Comparison of imagined and real behaviors in relation to active cooling methods under Japanese summer conditions

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ABSTRACT

Recently post-occupancy evaluation is often used to know the actual performance of so-called energy saving building components and to compare with simulated performance. In reality, the occupants choice how to achieve comfortable conditions, e.g. by switching on an air-conditioning unit or opening a window, influences significantly on the exergy balance of the building systems.

Measuring the occupants' behavior is cost- and time-consuming so that it would be favorable to use a method of survey alone to enable us to evaluate the occupants' behavior. This would lead to a broader knowledge about the occupants decision process, helping to improve the above-mentioned choice and thereby to save a significant amount of exergy supplied and consumed for creating comfortable condition.

This paper therefore discusses the reliability of the conclusions based on a set of answers found through a survey and a possibility of method to improve the outcome. The data used in this paper is from a field study conducted within an international student dormitory in Tokyo in summer 2007.

The occupants behavior was evaluated in two steps in this field study. First, a written survey about current behavior, behavioral background and actual preferences was conducted; this is to know the "imagined" behavior. Second, the indoor conditions within the rooms of 38 students were measured together with the outdoor condition for six continuous weeks from June to August. This allowed the analysis of the "real" behavior.

In a first comparison, the "imagined" behavior obtained from the written survey and the "real" behavior obtained from the measurement agreed only in around 42% of the cases. Five individual factors: preference; "imagined effectiveness" of passive strategies; knowledge of passive strategies; air-conditioning unit usage during childhood; and climate in the home country were found to influence very much on the judgment of imagined behavior. Taking this into consideration, the above percentage increased up to over 80%.

1. INTRODUCTION

Recently post-occupancy evaluation gets more common to compare simulated and real performances of so-called energy saving building components and building systems (e.g. Donn, 1999; Bulteau et al. 2007). In reality, the occupants have several choices how to achieve comfortable conditions, e.g. by switching on an air-conditioning unit (AC-unit) or opening a window. The decision and the resulting behavior have a significant influence on the exergy balance of the building systems (Andersen et al. 2007).

Measuring the occupants behavior is cost- and time-consuming, due to the necessary instrument set-up, which may cause a difference from daily occupancy. In order to minimize cost and time, it would be favorable to use a method of survey alone to enable us to evaluate the occupants behavior. This would lead to building a broader database and knowledge about the occupants decision process and hence helping to

improve the above-mentioned choice and thereby to save a significant amount of exergy supplied and consumed for creating comfortable condition.

This paper therefore discusses the reliability of the conclusions based on the answers found through surveys, which we call the "imagined behavior", and a method to improve the outcome in order to have a higher consistence with the "real behavior".

2. THE SURVEY AND THE MEASUREMENT FOR ANALYSIS

Our survey together with the physical measurement was conducted during summer 2007 at an international student dormitory opened in 1989 in Tokyo area, which is a 5-storied building with 320 identical single rooms made of concrete with little thermal insulation and single glazed windows (Fig. 1). The single rooms of 15m^2 each including the bathroom are oriented to east, south or west. Each room has one door facing to the corridor and one window on the opposite side, and is equipped with one AC-unit. The residents are free to use electrical fans or other measures to keep their rooms as comfortable as possible.

All of the residents are foreign students originating from countries other than Japan. The 39 students who agreed to participate in our measurement came from 27 countries from all continents with the majority from Europe and Asia. The period the students are allowed to live in the dormitory is limited up to two years so that most students came to Japan within three and twenty months before the measurement.

The whole investigation consists of two steps. As the first step, we conducted a questionnaire survey with 35 questions written in English about their current behavior, behavioral background, their preferences and knowledge about alternative methods to keep the room cool in summer. In total 310 questionnaires were distributed at the dormitory, from which 71 questionnaires filled-out were returned.

In the second step, the 38 students who agreed to participate in this survey received two sensors: one wireless sensor collecting temperature and humidity values; and the other one, which can indicate if the window is open or closed. In order to prevent a disturbance of privacy, these students were asked to install those sensors themselves. Starting one week later, the room air temperature and humidity values of these 38 students were collected at a two minute interval for six continuous weeks starting from the end of June to the mid of August. During this period, the outdoor temperature, humidity, air current and solar radiation were also measured.

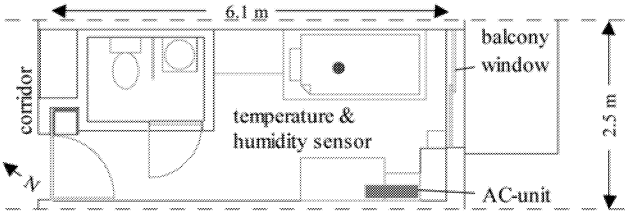


Figure 1. Floor plan of a student room and placement of the sensor.

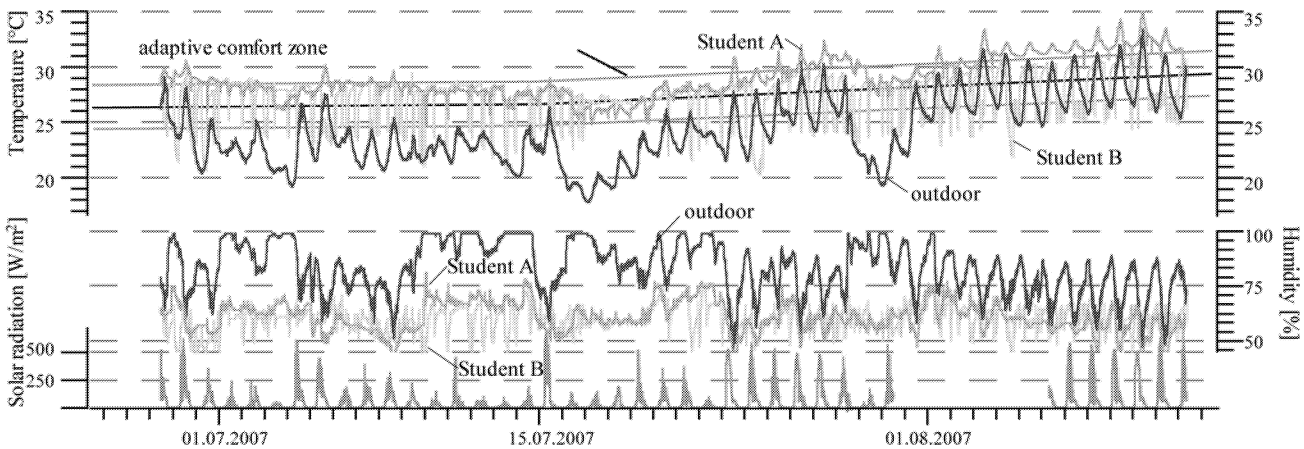


Figure 2. Thermal conditions during the measurement period and adaptive comfort zone for Tokyo (Student A did not use the AC-unit, while Student B did).

Figure 2 shows the outside conditions during the measurement period together with the inside conditions of two student rooms and the adaptive comfort zone for Tokyo. The adaptive comfort zone is the range of ±2°C around the comfort temperature, which is most likely to be evaluated as comfortable, introduced by Nicol and Humphreys (Nicol & Humphreys, 2002). While the first two weeks were still relatively moderate as a Japanese summer, the last ten days were with the daily highest temperature of above 30°C and the relative humidity of over 70% so that the survey was made both under moderate and extreme weather conditions.

The indoor conditions were even worse than the outdoor conditions due to the density of occupancy, lights, and electrical appliances in combination with little thermal insulation of the building envelope. The difference in the interior conditions between student room A and B is the result of student A not using the AC-unit and student B using it frequently.

3. GROUPING PROCEDURES

In order to compare the imagined behavior stated in the questionnaire and the real behavior, the students were divided into four groups labeled with "N", "E", "L", and "A".

Group "N" consists of those never using the AC-unit; when the conditions get unbearable, they prefer to stand the heat or change the place to stay. Group "E" are those using AC-unit only when the conditions get unbearable for them and other measures such as the use of a fan are failed. Group "L" are those trying not to use AC-unit, but are likely to use it before trying other strategies. Finally, group "A" are those using AC-unit all the time, even when it should not be necessary.

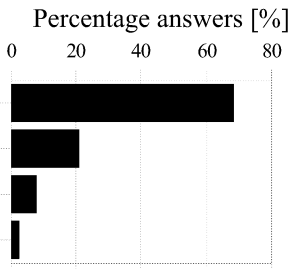
We made two grouping processes: one based on the answers given in the questionnaire, resulting in a group of the "imagined behavior", and the other one based on the data from the measurement, resulting in the other group of the "real behavior".

3.1 Grouping of imagined behavior

The grouping process resulting in the "imagined behavior" group was based on the ways of answers given within the following three questions: those with regard to a) the frequency of AC-unit usage during the week before the survey, b) their strategies to keep their room cool during daytime in summer stated in an open-answer-type question and c) the strategies while sleeping checked in a multiple-choice-question. Figure 3 shows the percentage of the answers to these three questions.

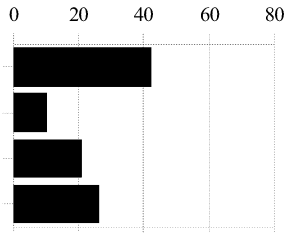
We assigned four integers as values from 1 to 4 as indicated in the middle of Figure 3 to

Answer	Assigned Value
Never	1
1 – 4 times	2
5 – 7 times	4
More than 7 times	4



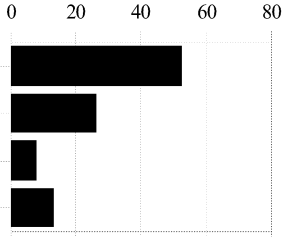
a) AC-unit usage: The use of the AC-unit was not necessary due to the fact that the average values of daily highest and lowest temperature were 24.1°C and 15.8°C respectively and the average value of relative humidity was 53% in the period of the questionnaire survey.

Answer	Assigned Value
Passive	1
Nearly passive	2
Passive or AC-unit	3
Only AC-unit	4



b) Strategies to keep room cool during daytime: The number and type of stated strategies were judged. The more passive strategies were raised, the lower is the expected usage of AC-unit and therefore the smaller the assigned value.

Answer	Assigned Value
Passive	1
Nearly passive	2
Passive or AC-unit	3
Only AC-unit	4



c) Strategies to keep room cool during nighttime: The number and type of checked strategies were judged as for question b).

Figure 3. Answers in the questionnaire and assigned values for the evaluation of "imagined behavior" group.

respective answers in the three questions and then calculated the non-weighted rounded up average of the three assigned values. Those students with the average of assigned values to be 1 are grouped in “N”, 2 in “E”, 3 in “L”, and 4 in “A”. In the process of determining the assigned values and possible weighting factors for the calculation of the average, we assumed that “imagined” and “real behavior” are congruent. Therefore, we chose the combination of assigned values and calculation method as described above, which led to the highest consistency with the “real behavior” group to be explained in the following section.

3.2 Grouping of real behavior

For grouping “real behavior”, we first analyzed when each student turns on the AC-unit and how long he or she keeps it on. This was judged by looking at the room air temperature variations. The measurement period was then divided into three categories, using the data of the indoor conditions in the rooms of the students together with the outdoor conditions.

If the indoor air temperature inside the rooms with no AC-unit on is within the limit of the adaptive comfort zone, we call the usage of an AC-unit during this period “not-necessary” (“NN”). If the room air temperature is lower than 1°C above the upper limit of the comfort zone and the outdoor air temperature within the comfort zone, the usage of the AC-unit is called “necessary unless applying other strategies” (“NU”). If the room air temperature exceeds the upper limit of the comfort zone more than 1°C or the outdoor air temperature is above the comfort zone, the usage is called “necessary even with other strategies” (“NE”).

The students never using the AC-unit during the measurement period were first placed in group “N”. The period and frequency of air-conditioning usage of other students were then judged according to the three categories mentioned above. Those students using their AC-unit in period “NN” were placed in group “A”, those using it in period “NU” were placed in group “L” and those only using the AC-unit in period “NE” were placed in group “E”.

3.3 A comparison of imagined and real behaviors

Figure 4 shows the distribution of imagined and real behavior groups after the above mentioned grouping process. The difference is 15% at maximum and the average is 12%; we can say that “imagined” and “real” behaviors are not always congruent. Figure 5 shows the difference in the AC-unit usage between “imagined” and “real”. Only 42% behave the same in reality as imagined and most of the rest use their AC-units more often.

4. OPTIMIZATION OF GROUPING PROCEDURE

In order to have a better understanding what Figures 4 and 5 imply and to find a higher congruence between “real” and “imagined behavior” group, we modified the grouping procedure of “imagined behavior” group with additional individual factors using a series of macros.

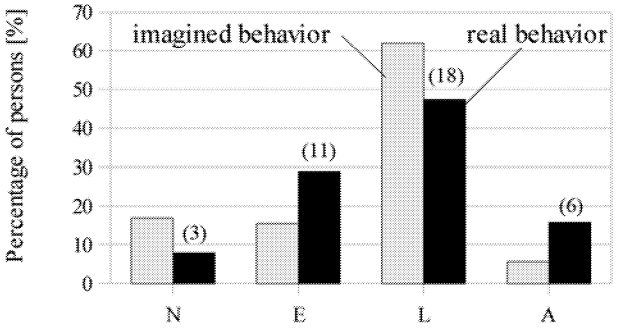


Figure 4. Comparison of imagined and real behavior groups after first grouping process. (N=38)

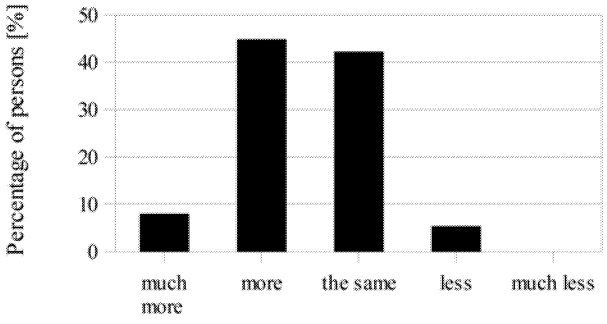


Figure 5. Difference in the AC-unit usage between “imagined” and “real” after first grouping process. In reality the air-conditioning unit is used more often than imagined. (N=38)

For this procedure, the previous calculated value of the "imagined behavior" group was taken as step 1 (s1), because it combined the three most direct questions about the behavior to the highest consistency possible taking no further factor into account. Additional questions were analyzed and categorized to individual factors and then each factor was considered as one step. All of these factors were examined by adding or removing and by changing their relative positions within the macro until we could not achieve a higher percentage of congruence bet-ween imagined and real behavior groups. This optimization procedure was done by hand, this means the algorithm of the macro was changed manually and not by using another program.

The above mentioned procedure allowed to test different hypothesis's about the effect of a certain factor. Though multiple factors result in numerous possibilities of combination, not all possible combinations have been tested. Therefore there is a small chance that the current result is not the best result achievable. Multiple regression analysis commonly used could not be used with the existing data due to the variety of factors and relatively small number of subjects.

Figure 6 shows the comparison of "imagined" and "real behavior" group after the last grouping process. The difference turned out to be 3% at maximum and the average 2%. The congruence between "imagined" and "real behaviors" group is 82% as shown in Figure 7. What follows describes the additional individual factors in the step-order they appear in the macro, which resulted in this so far highest achievable congruence. The influence of each step on the congruence is shown in Figure 8.

The first factor added after the above described grouping process is the preference of AC-unit use during nighttime and is the single factor having the highest influence as can be seen in Figure 8 between s1 to s2. A person claiming to like the AC-unit usage at night time seems to use it more often than imagined and therefore is grouped into the next higher group if he or she belonged to group "N" or "E" (s2).

No knowledge of passive strategies would not allow a person to cope with the summer conditions in Japan without the use of the AC-unit. Therefore a person belonging to group "N" with no knowledge of passive strategies was placed in the next higher group (s3).

The "imagined effectiveness" on the personal comfort of a strategy is taken into consideration in two ways. A person believing that switching on an AC-unit makes it more comfortable is unlikely to be in group "N" and is therefore placed in group "E" (s4a). On the other hand, a person believing that switching on the AC-unit makes it less comfortable, but opening windows

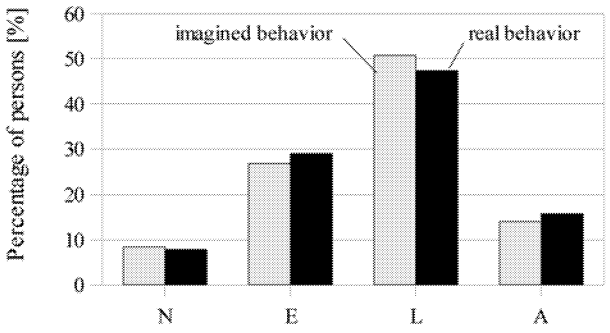


Figure 6. Comparison of imagined and real behavior group after the six steps described. (N=38)

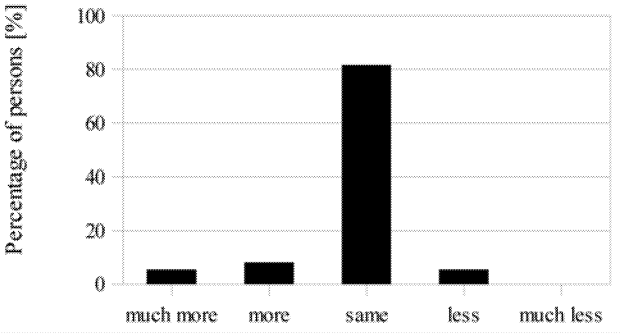


Figure 7. Difference in the AC-unit usage between "imagination" and "real performance" after after the six steps described. (N=38)

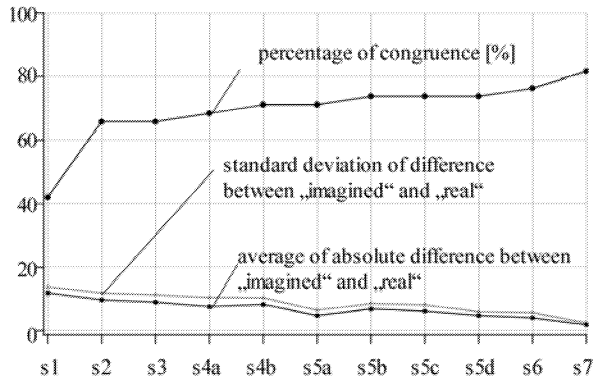


Figure 8. Development of consistency between imagined and real behavior groups. After each step the percentage of congruence increases, the average difference decreases.

results in more comfort, will react this way more likely and was therefore placed in one group lower than just one step before (s4b).

The next factor is the AC-unit usage at home during childhood, which must have been mainly done by the parents. The influence of this factor is diverse. Someone who always slept with the AC-unit switched on is supposed to be used to it and therefore we placed them in group “L”, if they were in group “N” or “E” just one step before, or we let them stay in group “A”. On the other hand, someone belonging to group “L” who slept sometimes during childhood with the AC-unit switched on, must still be able to judge whether it is necessary to use the AC-unit and therefore placed in group “E” (s5a). In the case the AC-unit was sometimes used at school and at home during childhood, the person again must have been exposed to the indoor environment controlled by the AC-unit more likely and was therefore placed in group “L”, if he or she was in group “E” one step before (s5b). Someone claiming that the AC-unit was not used at school or at home at all was placed in group “E”, if he or she was group “N” (s5c). Finally, someone claiming that the AC-unit was always used at school and at home must regard the usage of an AC-unit as normal and therefore we assumed that they use it automatically without consciousness. He or she was therefore placed in group “A” (s5d).

The combination of knowledge of passive strategies and climate in the home country is the next factor. A person having no or little knowledge of alternatives and originating from a cool climate according to the categorization of Koeppen (Kottek et al. 2006) will not be able to cope with the summer conditions in Japan so that he or she is placed in the next higher group (s6).

Finally a correction is done based on the frequency of usage and the strategies to cool the room during daytime. To balance prior placement, those who used the AC-unit in the week before the survey more than seven times and at the same time stated only to use the AC-unit to cool the room during daytime were placed one group higher than that in the step before (s7).

5. CONCLUSION

This paper discussed a comparison of “imagined” and “real” behavior of students living in an international student dormitory in Tokyo. A written survey and physical measurement was done and the behavior stated within the questionnaire, which is called the “imagined behavior”, and that performed in their rooms, which is called the “real behavior” were analyzed. According to the grouping process made first for imagined and real behaviors simply assuming that they are independent from each other, there were only 42% of the students who's “imagined” and “real” behaviors agreed. Five individual factors: preference; imagined effectiveness of passive strategies; knowledge of passive strategies; AC-unit usage during childhood; and climate in their home country were then included in the grouping process and thereby the above percentage was raised up to over 80%. This implies that what they answer in the questions given in the questionnaire influence very much on the judgment of the real behavior.

This result shows that imagined and real behavior may differ quite far from each other. In order to have a good prediction of the “real” behavior on the basis of a written survey only, it is useful to add individual factors.

REFERENCES

Andersen, R.V. et al. (2007), Simulation of the Effects of Occupant Behaviour on Indoor Climate and Energy Consumption; in: Seppänen, O. & Säteri, J. (Eds.), *Proceedings of Clima 2007 WellBeing Indoors*; FINVAC, Helsinki, Finland

Bulteau, V. et al. (2007). Very Low Energy Buildings: Analyse of Two Case Studies in France; in: Santamouris, M. & Wouters, P. (Eds.), *Proceedings of the 2nd PALENC Conference and 28th AIVC Conference*; pp. 152-6; Heliotopos Conferences

Donn, M. (1999). Quality Assurance - Simulation and Real World; in: *Proceedings of the IBPSA Conference, Kyoto, Japan*; P-05

Kottek, M. et al. (2006). World Map of the Koeppen-Geiger climate classification updated, Meteorologische Zeitung, 15, pp. 259-63

Nicol, J.F. & Humphreys, M.A. (2002). Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings, Energy and Buildings, 34, pp. 563-72