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Published in:
NSB 2023 - Book of Technical Papers: 13th Nordic Symposium on Building Physics

DOI (link to publication from Publisher):
10.54337/aau541563857

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Unspecified

Publication date:
2023

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

Link to publication from Aalborg University

Citation for published version (APA):
Tuniki, H. P., Bekö, G., & Jurelionis, A. (2023). Using Adaptive Behaviour Patterns of Open Plan Office Occupants in Energy Consumption Predictions. In H. Johra (Ed.), *NSB 2023 - Book of Technical Papers: 13th Nordic Symposium on Building Physics* (Vol. 13). Article 144 Department of the Built Environment, Aalborg University. https://doi.org/10.54337/aau541563857

Using Adaptive Behaviour Patterns of Open Plan Office Occupants in Energy Consumption Predictions

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Abstract. One of the factors that affects energy consumption in buildings is the level of control that occupants have over their environment, as well as their adaptive behaviour. The aim of this study was to focus on the adaptive clothing behaviour pattern, and to analyse its impact on energy consumption when integrated into a dynamic energy prediction tool. A questionnaire survey was conducted in an office building to collect the occupant behaviour data. The occupant clothing levels and the window opening behaviour were integrated into the dynamic energy performance prediction software, IDA ICE. The results of the simulations showed that the impact of adaptive clothing behaviour on energy consumption is relatively small, but it can meaningfully improve thermal comfort. Including adaptive behaviour in energy simulations can help in improving the accuracy of the energy performance and comfort predictions.

Keywords: adaptability; open plan office; clothing adaptation; window-opening behaviour; building energy consumption.

1. Introduction

As buildings contribute to about 40% to the global CO_2 emissions, it is an ever increasingly important task to make them energy efficient [1]. Occupant behaviour meaningfully contributes to the building's energy consumption. Energy performance simulation tools enable energy consumption predictions, however, the accuracy of the simulation results is often different from the real energy consumption. This difference is termed the energy performance gap, which needs to be addressed to make prediction results more accurate [2]. One of the main challenges in building modelling and energy studies has been to study and develop new ways to reduce the performance gap to an acceptable margin of error. An investigation of 23 buildings revealed a 34% higher actual energy consumption value than the predicted, with a standard deviation of 55% [3]. Studies reveal that the actual building energy consumption could be up to two times higher than the predicted value [4]. There are a couple of underlying causes for this gap, which were identified in a review [3], such as deterioration of the building systems, occupant behaviour, equipment malfunctioning, limitations in the measurement system, etc. Among these causes, the factor having a considerable impact on the energy predictions is the occupant behaviour. As behaviour is a subjective quantity, it varies depending on the region or location of the building, purpose of the building, income disparity and a wide range of other factors. To analyse this, various methods and tools have been employed, which include stakeholder collaboration [5], Post-Occupancy Evaluation studies [6], etc. But the most common tool used for behaviour studies are the occupant surveys, which could be conducted to understand the energy consumption patterns that can be attributed to occupant behaviour. These patterns, if identified and transferred into the building energy performance predictions, could have a meaningful impact on the performance. Additionally, occupant behaviour patterns can help in making better energy related decisions for the facilities managers. There are several patterns that impact the energy consumption of the building, such as, lighting usage, temperature preferences, HVAC usage, etc. In most office buildings, the energy demand is higher due to increased number of occupants indoors. Studies show that the impact of the window opening behaviour on the energy use is comparatively low [7]. But, in general, it is not common to operate the windows in central air-conditioned buildings [8]. This study aims to quantify the effect of occupant behaviour patterns on the predicted energy consumption, with focus on clothing adaptation and window opening behaviour.

2. Methodology

The field study was conducted in a mechanically ventilated office in the south Indian city of Hyderabad. The building was located 20 km away from the city centre. The study was conducted in the summer season in the month of May 2022. The office on the third floor of the building which was run by an architecture firm with a seating capacity of 90 occupants with workstations and about 15 visitors per day. Since the office required the employees to work on computers, their physical activity level within the office was low. As per ASHRAE 55 [9], their MET value was between 1.2 and 1.4. The office had a Variable Refrigerant Flow (VRF) HVAC system installed for the open office spaces. The specifications and the details of the office are summarized in Table 1.

Table 1. Description of the analysed office

Area	700 m^2
Energy consumed for the month of May 2022 (as per energy meter)	14,446 kWh
No. of workstations	90
Equipment	Computers, 3D Printers, Laser printers
Cooling capacity of the HVAC system	• 30 kW VRF system for the open plan area • 19 kW VRF system for the cabins

2.1. *Questionnaire survey*

An online questionnaire survey was sent to all the occupants in the office floor, and about 62 responses were received from the occupants. The survey was designed to collect information about indoor air quality perception and comfort, thermal sensation, thermal comfort, and thermal preferences of the occupants, Sick-Building Syndrome (SBS) symptoms, etc. The questions were framed following the guidelines specified in the ASHRAE 55 standard [9]. Possible answer choices varied from “Very uncomfortable” to “Very comfortable”, “Very hot” to “Very cold”, etc. depending on the type of the question. The first page of the survey contained questions related to the basic details of the occupants (age, gender, working hours, etc.). The second page of the survey contained questions about the occupants’ current perception of the indoor environment at the time of filling the survey. The same questions were repeated on the third page of the survey, but with respect to the whole year, considering seasonal variations (winter, summer, autumn, and monsoon). The final page consisted of questions regarding the adaptive behaviour of the occupants; the questions focussed on the adjustments that the occupants prefer to undertake when feeling uncomfortable and on the frequency of the adaptation.

2.1.1. *Dynamic simulation software*

The software IDA ICE (Indoor Climate and Energy) v5.0 was used for the building energy simulations. It has been validated by the European Committee for Standardization (CEN) EN 15265-2007 and EN 15255-2007 [10] [11]. The office floor used for the simulations has been designed in IDA ICE as shown in Figure 1. The model was calibrated using the detailed information available regarding the office, and it was validated with the electricity meter readings. The energy consumption of the office for May 2022 was 14,446 kWh, while the simulated value was 14,872 kWh. The simulated value was within 3% of the actual energy consumption [6].

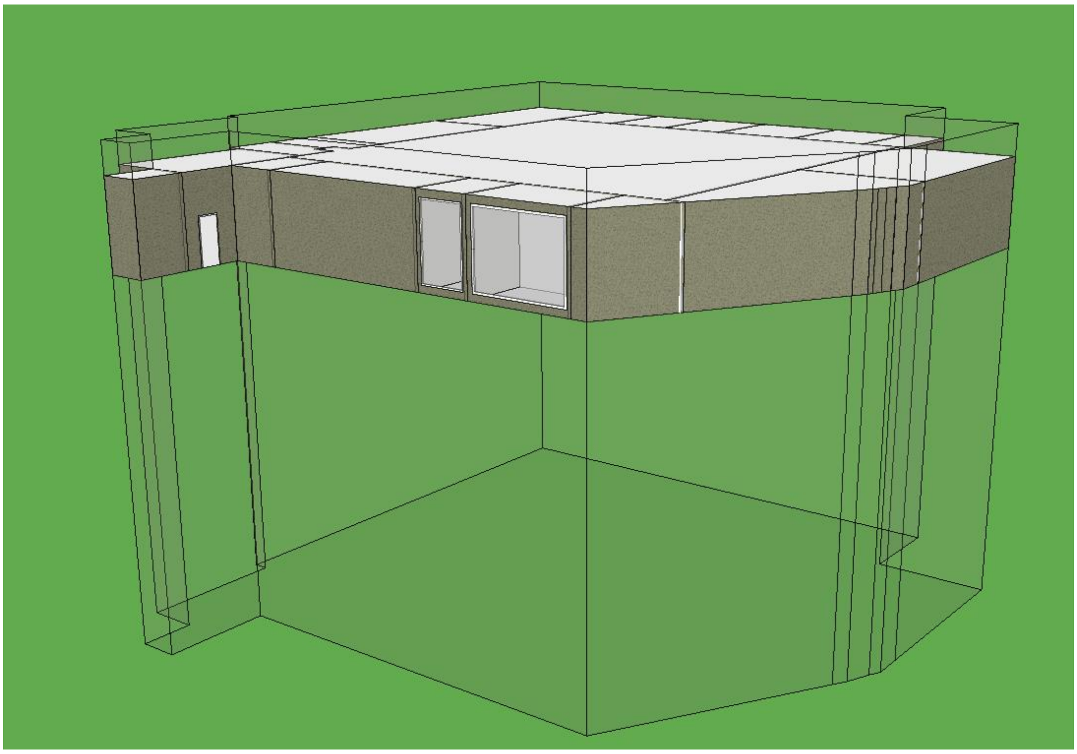

Figure 1. IDA ICE 5.0 model of office O1.

The base case simulation was run by using the information collected from the building. The occupancy profiles were designed in the model as per the obtained survey data. As mentioned by the occupants, the working hours of the office were from 9:30 AM to 6:30 PM. Since the office belonged to an architecture firm and all the occupants had a desk job, the activity level was set to 1.2 MET. The internal gains including lights and the equipment were also added to the model, as specified in Table 1. The temperature was maintained between 24°C–25°C [12]. Occupant clothing level was obtained from visual observations and was used for the base case simulation. There was no strict dress code as per the company policy, but formal attire was expected of the employees. The most observed attire for the occupants was business casual which can be calculated to 0.85 +/- 0.25 CLO (clothing is adjusted between these limits to obtain comfort).

The next simulation was run with a change in the CLO value of the occupants in the open plan office area. Since they did not have direct access to the windows, the clothing adaptation was assumed as the adaptation of choice for this simulation. The only change made to this simulation was the CLO value which was set to 0.6 +/- 0.25, for the open plan area.

For the third simulation, the window opening behaviour was considered for selected small offices (cabins), but all the remaining parameters were kept the same as the base case (Table 2). Only the occupants in the cabins had access to the windows. A graphical script was developed within IDA ICE which would allow for partially opening the windows when the indoor temperature is higher than the outside temperature, and the PPD value within the cabins would rise above 20%.

Table 2. Simulation cases

Simulation 1 (Base case)	**Simulation 2**	**Simulation 3**
CLO = 0.85 +/- 0.25	CLO = 0.6 +/- 0.25	CLO = 0.85 +/- 0.25
-	-	Window opening based on outdoor temperature and PPD

3. Results and discussion

Of the 62 responses received, 52% of the employees reported to be thermally uncomfortable, 48% were thermally comfortable during the summer season (Figure 2). The higher rate of discomfort among the occupants could have been a result of the lower capacity of the VRF system installed in the office, which was insufficient for the space and the number of occupants. The unknown performance, maintenance, and general condition of the VRF system adds to the uncertainty which is a limitation of this study. For the question about thermal preference, 81% of the respondents preferred to have cooler environment during the summer season (Figure 3). Note that the survey was conducted in the summer season; the results for other seasons reflect answers by recall.

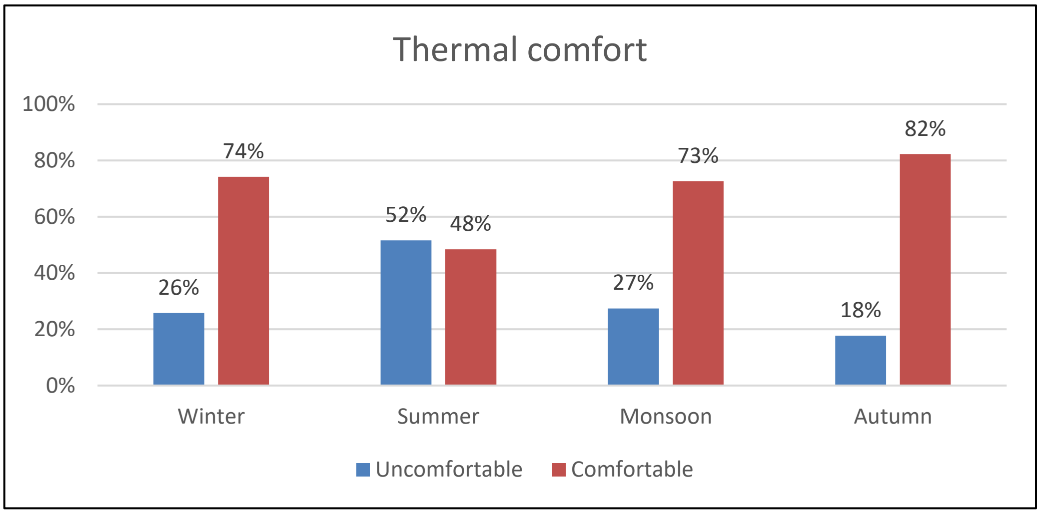

Figure 2. Thermal comfort responses for each season

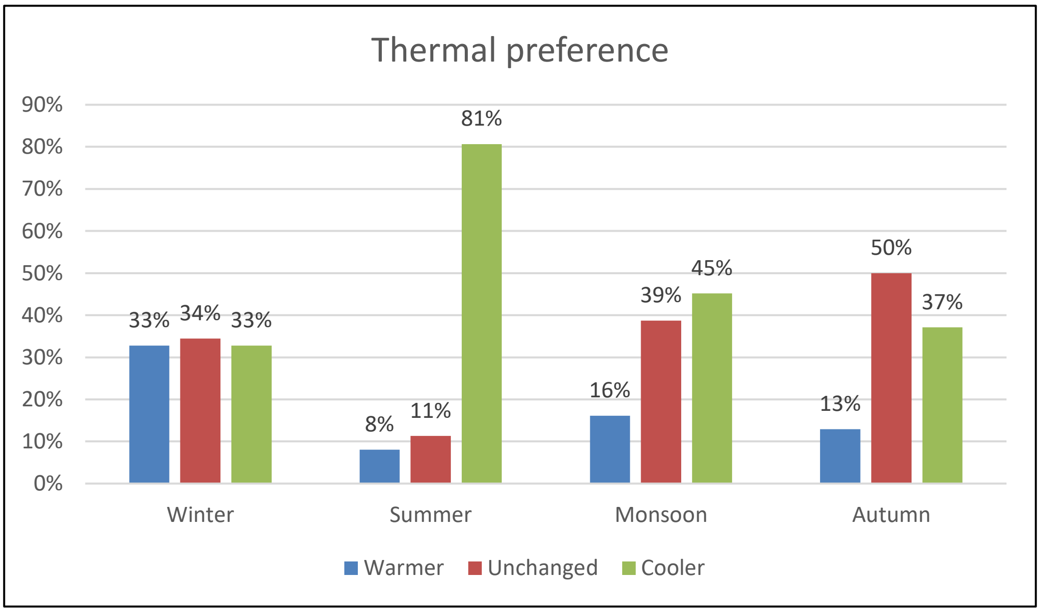

Figure 3. Thermal preference of occupants for each season

Based on all the information gathered from the office, the base case simulation was run, and it resulted in 14,872 kWh of energy consumed for the month of May 2022. The whole year simulation showed that the energy consumption by the office for the year of 2022 was 127,736 kWh with a maximum PPD of 31% in the open plan area. Simulation 2 showed a negligible 1 kWh increase with the whole year consumption to be 127,737 kWh, but the maximum PPD decreased to 18% in the open plan area, indicating that clothing adaptation can improve the comfort without a considerable impact on the energy consumption. Various simulations were run with different CLO values and the results did not show any change in the energy consumption but changes in the comfort levels were noticed (Table 4).

Simulation 3 revealed that in the zones where window opening behaviour was allowed, the comfort level remained unaffected. This behaviour increased the annual energy consumption by 79 kWh (Table 3).

Table 3. IDA ICE Simulation results

	Simulation 1 (Base case)	**Simulation 2**	**Simulation 3**
CLO value	0.85 +/- 0.25	0.6 +/- 0.25	0.85 +/- 0.25
Window opening behaviour	No	No	Yes
Annual energy consumption (kWh)	127,736	127,737	127,815

Table 4. Results of the PPD predictions under different CLO values

CLO value	**CLO value (limits)**	**PPD**
0.85 +/- 0.25	0.6 – 1.1	31%
0.7 +/- 0.25	0.55 – 0.85	28%
0.6 +/- 0.25	0.35 – 0.85	18%
0.6 +/- 0.15	0.45 – 0.75	23%

4. Conclusion

Since the beginning of the COVID pandemic, most organizations adopted remote and/or flexible working hours. This has resulted in buildings being occupied for fewer hours per day or with fewer occupants at any given time. The occupant behaviour studies can help in predicting the building's energy performance more accurately, for making better energy-related decisions. This paper focussed on the occupants' adaptive actions such as, clothing adaptation and the window opening behaviour. The simulation results showed that the clothing adaptation improved the comfort without affecting energy consumption, and the simulated comfort level depended on greater flexibility with regards to clothing. On the other hand, if the clothing adaptation were to be ignored, a higher level of target comfort maybe desirable which would require increased energy use. The window opening behaviour increased the energy consumption level while not affecting the comfort of the occupants. These adaptive behaviour patterns can help in improving the accuracy of energy performance predictions. It is essential to maintain the balance between the adaptive behaviours and the total energy consumption of the building. Also, the pandemic has underscored the importance of healthy indoor environment and practicing energy efficient strategies. Occupant behaviour studies can help in implementing these measures more effectively.

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