User Interactions with Environmental Control Systems in Buildings

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ABSTRACT: Buildings are typically equipped with components and systems that can act as control devices. Windows, shades, luminaries, radiators, fans, and other similar devices can be operated by building occupants with the intention of bringing about desirable indoor conditions. The design and operation of energy-efficient systems for indoor environment control (heating, cooling, ventilation, lighting) can benefit from reliable (empirically grounded) information on building occupants' needs and motives to bring about changes in the status of building control systems. Thus, multiple studies are being conducted internationally to collect data on building users' interactions with building control systems and devices.
The present contribution is part of an effort to observe control-oriented occupant behavior in a number of office buildings in Austria. In each building we study in average 20 workstations. These workstations are typically equipped with desktop or laptop computers. In some cases task lights are used. In the course of the study, we register the type and number of user control actions as related to one or more of the following building systems: ambient lighting, shading, window ventilation, and heating. Simultaneously, indoor and outdoor environmental conditions (e.g. temperature, relative humidity, illuminance, solar radiation) are measured. The collected data is analyzed to explore hypothesized relationships between the nature and frequency of the control actions on one side and the magnitude and dynamism of indoor and outdoor environmental changes on the other side. Moreover, the implications of user behavior for buildings' energy consumption are explored.

Keywords: user control actions, comfort, building systems

1. INTRODUCTION

Buildings are generally equipped with components and systems that can act as control devices. Windows, shades, luminaries, radiators, fans, and other similar devices can be operated by building occupants with the intention of bringing about desirable indoor conditions. The design and operation of systems for indoor environment control (heating, cooling, ventilation, and lighting) can benefit from reliable (empirically grounded) information on building occupants' needs and motives to change the status of building control systems. Likewise, performance simulation applications can provide more accurate predictions of buildings' indoor climate conditions and energy consumption if the patterns of user presence and control actions are modeled on a more realistic basis.

While there have been a number of past research efforts in this area (see for example, [1], [2], [3], and [4]), there is still a need for further detailed data in different types of buildings and in different climatic and cultural settings. Thus, multiple studies are being conducted internationally, to collect data on building users' interactions with building control systems and devices.

The present paper entails the results of one such effort. In this case, the control-oriented actions of a number of occupants in two office buildings in Vienna were monitored over a period of a year. Simultaneously, indoor and outdoor environmental conditions (e.g. temperature, relative humidity, illuminance, solar radiation) were measured. The collected data was analyzed to explore hypothesized relationships between the nature and frequency of the control actions on one side and the magnitude and dynamism of indoor and outdoor environmental changes on the other side.

2. METHODOLOGY

2.1 General approach

The present contribution is part of a larger effort to observe control-oriented occupant behavior in a number of office buildings in Austria. In each building we study in average 20 workstations (both in closed and open office layouts). These workstations are typically equipped with desktop or laptop computers. In some cases task lights are used. The measurements are long term, spreading typically over a period of one year. In the course of the study, we register the type and number of user control actions as related to one or more of the following building systems: ambient lighting, shading, window ventilation, heating, and cooling. The change in the status of ambient light fixtures is captured using a dedicated sensor. Shading and window ventilation are monitored via time-lapse digital photography. The status of heating devices is either captured via user logbooks or automatically (in case of offices with a building automation system).

Parallel to monitoring of user actions, data is collected on external and internal conditions. The external weather conditions – temperature, humidity, global solar irradiance, and wind velocity – are monitored using a weather station, mounted on the top of each building. Internal climate conditions (temperature, relative humidity, illuminance) are measured with autarkic loggers distributed across the workstations. To obtain information regarding user presence and absence intervals, occupancy sensors are applied. All of the above parameters are logged regularly every 5 minutes.

Collected data are stored and processed in a data base for further analysis. Thereby, the primary data structure follows a distinction between various types of events and states that occur at a certain point in time or persist over a certain time period [5]. This data structure and primary data types are summarized in Table 1.

Table 1: The structure of collected data

Data	Type	Instances
Events (E)	System-related (E_s)	Switch lights on/off
		Pull shades up/down
		Open/close windows
	Occupancy-related (E_o)	Entering into (or leaving) an office
States (S)	System-related S_s	Lights on/off
		Position of shades/windows
	Indoor environment (S_i)	Air temperature
		Illuminance level
	Outdoor environment (S_e)	Outdoor temperature
		Global irradiance
	Occupancy-related (S_o)	Office/workstation occupied/vacant

2.2 Objects

The present contribution addresses data collection and analysis in two office buildings.

In the 4th, 5th, and 6th floors of the first object (an educational building of the Vienna University of Technology), we selected 10 single-occupancy staff offices facing east. We refer to this building hence using the code "FH_TU". Figure 1 shows, as an example, the schematic layout of two single-occupancy and one double-occupancy offices in the 5th floor of this building.

The second object is an office complex in Vienna which is primarily occupied by international organizations. We selected 15 offices (facing north) and 15 offices (facing south-west) in this complex. We refer to these office groups hence with the codes "VC_NO" and "VC_SW" respectively.

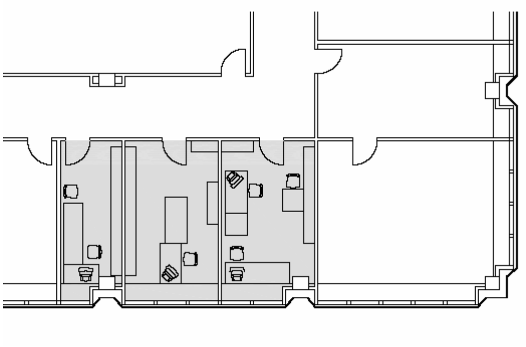

Figure 1: Sample office plan, FH_TU.

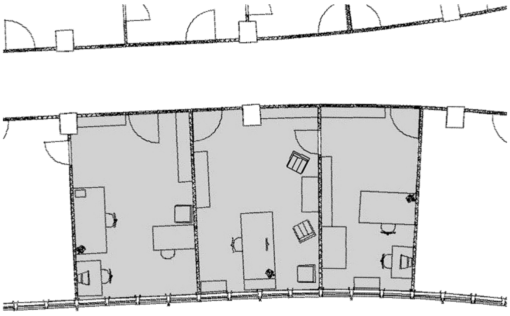

Figure 2: Office plan example, VC_SW.

2.3 Collected Data

As mentioned earlier, various parameters for indoor and outdoor environmental conditions were monitored over the course of data collection. Monitored indoor parameter included room air temperature (in °C), room air relative humidity (in %), ambient illuminance level at the workstation (in lx), luminaire status (on/off), and occupancy (present/absent). Monitored outdoor parameter included air temperature, relative humidity, wind speed (in $m.s^{-1}$) and wind direction, horizontal global illuminance and horizontal global irradiance (in $W.m^{-2}$). Vertical global irradiance incident on the façade was computationally derived based on measured horizontal global irradiance. As mentioned earlier, the degree of shade deployment for each office was derived based on regularly taken digital photographs of the façade. Shade deployment degree was expressed in percentage terms (0% no shades deployed, 100% full shading).

2.4 Systems

Building FH_TU: In this case, the bulk of the observed user-system interactions concern lighting and shading control. Electrical lighting is manually controlled by the users; light switches are located near the office entrance. Motorized external shades are controlled via a manually operated switch (located on a vertical panel under the window). The FH_TU building is air-conditioned using two independent systems. An air-based system with both supply and return air ducts located in the ceiling plenum, and a hydronic system with fan coils below the windows. The volume of supply air and the thermostat settings of the fan coils can be controlled by the users within certain limits. While a detailed monitoring of user changes in these settings could not be performed, random checks imply that they are not frequently used. The building has a double-skin facade. The inner layer consists of a conventional envelope with manually operable windows. The outer layer can be partially opened (20% of transparent elements). The operable elements in the inner and outer layers of the double-skin facade do not seem to be operated frequently. However, as with the supply air volume and the fan coil thermostat settings, detailed monitoring could not be performed for these devices.

Building VC_SW and VC_NO: In this case too, the primarily observed user-system interactions concern lighting and shading control. In each office, electrical lighting layout consists of three luminaire rows. The external row (next to the window) and the internal row (adjacent to the corridor) are switched on and off together by the users. However, this can be done, only if the external illuminance is below a threshold specified by the facility manager. The middle row can be operated by the user at any time. All window units are equipped with internal – manually operable – blinds. Space heating and cooling is provided via an air-based system involving fan coil units with adjustable thermostat settings. Windows are not operable.

2.5 Hypotheses

To explore the collected data in a structured fashion, we consider a number of exploratory queries. For example: *i)* Is there a relationship between the tendency of the occupants to switch on the light upon entering their offices and the prevailing indoor illuminance levels at the time of their arrival? *ii)* Does the occupants' tendency to switch off the light upon leaving their offices correlate with the time they stay away from their office? *iii)* Can a clear relationship be established between the degree of shades deployment and the intensity of incident solar radiation on the façade?

3. INITIAL RESULTS

3.1 State of occupancy

Figure 3 shows the occupancy patterns (mean worker presence level as a function of the time of the day) for FH_TU as well as for VC_SW+NO.

3.2 Switching the lights on

Figures 4 and 5 show (for FH_TU and for VC_SW+NO respectively) the probability (in %) that an occupant switches on lights upon arrival in the office as a function of the prevailing illuminance level (in lx) in the offices.

3.3 Switching the lights off

Figures 6 and 7 illustrate (for FH_TU and VC_SW+NO respectively) the probability that an occupant switches off the lights upon leaving his/her workstation as a function of the time (in minutes) that passes before he/she returns to his/her workstation.

3.4 Shades' position

Figures 8 and 9 illustrate the mean monthly shades deployment level over one year for FH_TU and VC_SW+NO respectively. Thereby, the degree of shade deployment is expressed as the percentage of window occlusion due to shades operation averaged over all windows of the observed offices. Thus, for example, 0% denotes no shades deployed, whereas 100% denotes full shades deployment.

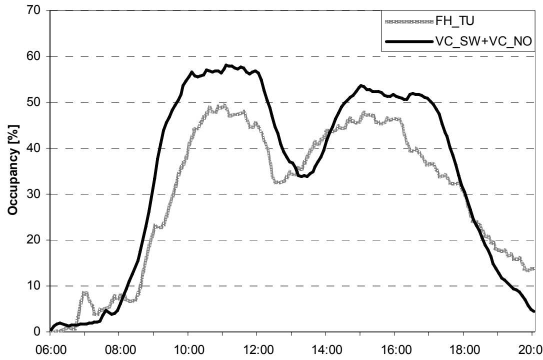

Figure 3: Mean presence level (in %) as a function of the time of the day for FH_TU and for VC_SW+NO

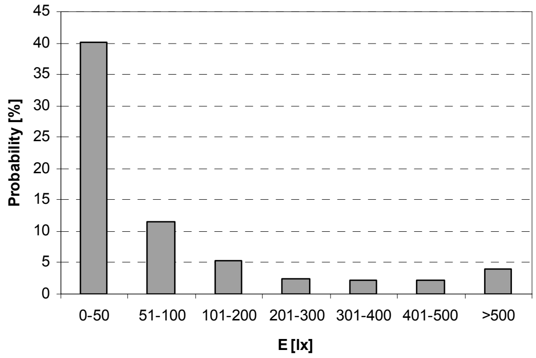

Figure 4: Switching on probability of electrical lights as a function of the prevailing illuminance level in the offices at occupant's arrival time in FH_TU.

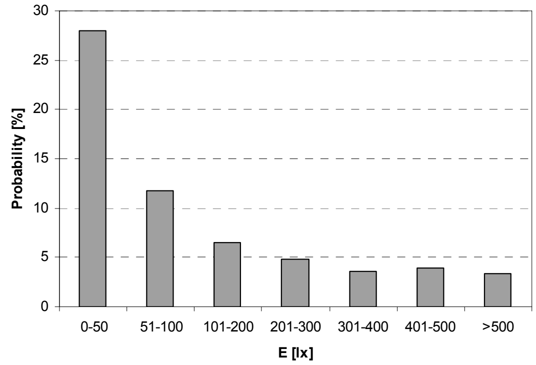

Figure 5: Switching on probability of electrical lights as a function of the prevailing illuminance level in the offices at occupant's arrival time in VC_SW+NO.

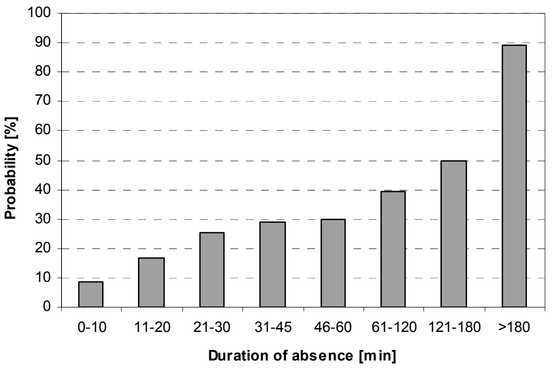

Figure 6: Switching off probability of electrical lights upon leaving the office as a function of the time that elapses (in minutes) before the occupant returns to his/her office in FH_TU.

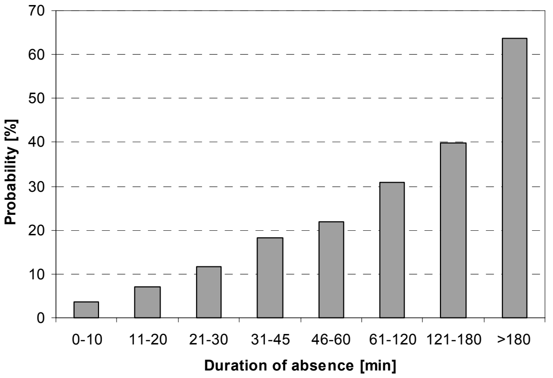

Figure 7: Switching off probability of electrical lights upon leaving the office as a function of the time that elapses (in minutes) before the occupant returns to his/her office in VC_SW+NO.

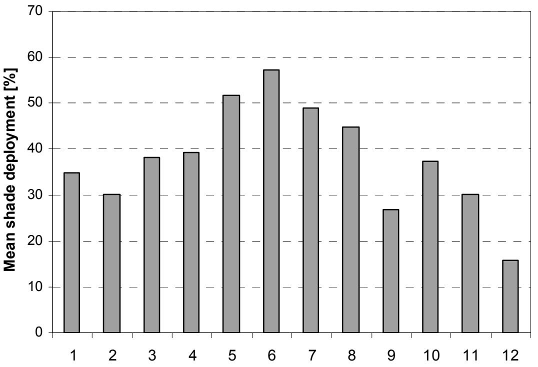

Figure 8: Mean shades deployment degree in FH_TU (in %) over a period of one year (1: January; 12: December).

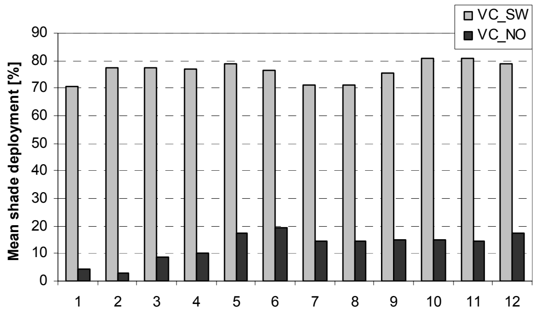

Figure 9: Mean shades deployment degree in VC_SW and VC_NO (in %) over a period of one year (1: January; 12: December).

3.5 Shades deployment events

Figures 10 to 13 display the results of a further analysis pertaining to shades deployment. Figure 10 and 11 illustrate the frequency distribution of the user actions pertaining to the opening of the shades in terms of irradiance value classes for FH_TU and VC_SW + VC_NO respectively.

Figure 12 and 13 illustrate the frequency distribution of the user actions pertaining to the closing of the shades in terms of irradiance value classes for FH_TU and VC_SW + VC_NO respectively.

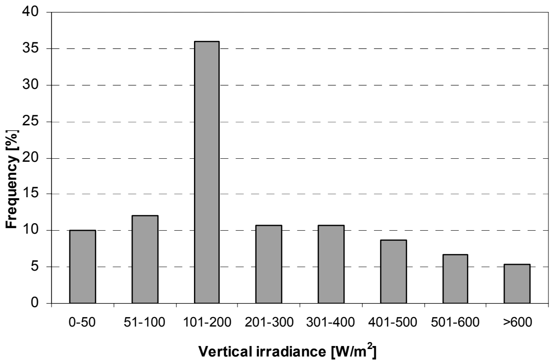

Figure 10: Frequency distribution of the event "opening shades" grouped in terms of vertical irradiance classes in FH_TU.

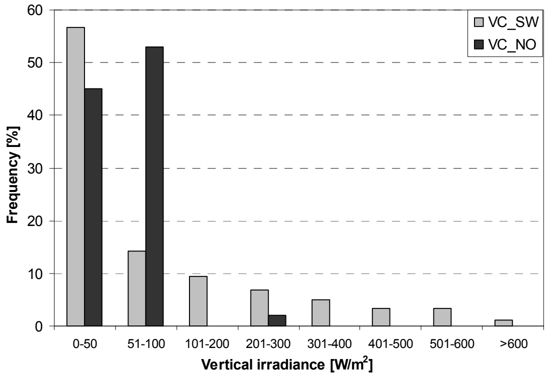

Figure 11: Frequency distribution of the event "opening shades" grouped in terms of vertical irradiance classes in VC_SW and VC_NO.

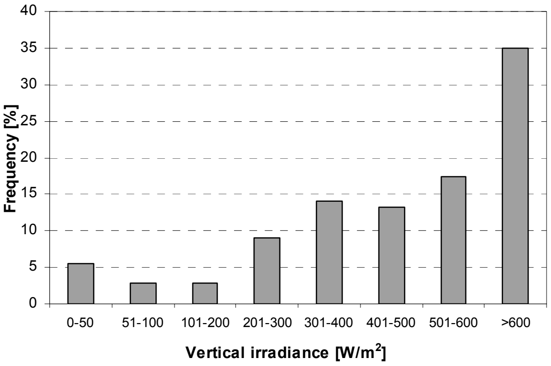

Figure 12: Frequency distribution of the event "closing shades" grouped in terms of vertical irradiance classes in FH_TU.

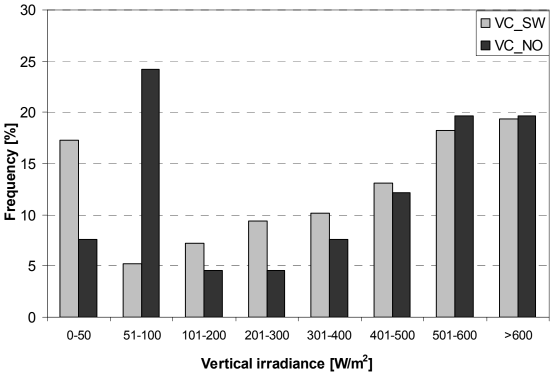

Figure 13: Frequency distribution of the event "closing shades" grouped in terms of vertical irradiance classes in VC_SW and VC_NO.

Figures 14 to 17 illustrate the relationship between shades deployment actions and the time of the day. To arrive at these figures, shade deployment actions at a certain hour of the day were averaged over all working days during the observation period.

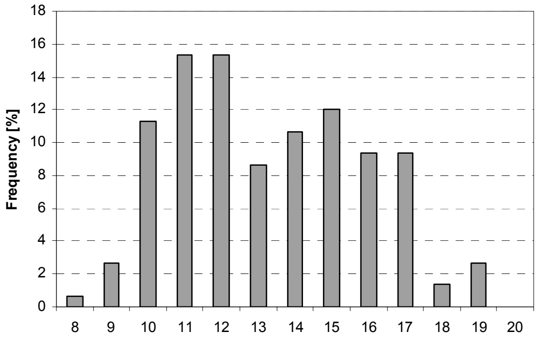

Figure 14: Frequency distribution of the event "opening shades" as a function of the time of the day for FH_TU.

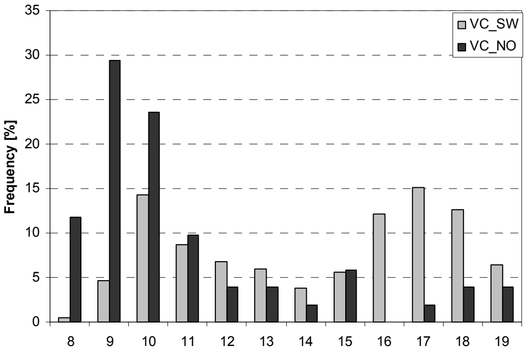

Figure 15: Frequency distribution of the event "opening shades" as a function of the time of the day in VC_SW and VC_NO.

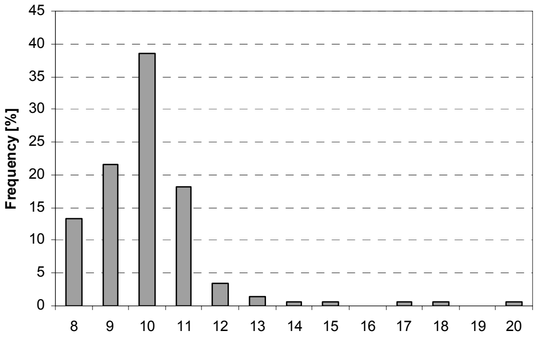

Figure 16: Frequency distribution of the event "closing shades" as a function of the time of the day for FH_TU.

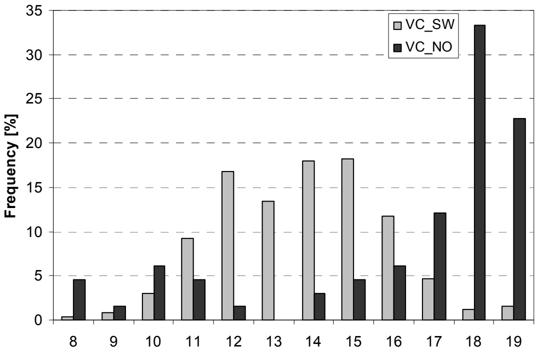

Figure 17: Frequency distribution of the event "closing shades" as a function of the time of the day for VC_SW and VC_NO.

4. Discussion

Data collection in FH_TU, VC_SW, and VC_NO was recently completed. Data collection in other buildings is ongoing. As such, definitive inferences from data can be made only after the quality of the data collected to date is comprehensively examined. However, data already collected seems to warrant certain initial observations:

i) Office users are more likely to switch on the light upon entering their offices only if the prevailing ambient illuminance is less than 100 lx (cp. Figures 4 and 5);

ii) Office users are less likely to switch off the lights upon leaving their offices unless they remain absent for one hour or more (see figures 6 and 7). This circumstance points to a significant electrical energy saving potential (for lighting) using occupancy sensing technologies;

iii) The position of shades does seem to be affected by incident solar radiation. The relationship is, however, rather complex and different from building to building and façade to façade. In FH_TU, where we studied the east-facing façade, a significant difference in the level of shades deployment can be seen between the high-radiation summer months and the low-radiation winter months (cp. Figure 8). In case of VC_SW and VC_NO the shades deployment level does not vary too much in the course of the year (cp. Figure 9), but there is a highly significant difference in the overall shades deployment level between these two facades (approximately 75% in the case of south-west-facing façade and some 10% in the case of the north-facing façade);

iv) In the east-facing offices of FH_TU, occupants close the shades primarily in the morning hours, probably to avoid direct solar penetration (see Figure 16). The shades are then opened in the course of the day with no clear relationship to the time of day or incident irradiance (see Figures 10 and 14). VC_NO receives some late afternoon direct sun, which may explain the shade closing activity in the late afternoon hours (see Figure 17). The shades are then opened mainly in the morning hours (see figure 15).

5. CONCLUSION

We presented the motivation behind and the scope of an ongoing empirical study of user control actions in office buildings in Austria. Specifically, we presented partial results of two case studies in Vienna. These results imply the possibility of identifying general patterns of user control behavior as a function of indoor and outdoor environmental parameters such as illuminance and irradiance. Future work is expected to help to further explore – inter alia – the following questions: *i)* Are there distinct "user types" in view of the tendency to switch on/off the lights as a function of daylight availability? *ii)* Is there a clear relationship between the probability of operating shades and the depth of direct solar penetration into the office? *iii)* Is the probability of opening/closing the windows or turning the heating on/off fully determined by indoor environment conditions, or does the prevailing outdoor temperature have an influence?

The compound results of the ongoing case studies are expected to enrich the existing databases towards development of more robust occupant behavior models. Such models can: *i)* improve the reliability of computational building performance simulation applications; *ii)* provide a more dependable basis for the design and configuration of user interfaces and control algorithms for buildings' environmental control systems; *iii)* deliver a quantitative basis for the evaluation of the impact of occupancy behavior on buildings' energy consumption: *iv)* help develop strategies to inform building occupants regarding the energy and comfort implications of their control actions.

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REFERENCES

[1] D. Bourgeiois, C. Reinhart, I. A. Macdonald, Assessing the Total Energy Impact of Occupant Behavioural Response to Manual and Automated Lighting Systems, Proceedings of the IBPSA International Conference - Montreal, Canada (2005), 99 – 106.

[2] D. Hunt, The Use of Artificial Lighting in Relation to Daylight Levels and Occupancy, Bldg. Envir. (1979), 14: 21–33.

[3] G. R. Newsham, Manual Control of Window Blinds and Electric Lighting: Implications for Comfort and Energy Consumption", Indoor Environment (1994), 3: 135–44.

[4] C. Reinhart, *LIGHTSWITCH-2002:* A Model for Manual Control of Electric Lighting and Blinds, Solar Energy (2002), v.77 no. 1, 15-28.

[5] A. Mahdavi, A data structure for the empirical study of user control actions in buildings. Internal report. Department of Building Physics and Building Ecology. Vienna University of Technology.