HOW DO PEOPLE INTERACT WITH BUILDINGS`ENVIRONMENTAL SYSTEMS? AN EMPIRICAL CASE STUDY OF AN OFFICE BUILDING

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ABSTRACT

The effectiveness of building performance simulation can be increased if more reliable information regarding user presence and behavior in buildings become available. In this context, the present contribution describes a study of control-oriented actions by the occupants of 6 offices in an office building over a period of nine months. The results suggest that control behavior may be related to both indoor environmental conditions and outdoor environment parameters. Such relationships can contribute to generation of dependable user action models that could be used in building performance simulation applications.

KEYWORDS

Building performance simulation, building control systems, user control actions, behavioral models

INTRODUCTION

Empirically based information on user control behavior in buildings (i.e., operation of building control devices and systems such as windows, shades, luminaries, radiators, fans) can lead to more accurate predictions of building performance (e.g. energy consumption, indoor environment). Accordingly, there have been a number studies toward collection of data on building users' interactions with building control systems and devices (see, for example, Bourgeioois et al. 2005, Newsham 1994, Hunt 1979, Mahdavi et al. 2006). Such data can bring about a better understanding of control-oriented user behavior in buildings and thus support the development of corresponding models for integration in building performance simulation applications. The present contribution describes an effort to observe control-oriented occupant behavior in 6 offices (10 workstations) of an office building over a period of nine months. Specifically, states and events pertaining to occupancy, systems, indoor environment and external environment were monitored. A weather station, a number of indoor data loggers and a digital camera were used to continuously monitor such events and states (occupancy, indoor and outdoor temperature and relative humidity, internal illuminance, external air velocity and global horizontal irradiance, status of electrical light fixtures, position of shades) and record them every five minutes.

APPROACH

The measurements were conducted in 2 single-occupancy and 4 double-occupancy offices (10 workstations) of an office building (referred to, in this paper, as "HB") over a period of nine months (from October 2005 to July 2006). A characteristic feature of this building is its use as a governmental service unit: The workers arrive rather early in their offices and regularly receive clientele with administrative questions and requests. All monitored offices face the northeast direction. Half of workstations are located on the first floor and the other half on the second floor of the building. A schematic layout of three offices on the second floor is given in Figure 1. The work stations are equipped with desktop computers and (in some cases) printers. Both screen-based and paper-based tasks are performend by the occupants.

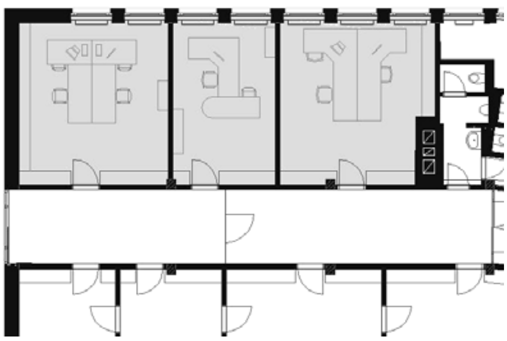

Figure 1 Second floor in HB

The offices are equipped with the followings systems: Two rows of luminaries with 4 or 6 (58 W) fluorescent lamps divided into two circuits and manually controlled by two switches near the entrance door, external manually operated shading elements and internal curtains, two or three operable windows, and two or three radiator units under each window.

The intention was to observe user control actions pertaining to lighting and shading as well as to monitor the respective prevailing indoor and outdoor conditions under which such actions occur. The state of occupancy and ambient light fixtures was captured using a sensor mounted under the luminaire. The state of windows and shades/curtains was monitored via regularly taken digital photographs of the façade. Shade deployment degree was expressed in percentage terms (0%: no shades deployed, 100%: full shading).

The external weather was monitored using a weather station, mounted on the top of the building. Collected data included air temperature, relative humidity, wind speed, as well as global horizontal irradiance. Indoor climate parameters (temperature, relative humidity, illuminance) were measured with loggers distributed across the workstations. The analysis was limited to working hours (weekends and hours between 18:00 and 4:00 were excluded).

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. The respective results were visualized primarily in terms of probability and frequency (relative/normalized) distribution graphs.

Moreover, the saving potential in electrical energy use for office lighting was estimated based on three (cumulative) energy saving scenarios involving occupancy detection and daylight-responsive operation of electrical lighting. These scenarios were as follows: *i)* lights are automatically switched off if the office is not occupied; *ii)* lights are switched off, if the daylight-based task illuminance level equals or exceeds 500 lx; *iii)* an automated dimming regime is applied, whereby luminaires are dimmed down so as to maintain a task illuminance level of 500 lx.

RESULTS

Occupancy

Figure 2 shows the mean occupancy level over the course of a reference day (averaged over the entire observation period). Note that this Figure represents the presence in (at) the user’s office/workstation and not the building. The mean occupancy in this office does not vary much in different months of the measurement period. However, as figure 3 demonstrates, the occupancy patterns in individual workstations can vary considerably.

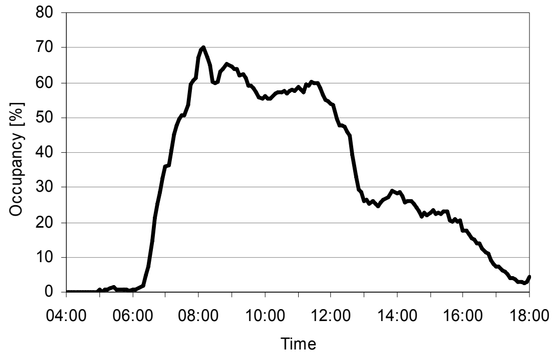

Figure 2 Mean occupancy level in HB over the course of a reference day, averaged over all observed workstations

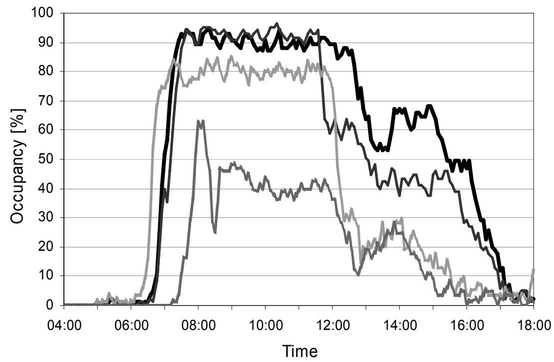

Figure 3 Observed occupancy levels in 4 different workstations over the course of a reference day

Lighting

Figure 4 shows the observed effective lighting load in the course of a reference day. To provide an impression of the differences amongst individual light usage profiles, Figure 5 shows the lighting operation in each observed office for the entire monitoring period expressed in terms of the ratio of the lighting operation duration in the occupied office to the overall occupancy duration.

Figure 6 shows the probability that an occupant would switch the lights on upon arrival in his/her office as a function of the prevailing task illuminance level immediately before the arrival. Figure 7 shows the normalized relative frequency of (intermediate) actions "switching the lights on" by occupants who have been in their offices for about 15 minutes before and after the occurrence of the action as a function of the prevailing task illuminance level immediately prior to the action's occurrence. Normalization denotes in this context that the actions are related to both occupancy and the duration of the time in which the relevant illuminance ranges (bins) applied.

Figure 8 shows the normalized relative frequency of all "switching the lights on" actions (upon arrival and intermediate) as a function of the time of the day. In this case too, actions are normalized with regard to occupancy. Figure 9 shows the probability that an occupant would switch off the lights upon leaving his/her office as a function of the time that passes before he/she returns to the office.

Shades

Figure 10 shows the mean monthly shade deployment degree together with mean monthly global horizontal irradiance. Figures 11 and 12 show the normalized relative frequency of "opening shades" and "closing shades" as a function of the global horizontal irradiance in HB. The number of actions is normalized with regard to occupancy and the time during which the respective irradiance bins applied.

Figures 13 and 14 show the normalized relative frequency of "opening shade" and "closing shade" actions over the course of a reference day. Figure 15 illustrates mean shade deployment degree as function of global horizontal irradiance averaged over all observed offices. Figure 16 represents mean shade deployment degree together with mean global horizontal irradiance over the course of a reference day.

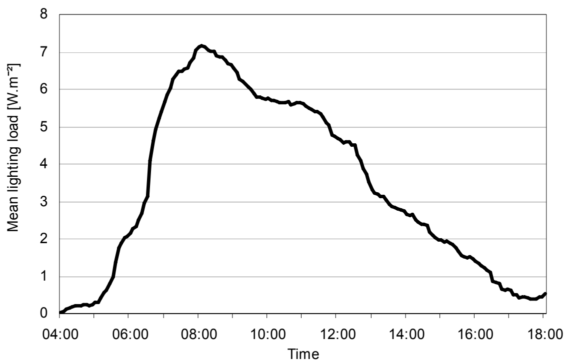

Figure 4 Lighting operation in HB offices

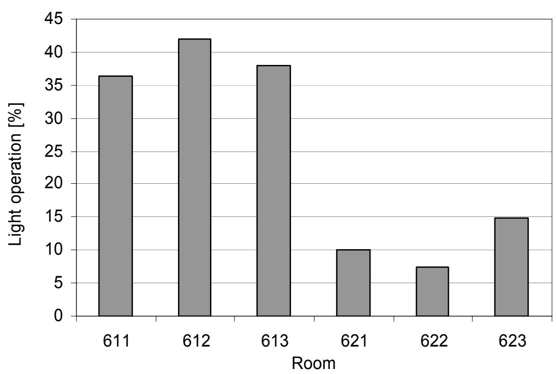

Figure 5 Duration of lighting operation (in percentage of respective overall working hours) in offices of HB

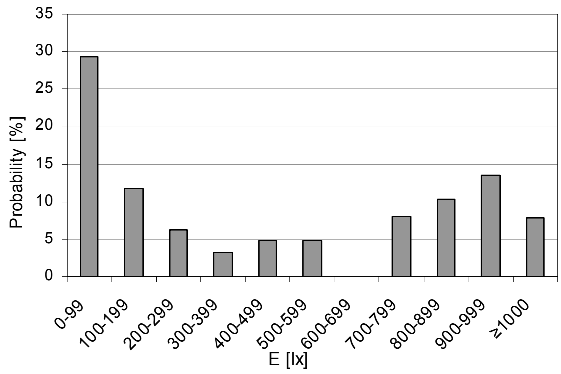

Figure 6 Probability of switching the lights on upon arrival in the office

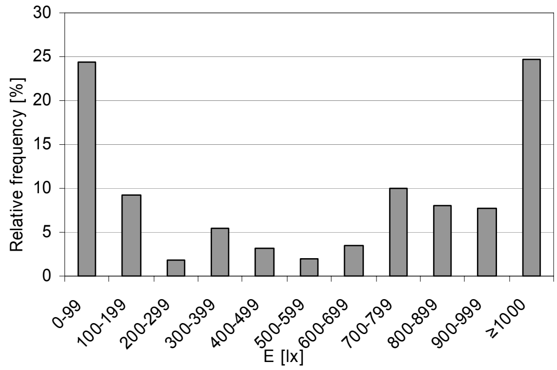

Figure 7 Normalized relative frequency of intermediate light switching on actions

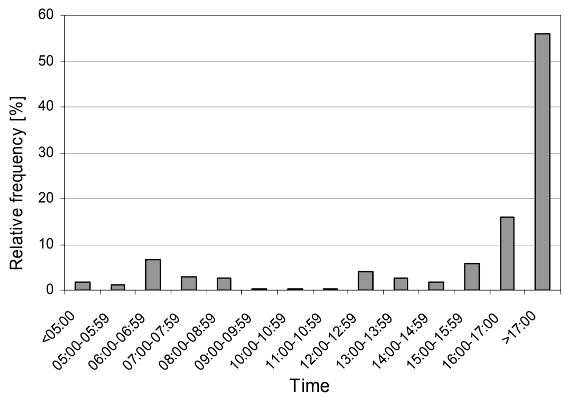

Figure 8 Normalized relative frequency of switching the lights on actions for a reference day

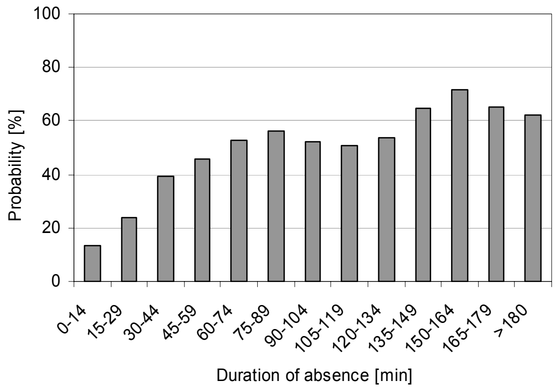

Figure 9 Probability of switching the lights off as a function of the duration of absence from the offices

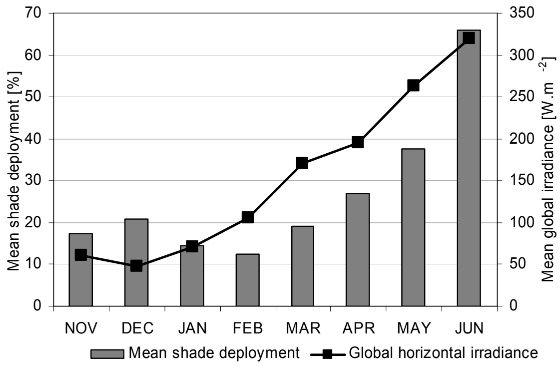

Figure 10 Mean monthly shade deployment degree together with mean global horizontal irradiance

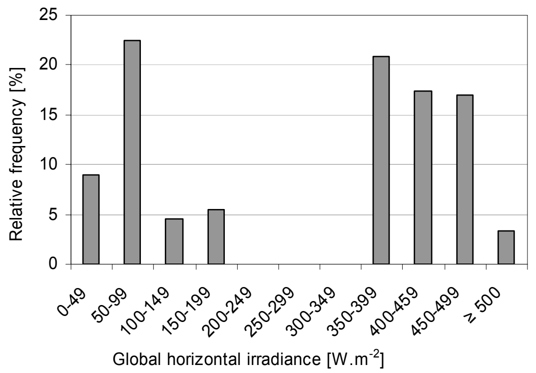

Figure 11 Normalized relative frequency of opening external shades as a function of global horizontal irradiance

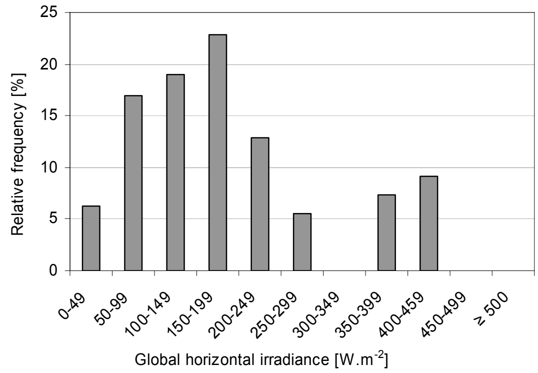

Figure 12 Normalized relative frequency of closing external shades as a function of global horizontal irradiance

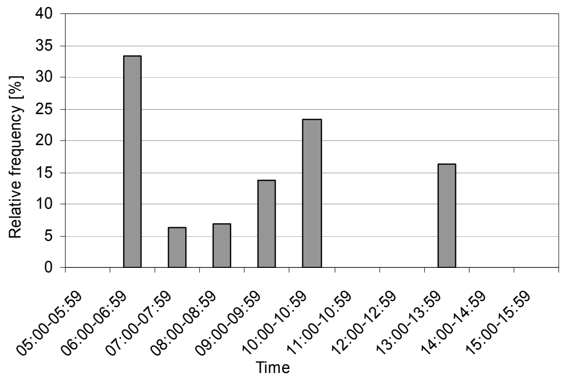

Figure 13 Normalized relative frequency of "opening shade" actions over the course of a reference day

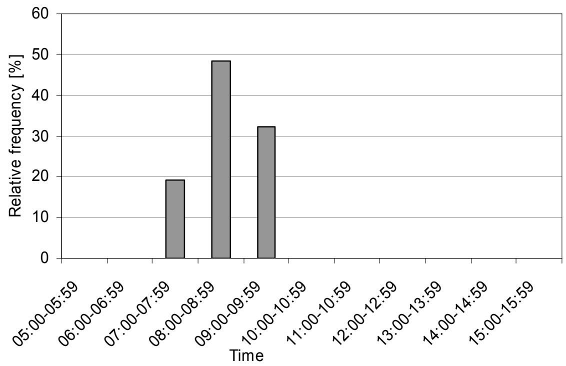

Figure 14 Normalized relative frequency of "closing shade" actions over the course of a reference day

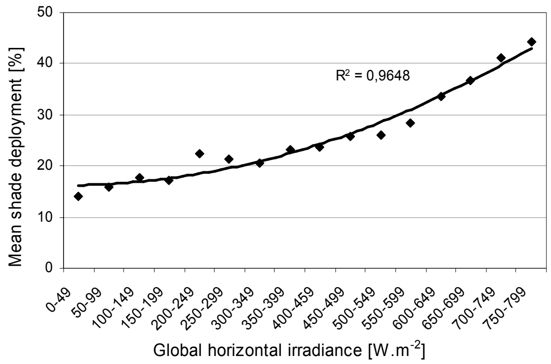

Figure 15 Mean shade deployment degree as a function of global horizontal irradiance averaged over all observed offices

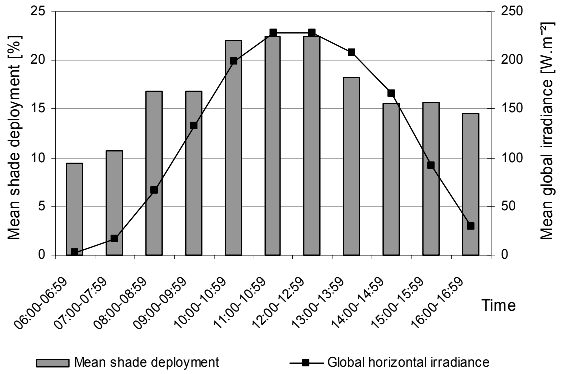

Figure 16 Mean shade deployment degree together with mean global horizontal irradiance over the course of a reference day

Energy

Figures 17 and 18 illustrate the potential for reduction of electrical energy use for lighting in HB. Thereby, three (cumulative) energy saving scenarios are computationally derived. The first scenario requires that the lights are automatically switched off after 10 minutes if the office is not occupied. The second scenario implies, in addition, that lights are switched off, if the daylight-based task illuminance level equals or exceeds 500 lx. Finally, the third scenario assumes furthermore an automated dimming regime, whereby luminaires are dimmed down so as to maintain a task illuminance level of 500 lx while minimizing the electrical energy use for lighting.

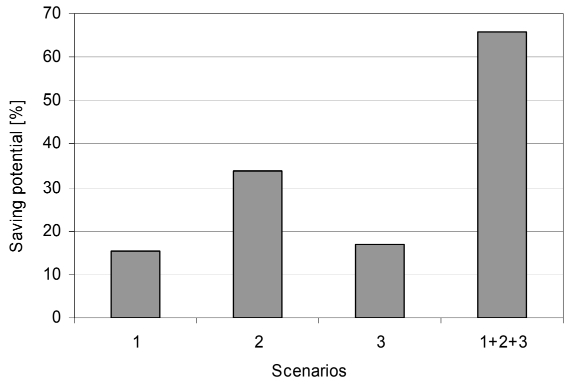

Figure 17 Estimated saving potential (in % of status quo) in electrical energy use for lighting in HB for different operation scenarios (see text)

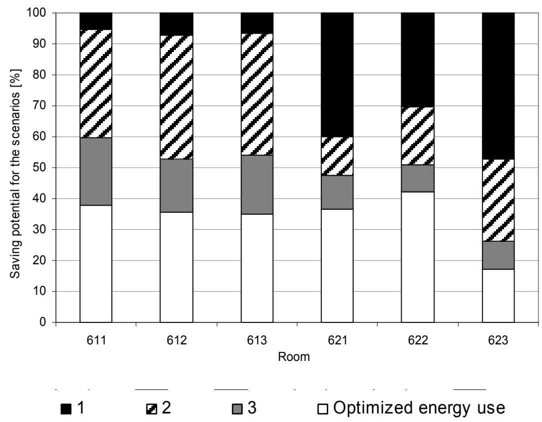

Figure 18 Estimated saving potential (in % of status quo) in electrical energy use for lighting in 6 different offices in HB for different operation scenarios (see text)

DISCUSSION

The monitored occupancy in HB (Figure 2) and the corresponding people and lighting loads (Figure 4) reveal patterns that deviate from typical schedule assumptions for office buildings. To illustrate this point, Figures 19 and 20 show a comparison between HB patterns and those observed in a more typical office building (referred to here as VC_NO+SW), which was the subject of a different case study (Mahdavi et al. 2006). This underscores the importance of the availability of a larger set of empirically-derived occupancy and light use patterns to accommodate the simulation input requirements for typologically and functionally distinct instances of buildings.

The use of electrical lighting in the observed offices (see Figure 5) shows a noteworthy difference between offices located in the first floor (611, 612, and 613) versus those located in the second floor (621, 622, and 623). This may be due to the presence of trees in the close proximity of the building, resulting in longer periods of shading in the rooms on the first floor.

Concerning the dependency of the action "switching on the lights upon arrival" on prevailing illuminance levels, Figure 6 suggests that only illuminance levels below 100 lx are likely to trigger actions at a non-random rate. If the frequency of the action is viewed in terms of the time of the day (Figure 8), a higher frequency of the "switching the lights on" actions can be observed after 4 pm. This should be expected, since the daylight-based illuminance levels in the offices decline significantly in the afternoon hours.

As to the action "switching the lights off", a clear relationship to the subsequent duration of absence is evident (Figure 9). We have found similar patterns in the course of our data collection activities in other office buildings. For example, Figure 21 shows a comparison of the HB results with those gained in two other office buildings that are located in Vienna (referred here to as VC_NO+SW and FH).

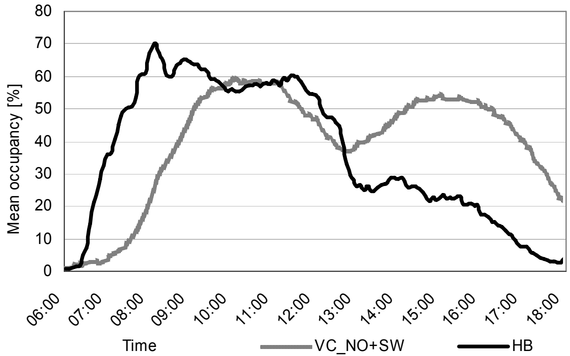

Figure 19 Mean occupancy level in VC_NO+SW and HB offices over the course of a reference day, averaged over all observed offices

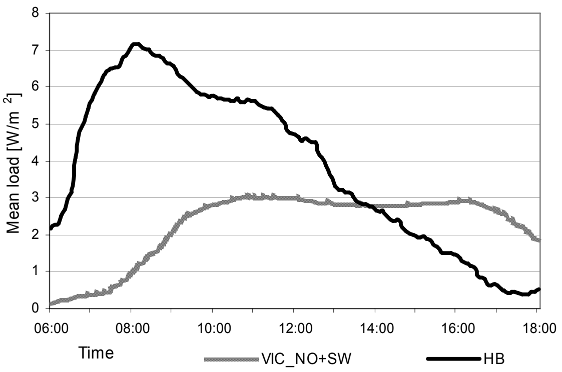

Figure 20 Lighting load in VC_NO+SW and HB offices over the course of a reference day, averaged over all observed offices

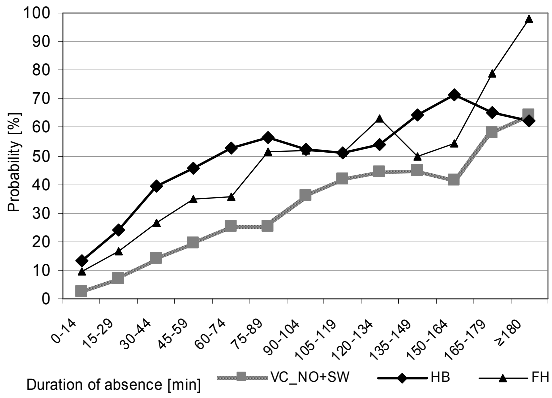

Figure 21 Probability of switching the lights off as a function of the duration of absence from the offices in FH, VC_NO+SW and HB

There is clear relationship between the mean shade deployment degree in HB and the mean monthly global horizontal irradiance values (Figure 10). Our observations did not reveal a clear relationship between the frequency of "opening shades" and "closing shades" actions and global horizontal irradiance (Figure 11 and 12). However, certain patterns emerge, if we plot the frequency of "opening and closing shades actions" over the course of a reference day.

As Figure 14 illustrates, most shades are closed during the early morning hours (from 6 to 9 am) due to orientation of the façade (north-east) and the resulting direct insolation of the windows. Shades are then reopened more frequently after 9 am (see Figure 13). Moreover, as Figures 15 and 16 illustrate, the mean shade deployment degree clearly correlates with measured global irradiance levels.

The estimated saving potential in electrical energy use for lighting of the sampled offices is significant (Figures 17 and 18). The overall cumulative energy saving potential for all offices is 67%. This result agrees well with similar calculations made for other office buildings. Figure 22 shows, as a comparison, the aforementioned saving potential for HB, VC_NO+SW, and FH).

Note that a lighting system retrofit and the resulting electrical energy use reduction would increase the heating loads and decrease the cooling loads. However, as previous studies have shown, given the magnitude of required cooling loads in office buildings, the overall thermal implications of a lighting retrofit are positive both in energetic and monetary terms.

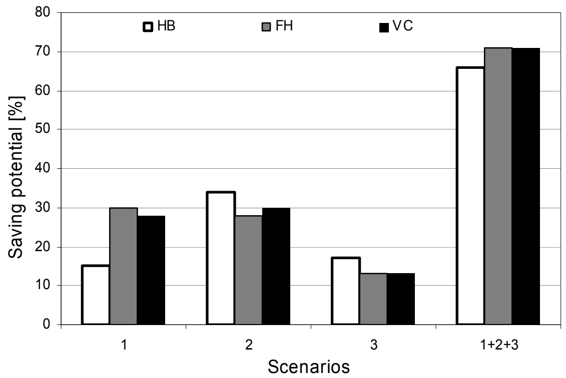

Figure 22 Estimated saving potential (in % of status quo) in electrical energy use for lighting in HB, FH and VC for different operation scenarios (see text)

CONCLUSION

We presented a case study from an ongoing project concerning user control actions in an office building in Austria. The 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. Moreover, the results suggest a significant saving potential in electricity energy use for lighting, given intelligent (occupancy-sensitive and daylight-responsive) lighting devices and control systems.

Future analyses are to place the results of the present paper in the broader context of other ongoing case studies in order to expedite the development of robust occupant behavior models that can, amongst other things, improve the reliability of computational building performance simulation applications.

ACKNOWLEDGMENT

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