A COMPARISON OF THE THERMAL RESPONSE OF CHINESE AND NORTH AMERICAN PEOPLE

by

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A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

College of Engineering
Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1988

Approved by:

Major Professor

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ACKNOWLEDGMENTS

I wish to express my sincere gratitude to my major professor, Dr. Byron W. Jones for his extraordinary help, guidance and encouragement which he gave me. In addition, I would like to acknowledge the other members of my advisory committee, Dr. Elizabeth A. McCullough and Dr. Robert Gorton for their counsel and personal involvement.

I wish to express my deep and special appreciation to Dr. Jones and Dr. McCullough for their kind consideration and sponsoring my financial support to finish this work.

I am grateful to Mr. Tom Shrimplin for his assistance in preparing equipment and data acquisition.

I would like to express my thankfulness to my relatives in China. In particular, to my mother, my wife Xiaomei and my daughter Yue for their sacrifices, support and understanding during the period when I was in the U.S.A.

CHAPTER 1 INTRODUCTION AND REVIEW OF LITERATURE

Introduction

ASHRAE Standard 55-1981 "Thermal Environmental Conditions for Human Occupancy", and ISO Standard 7730 "Moderate Thermal Environments-Determination of PMV and PPD Indices and Specification of the Condition for Thermal Comfort" (ISO 1984) specify the environmental conditions required for thermal comfort in the winter and summer.

These environmental conditions will provide thermal comfort for most people, healthy, normally clothed and engaged in sedentary or near sedentary activities. These standards are all based on the physiological and psychological response of people to the thermal environment, and are used widely throughout of the world. However, these standards are all based on experiments using primarily the United States residents of college age. (Nevins, et al, 1966). Considering the great differences in climates, geographic locations, physiques, diets, customs and standards of living among different ethnic groups throughout the world, questions arise as to the applicability of these standards to all people and to all parts of the world. In the present study, an attempt is made to address these questions by investigating the thermal response of subjects from the United States and from China exposed to identical thermal environments.

The Historical Development of Thermal Comfort Research

Modern thermal comfort research as we know it today began about 70 years ago in America with foundation of the ASHVE laboratory in Pittsburg in 1919. Since then many experiments have been conducted. During the 1930's, physiologists of the John B. Pierce Foundation formulated methods to quantify the energy exchange between humans and their thermal environment (Gagge, Herrington, and Winslow 1937; Hardy and DuBois 1938). Hick and associates (1938) at University of Illinois also extend their original studies. During the Second World War, thermal comfort research was directed toward the limitation of the human performance of the military in the heat or cold stress environment (Gagge, Gonzalez, and Nishi 1974). Interest in comfort research was revived in the U.S.A. in the mid-1960's, when ASHRAE disbanded its laboratory in Cleveland, Ohio, and donated its environmental chamber to Kansas State University in 1962. Since then, major reassessment of relationship between air temperature and humidity and their effect on thermal sensation has been investigated (Nevins, Rohles, Springer and Feyerherm 1966). The research work at KSU have provided data on comfort conditions which have formed the basis of Fanger's comfort equation and the ASHRAE standard which defined the indoor thermal requirements for human occupancy. Rohles and Nevins (1973) reviewed and summarized the earlier thermal comfort research. It was interesting to find the recommended comfort temperature was 68F (20.0^{o}C) in 1914, however, it increased to 78F (25.6^{o}C) in 1966. Nevins (1966) attributed this phenomenon to the changes in clothing habits and life-styles of the general population such as eating patterns, more indoor working, and better heating and cooling of the indoor environment. Gagge, Stolwijk and Nishi (1967) modified the effective temperature index (ET) which was developed by Houghten and Yagloglou in 1924 and proposed New Effective Temperature (ET^*), which is an important environment index used in ASHRAE thermal comfort standard [*]. Rohles et al (1973) developed a model to predict the ET^* necessary to maintain a thermal sensation of 4.14 and developed a regression equation which can predict thermal sensation by using New Effective Temperature.

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[*] ET^* is the uniform temperature of a radiant black enclosure at 50 % relative humidity, in which an occupant would experience the same comfort, physiological strain and heat exchange as in the actual environment with the same air motion. (ASHRAE 1981).

Fanger addressed the problem of producing a comprehensive comfort index by starting from a premise that it is possible to define the comfortable state of the body in physical terms which relate to the body rather than to the environment. Fanger's comfort equation contains the following variables: clothing insulation (I_{cl}) and the clothing area factor (f_{cl}); metabolic heat production (W/m^2) and metabolic free energy production for the functions of activity; and air temperature, mean radiant temperature, relative air speed, and water vapor pressure as environmental variables. This set of variables must satisfy the three requirements for comfort: thermal equilibrium, appropriate mean skin temperature and preferred rate of sweating (Fanger 1970). Much of the above research has been incorporated into ASHRAE Standard 55-1981. This specifies the comfort zone for winter, with 0.9 clo units and operative temperature range of 20-23.6^{o}CET*, and for summer,with 0.5 clo units and an operative temperature range of 22.8--26.1^{o}CET*. These environmental conditions, however, can not meet 100 percent individual satisfaction as Fanger pointed out. The ASHRAE Standard 55-1981 specifies the conditions under which 80 % or more of the occupants find the environment thermally acceptable.

A lot of research also has been conducted in other countries in recent decades. A standard, "Thermal Comfort

Within Residential and Civic Buildings" (Jokl 1986), has been used in East European countries. The data base comes mainly from European or U.S. subjects.

In Japan, a lot of research has been conducted actively since 1970s. But the thermal comfort standard recommended by many books and research papers are also essentially based on ASHRAE and ISO Comfort Standards.

In China, a movable thermal manikin was developed in recent years (Garment Research & Design Center of China, 1984) and more and more research concerning thermal comfort of the indoor environment for the civilian has been conducted.

The ASHRAE Thermal Comfort Standard 55-1981 and ISO Standard 7730 have been widely recommended or used in many countries all over the world. There is still no thermal comfort standard based on experimental data from Asian people at the present time.

Three Approaches to Thermal Comfort Research

In order to determine the thermal comfort condition for people, a lot of research has done with different approaches. McIntyre (1978) catagorized the approaches to thermal comfort research by the following three techniques: 1) direct determination of preferred temperature; 2) field surveys and 3) environmental chamber studies which employ rating scales. The first method is associated with the work of Fanger at the Technical University of Denmark: the subject sat in an environmental chamber by himself and was given the temperature controller. This technique produces a single measurement of the preferred temperature of the individual. However, it is a time consuming and expensive technique. Jones (1988) modified this approach by giving the subjects the controller of a radiant electrical heater and a table fan during the different temperature tests. The above research techniques are similar in nature, they can provide a great deal of information both on the variation of preferred temperature between groups of people, and on the rules of combinations of environmental variables to produce neutrality. The second approach is field surveys. For examper, Dedear and Auliciens conducted the field study of six different climatic conditions in Australia (1985). Arens et al at University of California at Berkeley also completed a field study recently. The advantage of field surveys is that they generally yield more realistic information since the responses are taken in the subjects' normal surroundings. However, it is difficult to control the effect of unwanted variables. The third approach is environmental chamber study. It has been used extensively at KSU. The subjects are exposed to a given temperature in an environmental chamber for a set exposure time and are asked to evaluate their thermal sensation at certain time intervals. With this method, several subjects can be examined at a time, thus it is less time consuming and less expensive than the direct method of determining the preferred temperature. And also, this approach can provide information not only in "neutral", but also in "non-neutral" thermal environmental conditions. Therefore, this method is probably the most familiar approach on which much of the ASHRAE Standard is based.

Method for Comparison of Different Ethnic Groups

The question concerning whether there is difference in response to a thermal environment between various ethnic groups has been addressed by several researchers and some related research has been conducted.

Fanger (1970) conducted a study with 128 Danish college age subjects. The results compared with the study conducted by Nevins et al (1966) by using 1600 American college-age subjects in Kansas State University in the U.S. Fanger found no significant difference in thermal comfort response between the Danish subjects and U.S. subjects.

Recently, a similar experiment was conducted by using 172 Japanese subjects in Japan. (Tanabe et al 1987) They compared the responses of the Japanese subjects to the responses with the Danish subjects' in Fanger's study

(1970) and the responses of the United States subjects in Nevins' study (1966). They found there were only minor differences between the above ethnic groups.

The advantage of the above experimental method is that the tests were conducted in different locations, so that the subjects were all in their home countries. Therefore, no disturbance may occur for the subjects away from their home environment. The draw-back of this method is that, any difference between the two tests, such as differences in room furniture, wall painting and test protocol will always interfere with the thermal response of the subjects involved and hence the results of the test. Rohles (1976) showed that using different wall treatments (wood treatment vs painted metal) under similar thermal conditions significantly affected the thermal response of the subjects, even though they produce no measurable effect on the thermal conditions.

Several researchers used another "side-by-side" method to compare thermal comfort responses between people of different ethnic origins. They conducted the tests by having all the subjects from different ethnic groups participate at the same location at the same time as were done by Ellis (1953), Angus (1957), Wyon et al (1968). Ellis compared Asian and European residents in Singapore. He found that in Singapore, the comfortable level of warmth for the groups of acclimatized European men and women and Asian men and women residents were very similar and were not markedly affected by differences in race, age or gender. Angus compared students of many different ethnic origins in London. Wyon (1968) investigated the thermal comfort of people of different races in British operating rooms. He found that age, gender and race produced minor differences in thermal comfort.

When the second method is used to compare the different ethnic groups, it is possible for the people to change their diet, cultural customs and even their physiology when they are removed from their home environment. These changes may in turn affect their thermal comfort responses.

The results of these studies using either of the two methods, taken as a whole, are not conclusive and it is not clear just how much difference may exist in thermal comfort responses for various peoples. Also, these studies mainly concentrated on thermal comfort and preferred temperatures. It is possible that as environmental conditions move away from the optimum and into the zone of mild to moderate discomfort that differences will occur that are not otherwise evident. Furthermore, none of the studies specifically addressed the Chinese population.

CHAPTER 2 METHODOLOGY

In the present study, the second method (side by side comparison) was used to make a direct comparison of people from various cultures and ethnic groups. The subjects selected from U.S. and Chinese college students were exposed to identical environmental conditions and evaluated by identical methods. Attempts were made to avoid the effects of the subjects not being disturbed from their home environments.

The objective of this study was to make a direct comparison of the thermal responses to different environment temperatures between Chinese and U.S. subjects. The comparison was based on measurements both for the physiological and psychological points of view. The whole study was divided into two phases, according to the test temperatures. In the first phase, the test temperatures were 71F, 76F and 81F. The conditions were selected to determine the thermal responses in the middle of the ASHRAE (1981) summer comfort zone and slightly above and slightly below this zone. In the second phase, the temperatures were 86F and 91F, which are above the comfort zone. For either of the above two phases, the measurements were made in order to get the following information between two ethnic groups:

1, Whether there is difference in response to a certain thermal environment in terms of the thermal sensation and environmental quality ballot voting.

2, Whether there is difference in sweating between Chinese and U.S. subjects.

3, Whether there is difference in mean weighted skin temperature between two ethnic groups.

Subjects

Subjects from Kansas State University student population were selected to represent the U.S. and subjects from newly arrived students from China represented that country. All subjects were tested at the same location, the ASHRAE chamber at KSU. The U.S. subjects were required to be native bone U.S. citizens and to have lived in the U.S. continuously for the year preceding the test. In order to minimize the effects of acclimation for the Chinese subjects, they were required not to have been in the U.S. for more than three months at the time of tests.

In each phase of the tests, a sample size of 10 Chinese and 10 U.S. subjects was selected from the volunteers in order to get a comparison at $p < 0.10$ significant level according to the T-statistical test. There were 5 females and 5 males in each ethnic group with the age from 18 to 30 years. For the two phases, a total number of 20 Chinese and 20 U.S. subjects were selected with half females and half males. Anthropometric data for the subjects are summarized in Table 1. Subjects were selected so as to have their mean heights and weights representative of the mean heights and weights for males and females from their home countries. No subjects were selected from outside the 5%-95% range for the general population of their home countries for either weight or height.

Subjects completed a release form prior to beginning the test. An Informed Constant Statement and Subject Orientation and Test Procedure form are included in Appendices 1 and 2.

Among the total 20 Chinese and 20 U.S. subjects, 10 Chinese and 10 U.S. subjects with 5 females and 5 males in each group were exposed to 71F, 76F and 81F temperature tests in October 1986. Another 10 Chinese and 10 U.S. subjects, also with 5 females and 5 males in each group, were exposed to 86F and 91F temperature tests in March, 1988, in order to investigate the differences that would result in warm discomfort environments.

After the experiment, each subject was paid either $36 or $26 for participating in either 3 tests or 2 tests.

Clothing

The subjects were provided cotton/polyester sweat suits to wear during each test. The sweat suits were all

Table 1. Anthropometric Data of Subjects*

Subjects	Height (cm)	Weight (kg)	DuBois Area** (m^2)
U.S. Females	169.42(5.20)	62.20(10.58)	1.72(0.14)
Chinese Females	163.77(5.46)	53.25(7.24)	1.57(0.12)
Difference	5.64	8.98	0.15
Significance	< 0.05	< 0.10	< 0.05
U.S. Males	178.18(4.85)	53.25(7.30)	1.90(0.11)
Chinese Males	171.32(3.61)	68.21(8.79)	1.80(0.10)
Difference	6.86	4.63	0.10
Significance	< 0.01	< 0.10	< 0.01
U.S. Females and Males	173.81(6.65)	67.56(10.36)2	1.81(0.16)
Chinese Females and Males	167.54(5.94)	60.75(10.96)	1.68(0.16)
Difference	6.27	6.81	0.13
Significance	< 0.01	< 0.10	< 0.05

* mean (std. dev.)
**Subjects' DuBois Area were calculated by using the formula:

$$S = 71.84\ W^{0.425} \times H^{0.725}$$

where
S = DuBois Area (the surface area of nude body cm^2)
W = Weight (kg)
H = Height (cm)

identicalother than for size. the sweat suits were worn over the subjects' own underwear (briefs only for males and panties and bra only for females). Subjects also wore their own shoes and socks. This clothing ensemble had a total thermal insulation (I_t) of 1.4 clo as measured on the KSU-Nordic manikin with an estimated intrinsic insulation (I_{cl}) of 0.7 clo with an air layer insulation (I_a) of 0.75 clo and a clothing area factor (f_{cl}) of 1.07. A similar clothing ensemble measured by another manikin at KSU IER resulted in: I_t = 1.37, I_{cl} = 0.77 clo.

The computer printout of the clo value measurement for the test clothing ensemble is presented in Appendix 4.

Environmental Conditions For The Tests

Tests were conducted at 71F (21.7^{o}C), 76F (24.4^{o}C), 81F (27.2^{o}C), 86F (30^{o}C), and 91F (32.8^{o}C). The humidity ratio was 0.009 for all temperatures. These conditions were selected to give tests in the middle of ASHRAE (1981) summer comfort zone (76F), slightly below this zone (71F) and slightly above this zone (81F). Two warmer conditions (86F and 91F) were also selected, therefore, the comparisons between Chinese and U.S.subjects could be made under "cool", "neutral", "warm" and/or "slightly hot" conditions. Air velocity in the test chamber was less than 0.2 m/s. A psychrometric chart showing the ASHRAE Comfort Zone and the

5 test conditions can be seen in Figure 1.

Activity Level of The Subjects

All the subjects were seated in the chamber during the 2 1/2 hours test period. They were either reading, writing or talking quietly. Their metabolic rate was about 50 Kcal/hr/m^2, or about 1.0 met for each subject (ASHRAE Standard 55-1981).

Measurement and Facilities

The Test Chamber

The experiment was conducted at the KSU-ASHRAE chamber in the Institute for Environmental Research. The dimensions of the test chamber are 24 ft (7.3m) by 12 ft (3.65m) with a 10 ft (3.03m) ceiling height. The chamber has its own heating and air conditioning system to provide precisely controlled air temperature and humidity. The test room temperature was recorded every 5 minutes during the tests. Figure 2 shows the layout of the chamber and the locations for the subjects. During the test, each subject was assigned a chair and two subjects of different national origin shared one table with a fluorescent lamp on it for reading or writing. The pretest room was adjacent to the test chamber for the preparation before the tests. The

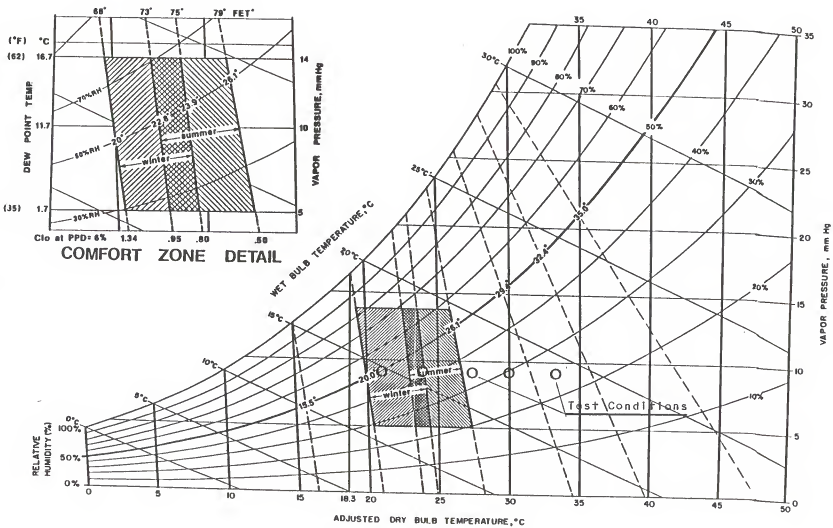

Figure 1. Psychrometric Chart for ASHRAE Comfort Zone and Test Conditions.

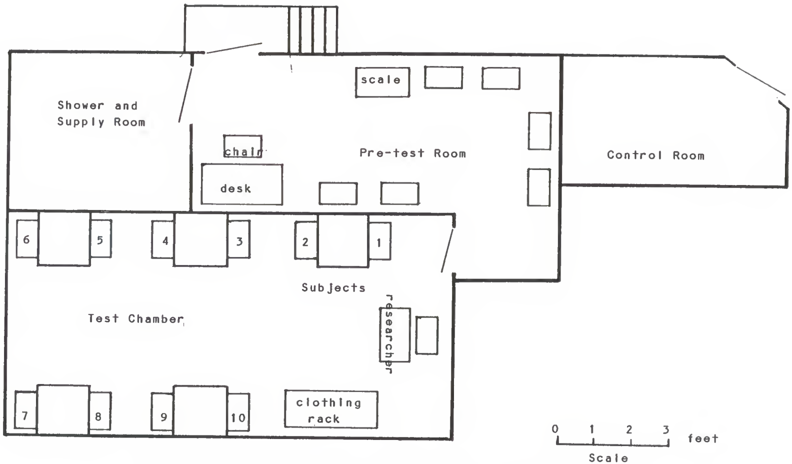

Figure 2. Layout of the KSU-ASHRAE test chamber complex and locations for subjects

environmental condition was controlled and recorded in the control room outside of the KSU-ASHRAE chamber.

The Measurement of clo Values of Clothing Using Manikin

The total insulation value (I_t) of the clothing was measured using a computerized and thermally segmented manikin "Fred" (Figure 3). The background information of this manikin is in Appendix 3. The computer printout of the clo value in Appendix 4 is the total insulation of the clothing which was calculated according to the following formula:

$$I_t = K * (T_s - T_a) * A_s/H$$

where: It = total thermal insulation (clo).

K = units constant. (K=6.45 clo W/m$^{2\circ}$C)

T_s = mean skin temperature ($^\circ$C).

T_a = ambient air temperature ($^\circ$C).

A_s = manikin surface area (m^2).

H = power input (W).

In ASHRAE Standard 55-1981, the Intrinsic Clothing Insulation (I_{cl}) is used. It can be determined by the following equation:

$$I_{cl} = I_t - I_a/f_{cl}$$

where:

Figure 3. Thermal Manikin used to Measure the Clothing clo Value.

I_{cl} = intrinsic clothing insulation (clo).

f_{cl} = clothing area factor expressed as the ratio of the surface area of the manikin clothed and nude.

I_a = insulation of the air layer on the surface of the nude manikin (clo).

The clothing area factor (f_{cl}) for the clothing ensemble was estimated from photographs of the manikin by using a planimeter (McCullough and Jones 1984).

The Measurement of Skin Temperature

Skin temperature has been considered a sensitive physiological criterion of thermal sensation by many researchers (Gagge et al 1937; Hardy 1970; Gagge, Gonzalez, and Nishi 1974; Rohles, Woods, and Nevins 1974). When the skin temperature is 91.4-93.2F (33-34^{o}C), the average sedentary person feels thermally comfortable and sweating does not occur on the skin (Fanger 1970, 1973; Gagge et al 1974). Fanger also specified skin temperature and sweat secretion in his heat balance equation as the only physiological variables influencing the heat balance. Skin temperature is a good predictor of thermal comfort especially in cold environments; however, skin wettedness is a better criterion for comfort in a warm environment (Gagge, Nishi and Gonzalez 1973, 1974).

In this study, the subject's skin temperature is measured by thermistors taped on the designated surface of the body for each subject. (Figure 4) The number of measurement points varies with various researchers, from 20 points (Hardy and DuBis 1938), 15 points (Winslow, Herrington and Gagge 1937), 7 points (Hardy 1968), 3 points (Burton 1935) and 1 point (Teichner 1958 and Ramanthan 1964). Mean Weighted Skin Temperature (MWST) is then calculated by multiplying each skin temperature by the fraction of the body area represented by that measurement.

In the present study, 3 skin temperatures were measured: on the chest, forearm and calf of each subject. These temperatures were recorded continuously throughout the test. The formula (Burton 1935) used for the Mean Weighted Skin temperature is as the following:

$$\mathbf{MWST = 0.5*T_{ch} + 0.36*T_{lg} + 0.14*T_{ar}}$$

where:

T_{ch} = the chest temperature.

T_{lg} = the leg temperature.

T_{ar} = the arm temperature.

The Measurement of Clothing Moisture Gain

Since sweating is an important factor in a warm environment to predict the thermal sensation, this variable

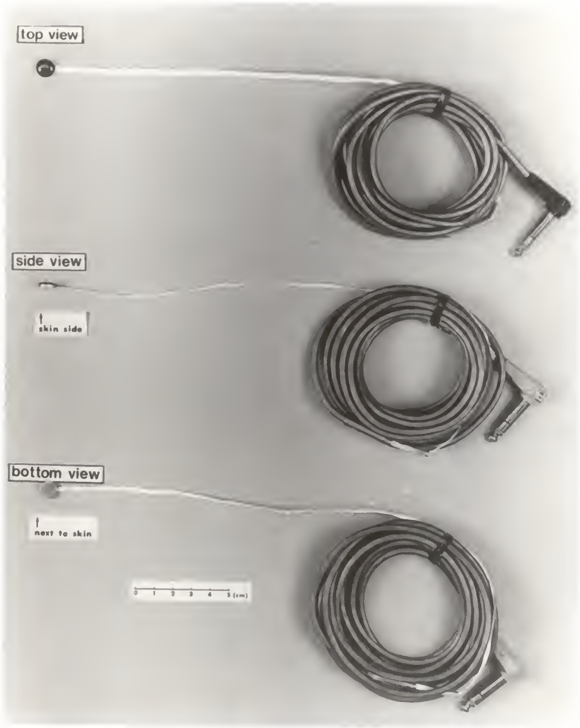

Figure 4. The Thermistors for Measuring the Skin Temperature.

should have been measured by very precisely weighing each subject before and after each test. Unfortunately, such a measurement was not possible for this study. Instead, the weight gain of clothing during the test was used as an indirect measurement of the level of sweating. Since the environmental conditions and activities posed little or no heat stress, most moisture generated by sweat was expected to be evaporated into the air with little accumulation in the clothing. However, differences in sweat generation and/or skin diffusion would be expected to raise the humidity level near the body. The moisture content of the fabric in the clothing at equilibrium is a function of the relative humidity. Thus, it was expected that higher sweating rates would yield measurable differences in weight increase in the clothing.

The clothing worn during the tests was laid out in the chamber at least 2 hours before each test while the chamber was held at the test conditions. Shortly before the subjects arrived for a test, each shirt and each pair of trousers were sealed in a plastic bag and weighed. The subjects then removed the garments from the plastic bags when they dressed in the chamber. At the end of the test, the subjects put the garments back into the same bags and sealed them immediately upon undressing. The garments were then weighed without removing them from the bags.

Balloting

In order to evaluate subject's effect or how he/she feels in a particular thermal environment, various thermal sensation ballots have been used by different researchers. Generally speaking, assessments and quantification of feelings of affective quality for the thermal environment are more difficult than measuring physiological criteria, since these responses are involved with a number of uncontrollable variables which are highly subjective. In this study, three different ballots were used to evaluate the thermal environment.

Thermal Sensation Ballot

The "thermal sensation" is defined as "a conscious experience resulting from exposure to a group of variables making up the thermal environment" (Rohles 1974). The most extensively used technique for assessing thermal feelings employs rating scales which consist of a number of different categories. The categories of the scale are assigned numbers, so that the statistical analysis of thermal feeling can be carried out.

Rating scale have been used for over 50 years. Houghton originally devised the verbal scales and Yaglou (1927) developed the earliest five-point scale. Thomas Bedford developed the first seven-point scale for the comfort research of factory workers in England in 1936 (McIntyre 1980) (see Table 2). The ASHRAE scale also has seven points, it was developed in the 1940's. The seven-point scale has been modified and extended by several researchers. Gagge, Stolwijk and Hardy (1967) substituted the term "neutral" for the original comfortable vote of 4. Rohles (1974) added a "very cold" and "very hot" categories, thus forming a nine-point scale and shifting the "neutral" vote to a value of 5. Rohles' rationale was to spread the distribution of ratings because he found that subjects tend to avoid end categories (Rohles 1978). Moreover, the extra categories are considered to be important for testing in heat or cold stress experiments.

In this study, a modified Rohles' scale was used. The nine-point scale was changed to a continuous scale so that the subjects indicated their sensation by marking a horizontal line at the appropriate location. The vote was later converted to a numerical score with -4 being very cold, +4 being very hot (Figure 5).

Thermal Environmental Quality Ballot

In the present study, another ballot, referred to as an Thermal Environmental Quality ballot was also used (Figure 6A). A ballot of this nature was considered important since satisfaction with the environment is as much a

Table 2. The Various Thermal Sensation Scales

Bedford Scale 1936		ASHRAE Scale 1940's		Rohles Scale 1974	
Much too warm	7	Hot	7	Very hot	9
Too warm	6	Warm	6	Hot	8
Comfortably warm	5	Slightly warm	5	Warm	7
Comfortable	4	Neutral	4	Slightly warm	6
Comfortably cool	3	Slightly cool	3	Neutral	5
Too cool	2	Cool	2	Slightly cool	4
Much too cool	1	Cold	1	Cool	3
				Cold	2
				Very cold	1

THERMAL SENSATION

The thermal sensation ballot is designed for you to assess the current overall thermal state of your body; that is, it shows how you feel at this point in time. Select the level that best indicates how you feel and make a horizontal mark at the appropriate location on the vertical scale. You may mark anywhere on the scale.

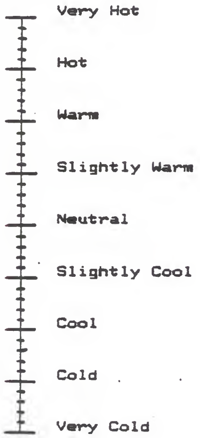

Figure 5. Thermal Sensation Ballot

ENVIRONMENTAL QUALITY BALLOT

Wonderful

Pleasant

Satisfactory

Acceptable

Tolerable

Intolerable

Figure 6A. Thermal Environmental Quality Ballot (71F, 76F, and 81F) psychological consideration as it is a physiological consideration. It has been noted that the neutral temperature of thermal sensation ballot does not necessarily coincide with the satisfaction on a given thermal environment (Rohles et al 1977; McIntyre 1978). A person may vote "neutral", but still find the environment to be unsatisfactory. Likewise, two people may both vote "warm", for example, but they may disagree about how unsatisfactory that condition makes the environment. Thus, the thermal sensation ballot does not provide a complete picture of thermal comfort. Rohles and Milliken (1976) developed a thermal comfort ballot and factor analysis to supplement the thermal sensation ballot. However, the sample size in the present study was not adequate to yield a good factor analysis. The environmental quality ballot used provides a simple and readily understood means of expressing satisfaction or dissatisfaction with the environment. The ballot also provides a means of addressing positive attributes in the thermal environment as well as negative attributes (or lack of negative attributes).

With both Thermal Sensation and Environmental Quality ballots, it is possible to evaluate combined sensations which we have often experienced in the winter as "pleasantly warm" and in the summer as "pleasantly cool".

Voting was accomplished in the same way as for the thermal sensation ballot. Votes were later converted to a numerical score with -2 being "intolerable" and +3 being "wonderful" for phase 1 tests.

In the temperature conditions of 86F and 91F (phase 2), a modified Environmental Quality ballot was used (Figure 6B). This ballot is more straight forward and therefore, more easily interpreted, especially for the international subjects who use the English as their second language. Since the main objective of this study is not to compare different temperatures but rather to compare different people at given temperature, using different ballots for different test phases should not affect the validity of the results.

Ballots were filled out at the beginning of each test and every 30 minutes there after. Ballots were collected after they were filled out.

Most of the Chinese subjects were KSU students and they had a good command of written English, however, there was some concern about their ability to understand verbal instructions. Detailed written instructions explaining the meaning of each of the terms on the ballots were printed on the ballots for the subjects and they were required to read them carefully. Some of them were explained in Chinese individually by the researcher before the test. A researcher fluent in both English and Chinese was present

THERMAL ENVIRONMENTAL QUALITY

The thermal environmental quality ballot is designed for you to assess the thermal suitability of your surroudings. given the activity you are performing and the clothing you are wearing. Ranges on the ballot are defined as follows:

Pleasant: You find the thermal environment to be pleasing. Any warmth or coolness you feel is pleasant to you.

Acceptable: The thermal conditions are satisfactory for your current level of activity and the clothing you are wearing. You have no major complaints.

Unacceptable: The thermal conditions are not satisfactory (too hot, too cold, etc.). You could tolerate these conditions but would complain and/or seek better conditions if possible.

Intolerable: The thermal conditions are very stressful and you can only tolerate them for a limited period of time. (The bottom end of the scale is the point at which you would find it impossible to stay in the environment.)

Indicate your assessment of the thermal environment by placing a horizontal mark on the appropriate location on the scale.

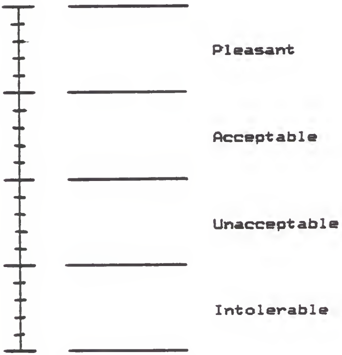

Figure 6B. Thermal Environmental Quality Ballot (86F and 91F) during every test to answer any questions the subjects had.

Testing Procedure

When the subjects reported to the experiment, they were seated in the pretest room and their oral temperatures were taken. If their oral temperature was not over 99.1F (37.3^{o}C), they were allowed to participate the test. The height and weight of the subjects were measured and recorded as well as other information about the subjects on the subjects' information sheet. Then they went into the test chamber and were seated at designated tables. The subjects changed from their own clothing into the test shirt and trousers which were kept in the sealed plastic bags. They wore their own shoes and socks. Skin temperature sensors were taped to the right pectoral region of the chest, the radial surface of the left arm and the fibular surface of the left leg with the Micropore surgical tape.

The researcher then went over the test procedures and explained the ballots to the subjects. As soon as every subject understood the procedure of the test and the meaning of the ballots, the test began and the first set of ballots were distributed and were filled in by the subjects. The time period for each test was 2 1/2 hours. During the time of the test, the subjects were studying or reading at sedentary activity level (see Figure 7). They were provided water to drink during the test. Ballots were collected by the researcher every 30 minutes. The skin temperature and air temperature readings were monitored and recorded continuously by a technician.

After each test, the subjects removed the thermistors and changed into their own clothing, and put the test clothing ensemble into the the plastic bags and sealed them.

Figure 7. The Subjects are in the KSU-ASHRAE Test Chamber.

CHAPTER 3 RESULTS AND DISCUSSION

The data for the five different air temperatures, both for Chinese and U.S. male and female subjects were entered into computer files, identified by test condition, gender and national origin and the time of vote (0, 30, 60, 90, 120 and 150 minutes).

These data were treated by calculation of mean and analysis of variance for Thermal Sensation, Environmental Quality Vote, Mean Weighted Skin Temperature and Moisture Gain of the Clothing, separately. The data are presented to show comparisons of the differences in mean values, the time dependent variables, and the individual data points.

Comparison of Mean

Thermal Sensation vote

The comparison of thermal sensation votes between Chinese and U.S. subjects is summarized in Table 3. All data were based on the 150 minute vote (end of test). A "T" statistic was calculated for the difference in means between the two ethnic groups.

The results from the thermal sensation ballots showed the differences are small and none are statistically significant except for the 86F test, in which both the Chinese male and female subjects tended to vote significantly lower than that of U.S. subjects. In the 91F

Table 3. The Data of the Thermal Sensation Votes (150 min Vote)*

Subject Group	Air Temperature 71F	76F	81F	86F	91F
U.S. Females	-.62(.67)	-.06(.78)	1.42(1.09)	1.98(1.0)	2.18(.69)
China Females	-.18(1.05)	.64(1.13)	.88(.83)	.84(1.28)	2.64(.79)
China-U.S.	.44	.70	-.54	-1.14	.46
Significance**	--	--	--	$p<.05$	--
U.S. Males	-.34(.56)	.36(.61)	.76(1.01)	2.32(.54)	2.42(.79)
China Males	-1.10(.72)	-.44(.59)	1.12(.89)	1.02(.84)	1.50(.98)
China-U.S.	-.76	-.80	.36	-1.3	-.9
Significance	--	$p<.05$	--	$p<.01$	$p<.01$
US Fem+Mal	-.48(.56)	.15(.63)	1.09(.98)	2.15(.78)	2.3(.71)
Ch Fem+Mal	-.64(.93)	.10(.99)	1.00(.76)	.93(1.02)	2.07(1.03)
China-U.S.	-.16	-.05	-.09	-1.22	-.23
Significance	--	--	--	$p<.01$	--

* Mean (std. dev.)
** Significance levels greater than 0.10 are shown as [--].

test, the Chinese females voted higher than the U.S. females while in the 71F test, the Chinese females voted lower than that of U.S. females. It seems that the Chinese females are more sensitive than U.S. females though it can not be proven statistically with the data in this study.

Thermal Environmental Quality Vote

The data and comparison for thermal environmental quality vote are shown in Table 4. In the lower temperature environments (71F and 76F), no consistent trends are evident. However, the differences between Chinese and U.S. subjects become obvious with the increase of the environmental temperatures (81F, 86F and 91F). The differences are statistically significant from the T-test analysis both for females and male subjects. The Chinese subjects appear to view the warmer environments more tolerably than do the U.S. subjects. However, this result does not necessarily mean that the Chinese subjects more favor warmer environments than the U.S. subjects, but only that they may be more tolerant of environments.

Since the thermal environmental quality ballot measures the "feeling" of the subjects, it involves some uncertain influences with effects that are highly subjective, e.g., the difference in culture and social background and the difference in understanding or

Table 4. The Data of Thermal Environmental Quality Votes (150 min Vote)*

Subject Group	Air Temperature 71F	76F	81F	86F	91F
U.S. Females	-.22(1.12)	.2(.71)	-.8(1.07)	-.42(.46)	-.22(.45)
China Females	-.02(.79)	.32(.76)	-.22(.45)	.82(.33)	.34(.53)
China-U.S.	.20	.12	-.58	1.24	.56
Significance**	--	--	--	p<.01	p<.05
U.S. Males	.26(.86)	-.36(1.31)	-.8(.96)	-.12(.70)	-.22(.79)
China Males	-.44(1.07)	-.62(.99)	-.52(.80)	.78(.58)	.66(.46)
China-U.S.	-.70	-.98	.28	.90	.88
Significance	--	--	--	p<.025	p<.025
US Fem+Mal	.02(.92)	-.08(.99)	-.80(.89)	-.30(.76)	-.22(.61)
Ch Fem+Mal	-.23(.86)	.47(.79)	-.15(.68)	.80(.44)	.50(.49)
China-U.S.	-.25	.55	.65	1.10	.72
Significance	--	--	--	p<.005	p<.005

* Mean (std. dev.)
** Significant levels greater than 0.10 are shown as [--].

interpreting the English terms on the ballots. These effects should not be overlooked.

The Moisture Gain of the Clothing

The clothing moisture gain results are in Table 5. The differences and the trends are consistent and evident. In all of the tests, both cooler and warmer environmental conditions, the results indicate that the U.S. subjects tend to have more sweat gain than the Chinese subjects. The differences in the lower temperature conditions are not all statistically significant, but are generally statistically significant in the warmer environments (86F and 91F). This may be attributed to the differences in height, weight, physique etc. between the ethnic groups from the anthropological point of view.

Some care must be exercised in analyzing the moisture gain results. Gains were relatively small compared with the total clothing weight. Since moisture absorption by individual fibers is relative humidity dependent, the differences in subject skin temperature may influence the results. Also, moisture gain will be greatest where it is prevented from evaporating, such as between the buttocks and the chair seat, between the back and the chair back, and where body parts overlap. Differences in posture could affect these small moisture gains. In spite of these

Table 5. The Moisture Gain of the Clothing (grams)*

Subject Group	Air Temperature 71F	76F	81F	86F	91F
U.S. Females	-.09(.36)	1.6(1.15)	.96(.72)	5.66(1.28)	11.26(2.01)
China Females	-.21(.29)	.60(1.49)	.77(.56)	3.50(1.74)	7.89(2.14)
China-U.S.	-.12	-1.0	-.19	-2.16	-3.37
Significance**	--	--	--	p<.01	p<.05
U.S. Males	1.0(1.65)	1.38(1.19)	1.81(1.36)	8.18(1.62)	13.38(1.52)
China Males	.55(1.05)	.46(.53)	.39(.84)	5.37(.93)	10.81(2.72)
China-U.S.	-.45	-.92	-1.42	-2.81	-2.57
Significance	--	p<.1	p<.01	p<.02	p<.10
US Fem+Mal	.45(1.29)	1.49(1.15)	1.38(1.15)	6.92(1.91)	12.32(2.01)
Ch Fem+Mal	.17(.84)	.53(1.09)	.58(.72)	4.43(1.64)	9.35(2.78)
China-U.S.	-.28	-.96	-.8	-2.49	-2.97
Significance	--	p<.10	p<.10	p<.005	p<.005

* Mean (std.dev.)
** Significance levels greater than 0.10 are shown as [--].

difficulties, the clothing moisture gain did yield useful results. It is expected that similar measurements would provide better discrimination in tests where more clothing is worn and inner garments are weighed separately.

The Mean Weighted Skin Temperature

The comparison of mean weighted skin temperature is shown in Table 6. The results indicate that Chinese subjects consistently had slightly higher skin temperatures for all environmental temperatures, except for the 91F condition. None of the differences were statistically significant; but the consistency of the difference indicates it is real.

Time Dependent Behavior

A subject's responses to a thermal environment are associated with both the thermal sensation (feelings) and the body's thermoregulatory response. They are influenced by many psychological and physiological factors and the time duration of exposure to that environment. It might be assumed that after 2 1/2 hours of exposure to a constant (moderate) thermal environment with a constant metabolic rate, a heat balance will exist for the human body, i.e. the heat production will equal the heat dissipation. In order to investigate the transient responses and

Table 6. The Mean Weighted Skin Temperature (F) (150 min measurement)*

	Air Temperature				
Subject Group	71F	76F	81F	86F	91F
U.S. Females	91.76(1.76)	92.31(.89)	95.24(1.27)	94.92(1.17)	95.97(.59)
China Females	91.86(1.36)	93.33(1.23)	95.66(1.06)	95.02(1.10)	95.38(.73)
China-U.S.	.1	1.02	.42	.1	-.59
Significance**	--	--	--	--	--
U.S. Males	91.02(1.24)	93.07(1.18)	94.34(.62)	95.41(.35)	95.87(.95)
China Males	92.61(1.19)	93.61(.91)	95.05(.67)	95.51(1.3)	96.24(1.06)
China-U.S.	1.59	.54	.71	.1	.37
Significance	p<.01	--	--	--	--
US Fem+Mal	91.41(1.43)	92.69(.99)	94.79(1.05)	95.17(.85)	95.92(.75)
Ch Fem+Mal	92.24(1.2)	93.47(.96)	95.35(.83)	95.26(1.17)	95.81(.97)
China-U.S.	.83	.78	.56	.09	-.11
Significance	--	--	--	--	--

* Mean (std.dev.)
** Significance levels greater than 0.10 are shown as [--].

the difference between the two ethnic groups, the votes and measurements versus time duration are plotted in Figure 8 through 13. The mean thermal sensation votes as a function of time are shown in Figure 8. The 76F condition yielded votes closest to neutral while the 91F condition yielded the result furthest from neutral in the thermal sensation response. The mean environmental quality votes versus time are shown in Figure 9(A) and Figure 9(B). The 76F condition is preferred over the lower and higher temperature after the first hour of testing. This is consistent with the thermal sensation results that the 76F yielded the votes closest to neutral. The reversal of the neutral in the thermal environmental quality responses for the 71F and 76F at about 60 minutes into the tests is explicable. In general, most subjects had an activity level greater than sedentary before the test. Most at least walked some distance to get to the test. This activity combined with the activity of getting dressed and instrumented for the test probably resulted in a raised metabolic rate at the beginning of the test. Also, the results indicate the body's physiological response is qualitatively different for raised and lowered temperatures. There is therefore no reason to expect that the rate of change in the sensation with temperature will be the same for temperatures deviating from the neutral condition.

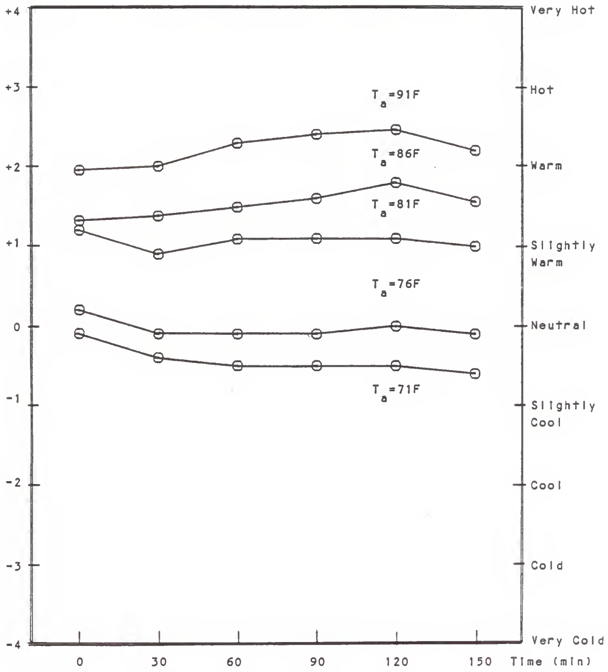

Figure 8. Mean Thermal Sensation Votes vs. Time

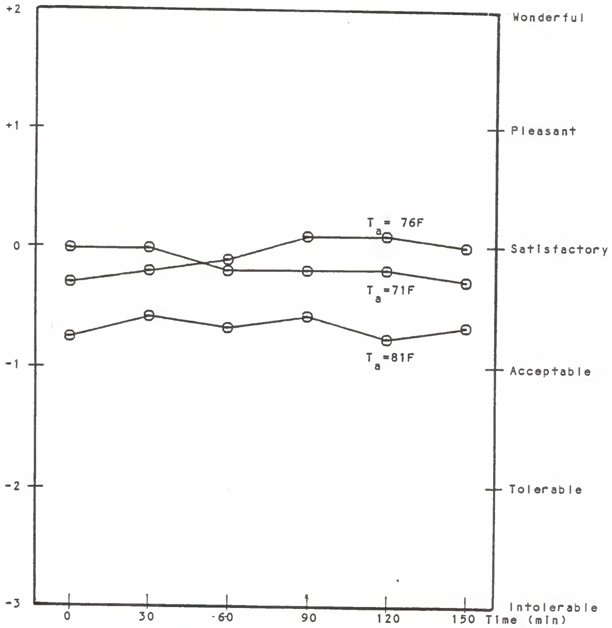

Figure 9A. Environment Quality Votes vs. Time (71F, 76F and 81F)

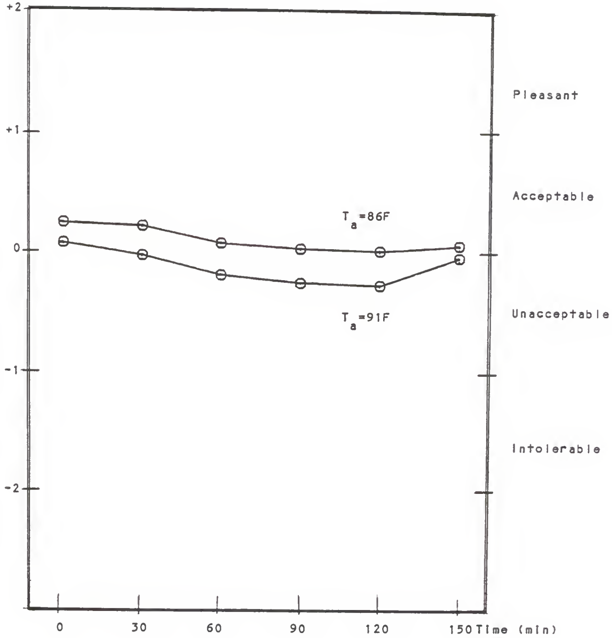

Figure 9B. Environment Quality Votes vs. Time
(86F and 91F)

The skin temperature data in Figure 10 indicates that the mean weighted skin temperature of the subjects is consistent with the test conditions. The warmest environment yielded the highest skin temperature. The overlapping of the two conditions (81F and 86F) indicates the body temperature regulation responses of the subjects. When they are exposed to the warm environmental conditions (about 81F), their skin began to sweat, but the skin temperature rose slowly, and because of the thermoregulatory system, their body temperature should have no marked change. (Gagge et al 1967). Since the above two temperature tests were conducted in different seasons and with the different subject groups, it is also possible that the overlapping is due to these diferences. At the 91F temperature, the wettedness of the subjects' skin probably increased rapidly (from the data of sweat gain), and also the skin temperatures were higher. This may indicate the body temperatures of the subjects began to increase, even though the changes were still small.

At the 71F, 76F and 81F temperatures, the subjects gradually cooled down after about 60 minutes. This may be ascribed to a slow decrease in metabolic rate as the subjects settled down to a sedentary activity level. This validated the results of other researchers (Rohles et al 1973; Griffith and McIntyre 1974). In the temperature of

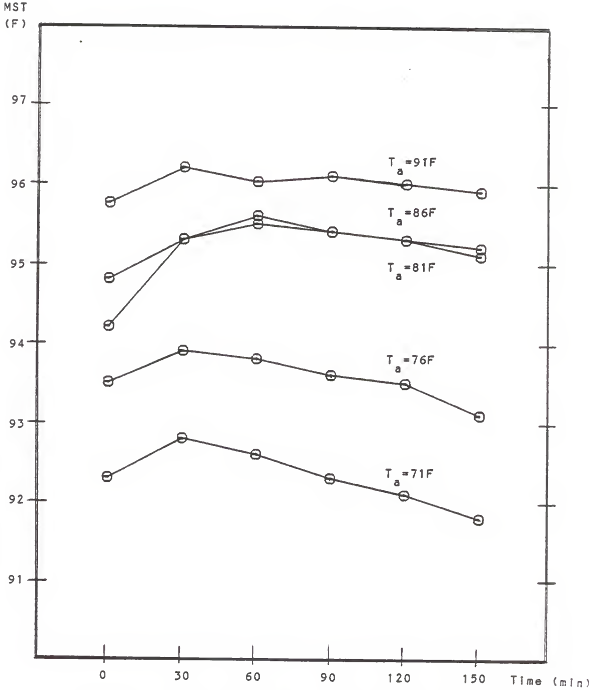

Figure 10. Mean Weighted Skin Temperature vs. Time

85F and 91F, the subjects kept sweating in the warm environments and the trend of decline is less evident. In the lower temperature conditions (71F, 76F and 81F), there is a continuing decline in the skin temperature and it shows no sign of ending. This indicates actual cooling of the body and is in contradiction with the initial hypothesis that after 2 1/2 hours of exposure at the same thermal environment with the same activity level, the subjects will be at steady state.

Figure 11 shows the comparison of thermal sensation votes versus time between two ethnic groups. The difference is less evident, except for the temperature of 86F. The Chinese subjects appear to be more tolerant of the warm environmental condition; this is consistent with the results in Figure 12, which indicates the Chinese subjects view the warm environment more acceptable than do the U.S. subjects.

Since thermal sensation and environmental quality votes are all based on verbal scales, the judgment of thermal comfort and discomfort, warm, neutral or cool is affected greatly by the English words, and may be different from one subject to another, even in the same ethnic group. Therefore, it is not possible to specify exact differences in preferred conditions using data from the present study.

Figure 13 shows the difference in Mean Weighted Skin

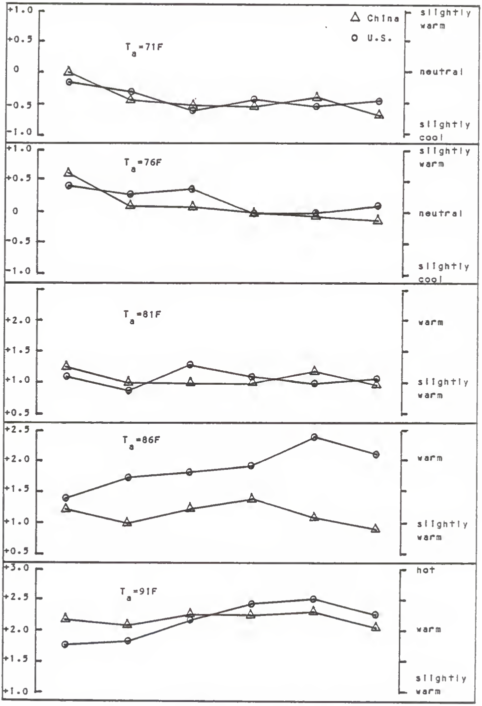

Figure 11. The Comparison of Thermal Sensation Votes vs. time

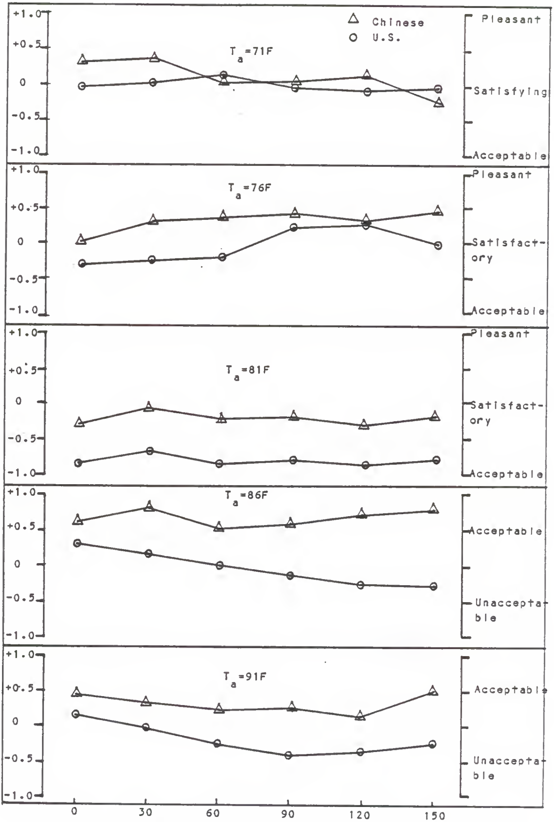

Figure 12. The Comparison of Environmental Quality Votes vs. Time

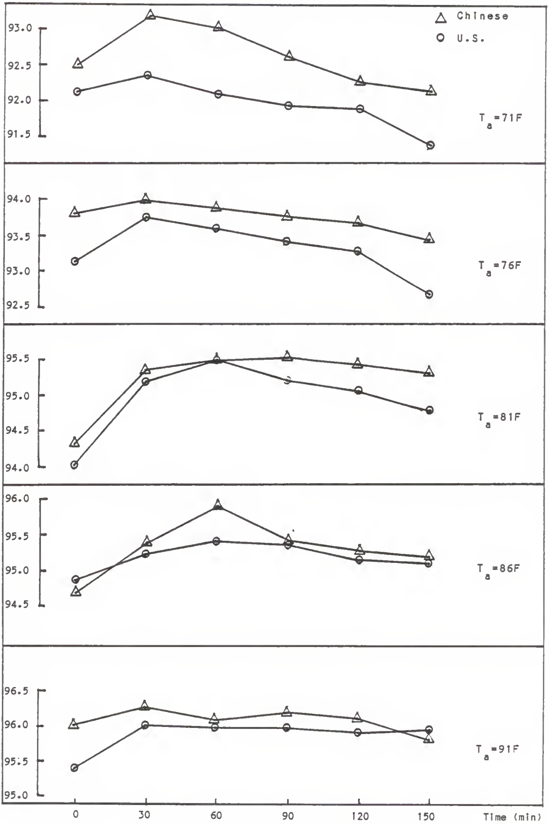

Figure 13. The Comparison of Mean Skin Temperature vs. Time

Temperature between two groups. The Chinese subjects had a slightly higher skin temperatures in 71F, 76F and 81F conditions but the difference are less evident in warmer conditions. Since in the warm environmental conditions, the wettedness of the skin surface increases and the temperature of the skin surface changes slowly.

Individual Results

The individual votes and measurements for each subject are summarized in Figures 14 to 17. In the preceding sections, the mean values of votes and measurement were compared, however, thermal environments must be designed for all occupants, not just the average occupant, therefore, the individual variations within a population must also be considered. Figure 14 shows the individual votes for thermal sensation. The intra-population differences are great and the inter-population differences are not evident.

From Figure 15A and Figure 15B, the environmental quality votes, the trend is evident in the higher temperature conditions (see Figure 15B). Both Chinese male and female subjects view the warm environment more acceptable than do the U.S. subjects. A similar trend can also be found in Figure 16 for the clothing moisture gain of the individuals. In all the test conditions, the

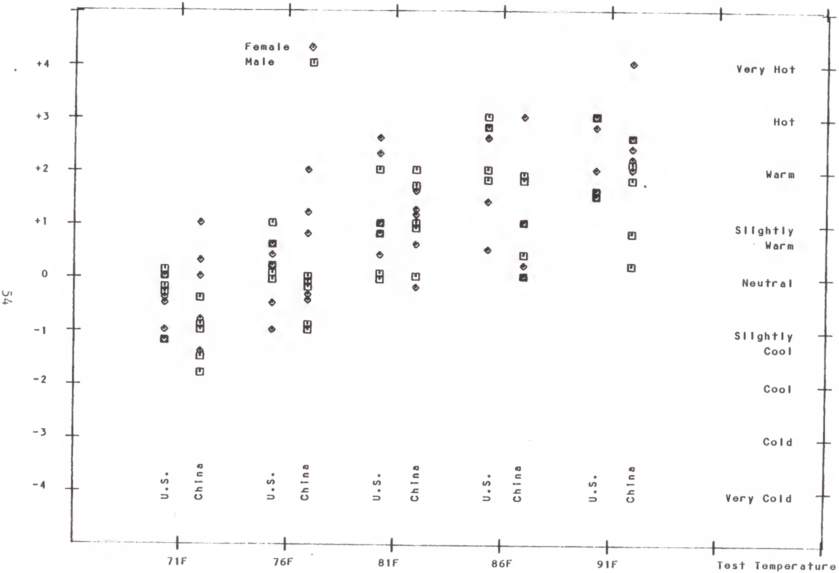

Figure 14. Individual Thermal Sensation Votes (150 minutes)

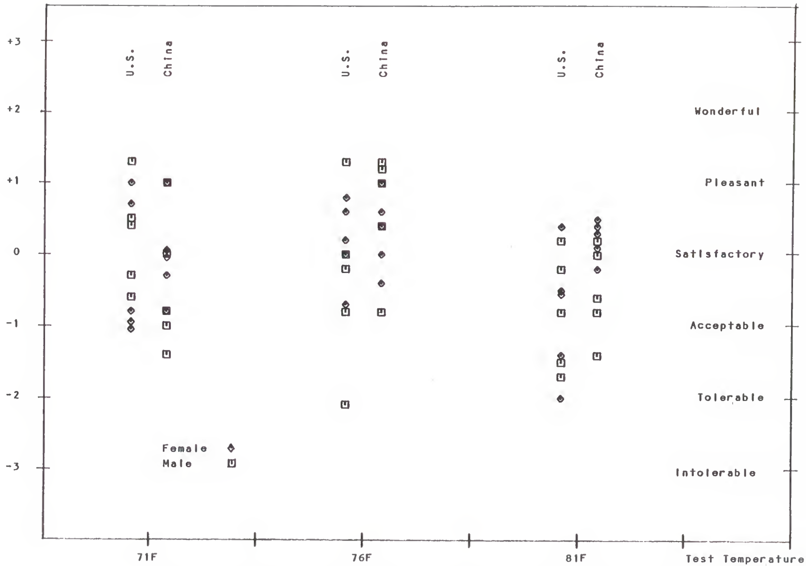

Figure 15A. Individual Environment Quality Votes (71F, 76F and 81F)
(150 minutes)

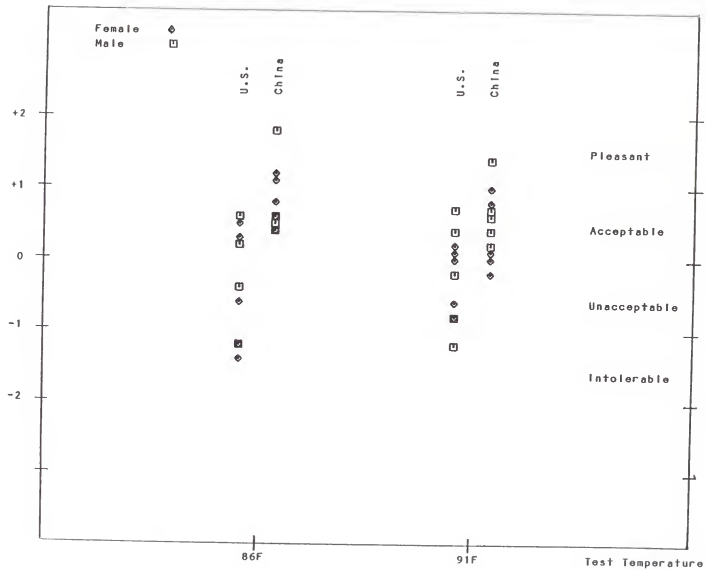

Figure15B. Individual Environment Quality Votes (86F and 91F)
(150 minutes)

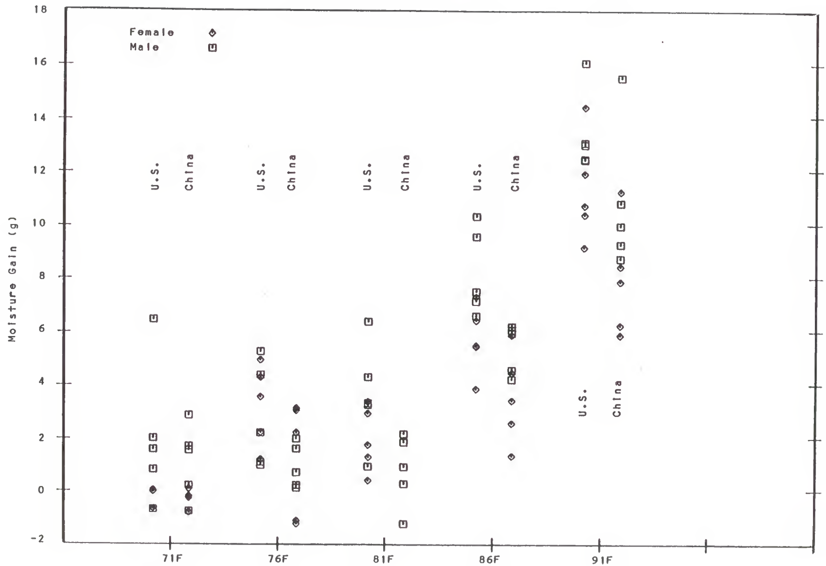

Figure 16. Clothing Moisture Gain

U.S. subjects had more sweat gain than that of Chinese subjects, especially in the warmer conditions, the trends are consistent and evident. This result is quite understandable since the average weights, heights and DuBois areas are significantly different between two ethnic groups (see Table 1).

Figure 17 shows the individual data of mean weighted skin temperature. The variations within the ethnic groups are great and the differences between the ethnic groups are not significant.

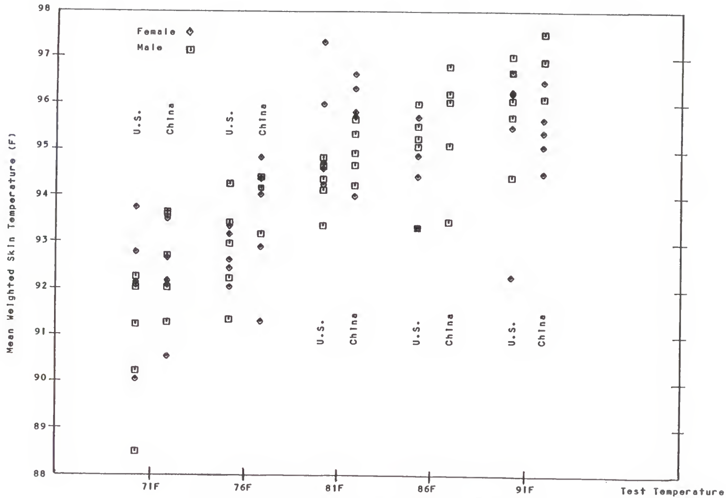

Figure 17. Individual Mean Weighted Skin Temperature
(150 minutes)

CHAPTER 4 CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

Conclusions

A direct comparison was made in this study to evaluate the differences in thermal comfort responses between Chinese and U.S. subjects. Some differences in physiological responses may exist but are relatively small. The U.S. subjects appear to sweat more than the Chinese subjects, consistently in all test temperatures. The differences are more evident and statistically significant in the higher temperatures (81F, 86F and 91F). The Chinese subjects appear to have higher skin temperature consistently in all except for 91F test temperature conditions, the differences between ethnic groups are small and not statistically significant, while the variations within the population are large.

In the warmer environmental conditions (86F and 91F), the mean environmental quality votes of the Chinese subjects are higher than that of U.S. subjects. This does not necessarily indicate that the Chinese subjects view the warm environments favorably; however, it shows the Chinese subjects were more tolerant of warm environments and less tolerant of cool environments than the U.S. subjects.

The variations within the Chinese and the U.S. sample populations are large compared to the variations between the population in thermal sensation votes; therefore, no conclusions about differences between the populations can be made.

It was also found that even after 150 minutes duration, the subjects were not at true thermal steady-state conditions.

Since the thermal responses have no significant difference within the ASHRAE comfort zone between Chinese and U.S. subjects, the ASHRAE Standard 55-1981 should also apply to Chinese people. However, because of the anthropometric difference between two ethnic groups, the upper and lower limits of the comfort zone may be shifted for Chinese people, further research is recommended for additional quantitative analysis.

Limitations

Because of the limitation of the sample size of this study, further comparisons between two ethnic groups for the same gender (e.g. the Chinese males versus U.S. males, and Chinese females versus U.S. females) were not appropriate.

In this study, the whole experiment was divided into two phases which were conducted in different seasons and using different subjects. Even in the same phase, the subjects were not consistently the same because of the absence of the individual subjects. Also, different environmental quality ballots were used. Therefore, the comparison between the individuals and the responses to different environments for particular subjects were not available. However, considering the main objective of this study is to investigate the difference between two ethnic groups, the above limitation does not directly affect the comparison.

Recommendations

For further research, a large sample population would be desirable to get better analysis. Since the physiological response of discomfort increases more rapidly for ambient temperature below the neutral condition than for those above neutral condition, the range of test temperatures should also extend to lower temperature conditions (Gagge et al 1967).

In order to determine the difference in psychological responses and get the quantitative analysis, more precise measurements e.g. the subjects' body temperature (both tympanic and rectal temperatures), metabolic rate and evaporative heat loss are also recommended.

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INFORMED CONSENT STATEMENT

Comparison of the Thermal Comfort of U.S. and Asian Peoples

1. I, ______________________ volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I fully understand the purpose of the study as outlined in the orientation statement.

3. I understand that I may be observed during my participation and that my conduct and/or voice may be recorded by photographic and/or recording devices. I also realize that public reports and articles may be made of the experiments and all of the observations, and I consent to publication of such including the use of photographs if my face is "blanked" out.

4. I also understand that my performance as an individual will be treated as research data and will in no way be associated with me for other than identification purposes, thereby assuring anonymity of my performance and response.

5. I understand that I will be permitted to leave the test at any time and I may discontinue participation without penalty or loss of benefits to which I am otherwise entitled.

6. As compensation for my voluntary services as a participant in the aforesaid studies, Kansas State University may pay me. It is clearly understood and agreed, however, that in no event am I to be considered an employee of Kansas State University during participation. Therefore, no Social Security, income tax, retirement or other benefits of employment will be deducted or accrued.

7. I hereby agree, under penalty of forefeiture of all compensation due me, not to give information regarding these studies to any public news media nor to publicize any articles or other accounts thereof without prior written approval of Kansas State University.

8. If I have any questions concerning my rights as a test subject, injuries or emergencies resulting from my participation or any questions concerning the study, I understand that I can contact Dr. Byron Jones at 532-5620.

I have read the Subject Orientation and Test Protocol Statement and signed the herein Informed Consent this ______________ day of ______________, 19____.

____
Signature

Sign and return one copy. The second copy is for your records.

APPROVED

OCT 1 0 1986

Committee on Research
Involving Human Subjects
Kansas State University

Appendix 1. Informed Consent Statement

Subject Orientation and Test Protocol Statement
Comparison of the Thermal Comfort of
U. S. and Asian Peoples

The purpose of this study is to measure your thermal response to various indoor environment conditions. You should be aware that the conditions to which you will be exposed entail minimal physical risk or mental stress. If you decide to become a subject, you should be aware of the following: (1) you are volunteering to act as a subject and are participating on your own volition; (2) if you choose not to participate there will be no penalty or loss of benefits to which you are otherwise entitled; (3) you may leave the experiment any time you wish; (4) your identity as a subject will not be disclosed and anonymity will be maintained; and (5) the results of this study will help us to learn more about the environmental conditions required to provide thermal comfort for people from Asia and the United States.

When you report to the experiment, your oral temperature will be taken and if it is not over 99.1°F (37.3°C) you will be allowed to continue. A researcher will give you a shirt and a pair of trousers to put on. You will wear these over your own underwear (no t-shirts will be worn). You will also wear your own shoes and socks. Skin temperature sensors will be taped to the calf of your leg, to your forearm, and to your chest. The researcher will then go over the test procedures with you and explain the ballots you will be filling out during the test. You will also be weighed and have your height measured.

You will then enter the environmental chamber where you will remain for 2 1/2 hours. All subjects in a test will be of the same sex. You will be seated at a table where you may read, do homework or other book work, or talk quietly with the other subjects in the test. You may not sleep and you may not discuss your thermal sensations or other aspects of the environment. You may not take any food or water into the chamber. You will be provided water to drink during the test. Every 1/2 hour you will be given ballots which you will fill out to describe your thermal feelings. At the end of the 2 1/2 hours, the temperature sensors will be removed. You will change back into your own clothes and place the garments you wore during the test into a plastic bag. They will be measured later for moisture absorption. Total time for the test including preparation will be approximately 3 hours.

You must be at least 18 years old and in good health to participate. The environmental conditions during the tests pose no significant risks to a healthy person. You may, however, experience warm discomfort during one or both of the tests. The temperature during all tests will be within the range of 85°F to 91°F (29°C to 33°C).

You will be required to participate in two such tests. At the end of the second test you will be paid $26. Should you drop out of the test before completing both tests, one half of this amount will be prorated according to the amount of time you actually participated. Should the researcher request you to drop out or should both tests not be conducted, the full $26 will be paid, prorated in the same manner.

Appendix 2. Subject Orientation and Test Protocol Statement

Appendix 3. The Background Information of the Manikin

The manikin used in this study to measure the total insulation of clothing is a computerized and thermally segmented manikin "Fred" which was developed by a group of Scandinavian scientists (Figure 3). Each section of the manikin consists of a light plastic form casting which fits onto the metal skeleton of the manikin.

Electrical connections to the sections are made via internal replaceable wiring to flat cables which leave the manikin at the back of his neck. The heating and measurement wires are located near the surface of the manikin. Heating wires are embedded in the plastic form, evenly distributed over the surface of each segment, with a resistance giving a maximum heating effect of 300 W/m^2 at full voltage. The heating wires are of constantan with a negligible thermal coefficient so that the electrical resistance of each section is in practice independent of the thermal load. External to the layer of heating wires and electrically insulated from them, is a metallic layer which serves to spread the heat and create an even surface temperature.External to this layer, and electrically insulated from it, are nickel wires with a known thermal coefficient for measurement of the surface or skin temperature.

Measurement and control of heat supply for each section is achieved by using a digital process computer. Presentation and recording is carried out by another Zenith PC 150 computer which communicates with the process via a serial interface. The temperature reading and power input values for each segment are area weighted when calculating the total insulation value. This manikin is a full-size male manikin with 19 electrically separate segments or sections. 18 of which are in operation at one time. The lap section is used when the manikin is standing; the bottom section is used when it is sitting. The manikin has knee, hip, shoulder and elbow joints that can be flexible or locked in an immobile position. It can be attached to an external motion system at the wrists and ankles and made to walk at various speeds.

In the control system of this manikin, two industrial process controllers are used. Each controller has 16 analogue inputs and 16 digital outputs and each has 12 software regulators for variable-parameter proportional-integral control. Each body segment on the manikin is connected to one analogue input and one digital output, and assigned one regulator. The parameters of each regulator are adjusted to the characteristics of the controlled body section to give stable control. Each regulator is calculated once every 30 seconds, and a program loop is executed every second to adjust the pulse length to the nearest 1/8 second so that the required power output, as calculated by the regulator, is successively approximated during the 30-second integration period and is evenly distributed over time.

The DC voltages are maintained at 60 or 30 voltages as appropriate for different sections, and the power output to each section is a linear function of the sum of the output pulse lengths. The process computer stores the set values of the target resistance for each body section and responds with the current regulator output as calculated to maintain set values. Current values of body segment resistance are measured every second and filtered for measurement artifact. If any body section resistance lines outside the permissible range, either too low, which can indicate measurement error, or too high, which can indicate dangerous overheating, the DC voltage is switched off at once via a "watch dog" digital output, to saveguard the manikin.

A Zenith 150 (IBM compatible) controlling PC is used to transmit set values to the process controllers, alter regulator parameters and acquire regulator outputs and body section resistance values for calculation, storage and presentation. A calibration file contains constants for each body section relating measured resistance to skin temperature and regulator output to power dissipation in watts per square meter. This latter calculation involves prior knowledge of the heating wire resistance, the voltage applied and the power loss in the cable to each section, as well as the heated surface area of the section. Electrical resistances are measured to an accuracy of 0.01 volts. The relationship between measuring wire resistance and surface temperature is empirically derived as a regression equation after passive exposure of the unheated manikin to know homogeneous temperatures in the skin temperature region 30-35^{o}C.

All measurements are made by the control system, which calibrates itself under program control. Set values of resistance are calculated from these regression and transmitted to the process controllers before each measurement series and measured resistances are converted to degree C by the presentation computer after each scan.

During the measurement, the air temperature set in the chamber was 68F (20^{o}C). The dew point temperature was 47.5F (8.5^{o}C). The air velocity was less than 30 fpm (0.15 m/s), (essentially still air-only natural convection around the body).

TEST RESULTS STANDING TEST 09:26:34 11-18-1986 AIR TEMP 20.07

CHN	SEG	TMP	SET	WATTS	CLO	STAB
1	HEAD	33.98	34.00	17.25	0.69	0.02
2	CHEST	35.00	35.00	12.62	1.44	0.00
3	BACK	35.01	35.00	11.49	1.62	0.01
4	LU ARM	33.49	33.50	5.90	1.56	0.00
5	RU ARM	33.50	33.51	5.59	1.63	-0.00
6	LL ARM	32.01	32.01	3.16	1.36	0.00
7	RL ARM	31.99	32.00	2.97	1.42	0.00
8	L HAND	29.49	29.50	3.60	0.75	0.00
9	R HAND	29.50	29.51	3.44	0.74	0.00
10	L THIGH	33.50	33.49	11.16	1.27	0.00
11	R THIGH	33.49	33.50	10.12	1.41	0.00
12	L CALF	31.50	31.51	4.53	1.72	-0.00
13	R CALF	31.51	31.50	4.35	1.76	0.00
14	L FOOT	29.51	29.51	2.07	1.92	-0.00
15	R FOOT	29.50	29.50	1.89	2.07	0.00
16	STOMACH	35.00	35.01	3.91	2.69	-0.00
17	LAP	34.99	35.00	2.33	1.51	0.00
18	BUTTOCKS	33.99	33.99	3.26	2.33	-0.00
19	BOTTOM	33.27				
	AVG/TOT	33.20	33.20	109.63	1.41	0.05
						1.01

Appendix 4. Computer Printout of the Measurement Data for the Clothing Ensemble

A COMPARISON OF THE THERMAL RESPONSE OF

CHINESE AND NORTH AMERICAN PEOPLE

by

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B.S.,SHANGHAI INSTITUTE OF MECHANICAL ENGINEERING, 1982

AN ABSTRACT OF MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

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1988

ABSTRACT

ASHRAE Standard 55-1985 and ISO Standard 7730 prescribe thermal conditions for human occupancy and are often applied in many countries all over the world. The data bases used for these standards come primarily from studies with U.S. subjects. Questions arise regarding the applicability of data bases for people living in different climates or from different cultures. A study was conducted to investigate the differences that exist in the thermal response of people from China and the United States. There were a total of 40 subjects, with 20 from each country; half were females and half were males, that participated in a total of 5 tests. The environmental temperatures were 71F, 76F, 81F, 86F and 91F.

The results indicate that the Chinese subjects had less sweating than the U.S. subjects. The differences were consistent and evident especially in the warm environmental conditions. Also, the Chinese subjects had slightly higher skin temperatures than that of U.S. subjects but the differences were not statistically significant.

The results also indicate the Chinese subjects were more tolerant of warm environments and less tolerant of cool environments than the U.S. subjects. The individual responses show that the intra-population differences in individuals are greater than the inter-population

differences in means for both skin temperature measurements and thermal sensation ballots.

The thermal responses have no statistically significant differences within the ASHRAE comfort zone between Chinese and U.S. subjects. These results indicate that the ASHRAE Standard 55-1981 should also apply to Chinese peole; but the upper and lower limits of the comfort zone may be shifted.