A PRACTICAL APPROACH TO THERMAL COMFORT SURVEYS IN HOMES AND OFFICES: DISCUSSION OF METHODS AND CONCERNS

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ABSTRACT

A discussion of some of the techniques involved in thermal comfort studies conducted in the field is presented. Selected aspects of measurement protocol are discussed in the context of the authors' own studies. Thermal comfort surveys in homes usually require a more specific approach to secure cooperation of the subjects than do office surveys. Sociopsychological scales, such as the SELF Scale, could be broadened from the original application with the elderly and be used to assess emotional and social dimensions among the general population. This could help to investigate the relationship between thermal comfort and other factors. Field surveys require more practical methods of assessing the subjects' activity levels. When comparing surveys from different climatic or socioeconomic regions, it is important to consider the influence of local conditions and norms of behavior on the perceptions of the survey group. Extensive discussion of methodology of thermal comfort surveys is needed to allow for better comparison between various studies.

INTRODUCTION

The growing importance of thermal comfort field surveys requires that there be an attempt to standardize many of the techniques that are employed. Although specific standards have been determined (ASHRAE 1981; ISO 1984), some of the technical aspects of the methods used in surveys are not presented fully in these documents. The multidisciplinary nature of field surveys, in contrast with laboratory studies, means that a number of factors that need not be considered in the laboratory may greatly influence the results of a field survey. It is the nature of any thermal comfort survey that the physical, physiological, and psychological components are likely to interact.

The purpose of this paper is to discuss selected aspects of the methodology used in thermal comfort studies and to provide a conceptual guide to those interested in conducting such field studies. It is not intended to provide a comprehensive overview of all techniques used in various studies but, rather, to stimulate a discussion in this important field (Fanger 1970; McIntyre 1980; Cena and Clark 1981a). The following discussion is based on two extensive field surveys of the elderly, a survey in apartment blocks, and two recent (as yet unpublished) studies conducted in offices.

The surveys of the elderly (Cena et al. 1986, 1988) conducted during winter seasons involved more than 300 subjects with an average age of 75 years, all living independently in individual homes in Hamilton, Ontario, and in Buffalo, NY. The field survey of occupants in 411 apartments was conducted in winter and summer in Wroclaw, Poland (Sliwowski et al. 1983). The two studies in offices were carried out in the first quarter of 1989. Fifty office and laboratory workers were studied during the winter season in Philadelphia, PA, while in Perth, Western Australia, at the peak of summer, a thermal comfort study was conducted on a group of 18 female secretaries. In the latter survey, each subject was monitored continuously for three consecutive working days.

RESULTS AND DISCUSSION

Surveys in Homes

There are two principal locations where thermal comfort surveys may be conducted: the places where people live and the places where they work. Other areas of importance are recreation and transportation. The two basic areas have peculiarities specific to each that need to be considered when planning the survey. In our experience, it tends to be more difficult to organize an extensive study in private homes than in workplaces. This is due to the natural reservation of the occupants to have any intrusion into their private lives. During our studies with the elderly, we found that the most limiting factor in acquiring our subjects was the reservation, even some suspicion, in agreeing to a project involving the visit of strangers in the subject's home.

The initial approach to seeking subjects for a survey is an important aspect affecting the success of a study. The general impersonal approach, such as the distribution of a circulated letter or a media campaign inviting people to

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volunteer, is rarely a fruitful method. A substantially more effective approach is through a chain of recommendations, where acquaintances or friends approach potential subjects and ask their initial permission for the researchers to make more direct contact. This method has proved successful in obtaining statistically representative samples for our surveys with the elderly. We found that about one-third of the subjects participated in the recommendation process, some of them very actively, and that about 90% of the recommended individuals finally agreed to a home visit.

The situation is generally easier with younger subjects, particularly if they form part of a community, for example, the 411 apartments located in large buildings and reported in the Wroclaw study. Although younger people tolerate more uncertainties than older subjects, they still prefer that any verbal contacts be followed by a confirmatory letter. Older subjects, on the other hand, are more cautious. Nevertheless, this attitude is, in general, readily overcome by providing an outline of the purposes and procedures involved in the survey.

Surveys in Offices

The approach to people in workplaces is generally much more straightforward. Workers are often accustomed to surveys of various types being conducted in the workplace, and there is less likelihood that a survey will be viewed as an intrusion into a subject's personal space than might occur in a private dwelling. The agreement of supervisors is essential and results in a positive reaction to the survey from the company's employees. Surveys are most likely to be acceptable to management if they are planned to provide a minimum of disruption to the work schedule. This is, of course, also of benefit to the survey itself, as the results will be most valid if normal work practice is maintained as closely as possible. People prefer to participate in surveys if they believe that some benefits will accrue to them in terms of improvement in their general working conditions. The principles of courteous approach also apply to workplaces, at least as much as they do for studies in homes, but once the scope of the survey has been presented to supervisors and employees, it can proceed without the problems and delicacies associated with surveys in homes. Certain aspects of office surveys do parallel the situation in private dwellings. Personal recommendations from former to prospective subjects greatly facilitate conduct of the research and emphasize the value of maintaining good public relations at all times.

The representation of sexes in surveys depends to a large extent on the occupations being surveyed and also on the age group targeted. When surveying thermal comfort in offices, one would nearly always encounter female secretaries. In the same way, surveys in average homes conducted during the day would also mostly find female subjects. In certain groups like the elderly, the ratio of the sexes will be toward females. These are natural constraints which should be accepted, unless there is likely to be a large discrepancy in the reactions or perceptions of males vs. females, which could mar the general acceptability of the results if the discrepancy were unacknowledged. Thus, in offices it is necessary to match sexes with job descriptions or positions. In a university laboratory, both males and females are common in laboratory settings. In a corporate office, both male and female managers should be surveyed and numbers of subjects balanced by job category. For example, it would be inappropriate to compare female secretaries or general office workers with male managers.

SELF Scale

In thermal comfort surveys there are two components to the gathering of data: the physical measurement of thermal conditions and the individual responses of the subjects. The latter are influenced by the physical, emotional, and social status of the individuals. One of the methods we used with the elderly (Cena et al. 1988) was a Self-Evaluation of Life Function (SELF) Scale. The SELF Scale (Linn and Linn 1984) consisted of 54 questions with 4 possible answers to each and was designed to measure the following dimensions among older persons: physical disability, symptoms of aging, self-esteem, social satisfaction, depression, and personal control. These factors were scored separately and also combined to form an overall score. The SELF Scale was administered in writing and subjects took from 15 to 20 minutes to respond to all questions. In the Canadian study of the elderly, the low-income people had physical disability ratings on the SELF Scale substantially worse than the sample mean. Therefore, this group was older and less healthy and scored less favorably than the overall sample. The elderly in the low-income group were aware of the need for energy conservation and of the high cost of heating their homes. Yet they continued to regulate their thermostats so that they had relatively higher indoor temperatures than the more affluent group.

We applied the SELF questionnaire to two groups of office workers in the Philadelphia study, each consisting of 25 subjects. Their mean age was 36 years and they all scored favorably, as expected, on the physical disability factor and symptoms of aging. However, these much younger office workers had a surprisingly similar score for the social satisfaction and depression factors when compared with the Canadian elderly (Table 1). On the self-esteem factor, the male office workers scored less favorably than the females, which indicated that the younger office workers were not satisfied, even were depressed, by the general conditions in which they worked. It would be valuable to find out how much of this negative reaction could be directly attributed to the environment of their offices. The factors of physical health and symptoms of aging reflected the much younger age of the subjects in the

TABLE 1

Mean Values of Factors of Self-Evaluation of Life Function (SELF) Scale for a Group of Elderly and a Group of Office Workers

Characteristic	Elderly n = 101 $\bar{x}$	S.D.	Office Workers n = 50 $\bar{x}$	S.D.
Age, years	73.5	6.0	36.4	10.3
Physical Disability (1)	14.4	2.3	13.2	0.4
Symptoms of Aging (2)	18.2	5.9	14.2	2.6
Self-esteem (3)	12.9	3.1	10.4	3.5
Social Satisfaction (4)	9.6	2.4	10.1	2.6
Depression (5)	19.1	3.4	18.7	3.7
Personal Control (6)	9.1	1.9	8.7	2.0
Sum of all factors (1-6)	83.5	13.2	75.3	9.4

Note: Higher scores on SELF Scale are less favorable responses.
There are no significant differences between the means for factors 4, 5, and 6.
All other means are different at $p < 0.001$.

TABLE 2

Cross-tabulation of the Sum of All Factors on SELF Scale Against the Number of Subjects in Age Categories for a Group of Office Workers

	Sum of all factors on SELF Scale					
Age	50-59	60-69	70-79	80-89	90-100	Total
Under 30	1 (0)	6 (5)	3 (3)	2 (1)	3 (3)	19 (12)
30-39	0	3 (0)	5 (3)	5 (4)	0	13 (7)
40-49	1 (0)	5 (4)	4 (3)	2 (1)	0	12 (8)
Over 50	0	2 (0)	3 (1)	1 (0)	0	6 (1)
Total	2 (0)	16 (9)	19 (10)	10 (6)	3 (3)	50 (28)

Note: Higher scores on SELF Scale are less favorable. The numbers in parentheses indicate male subjects. The mean score was 75.3 (S.D. = 9.4).

offices. Table 2 presents cross-tabulation of the sums of all factors on the SELF Scale against the number of subjects in age categories for the Philadelphia study. It is interesting to note that the distribution of subjects indicates, in this case, a trend toward more unfavorable scores (above 90) for young males. Females, on the other hand, were the only subjects with the best score, less than 60.

We believe the SELF Scale can be transported from its original application in the elderly to test the emotional and social dimensions of younger subjects in order to investigate if there is any relationship in particular circumstances between these factors and thermal comfort sensations. This may be of special help in determining the psychological factors involved in cases where workers complain of the "sick building syndrome."

Air-Conditioned and Free-Running Buildings

It is important to note that most North American office studies are conducted in air-conditioned buildings where it can be assumed that the environment is quite well controlled. In the study by Schiller and Arens (1988) a high proportion of office workers indicated that they were moderately or very dissatisfied with air temperature levels in the buildings. In contrast, in the Perth offices studied, there was no air conditioning, although fans were regularly used. On typical summer days, the average indoor air temperature at 2 p.m. was about 27°C, with the maximum recorded during our study reaching 34°C. The female office workers ranked air temperature in fifth position after lighting, air quality, office furniture, and comfort of chairs on a list of attributes they felt were important for a satisfactory office environment. The attributes ranked below air temperature were amount of space available, type and levels of sound, provision of nonsmoking areas, and color of walls. In this survey, although all other attributes were ranked as highest priority at least once by one person, only air temperature lacked this distinction. This is surprising, as the question asked, "Which attributes of the work area are most important?" Despite the high air temperatures in the offices, the average response to a question about the general satisfaction with the office environment was between the votes of slightly and moderately satisfied. Air-conditioning was considered on average to be only "occasionally useful" by all of the Perth respondents.

In North America, clerical workers and students investigated by Rohles et al. (1989) judged that the thermal environment was more important than the acoustical, lighting, and air quality constituents, with more importance attached to air temperature by the clerical workers. The above results of the Perth survey are a good illustration of the main conclusion from Humphreys' (1981) compilation of thermal comfort surveys conducted in a free-running building (without heating or cooling installations). After reviewing a large number of surveys, Humphreys observed that people accept the climatic conditions to which they are accustomed. This implies that humans may be habituated to the environments they experience over a much wider range than is usually considered desirable in air-conditioned buildings.

Effects of Media

Various behaviors and practices related to thermal comfort, energy consumption, clothing, and behavioral strategies can be structured and even manipulated. Winett et al. (1981, 1983) studied the effectiveness of daily feedback of various types of video tutorials on electricity consumption by 200 residents of all-electric townhouse apartments. The video presentations motivated people to reduce indoor temperatures in winter by 2°C. The subjects voluntarily accepted indoor air temperatures of 16°C and increased their clothing insulation to only 0.8 clo. It is interesting that the subjects maintained their energy-saving attitudes until the end of the heating season. Winett et al. stressed that thermal comfort needs to be conceptualized in broad terms and studied under field conditions. They regarded thermal comfort as a function of various cultural expectations and practices, current information and misinformation, and environmental prompts and were influenced by financial considerations as well as a set of behavioral and cognitive processes including adjustment of clothing insulation.

Media campaigns were postulated by Avery and Pestle (1987) to inform the elderly about the risk of hypothermia. They interviewed a large group of elderly subjects in Florida and found that only 1 in 10 was aware of the dangers of accidental hypothermia occuring in winter. Because Florida was considered to be a best-case situation, Avery and Pestle proposed that it was necessary to develop, present, and evaluate educational programs for the elderly about indoor thermal environments even in comparatively warm climates.

Attention should be paid when conducting field studies to the possible exposure of subjects to various media presentations and other factors that might have an influence on peoples' acceptance of various levels of thermal comfort. It is obvious, on the other hand, that finding completely unbiased subjects would be difficult. One way to approach the problem might be through a suitable questionnaire testing subjects' current attitudes to, for example, energy saving or thermostat control.

Cultural and Climatic Differences

Care should also be taken when comparing the analyses of surveys performed in different circumstances. The reactions of subjects are conditioned by their previous and current experience, which is unlikely to be the same in different countries or regions. When conducting our surveys in Hamilton, Ontario, and Buffalo, NY, we could not find apartments with heating controlled by individual thermostats, although all people in single homes did have control of their thermostats. The same situation was present in the study in Wroclaw. Apartment occupants in all of these

locations simply opened the windows when it was too hot and used supplementary, usually electric, heating when it was too cold. The participants in the Wroclaw study compensated for the relatively high indoor temperature in their apartments by keeping a low clothing insulation of less than 0.6 clo during the heating season (Table 3). Perhaps because their apartments were well heated and the financial aspects of maintaining proper levels of thermal comfort were not an issue, the most common preference was for a better design layout of the apartment. Standards of heating and ventilation were awarded the third most important ranking followed by low noise levels. In contrast to these studies were the results described by Winett et al. (1981, 1983), where townhouse occupants who had individual control of thermostats were shown to carefully regulate the temperatures in their homes.

The seven-point ASHRAE scale of thermal sensation is usually easy to apply in the field and to explain to the subjects. Although the scale can be used in various English-speaking countries in its original form and phraseology, the perception of the meaning of various categories may vary depending on the experience of the respondents (Cena and Clark 1981b). In our office survey in Perth, Western Australia, virtually none of the secretaries considered the conditions to be "hot" (3 on the scale) despite the fact that the mean indoor temperature could be more than 28°C. The mean vote for these temperatures was 2.3 on the ASHRAE scale. Moreover, there were some individuals who occasionally voted zero ("neutral"). The mean clothing insulation of the subjects was low at 0.37 clo. The notion of terms such as "hot" for the inhabitants of Western Australia was obviously more extreme than for their counterparts in the northern hemisphere.

The survey in Perth was extended over three full consecutive working days with thermal sensation and comfort ratings taken every hour. In cases where there was a marked drop in indoor temperature (say, from 30°C to 27°C) from one day to another, the participants would subjectively consider the new conditions much cooler, some voting next day even -1.0 ("slightly cool") on the scale. They would also report less usage of fans and a reduction in liquid intake. These thermal conditions would not be considered an improvement by people who had not experienced the full range of temperatures in Western Australia. This sort of information could not be obtained by a single session with each subject. Assessment of a single subject over several days is particularly important in free-running buildings. In air-conditioned premises, it is likely that thermal conditions will vary less over long time periods. However, this is not the case in the absence of air-conditioning, where the indoor microclimate is more closely related to outside weather. Single assessments from different subjects are likely to produce data with less general applicability than is desirable due to the chance of collection on a day of extreme weather conditions. We would consider that some specialized thermal comfort surveys should be conducted in a similarly extended way to allow for greater variability of natural conditions.

Determination of Metabolic Rate

Calculation of predicted mean vote (PMV) is one of the important methods of predicting thermal comfort of the subjects. This can be performed quickly using a thermal comfort meter (Olesen 1982). In our experience, the main problem is an accurate assessment of the subjects' activity. We used the meter in the two surveys with the elderly and soon discovered that the estimation of metabolic rate from tables of characteristic activities was often inaccurate. The reason was that the direct application of the tables could introduce a substantial error. For example, in the study of the elderly, when the subjects were asked to remain seated during a measurement session, activity could not always be assessed as that of a sedentary person. In nearly all cases, they needed to stand up and let the researchers into their homes and very often they were busy with various household chores for extended periods before the session. The elderly subjects were all living independently and were not only able to look after themselves but also often engaged in prolonged activities beyond ordinary expectations. Indeed, one of the main conclusions of these studies was that the elderly thermoregulated by increasing their activity rather than by increasing their clothing insulation (Table 3).

Another factor that might introduce errors in activity measurement is any misjudgement on the part of the researcher when using the standard activity tables (ASHRAE 1985). We have found that unless the individual researchers conducting the survey in the field are well trained and are fully aware of the complexities, their individual assessments of metabolism can vary substantially. It is also important to allow the subjects to relax prior to the measurement session, and we found in the second survey with the elderly (Cena et al. 1988), where we used two periods of rest and two periods of light activity, that the repeated measurements were always more reliable. We considered this an effect of subjects being more relaxed when repeating an already familiar procedure. In that survey we induced light activity periods by pacing the subjects for 10 to 20 minutes at 2 km h^{-1} when walking indoors and, after a rest, repeating the higher activity period by inviting the subjects to engage in light household activity at the same level. The fact that the measurements were repeatable increased our confidence in the method used.

TABLE 3

Data Summary for Surveys Discussed

Location Season	Age (yrs)	Clothing clo	Activity met	Indoor Air Temp. °C	Comfort Vote
Hamilton[1] winter	75.0	0.88	1.4	20.5	-0.1
homes n = 112	(6.4)	(0.18)	(0.3)	(1.8)	(0.7)
Buffalo[1] winter	73.3	0.74	1.4	21.1	0.1
homes n = 99	(6.4)	(0.17)	(0.4)	(1.7)	(0.7)
Hamilton[2] winter	73.5	0.8	1.5	21.2	0.0
homes n = 101	(6.0)	(0.1)	(0.2)	(1.8)	(0.3)
			1.9		0.3
			(0.2)		(0.3)
Philadelphia winter	36.4	0.6	1.6	23.8	0.2
offices n = 50	(10.3)	(0.1)	(0.5)	(3.0)	(1.2)
Perth summer	40.0	0.37	1.6	27.2	1.2
offices n = 18	(11.0)	(0.05)	(0.2)	(2.8)	(1.3)
Wroclaw summer	46.5	0.50	1.6	21.6	0.0
apartments n = 411	(11.0)	(0.1)	(0.2)	(1.5)	(1.0)
Wroclaw winter	46.4	0.59	1.6	21.8	0.0
apartments n = 411	(11.0)	(0.2)	(0.2)	(1.9)	(1.2)

Note: Number is *mean*, number in parentheses is S.D.
The thermal comfort votes are on a linear scale, from −3 (cold) to 3 (hot).
Surveys[1] were conducted in 1984, and survey[2] was conducted in 1986.

Furthermore, in order to better estimate the subject's metabolism, we utilized the Borg scale of perceived exertion. This is a standard method for indirectly determining metabolic rate by perceived ratings on a 15-point scale developed by Borg (1970). The scale rises linearly with both the exercise intensity and heart rate. It has values ranging from 6 to 20, which match the variation in heart rate from 60 to 200 min^{-1}. This scale did not give absolute indications of metabolic rate, only indications of relative increases. However, the mean increase in Borg scale between rest and walking at 2 km h^{-1} was about two rating units, and this correlated with the measured heart rates corresponding to a difference in activity between 1.5 and 1.9 met and confirmed our original assessment of activity levels.

Further research is necessary to develop field techniques that could be used in surveys to verify values determined from the activity tables. These methods have to be acceptable to the subjects and simple enough to be used in surveys involving larger populations away from laboratory facilities. Another solution might involve occasional application of gas sampling techniques to verify other, more simple methods of metabolic rate assessment.

Determination of clo values during thermal comfort studies is well developed and easily performed. The basic tables, however, should be supplemented by the data from McCullough et al. (1983) when allowing for different styles and cuts, mostly in women's clothing. It is our experience that field researchers learned to use these tables with fewer problems than when assessing metabolic rate.

CONCLUSIONS

This paper presents a discussion of some of the techniques involved in thermal comfort studies conducted in the field by the authors. The specific conclusions are as follows:

1. Thermal comfort surveys in homes and offices need to consider social and behavioral influences on peoples' perception of the thermal environment, as well as recording physical and physiological variables. This emphasizes the need for a multidisciplinary approach to such studies.

2. Thermal comfort surveys in homes usually require greater perspicacity on the part of the researcher than is the case in office surveys. In the office environment, privacy and personal space constraints are less of an issue than in a private residence.

3. The sociopsychological scales, such as the SELF Scale (Linn and Linn 1984), could be broadened from their original application with the elderly and used to assess emotional and social dimensions among younger subjects. The summary scores so produced facilitate investigation of the relationship between thermal comfort and the latter factors.

4. A more accurate but still practical method for assessing subject activity levels needs to be developed for field surveys.

5. When comparing surveys from different climatic or socioeconomic regions, it is important to consider the influence of local conditions and norms of behavior on the perceptions of the survey groups.

6. More detailed consideration of methods used in thermal comfort surveys is needed to permit the development of a standard methodology that would allow more useful comparisons between various studies.

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