Effect of Window Blind Use in Residential Buildings: Observation and Simulation Study

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Abstract

Occupants' use of window blinds accounts for a significant uncertainty in building energy use and peak electricity demand. However, minimal research has gone into gaining an understanding of blind use in residential buildings. Blinds in homes are operated significantly differently than commercial buildings because of the increased need for privacy and the vastly different occupancy schedules. The blinds of a multi-unit residential building high-rise condominium in Ottawa were monitored for six summer days during a variety of weather conditions on weekdays and a weekend day. Results indicate that most occupants move their blinds infrequently similarly to in offices but with a significantly different schedule. Based on these observations, a simulation study was carried out to investigate the influence of different blind configurations on the comfort, peak load and energy use. The results indicate that blinds can be effective for mitigating overheating and reducing peak cooling loads.

1 Introduction

Space conditioning in residential buildings places considerable demand on energy infrastructure. For instance, in Ontario, Canada, which has a temperate climate with very warm and humid summers and cold winters, space heating and cooling accounts for 60% of household energy consumption. This is typical for other regions of a similar climate. Despite the temperate summer climate, peak electricity use is driven by space cooling and occurs in summer afternoons (Figure 1) (Galasiu et al., 2009; Laouadi, 2010; Natural Resources Canada (NRCan), 2008). Air conditioning in residential buildings is responsible for about 20% of peak electricity in Ontario and is increasing as air conditioners become commonplace (Hydro One, 2003). Window blind position, particularly for highly-glazed buildings can have a significant impact on air-conditioning loads (Steemers and Yun, 2009). Notably, despite the 40% window-to-wall ratio limit for many locales (e.g., ASHRAE Standard 90.1-2013), performance-based code compliance approaches enable designs with bigger glazing areas by compensating with efficient mechanical and electrical systems. By understanding and controlling the factors that affect cooling energy, some of Ontario's peak load can be reduced or shifted.

A reduction in peak electricity consumption is highly-desirable because it can reduce energy costs for individual homeowners as well as reducing the electricity generation and distribution capacity. Reducing the use of peak capacity is important since it comes from expensive and often fossil fuel-based energy production (Hydro One, 2003; Laouadi, 2010). Also, in Ontario's growing cities, reducing peak demand can reduce the need for new power plants (OPA, 2012) and expensive electricity imports. The Ontario Power Authority (OPA) has acknowledged the benefits of conserving energy by a planned investment of $10.2 billion over 20 years (OPA, 2008). This investment is dedicated to funding conservation programs such as the efficient appliance trade-in, improved conditioning system incentives and the peaksaver™ program. The peaksaver program allows the power utilities to remotely control residential thermostats to temporarily (four hours or less) reduce the amount of air conditioning use (Ontario Power Authority (OPA), 2008). This override of residential occupant's thermostats is employed only during peak demand periods in order to reduce electricity loads, which could prevent brownouts and blackouts. Peaksaver has been proven to be effective; in the summer of 2010 the peak electricity demand was reduced by 117 MW or the equivalent to powering 50,000 homes.

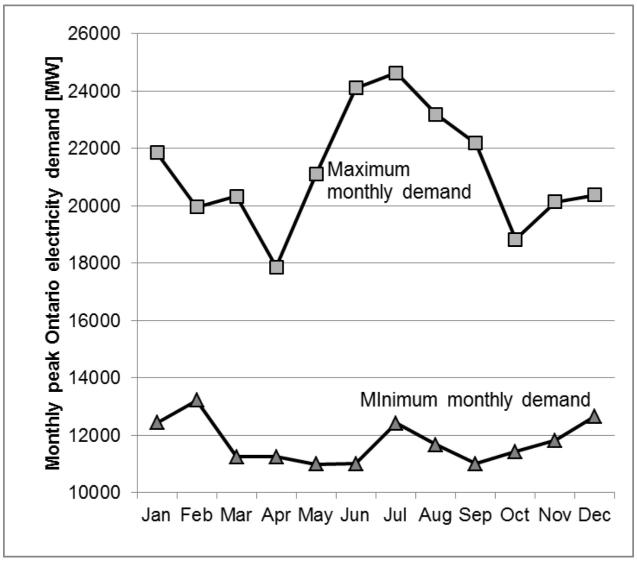

Figure 1: Monthly maximum and minimum electricity demand (IESO, 2013).

Another effective strategy to reduce peak power caused by residential air conditioners is to reduce solar gains by deploying movable shading devices (e.g., venetian blinds, roller shades, curtains, and shutters) – especially if they are mounted outside the glazing.

In prior research, thorough investigation has been conducted on the impact of general occupant behaviour. Steemers and Yun (2009) analysed the 2001 US Residential Energy Consumption Survey and determined that occupant behaviour accounted for 47% of the variation in residential cooling energy. Emery and Kippenhan (2006) conducted a 15-year study which determined that occupant behaviour played a greater role in household energy use than improvements and variations in the building's construction and insulation. Schweiker et al. (2012) suggested that many factors influence occupant behaviour, since there is a 40% variation in air-conditioning usage at the same exterior temperature. Furthermore, Bahaj and James (2007) reported a large variation between energy consumption in nine identical homes, where the greatest difference was 600%, observed in July.

These studies indicate the importance of residential occupant behaviour, but do not go further to address specific occupant actions such as blinds deployment, window opening, and light switching. In particular, there have been over a dozen extensive studies on blind use in office buildings (Gunay et al., 2013; O'Brien et al., 2013; Van Den Wymelenberg, 2012). However, differences between office and residential usage prevent the generalization of office occupant data. For instance, occupants in offices are generally present during daylit hours, often have to adhere to implicit or explicit dress codes, and their primary tasks often involve paper or computer work from a relatively fixed region of the building. Residential occupants are often absent during periods of greatest solar intensity, but may worry about privacy, sleeping conditions (e.g., sufficient darkness), and often have greater flexibility to relocate under conditions of localized discomfort.

Research concerning residential blind usage is sparse. Veitch et al. (2009) performed a household survey and concluded that Canadians adjust blinds in their homes less for energy and thermal comfort related objectives than for other reasons. This contrasts the mentality of many building performance simulation users and building designers who may assume that occupants adjust blinds to conserve energy (Cole and Brown, 2009). Figures 2 and 3 summarize the findings from two extensive surveys on the motivation of blind use in commercial buildings (Inkarojrit, 2005) and residential buildings (Veitch et al., 2009).

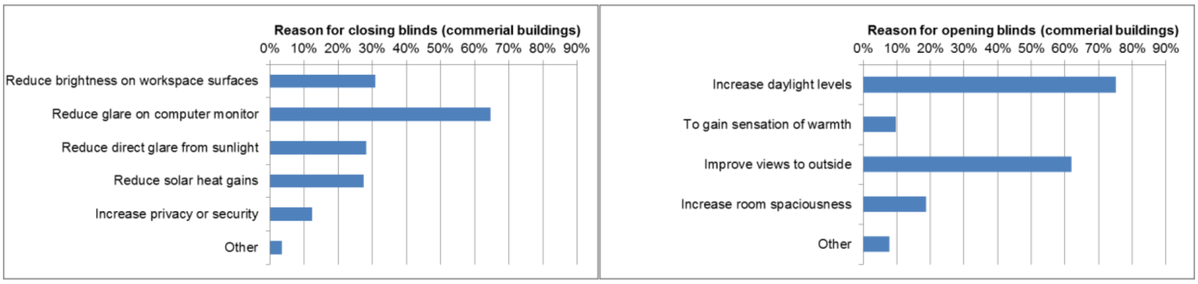

Figure 2: Reasons for closing (left) and opening (right) blinds in commercial buildings

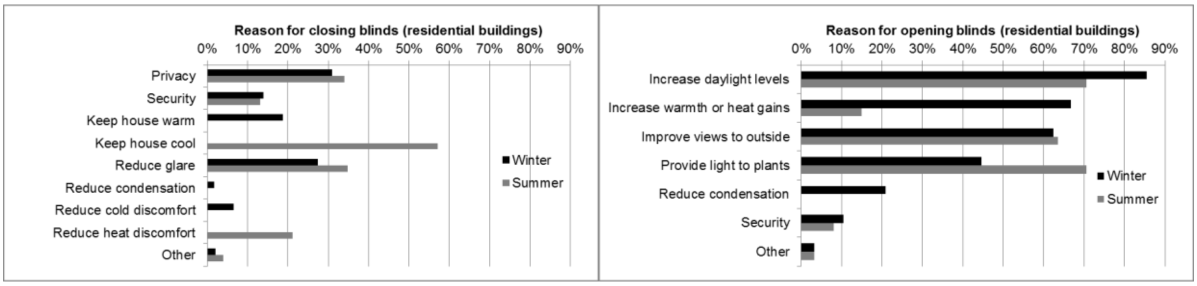

Figure 3: Reasons for closing (left) and opening (right) blinds in residential buildings

Laouadi (2010) found a 9% reduction in household cooling energy is possible when typical shades are added to previously unshaded windows. In addition to blind movement, the type of blind an occupant chooses has been shown to significantly affect interior cooling loads. A further energy reduction of 13% can be achieved by switching shading devices from typical blinds to interior reflective screens. Galasiu et al. (2005) found the largest reduction in cooling to be 70% when opaque exterior shades were installed.

Actual reductions in energy use may not be as great since the above studies assume the shading devices are fully closed during the day. An occupant's chosen blind occlusion will affect the cooling loads regardless of shading type. When an occupant opens their blinds they are increasing their home's solar heat gains and, in turn, increasing cooling loads (Mahdavi, 2009; Van Den Wymelenberg, 2012). Therefore both the type of blind and blind occlusion are important factors affecting residential cooling loads.

It is also important to understand residential blind use in order to improve building design. When factors controlling residential shade movement are understood, better occupant models can be created. Stochastic occupant behaviour models can be used to predict energy usage in the design phase of buildings. This more accurate approach may also support the design of buildings that are most robust against occupant behaviour. For example, fixed shading could help prevent excessive solar heat gains through windows where shades are not operated energy efficiently.

Many new high-rise residential buildings have very high window to wall ratio. This causes building performance to be even more sensitive to occupant control of blinds. However, these residential buildings are valued by prospective buyers for their views (Ge, 2002). Despite their popularity, glass buildings are not practical for the cold Canadian climate. The glass building facades are very low in thermal insulating properties which results in large heating energy demands, uneven temperature distributions and drafts within the residential units (Ge, 2002; Straube, 2008). There are also issues during the summer months, where the solar heat gain through the extensive glazing can result in too much daylight glare and a high cooling load. Through the use of moveable shading devices, occupants can partially mediate these effects.

The main objective of this paper is to demonstrate the impact that window shade position has on electricity demand for cooling in a high-rise residential building. Summer cooling loads are of interest since peak electricity demand occurs in summer and residential cooling is a significant portion of this electricity demand. This paper also aims to determine if other factors, such as privacy and weather, affect residential shade use. The methodology section provides details of the simulations approach used and the observation methods for assessing shade use. The results contain both simulation and observational data for the residential building.

2 Simulation study

A brief simulation study was performed to assess the impact of window blind positions on energy use, comfort, and peak loads. This serves as motivation for the second part of the paper which describes the observation study. Specific research questions that were investigated include:

1. What is the impact of blind position on energy use, peak loads, and comfort?
2. What is the impact on comfort when peaksaver and other systems that centrally deactivate air conditioners during peak loads periods?
3. What is the impact of thermal mass on thermal comfort?

Methodology

The model was developed in EnergyPlus V8.1 using BEOpt V2.1 as a starting point. It is a square 872 square foot (81 m^2) apartment with one exposed façade (all other surfaces are interior and assumed adiabatic). The façade and HVAC systems are code-minimum for the prescriptive path of Ontario Building Code (OBC) SB-10, which was published in 2011. The window to wall ratio (WWR) is 80%, which is representative of many new high-rise residential buildings, including the one from the field study described later. The OBC permits this as long as efficiencies are achieved for other building characteristics. The code-minimum window has a solar heat gain coefficient (SHGC) of 0.40 and a total system USI-value of 1.41 (W/m^2K). Window shades with a transmittance of 5% and a reflectance of 80% were modelled. The apartment was assumed to be west-facing because this is likely to be most susceptible to overheating in the summer. The floor consists of a 6" (15 cm) slab of concrete which is nominally covered in 25 mm of carpeting. The apartment has electric baseboard heaters with a split-system air conditioner (coefficient of performance = 3.1) to maintain the air temperature at or below 25°C. The simulations were run using Ottawa weather data (from SIMEB) from July 15, 2013 – a very warm sunny day in Ottawa. To explore the relationship between building design, blind position, and use of demand response techniques (e.g., peaksaver), air conditioning was deactivated for one hour in the afternoon during the typical peak load on the grid – from 15:00 to 16:00.

Simulation results and discussion

To address the above questions, five simulations cases were run, including: 1) nominal (blinds open); 2) interior blinds in closed position; 3) exterior blinds (instead of interior blinds, but the same optical properties) in closed position; 4) 40% WWR instead of 80%; 5) blinds open, 80% WWR, but no carpet (exposed slab). The results are summarized in the following four graphs (Figure 4). Note that operative temperature (T_{OP}) was reported (the average of mean radiant temperature and air temperature). However, thermostats primarily sense air temperature; thus, the air-conditioning was controlled based on sensed air temperature.

The simulation results demonstrate that design (window size, blind type, and exposed mass) have a profound impact on cooling loads and comfort. This effect is particularly pronounced when the air conditioning is deactivated for an hour in the afternoon during peak solar gains. The situation would be no different if the air conditioner failed, if there was a power outage, or if air conditioning simply was not present. Closed interior shades are clearly beneficial in mitigating overheating, but are not nearly as effective as exterior shades. A more modest windows size (40% WWR) with no shades responded very similarly to closed interior shades. Perhaps surprisingly, the apartment with no shades but exposed thermal mass on the floor responded similarly to that with closed interior shades. Thus, the importance of exposed thermal mass is identified. Notably, thermal mass does not rely on the daily habits of occupants that shades do. However, care must be taken to ensure that furnishings do not cover significant portions of the mass. Furthermore, highly conductive floors (e.g., concrete and ceramic tiles) may cause a cold sensation on feet in the winter. ASHRAE (2009) recommends that concrete floors upon which occupants are likely to be standing with bare feet should be maintained at 26 to 29°C.

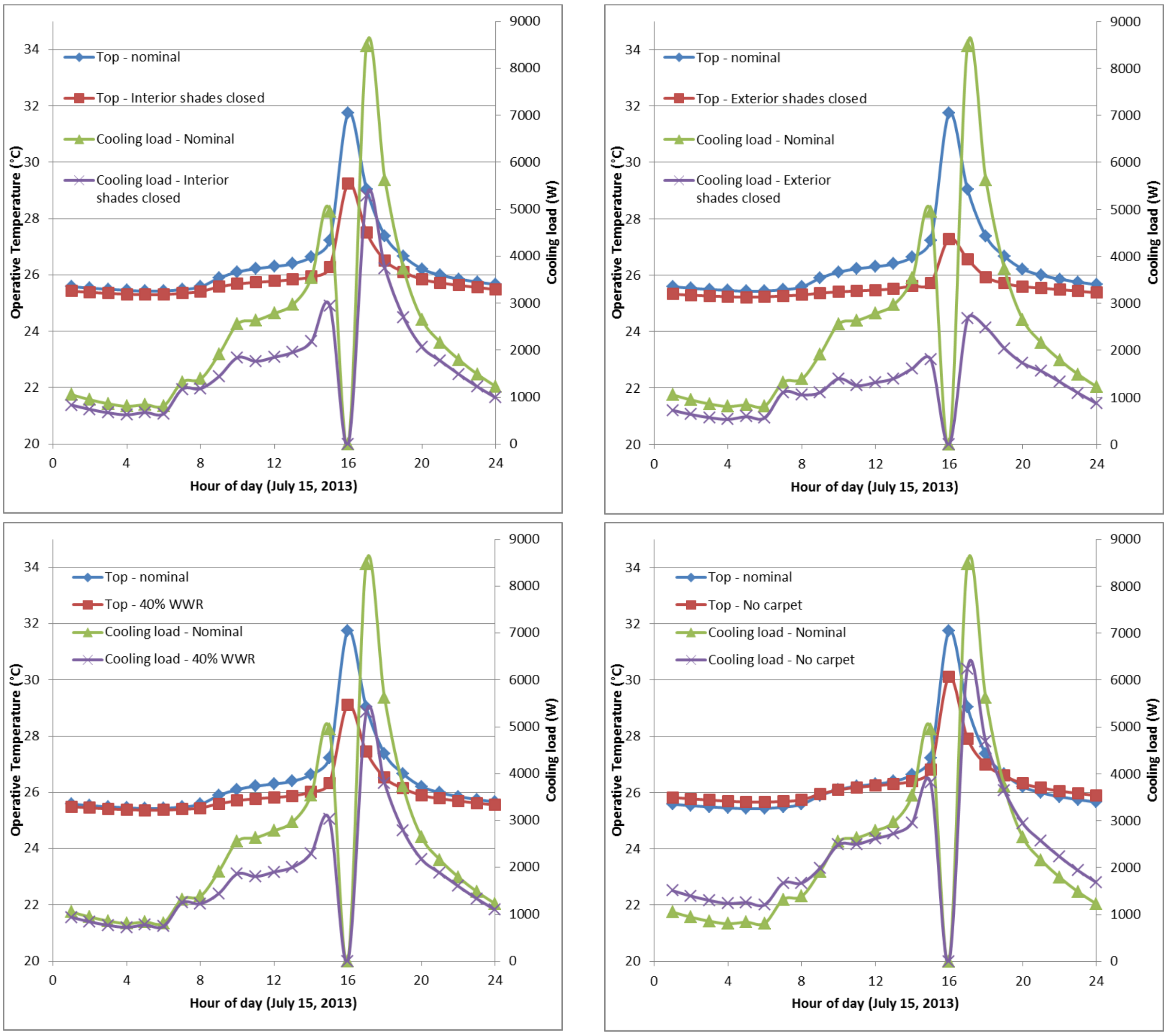

Figure 4: Simulation results comparing the nominal case (1) to cases 2 (top-left), 3 (top-right), 4 (bottom-left), and 5 (bottom-right)

The current simulation results demonstrate the importance of capturing homeowner control of shading devices. They also suggest that other overheating mitigation strategies can be nearly as effective as good blind control without the reliance on occupants.

3 Field study

To assess how window blinds are manually adjusted by occupants in residential buildings, a field study was conducted, as described below.

Field study methodology

The building of choice was a new (constructed in 2012) condominium in Ottawa with a LEED Silver rating. The building's facade has a window to wall ratio of about 80%. Each unit was sold with installed white roller blinds, although a small minority have been changed to another shade type (described later). This results in more consistent shades whose occlusion is easily observed, but reduces the variation of blind type chosen by occupants.

The observed facades are oriented north-west, south-west, and south-east (Figure 5). The north-west (NW) units face a moderately busy street and a three storey commercial building; the south-east (SE) units face a quiet street and the construction site of a similarly sized building; the south-west (SW) units face a busy street and a gas station.

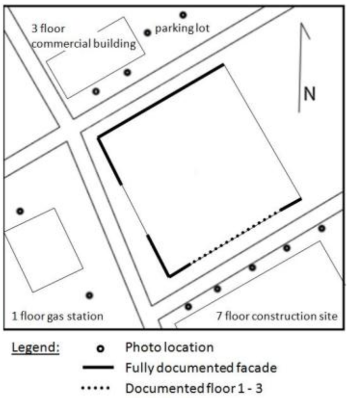

Figure 5: Top view of the observed building, indicating photo vantage points.

The observed facades exclude windows which are not fully visible from street level, due to either balcony overhangs or a setback facade. The windows are fully visible up to the 9th floor on the west and north facades and the 7th floor on the south facade. This results in 618 windows visible from street level that are observed in this study, 186 on the SW facade, 288 on the NW facade and 144 on the SW facade. Each condominium unit has between four and ten windows with independent shades, where the vast majority have five windows. The floor area of the condominium units range from 57.6 m^2 to 113.3 m^2 (620 ft^2 to 1220 ft^2).

All units in this condominium have been sold from the developer to the individual unit owners. Unit ownership does not guarantee an occupied unit since condominiums are often bought for investment purposes to be rented. Therefore occupancy was observationally determined by a combination of factors including shade movements, shade position changes between observation periods, the existence of balcony furniture and presence of occupants on their balconies. This results in the estimation that 4 of 102 units (3.9%) were unoccupied.

Data collection

Photography was used to record the instantaneous shade position every two hours, from 7:00 to 19:00. This method and timing was chosen to allow for a large sample size while maintain-ing a manageable amount of data and is at least as frequent as most similar studies (Inoue et al., 1988; Rea, 1984; Zhang and Barrett, 2012).

A point-and-shoot style camera was used to take photos from street level. To collect an adequate amount of data, the condominium was recorded for six days. Four sunny weekdays were chosen as a base case: two with temperatures in the 20s °C (July 12, 22) and two above 30°C (July 15, 16). In addition, a cloudy weekday (July 29) and a mostly sunny weekend (Sunday, Aug 4) are observed for comparison purposes.

The photo vantage points were indicated in Figure 5, where the bold sections of facade were fully recorded, and the dotted section indicates that only the first three floors were recorded. The photographs were interpreted manually. This is because the blind type, facade and window sizes are irregular and therefore too complex for a simple computer program (e.g., O'Brien et al., 2010). When analysed, the instantaneous shade position and window openings were recorded. The shade occlusions are discretized into a scale from 0 to 1 in increments of 0.25, where 0 is fully open and 1 is fully closed (occluded). Window location was recorded including the floor number, facade orientation, and if the window was shaded by a balcony above. The type of interior shades and the weather conditions were also recorded.

Results of field study

The observational shading results, unless explicitly stated, assess trends in shade use on the four sunny days. These results were then compared with the cloudy weekday and sunny weekend observation days, where differences in shade use are highlighted.

Facade average occlusion

The average daily occlusion over the four day study period was 62.9% on the NW facade, 74.1% on the SE façade, and 85.3% on the SW facade. The SW facade has more intense sun than the SE facade in the evening, which could result from a lower solar altitude and deeper solar penetration into the condominiums, encouraging higher shade occlusion. Also, higher occupancy is typical in the evening which coincides with high incident solar radiation on the SW facade.

The average daily occlusion results agree with other studies that northerly facades tend to be less occluded than the other orientations (Foster and Oreszczyn, 2001; Pigg et al., 1996). Office studies conclude that shade use on the north orientation is primarily determined by privacy and view (O'Brien et al., 2013) and any previous glare conditions. In residential buildings privacy is a much greater factor since occupants are not constrained to professional attire or activities. This privacy difference is demonstrated by the extent which the NW facade is occluded. Pigg et al. (1996) observed 83% of all north shades open and Inkarojrit (2005) found the north facade to be 53% occluded. These two studies demonstrate the large variability in occlusion between buildings, but both office studies find the north facade significantly less occluded than in the observed condominium.

Figure 6 shows that there is some variation in hourly mean occlusion for the condominium throughout the day. The SE and NW facades have a similar pattern where the windows are significantly more occluded at 7:00 which could be for nighttime privacy and darkness. The SW facade also has a greater occlusion at 7:00 relative 9:00, but occlusion increases as the day progresses, which coincides with increased light intensity. The hourly mean occlusion pattern on the SW side is consistent with findings of Inoue et al. (1988) that the office occupants gradually close west facing shades throughout the day.

For the days studied, outdoor temperature does not appear to have directly affected daily or hourly occlusion because there is not a significant difference in occlusions between the warmer sunny days, with temperatures above 30°C and cooler sunny days with temperatures in the mid-20s °C. Though, as found by Veitch et al. (2009), there is a strong seasonal effect of motiving reasons for controlling blinds.

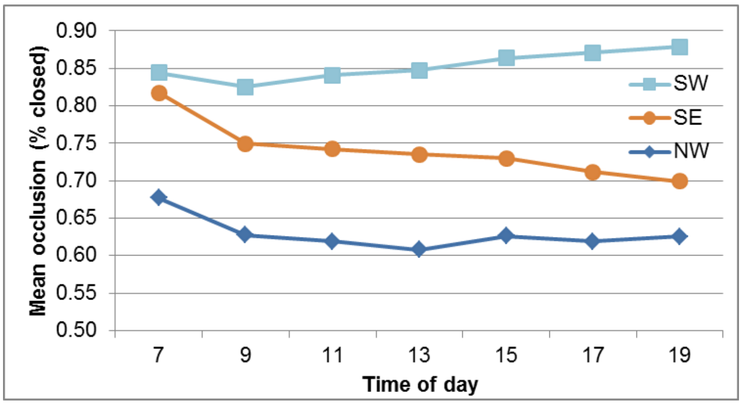

Figure 6: Hourly mean occlusion on sunny days.

Floor average occlusion

Privacy appears to be a factor in blind occlusion in this residential building, where street level has the least privacy. This relationship is clearest, where for the SE façade, the shade occlusion at ground level is 33 percentage points higher than the occlusion for the second floor.

Factors other than privacy can affect shade occlusion differences between floors. On the south facade, occlusion increases as elevation increases, this is likely due to progressively less shading from the neighbouring building. The neighbouring building's effect is supported by the difference between incident solar radiation on the south first floor and south top floor, as seen later in Figure 7.

The NW and SW facades occlusions are not reported for the first and second floors since they are not residential. The SE façade blind occlusions are not reported for the eighth and ninth floor since they cannot be photographed from street level due to the setback of their facades to accommodate a terrace.

Shade opening actions

Of 370 observed shade opening actions during the observed days, the majority occurred in the morning, with 48.6% between 7:00 and 9:00 (Figure 8). The typical weekday absence for departure to work starts from 9:00 to 18:00 [14]. This could prompt a morning schedule where occupants wake up, open shades, and leave for work.

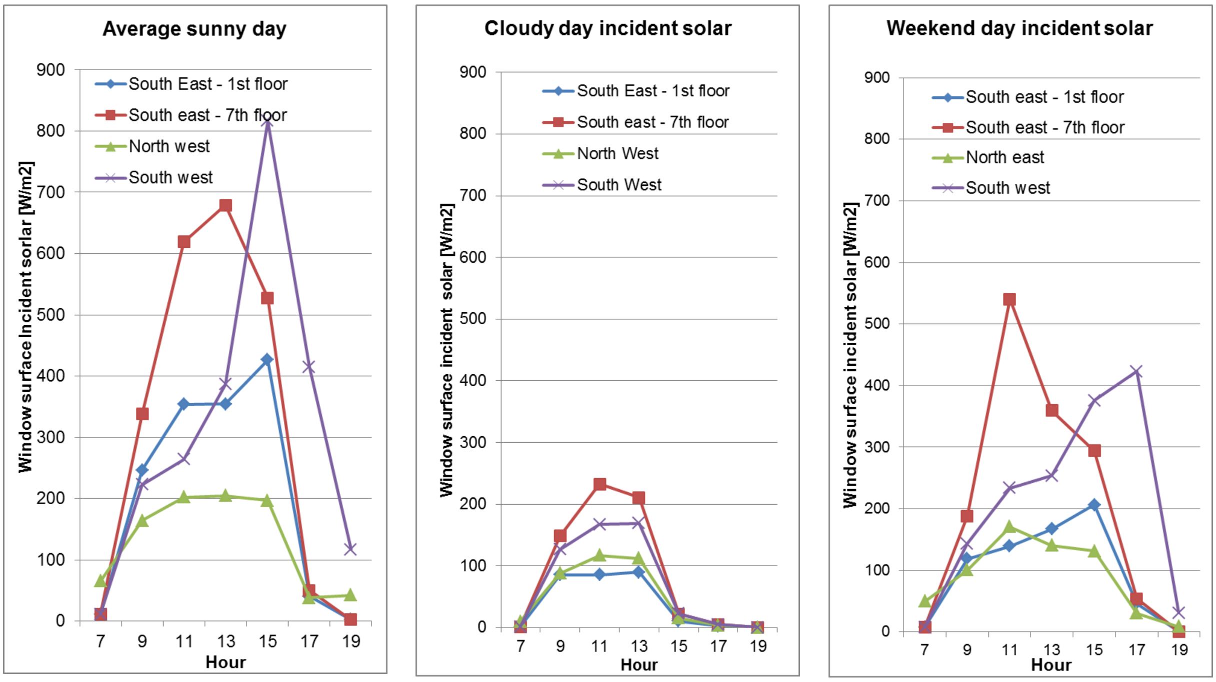

Figure 7: The incident light conditions were estimated using EnergyPlus and SIMEB weather data for Ottawa. Due to the neighbouring building, the incident solar radiation is different on the 1st and 7th floor on the SE facade.

Shade closing actions

When these closing actions are categorized by timing there is no clear pattern as in opening actions, but there are more closing actions on the NW and SE facade observed between 17:00 and 19:00 (Figure 8). During that period, 86 of 318 closing actions occurred. This could be a result of closing for evening privacy or shade movements directly following the arrival of residents after work. In office studies the majority of shade movements occur upon the occupant's arrival (Haldi and Robinson, 2009).

Over the four sunny day period there were 370 opening actions and 318 closing actions. The numbers of closing and opening actions are not necessarily equal since shade movements range from a 1/4 to a full shade position change.

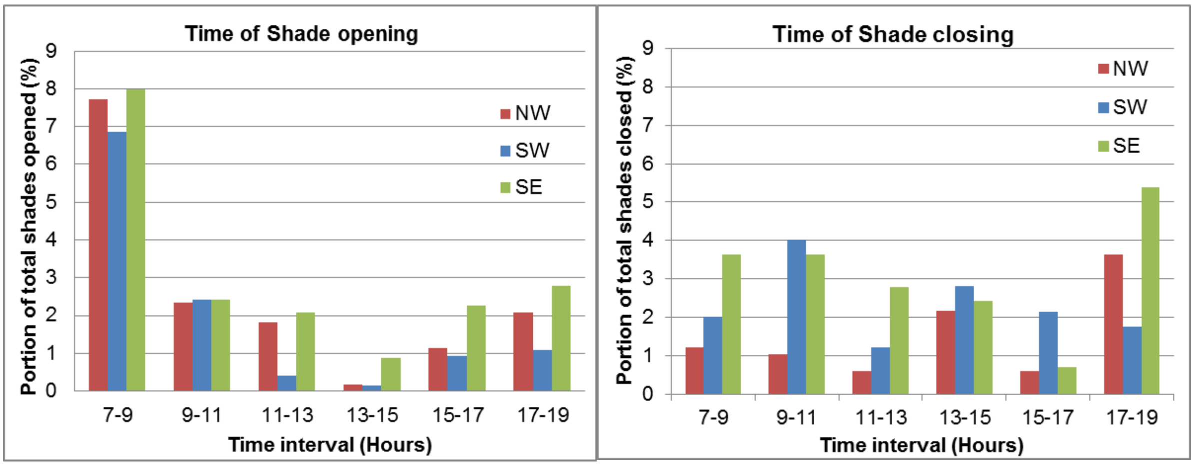

Figure 8: Time when shades are opened (left) and closed (right), expressed as a fraction of the total number of shades.

Shade movement frequency

The shade movement frequency is reported for all six observation days. There were 889 shade movements during this period. The total shade movements were separated and recorded on a daily basis. The study did not track each shade between days, since movements can occur overnight (outside of the observation period) and since the observation days are not all consecutive. To identify if some occupants are more active shade users, the movements were grouped by condominium unit. The vast majority of condominium units have five window shades, where the minimum is four and the maximum is ten.

Figure 9 indicates that of the 102 condominium units, there were 25 households that never moved their shades during the six days. This could indicate that the occupant either never interacted with their shades or that the unit was unoccupied during the study period (not an unlikely event considering summer is prime vacation time). This figure also includes condominiums where there were no shade movements during observation hours, but shade positioning may change between observation days. Of these units that never move their shades, 17 (68%) were located on the NW facade.

During the six day period the maximum shade movements in one condominium was 34. This shows that some occupants consistently move their shades. This condominium is on the SW facade and has five shades. This condominium is one of the few that appear to have a consistent shading schedule, where all shades are opened in the morning and closed later in the day (excluding the weekend day). This indicates that a personalized shading schedule may be responsible for some shade movements, not just movements for view, privacy and glare.

There were 382 instances (62.4% of total) where a condominium unit does not move their shades during the period of one day. Only 150 of these are from condominiums that never move their shades over the six day period. This indicates that there are many units that do not move their shades on a daily basis, reinforcing the conclusion that they infrequently interact with their shades. Of the 230 instances where condominium units do move their shades during the observation hours, most have few movements; there are 173 instances (28% of total, 75% of moved shades) where a condominium has one to four daily movements.

The finding that occupants infrequently move their shades is consistent with office studies (Inkarojrit, 2008; Pigg et al., 1996). The current residential results also agree with Inoue et al. (1988) who found that up to 60% of office shades never get moved.

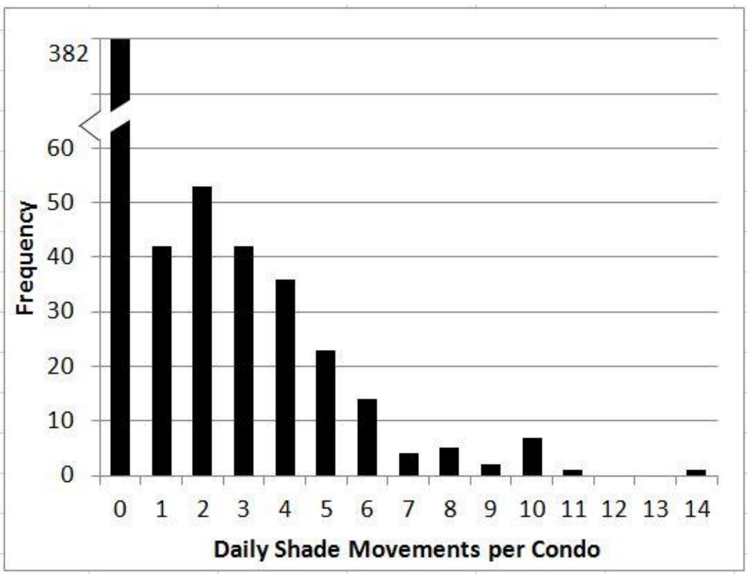

Figure 9: Daily shade movements per condominium.

Effect of exterior shading surfaces

The mean shade occlusion can be affected by exterior shading surfaces. On the observed building, some windows are shaded by the above balcony. To quantify the difference between unshaded and balcony shaded windows their mean occlusions were compared. On all three building facade orientations there was a lower mean occlusion for balcony-shaded windows. The biggest difference is observed on the SE side, where balcony shaded windows were 26.8 percentage points less occluded than the unshaded windows, followed by the NW facade with a 17.9 points difference and the SW facade with an 8.2 points difference.

Cloudy versus sunny shade use behaviour

Shade movement on a cloudy day was recorded so that it could be compared to the four sunny days. The solar intensity on the cloudy observation day was much lower than on the average sunny day, as seen in Figure 7.

When compared to sunny days, the NW facade was 6% less occluded when cloudy; occlusion is consistent throughout the day except at 19:00, where the windows are 15.4% less occluded. The SW facade follows a similar pattern, where the windows are 4.4% less occluded on average, and 15.0% less occluded at 19:00. The SE facade shows no significant difference in occlusion between sky conditions.

Another significant difference between sunny and cloudy days is observed in the time shades were opened. While there was still an early morning peak in shade opening, 44% of all shade opening actions occurred between 17:00 and 19:00. This peak in opening behaviour explains the large difference in mean occlusion at 19:00. This peak in opening activity could coincide with occupants returning from work and their desire for view. It could also indicate that occupants take an extended period of time to respond to changes in exterior light conditions.

Another difference between sunny and cloudy days was the balance between opening and closing actions. On the cloudy day there were 119 openings and only 40 closing actions, whereas the sunny days had about equal numbers of opening and closing actions. This could mean that there were no closing actions due to glare, thus showing main privacy related closing actions. The overall number of shade movements was the same as on a sunny day, with more opening than closing actions.

The current residential study did not find as significant a difference in shade use between sky conditions as some office shade use studies. (Inkarojrit, 2005) found half as many shades are moved on a cloudy day, and (Lindsay and Littlefair, 1992) found half the mean shade occlusion on cloudy days.

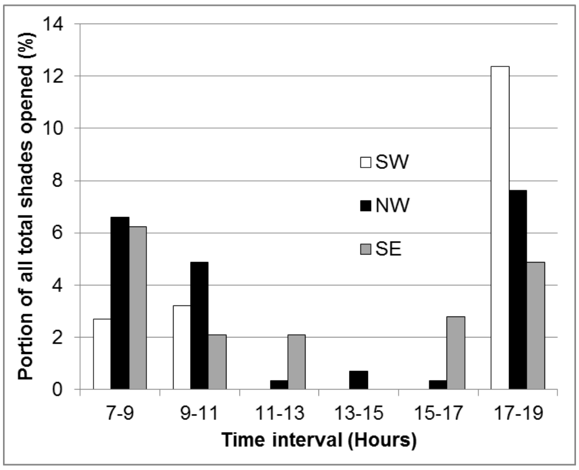

Figure 10: Cloudy day time of shade opening actions

Weekend versus weekday shading behaviour

One observation day was on a weekend - Sunday August 4 - so that shading behaviours then could be compared with weekdays. A mix of sun and clouds resulted in less bright solar irradiance than the average sunny weekday, as seen in Figure 7.

The mean occlusion on the weekend was about the same as on the sunny weekdays for the SW and SE facade. On the NW façade, the windows were 13.7% less occluded, but followed the same daily pattern. This could be due to the peak irradiance intensity being lower, but is unlikely since the cloudy day was less bright. There was a significant reduction in occlusion only at 19:00. The reduced occlusion could be due to more occupants staying home during the day and desiring a view to the outdoors.

The timing of shade opening actions is different than on a sunny weekday. During the week there was a significant peak in openings between 7:00 and 9:00. The weekend also had a shade opening peak at the same time but not as large. There was still a large proportion of shade openings between 9:00 and 13:00, this could be the result of later morning routines. Also, there is a secondary peak in opening behaviours between 17:00 and 19:00, which is similar to the primary peak in closing actions at the same time. During the day there are 71 shade openings and 43 closing actions, this is uneven and may be the result of shade closing actions taking place after 19:00 (when the observations ended).

With a total of 114 shade movements, the weekend day had 26% fewer movements than the average sunny day (with 154 movements) and 6.6% fewer movements than July 12, which had the fewest movements for a sunny day (with 122 movements). This could be partially due to a change in daily routine, where shades are adjusted less, or where occupants are absent during their day off.

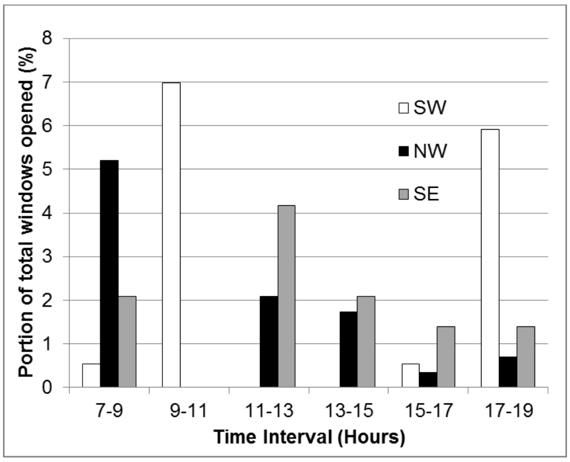

Figure 11: Timing of weekend shade opening actions

In conclusion of the observation study, it is evident that some common trends between previous office studies and the current residential study exist. Time of day, cloudiness, façade orientation, and day time (weekend vs. weekday) all play a significant role in shade movement rates and mean shade occlusion. Furthermore, shade movement rates are quite low, which corroborates the findings of previous studies on office buildings.

4 Conclusion and Future work

As demonstrated by previous studies and a simulation study in the current paper, blind position in residential buildings can have a profound impact on cooling energy and thermal comfort of occupants. However, few studies that explore the use of blinds in residential buildings exist, unlike in office buildings for which there are at least a dozen comprehensive observational studies. The current study on blinds in a large residential building revealed that, similarly to office buildings, occupants move their blinds infrequently and that the mean occlusions are quite high (60 to 90%). Blinds on the more southerly oriented facades tend to be more occluded than northerly facades. The majority of blind-opening actions occur in the morning from 7:00 to 9:00, while the majority of closing actions occur from 17:00 to 19:00. Blinds were not monitored at night. The cloudy day had a lower mean occlusion of 4 to 16 percentage points, depending on the façade. The weekend day had similar occlusion levels to the weekdays, but opening actions occurred over a longer period in the morning (until 13:00) and then inexplicably again in the evening. A simulation study revealed the significance of blind position on comfort and cooling loads. It demonstrated that highly-glazed buildings suffer from overheating if air-conditioning is disabled for demand response programs (e.g., peaksaver). Exterior shades and exposed thermal mass are both effective ways to mitigate peak loads and temperatures.

Future research is required to develop detailed models on occupant use of shades in residential buildings so that simulations can be used to better estimate building performance and also to guide design.

5 Acknowledgements

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