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The influence of window opening habits on the residential energy use in nearly zero energy buildings

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ABSTRACT
In this paper, we discuss the presence of habits in the window opening behaviour of social housing tenants in a nearly zero-energy development in Belgium. A window opening habit can be defined as an action with a window that is repeated daily around the same time independently of the prevailing weather conditions. A carbon neutral social housing estate (106 apartments and 90 single family dwellings) was used as a test case. Questionnaires, window opening logging with a building monitoring system and cross-sectional surveys were used to collect window opening data. A method to identify window opening habits is determined. Up to 45% of the occupants act on some sort of habit in wintertime, predominantly in the bedrooms and in the morning. In summer these habits dissipate due to very long window openings. Weather variables and indoor climate parameters, traditionally used as the basis for window opening behaviour models, are rather poor predictors of opening behaviour in winter. The incorporation of habits in window opening models can lead to more reliable predictions of window opening behaviour.

KEYWORDS
Habits, Windows, Occupant behaviour, Residential energy use, NZEB

INTRODUCTION
The occupants' window opening behaviour can have a substantial influence on the indoor climate and the energy use in a dwelling. In order to implement this behaviour in energy simulation tools, window opening models have been developed. In literature, most window opening models are based on outdoor and/or indoor climate variables (Brundrett and Poultney, 1982; Conan, 1982; Erhorn, 1988; Fabi et al. 2013; Lyberg, 1983; Maeyens and Janssens, 2000; Rijal et al. 2007). However, the study of Verbruggen et al. (2017) on the window opening behaviour of social housing tenants in a Belgian case study revealed that weather variables cannot accurately predict the window opening behaviour in winter time. The weather variables have a significant influence on the window opening behaviour when yearly data are considered, nevertheless the influence is not significant when only winter data are analysed. It was revealed that most occupants who opened their windows in wintertime either could not define an explanation for their actions or linked it to the need to 'air' the dwelling. A recent study (Clarysse, 2018) did not reveal any performance issues with the heat recovery ventilation system. The lack of (accurate) motivation to perform these window openings leads to the hypothesis that the occupants interact with the windows out of habit.

A habit can be defined as an automatic action carried out without conscious effort that is the consequence of frequently repeating this action in a stable context (Ouellette and Wood, 1998). Consequently, a window opening habit is an action with a window that is repeated daily around the same time independently of the prevailing weather conditions. Habits have been elaborately researched in the field of sociology and psychology (Ajzen, 2002; Ouellette and Wood, 1998; Verplanken et al. 1998); however, little research has been carried out in the building sciences.

In several window opening studies, occupant characteristics have been reviewed, such as age, income, sex and household size, but the habits of the occupants have not been considered. Habits are very personal and vary greatly among the different occupants. It is consequently difficult to incorporate them into a window opening model. Nonetheless, it is interesting to investigate these habits, since window opening actions can considerably influence the ventilation rate and accompanying energy losses.

This paper first explains how the presence of window opening habits is determined in a case study. Subsequently, the observed habits are discussed and their influence on the energy use is assessed.

METHODS

Case study

The research is based on data collected in a nearly zero-energy social housing development in Belgium (Himpe et al. 2015). The housing project is equipped with a building monitoring system which is directly linked to a university server. The project, built between 2010 and 2015, consists of 106 apartments and 90 single family houses. All apartments and 39 houses are fitted with a balanced mechanical ventilation system with heat recovery, while the other dwellings have demand controlled exhaust ventilation with trickle vents.

Data-acquisition

In 14 apartments and 16 houses, window sensors were installed which provided direct measurements on the window opening actions. The time and state of the windows were registered when a window is opened or closed. Only one sensor was installed on each window; therefore, it was not possible to differentiate between turning and tilting actions. In the apartments, the signals of the sensors were combined into one signal per apartment. Consequently, the individual actions with a single window were not registered. The window sensor data were analysed for the years 2015 and 2016 for the apartments, but only for the year 2016 for the houses since they were inhabited later. In four apartments, the data was corrupted so these were discarded from the analysis. To broaden the window opening data, a logbook study was carried out between 20 January and 27 February 2017. The occupants were asked to write down when the windows were opened and closed, and to mention whether those were opened completely or tilted. A total of 47 occupants filled in a logbook. However, the motivation of occupants to participate dropped considerably after a few weeks. The validity of the logbooks was checked by visual observations carried out during the same period, and compared with window sensor data if available. In total, 62% (20 apartments, 9 houses) of the logbooks were evaluated as correct. Additionally, the occupants were queried on the reasons for opening and closing the windows, the family composition, the presence in the house and the occupants' satisfaction with the ventilation system. In Himpe et al. (2015) and Verbruggen et al. (2017) respectively, the case study is discussed in more detail and a summary is provided of the observed window opening behaviour.

Determining Habits

The data of the logbook study was used to determine which occupants perform habitual actions. Indications of a habit can be observed when examining the opening percentage per hour, this is the fraction of the hour that the window is opened. When the opening percentage approximates a value of 1 (100%), it indicates that the window is always opened at that time (independently of e.g. indoor and/or outdoor climate); consequently, the presence of an opening habit is very likely. This was visually checked by plotting the average opening percentages per hour over the measuring period (Jan-Feb 2017) for every hour of the day (Figure 1). When a clear peak in

opening percentages was observed, but the 100% mark was not reached, an opening habit could still be present. This can indicate an opening habit that occurred a limited number of times per week (e.g. only on weekdays), a habit that has slightly shifted in time throughout the days or a habit with a duration shorter than one hour. For example, clear habits could be observed in apartments 6 and 21 (Figure 1), while the opening percentages of apartments 20 and 22 merely suggest a habit. Additionally, indications of habits were derived from conversations with the occupants.

Next, these habits were more precisely determined by examining the exact data of the logbook papers. In all dwellings with an indication of a habit, it was checked if the windows were actually opened every day at that time. First, an average starting-time of the habit was determined, as well as an average end-time. Subsequently, it was checked if this habit is present every day during the measuring period. A deviation of the starting- and end-time of one hour was allowed to compensate for incorrect clock-setting and the lack of accuracy in time notation. Generally, the habit will not be present every single day at the exact time-slot; therefore, it was also determined on how many days the habit was present. This value was corrected when a habit was only performed on specific days of the week (e.g. only on Mondays), for the number of these specific days present in the measuring period. The analysis was repeated for the data of the window sensors, considering the same winter period as the logbook study (Jan-Feb 2017).

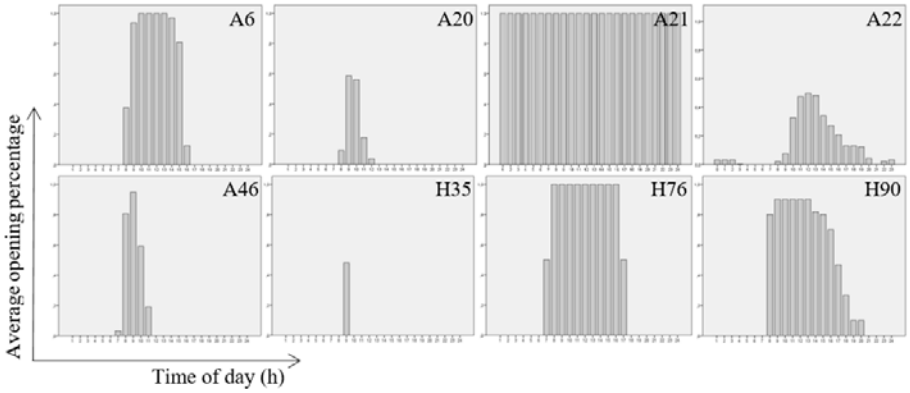

Figure 1. Average opening percentages per hour – Dwellings with a window opening habit.

RESULTS & DISCUSSION

Habits in winter

In 17 of the 47 dwellings (36 %) that participated in the logbook study, at least one opening habit was registered. This percentage rose to 45% when not all logbooks were considered, but only those that were assumed to be correct. When assessing the window sensor data, only in 5 of the 26 dwellings (19 %) a habit could be observed. This habit presence is lower than observed from the logbook data. However, 4 from the 5 dwellings where habits were observed are apartments which leads to a habit presence of 40% in the apartments, while in merely 1 out of 16 houses (6%) a habit is present. In Table 1, the dwellings that exhibited a window opening habit are presented with the corresponding percentage of the day that the habit occurred. The table also shows in which rooms and on which days of the week the habit was carried out. Even if no habits were found in certain dwellings, they may still be present. The presence of a habit can be missed by the determination method when the habit is performed on varying times during the day or is repeated on only a few days in the week/month. The difference in the number of detected habits between the logbook-data and sensor-data may be attributed to the occupants' participation in the survey. Most participants of the logbook-study partook in the survey, wherein some mentioned specific habits that could have been missed by the determination

Table 1. Dwellings with window opening habits: logbooks (underlined) & window sensors (*).

ID	Room	Habit	Day	Habit presence	Reason
A6	Master Bedroom	07:30 – 14:30	Always	87%	-
A20	Master Bedroom	08:00 - 09:30	Always	72%	-
A21*	Master Bedroom	00:00 - 24:00	Always	100%	-
A22*	All	09:45 - 14:30	Weekdays	69%	-
A46*	Master Bedroom	07:30 - 10:00	Always	91%	-
A49	Master Bedroom	14:00 - 17:00	Always	87%	-
A51*	Master Bedroom	08:30 - 09:30	Always	86%	-
	Living room	08:30 - 09:30	Always	86%	-
A54	Master Bedroom	07:30 - 08:00	Always	93%	-
A75	Master Bedroom	08:00 - 12:00	Thursday	100%	Cleaning
H26*	Second Bedroom	00:00 - 24:00	Always	100%	-
H35	Master Bedroom	08:00 - 08:30	Always	100%	-
	Second Bedroom	07:30 - 08:00	Always	100%	-
H40	Master Bedroom	12:00 - 14:00	Always	59%	-
	Living room	12:00 - 12:30	Always	100%	-
H76	Second Bedroom	06:30 - 16:30	Always	100%	-
H90	Master Bedroom	07:30 - 17:00	Always	100%	-
	Second Bedroom	07:30 - 17:00	Always	56%	-
	Third Bedroom	07:30 - 17:00	Always	56%	-
	Bathroom	08:30 - 12:00	Always	44%	-
	Living room	08:00 - 12:00	Always	67%	-
	Kitchen	08:00 - 11:00	Always	44%	-
H97	Living room	07:40 - 07:50	Weekdays	84%	-

method (e.g. cleaning every Thursday). Of the dwellings with window sensors, only a few occupants participated in the survey consequently lowering the probability of detecting habits. Accordingly the substantial difference between apartments and houses may be attributed as well to the limitations of the determination method or the small data sample. However, it may also be due to a better understanding of the working of the ventilation system by the inhabitants of the houses. Further research is needed on the occupants' knowledge of the ventilation system and the corresponding relationship with the presence of habits.

Most habits occurred in the bedrooms in the morning (Table 1). This observation corresponds to the findings of Fabi et al. (2013) that the probability of opening a window is the highest in the morning. However, they attribute the opening actions to the presence of high CO_2-levels, while it is more likely that occupants open their windows when they wake up, as a habit. The windows will not necessarily be opened due to high CO_2-levels, rather due to the fact that occupants are only able to interact with the windows when they are awake and because the CO_2-levels will only decrease as a result of the opening of the windows. In merely four dwellings a living room opening habit was observed. Other habits were present when a recurring activity took place every week that demanded the opening of windows or doors. For example, cleaning personnel may clean the dwelling every week at the exact same time and open the windows while doing so. On average, the habits were present during more than 80% of the measuring period, so on more than 80% of the days the habits were executed. Some dwellings showed just a 50% presence of habits; in these dwellings the hours at which the opening actions occurred were shifted. This may indicate that the habits are linked to a certain activity rather than to a certain time-slot. For example, the opening of the bedroom windows in the morning will be closely linked to the waking-up event, which may not happen every day at exact the same time. Other dwellings revealed a 100% habit-presence; in these dwellings the habit was punctually repeated every day.

Habits in summer

The discussed habits are the results of a winter study; additionally, it was checked if these habits were similarly present in summer. No logbook study has been performed in summer,

consequently solely the window sensor data could be used. The month August in 2016 was selected since in June and July the monitoring system was not working properly and in previous years the sensors in the houses were not yet operational. It was observed that the winter-habits were not present anymore in summer, as visualised in Figure 2. The majority of the windows were continuously opened in summer, which leads to the dissipation of the winter-habits. This may evidently be a habit as well. It is necessary to do more research on the 'survival time' of these habits, this is the time that the context is stable and habits are executed (Ouellette and Wood, 1998), in order to examine in which period the winter-habits and summer-habits are present and to develop a window opening model accordingly. There may be spring- and autumn-habits as well, but this needs to be analysed further.

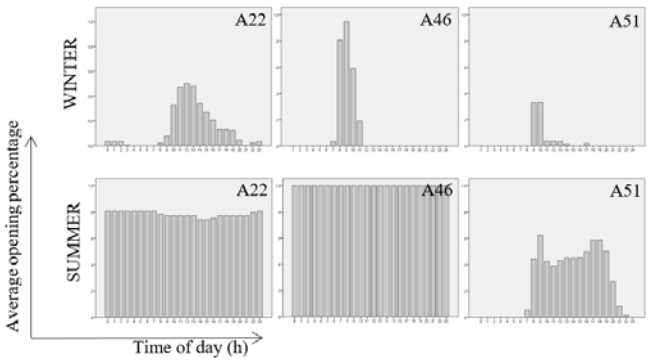

Figure 2. Average opening percentages per hour in winter and summer

Influence of window opening habits on opening percentages and energy use

The average window opening percentages per day in winter were higher for dwellings where a habit was present, compared to dwellings without a habit. In the master bedrooms the average opening percentages for dwellings with a habit was 19%, while for dwellings without habits it was 9%. In the living room the opening percentages were lower, but the difference was still present with respectively 3% and 1% for dwellings with and without habits. Consequently, a large part of the opening actions happened independently of any weather variables. This demonstrates why the window opening models based on weather variables were not able to correctly predict the opening behaviour in winter. There is a potential large effect on the energy use when the opening percentages increase. Nevertheless, no significant correlation was found between the monitored energy use and the presence of a habit, which could be caused by the limited number of cases or the multitude of other factors that simultaneously influence the energy use.

CONCLUSION

Using logbook and window sensor data the presence of habits in winter was determined for the residents of a nearly zero-energy social housing neighbourhood. In 45% of the dwellings a habit was performed with an average presence of 80% during the measuring period. A 100% habit-presence could not be observed in all dwellings since the habitual opening actions could differ slightly in time. Consequently, it is assumed that the window openings are rather linked to an activity which is performed consistently every day than to an exact time-slot. Most habits occurred in the morning in the bedrooms, this may be closely linked to the waking-up event. Other habits were present due to repeated activities during the week such as cleaning. In summertime these winter-habits dissipated due to the extended duration of the window openings. Further research is needed to determine the presence of summer-habits and the 'survival time' of these habits. The winter-habits have an important influence on the opening percentage of the windows. With the window opening models based on weather variables

lacking accuracy in winter time, developing a model that includes these habits may lead to more precise predictions of the window opening behaviour.

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