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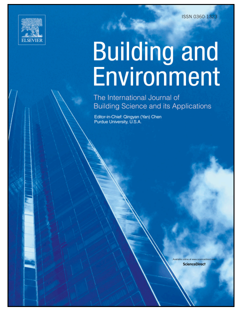


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# Window Opening Model using Deep Learning Methods

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**Abstract**

Occupant behavior (OB) and in particular window openings need to be considered in building performance simulation (BPS), in order to realistically model the indoor climate and energy consumption for heating ventilation and air conditioning (HVAC). However, the proposed OB window opening models are often biased towards the over-represented class where windows remained closed. In addition, they require tuning for each occupant which can not be efficiently scaled to the increased number of occupants. This paper presents a window opening model for commercial buildings using deep learning methods. The model is trained using data from occupants from an office building in Germany. In total, the model is evaluated using almost 20 mio. data points from 3 independent buildings, located in Aachen, Frankfurt and Philadelphia. Eventually, the results of 3100 core hours of model development are summarized, which makes this study the largest of its kind in window states modeling. Additionally, the practical potential of the proposed model was tested by incorporating it in the Modelica-based thermal building simulation. The resulting evaluation accuracy and *F1* scores on the office buildings ranged between 86-89 % and 0.53-0.65 respectively. The performance dropped around 15 % points in case of sparse input data, while the F1 score remained high.

*Keywords:* deep learning, neural networks, occupant behavior, window opening, natural ventilation

## 1. Introduction

Window openings were identified to have a high impact on the energy consumed to sustain the desired indoor environmental quality level [1]. In addition, it is common knowledge that the window states are one of the required information for modeling the natural ventilation in commercial and residential buildings and they are an important part of thermal building simulation [2]. However, window openings and closings are a product of the complex combination of physical, comfort and behavioral models of building occupants [3]. As such, the position of operable windows can not be modelled using a physical analytical approach similarly to other physical heat transfer systems in buildings. Therefore, window states are modelled using either stochastic or machine learning approaches.

Data driven approaches, including stochastic and machine learning modeling of window states have shown satisfying performance regarding the prediction of the window states. However, they show poor generalization capabilities and low performance when applied to an unknown building or even to a previously unseen user in the same building. As a result, a model fine-tuning for each occupant is required, which results in high computational costs.

This paper proposes a generic model that identifies window states using a deep feed-forward neural network. Optimal model formulation is conducted using an extensive hyperparameter search and the model is trained using the data from a subset of three monitored offices. The evaluation is conducted using the data from another 49 offices, resulting in approximately 19 mio. evaluation samples. The research questions addressed by this study are the following:

- what are suitable multi-layer perceptron architecture and hyperparameters for modeling the window states in commercial buildings?
- could the window opening habits of a large number of occupants be learned using the data from a relatively small (3 out of 52 offices) subset?

To present the practical potential and limitations of the proposed modeling approach, additional case studies were conducted:

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