On the Influence of Users' Actions on Thermal Performance of Buildings

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ABSTRACT: The thermal exchanges between the buildings and its surroundings may be easily evaluated from balance equations. However, some parameters in the equations are prone to changes due to decisions taken by the users at some time, and further decisions and even computations on thermal behaviour may be strongly affected by the users' attitudes and actions. This can produce wrong computation of energy consumption and savings, and then they have to be avoided. On the other hand, "wrong" actions of the users or misuses might produce uncomfortable conditions that are difficult or expensive to handle. One of the ways to avoid wrong actions of the users is through "training" them, but another reliable way to avoid problems is by means of "robust design", where robust design stands for whole architectural design that difficults the taking of inappropriate decisions by the users, concerning for instance door use, protection of windows, ventilation and related, and some protections on the use of machinery (heating, cooling, air conditioning). In this work, we analyse the sensitivity of the thermal performance results to some actions taken by users in buildings with different building designs. The importance of the control on the conditioning devices, and on the actions that the users can undertake, is emphasized, and the effect on energy consumption and on comfort is also considered.

KEYWORDS: energy, comfort, user's actions, robust design

INTRODUCTION

In this study we classify some actions that the users can undertake in two different schemes, the first one ranking actions based on the influence on the consumption of the buildings and the second ranking actions based on the sensation of comfort perceived inside them. The purpose of the work is to obtain a preliminary classification that underlines the role of an action in the thermal behaviour of the buildings and in the sensation of comfort that generates inside. Then, a sensitivity analysis on the actions of the users that produce changes in the parameters that define the thermal performance of a building is done, for buildings with different designs. The sensitivity analysis of the thermal parameters changes that the users can undertake shows that different building designs lead to different sensitivities. Also, the actions on the control systems and machinery might have large influence on thermal performance. Then, it seems reasonable to limit the actions the users' can do, taking care to preserve the appropriate control impression by the users. Our results suggest the importance to choose correctly the design, in order to be "robust" facing users' actions, maintaining an appropriate thermal and comfort performance.

EVALUATION METHOD

Energy consumption and the sensation of comfort are two very different terms, but both are very important for evaluating the energy efficiency and performance of buildings. A primary criterion for assessing comfort and energy consumption can be obtained from heat transfer equation. This may be written as Eqn. 1 [1, 2]:

$$M \frac{dT_i}{dt} = I + D + G (T_e - T_i) \quad (1)$$

where Ti is a representative internal temperature, Te is the external temperature, I is a term for radiation gains, G is a loss coefficient (which includes thermal conductivity and air exchanges), D is the consumption term and M is the thermal mass. These terms are expressed as specific terms (per cubic meter of building space), in order to asses the behaviour of a generic portion of space and to compare buildings with different size, plan shape and space distribution. For a first asses, average values may be used, and the above equation may be written as a balance equation Eqn. 2 , without the accumulation term (the left term of Eqn. 1):

$$D_c = G (T_i - T_e) - I - D_o \quad (2)$$

where the consumption term D is divided in two parts, the first one related to the cooling/heating system and the second one related to others contributions, as human body, electrical lights and appliances, presence of animals or plants. This equation refers to average conditions, and is most useful in relatively stable conditions. In order to evaluate changes in the temperature or in the consumption caused for actions of the users, the balance equation may be used. Clearly, the first step is determine which actions are to be considered. This work focused on actions that a normal user can undertake easily, as opening or closing windows and doors, turning on or off lights and others appliances, opening or closing shutters or blinds, resetting base temperature for heating or cooling system. The actions selected try to be representative of a normal use of a flat or of a working space.

To obtain an indicative classification of the actions that have relevant influence on the comfort is more difficult. The sensation of comfort depends on a variety of factors, and cultural and social influences can be determinant on the experienced comfort. The easiest way to evaluate the sensation of comfort is to relate this sensation to a temperature index that may asses, with the same balance equation used to asses the energy consumption.

The equation may be written as Eqn. 3:

$$T_i = T_e + \frac{I + D}{G} \quad (3)$$

where Ti is the temperature sensed by the users.

The method of analysis of the relevance of all these actions is the following: once an action is selected:

1. the action changes one or more of the terms of the balance equation, these terms are evaluated before and after the action (the others terms are considered constant);
2. the increase or decrease of the temperature Ti is evaluated with Eqn. 3, in order to classify the relevance of the action on the sensation of comfort;

3. the increase of the consumption necessary to maintain an acceptable Ti is evaluated with Eqn. 2, in order to classify the relevance of the action on the consumption;
4. the action is classified in a scale of very low, low, medium, high or very high repercussion on comfort and energy saving.

To obtain a numerical asses of the relevance of these actions on the energy consumption, we assume that:

- any action that increases the consumption by 0-0.5 W/m^3 has a very low repercussion on consumption
- any action that increases the consumption by 0.5-2 W/m^3 has a low repercussion on consumption
- any action that increases the consumption by 2-4 W/m^3 has a medium repercussion on consumption
- any action that increases the consumption by 4-10 W/m^3 has a high repercussion on consumption
- any action that increases the consumption by more than 10 W/m^3 has a very high repercussion on consumption

And to obtain a numerical asses of the relevance of these actions on the comfort, we assume that:

- any action that increases or decreases the internal temperature by 0-1 ºC has a relatively low repercussion on comfort
- any action that increases or decreases the internal temperature by 1-2 ºC has a medium repercussion on comfort
- any action that increases or decreases the internal temperature by 2-4 ºC has a high repercussion on comfort
- any action that increases or decreases the internal temperature by more than 4 ºC has a very high repercussion on comfort

A more complete study of the comfort dependence on various parameters should consider the presence in the space of important differences in this temperature. An action as “turn on two lights of 15 W” has not a strong influence on the average internal temperature of the space, but the sensation of a user near this light may be strongly affected by this action [3]. Also, the temperature may change much more near the lamp. In this first approach the actions selected to be compared are:

- 1. opening a ordinary window
- 2. opening an internal door
- 3. opening two windows in opposite façades to cross ventilate
- 4. opening or not closing a shutter in presence of relevant solar radiation
- 5. turning on from one to five lights of 15 W
- 6. turning on from one to five lights of 60 W
- 7. turning on various appliances for a total of 500 W

NUMERICAL ASSES OF THE ACTIONS

1 – Opening an ordinary window: the parameters that change with this action are G and I, but in a first approach the variation of the term I can be not considered (is low if the window is an ordinary window). So, the variation of G is the important change to be considered. The G term of loss is divided in two terms, one depending on the thermal transmission and other depending on ventilation. It is the second that strongly changes with this action (the first has only a low variation). The G ventilation term is normally expressed with Gv = 0.30 rh, where rh is the total number of air exchange in one hour. The unit for rh is 1/h. So, opening an ordinary window causes an increase of rh. We consider for rh the value of 1.5 before the action (according to the indications of [4, 5]) and 2.5 after the action. All the other terms are constant, and its values are: Te = 20 ºC, I = 1.5 W/m³, Gt = 0.2 W/(m³ ºC), Dc = 0 W/m³ and Do = 1 W/m³. The internal temperature decreases with the action from 23.8 to 22.6 ºC. The action so is considered having a medium repercussion on the comfort.

2 – Opening an internal door: we expect that this action has low repercussion. The asses is done with the values: Te = 20 ºC, I = 1.5 W/m³, Dc = 0 W/m³, Do = 1 W/m³, Gt = 0.2 W/(m³ ºC), rh = 1.5 before and at most 1.7 h^{-1} after the action. The decrease of the Ti is very low: 0.3 ºC. The increase of the consumption to maintain Ti = 23.8 ºC is also very low: 0.2 W/m³. A change on the climatic data for this action should be not very important and the action is also classified to have a "very low repercussion".

3 – Opening two windows in the opposite façades to cross ventilate: with the climatic dates of the first asses and considering the variation of rh from 1.5 to 4 h^{-1}, the internal temperature decreases 2.2 ºC. This action is classified also to have a "high repercussion on the comfort" in this climatic situation. The increase on the consumption to maintain Ti = 23.8 ºC is 2.8 W/m³. The repercussion on the consumption is also classified as "medium" in this climatic condition. As well in the first asses, the winter conditions change strongly the results: the action is clearly very relevant on the comfort and on the consumption. The summer conditions analysis shows that the relevance of this action is not very high. In fact, it should be very important, because of the importance on the sensed temperature of a user of the velocity of the air. The comfort sensation depends strongly on this factor: a relatively high temperature can be tolerated if in the ambient the air velocity is relatively high.

4 – Opening or forgetting to close a shutter in presence of relevant solar radiation: the term that most changes is I. We suppose a relevant radiation contribution of 10 W/m³, which in presence of the shutter is reduced to 1.5 W/m³. First we assume climatic data of summer: Te = 30 ºC, Do = 1 W/m³, Gt = 0,2 W/(m³ ºC), Gv = 0.75 W/(m³ ºC), Dc = -8.2 W/(m³ ºC). A positive Dc term in Eqn. 2 is a contribution in heating, a negative term means cooling. The increase of the temperature Ti when the shutter is opened results 9 ºC. This is clearly a very high variation that generates a very uncomfortable sensation. The increase on the consumption to maintain an acceptable internal temperature is also very high: 9 W/m³. The action is classified to have a very high repercussion on the comfort and consumption. This result shows the importance of the solar radiation, maybe not always sufficiently considered. The case of winter can also be evaluated. The solar radiation is a thermal gain and the internal temperature increases, so the consumption can decrease. Here the problem is other: in proximity of the window the sensation of heat can generate in the users

the idea to reset the temperature base in the heating system, but other users, don't standing near this window, may have also the opposite sensation of cold. The snow ball effect that this situation can generate is absolutely dangerous and has to be controlled. The importance of the design (orientation of the windows, presence of protections, homogeneity of the space, for example) appears to be fundamental.

5 – Turning on from one to five lights of 15 W: this case is illustrated in Figure 1: the increase of the internal temperature is low (near 0.5 ºC for 5 lights), so the action is considered as have a low repercussion on the comfort sensation. The energetic repercussion is also very low.

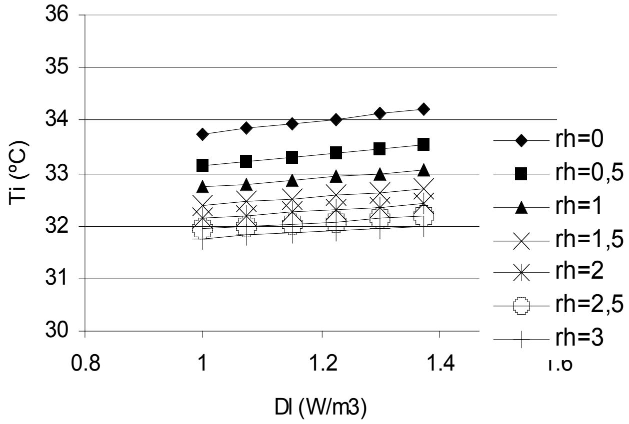

Figure 1: variation of the internal temperature turning on for one to five lights of 15 W

6 – Turning on for one to five lights of 60 W: this case is the similar to the precedent, but with a higher value of the power of the light. The result is also different, Table 1 gives the values.

Table 1: increase of the D term and change of the internal temperature turning on lights

light (W)	consumption (W/m^3)	internal temperature (ºC)
300	1.86	34
240	1.5	33.7
180	1.25	33.4
120	0.75	33
60	0.36	32.7
0	0	32.4

Turning on five lights of 60 W causes an increase of near 1.5 ºC, the action is also considered to have a medium repercussion on the comfort. The relevance on the consumption is always relatively low.

7 – Turning on a computer or others appliances: it is clear that the following results may be extended, and that the role of 500 W of various appliances is starting to be important. These appliances may increase the internal temperature of 2-3 ºC, and the relevance on the comfort may be high.

If the internal consumption increases, in summer the power of the cooling system further increases, but we consider here only that this effect has to be taken into account.

CONCLUSIONS

Analysing comfort or assessing energy consumption might be difficult, in particular when human behaviour plays a relevant role. For this reason, a complete classification of the actions and decisions that users can carry out is needed. We classified some actions that users can undertake in two different schemes, the first ranking actions based on the influence on the consumption of the buildings and the second ranking actions based on the sensation of comfort perceived inside them.

Average thermal balance equations are clearly insufficient when one is making a full analysis of the summer scenario, because when changes in internal temperature are not mechanically controlled, there is typically an ample amount of ventilation with considerable incertitude on its value. Furthermore, changes in use over the course of the day and thermal mass effects are also significant when one is assessing the dynamic behaviour of the building. One must also discuss the spaces of a typical building layout in order to provide a reference framework for analysing unique scenarios.

Temperature and lighting gradients and particularities of air movement, in addition to other factors, may have a large influence on energy savings and a very high repercussion on comfort. We highlight the significance of a building's design with regard to its ability to effectively "resist" the actions of its users – that is, its ability to remain thermally stable without consumption singularities in the light of inappropriate actions carried out by its users, given its energy and/or comfort conditions. These actions could be due to erroneous judgement or other causes, such as simple omissions. When architects tackle issues concerning energy efficiency and comfort, all design solutions should aim to make it easy, or even "unavoidable", for users to inhabit these buildings in a correct fashion. Training users may not be enough to ensure that buildings are used in a suitable way. In conclusion, design strategies and project solutions must be taken into serious consideration in order to minimise the possibilities of misusing energy and stifling comfort. Furthermore, the sensations of users must be correlated to the actions and decisions they can actually carry out, as it should be recalled that cultural and sociological factors play a significant role in determining human behaviour.

Further investigations should consider all these factors. As we have pointed out, however, most times the current situation underscores the fundamental role played by design strategies on the sensation of comfort inside buildings. Suitable designs should not only be energy-efficient and comfortable, but also robust in order to make it difficult for incorrect actions to take place.

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