Field study of office thermal comfort using questionnaire software

Newsham, G. R.; Tiller, D. K.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20375335
Internal Report (National Research Council of Canada. Institute for Research in Construction); no. IRC-IR-708, 1995-11-01

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

NRC·CNRC

A Field Study of Office Thermal Comfort Using Questionnaire Software

by Guy R. Newsham, Ph.D., Dale K. Tiller, D.Phil.

Internal Report No. 708

Date of Issue: November 1995

This is an internal report of the Institute for Research in Construction. Although not intended for general distribution, it may be cited as a reference in other publications.

A Field Study of Office Thermal Comfort using Questionnaire Software

Guy R. Newsham, Ph.D.
Dale K. Tiller, D. Phil.

Institute for Research in Construction
National Research Council Canada
Montreal Road, Ottawa, Ontario
CANADA, K1A 0R6

IRC Internal Report No. 708

November, 1995

Acknowledgments

The authors have many people to thank for the successful completion of this project:

Sequence Electronics for development of the version of the *ScreenSurvey* software package used in this study;

Dr. Jennifer Veitch (IRC) for her help in the statistical analysis of the data;

All the people who agreed to participate in this thermal comfort study and to have the software installed on their computers, in particular: Tony Fisher, Albert Joseph, Ian Beausoleil-Morrison, and Scott Mellon, who acted as local coordinators at each of the study sites.

We would also like to acknowledge the financial support of Public Works and Government Services Canada in the development of the *ScreenSurvey* software package.

Abstract

ScreenSurvey, custom software to automatically administer questionnaires on computer screens, was installed on the computers in open-plan office spaces at four sites. Five questions related to thermal comfort were presented twice per day for three months; internal and external climate data were collected simultaneously. Data from a 10 week period were recovered from 55 participants. Results indicate that this new method of subjective data collection was successful and efficient: the participants had few complaints about the method of questionnaire delivery; and a substantial literature review demonstrates that the results of our study are comparable with results from other field studies of thermal comfort conducted using different methods. Participants responded to the questionnaire 29 % of the occasions on which it could have been presented, and took an average of 45 seconds to answer the five questions. 87 % of votes were in the central three categories ('slightly cool' to 'slightly warm') of the ASHRAE thermal sensation scale, and 70 % of thermal preference votes indicated a desire for no change in temperature; we derived a neutral temperature of 22.7 °C. Overall, the number of thermal sensation votes indicating thermal acceptability was as predicted by ANSI/ASHRAE Standard, and by the comfort theory on which this Standard was based. However, our results indicate a greater sensitivity to temperatures away from the neutral temperature than theory predicts. Only 11 % of the variance in thermal sensation vote was explained by indoor air temperature, which rose to only 14 % when other measured physical and personal parameters were included in the regression. Differences in thermal sensation vote by age, sex, or office orientation were either not significant, or small. There were no significant differences in thermal sensation vote by week or hour, though the small changes in mean vote were in the expected direction. Around 15 % of people changed their clothing in the hour prior to the questionnaire appearing, suggesting that clothing change may be an important mechanism for achieving thermal comfort.

Contents

1.0 Introduction

1.1 Background

Longitudinal studies of subjective reactions can be very useful in identifying problems with the indoor environment, particularly those that change over time. Comparing subjective reactions with the prevailing physical aspects of the indoor environment can help identify the sources of problems, which facilitates solving the problems.

While the physical aspects of the indoor environment can be easily measured over time using automatic data logging technology, measuring the concurrent subjective reactions is difficult. The traditional method of obtaining subjective reactions data is the paper questionnaire. However, using paper questionnaires to perform longitudinal surveys -- which requires administering the same questionnaire many times -- would be disruptive, expensive, and labour intensive.

To overcome these problems, the National Research Council of Canada (NRC) has developed custom software, called *ScreenSurvey*, to automatically administer questionnaires on computer users' screens at dates and times specified by the experimenter in a data file. The software is described in more detail in Section 2.6.

This study had two aims:

1. To test *ScreenSurvey*'s usefulness as a tool for gathering longitudinal subjective reactions data in the field.

2. To use the field test data to study the relationship between the thermal environment in open-plan office spaces and the thermal comfort of its occupants.

1.2 A Brief Summary of Thermal Comfort Research

In post-occupancy studies, the thermal environment is frequently rated as one of the most important aspects of a healthy, pleasing, and productive workplace [Baillie et. al, 1988; de Dear et al., 1993; Jaakkola et al., 1989; Rohles et al., 1989]. Many studies have been performed to try to elucidate the relationship between human thermal sensation and the physical environment. The principal goal of this research is to determine what physical parameters are conducive to a comfortable, and productive[1] indoor environment, and how best to deliver those physical parameters. Research has focused on the physical parameters (rather than on psychological parameters, for example) because, in practice, these are the parameters that designers and building managers can directly influence.

---

[1] Research attempting to link productivity, learning and related factors to the thermal environment in various settings has been extensive. The results are varied and remain largely inconclusive. See, for example: Allen & Fischer [1978], Howell & Kennedy [1979], Langkilde et al. [1973], Lorsch & Abdou [1974], McNall [1979], Pepler [1968], Wyon et al. [1973], Wyon [1973].

The research falls into two camps: laboratory studies, and field studies. In laboratory studies, participants typically sit in climate chambers wearing fixed standardized clothing ensembles and remain sedentary while experiencing thermal environments chosen by the experimenters, or adjusting the thermal environment (normally air temperature) themselves in order to achieve an optimum environment. Most codes and standards are based on laboratory studies of this type, particularly the seminal work of Fanger [1970]. Fanger found that in climate chamber studies the mean reported thermal sensation of a group of people exposed to the same thermal environment was a function of four physical parameters (air temperature, mean radiant temperature, humidity, air speed), and two personal parameters (clothing, metabolic rate).

While the laboratory affords the usual advantages of being able to manipulate and measure the stimuli exactly, there have been numerous criticisms of laboratory studies of thermal comfort. The criticisms can generally be grouped under the heading of external validity, that is, how well do the results translate to the real world where they will be applied. Firstly, the climate chambers tend to be stark, sterile spaces, not aesthetically similar to most real world interiors. Secondly, the participants do not perform tasks representative of real world tasks. Thirdly, many of the parameters held constant in laboratory studies are not constant in the real world: clothing, for example. Fourthly, the participants in laboratory studies are usually college students, not very representative of the real world population.

In field studies, participants typically report their thermal sensations *in situ* while all important parameters are recorded at their prevailing values. The results are usually compared to the predictions made from the results of laboratory studies in order to test the validity of the laboratory studies; in many cases, the data collected in field studies have proven incompatible with the laboratory studies. However, these comparisons are complicated by the difficulty of precisely defining the relevant parameters in the field. For example, in the context of Fanger's equation, accurately determining an individual's clothing insulation and metabolic rate in a practical manner in the field is extremely difficult. Baker and Standeven [1995] argue that Fanger's physics and physiology are correct, and that field and laboratory measurements are perfectly consistent. Differences are due to uncertainty in physical and personal parameters due to measurement errors or behavioral adjustments made by occupants, resulting in local thermal conditions that differ from those at measurement points and from assumptions. However, Oseland [1994] found that the same participants in similar clothing and thermal environments felt warmest in their homes, next warmest in their office, and coolest in climate chambers. Oseland argues that this finding points to a genuine context effect that goes beyond physics and physiology. There has been a considerable and on-going effort to conduct field studies on many different populations in many different geographical locations. The data collected in our study add to this body of work, and comparisons to prior research, particularly to other field studies, will be made throughout this report.

1.3 Transient Conditions and the Need for Longitudinal Studies

The vast majority of laboratory studies have examined thermal comfort under fixed thermal conditions. Those laboratory studies that have looked at transient conditions [Purcell & Thorne, 1987] have done so in a very mechanistic way, with the changes being provided by a climate control system invisible to the participants, and according to regular mathematical functions. Baillie et al. [1988], Hensen [1990], and Oseland & Humphreys [1993] called for an investigation of the effect of more realistic changes in the thermal environment, such as those caused by solar radiation, or by moving between different spaces. Indeed, Black & Milroy [1966] observed in a field study that overheating was reported not on a regular schedule, but at times of day when the sun was shining.

The only way to capture this kind of information in a field study is to conduct a longitudinal (or time-series) study; that is, a study in which opinions (in this case, thermal sensation votes) are surveyed many times over the study period. In this way, the investigator can: observe how participants' reactions change in response to a changing physical environment; observe how past experience influences reactions; avoid the possibility that a snapshot survey captured atypical information [Cena et al., 1990; Humphreys, 1994; Nicol & Humphreys, 1973]. Longitudinal data could also be used to establish behaviour patterns as input to an adaptive model of thermal comfort which would take into account people's ability to temper their environment through personal or physical changes [Baker & Standeven, 1985; de Dear 1994; Hensen 1990; Humphreys & Nicol, 1970; Humphreys, 1994; Paciuk, 1989]

As noted in Section 1.1, conducting longitudinal surveys in the field using paper questionnaires would be disruptive, expensive, and labour intensive. Recognizing this, Humphreys & Nicol [1970] and Fishman & Pimbert [1982] conducted longitudinal studies in the field using voting box hardware to collect thermal sensation votes automatically. Each participant in each study had a box about the size of a telephone placed on their desk. At regular intervals the box cued the participant to vote using an audible tone. The participant voted by pressing one of seven buttons on the box, each button corresponding to a response on a thermal comfort scale. Sensors attached to the box simultaneously recorded various physical parameters of the thermal environment. These systems worked reliably, collecting much valuable data. However, the number of participants was limited (presumably by the cost of manufacturing the boxes), and the number and variety of responses were limited by the arrangement of buttons on the box. With *ScreenSurvey* we hoped to build on the success of these longitudinal studies. Embodiment of the voting box principal in software provided a great deal more flexibility in the number of questions asked and the variety of responses offered, and allowed us to increase the number of participants, because the cost of reproducing software is negligible.

2.0 Materials and Methods

2.1 Period of Study

Data collection took place during the period October, 1994 to January, 1995, or late Fall and early Winter.

2.2 Study Sites

The study was carried out at four sites. All sites were federal government facilities in Ottawa, Ontario, Canada. Figure 1 shows general outdoor climate data for this region. Ottawa is located at latitude 45° 19' N, longitude 75° 40' W (see Figure 2). Figure 3 is a street map of Ottawa showing the locations of the four sites within the city.

2.2.1 Site 1

Site 1 was an open-plan office occupying part of the second floor of a three storey suburban building. The occupants of this site did facilities design work. Figure 4 is a floor plan of the site, indicating the positions of the study participants. Figure 5 illustrates the appearance of the site.

2.2.2 Site 2

Site 2 was an open-plan office occupying part of the first floor of a seven storey suburban building. The occupants of this site did a variety of bibliographic tasks. Figure 6 is a floor plan of the site, indicating the positions of the study participants. Figure 7 illustrates the appearance of the site.

2.2.3 Site 3

Site 3 was a mostly open-plan office occupying the whole of the seventh floor, and part of the ninth floor, of a twenty-four storey downtown building. The occupants of this site did a variety of administrative, technical and scientific tasks. Figures 8(a) and 8(b) are floor plans of the site, indicating the positions of the study participants. Figure 9 illustrates the appearance of the site.

2.2.4 Site 4

Site 4 was an open-plan office occupying part of the second floor of a three storey suburban building. The occupants of this site did a variety of bibliographic tasks. Figure 10 is a floor plan of the site, indicating the positions of the study participants. Figure 11 illustrates the appearance of the site.

2.3 Participants

After receiving approval from NRC's Human Subjects Research Ethics Committee (HSREC) for the study, we asked the managers at various sites for permission to approach their staff and to invite them to volunteer for the study. Managers at the four sites described in Section 2.2 agreed to this. At each site we met with each staff member face-to-face, explained the project to them and invited them to participate. Those who agreed to participate were asked to sign a consent form (shown in Appendix A), and were given some written information on the project (see Appendix A). They were told that the software would be installed on their computer within a week, and that it would be installed outside of normal working hours. When we installed the software we left each participant written information on each of the questions that would be asked (see Appendix A).

The software was installed on over 60 computers at the four sites. At the conclusion of the study period, useful data were recovered from 55 participants. Of these 55 participants, 50 returned the basic demographic information shown in Table 1.

Table 1. Participant demographic information.

	Sex		
Age	Female	Male	Σ
20 - 29	8	1	9
30 - 39	5	13	18
40 - 49	7	11	18
50 - 59	1	3	4
60 - 69	0	1	1
Σ	21	29	50

All written information was supplied in either English or French, according to the participant's preference. In addition, the on-screen questionnaire was delivered in the language of the participant's preference. Table 2 shows the language of preference of the 55 participants from whom useful data were collected.

Table 2. Participant language of preference.

Language of Preference		
French	English	Σ
7	48	55

2.4 Measurement of Outdoor Climate

Outdoor climate data were recorded at an electronic weather station located close to site 4. The data recorded at this station were used for all sites, though some local differences may have occurred.

The weather station recorded many climate parameters. The parameters of interest to this study were: mean relative humidity, mean air temperature, and total solar radiation on a horizontal plane. Each of these parameters was recorded hourly during the study period.

The weather data were recorded by a Sciemetrics 200 Data Acquisition System. The raw data was stored in ASCII format, and were made available on the local computer network at the end of each month.

Total solar radiation on a horizontal plane was converted to total solar radiation on a vertical plane in each of the four cardinal directions using correlation equations [Barakat, 1983; Orgill & Hollands, 1977].

2.5 Measurement of Indoor Climate

Indoor air temperature and relative humidity were measured at the four sites using ACR Smartreader 2 dataloggers (shown in Figure 12). These dataloggers have a local capacity of 32,000 readings; these data were downloaded into a personal computer for analysis. Climate chamber tests confirmed the factory calibration and claimed accuracy of the loggers' sensors, as shown in Table 3.

Table 3. Accuracy of the indoor climate sensors.

Sensor	Accuracy
Air temperature	± 0.4 °C
Relative Humidity	± 4 %

Ideally, physical measures would have been taken at each of the participants' workstations. However, only a limited number of dataloggers were available. Therefore, we placed the loggers at representative points at the four sites (shown in Figures 4, 6, 8, and 10). Sites 1, 2, 4, and the ninth floor of site 3, where the office spaces were predominantly on a single facade, received one logger each. Five loggers were placed on the seventh floor of site 3, where there were offices on four facades and in a core area. Care was taken not to place the loggers in unrepresentative locations, such as: places where they would receive direct sunlight, and places close to sources of internal heat gain. The loggers are small (107 x 74 x 22 mm) and highly portable, and were secured to office furniture using $^{3}/_{32}$" steel cable.

The dataloggers were programmed to record both indoor air temperature and relative humidity every 20 minutes for the duration of the study period. About two weeks after installing the dataloggers, we returned to check that they working correctly. After that, we did not visit them again until the end of the study period, when the data were downloaded.

2.6 Recording Participants' Reactions and Personal Information

2.6.1 ScreenSurvey Software

Subjective reactions to the indoor thermal environment were collected using NRC's *ScreenSurvey* software. This study was carried out using version 1 of the software, and it is version 1 that is described here. NRC has since developed version 2 of the software, which has enhanced capabilities (described briefly in Section 5.9).

ScreenSurvey automatically administers questionnaires on computer users' screens. When administered, the questionnaire takes the form of a "window" over the user's other open applications. The individual questions are designed using custom *Form Builder* software. The questions have one of three response types:

1. A list of responses from which the participant may pick only one;
2. A list of responses from which the participant may pick as many as apply;
3. A sliding scale labeled with descriptors: the participant places a pointer on the scale at a position which best describes their response.

Once created, the questions can then be administered in any order, at dates and times specified by the experimenter in a data file. Any number of questions may be asked with any frequency. The questions are always preceded by a "Warning Banner", that asks the participant if they would like to continue with the questionnaire (see Figure 13). If the participant clicks "Cancel", or if there is no reply after a given time period, then the questionnaire can be rescheduled. In addition, certain questions can be defined as "demographic" questions, which are asked only once; these are questions for which the answers would not be expected to change over time. The responses to the questions are stored on the host computer's hard disk for collection at the end of the study by the experimenter.

ScreenSurvey was available for both Macintosh™ and Windows™ operating systems. Table 4 shows the number of each type of computer operating system used by the participants.

Table 4. Operating system of Participants' computers.

Operating System		
Macintosh™	Windows™	Σ
31	24	55

2.6.2 Questions Asked

The questions asked were divided into two types: demographic questions, and recurring questions.

Demographic questions are asked only once because answers are not expected to change with time (e.g., sex, mother tongue). The demographic questions were asked within one minute of the participant switching their computer on following installation of the *ScreenSurvey* software.

Recurring questions are questions that are asked many times; they are questions to which the answer would be expected to change with time. Recurring questions were asked twice per day, once before 1300 hrs and once after 1300 hrs, for the duration of the study. The times at which the questions appeared, and the order in which they appeared followed a pseudo-random but pre-defined schedule, described in Appendix B. Each participant followed the same schedule. Appendix A shows the four demographic and five recurring questions asked.

2.7 Final Evaluation Questionnaire

When we returned at the end of the study period to remove *ScreenSurvey* from participants' computers and collect the recorded data, we left behind a paper-based, final evaluation questionnaire. The purpose of the questionnaire was to evaluate the performance of *ScreenSurvey* and to invite any suggestions for improvements. We anticipated that suggested improvements would be taken into consideration when upgrading *ScreenSurvey*. Appendix C shows the content of the final evaluation questionnaire.

Participants returned the completed final evaluation questionnaire via normal internal mail channels.

3.0 Results

Results are presented in this section with minimal accompanying comments. Detailed discussion of results is reserved for Section 4. Participant data collected using *ScreenSurvey* is presented for the 10 week period: October 15th, 1994 to December 23rd, 1994.

3.1 Outdoor Climate vs. time

Figure 14(a) shows the outdoor air temperature recorded at the weather station during the period of the study. Figures 14(b) and 14(c) show similar plots for relative humidity and total solar radiation respectively. The thick lines show the mean values for each day; for air temperature and relative humidity the "whiskers" show the maximum and minimum values for each day.

3.2 Indoor Climate vs. time

Figure 15 plots indoor air temperature and relative humidity at Site 1 for during the period 21st - 27th November, 1994. These data represent a typical week's readings, and illustrates the typical within-day and between-day variations that occurred at the sites.

3.3 Response Rate and Response Time

Each recurring question could have been answered a maximum of 100 times over the 10 week period. The mean response rate to the ASHRAE thermal sensation question (Appendix A) was 29.1 % (n = 55), s.d. = 12.7., which represents 1600 data points. In other words, each participant answered the ASHRAE thermal sensation question an average of 29 times during the ten week period (the response rate to other questions differed, response rates to each question are discussed later). Figure 16 shows the actual response rate of each participant. The minimum response rate was 2 %, the maximum response rate was 62 %.

When participants responded, it took an average of 45.3 s (n = 1600), s.d. = 32.6 to answer all five questions. Figure 17 shows the mean response time of each participant. The minimum mean response time was 29.6 s, the maximum mean response time was 100.7 s.

3.4 Aggregate Frequency Data

In this section, the data from all sites and participants has been grouped.

Figure 18 shows the frequency of indoor air temperature prevailing when the participants responded to the *ScreenSurvey* questionnaire (to at least the ASHRAE thermal sensation question). For Figure 18, the air temperatures were sorted into 1 °C bins. Remember, temperature was recorded every 20 minutes independent of the operation of

ScreenSurvey. Therefore, in this context, 'prevailing when the participant responded to the *ScreenSurvey* questionnaire' means: recorded within 20 minutes of the time when the participant responded to the *ScreenSurvey* questionnaire. The mean indoor air temperature was 22.7 °C (n = 1600), s.d. = 1.0. The modal indoor air temperature was 22.1 - 23.0 °C, this bin represented 34.6 % of the recorded temperatures.

Figure 19 shows similar frequency information for the indoor relative humidity prevailing when the participant responded to the *ScreenSurvey* questionnaire. For Figure 19, the relative humidity was sorted into 10 % bins. The mean indoor relative humidity was 28.3 % (n = 1600), s.d. = 8.6. The modal relative humidity was 21 - 30 %, this bin represented 41.4 % of the recorded relative humidities.

Figure 20 shows the frequency of responses to the ASHRAE thermal sensation question. The response frequencies form a normal distribution (skewness = 0.045, not significantly different from zero, z = 0.735). The modal response was '0' or 'neutral' (n=1600), this response represented 51.3 % of the recorded responses. Figure 21 shows the frequency of votes in the central category ('0') and the central three categories ('-1', '0', '+1') of the ASHRAE thermal sensation scale at each indoor air temperature. In this Figure the ASHRAE votes were grouped according to the corresponding indoor air temperature. The mean ASHRAE vote in each 1 °C temperature bin was then calculated. Then the mean vote of each bin was plotted vs. the mean temperature of the bin. The peak for both curves occurs for the temperature bin 23.1 - 24 °C, with a mean bin temperature of 23.4 °C. Figure 22 shows the cumulative frequencies of votes on the ASHRAE thermal sensation scale. Again, the cumulative frequencies were plotted vs. mean bin temperatures, as in Figure 22. Each curve represents the percentage of votes in any of the categories labeled below the curve.

Figure 23 shows the frequency of responses to the McIntyre thermal preference question (see Appendix A). The response frequencies form a normal distribution (skewness = 0.033, not significantly different from zero, z = 0.539). The modal response was '0' or 'no change' (n=1599), this response represented 69.6 % of the recorded responses. Figure 24 shows the frequency of votes in each of the McIntyre thermal preference categories at each indoor air temperature; the Figure was constructed in the same way as Figure 21. The peak for the 'no change' curve occurs for the temperature bin 23.1 - 24 °C, with a mean bin temperature of 23.4 °C.

Figure 25 shows the frequency of responses to the question regarding clothing modification (see Appendix A). The modal response was 0 or 'none' (n=1601), this response represented 85.3 % of the recorded responses.

Figure 26 shows the frequency of responses to the question regarding clothing insulation worn at the start of the working day (see Appendix A). For Figure 26, clothing insulation was sorted into 0.1 clo bins. The mean clothing insulation worn was 0.78 (n = 1250), s.d. = 0.21. The frequency distribution is bimodal. The first peak occurs for a clothing insulation of 0.61 to 0.7 clo, the second at 1.01 to 1.1 clo.

Interpreting the responses to the question regarding clothing worn was more difficult than interpreting the responses to any of the other questions. The question asked 'What clothing were you wearing when you arrived at work today'. Clearly, the response to this question should not change within a day, yet limitations of *ScreenSurvey* meant that this question was asked twice per day, like all the other questions. Some participants answered twice in a day, while others ignored it if it appeared a second time in the same day. To avoid weighting the data towards those who answered the question more than once in a day, we post-processed the data, removing (for this question only) any data which represented a particular participant's second response to this question on a particular day. In cases where the participant answered the question more than once in a day and gave a different response each time, we assumed that the response representing the higher level of clothing insulation was the valid response. This explains why the number of responses to this question is substantially lower than the number of responses to the thermal sensation, thermal preference, and clothing change questions.

The question required the participants to complete a checklist of clothing items. To be of use in a quantitative sense, the completed checklist had to be converted into an equivalent clothing insulation. To do this, we used the insulation values from ANSI/ASHRAE 55-1992 [1992], with some slight modifications, as detailed in Table 5. Following ANSI/ASHRAE 55-1992, we assumed:

$$I_{cl} = \Sigma I_{clu} \quad (1)$$

where,

I_{cl} = total clothing insulation of ensemble, clo
I_{clu} = clothing insulation of individual item, clo

Some participants expressed reluctance to detail information regarding certain items of clothing (see Section 4.12), and did not include them in their responses. On other occasions it appeared that participants simply mistakenly omitted clothing items from their completed checklist. We thought it reasonable to assume that the following items of clothing were being worn, even if omitted from the occupants response: briefs, either shoes or sandals, either dress or skirt or pants or shorts. If these items were missing, then in post-processing we added clothing insulation values for briefs, shoes, skirt (if female) and pants (if male).

Our clothing checklist was also very generic. Clothing thermal resistance is governed by many factors, including: thickness, porosity, textile fibre, air layers, body posture, vapour diffusion, fit, layering, surface finish, activity of wearer [Boonlualohr, 1989; Goldman, 1980; Markee White, 1986; McCullough et al., 1994; Olesen, 1985; Oseland & Humphreys, 1993]. However, we judged that any attempt to capture this information in our study would have made the questionnaire too cumbersome to be administered on a frequent basis.

Table 5. Items on the clothing checklist and their clothing insulation values.

Description	I_{clu}, clo	Notes
Bra/Camisole	0.01	ANSI/ASHRAE contains no value for camisole
T-shirt	0.03	
Briefs	0.08	Includes women's underwear
Long Underwear	0.15	
Half Slip	0.14	
Full Slip	0.16	
Socks	0.02	Assuming ankle socks value from ANSI/ASHRAE
Pantyhose	0.02	
Sandals	0.02	
Shoes/Boots	0.03	Assuming shoes value from ANSI/ASHRAE
Tie/Scarf	0.02	Guess, no value in ANSI/ASHRAE, tightens collar fit
Short Sleeved Shirt	0.17	Assuming knit sports shirt value from ANSI/ASHRAE
Long Sleeved Shirt	0.30	Mean of dress shirt and flannel shirt value from ANSI/ASHRAE
Dress	0.33	Assuming long sleeved thin dress value from ANSI/ASHRAE
Skirt	0.19	Mean of thin skirt and thick skirt value from ANSI/ASHRAE
Pants	0.24	Assuming thick pants value from ANSI/ASHRAE
Shorts	0.08	Assuming walking shorts value from ANSI/ASHRAE
Sweater	0.34	Mean of sweatshirt and long-sleeve sweater, ANSI/ASHRAE
Vest	0.13	Mean of thin vest and thick vest value from ANSI/ASHRAE
Jacket	0.42	Assuming single-breasted thick jacket from ANSI/ASHRAE

Clearly, there is a lot of uncertainty in the derived clothing insulation values.

Figure 27 shows the frequency of responses to the question regarding blind position (Appendix A). The mean blind position was 0.54 (n = 1111), s.d. = 0.40. The frequency distribution is bimodal, at responses indicating blinds fully open (1) or fully closed (0). Blinds were fully open 31 % of the time, and fully closed 20 % of the time.

Obviously, this question was only relevant to those participants with windows at their workstations; limitations of *ScreenSurvey* meant that this question was asked of all participants. Participants who did not have windows at their workstations were instructed to ignore this question.(see Appendix A). However, some participants without windows did answer it, presumably giving a value for a distant window they could see from their workstation. In post-processing the data, we removed (for this question only) any data from participants without windows at their workstations. This explains why the number of responses to this question is substantially lower than the number of responses to the thermal sensation, thermal preference, and clothing change questions.

3.5 Order Effect

We tested whether the order in which the ASHRAE thermal sensation and McIntyre thermal preference questions were asked influenced the responses. For each participant, we examined ASHRAE votes when the concurrent McIntyre vote was '0' ('no change'). We divided the ASHRAE votes into two 'order groups': those made when the McIntyre question was asked before the ASHRAE question, and those made when the ASHRAE question was asked before the McIntyre question. Then, for each participant, we calculated the mean ASHRAE vote for each order group (note, the number of votes in each group differed by group and by participant). We then used the Wilcoxon Signed Ranks method to test for differences between the two order groups. Differences in ASHRAE vote by order of question presentation were not significant ($z = -0.736$, $p = 0.46$, $n = 51$).

Note that the total number of occasions when the ASHRAE question was asked first was less than half of the occasions when the McIntyre question was asked first. Appendix B shows that the TIMES.DAT files scheduled the ASHRAE question ahead of the McIntyre question only 40 % of the time. Further, the times at which the ASHRAE question was asked before the McIntyre question tended to cluster around early morning and late afternoon, when the participant may not have been at work.

3.6 Correlations between Data

Table 6 shows the correlation coefficients (r) between several of the participant-related and physical parameters and votes on the ASHRAE thermal sensation and McIntyre thermal preference questions. Responses from all participants have been grouped. Only occasions where responses to both questions were made are considered.

Table 6. Correlation coefficients (r) between variables.
** indicates significant at the 0.05 level, ** indicates significant at the 0.01 level.*

	n = 1544	ASHRAE	McIntyre	Clo_change	Clo
Participant-related	ASHRAE	-			
	McIntyre	-0.712 **	-		
	Clo_change	-0.203 **	0.179 **	-	
	Clo	0.025	0.010	-0.130 **	-
Physical	Ind_air_temp	0.335 **	-0.303 **	-0.189 **	-0.045
	Ind_humid	0.005	-0.032	0.061 *	-0.013
	Out_air_temp	0.122 **	-0.148 **	-0.058 *	-0.085 **
	Out_humid	-0.123 **	0.103 **	0.055 *	-0.014
	Tot_horiz_solar	0.165 **	-0.137 **	-0.064 *	-0.043

3.7 Regressions between Participant Responses and Physical Measures

Figure 28 shows a bubble plot of all the individual responses to the ASHRAE thermal sensation question vs. the corresponding indoor air temperature. A bubble plot is a variation on the scatter plot where the size of the bubble is proportional to the number of data points at a particular location on the plot. A regression line is drawn through the data, and has the equation:

$$TS = -7.69 + 0.34\ T_{ia} \quad (n = 1600,\ r^2 = 0.11,\ p < 0.001) \qquad (2)$$

where,

TS = ASHRAE thermal sensation vote
T_{ia} = Indoor air temperature (°C)

Note that in performing this regression we are defying the strict requirements of linear regression models, which require an equal-interval-type dependent variable [de Dear & Auliciems, 1985]. The ASHRAE thermal sensation scale is ordinal: the responses are unambiguously ordered, but the width of each category is not necessarily the same (see Figure 22). In the case of such ordinal scales Probit analysis is more appropriate [de Dear, 1994]. However, grouped data collected using the ASHRAE scale are commonly treated as if collected using a continuous, equal-interval scale, and studies that have used both this treatment and Probit analysis have found very similar results [McIntyre, 1978].

Figure 29 shows a more traditional plot of the same data. In this Figure the ASHRAE votes were grouped according to the corresponding indoor air temperature bin. The mean ASHRAE vote in each bin was calculated. Finally, the mean vote of each bin was plotted vs. the mean temperature of the bin. Also shown on the Figure are the number of data points in each bin, the standard deviations in the ASHRAE votes for each bin (represented by the error bars), and a regression line. The regression line is weighted according to the number of observations associated with each mean, and has the equation:

$$TS = -7.56 + 0.33\ T_{ia} \quad (n = 1600,\ r^2 = 0.77,\ p < 0.001) \qquad (3)$$

If we calculate the regression line without weighting each point according to the number of observations, the regression equation becomes:

$$TS = -8.04 + 0.36\ T_{ia} \quad (n = 8,\ r^2 = 0.73,\ p = 0.007) \qquad (4)$$

A regression of the McIntyre thermal preference votes vs. indoor air temperature, analogous to Equation 2 has the equation:

$$TP = 3.84 - 0.17\ T_{ia} \quad (n = 1599,\ r^2 = 0.09,\ p < 0.001) \qquad (5)$$

where,

TP = McIntyre thermal preference vote

Figure 30 shows (like Figure 29) the mean McIntyre vote in each indoor air temperature bin vs. the mean temperature of the bin. Also shown on the Figure are the number of data points in each bin, the standard deviations in the McIntyre votes for each bin (represented by the error bars), and a regression line. The regression line is weighted according to the number of observations associated with each mean, and has the equation:

$$TP = 3.70 - 0.16\ T_{ia} \quad (n = 1599,\ r^2 = 0.76,\ p < 0.001) \qquad (6)$$

If we calculate the regression line without weighting each point according to the number of observations, the regression equation becomes:

$$TP = 4.37 - 0.19\ T_{ia} \quad (n = 8,\ r^2 = 0.86,\ p = 0.001) \qquad (7)$$

A multiple regression of the individual ASHRAE thermal sensation votes on the following variables: clothing insulation, measured indoor air temperature, indoor relative humidity, outdoor air temperature, outdoor relative humidity, total horizontal solar radiation, calculated vertical solar radiation on the relevant orientation, and forecast temperature (outdoor air temperature at 8 am each morning, a temperature that might have influenced morning clothing choice) did not substantially increase r^2 over using indoor air temperature alone ($r^2 = 0.14$ vs. $r^2 = 0.11$, see Eq. 2).

Figure 31 is a plot of mean weekly ASHRAE vote vs. mean weekly forecast temperature. The regression line through the scatter points has the equation:

$$TS = -0.01 + 0.0092\ T_f \quad (n = 10,\ r^2 = 0.08,\ p = 0.43) \qquad (9)$$

where,

T_f = Forecast air temperature (°C)

3.8 The Effect of Response Rate on Regressions

In the correlations and regressions of Sections 3.6 and 3.7 we grouped all responses into a single data set. However, Figure 16 shows quite clearly that each respondent voted a different number of times. It is reasonable to ask whether it is appropriate to group the data given that the respondents with a greater response rate will be more represented in the data set than the respondents who voted less frequently.

We addressed this issue in two, essentially equivalent ways. First, we regressed ASHRAE vote on indoor air temperature for each participant. We then plotted, for each participant, the mean square residual, $MS_{Residual}$ (variance in ASHRAE vote not accounted for by indoor air temperature) vs. the number of responses; this graph is shown in Figure 32. There appears to be no correlation between $MS_{Residual}$ and response rate, and this was confirmed by an F-test ($F = 0.008$, $n = 54$, $r^2 < 0.001$, $p = 0.93$). Secondly, we created a new variable "Number of Votes" and performed a multiple regression for the grouped data set, regressing ASHRAE vote on indoor air temperature and Number of Votes. Note, if a particular participant made 20 votes, that participant would contribute 20 potentially different ASHRAE votes and corresponding indoor air temperatures to the data set, but their value for the Number of Votes variable would be the same in each case (= 20). While the t-test for the regression coefficient associated with temperature was highly significant, the t-test for the regression coefficient associated with Number of Votes was not significant ($t = -0.064$, $n = 1600$, $p = 0.55$).

Since response rate appears to have no significant effect on ASHRAE vote, we conclude that it was appropriate to group all the response data for the purposes of the correlations and regressions of Sections 3.6 and 3.7.

3.9 Neutral and Preferred Temperatures

The neutral temperature (T_n) is the indoor air temperature most likely to produce the response '0' or 'neutral' on the ASHRAE thermal sensation scale. T_n can be derived in two ways. First, from the regression of Equations 2, 3 and 4; second, from the frequency distribution of Figure 21. Inserting the value TS = 0 into Equations 2, 3 and 4 yields a T_n of 22.7 °C, 22.9 °C, and 22.3 °C respectively. Figure 21 shows that the temperature bin with the highest frequency of 'neutral' responses was 23 - 24 °C.

The preferred temperature (T_p) is the indoor air temperature most likely to produce the response '0' or 'no change' on the McIntyre thermal preference scale. T_p can be derived in the same two ways as T_n. Inserting the value TP = 0 into Equations 5, 6 and 7 yields a T_p of 22.7 °C, 23.1 °C, and 23.0 °C respectively. Figure 24 shows that the temperature bin with the highest frequency of 'no change' responses was 23 - 24 °C.

3.10 Comparison with Predicted Mean Vote (PMV)

PMV is the mean thermal sensation vote for a population as predicted from Fanger's thermal comfort equations [Fanger, 1970]. We calculated the PMV associated with each questionnaire response using Sherman's simplification of Fanger's equations [Sherman, 1985]. As inputs to the equations, we used the measured values of indoor temperature, humidity, and reported clothing (with the addition of 0.15 clo to account for the insulative value of an office chair, as recommended in Brager et al. [1994]; de Dear & Fountain [1994]; McCullough et al. [1994]; Palonen et al. [1993]), and assumed mean radiant temperature equal to air temperature, an air velocity[2] of 0.1 ms^{-1}, and an activity[3] of 1.2

---

[2] This is a common assumption for the office environment. Several studies have measured air velocity in the field, and reported the following values (in ms^{-1}):
Auliciems & de Dear [1986b], Darwin "Buildup": 0.14, Darwin "Dry": 0.07; Baillie et al. [1988]: ~ 0.1; Boyce [1974]: 0.12; Busch [1990]: 0.12; Croome et al. [1992]: 0.08; de Dear & Auliciems [1985], Brisbane: 0.15, Melbourne: 0.11; de Dear et al. [1991]: 0.11; de Dear & Fountain [1994], "Dry": 0.12±0.03, "Wet": 0.13±0.04; Grivel & Barth [1980]: 0.07; Kahkonen et al. [1990]: 0.08±0.03; Markee White [1986]: 0.11±0.05; Oseland [1994]: 0.10; Palonen et al. [1993]: <0.05; Schiller et al. [1988a], Winter: 0.06±0.05, Summer: 0.10±0.09.

[3] This is the mean value commonly assumed for office work. Several field studies have tried to measure mean metabolic rate in the office through participant self report of recent activity, and reported the following values in met units (1 met = 58.2 Wm^{-2}):

met. These assumptions clearly introduce uncertainty into the calculation of PMV.

Figure 33 compares our reported mean ASHRAE vote and mean PMV in each temperature bin. Also shown on Figure 33 are regression lines through the two sets of points. The regression equation for the PMV data, without weighting for the number of observations in each temperature bin, is:

$$PMV = -4.73 + 0.22\ T_{ia} \quad (n = 8,\ r^2 = 0.99,\ p < 0.001) \tag{10}$$

3.11 Differences between Demographic Groupings

In this section the data are presented after being sub-divided into appropriate site-based and demographic-based groups.

Table 7 shows the mean indoor air temperature at each of the four sites; this is for the subset of indoor air temperatures measured at the time that the ASHRAE thermal sensation question was answered by at least one participant at the site. Table 7 shows, for each site, the number of responses, the mean indoor air temperature, and the standard deviation in the mean indoor air temperature. It also shows the results of an analysis of variance between sites.

Table 7. Mean indoor air temperature measured at each site. A lower-case letter in the ANOVA row indicates the site is significantly different at the 5 % level from the site with the same letter in upper case, as determined by an analysis of variance.

	Site			
	1	2	3	4
n	337	374	847	42
mean, °C	23.0	23.3	22.4	23.3
s.d., °C	0.9	0.4	1.1	0.4
ANOVA	A	a B	a b C	c

There was a difference between the mean indoor air temperature of up to 1.0 °C between sites. Note, the highest standard deviation was observed at Site 3, where temperatures were recorded at five different locations; the lowest standard deviation was observed at Site 4, where temperatures were recorded at only one location, and the number of observations was relatively small.

Table 8 shows the mean indoor air temperature for each orientation at Site 3. Table 8 shows, for each orientation, the number of responses, the mean indoor air temperature, and the standard deviation in the mean indoor air temperature. It also shows the results of

---

Baillie et al. [1988]: 1.4±0.3; Brager et al. [1994]: 1.1; Cena et al. [1990], Philadelphia: 1.6±0.5, Perth: 1.6±0.2; de Dear et al. [1991]: 1.2; de Dear & Fountain [1994]: 1.3±0.2; Grivel & Barth [1982]: 1.7±0.3; Grivel & Barth [1980]: 1.2; Markee White [1986]: 1.1±0.1; Oseland [1994]: 1.2.

an analysis of variance between orientations.

Table 8. Mean indoor air temperature measured for each orientation at each Site 3. A lower-case letter in the ANOVA row indicates the orientation is significantly different at the 5 % level from the orientation with the same letter in upper case, as determined by an analysis of variance.

	Site 3			
	east	north	south	west
n	150	113	201	112
mean, °C	22.6	21.8	22.4	22.3
s.d., °C	1.3	0.8	1.1	1.1
ANOVA	a	A	a	a

Table 9 shows the mean response to the ASHRAE thermal sensation question at each site. Table 9 shows, for each site, the number of responses, the mean ASHRAE vote, and the standard deviation in the mean ASHRAE vote. It also shows the results of an analysis of variance between sites. Site 4 is not shown because there was only one participant at this site making comparisons to other sites meaningless.

Table 9. Mean ASHRAE vote recorded at each site. A lower-case letter in the ANOVA row indicates the site is significantly different at the 5 % level from the site with the same letter in upper case, as determined by an analysis of variance.

	Site		
	1	2	3
n	337	374	847
mean vote	0.28	-0.12	-0.03
s.d.	0.97	0.79	1.09
ANOVA	A	a	a

Figure 34 shows the frequency of responses to the ASHRAE thermal sensation question at each site; Site 4 was excluded because of the relatively small number of responses (n = 42). The modal response was 0 or 'neutral' at each of the sites. The data from Site 1 are skewed significantly toward warm responses (skewness = 0.577, n = 337, z = 4.32). A χ^2 test shows that the distribution of ASHRAE votes differed significantly between all site pairs, as detailed in Table 10.

Table 10. χ^2 test of ASHRAE vote distributions pairwise by site.

	Site		
	1 vs 2	1 vs 3	2 vs 3
df	6	6	6
χ^2 value	38.5	39.0	44.8
p	<0.01	<0.01	<0.01

Table 11 shows the mean response to the ASHRAE thermal sensation question for each sex. Table 11 shows, for each sex, the number of responses, the mean ASHRAE vote, and the standard deviation in the mean ASHRAE vote. It also shows the results of an analysis of variance between sites.

Table 11. Mean ASHRAE vote by sex. A lower-case letter in the ANOVA row indicates the sex is significantly different at the 5 % level from the sex with the same letter in upper case, as determined by an analysis of variance.

	Sex	
	female	male
n	712	801
mean vote	-0.12	0.08
s.d.	1.02	0.94
ANOVA	A	a

Figure 35 shows the frequency of responses to the ASHRAE thermal sensation question of each sex. The modal response was 0 or 'neutral' at each of the sites. A χ^2 test shows the two distributions to be significantly different ($\chi^2 = 23.9$, df = 6, $p = 0.001$)

Table 12 shows, for each age category, the number of responses, the mean ASHRAE vote, and the standard deviation in the mean ASHRAE vote. An analysis of variance indicated no significant difference in mean vote between age categories (category 60 - 69 was excluded from the analysis of variance because the data came from a single participant only).

Table 12. Mean ASHRAE vote by age.

	Age				
	20 - 29	30 - 39	40 - 49	50 - 59	60 - 69
n	345	507	541	107	13
mean vote	-0.01	0.03	-0.07	-0.04	0.69
s.d.	1.04	1.07	0.93	0.55	0.95

Table 13 shows the mean response to the ASHRAE thermal sensation question for each orientation. Only responses from Site 3 are shown, as this was the only site with participants with offices in all four orientations. Further, only responses from participants whose offices had an outside window were included. Table 13 shows, for each orientation, the number of responses, the mean ASHRAE vote, and the standard deviation in the mean vote. An analysis of variance indicated no significant difference in mean vote between sites.

Table 13. Mean ASHRAE vote by orientation at Site 3.

	Site			
	East	North	South	West
n	150	113	201	112
mean vote	0.02	-0.04	0.15	0.05
s.d.	0.97	0.93	1.12	0.90

Table 14 shows the mean clothing insulation worn to work, by site. Site 4 is not shown because there was only one participant at this site making comparisons to other sites meaningless in this case. Table 14 shows, for each site, the number of responses, the mean clothing insulation, and the standard deviation in the mean clothing insulation. An analysis of variance showed no significant difference between the clothing insulation adopted at each of the sites, at the 5 % level.

Table 14. Mean clothing insulation reported at each site.

	Site		
	1	2	3
n	267	295	651
mean clo	0.79	0.76	0.79
s.d.	0.21	0.25	0.20

Table 15 shows the mean clothing insulation worn to work, for each sex (remember that only 50 of the 55 participants identified themselves by sex). Table 15 shows, for each sex, the number of observations, the mean clothing insulation, and the standard deviation in the mean clothing insulation. It also shows the results of an analysis of variance between sites.

Table 15. Mean reported clothing insulation by sex. A lower-case letter in the ANOVA row indicates the sex is significantly different at the 5 % level from the sex with the same letter in upper case, as determined by an analysis of variance.

	Sex	
	female	male
n	553	622
mean clo	0.74	0.80
s.d.	0.22	0.21
ANOVA	A	a

Figure 36 shows the mean reported blind position for each site and for each orientation; only those responses from participants whose offices had external windows were included. Both Site 2 and Site 3 had south facing offices; at Site 2 the mean blind position was 0.30 (n = 209), s.d. = 0.33, whereas at Site 3 the mean blind position was 0.52 (n = 200), s.d. = 0.40; an analysis of variance indicated that the two were significantly different (F = 39.9, p < 0.001). Site 1 and Site 3 had west facing offices; at Site 1 the mean blind position was

0.10 (n = 155), s.d. = 0.18, whereas at Site 3 the mean blind position was 0.65 (n = 113), s.d. = 0.32; an analysis of variance indicated that the two were significantly different ($F = 318.6$, $p < 0.001$).

The data from Site 3 only reveals that there was also a difference in mean blind position between orientations. The mean blind positions for the south and west facing offices are lower than those for the east (mean = 0.80, n = 150, s.d. = 0.31) and north (mean = 0.95, n = 114, s.d. = 0.13) facing offices. A pairwise analysis of variance indicated significant differences in blind position between all orientations ($p < 0.01$)

3.12 Longitudinal Data

Figure 37 shows the weekly (Monday to Friday) mean response to the ASHRAE thermal sensation question for all four sites. The standard deviation in the weekly data is indicated by the error bars. There may be a slight tendency for mean response to decrease with time (as the outdoor climate gets colder), though the week ending November 4th is an obvious exception to this. We tested this tendency by collapsing the ASHRAE votes into two sub-sets: those of the first five weeks of the study (mean = 0.09, n = 854), and those from the second half (mean = -0.09, n = 746). The two sub-sets were then compared by an analysis of variance, which showed them to be significantly different (n = 1600, $F = 13.0$, $p < 0.001$).

Figure 38 shows the hourly mean response to the ASHRAE thermal sensation question for all four sites and for all 10 weeks of the study period. The standard deviation in the hourly data is indicated by the error bars. There may be a slight tendency for mean response to increase in the afternoon. We tested this tendency by collapsing the ASHRAE votes into two sub-sets: those of hours 9 to 12 (morning, mean = -0.09, n = 715), and those of hours 13 to 16 (afternoon, mean = 0.13, n = 780); hours 17 and 18 were excluded because of their small data sets, $n_{17+18} = 105$. The two sub-sets were then compared by an analysis of variance, which showed them to be significantly different (n = 1495, $F = 18.5$, $p < 0.001$).

Figure 39 shows the mean response to the ASHRAE thermal sensation question in the morning and afternoon for each orientation at Site 3 (the only site with participants in offices with windows facing the 4 cardinal directions) and for all 10 weeks of the study period. An analysis of variance showed that the differences in the means in the morning and afternoon were not significant, except for the south orientation (n = 185, $F = 8.1$, $p = 0.005$). Figures 40 and 41 show a similar plot for the single orientation at Site 1 (west) and Site 2 (south). An analysis of variance showed that the differences in the means in the morning and afternoon were not significant at Site 2, but were significant at Site 1 (n = 154, $F = 11.4$, $p = 0.001$).

Figure 42 shows the weekly mean clothing insulation level value for each sex. Clothing insulation worn by males was consistently slightly higher than clothing insulation worn by females. The mean clothing level for males in the first five weeks of the study was 0.79 clo (n = 332), slightly lower than that in the second five weeks, 0.82 clo (n = 290). The mean clothing level for females in the first five weeks of the study was 0.72 clo (n = 283), slightly lower than that in the second five weeks, 0.76 clo (n = 270). However, an analysis of variance indicated that these differences were not significant at the 5 % level.

3.13 Analysis of Final Evaluation Questionnaire

Figures 43 to 48 show the frequency distribution of responses to the final evaluation questionnaire.

As described in Section 2.6, a Warning Banner window appeared on screen prior to the thermal comfort question. The Warning Banner informed the participant that the questionnaire was due to be administered and gave them the opportunity to postpone the questionnaire. When asked if they found the appearance of the Warning Banner obtrusive, Figure 43 shows that only 4 % of respondents voted 3 or 4 on the 5 point scale (0 = 'not at all', 4 = 'very'). Further, when asked about the size of the Warning Banner (the question screens were the same size as the Warning Banner), Figure 44 shows that 90 % of respondents found the size of the Warning Banner 'acceptable'. Figure 45 shows the responses to perhaps the most pertinent of the follow-up questions, 'Did this method of automatic questionnaire administration distract you from your work?' Figure 45 shows that only 11 % of respondents voted 3 or 4 on the 5 point scale (0 = 'not at all', 4 = 'very much'). When asked about the number of questions asked at each scheduled time, Figure 46 shows that 79 % of respondents found the number of questions 'acceptable', whereas 19 % thought 'too many' questions were asked each time. When asked if the questionnaire appeared too often, Figure 47 shows that only 6 % of respondents said 'Yes'. Finally, when asked if they would have liked to make the questionnaire appear on demand (remember, in our study the questionnaire appeared according to an experimenter defined schedule), Figure 48 shows that 75 % said 'No', and '25 % said 'Yes'.

4.0 Discussion

This section contains discussion of the results presented in Section 3.

4.1 Frequency of Response

The principal aim of this study was to evaluate the software as a technique for delivering questionnaires. Figure 16 shows that the mean response rate was 29.1 %. This means that each participant answered the questions an average of 29 times during the ten week period, not that only 29 % of participants responded (in fact all 55 participants responded at least twice over the study period). Thus, the volume of data collected was actually relatively high, over 1500 data points for several of the questions, and was in-line with our expectations. By comparison, Humphreys and Nicol [1970] used voting hardware to poll participants hourly for 15 months and obtained an overall response rate of about 11 %.

There was no evidence to indicate that the software malfunctioned during the study period. Therefore, the only possible reasons why the response rate was not higher are:

1. The participants were at work but their computers were not switched on.

2. The participants were at work but did not respond to the questionnaire when it appeared; they were away from their desks temporarily, or canceled the questionnaire when it appeared.

3. Participants were not at work and their computers were not switched on.

It is unlikely that the first reason contributes to a reduction in response rate. Other research [Newsham & Tiller, 1994] shows that workers at these and other similar sites have their computers switched on all of the time they are at work.

The data file recorded when there was no response to the questionnaire when it appeared. Over the survey period this occurred on 22.8 % of the occasions when the questionnaire was presented. Only on a few occasions did the participant actively cancel the questionnaire, therefore we can assume that the lack of response was due to occupants being temporarily absent from their desks (the questionnaire "timed out" if there was no response within 1 minute of appearing). Thus, we can infer from these data that our sample of participants were temporarily away from their desks about 20 % of a typical working week.

Since we know the response rate to the questionnaire (29.1 %), and the "no response" rate (22.8 %), the remainder (48.1 %) are occasions when the questionnaire was scheduled to appear but for which no data were recorded in the data file. This could only happen if the computer was not switched on at the scheduled time, which almost certainly means the participant was not in the building (on travel, working at another site, on leave etc.). Questionnaires were scheduled to appear at regular intervals from 0800 hrs to 1800 hrs, which covers 10 hours, whereas a typical working day might only cover 8 hours. Therefore we might expect a missing data rate of 20 % due to question scheduling alone. Vacation leave might normally account for another 5 %. That still leaves a large degree of absenteeism. We have no evidence to suggest that this absenteeism is anything other than legitimate. Neither do we know whether the high degree of absenteeism is due to the nature of our participants' jobs, or if it is representative of modern office workers in general. Opdal & Brekke [1995], observing nine Norwegian offices, found workers away from their desks 72 % of the working week! While these findings are of no direct consequence to thermal comfort, it may be useful data to those constructing occupancy profiles for office buildings.

4.2 Comparison of Frequency Data with Thermal Comfort Standards

ANSI/ASHRAE [1992] and ISO Standards [1984] have requirements for acceptable indoor thermal comfort conditions. The goal of these standards is that 80 % of the occupants should be satisfied. Satisfaction is defined as being a vote in the central three categories (-1, 0, +1, or 'slightly cool', 'neutral', 'slightly warm') of the ASHRAE thermal sensation scale. The standards use Fanger's PMV model [1970] to derive acceptable operative temperature ranges based on the above goal, given assumptions for the other environmental and personal variables required by Fanger's model. Table 16 shows the required temperature ranges, and assumptions, by season. Note, Table 16 quotes the required temperature ranges for 10 % dissatisfaction whereas the overall goal of the standard is to achieve the less stringent 20 % dissatisfaction. Presumably the temperature requirements in the standards are more rigorous to allow for some variation of conditions spatially within the building, and for values for other physical and personal parameters that differ from the assumptions within the population.

Table 16. ANSI/ASHRAE and ISO Standard acceptable operative temperatures for thermal comfort, by season [ANSI/ASHRAE, 1992; ISO, 1984].

Season	Optimum Temperature, °C	Range for 10 % Dissatisfaction, °C	Assumptions
Winter	22.0	20.0 to 23.5	RH=50 %, mean air speed ≤ 0.15 ms^{-1}, 1.2 met, 0.9 clo
Summer	24.5	23.0 to 26.0	RH=50 %, mean air speed ≤ 0.15 ms^{-1}, 1.2 met, 0.5 clo

Figure 20 shows that in our study, 87 % of responses to the ASHRAE thermal sensation question were within the central three categories. This indicates that, according to ASHRAE and ISO standards, the sites as a whole exhibited acceptable thermal comfort.

But was this acceptable thermal comfort achieved by adhering to the temperature ranges specified in the Standards? Although our study was conducted during winter, the mean clothing insulation we recorded was 0.78 clo, less than the 0.9 clo assumption of the

Standards (note, the Standards do not include an allowance for the insulation value of an office chair). The Standards offer a method for deriving temperature ranges in environments where different clothing insulation levels are worn. If we use this method, we derive an acceptable temperature range for our reported clothing level of 21.0 to 24.5 °C for 10 % dissatisfaction (90 % satisfaction). Further, we observed a mean indoor relative humidity of 28 %, significantly lower than the Standard's assumption of 50 %. The psychometric charts supplied with the Standards indicates this lower humidity shifts the range of acceptable temperatures up by about 0.5 °C to 21.5 to 25.0 °C. The Standard's assumptions regarding activity and air speed are consistent with our assumptions. Note that the Standards specify operative temperature, whereas we measured air temperature. Operative temperature is a weighted mean of air temperature and MRT. The common assumption, valid in most office spaces, is that air temperature and MRT are equal, in which case air temperature and operative temperature are identical. For the purposes of this comparison, we shall make this assumption.

Figure 49 shows the temperature limits 21.5 to 25.0 °C, and limits defining the central three categories of the ASHRAE thermal sensation scale superimposed on Figure 28. Note that while a large majority of responses fall within the required limits of temperature and thermal sensation, there are both acceptable thermal sensation votes at temperatures outside the recommended range, and unacceptable thermal sensation votes at temperatures within the recommended range. Table 17 shows the frequency of observations according to various criteria suggested by Figure 49.

Table 17 shows that 89 % of the observed temperatures were within the temperature limits suggested by the Standard, though we were unable to ascertain whether the building managers were expressly following the Standard. When the observed temperature was within the required limits, only 10 % of the thermal sensation votes were outside the central three categories of the scale. This is precisely the goal criterion from which the temperature limits were derived. Therefore, our observations in the field seem to support the thermal comfort theory on which the Standard was based. Schiller et al. [1988a] reached a similar conclusion from the results of their field study.

Table 17. Frequency of responses according to various criteria of acceptable thermal sensation (central three categories of the ASHRAE scale) and temperature (21.5 to 25.0 °C, as suggested by ANSI/ASHRAE and ISO Standards)

Criteria	Frequency
Acceptable thermal sensation	87 %
Within temperature limits	89 %
Within temperature limits AND Acceptable thermal sensation	79 %
Within temperature limits NOT Acceptable thermal sensation	10 %
Acceptable thermal sensation NOT Within temperature limits	8 %

4.3 Correlations between Parameters

In Table 6 we observed a strong correlation between responses to the ASHRAE and McIntyre scales (r = -0.71). A strong correlation would certainly be expected, and similar results have been reported by Busch [1990] (r = -0.69), and Schiller et al. [1988a] (in summer, r = -0.66, in winter, r = -0.45).

Busch [1990] also reports a strong correlation between ASHRAE thermal sensation vote indoors and outdoor air temperature (r = 0.44). In our study the correlation was significant ($p < 0.01$) but small (r = 0.12). Speculation suggests one reason for the much higher correlation in Busch's study might be the fact that although both studies were conducted in air-conditioned office buildings, Busch's study was carried out in Thailand when the temperature outdoors was high, whereas our study was carried out during a Canadian winter. Because of the severe cold, Canadians in winter have very little contact with the outdoor climate, even outside of the office. Thais, on the other hand, probably spend much more of their time outside the office in contact with the outdoor climate; it is therefore not surprising that their votes of indoor thermal sensation are more influenced by the outdoor climate.

Busch [1990] also reports a small but significant correlation between clothing insulation and indoor temperature (r = -0.16). Schiller et al. [1988a] report a larger, significant correlation for their winter survey (males: r = -0.32, females: r = -0.24), but no significant correlation in the summer. Comparisons with our study are harder to make since our reported clothing insulation level was based on clothing worn at the start of the working day, and is therefore unlikely to be influenced by the indoor air temperature prevailing when the questionnaire was presented. Thus, we should be relieved to note the small, insignificant correlation between our reported clothing insulation and indoor air temperature. More relevant in the context of our study is the correlation between reported clothing change and indoor air temperature. In this case, we observed a significant ($p < 0.01$) correlation of about the same magnitude (r = -0.19) as the correlations between clothing and temperature reported by Busch [1990] and Schiller et al. [1988a].

Note also our significant negative correlation between ASHRAE thermal sensation vote and clothing change (r = -0.20, $p < 0.01$); those participants that felt warm tended to reduce clothing insulation, and those that felt cool tended to increase clothing insulation. Also interesting is the smaller significant negative correlation between reported clothing worn to work and clothing change (r = -0.13, $p < 0.01$); those participants who arrived at work wearing more clothing tended to decrease their clothing insulation, those who arrived wearing less clothing tended to increase their clothing insulation.

4.4 Effect of Response Rate

A number of field studies have collected multiple thermal comfort votes from each of their participants [Ballantyne, 1977; Black, 1954; Fishman & Pimbert, 1982; Hindmarsh &

Macpherson, 1962; Humphreys & Nicol, 1970; Palonen et al., 1993; Rowley et al., 1947]. Inevitably, a different number of votes were collected from each participant in these studies. Generally, these studies grouped all the data together for analysis, with little reference to the fact that some participants would thus be over-represented in the grouped data, and other participants under-represented. The issues here are complex. Statistically, one might desire an equal number of votes from each participant[4]. However, if our aim is to produce better indoor thermal environments, perhaps it is advantageous from a practical point of view to bias the data set towards the responses of those subjects most frequently in the indoor environment in question. Since lack of response to the questionnaire was principally a function of absence from the workstation rather than cancellation of the questionnaire by a participant who was at their workstation, this practical consideration might justify us in analyzing grouped data irrespective of the biases which might be introduced. In fact, our analysis of Section 3.8 showed that ASHRAE vote was not significantly correlated to frequency of response.

4.5 Overall Satisfaction

Table 18 presents a comparison of frequency responses to the ASHRAE thermal sensation scale and McIntyre thermal preference scale from various field studies in office or office-like environments. The level of thermal satisfaction according to responses on the ASHRAE scale in our study is similar to that reported in previous studies.

When comparing votes in the central category of the McIntyre scale, we find that the level of satisfaction reported in our study is substantially higher than in other studies. The reason for the high degree of satisfaction expressed in our study is not known. However, we did observe temperatures in the space in close agreement with those required by Standards for thermal comfort (Section 4.2); space temperatures might not have been as well regulated at the sites where the comparison studies were conducted. Brager et al. [1994] argue that the central category of the McIntyre scale is too strict a measure of thermal satisfaction. They also suggest that votes outside the central category, indicating a desire for a change in temperature, might not indicate dissatisfaction. Just because, in an ideal world, a participant might prefer a different temperature, doesn't necessarily mean that the prevailing thermal conditions are unsatisfactory. Conversely, with regard to current building environmental control technology, the thermal preference scale is more relevant than the thermal sensation scale; people adjust thermostats based on the question: "Would I prefer to be warmer, cooler, or the same?"

---

[4] The desirability of having more than one vote from each participant is also contentious, some statistical procedures strictly require indepenedence between data points.

Table 18. Thermal acceptability recorded by various field studies.

Field Study	ASHRAE Thermal Sensation		McIntyre Thermal Preference
	3 central categories ('-1', '0', '+1')	central category only ('0')	central category ('no change')
Auliciems & de Dear [1986a, 1986b]			
Darwin "Buildup"	82 %		
Darwin "Dry"	76 %		
Brisbane	84 %		
Melbourne	85 %		
Auliciems [1977]			
Adelaide	84 %		
Melbourne	73 %		
Armidale	85 %		
Perth	80 %		
Brisbane	86 %		
Boonlualohr [1989]	~ 80 %		
Busch [1992]	88 %	43 %	51 %
de Dear et al. [1991]	78 %		
de Dear & Fountain [1994]			
"Dry"	76 %	61 %	
"Wet"	74 %	55 %	
Hindmarsh & Macpherson [1962]	93 %	62 %	
Howell & Kennedy [1979]	72 %	24 %	
Humphreys & Nicol [1970], Humphreys [1976]	95 %	50 %	
Paciuk [1989]	77 %	47 %	
Schiller et al. [1988a], Schiller & Arens [1988]			
Winter	82 %	41 %	53 %
Summer	84 %	43 %	52 %
Wong [1967]			
Summer	87 %	39 %	
Winter	68 %	32 %	
Newsham & Tiller [1995]	**87 %**	**51 %**	**70 %**

4.6 Regressing Thermal Sensation on Temperature

Many authors have used field study data to derive a regression of thermal sensation vote on room temperature with the goal of generating a predictive equation. Such an equation can then be used, at the very least, to derive T_n for the studied population. Table 19 shows the regression coefficients, along with several other relevant observed and derived parameters, for a number of field studies in office or office-like environments (for example, college lecture theatres have also been included). The regression coefficients stated in Table 19 all refer to an equation of the form:

$$TS = a + b \cdot T \tag{11}$$

Note that in some cases the thermal sensation response was made on the ASHRAE scale, and in others on a Bedford Scale[5]. Note further that the temperature parameter was variously: air temperature, operative temperature, environmental temperature, or some other composite temperature. However, in most cases, the authors (and others) have observed that the performance of the two response scales, and the various temperature parameters, are very similar [Auliciems & de Dear, 1986a and 1986b; Auliciems, 1977; Ballantyne et al., 1977; Boolualohr, 1989; Brager et al., 1994; Busch, 1990; Croome et al., 1992; de Dear & Auliciems, 1985; de Dear & Fountain, 1994; Fishman & Pimbert, 1982; Grivel & Barth, 1982; Hindmarsh & Macpherson, 1962; Kakhonen et al., 1990; McIntyre, 1978; Oseland, 1994; Palonen et al., 1993; Schiller et al., 1988b] and so it seems reasonable to present these various field studies side by side. To facilitate comparison, only studies that employed a seven point thermal sensation scale are presented in Table 19. In some studies certain of the values presented were not explicitly stated by the author. Where appropriate, we have used published data to derive approximate values for certain parameters.

[5] The Bedford Scale is another seven point scale, with the following descriptors: Much too warm, Too warm, Comfortably warm, Comfortable, Comfortably cool, Too cool, Much too cool. Whereas the ASHRAE scale deals solely with thermal sensation, the Bedford scale confounds thermal sensation and comfort.

Table 19. Regression coefficients for thermal sensation vs. temperature for various field studies. Other relevant parameters are also listed. Proportion of variance in thermal sensation vote accounted for by temperature (r^2) is only shown when the regression was done with individual data points, and not with binned data.

Study	Regression coeffs			Neutral temperature, T_n		Central category width	Mean TS	Mean environment parameters		Notes
	a	b	r^2	obs.	pred.	°C		T_{air}, °C	RH, %	
Auliciems & de Dear [1986a, 1986b], de Dear & Auliciems [1985]										T_n from Probit
Darwin "Buildup"	-9.65	0.40	0.27	24.1	25.3	2.3	-0.43	23.7±0.14	56	
Darwin "Dry"	-10.53	0.44	0.25	24.0	24.7	2.0	-0.16	23.3±0.07	47	
Brisbane				23.8	25.1	2.3	0.03	23.8±0.05		
Melbourne				22.6	24.8	3.7	0.25	23.4±0.11		
Auliciems [1977]										TS=Bedford
Adelaide	-4.56	0.22	0.11	20.6			-0.30±1.07	19.5±1.7		
Melbourne	-6.75	0.33	0.32	20.5			-0.04±1.22	20.4±2.1		
Armidale	-6.33	0.30	0.24	21.3			0.31±1.09	22.4±1.8		
Perth	-4.52	0.29	0.08	21.9			-0.47±1.18	19.6±1.5		
Brisbane	-5.03	0.22	0.20	23.1			-0.10±1.03	22.6±2.2		
Auliciems & Parlow [1975]							0.17±0.88			TS=Bedford
Ballantyne et al. [1977]										T_n from Probit
Summer				22.7				22.8		
Winter				21.3				20.7		
Gagge & Nevins [Berglund, 1979]	-12.10	0.48		25.2						
Boolualohr										
Winter			0.08				0.14±1.06	22.8±1.1	34.0±2.0	
Summer			0.10				-0.02±0.91	23.3±1.1	73.1±3.0	
Fall			0.27				0.63±1.12	23.5±1.0	36.9±14.6	
Brager et al. [1994]	-6.40	0.29		22.4	22.6					$T=T_{operative}$
Busch [1990]	-8.09	0.33	0.20	24.8		5.0				T=ET

Cena et al. [1990]									
Philadelphia							0.2±1.2	23.8±3.0		
Perth							1.2±1.3	27.2±2.8		
Croome et al. [1992]	-10.01	0.46	0.53	21.8	22.7			24.0	45.5	
de Dear et al. [1991]	-9.68	0.40	0.18	24.2			-0.34±1.2	22.9±1.3	55.5±7.6	T_n from Probit, $T=T_{operative}$
de Dear & Fountain [1994]										
"Dry"	-12.31	0.51	0.18	24.2			-0.4±1.1	23.3±0.9	51±9	T_n from Probit
"Wet"	-13.75	0.57	0.23	24.6		4.9	-0.3±1.1	23.6±1.0	56±6	
Fishman & Pimbert [1982]		0.24		22.0	22.6					$T=T_{globe}$
Grivel & Barth [1982]	-3.47	0.18	0.04	19.6			0.00	22.5±1.3	49±7	
Grivel & Barth [1980]							0.82	22.8		
Hindmarsh & Macpherson [1962]	-3.69	0.16	0.42				0.06±0.80	22.9±3.2		TS=Bedford
Howell & Kennedy [1979]							-0.59	23.2		
Humphreys & Nicol [1970], Humphreys [1976]		0.20		20.3		4.6	0.24			T_n from Probit, TS=Bedford
Kakhonen et al. [1990]	-7.68	0.36		21.1			0.66±0.63	22.9±1.4	30±3	
Markee White [1986]										
Summer				24.9				24.0±0.9	52±4	
Winter				23.4				22.8±0.8	29±8	
Oseland [1994]	-4.57	0.21	0.40	21.8			-0.5	20.7	41	$T=T_{operative}$
Paciuk [1989]		0.30	0.14	21.7	23.4		0.41±1.17	21.7±1.4	58±10	$T=T_{operative}$
Schiller et al. [1988a, 1988b]										$T=ET^*$
Winter	-7.20	0.33	0.09	22.0		3.3	0.18	22.8±1.2		
Summer	-7.04	0.31	0.13	22.6		3.8	0.23	23.3±1.3		
Wong [1967]										
Summer							-0.09	23.2		
Winter							0.11	21.2		
Newsham & Tiller [1995]	**-7.69**	**0.34**	**0.11**	**22.7**	**21.9**	**~3.3**	**0.01±1.00**	**22.7±1.0**	**28.3±8.6**	

The results of our field study, conducted using a new and original method for collecting participant responses (*ScreenSurvey*) compare very well with other field studies. The similarity to the results of the study of Schiller et al. [1988a, 1988b] is remarkable. Although Schiller et al, conducted their study in a very different climatic zone (San Francisco Bay area), the buildings studied were very similar to ours, being largely typical North American air-conditioned offices populated with professional/government workers. Schiller et al.'s study was arguably the most rigorously conducted study of its kind at the time, and their procedure was adopted as a model by ASHRAE and recently replicated by de Dear & Fountain [1994] in north-eastern Australia.

McIntyre [1978] performed separate regressions for field-gathered thermal sensation votes above and below the observed T_n. McIntyre found a steeper sloped regression line below T_n and concluded that the observed population was more sensitive to temperatures below T_n than to temperatures above T_n. Schiller et al. [1988a] found a similar result in their field study, and Berglund [1979] and Rohles et al. [1975] reported the same finding in laboratory studies. We also performed separate regressions of thermal sensation vote vs. indoor air temperature above and below the observed T_n (22.7 °C, determined from the regression of all thermal sensation votes on temperature):

$T_{air} < T_n$: slope = 0.33 (n = 762);
$T_{air} > T_n$: slope = 0.35 (n = 838).

Therefore, in our population, there was no substantial difference in sensitivity to temperature above and below T_n.

Mean thermal preference (McIntyre scale) was not recorded in Table 19 because it is not commonly reported in field studies. Schiller et al. [1998a] report a mean thermal preference vote of -0.09 in winter, and -0.26 in summer (s.d. ~ 0.68). This is consistent with our result of 0.06 ± 0.55, given that our mean thermal sensation was around 0.2 scale units lower than that reported by Schiller et al.

The proportion of variance in individual thermal sensation votes accounted for indoor air temperature in our study is small ($r^2 = 0.11$), but within the range of variance explained by temperature reported by other field studies. Even when we regress thermal sensation on a wider range of measured physical and personal parameters (clothing insulation, measured indoor air temperature, indoor relative humidity, outdoor air temperature, outdoor relative humidity, total horizontal solar radiation, vertical solar radiation on the relevant orientation, and forecast temperature), explained proportion of variance only rises to 0.14. Similar observations have been made by other authors. Grivel and Barth [1982] found an $r^2 = 0.04$ for thermal sensation vs. air temperature, which rose to $r^2 = 0.09$ when air velocity, clothing and metabolic rate were included in the regression. Schiller et al. [1988b] found an $r^2 = 0.10$ for thermal sensation vs. air temperature, which rose to $r^2 = 0.12$ when vapour pressure, air velocity, age, sex, clothing and metabolic rate were added as predictors. Paciuk [1989] found an $r^2 = 0.14$ for thermal sensation vs. operative temperature, and adding relative humidity, and clothing as predictors did not increase the proportion of variance in thermal sensation accounted for.

One reason why r^2 is so small is an unavoidable problem with the experimental design inherent in field studies. That is, in most offices, particularly air-conditioned offices, the range of temperatures to which the participants are exposed is small, compared to the range of temperatures which the human body can physiologically accommodate. A narrow stimulus range is a fundamental cause of low correlation [Howell & Kennedy, 1979; Markee White, 1986; McIntyre, 1978]. Nevertheless, we are faced with the fact that the traditional physical and personal parameters are not very good predictors of individual thermal comfort votes in the field. Schiller et al. [1988a] suggests that this highlights the importance of psychological parameters, and Cena et al. [1990] states that thermal comfort should be treated as a function of physical, emotional and social parameters.

A number of studies have attempted to quantify the importance of personality and other psychological factors in thermal comfort ratings. For example, Auliciems & Parlow [1975] found that individual ratings of "Impulsivity" and "Social Recognition" together accounted for 15 % of the variance in thermal sensation vote. Although not quantified, Baillie et al. [1988] found significant correlations between thermal discomfort and "satisfaction with workplace" and "pleasantness of office environment appearance". Baker and Standeven [1995] suggest that tolerance of thermal discomfort is higher when the cause is understood[6] (e.g., a sunbeam or a breeze from an open window) than when the cause is not understood (a distant, hidden, malfunctioning HVAC system). Carlton-Foss and Rohles [1982] found that the personality factor "self-definition" accounted for 15 % of the variance in thermal comfort data for people expressing thermal comfort, and 37 % of the variance for those expressing thermal discomfort. Howell & Stramler [1981] found a maximum $r^2 = 0.17$ with non-psychological predictors (temperature, relative humidity, clothing, age, sex), that rose to $r^2 = 0.62$ when psychological parameters were included. Howell and Kennedy report that temperature, relative humidity and clothing accounted for only 8 % of the variance in thermal sensation vote, with "perceived temperature" and "perceived coldnaturedness" accounting for another 31 %. On the other hand, Griffiths & McIntyre [1973] found "introvert/extrovert" and "neuroticism" ratings to be uncorrelated with thermal comfort, and McIntyre [1978] found no effect with ratings on the Eysenck Personality Inventory.

As well as psychological variables, there are some aspects of the physical environment, not traditionally considered in field studies, that have been reported to be correlated to thermal comfort ratings. For example, Paciuk [1989] found that higher perceived control enhanced satisfaction with the thermal environment. Laboratory studies have also demonstrated a significant effect due to furnishings, decor, lamp type, occupancy density, and ceiling height [Rohles 1980; Rohles et al., 1981; Rohles, 1983].

[6] Perhaps "understood" could be replaced with "not caused by someone else"?

It is clear that if we are to improve prediction of individual thermal sensation votes we will have to consider many more parameters that the physical, personal and demographic parameters traditionally considered. Many of these psychological and other non-traditional parameters may also change significantly with time. Therefore a longitudinal study using a flexible tool like *ScreenSurvey* might prove useful in future studies addressing a wider range of parameters.

4.7 Desirability of Thermal Neutrality

Regressing observed thermal sensation votes on temperature allows us to derive T_n for the studied population, the temperature at which the mean thermal sensation on the ASHRAE scale is zero, or 'neutral'. Given the physiology theory that is the basis of the Fanger equation, thermal neutrality, a state in which there is no net heat exchange between the body and the environment, was assumed to be the ideal thermal state. However, Brager et al. [1994] suggested a preferred state that deviates from neutral depending on the season. Common sense suggests that in a cold winter, for example, people do not dream of being neutral, they probably desire to be warm. Similarly, in a hot summer climate, the desired state is probably cooler than neutral. Several other authors have made the same observation [Busch, 1992; Humphreys, 1976; Markee White, 1986; McIntyre, 1978; Oseland & Humphreys, 1993; Rohles, 1980].

Because our study did not cover more than one season, our ability to examine this issue is limited. Of 786 votes of 'neutral' on the ASHRAE scale, 4 preferred to be cooler on the McIntyre scale, 762 preferred no change, and 20 preferred to be warmer. Thus, there was a slight preference warmer temperatures for those participants reporting thermal neutrality during a period when the outdoor climate was cold. Still, 97 % expressed a preference for no change in temperature when reporting thermal neutrality, which seems to support the Fanger theory, that thermal neutrality is an ideal state, at least for our studied population in air-conditioned office buildings.

4.8 Comparison with PMV

In Section 4.2 we noted that the data from our study seemed in good agreement with the ASHRAE and ISO Standards for thermal comfort. These Standards are based on Fanger's theory. Figure 33 compares the mean observed ASHRAE votes vs. temperature and PMV vs. temperature, given the assumptions and uncertainties described in Section 3.10. Since PMV predicts the mean response of large populations, it is appropriate to make comparisons between the mean responses of grouped data, and not between the responses of individuals at specific times.

The mean response data from our study fits the PMV values quite well. The fit around the neutral temperature (temperature at which mean thermal sensation = 0) is close, with T_n within 1 °C. However, the field data shows a tendency to diverge toward more extreme responses both above and below T_n, indicating that our participants were more sensitive to temperature deviations away from T_n than would have been predicted by Fanger's theory.

Our comparison of thermal sensation votes vs. predicted mean vote is clouded by the assumptions and estimations made for input variables to the PMV equation which were not measured. Perhaps chief amongst these is the estimation of clothing insulation made from clothing reported on the clothing checklist question (Appendix A). A good estimation of clothing insulation is extremely important to the prediction of PMV since the PMV equation is so sensitive to clothing; a change in clothing insulation of only 0.2 clo leads to a change in T_n of around 1 °C in a typical office situation. As noted in Section 3.4, clothing insulation is a function not only of the garment being worn, but also its fabric, cut, weave, and the posture of the person wearing it. While these factors can be accurately accounted for in laboratory studies of clothed thermal manikins, even an extensive clothing questionnaire (and the one used in our study was admittedly crude) would have trouble capturing the necessary information in a practical way in the field. However, provided we use PMV in the manner for which it was intended -- that is, for predicting the mean thermal sensation of a large group of people, and not for individuals -- errors in clothing insulation estimation are probably averaged out over the group.

Another concern is that the clothing insulation value we used as input to the PMV equation came from a question that asked participants what clothing they were wearing when they arrived for work, and not what clothing they were wearing at the time they answered the questionnaire. We made this choice because we wanted to correlate clothing chosen in the morning with outdoor climate[7]. However, this choice did not facilitate comparisons between reported thermal sensation and PMV. Although for the majority of participants on the majority of occasions clothing did not change between arrival at work and time of voting, there might have been a significant minority for whom clothing changes were important (Figure 25).

The question of whether the slope of the regression of reported thermal sensation vs. temperature should be steeper or shallower than the slope of PMV vs. temperature is an interesting one. If Fanger's comfort equation applies in the field, and if the inputs to the equation can be accurately defined in the field, then the two slopes should be identical. Boonlualohr [1989], Howell & Kennedy [1979], Humphreys [1976, 1994], Brager & Arens [1988] suggest that in the field people's ability to alter their clothing to improve their thermal comfort will skew thermal sensation votes towards neutral. As these clothing modifications will probably not be captured for input to the PMV equation, the slope of the observed data regression line should be lower than that of the PMV regression line. On the other hand, Boonlualohr [1989] proposes that there might be a context effect: people might be more critical of temperature changes in their office than in the laboratory because they expect to be comfortable in their offices; given this scenario the slope of the regression line of reported thermal sensation should be higher than that of the PMV regression line. The data from field studies falls into both camps. Fishman & Pimbert [1982], and Kahkonen et al. [1990] concur with our finding: the slope of the observed data regression line is higher than that of the PMV regression line; Oseland

[7] Specifically we correlated clothing with forecast temperature, the correlation was significant but not substantive: $r = -0.065$, $n = 1254$, $p < 0.03$.

[1994] found the opposite, and Paciuk [1989] found the slopes to be about the same.

There is clearly a discrepancy between field measurements and predictions based on laboratory studies. However, the body of evidence is not yet large enough to conclude whether the discrepancy is due inaccuracies in field measured parameters (particularly clothing insulation and metabolic rate) input to the Fanger model, or to shortcomings in the Fanger model itself. Systematic inaccuracies in the measurement of clothing and metabolic rate tend to affect T_n rather than significantly affecting the slope of the regression line [Oseland, 1992; Brager et al., 1994]. Therefore, inaccuracies in input parameters affecting the slope of the regression line are more likely to be behavioral in nature, that is, dependent on transient factors. But, as noted above, these behavioral effects will likely act to make the slope of the regression line of the observed data less than the slope of the PMV regression line. Yet, the majority of studies thus far, including ours, find a steeper regression slope for the field observations. This fact tends to support the importance of the proposed context effect, but more field study data is required to confirm this tendency.

4.9 Clothing and Clothing Modification

Figure 42 shows the weekly mean clothing insulation value for each sex. There was no statistically significant change in clothing insulation worn between the first and second halves of the study for either sex (though differences did approach significance; males: $p = 0.09$, females: $p = 0.07$). The outdoor temperature over the study period dropped by around 20 °C over the study period (Figure 14(a)), with little apparent affect on mean clothing worn. This suggests that the clothing the participants wore to the office was chosen purely for the expected indoor thermal environment, and in cold outdoor climates is supplemented by clothing worn only outdoors.

Note, our finding that females tend to wear less clothing than males is consistent with other studies in office or office-like environments (see Table 20).

Interestingly, the clothing insulation reported in our study is less than that assumed in the Standards (and in modeling studies) for winter in North American Office buildings. The assumption in the Standards is 0.9 clo, whereas the occupants in our study reported an average of 0.78 clo (though remember the major assumptions and simplifications in deriving this value). This finding is consistent with other field studies conducted in North America. It is apparent the Standards may need revising in this regard. Note that the mean clothing worn in our study in the Ottawa winter is significantly higher than that worn in both summer and winter in office buildings in the much warmer climate of Northern California [Schiller et al., 1988a]. So although there was little effect of changes in the local Ottawa climate on clothing insulation worn, there might be an effect due to climatic zone.

Table 20. Mean clothing insulation for all participants, and broken down by sex, as reported by various field studies.

Field Study	Mean Clothing Insulation, clo		
	All	Males	Females
Auliciems & de Dear [1986a, 1986b]			
Darwin "Buildup"	0.43	0.46±0.10	0.41±0.11
Darwin "Dry"	0.49	0.52±0.10	0.47±0.14
Brisbane	0.48		
Melbourne	0.55		
Baillie et al. [1988]	0.63±0.12		
Ballantyne et al. [1977]			
Summer	0.67	0.69	0.60
Winter	1.03	1.07	0.91
Gagge & Nevins [in Berglund, 1979]	0.85		
Boolualohr [1989]			
Winter	0.66±0.15		
Summer	0.48±0.09		
Fall	0.67±0.17		
Busch [1992]	0.56±0.12		
Cena et al. [1990]			
Philadelphia	0.60±0.10		
Perth	0.37±0.05		
de Dear et al. [1991]	0.44±0.10		
de Dear & Fountain [1994]			
Dry	0.54±0.19	0.52±0.17	0.55±0.20
Wet	0.44±0.13	0.45±0.12	0.44±0.13
Fishman & Pimbert [1982]		0.82	0.64
Griffiths & McIntyre [1974]	0.74±0.10		
Grivel & Barth [1982]	0.76±0.19		
Grivel & Barth [1980]	0.78	0.87	0.73
Howell & Stramler [1981]	0.68		
Kahkonen et al. [1990]	0.63±0.10		
Markee White [1986]			
Summer	0.60±0.11	0.61	0.59
Fall	0.76±0.17	0.78	0.74
Winter	0.81±0.17	0.82	0.80
Spring	0.69±0.15	0.68	0.70
Oseland [1994]	0.8		
Paciuk [1989]	0.66±0.12	0.69±0.13	0.64±0.12
Schiller et al. [1988a]			
Winter	0.58	0.62±0.12	0.56±0.14
Summer	0.52	0.57±0.08	0.49±0.13
Newsham & Tiller [1995]	**0.78±0.21**	**0.80±0.21**	**0.74±0.22**

The bimodality of the reported clothing insulation shown in Figure 26 may be due to unofficial dress codes at the sites. Although none of the sites had official dress codes, it was common for managers and other more senior staff to wear jackets and ties/scarves, whereas more junior staff tended to dress less formally. Thus the peak at around 1 clo may be due to clothing reports from more senior staff, and the peak at around 0.7 clo to more junior staff. However, because participants were not explicitly asked about their seniority, we cannot investigate this hypothesis any further.

Figure 25 shows that 14.7 % or participants had modified their clothing in the hour prior to the questionnaire appearing. This modification was presumably made to improve thermal comfort. In the context of trying to produce a thermal environment dissatisfactory to only 20 % of occupants (according to ANSI/ASHRAE and ISO standards), the fact that 14.7 % used clothing modification to achieve improved thermal comfort becomes significant. Clothing modification may be an important mechanism for meeting thermal comfort standards. Though it is likely that in environments with strict dress codes or other informal social conventions, clothing modifications will be constrained [Humphreys, 1994; Markee White 1986; Nicol & Humphreys, 1973], and thus thermal comfort standards harder to satisfy.

The level of clothing modification we observed was substantially higher than that observed by Baker & Standeven [1995]. In their field study, participants reported clothing modification during 7.2 % of observed hours. Baker & Standeven's study was carried out during the cooling season in Athens when the mean room temperature was 27.8 °C. A possible explanation for the low rate of clothing modification compared to our study is that, because of the high temperatures, participants in Athens arrived at work wearing very light clothing ensembles. Their potential modifications would be thus be limited, principally to adding clothing, removing clothing would likely be socially unacceptable. Wyon & Holmberg [1973] found small but significant changes in clothing insulation worn by schoolchildren from hour to hour. Humphreys [1985] did not observe significant clothing changes during a day, but the minimum clothing change considered was a whole layer, Humphreys did not record the minor changes that we recorded in our study.

4.10 Longitudinal Data

Humphreys well-known meta-analysis [1978] found a strong relationship between monthly mean outdoor air temperature and thermal comfort indoors, even in air-conditioned buildings ($r^2 = 0.5$ to 0.6). However, studies carried out between seasons in the same location have found little variation in thermal comfort data that could not be explained by seasonal clothing changes [Auliciems & de Dear, 1986; Fishman & Pimbert, 1982; Markee White, 1986; Schiller et al., 1988a; Hindmarsh & Macpherson, 1962 is an exception]. In our study, the tendency for mean ASHRAE vote to vary with week (Figure 37) is statistically significant, but small. Nevertheless, the small change is in the expected direction. Although our study covered only 10 weeks, and could not be strictly termed a study between seasons, as Figure 14(a) shows, outdoor air temperature changed substantially (by about 20 °C) over the period of the study. Figures 37 and 14(a) have some trends in common: Mean ASHRAE vote is above '0' up until the week of the 25th November (with the obvious exception of the week of 4th November), mean outdoor air temperature is above 0 °C for the same period; for the rest of the study period the mean ASHRAE vote is below '0' and the mean outdoor air temperature below 0 °C. Nevertheless, the change in mean ASHRAE vote over the study period is much smaller than previous studies suggested, for such a large change in outdoor temperature. However, previous studies have generally been conducted at sites in much warmer climates than that prevailing in our study. It is possible that sensitivity to outdoor climate is reduced as the climate gets colder.

A number of laboratory studies have found no effect of time of day on thermal sensation [for example: Fanger et al., 1973; Griffiths & McIntyre, 1973; Rohles, 1980]. In these studies the thermal conditions were maintained constant, or were manipulated toward thermal neutrality by the participants; what they were essentially looking for was whether diurnal changes in human internal body temperature affected thermal preference [Boolualohr, 1989; Hansen, 1990; Purcell & Thorne, 1987]. In a field study, the effect of time of day is confounded by many other factors that also change systematically with time: solar radiation, work schedule, caffeine intake, for example. However, from a practical point of view, systematic variations in thermal comfort with time could have important implications for building controls technology, whatever their cause. For example, if occupants are consistently warmer than neutral during winter afternoons, it may be possible to reduce the heating setpoint to save energy and improve thermal comfort (bring the mean vote closer to neutral). Figure 38 shows mean ASHRAE vote vs. time of day. Variations with time are statistically significant, but small. Nevertheless, the small variations are in the expected direction. We would expect a tendency towards warmer indoor climates in the afternoon, as effects of any nighttime setback wear off, and as solar and internal gains accumulate. Time of day effects in other field studies have also been small. Fishman & Pimbert [1982] found no significant difference in T_n between morning and afternoon, and Black [1954] found no consistent difference with time of day when controlling only for the effect of temperature.

Although time of day itself appears to have little effect on thermal sensation, it is possible that certain time-dependent parameters do have an effect. One such parameter we would expect to be important is solar gain. To pursue the effects of solar gain on thermal sensation we plotted the mean ASHRAE vote vs. time (morning or afternoon) for each orientation at Site 3 in Figure 39, and for the other two sites (each of a single orientation) in Figures 40 and 41. Differences between morning and afternoon at Site 3 are small and are not statistically significant, with the exception of the south orientation where the difference is 0.46 on the ASHRAE scale. Nevertheless, the differences in the mean response are in the expected directions: the east orientation is warmer than neutral during the morning, and on the cold side of neutral during the afternoon; whereas the opposite tendency is apparent for the west and south orientations. The same trends for the west and south orientations are exhibited at Site 1 and Site 2 respectively. Though in these cases it is the west orientation (Site 1) where the difference between morning and afternoon is statistically significant, and not small (0.59 on the ASHRAE scale). These results suggest that solar gain plays a role in determining thermal comfort, and that this relationship would be worth pursuing in a more focused study.

Littlefair & Lindsay [1992] concluded that glare and not solar gain was the main stimulus for blind use; Rubin et al. [1978] concluded similarly. Figure 36 shows that in our study the ordering of mean blind positions across orientations follows what might be expected from considerations of glare. That is, north-east-west-south in the order of least blind use to most blind use. Rea [1984] found this ordering too (mean occlusion, south: 0.35; west: 0.38; east: 0.50), as did Rubin et al. [1978] (south: 0.24; north: 0.49).

Note that the prior work on blind use cited here was based on direct measurement of blind position (through photography of building facades typically) rather than relying on occupant reporting.

4.11 Other Demographic Groupings Data

Table 7 shows there was a difference in the mean indoor air temperature between sites of up to 0.9 °C. This small difference may be due to the fact that all sites were air-conditioned Canadian federal government buildings likely following similar building management guidelines. It is interesting to note that the mean temperature at Site 3 was statistically significantly different from the mean temperatures at the other sites; Sites 1, 2 and 4 were all on the same campus with the same team of building managers, whereas Site 3 was geographically separate, part of a different federal government department, and had a different team of building managers. The difference between the mean indoor air temperature at Sites 1 and 2 was also statistically significant. Though these two sites were on the same campus, they differed in orientation.

Comparing Tables 7 and 9 we see that although Site 2 had the highest mean indoor air temperature, it had the lowest mean ASHRAE vote.

Table 11 shows that on average females felt slightly cooler than males; the difference in the means is small (0.2 on the ASHRAE scale) but statistically significant. Many other field studies have looked at thermal sensation by sex: Grivel & Barth [1982] report a difference in mean thermal sensation between males and females of 0.36 units, with males feeling warmer; Grivel & Barth [1980] report a difference of 0.17 units, but in this case females were warmer; Humphreys & Nicol [1970] reported a small but significant difference of 0.23 units, with females again feeling warmer; Wong [1967] found that males felt warmer, but the difference was only 0.10 units in Summer and 0.03 units in Winter; and Boyce [1974] found a difference in median thermal sensation of 1 unit, with females feeling cooler. Other authors report results in terms of T_n: Ballantyne et al. [1977] found T_n for males 1.7°C higher than that for females; Black [1954] found T_n for males 0.6°C lower than for females; Fishman & Pimbert [1982] found T_n for males 0.3 °C higher. Yet more studies report differences in terms of sensitivity to temperature: Black & Milroy [1966] reported that women were more sensitive to cooler temperatures; Humphreys [1976] reported very small differences between the sexes, with women feeling slightly cooler, and being more sensitive to temperature changes; Busch [1990] performed separate regressions of thermal sensation vote vs. temperature for males and females and found the regression coefficient for females to be higher, indicating greater sensitivity to temperature change; McIntyre [1978] also found a higher regression coefficient for females, but noted that the difference was small; in our study, we found a small difference in regression coefficient with sex, but with males having a slightly larger slope (females: 0.34, n = 712; males: 0.37, n = 801). The conclusion of other field studies is that sex is not correlated with thermal sensation [Howell & Stramler, 1981; Markee White, 1986].

To summarize, differences in thermal sensation between males and females are likely non-existent, or small, but there is little consensus as to which sex generally feels warmer or cooler (though a slight majority of studies report women being more sensitive to changes in temperature). An interesting question is whether the small differences that do exist are due fundamental physiological differences between the sexes, or due to systematic differences in other parameters already described by Fanger's equation. Clothing differences are most commonly cited as an explanation for thermal comfort differences. In our study we observed that females wore less clothing insulation than males (Table 15). This difference in clothing may account for a large part of the difference in mean ASHRAE vote, indicating that the differences between male and female thermal comfort are behavioural rather than physiological. Howell & Kennedy [1979] raise the possibility of psychological differences explaining differences in thermal sensation. They reported a weak correlation between sex and thermal sensation that may be explained by differences in "perceived coldnaturedness".

One laboratory study [Collins & Hoinville, 1980] reported no statistically significant difference in thermal sensation vote with age. Collins & Hoinville's study was conducted for constant metabolic rates, but they did suggest that in field studies older people would prefer higher temperatures because they tend to be more sedentary. Grivel & Barth [1980] did indeed find that young people tended to suffer more from warmth discomfort, though no link with activity level was made. On the other hand, a field study by Markee White [1986] reported no significant relationship between age and thermal sensation. We also found no statistically significant relationship between age and thermal sensation (see Table 12). One possibility is that older people were compensating for lower activity level by wearing more clothing. However, Table 21 shows that there were no significant differences in mean clothing worn by age, except between age groups 20 - 29 and 40 - 49, and this difference is small, only 0.07 clo.

Table 21. Mean clothing insulation by age. A lower-case letter in the ANOVA row indicates the mean clothing insulation is significantly different at the 5 % level from the mean clothing insulation with the same letter in upper case, as determined by an analysis of variance.

	Age				
	20 - 29	30 - 39	40 - 49	50 - 59	60 - 69
n	254	400	434	75	12
mean clo	0.73	0.78	0.80	0.75	0.70
s.d.	0.21	0.20	0.23	0.19	0.13
ANOVA	A		a		

Figure 14 shows the mean response to the ASHRAE thermal sensation question for each orientation at Site 3. The differences between the orientations are small (no larger than 0.18 on the ASHRAE scale) and none of the differences in the means are statistically significant. Nevertheless, the differences in mean ASHRAE vote are in the expected direction; that is, occupants of south-facing offices tend to be the warmest, and occupants of north-facing offices tend to be the coolest. The mean ASHRAE votes by orientation correlate quite well with the mean indoor air temperature for each orientation (Table 8). The obvious exception is the East orientation, which had the highest temperature, but a mean vote lower than both South and West orientations. Several other field studies have reported thermal satisfaction differences with orientation. Baillie et al., [1988] found mean temperatures in south-facing offices 1.7 °C higher than in north-facing offices, with a corresponding difference in mean thermal sensation vote of 1.6 units (9 point scale). Langdon [1966] found thermal satisfaction in north-facing offices during a UK summer substantially higher than in south-facing offices, presumably because of lower solar gain and overheating. Boonlualohr [1989] looked at differences in mean thermal sensation vote between perimeter and interior workstations. A significant difference of 0.9 units on the ASHRAE scale was found for Winter and Fall. But in Summer the difference was not significant.

4.12 Final Evaluation Questionnaire

The principal aim of the final evaluation questionnaire was to evaluate the acceptability to participants of the computer-based questionnaire method, and to solicit suggestions for improvements. Figures 43 to 48 generally indicate that the respondents found the *ScreenSurvey* method acceptable. While no direct comparisons to paper-based questionnaires were made, it seems unlikely that a paper-based questionnaire, especially one administered as frequently as the questionnaire was administered in our study, would have produced the same low ratings of distraction. Cena et al. [1990] suggest that minimum disruption is an important consideration because normal work practices are maintained and the results are likely more valid. Some have argued [e.g., Fanger, 1992] that the stress of being interviewed can increase metabolic rate and thus bias thermal sensation ratings; the computer-based questionnaire, which eliminates the interviewer-interviewee relationship, might serve to reduce these biases.

Neither the frequency of questionnaire administration nor the number of questions asked at each administration were judged excessive. This finding will serve as a useful guideline in future studies.

The Final Evaluation Questionnaire offered the participants the chance to make other comments. Their comments generally focused on the composition of the questions themselves rather than on the method of questionnaire administration. Many respondents criticized the clothing checklist. Principally, their criticisms were:

1. The inclusion of items of underwear on the checklist;

2. The presentation of a checklist combining male and female clothing items.

Many prior thermal comfort studies have included items of underwear on their clothing checklists [e.g., Schiller et al., 1988b]. Clothing insulation has a large influence on the prediction of thermal comfort (PMV), and it is very important to make as good an estimation of clothing insulation as possible. However, many participants felt this question was overly personal, and reluctance to report underwear may have made some participants reluctant to answer the questionnaire, and thus reduced the overall response rate. In estimating clothing insulation from the reported checklist items, we assumed some underwear if none was reported (Section 3.4). In future studies it might be a good idea to assume a certain clothing insulation for underwear, and only include outerwear items on a clothing checklist.

The presentation of a combined male and female clothing checklist was a limitation of *ScreenSurvey*. *ScreenSurvey* lacked the ability to present questions based on the responses to prior questions, i.e., presenting a male clothing checklist to participants identifying themselves as male, and a female clothing checklist to participants identifying themselves as female.

A similar limitation led to participants who had indicated that they had no windows being asked the question regarding window blinds. Although these participants were instructed to Cancel this question when it appeared, it was nevertheless identified as a source of annoyance.

4.13 Questionnaire Success

Given the results of the Final Evaluation Questionnaire (Section 3.13) and the measures of response rate and response time (Section 3.3), we can conclude that *ScreenSurvey* was successful in achieving its goals of being an effective way of administering questionnaires. Participants indicated that the method was not distracting, and that the number of questions they were asked, and the frequency with which the questions appeared, were not excessive. This is supported by our direct measurements of the time taken to complete the questions each time they appeared (an average of 45 seconds for the five questions). The response rate was high (an average of 29 responses from each participant) indicating that this method was successful in eliciting responses to the same questions administered many times during a given time period.

Further, as demonstrated throughout Section 4, the results of our study were consistent with the results of other field studies of thermal comfort conducted using more traditional methods, as well as obtaining additional data (longitudinal) which would have been extremely hard to gather using traditional methods.

5.0 Conclusions

This section presents the major conclusions of the study. Remember, this study had two aims: to field test *ScreenSurvey* to assess its usefulness as a survey tool; and, to examine the relationship between the thermal environment in open-plan office spaces, and the thermal comfort of its occupants. The conclusions are presented according to these aims. Finally, the enhancements subsequently made to *ScreenSurvey* following the experiences of this study are described.

5.1 Success of Method

ScreenSurvey proved to be a useful tool for administering questionnaires, particularly in longitudinal studies. This conclusion is based on the following findings:

- The vast majority of participants (89 %) said that the computer-based questionnaire did not distract them significantly from their work, only 6 % said the questionnaire appeared too often, and 19 % said the number of questions asked each time was too many.

- The five thermal comfort-related questions took an average of only 45 seconds to answer.

- Each participant answered the questions an average of 29 times; the questions were presented a maximum of 100 times. (Observation of response rate also indicates that our respondents were away from their desks 30 - 40 % of the studied period).

- The results of the thermal comfort study were consistent with the results of prior field studies of thermal comfort conducted using more traditional survey methods.

5.2 Aggregate Frequency Data

- Thermal sensation votes were normally distributed. 51 % of votes were in the central category ('neutral'); 87 % were in the central three categories ('slightly cool' to 'slightly warm').

- Thermal preference votes were normally distributed. 70 % of votes were in the central category ('no change').

- The mean clothing insulation worn was 0.78 clo. The frequency distribution of clothing insulation was bimodal. The first peak occurred for a clothing insulation of 0.61 to 0.7 clo, the second at 1.01 to 1.1 clo. However, accurate evaluation of clothing insulation was difficult.

- Within-day clothing modifications were not common, with only 15 % of respondents indicating that they modified their clothing during the hour before questionnaire administration. Nevertheless, in the context of trying to achieve no more than 20 % dissatisfaction with the thermal environment, the fact that up to 15 % of respondents used clothing changes to improve thermal comfort becomes important. Respondents removing clothing outweighed those adding clothing 2:1.

- The mean blind position was 0.54. The frequency distribution was bimodal at responses indicating blinds fully open (1) or fully closed (0).

5.3 Thermal Sensation Correlations and Regressions

- The order in which the ASHRAE thermal sensation and McIntyre thermal preference questions were asked had no effect on thermal sensation vote.

- An individual's frequency of response and their ASHRAE thermal sensation vote were not significantly correlated, which allowed us to group data for statistical analysis.

- Significant correlations (at the 0.01 level) in the expected directions were found between ASHRAE thermal sensation responses and prevailing indoor air temperature ($r = 0.335$), outdoor air temperature ($r = 0.122$), and total horizontal solar radiation ($r = 0.165$); ASHRAE vote was also significantly correlated with clothing change ($r = -0.203$). ASHRAE vote was significantly correlated with outdoor humidity ($r = -0.123$), but in a direction opposite to that expected. As would be expected, ASHRAE and McIntyre votes were significantly negatively correlated ($r = -0.712$).

- 11 % of the variance in individual ASHRAE thermal sensation votes was explained by indoor air temperature ($r^2 = 0.11$). A multiple regression of the ASHRAE thermal sensation votes with the following variables: clothing insulation, measured indoor air temperature, indoor relative humidity, outdoor air temperature, outdoor relative humidity, total horizontal solar radiation, calculated vertical solar radiation on the relevant orientation, and outdoor air temperature at 8 am each morning did not significantly increase r^2 over using indoor air temperature alone ($r^2 = 0.14$). In other words, only 14 % of the variability in individual thermal sensation votes could be predicted by commonly measured physical and personal variables. This result indicates potential for further investigation of the factors which effect individual thermal comfort votes.

- The slope of the regression line for thermal sensation votes made at temperatures above the neutral temperature (22.7 °C) was not significantly different from the slope of the regression line for thermal sensation votes made at temperatures above the neutral temperature.

- We found indoor air temperature was a good predictor of mean ASHRAE votes from many different subjects at many different times ($r^2 = 0.77$). But this raises the question of how useful a prediction of mean vote is when the individual votes making up the mean are not well predicted by air temperature.

5.4 Neutral and Preferred Temperatures

- A neutral temperature (T_n) of 22.3 - 22.9 °C was derived, depending on the regression equation used. Whereas the temperature bin with the highest frequency of 'neutral' responses to the ASHRAE thermal sensation question was 23 - 24 °C.

- A preferred temperature (T_p) of 22.7 - 23.1 °C was derived, depending on the regression equation used. Whereas the temperature bin with the highest frequency of 'no change' responses to the McIntyre thermal preference question was 23 - 24 °C.

- We found no evidence to indicate that "neutral" was not the preferred thermal state among our respondents.

5.5 Comparison with PMV

- The measured data on mean thermal sensation compare quite well with PMV around the neutral temperature. However, the PMV vs. indoor air temperature curve has a lower gradient than the measured thermal sensation data. This indicates that the respondents were more sensitive to the indoor air temperature than Fanger's thermal comfort equation would suggest.

5.6 Differences between Demographic Groupings

- There was a small but significant difference between the mean response to the ASHRAE thermal sensation question at each site. Although the distribution of observations at Sites 2 and 3 was normal, at Site 1 the data was skewed towards the warm responses.

- There was a small but significant difference between the mean response to the ASHRAE thermal sensation question for each sex, males on average feeling warmer than females.

- There was no significant difference in thermal sensation with age of participant.

- The was no significant difference between the mean response to the ASHRAE thermal sensation question for each orientation. However, the means did vary in the expected direction: those respondents in south- and west-facing offices feeling warmest, and those in north-facing offices feeling coolest.

- There was a small but significant difference between the clothing insulation adopted by each of the sexes.

- There was no significant difference in clothing insulation with age of respondent.

- The mean level of clothing insulation worn by participants was lower than that assumed by prevailing comfort standards, though it was higher than that reported in other field studies in warmer climates.

- There was a significant difference in mean blind position between sites, independent of orientation. There was also a significant difference in mean blind position between some orientations at the same site consistent with considerations of glare and solar gain; blinds were drawn most in south- and west-facing offices, least north- and east-facing offices.

5.7 Longitudinal Response/Comfort Data

- The mean response to the ASHRAE thermal sensation question varied little from week to week despite a dramatic change in outdoor climate over the period of the study.

- The mean response to the ASHRAE thermal sensation question varied little from hour to hour. However, when the data were sub-divided by orientation variations with time of day were revealed. Although the differences were, for the most part, insignificant, they were in the expected direction. The mean response for the east orientation was warmer than neutral for mid-to-late morning, and on the cold side of neutral during the afternoon. The opposite tendency was shown for the west orientation.

- There was no substantial change in mean clothing insulation worn indoors from week to week despite a dramatic change in outdoor climate over the period of the study.

5.8 Comparison of Frequency Data with Thermal Comfort Standards

- 87 % of responses to the ASHRAE thermal sensation question were within the central three categories ('slightly cool' to 'slightly warm'). This indicates that, according to ANSI/ASHRAE and ISO standards, the sites exhibited acceptable thermal comfort.

- 89 % of the observed temperatures were within the temperature limits suggested by the Standards. When the observed temperature was within the suggested limits, only 10 % of the thermal sensation votes were outside the central three categories of the ASHRAE thermal sensation scale. This is precisely the goal criterion from which the temperature limits were derived. Therefore, our observations in the field seem to support Fanger's thermal comfort model on which the Standards were based.

5.9 *ScreenSurvey* Development

Given the success of *ScreenSurvey* as a survey method, and as a direct result of our experiences in this study, and comments we received from the study participants, we decided that further development of *ScreenSurvey* to improve its utility was warranted. New features are detailed below:

- Development of a new program (*FormBuilder*) to create question screens that makes full use of Windows™ display features. Objects can be positioned anywhere on the screen, colour and size of objects can be varied, the size of the display window can be varied.

- Graphics objects (BMP, WMF, ICO formats) can be displayed on the question screens. These images can be sized, and can be used to illustrate the question, as descriptors, or as custom backgrounds.

- Command buttons can be customized and placed on the question screens. As well as the usual OK and Cancel functions, they can initiate further question screens, or execute other programs. This latter feature allows, for example, sound or video clips to be attached to question screens.

- A fourth response type, open-ended text entry, has been added.

- More than one question and response type can be included on a single question screen.

- Some branching capability has been added. That is, the experimenter can specify that certain questions will be asked only if specific conditions are true. These conditions are based on the responses to the demographic-type questions. This feature can be used, for example, to ensure that participants identifying themselves as male receive a clothing checklist aimed specifically at males.

- The participant has the ability to initiate a questionnaire on demand. For example, this feature allows the participant to register an opinion related to a specific event (e.g., a sudden increase in temperature) at the time of the event, instead of having to wait until the next questionnaire scheduled by the experimenter.

- A utility which converts the data files directly into spreadsheet format has been developed. This utility provides for easier date analysis.

Examples of question screens created using the new *FormBuilder* are shown in Appendix D.

6.0 References

Allen, M. A.; Fischer, G. J. 1978. Ambient temperature effects on paired associate learning. *Ergonomics*, **21** (2), pp. 95 - 101.

ANSI/ASHRAE. 1992. Thermal Environmental Conditions for Human Occupancy. ANSI/ASHRAE 55-1992 Standard. American Society of Heating, Refrigerating and Air-Conditioning Engineers (Atlanta, USA).

Auliciems, A. 1977. Thermal comfort criteria for indoor design temperatures in the Australian winter. *Architectural Science Review* (Dec.), pp. 86 - 90.

Auliciems, A.; de Dear, R. 1986a. Airconditioning in Australia I - human thermal factors. *Architectural Science Review*, **29** (Sept.), pp. 67 - 75.

Auliciems, A.; de Dear, R. 1986b. Air conditioning in a tropical climate: impacts upon European residents in Darwin, Australia. *International Journal of Biometeorology*, **30** (3), pp. 259 - 282.

Auliciems, A.; Parlow, J. 1975. Thermal comfort and personality. *Building Services Engineer*, **43** (Aug.), pp. 94 - 97.

Baillie, A. P.; Griffiths, I. D.; Huber, J. W. 1988. Thermal Comfort Assessment: A New Approach to Comfort Criteria in Buildings. ETSU Report No. S-1177.

Baker, N.; Standeven, M. 1995. Adaptive opportunity as a comfort parameter. Workplace and Comfort Forum, Royal Institute of British Architects (London).

Ballantyne, E. R.; Hill, R. K.; Spencer, J. W. 1977. Probit analysis of thermal sensation assessments. *International Journal of Biometeorology*, **21** (1), pp. 29 - 43.

Barakat, S. A. 1983. Comparison of models for calculating solar radiation on tilted surfaces. Proceedings of 4th International Symposium on the Use of Computers for Environmental Engineering Related to Buildings (Tokyo), pp. 317 - 322.

Berglund, L. G. 1979. Thermal acceptability. *ASHRAE Transactions*, **85** (2), pp. 825 - 834.

Black, F. W. 1954. Desirable temperatures in offices. *Journal of the Institution of Heating and Ventilating Engineers*, **22** (Nov.), pp. 319 - 328.

Black, F. A.; Milroy, E. A. 1966. Experience of air-conditioning in offices. *Journal of the Institution of Heating and Ventilating Engineers*, **34** (Sept.), pp. 188 - 196.

Boonlualohr, P. 1989. The effect of radiant heat exchange on thermal comfort in the workplace. University of Michigan, Ph.D. Thesis.

Boyce, P. R. 1974. User's assessments of a landscaped office. *Journal of Architectural Research*, **3** (3), pp. 44 - 62.

Brager, G. S.; Fountain, M. E.; Benton, C. C.; Arens, A. E.; Bauman, F. S. 1994. A comparison of methods for assessing thermal sensation and acceptability in the field. Proceedings of Thermal Comfort: Past, Present and Future (Garston, UK), pp. 17 - 39.

Busch, J. F. 1990. Thermal responses to the Thai office environment. *ASHRAE Transactions*, **96** (1), pp. 859 - 872.

Busch, J. F. 1992. A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand. *Energy and Buildings*, **18**, pp. 235 - 249.

Carlton-Foss, J. A.; Rohles, F. H. 1982. Personality factors in thermal acceptability and comfort. *ASHRAE Transactions*, **88** (2), pp. 776 - 790.

Cena, K. M.; Ladd, P. G.; Spotila, J. R. 1990. A practical approach to thermal comfort surveys in homes and offices: discussion of methods and concerns. *ASHRAE Transactions*, **96** (1), pp. 853 - 858.

Collins, K. J.; Hoinville, E. 1980. Temperature requirements in old age. *Building Services Engineering Research and Technology*, **1** (4), pp. 165 - 172.

Croome, D. J.; Gan, G.; Awbi, H. B. 1992. Field evaluation of the indoor environment of naturally ventilated offices. Proceeding of 13th AIVC Conference (Nice, France), pp. 333 - 342.

de Dear, R. J. 1994. Outdoor climatic influences on indoor thermal comfort requirements. Proceedings of Thermal Comfort: Past, Present and Future (Garston, UK), pp. 106 - 132.

de Dear, R. J.; Auliciems, A. 1985. Validation of the predicted mean vote model of thermal comfort in six Australian field studies. *ASHRAE Transactions*, **91** (2B), pp. 452 - 468.

de Dear, R. J.; Fountain, M. E. 1994. Field experiments on occupant comfort and office thermal environments in a hot humid climate. *ASHRAE Transactions*, **100** (2), pp. 457 - 475.

de Dear, R.; Fountain, M.; Popovic, S.; Watkins, S.; Brager, G.; Arens, E.; Benton, C. 1993. A Field Study of Occupant Comfort and Office Thermal Environments in a Hot-humid Climate. ASHRAE Report No. RP-702, American Society of Heating, Refrigerating and Air-Conditioning Engineers (Atlanta, USA).

de Dear, R. J.; Leow, K. G.; Foo, S. C. 1991. Thermal comfort in the humid tropics: field experiments in air conditioned and naturally ventilated buildings in Singapore. *International Journal of Biometeorology*, **34**, pp. 259 - 265.

Fanger, P. O. 1970. Thermal Comfort. Danish Technical Press (Copenhagen, Denmark).

Fanger, P. O. 1973. The variability of man's preferred ambient temperature from day to day. *Archives des Sciences Physiologiques*, **27**, A403 - A407.

Fanger, P. O. 1992. *Building Services*, November, p. 15.

Fanger, P. O.; Hojbjerre, J.; Thomsen, J. O. B. 1973. Man's preferred ambient temperature during the day. *Archives des Sciences Physiologiques*, **27**, A395 - A402.

Fishman, P. S.; Pimbert, S. L. 1982. The thermal environment in offices. *Energy and Buildings*, **5** (1), 109 - 116.

Goldman, R. F. 1980. Evaluating the effects of clothing on the wearer. Bioengineering, Thermal Physiology and Comfort, Chapter 3. Elsevier (New York, USA).

Griffiths, I. D.; McIntyre, D. A. 1973. Subjective response to relative humidity at two air temperatures. *Archives des Sciences Physiologiques*, **27**, A459 - A466.

Griffiths, I. D.; McIntyre, D. A. 1974. The Effect of Dummy and Real Controls on Thermal Comfort and Perceived Warmth. Electricity Council Research Centre Report No. N752 (Capenhurst, UK).

Grivel, F.; Barth, M. 1980. Thermal comfort in office spaces: predictions and observations. Proceedings of Building Energy Management (Povoa de Varzim, Portugal), pp. 681 - 693.

Grivel, F.; Barth, M. 1982. Personal characteristics related to interpersonal differences of thermal comfort expressed in office spaces. Proceedings of Persons not People, CIB (Chester, UK), pp. 8.1 - 8.12.

Hensen, J. L. M. 1990. Literature review on thermal comfort in transient conditions. *Building and Environment*, **25** (4), pp. 309 - 316.

Hindmarsh, M. E.; Macpherson, R. K. 1962. Thermal comfort in Australia. *Australian Journal of Science*, **24** (8), pp. 335 - 339.

Howell, W. C.; Stramler, C. S. 1981. The contribution of psychological variables to the prediction of thermal comfort judgments in real world settings. *ASHRAE Transactions*, **87** (1), pp. 609 - 621.

Howell, W. C.; Kennedy, P. A. 1979. Field validation of the Fanger thermal comfort model. *Human Factors*, **21** (2), pp. 229 - 239.

Humphreys, M. A. 1976. Field studies of thermal comfort compared and applied. *Building Services Engineer*, **44** (Apr.), pp. 5 - 27.

Humphreys, M. A. 1978. Outdoor temperature and comfort indoors. *Building Research and Practice*, April, pp. 92 - 105.

Humphreys, M. A. 1985. The influence of season and ambient temperature on human clothing behaviour. Proceedings of Indoor Climate, CLIMA 2000 (Copenhagen, Denmark), pp. 699 - 713.

Humphreys, M. A. 1994. Field studies and climate chamber experiments in thermal comfort research. Proceedings of Thermal Comfort: Past, Present and Future (Garston, UK), pp. 52 - 72.

Humphreys, M. A.; Nicol, J. F. 1970. Thermal comfort of office workers. *Journal of the Institution of Heating and Ventilating Engineers*, **38** (Nov.), pp. 181 - 189.

ISO. 1984. Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort. International Standard 7730. International Standards Organisation (Switzerland).

Jaakkola, J. J. K.; Heinonen, O. P.; Seppanen, O. 1989. Sick building syndrome, sensation of dryness and thermal comfort in relation to room temperature in an office building: need for individual control of temperature. *Environment International*, **15**, 163 - 168.

Kahkonen, E.; Virtamo, M.; Sunden, M.; Leikas, M. 1990. Proceedings of Indoor Air '90 (Ottawa, Canada) **1**, pp. 687 - 691.

Langdon, F. J. 1966. Modern Offices: A User Survey. National Building Studies Research Paper No. 41, Building Research Station.

Langkilde, G.; Alexandersen, K.; Wyon, D. P.; Fanger, P. O. 1973. Mental performance during slight cool or warm discomfort. *Archives des Sciences Physiologiques*, **27**, A511 - A518.

Lindsay, C. R. T.; Littlefair, P. J. 1992. Occupant use of venetian blinds in offices. BRE Paper No. 233/92. Building Research Establishment (Garston, UK).

Lorsch, H. G.; Abdou, O. A. 1994. The impact of building indoor environment on occupant productivity -- Part 2: Effects of temperature. *ASHRAE Transactions*, **100** (2).

Markee White, N. L. 1986. Quantification of Factors Influencing Thermal Comfort in an Office Environment: implications for energy conservation. University of California Davis Ph. D. Thesis.

McCullough, E. A.; Olesen, B. W.; Hong, S. Thermal insulation provided by chairs. *ASHRAE Transactions*, **100** (1), 795 - 802.

McIntyre, D. A. 1978. Seven point scales of warmth. *Building Services Engineer*, **45** (Mar.), pp. 215 - 226.

McNall, P. E. 1979. The relation of thermal comfort to learning and performance: a state-of-the-art report. *ASHRAE Transactions*, **85** (1), pp. 759 - 767.

Newsham, G. R.; Tiller, D. K. 1994. The energy consumption of desktop computers: measurement and savings potential. *IEEE Transactions on Industry Applications*, **30** (4), pp. 1065 - 1072.

Nicol, J. F.; Humphreys, M. A. 1973. Thermal comfort as part of a self-regulating system. Proceedings of Thermal Comfort and Moderate Heat Stress, CIB W45 (Garston, UK), pp. 263 - 274.

Olesen, B. W. 1985. A new simpler method for estimating the thermal insulation of a clothing ensemble. *ASHRAE Transactions*, **91** (2B), pp. 478 - 492.

Opdal, L.; Brekke, B. 1995. Energy saving in lighting by utilization of daylight. Proceedings of the 3rd European Conference on Energy-Efficient Lighting (Newcastle, UK), pp. 67 - 74.

Orgill, J. F.; Hollands, K. G. T. 1977. Correlation equation for hourly diffuse radiation on a horizontal surface. *Solar Energy*, **19**, pp. 357 - 359.

Oseland, N. 1992. *Building Services*, December, p. 13.

Oseland, N. 1994. Predicted and reported thermal sensation in climate chambers, offices and homes. *Energy and Buildings*, **23**, pp. 105 - 115.

Oseland, N. A.; Humphreys, M. A. 1993. Trends in thermal comfort research. BRE Draft PD 323/93, Building Research Establishment (Garston, UK).

Paciuk, M. T. 1989. The role of personal control of the environment in thermal comfort and satisfaction in the workplace. University of Wisconsin Ph. D. Thesis.

Palonen, J.; Seppanen, O.; Jaakkola, J. J. K. 1993. The effects of air temperature and relative humidity on thermal comfort in the office environment. *Indoor Air* , **3**, pp. 391 - 397.

Pepler, R. D. 1968. Temperature and learning. *ASHRAE Transactions*, **74**, pp. 211 - 219.

Purcell, A. T.; Thorne, R. H. 1987. The thermal environment and level of arousal: field studies to ascertain the effects of airconditioned environments on office workers. Architectural Science Review, **30** (4), pp. 91 - 116.

Rea, M. S. 1984. Window blind occlusion: a pilot study. *Building and Environment*, **19** (2), pp. 133 - 137.

Rohles, F. H. 1980. Temperature or temperament: a psychologist looks at thermal comfort. *ASHRAE Transactions*, **86** (1), pp. 541 - 551.

Rohles, F. H. 1983. New directions in comfort research. *ASHRAE Transactions*, **89** (2B), pp. 634 - 646.

Rohles, F. H.; Bennett, C. A.; Milliken, G. A. 1981. The effects of lighting, color, and room decor on thermal comfort. *ASHRAE Transactions*, **87** (2), pp. 511 - 527.

Rohles, F. H.; Hayter, R. B.; Milliken, G. 1975. Effective temperature (ET*) as a predictor of thermal comfort. *ASHRAE Transactions*, **81** (2), pp. 148 - 156.

Rohles, F. H.; Woods, J. E.; Morey, P. R. 1989. Indoor environment acceptability: the developing of a rating scale. *ASHRAE Transactions*, **95** (1), pp. 23 - 27.

Rowley, F. B.; Jordan, R. C.; Snyder, W. E. 1947. Comfort reactions of workers during occupancy of air conditioned offices. *ASHVE Transactions*, **53**, pp. 357 - 368.

Rubin, A. I.; Collins, B. L.; Tibbott, R. L. 1978. Window Blinds as a Potential Energy Saver - A Case Study. NBS Building Science Series No. 112., National Bureau of Standards (Washington D.C., USA).

Schiller, G. E.; Arens, E. A. 1988. Thermal comfort in office buildings. *ASHRAE Journal*, October, pp. 26 - 32.

Schiller, G. E.; Arens, E. A.; Bauman, F. S.; Benton, C.; Fountain, M.; Doherty, T. 1988a. A field study of thermal environments and comfort in office buildings. *ASHRAE Transactions*, **94** (2), pp. 280 - 308.

Schiller, G. E.; Arens, E. A.; Baumann, F. S.; Benton, C.; Fountain, M.; Doherty, T. 1988b. A field study of thermal environments and comfort in office buildings. ASHRAE Report No. 462-RP. American Society of Heating, Refrigerating and Air-Conditioning Engineers (Atlanta, USA).

Sherman, M. 1985. A simplified model of thermal comfort. *Energy and Buildings*, **8**, pp. 37 - 50.

Wong, F. M. 1967. The significance of work comfort in architecture. *Architectural Science Review*, **10** (Dec.), pp. 119 - 130.

Wyon, D. P. 1973. The effects of moderate heat stress on typewriting performance. *Archives des Sciences Physiologiques*, **27**, A403 - A407.

Wyon, D. P.; Asgeirsdottir, T.; Kjerulf-Jensen, P.; Fanger, P. O. 1973. The effects of ambient temperature swings on comfort, performance and behaviour. *Archives des Sciences Physiologiques*, **27**, A499 - A509.

Wyon, D. P.; Holmberg, I. 1973. Systematic observation of classroom behaviour during moderate heat stress. Proceedings of Thermal Comfort and Moderate Heat Stress, CIB W45 (Garston, UK), pp. 19 - 33.

Figures

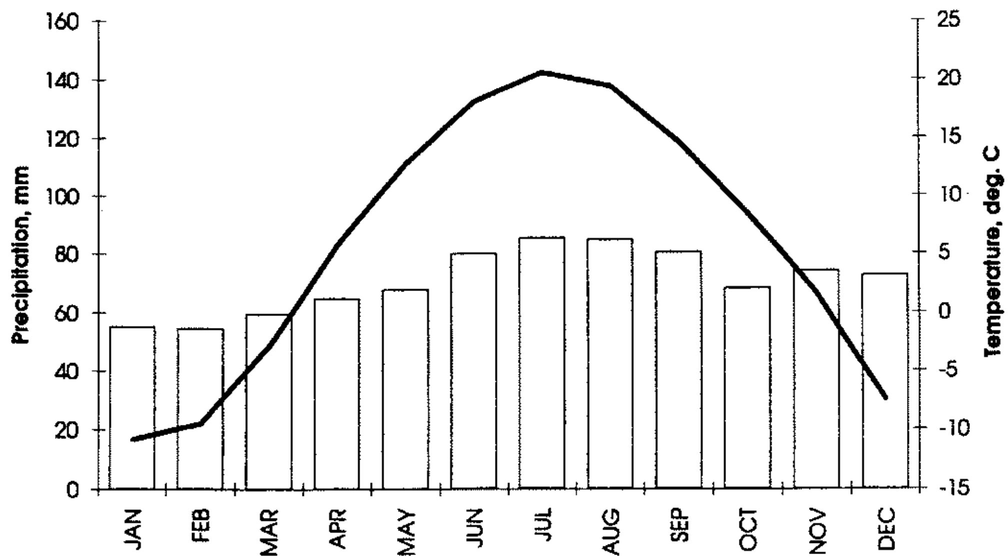


Figure 1. General climate data for Ottawa, Ontario, Canada.

Figure 2. Geographical Location of Ottawa, Ontario, Canada.

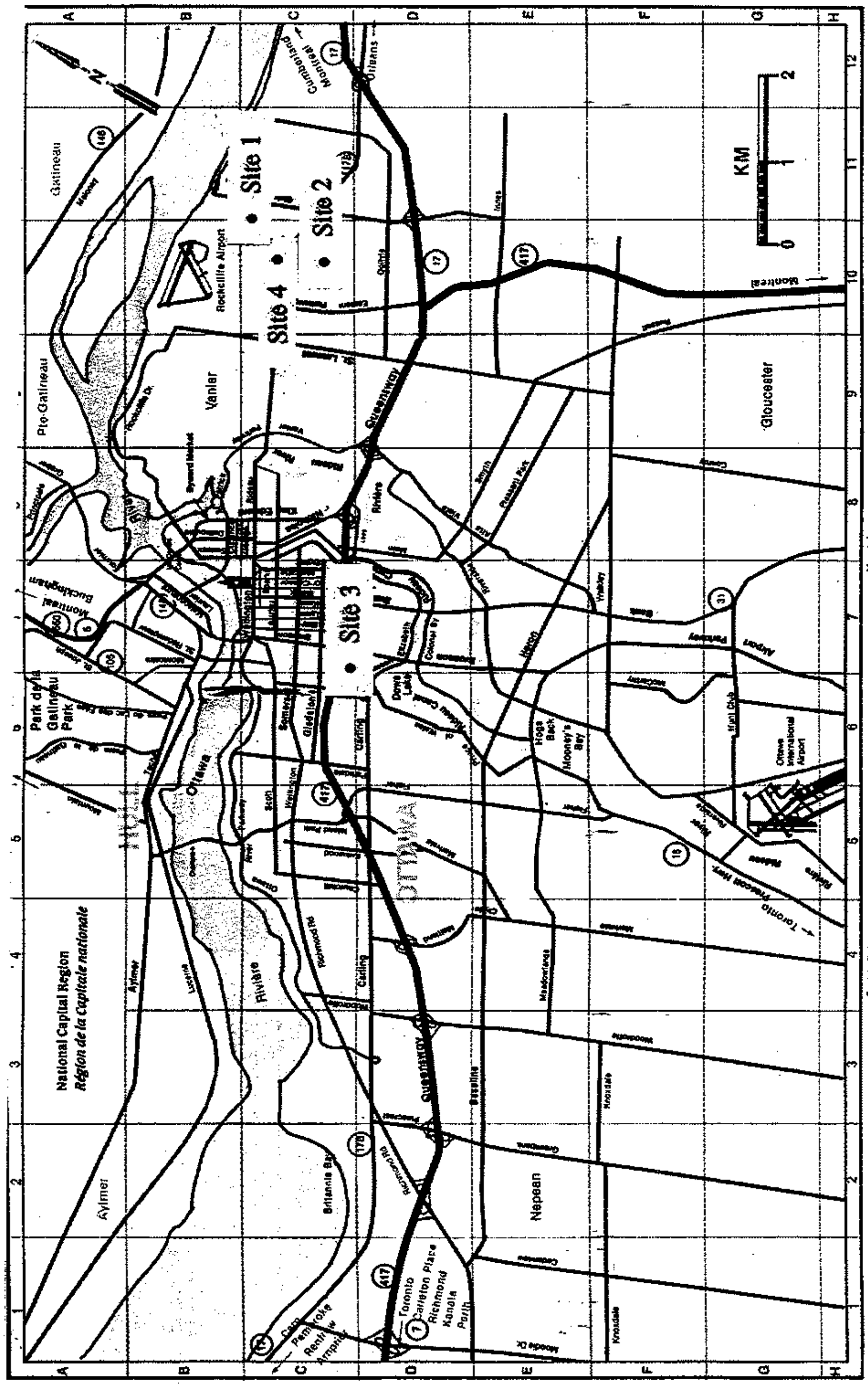


Figure 3. Street plan of Ottawa showing the locations of the study sites.

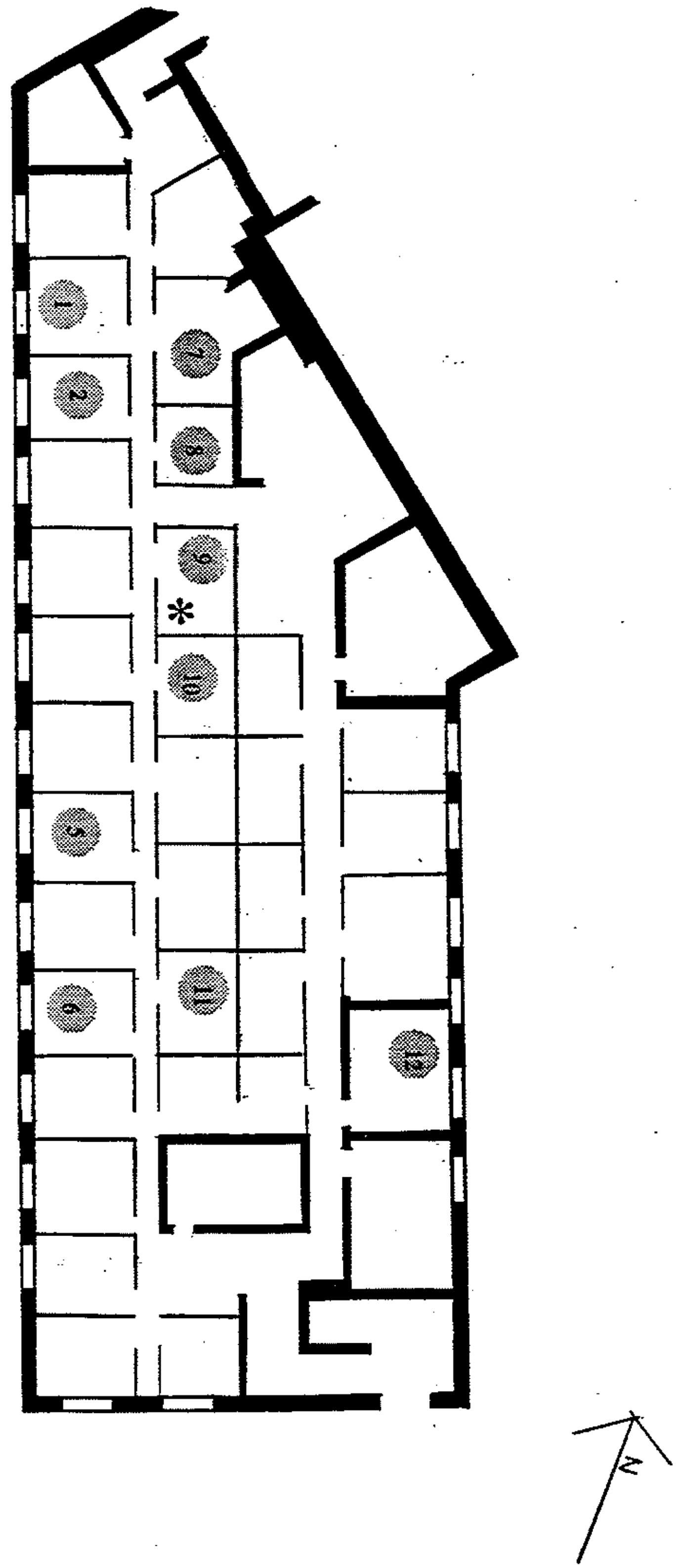


*Figure 4. Floor plan of Site 1. The * indicates the position of the temperature/humidity datalogger.*

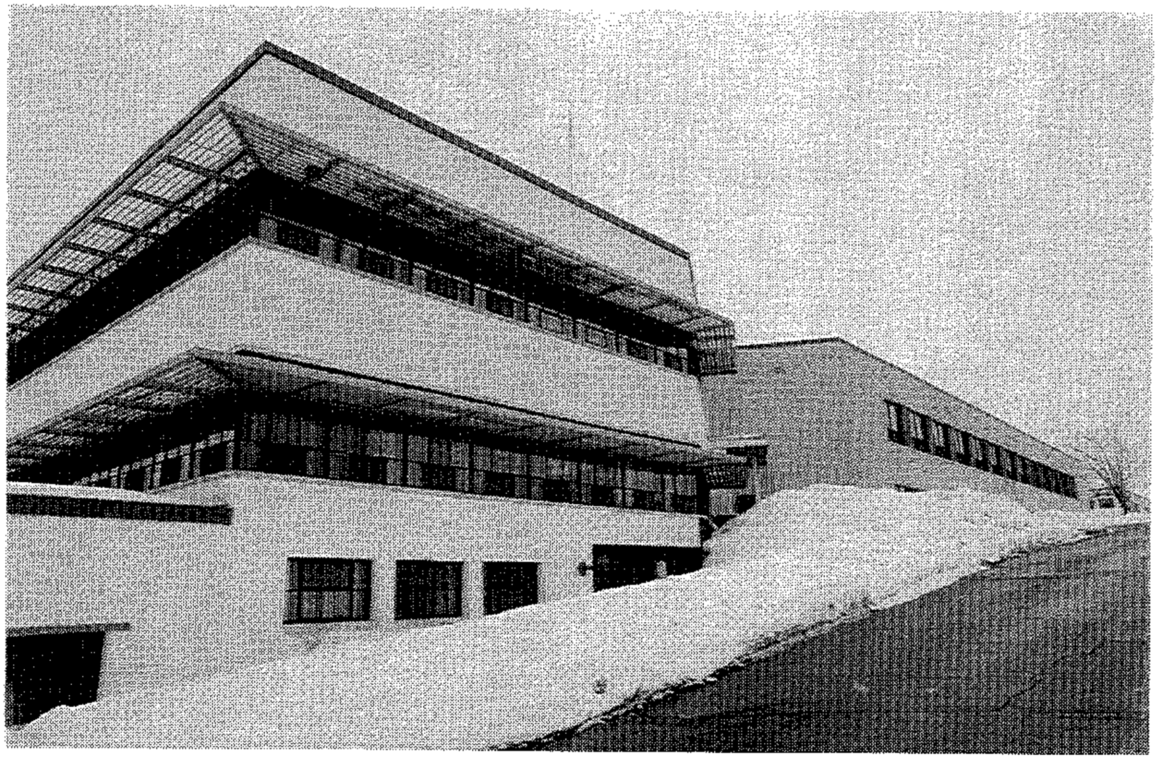


Figure 5. Exterior and interior photographs of Site 1.

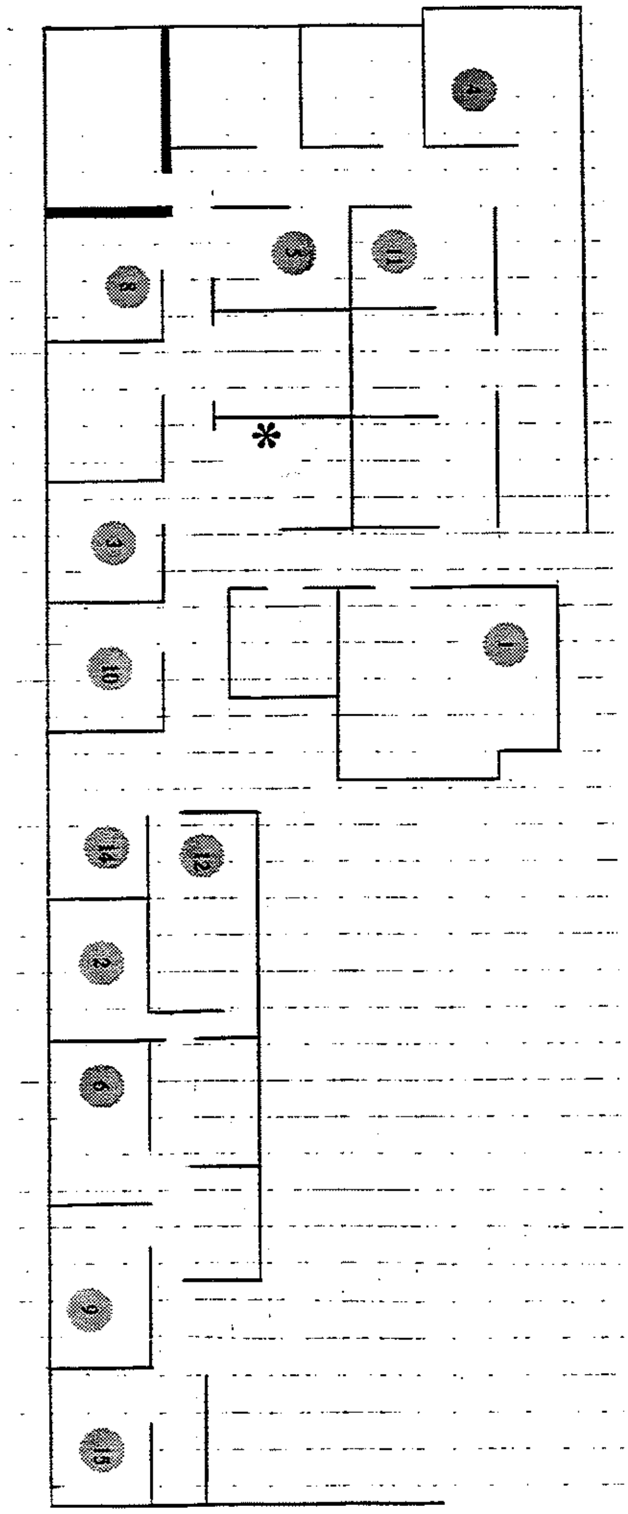


*Figure 6. Floor plan of Site 2. The * indicates the position of the temperature/humidity datalogger.*

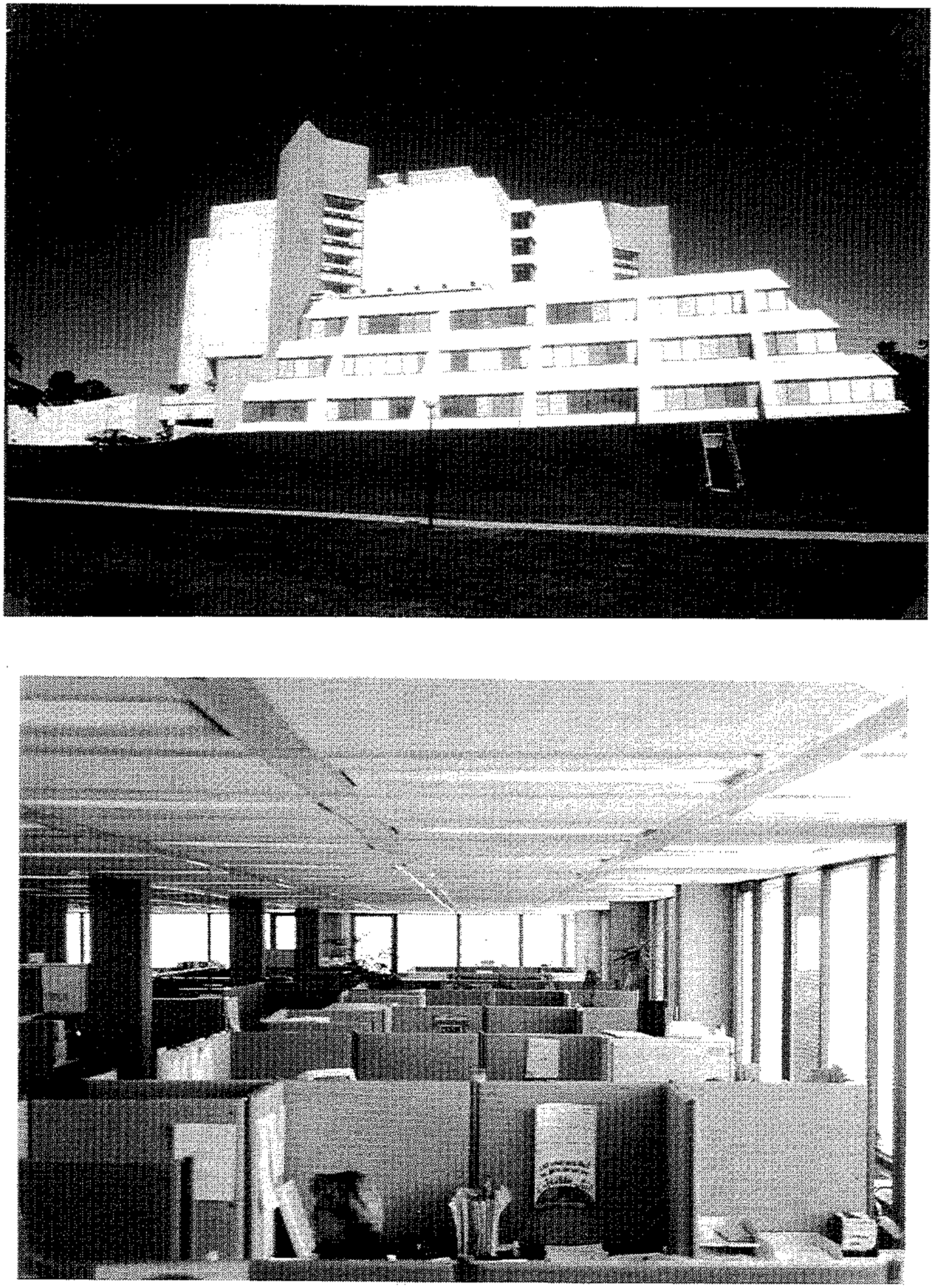


Figure 7. Exterior and interior photographs of Site 2.

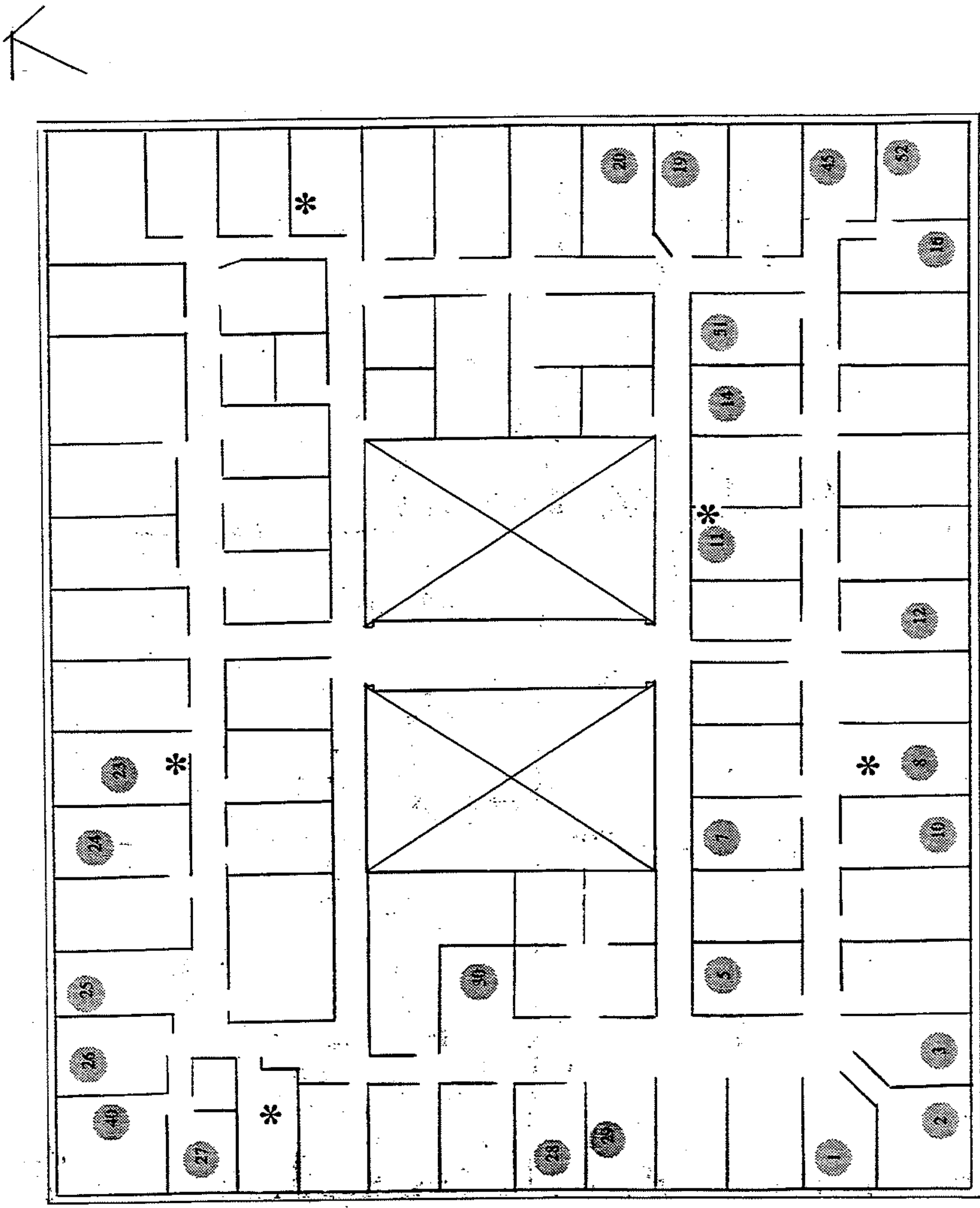


*Figure 8(a). Floor plan of the 7th Floor, Site 3. The * indicates the position of the temperature/humidity datalogger.*

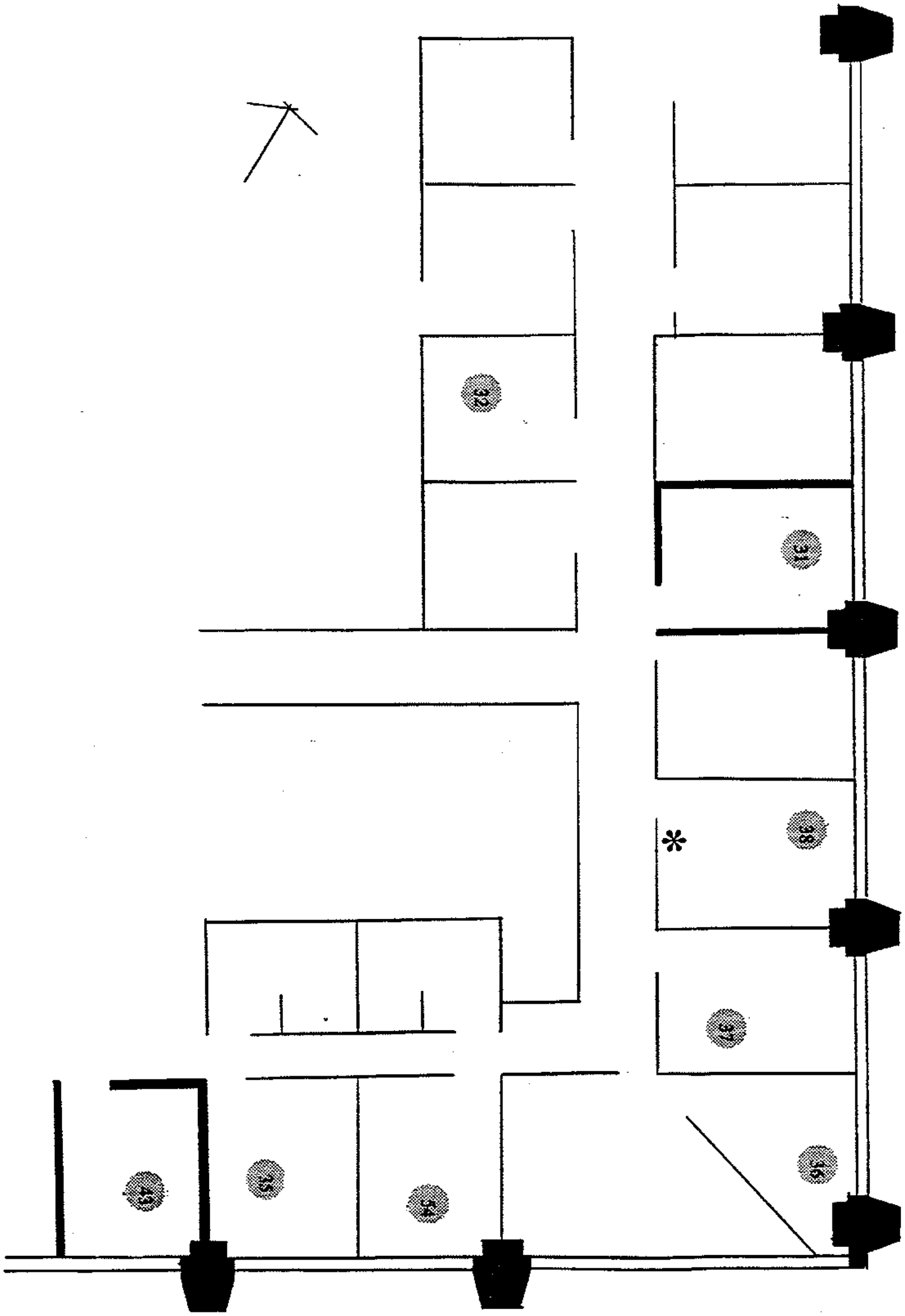


*Figure 8(b). Floor plan of the 9th Floor, Site 3. The * indicates the position of the temperature/humidity datalogger.*

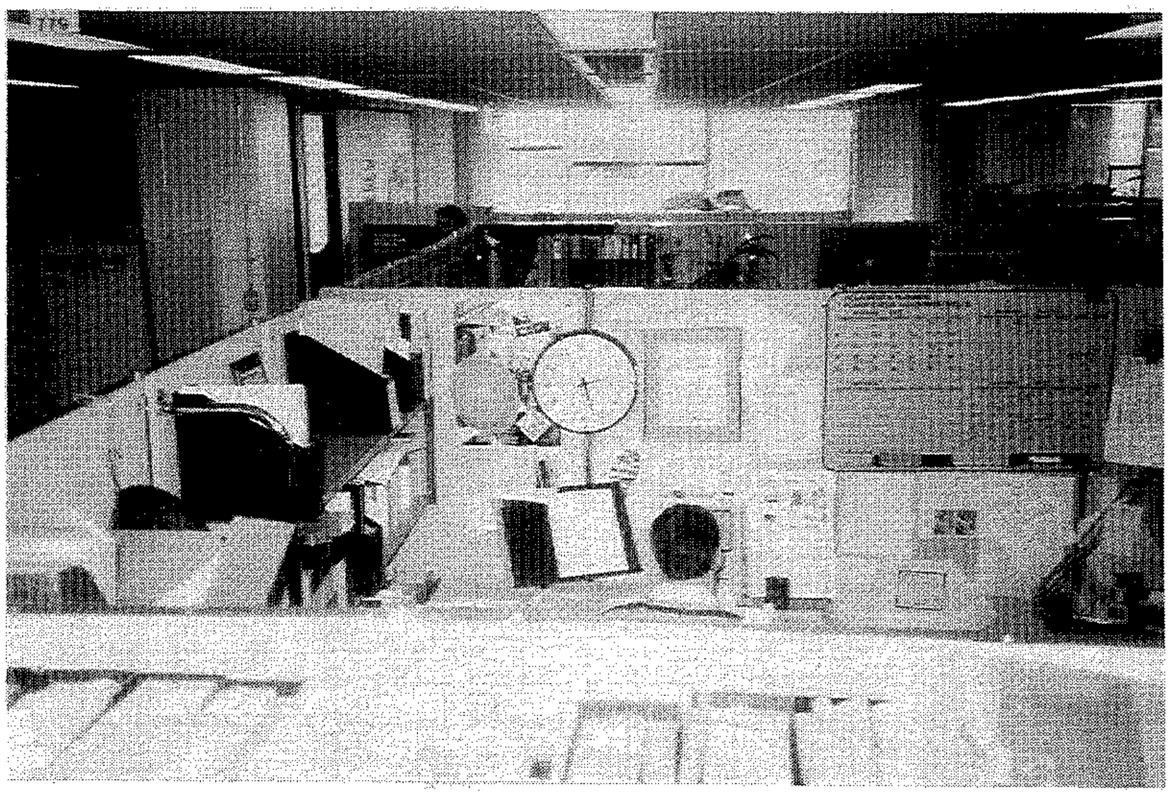


Figure 9. Exterior and interior photographs of Site 2.

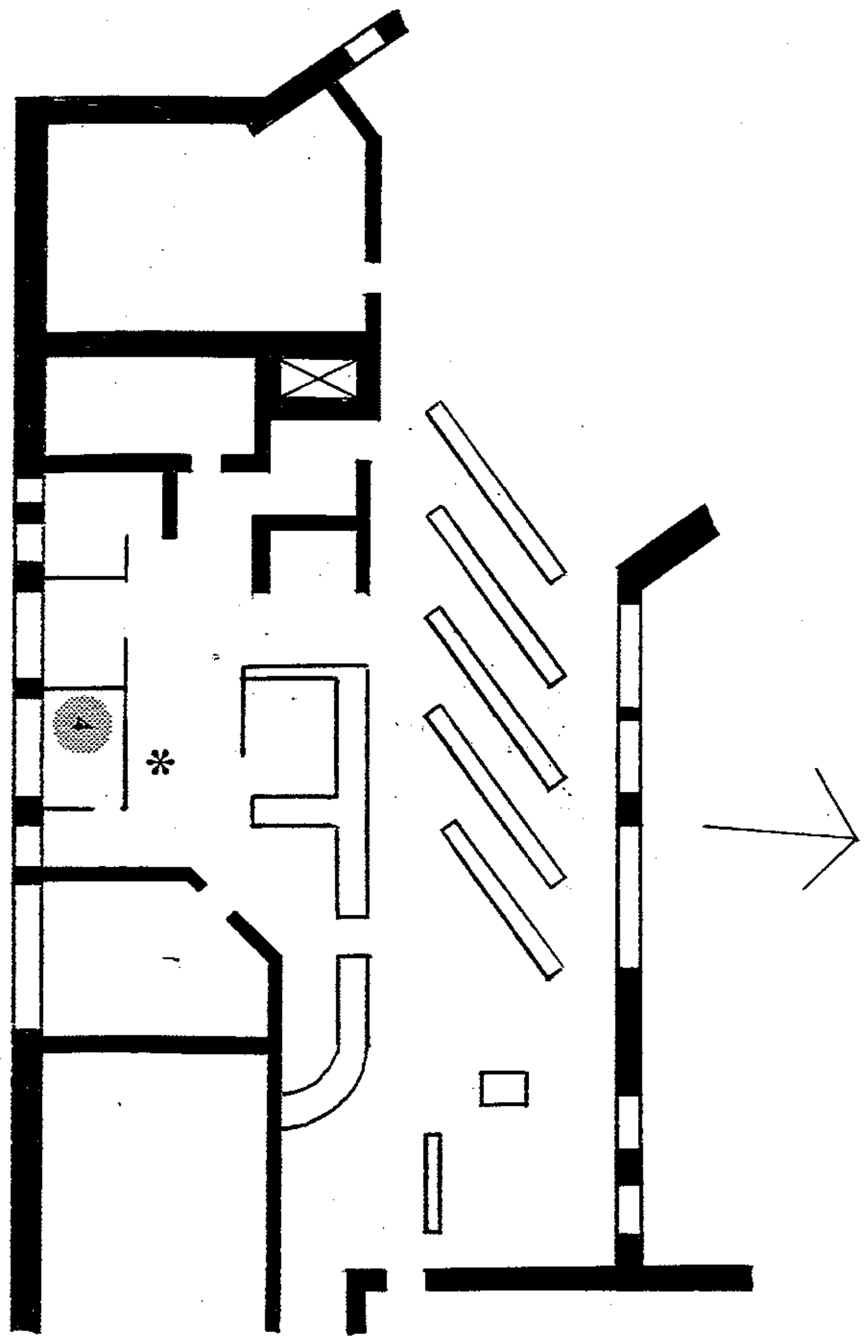


*Figure 10. Floor plan of Site 4. The * indicates the position of the temperature/humidity datalogger.*

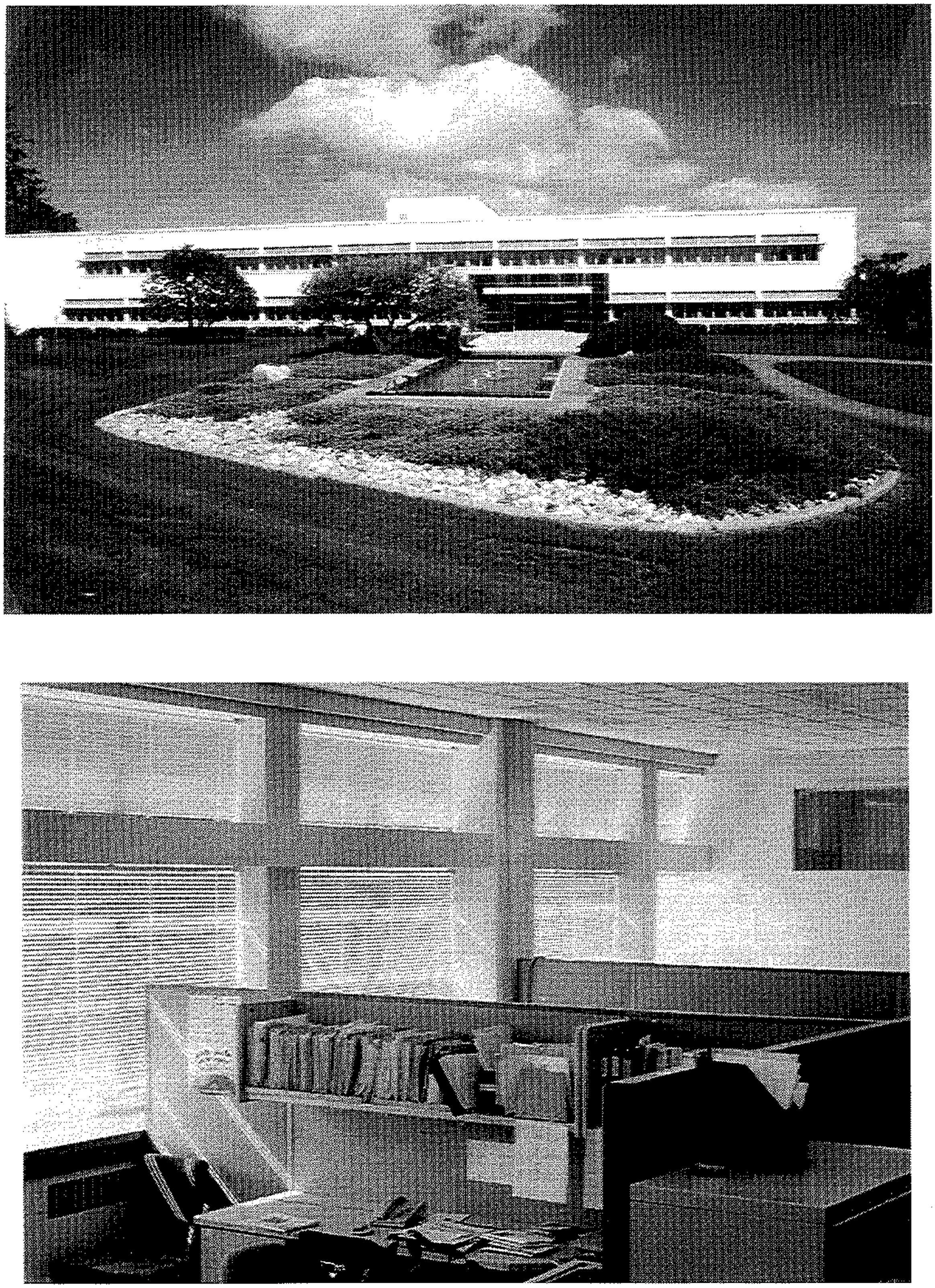


Figure 11. Exterior and interior photographs of Site 4.

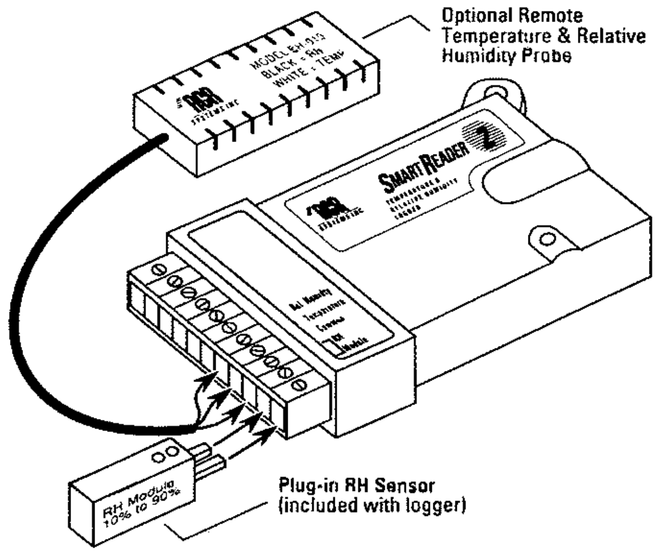


Figure 12. The temperature/humidity logger used for recording interior climate.

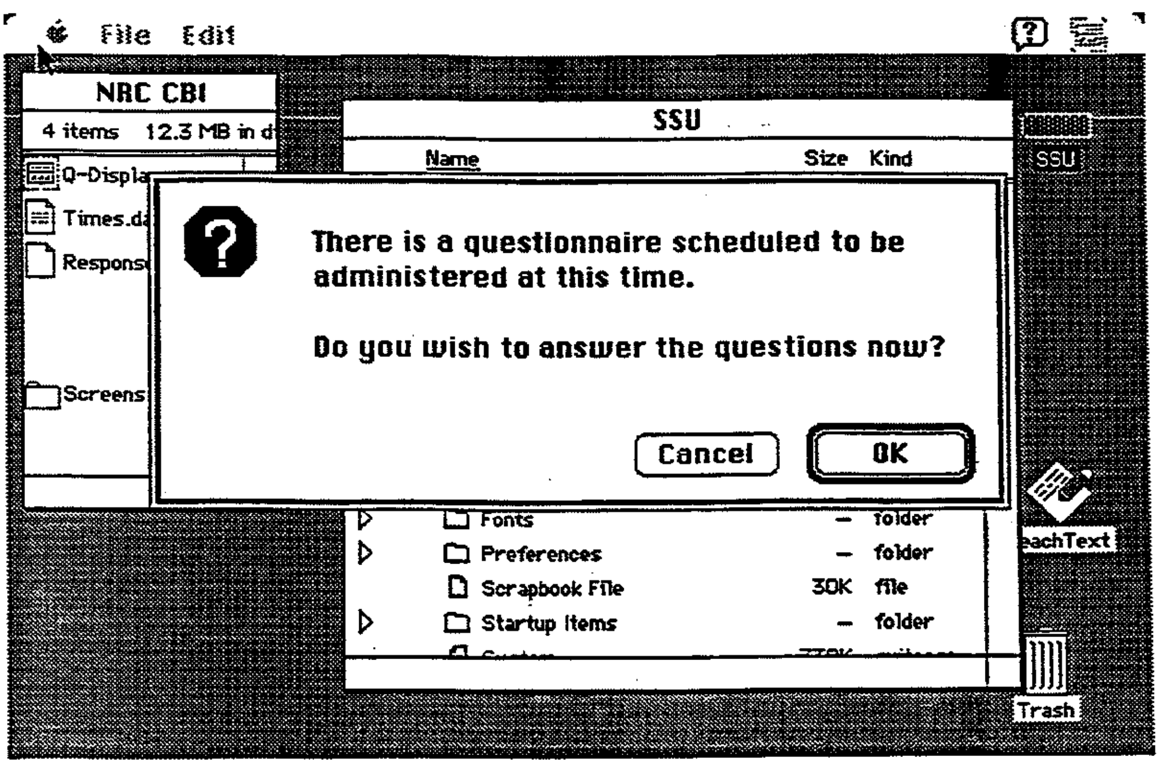


Figure 13. The Warning Banner which preceded questionnaire sessions.

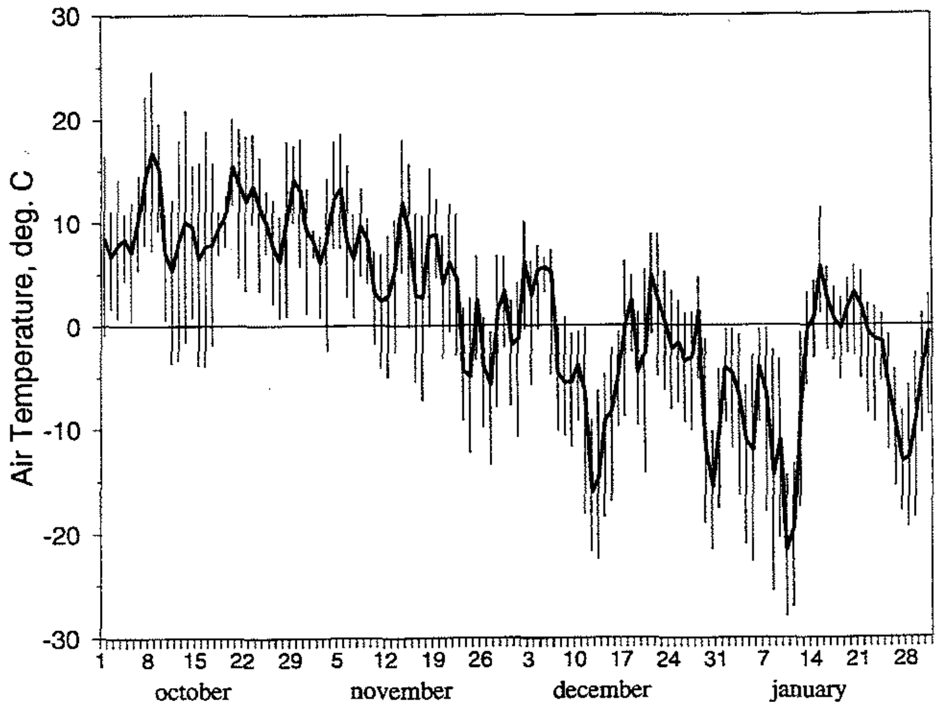


Figure 14(a). External air temperature over the study period. The thick line indicates daily means, the "whiskers" indicate daily maximums and minimums.

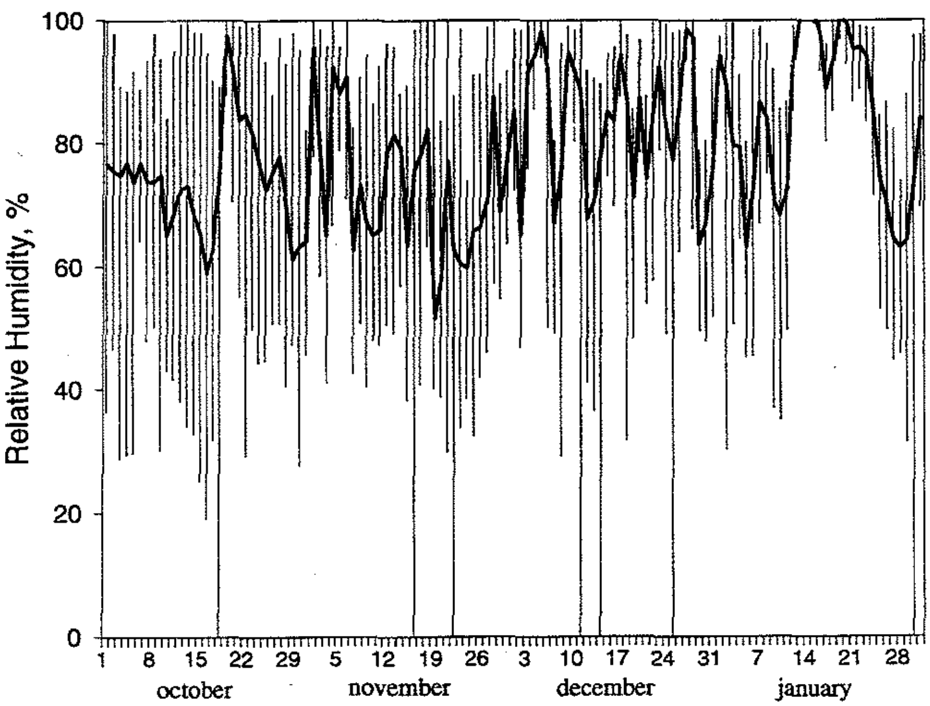


Figure 14(b). External relative humidity over the study period. The thick line indicates daily means, the "whiskers" indicate daily maximums and minimums.

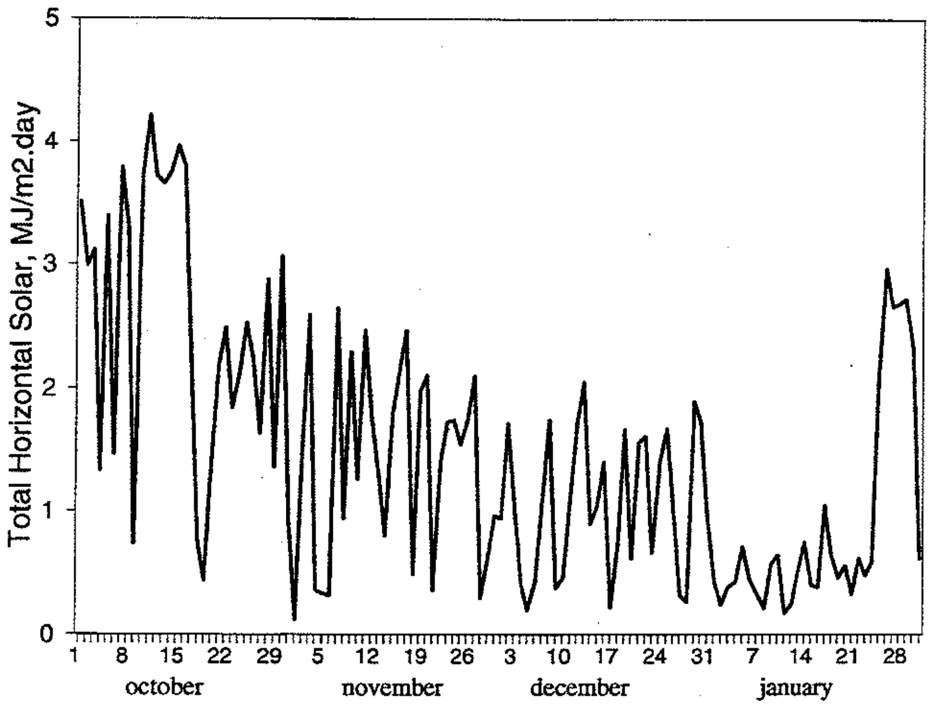


Figure 14(c). External total horizontal solar radiation over the study period.

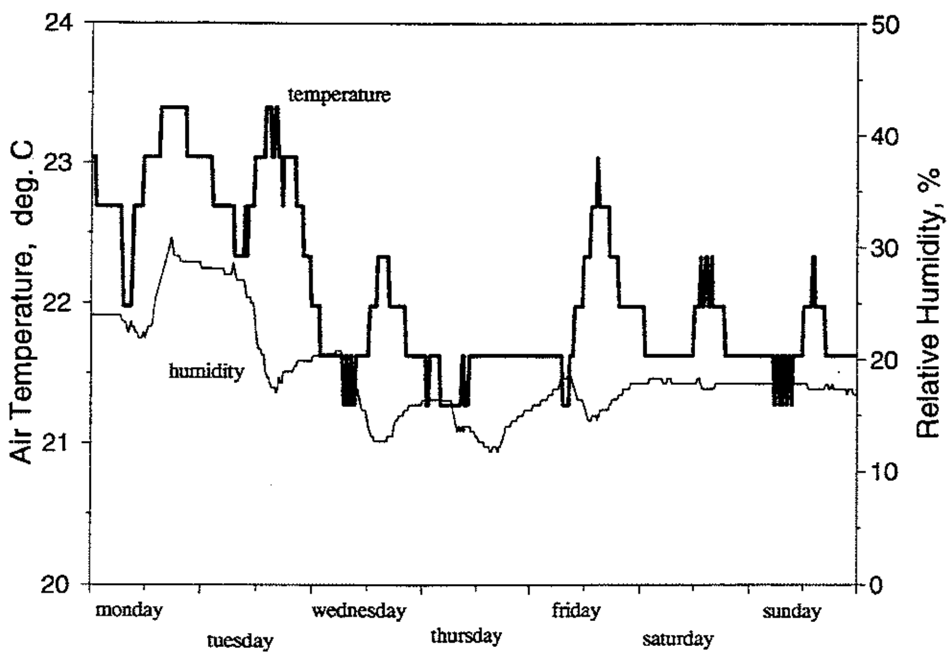


Figure 15. A typical week's indoor air temperature and relative humidity at Site 1.

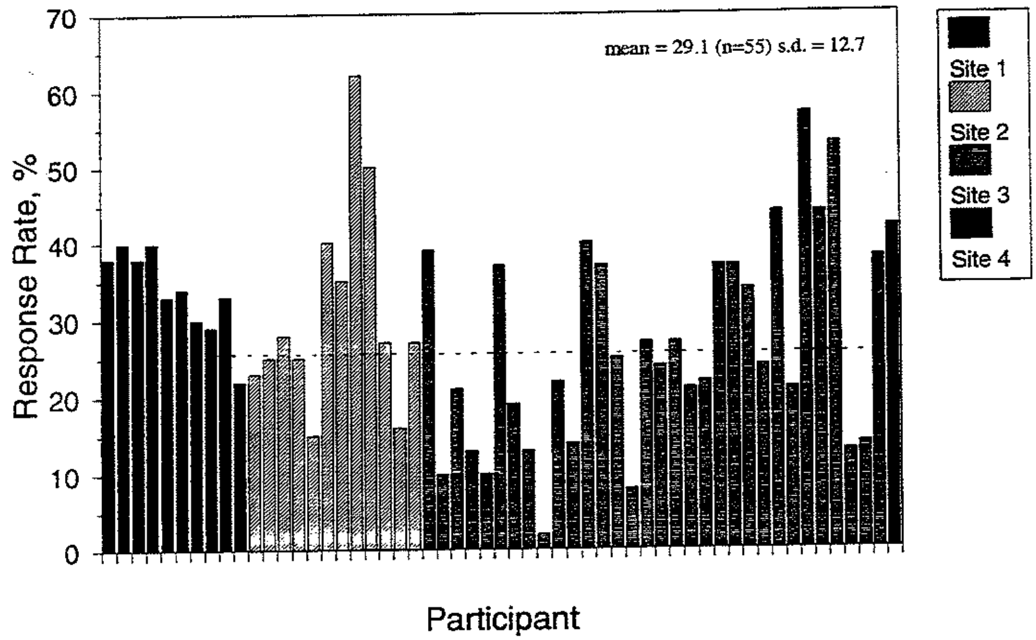


Figure 16. Mean response rate to the recurring questionnaire, by participant.

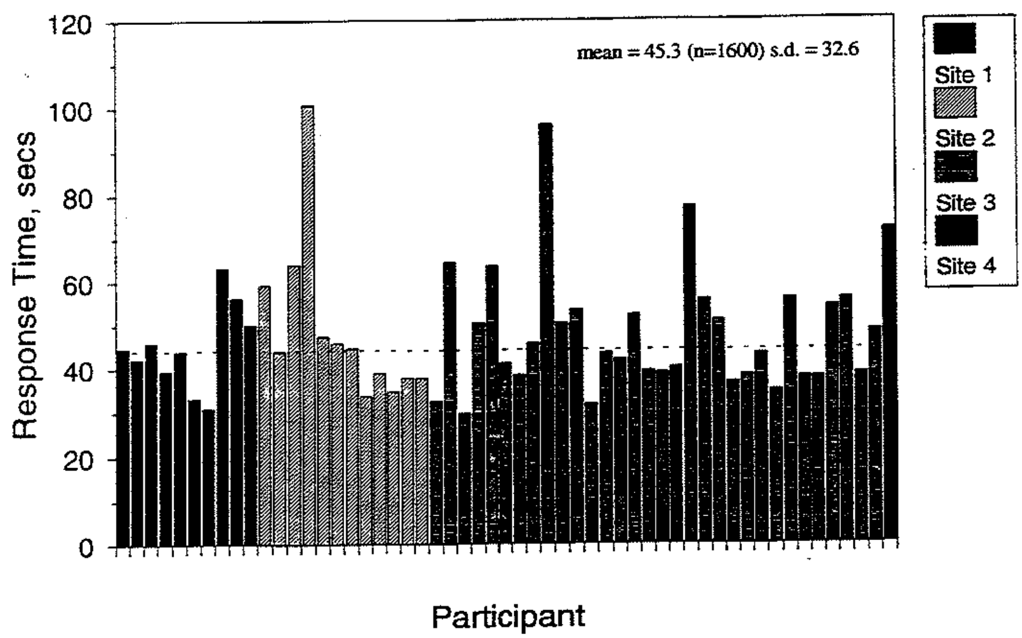


Figure 17. Mean time taken to complete the five questions, by participant.

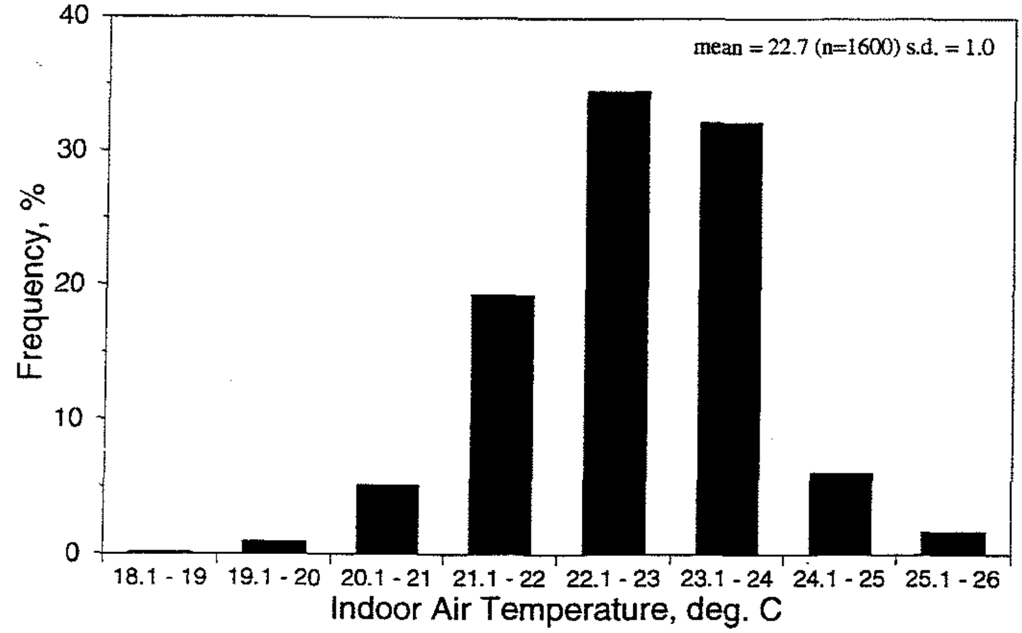


Figure 18. Frequency of indoor air temperature recorded at times when the questionnaire was answered, at all Sites.

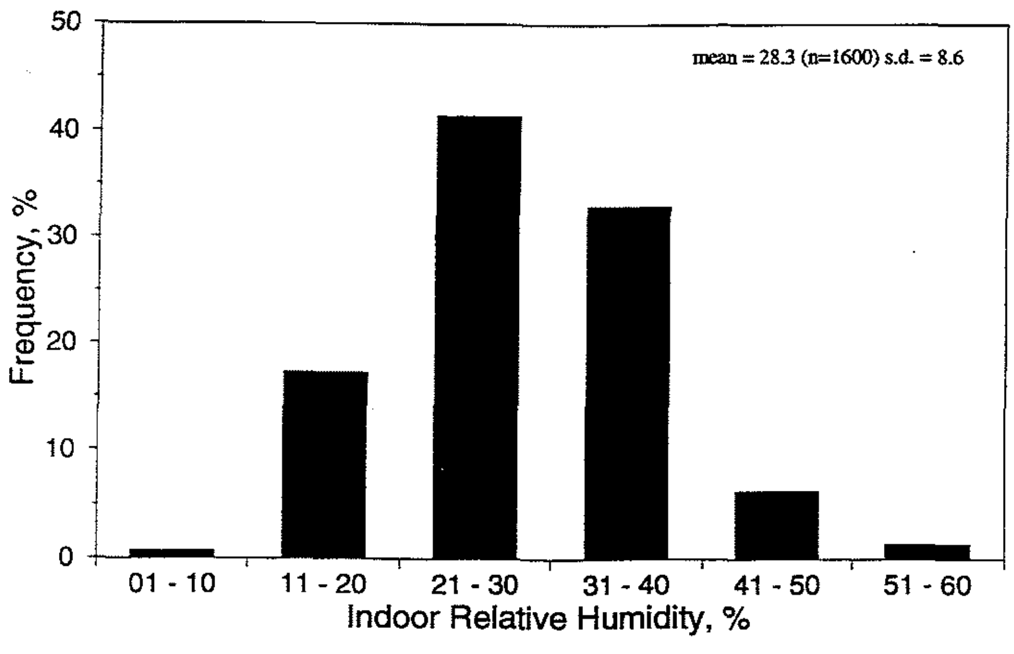


Figure 19. Frequency of indoor relative humidity recorded at times when the questionnaire was answered, at all Sites.

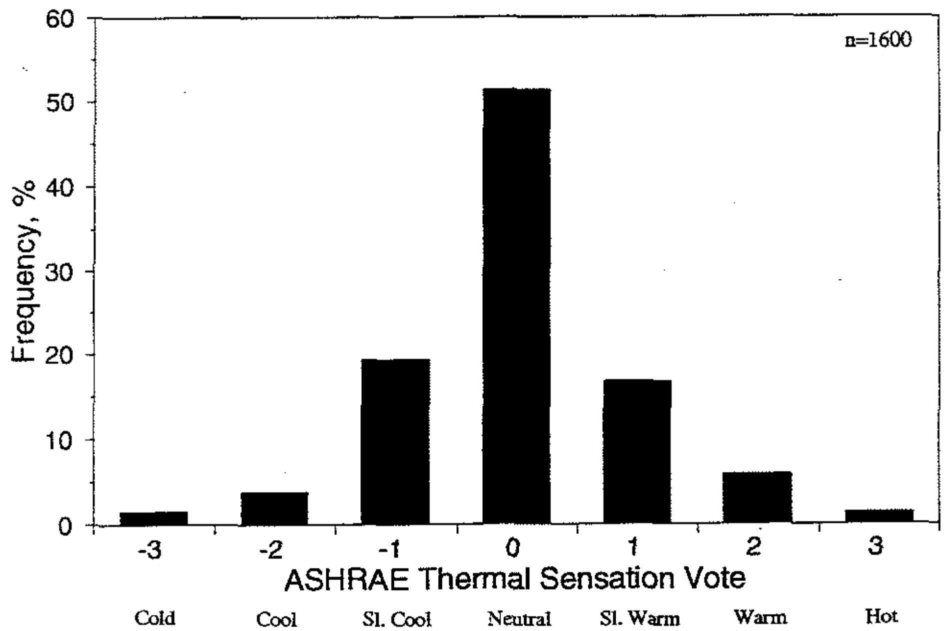


Figure 20. Frequency of response to the ASHRAE thermal sensation question, at all Sites.

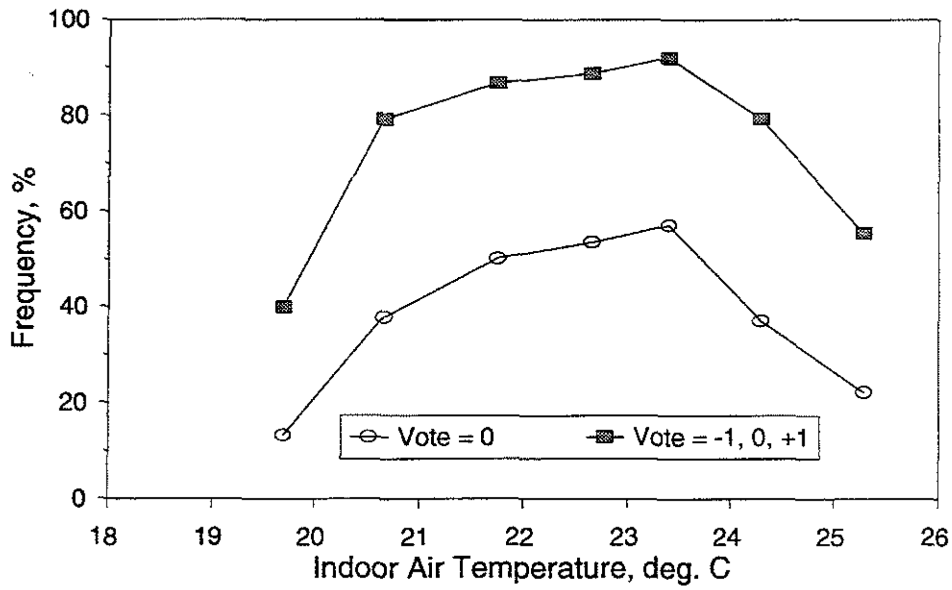


Figure 21. Frequency of response to the ASHRAE thermal sensation question vs. indoor air temperature, at all Sites. The lower curve shows the frequency of '0' ('neutral') votes; the upper curve shows the frequency of votes in the central three categories, '-1', '0', '+1' ('slightly cool', 'neutral', 'slightly warm').

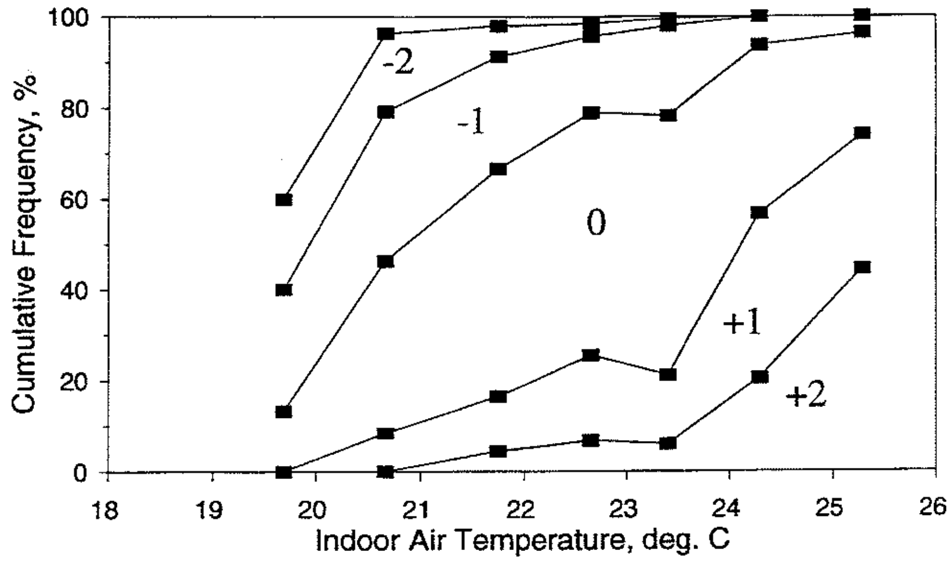


Figure 22. Cumulative frequency response to the ASHRAE thermal sensation question vs. indoor air temperature, at all Sites. Each curve shows the percentage of votes in all categories labeled below it.

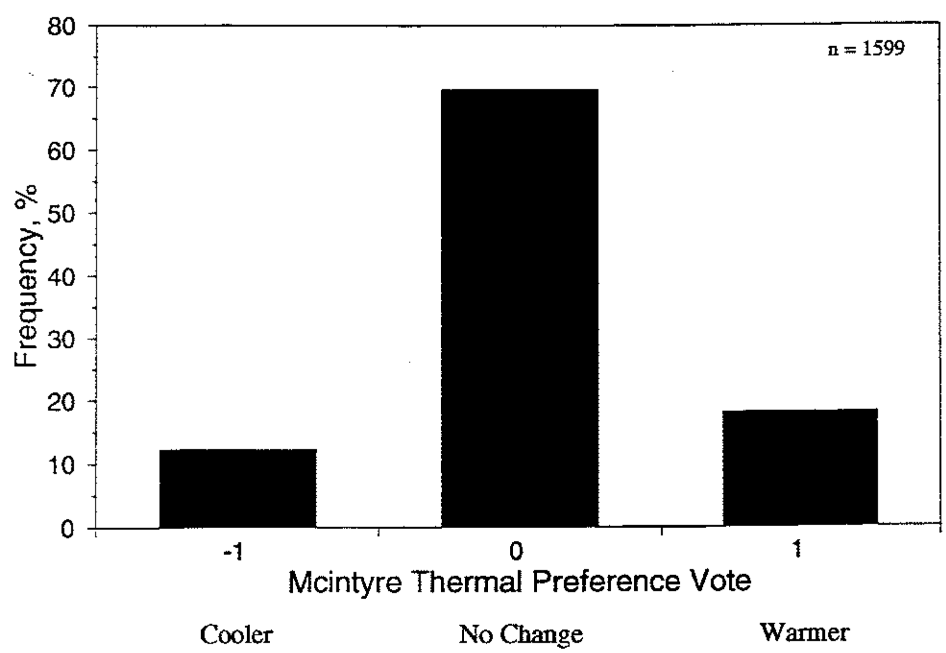


Figure 23. Frequency of response to the McIntyre thermal preference question, at all Sites.

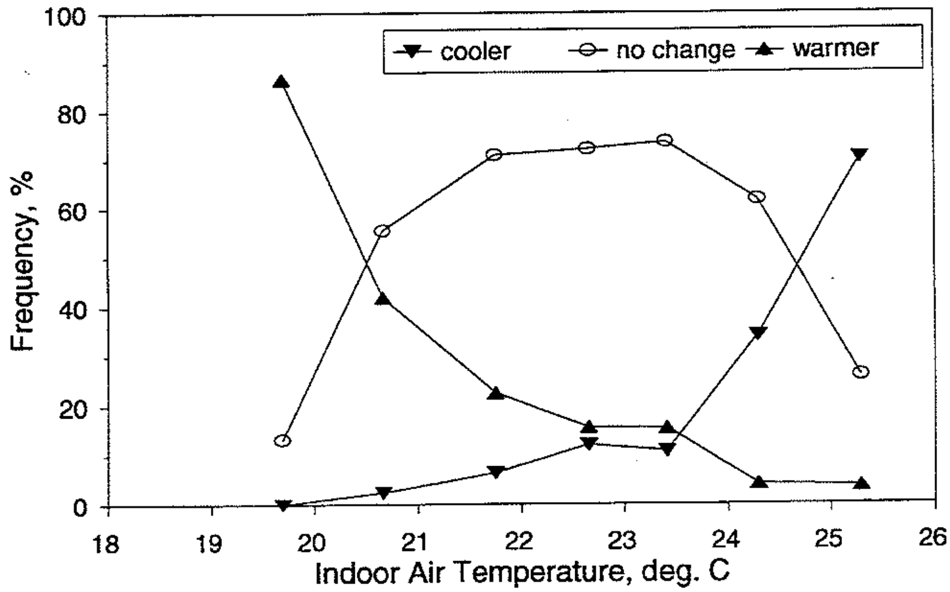


Figure 24. Frequency of response to the McIntyre thermal preference question vs. indoor air temperature, at all Sites.

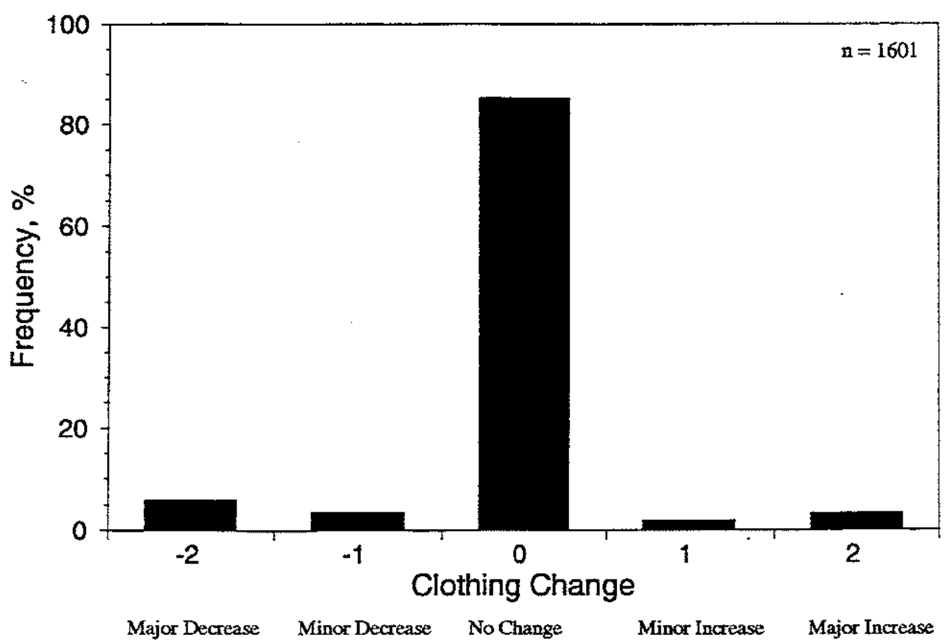


Figure 25. Frequency of response to the question regarding clothing change within the previous hour, at all Sites.

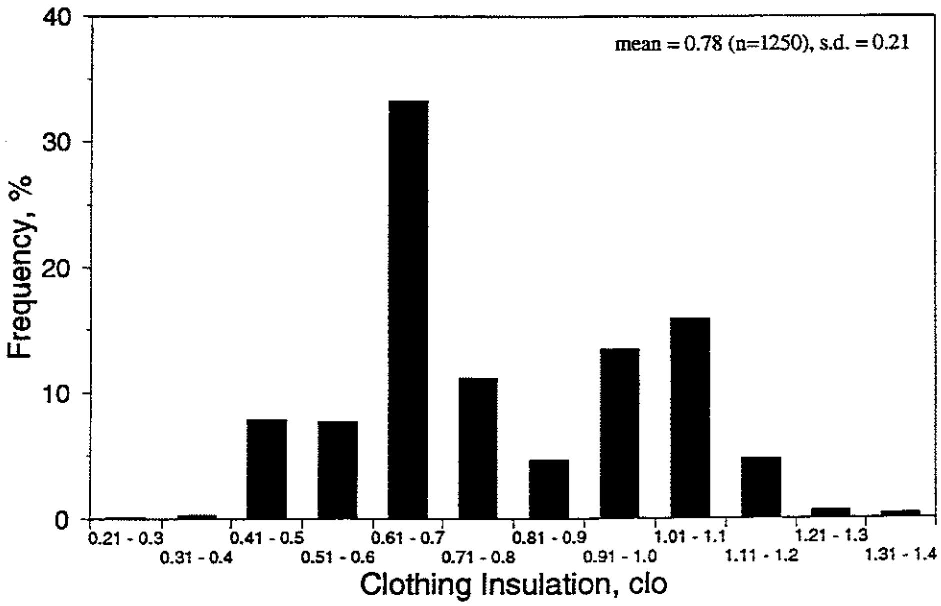


Figure 26. Frequency of response to the question regarding clothing insulation worn to work, at all Sites.

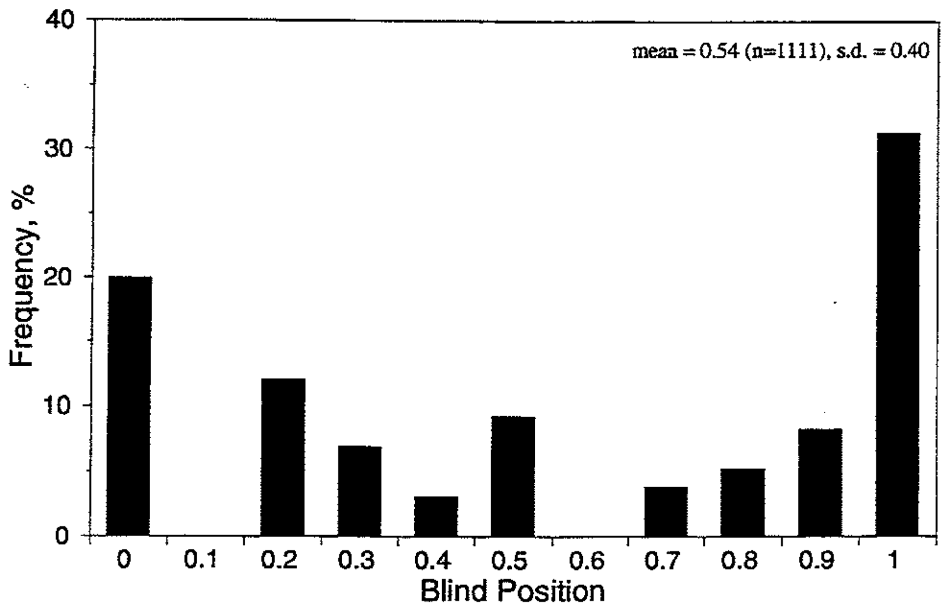


Figure 27. Frequency of response to the question regarding window blind position, at all Sites. '1' was fully open, '0' fully closed.

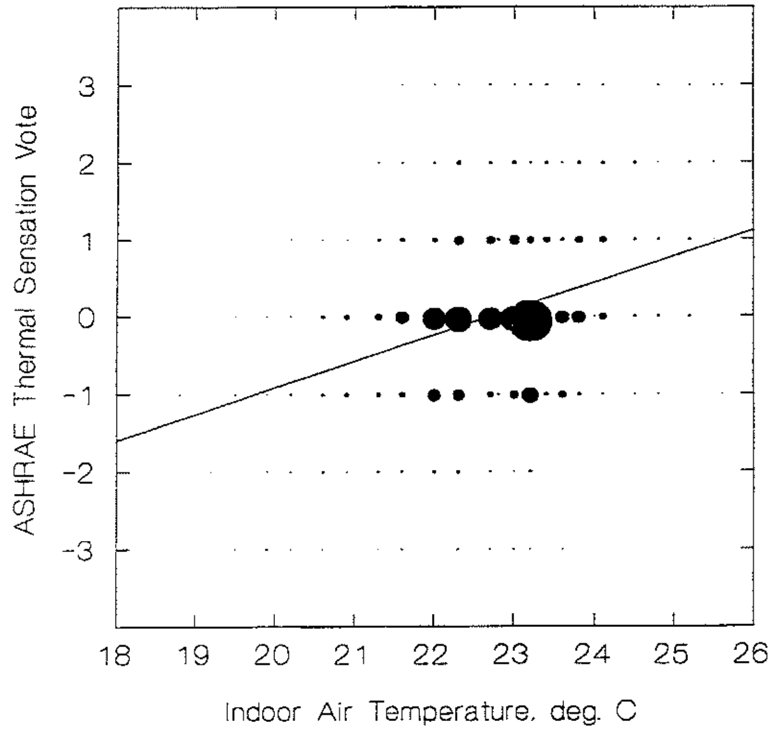


Figure 28. A bubble plot of ASHRAE thermal sensation vote vs. indoor air temperature, at all Sites. The bubble size is proportional to the number of votes at the particular ASHRAE vote/air temperature combination.

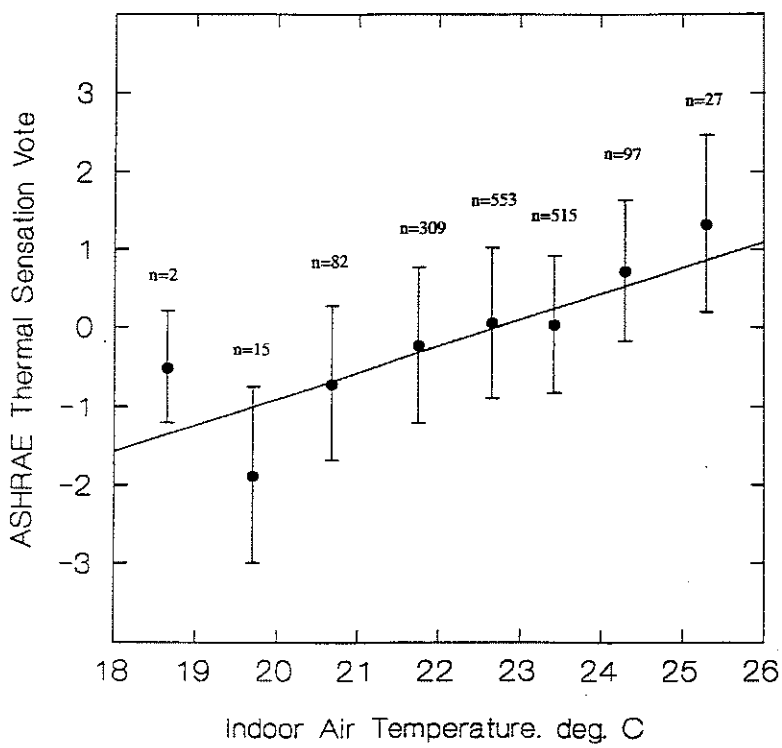


Figure 29. Mean ASHRAE thermal sensation vote per temperature bin vs. mean temperature in the bin, data from all Sites. The number of votes per bin is shown; error bars indicate standard deviations.

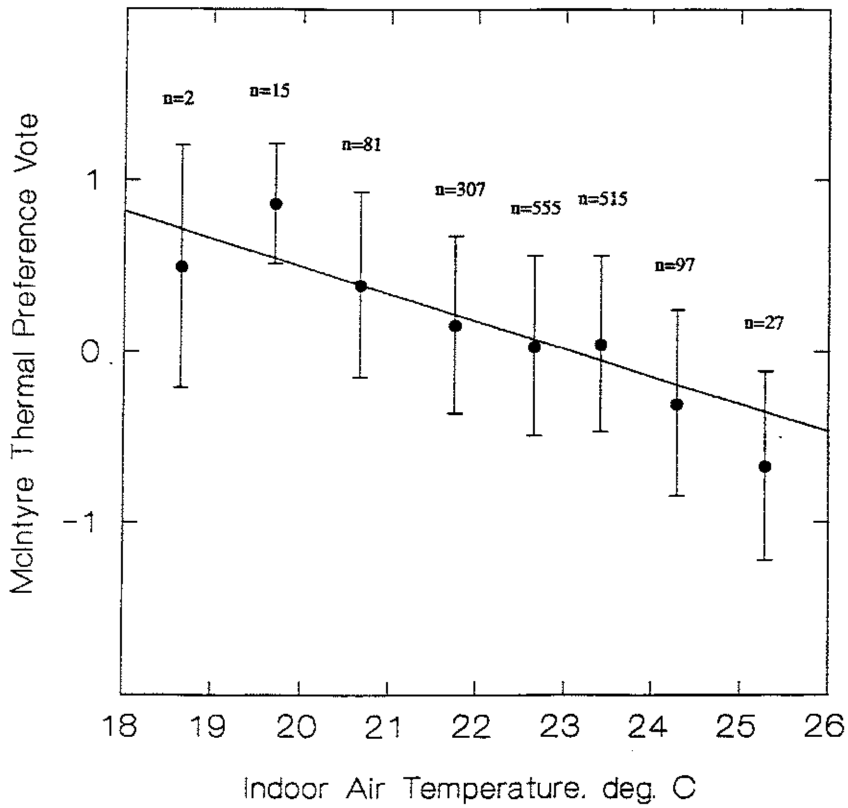


Figure 30. Mean McIntyre thermal preference vote per temperature bin vs. mean temperature in the bin, data from all Sites. The number of votes per bin is shown; error bars indicate standard deviations.

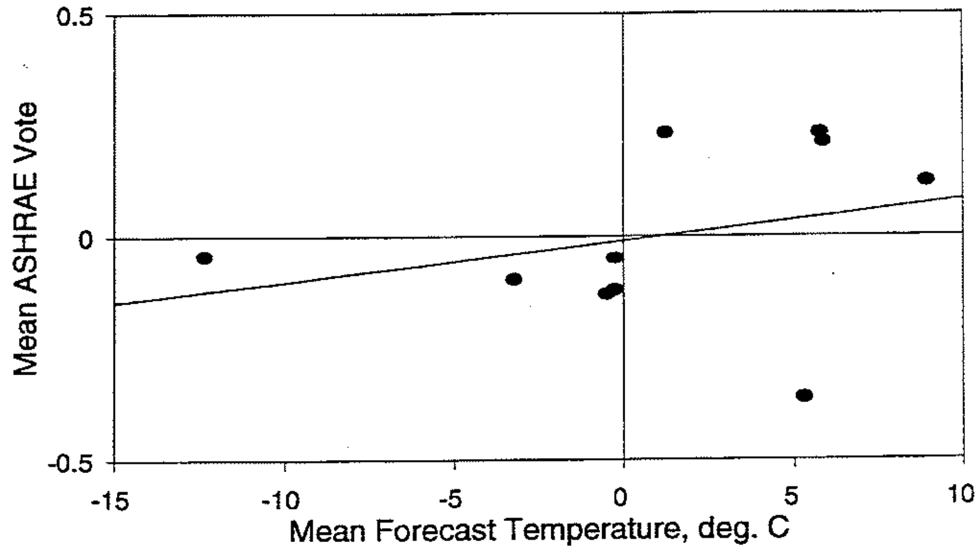


Figure 31. Mean weekly ASHRAE thermal sensation vote vs. mean weekly forecast temperature, data from all Sites. Forecast temperature is the outdoor air temperature at 8 am.

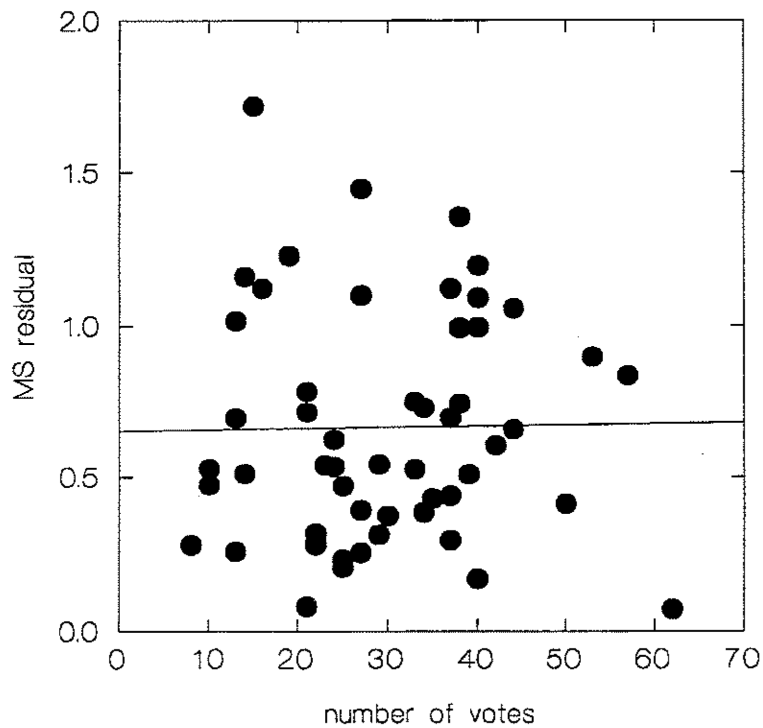


Figure 32. Variance in ASHRAE thermal sensation vote not due to indoor air temperature (MS residual) for each participant vs. total number of votes made by the participant.

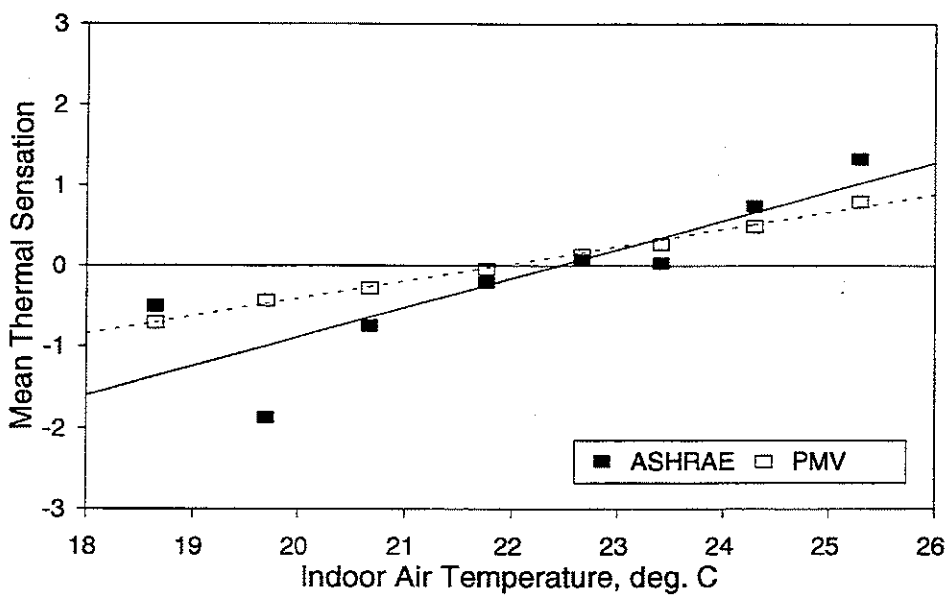


Figure 33. A comparison of mean ASHRAE thermal sensation vote and Predicted Mean Vote (PMV) vs. indoor air temperature, data from all Sites.

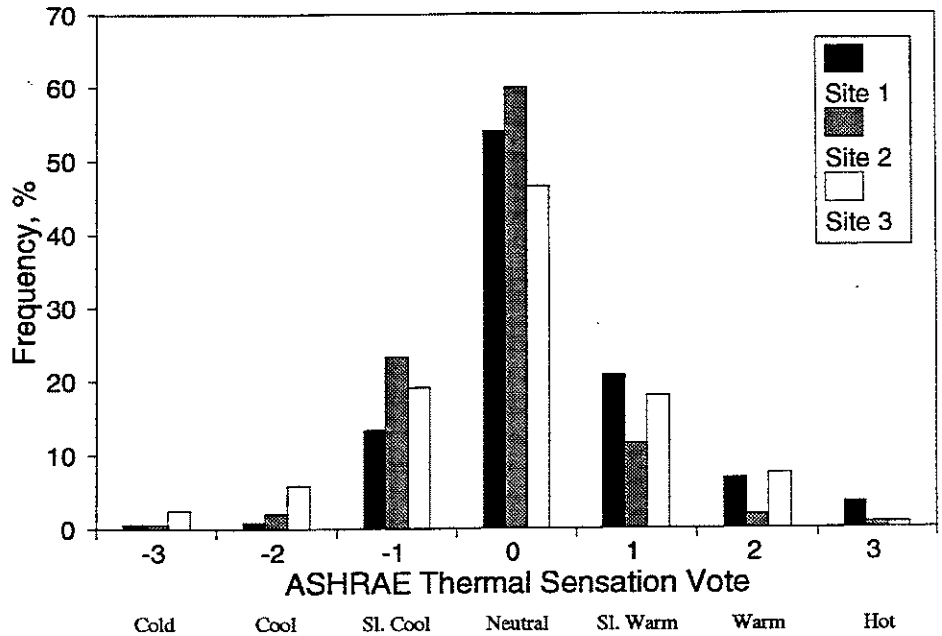


Figure 34. Frequency of response to the ASHRAE thermal sensation question, by Site.

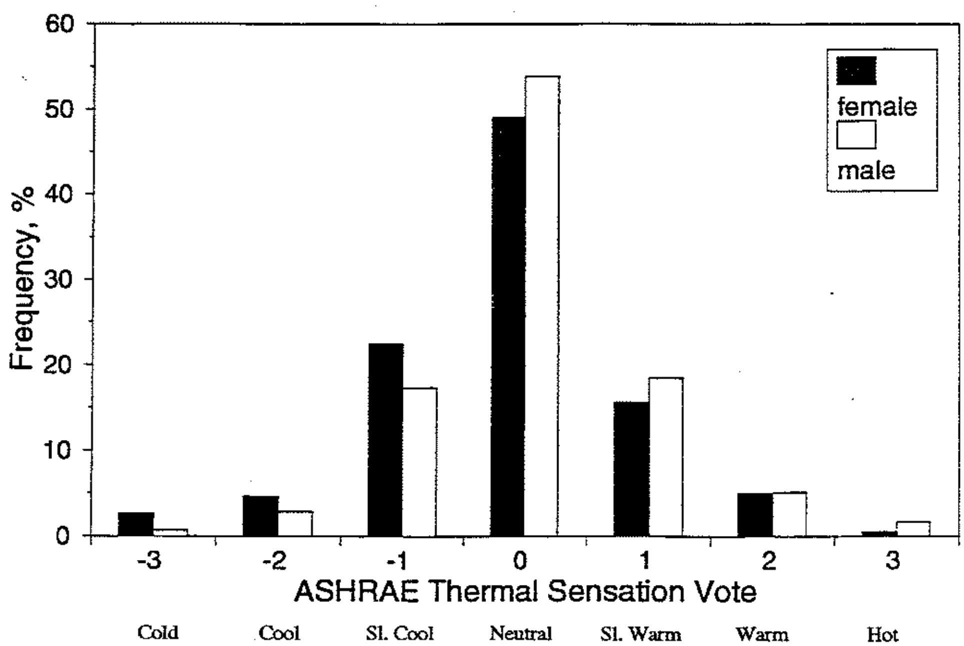


Figure 35. Frequency of response to the ASHRAE thermal sensation question, by Sex, data from all Sites pooled.

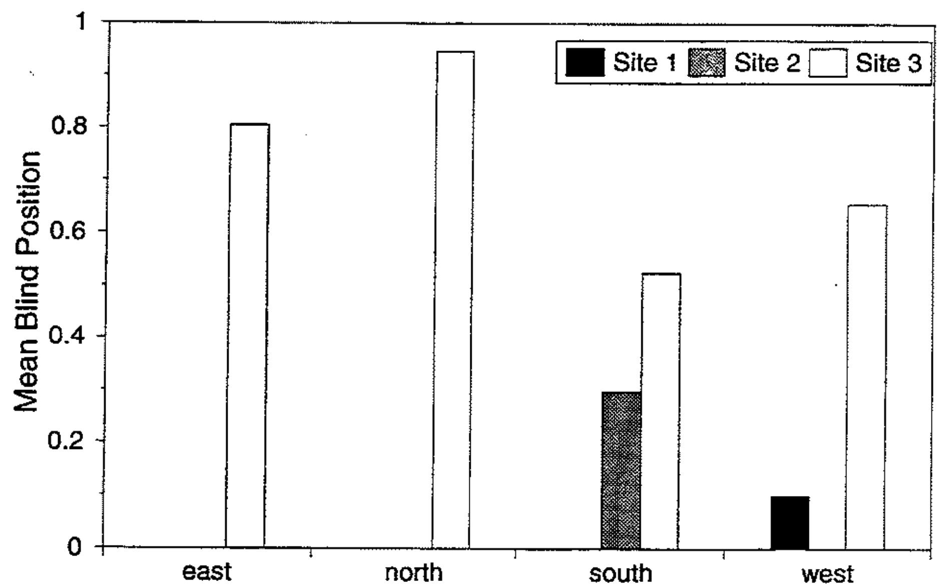


Figure 36. Mean reported window blind position, by Site and Orientation. '0' indicates blind fully closed, '1' indicates blind fully open.

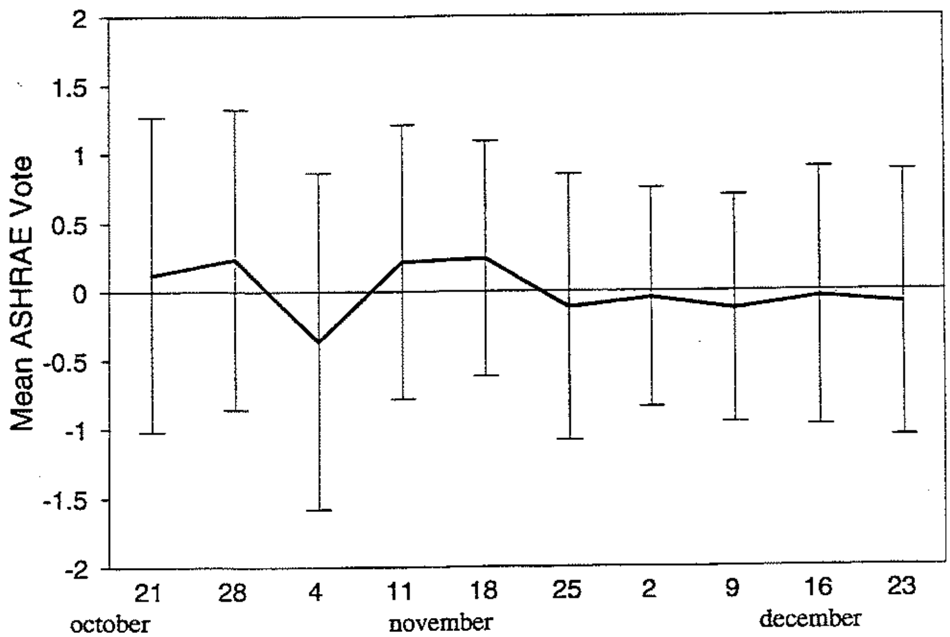


Figure 37. Mean weekly ASHRAE thermal sensation vote, data from all Sites. Error bars indicate standard deviations.

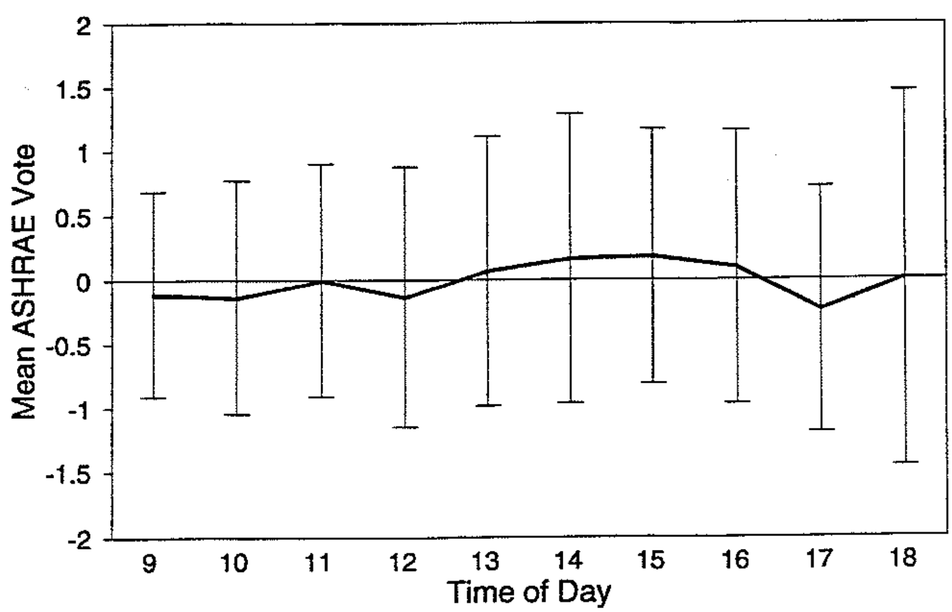


Figure 38. Mean hourly ASHRAE thermal sensation vote, data from all Sites. Error bars indicate standard deviations.

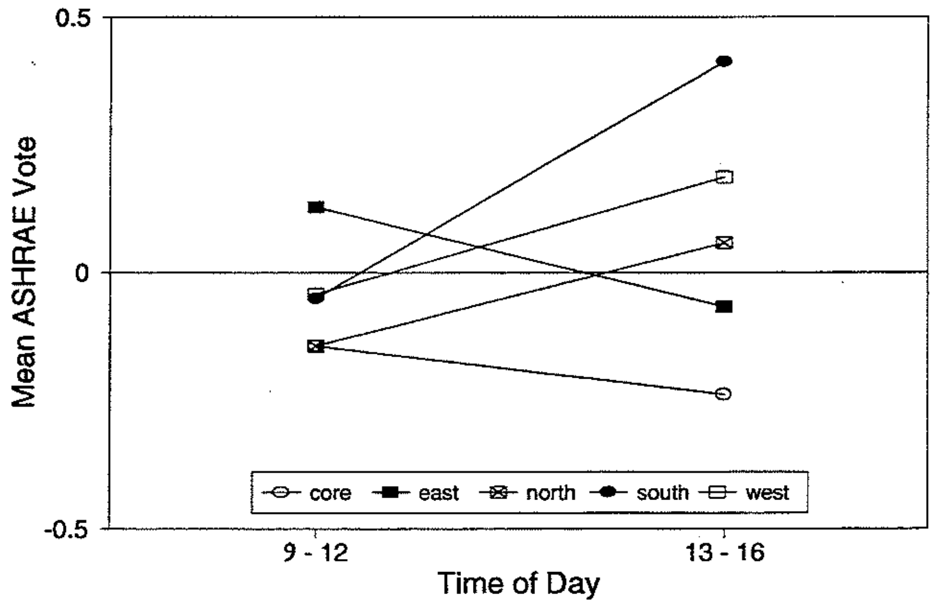


Figure 39. Mean ASHRAE thermal sensation vote in morning and afternoon, by orientation, for Site 3 only.

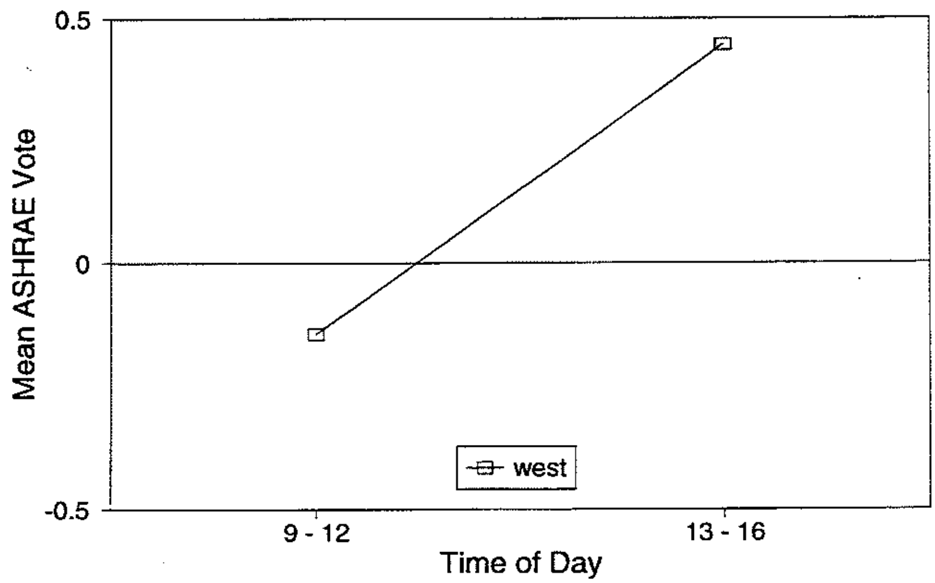


Figure 40. Mean ASHRAE thermal sensation vote in morning and afternoon, by orientation, for Site 1 only.

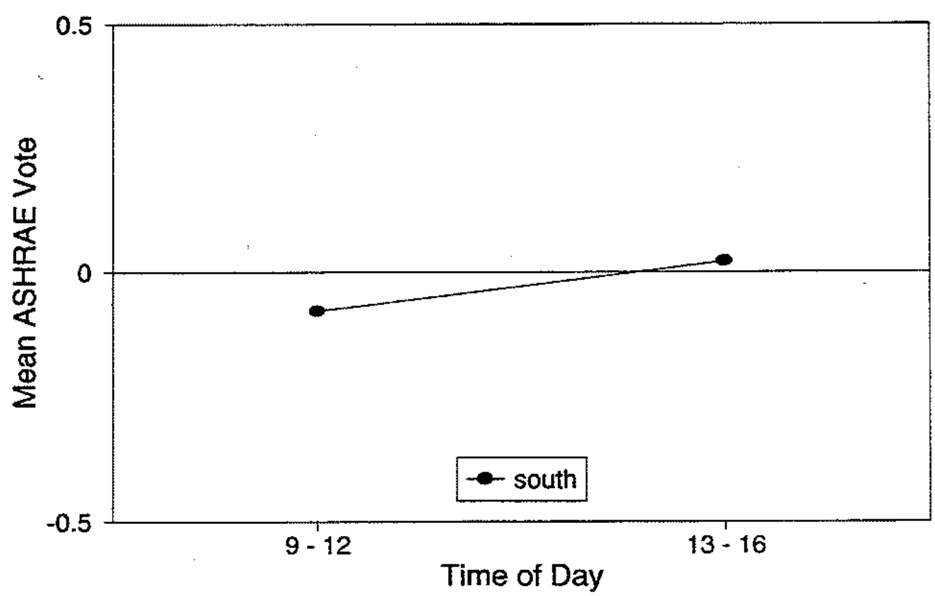


Figure 41. Mean ASHRAE thermal sensation vote in morning and afternoon, by orientation, for Site 2 only.

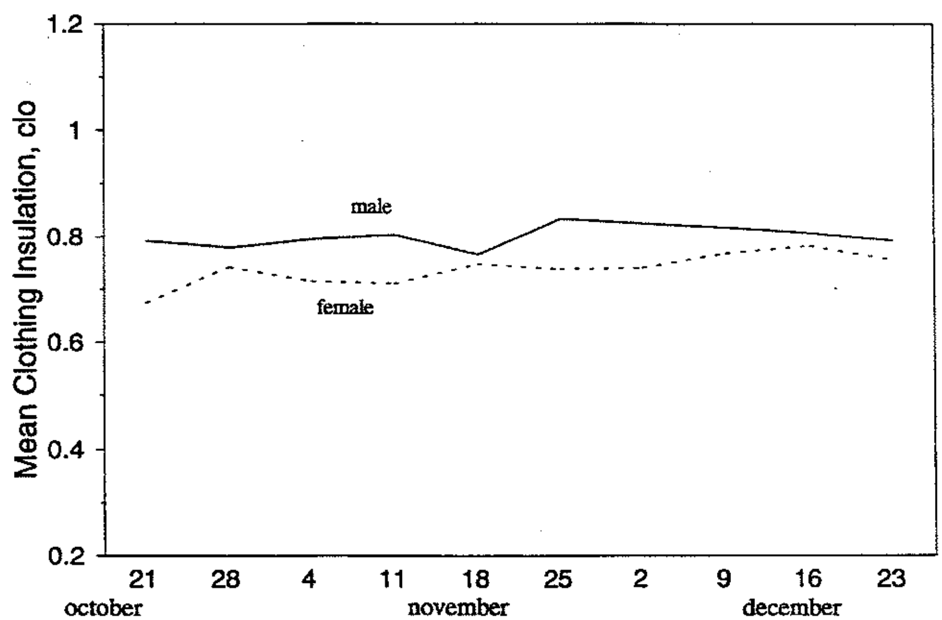


Figure 42. Mean weekly reported clothing insulation, by Sex, data from all Sites pooled.

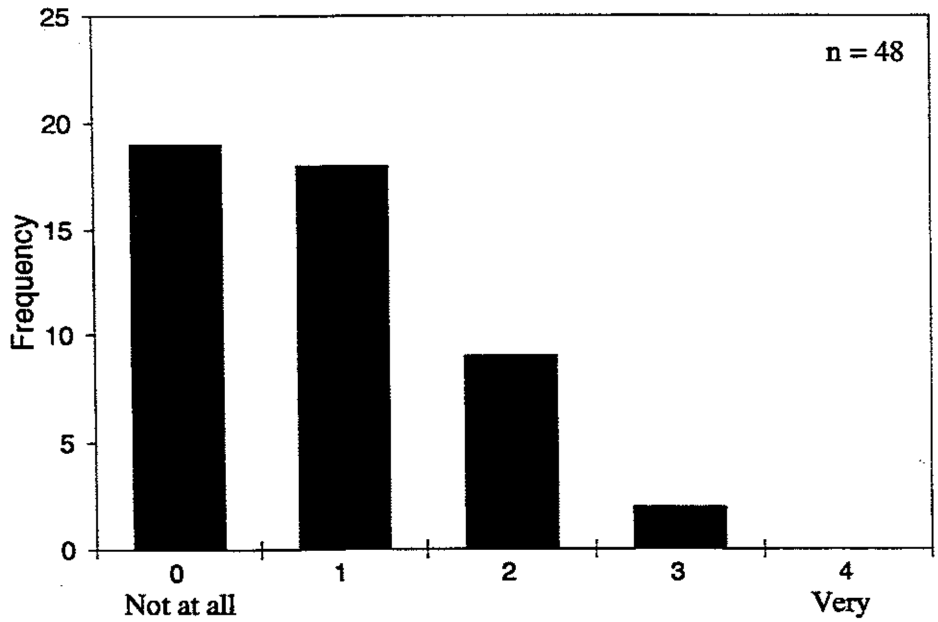


Figure 43. Final Evaluation Questionnaire: frequency of response to the question: 'Was the Warning Banner obtrusive?'

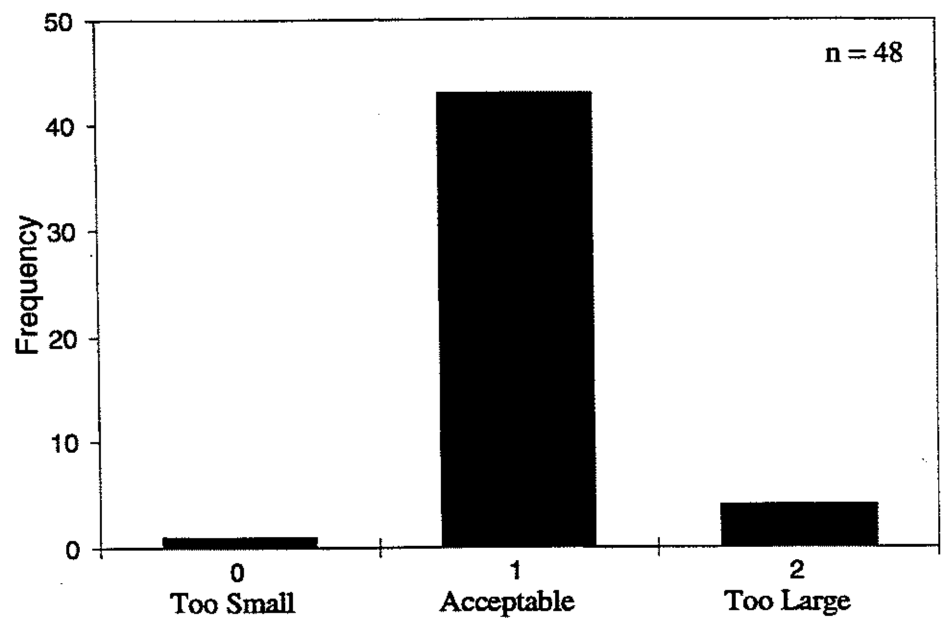


Figure 44. Final Evaluation Questionnaire: frequency of response to the question: 'Was the size of the Warning Banner ...?'

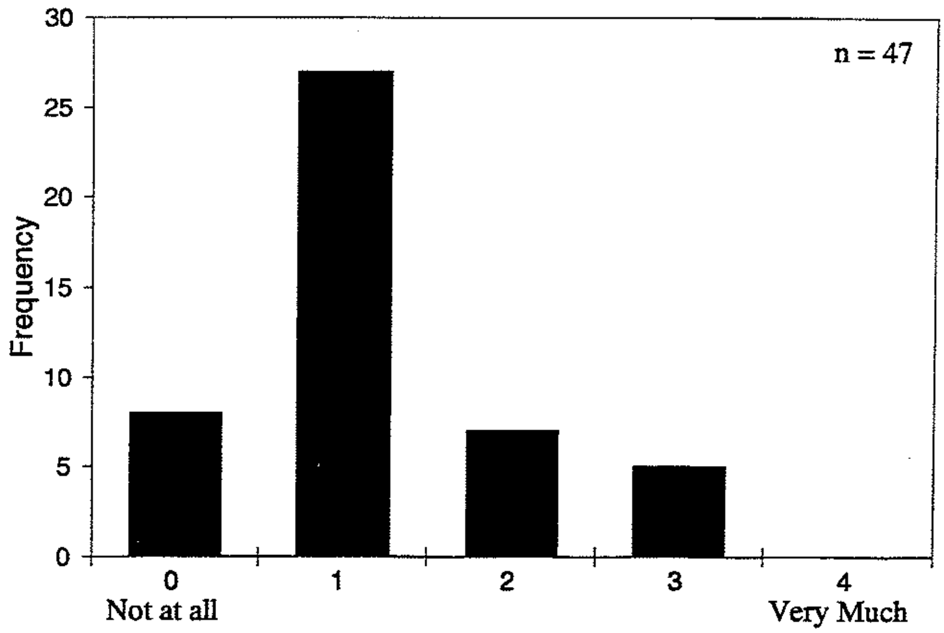


Figure 45. Final Evaluation Questionnaire: frequency of response to the question: 'Did the questionnaire distract you?'

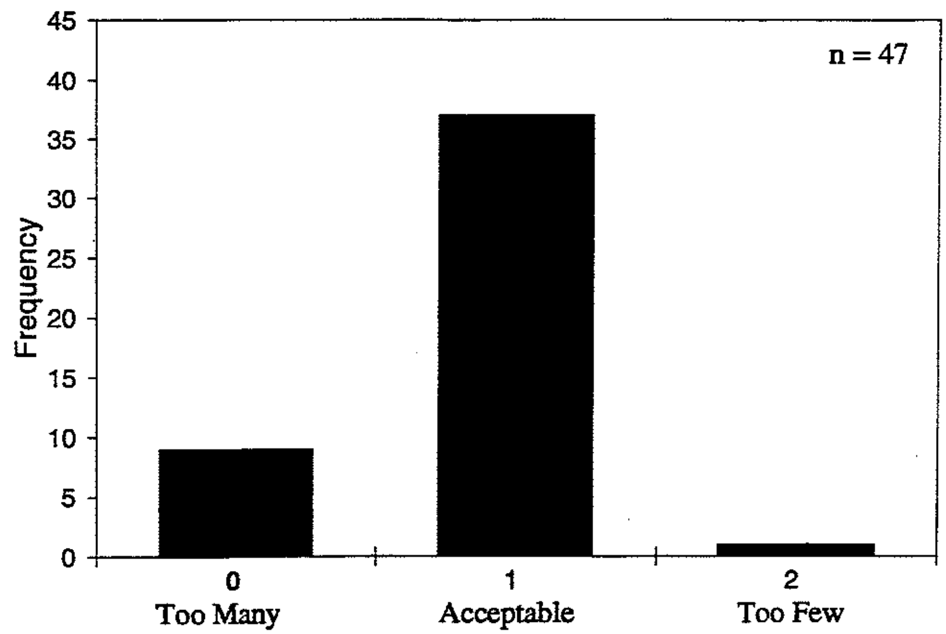


Figure 46. Final Evaluation Questionnaire: frequency of response to the question: 'Was the number of questions presented by the computer-based questionnaire each time ...?'

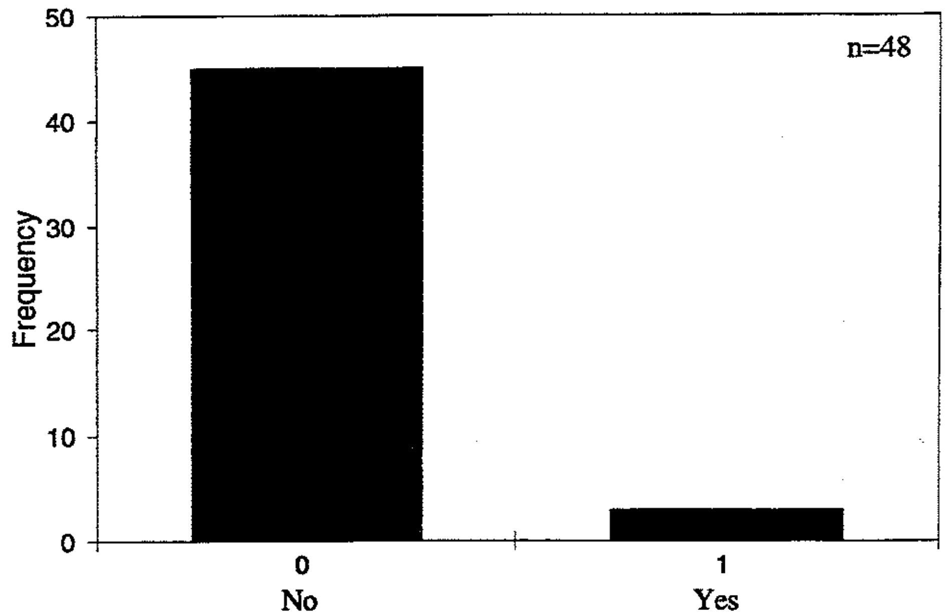


Figure 47. Final Evaluation Questionnaire: frequency of response to the question: 'Did the questionnaire appear too often?'

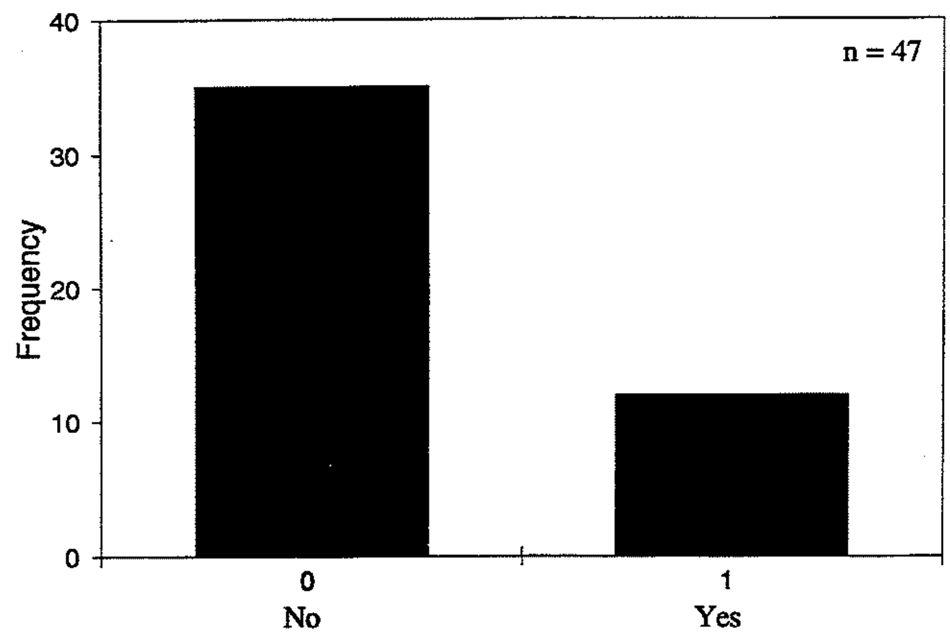


Figure 48. Final Evaluation Questionnaire: frequency of response to the question: 'Would you have liked to make the questionnaire appear on demand?'

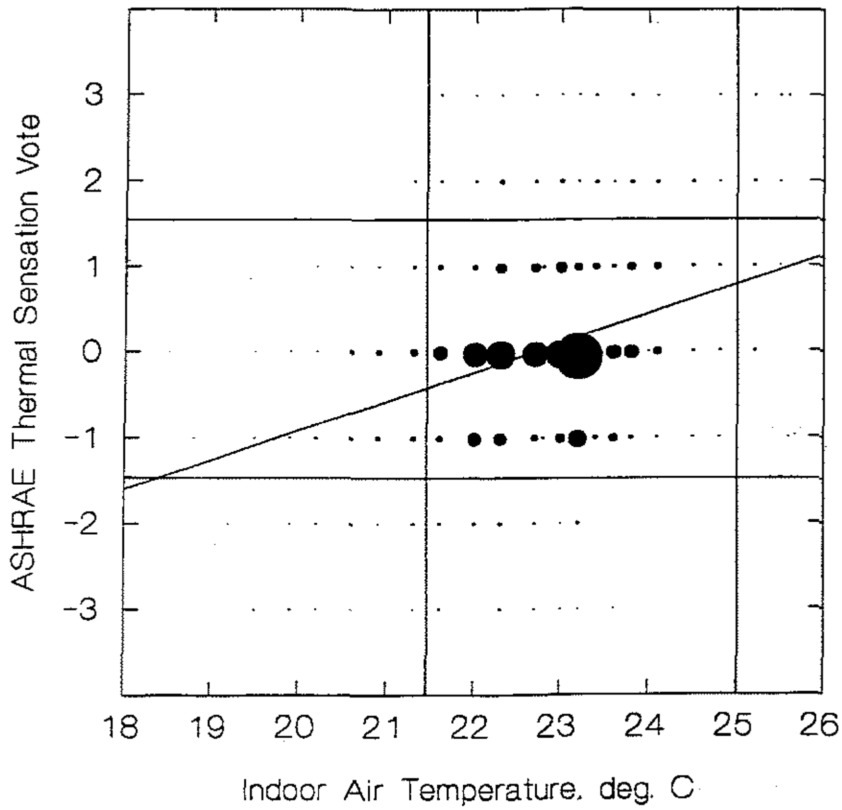


Figure 49. A bubble plot of ASHRAE thermal sensation vote vs. indoor air temperature, at all Sites. Horizontal lines indicate the range of votes considered acceptable; Vertical lines indicate the range of temperature recommended by ANSI/ASHRAE Standard.

Appendices

Appendix A

Consent Form for Participation in Indoor Environment Research Involving the National Research Council of Canada (NRC)

I have been asked to participate in a study concerning thermal comfort in the workplace.

I have received satisfactory answers to all my questions concerning the study.

I understand that I will receive no benefits from participation in this experiment.

I have been informed that I may withdraw my consent and discontinue my service as a research subject at any time I so desire. I have been informed that the researchers may end my participation in the project at any time.

I understand that the experiment will involve answering questionnaires administered on my computer screen by software resident on my computer. I understand that the software will not interfere with the normal operation of my computer, other than the inconvenience caused by the answering of the questions themselves.

I understand there are no known risks or hazards involved in this experiment.

I have been informed that my identity will not be revealed in any publication or document resulting from this research.

I understand that at the end of the study the results of the experiment will be made available to me.

Based on this information, I freely and voluntarily consent to serve as a subject in the research investigation entitled: **The effect of solar gain on subjective thermal sensation - a pilot study using a computer-based questionnaire.**

Signed this day of 19

In the City of in the Province of

Signature of Subject

Printed name of Subject

Principal Investigator:

Guy R. Newsham, Ph.D.
National Research Council of Canada
Ottawa, Ontario K1A 0R6

Sample Introductory Letter to Building Occupants

The Institute for Research in Construction of the National Research Council (IRC/NRC) has as one of its goals, improving the indoor environment of Canadian buildings while maintaining energy efficiency. Improvements should enhance the well-being of building occupants.

One aspect of the indoor environment which concerns occupants most is the thermal environment. Some people are dissatisfied with the thermal environment even in office buildings where accepted thermal guidelines are followed. Researchers have proposed that this dissatisfaction may be caused by short-term fluctuations in the thermal environment due to the incidence of sunshine on office buildings. We have developed a new computer-based questionnaire which will allow us to study these short-term fluctuations.

We would like to carry out a study in your building using the computer-based questionnaire. The study will serve as both a trial of this new software, and a means of gathering information on the thermal comfort conditions in your building.

We would be grateful if you would volunteer to participate in this study. You will not be rewarded for participating in the study; neither will a refusal to participate prejudice you in any way. Should you volunteer, you will be free to withdraw from the study at any subsequent time. The researchers also reserve the right to end your participation in the study at any subsequent time. Your identity will not be revealed in any document resulting from this study.

Should you choose to participate in this study software for administering questionnaires will be installed on your computer's hard disk. At dates and times specified by the researchers, a questionnaire will be administered on your computer screen. **Your answers to the questions will be saved in a hidden data file on your hard disk for later collection by researchers. All data collected will be treated confidentially; information identifying subjects with data will be known only to the researchers.** The software will not affect the normal operation of you computer in any way. There are no other known risks or hazards involved in this study.

In order to investigate changes in the thermal environment over time it is necessary to ask the same questions frequently. Therefore, you will be asked the same 5 questions twice per day (once in the morning and once in the afternoon) for a period of approximately 10 weeks. The time when the questions appear will vary from day-to-day. These questions will relate to your thermal comfort and your clothing. It should take no longer than 2 minutes to answer the questions each time they are asked. You may always cancel the questionnaire should you not wish to answer the questions at that time. It does not matter if you are away from your desk when the questions appear, if there is no response to the questionnaire the software will record this fact and return your computer to its previous state.

The study will begin in your department during August. An IRC researcher will visit you to demonstrate the software, explain the questions being asked, answer any questions you might have concerning the research, and obtain your written consent to participate in the research. The researcher will also arrange for a convenient time to install the software. The researcher will return a few days after the software is installed to ensure that is operating correctly.

We hope you will assist us in making this research project a success.

Should you require further information, please do not hesitate to contact Dr. Guy Newsham at (613) 993-9607.

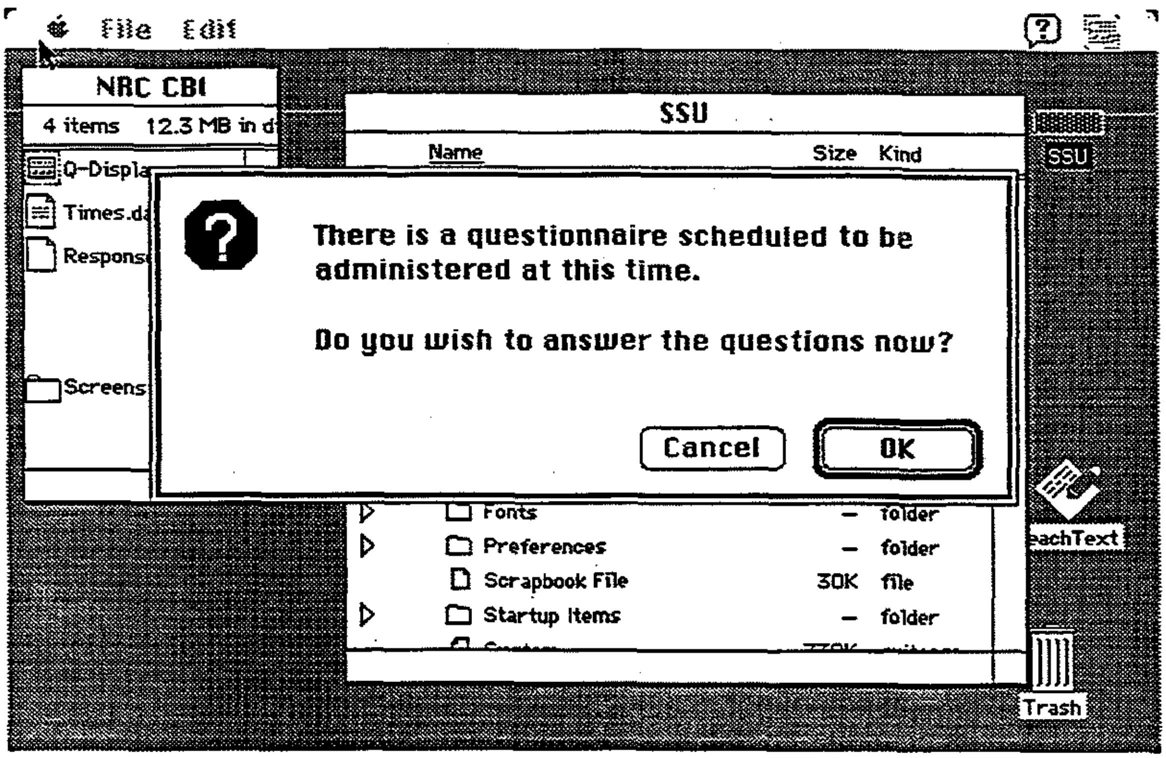
Thank you in advance for your co-operation.

****

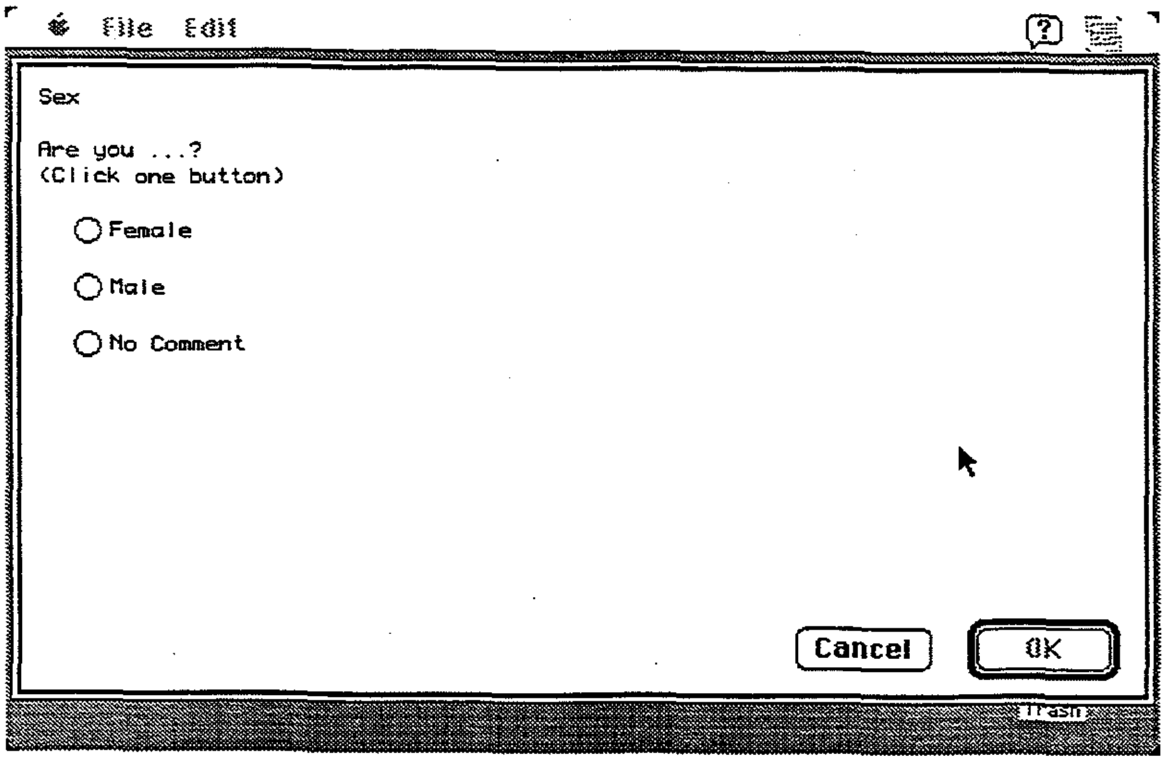
THE NRC THERMAL COMFORT QUESTIONNAIRE SOFTWARE HAS BEEN INSTALLED ON YOUR COMPUTER

****

Attached is some further information regarding each of the questions you will be asked.



Questions will always be preceded by a Warning Banner, asking you if you would like to answer the questions at that time. If you click "OK" the questions will follow immediately; if you click "Cancel", or if there is no response because you are away from your desk, the questions will be delayed until a later time.



The following four (4) *Demographic questions* will be asked only once, within a few minutes of first switching your computer on following software installation. They are asked only once because their answers are not expected to vary on a day-to-day basis.

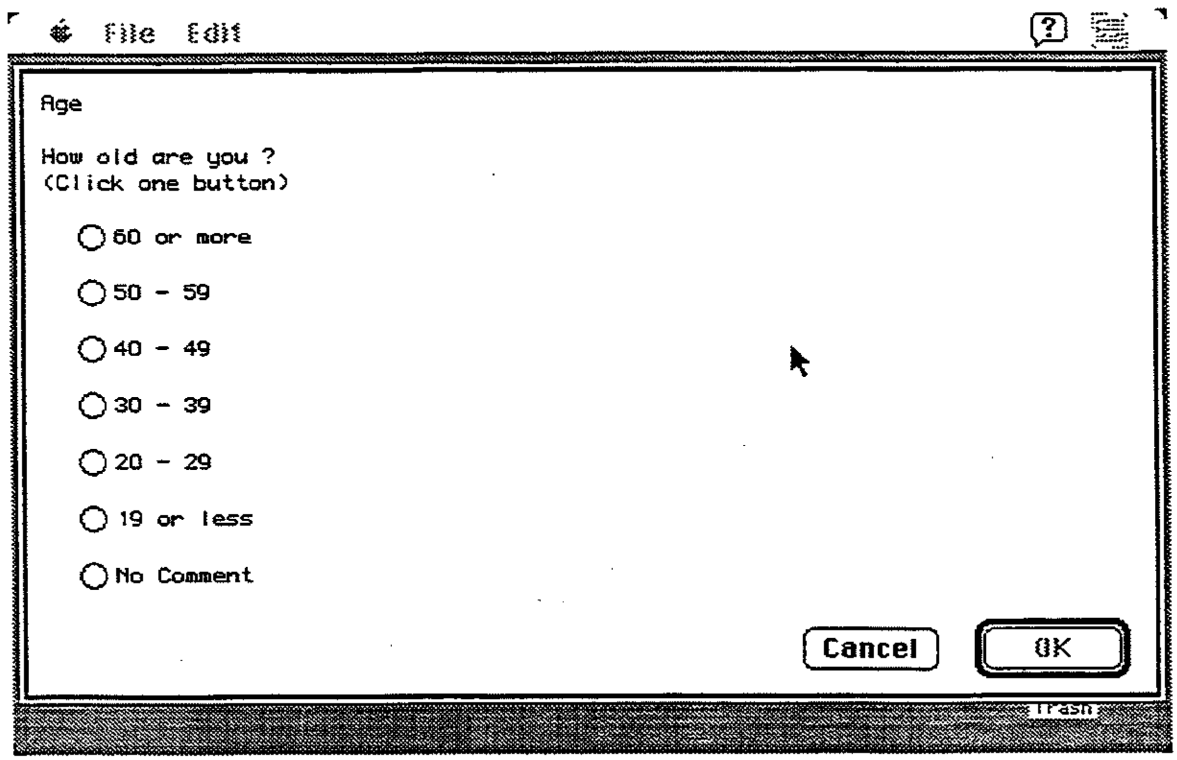
If you click "Cancel" (or do not respond) at the Warning Banner the Warning Banner will re-appear one hour later, and will continue to do so until the questions are answered. Similarly, if you click "Cancel" (or do not respond) when presented with an individual question that question will be asked again one hour later. If you do not wish to answer the question click "No Comment" followed by "OK"

Sex (Demographic Question)

"No Comment" is provided for those who do not wish to answer the question.

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

You must click one button before "OK" can be pressed.

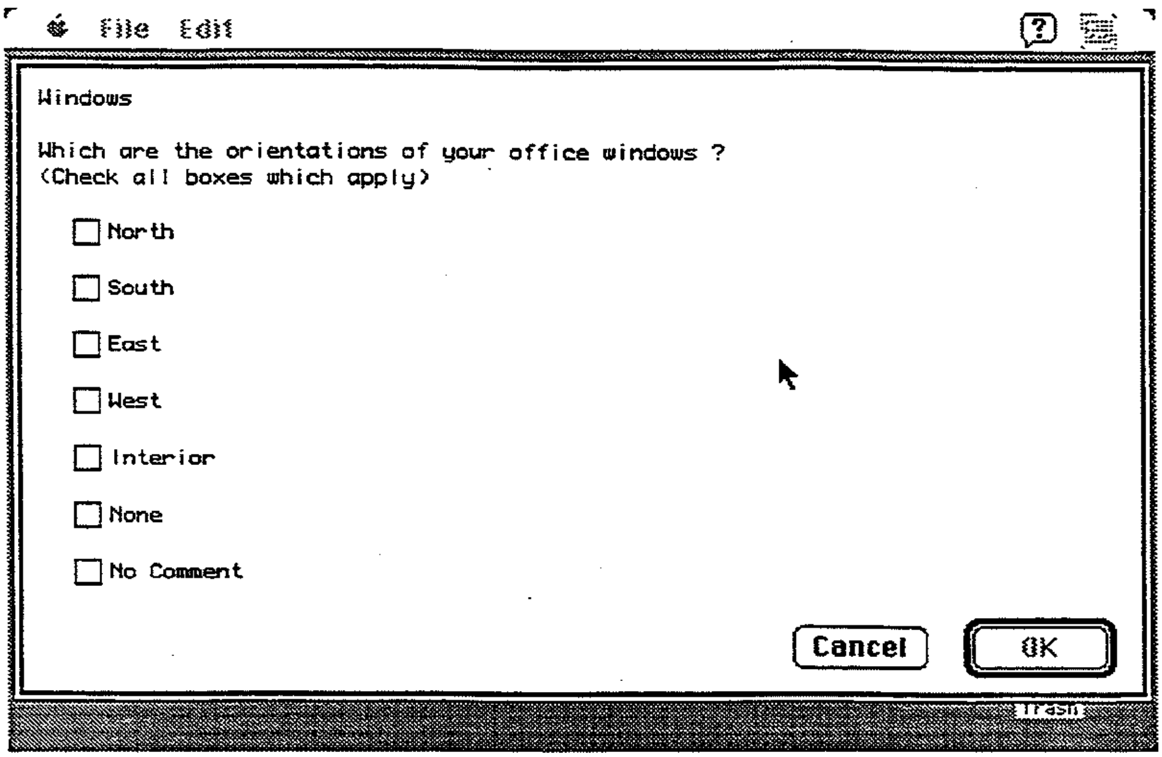


Age (Demographic Question)

"No Comment" is provided for those who do not wish to answer the question.

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

You must click one button before "OK" can be pressed.



Windows (Demographic Question)

"No Comment" is provided for those who do not wish to answer the question.

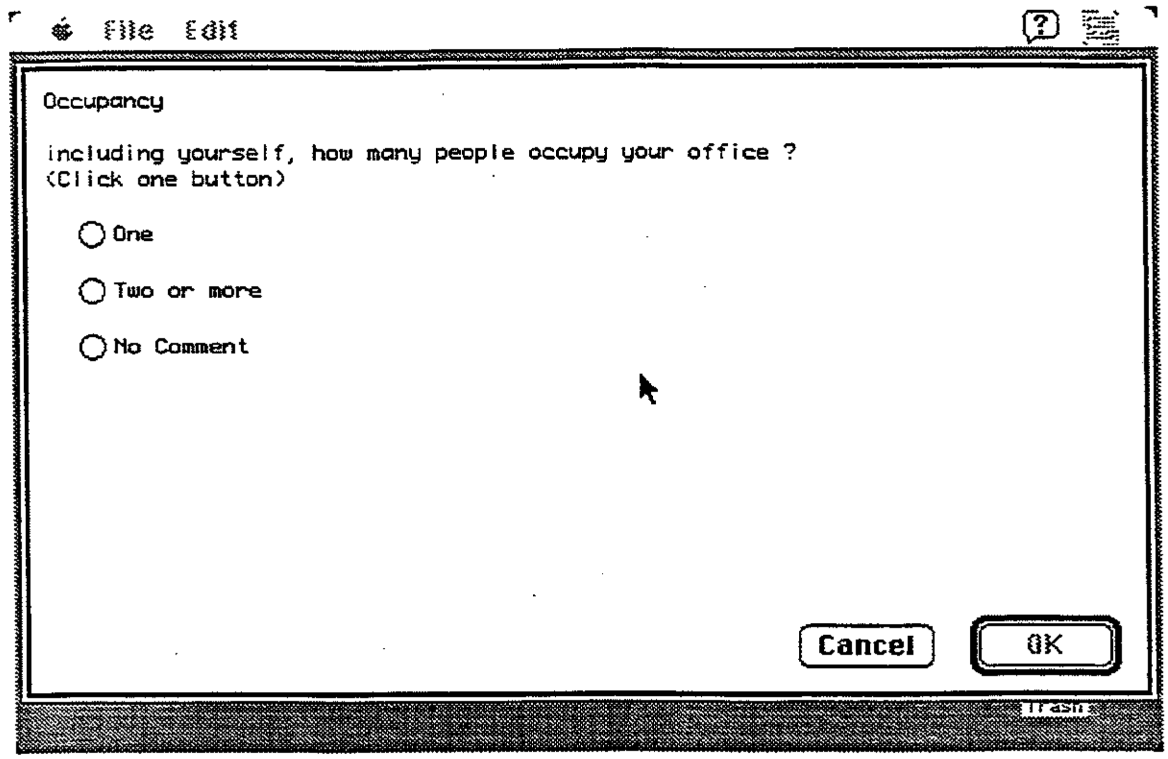
Record only windows in your own office, <u>not</u> windows in other people's offices which you can 'see' from your desk.

"North, South, East, West" should be used to describe the orientations of windows to the outside. "Interior" describes a glass window which faces onto another indoor space. "None" could be used to describe an office with opaque partition walls only, for example.

Approximate the orientation of a window to one of the four cardinal directions (North, South, East, West). A window facing South-East should be described as South or East <u>not</u> South and East; South and East should be used to describe two windows, one facing South and the other facing East.

You may check more than one box. Checking a box which was unchecked activates that box; checking a box which was already checked de-activates that box.

You must check one box before "OK" can be pressed.



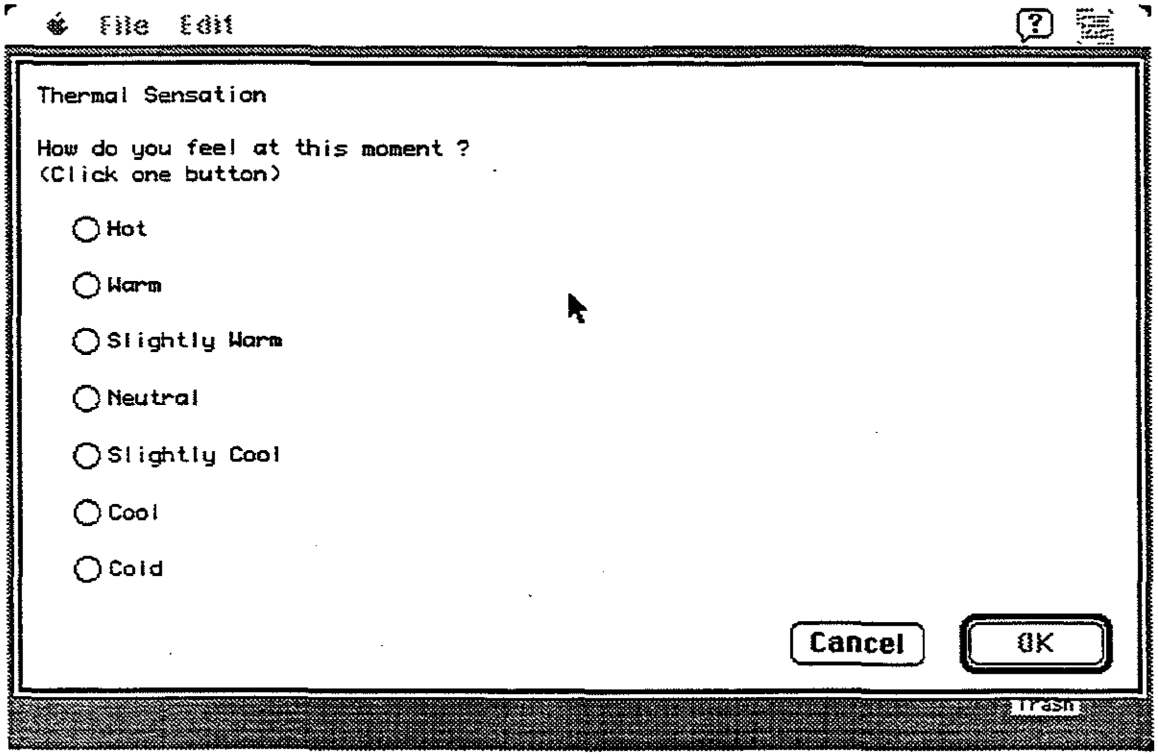
Occupancy (Demographic Question)

"No Comment" is provided for those who do not wish to answer the question.

Include only those who currently occupy desks 'within the walls' of your office, not others who work on the same floor but who are separated from you by a partition wall etc.

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

You must click one button before "OK" can be pressed.



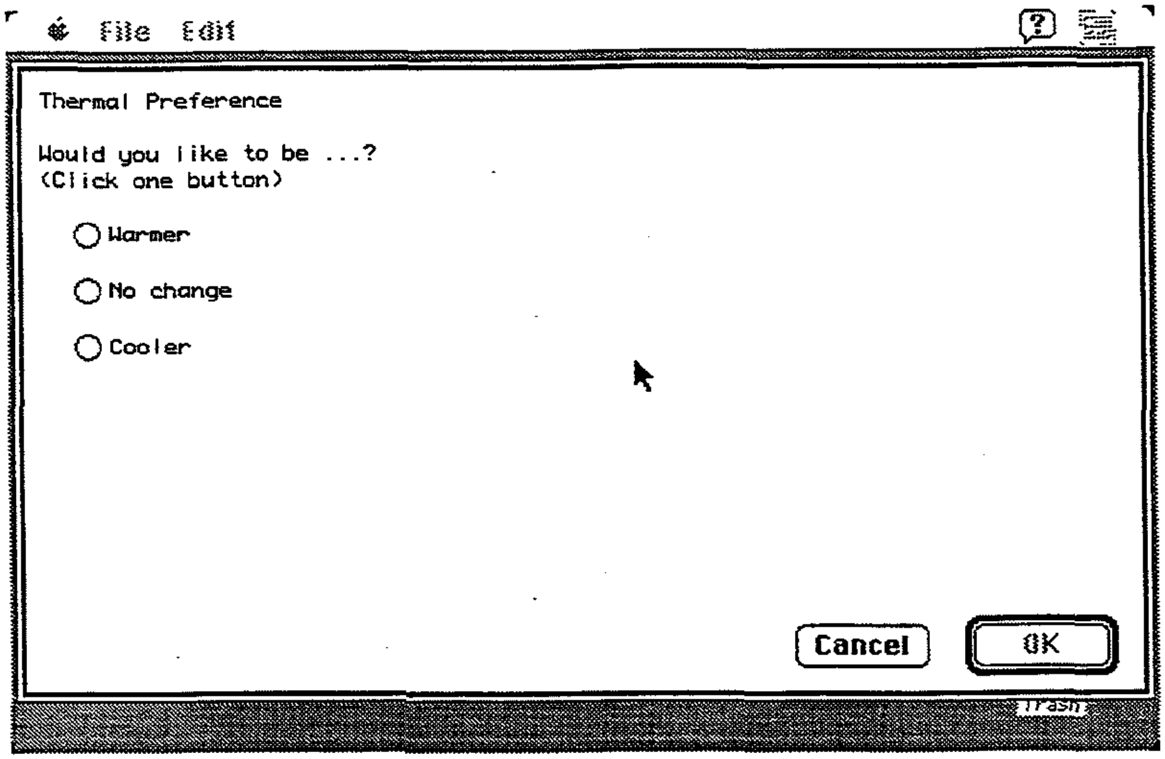
The following five (5) *Recurring questions* are scheduled to appear twice per day, once in the morning and once in the afternoon. They are asked with this frequency because their answers may vary on a day-to-day, or even hour-by-hour, basis.

If you click "Cancel" (or do not respond) at the Warning Banner the Warning Banner will re-appear one hour later, if there is still no answer the Warning Banner will not re-appear until the following morning or afternoon, as scheduled. You may click "Cancel" to avoid answering a question; the question will not be asked again until the whole set of five (5) questions are scheduled to be asked.

Thermal Sensation (Recurring Question)

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

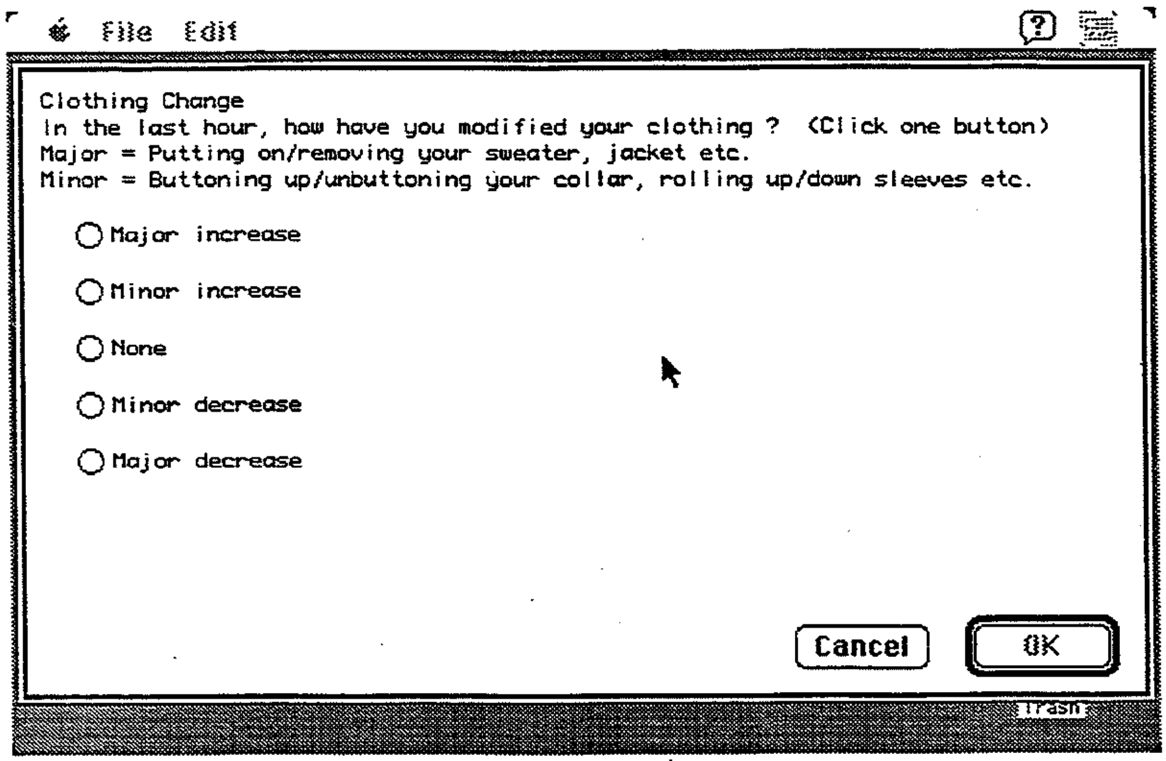
You must click one button before "OK" can be pressed.



Thermal Preference (Recurring Question)

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

You must click one button before "OK" can be pressed.



Clothing Change (Recurring Question)

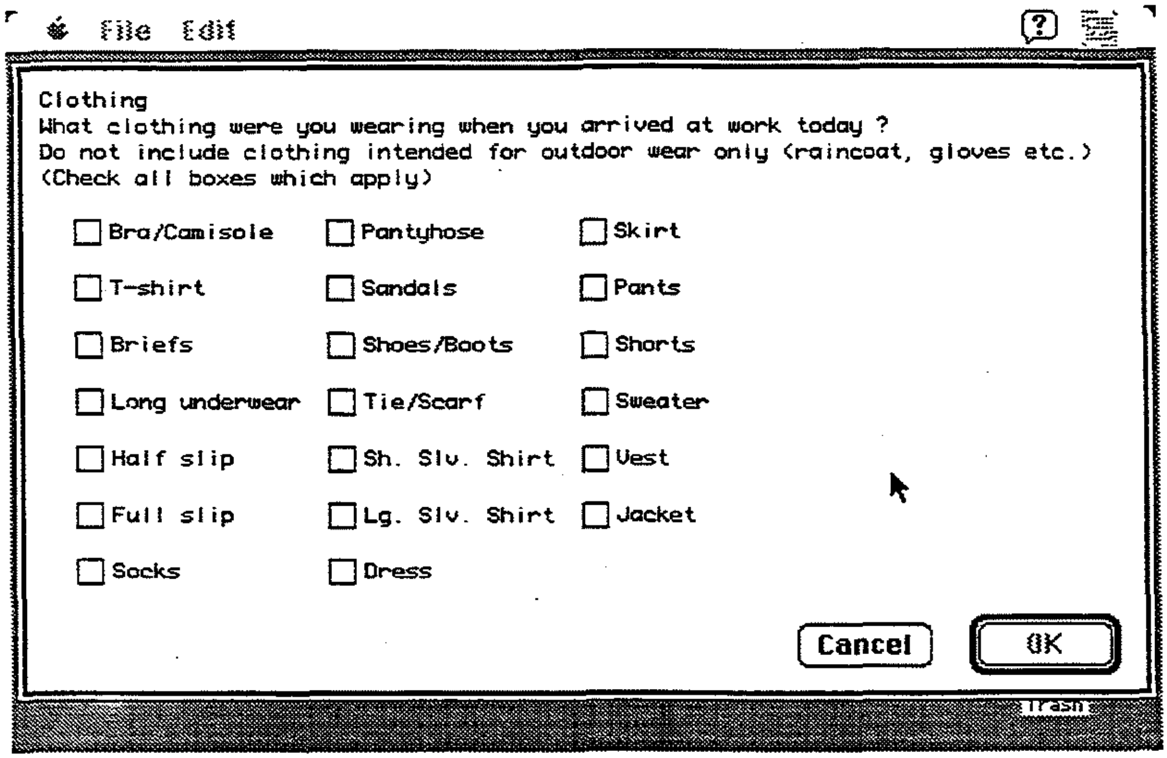
For example:

Major increase could be putting on a sweater or jacket
Minor increase could be rolling down sleeves or buttoning a collar
Minor decrease could be rolling up sleeves or unbuttoning a collar
Major decrease could be removing a sweater or jacket

If you have made more than one clothing change in the last hour, record the most recent change.

You may only click one button. Clicking a button activates that button and de-activates any other button which may have been activated.

You must click one button before "OK" can be pressed.



Clothing (Recurring Question)

Try to account for everything you are wearing. If the exact clothing type is not in the list of options choose something which is as close as possible; e.g., culottes could be described as "shorts".

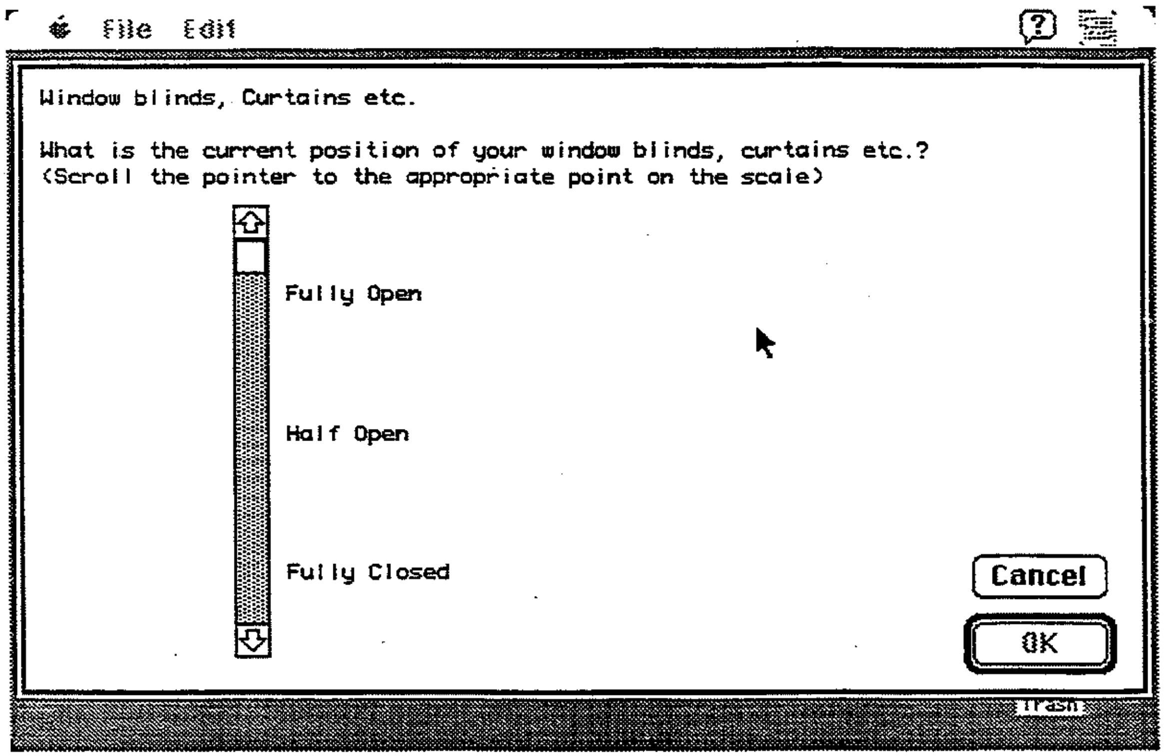
Abbreviations:

"Sh. Slv. Shirt"	= short sleeved shirt
"Lg. Slv. Shirt"	= long sleeved shirt

Include everything you were wearing at the <u>start</u> of the working day, do not include clothing for outdoor wear only (rain coat, gloves etc.).

You may check more than one box. Checking a box which was unchecked activates that box; checking a box which was already checked de-activates that box.

You must check one box before "OK" can be pressed.



Window Blinds, Curtains etc. (Recurring Question)

Whether your blinds/curtains are horizontal or vertical, use the scale as a graphic representation of how much of the window is covered. For example, if your blinds are three-quarters closed the pointer should be placed three-quarters of the way down the scale, between "half open" and "fully closed".

If you do not have a window to the outdoors just click "CANCEL" when this question appears.

Use the arrows to move the pointer to the appropriate part of the scale, or drag the pointer directly.

You must move the pointer before "OK" can be pressed.

Appendix B

The Questionnaire Schedule (TIMES.DAT file)

The following is a list of dates and times at which the questionnaire was scheduled to appear on the computer screens of the participants in our study. The codes Q1 to Q5 following the dates and times indicate the order in which the 5 recurring questions shown in Appendix A appeared.

Q1 = ASHRAE thermal sensation question.
Q2 = McIntyre thermal preference question.
Q3 = Clothing change question.
Q4 = Clothing worn to work question.
Q5 = Window blinds position question.

The questions were presented twice per day, once at a time up to and including 1300 hrs, and a second time after 1300 hrs. A two week schedule was repeated throughout the study period. During the two weeks, no presentation time appeared twice. The order of presentation of questions followed a pseudo-random sequence which was also repeated every two weeks. During a two week period there were 20 presentations of the questionnaire, but there are 120 possible ways of ordering the five questions. We used two rules to reduce the number of combinations:

Rule 1: Always ask Q4 before Q3; this was done to reduce confusion as to what clothing was to be recorded for Q4.

Rule 2: Always ask Q5 first or last; this question was not as directly related to the other questions, and not all participants had windows, therefore we felt we could reduce the number of question order combinations without seriously compromising the principal of randomness.

These two rules left 24 combinations of order of question presentation from which we chose 20.

26,09,94;08:30 Q5,Q1,Q4,Q2,Q3
26,09,94;13:30 Q4,Q2,Q1,Q3,Q5
27,09,94;09:30 Q5,Q1,Q2,Q4,Q3
27,09,94;14:30 Q5,Q4,Q2,Q1,Q3
28,09,94;10:30 Q4,Q2,Q3,Q1,Q5
28,09,94;15:30 Q5,Q4,Q3,Q1,Q2
29,09,94;11:30 Q4,Q1,Q3,Q2,Q5
29,09,94;16:30 Q4,Q3,Q2,Q1,Q5
30,09,94;12:30 Q2,Q4,Q1,Q3,Q5
30,09,94;17:30 Q1,Q4,Q2,Q3,Q5
03,10,94;13:00 Q4,Q3,Q2,Q1,Q5
03,10,94;17:00 Q5,Q4,Q1,Q3,Q2
04,10,94;12:00 Q5,Q4,Q2,Q3,Q1
04,10,94;18:00 Q1,Q2,Q4,Q3,Q5
05,10,94;10:00 Q5,Q2,Q4,Q3,Q1
05,10,94;15:00 Q2,Q4,Q3,Q1,Q5
06,10,94;11:00 Q2,Q1,Q4,Q3,Q5
06,10,94;14:00 Q5,Q2,Q4,Q1,Q3
07,10,94;09:00 Q5,Q4,Q1,Q2,Q3
07,10,94;16:00 Q5,Q2,Q4,Q3,Q1
10,10,94;08:30 Q5,Q1,Q4,Q2,Q3
10,10,94;13:30 Q4,Q2,Q1,Q3,Q5
11,10,94;09:30 Q5,Q1,Q2,Q4,Q3
11,10,94;14:30 Q5,Q4,Q2,Q1,Q3
12,10,94;10:30 Q4,Q2,Q3,Q1,Q5
12,10,94;15:30 Q5,Q4,Q3,Q1,Q2
13,10,94;11:30 Q4,Q1,Q3,Q2,Q5
13,10,94;16:30 Q4,Q3,Q2,Q1,Q5
14,10,94;12:30 Q2,Q4,Q1,Q3,Q5
14,10,94;17:30 Q1,Q4,Q2,Q3,Q5
17,10,94;13:00 Q4,Q3,Q2,Q1,Q5
17,10,94;17:00 Q5,Q4,Q1,Q3,Q2
18,10,94;12:00 Q5,Q4,Q2,Q3,Q1
18,10,94;18:00 Q1,Q2,Q4,Q3,Q5
19,10,94;10:00 Q5,Q2,Q4,Q3,Q1
19,10,94;15:00 Q2,Q4,Q3,Q1,Q5
20,10,94;11:00 Q2,Q1,Q4,Q3,Q5
20,10,94;14:00 Q5,Q2,Q4,Q1,Q3
21,10,94;09:00 Q5,Q4,Q1,Q2,Q3
21,10,94;16:00 Q5,Q2,Q4,Q3,Q1
24,10,94;08:30 Q5,Q1,Q4,Q2,Q3
24,10,94;13:30 Q4,Q2,Q1,Q3,Q5
25,10,94;09:30 Q5,Q1,Q2,Q4,Q3
25,10,94;14:30 Q5,Q4,Q2,Q1,Q3
26,10,94;10:30 Q4,Q2,Q3,Q1,Q5
26,10,94;15:30 Q5,Q4,Q3,Q1,Q2
27,10,94;11:30 Q4,Q1,Q3,Q2,Q5
27,10,94;16:30 Q4,Q3,Q2,Q1,Q5
28,10,94;12:30 Q2,Q4,Q1,Q3,Q5
28,10,94;17:30 Q1,Q4,Q2,Q3,Q5
31,10,94;13:00 Q4,Q3,Q2,Q1,Q5
31,10,94;17:00 Q5,Q4,Q1,Q3,Q2
01,11,94;12:00 Q5,Q4,Q2,Q3,Q1
01,11,94;18:00 Q1,Q2,Q4,Q3,Q5
02,11,94;10:00 Q5,Q2,Q4,Q3,Q1
02,11,94;15:00 Q2,Q4,Q3,Q1,Q5
03,11,94;11:00 Q2,Q1,Q4,Q3,Q5
03,11,94;14:00 Q5,Q2,Q4,Q1,Q3
04,11,94;09:00 Q5,Q4,Q1,Q2,Q3
04,11,94;16:00 Q5,Q2,Q4,Q3,Q1
07,11,94;08:30 Q5,Q1,Q4,Q2,Q3
07,11,94;13:30 Q4,Q2,Q1,Q3,Q5
08,11,94;09:30 Q5,Q1,Q2,Q4,Q3
08,11,94;14:30 Q5,Q4,Q2,Q1,Q3
09,11,94;10:30 Q4,Q2,Q3,Q1,Q5
09,11,94;15:30 Q5,Q4,Q3,Q1,Q2
10,11,94;11:30 Q4,Q1,Q3,Q2,Q5
10,11,94;16:30 Q4,Q3,Q2,Q1,Q5
11,11,94;12:30 Q2,Q4,Q1,Q3,Q5
11,11,94;17:30 Q1,Q4,Q2,Q3,Q5
14,11,94;13:00 Q4,Q3,Q2,Q1,Q5
14,11,94;17:00 Q5,Q4,Q1,Q3,Q2
15,11,94;12:00 Q5,Q4,Q2,Q3,Q1
15,11,94;18:00 Q1,Q2,Q4,Q3,Q5
16,11,94;10:00 Q5,Q2,Q4,Q3,Q1
16,11,94;15:00 Q2,Q4,Q3,Q1,Q5
17,11,94;11:00 Q2,Q1,Q4,Q3,Q5
17,11,94;14:00 Q5,Q2,Q4,Q1,Q3
18,11,94;09:00 Q5,Q4,Q1,Q2,Q3
18,11,94;16:00 Q5,Q2,Q4,Q3,Q1
21,11,94;08:30 Q5,Q1,Q4,Q2,Q3
21,11,94;13:30 Q4,Q2,Q1,Q3,Q5
22,11,94;09:30 Q5,Q1,Q2,Q4,Q3
22,11,94;14:30 Q5,Q4,Q2,Q1,Q3
23,11,94;10:30 Q4,Q2,Q3,Q1,Q5
23,11,94;15:30 Q5,Q4,Q3,Q1,Q2
24,11,94;11:30 Q4,Q1,Q3,Q2,Q5
24,11,94;16:30 Q4,Q3,Q2,Q1,Q5

25,11,94;12:30 Q2,Q4,Q1,Q3,Q5
25,11,94;17:30 Q1,Q4,Q2,Q3,Q5
28,11,94;13:00 Q4,Q3,Q2,Q1,Q5
28,11,94;17:00 Q5,Q4,Q1,Q3,Q2
29,11,94;12:00 Q5,Q4,Q2,Q3,Q1
29,11,94;18:00 Q1,Q2,Q4,Q3,Q5
30,11,94;10:00 Q5,Q2,Q4,Q3,Q1
30,11,94;15:00 Q2,Q4,Q3,Q1,Q5
01,12,94;11:00 Q2,Q1,Q4,Q3,Q5
01,12,94;14:00 Q5,Q2,Q4,Q1,Q3
02,12,94;09:00 Q5,Q4,Q1,Q2,Q3
02,12,94;16:00 Q5,Q2,Q4,Q3,Q1
05,12,94;08:30 Q5,Q1,Q4,Q2,Q3
05,12,94;13:30 Q4,Q2,Q1,Q3,Q5
06,12,94;09:30 Q5,Q1,Q2,Q4,Q3
06,12,94;14:30 Q5,Q4,Q2,Q1,Q3
07,12,94;10:30 Q4,Q2,Q3,Q1,Q5
07,12,94;15:30 Q5,Q4,Q3,Q1,Q2
08,12,94;11:30 Q4,Q1,Q3,Q2,Q5
08,12,94;16:30 Q4,Q3,Q2,Q1,Q5
09,12,94;12:30 Q2,Q4,Q1,Q3,Q5
09,12,94;17:30 Q1,Q4,Q2,Q3,Q5
12,12,94;13:00 Q4,Q3,Q2,Q1,Q5
12,12,94;17:00 Q5,Q4,Q1,Q3,Q2
13,12,94;12:00 Q5,Q4,Q2,Q3,Q1
13,12,94;18:00 Q1,Q2,Q4,Q3,Q5
14,12,94;10:00 Q5,Q2,Q4,Q3,Q1
14,12,94;15:00 Q2,Q4,Q3,Q1,Q5
15,12,94;11:00 Q2,Q1,Q4,Q3,Q5
15,12,94;14:00 Q5,Q2,Q4,Q1,Q3
16,12,94;09:00 Q5,Q4,Q1,Q2,Q3
16,12,94;16:00 Q5,Q2,Q4,Q3,Q1
19,12,94;08:30 Q5,Q1,Q4,Q2,Q3
19,12,94;13:30 Q4,Q2,Q1,Q3,Q5
20,12,94;09:30 Q5,Q1,Q2,Q4,Q3
20,12,94;14:30 Q5,Q4,Q2,Q1,Q3
21,12,94;10:30 Q4,Q2,Q3,Q1,Q5
21,12,94;15:30 Q5,Q4,Q3,Q1,Q2
22,12,94;11:30 Q4,Q1,Q3,Q2,Q5
22,12,94;16:30 Q4,Q3,Q2,Q1,Q5
23,12,94;12:30 Q2,Q4,Q1,Q3,Q5
23,12,94;17:30 Q1,Q4,Q2,Q3,Q5
26,12,94;13:00 Q4,Q3,Q2,Q1,Q5
26,12,94;17:00 Q5,Q4,Q1,Q3,Q2
27,12,94;12:00 Q5,Q4,Q2,Q3,Q1
27,12,94;18:00 Q1,Q2,Q4,Q3,Q5
28,12,94;10:00 Q5,Q2,Q4,Q3,Q1
28,12,94;15:00 Q2,Q4,Q3,Q1,Q5
29,12,94;11:00 Q2,Q1,Q4,Q3,Q5
29,12,94;14:00 Q5,Q2,Q4,Q1,Q3
30,12,94;09:00 Q5,Q4,Q1,Q2,Q3
30,12,94;16:00 Q5,Q2,Q4,Q3,Q1
02,01,95;08:30 Q5,Q1,Q4,Q2,Q3
02,01,95;13:30 Q4,Q2,Q1,Q3,Q5
03,01,95;09:30 Q5,Q1,Q2,Q4,Q3
03,01,95;14:30 Q5,Q4,Q2,Q1,Q3
04,01,95;10:30 Q4,Q2,Q3,Q1,Q5
04,01,95;15:30 Q5,Q4,Q3,Q1,Q2
05,01,95;11:30 Q4,Q1,Q3,Q2,Q5
05,01,95;16:30 Q4,Q3,Q2,Q1,Q5
06,01,95;12:30 Q2,Q4,Q1,Q3,Q5
06,01,95;17:30 Q1,Q4,Q2,Q3,Q5
09,01,95;13:00 Q4,Q3,Q2,Q1,Q5
09,01,95;17:00 Q5,Q4,Q1,Q3,Q2
10,01,95;12:00 Q5,Q4,Q2,Q3,Q1
10,01,95;18:00 Q1,Q2,Q4,Q3,Q5
11,01,95;10:00 Q5,Q2,Q4,Q3,Q1
11,01,95;15:00 Q2,Q4,Q3,Q1,Q5
12,01,95;11:00 Q2,Q1,Q4,Q3,Q5
12,01,95;14:00 Q5,Q2,Q4,Q1,Q3
13,01,95;09:00 Q5,Q4,Q1,Q2,Q3
13,01,95;16:00 Q5,Q2,Q4,Q3,Q1

Appendix C

Post-study Questionnaire

i.d. # ________

Thank you for participating in IRC/NRC's study of your office's thermal environment. You were informed at the start of the study that this study would serve as a trial of the computer-based questionnaire. We would be grateful if you would answer the following questions. Your responses will help us to improve the software and its application.

Please answer by circling the appropriate response

Did you answer any of the questions presented by the software ...?

YES NO

If you answered YES to this question please proceed to the following questions. If you answered NO to there is no need to answer further questions. Thank you.

Was the appearance of the Warning Banner obtrusive ?

Not at all				Very
0	1	2	3	4

Was the size of the Warning Banner ...?

Too Small Acceptable Too Large

Did this method of automatic questionnaire administration distract you from your work ?

Not at all				Very Much
0	1	2	3	4

Were the number of questions asked each time the questionnaire appeared ...?

Too Many Acceptable Too Few

Did the questionnaire appear too often?

YES NO

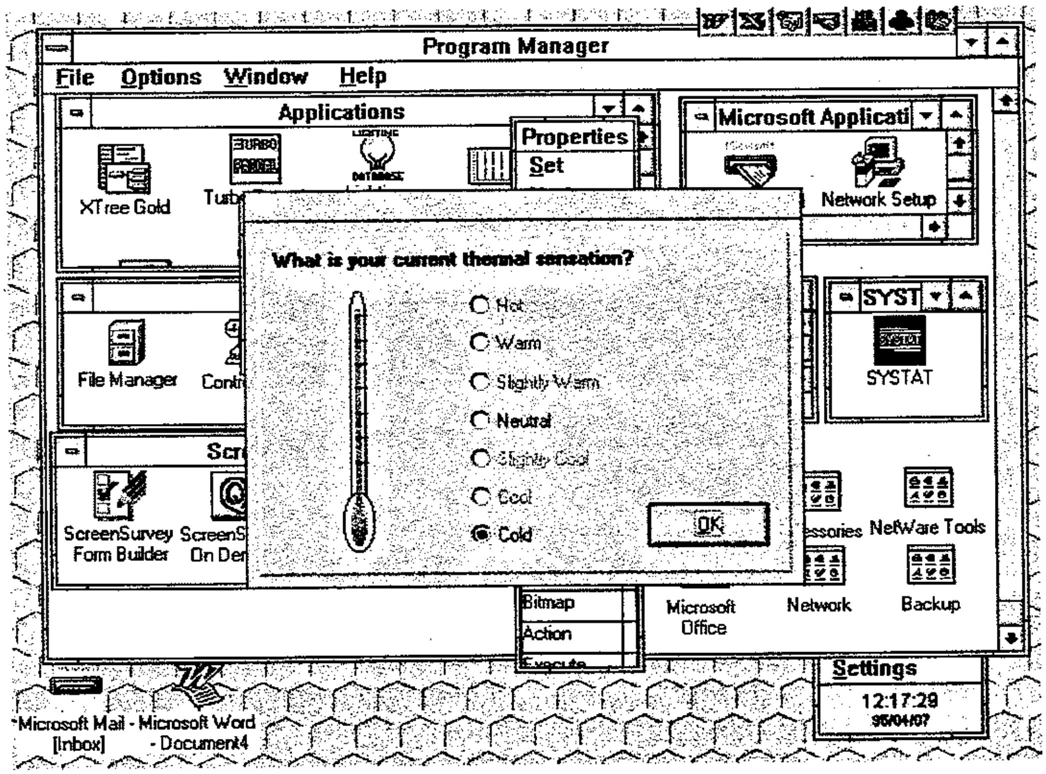
Would you have liked to make the questionnaire appear on demand?

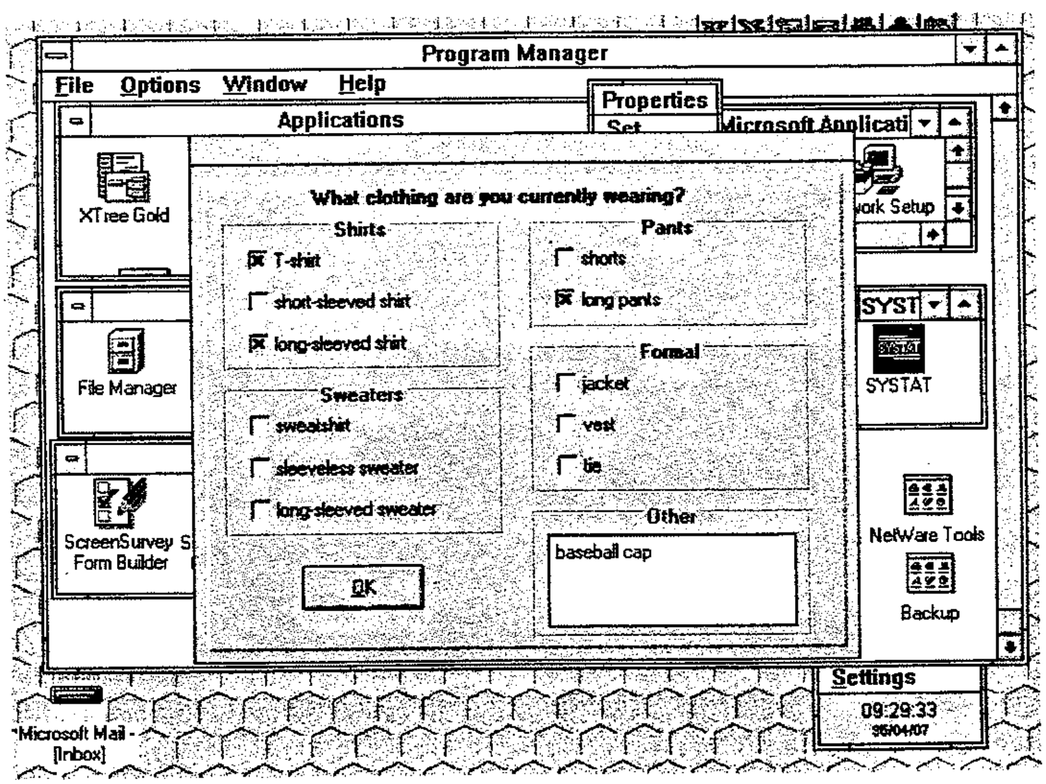
YES NO

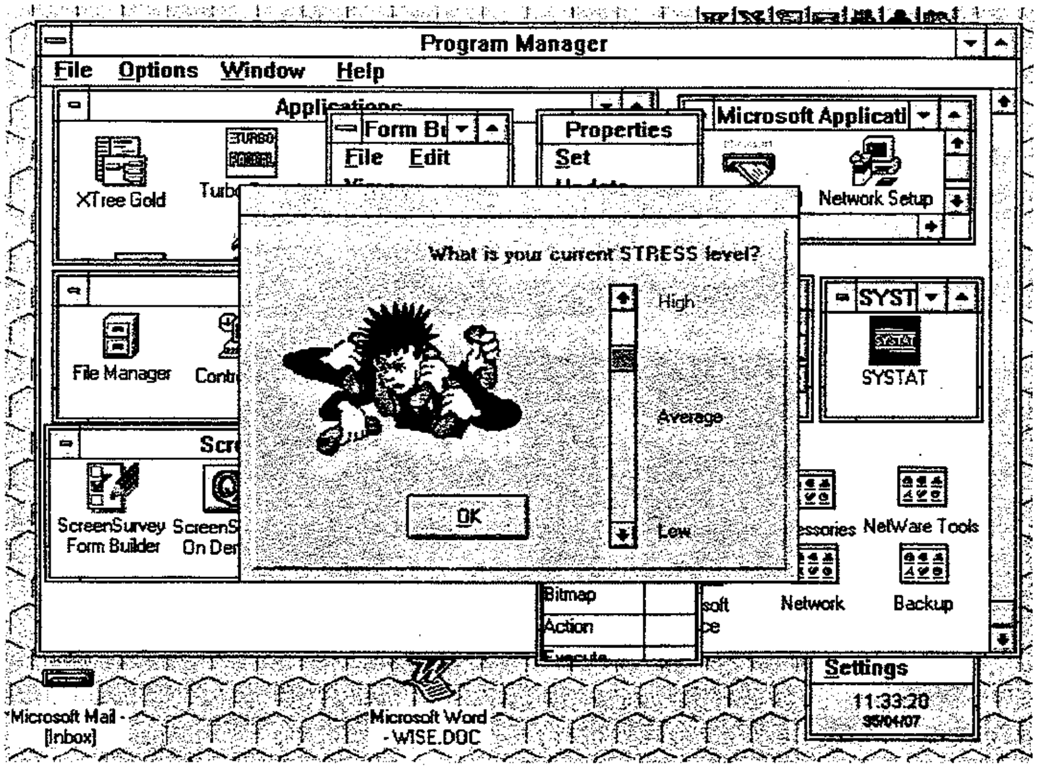
Any other comments ...?

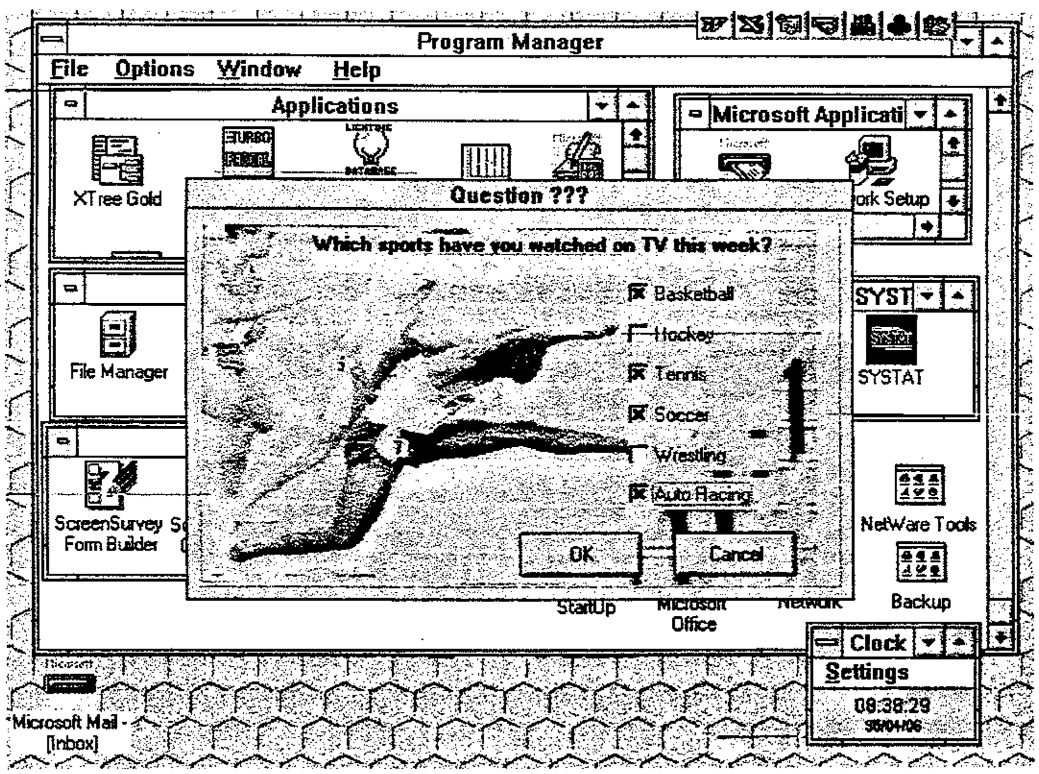
Thank you for your co-operation. Should you require further information, please do not hesitate to contact Dr. Guy Newsham at (613) 993-9607.

Appendix D


Program Manager
File Options Window Help
Applications
Properties
Set
Microsoft Applicati
XTree Gold
Network Setup
What is your current thermal sensation?
Hot
Warm
Slightly Warm
Neutral
Slightly Cool
Cool
Cold
OK
File Manager
SYSTAT
ScreenSurvey Form Builder
NetWare Tools
Bitmap
Action
Microsoft Office
Network
Backup
Settings
12:17:29
Microsoft Mail - [Inbox]
Microsoft Word - Document4


Program Manager
File Options Window Help
Properties
Applications
XTree Gold
What clothing are you currently wearing?
Shirts
T-shirt
short-sleeved shirt
long-sleeved shirt
Pants
shorts
long pants
Sweaters
sweatshirt
sleeveless sweater
long-sleeved sweater
Formal
jacket
vest
tie
Other
baseball cap
OK
File Manager
SYSTAT
ScreenSurvey Form Builder
NetWare Tools
Backup
Settings
09:29:33
Microsoft Mail - [Inbox]


Program Manager
File Options Window Help
Applications
Form Bu
File Edit
Properties
Set
Microsoft Applicati
Network Setup
XTree Gold
What is your current STRESS level?
High
Average
Low
OK
SYST
SYSTAT
File Manager
ScreenSurvey Form Builder
NetWare Tools
Network
Backup
Bitmap
Action
Settings
11:33:20
Microsoft Mail - [Inbox]
Microsoft Word - WISE.DOC


Program Manager
File Options Window Help
Applications
Microsoft Applicati
XTree Gold
Question ???
Which sports have you watched on TV this week?
Basketball
Hockey
Tennis
Soccer
Wrestling
Auto Racing
OK
Cancel
SYST
SYSTAT
File Manager
ScreenSurvey Form Builder
NetWare Tools
Backup
StartUp
Office
Clock
Settings
08:38:29
Microsoft Mail - [Inbox]