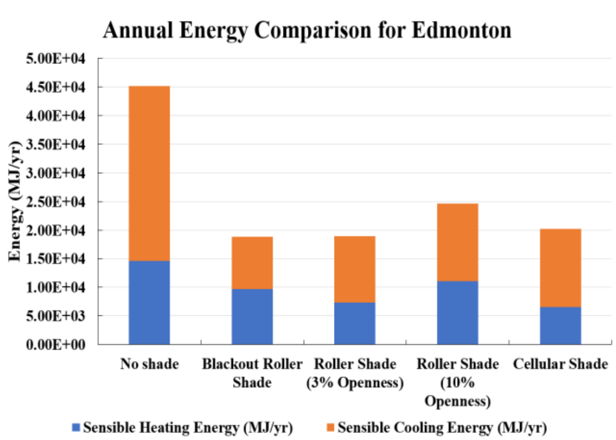

Figure 2: Annual Energy Comparison for Edmonton

Figure 2 shows the annual sensible energy (heating and cooling) for Edmonton (Zone 7). As expected, the use of window attachments brings about a significant reduction in terms of both sensible heating and cooling energy requirements.

Cellular shades reduce heating energy requirements to the maximum extent possible. This is because the window system with cellular shades has the lowest value of Thermal Transmittance (Table 3). The construction of cellular shades allows for the entrapment of pockets of air in the fabric space (20 mm in thickness), which adds to the shades' insulating effect.

However, these pockets have the opposite effect on cooling energy consumption, as they trap heated air, leading to an increase in cooling loads when compared to roller shades. Blackout Roller Shades bring about the maximum reduction in cooling energy requirements, owing primarily to their low value of SHGC (Solar Heat Gain Coefficient). As the openness factor for the roller shades increases, the SHGC increases, due to which the cooling energy requirement increases.

Table 5: Energy Reduction for Edmonton

Shading Device	Sensible Heating Energy (MJ/yr)	Sensible Cooling Energy (MJ/yr)	Percentage Reduction (%Heating)	Percentage Reduction (%Cooling)
No shade	14636	30556	-	-
Blackout Roller Shade	9670	9197	34	70
Roller Shade (3% Openness)	7294	11634	50	62
Roller Shade (10% Openness)	11041	13630	25	55
Cellular Shade	6534	13715	55	55

Variation due to Climate Zone:

Figure 3 shows the cooling load reduction comparison among different climate zones. The maximum reduction in cooling energy is seen in Edmonton. The value of the average Mean Daily Global Insolation, a metric used to measure the amount of solar exposure received by a city, is the highest for Edmonton (17 MJ/m^2 for winter, and 12.7 MJ/m^2) among the test cities, making it the sunniest city among the selected cities (Shum and Zhong, 2023). This explains the highest cooling energy reduction in terms of absolute value.

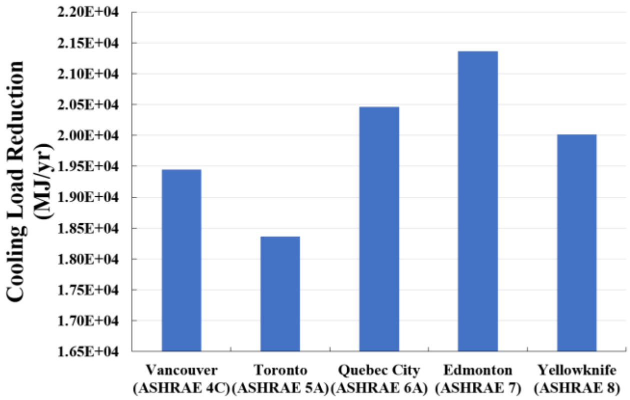

Figure 3: Cooling Load Reduction using fully shaded Roller Shades

Among the selected cities, Yellowknife lies in ASHRAE climate zone 8, with the coldest climate. As a result, the heating load is highest among the selected cities, which ultimately results in a higher load reduction value, as observed in Figure 4. The absolute value of the heating load reduction is higher as the climate gets colder.

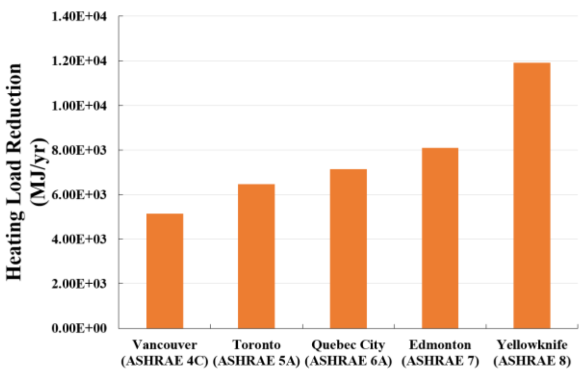

Figure 4: Heating Load Reduction using fully shaded Cellular Shades

Table 6 looks at the heating load reduction brought about by the use of cellular shades and the cooling load reduction brought about by the use of blackout roller shades. While the absolute values of the load reductions differ according to the climate zone, the percentage reduction remains comparable for all the cities.

Monthly Energy Requirements

Figures 5 and 6 show the monthly cooling and heating loads for unshaded and fully shaded with Blackout Roller Shades, respectively, for Edmonton.

Table 6: Heating and Cooling Load Reductions in Different Climate Zones

City	Cooling Load Reduction (MJ/yr) (Blackout Roller Shades)	% Reduction (Blackout Roller Shades)	Heating Load Reduction (MJ/yr) (Cellular Shades)	% Reduction (Cellular Shades)
Vancouver (ASHRAE 4C)	19447	67	5155	60
Toronto (ASHRAE 5A)	18363	67	6461	57
Quebec City (ASHRAE 6A)	20460	69	7149	55
Edmonton (ASHRAE 7)	21359	70	8101	55
Yellowknife (ASHRAE 8)	20016	71	11915	51

Looking at the cooling season, there is a huge cooling load requirement in the summer months, which can be brought down significantly by operating the shades in a fully deployed condition. However, in the transitioning seasons (spring and fall), there is a significant demand for both cooling and heating energy simultaneously. In the unshaded position, the cooling load requirement is significantly higher than the heating load requirements for the months of October and March.

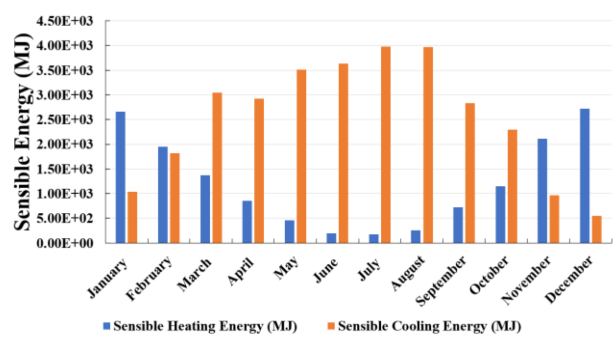

Figure 5: Monthly Energy Requirement for Unshaded condition, Edmonton

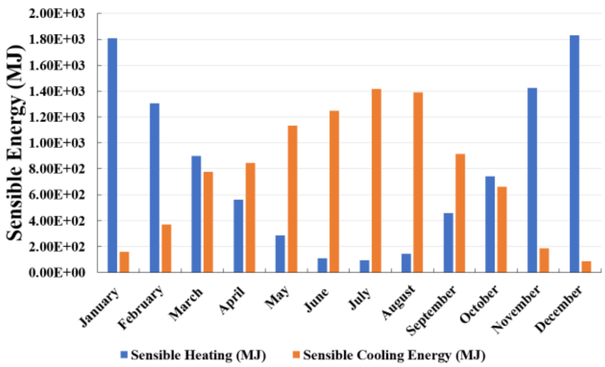

Figure 6: Monthly Energy Requirement for Blackout Roller Shaded Window, Edmonton

However, the use of blackout roller shades can reduce the cooling energy requirement to below the heating energy requirement.

A closer look at Figure 5 suggests that there is a significant cooling load requirement even for the months of February and March, which belong to the heating season. This is due to the fact that Edmonton receives the highest Mean Daily Global Insolation, among the test cities (Shum and Zhong, 2023). This suggests the potential of harvesting this solar energy to reduce heating loads.

Such harvesting of solar energy can be brought about by using appropriate control strategies which can be used to control the position of the shades at a particular instant on the basis of the environmental conditions at that time, taking into account both the conductive and convective losses due to the temperature difference and the radiative gains from the window.

Limitations of this Study

This study has explored the sensible and heating energy reduction potential for an office space by employing shading systems in various climate zones. As previously defined, shading systems only represent the sensible energy required to raise or drop the space's temperature at that time to the set point temperature. The heating and cooling energy consumption in the presence of HVAC systems installed in space has not been studied.

This study compares the energy performance of different shading devices in fully deployed conditions. It does not involve a shading schedule, which is what happens in practice. In real time scenarios, the shades are usually adjusted on the basis of user preferences and/or occupancy schedules.

Finally, the current study has been performed on a CAD model of an office space which replicates an office scenario. A whole building has not been studied.

Conclusion

In this study, the sensible heating and cooling energy requirements for an office space with 9 double-pane windows were estimated using EnergyPlus across 5 different climate zones in Canada. The baseline unshaded condition has been compared with an always shaded condition with 5 different types of shading attachments: Blackout Roller Shades, Roller Shades with 3% openness, Roller Shades with 10% openness, and Cellular Shades.

Full-year simulations show that, when operated at always shaded conditions, blackout roller shades are the most effective at reducing the sensible cooling energy requirements, with a 70% reduction in the cooling loads, and cellular shades are the most effective at reducing sensible heating energy requirements, with a 55% reduction, both for Edmonton (ASHRAE 7). Overall, blackout roller shades, roller shades with 3% openness, and cellular shades are comparable in terms of combined heating and cooling energy reduction. The percentage reduction of heating and cooling loads is comparable for all the cities, suggesting that the shading attachments can be deployed in all the climate zones studied.

Future work includes implementation of different control strategies for the shading attachments to optimize the heating and cooling load reductions for the particular climate zone. This study will be extended to a larger office space, with detailed descriptions of HVAC systems in place, and occupancy schedules. The control strategies will take into account the radiative heat gain and the heat losses from the indoor-outdoor temperature differences, which will be coupled with user preferences and thermal comfort considerations.

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