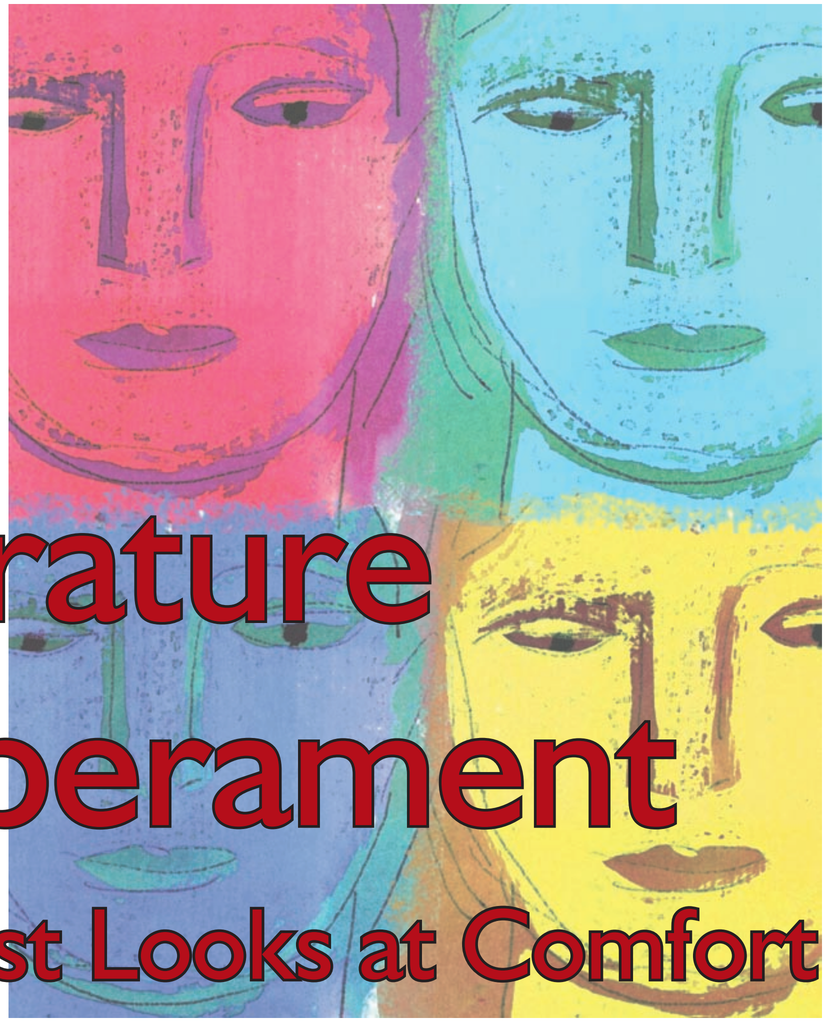

Temperature & Temperament

A Psychologist Looks at Comfort

By Frederick H. Rohles Jr., Ph.D., Fellow/Life Member ASHRAE

As defined by ANSI/ASHRAE Standard 55-2004, *Thermal Environmental Conditions for Human Occupancy,* thermal comfort is "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation." In the discussion that follows, I address several aspects of this definition, namely, the thermal environment itself, subjective evaluation, the condition of mind—this usually being in the domain of the psychologist and includes satisfaction, acceptance, pleasantness and the plethora of other emotional responses. Much of the material that follows is based on almost 40 years of research concerning thermal comfort.

In the context of this definition, the thermal environment is considered to contain six variables: dry-bulb temperature; relative humidity; mean radiant temperature; air movement; and (when people are involved) physical activity (metabolism) and clothing. Prominent by their omission from this list is time (exposure duration), time of day, time of year, adaptation, age, gender, mental activity, preference and past experience.

Subjective Measurement

The other item in the definition is subjective measurement. This usually takes the

About the Author
Frederick H. Rohles Jr., Ph.D., is professor emeritus at Kansas State University, Manhattan, Kan. He is a past member of Standing Standard Project Committee 55.

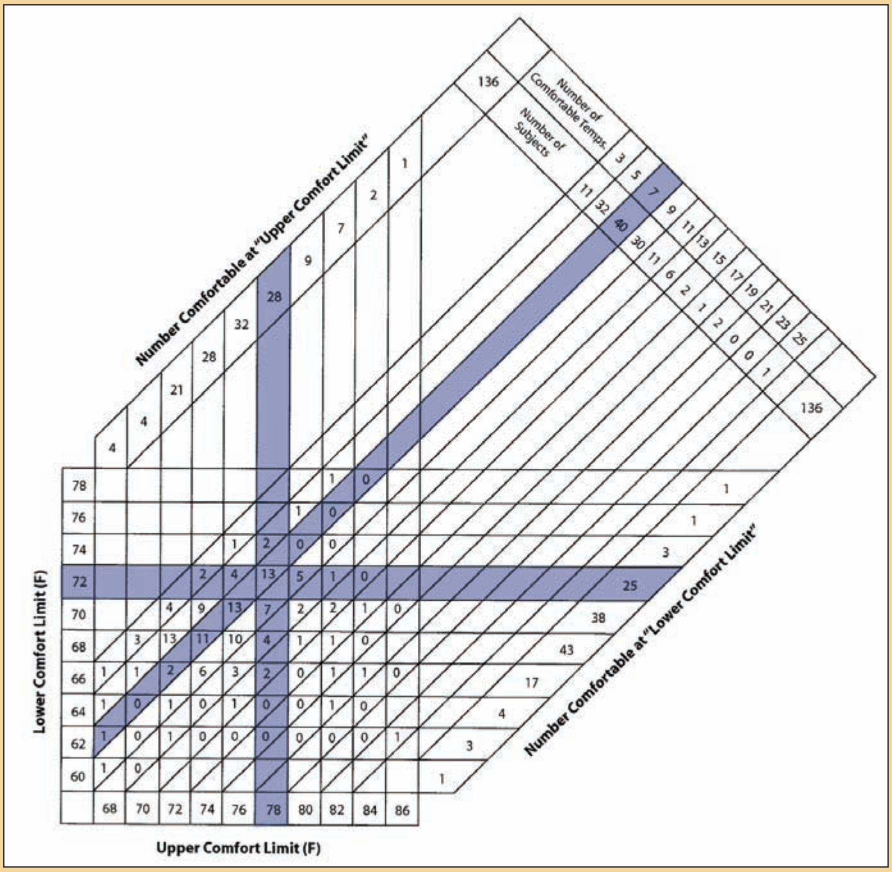

Figure 1: This shows the results of a survey given to 136 subjects asked to indicate a comfortable temperature from a random list of 40 temperatures ranging in two degree increments from 32°F to 110°F (0°C to 43°C). The number of temperatures selected as comfortable by the 136 subjects is listed diagonally across the top of the chart, i.e., 11 subjects selected three temperatures as comfortable; 32 subjects selected five temperatures as comfortable, 40 subjects selected seven temperatures as comfortable, etc.

The first number listed down the shaded diagonal line from these 40 subjects is 13. This is the number of subjects who had a group of temperatures or an "envelope of comfortable temperatures" ranging from 72°F (22°C) as shown on the left side of the horizontal shaded line to 78°F (26°C) as shown by the lower half of the vertical shaded line. Continuing down the diagonal line we find that there were 13 additional subjects and they had an "envelope" of temperatures ranging from 70°F to 76°F (21°C to 24°C); and continuing down the diagonal, 11 subjects had an envelope ranging from 68°F to 74°F (20°C to 23°C). Examining the right side of the shaded horizontal shaded line is the number 25, which is the number of subjects who listed 72°F (22°C) as the lower limit of their comfort envelope, and examining the upper half of the vertical shaded line we find that 28 of the subjects indicated that 78°F (26°C) was the upper limit of their comfort envelope.

If we consider the "modal" frequencies, the temperatures with the greatest number of responses, we find the "Lower Comfort Limit" temperature with a frequency of 43 subjects to be 68°F (20°C) and the "Upper Comfort Limit " temperature with a frequency of 32 subjects to be 76°F (24°C). Thus, we conclude that for comfort *most* people, the modal number, would fall within an "envelope" whose temperatures range from 68°F to 76°F (20°C to 24°C), inclusive. Moreover, this nine temperature envelope would take care of variations in activity, clothing, age, and other factors. (Along with the mean and median, as measures of central tendency, the mode is the value having the highest frequency. For example if you have a shoe store the mean shoe size would be of little use; the shoe size called for most often, the modal size, would be what you need; thus the modal temperature for comfort is our concern.)

form of a rating scale. When the results of the Kansas State University (KSU) study[1] involving 1,600 subjects were presented, the scale that was used was questioned. It involved seven categories: 1-cold, 2-cool, 3-slightly cool, 4-comfortable, 5-slightly warm, 6-warm, and 7-hot. Could this scale measure both a thermal sensation *and* comfort? To address this question in subsequent research, two scales were used. The result was a semantic differential scale that is presented in *Table 1*. I hasten to add that this scale is presented only as an example of a scale that has been used to assess thermal comfort. It is not suggested as a final and definitive instrument.

Currently, ASHRAE uses a single scale with the categories –3 cold, –2 cool, –1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, and +3 hot. Comfort is not measured directly; instead it is assumed that votes of –3 cold, –2 cool, +3 hot, and +2 warm represent discomfort with the remaining choices of –1 slightly cool, 0 neutral, and +1 slightly warm being in the domain of comfort. I have a problem with this. Why not use a separate ballot or better still, change the verbiage. Moreover, by fractionating the votes into tenths, which has been done on occasion, we not only have a seven-category scale, but one that is considerably larger.

Evaluation of the thermal environment is incorporated in a recent scale designed to measure the *acceptability* of the workplace. It addresses the acoustics, air quality, lighting and thermal

Comfortable	9	8	7	6	5	4	3	2	1	Uncomfortable
Bad Temperature	1	2	3	4	5	6	7	8	9	Good Temperature
Pleasant	9	8	7	6	5	4	3	2	1	Unpleasant
Unacceptable	1	2	3	4	5	6	7	8	9	Acceptable
Uncomfortable Temperature	1	2	3	4	5	6	7	8	9	Comfortable Temperature
Satisfied	9	8	7	6	5	4	3	2	1	Dissatisfied

Table 1: Semantic differential scale for measuring thermal comfort. Numbers in the cells are the values assigned to the ratings; loadings are as follows: comfortable–uncomfortable, 0.555; bad temperature–good temperature, 0.693; pleasant–unpleasant, 0.628; unacceptable–acceptable, 0.521; uncomfortable temperature–comfortable temperature, 0.726; satisfied–dissatisfied, 0.568; the sum of the loadings = 3.691. Thermal comfort is determined by the following formula: Thermal Comfort (%) = {Σ (rating × loading) – 3.691} 3.387. The loadings were derived by factor analysis.

aspects of the environment. As such, it represents a more complete view of the environment instead of just the thermal aspect and replaces the term comfort with acceptability.[2]

Condition of Mind

Many of you who have heard me speak on thermal comfort will recall my saying, "All of us have a range of temperatures that we deem as comfortable; now jot this down: the lowest to the highest—the whole range." I then ask for a show of hands of the people for whom 72°F (22°C) falls within their range. The result never fails. About 93% percent of the adults who participated in this exercise raise their hands.

I also asked this question to a large group of people who attended a seminar I conducted in Japan, and they gave the same response—22°C (72°F). Equally interesting and certainly more than a coincidence, Chrysler's *1995 New Yorker Owner's Manual* states that "72 degrees is the recommended setting on the thermostat for maximum comfort for the average person, however, this may vary." Perhaps, Chrysler was reading our stuff.

But it is this "stuff" that dictates, yes, even controls much of our behavior. It is this stuff that governs our well-being and health. And, it is this stuff that makes us alike or different from one another. We call this environmental preference, and it is based on value judgments. For example, will this temperature make me comfortable? Will this background music make my dinner more enjoyable? Or will the brightness of this lighting enable me to do my job better? The responses to these and similar questions are value judgments and are learned through past experience. They are influenced by our background and social-economic level and age is an important catalyst.

As evidence, in a study Kansas State University did on temperature preference, we found that college students (mean age, 20 years) prefer a temperature of 72°F (22°C) for comfort, middle age subjects (mean age, 44 years) prefer 74°F (23°C) for comfort, and seniors (mean age, 75 years) like their environment at 76°F (24°C). Relevant to this is the following: "....if people say they like something or show by their behavior that they prefer it, this value should be fed into the design process even though it cannot be proven that it makes a difference on a profit or loss statement or academic record."[3]

As profound as this statement may be, the measurement of environmental preference is difficult. The results of one study are presented in *Figure 1*. They suggest a group of temperatures that is judged as comfortable by most of the subjects, or what I call a modal comfort envelope. These include temperatures ranging from 68°F to 76°F (20°C to 24°C) inclusive and takes into account variations in activity, clothing, age, and other factors.

One rather subtle aspect of personal preference and one that affects our satisfaction with the surroundings is the ability of the individual to control his or her environment. Consider this anecdote based on actual observation: a widow living in a low-income housing facility for the elderly has just gotten out of bed. She has eased into her slippers and robe and is about to set her thermostat. But what if she has a lousy thermostat? What if she has an inferior heating system? What if the thermostat is misplaced on the wall or even in the apartment itself? If any of these possibilities occur, she takes control and in doing so, ignores the degrees scale on the thermostat and sets the dial on the temperature where she knows she has been comfortable in the past. In short, she was in control; she was calling her own shots.

A study done in the late 1970s by Kansas State University is relevant to this and involves the importance that the knowledge of the temperature contributes to our feelings of comfort and acceptability. At the outset we were asked to evaluate the comfort-producing features of a small 200 W heater that attached to the modesty panel of a desk. We used the usual protocol and procedures and exposed our subjects who were in a secretarial pool to 65°F (18°C) for two hours with and without the heaters. Much to our surprise, not to mention that of the heater manufacturer, we found that the level of comfort as measured by subjective ballots was the same whether the heater was on or not. When we desperately searched for a logical explanation, three possibilities surfaced: 1) the tests were conducted in the summer and the 65°F (18°C) probably felt good regardless of the heater; 2) a wooden desk was used, which would not conduct the heat as well as a metal one; and 3) the subjects were not informed that the heater was operating.

As a result, and in an attempt to address these factors, the tests were repeated in the winter using metal desks and three groups of secretaries as subjects. For one of the groups, the

Rohles Trained the Chimps For Historic Space Flights

Editor's note: As we were going to press, The Topeka Capital-Journal published an article about our author's career. We decided we should share it with ASHRAE Journal readers.

By Jan Biles, The Topeka Capital-Journal

MANHATTAN, Kan.—In Fred Rohles' study in his Manhattan home hangs a large portrait of Ham, the chimpanzee who was strapped into a Mercury space capsule and launched into space on Jan. 31, 1961, four months before astronaut Alan Shepard made his historic space flight on May 5, 1961.

Rohles, 85, an emeritus professor at Kansas State University, was among the men who trained Ham at the Aeromedical Research Laboratory at Holloman Air Force Base in New Mexico prior to his flight.

"The Russians had put up a dog," he said, referring to Laika, who orbited the Earth aboard Sputnik II on Nov. 3, 1957. "I had worked with monkeys but never chimps. Ham was in a ballistic shot -- up and down -- that was weightless for a very short time."


The Topeka Capital-Journal

Rohles holds a photograph of Ham, a chimpanzee he helped train for NASA.

Rohles also trained Enos, a chimp who was launched into space in a Mercury capsule on Sept. 13, 1961, to make the first U.S. orbital animal flight. Enos was supposed to make three orbits around the Earth but was brought back after the second orbit because the spacecraft was getting overheated, he said.

Enos' trip was the precursor of the first U.S. manned orbital mission, which sent astronaut John Glenn into space on Feb. 20, 1962, to successfully make three orbits around the Earth.

At that time, the United States was entrenched in the "space race" to land a man on the moon, as directed by President Kennedy, who Rohles met during a briefing in June 1963 at Holloman. Also at the briefing was Vice President Lyndon Johnson.

"We opened up areas that had never been done before," Rohles said of the research he and others did in the early days of the space program.

Rohles, who was born in Chicago and grew up in nearby Evanston, Ill., earned a degree in personnel management in 1942 from Roosevelt University in Chicago. He enlisted in the U.S. Air Force that year and spent the next 22 years as an Air Force officer and psychologist doing research in aviation, engineering psychology and aerospace medicine at major aeromedical research laboratories throughout the United States, including the School of Aerospace Medicine at Randolph Air Force Base near San Antonio and the Arctic Aeromedical Laboratory in Fairbanks, Alaska.

He earned a master's degree in experimental psychology and a Ph.D. in experimental psychology from the University of Texas in 1950 and 1956, respectively. He returned to the School of Aerospace Medicine to lead its experimental psychology department and then was transferred to the U.S. Air Force Aeromedical Laboratory at Wright-Patterson Air Force Base in Dayton, Ohio.

"This is where I got in the space business. I headed the unusual environment department," he said, explaining how he and his colleagues developed a model and equipment for measuring behavior of mice during space flight while there.

He was appointed to the Joint Armed Services Biosatellite Coordination Committee, and while with this group presented a paper in 1958 at the annual American Astronautical Society meeting that stressed both behavioral and physiological measurements needed to be documented when animals were sent into space to obtain a complete assessment of the effects of the space environment.

Shortly after this, he and his entire section were transferred to Holloman Air Force Base in New Mexico to set up a facility for measuring animal performance during space flight. The base had a sizable colony of chimpanzees.

He and his team developed performance programs and restraint systems for the animals, including feeders and watering devices that could be operated in weightlessness. He also compiled a much-needed topical bibliography on all aspects of the chimpanzee.

Rohles said he retired as a lieutenant colonel on Oct. 31, 1963, and the next day started working at K-State's Institute for Environmental Research with a joint faculty appointment in psychology and mechanical engineering. In 1973, he was named director for the Institute for Environmental Research at K-State.

"We had chimps here for a couple of years," he said. "We had two chimps here on loan from the Delta Regional Primate Center in New Orleans."

His research, he said, centered on the concept of "middleness" and whether chimps could determine what item was in the middle of a series of objects. One of his studies was filmed and is on deposit at the Psychological Film Institute at Pennsylvania State University.

"Then I got out of the monkey business because I didn't feel we could adequately take care of them," he said. "And I got into the people business."

The American Society of Heating, Refrigerating and Air Conditioning had donated an environmental chamber to the university, which became the heart of the Institute for Environmental Research.

"We worked to develop a standard for human thermal comfort," he said, adding that he also worked with the Ford Motor Co. to evaluate its automotive air conditioning system and did research on environmental ergonomics.

Rohles, who retired from K-State in 1986, has authored more than 150 technical papers and is the recipient of the Raymond F. Longacre Award for psychological and psychiatric aspects of aviation medicine and ASHRAE's Holladay Distinguished Fellow Award.

heaters were turned on and we told the subjects about it. "Put your hand here," we said. "You can feel that the heater is on, and you can see by this red light that there is power to the heater." For the second group, the heater was turned on but the subjects were not informed. For the third group, neither heater nor explanation was provided. Needless to say, the results were interesting. Both groups who had heaters were warmer than the third group who did not have them. However, the group who had the heaters and knew they were operating were significantly and consistently warmer than the group who had the heater but did not know it was on.

Did I say the results were interesting? What an understatement! These are the kind of things that drive my engineering colleagues crazy. Going back to comfort as a state of mind, consider a follow-up study. For this exercise we asked the question, "Do we feel differently when we know the temperature of the room is than when we don't know what it is? To answer this, we exposed two groups of subjects to 68°F, 70°F, 72°F, and 74°F (20°C, 21°C, 22°C, 23°C) respectively. One group knew the temperature; the other did not. And, of course, the results were what we predicted. The group who knew the temperature level was consistently warmer than their counterparts who were not informed of the temperature.

However, the study was not over. Granted we had an "informed" and an "uninformed" group but what we needed now was a "misinformed" group. To accomplish the "misinforming," we installed a large outdoor thermometer in the test room. Its pointer was fixed so that it always read 74°F (23°C). This was the case regardless of the actual temperature. The findings (*Figure 2*) show that at 68°F (20°C) the subjects in the misinformed group were warmer than the subjects in both the informed and uninformed groups. In turn, at 70°F and 72°F (21°C and 22°C) the misinformed subjects were warmer than the uninformed but cooler than the informed subjects.[4] Yes, comfort is a state of mind!

A different study dealt with what I call "the supermarket syndrome." This relates to the feeling we experience when we go into an air-conditioned store in the summer. And just about freeze! Then after we finish our shopping and walk outside, the hot air feels like we're walking into a blast furnace. Add this to the 110°F (43°C) temperature inside your car and you think you're going to cook. This all-too familiar scenario involves what are known as thermal transients. Essentially, the purpose of the supermarket syndrome study was to determine how long it took people to adapt to a comfortable temperature after being exposed to a hot condition in one case and to a cold temperature in a second situation. For this we used two chambers.

In the first phase the subjects were kept in Chamber A for one hour where the temperature was 74°F (23°C). Then they walked to Chamber B where the temperature was 90°F (32°C) and stayed there for one hour and after this returned to the 74°F (23°C) of Chamber A for the third hour. The second phase was similar except the temperature in Chamber B was 60°F (16°C). In both phases the results showed that the subjects adapted very quickly to the thermal condition of the new environment whether it was 60°F or 90°F (16°C or 32°C) and that the supermarket syndrome was not as personally disturbing as originally expected.

However, the study was not over. We needed a control group and the results from the test with this group were extremely puzzling. Their regimen was this: one hour in Chamber A at 74°F (23°C), the next hour in Chamber B at 74°F (23°C); and then back to the 74°F (23°C) of Chamber A for the third hour. The results were that the subjects were colder in Chamber B even though the temperature in Chamber B was the same 74°F (23°C) as it was in Chamber A. How could this be? Perhaps some glitch was operating in the temperature controls. Maybe

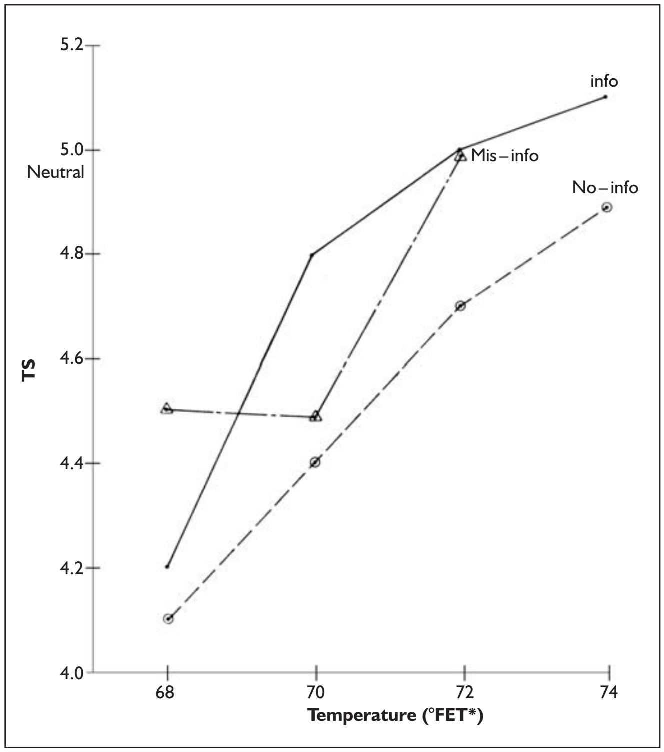

Figure 2: Thermal sensations (TS) at different temperatures by groups who were informed of the temperature, not informed of the temperature and misinformed about the temperature; TS is based on a nine category scale in which 5.0 is neutral.

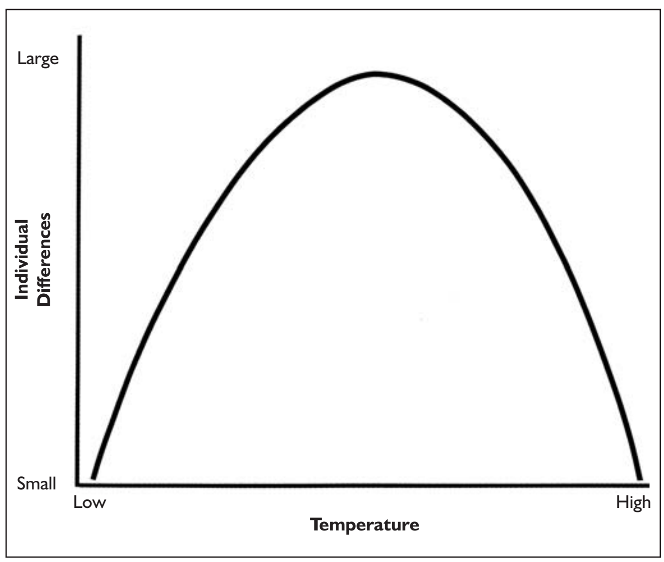

Figure 3: Hypothetical relationship between temperature and individual differences.

Temp. at 80% RH	Time for Rectal Temp. To Rise 2°F Mean	SD
120°F	21.7 min.	2.7 min.
110°F	38.5 min.	8.1 min.
105°F	56.0 min.	11.4 min.
100°F	99.6 min.	32.4 min.

Table 2: Time for the rectal temperature to rise 2°F under four ambient temperature conditions.[5]

we missed some subtle difference in the procedures. Regardless, we repeated this phase but again we obtained the same disturbing, findings. Then it hit us. Chamber B was an 8 ft by 10 ft (2.4 m by 3 m) walk-in commercial refrigerator and anyone knows (recall the role of past experience and state of mind) that when you go into a refrigerator you feel cold. And this, indeed, is what our subjects experienced.

To address this feeling "cold in a cooler," I enlisted the help of my interior architecture colleague, Prof. Ward Wells, and together we began to modify the interior of Chamber B. First, we installed carpet on the floor. Next, we covered the white walls with walnut panels. We fitted the bare fluorescent lamps with deflectors so the lighting was both subdued and indirect. We then added two floor lamps, comfortable chairs and a coffee table and two end tables. In short, everything in the chamber was altered or removed that gave the impression (state of mind) that the subjects were in a meat locker. When we were finished, we ran the experiment again and the results were amazing. To begin with, the subjects initially felt warmer in Chamber B even though the temperature was the same 74°F (23°C). In fact, there was no difference in their responses in either Chambers A or B. Moreover, using the models we developed from our earlier comfort studies we calculated that adding the embellishments and changes to Chamber B was equivalent to raising the temperature two and one-half degrees. Also, because of this finding, the interior walls of all of the KSU chambers were covered with birch plywood that replaced the stark white steel of the coolers.

To say our colleagues looked askance at this as well as the study in which we misinformed our subjects about the temperature is an understatement. I tend to reflect back to Gertrude Stein's "a rose is a rose is a rose." Or, as our friends in the hard sciences believe, "74°F is 74°F is 74°F" and don't clutter our thinking beyond this. When I presented some of these findings I was accused of using psychological tricks. Is 74°F (23°C) in the space station perceived the same as at a football game or at an intimate candlelight dinner? If I am catching fish when it is so cold that the water from my line is freezing in the guides on my rod, the coldness appears to get worse when the fish stop biting although the temperature is the same. Psychological tricks? Hardly.

In short, one concept exists in all of the human testing—and that is individual differences. As shown in the hypothetical curve in *Figure 3*, responses by people in hot and cold environments are similar. We all respond alike. As evidence, I like to cite the data from a heat stress study (*Table 2*). As shown by the standard deviation or variance, the higher the temperature, the greater similarity or fewer differences between our responses; in other words we all respond the same when exposed to extreme heat and it can be said that the same is true to extreme cold. It's at the so called "comfortable" temperatures that we differ the most. It is this fact, and this fact alone, that dictates that caution should be used when predicting a response to a temperature value in the middle range.

In summary, it must be realized that comfort research has played its major role from the mid-sixties to the turn of the century. This research has taken two routes: the laboratory efforts of Kansas State University and the unique work of P. Ole Fanger, Ph.D., at the Technical University in Denmark. The second route is fieldwork by Gail S. Brager, Ph.D., Fellow ASHRAE, and her colleagues at the University of California, Berkeley. Efforts from these three sources may be found in Standard 55-2004. Another source that I favor because it includes all aspects of the human environment is ASHRAE proposed Guideline 10, *Criteria for Achieving Acceptable Indoor Environments.*

Yet as was pointed out in the earlier discussion, we have emphasized the importance of the personal preference of the individual, and that minor and apparent insignificant variations in the environment can alter a person's condition of mind. The modal comfort envelope and the thermal conditions it contains is a starting point for establishing design criteria. Although we may apply heat transfer equations to people, they break down when we consider the subtleties involved in human thermal comfort, not to mention the subjective nature of its measurement. In conclusion, recognition of this subjectiveness is paramount and basic to future studies of humans and their thermal environment.

References

1. Nevins, R.G., et al. 1966. "A temperature-humidity chart for thermal comfort of seated persons." *ASHRAE Transactions* 72(1):283–291.

2. Rohles, F.H., J.E. Woods and P.R. Morey. 1989. "Indoor environment acceptability: the development of a rating scale." *ASHRAE Transactions* 95(1):23–27.

3. Sommer, R. 1969. *Personal Space—The Behavioral Basis of Design*. Englewood Cliffs, N.J.: Prentice-Hall.

4. Rohles, F.H. and K. Kerulis. 1980. "Thermal comfort as Affected by Informing, Not Informing or Misinforming the Subjects of the Thermal Conditions." Institute for Environmental Research Technical Report 80-03, Kansas State University, Manhattan, Kan.

5. Rohles, F.H., R.G. Nevins and W.E. Springer. 1967. "Temporal characteristics of body temperature during high thermal stress." *Aerospace Medicine* 38(3):286–290.

Bibliography

Rohles, F.H. 1971. "Psychological aspects of thermal comfort." *ASHRAE Journal*, 13(1):86–90.

Rohles, F.H. 1979. "The Effect of time of day and time of year on thermal comfort." *Proceedings of the Human Factors Society 23rd Annual Meeting* pp. 129–133.

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

Rohles, F.H. 1983. "New directions in comfort research." *ASHRAE Transactions* 89(2):327–352.