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On the utility of occupants' behavioural diversity information for building performance simulation: An exploratory case study

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ABSTRACT

The present study aims at investigating the potential advantages of integrating inter-occupant diversity information into occupant behaviour models used in building performance simulation. To this end, the authors model the operation of windows by occupants in a monitored open-plan office at aggregate and individual levels. The models use indoor and outdoor temperature as well as the interaction of these variables to estimate the probability of opening and closing windows in the building located in Vienna, Austria. Subsequently, a number of existing and novel metrics serve to compare the predictive performance of the aggregate and individual models. In addition, a calibrated energy model of the office area incorporates the window operation models to evaluate their potential contribution to the reliability of building performance assessments. The results of this exploratory case study suggest that individual window operation models outperform the aggregate model in capturing the peak and variations of window operation across occupants. This resulted in a more reliable thermal comfort assessment in the free-running season. The individual models, however, overestimated peak heating demand, as compared with the benchmark value resulting from the actual window operations in a single year.

1. Introduction

A number of empirical and simulation-aided studies have addressed the possible impact of occupants on the buildings' environmental and energy performance [1,2,3,4]. The role of occupant behaviour has been also highlighted as one of the contributing factors in cases of mismatch between the predicted and measured energy performance of buildings [5,6]. Consequently, the building simulation community has increased its efforts to improve the reliability of simulation tools through more advanced (e.g., probabilistic) representations of occupant behaviour in buildings [7,8,9]. However, several studies have demonstrated that the use of existing occupant behaviour models involves considerable uncertainties and does not necessarily lead to a more reliable building performance assessment [10,11]. Specifically, it is shown that without proper treatment of the diversity in occupants' behaviour, probabilistic occupancy-related models fail to provide representative ranges of occupant behaviour possibilities as intended [12,13]. To address this issue, different approaches for inclusion of diversity in occupant behaviour modelling efforts have been examined: *i)* Clustering of occupant types [14], *ii)* Random selection of occupancy-related traits while maintaining the correlations between the traits [12], *iii)* Use of the errors associated with estimated coefficients of the aggregate data models [15], and *iv)* Developing models for each occupant together with meta-models defining the distribution of model coefficients [16,17]. However, it has been also suggested that for specific cases, such as large open-plan offices [18], a detailed treatment of occupants' diversity may not be beneficial. Consequently, further studies in this area are needed, as the potential benefits of supplying probabilistic occupant behaviour models with inter-occupant diversity information are not conclusively established. In this context, the current contribution revisits the problem through an explorative case study. Specifically, the study explores two essential questions with regard to the use of probabilistic window operation models: To which extent do the predictions of window operation models that do not reflect behavioural diversity differ from actually observed occupants' behaviour? To what degree does the inclusion of occupants' behavioural diversity enhance the building models' potential to provide reliable estimations of key building performance indicators?

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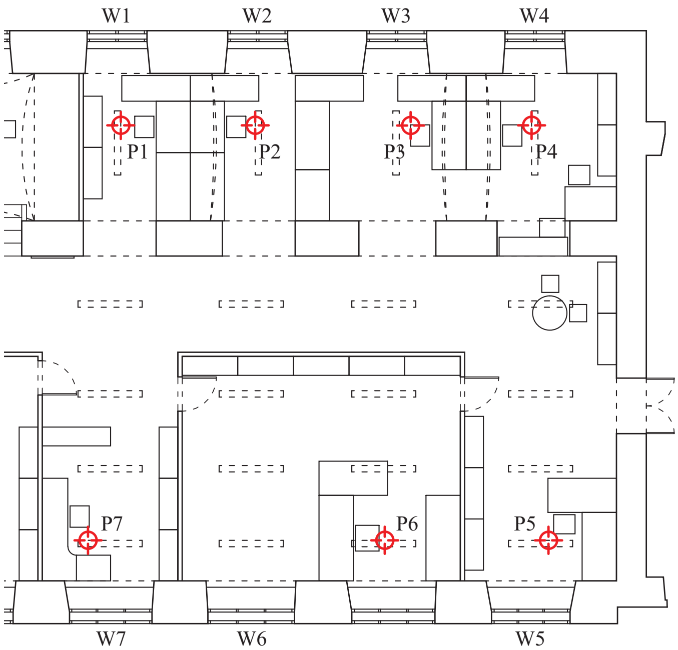

Fig. 1. Schematic illustration of the office area, observed occupants and operable windows.

Table 1
Basic information on the office area and modelling assumptions.

Building data / Modelling assumptions	Value
Net conditioned floor area [m^2]	187.6
Gross wall area [m^2]	120.1
Average window-wall ratio [%]	26.7
Exterior walls U-value [$W.m^{-2}.K^{-1}$]	0.65
Exterior windows U-value [$W.m^{-2}.K^{-1}$]	2.79
Exterior windows SHGC [-]	0.77
Number of occupants [-]	7
Maximum lighting power density [$W.m^{-2}$]	4.1
Maximum equipment power density [$W.m^{-2}$]	9.9
Number of operable windows [-]	7
Windows discharge coefficient when open [-]	0.28
Windows air mass flow coefficient when closed [$kg.s^{-1}.m^{-1}$]	4.15×10^{-4}

2. Method

2.1. Overview

The present study uses long-term monitored data on indoor and outdoor environment and state of windows in an open-plan office area to model the occupants' operation of windows with and without integration of inter-occupant variations in this regard. Subsequently, using the monitored window operation data, a calibrated model of the office area, and a number of existing and novel metrics, the study investigates if modelling the inter-occupant diversity in operation of windows contributes to a more reliable building performance analysis.

2.2. Building and observational data

The current study focuses on an office area with seven workstations in Vienna, Austria, where each occupant has access to one manually operable casement window (Fig. 1). Six of these workstations are in an open-plan area. In this area, the placement of furniture between working places defines separate zones with one window for each occupant. The air, however, can freely flow across the entire open-plan area. The building is not air-conditioned and it only uses a hydronic heating system to actively maintain thermal comfort in the cold season. In this office, the occupants' presence, state of windows and several environmental parameters (including indoor and outdoor air temperature) are monitored on a continuous basis. The study uses the monitored data from a calendar year (referred to as estimation period) to derive the window operation models. A separate set of data obtained from another calendar year (referred to as validation period) is used to evaluate the performance of the models.

2.3. Office area calibrated simulation model

The office area was modelled in the building energy simulation tool EnergyPlus 8.8.0. In the zoning scheme, the open-plan south and north-oriented spaces were separated from the central corridor. However, using the network-based multi-zone airflow model of EnergyPlus, the airflows across the external windows and the connected spaces were simulated. The constant input parameters governing airflow simulation in the EnergyPlus model (namely open windows discharge coefficient and closed windows air mass flow coefficient) were set based on a previous model calibration effort [19]. Table 1 summarizes the basic information about the calibrated office area energy model.

The calibrated building simulation model served as a test bed for evaluation of window operation models with consideration of models' feedback, i.e. the impact of models' output (window states) on models' input (indoor temperature). The building model also made it possible to determine the implications of window operation (and use of different window operation models) for the values of relevant building performance indicators. To this end, the monitored data streams of occupants' presence and use of lights and equipment in the validation year were fed into the model. In addition, the aggregate and individual window operation models (see Section 2.4) were successively integrated into the building model using EnergyPlus runtime language. The study also benefited from a benchmark building model, which contained the actual states of windows based on the monitored data obtained in the validation period. Moreover, the building model was exposed to the outdoor environmental conditions in the validation period using a weather data file generated from on-site weather station measurements. The measured dataset included outdoor air temperature, air humidity, atmospheric pressure, global horizontal radiation, diffuse radiation, wind speed, and wind direction. Lastly, due to the stochastic nature of the window operation models, the building model was simulated 50 times to obtain representative ranges of outputs.

It should be also noted that, an ideal unlimited heating system is set in the model to maintain the temperature of different zones according to the measured indoor temperatures in the validation period and to estimate the space heating demands. However, since such a system fully counteracts the impact of window openings, the building model is not strictly applicable to evaluation of window operation models in heating season. Therefore, for the purpose of the current study, the performance of window operation models (in terms of their primary predictions of window states) is only considered in the free-running season (from April 22 to September 25).

2.4. Window operation models

To explore the research questions, the authors developed the following two types of window operation models based on the monitored data in the estimation period: