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Published in:
Conference Proceedings

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Forgiarini Rupp, R., Andersen, R. K., Toftum, J., & Ghisi, E. (2021). Understanding occupants' behaviour and the mixed-mode strategy in office buildings in southern Brazil. In *Conference Proceedings: BEHAVE 2020-2021* (pp. 66-70)

4.2 Understanding Occupants' Behavior and the Mixed-Mode Strategy in Office Buildings in Southern Brazil

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KEYWORDS

mixed-mode buildings, behaviour, subtropical climate

1. Introduction

Occupants' behaviour is one of the most important factors to impact on indoor building environments and energy use[1]. Studies have shown that there is a gap between predicted and actual energy use due to poor consideration of the occupants' behaviour[2,4]. The objective of this study is to improve understanding of occupants' behavior and describe a mixed-mode strategy for ventilating and climatizing office buildings in southern Brazil. Mixed-mode or hybrid ventilated buildings integrate the natural ventilation and the air-conditioning system by responding to thermal conditions (e.g., through an automation system) or through occupant intervention (e.g., opening windows). Models of adaptive behaviour often focus on actions aimed at adapting the environment to the occupant's needs (e.g. window and solar-shading operations, adjusting thermostats, etc.)[5,8]. Few papers have focused on actions aimed at occupants' adaptation to the prevailing conditions such as adjusting one's clothing or the consumption of hot and cold beverages[9,10]. In this work, we intend to go beyond the typical behavioural models of building simulation to provide insights into other adaptive actions, such as changing clothes and drinking habits during working hours.

2. Method

This research is based on data collected during two years in three mixed-mode office buildings located in southern Brazil. The buildings are located in the humid subtropical climate of Florianópolis (latitude: -27° 36′, longitude: -48° 33′ and altitude: 7m). The mixed-mode strategy was manually controlled, that is, the occupants decided themselves when to shift between natural ventilation and air-conditioning (AC) mode.

Classic field studies were carried out of thermal comfort, along with simultaneous indoor environmental measurements and the circulation of questionnaires. The detailed methodology and the results were published in[11]. Questionnaires included background questions and asked the occupants about their thermal perceptions and adaptive actions (e.g., drink intake and clothes adjustments) just before answering the survey. During the field studies, the researchers monitored the operation of the AC system, fans and windows, and occupants' drink intake and clothes adjustment in real time and then analysed these data.

In order to understand occupants' behaviour and the principle of mixed-mode operation, multiple logistic regressions were performed with environmental variables (e.g., indoor and outdoor temperatures) as predictors, and windows, fans or AC operation as the binary outcome (0 = windows closed, fans off or AC system off; 1 = windows open, fans on or AC system on). Also, four sets of multiple logistic regression analyses were conducted with environmental variables and thermal responses (e.g., thermal sensation vote) as predictors and drink intake (hot or cold beverages) or clothes adjustments (adding or removing an item of clothing) as the binary outcome (Table 1). We also performed simple logistic regression between the outdoor temperature and AC operation with the aim of providing some guidance for building energy simulation practitioners.

3. Results and Findings

The data we collected consist of 5,470 indoor environmental measurements linked to subjective data and behavioural observations.

We found that the probabilities of either adding or removing an item of clothing were associated with the thermal sensation vote and the outdoor air temperature (Table 1). The probability of drinking a cold beverage was associated with the indoor operative temperature, outdoor temperature and mode of operation (natural ventilation or AC) (Table 1). The probability of drinking a hot beverage was related to the thermal sensation vote and indoor operative temperature (Table 1), but this model cannot be generalized beyond the actual data due to local cultural aspects influencing the consumption of hot beverages. A statistically significant model was not achieved for the fan operation.

The outdoor temperature and indoor operative temperature were strong predictors of AC operation (Table 2). The AC operation (i.e., AC is turned on) is 2.09 times (OR=2.09) more likely to happen for each 1.0ºC increase in the outdoor temperature. In contrast, the AC operation is 0.64 times less likely to happen for each 1.0ºC increase in the indoor operative temperature.

The negative association between indoor temperature and AC operation may lead to the counterintuitive conclusion that occupants were less likely to turn on the AC at high temperatures. However, the negative correlation may simply be an effect of the lower indoor temperatures caused by AC. As a consequence, measurements of indoor conditions cannot be used to predict the AC operation, since they are affected by the variable they are predicting. In contrast, climate data used for building energy simulation is not affected by the AC operation and may be used as a predictor. We derived a logistic model that treated only the outdoor temperature as a predictor of AC operation. Figure 1 shows the probability of AC operation as a function of the outdoor air temperature. As expected, the AC operation occurred mainly in warmer outdoor conditions. Above 25.0°C it was highly likely (>90% probability) that offices relied on cooling. Below 19.0°C, there was a lower probability (<10%) that the AC was operating.

Table 1.

Logistic regression models of drink intake and clothing adjustments as a function of environmental variables and thermal responses.

Outcome variable	Binary outcome	Logistic model
Probability of drinking a hot beverage - P(Hdri)	0 - Drank nothing 1 - Drank a hot beverage	$P(Hdri) = \frac{1}{1 + e^{-(1.55 - 0.16To - 0.13TSV)}}$
Probability of drinking a cold beverage - P(Cdri)	0 - Drank nothing 1 - Drank a cold beverage	$P(Cdri) = \frac{1}{1 + e^{-(-3.78 - 0.27MO + 0.09To + 0.05Text)}}$
Probability of adding an item of clothing - P(Aclo)	0 - No clothes changed 1 - Add an item of clothing	$P(Aclo) = \frac{1}{1 + e^{-(-1.99 - 1.15TSV - 0.11Text)}}$
Probability of removing an item of clothing - P(Rclo)	0 - No clothes changed 1 - Remove an item of clothing	$P(Rclo) = \frac{1}{1 + e^{-(-0.93 + 0.84TSV - 0.16Text)}}$

Note: all parameters and models with $p<0.001$. N=5,470. *To:* indoor operative temperature; *Text:* outdoor air temperature; *TSV:* thermal sensation vote (seven-point scale from -3 to +3); *MO:* mode of operation (0=Natural ventilation; 1=AC).

Table 2.

Logistic regression model of air-conditioning operation as a function of outdoor temperature and indoor operative temperature.

AC operation	Coefficients (*b*)			95% CI of Odds Ratio (OR)		
Predictors	*b*	Wald	Sig.	Lower	OR	Upper
Outdoor temperature (°C)	0.74	1168.87	*p*<0.001	2.00	2.09	2.18
Indoor operative temperature (°C)	-0.45	163.87	*p*<0.001	0.59	0.64	0.68

Note: Model intercept= -4.91, p<0.001. Model $\chi^2(2)=3058.96$, $p<0.001$. $R^2=0.57$(Nagelkerke). *N*=5,470.

4. Discussion and Conclusions

The study produced some insights into occupants' behaviour, such as patterns of changing clothes and drink-intake habits. Further studies are needed to assess the impact of such actions on workers' productivity and well-being and to perform a thorough evaluation of the indoor environmental quality (e.g., air quality) of mixed-mode buildings.

Figure 1 may provide a better understanding of the mixed-mode strategy in office buildings in southern Brazil. As expected, the air-conditioning was more likely to be operating in warmer outdoor conditions. A logistic model was generated for office buildings in southern Brazil, which may be used as input to building simulations, improving the prediction of energy use. It is important to stress that during the field studies more than 80% of the occupants reported being in thermal comfort, i.e., the mixed-mode strategy provided good indoor thermal conditions. In the studied climate, it was predicted that mixed-mode buildings could save 30-35% of energy used for climatization in comparison with fully air-conditioned buildings[12]. Besides the energy savings potential, this work shows that adoption of the mixed-mode strategy provided thermal comfort to occupants.

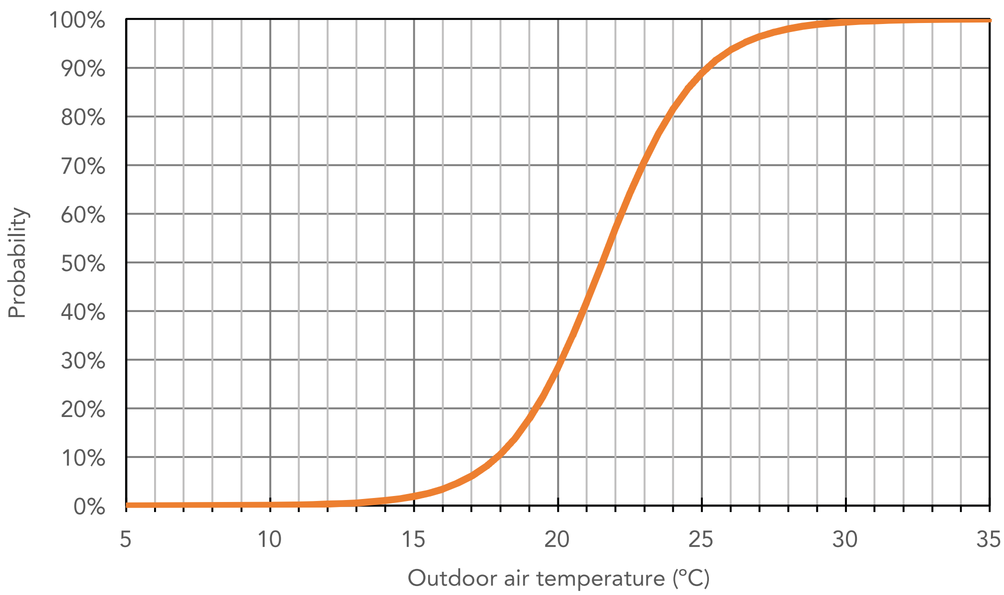

Figure 1.

Probability of air-conditioning operation as a function of the outdoor air temperature for mixed-mode office buildings in southern Brazil (Logistic model intercept= -12.99; b=0.60, p<0.001).

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