No. 1860

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The effect of floor surface temperature on comfort Part II, college age females

In the early 1950's, a study was initiated at Kansas State University to determine, in general, the effect of floor surface temperatures on comfort. A specific aim of this investigation was to obtain experimental data upon which the upper limit of the floor surface temperature could be based, thereby providing a practical and more satisfactory design guide.

The results of the first phase of this investigation were reported by Nevins and Flinner[1] in 1958. Both male and female subjects were subjected to various levels of floor surface temperature for a period of 60 min while seated at rest. The air temperature was maintained at 75 F. The results of the second phase of the study covering male subjects, both seated and standing, with 3 hr exposure periods were reported in 1964.[2] The subjects were exposed to various levels of floor surface temperature with the air temperature held constant at 75 F. The present paper deals with a study of college age women exposed to a variety of floor surface temperatures for periods of three hr, again at two different activity levels and represents an extension of the previous work.

TEST FACILITIES

Since no substantial changes were made in the test facilities since the conclusion of the first part of this study, and since the test facilities are described in detail in "The Effect of Floor Surface Temperature on Comfort, Part 1, College Age Males,"[2] no further description will be made here. The reader is referred to the earlier paper for a description of the facilities.

SUBJECTS

Two groups of subjects participated in these tests. The first group, composed of 18 college-age females, took part in Series 1 in the spring of 1961. The second group, composed of 18 college-age females, took part in Series 2 in the fall of 1961. The pertinent subject data are shown in Table 1.

Each subject was given a thorough physical examination by the consulting physician at the Kansas State University Health Center.

EXPERIMENTAL PROCEDURE

The tests were divided into two parts, depending upon subject activity. In Series 1, the subjects were seated and occupied in reading or studying lesson assignments. In Series 2, the subjects stood and were occupied in writing and sorting bibliography cards. This latter activity was designed to simulate light office work.

The test conditions, other than activity, were the same for both Series 1 and 2. Each subject was exposed to six different floor temperatures; 75, 80, 85, 90, 95, and 100 F, in a random order, for periods of three hr. The air temperature during Series 1 and 2 was maintained at 75 F and air velocity was held to about 25

The experimental work was supported by a grant (OH-7) from the Div of Occupational Health, U.S. Public Health Service. *K. B. Michaels is assistant Professor of Mechanical Engineering, R. G. Nevins is Professor and Head, Department of Mechanical Engineering and Director, Institute for Environmental Research, and A. M. Feyerherm is Associate Professor of Statistics, Kansas State University, Manhattan, Kansas.* *This paper has been prepared for presentation at the ASHRAE Semiannual Meeting, Jan 27-29, 1964, New Orleans, La.*

Fig. 1 Typical female subject, showing wearing apparel

fpm or less in the vicinity of the subjects. The rh varied between 30 and 80%.

Due to the great variability of the clothing normally worn by women in the fall and spring, it was felt that a more uniform dress was needed. Therefore, during these tests, the subjects wore a lightweight, sleeveless cotton smock over their normal underclothing. They also wore a light weight leather shoe with a quarter-inch foam plastic sole. A typical subject wearing this apparel is shown in Fig. 1.

Usually, two tests were run each test day; one in the afternoon from 1:00 to 5:00 p.m., and one in the evening from 6:30 to 10:30 p.m. The subjects, normally two at a time, reported to the test room one hr before the test period. During most of this first hr, the subjects were seated at rest in a reasonably comfortable indoor environment. During about 10 min of this time, the subjects were required to disrobe and stand while the thermocouple harness was applied. They then dressed in the outer garments described above. A record was made, at this time, of the subject's previous activity, her general state of health, and oral temperature.

Following the one hr acclimation period, the subjects entered the test room and began the required activity. Data were recorded at the end of each 15 min interval for the first hr and at the end of each succeeding 30 minute interval.

In addition to the physical data recorded during the test, two subjective votes were obtained from the subjects. The first was a thermal sensation vote relating to the subject's overall feeling of comfort. This was indicated by the following scale:

1. Cold
2. Cool
3. Slightly cool
4. Comfortable
5. Slightly warm
6. Warm
7. Hot

The second was a foot comfort vote relating specifically to the feet, and was indicated by the following scale:

1. Cold
2. Comfortable
3. Hot

The subjects were encouraged to utilize votes such as 2.5, 5.5, etc., but the votes were generally indicated as integers.

RESULTS AND DISCUSSION

The presentation of results in this report follows closely the presentation in "The Effect of Floor Surface Temperature, Part I, College Age Males."[2]

Table I Subject Data

Series 1				Series 2			
Subj No.	Age	Height (in.)	Weight (lbs)	Subj No.	Age	Height (in.)	Weight (lbs)
49	19	62	125	67	21	61	122
50	26	69	160	68	18	64	126
51	20	65	118	69	20	65	157
52	21	66	142	70	19	66	160
53	19	65	125	71	19	65	122
54	20	61	102	72	20	66	152
55	21	65	126	73	19	59	110
56	23	68	125	74	18	65	133
57	19	70	165	75	20	63	118
58	19	66	165	76	19	66	133
59	22	62	111	77	19	65	128
60	21	66	147	78	21	66	111
61	20	67	123	79	23	54	116
62	19	65	140	80	21	60	125
63	18	63	125	81	20	65	122
64	18	64	123	82	24	62	121
65	19	69	127	83	19	61	116
66	21	63	118	84	18	61	107

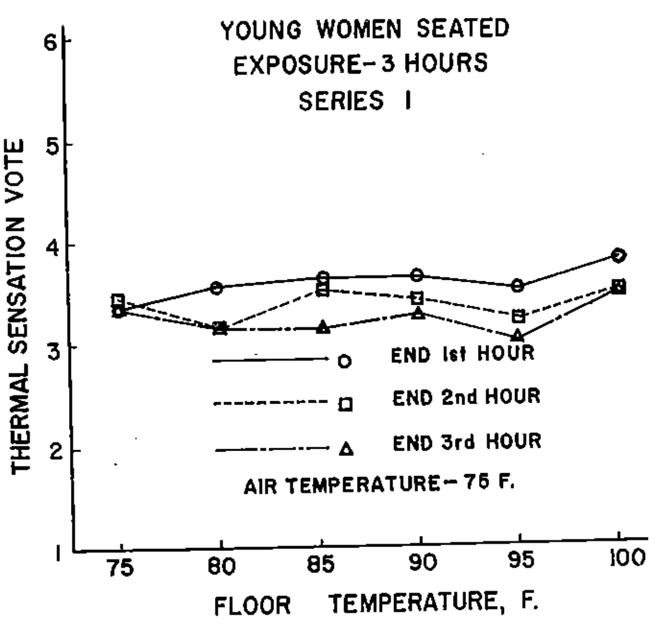


Fig. 2 Effect of floor temperature on thermal sensation vote for seated young women

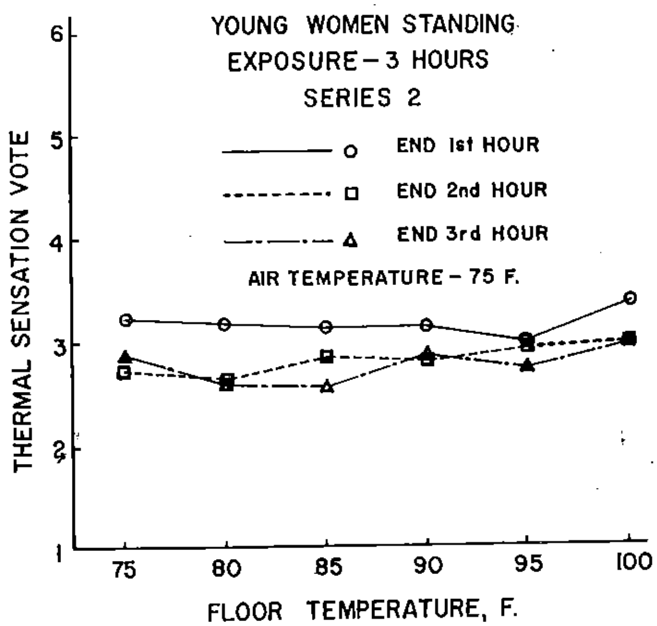


Fig. 3 Effect of floor temperature on thermal sensation vote for standing young women

The relationship between Thermal Sensation Vote and floor temperature is shown graphically in Figs. 2 and 3. The values shown represent average values of Thermal Sensation Vote at the end of each one hr interval. Neither set of curves indicate any increase or decrease of comfort vote with increasing floor temperature. Further, both sets of curves are below the comfort level represented by a vote of 4. To explain this depression of Thermal Sensation Vote it should be remembered that the outer garments worn by the female subjects were rather lightweight and it may be presumed that the air temperature of 75 F used in the tests was too low to permit a Thermal Sensation Vote of 4.

The relationship between Foot Comfort Vote and floor temperature shown in Figs. 4 and 5 clearly indicates an increase in Foot Comfort Vote with increasing floor temperature. Further, the level of votes for each floor temperature is practically the same for both series of tests. If the range of foot comfort can be assumed to be between a vote of 1.5 and 2.5, then discomfort occurs at a floor temperature of 95 F and above.

The relationship between mean skin temperature and foot temperature with floor temperature is shown in Figs. 6 and 7. The increasing trend of both sets of curves with floor temperature is again obvious. The increase of mean skin temperature with increasing floor temperature is slight however. The relatively greater increase in foot temperature with increasing floor temperature results from direct contact of the feet with the floor so that conduction plays the major role in heat transfer. While it may be stated that the data indicate a general increase in blood flow in the feet, no quantitative statement can

Fig. 4 Effect of floor temperature on foot comfort vote for seated young women

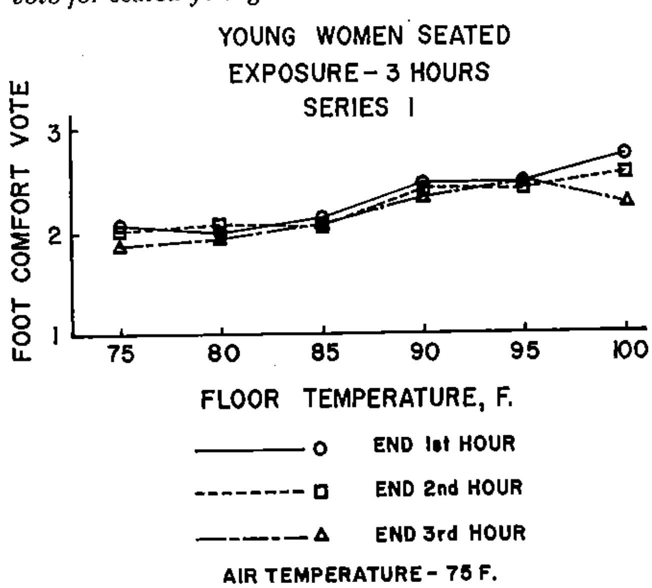
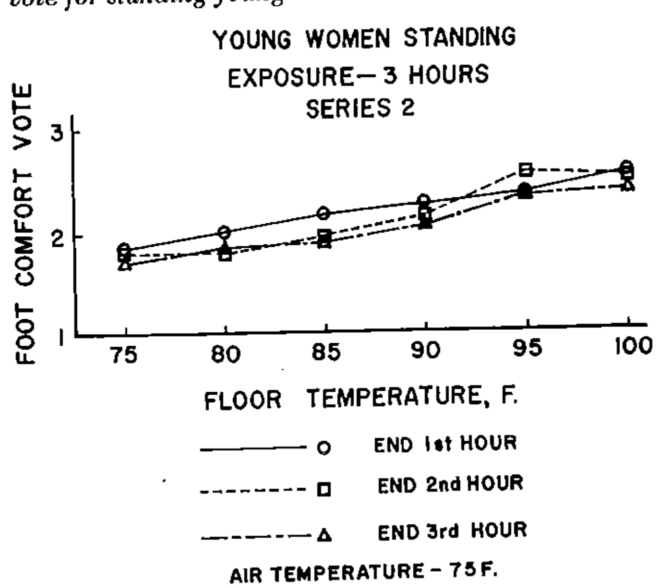


Fig. 5 Effect of floor temperature on foot comfort vote for standing young women



be made about the increase due to the temperature depressing effects of perspiration.

Figs. 8 and 9 show the percentage of foot discomfort votes cast for each floor temperature. The data shown were established by dividing the number of votes of 3 (hot) cast at each one-half hr interval at each floor temperature by the total number of votes cast over the same time interval and floor temperature. Thus a vote of 3 (hot), which clearly indicated foot discomfort, was the criteria used to establish subject discomfort. Each curve indicates increasing discomfort with increasing floor temperature.

Unlike the data for Series 2 which shows remarkable consistency, the data for Series 1 shows a certain amount of scatter. This scatter is better understood if it is recalled that only one subject voting consistently uncomfortable can affect the result by about 5.5%. Thus the apparent scatter in the data probably represents the effect of only one or at the most two subjects who are perhaps voting inconsistently.

A third series of tests, called Series 4, was run in the fall of 1962 to evaluate the effect on the Foot Comfort Votes of the 75 F air temperatures, which produced the depressed Thermal Sensation Votes in Series 1 and 2. This test was similar to Series 2 except that the air temperature was increased to 78 F. The floor temperatures investigated were 75, 90, 95, 100, and 110 F which covered and actually extended the range of floor temperatures used in Series 1 and 2. Seventeen healthy college-age women were used in this series.

A complete set of data and results is not included for Series 4 but Figs. 10 and 11 show the pertinent results relating to the purpose of this series of tests. Fig. 10 shows the relationship between Thermal Sensation Vote and floor temperature. It is obvious from these curves that the Thermal Sensation Votes for an air temperature of 78 F did indeed fall very close to a vote of 4 indicating subjective comfort. Further, it is apparent that there is little increase in Thermal Sensation Vote with increasing floor temperature; an observation also

Fig. 6 Effect of floor temperature on mean skin temperature and foot temperature for seated young women

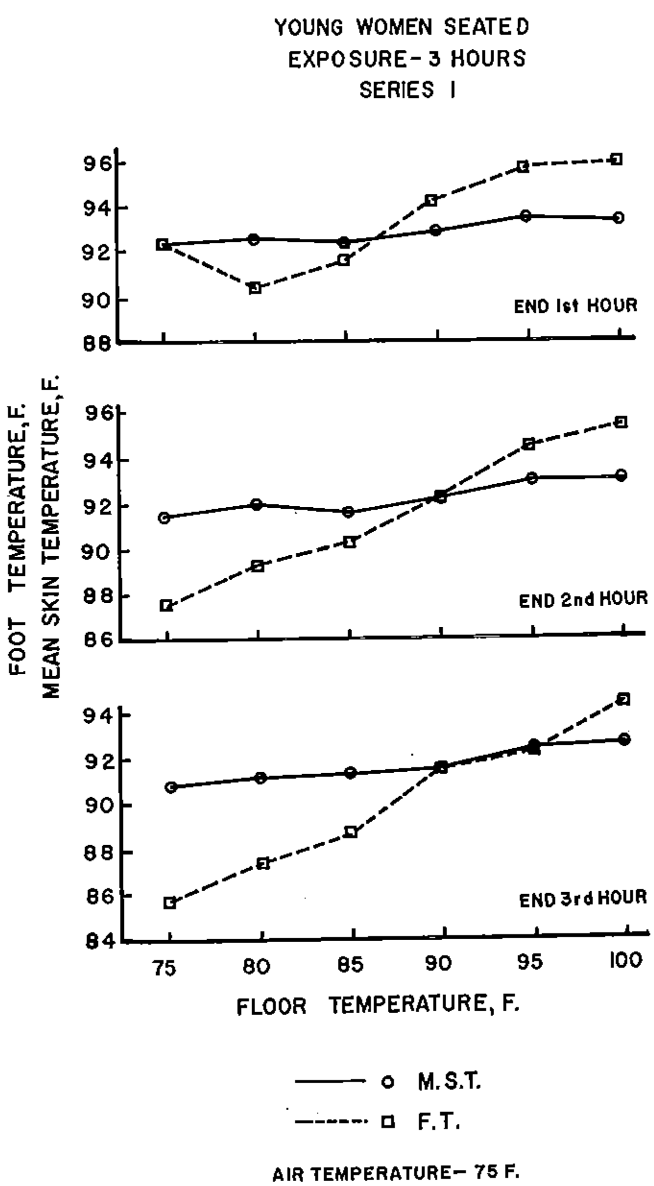
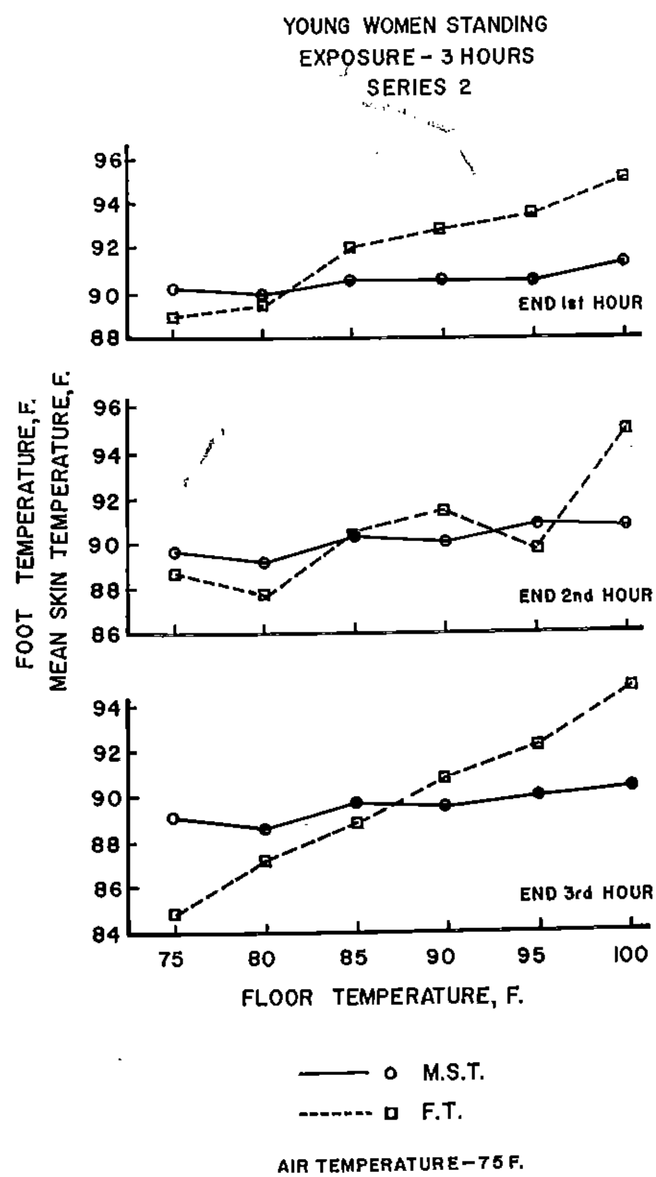


Fig. 7 Effect of floor temperature on mean skin temperature and foot temperature for standing young women



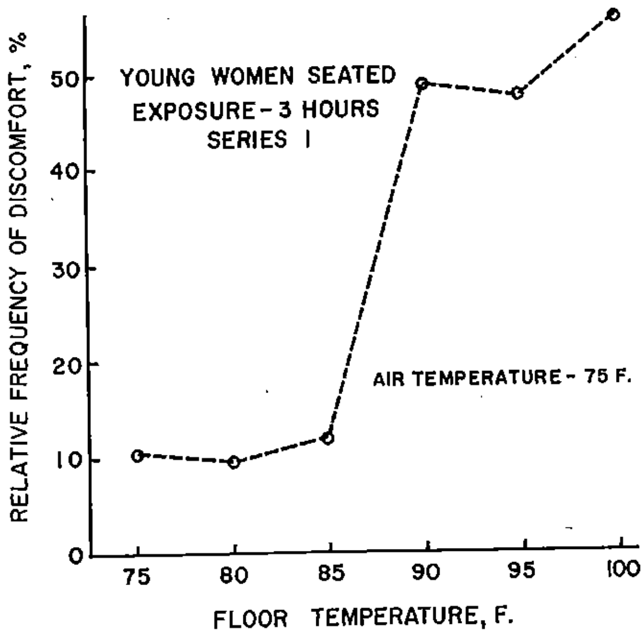


Fig. 8 Effect of floor temperature on relative frequency of discomfort for seated young women

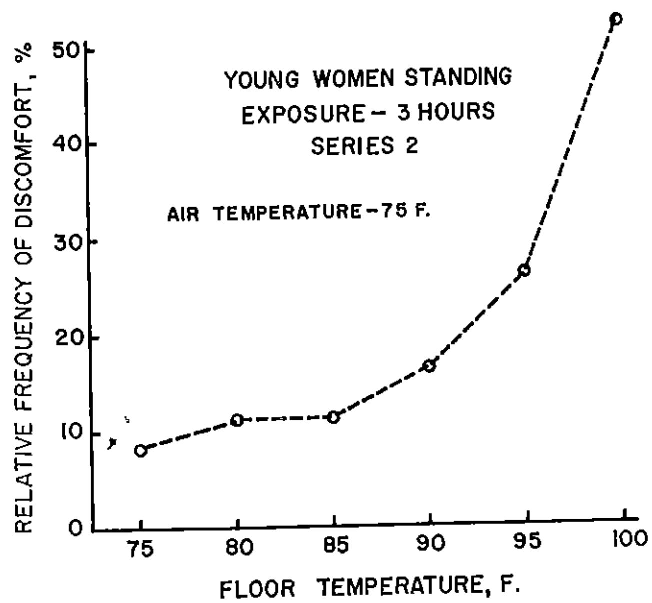


Fig. 9 Effect of floor temperature on relative frequency of discomfort for standing young women

made with regard to Series 1 and 2.

Fig. 11 shows the relationship between Foot Comfort Vote and floor temperature. A comparison of these curves with the corresponding ones for Series 2 indicates that except for the 75 F floor temperature the two sets of curves are almost identical. Apparently the conditions producing a lower Thermal Sensation Vote in Series 1 and 2 as compared with Series 4 do not produce any significant differences in the Foot Comfort Vote at the higher temperatures.

STATISTICAL ANALYSIS

Analysis of variance techniques were used to analyze these data to determine the effect of varying floor temperature on three different characteristics; namely, thermal sensation, foot comfort, and mean skin temperature. The experiment was conducted in the spring and fall (Series 1 and 2) and a separated analysis was performed for each series. Thirteen individuals were used in Series 1 and 17 in Series 2. For each series the following additive model was used to represent the relation of the effects of various factors to a given characteristic:

$$Y_{ijk} = \mu + T_i + I_j + (TI)_{ij} + E_{k(j)} + \varepsilon_{ijk}$$
$$i = 1, 2, \ldots, 6;\ j = 1, 2, \ldots, 13 \text{ or } 17;\ k = 1, 2, \ldots, 8$$

where

Y_{ijk} = observation on the j^{th} individual at the k^{th} point of elapsed time for the i^{th} temperature level
μ = overall mean for the experiment
T_i = effect common to the i^{th} temperature level
I_j = effect common to the j^{th} individual
$(TI)_{ij}$ = effect common to the j^{th} individual at the i^{th} temperature level
$E_{k(j)}$ = effect common to the k^{th} time period for the j^{th} individual
ε_{ijk} = random component for the observation on the j^{th} individual at the k^{th} point of elapsed time while under the i^{th} temperature level.

The T_i's were considered as fixed effects and the I_j's, $E_{k(j)}$'s, and ε_{ijk}'s were considered random variables with means zero and variances σ_I^2, $\sigma_{E(I)}^2$, and σ_e^2, respectively. These assumptions led to the use of the treatment by individual interaction mean square as the denominator for statistical F-tests to determine whether or not these

Fig. 10 Effect of floor temperature on thermal sensation vote for standing young women

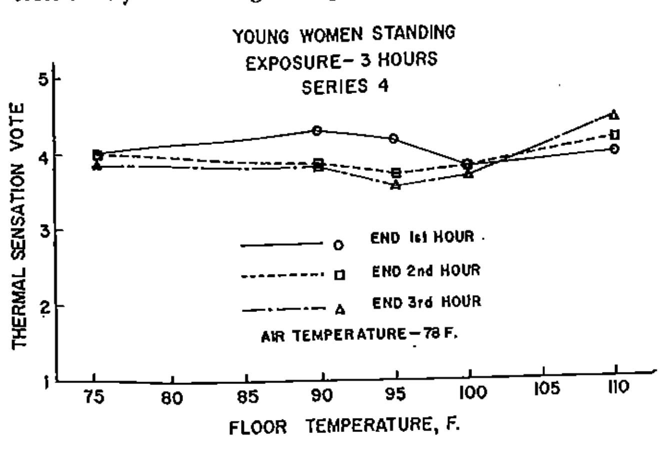


Fig. 11 Effect of floor temperature on foot comfort vote for standing young women

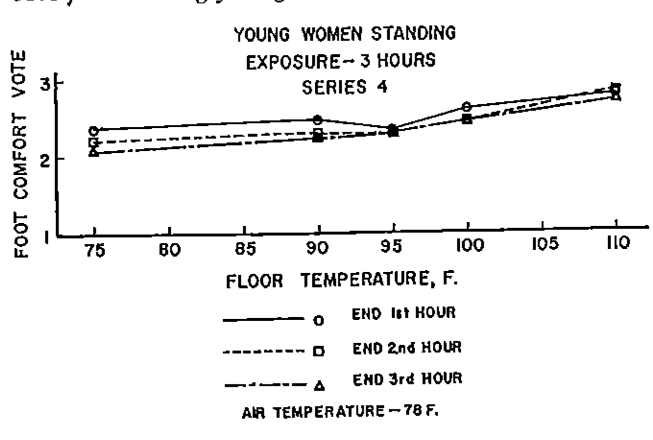


Table II Table of Means Thermal Sensation Votes

Series	75	80	85	90	95	100
	Floor Temperature, F					
1	3.38	3.42	3.49	3.59	3.39	3.76
2	3.07	3.06	2.98	3.00	2.93	3.24

data agree with the null hypothesis on temperature level effects.

Table II shows means of Thermal Sensation Comfort Votes for the six floor temperature levels in the two series. Nonsignificant "F" values ($P>0.05$) were obtained for both series.* Except for the 100 F means being higher than the others, there is no apparent upward trend. Hence these data do not rule out use of floor temperatures as high as 90 or, even, 95 F insofar as thermal sensation is concerned; provided the air temperature is held at 75 F.

Table III contains means and LSD's for Foot Comfort Votes as a function of floor temperatures. The hypothesis of equal effects at all floor temperatures was rejected at the $P = 0.001$ significance level for both series. As might be expected, a pattern of increasing means with increasing floor temperatures is apparent. Use of the LSD's for comparison of means further substantiates that the differences among means are not due to chance alone but that a floor temperature effect is present. It appears that with air temperature at 75 F, use of floor temperatures as high as 85 or, possibly, 90 F do not cause serious discomfort.

Mean skin temperatures for Series 1 and 2 are shown in Table IV. For Series 1, the least significant difference was 0.74 F. There is a significant difference between the means obtained for 75 F compared with 90, 95, and 100 F. A prior F-test rejected the null hypothesis of no differences among floor temperature effects at the $P = 0.01$ level. In Series 2, the null hypothesis could not be rejected at the $P = 0.05$ level. Hence no LSD was computed. However, in general the mean skin temperatures do tend to increase with increasing floor temperatures.

A quantitative comparison of the results obtained using female subjects as reported in this paper and the results obtained using male subjects[2] is difficult due, for the most part, to the difference in clothing worn by the subjects. The male subjects were dressed in their normal everyday school clothing while the female subjects wore a light cotton smock.

Thermal Sensation Votes for the female subjects were lower than those reported by the male subjects at an air temperature of 75F for all floor temperature levels. When the air temperature was raised to 78 F, the female subjects reported Thermal Sensation Votes essentially the same as those reported by the male subjects at 75 F.

Foot Comfort Votes for both groups, however, were fairly close for both levels of air temperature. Mean skin temperatures for both groups in Series 1, seated at rest, were likewise essentially the same. However, in Series 2, the female subjects had mean skin temperatures 2 to 3 degrees lower than the male subjects.

*$P = .01$ indicates a less than one-in-100 chance that the differences in means could be attributed to chance variation alone.

Table III Table of Means Foot Comfort Votes

Series	75	80	85	90	95	100	LSD*
	Floor Temperature, F						
1	2.03	2.04	2.14	2.46	2.54	2.63	0.27
2	1.87	1.90	2.07	2.20	2.32	2.59	0.25

*Least Significant Difference—The smallest difference between two means that would indicate significance at the 5 percent level.

Table IV Table of Means Mean Skin Temperatures

Series	75	80	85	90	95	100	LSD
	Floor Temperature, F						
1	91.80	92.37	92.24	92.83	93.38	93.27	0.74
2	90.15	89.58	90.54	90.37	90.84	90.92	

In both groups, the relative frequency of discomfort reported by 20% of the subjects occurs without question at floor temperatures greater than 90 F. The data show a steep break in the curve for both series using female subjects and for Series 2 using male subjects.

CONCLUSIONS

1. For college-age females undergoing 3-hr test periods at rest with air temperature at 75 F and floor temperatures ranging from 75 to 100 F, the data show that there exists a statistically significant effect of floor temperature on foot comfort vote. A statistically significant effect of floor temperature on thermal sensation was not found to exist. With increasing floor temperatures means for foot comfort scores, ranging from 2.03 to 2.63, moved away from an ideal "2" for comfortable toward "3" for hot. At the same time the means for thermal sensation, ranging from 3.38 to 3.76, moved from slightly cool "3" toward an ideal "4" for comfortable.

2. Results for tests with college-age females standing while performing light work also showed significant effects of floor temperature on foot comfort but not on thermal sensation. Sample means for thermal sensation scores ranged from 3.07 to 3.24 for floor temperatures from 75 to 100 F. The mean for foot comfort scores ranged from 1.87 to 2.59.

3. Based on foot comfort, floor surface temperatures as high as 85 F do not cause serious discomfort when the air temperature is 75 F.

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DISCUSSION

J. D. HARDY, New Haven, Conn.: I have followed this work of Professor Nevins with great interest, partly because we have been involved in a somewhat similar study, and also because I think that he is opening up new areas as far as comfort is concerned.

For example, it is well known to everyone that thermal sensation, per se, is not necessarily correlatable with comfort. One can have a very strong sensation of warmth or cold and these sensations can indeed be comfortable. Immediately after coming out of the cold into a warm house, the strong sensation of warmth which is felt will be interpreted as comfortable. On the other hand, you have a similar sensation of warmth if perceived on a hot summer day will be interpreted as very uncomfortable. Thus, by the actual nature of the problem we are forced to separate impressions of comfort from thermal sensations and to study the two separately. Also, when one is speaking about comfort, does one refer to comfort generally over the body or to comfort locally--the hands or of the feet? The hands, the feet and the head may be dominant in the comfort situation. These are not easy questions to answer. At present there is no psychophysical scale for discomfort, although there are scales for warmth sensation. A further problem is the relationship of thermal discomfort to observable physiological changes in the body. I would like to ask Dr. Nevins if he has any idea as to what physiological change is taking place in the individual when he or she reports comfort as distinguished from discomfort?

AUTHOR NEVINS: I would like to make a comment about the last question and then comment about the comfort scale. One of the reasons for this particular investigation was to determine the physiological changes which occur when people are exposed to a warm floor, and to determine the relationship between these changes and the subjective comfort responses. We have not been too successful, as yet. However, we are continuing our investigations. We had hoped that the regional skin temperature shifts would provide an insight to the physiological changes. As Dr. Hardy is aware, these data have not produced any conclusive results.

In regard to the comfort scale, our staff is working on this phase of the project and our physiological-psychologist has initiated a program to verify or modify the seven point comfort scale. We may find the present scale perfectly suitable or we may find another group of words that will better define thermal comfort on a scale from cold to hot.

F. LINSENMEYER, Detroit, Mich.: This is really a four point question; and since I didn't read the paper, I should like to ask what the air temperature in the space was? What was the velocity of the air on the head? Was the purpose of the test to simulate a cooling cycle for a building or a heating cycle? Since the heat emission of the floor was more than 40 Btu/sq ft, we might assume we are on the heating cycle; but, if this is the case, you did say you were delivering conditioned air to the space.

AUTHOR NEVINS: Extensive velocity surveys were made in the test chamber, and none of the velocity measurements taken below the 80 in. level were greater than 40 to 50 fpm, and at the five ft level, the velocities were 25 to 30 fpm. The supply air temperature, I do not recall. This temperature was regulated to absorb the heat load given up by the warm floor and the subjects.

The room walls were not cooled. They were allowed to float with the room air temperature and were within one to two degrees of the air temperature. The test environment does not duplicate a heating or a cooling system, it is a combination. The M.R.T. values were not too different from the air temperature.

MR. LINSENMEYER: I did want to ask you why the average was three and a half, instead of four; four being the ideal for the seven points of comfort.

AUTHOR NEVINS: A vote of 4.0 would indicate comfort. However, because of a given subject's variability, a vote of 3.5 could be considered as a comfortable vote. In the female tests, we found that the clothing worn by the subjects lowered the average vote to 2.3 for the seated tests and to approximately 3.0 for the standing tests. These tests were repeated. A three degree increase in dry-bulb temperature was required to shift the average vote to 4.0.

D. SMEDLEY, Washington, D. C.: In your tests, the results that were presented here today were all average values, and yet the two groups that you used, both the male and female, had a rather wide range in size and weight, and also a fair amount of range in age. In your analysis, did you make any attempt at all to see whether there was any variation that was systematic with relation to age, size and weight?

AUTHOR NEVINS: No, we didn't. This variability was considered in the statistical analysis and is contained in the air temperature error term. No attempt was made to factor out the effect of age, weight or size. We were looking for data representative of a typical population group. In other words, a heterogeneous group rather that a homogeneous group.

M. K. FAHNESTOCK, Urbana, Ill.: I am very much interested in this particular project since it involves a subject on which Dr. Nevins and I have consulted from time to time. One thing about it that concerns me is that he had to raise the air temperature up to 78F for the women to get a comfort vote of four, where he got the comfort vote regularly with the men when the air temperature was 75F.

Our experience with both male and female sedentary subjects in this age group, exposed to a given environmental condition for as long as three hours, has been that both sexes are comfortable with a dry-bulb temperature of 75F. We do not have to shift the dry-bulb temperature up, say, several degrees in order to get a comfort vote of four from the female subjects.

There are several things besides the environmental condition which affect the thermal comfort of human subjects. Dr. Nevins mentioned the weight of clothing. I would like to ask what was the weight and fiber content of the clothing worn by both the male and female subjects. Were the fibers man-made, plant or animal fibers? The question of air movement might be unusually important when one considers that with the female subjects a larger area of the skin was probably exposed than with the male subjects. I understand that the relative humidity was of the order of 30 to 60%. Was the air movement near the subjects horizontal or vertical?

AUTHOR NEVINS: Thank you, Professor Fahnestock. The clothing worn by the female subjects was found to weigh 7.52 oz.

We were concerned about the air motion in the test room and have made smoke studies in addition to velocity measurements. Air motion is essentially in a downward, vertical direction except near the floor. The center ceiling panels are perforated so that the supply air enters through the center 40 or 50% of the ceiling area. The air exhausts around the periphery of the floor. The air motion was determined with University of Illinois' small sphere heated thermocouple anemometers and associated instruments. These instruments are non-directional. Directional information was obtained from our smoke studies. We feel that the difference in average comfort vote cannot be explained by the amount of air motion in the test room.

MR. FAHNESTOCK: We have found that very accurate weights of clothing determined at the beginning and at the end of the tests give us a considerable amount of information. For example, if the warmer floors induce sweating, this would be reflected in the change in the weights of the shoes and socks during the tests. Similarly, changes in the weights of other components of the accouterments might give you some very good information that you would not otherwise note.

W. VIESSMAN, Baltimore, Md.: This subject and the current presentation is very interesting to me. I have had a problem at a large club where a combination ballroom and dining room has a perimeter radiant floor. It was designed that way because of the large floor to ceiling glass walls or windows. When the room is used for dancing in winter, it is called the "hot foot" room because of the effects of the radiant heated floor, which cannot be rapidly dissipated. When the area has low occupancy during the day, the heat is needed. However, for large dinners and dancing at night, ventilation will not bring the room temperature down to a comfortable condition. It appears that radiant floors should be avoided where there is a rapid variation in the heat requirement. More knowledge is needed for activity levels above standing and seated, approaching the workshop and dancing levels. Radiant heated floors have been found to be an ideal heating medium for aircraft repair hangers where the ceilings are high, and frequently the whole end of the building is open for an extended period.

It would also be helpful if data were available on the effect of floor temperatures on comfort for an air temperature of 70 degrees or less. With radiant heating, a lower air temperature would be expected to provide perhaps more comfort than a 75 degree hot air system.

In my paper, "Ondol—Radiant Heat in Korea", published by the Royal Asiatic Society of Korea, 1948, and the American Artisan, Sept. 1948, radiant heated floors were discussed. The Koreans have been using such a heating system for 1300 years and continue to build and use them. Only a light wood fire, with natural draft, heats the masonry floor flues covered with clay and paper. An eighty five to ninety degree floor temperature is the limit that can be endured without causing foot discomfort. Heavy socks, but not shoes are worn in the house. When sitting on the floor, as is customary, a cushion is used. Room air temperatures may be 60 to 70 degrees. This compares with Japanese designed western style commercial buildings having hot water or steam radiator heating systems in Korea for 55 degree room temperatures. I can say from experience they were not comfortable for the Americans. The native radiant heated cottages were found to be comfortable by the American missionaries over a long period of occupancy.

A study of the comfort effects of lower air temperatures, various activity levels and clothing weights in relation to radiant floor temperatures would be a future material addition to the excellent work documented by the authors.

AUTHOR NEVINS: Thank you very much for that comment. We are aware of the Korean data and this would be a very interesting test. The activity is something we do want to get into, and ASHRAE Technical Committee 1.4 is interested in this particular aspect of environmental activity.

C. M. HUMPHREYS, Cincinnati, Ohio: The paper indicates that the female subjects wore shoes having one-quarter inch foam plastic soles. Do you have any comparative data on the insulating value of these relatively thick plastic soles, and the thin leather soles more commonly worn by women?

AUTHOR NEVINS: No, not directly. We did compare data from our first paper with the present data in an attempt to answer this question. In the first paper, the subjects wore normal everyday footwear, whatever they had, and in most cases, it was a leather soled oxford. A comparison was made of the sole temperature in the two tests and only slight differences were noted.