Aspects of uncertainty in representation of occupants' diversity in building performance simulation

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Abstract

Recently, increased efforts have been invested to enhance the sophistication of occupancy modelling approaches in building performance simulation. However, the effectiveness of such approaches depends on the robustness of the underlying empirical information. Thereby, an important question pertains to the existence and level of inter-individual differences in occupancy patterns. In the present contribution, we use a repository of monitored occupancy data in an office building to address this problem empirically. The results of the study facilitate a discussion of the diversity in observed occupancy profiles and the implications for relevant occupancy models in building performance simulation.

1. Introduction

Given the impact of occupants on building performance, modelling occupants' presence and behaviour is one of the critical topics in the studies pertaining to building performance simulation (Mahdavi 2011). Specifically, numerous libraries of typical occupancy profiles (see, for example, ASHRAE 2013, Davis et al. 2010, Duarte et al. 2013) and a number of probabilistic and non-probabilistic models (e.g., Reinhart 2001, Page et al. 2008, Richardson et al. 2008, Mahdavi et al. 2015) have been proposed to represent the complex nature of occupancy patterns in building performance simulation tools. In this context, one important open question concerns the differences between building occupants with regard to their patterns of presence. Independent of the characteristics of the proposed and applied occupancy models, the diversity of occupants and its implications must be addressed, lest systematic representation of occupancy processes in building performance simulation would not be warranted.

While extensive and comprehensive occupancy information is rarely available for model development purposes, systematic statistical analyses of existing data can improve the state of art in consideration of occupancy diversity in respective modelling efforts. Knowledge of the diversity among the occupants and corresponding models could also help to bring about a proper balance between simulation accuracy and computational costs by selecting the optimum sample size and targeting for the suitable complexity level in occupancy-related models.

Given this background, the present study focuses on the extent of uncertainty related to occupancy related events in office buildings (e.g., arrivals, short-term absences, departures). Specifically, observational occupancy data are used to explore if and to which extent event-related uncertainties may be influenced by the diversity of individual occupancy patterns. Toward this end, occupancy-related data obtained from a university campus office area were subjected to statistical analysis. The office area is equipped with a monitoring infrastructure and accommodates a number of staff in administrative and academic positions. Long-term high-resolution monitored occupancy data from a number of workspaces in this office area was obtained.

2. Methodology

For the purpose of the present study, we use data obtained from an office area in a university building in Vienna, Austria. This office area is equipped with a monitoring infrastructure to continuously collect data on indoor environmental conditions, state of devices (luminaires, radiators, windows and doors), and occupancy (presence). Specifically, we present and discuss here data regarding the presence of eight occupants who work in this area. The occupants include both academic and administrative staff, and both faculty members and graduate students. The area layout includes a single-occupancy closed office, two single-occupancy semi-closed offices, and an open plan office area.

The occupancy data have been obtained via wireless ceiling-mounted sensors (motion detectors). The internal microprocessors of the sensors are activated within a time interval of 1.6 minutes to detect movements. The resulting data log entails a sequence of time-stamped occupied to vacant (values of 0) or vacant to occupied (values of 1) events. To facilitate data analysis, the event-based data streams were processed to generate 15-minute interval data. This procedure derives the duration of occupancy states (occupied / vacant) from the stored events and returns the dominant occupancy state of each interval. Occupancy periods before 8:00 and after 19:45 were not included in the study to exclude, amongst other things, the presence of janitorial staff at the offices. Occupancy data for a 35-month period (April 2011 to February 2014) were used to conduct the current study.

Data was analysed via basic means of visualisation and descriptive statistics. The results are expressed in terms of the following indicators:

- First arrival time (FA)
- Last departure time (LD)
- Occupancy duration (OD)
- Number of transitions (NT)

The first arrival time (FA) and last departure time (LD) are derived by detecting the first and last occupied 15-min intervals in a day. The occupancy duration (OD) is calculated by counting the number of occupied intervals in a day. Number of transitions (NT) represents the number of daily occupied-to-vacant transitions.

Note that, given the very small number of occupants, the present analysis is merely of exploratory nature. The idea is to obtain a first impression of the critical issues and examine the structure of the research conducted as a starting framework for future – more detailed and more comprehensive – studies.

3. Results

Table 1 summarizes the eight occupants' presence monitoring results in terms of six basic statistics, namely mean, standard deviation, coefficient of variation (CV), median, mode, and interquartile range for the four indicators (FA, LD, OD, and NT). Despite the small number of occupants, the values of the four indicators for all occupants were displayed in terms of box plots. Figures 1 and 2 provide two instances of such box plots (for FA and NT).

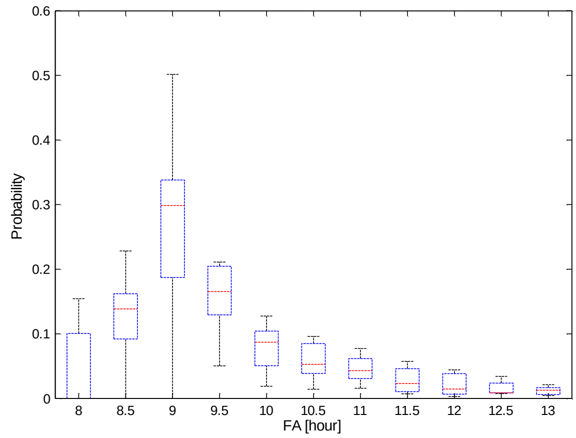

Fig 1 – First arrival time boxplot

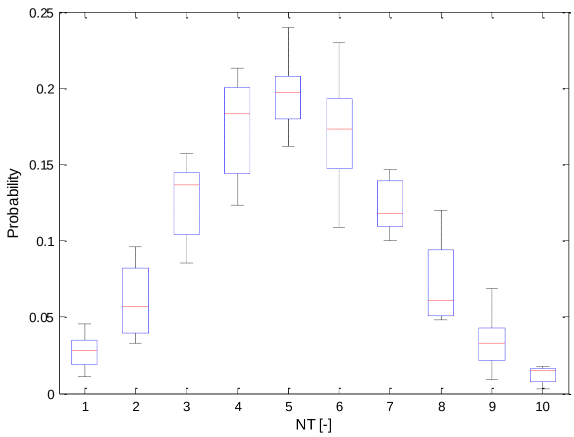

Fig. 2 – Number of transitions boxplot

Table 1 – Summary of the statistical analysis results

Indicators	Statistical measures	Occupants							
		P1	P2	P3	P4	P5	P6	P7	P8
FA	*mean*	11.1	8.7	9.7	9.8	9.6	10.0	10.0	9.4
	median	10.75	8.25	9.25	9.50	9.25	9.50	9.63	9.25
	standard deviation	1.2	1.1	1.2	1.3	1.4	1.4	1.4	0.8
	mode	10.8	8.3	8.8	9.3	9.3	9.3	9.0	9.3
	CV	0.11	0.13	0.13	0.13	0.15	0.14	0.14	0.08
	IQR	0.75	0.75	1.00	1.00	1.00	1.50	1.75	0.50
LD	*mean*	18.0	16.7	18.2	18.0	17.7	17.6	18.3	16.2
	median	18.25	17.00	18.50	18.50	18.25	17.75	18.50	16.50
	standard deviation	1.4	0.9	1.6	1.7	1.8	1.7	1.2	1.2
	mode	18.8	17.3	20.0	19.3	19.0	17.8	18.8	17.3
	CV	0.08	0.05	0.09	0.09	0.10	0.09	0.07	0.07
	IQR	1.88	0.75	2.00	2.00	2.25	2.00	1.25	1.25
OD	*mean*	3.3	4.4	4.0	3.9	3.7	3.4	3.9	3.2
	median	3.25	4.50	4.00	3.75	3.75	3.25	3.75	3.25
	standard deviation	1.3	1.4	1.4	1.5	1.4	1.3	1.2	1.0
	mode	3.0	4.8	4.3	3.3	3.8	3.3	3.5	2.5
	CV	0.40	0.31	0.36	0.37	0.37	0.39	0.31	0.31
	IQR	2.00	1.75	2.00	2.00	1.75	1.75	1.75	1.50
NT	*mean*	4.7	5.4	5.6	4.9	5.0	4.8	5.6	4.9
	median	5.00	5.50	6.00	5.00	5.00	5.00	6.00	5.00
	standard deviation	1.9	1.9	2.2	2.1	2.1	2.0	1.9	1.7
	mode	4.0	6.0	5.0	5.0	6.0	4.0	6.0	5.0
	CV	0.40	0.34	0.40	0.43	0.41	0.42	0.34	0.34
	IQR	3.00	3.00	3.00	3.00	2.00	3.00	3.00	2.00

4. Discussion and conclusion

The monitoring results and the associated statistics support a number of observations:

- Some indicators (OD, NT) appear to display a normal (symmetrical) distribution pattern, whereas others (FA, LD) are non-symmetric. Specifically, as one could expect, FA is left skewed (most arrivals before noon) and LD is right skewed (most departures after noon).
- The skewedness of FA and LD is not well represented in the statistical mean, but the position of median (and mode) with regard to mean provides pertinent information. For instance, in case of FA, all median and mode values are smaller than mean, whereas in case of LD, median and mode values are consistently larger than mean. This observation is also consistent with the relative magnitude of the interquartile range and the mean values. The former values are smaller in the FA case whereas they are larger in the LD case.

- The values of the standard deviation and CV suggest a larger spread of data in case of the OD and NT as compared to FA and LD.
- When thinking about the level of the diversity amongst the occupants, the following impression emerges: In those cases, where the inter-individual differences appear to be large, the absolute magnitude of variance is rather small (FA, LD). On the other hand, in those cases where the absolute magnitude of variance is larger (OD, NT), the inter-individual differences are relatively small. This observation, if confirmed by future studies (involving larger sets of occupants in a multitude of buildings), could imply that the inter-individual differences amongst occupants' presence patterns do not necessarily represent a major statistically relevant concern.
- The indicator NT shows remarkable consistency across multiple occupants (as expressed in the values of almost all statistics considered). Again, one could cautiously suggest that this indicator might display – to a certain degree – values that are fairly consistent across multiple occupants

5. Acknowledgement

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References

ASHRAE, 2013. ASHRAE 90.1-2013 Appendix G. Building Performance Rating Method, ASHRAE.

Davis, J.A., Nutter, D.W., 2010. Occupancy diversity factors for common university building types, Energy and Buildings 42 (2010) 1543–1551.

Duarte, C., Wymelenberg, K.V.D., Rieger, C., 2013. Revealing occupancy patterns in an office building through the use of occupancy sensor data, Energy and Buildings 67 (2013) 587–595.

Mahdavi, A., 2011. People in building performance simulation, in J. Hensen, R. Lamberts (Eds.), Building Performance Simulation for Design and Operation, Taylor & Francis, New York, ISBN: 9780415474146, pp. 56-83.

Mahdavi, A., Tahmasebi F., 2015. Predicting people's presence in buildings: An empirically based model performance analysis, Energy and Buildings 86 (2015), pp. 349–355.

Page, J., Robinson, D., Morel, N., Scartezzini, J. L., 2008. A generalized stochastic model for the simulation of occupant presence, Energy and Buildings 40 (2008), pp. 83–98.

Reinhart, C.F., 2001. Daylight availability and manual lighting control in office buildings simulation studies and analysis of measurements, Ph.D. thesis, Technical University of Karlsruhe, Germany.

Richardson I., Thomson, M., Infield, D., 2008. A high-resolution domestic building occupancy model for energy demand simulations, Energy and Buildings 40 (2008), pp. 1560–1566.