Proceedings of Conference: ***Adapting to Change: New Thinking on Comfort*** Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

A web-based survey of thermal factors as predictors for occupant behaviour – Towards a purpose-rank based model of reference levels

Marcel Schweiker and Masanori Shukuya

Graduate School of Environmental and Information Studies, Tokyo City University, Japan. marcelschweiker@gmail.com

Abstract: This paper investigates the importance of thermal factors as driving forces for six different interactions of the occupant with the built environment. Thereby, it focuses on the "why" of the interaction, i.e. the purpose, together with the order of actions performed, i.e. the ranking. The data from a dynamic Internet-based survey, which was presented in four languages and conducted in winter 2008/09 and summer 2009, was used and it was shown that temperature alone does not necessarily cause the majority of interactions and that especially the indoor air quality plays an important role for window opening behaviour. Furthermore a first ranking was derived showing the order of interactions performed by the occupants to combat the feeling of thermal discomfort. Both findings support our previously published theoretical model of occupant behaviour and the results are set in relation to the concept of reference level.

Keywords: Occupant behaviour, Survey, Purpose, Expectation, Order

1 Introduction

Danchin et al. (2008), who are looking at behaviour from an evolutionary perspective, state that the purpose of behaviour is – beside the survival of the individual – the survival and replication of the genes carried by that individual. In case of occupant behaviour, there is in general no immediate danger of passing away due to a not performed behaviour. However, conditions with very high or very low temperature prevailing for a longer period can lead to a damage of the human organism. Some examples of injuries caused by heat are (1) heat oedema, (2) heat syncope, (3) heat cramps, and (4) heat stroke (Lee-Chiong and Stitt 1995). Even though not all of the named injuries are as dramatic as the last one and some of them have no permanent effect, they should be avoided. Also conditions with the lack of oxygen can lead to performance losses or even damages, which together with the thermal aspect lead to two basic purposes of occupant behaviour: (1) staying in conditions thermally favourable for the human body, and (2) staying in conditions with sufficient fresh air. These can be summarized in thermal comfortable conditions and conditions with a high indoor air quality (IAQ).

Past studies got to the conclusion that the outdoor air temperature accounts for most of the variations in the interaction of the occupants with the elements of the built environment (Dick and Thomas, 1951; Brundrett, 1977) and consequently the behaviour is set in relation to the outdoor and/or indoor air temperature by recent studies (e.g., Rijal et al., 2007; Haldi and Robinson, 2008). However, few is known about how often the behaviour was performed for one of the two explained purposes and how often other reasons were decisive.

This paper presents the result of asking occupants about the success of their past behaviour concerning five factors, namely thermal comfort, noise, illuminance, air quality and humidity, their purpose of behaviour and the order of their behaviours when facing thermally not comfortable conditions. This knowledge of the main purposes as well as the order of behaviours will lead to a better understanding of occupant behaviour as well as insights into the type and nature of the reference levels as introduced in the frame of the theoretical occupant behavioural model by Schweiker and Shukuya (2009).

2 Methodology

The analysis for this paper is based on data deriving from an Internet-based investigation, which was conducted during the winter period of 2008/09 and the summer period 2009. While the surveys related to summer could be conducted only during the northern-hemisphere summer-period, those concerning winter were conducted both in the northern-hemisphere winter 2008/09 and the southern-hemisphere winter 2009. The survey was announced by electronic mail via friends and colleagues of the authors with the request to forward it to their colleagues and friends; and also by a few organizations, who kindly sent the announcement to their mailing lists members most of whom were Japanese or Germans.

Summer and winter investigations of the Internet-based survey consisted of three steps each. First, the participants filled out an introductory survey, which included questions concerning the actual state of heating devices and windows; the frequency of interaction with heating devices, windows, and curtains during the last 14 days before the questionnaire; preferences and attitudes towards or against certain interactions; and detailed questions about the current living conditions as well as those prevailing during the childhood of the participants. The medium of the Internet allowed the survey design to be dynamically, in such a way that following questions were based on answers given to previous questions, e.g. the question “Please choose the current state of your window.” was followed either by “When did you open the window?” or “When did you close the window?” according to the state of window chosen before. This allowed the adjustment of questions to be suitable to the conditions present at the participants place.

Second, those who answered all questions and entered their e-mail address received an access code for an information area, which is out of scope here in this paper. Third, four to eight weeks after the initial survey, the participants were asked to fill out a second survey, dealing with the information gathered, the strategies tried and the current behaviour. All materials were presented in four languages: English, German, Japanese and Spanish.

3 Results

Due to the fact that the total number of e-mails sent to announce the survey is unknown, it is not possible to state the response rate here. Out of the 854 persons in winter and 435 in summer who started participating in the survey, 686 persons (80%) and 390 (90%) completed it, respectively. The answers of the participants were written into the database in between the completion process, so that the answers of incomplete questionnaires could also be partly used for this analysis.

A majority of the participants (71%) is in the age from 20 to 39 years old and most of them (70%) have a university degree, which is probably due to the way of announcement and media of the survey. The genders are well distributed.

Table 1 shows the number of observations for the heating/cooling devices as well as the windows during summer and winter surveys, which shows that only few persons have no heating device, but more than half do not possess any cooling device. As one would expect, most windows are closed during wintertime, while nearly half of the windows are opened in summer.

Table 1. Number of observations for each state

	Winter		Summer	
	N	%	N	%
Heating/Cooling device				
Running	654	70	129	21
Stopped	238	25	142	23
No device	34	4	336	55
No idea	15	2	7	1
Window				
Opened	87	9	313	50
Closed	844	90	291	47
No window	10	1	21	3

The results were analysed on (1) the success of the past behaviours, (2) the purpose of past and future behaviours, and (3) the order of behaviours.

3.1 Success of behaviour

Figure 1 shows the comfort votes given by the participants divided by survey period and whether those persons were at home or at work in the moment of answering the questionnaire. It therefore shows the success of the adjustments of the built environment previously done. The votes were given by clicking at a place on the continuous bar whose ends show either of the extreme statements such as “too bright” and “too dark” for all cases, except the 7-point scale for thermal comfort.

The three middle votes of the 7-point scale for thermal comfort are regarded as representing a state of thermal comfort (de Dear and Brager, 2002). Considering this, 10% to 20% of persons stated a feeling of discomfort in winter, while only 1% to 5% stated the same in summer. Except a small number of persons feeling too warm at work in winter, many claim discomfort due much to coolness in both seasons. It suggests that wrong utilization or setting of cooling devices is highly probable in summer.

With respect to the IAQ, 20% to 75% of persons stated to have a bad IAQ, with the highest value of dissatisfied in winter at work and the lowest value in summer at home. In general it can be seen that a higher percentage of participants managed to achieve satisfactory IAQ-conditions at home compared to work and in summer compared to winter. The former can be explained with the lower density of persons and equipment and the latter with the higher percentage of windows open in summer compared to winter.

The illuminance level is judged by 50% to 60% as neutral, i.e. in this case as comfortable, while there is a small tendency that it is a bit too bright at work and too dark at home. The noise level is perceived by 40% to 60% as neutral, whereby this percentage is a bit higher at home compared to work.

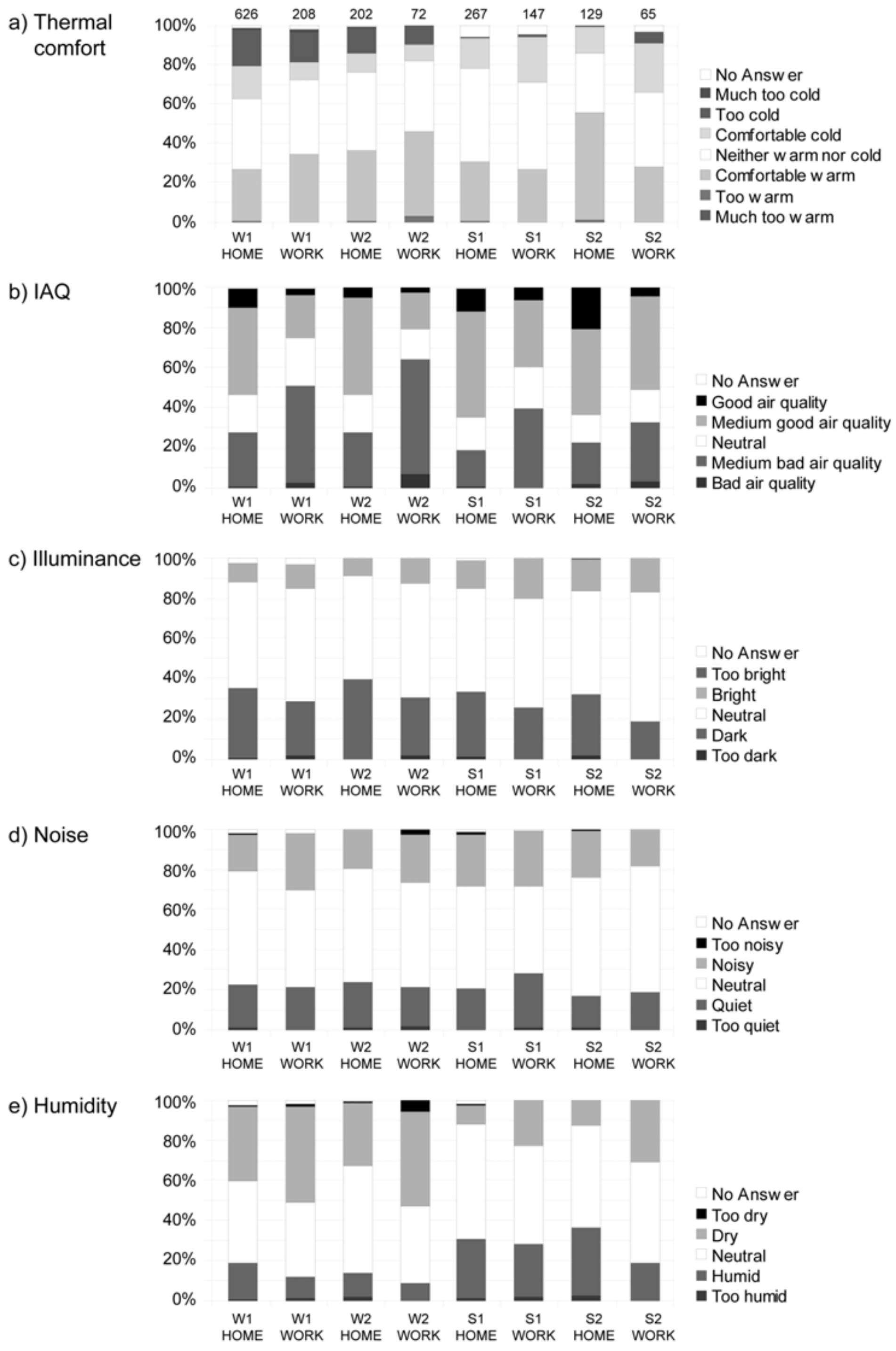

Fig. 1. Comfort votes for thermal environment, IAQ, noise, illuminance and humidity (W1 and S1 are the introductory survey in winter/summer; W2 and S2 are the follow up survey in winter/summer; Numbers above the bars show the total number of participants answering the respective questions).

Finally, the humidity level is found to be neutral by less than 40% of the persons. In winter and thereby especially at work it is judged as dry or too dry by some 50% of the persons, which is due to the dried air by the heating devices. In summer, 30% to 40% feel it to be humid at home while the same percentage of persons feels it dry at work, which can be explained with the higher percentage of cooling devices at work compared to home.

3.2 Purpose of Behaviour

The purpose of behaviour was analysed in two ways. On the one hand, the reasons for an interaction were analysed in order to see what kind of external influences such as temperature, humidity, and noise are triggering certain behaviours. On the other hand, the expectation was analysed in order to see the individual judgement how a change in the prevailing condition would affect external factors such as the energy used within the built environment as well as internal factors such as health.

Figures 2 and 3 show the distributions of the reasons stated for the last interaction with the window, heating or cooling device in the past as well as the reasons stated to interact with the same elements in the future. The former are concerning the already performed action, while the latter are concerning the possible future interactions.

Furthermore, the former were asked as closed-ended questions giving the options “It was warm”, “It was cold”, “It was humid”, “I needed fresh air”/”It was noisy outside”, “I wanted more light”, “I don't remember” and the possibility to answer “other” and specify the reason by a free text input. “I needed fresh air”/”It was noisy outside”, and “I wanted more light” was shown only for the questions concerning the operation of the window. The latter, on the other hand, were asked as open-ended questions. According to Woods (2008), the difference is that closed-ended questions can create a feeling of being prompted to answer in a positive way, i.e. there is a high probability that some of the participants state more reasons than there were in reality. On the other hand, participants will not think of all possible reasons in an open-ended question. The combination of both questions therefore balances the advantages and disadvantages of using one method alone, even though the magnitude of the options presented in the closed-ended questions might be overestimated, while those of the open-ended questions a bit underestimated.

Keeping these limitations in mind, opening the window is in both seasons mainly related to the wish for fresh air, followed by ventilation in winter (Fig. 2) and temperature related factors in summer (Fig. 3). While fresh air is clearly a matter of IAQ, ventilation could mean either a matter of IAQ or a temperature related reason. Closing the window in winter is mainly related to uncomfortable thermal conditions. In summer, temperature regulation is the main reason besides being responsible for less than 50% of the interactions. Apart from the reason that the window is closed because the person is leaving the room, noisy, rainy or windy conditions outside the room account together for the same percentage as temperature does.

Switching on the heating or cooling device is to a great extent related to temperature. It is surprising that humidity accounted for less than 20% in summertime although being considered by many as important factor for such behaviour. In fact, of the 84 persons living in Japan and having the AC-unit switched on, only one person stated humidity as the reason for switching it on and of the 92 persons who are living in

Japan and had the AC-unit switched off, seven stated humidity as reason for switching on the AC-unit in the future.

As the purpose for stopping the heating or cooling device, several factors have equal proportions: temperature, leaving the room and going to bed for winter and temperature, leaving the room and the fact that the cooling device is not used at all in summer. In general it can be said that the control of the prevailing temperature is the main purpose for closing the window and starting the heating and cooling device, while the control of IAQ is the main purpose for opening a window.

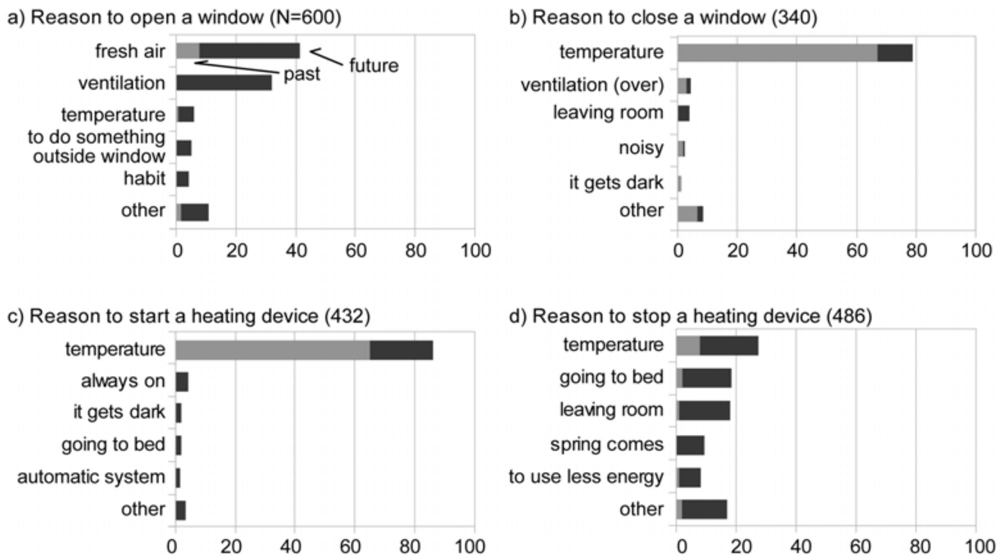

Fig. 2. Past and future reasons for interacting with the built environment in winter. The bar for each reason consists of the part for the last interaction in the past and the one for a possible future interaction. The category "other" includes e.g. cooking, smoking, security, when spring comes, and to feel the outside.

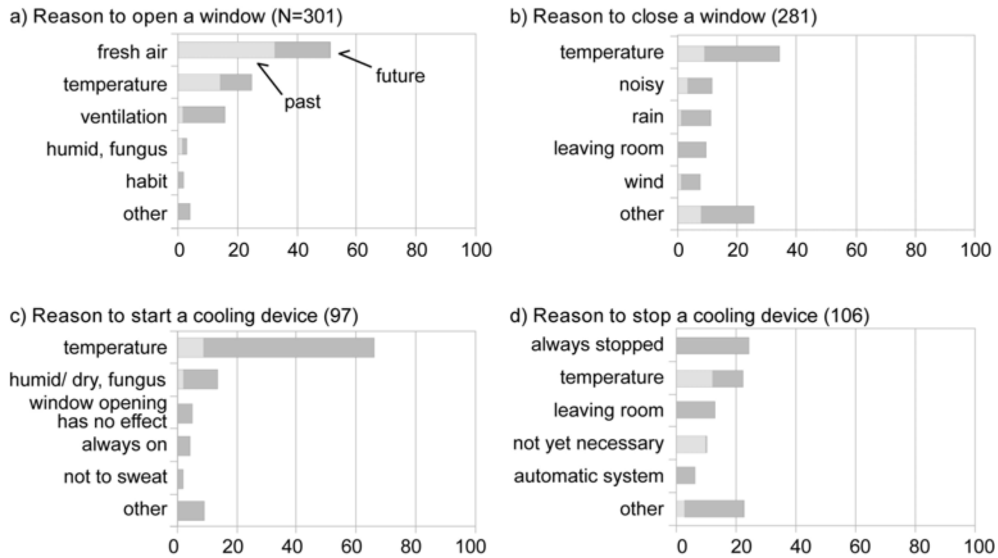

Fig. 3. Past and future reasons for interacting with the built environment in summer. The bar for each reason consists of the part for the last interaction in the past and the one for a possible future interaction. The category "other" includes e.g. coming visitors, using alternative, problem with device, save money, health reasons, and to listen to the rain.

Figure 4 shows the distribution of persons evaluating the possibility that a change of the window state or heating/cooling device state would lead to a certain outcome as positive, neutral or negative. It can be seen that a majority of persons evaluates a change of the current conditions in nearly all cases as bad and leading to less comfortable conditions. Closing the window in summer has the highest percentage of votes with respect to a negative outcome. Additionally, in all cases around 80% or more of the participants judged that it would be easy to change the state.

However, looking at the question concerning healthy or unhealthy conditions a majority of persons stated that an open window would be healthier than a closed one. In the case of the heating/cooling device, it is interesting to see that one half believes that a running device is healthier, while the other half believes the opposite. This shows that people are able to distinguish between thermal comfort and health aspects and that they evaluate the thermal comfort to be more important in winter than the health aspect.

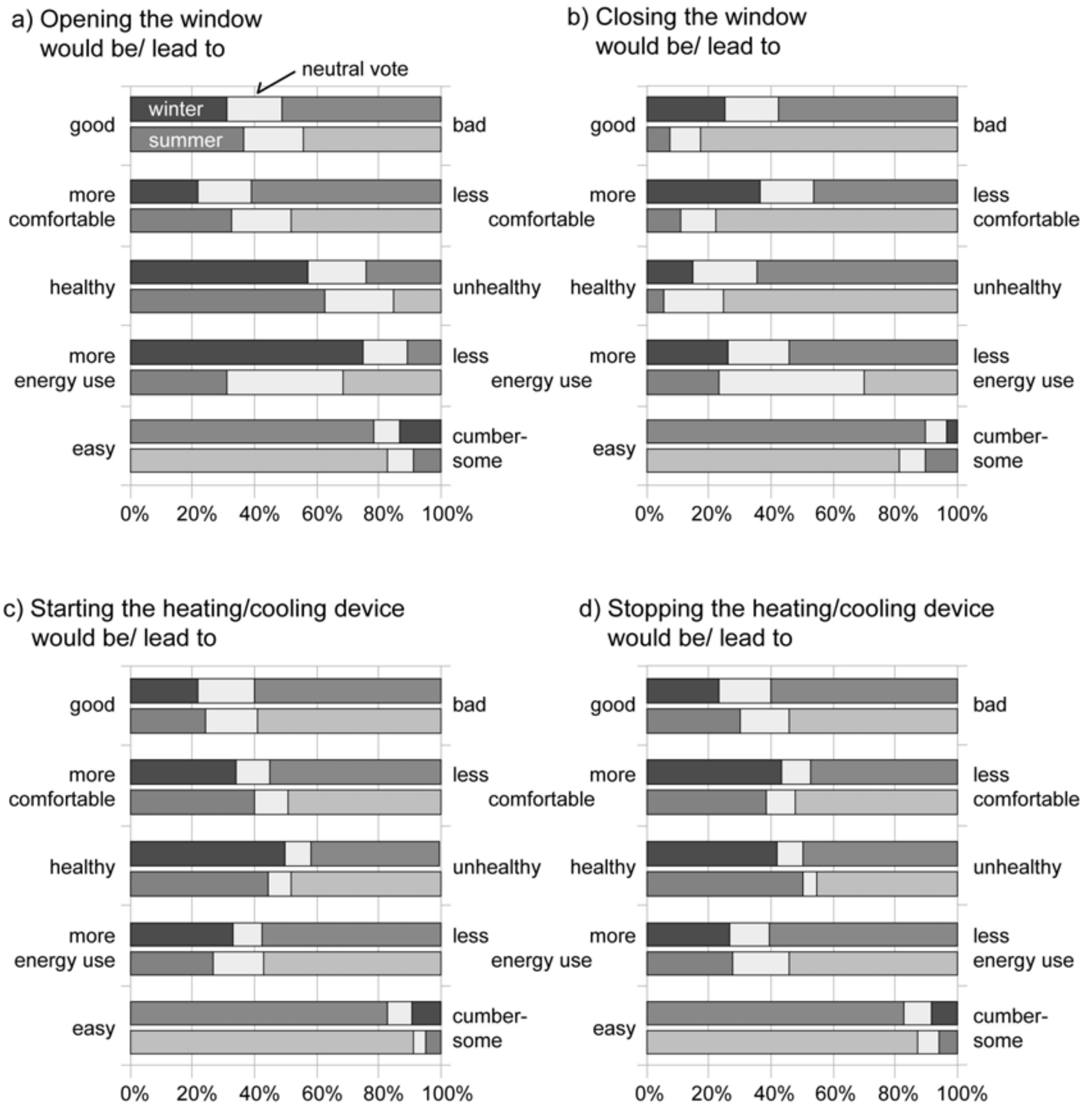

Fig. 4. Evaluation of a possible change in the state of window or heating/cooling device with respect to overall goodness, thermal comfort, health, energy use and easiness.

The question why people do not change the condition in the case they believe a change would lead to better conditions needs to be investigated further in the future.

3.3 Order of Behaviour

Here we discuss the results of the answers to the question asking the participants to state the order of the first three actions they would perform to combat thermal discomfort. It should be kept in mind that this order is hypothetical and not based on any observation. That is, there may be some differences between imagination and reality. However, for the first overview it must be interesting to see if any tendencies can be found in the type of actions believed to be performed first.

The question about the order of the performed behaviour in order to combat thermal discomfort was asked a little bit differently in the summer and in the winter survey. In the summer survey, the starting conditions were fixed to be window closed, cooling device off and summer clothes in the description of the question, but in the winter survey, no such starting conditions were described. The distribution of answers given in summer and winter are shown in Figure 5.

The ranking of the first action to be done in winter clearly shows a structure from the easiest to perform to the most difficult to perform, i.e. most people first put on more clothes, the second biggest group would first close the window and a third group would switch on the heating device first. In summer, a half of the persons stated to open the window first and another 37% stated to take off some clothes.

In general it can be seen that there is not one single action performed first by more than 60% of the persons. This leads to the conclusion that the order of action is highly different from individual to individual. Especially whether a person switches on the heating device first, second, or third leads to very different energy usage patterns.

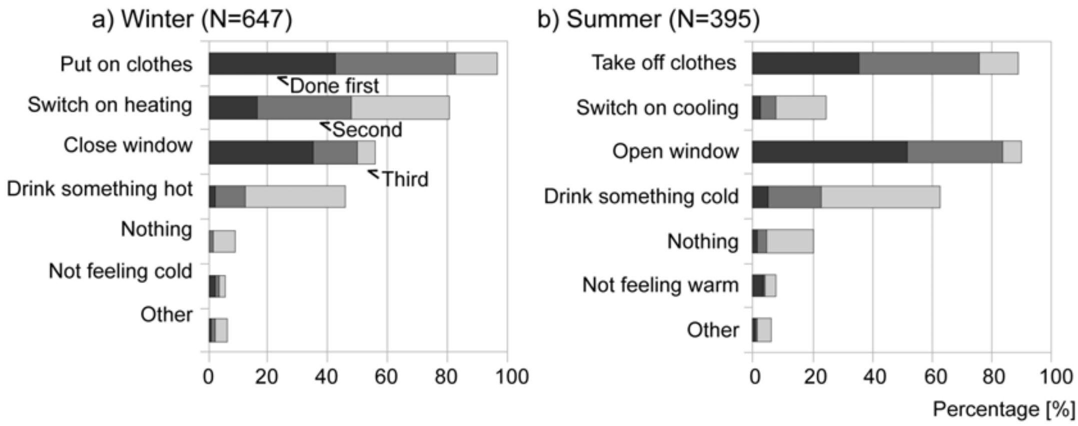

Fig. 5. Distribution of votes given for the actions to be performed first, second, and third in the case of thermal discomfort for winter and summer.

4 Discussion

In our previous work published (Schweiker and Shukuya, 2009), we discussed a theoretical occupant behaviour model. This model was derived from findings of a comprehensive literature review within the fields of built environmental research, neurology, psychology, control theory and behavioural ecology. From neurology, we learned that each neuron inside the brain has a specific threshold level and in case the stimuli, e.g. the amount of heat perceived by the skin, is greater than this level, the neuron is sending an electric impulse via its axon to the neurons to which it is connected – this process is called “firing”. Nevertheless, for one simple thought or action, millions of neurons have to fire at the same time (Carter, 1998). This led to the definition of the reference level included in the theoretical occupant behaviour model to be the level at which sufficient neurons fire due to a certain sensation in order to trigger a change of the thermoregulatory settings or an interaction with the built environment. A decision for or against a certain action is thereby formed based on all input values deriving from the body’s sensual system.

Taking the results presented above, the nature of the reference level can be made more concrete and thereby we may come up with a purpose-rank based occupant behavioural model.

As shown with the results concerning the purpose of behaviour, on one hand, the decision seems to depend on the type of input value so that there must be a separate reference level either for each input or a combination of related input values, which is symbolized in Table 2 by the different capital letters of the reference levels' indices. On the other hand, as shown with the results concerning the order of actions, there must be also a separate reference level for each alternative, which is shown by the change in the minor letters.

The reference levels having different capital letters are independent from each other and one can only observe the percentage of actions related to each purpose as shown above. In contrast, the reference levels having different minor letters are dependent from each other, one can observe them by field measurements or questions asking about the order of actions performed in reaction to one input value being out of the limits as also shown above.

Table 2. Reference levels

	Thermal comfort - Core temperature - Skin temperature - Air current - Overall comfort - HBx-rate	Air quality (IAQ) - CO_2- concentration - Odours -...	Sound - Noise level - Type of sound -...	...
Open window	Ref.-level Aa	Ref.-level Ba	Ref.-level Ca	.
Close window	Ref.-level Ab	Ref.-level Bb	.	.
Start heating	Ref.-level Ac	.	.	.
Stop heating	.	.	.	.
..	.	.	.	.

Furthermore it should be mentioned that based on our previous findings, each of these reference levels is different from individual to individual and also not fixed at one point in one’s life, but rather (1) partly given by the genome (human biological nature) and (2) constantly adapted and changed by personal experience(s), e.g. experience of seasonal changes, or changes in the surrounding environment or the personal attitude.

Additionally, in the field of cognitive mapping, it was found that persons distinguish indoor scenes from outdoor scenes. This means, e.g. at the basic level, people categorize outdoor scenes into beach scenes, city scenes, or forest scenes and categorize indoor scenes into schools, restaurants, or grocery stores (Tversky and Hemenway, 1983). Scenes seem to be so important to human behaviour that a region of the parahippocampal cortex appears to be dedicated to their recognition (Brewer et al., 1998; Epstein and Kanwisher, 1998). This means that the human mind has a different pattern of behaviour e.g., when eating out in a public restaurant or eating at home, which we can easily be proved by observing our own behaviour in those situations. Following those findings, one could add a third dimension to Table 2 by defining another set of reference levels, for home, work and other places. Whether this is sensible and true has to be found by well-designed measurements, which would be beyond the scope of this paper.

5 Conclusions

The importance of temperature compared to other purposes was evaluated for six different interactions. It was shown that temperature alone does not necessarily cause the majority of them and that especially the indoor air quality plays an important role for window opening behaviour. Furthermore a first ranking was derived showing the order of interactions performed by the occupants to combat the feeling of thermal discomfort and it was shown that this ranking is different for individuals.

Both findings support our previously published theoretical model of occupant behaviour and our results with regard to the reference level. Based on these findings the concept of reference levels was concreted by defining one reference level for each input value or purpose and each possible interaction with the built environment.

Further research is recommended in order to quantify the “when” of an interaction for indoor air quality and other factors, such as noise. Together with further research about the order of interactions, this can lead to a better understanding of occupant behaviour and a powerful purpose-rank based occupant behavioural model.

References

Brewer, JB, et al. (1998), Making Memories: Brain Activity Predicts How Well Visual Experience Will be Remembered. Science, Vol. 281, pp. 1185-1187.

Brundrett, GW (1977), Ventilation: A Behavioural Approach. International Journal of Energy Research, Vol. 1, No. 4, pp. 289-298.

Carter, R (1998), Mapping the Mind. Weidenfeld & Nicholson, London, UK

Danchin, E et al. (2008), Fundamental Concepts in Behavioural Ecology, in: Danchin, É., Giraldeau, L. & Cézilly, F. (Eds.), Behavioural Ecology, pp. 29-54, Oxford University Press.

DeDear, RJ and Brager, GS (2002), Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55. Energy and Buildings, Vol. 34, No. 6, pp. 549-561.

Dick, JB and Thomas, DA (1951), Ventilation Research in Occupied Houses. Journal of the Institution of Heating and Ventilating Engineers, Vol. 19, No. 194, pp. 279-305.

Epstein, R and Kanwisher, N, (1998), A Cortial Representation of the Local Visual Environment. Nature, Vol. 392, pp. 599-601.

Haldi, F and Robinson, D (2008), On the Behaviour and Adaptation of Office Occupants. Building and Environment, Vol. 43, pp. 2163-2177.

Lee-Chiong, TLJ and Stitt, JT (1995), Heatstroke and other heat-related illnessess. The maladies of summer. Postgraduate Medicine, Vol. 98, No. 1, pp. 26-36.

Rijal, HB, et al. (2007), Using Results from Field Surveys to Predict the Effect of Open Windows on Thermal Comfort and Energy Use in Buildings. Energy and Buildings, Vol. 39, No. 7, pp. 823-836.

Schweiker, M. and Shukuya, M. (2009), Comparison of Theoretical and Statistical Models of Air-Conditioning-Unit Usage Behaviour in a Residential Setting under Japanese Climatic Conditions. Building and Environment, Vol. 44, pp. 2137-2149.

Tversky, B and Hemenway, K, (1983), Categories of Scenes. Cognitive Psychology, Vol. 15, pp. 121-149.

Woods, J (2008), What People Do When They Say They Are Conserving Electricity. Energy Policy, Vol. 36, pp. 1945-1956.