A Case Study on the Daylighting and Thermal Effects of Fixed and Motorized Light Louvers

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Abstract

This study investigates the effects of fixed and motorized light louvers on building daylighting and thermal performance. These two types of light louvers have significantly different daylight transmitting characteristics. An energy-efficient office building with interior fixed light louvers installed on the top section of its equator-facing windows is used as the base case. A combined daylighting and thermal model for a typical section of this building with interior fixed or motorized interior light louvers is developed using a simplified approach. The model contains three thermal zones. The distributions of longwave radiation, solar radiation, and daylight of the enclosing surfaces of the thermal zones are calculated using a radiosity method. The model is verified with measured data for the base case. Using this model, the daylighting and thermal performance for different daylighting design and operation options for different climates are assessed. Results show that this simplified approach is suitable for integrated daylighting and thermal design. Motorized light louvers can effectively optimize useful solar heat gain and daylight. Suggestions for integrated design and operation are presented.

1 Introduction

Transmitted solar radiation can be reflected by light louvers (typically towards the ceiling) and then diffusely reflected again deeper into interior space, onto the workplane. Important benefits of using light louvers include reduction of glare, particularly for occupants adjacent to daylighting windows, and increased daylight level on work surfaces further from the windows (Torcellini et al. 2010). Daylighting should have higher priority over electric lighting since daylighting has significantly higher luminous efficacy (Murdoch 2003), and enhances the lighting quality and productivity of the office occupants (Heschong 2002).

In addition to enhancing daylighting, light louvers also affect passive solar heat gain. Motorized louvers can control incoming solar heat gain and daylight intensity. These louvers can be adjacent to a window or inside a sealed glazing unit. In a space heating period, useful solar heat gain can be maximized without causing glare. In a cooling period, excessive solar heat gain can be avoided while maximizing daylight level.

Light louvers have significantly different solar radiation transmittance. Peng (2009) conducted an experimental study on motorized louvers between glass panes. When the beam component is reflected, the maximum daylight transmittance was measured (Figure 1). Figure 1 also shows the typical transmittance of a fixed light louver as a function of the solar profile angle. The fixed light louvers have higher transmittance in low latitude area since it has higher transmittance for larger profile angles. On the other hand, the motorized light louvers are better for passive solar heating applications in high latitude areas (e.g. higher than 40-45 degrees). A major advantage of motorized light louvers is that their effective daylight transmittances can be controlled to avoid excessive solar heat gain during cooling months and

direct solar radiation transmission that causes glare. This difference needs to be considered when selecting light louvers.

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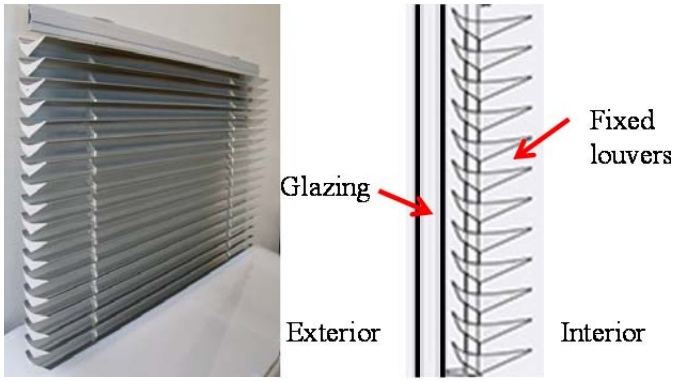

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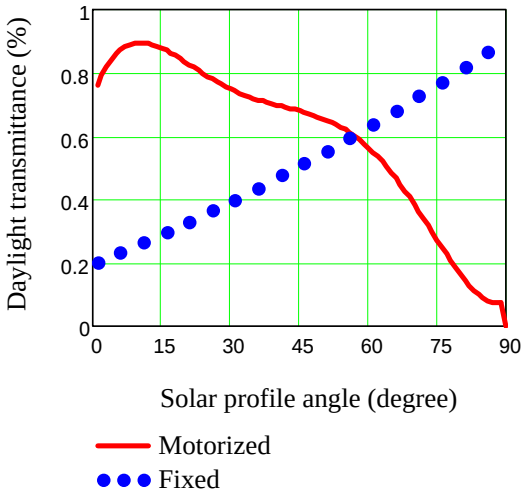

(c)

Figure 1: Two types of light louvers. (a) Motorized light louvers between glass panes (www.unicelarchitectural.com); (b) Fixed light louvers on the interior side of the window (www.lightlouver.com); (c) Daylight transmittance (data source for fixed type is www.lightlouver.com).

Other than the optical properties of light louvers, the window-to-wall ratio is also important as it determines passive solar gains and useful daylight throughout the year. The optimum window area as a percentage of façade area depends on climate, function, selected shading/daylighting device, control strategy and importance of views to the exterior (Tzempelikos et al. 2007).

In this study, the effects of the two above mentioned light louvers on the overall daylighting and thermal performance are presented, in the context of an energy-efficient office building in heating and cooling periods. Both light louvers are for facade applications. The approach is as follows:

1. With available as-built information, a combined daylighting and thermal custom model is created for a typical section of an existing office building. The model is verified, and calibrated with monitored data.
2. Evaluate the daylighting and thermal performance of the cross section with two types of light louvers, after integrating active daylighting and solar heating control.

3. Abstract the key elements in design and operation, and suggest potential design options for better performance.

The Research Support Facility (RSF) building of the National Renewable Energy Laboratory (NREL) is the case for study. The RSF is located in Golden, Colorado, U.S.A. The latitude is 39.7°N, and the altitude is 1829 meters above sea level. The local climate is space heating dominated with large daily temperature fluctuations of about 8°C in the winter and 12°C in the summer. Most days of the year are sunny and the air is dry. The RSF building is a 20 440 m^2 (220 000 ft^2) office building designed to hold 822 occupants. With its roof-mounted photovoltaic system, the RSF was designed to produce about as much renewable energy as it consumes on an annual basis. The monitored energy consumption for the first year of building occupation is 111.7 kWh/m^2/yr (Hootman 2012). Figure 2 shows the measured complete energy consumption for 2011[1].

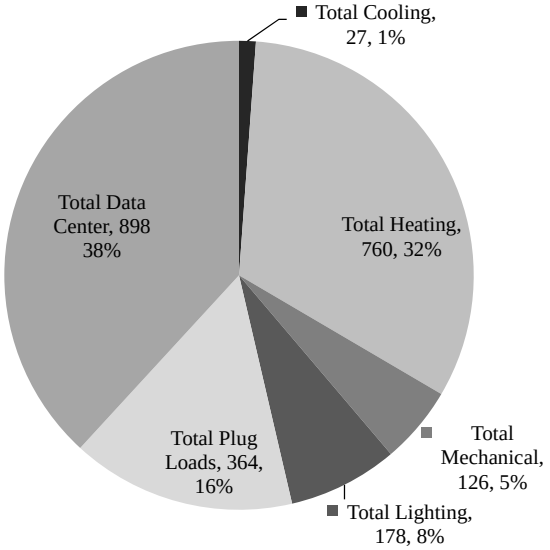

Figure 2: Total annual energy consumption (MWh)[1].

The building being investigated in this study is Phase 1 of the RSF building, which comprises a north wing and a south wing (Figure 3). In Phase 2 of the RSF, a third wing was added to the north of the Phase 1 building shown. Figure 4 shows the interior of a typical section.

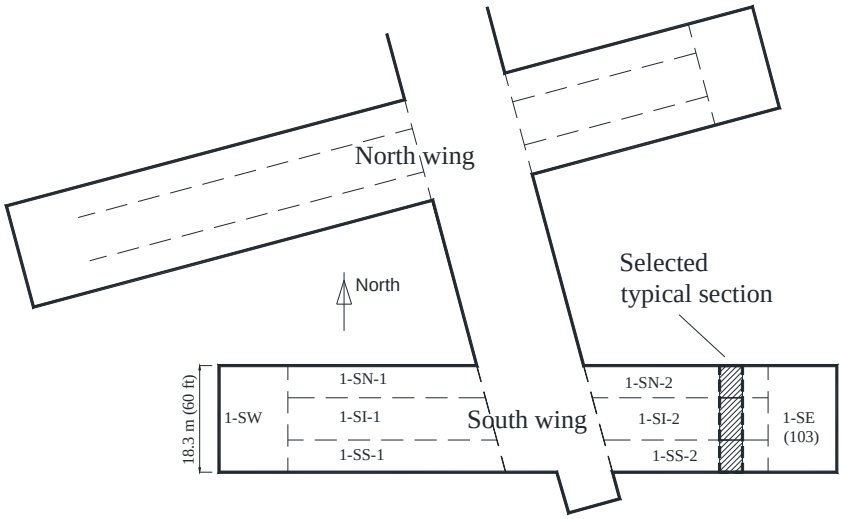

Figure 3: Sketch of the floor plan and space heating/cooling zoning of Phase 1

[1] http://en.openei.org/datasets/node/933

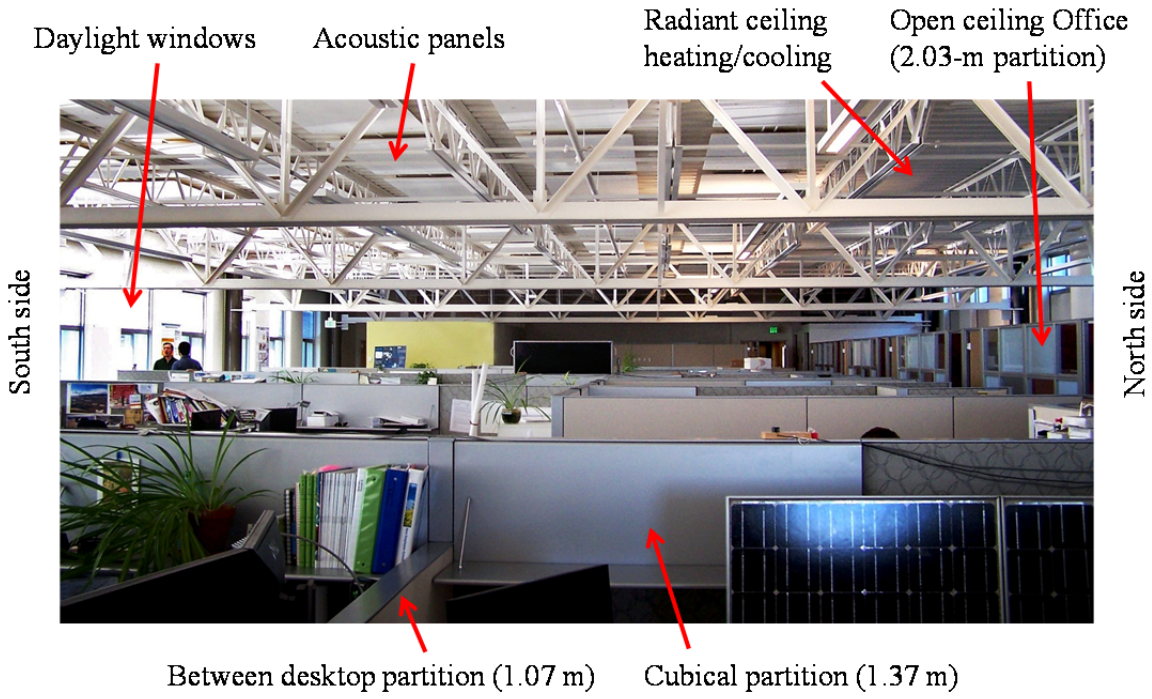

Figure 4: Interior space of the typical section shown in Figure 3.

2 Key design features and energy performance

The window areas as a percentage of the façade areas are as follows: South: 30%, North: 21%. The RSF has no separate interior zone and has an open plan in order to maximize daylight penetration and natural ventilation. The floor plate depth was chosen to be 18 m (60 ft) as a compromise between the ratio of exposed exterior wall area to volume and daylight availability.

The south facing window aperture is divided into two portions (Figure 5). The lower *vision window* is triple-glazed. Its low-e glazing has a RSI-value of 1.04. Insulated framing decreases the assembly RSI-value to 0.52 – half of the glazing value. The upper *daylighting window* is double-glazed. Its low-e glazing has a RSI-value of 0.65. Insulated framing decreases the assembly RSI-value to 0.4. The vision window is used for all of the north facing windows. Their optical characteristics are tabulated in Table 1.

Table 1: Window optical characteristics (SHGC: solar heat gain coefficient; transmittance for diffuse component is taken from fenestration database (ASHRAE 2009). Windows types not used in the RSF are for later analysis).

Glazing type		SHGC		Daylight transmittance	
		Normal incidence	Diffuse	Normal incidence	Diffuse
Triple-glazed	Low SHGC (RSF vision window)	0.23	0.15	0.43	0.28
	High SHGC	0.62	0.52	0.68	0.57
Double-glazed	Low SHGC (RSF daylighting window)	0.38	0.32	0.7	0.59
	High SHGC	0.70	0.61	0.76	0.66

The daylighting windows are equipped with interior light louvers. Incoming transmitted solar radiation is reflected towards the ceiling, and then diffusely reflected again deeper into the space, onto the workplane (as shown in Figure 5). The view window portion is equipped with exterior shading, which is designed to block low-altitude beam radiation from entering through the window. The north glazing is not shaded and permits indirect natural light to enter.

Figure 5: Fixed light louvers installed on the interior side of south windows (measured illuminance levels are shown later in Figure 8, for 12:00 P.M.)

The space conditioning of the office area is provided through a hydronic ceiling slab radiant conditioning system with 0.125 m thick concrete. A displacement ventilation strategy was adopted, partially in order to fully expose the ceiling to the office space below. A raised floor creates a 0.3 m high space for under floor air distribution. The 100% fresh air is supplied at a neutral temperature of about 19.5°C.

3 Model development

A combined daylighting and thermal model is created for a typical cross section of an intermediate floor. See Figure 3 for location. The width of the typical section in the numerical model is 3.05 m, equal to the building's modular width and windows' spacing. The interior space, along with its associated ceiling and floor slabs, is divided into three thermal zones – south, interior, and north, corresponding to surfaces "3", "4", and "5" as indicated in Figure 6. The surrounding surfaces of these three zones (i.e. surfaces "1" to "15" in Figure 6) are used for longwave radiation, solar radiation, and daylight distribution calculation with a radiosity method. The workplane (0.9 m above raised floor) is used for calculations, instead of the floor.

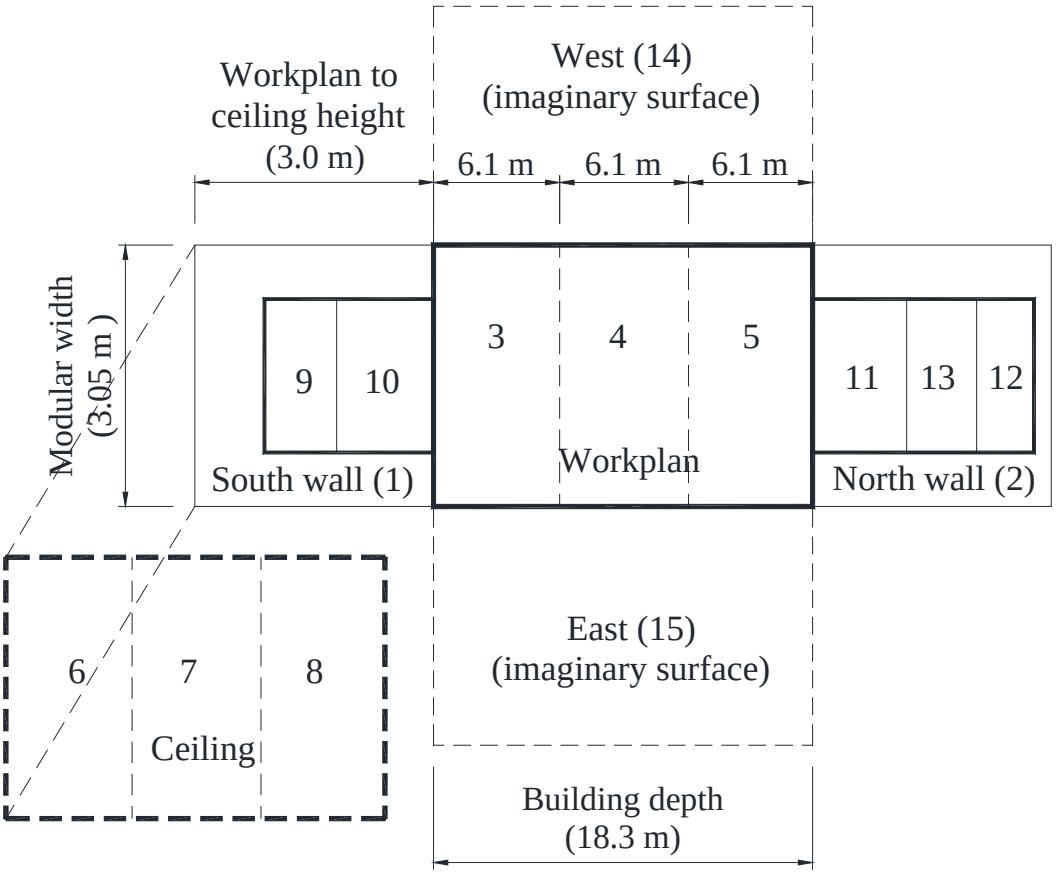

Figure 6: Surface division for radiosity calculation.

Perez's model (Perez et al. 1990) is used to estimate the exterior illuminance on facades based on beam and horizontal diffuse radiation. Transmittance for beam radiation of all windows is a function of incidence angle. For daylighting windows, it is assumed that 90% of the transmitted solar radiation is reflected evenly to the ceiling surface "6" of the south zone. The remaining 10% becomes diffuse radiation. All transmitted solar radiation through the other windows is assumed to be perfectly diffuse since the windows are designed to avoid direct beam radiation.

All surfaces are assumed to have diffuse reflection. Hence, the solar radiation leaving from surface "6" after reflection is considered perfectly diffuse. The reflectance of each surface is tabulated in Table 2. These are deduced values from the properties of the surface material, taking into account influencing factors, mainly the ceiling acoustic panels, structural trusses, corrugated surface of the steel decking, cavity effects of the workstations. Using the radiosity method, the radiant heat and illuminance of each surface are calculated.

Table 2: Surface reflectance (see Figure 6 for surface numbering)

Type of radiation	Surface number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Daylight	0.6	0.6	0.2	0.2	0.2	0.5	0.5	0.5	0.2	0.2	0.2	0.2	0.6	1	1
Solar	0.3	0.3	0.2	0.2	0.2	0.4	0.4	0.4	0.6	0.4	0.4	0.4	0.3	1	1
Longwave	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	1	1

Thermal network with explicit finite differencing techniques are applied in the thermal modeling. One-dimension heat conduction is assumed for the exterior walls; two-dimensional conduction for the ceiling/floor concrete slabs. Eq. (1) (Barakat 1987) is used for calculating inter-zonal heat transfer due to air convection.

$$U_{zn}(T_{z1}, T_{z2}) = \frac{0.3 \cdot Gr(T_{z1}, T_{z2}, H_{zn})^{0.5} \cdot Pr_{air} \cdot k_{air}}{H_{zn}} \cdot A_{open} \quad (1)$$

where H_{zn} is the effective height of the zone (3.0 m, from the top of workplane to ceiling). It is also used as the characteristic height in the calculation of the Grashof number, Gr. T_{z1} and T_{z2} are the air temperatures of the two adjacent zones. k_{air} is the air conductivity. Pr_{air} is the Prandtl number of air (0.71). A_{open} is the area of an opening between two thermal zones, 3.0 m x 3.05 m in this case.

Measured data from a winter period (Figure 7) are used to verify and calibrate the numerical model. Figure 8 compares the simulated and measured workstation illuminance on the first sunny day. All electric lights were off, except emergency lights. The main potential factors that cause the discrepancies between measurement and simulation values include:

- Partitions (Figure 4): a desktop is 0.7 m in height. The partitions between desktops are 1.1 m high. The workplane is taken as 0.9 m high in the radiosity enclosure. The partitions between workstations are 1.0 m high. The open-ceiling offices in the north zone have walls 2.0 m high;
- The assumption that 90% the transmitted solar radiation from window surface "9" is reflected to the ceiling of the south zone (surface "6" in Figure 6);
- Obstruction of adjacent buildings.

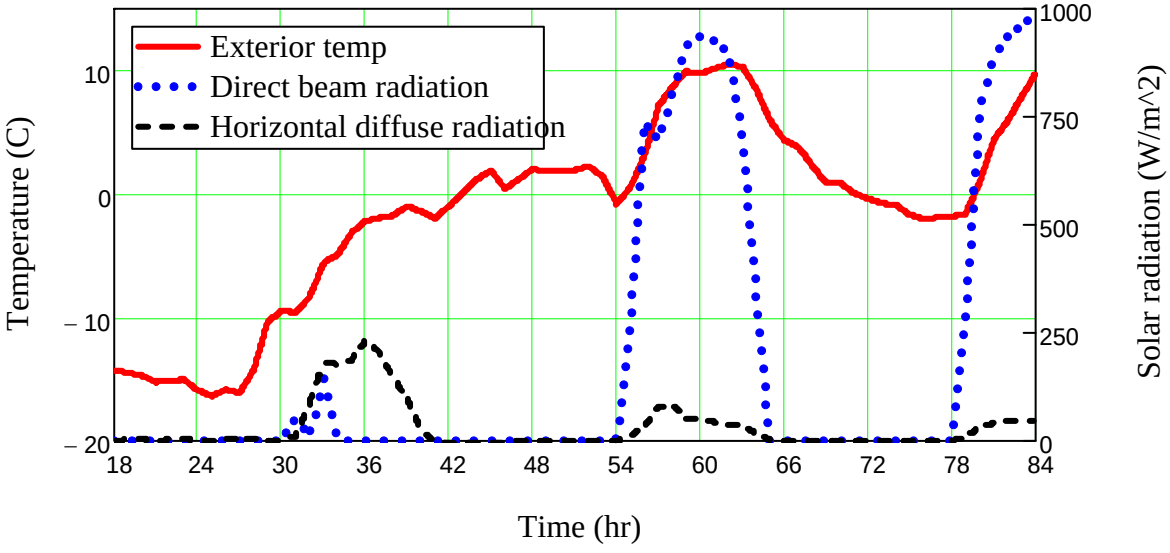

Figure 7: Weather conditions for model calibration

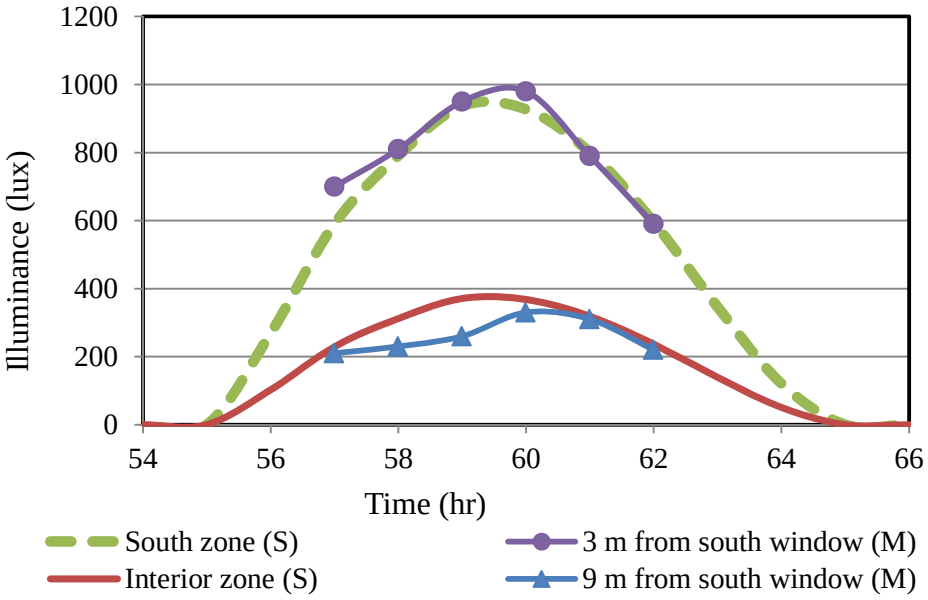

Figure 8: Measured (M) and simulated (S) daylight levels on a winter sunny day, Jan 16th, 2013 (3 m is at the common edge of the south zone and the interior zones, 9 m is at the center of the interior zone)

Figure 9 compares the simulated and measured temperatures of the south zone. Calibration indicates that the effective thermal capacity of the room control volume is about 50 to 60 times the thermal capacity of room air. Acoustic panels are estimated to weaken (by about 40 to 60%) the heat exchange rate between the radiating ceiling slab and the thermal zones. The discrepancies are mainly due to uncertainties of infiltration rates, internal heat gain, and the assumptions and other factors listed above.

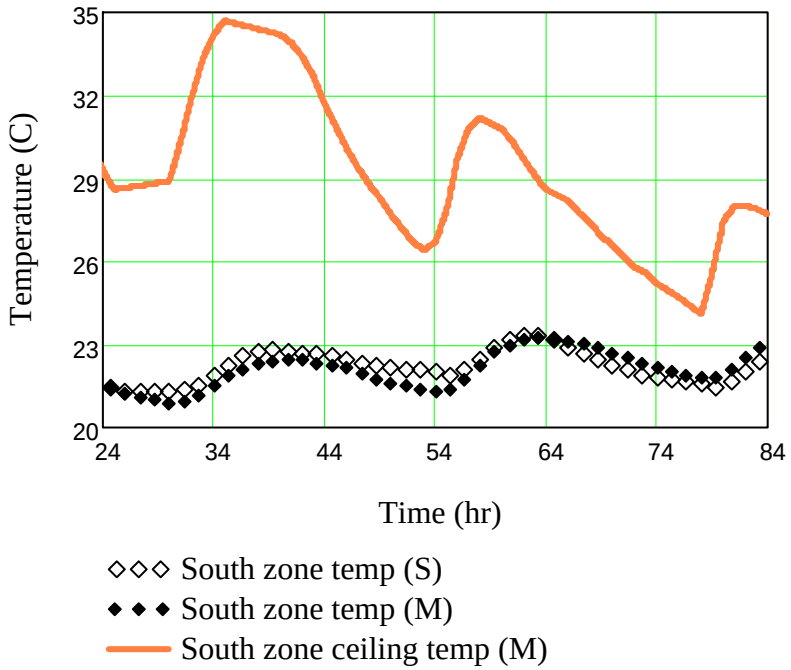

Figure 9: Comparison of simulated (s) and measured (m) temperatures.

4 Daylighting and thermal performance

In this section, the daylighting and thermal performance under two light louver scenarios in two seasons is investigated using the calibrated model. Weather conditions of typical two-day

design periods are used – August 1st and 2nd for summer period and Feb. 12th and 13th for winter period (different from that in Figure 7). Two-day periods allow better observations of the transient thermal response of buildings with significant thermal mass, which is the case in this study. The daylighting illuminance level of the interior zone needs to exceed 300 lux before reducing the transmittance of the motorized light louvers to avoid excessive solar heat gain.

The corresponding space heating/cooling energy consumption per meter width of facade (excluding ventilation portion) is presented in Table 3. The room temperature set point for heating demand is 22°C between 6 A.M. and 6 P.M., 19°C for the rest of the time. It is 24°C and 27°C respectively, for the cooling demand. The existing window-to-wall- ratio (WWR) for the daylight window (surface "9") is about 13%, and 3.5% for window-to-floor ratio. Effects of different window-to-wall ratio on daylighting and thermal performance are investigated.

Table 3: Space heating/cooling energy consumption (kWh per meter façade width). (Note: energy consumption for ventilation is not included; a negative sign indicates space cooling provided; no heating provided in summer and no cooling in winter)

Season	Daylighting WWR	Type of light louvers	
		Fixed	Motorized
Winter	13% (original)	10.5	9.7
	25%	10.3	8.7
	40%	10.1	7.1
Summer	13% (original)	-1.9	-1.8
	25%	-2.2	-1.9
	40%	-2.6	-2.0

Winter design period

Windows with high solar heat gain SHGC (Table 1) are used for the winter design period, double-glazing for daylighting window and triple-glazing for other windows. The selected typical weather conditions are shown in Figure 10 – a cold sunny day followed by an overcast day. The reason for this choice is that, in order to save purchasing energy for space heating, buildings should be able to collect and store significant solar heat from a sunny period to compensate for their heat loss for a significantly long period of time. Daylight performance of the south and interior zones is provided in Figure 11 and Figure 12. The north zone has a similar but slightly higher daylighting illuminance level than the interior zone.

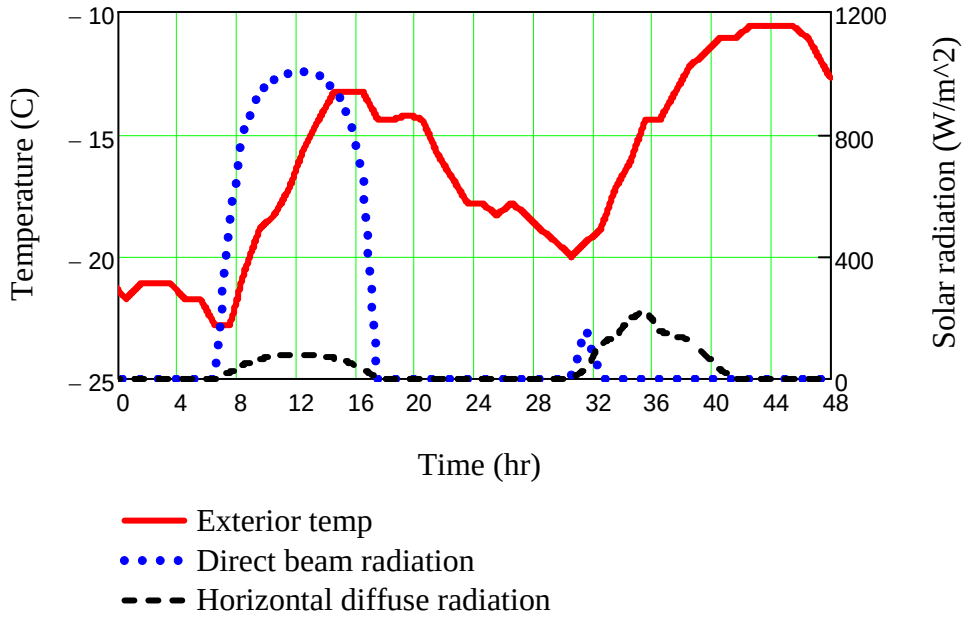

Figure 10: Winter design weather conditions for a heating dominated climate

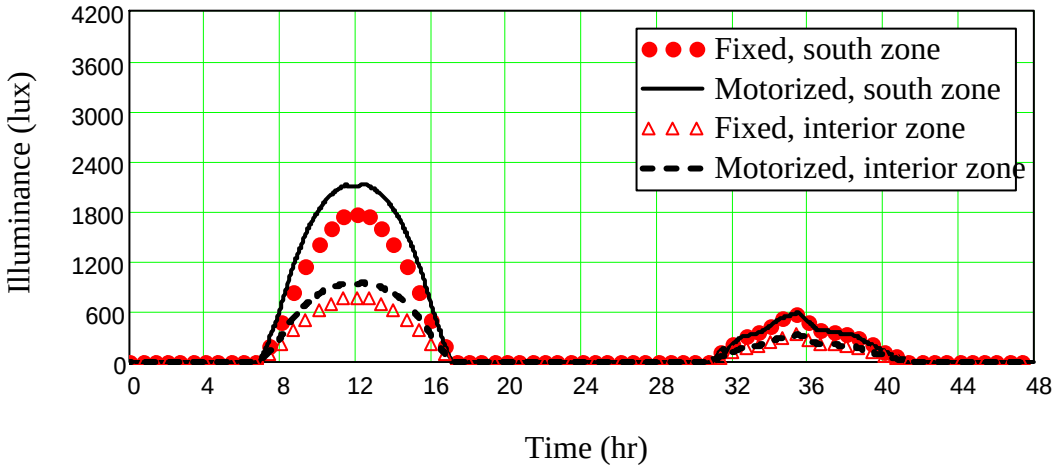

Figure 11: Daylight illuminance levels with original daylighting window area (13% WWR), winter

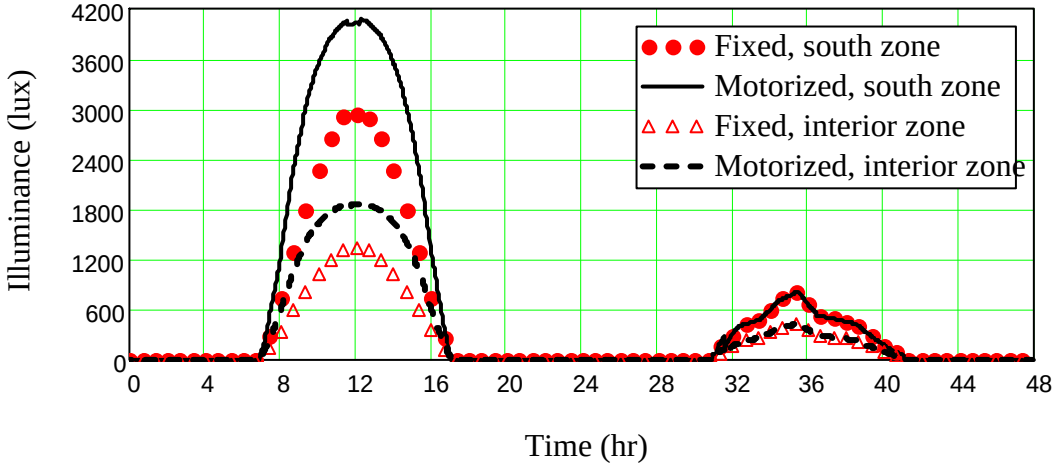

Figure 12: Daylight illuminance levels with 40% daylighting WWR, winter

Summer design period

Double-glazed windows with low SHGC but high daylight transmittance (Table 1) are used for all windows for the summer design period. The selected typical weather conditions are shown in Figure 13. Daylight performance of the south and interior zones is provided in Figure 14 and Figure 15. The north zone has a slightly higher daylighting illuminance level than the interior zone. For summer conditions, since the day 1 and day 2 daylighting conditions are similar, only the illuminance levels of the first 24 hours are plotted.

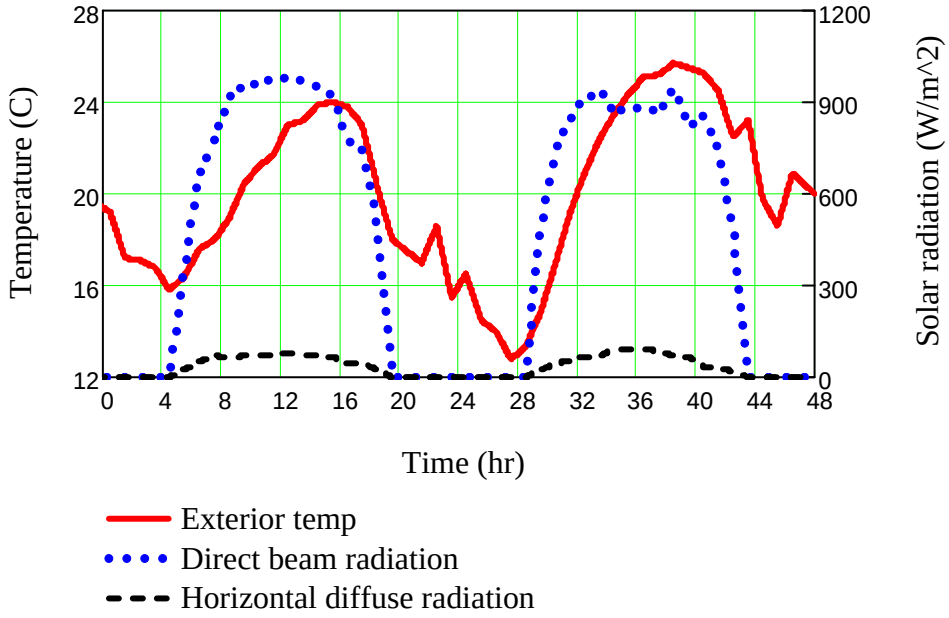

Figure 13: Summer design weather conditions for a cooling dominated climate

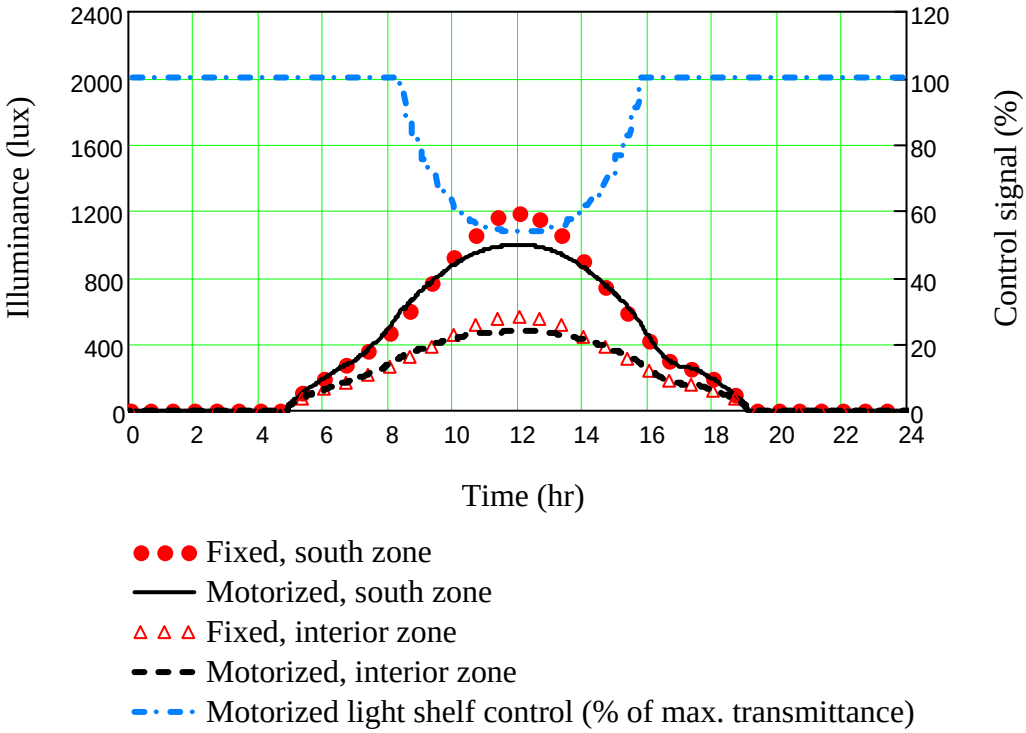

Figure 14: Daylight illuminance levels with original daylighting window area (13% WWR), summer

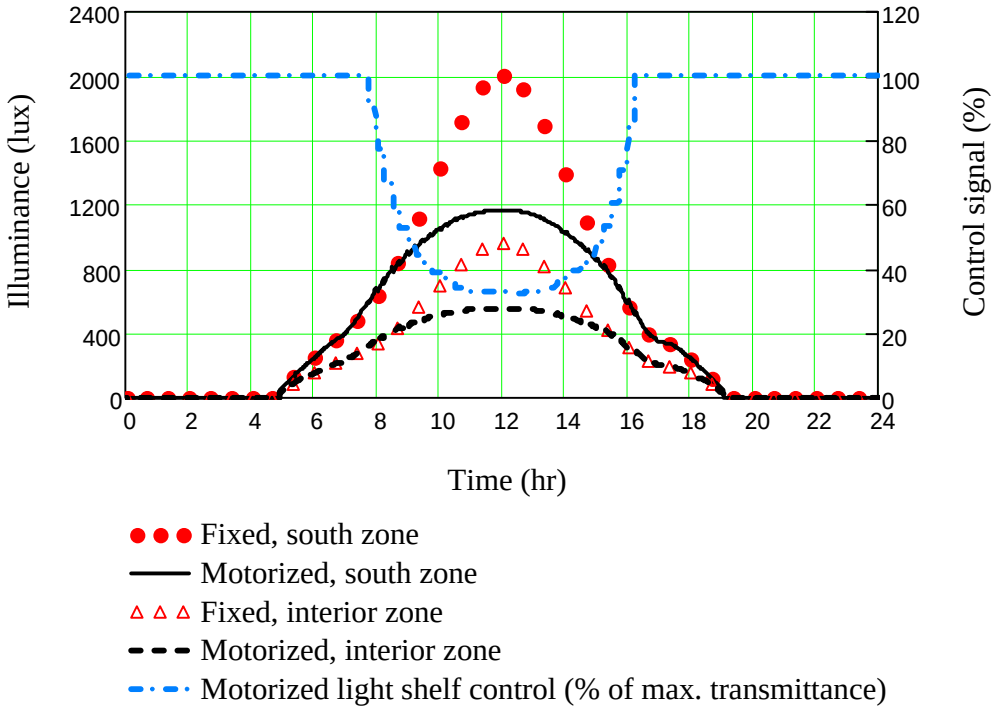

Figure 15: Daylight illuminance levels with 40% daylighting WWR, summer

5 Discussion

For the winter period, the simulated daylighting and thermal performance of the two types of light louvers with 13% WWR are similar, especially for the interior zone. Motorized light louvers have better performance, mainly because the solar altitude is low in the winter period. As the WWR increases, using motorized light louvers allows more and more daylight penetration into the building, and consequently more solar heat gain and hence less space heating energy consumption (Table 3). However, with 40% WWR, electric lighting is necessary in the morning and afternoon on an overcast day in order to have illuminance level higher than 300 lux, as expected. Increasing the WWR from 13% to 40% increases the illuminance level of the interior zone by about 20%.

At noontime on a sunny day in the summer period, less daylight is able to penetrate than that in the winter period, for respective types of light louvers. Furthermore, the fixed light louvers does not admit significantly more daylight than the motorized ones, contrary to what is suggested by its higher transmittance for larger solar altitude. This is mainly because high solar altitude results in less solar radiation on the facades and smaller transmittance of the glazing. For an overcast day, the daylight levels are similar to that of the winter period. Motorized slats were operated to reduce the transmittance to avoid unnecessary daylight penetration.

Judging from the two analysis periods, the motorized light louvers have better overall daylighting and thermal performance. With 13% WWR, switching from fixed to motorized light louvers will not result in significant energy savings in space heating/cooling. However, it is above 15% for 25% WWR, and above 30% with 40% WWR. On the other hand, one important characteristic of fixed light louvers is that they have no moving parts. This means lower costs in control commissioning and operation and maintenance.

For an average size window (about 1 m by 1 m), the material cost of fixed louvers is about $500 per square meter, and it is about $550 for motorized louvers excluding the glazing. These prices are sensitive to louver and window size. Further study of economic aspects is worthwhile.

6 Conclusions

The effects of fixed and motorized light louvers on buildings' daylighting and thermal performance were investigated in this study. A combined daylighting and thermal model for buildings with interior fixed and motorized interior light louvers was developed using a simplified approach. Using this model, the daylighting and thermal performance for different daylighting design and operation options for different climates are assessed. Results show that this simplified approach is suitable for integrated daylighting and thermal design. Motorized light louvers can effectively optimize useful solar heat gain and daylight both in heating and cooling seasons. They generally give better daylighting and thermal performance over fixed light louvers.

7 Acknowledgement

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8 Nomenclature

RSF	Research Support Facility
SHGC	Solar heat gain coefficient
WWR	Window to wall ratio

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