Indoor climate and perceived comfort in offices

Jacques Ribéron[a,*], Patrick O'Kelly[a], Gaëlle Orset[b]

[a]*Sustainable Development Department, Centre Scientifique et Technique du Bâtiment (CSTB), Marne-la-Vallée, France;* [b]*Research and Development Division, Electricité de France (EDF), Chatou, France*

ABSTRACT

A method has been developed to investigate the comfort in office buildings. It is based on both measurements and a questionnaire. The measurement apparatus, the so-called Ambiometer, can record both the main comfort parameters, such as temperature, humidity, noise, light and odours, and the occupant's perceived comfort. Information regarding the indoor climate and the working environment is noted on the questionnaire.

Experiments were conducted on about 50 offices in France. The analysis of results enabled us to qualify the indoor climate and to organize into a hierarchy the comfort components: discomfort is reported more often on thermal and visual aspects than on acoustic and olfactory aspects. Relationships between physical measurement and perceived comfort have also been established. Statistical analysis was carried out with regard to three discrimination factors: air conditioning, ventilation, sex. Differences in perception between men and women were noticed: the women seemed to be more demanding and more sensitive with regard to thermal comfort.

INDEX TERMS

Office; Field experiment; Measurement method; Questionnaire; Comfort

INTRODUCTION

The indoor environment quality is affected by a set of parameters, which interact with each other and with the building's users. The main parameters relate to the thermal, lighting, acoustic and air qualities indoors. Often, measures to reduce one cause of discomfort may increase other types of discomfort. For example, when opening a window to a noisy environment, acoustic comfort is sacrificed for increased thermal comfort or air quality. When using solar protection to avoid overheating in buildings, visual discomfort can occur because of daylight reduction. Therefore, we require a global approach to comfort that takes into account the polyfactorial aspects.

In the literature, we can find some studies dealing with the combined effects of two or more parameters: for example, lighting and temperature (Greene and Bell, 1980); noise, lighting and temperature (Horie *et al.*, 1985); noise, odour and temperature (Clausen *et al.*, 1993); noise and air pollution (Witterseh *et al.*, 1999). These multi-parameters studies are generally carried out in experimental chambers under controlled environmental conditions. Thus, field investigations are needed in order to improve knowledge of the different components of comfort in office buildings and also to explore the possible sensory interactions.

METHOD

The method is devoted to the assessment of perceived comfort in the indoor environment of office buildings and mainly the thermal, olfactory, visual and acoustic comfort. It is based on both a measurement apparatus, called the Ambiometer, and a self-administered questionnaire. For each office selected the investigations last for two consecutive days.

[*]Corresponding author. E-mail: riberon@cstb.fr

Ambiometer

The Ambiometer is a research tool, developed at CSTB, which can record both the physical parameters of comfort and the perceived comfort of the occupant (Ribéron *et al.*, 1999). The main environmental parameters measured are: air temperature at the head and ankle levels of the seated occupant, operative temperature, relative humidity, equivalent sound pressure level, Leq, and the concentration of carbon dioxide (CO_2). The Ambiometer is composed of a keyboard, which allows the occupant to continuously describe his own feelings on thermal, acoustic, olfactory, visual and overall comfort. For each comfort component a two-level key is used (comfortable/uncomfortable), whereas for overall comfort a three-level key is used (comfortable/quite comfortable/uncomfortable). Furthermore, the keyboard is equipped with a validation push-button for the occupant presence making sure of the relevance of recorded data.

Questionnaire

A questionnaire is used during the experiment to collect further information on the perceived comfort, the working environment, the means by which the environment can be controlled and the importance that the occupant gives to different parameters acting on comfort conditions. The questions about environment use bipolar semantic scales based on double rating: your opinion (satisfecit) and your preference (preferendum). The double rating makes it possible to minimize the bias of the occupant's response due to the calibration of the scale.

RESULTS

Investigations were performed in 49 offices located in nine buildings (Table 1). Five buildings were investigated in winter, two buildings in summer and two buildings both in winter and summer. Thus, on the whole, 60 investigations are available in the database. The buildings were selected such that the sample covers a large variety of ventilation systems. Other selection criteria include: year of construction, type of office, outdoor noise and operability of windows. Among the air-conditioned buildings, only building #7502 and building #9202 have operable windows.

Table 1 Building characteristics

Building	Location	Air conditioning	Ventilation	Office investigated	
				Cellular	Open space
7501	Paris	Yes	Balanced	4	
7502	Paris	Yes	Balanced	3	3
7503	Paris	Yes	Balanced	3	2
7701	Paris suburb	No	Operable windows	2	
3401	Montpellier	No	Balanced	5	1
7801	Paris suburb	No	Exhaust only	5	5
6901	Lyon region	No	Operable windows	8	
9201	Paris suburb	Yes	Balanced system	3	
9202	Paris suburb	Yes	Exhaust only	5	
Total				38	11

Indoor Climate and Perceived Comfort

A first analysis was based on descriptive statistics (Ribéron and O'Kelly, 2002). It has been shown that measured indoor climate parameters are generally in the standard range of comfort conditions. The analysis of occupant's sensitive response, reported both on the Ambiometer and questionnaire, has shown that people are satisfied with the indoor climate. The indoor environment can be classified based on the response in the Ambiometer keyboard, ranging from 0 (‘uncomfortable’) to 10 (‘comfortable’). The results show that the mean marks of comfort were greater than 8/10 in three-quarters of the cases; except for thermal comfort that is greater than 8/10 only in 60% of the cases.

In addition, the results have shown the relative weights of comfort components contributing to the overall comfort. The components in order of importance are: thermal, visual, acoustic and olfactory comfort. The main expectations of occupants have been identified: people desire more thermal comfort especially in summer in non-air-conditioned buildings without efficient solar protection; people desire more natural lighting and less artificial lighting as well as better lighting when working at VDUs; they also want to be able to control indoor environment parameters more (noise, ventilation, lighting, temperature, etc.).

Sensitive Data versus Physical Data

We have tried to determine the relationships between the physical and sensitive parameters of comfort. For each investigation, the distribution of measured temperature values is determined using 0.5°C ranged classes. Then, for each class, the mean value of thermal and overall comfort marks is determined (see Figure 1). The temperatures and the questionnaire responses have been correlated. The results show that the comfort conditions in winter range about from 22°C to 24°C and in summer from 23°C to 26°C. Beyond and below these values perceived discomfort occurs. The curves of overall comfort are closely connected with the thermal comfort curves, which confirms that temperature plays a key role in overall comfort.

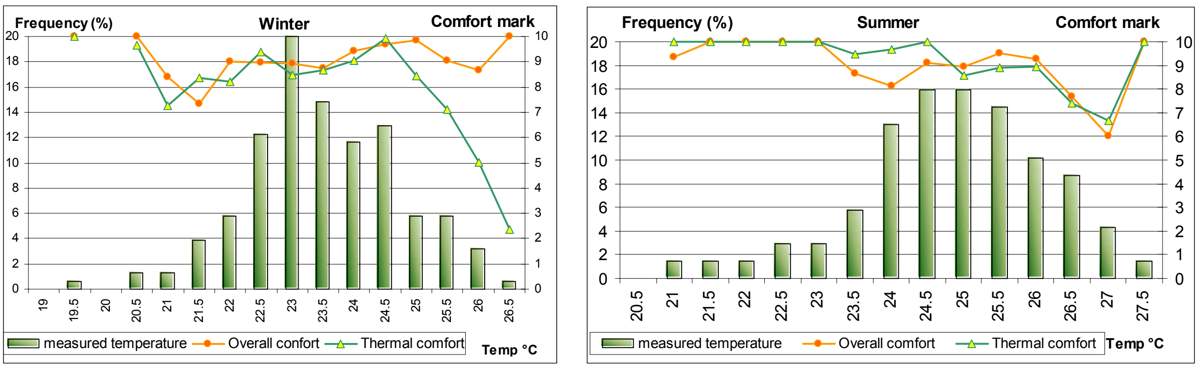


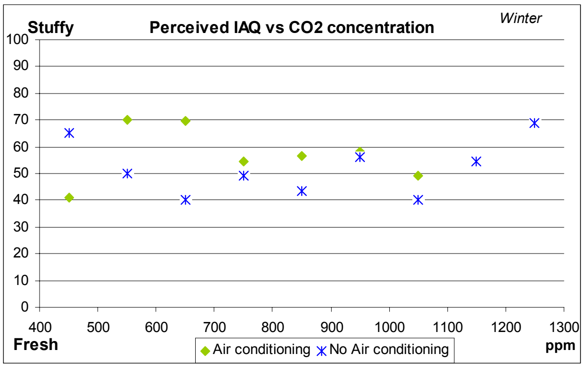
Figure 1 Thermal and overall comfort marks associated with the temperature distribution.

The feeling of dryness/wetness is poorly connected with measured relative humidity. Whatever the values—from 20% RH to 75% RH—some people are satisfied, others wish drier air, others wish more humid air. The acoustic environment in the office was seen to be quite comfortable—the sound level Leq exceeds rarely 65 dB(A)—even though a lower level is naturally demanded. A direct relationship between measured illuminance and perceived visual comfort was not found, but the visual comfort mark tends upwards as illuminance increases. When CO_2 concentrations reach around 1100 ppm, perceived olfactory comfort decreases. The overall comfort marks are quite closely connected with the olfactory comfort marks.

Discrimination Factors

Statistical analysis has been conducted in order to assess the possible impact of certain factors on the obtained results in terms of physical measurements and perceived comfort. Three discrimination factors were usedfor this analysis: air-conditioning, ventilation and sex.

In air-conditioned offices, principally in summer, thermal comfort is better. The mean values of thermal comfort marks are 9/10, versus 7/10 in the other offices. In winter, the temperatures range from 21.5°C to 24.5°C in air-conditioned offices and from 20.5°C to 26.5°C in non-air-conditioned offices; in summer they range from 22.5C to 26.5°C in air-conditioned offices and from 21.5°C to 31°C in non-air-conditioned offices. In air-conditioned offices the indoor air is perceived as odorous and found to be on the stuffy side, despite low measured CO_2 levels (see Figure 2). This might be explained by subjective parameters influencing the occupants' responses. Figure 2 shows the perceived air quality reported on the questionnaire according to CO_2 concentrations distributed with 100 ppm ranged classes. The scale in the questionnaire ranges from 0 (fresh/odourless) to 100 (stuffy/smelly). In air-conditioned offices, indoor noise is more upsetting than outdoor noise.



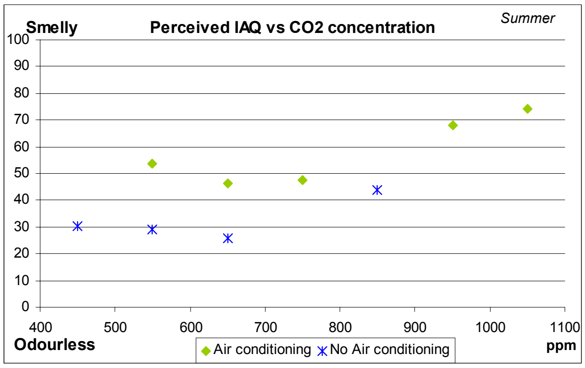


Figure 2 Perceived air quality associated to the CO_2 concentration distribution according to the air-conditioning factor.

The CO_2 concentration measurements show that a balanced ventilation system provides better air renewal than a mechanical exhaust ventilation system; the poorest air renewal occurs in offices aired by operable windows. Figure 3 shows that in winter, for a given CO_2 level, the perceived olfactory comfort is better with mechanical ventilation than with airing from operable windows (marked 'Natural' on the figure).

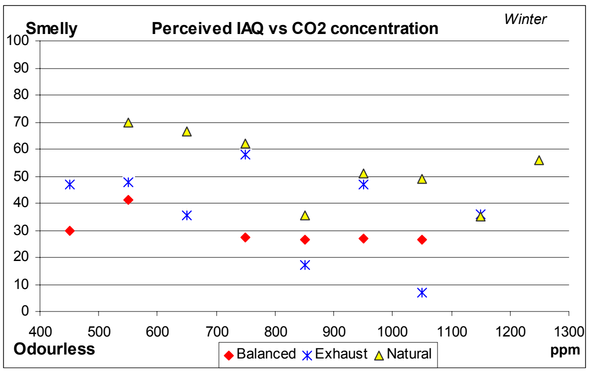


Figure 3 Perceived air quality associated to the CO_2 concentration distribution for three ventilation types.

The temperatures inside mechanically ventilated buildings are close whatever the season is; in buildings aired by operable windows, the temperatures are similar in winter but are higher in summer: up to 31°C versus 28°C. The worst perceived thermal comfort is in offices with airing form operable windows, in summer, when the temperature is over 26°C. In this group, the offices are not air-conditioned, which can explain this phenomenon. Where the acoustic environment is concerned, no significant difference, both in physical and sensitive data, is found between the ventilation types.

Women seem to be more sensitive and demanding than men where thermal comfort is concerned. Even though the comfort range is the same for men and women, when we move away from this range, women express their dissatisfaction more than men (see Figure 4). The thermal responses of men and women have been analysed from questionnaire responses using a self-differentiated mark (SDM), as the difference between the preferendum mark and the satisfecit mark. SDM is standardized from –100 (‘occupant wishes a temperature a lot warmer’) to +100 (‘occupant wishes a temperature a lot colder’); mark 0 corresponds to the optimum condition. Concerning the other indoor environment parameters, it seems that there is no significant difference in terms of perceived comfort between men and women.

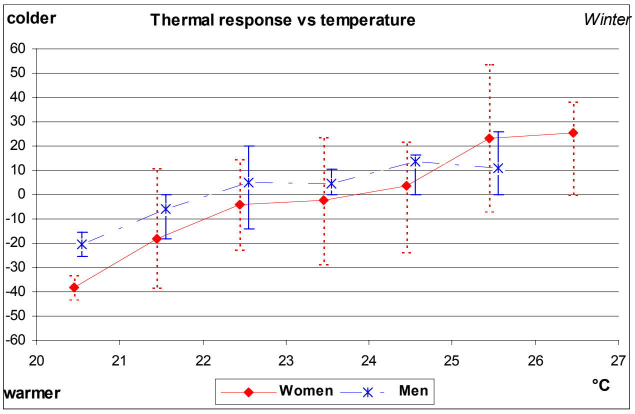


Figure 4 Perceived thermal comfort associated to the temperature distribution according to sex.

DISCUSSION

For each component of comfort, we have tried to find out relationships between physical and sensitive parameters of comfort. For thermal comfort, the temperature levels are well connected with sensitive responses reported on both the questionnaire and the Ambiometer keyboard. In addition, it was found that thermal comfort is a major contribution to overall comfort. For the other components of comfort, relationships are not so plain. One of the reasons which can explain the lack of correlation is that most of the data are around the comfort conditions and no relationship can be found because the parameter range is too small. Concerning olfactory comfort, the satisfaction with the environment could be explained by sensory adaptation to olfactory stimuli. As for the feeling of dryness/wetness, parameters other than humidity must be investigated to explain the occupants’ responses.

The stuffiness perceived inside air-conditioned buildings cannot be explained just by the air renewal rate, which is satisfactory. Psychological factors related to non-operable windows could be involved.

Studies dealing with temperature/noise and temperature/lighting interactions have been carried out in the laboratory with subjects located in environment-controlled rooms. They have shown that subjects’ responses are different according to the subject’s sex (Candas *et al.*, 2000). Generally speaking, women are more ‘thermal’ than men. In other words, in case of conflicting comfort conditions, in order to keep their thermal comfort women will tolerate some other discomfort better than men. This sex effect has been observed also for judgements on the visual environment in the laboratory but not in these field investigations. The sex effect on thermal response seems to be more pronounced for investigations conducted during winter than in summer. This effect is observed in responses reported on the double rating scale (see

Figure 4), but does not appear clearly on comfort marks reported on the Ambiometer keyboard. So, more investigation is needed to confirm this trend.

CONCLUSION

The field study enabled us to qualify the indoor climate within office buildings and to organize into a hierarchy the different discomforts. The occupants' behaviours and their expectations have been identified. The primary elements necessary to define acceptable conditions of comfort and especially to know how to solve conflicting comfort conditions are available. Correlating physical and sensitive data have led to certain relationships. The explanatory factors for comfort not only concern physical issues but also psychosociological issues: for example, the stuffiness in air-conditioned buildings.

The results seem to show that the sex factor can affect the occupants' thermal responses. Further investigation is needed to confirm this result. A more anthropocentric approach should be used in building design since people want more and more personalized comfort. Lastly, the analysis concerns the database of 60 investigations conducted on buildings without particular pathologies with regard to comfort. It would be useful to carry out field investigations in offices where discomfort conditions are more marked.

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