Exploring the occupancy behaviour and perception in an office building

Livia Seres – livia.seres@yahoo.com
Ulrich J. Pont – BPI, Vienna University of Technology – ulrich.pont@tuwien.ac.at
Matthias Schuss – BPI, Vienna University of Technology – Matthias.schuss@tuwien.ac.at
Ardeshir Mahdavi – BPI, Vienna University of Technology – amahdavi@tuwien.ac.at

Abstract

The representation of people's presence and control-oriented behaviour in building performance representation requires a large empirical database for model development and evaluation. Toward this end, empirical case studies in different buildings and different locations are necessary. In this context, this contribution presents the results of a study of user behaviour regarding building systems operation in an office building located in the south of Vienna, Austria, ventilated by mechanical means only. Moreover, users' perception of the indoor climate conditions at their workspaces was assessed. Empirical data concerning indoor climate conditions were collected by measuring the inside temperature, relative humidity, and illuminance levels over a period of ten months. Data regarding external weather conditions were obtained from the Central Institute for Meteorology and Geodynamics, Vienna. Occupancy data and the status of the user-controlled building's systems (thermostat, electrical lighting and shades) were additionally collected via hourly observations over a period of six months.

The main objective of the study was to explore the general patterns of occupant’s control-orientated behaviour at their workplaces in relation to the indoor/outdoor conditions. The results contribute to a better understanding of user behaviour in office buildings and the evaluation of the influence of occupancy on building energy use. The results also support the efforts toward integrating behavioural models in building performance simulation applications and improving building management and automation

1. Introduction & Background

The interaction between building systems and building occupants is generally considered to be one major influence on both the thermal comfort inside the building and the energy consumption of the building. Knowledge in this field can help in many fields of planning and operation of buildings. For instance, building control and automations systems can be adapted to the needs of the building occupants to optimize both comfort and energy consumption. Furthermore, the detailed knowledge about occupant behavioural patterns can help to better educate people in sustainable operation of the building systems in the future.

Multiple studies were carried out internationally to collect data on building user behaviour towards the building systems and devices. The following list of prior research efforts, for instance, states publications in the field of artificial lighting, and shade operation. Studies addressing the operation of artificial lighting systems include the following findings:

- Boyce (1980) found that generally the absolute number of operated luminaries is less in summer than in winter (following the seasonal change in daylight availability). Carter et al. (1999) further established this seasonal dependency of the lighting loads within buildings.
- Concerning the time of operation, Hunt (1979) identified the beginning and end of working days as the most frequent operation of lighting systems in offices with constant daytime occupancy. Reinhart and Voss (2003) observed that 86% of switching-on-operations are conducted upon arrival in the office.
- The correlation between illuminance levels on workplanes and switching on probability were examined by Hunt (1979), Love (1998), Reinhart and Voss (2003), and Mahdavi et al. (2007).

Part of
Baratieri, M., Corrado, V., Gasparella, A. & Patuzzi, F. (Eds.). 2015.
Building simulation applications BSA 2015. bu,press.
https://doi.org/10.13124/9788860460745

- Pigg (1996), Boyce (1980), Reinhart (2001) and Mahdavi et al. (2007) illustrate a strong connection between the probability of switching off the lights and the time elapsing until the user returns to the office: people are more likely to switch off the light if they leave their workplaces for a long period of time.

Studies addressing the manual operation of shades include the following findings:

- Rubin et al. (1978), Inoue et al. (1988) and Mahdavi et al. (2007) all document a strong dependency between shade operation and façade orientation.
- The main motivation for the blind operation is overheating and avoidance of direct insolation of the working spaces, according to Rubin el al. (1978), Rea (1984), Inoue (1988), Bülow-Hube (2000), and Reinhart (2001).
- Blinds are rarely changed, once they are set up following Rea (1984), Rubin et al. (1978), and Inoue (1988). Short-term changes in irradiance values are regularly not considered by building users.

The majority of the mentioned studies only considered the operation of the systems, and not the occupancy in the buildings. Therefore, there is a need for further research of user behaviour including both operation of systems and user occupancy behaviour. This could help to eliminate uncertainties if certain system operations take place or do not take place due to tolerable inside/outside conditions or due to the absence of users from the monitored spaces.

This contribution describes the efforts and results of observations of control-oriented occupant behaviour in a mechanically ventilated office building in Austria over a monitoring period of 10 months.

2. Methodology

2.1 Object description

The offices spaces monitored in this study are situated on the fifth floor of an office building that is situated in Lower Austria close to Vienna and was erected in 1963. The building will be referred to as SV in this contribution. The object serves as the headquarters of a big international company. The building features 7 floors plus a setback roof floor, and a reinforced concrete frame structure enveloped by curtain façade elements consisting of alloy metal and insulated glazing. The overall dimensions of the building measure 138 m length, 14 m width and 31.5 m height. The building's longitudinal axis is aligned to north, leading to offices with east and west oriented windows. The building is fully air-conditioned and its windows are not operable for ventilation purposes. Figure 1 illustrates the west façade of the building and highlights the floor housing the monitored offices.

Fig. 1 – View of west façade of SV. The floor housing the monitored offices is highlighted.

Two types of offices can be found in SV: single workplace offices (1 workstation, "closed", area from 13.41 to 27.22 m^2,), and multiple workplace offices (2 – 5 workstations, "open"-space, area from 27.22 and 41.03 m^2.). Separation walls follow the 2.50 m distance between structural axes and are made of glass or fabric-covered wood elements. The space between two axes is occupied by one or two workspaces and features a window that is inoperable including internal horizontal blind, one heating/cooling and air-conditioning unit and 2 rows of fluorescent luminaries. Figures 2 and 3 illustrate typical open and closed offices.

The heating/cooling and air-conditioning system of the building is controlled centrally. However, users can adjust the function of the units within each axis module. The system is capable of exchanging air (that can be pre-heated or pre-cooled) up to a maximum air change rate of 4 h-1 (180 $m^3.h^{-1}$). The HVAC-system is operated during working days between 05:00 am and 20:00 pm.

The luminaries are set in 2 rows (one close to the window, one close to the central hallway). Each

luminaire is equipped with 2 x 38 W fluorescent tubes. Luminaires rows can independently switched on / off by the users via switches next to the corresponding office door.
Each window features an adjustable internal horizontal blind, which can be manually operated by the users.

Fig. 2 (left) – closed office; Fig. 3 (right) – open-space office.

2.2 Data collection & processing

Monitoring was realized in 22 offices for a time period between May 2013 and March 2014. The data collection included both objective (measurements) and subjective (via interviews) methods. An overview about the monitored offices is provided in table 1.
Objective data collection included recording of temperature, relative humidity and illuminance in the offices via data loggers in five minute intervals, as well as hourly observations of occupancy and building systems status (shades, electrical lighting and thermostat) on random days during the observation period.
The status of the building systems was assessed according to the following scheme:

- The status of the heating/cooling & air-conditioning units was derived in steps of 0.1 from the state of the control unit, as depicted in Figure 4. During the winter period the "Max" setting represents a maximum of space heating, while "Min" represents the heating turned to minimum. During the summer period "Max" represents a maximum of cooling, while "Min" denotes that the system is barely cooling.
- The luminaries were assessed as rows. A value of 1 was logged if both rows inside of an office were turned on, a value of 0.5 was logged if just one row was switched on. A value of zero was noted in the record log if no artificial light was turned on at all at the moment of observation.

Table 1 – Monitored offices in the SV building. Data logger abbreviations: θ… temperature [°C], RH… relative humidity [%], I… Illuminance [lx]

Orientation	Office No	Type	Installed Data logger	Users	Area [m^2]
E	1	Closed	θ	1	13.41
E	2	Open	Θ, RH, I	4	41.03
E	3	Open	θ	3	41.03
E	4	Closed	θ	1	13.41
E	5	Closed		1	13.41
E	6	Closed		1	27.22
E	7	Closed	θ	1	13.41
E	8	Closed	θ	1	13.41
E	9	Open		3	27.22
E	10	Open	Θ, RH, I	3	41.03
E	11	Closed	θ	1	13.41
E	12	Open	θ	3	27.22
W	13	Closed	Θ, RH, I	1	13.41
W	14	Closed	θ	1	13.41
W	15	Open	Θ, RH, I	3	41.03
W	16	Open		2	27.22
W	17	Closed	θ	1	27.22
W	18	Open	Θ, RH, I	5	41.03
W	19	Open	θ	2	27.22
W	20	Closed	θ	1	13.41
W	21	Open	θ	3	27.22
W	22	Closed	Θ, RH, I	1	13.41
			Total	**43**	**530**

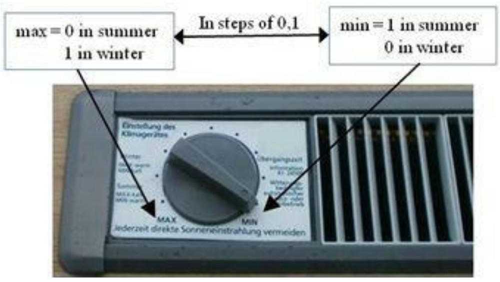

Fig. 4 – Heating/Cooling & Air Conditioning control settings.

- The position of the shades was recorded according to the percentage of shade deployment from completely open (0%) to completely closed shade (100%) in a step width of 20%, as illustrated in Figure 5. Additionally the angle of the shade elements was assessed following its daylight transmission: A value of 0 was recorded for completely closed angle on both sides, 0.8 for an angle 45° upwards, 0.6 for a 90° angle, and 0 for an angle of 45° downwards.

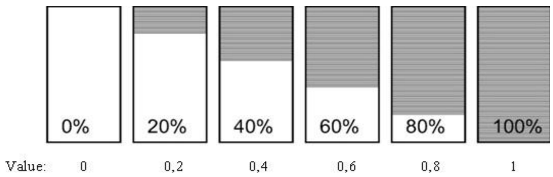

Fig. 5 – Shades positions and derived values.

External weather data were acquired from the ZAMG (Central Institute for Geometry and Geodynamics, Vienna) from a nearby weather station. This data included temperature, relative humidity, and solar irradiance for six months of the observation period.

The subjective evaluations of the offices were assessed via interviews. In sum, 35 building users were asked a structured query, containing personal information, perception of the indoor climate and control systems, operation and accessibility of the control systems, energy conscious behaviour and personal preferences. The results of the subjective queries were added to the fitting sections in the result section of this contribution.

Data processing was performed with standard spreadsheet applications and Matlab (2014). Data processing included generation of psychrometric charts out of the 5-minute interval data, and hourly aggregation of the values to couple them with the hourly observation data.

3. Results & Discussion

3.1 Occupancy

Occupancy patterns inside the offices can vary considerably. Figure 6 illustrates the mean occupancy load of the examined offices for a reference day. A heating load per person inside the office was defined via division of the standard load of 100 W (by a person) through the office's total area of 530 m². This value of roughly 0.2 W.m^{-2} was then used as multiplier for the average percentage of occupancy. The reference day shows peaks of occupancy loads around 10 am (11 W.m^{-2}) and on early afternoon (10 W.m^{-2}). Such estimations can be used as input data for detailed numeric building simulation.

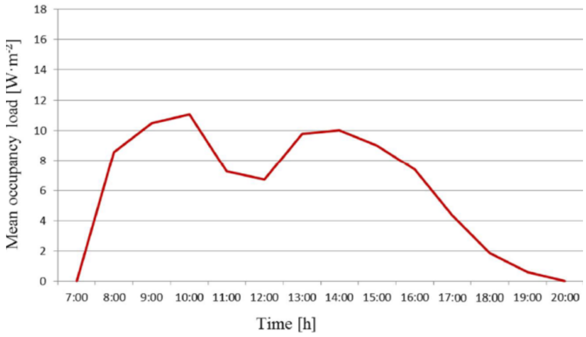

Fig. 6 – Occupancy load on a reference day.

The mean occupancy is 31% during working hours. This reveals that offices are not fully used during the day. An explanation could be that the structure of the people's work often includes external meetings and to be away on construction jobs. Furthermore, the time considered as working hours was assumed from 08:00 am to 07:00 pm, exceeding the average employee's 8-hour day. Moreover, many employees do not work full time but part time, limiting their time in the offices.

3.2 Heating/Cooling Units

A total of 39 heating/cooling units were observed in the 22 monitored offices. The different units vary in the frequency of control actions. Figure 7 shows the number of control actions in relation to the adjusted units. The majority of units were adjusted twice or less during the observation period. It can be said that the status of the heating/cooling units was very seldom changed in the observation period.

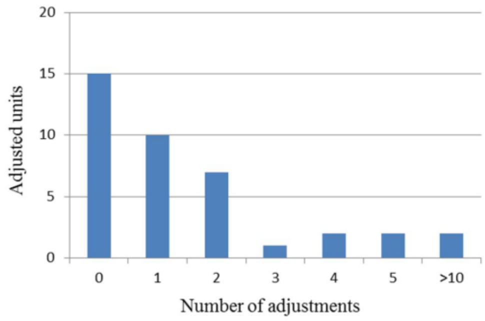

Fig. 7 – Adjusted thermostat units in relation to the number of adjustments over the observation period.

Figures 8 and 9 illustrate the monthly frequencies of attempts to increase and decrease the temperature. In both cases, October showed the highest tendency for control actions to change the internal conditions.

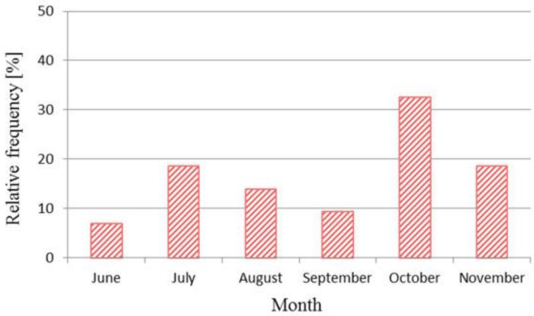

Fig. 8 – Monthly frequency of attempts to increase the temperature

To determine possible correlations between the performed control actions and indoor and outdoor temperatures, the frequencies of control actions were expressed as functions of indoor and outdoor temperatures. Figure 10 illustrates these frequencies.

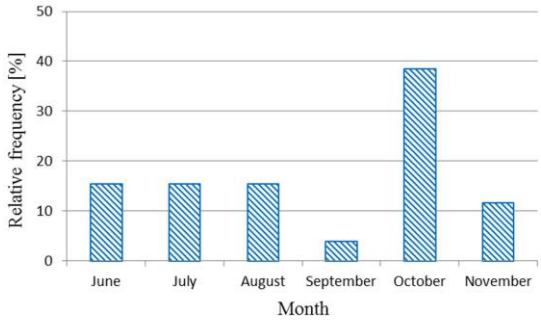

Fig. 9 – Monthly frequency of attempts to decrease the temperature

While attempts to increase temperature occurred for indoor temperatures between 20 and 24 °C and attempts to cool the indoor environment occurred for indoor temperatures between 23 and 28 °C, no clear pattern can be identified. The same is true for the relation between control actions and outdoor temperatures.

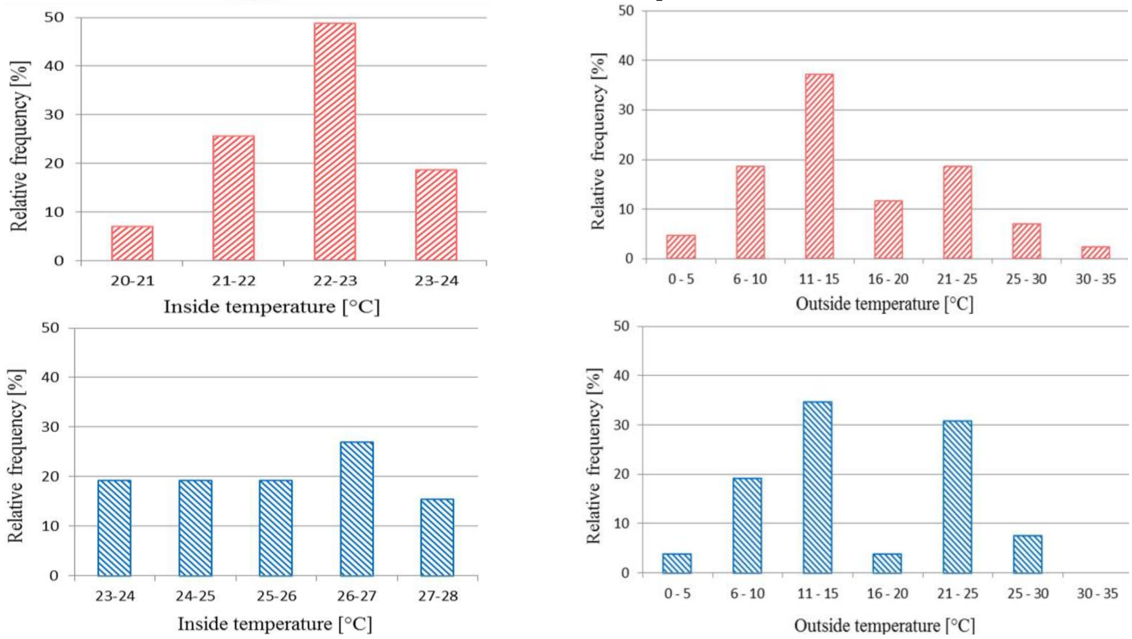

Fig. 10 – Frequency of attempts to increase the temperature as a function of the indoor (up left) and outdoor (up right) temperature. Frequency of attempts to decrease the temperature as a function of the indoor (low left) and outdoor (low right) temperature.

The high number of control actions in October could be explained by the fact that the general system changed from cooling to heating mode in that month. Interviews with the employees (as described in the data collection section) reveal that users mostly think that the adjustment of the control units barely changes the indoor temperatures, and is considered not able to be adapted to personal requirements. Although the building's system was quite well designed for the time of the building's erection, and since then constantly checked and updated, 54% of the building's users consider the improvement of the heating/cooling system in the building as an urgent improvement necessity. Moreover, 80% of the building users felt dissatisfied with the fact that the windows of the buildings cannot be opened and that they are dependent on the fresh air from the heating/cooling and air conditioning units.

3.3 Electrical Lighting

Both the status of the luminaries and the operation of turning on and off the luminaries were examined. The overall mean lighting operation probability of luminaries turned on in SV ranges between 30 and 40% between 8:00 am and 4:00 pm, and drops to 10% at 7:00 pm (Figure 11). To examine the impact of season and orientation on the lighting operation, corresponding data splits were analysed. Figures 12 and 13 illustrate these impacts. Summertime shows significantly lower lighting operation probability. The same is true for east-oriented offices. During the observation period, the different offices showed a probability of between 5 and 100% that the light is turned on when offices are occupied, and a probability of between 0 and 40% that the light is turned on when offices are unoccupied. On average, the luminaries were switched on 56% of the occupied time and 15% of the unoccupied time.

Similar to the mentioned studies before, a high probability of switching the luminaries on could be found at the beginning of the workday: over 70% of all switching on actions were performed between 8:00 and 9:00 am. This seems to be widely independent from the mean global irradiance (Figure 14).

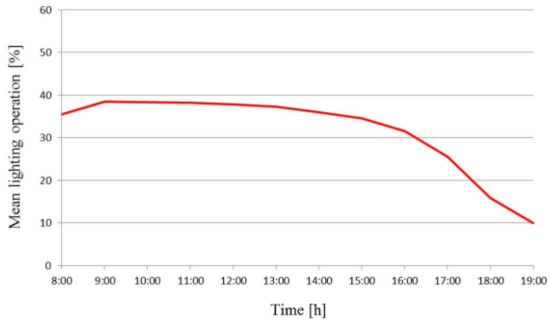

Fig. 11 – Mean lighting operation in the offices of SV

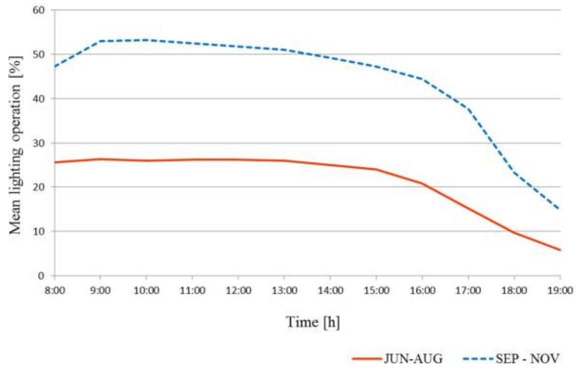

Fig. 12 – Seasonal differences in lighting operation probability

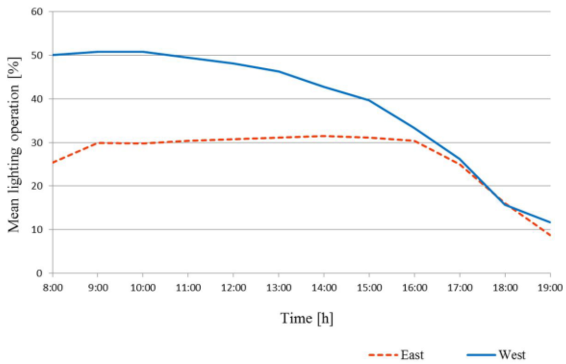

Fig. 13 – Operational differences in lighting operation probability.

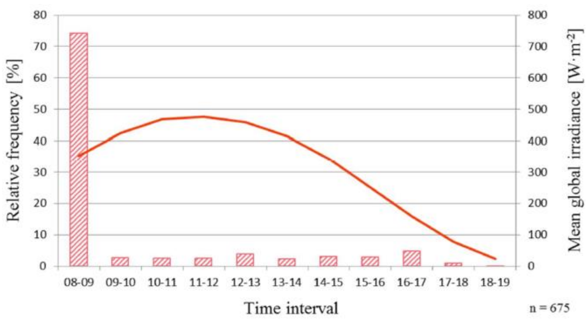

Fig. 14 – Light switching on operations over the course of the day. Line: course of global irradiance.

Furthermore, a correlation between the prevailing illuminance levels inside the offices and the frequency of switching on operations can be seen: the lower the prevailing illuminance is, the higher the probability for switching operation is (for an illuminance between 0 and 100 lux a switching on probability of 73% could be assessed). Switching off operations are high likely to be performed if the occupancy absence is long (71% for absences of over 180 minutes), while medium absence times only show low probabilities of switching the light off.

3.4 Internal Shades

Shading deployment is dependent on season and orientation of the offices. In summer (Jun – Aug) the mean shade deployment ranges on the east façade between 73 and 82% and on the west façade between 61 and 73%. In autumn (Sep – Nov) these values range between 60 and 65% (east) and 60 and 70% (west). A correlation between both global irradiance and outdoor temperature and the deployment of shades could be recognized. Figure 15 illustrates the monthly shade deployment degree in the SV offices and the mean global irradiance.

Concerning the opening and closing of shades, similar to the luminaries, a strong operation could be identified between 8:00 and 9:00 am. Later, the deployment and opening probabilities barely surmount 10%, depending on orientation and corresponding sun penetration.

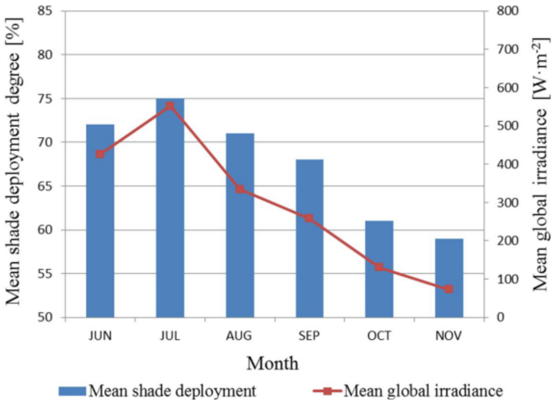

Fig. 15 – Mean monthly shade deployment degree and mean global irradiance.

3.5 Thermal Comfort

Concerning thermal comfort, the majority of observation data points were found to be within the limits of comfort zones. Figure 16 illustrates the psychrometric charts for office no. 2 in all four seasons.

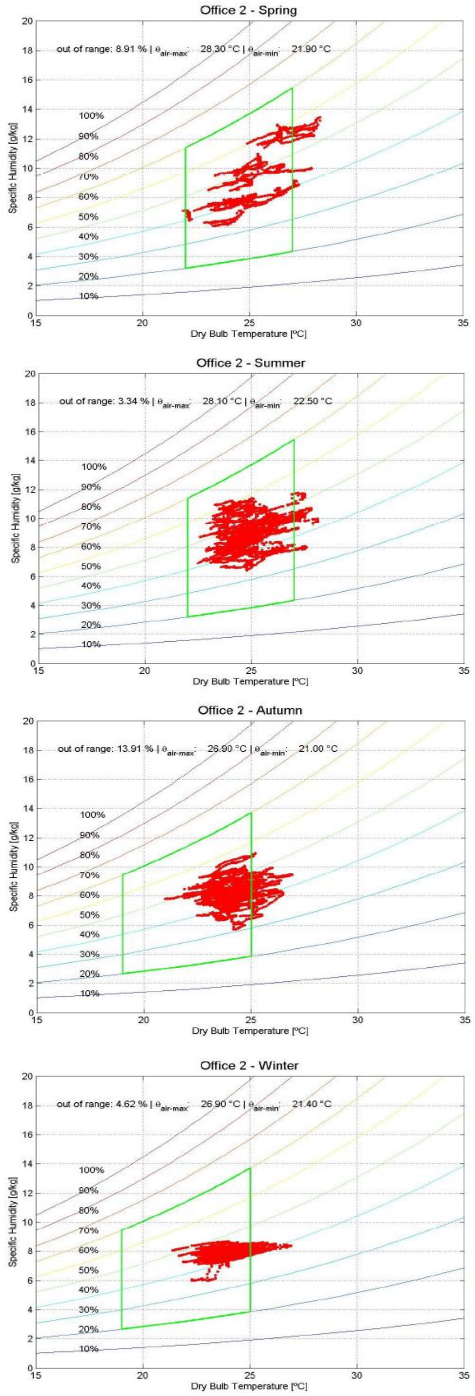

Fig. 16 – Psychrometric charts for office no 2 for spring, summer, autumn and winter

Averaged over all offices, spring months (May – Jun 2013) showed around 8.13% data tuples outside the comfort limits. In summer (Jun–Sep 2013) 3.13%, in autumn (Sep–Dec. 2013) 9.7% and in winter (Dec 2013–Mar 2014) 4.44% of the data tuples were in average found outside of the comfort limits. Detailed graphs can be found in Seres (2014).

4. Conclusion

This contribution analysed system operation and user behaviour patterns in the offices of a mechanically ventilated building. Results show distinctive patterns: for instance, the lighting load profile and the mean occupancy profile are not similar to each other, portraying that users do not show a very energy conscious behaviour. Even if the indoor climate conditions in the building stay within the comfort limits, users show a big dissatisfaction with the HVAC system.

The findings of this study are expected to increase the knowledge of user behaviour in office buildings. This potentially will help to model user behaviour in numeric thermal building simulation.

Future research in the field of user behaviour should focus on a larger sample of buildings with different geographical and cultural backgrounds. This could improve the understanding of control-oriented behaviour and the human factor of buildings.

Furthermore, the results of the multitudes of studies conducted on human behaviour in buildings could be unified and compared based on the research methodology. As a long-term goal, research efforts could adopt the best approaches of the different research techniques to develop a unique and ubiquitous method for developing occupancy models through building observation. Such a standardized assessment method would ease further investigation in the field of occupancy monitoring and occupancy modelling.

References

Boyce, P. 1980 Observations of the manual switching of lighting. *Lighting Research & Technology* 12(4): 195-205

Bülow-Hube, H. 2000. *Office worker preferences of exterior shading devices: a pilot study*. EuroSun2000. June 19-22, Copenhagen, Denmark

Carter, D., Slater, A. & Moore, T. 1999. *A study of lighting in offices equipped with occupant controlled systems*. Proceedings of the 24th Session of CIE, Warsaw, Poland; CIE, Vienna, Austria: 1999; 108-110, 1(2).

Hunt, D. 1979. The use of artificial lighting in relation to daylight levels and occupancy. *Building Environment* 14, 21-33

Inoue, T., Kawase, T., Ibamoto, T., Takakusa, S. & Matsuo, Y. 1988. The development of an optimal control system for window shading devices based on investigations in office buildings. *ASHRAE Transaction* 94, 1034-1049

Mahdavi, A., Suter, G., Pröglhöf, C., Mohammadi, A., Lambeva, L., & Kabir, E. 2007. *People as power plant – Final Report*. Energiesysteme der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Projektnummer 80808563-8846

Matlab 2014. http://de.mathworks.com/ (last accessed Nov 2014)

Pigg, S., Eilers, M., Reed, J. 1996. Behavioral aspects of lighting and occupancy sensors in private offices: a case study of a university office building. Proceedings of the 1996 ACEEE Summer Study on Energy Efficicency in Buildings, 8.161-8.171

Rea, M.S. 1984. Window blind occlusion: a pilot study. *Building & Environment* 19(2), 1984, 133-137

Reinhart, C. 2001. *Daylight availability and manual lighting control in office buildings – simulation studies and analysis of measurements*. PhD.-Dissertation, University of Karlsruhe, Germany

Reinhart, C. & Voss, K. 2003. Monitoring manual control of electric lighting and blinds. *Lighting Research & Technology* 35(3), 243-260

Rubin, A.I., Collins, B.L., & Tibbott, R.L. 1978. *Window blinds as potential energy saver – a case study*. NBS Building Science Series, Vol. 112, National Institute for Standards and Technology, Gaithersburg, MA, USA.

Seres, L. 2014. User's Behaviour and Perception of the Indoor Climate in a mechanically ventilated office Building. Diploma Thesis, Vienna University of Technology, 2014.