Multicriteria Characterization of Adaptive Comfort Variables in Office Buildings

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Abstract

Analytic models and static approaches as the case of Fanger, Deval, Sherman, Gagge, and Stolwijk models cannot completely predict indoor thermal comfort. Building designers could take advantage of adaptive approach of thermal comfort which can account for the complex interaction between occupants and their environment that could affect their comfort.
We had carried a field study in two office buildings on March 2005. It has included physical measurements and questionnaires on thermal perception and appreciation. We followed multicritaria and structural approaches for analyzing questionnaires results and measurements. This method enables us to identify new quantitative and qualitative variables of adaptive comfort. The results of the study are new link of essential variables, with the way that they characterize thermal comfort.

KEYWORDS

Adaptive thermal comfort, indoor environment, occupant, office building.

INTRODUCTION

Nowadays, there is an urgent need to reduce energy consumption in buildings with respect to the indoor comfort and health. Adaptive approach of thermal comfort is a way to purpose in building design to reduce energy consumption. In addition, this approach is better to define indoor thermal comfort than analytic models. We had followed a study about identifying and characterising new variables of thermal comfort. This paper summarizes the method used for the experimentation, followed by its analysis and we end with its result. It shows a multidisciplinary thermal comfort and its potential on energy consumption reduction.

METHODOLOGY

This study focus on interaction between occupant and his environment. During March 2005, we realized a field study of thermal comfort combining physical measurements and questionnaires filled by office occupants, who evaluated their perceived thermal comfort. Further to data collection of field study, we followed an analysis and data exploitation for determining predicted thermal comfort by analytical models.
Then we use mechanism of adaptive thermal comfort to find another variable. In addition, we've listed opportunities and constraints for adaptation in these offices. That allowed finding all adaptive variables which number need to be reduced into the most significant variables. We applied responses data from occupants to characterize these adaptive variables. So, we transformed qualitative scale for subjective evaluation into quantitative one.

Second part of this method was to find essential adaptive variables from the list. We combine statistical, multicriteria and structural analysis to find the results. The following paragraphs explain more about the whole levels of the methodology.

Presentation of field study

We followed a field study in two office buildings during March 2005. These two buildings are situated in the same climatic zone of south east of France (ENTPE in Vaulx en Velin and CETE in Isle d'Abeau), they have the same structure: heavy concrete and large glazed, and they are almost naturally ventilated. We choose offices according to occupant's willingness to participate. They had to fill questionnaires at the same time of physical measurements.
All buildings were visited 5 times during a week on working days. Visits last half day each, they were alternated between the morning and the afternoon, and took ten minutes per each participant. As a protocol for each work station visit, we approach the occupant and present the comfort survey if convenient; meanwhile we put the instruments for measurements on the desk of subject and set it for a 10 minutes measurement sequence with a 30 seconds time step [Moujalled].
Physical measurement consists on thermal comfort estimation using variables of analytical models (de Dear & Brager, 2002): temperature [°C], air velocity [$m.s^{-1}$], relative humidity [%], clothing [clo], and metabolic activity [met]. It predicts thermal comfort in offices with the calculation of indices (ISO 7730).
And the questionnaire consists of four different sections. The first section asks the subjects to evaluate their thermal environment at the moment of measurements according to the standard ISO 10551 (ISO, 2003). The second section is the clothing and activity checklists. In the third section, we ask the subject to evaluate the interior air quality, the lighting and the sound quality, and the overall quality of the indoor environment at the moment of measurements. Table 1 summarises physical measurement corresponding to 31 office occupants.

Office thermal comfort

Due to their willingness to participate, we had not the same number of occupants every day. That is the reason why 31 subjects gave 109 responses during five working days.

TABLE 1
Distribution of the physical data

	Buildings	ENTPE	CETE
	Number of occupants	69	40
T air (°C)	Average	23,16	23,99
	Standard deviation	0,95	0,82
	Min	21,1	21,6
	Max	25,4	25,8
Top (°C)	Average	23,18	23,81
	Standard deviation	1,12	0,95
	Min	20,9	21,7
	Max	25,6	26
Vair (m/s)	Average	0,05	0,06
	Standard deviation	0,02	0,02
	Min	0,00	0,02
	Max	0,1	0,09

Conc° CO_2 (ppm)	Average Standard deviation Min Max	961 218 530 1540	887 116 590 1150
Clothing (Clo)	Average Standard deviation Min Max	0,79 0,22 0,34 1,31	0,67 0,21 0,32 1,3

72% of these occupants were satisfied and they didn't need any change in their indoor thermal environment. However, a Matlab program was developed, using the method specified in the standard ISO 7730 (ISO, 2003), to calculate the PMV and PPD indices.
One of data analysis provided a comparison between PMV indices and thermal sensation which noticed a difference of 1,4°C when occupants were in thermal neutrality. It confirms that occupant can tolerate more coolness than with thermal prediction [Harijaona].

Further to data collection, we have found adaptive variables described in the following.

ADAPTIVE VARIABLES

We used adaptive mechanisms and adaptation opportunities or constraints in these offices to define adaptive variables or thermal comfort.
The generic term "adaptation" might broadly be interpreted as the gradual diminution of the organism's response to repeated environmental stimulation. Adaptation includes all physiological mechanisms of acclimatization, all behavioural and psychological processes for thermal requirements [Ashrae RP-884, 1997]. Within this broad definition, it is possible to distinguish three categories of adaptation:

1. **Behavioural adjustment**: including personal adjustment, technological or environmental adjustment, cultural adjustments (activities, siestas, dress codes).

2. **Physiological**: the physiological responses which result from exposure to thermal environmental factors, and which lead to a gradual diminution in the strain induced by such exposure. It includes genetic adaptation and acclimation or acclimatization.

3. **Psychological**: the psychological aspect of adaptation to indoor climate refers to an altered perception of, and reaction to, sensory information. Thermal perceptions are directly and significantly attenuated by experiences and expectations of the indoor climate. This form of adaptation involves building occupant comfort which may vary take into account time and space.

Then we define 18 adaptive variables characterised by field results according to these three categories:

- **Personal adjustment**: eating, drinking, adjusting cloths or moving. This variable was evaluated with frequencies of each action (often = 1, sometimes = 0,75, rarely = 0,5, accidentally = 0,25 and never = 0)

- **Practised actions on the office**: turning on fan, air conditioner, action on windows, door, blind or curtain. This variable was also evaluated with frequency of action.
- **Proposed actions** which considered the disposable number of equipments in each office: the maximum number is 11 including window, internal door, external door, blind or curtain, fan, desk lighting, general lighting, air conditioner, radiator, thermostat, distributor of food or drink.
- **Commands** evaluated with the difficulty of manipulation : manual simple = 1 (ex : switch), remote control = 0,75, manual with effort = 0,5
- **Distance from opportunities**: near=1, near with moving = 0,75, far = 0,5, far with deviation = 0,25, inaccessible = 0.
- **Office habituation** evaluated by the number of seasons that occupant past in the office (1year = 2 seasons)
- **Building habituation** : number of seasons that occupant past in the building
- **Environment change number**: including different environments met by occupant between his dwelling and his office: means of conveyance, outside environment...
- **Comparison between office and home** : it account for the number of the votes (occupant feel the same in the office and at home, home is colder than office, or home is warmer than office)
- **Physical parameters** especially temperature which is more felt by occupants
- **Clothing quantity** : evaluated with Clo
- **Activity :** Met (according to office occupation)
- **PMV indices** : to account for all the analytical variables
- **Thermal sensation votes** : a seven step scale was used from very cold to hot and we took the votes
- **Tolerance of occupants to indoor environment** : number of occupants who tolerate the environment
- **Acoustic comfort** : vote on seven scale appreciation from imperceptible to loud
- **Visual comfort** : vote on seven scale appreciation from too much light to too much dark
- **Indoor air quality** : vote on seven scale appreciation from mediocre to excellent

As we see in these definitions, we had to convert some qualitative responses (ex: cold, cool, slightly cool, neutral, slightly warm, warm, hot) into quantitative one with an ordinal scales (-3, -2, -1, 0, 1, 2, 3). This conversion was used for characterisation of adaptive variables that we pursue with the following analysis.

ANALYSIS AND RESULTS

At the end of this analysis, we need to find essential variables. We have chosen structural analysis as method.

First, we used linear regression to detect relation between variables.

$$r = \frac{\sum (X-\overline{X}).(Y-\overline{Y})}{\sqrt{\sum (X-\overline{X})^2 \sum (Y-\overline{Y})^2}} \text{ (PEARSON coefficient)}$$

When the value of r approaches ±1, the linear relation between two variables is stronger and the variables follow a straight regression line in the same direction or in opposite direction, and if the value of r approaches 0, the linear relation is low: the variables do not follow line.

After detecting significant relations, Electre II multicritaria analysis permitted to arrange these relations in a scale of influence according to two families of criteria. They emphasize, first, “thermal comfort”, and second, “adaptation of occupants”. This method accepts incomparability of alternatives and we compare by the use of weight of the two criteria.
From all variables, we could create a group of alternatives, and they were evaluated in a table called: “performance” [Vincke], which came from occupant responses.

Ex : Var = Practised actions on the office
We could found 4 alternatives to compare (they are in a group according to opportunity for adaptation and they have significant regression coefficient on Var):

1- easy commands (performance according to the number of note = 1)
2- maximum number of proposed actions (performance according to the number of note upper average)
3- distance perceived near the occupant (performance according to the number of note upper average)
4- office comfort gessed like at home (performance according to the number of occupant who feel the same in office and at home)

Then, we arrange from less significant alternative (note = 0) into the most significant one (note = 3) with the calculation of concordance, discordance indicators and levels [Vincke]. This method let fill out a matrix with the notes of relations between the 18 variables. It is called “structural matrix” and it is the first part of Micmac structural analysis.

The second level of the structural analysis is to carry out the classification of the variables by order ascending of the influence and order ascending of the dependence. Matrix of order 1 indicates the direct relations between the variables and we detect indirect relations with matrix multiplications till the order is stable. We obtain a new influence-dependence plan which gives indirect relations between variables [Godet]. Then, we find a link of 8 variables with the weight of influences.

TABLE 2
Distribution of the physical data

Variables n°	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1- Environment change number			3					
2- Comparison between office-home			2	2	1	3		
3-Office habituation							2	
4-Buiding habituation		2	3					
5-Practised actions							2	
6-Thermal sensation							3	
7-Thermal preference					2			
8-Proposed actions				2	3		1	

CONCLUSION

A field study has been conducted in two office buildings in south east of France. The results allow us to find following conclusion.
The actual thermal comfort standard didn't match the comfort votes of subjects. In fact, occupants have a capacity of adaptation which encourages them to operate on building equipement or to tolerate environment.
With a listing of all adaptive opportunities and constraints in parallel with the adaptive mechanism, we have identified variables of adaptive thermal comfort. A combination of methods allowed to set a structural analysis which reduced the number of variables into essential variables one.
In spite of several simplifications in the application of methods, this study reflects thermal requirements and perceptions from occupants in the two office buildings. As argument, we carried out the same study in the two buildings taken separately and which gave the same results.
Concerning building consumption, considering the occupant skills and tolerance with indoor invironment reduces the requirement to use mechanical equipements. One proof is the ability to tolerate 1,4°C more coolness than the comfort predicted by analytical models. In addition, result variables could be available in an adaptive thermal comfort model which is a current survey in building Sciences laboratory. However, these essential variables of adaptive thermal comfort need to be validated with a study in another kind of buildings or another uses.

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