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Validation of Occupants' Behaviour Models for Indoor Quality Parameter and Energy Consumption Prediction

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Abstract

Occupants' behaviour related to building control system plays a significant role to achieve thermal comfort and air quality in naturally-ventilated buildings. Generally, the published models of occupant's behavior are not validated, meaning that the predictive power has not yet been tested. For this reason, the validation of occupant's behavioral models is an issue that is gaining importance.

In this paper validation was carried out through dynamic Building Energy Performance simulation (BEPS); behavioral models of windows opening and thermostats set-point published in literature were implemented in a dynamic BEPS software and the obtained results in terms of temperature, relative humidity and CO2 concentration were compared to real measurements. Through this comparison it will be possible to verify the accuracy of the implemented behavioral models.

The models were able to reproduce the general tendencies in the measured temperatures but the simulation results diverged from the measured CO2 concentrations and relative humidity.

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Keywords: Validation of behavioural models; indoor environmental quality; dynamic simulation

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1. Introduction

A significant amount of global energy consumption is still employed in the building sector in order to maintain an adequate level of interior comfort; however, this leads to drastic environmental consequences. In Europe 40% of primary energy is consumed in buildings; in particular a share of 27% comes from the residential sector, while 13% is used for the management of office buildings.

Residential energy consumption appears to be increasingly influenced by the occupant behavior in the attempt to reach comfortable and healthy living spaces by heating, cooling, ventilation and lighting. In fact, all these actions have an impact on energy consumption.

Consequently, the efforts are directed to the identification of the impacts that the occupant behavior have on the building's energy consumption and thermal comfort.

However, the technical solutions adopted today are not sufficient to deal with the energy savings: the buildings are well designed but the people who live inside are not reliable and sometimes unpredictable and irrational [1; 2; 3]. In other word, the discrepancy between the way the designers expect that the occupant uses the building and the real use produces a significant gap between the effective energy consumption and the expected one. The international project IEA Annex 66 EBC promotes extensive research on the assumption that the reasons for this discrepancy are little known and often related to human behavior, rather than the design of the building.

Starting from the knowledge that the occupants' behavior affects the energy consumption and the indoor thermal comfort [4; 5; 6; 7], the attention is focused on the users' control of the building systems, as the interaction with the windows and thermostatic valves to better understand and predict the performance of the building.

Several statistical models have been developed [1; 6; 8] with the aim to describe the presence and interaction of the occupants in buildings. Generally, however, the predictive power of these models has not yet been tested as they have not been validated; they are applied in simulation tools without knowing the validity of the predicted results. Accordingly, the occupant's behavioral models, such as those used to represent the interaction of the occupants' with the built environment in building energy simulations, need to be validated in order to achieve an accurate evaluation of energy consumption in the residential buildings.

For this reason, the aim of the study was to validate the existing behavioral models of windows opening and thermostats adjustments through their implementation in a dynamic building energy performance simulation software. The verification was based on the comparison in terms of indoor environmental variables between the results obtained from the simulations software and the real values measured in two apartments.

2. Method

The use of stochastic models for the simulation of occupants' interactions with the built environment has greatly affected the modelling approach in the last years. Actually, these models are able to consider the extreme variability and the combination of human behaviour and consequently its actions on building devices.

Since two of the main actions that can influence the environmental conditions are related to window opening/closing and to thermostat set-point adjustment, stochastic models of occupants' interactions with these devices were implemented in an energy simulation tool (IDA ICE).

The aim was to estimate the predictive accuracy of the existing models through their validation based on their ability to replicate the indoor environmental variables in residential buildings. This validation was carried out by comparing the simulated values of indoor temperature, relative humidity and CO_2 concentration with the measurements of two apartments.

The case study involves a residential building located in Ryesgade 25, Copenhagen (Figure 1)

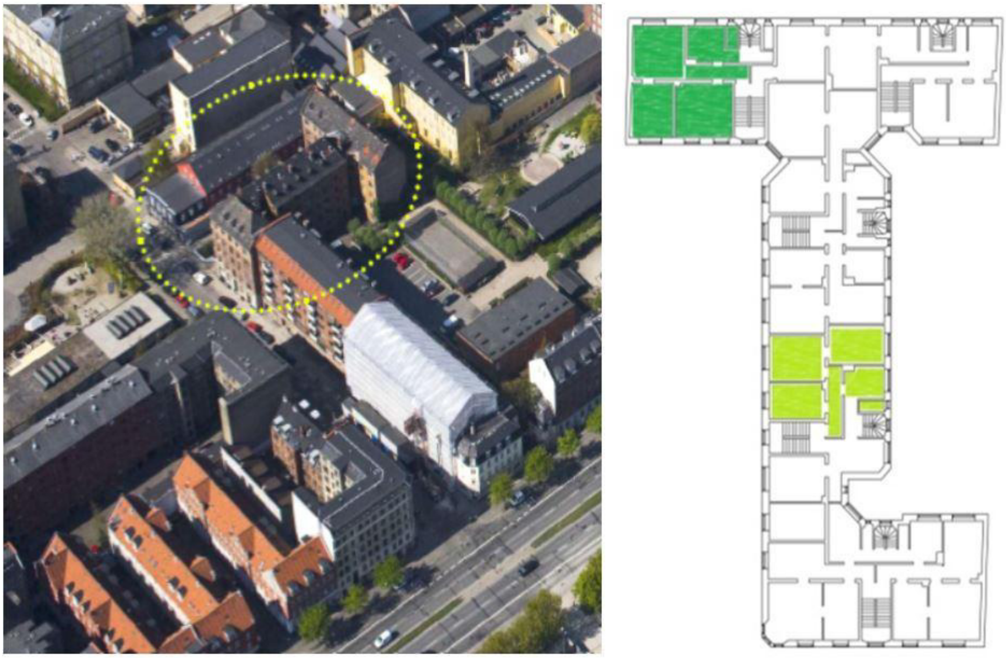

Fig. 1. Location and layout of the building.

Firstly, the research considers the studies made by Andersen et al. [1] about the window opening and closing. Since the case study is a naturally ventilated dwelling and people living there rented the apartment, models for Group 3 in Andersen et al. [1] (rented and naturally ventilated dwellings) was used to represent the occupants' window opening behaviour.

The other model included into validation is the one related to the thermostat set-point adjustment carried out by Fabi et al. [6]. The simulated model has been chosen knowing the typology of occupants inside the dwellings: active users (they interact very often with the heating control; 9 - 22 number of interactions with heating control system) and medium ones (the interactions are less frequent than the previous, between 0 and 2).

The validation was conduced by moving step by step from a deterministic approach to a probabilistic one.

As a matter of fact the research method was based on several scenarios:

- Scenario I: totally deterministic.
  The input variables assume fixed values, therefore the outputs are completely determined, since it does not take into account the uncertainty associated with the initial parameters.;
- Scenario II: semi-probabilistic A (influence of window opening and closing behaviour).
  Probabilistic function the interaction between occupants and windows opening and closing, are considered as probabilistic function although the heating set-point as a fixed input value;
- Scenario III: semi-probabilistic B (influence of heating set-point adjustment)
  The actions on the windows are considered as deterministic functions whereas the ones on the thermostats as probabilistic variables.
- Scenario IV: totally probabilistic
  Both window opening and thermostat adjustment are described by probabilistic equation.

In other words, firstly the simulation has been done with deterministic consideration of input values (defined in Standard EN 15251 [5]). Then the attention passes to single interaction within building envelope and control systems, considering one by one the window opening and heating set-point setting as probabilistic function. At the end both the models are used as probabilistic functions in the software simulations with the scope to obtain results closest to the reality.

3. Results

The results of the deterministic model find a confirmation in the nature of the model itself; it does not take into account the occupants controls for the window opening and the thermostat adjustments consequently it cannot simulate precisely neither the real indoor quality parameters and consequently nor the energy building consumptions.

Figure 2 shows that both simulated and measured results of temperature reach the maximum value of frequency between 21°C – 23°C, while there is a big gap between simulated and real values of relative humidity and CO_2 concentration. In fact the measured CO_2 concentration assumes values between 400 – 1200 ppm, while the simulated ones are higher than 1400 ppm. The same happens with values of relative humidity which are not able to replicate the real values because they always assume values of 100%.

It could due to the fact the window behaviour is not sufficient to guaranteed a correct ventilation rate in the rooms: the window are closed when simulated values of temperature are below 25 °C (set-point window opening) and consequently simulated CO_2 concentration and relative humidity reach values highest respect real ones.

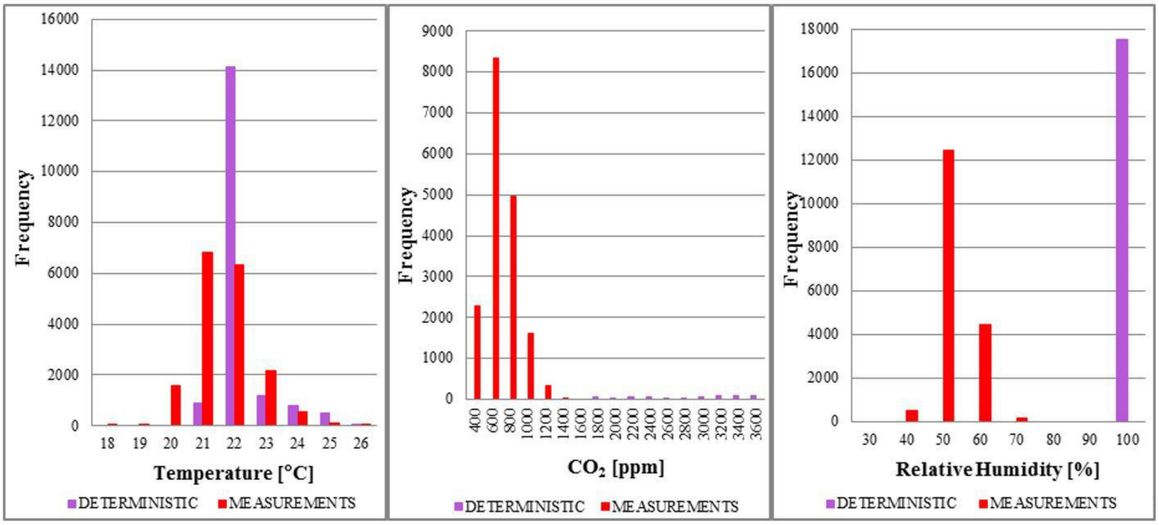

Fig. 2. Temperature, CO_2 concentration, relative humidity comparison between measurements and simulated value of deterministic scenario.

The study keeps on analysing of the first semi-probabilistic scenario.

As shown in Figure 3, the temperature values obtained with this simulation can be justified knowing that the model considers interaction between occupants and window opening/closing as probabilistic function, while heating set point is still considered in a deterministic way, imposing as a fixed input value dependent on the comfort category.

All these considerations can explain why the highest frequencies for the simulation are between 20°C - 21°C instead for the measurements that are in the range of 21°C - 22 °C. In other words the simulation results of temperature seem to be moved to lower values of about 1°C.

As far as relative humidity concerns the simulation results fit in a better way the measurements respect CO_2 concentration. In fact the for the relative humidity both measurements and simulated values assume the maximum in 50%, on the contrary the maximum value of the measured CO_2 is 600 ppm while the real one is 1200 ppm.

The relative weight of the semi-probabilistic model for the window opening is also perceptible considering that in this scenario the adjustment of the radiator thermostats remains deterministic with the attempt to reach 21°C in each room. Therefore it is not sufficient to respond to the effects produced by windows opening/ closing.

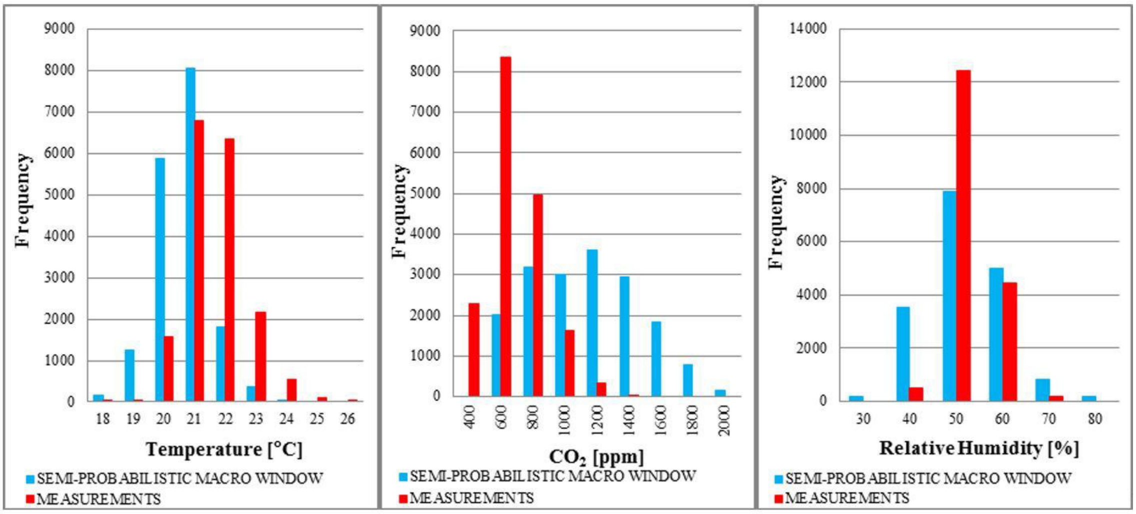

Fig. 3. Temperature, CO2 concentration, relative humidity comparison between measurements and simulated value of semi-probabilistic scenario (influence of window opening and closing behaviour).

Figure 4 depicts the results from the third scenario: standard control regulates the window opening/closing (if the temperature is above 25 °C the window is opened, while it falls down to 21 °C the window is closed).

Compared to the scenario II, in this simulated temperatures are shifted to higher values. This results underlines what had been discussed by Fabi et al. [6]: if the users have the freedom to interact with control systems for adjusting the temperature set-point, then they try to maintain temperature higher than 21°C. All these considerations are shown in Figure 4 where obtained temperature with this semi-probabilistic model are always above 22°C in each room

When the most of simulated temperature values are below 25°C, the windows often result closed; both relative humidity and CO_2 concentration raise to high values because the necessary ventilation rate is not guaranteed. In fact, simulated values of CO_2 concentration are always above 1200 ppm, and on the other hand simulated relative humidity assumes often value of 100%. Consequently, it generates a situation of severe discomfort.

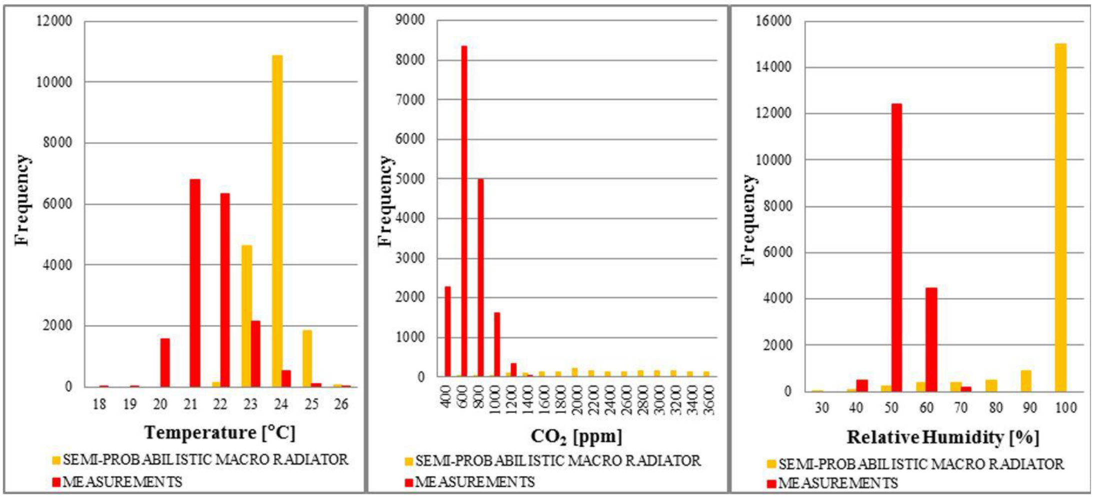

Fig. 4. Temperature, CO_2 concentration, relative humidity comparison between measurements and simulated value of semi-probabilistic scenario (influence of heating set-point adjustment).

Finally this paper studied how the occupants interact within building envelope and control systems to reach their needs in term of personal comfort.

In particular the scenario IV permits to evaluate at the same time the influences of stochastic window opening/closing and stochastic heating set point adjustments have on the indoor quality parameters.

Figure 5 shows the results carried out from the implementation of this scenario; the trend of the simulated internal variables: temperature, relative humidity and CO_2 concentration was similar to the measurements.

At first the simulated and measured temperatures assume almost the same values of frequency in particular in the range of 20° - 21°C with a percentage deviation around 4% - 5%.

The simulated values of CO_2 concentration and the relative humidity are closer to the reality compared to previous models, even if they are not particularly accurate. In fact simulated values of CO_2 concentration are around 400 – 1200 ppm, while the measured ones are around 600 – 1800 ppm. The simulated and measured trends of relative humidity are similar, in fact the highest value of relative humidity is 50% in both cases.

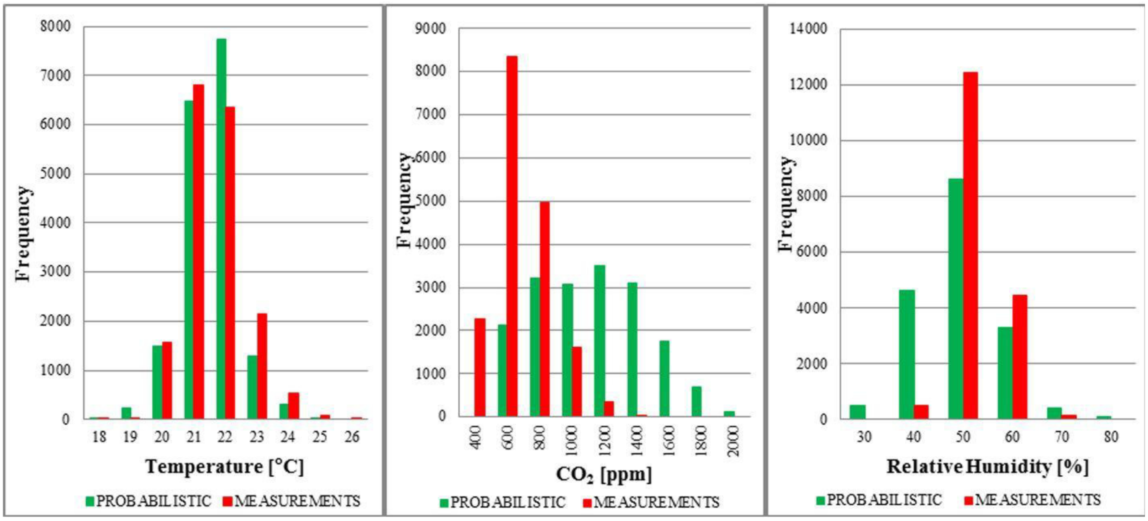

Fig. 5. Temperature, CO_2 concentration, relative humidity comparison between measurements and simulated value of probabilistic scenario

4. Conclusion

Results revealed the ability of the tested stochastic models to reproduce the real indoor environmental patterns in two apartments. Overall, the models reproduced the general trend of the measured temperatures, while the obtained patterns for relative humidity and CO_2 concentration diverged from the real conditions. These errors can be due to several aspects, for example the variability of the boundary conditions, the number of occupants, the typology of the building, etc. Finally some of the errors may be attributed to the modelling of the physical properties of the building, which may have been different to the real building.

The analysis reveals the influence of the real occupants behaviour on the parameters of the internal quality and consequently on the final energy consumption, in particular during the design phase. In fact, the internal temperature, relative humidity and CO_2 concentration greatly vary according to the habits and preferences of users.

However, only the implementation of fully probabilistic model can simulate the real conditions within the residential structures in accurate way, as this model considers the major variability of human behaviour in buildings.

This research represents a forward step in predicting indoor quality parameters item by item and at the same time an input in starting future studies which focus the attention on the relationship between energy consumptions and internal comfort variables in residential buildings.

Starting from the expectation to obtain simulations capable to approximate as much as possible the reality, the database to get the results could be even more precise and extended to a large variety of building typologies with several boundary conditions and of occupants' interactions within building envelope (lighting, blind adjustments, etc.)..

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