Impact of an occupancy and activity based window use model on the prediction of the residential energy use and thermal comfort

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ABSTRACT

The opening of windows can lead to high energy losses in wintertime, especially in nearly zero-energy buildings. But can reduce overheating significantly in summertime. Therefore, window use models have been created in the past to assess the energy use and thermal comfort in residential buildings. The models are mostly based on weather-variables. However, a recent study (Verbruggen, Janssens, et al. 2018) indicated that these models were not able to accurately predict the window use in wintertime. For that reason, an occupancy and activity based model was developed. In this article, the impact of the application of the new window opening model on the residential energy use and thermal comfort was assessed. The object-oriented modelling language Modelica was used to simulate the energy use and temperatures in a nearly-zero energy house, which is a representation of an existing house in a nearly zero-energy neighbourhood in Kortrijk. From this neighbourhood, measured energy use data was available as well as window sensor data for some of the houses. These measured data were compared to the simulated data of the new window use model, a weather-based model and the Belgian EPBD-calculation method. The occupancy and activity based model could predict more accurately the average opening durations in wintertime and could better account for the large variation in window use compared to weather-based models. An optimal window opening strategy could limit the overheating significantly, even prevent it in the bedrooms and bathroom. However, opening the windows also implies an increase in energy use for heating. Some combinations of different window opening habits can limit the overheating, while limiting the increase in energy use at the same time.

KEYWORDS

Windows, occupant behaviour, residential energy use, thermal comfort

1 INTRODUCTION

Window opening behaviour is generally predicted by weather-based window opening models. These are models that predict when the windows are open based on different indoor and outdoor environmental variables such as temperature, CO2-concentration and relative humidity. However, the study of Verbruggen et al. (Verbruggen, Janssens, et al. 2018) revealed that weather variables are good predictors when considering an entire year, however, in wintertime the weather variables are rather poor predictors for window use.

In the Belgian EPBD-heat demand calculation method it is assumed that windows will not be opened if a mechanical ventilation system is installed. However, in dwellings with a ventilation system the windows are opened to the same extent as in dwellings without ventilation system (Dubrul 1988). It is important to predict the window opening behaviour correctly since it can largely impact the energy use, especially in winter. Furthermore, opening windows has a large impact on the thermal comfort of the occupants as well. Occupants tend to open windows to cool down their houses in summertime, therefore limiting the risk of overheating. In the Belgian

EPBD-calculation window use is included in the calculation of the overheating indicator by an extra ventilation rate based on the potential for intensive ventilation.
To be able to more accurately predict the window opening behaviour, a new window opening model is created based on the occupancy and activity patterns of the occupants rather than on weather variables. This model predicts a more realistic way of occupants' interactions with windows, since it includes the habits of the occupants, which are related to the occupancy and activity states of the occupants. Consequently, it only allows for window interactions when at least one occupant is present and awake.
In this paper, the occupancy and activity based model will be briefly explained and will be compared with a weather-based model and the EPBD-calculation method in terms of energy use for heating and thermal comfort.

2 METHODOLOGY

To compare the impact of the use of the different window opening models simulations are carried out with the object-oriented modelling language Modelica using the IDEAS-library (Jorissen et al. 2018). The simulated house is based on an existing two-storey, three-bedroom house from a social housing neighbourhood in Kortrijk, Belgium (Himpe, Janssens, and Rebollar 2015; Janssens et al. 2017).
In the simulations only the window opening behaviour is varied, all other types of occupant influences remained the same as in the Belgian EPBD-calculation method. These settings are summarised in Table 1. The set-point temperatures are 18°C in all zones. The ventilation rate, internal heat gains and domestic hot water use are calculated based on the volume of the building. The default internal heat gains for the entire building are distributed over the different zones based on the volume-fraction.

Table 1: Occupant behaviour settings in the model

SETTINGS	
Heating setpoint	18°C
Ventilation rate	183 m^3/h (building)
Internal heat gains	1057 kWh/year
Domestic hot water use	1380 kWh/year

The window opening behaviour is simulated based on the heat demand EPBD-calculations first. This means that the windows are always closed. Secondly, a simulation is carried out including the extra ventilation rate for opening windows from the EPBD-calculation for overheating. This ventilation rate is based on the potential for intensive ventilation. In this case a weak potential for extensive ventilation is present, which corresponds to an extra ventilation rate of 48 m^3/h. Next, the window opening behaviour is simulated using the stochastic weather-based model created by Maeyens and Janssens (Maeyens and Janssens 2000). This model describes the probability of opening a window every hour based on the outdoor temperature, wind velocity and solar irradiation. A correction factor is applied to compensate for the presence of the occupants. Thirty simulations are carried out to capture the variance implied when using a stochastic model. Finally, thirty simulations are carried out with an occupancy and activity based window use model, which will be explained in the next paragraph.
The simulation results of the energy use for heating and domestic hot water are compared for the different models, as well as the indoor temperatures as a measure for thermal comfort.

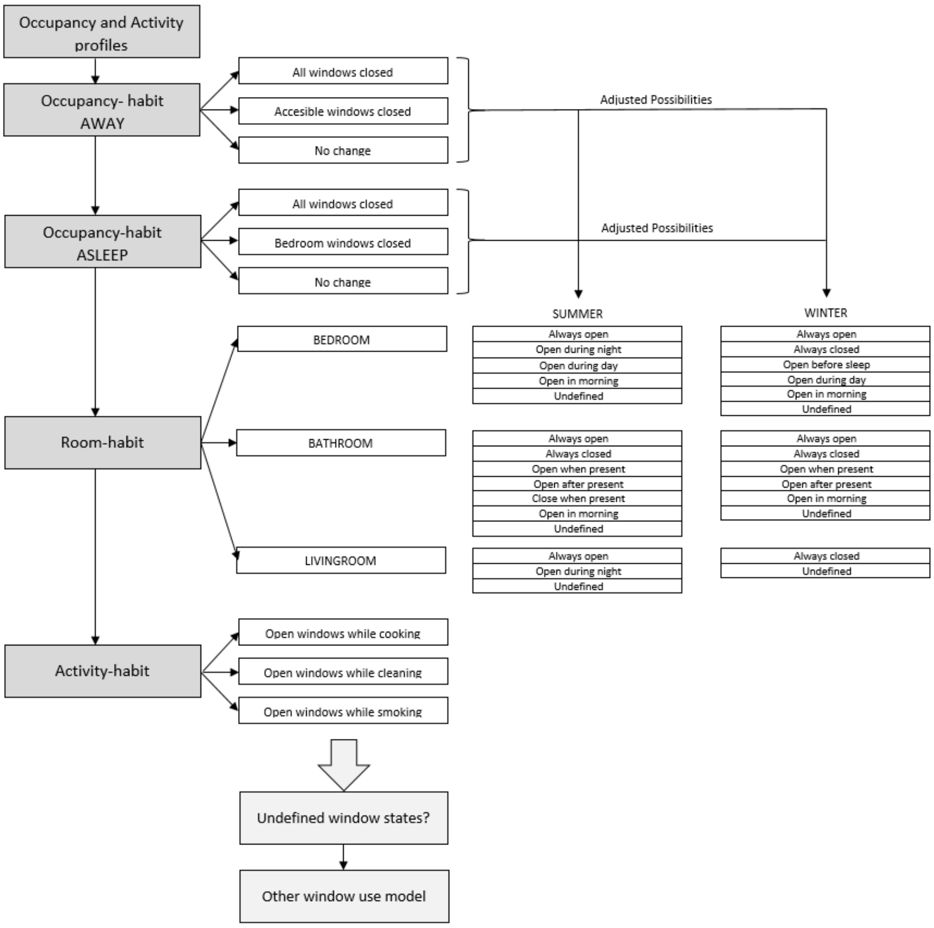

Figure 1: Workflow of occupancy and activity based window opening model

3 OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL

The newly developed window use model is based on occupancy and activity patterns of the inhabitants (Verbruggen et al. 2019). This is a more realistic way of modelling the occupant behaviour compared to weather-based models since it relates more closely to the occupant's time use. Occupants are not always able to change the window state (e.g. away from home or asleep) and will not evaluate the window state every few minutes. Furthermore, it was revealed that a lot of occupants have specific habits regarding the window use (Hauge 2016; Verbruggen, Delghust, et al. 2018). The occupants are less likely to make rational thoughtful decisions in relation to the window use, they rather just open the window out of habit.

The workflow of the model is presented in Figure 1. The model first determines stochastically the occupancy and activity patterns of the members of the household for an entire year. This step is based on the works of Aerts (Aerts 2015) and Baetens et al.(Baetens and Saelens 2016). Next, the model determines which habits are present in the household based on statistics from a survey in Belgium (Verbruggen et al. 2019). Different habits are selected for summer- and wintertime. In a final step, the occupancy and activity patterns are coupled to the selected habits, in this way window use profiles could be generated for an entire year for most of the households. For example, if the household has the habit of closing the windows when going to bed, the window state could be easily linked to the occupancy-state asleep.

In some cases, the household will not have habits that allow for the creation of full window use profiles. In these undetermined periods, the occupants do not have a real habit and may base their behaviour on the weather or some other variables. In this case, it was assumed that the

occupants act based on weather variables in these undetermined period, therefore the window model of Janssens & Maeyens (Maeyens and Janssens 2000) is applied.
The window opening duration in winter time could be accurately predicted with the new window opening model. In Figure 2 the average opening time per day in wintertime is compared for the different models in the different rooms and to measured data from the case-study site.
In the bedroom and bathroom the habit-based model predicts more accurately the average opening duration, while still capturing the variation between households very well. This variation is in correspondence to the measured data of houses of the same type on the case-study site. In the living room on the other hand, the weather-based model is able to better predict the window opening behaviour. This can be linked to the fact that in the living room the least window opening habits are present. In general the window opening model based on habits is able to accurately predict the window opening durations in wintertime.
When the opening durations in summertime are analysed, the model still captures the variability of opening behaviour very good in contrast to the weather based model. However, the average opening durations are less precise compared to wintertime, but still a good approximation.
It can be concluded that the window opening model based on occupancy and activity patterns is able to better capture the variability in window opening behaviour compared to a weather-based model and to the EPBD heat demand calculations. The opening durations are as well better estimated.

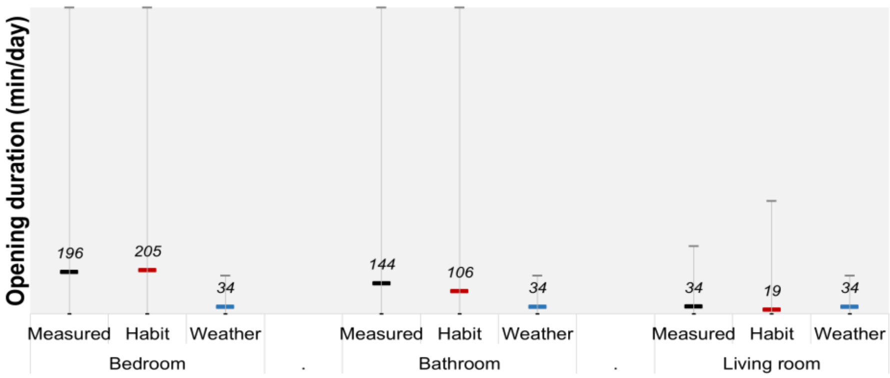

Figure 2: Window opening durations in wintertime: measured data in comparison to simulated data.

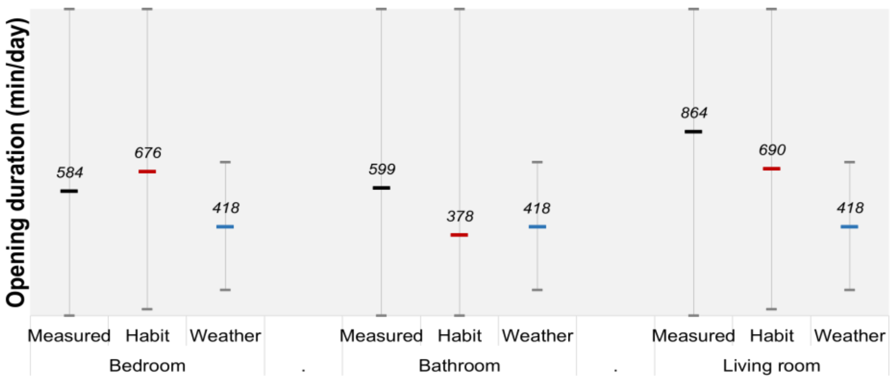

Figure 3: Window opening durations in summertime: measured data in comparison to simulated data.

4 IMPACT ON THERMAL COMFORT

Window opening behaviour is closely linked to thermal comfort, therefore the temperature is most often included as window opening driver in window opening models. But what is the impact of opening windows on the thermal comfort?

In Figure 4, a comparison is made of the indoor temperatures in the living room between the occupancy and activity based model (habit-model) and a simulation in which the windows were always closed (EPBD heat demand calculation). Logically, the simulations with the windows always closed predict higher indoor temperatures compared to the occupancy and activity based model. In the bedrooms (Figure 5), lower indoor temperatures are predicted. This is caused by the fact that the room has smaller windows compared to the large south-oriented windows in the living room. It should be remarked that with this simulation the internal heat gains are proportionally distributed over the different zones. In reality, most internal heat gains will be present in the living area, since this is the room in which most people are active and most appliances are present. This means that with a more realistic distribution of the internal heat gains, the overheating in the living rooms will be even higher.

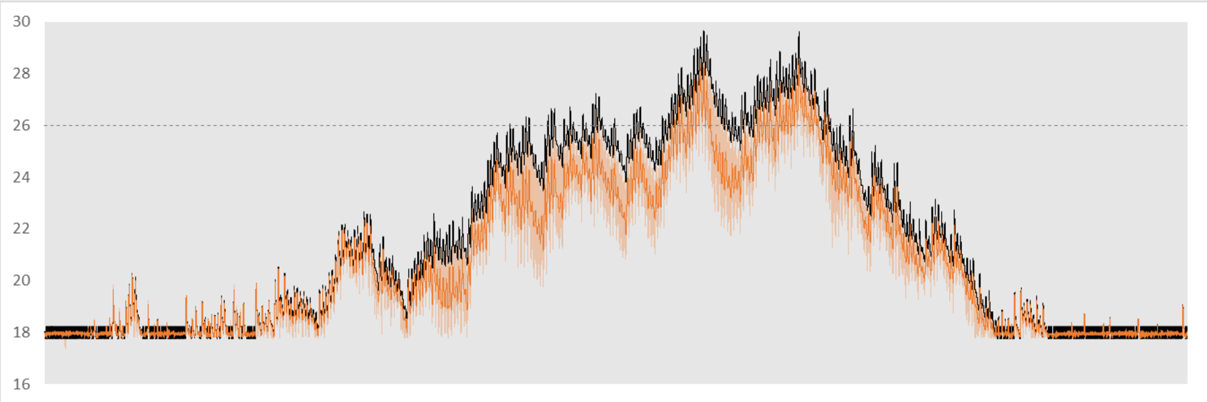

Figure 4: Simulated living room temperatures with habit-model (orange) and windows always closed (black)

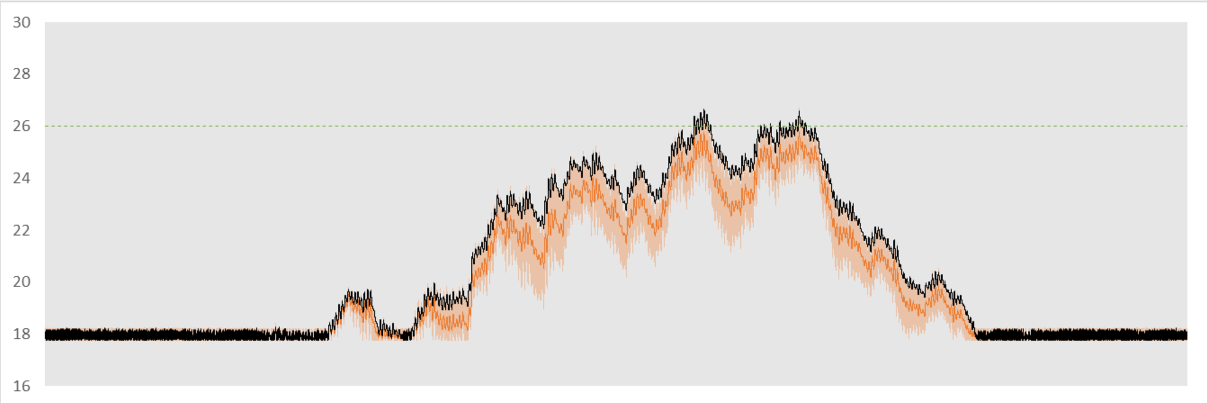

Figure 5: Simulated bedroom temperatures with habit-model (orange) and windows always closed (black)

The influence of using different window use models on the prediction of the indoor temperature is investigated; more specifically, the risk of overheating is evaluated. In Belgium a maximum overheating of 6500 Kh is allowed in newly constructed buildings. This indicator represents the hours that the threshold-temperature of 26°C is exceeded and with how much.

The overheating indicator in the living room when all windows remain closed is 1464 Kh which is still below the maximum allowed value of 6500Kh. If the extra ventilation rate from the overheating calculation of EPBD is included the overheating decreases to 665 Kh. When

applying a weather-based model (560 Kh) or occupancy and activity based model (434 Kh), the average overheating indicator decreases even more.
The occupancy and activity based model averagely predicts less overheating compared to the weather-based model. However, large variations are present, so the overheating indicator greatly depends on which habits the occupants perform. In the other rooms very little overheating is predicted, even with the windows always closed the overheating is only 223 Kh and 33 Kh for respectively the bathroom and bedroom. When the weather-based model the overheating decreases even further to 43 Kh in the bathroom and 2 Kh in the bedroom. If the habit-model is applied the average overheating drops to 32 Kh in the bathroom and 2 Kh in the bedroom. For one third of the simulations there was no overheating present in the bedroom. This proves that when the windows are opened in a specific way, it can be a good measure to prevent overheating.

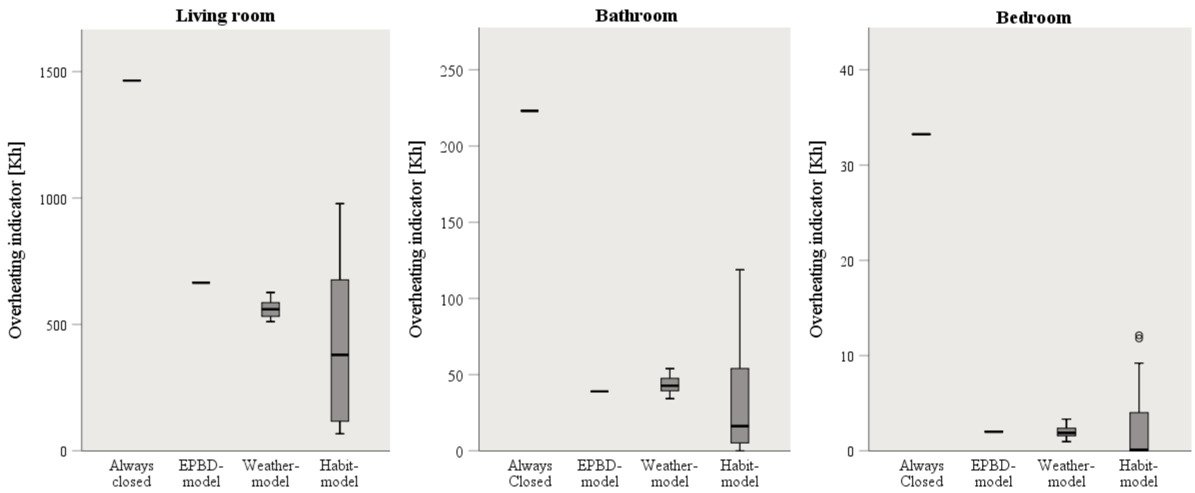

Figure 6: Overheating indicator [Kh] in the living room, bathroom and bedroom.

5 IMPACT ON ENERGY USE

The drawback of opening windows, especially in wintertime, is the increase in heating energy. As the occupancy and activity based window opening model better predicts the opening behaviour of the occupants it will probably be able to better estimate the energy use for heating of these occupants.
In Figure 7 the simulated energy use for heating and domestic hot water is given for the different models, as well as measured data in similar buildings from the case study neighbourhood in Kortrijk. As expected, the heat demand increases when the windows are opened more. With the EPBD-model, in which all windows are assumed to be closed, the energy use is 2920 kWh/year. While for the weather-based model the average energy use increased to 3194 kWh and for the habit-model to 3550 kWh. Again, the large variation can be seen in energy use due to the variability in window opening behaviour, with energy use ranging from 2975 kWh/year to 4766 kWh/year. This large variability is as well present with the measured data; however, the measured energy use is significantly lower with an average value of 1878 kWh. The discrepancies can be attributed to a lot of different factors. Since, it was assumed that the other types of occupant behaviour were similar as in the EPBD-calculation, the real occupant behaviour was grossly simplified.
There was a large influence of the window opening behaviour on the energy use, however, some habits contributed to a higher energy use than others.

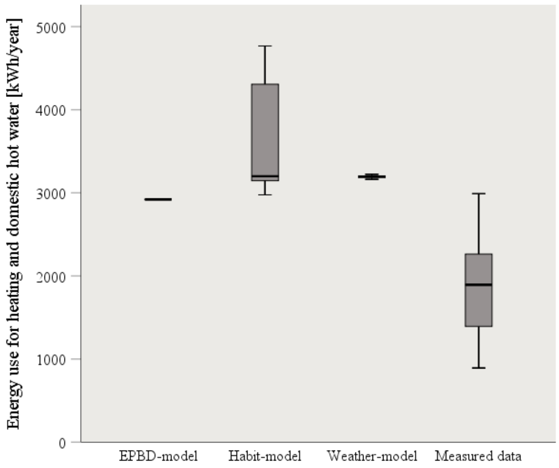

Figure 7: Energy use simulated with the different window opening models compared to measured data

6 IMPACT OF DIFFERENT HABITS

From the previous paragraphs it became apparent that the type of habit can have a large influence on the overheating and energy use in a building. Therefore, the impact of different habits is analysed as well.

In general, the influence of a specific type of habit was difficult to assess, since multiple habits are present in one household that work together or contradict each other in terms of preventing overheating or the energy use. Additionally, when no habit was present (Undefined), the weather-based model was applied, which could lead to high or low opening times due to the stochasticity of the model. In Figure 8, the relation between the energy use and overheating in the living room is given for the 30 simulations. Some of the simulations have low energy use and little overheating at the same time, which makes it optimal window opening strategies.

Only for the habit when going to sleep a clear significant influence could be distinguished. The least overheating is present when the windows remained in the state they were before going to sleep in comparison with the habits of closing all windows when going to sleep or closing the bedroom window when going to sleep. However, this led as well to a significant higher energy use compared to the ones that closed all windows (t=-2.025, p=.05). It can be concluded that due to the multitude of habits present in the household only the impact of the habit when going to sleep was significant. Other habits may have a significant influence when they are combined.

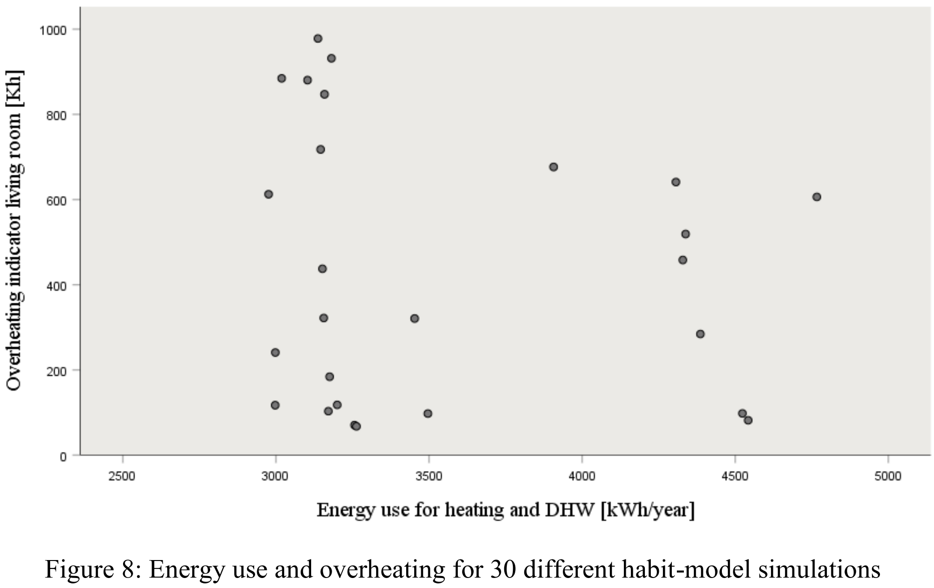

Figure 8: Energy use and overheating for 30 different habit-model simulations

7 CONCLUSIONS

The opening of windows has a high impact on the thermal comfort as on the energy use, therefore it is important to correctly assess it. The newly developed window opening model based on activity and occupancy patterns is able to better estimate the real window opening behaviour, especially the variability that is present between households. An optimal window opening strategy could limit the overheating significantly, even prevent it in the bedrooms and bathroom. Closing all windows when going to sleep will lead to a higher risk of overheating but will lead to less energy use. Next, to the ‘going to bed’-habit, none of the other habits had individually a significant influence on the overheating or energy use. Most habits should be combined to reduce overheating and/or energy use.

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