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Case Studies of Thermal Comfort for People with Physical Disabilities

Lynda H. Webb, Ph.D.

Kenneth C. Parsons, Ph.D.
Member ASHRAE

ABSTRACT

This paper presents the results of a comparative study of the thermal comfort requirements of people with physical disabilities and those of people without physical disabilities. In addition, the study also identifies if present comfort standards set by Fanger's thermal comfort model can be used to predict comfort conditions for people with and without physical disabilities.

Results indicate that when people with physical disabilities are grouped and mean scores are used, their thermal comfort requirements may not differ from those of people without physical disabilities. Results showed that subjects responded as predicted by Fanger's thermal comfort model with regard to the predicted mean vote (PMV). However, the range of responses for people with physical disabilities is much greater than that of people without physical disabilities at predicted mean votes (PMV) of −1.5 (slightly cool) and 0 (neutral). This study considers each subject with physical disabilities case by case. When considered individually, there was little agreement between the subjects' preferred environments. The relationship between actual votes and predicted mean votes also varied between individuals and between environments for the same individual.

INTRODUCTION

Thermal comfort requirements have been the topic of formal laboratory and "field" research for more than 100 years, and much is known about comfort conditions for "able bodied" workers in indoor environments. Little is known, however, about requirements for people with physical disabilities in terms of whether requirements are significantly different from those of people without physical disabilities, whether current methods used to establish comfort conditions are appropriate for people with physical disabilities, and the extent to which deviations from comfort conditions affect the degree of discomfort of people with physical disabilities. The answer to these questions may depend on the type of physical disability, but this is also not known. For the purpose of this study, people with physical disabilities were not grouped. The disabilities included were not restricted to those conditions for which physiological effects of the disability may be expected to affect the thermal comfort requirements of the person. Since little work has been carried out in this area, the study addressed the question of whether or not people with physical disabilities differed in thermal comfort requirements from those of people without physical disabilities. The study did not make any assumptions as to which disabilities would or would not affect thermal comfort requirements. Methods of grouping subjects with respect to thermal comfort requirements have yet to be determined, and this study will contribute to the establishment of such methods. The aim of the laboratory experiment presented in this report was to address the above questions for both male and female subjects. The results, as well as the experience in conducting the experiment, are intended to provide insight into thermal comfort requirements, issues, and paradigms relevant to a range of people with physical disabilities.

Thermal comfort has been defined as "the condition of mind that expresses satisfaction with the thermal environment" (ISO 1994). The reference to "mind" emphasizes that comfort is a psychological phenomena. It is, therefore, often "measured" using subjective methods. Over many years, empirical research has related environmental conditions to physiological and subjective responses of subjects. Rational analysis using equations for heat transfer between the clothed human and the environment has been combined with empirical thermal comfort research to produce established methods for predicting the thermal comfort, and degree of discomfort, of people exposed to a wide range of environmental conditions. This is the basis of Fanger's (1970) predicted mean vote (PMV) thermal comfort index, which is now accepted as ISO Standard 7730 (1994).

Lynda H. Webb is a research associate and **Kenneth C. Parsons** is head of the Department of Human Sciences and a professor of environmental ergonomics at Loughborough University, Loughborough, Leicestershire, U.K.

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The PMV is the predicted mean vote of a large group of people exposed to the thermal conditions of interest who provide a rating on the following scale:

+3	=	hot
+2	=	warm
+1	=	slightly warm
0	=	neutral
−1	=	slightly cool
−2	=	cool
−3	=	cold

For example, if the average sensation over the large group of people was "slightly warm," then the PMV would be +1. The predicted percentage dissatisfied is related to the PMV and is based upon the individual variation of response for a given set of conditions. A value of PMV= 0 is neutral and said to provide comfort conditions with an associated predicted percentage of dissatisfied(PPD) of 5%. A PMV of +1 or −1 provides a PPD of around 25%.

The PMV and PPD are calculated from a knowledge of the so-called "six basic parameters," which consist of air temperature, radiant temperature, air velocity, and humidity of the environment, as well as the clothing and activity level of the people. This method was developed using college students from the U.S. and Denmark, but comparisons have also been made with the responses from the aged and from both males and females. However, there has been little research into thermal comfort requirements for people with physical disabilities.

People with physical disabilities may differ in their comfort requirements from people without physical disabilities for a number of reasons. It may be that the disability interferes with the thermoregulatory responses of a person, such that vasoconstriction or vasodilation reactions are affected, which means that skin temperatures may be abnormally high or low. Sweating may also be affected, as may shivering and other responses. The method for coping with a disability may also be important. For example, some drugs will affect the thermoregulatory system, and technical aids such as wheelchairs or artificial limbs may have consequences for thermal comfort requirements. Psychological issues may also be important. Restriction in the ability to move or react in another way may make deviations from thermal comfort conditions more threatening than for those with full mobility.

There has been some research into the thermal comfort of people with physical disabilities. These studies have largely been conducted in Japan and Hungary. Yoshida et al. (1993a) report a joint Hungarian and Japanese study where fifteen people with physical disabilities were exposed to a variety of thermal conditions in a thermal chamber. It was concluded that there were differences in thermo-physiological responses between the disabled group and a control group. Risks of overheating due to restricted sweating responses and overcooling due to disorders of the peripheral blood flow were reported. Other relevant studies have been conducted by computer modeling of human responses (Yoshida et al. 1988) and by the relationship between cerebrovascular disease and indoor environments (Yoshino et al. 1993b). Girogi et al. (1996) provided a review of "Responses of Disabled People to Thermal Environments." Despite much information, they found a general lack of data on thermal responses that could be used to determine thermal sensation and comfort conditions They found that "physically handicapped persons (poliomyelitis, anterior acuta, infantalis cerebralis paresis, paraplegia, spina bifida and quadriplegia) demonstrate thermoregulatory abnormalities in the affected portion of their bodies." They suggested that further data were required to understand the categories of the population studied.

The aim of this study is to identify the thermal comfort requirements of people with physical disabilities. The work presented here describes a study carried out with sixteen people with physical disabilities and sixteen people without physical disabilities. When the subjects with physical disabilities were analyzed as a group, there was little difference between them and the subjects without physical disabilities. However, the range of responses varied widely. For the group of people with a variety of different disabilities, it is necessary to evaluate their thermal comfort needs on an individual basis. This paper presents the experimental procedure undertaken and a case study on each individual with a physical disability.

METHODOLOGY

Sixteen subjects with physical disabilities and sixteen subjects without physical disabilities were exposed to three environmental conditions. The conditions were set to achieve predicted mean votes of −1.5, 0, and +1.5, that is, slightly cool to cool, neutral, and slightly warm to warm. These conditions were chosen to emulate both moderate and extreme conditions that people may experience in indoor office-type environments. Data were recorded every 15 minutes over a three-hour period on subjects' subjective data and actual environmental conditions. This protocol was similar to the original experiments used to derive Fanger's (1970) predicted mean vote and predicted percentage dissatisfied (PMV/PPD) methodology. The methodology was based upon that of an earlier study by Breslin (1995), which compared the thermal comfort requirements of males and females.

Subject Details and Procedures

Thirty-two subjects were divided into two groups, sixteen people with physical disabilities and sixteen people without. These groups were further subdivided into eight male and eight female subjects. The subjects with physical disabilities were selected from a local day center and others living within a ten-mile radius of the laboratory. People with a range of disabilities were selected. Table 1 shows the characteristics of each of these sixteen subjects.

TABLE 1
Subject Characteristics

Subject Code	Disability	Gender	Age (Yrs)	Height (m)	Weight (Kg)
1	Diabetic. Heart Condition, Kidney Transplant, Visually Impaired, Asthma	Female	31	1.54	66.67
2	2 Strokes and Brain Surgery Twice	Female	46	1.76	95.26
3	Encephalitis	Female	61	1.66	69.07
4	Left-Side Weakness, Wheelchair User, Blackouts Due to Road Traffic Accident 1994, Asthma	Female	26	1.62	66.71
5	Injuries Due to Road Traffic Accident, Metal Work in Legs, Wheelchair User	Female	46	1.60	51.00
6	Spina Bifida	Female	41	1.22	54
7	Multiple Sclerosis	Female	59	Not Available	Not Available
8	Friedrichs Ataxia	Female	43	1.62	57.89
9	Cerebral Palsy	Male	32	1.50	59.96
10	Neck Injury (Road Traffic Accident)	Male	40	1.76	58.61
11	Guillain-Barre Syndrome	Male	67	1.71	101.2
12	Cerebral Palsy/Addisons Disease	Male	23	1.67	50.79
13	Paralysis/Epilepsy (Road Traffic Accident)	Male	29	1.75	81.99
14	Blind (Road Traffic Accident)	Male	43	1.79	104.62
15	Walking/Eyesight Problems, Diabetic	Male	56	1.75	81.78
16	Missing Lower Arm/Uses Prosthesis	Male	22	1.72	64.15

Experimental Design

Four groups, each consisting of eight subjects (each group made up of two females and two males with disabilities and two females and two males without disabilities), were exposed to three conditions designed to emulate the neutral and "extreme" conditions of an indoor office environment in a repeated measures design. The order of exposure was defined by following an incomplete block, 4 × 4 Latin square design (see Table 2).

All subjects sat in standard office chairs with arms and thin cushions, with a gap between the back and the seat of the chair (estimated chair insulation of 0.1 clo included in clo value). Subjects who used wheelchairs were asked to transfer to the office chair. Subjects remained seated for three hours. External work was assumed to be 0 W/m^2. The environmental conditions were predicted using Fanger's (1970) thermal comfort model. Table 3 shows the six basic parameters, plus partial vapor pressure for the three conditions: 18.5°C, PMV = −1.5, slightly cool to cool; 23°C, PMV = 0, neutral; and 29°C, PMV = +1.5, slightly warm to warm.

Clothing Ensemble. The clothing ensemble worn was as follows:

- Shirt: 65% polyester, 35% cotton

TABLE 2
Subject Group Exposure Design—Incomplete Block, 4×4 Latin Square

Group	Condition and Order of Exposure		
	18.5°C = PMV−1.5	23°C = PMV 0	29°C = PMV+1.5
A	1	3	2
B	3	2	1
C	3	2	1
D	2	1	3

TABLE 3
Experimental Conditions Required

PMV	−1.5	0	+1.5
Clo	1 (0.155 m^{2}C/W)		
Activity	Sitting at Rest (58 W/m^2)		
t_r =	ta		
v =	0.15 m/s		
t_a	18.5°C	23°C	29°C
rh	50%	70%	50%
Pa	1050	2000	2050

TABLE 4
Parameters of Environment Measured and Equipment Used to Measure Them

Parameters Measured	Equipment Used	No.	Probes Used
Radiant Temperature	"Squirrel" Data Loggers, 8 bit and 12 bit	4	Thermistors Type U in a 150 mm Black Globe
Air Temperature	"Squirrel" Data Loggers, 12 bit, and Indoor Climatic Analyser	11	Thermistors Type U and Air Temperature
Humidity Air Velocity	Indoor Climatic Analyser	1	Humidity Air Velocity
Humidity (Manual)	Sling Psychrometer (Whirling Hygrometer)	1	

- Trousers: 65% polyester, 35% cotton
- Sweatshirt: 30% polyester, 70% cotton
- Cotton underwear: the subjects' own
- Cotton socks: the subjects' own
- Leather shoes: the subjects' own.

The clothing, including the chair, was estimated to have a clo value of 1.

Measurements and Test Procedures

Subjects arrived at the laboratory 30 minutes prior to the experimental session. Identical clothing was provided to each subject. All subjects completed medical and consent forms. Where the medical form indicated that an emergency procedure may be required, i.e., for epileptic fits, asthma attacks, and so on, a further emergency procedure form was completed and agreed upon. At all times, first-aid was available within three minutes. The procedures and experimental methodology were given Ethical Clearance by the Loughborough University Ethical Advisory Committee in 1996.

Once seated in the chamber, in an upright but relaxed position, the subjects watched an unrelated video for the duration of the session, pausing every 15 minutes to complete the subjective recording forms.

Subjective Measurements. Subjective questionnaires were completed by the subjects at the beginning of the experimental session and every 15 minutes thereafter. The subjective scales used were as follows (see Appendix A):

1. The seven-point ASHRAE scale from "cold" to "hot" (Parsons 1993).
2. A three-point preference scale: "warmer," "no change," and "cooler."
3. Four-point scales for expression of thermal comfort, dryness, stickiness, and draught.
4. Response of satisfaction with the thermal environment.
5. Acceptance for long-term exposure to the environment.

Environmental Measurements. Environmental conditions were measured every minute over the three-hour session, at a number of points in the climatic chamber. Table 4 lists the environmental parameters measured and the related measuring equipment used. Table 5 lists the equipment used in the climatic chamber, and Figure 1 shows the layout of equipment in the climatic chamber. In addition, air temperature probes were also mounted around the chamber at head height (suspended from the ceiling in the middle of the room), on the ceiling, and on each of the walls.

TABLE 5
Items of Equipment Used in the Chamber

Item	No.
Tables	1
Stools	5
Chairs	8
Carpet	1
Television	1
Video Player	1
B&K Stand	1

RESULTS

The environmental conditions during the experimental sessions were achieved as required by Fanger's (1970) thermal comfort model to produce predicted mean votes of −1.5, 0, and +1.5. Table 6 presents the conditions achieved across all sessions.

The thermal sensation scale used in the presentation of the results is the ASHRAE scale of "cold" to "hot," 1 to 7. This scale can be compared directly with the measured predicted

TABLE 6
Actual Environmental Conditions

PMV	−1.5	0	+1.5
Clo	1 (0.155 m^2°C/W)		
Activity	Sitting at Rest (58 W/m^2)		
tg =	ta		
v =	0.15 m/s		
ta	18.5°C ± 0.6	23°C ± 0.7	29°C ± 0.8
rh	50% ± 5	64% ± 10	49% ± 7
Pa	1050	2000	2050

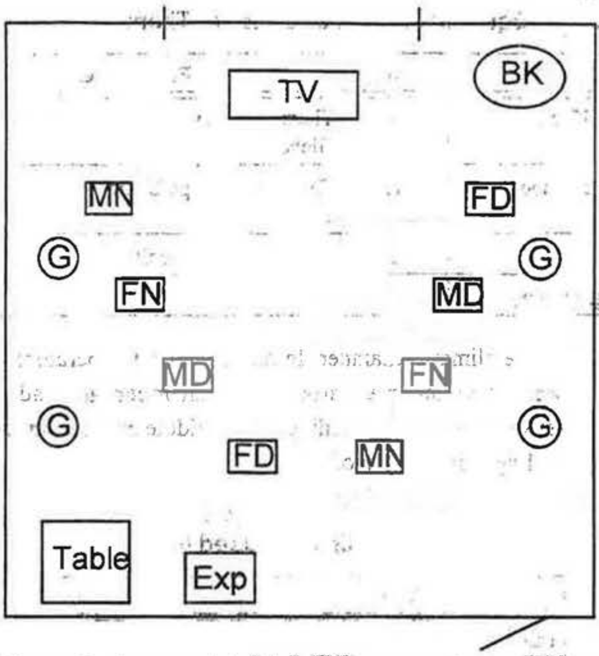

Figure 1 Layout of chamber. BK = measuring equipment; G = 150 mm globe; Exp = experimenter; M = male; F. = female; D = disabled; N = nondisabled.

mean vote thermal comfort index, as described in ISO 7730 (ISO 1994) (Table 7).

Thermal Sensation of the Groups

Taking into consideration the thermal sensation vote, over the last three scores of the three-hour experimental session, the mean comparison showed that there was no significant difference ($p > 0.05$) between the groups with and without disabilities. Figure 2 illustrates the overall body mean thermal sensation. The spread and range of votes within each group show that people with physical disabilities gave a greater variation in their responses and were less in agreement with each other's votes than people without physical disabilities at 18.5°C, PMV = −1.5, slightly cool to cool, and 23°C, PMV = 0, neutral. The situation is reversed at 29°C, PMV = +1.5, slightly warm to warm, where people without physical disabilities showed a wide range of response (see Figure 3).

TABLE 7
Comparison of Sensation Vote, PMV, and ASHRAE Scales

Sensation	Sensation Vote	PMV	ASHRAE
Hot	7	+3	7
Warm	6	+2	6
Slightly Warm	5	+1	5
Neutral	4	0	4
Slightly Cool	3	−1	3
Cool	2	−2	2
Cold	1	−3	1

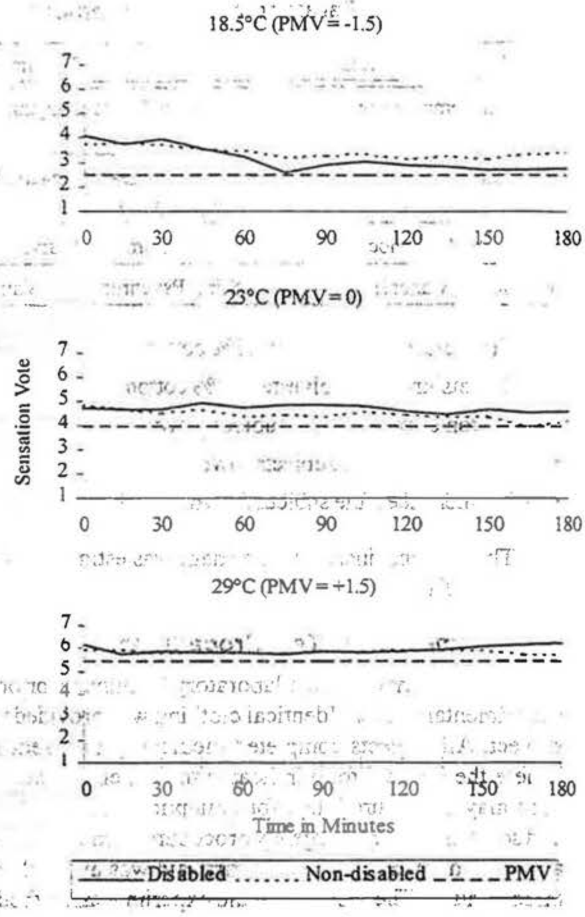

Figure 2 The actual mean vote (AMV) of overall thermal sensation for people with physical disabilities compared with those of people without physical disabilities and the PMV for the three experimental conditions.

Individual Responses

There was a wide variation in the responses of the individual subjects with physical disabilities. Table 8 lists a summary of each individual's response to the environmental conditions. This enables easy comparison between individuals, their physical disabilities, and their thermal responses.

Each subject's overall body sensation responses also varied widely. Figures 4, 5, and 6 show the thermal sensation responses of each person with physical disabilities in each of the three conditions. These graphs show a general drift in response to the actual environment toward that of the

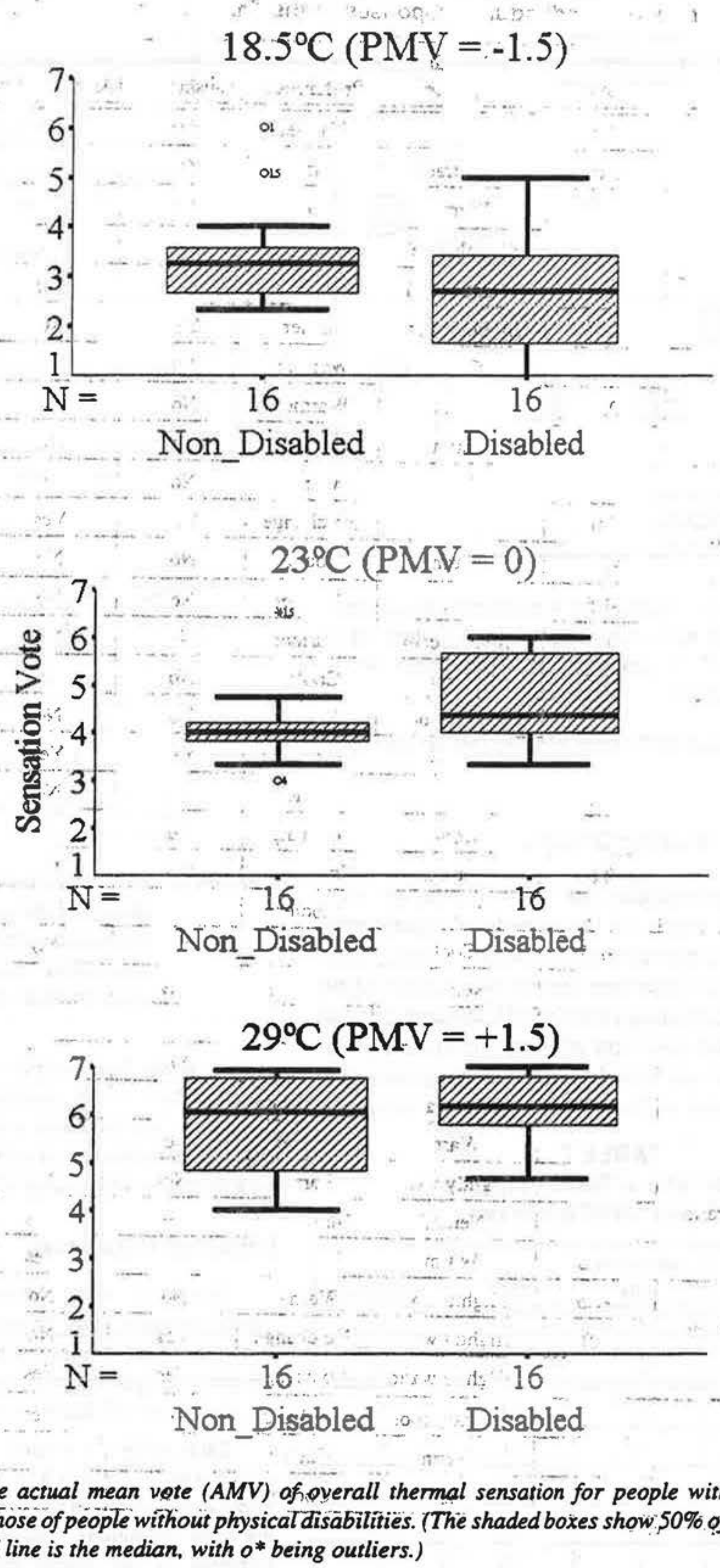

Figure 3 *The range of the actual mean vote (AMV) of overall thermal sensation for people with physical disabilities compared with those of people without physical disabilities. (The shaded boxes show 50% of responses, T bars are the ranges, solid line is the median, with o* being outliers.)*

TABLE 8
Summary of Individual Responses to the Three Environmental Conditions

Subject	PMV	Overall Sensation*	Preference	Satisfaction	Acceptability	Comment
No. 1 Heart Condition, Diabetic, Asthma, Kidney Transplant, Visually Impaired	−1.5	Neutral	Warmer	Yes	Yes	AMV similar to PMV in cool and neutral conditions; both appropriate.
	0.0	Neutral	Warmer	Yes	Yes	
	+1.5	Warm	Cooler	No	No	
No. 2 Two Strokes and Brain Surgery Twice	−1.5	Slightly cool	Warmer	No	No	Preferred neutral condition, AMV = PMV.
	0.0	Slightly cool	Warmer	Yes	Yes	
	+1.5	Slightly warm	Cooler	Yes	No	
No. 3 Encephalitis	−1.5	Cool	Warmer	No	No	Localization at knee and feet. AMV always warmer than PMV.
	0.0	Warm	Warmer	No	No	
	+1.5	Warm	Cooler	No	No	
No. 4 Left-Side Weakness, Asthma, Blackouts, Road Traffic Accident	−1.5	Cold	Warmer	No	No	Localization at knee and feet. Preference neutral. PMV −1.5 very uncomfortable.
	0.0	Neutral	No change	Yes	Yes	
	+1.5	Warm	Cooler	No	No	
No. 5 Metal Work in Legs, Road Traffic Accident	−1.5	Cold	Warmer	No	No	Severe localization issues, no satisfactory environment.
	0.0	Slightly cool	Warmer	No	No	
	+1.5	Warm	Cooler	No	No	
No. 6 Spina Bifida	−1.5	Slightly cool	Warmer	No	No	Preferred neutral environment, AMV always warmer than PMV.
	0.0	Warm	No change	Yes	Yes	
	+1.5	Hot	Cooler	No	No	
No. 7 Multiple Sclerosis	−1.5	Cool	No change	No	No	Preferred to be warmer. Only stable response was in PMV +1.5.
	0.0	Neutral	No change	Yes	No	
	+1.5	Warm	Cooler	Yes	Yes	
No. 8 Fredrichs Ataxia	−1.5	Cool	Warmer	No	No	Preferred neutral at PMV −1.5 and +1.5; AMV= −2 and +3, i.e., extreme response.
	0.0	Neutral	No change	Yes	No	
	+1.5	Warm	Cooler	No	No	
No. 9 Cerebral Palsy	−1.5	Cool	Warmer	No	No	Preferred neutral, −1.5 for short time, AMV = PMV.
	0.0	Neutral	No change	Yes	Yes	
	+1.5	Warm	Cooler	No	No	
No. 10 Neck Injury, Road Traffic Accident	−1.5	Slightly warm	Warmer	No	No	Neutral and slightly warm to warm both acceptable. Localization for below knee/feet.
	0.0	Neutral	No change	Yes	Yes	
	+1.5	Warm	No change	Yes	Yes	
No. 11 Guillain-Barré Syndrome	−1.5	Slightly cool	Warmer	No	No	Neutral and slightly warm to warm both acceptable. Little difference between conditions.
	0.0	Slightly warm	No change	Yes	No	
	+1.5	Slightly warm	No change	Yes	Yes	
No. 12 Cerebal Palsy/Addisons Disease	−1.5	Slightly cool	No change	Yes	Yes	All conditions acceptable. AMV always warmer than PMV.
	0.0	Warm	Cooler	Yes	Yes	
	+1.5	Hot	Cooler	Yes	Yes	

* Scores have been rounded to nearest whole number.

TABLE 9
Number of People Preferring "No Change" to the Environmental Condition

Conditions for Which Subjects Voted "No Change"	People with Physical Disabilities	People without Physical Disabilities
PMV = −1.5, Slightly cool to cool	2	0
PMV = 0 and −1.5, Neutral and slightly cool to cool	3	0
PMV = 0, Neutral	6	7
PMV = 0 and +1.5, Neutral and slightly warm to warm	3	2
PMV = +1.5, Slightly warm to warm	1	0
Always wanting the environment to be either warmer or cooler	1	6
All conditions— "no change" preferred	0	1

There was little consistency in the preferred environment and the occurrence of localization issues. They occurred for different people across the range of environments.

The relationship between subjects' votes and predicted mean vote also varied. Some subjects were consistently warmer than the predicted mean vote across all conditions. Some people matched the predicted mean vote in some conditions and not in other conditions. Some subjects experienced a wide variation in sensation across a single session.

CONCLUSIONS

There were no significant differences found in the thermal comfort requirements of the group of people with physical disabilities and the group of people without physical disabilities.

In the subjects tested, the people with physical disabilities had widely varying responses. In general, responses were in the direction expected; however, there was much overlap in subjects' responses between conditions.

It is, therefore, necessary to evaluate the needs of people with physical disabilities on an individual case-by-case study.

It is proposed that further work needs to take place to evaluate on a larger scale whether people with physical disabilities may be categorized in order to model their thermal responses.

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APPENDIX A

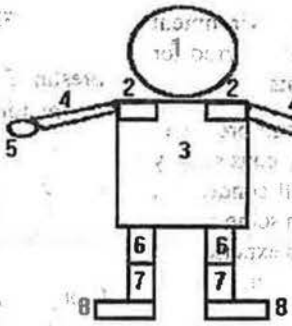
THERMAL COMFORT SUBJECTIVE SCALE

Session Number:................................. Subject No:....................... Time of Completion

Name:..

Session Start Time:....................................

before	0		
15	30	45	60
75	90	105	120
135	150	165	180



Please Answer the Following Questions Concerned With YOUR THERMAL COMFORT

1. With reference to the above diagram please indicate on the scales below how YOU feel NOW.

Overall | **Head 1** | **Shoulders 2** | **Trunk 3** | **Arms 4** | **Hands 5** | **Above Knee 6** | **Below Knee 7** | **Feet 8**

Hot
Warm
Slightly Warm
Neutral
Slightly Cool
Cool
Cold

2. Please indicate how YOU would like to be NOW.

Warmer No Change Cooler

3. Please indicate on the following scales how YOU feel NOW.

Very Uncomfortable	Very Dry	Very Sticky	Very Draughty
Uncomfortable	Dry	Sticky	Draughty
Slightly Uncomfortable	Slightly Dry	Slightly Sticky	Slightly Draughty
Not Uncomfortable	Not Dry	Not Sticky	Not Draughty

Please state the main area of discomfort in YOUR body...

....

Please Tick √

4. Are you satisfied with your thermal environment NOW? Yes ☐ No ☐

5. Would you find this an acceptable environment to be in everyday Yes ☐ No ☐

6. Please give any additional information or comments which you think are relevant to the assessment of your thermal environment now for example, draughts, dryness, clothing, etc.

....

....

Now please hand this form to your experimenter

Thank you.