# User control actions in buildings: Patterns and impact

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## SUMMARY

In most buildings, occupants operate control devices such as windows, shades, luminaries, radiators, and fans to bring about desirable indoor environmental conditions. Knowledge of such user actions is crucial toward accurate prediction of building performance (energy use, indoor climate) and effective operation of building service systems. This paper describes an effort to observe control-oriented occupant behavior in two office buildings in Austria over a period of one year. Thereby, user control actions as related to one or more of the building systems for ambient lighting, shading, window ventilation, and heating were monitored together with indoor and outdoor environmental parameters. The collected data is being analyzed to explore relationships between the kinds and frequency of the control actions and the magnitude and dynamism of indoor and outdoor environmental changes. Moreover, implications of user actions for building performance (e.g. energy consumption) are studied.

## INTRODUCTION

Multiple studies have been (and are being) conducted internationally to collect data on building users' interactions with building control systems and devices (see, for example, [1], [2], [3] and [4]). Such data can bring about a better understanding of the nature, type and frequency of control-oriented user behavior in buildings and thus support the development of corresponding behavioral models for integration in building performance simulation applications. Moreover, such data could support the effective (and proactive) operation of building service systems for indoor environmental control. The present contribution describes an effort to observe control-oriented occupant behavior in 42 offices in two office buildings over a period of one year. Specifically, states and events pertaining to occupancy, systems, indoor environment, and external environment were monitored. Weather stations, a number of indoor data loggers, and digital cameras were used to continuously monitor – and record every five minutes – such events and states (occupancy, indoor and outdoor temperature and relative humidity, internal illuminance, external air velocity and global irradiance, status of electrical light fixtures, position of shades). The results reveal distinct patterns in the collected data. Specifically, control behavior tendencies show dependencies both on indoor and outdoor environmental parameter. A summary of these tendencies are presented and their principal potential as the basis of empirically grounded user action models are explored.

## METHODS

### Object

Data collection was conducted in two office buildings in Vienna, Austria. One of these belongs to the Vienna University of Technology. We refer to this building henceforth as FH.

The second building is a large high-rise office complex (referred to, in this paper, as "VC"). An important feature of VC is its use as one of the major seats of international organizations, resulting in a very diverse occupancy profile in cultural terms. We selected 13 scientific staff offices in FH and 29 single-occupancy offices in VC. All selected offices in FH face east, situated on the 4th, 5th and 6th floors. Ten offices are single-occupancy, two are double-occupancy, and one is triple-occupancy. In case of VC, 15 offices face north (code: "VC_NO") and 14 face south-west (code: "VC_SW"). The offices are located on the 12th and 13th floor of the building. To exemplify the layout of these rooms, Figure 1 provides the schematic layout of two single-occupancy and one double-occupancy offices in the 5th floor of FH and three single occupancy offices in the 12th floor of VC_SW. The working stations are equipped with desktop computers and in some cases with task lights. Both VDT-based and paper-based tasks are performed.

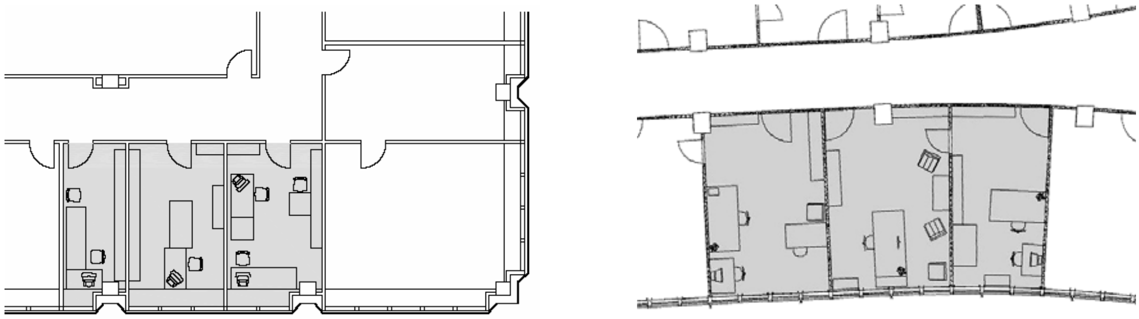

Figure 1. Schematic plan of sample offices: Left: FH; Right: VC_SW

The offices in FH are typically equipped with the followings environmental control systems: Three/four luminaries (58W each), divided into two circuits manually controlled via switches near the office door; External motorized screen shades operated by a switch mounted on a panel under the window; Fan coil under the window for fine adjustment of temperature.
The systems installed in the offices of VC_SW+NO are as follows: Three rows of luminaries with 9 or 12 fluorescent lamps (38 W) divided into two circuits and manually controlled by two switches near the entrance door; internal manually operated shading; Three to four fan coil units under each window for fine adjustment of temperature.

**Monitored parameters**

The intention was to observe user control actions pertaining to lighting and shading systems while considering the indoor and outdoor environmental conditions under which those actions occurred. Occupancy and the change in the status of ambient light fixtures were captured using a dedicated sensor. Shading was monitored via time-lapse digital photography: 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% denotes no shades deployed, whereas 100% denotes full shading). The external weather conditions were monitored using a weather station, mounted on the top of the building in case of VC_SW+NO and, in case of FH, on the rooftop of a close by university building. Internal climate conditions (temperature, relative humidity, illuminance) were measured with autarkic loggers distributed across the workstations. To obtain information regarding user presence and absence intervals, occupancy sensors were applied, which simultaneously monitored the state of the luminaries in the offices. All of the above parameters were logged regularly every 5 minutes. Monitored indoor parameters included room air temperature (in $^{o}C$), room air relative humidity (in %), ambient illuminance level at the workstation (in lx), luminaries' status (on/off), and occupancy (present/absent). Monitored outdoor environmental parameters included air temperature, relative humidity, wind speed (in $m.s^{-1}$) and wind direction, as well as 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 [5]. Collected data were 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 [2]. For the purposes of the present analysis the range of data considered was limited to working days between the hours 8:00 to 20:00. The collected data was primarily 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.

## RESULTS

### Occupancy

Figure 2 shows the mean occupancy level in FH and VC_SW+NO over the course of a reference day (averaged over the entire observation period). Note that these values represent the presence in/at the users' offices/workstations, not merely the presence in the building. Moreover, as Figure 3 demonstrates, the occupancy patterns can vary considerably from office to office.

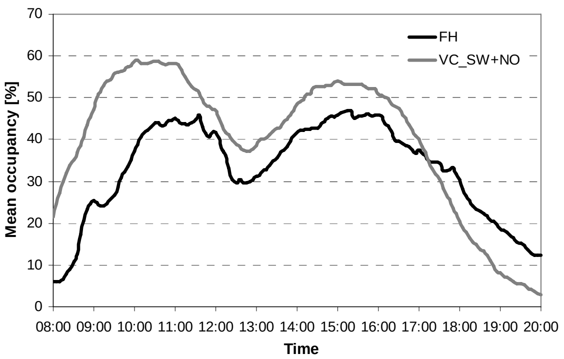


Figure 2. Mean occupancy level for a reference day in FH and VC_SW+NO.

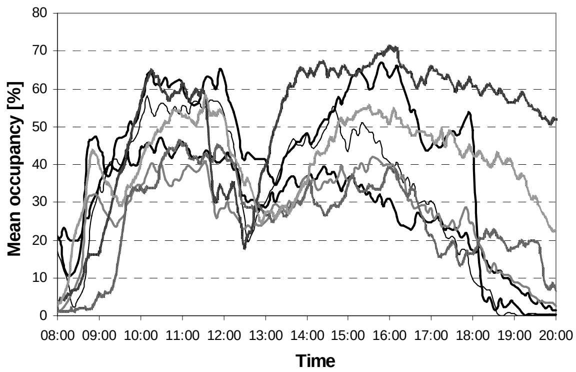


Figure 3. Observed occupancy levels in 7 different offices in FH for a reference day.

### Lighting

Figure 4 shows the observed effective lighting operation in the course of a reference day expressed in terms of effective electrical power. The information in this Figure concerns the general light usage in all observed offices. Figure 5 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 arrival. Figure 6 shows the normalized relative frequency of (intermediate) actions "switching the lights on" (by occupants who have been in their office 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 7 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. Note that Figure 7 includes also the corresponding mean global horizontal irradiance levels.

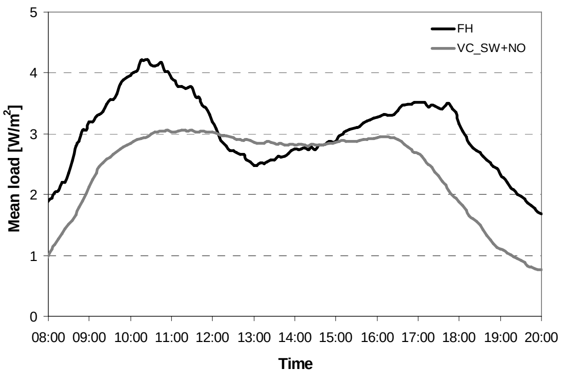


Figure 4. Lighting operation in FH and VC_SW+NO offices.

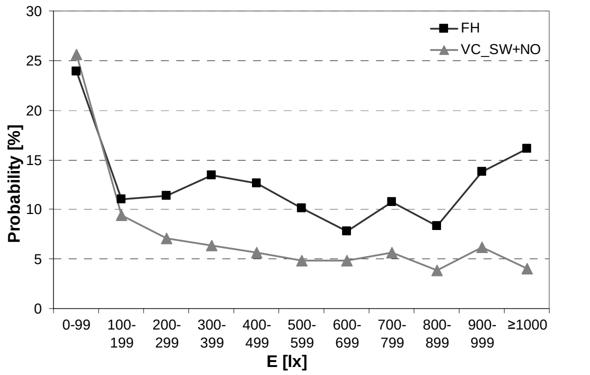


Figure 5. Probability of switching the lights on upon arrival in the office in FH and VC_SW+NO.

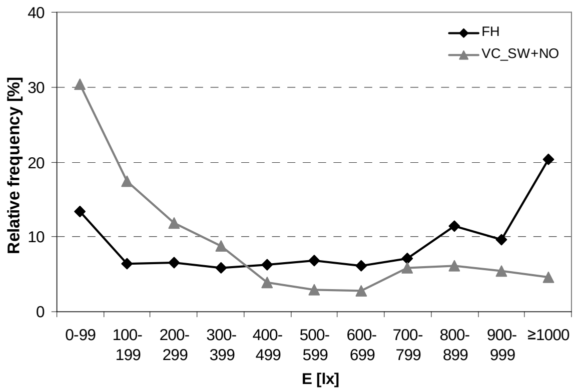


Figure 6. Normalized relative frequency of intermediate light switching on actions in FH and VC_SW+NO.

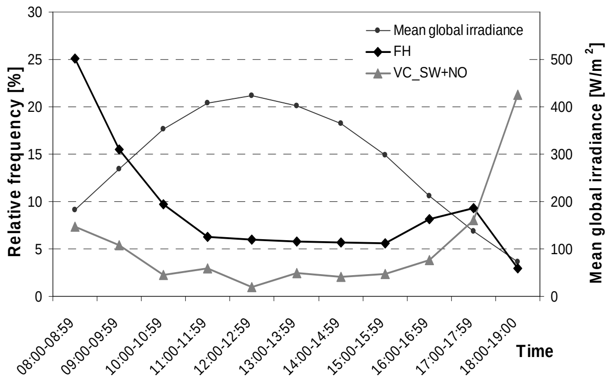


Figure 7. Normalized relative frequency of switching the lights on actions in FH and VC_SW+NO over the course of a reference day.

Figure 8 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. Figure 9 shows the normalized frequency of the (intermediate) "switching the lights off" actions as a function of the prevailing illuminance level immediately prior to the action's occurrence. Normalization denotes in this case the consideration of occupancy and the applicable durations of the respective illuminance bins while deriving the actions' frequency.

## Shades

Figure 10 shows the mean monthly shade deployment degree for FH, VC_NO and VC_SW. Figure 11 shows the mean shade deployment degree as a function of the incident irradiance on the façade. Figures 12 and 13 show the normalized relative frequency of the actions "opening shades" and "closing shades" as a function of global vertical irradiance incident on the facade. Normalization means that the frequency of actions (opening and closing shades) is related here to both occupancy and the duration of times in which the prevailing irradiance was within a certain range (bin).

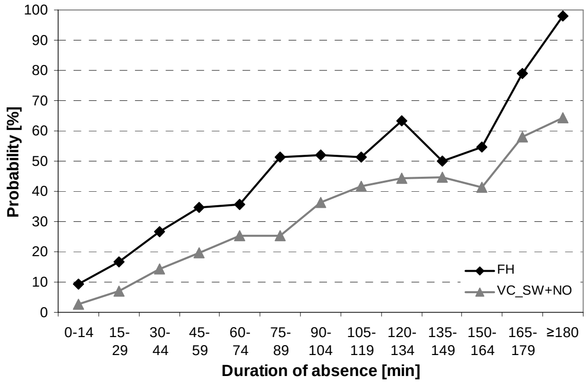


Figure 8. Probability of switching the lights off as a function of the duration of absence from the offices in FH and VC_SW+NO.

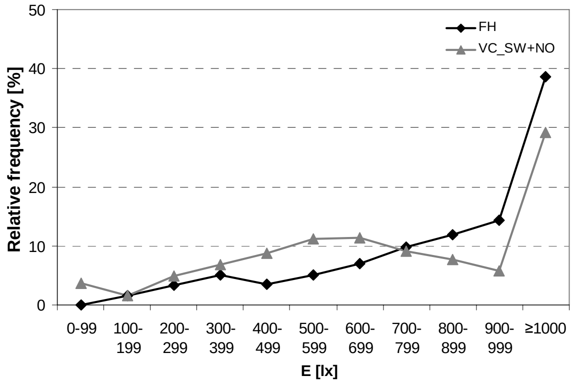


Figure 9. Normalized frequency of intermediate switching the lights off actions in FH and VC_SW+NO offices.

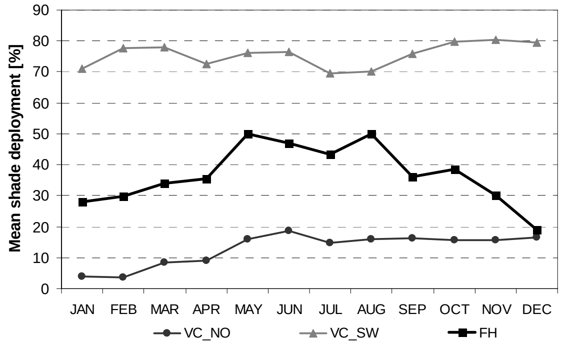


Figure 10. Mean monthly shade deployment degree in FH, VC_NO and VC_SW.

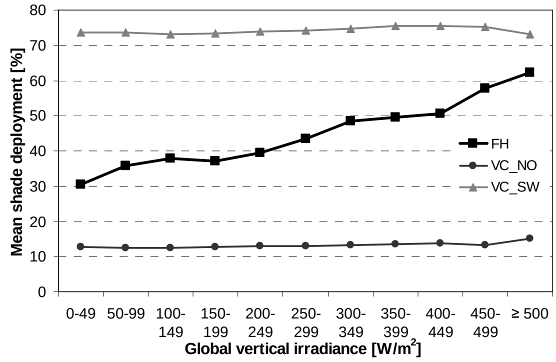


Figure 11. Mean shade deployment degree as function of global vertical irradiance in FH, VC_SW and VC_NO.

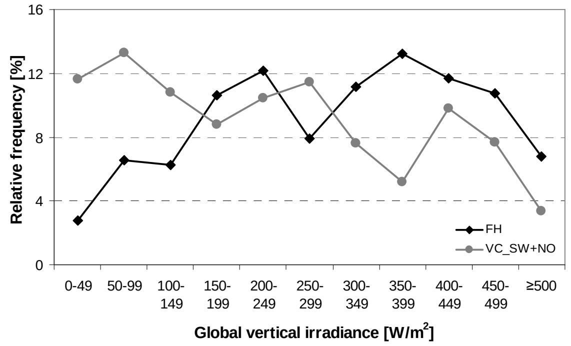


Figure 12. Normalized relative frequency of opening shades as a function of the global vertical irradiance in FH and VC_SW+NO.

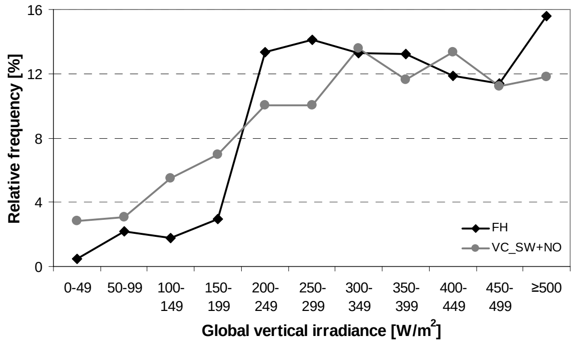


Figure 13. Normalized relative frequency of closing shades as a function of the global vertical irradiance in FH and VC_SW+NO.

Note that in the above figures opening/closing actions are not limited to actions resulting in fully opening/closing the shades. Rather, they denote a relative occupant-driven change in the position of the shades. This means that even an incremental change (e.g. changing from 80% to 40% or changing from 20% to 40%) is considered to be an opening/closing action.

## DISCUSSION

The monitored occupancy in FH and VC (Figure 2) and the obviously related lighting loads (see Figure 4) reveal a similar pattern (also known from other office buildings). However, the maximum occupancy levels are different. This may be due to the circumstance that FH houses offices for teaching and research staff, who spend a considerable amount of time in classrooms and laboratories. This underscores the need for typologically differentiated occupancy models for different buildings. Patterns of this kind can be used for simulation runs in terms of corresponding hourly schedules (see Figures 14 to 16). Such simulations can be applied, for example, to explore the impact of thermal improvement measures on the building's energy use. On a more general level, our observations regarding these buildings suggest that the environmental systems in a considerable number of office buildings may in fact be "over-designed", in a sense that they are dimensioned for occupancy levels that seldom occur. The dependency of the action "switching on the lights" on prevailing illuminance levels for the two monitored buildings (see Figures 5 and 6) shows no clear pattern. The data merely suggests that only illuminance levels below 100 lx are likely to trigger actions at a non-random rate.

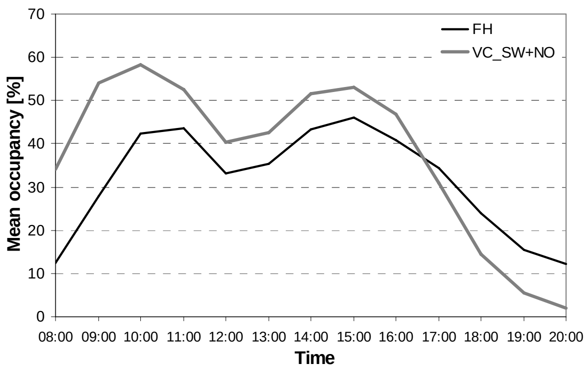


Figure 14. Illustrative simulation input data regarding mean hourly occupancy levels for FH and VC_SW+NO.

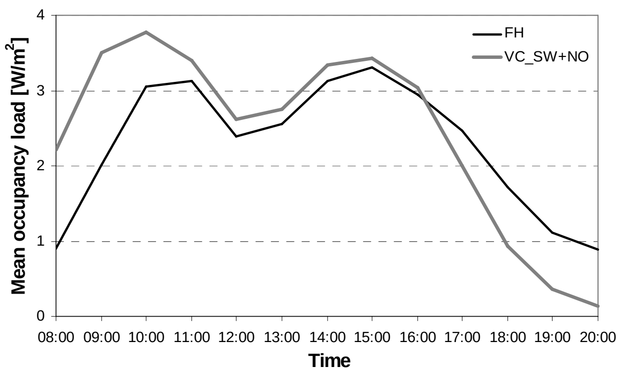


Figure 15. Illustrative simulation input data regarding mean hourly people (sensible) load for FH and VC_SW+NO.

As to the action "switching the lights off", a clear relationship to the subsequent duration of absence is evident for both FH and VC_SW+NO (see Figure 8). Occupants do switch off the lights more frequently if they are going to be away from the offices for longer periods. On the other hand, lights are not necessarily switched off by the occupants if the illuminance level in the office is already sufficient (or more than necessary) for performing typical tasks. In fact, such intermediate switching off actions appear to occur at a noticeably higher rate only once the illuminance level in the office rises above 1000 lx (see Figure 9).

The mean shade deployment levels differ from building to building and façade to façade (see Figures 10 and 11). In case of FH, where we studied the east-facing façade, a difference in the level of shade deployment can be seen between the high-radiation summer months and the low-radiation winter months (Figure 10). Moreover, an evident relationship between shade deployment and the magnitude of solar radiation is observable (Figure 11). The latter provides a very effective basis for modeling the state of shades for this building (see Figure 17). In case of VC_SW and VC_NO the shade deployment level does not vary much in the course of the year or in terms of vertical irradiance classes, but there is a significant difference in the overall shade deployment level between these two facades (approximately 75% in the case of south-west-facing façade, 10% in the case of the north-facing façade). The relative small variation range in the monthly shade deployment levels in VC_SW and VC_NO may be partly due to the fact that the manual shade operation mechanism is, in this case, much more difficult to handle than the mechanically supported shade operation system in FH.

Our observations did not reveal a clear relationship between "opening shades" actions and the incident radiation on the façade (see Figure 12). However, the corresponding analysis of the "closing shades" actions shows for both FH and VC_SW+NO a higher action frequency once the incident radiation rises above 200 W.m$^{-2}$ (see Figure 13).

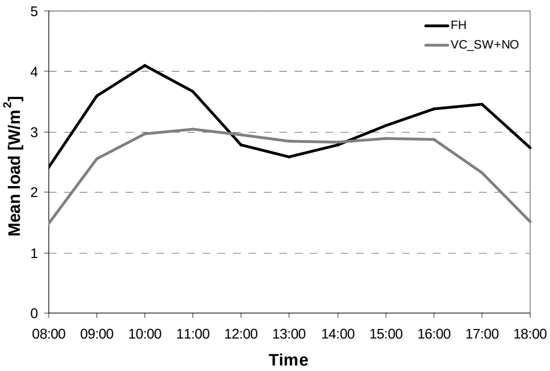


Figure 16. Illustrative simulation input data regarding mean hourly lighting load for FH and VC_SW+NO.

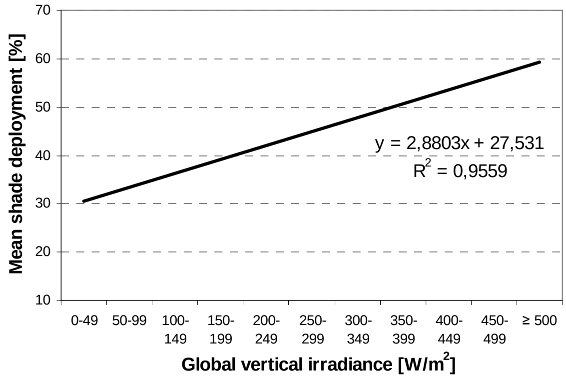


Figure 17. Illustrative model of shade deployment as a function of incident irradiance on FH's façade.

Figure 18 illustrates the potential for reduction of electrical energy use for lighting in the sampled offices. Thereby, three (cumulative) energy saving scenarios are calculated. 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. The third scenario assumes furthermore an automated dimming regime, whereby luminaries are dimmed down so as to maintain an illuminance level of 500 lx while minimizing electrical energy use for lighting.

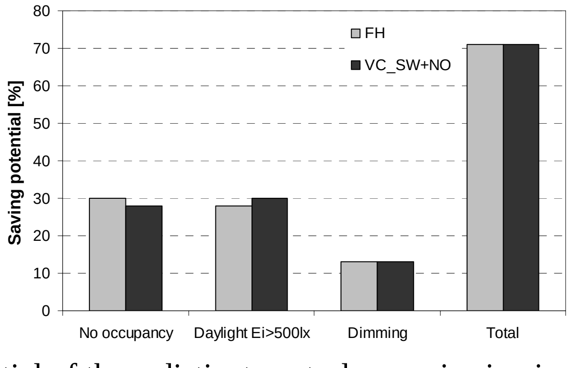


Figure 18. Saving potential of three distinct control scenarios in view of electrical energy use for lighting in FH and VC_SW+NO

The estimated saving potential in electrical energy use for lighting of the sampled offices is significant. The cumulative energy saving potential for all sampled offices in FH and VC_SW+NO is 71% (Table 1). This translates (for VC_SW+NO) into a cumulative annual energy saving potential of 17 kWh.m$^{-2}$ or (given current energy prices) 1.3 €.m$^{-2}$. This would imply, that in the VC complex, annually roughly 130,000 € could be saved by a comprehensive retrofit of the office lighting system toward dynamic consideration of occupancy patterns and daylight availability. (Note that a lighting system retrofit and the resulting electrical energy use reduction would increase the heating loads and decrease the cooling loads. 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.)

Table 1. Saving potential (electrical energy for lighting) for various scenarios and buildings

| | | Energy saving scenarios | | | |
|---|---|---|---|---|---|
| Building | Saving potential in | 1 | 2 | 3 | 1+2+3 |
| FH | % | 30 | 28 | 13 | 71 |
| VC_SW+NO | [%] | 28 | 30 | 13 | 71 |
| | $kWh.m^{-2}. a^{-1}$ | 6.8 | 7.2 | 3.0 | 17.0 |
| | $€.m^{-2}. a^{-1}$ | 0.53 | 0.56 | 0.24 | 1.32 |

## CONCLUSION

We presented a case study concerning user control actions in two office buildings in Vienna, 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. The compound results of the ongoing case studies are expected to lead to the development of robust occupant behavior models that can improve the reliability of building performance simulation applications and enrich the control logic in building automation systems. Moreover, the obtained information will support the assessment of energy saving potential due to consideration of occupancy and behavioral patterns in office buildings.

## ACKNOWLEDGEMENT

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