PERCEIVED THERMAL COMFORT AND ENERGY CONSERVATION STRATEGIES IN RESIDENTIAL HEATING

by

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(ABSTRACT)

The perception of thermal comfort is an important factor influencing the acceptability of residential heating strategies. The perceived thermal comfort may affect a person's inclination to try a strategy or to use it on a long-term basis. In the study, perceived thermal comfort was assessed in relation to room temperature, humidity, clothing worn, preferred room temperatures, personal control over the temperatures, and energy consumption. The relationships among these variables were examined for five families participating in a live-in study comparing five residential heating strategies. The strategies tested included closing off bedroom vents/doors, setting the thermostat at 65°F, and the use of a solar greenhouse and a woodstove as supplemental heat sources. The families lived in a retrofitted solar test house for a period of four to six weeks. The house was equipped with a computer which monitored 37 channels of information at ten second intervals and recorded the data hourly. The data collected included temperatures in every room, inside and outside humidity, wind velocity and other variables that interplay in comfort levels and energy use. The ten adult respondents completed daily and weekly questionnaires containing Likert-type scales of thermal comfort and checklists of clothing worn. The results suggest the following conclusions: 1) the use of a residential setting to measure thermal comfort under varying environmental conditions can be successfully accomplished, 2) psychological variables such as personal control should be considered and tested by persons involved in standards development for the thermal environment, 3) the ability and experience of the persons to use a strategy can affect the achieved energy saving benefits of the strategy, 4) personal preference in the amount of personal effort a person is willing or able to give will impact on the decision on whether to use certain strategies, 5) heating strategies that can produce a direct source of heat or at least some warmer areas were rated higher by the project participants, and 6) weather can play an important role in the effectiveness of the solar greenhouse as a heating source.

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CHAPTER I

INTRODUCTION

About 20 percent of the energy consumed in the United States is used by the residential sector and over half of this energy is used for home heating (Newman & Day, 1975; Stobaugh & Yergin, 1979). Consequently, major efforts in promoting residential energy conservation has been focused on ways to reduce the energy used in home heating. One approach used by groups promoting energy conservation has been to encourage residents to reduce the thermostat settings in their homes as well as to adopt supplemental heating systems such as solar greenhouses and wood-burning stoves.

Although these energy conservation strategies are designed to reduce energy consumption in residential heating, an important but less often asked question is what impact these strategies have on the thermal environment and the resulting comfort of the residents. The question is important not only because a family needs an acceptable environment in which to carry on routine activities and developmental tasks (Bennett, 1977; Compton & Hall, 1972; Deacon & Firebaugh, 1975; Gross, Crandall & Knoll, 1973) but also it can be an important factor in a family's decision-making concerning the long-term use of a given strategy.

The likelihood that an energy conservation strategy in home heating will be used by residents beyond their initial experience depends to a great extent on how the residents evaluate the perceived thermal comfort associated with the use of the strategy. In the long run, a strategy low in energy savings actually might save more energy nationwide than a strategy high in energy savings because more people find it acceptable and are willing to use it.

A related question arises as to whether a sacrifice of thermal comfort is necessary to save energy. From their research on consumer perception of energy conservation, Kempton, Harris, Keith, and Weihl (1982) concluded that consumers relate energy conservation to sacrifice. Is sacrifice of comfort necessary to save energy in residential heating? Is there automatically a trade-off of thermal comfort for reduced energy consumption? If a loss of thermal comfort exists, how does this relate to the energy savings that result? Winett et al. (1982) have concluded that a loss in thermal comfort is not necessarily associated with strategies that produce energy savings. Some lower energy using strategies can produce acceptable if not more increased comfort than some of the higher energy consuming methods to heat and cool spaces.

The methodologies employed to study thermal comfort under varying environmental conditions predominantly have been either the laboratory approach in which persons occupy chambers for short periods of time and respond to the environmental conditions (ASHRAE, 1981a) or field study approaches in which families are observed in their own home environments (Winett et al., 1982). The results of these studies have not been in close agreement. Researchers using the field approach have found that persons reported comfort at temperatures lower in winter and higher in summer than those reported by the laboratory tests. Reasons for these differences may relate to a number of factors including the structures used, the research methods, and certain psychological factors. Research that addresses these differences is needed to complement existing research.

Further, in predicting the response to the thermal environment in terms of comfort, a psychological variable that merits further study is the level of personal control the occupants can exert over the temperatures. Some researchers studying personal control and electric shock found that subjects who had control over the undesired stimulus reported less discomfort than those subjects who had no control in the situation (Gatchel, 1980; Geer & Maisel, 1972; Phares, 1976; Staub, Tursky & Schwartz, 1971). Is this the case in the perception of the thermal environment? Do people perceive less discomfort if they have control over the temperatures? This is an important question since about 20 percent of the occupants in this country cannot control the temperatures in their dwellings by a thermostat (Newman & Day, 1975). If personal control is an important variable in the perception of thermal comfort, it would suggest changes not only in the design of heating systems for residents but it would also give direction to future efforts to develop comfort standards, such as to assure that the respondents have some part in the setting of the thermostats or temperatures.

Data from a research project currently underway at North Carolina Agricultural and Technical State University were used to address some of these concerns about thermal comfort, energy conservation, personal control, and related variables. The project, entitled "The Effect of Home Energy Conservation Strategies on Lifestyle," is sponsored by the United States Department of Agriculture to study the impact of selected conservation strategies on thermal comfort and other variables. The study uses a highly-instrumented test house in which families individually live while tests of energy conservation strategies are alternately employed. The energy consumption as well as the thermal comfort of the respondents are monitored (Turner, Klett, & Ahmed, 1983).

Statement of the Problem

The purpose of this study was to complete a detailed, descriptive analysis of five families and the reactions of the husbands and wives to the thermal environment while each family lived in an energy test house and employed strategies with varying levels of personal control to reduce energy consumption in residential heating. The objectives of this study were the following:

1. To compare the thermal environment, the residents' perceived thermal comfort, and the level of energy consumption that result from the use of selected energy conservation strategies in residential heating.
2. To determine the level of sacrifice (if any) in perceived thermal comfort associated with the use of selected energy conservation strategies in home heating.
3. To describe trends or patterns that appear to exist between perceived thermal comfort and related variables including the resulting room temperatures, level of personal control, anticipated thermal comfort, energy consumption, clothing worn, and demographic and energy-related characteristics of the family participants.

To meet these objectives, the following specific research questions were developed:

1. When selected energy conservation strategies in residential heating are employed, what is the impact of their use in the following areas:
    a. variables influencing the physiological response (room temperatures, relative humidity, clothing worn, air velocity)
    b. perceived thermal comfort
    c. energy consumption
2. Does the level of personal control the respondent has over the strategies appear to affect the level of perceived thermal comfort?
3. What relationship exists between the perceived thermal comfort and the amount of energy saved?
4. How similar are the respondents' anticipated ratings of comfort to the actual ratings of comfort after use of the strategies?
5. What patterns or trends appear to exist between perceived thermal comfort and related variables including the family's preferred temperature and the demographic and energy-related characteristics of the family?

Justification

Research that addresses these questions concerning thermal comfort related to energy conservation in home heating is needed not only to complement existing methods of testing and setting standards but also by families themselves as input into their own decision-making process, by educators, and by policy makers.

Educators in residential energy conservation such as in the Cooperative Extension service, utility companies, and educational institutions can use the information to provide more meaningful answers to questions of potential users of the strategies. This is particularly important in the use of a solar greenhouse and a woodstove (that are included in the study), not only because an initial outlay of capital funds is required but also because the general public has had limited actual experience in using them before making the decision to actually add them to their living quarters or before renting or buying dwellings that have these features.

If energy conservation promoters are to correctly answer consumer questions and promote the use of specific strategies, more information is needed about how persons who use these strategies will evaluate the resulting thermal environment and comfort. Policy makers need to consider incentives that deal with lifestyle factors such as human comfort and human effort. Ritchie, McDougal and Claxton (1981) report that frequently strategies do not produce the anticipated energy savings. The researchers attribute the difference to the lifestyle differences of the inhabitants. Although the cost/energy saving benefits appear to be the primary motive to get persons to try various strategies, long-term use may depend more on the results of the use of the strategies as they relate to the family's specific comfort needs, as well as how well a strategy meets their expectations and past experiences. The results of the study may yield implications for future inferential studies concerning energy conservation in the home and how best to design conservation programs not only to decrease substantially the energy consumption but also to meet the thermal needs of the family. For these reasons, research on the perceived thermal comfort resulting from the use of energy conservation strategies in home heating was needed.

Assumptions

1. People seek to obtain a thermal environment that they consider to be comfortable for their families.
2. The family activity pattern while in the energy test house will be similar to the family activity pattern in the participant's own home and therefore will be representative of their living habits.

Limitations

The limitations of this study are related to the selection of the families and the selection of the strategies being tested. The data used were collected from families who volunteered to participate in the project entitled "The Effect of Home Energy Conservation Strategies on Lifestyle" currently underway in Garrett House at the North Carolina Agricultural and Technical State University in Greensboro, North Carolina. (A description of the project appears in Appendix A.) Although the families were selected to vary in composition, they cannot be construed to be representative of the general population. The families were studied in a detailed manner to offer insight into how families respond to energy conservation and the results should be helpful in directing future inferential studies. The results, therefore, cannot necessarily be generalized directly to a larger population. Instead, a list of testable hypotheses is suggested for further research.

The selection of energy conservation strategies in home heating for the study was made in 1980, based on strategies that were recommended in the literature and that could be tried in a reasonable period in the energy test house by a family. The strategies were designed to decrease the use of expensive energy sources used in a central heating system such as by lowered thermostats or the use of less expensive alternate energy sources. Thus, the study reports the relative impact of certain strategies in offsetting the use of expensive heating sources in a central heating system. The strategies are not exhaustive in terms of possibilities or combinations that families can use to heat houses. They are, however, representative of types that families can or frequently do use. Other possible methods can be tested in follow-up studies at North Carolina Agricultural and Technical State University or by researchers at other institutions.

Finally, because this study concentrated on determining the impact of selected conservation strategies in offsetting the heating demands of the central heating system, energy consumption data are reported for natural gas only. However, if total energy consumption were addressed, consideration would need to be given to the amount of wood burned as well as to the electricity used to run the furnace fan.

CHAPTER II

CONCEPTUAL FRAMEWORK AND REVIEW OF RELATED LITERATURE

A conceptual framework for perceived thermal comfort is presented in the first section of this chapter. Three models are discussed beginning with a generalized concept, proceeding to an identification of specific concepts, and culminating in the model containing the actual concepts under investigation. The literature supporting the inclusion of the concepts is also presented. The middle sections of the chapter contain the literature concerning thermal comfort as related to energy conservation and comfort standards. A brief summary gives direction and support for the methodology presented in Chapter III.

Conceptual Framework for Perceived Comfort

A conceptual framework was derived from identified factors in physiological studies of thermal comfort as well as from several concepts in the field of environmental psychology and housing. The conceptual framework is unique in including both physiological and psychological factors and is described by a progression of three models.

Generalized Framework

As depicted in Figure 1, perceived thermal comfort is influenced by two broad sets of factors. One set is the environmental factors which include certain characteristics of the building structure as well as the specific environmental conditions such as temperatures. The human factors include such physical parameters as clothing worn as well as several

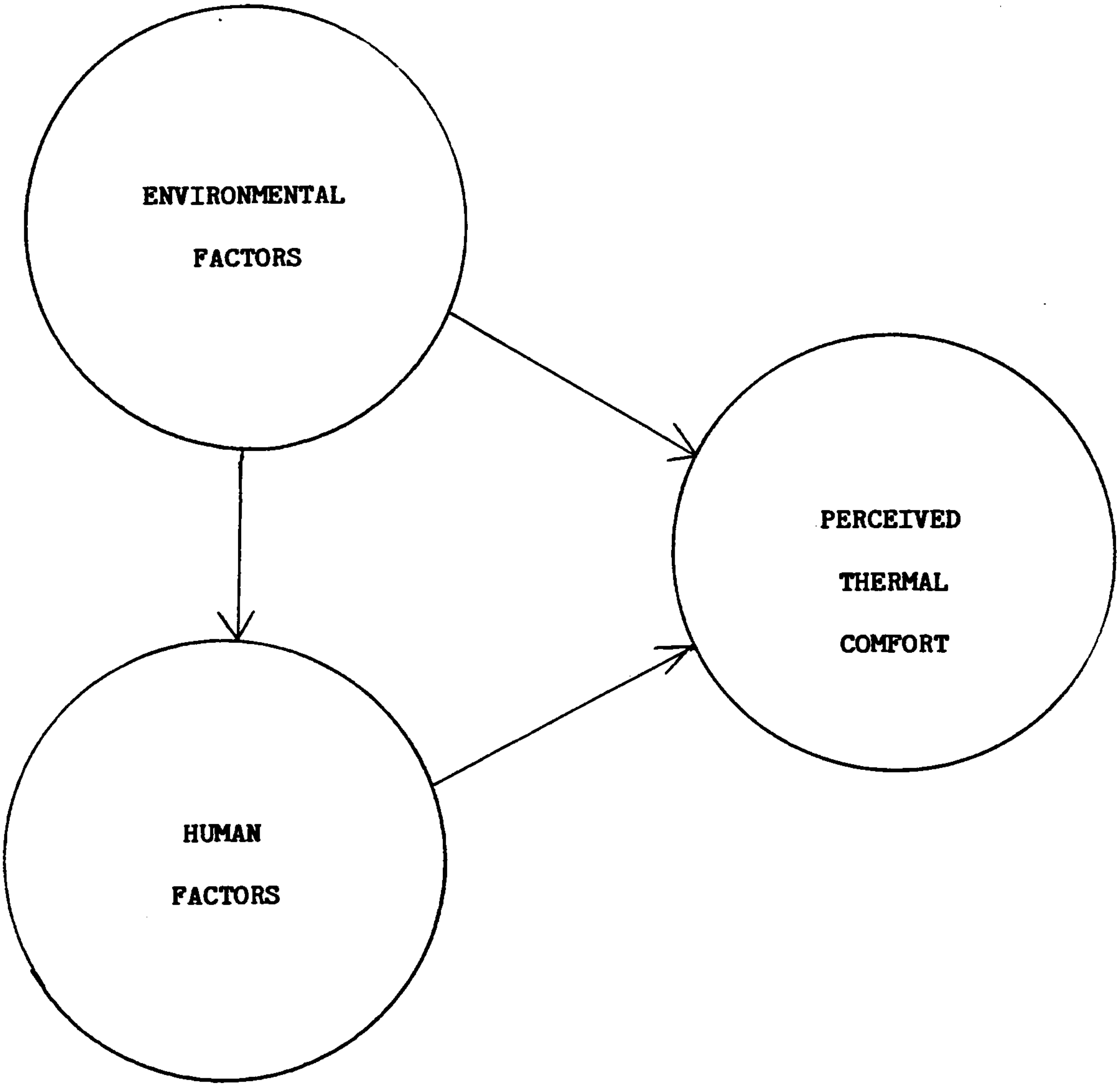

Figure 1

Conceptual Framework for Perceived Thermal Comfort

(Generalized Model)

psychological factors. In this model, the environmental factors directly affect the perceived thermal comfort and also have an indirect effect through the human factors. The human factors have a direct effect on perceived thermal comfort.

Framework with Specific Concepts

The specific concepts contained in the broad categories of environmental factors and human factors are shown in Figure 2. The specific concepts are discussed below.

Environmental factors. The environmental factors are divided into two main subsets--structural factors and environmental conditions. The structural factors include the basic construction materials and soundness of the structure as well as the specific design of the structure such as large windows, large rooms, and placement of halls. Also the heating, air-conditioning, and ventilating systems and their control impact on thermal comfort (ASHRAE, 1981a). The environmental conditions include the air temperature, mean radiant temperature, relative humidity, and air velocity (ASHRAE, 1981a; Heerwagen, Emery, Kippenhan, & Varey, 1978; Rohles, 1981).

Human factors. The human factors are divided into two main subsets--personal and psychological. The personal factors include the clothing worn, the activity level of the person, and the length of stay in the specific environment (such as a few minutes to several hours) (ASHRAE, 1981a; ASHRAE, 1981b; Heerwagen et al., 1978; Rohles, 1981). The psychological factors include the personal control a person has over the environmental conditions as well as the person's preferred temperature or standard of comfort, expectations, and beliefs.

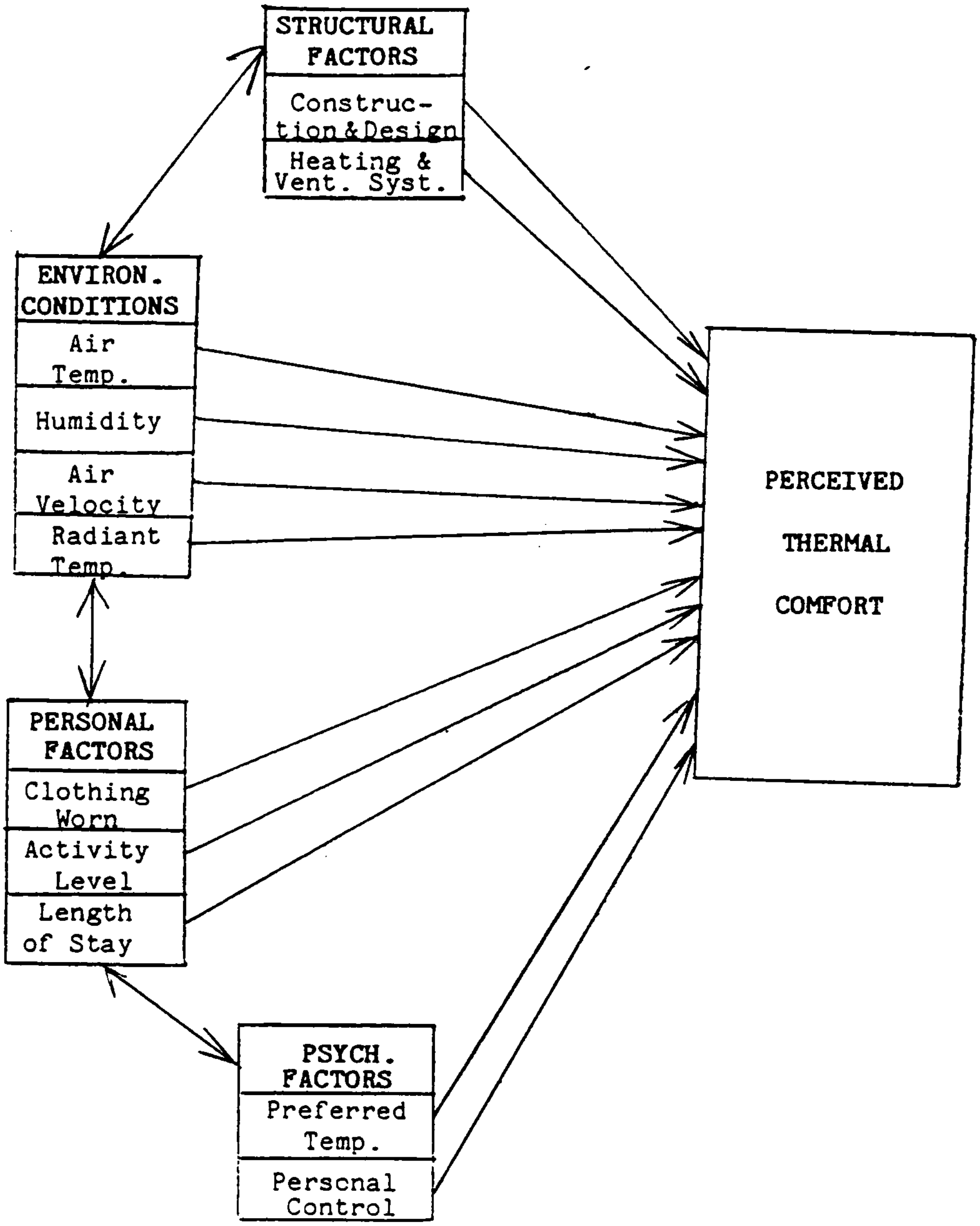

Figure 2

Conceptual Framework for Perceived Thermal Comfort

(Specific Concepts)

In studies concerning personal control or locus of control, the respondent perceives a level of control in a given situation in which he is involved (Rotter, 1954). In some studies involving electric shock, the ability of the subjects to terminate the undesired stimulus tends to reduce the impact of that stimulus. Subjects who had no predictability or personal control over the electric shock judged a less intense shock as more uncomfortable than did subjects with control over the electric shock (Staub, Tursky, & Schwartz, 1971; Geer & Maisel, 1972; Gatchel, 1980; Phares, 1976). Further, there is evidence that the perception of the lighting in buildings is influenced by the level of control the individual has over the environment (Hayward, 1974; Proshansky, Ittelson, and Rivlin, 1976). In a study testing the effectiveness of a three-stage automatic setback thermometer, Darley (1978) asked residents to set the thermostat at temperatures lower than their usual preferred temperatures but they were allowed to change the thermostat if they found it too cold. He found that the residents tolerated the lower thermostat settings and did not use the available override feature to raise the thermostat setting. Darley concluded that the override feature which allowed personal control over the temperatures was the reason that the residents tolerated lower thermostat settings.

The concept of personal control has particular importance when considering that about 20 percent of the residents in the United States do not have direct control over the temperatures in their dwelling (Newman & Day, 1975). Furthermore, the ASHRAE comfort standards discussed below were developed in the situation where the respondents had no control over the thermostat. In field studies involving energy conservation strategies with persons having control over the thermostats, Winett et al., (1982) reported that persons indicated comfort levels with temperatures higher in summer and lower in winter than the comfort levels recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. They state that ASHRAE approaches comfort as a "static" variable when actually it is "elastic" and relatively dynamic having a wider range. The element of personal control also appears to be an influencing factor.

The other psychological factor in the framework is the person's preferred temperature state or comfort level. This can be perceived as the person's temperature norm. In their theory of housing adjustment, Morris and Winter (1978) state that a difference between the family norm and the actual conditions will be expressed in terms of dissatisfaction. The greater the difference between the desired and the actual, the greater the dissatisfaction. When applied to perceived thermal comfort, which is the satisfaction with the thermal environment, the person will be expected to have a higher level of discomfort as the difference between the desired and actual conditions increase.

Actual Framework for Study

The above description of both a generalized framework and a more specific framework leads to a discussion of the variables included in this investigation as shown in Figure 3. Because one building structure was used in this study, the structural factors were dropped from the model. Also, because of the ability to control certain environmental factors, the only ones remaining in the model were air temperature and humidity. The activity level of the persons and the length of stay were also controlled so that the only personal factor remaining in the model was the clothing worn. Both psychological factors of the preferred

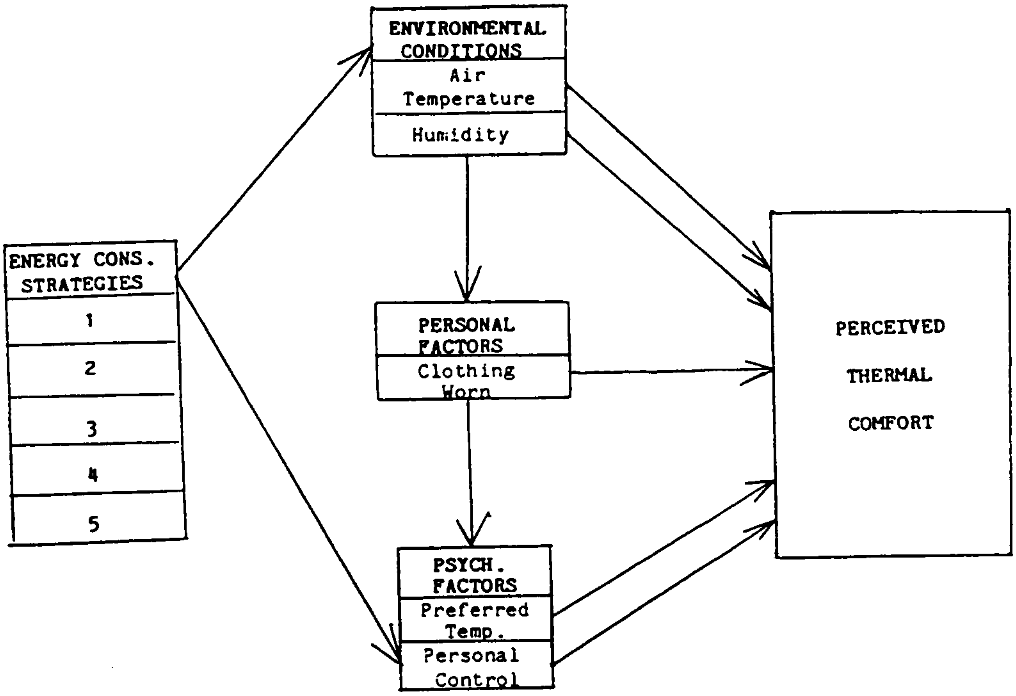

Figure 3

Conceptual Framework for Perceived Thermal Comfort

(Actual Concepts in Study)

temperatures and the level of personal control remained in the model. Personal control was incorporated into this dissertation through the ranking of the energy conservation strategies by the project participants according to their perceived control over the room temperatures.

Also, added to the framework were the energy conservation strategies that impact on the air temperature and humidity and are ranked according to the level of control the person has over the temperatures when using the strategy. The temperatures that result from the strategy affected the clothing worn and the perceived comfort. The clothing worn affected the psychological factors and perceived thermal comfort.

Related Literature on Thermal Comfort and Energy Conservation

A brief historical background provides perspective on occupant thermal comfort as related to energy consumption in the space heating of structures. Next, the development of thermal comfort standards is described including general considerations as well as the various indices and research methods used to establish the standards. Finally, research studies involving thermal comfort and energy conservation are discussed.

Historical Background

In prehistoric times, humans either inhabited warm climates which required little shelter or lived in caves and used the insulative quality of the earth to provide the needed warmth (Lindamood & Hannah, 1978). Later, as civilizations developed, people learned more about how to take advantage of the environment and the natural resources to warm or cool their dwelling, as observed when the Inca Indians of Peru oriented their shelters to capture the warming effect of the sun in winter and the cooling effect of the prevailing breezes in the summer (Gasparini and Margolies, 1980).

In the early settlement of the United States, wood initially was the primary source of energy used to heat homes. Fireplaces predominantly were used until the introduction of woodstoves in the 1800's. Coal came into major use in the 1850's along with natural gas and fuel oil that were then introduced for residential use (Lindamood & Hannah, 1978).

In 1882, the availability of electricity for use in residential dwellings through a public distribution system had a dramatic influence on how people heated their living environments. Greater dependence was placed on heating and cooling systems run by "cheap electricity" versus the placement of windows in relation to the sun and the use of trees for shading to provide a thermally acceptable residential environment. This dependency on electricity (which predominantly used fossil fuels for generation) was encouraged heavily in the 1950's and 1960's with the pitch for "all electric" homes.

The advent of the Industrial Revolution around the turn of the twentieth century brought with it concerns over the acceptability of the workplace for human occupancy because people left their homes and went into offices or factories to perform their work. Concern over the acceptability of the thermal environment was not only humane in focus to assure that workers were treated well but also profit-oriented as entrepreneurs wanted to increase productivity and profits by providing an adequate working environment. This concern led to the development of thermal standards for occupied structures.

Another important event was the 1974 oil embargo. The embargo not only brought a reduced supply and increased cost of fossil fuels but also added another perspective in the evaluation of occupant thermal comfort. The question was asked whether energy could be saved by lowering the thermostat and using other energy conservation measures while maintaining a thermally acceptable environment. Also, in an attempt to locate alternative ways to save energy in heating spaces, attention focused again on the natural resources. Passive and active solar energy uses in dwellings and other structures were and continue to be explored and developed. Various energy conservation strategies in home heating were developed or suggested such as the use of woodstoves and closing off certain rooms. Thus, the need to reduce the use of energy led to the question of what impact the resulting thermal environment would have on the thermal comfort of the occupants.

In summary, in prehistoric and early civilizations, people used natural resources and characteristics of the environment to heat their various shelters. Around the late nineteenth century and particularly in the 1950's and 1960's, greater dependency was placed on fossil fuels to heat spaces. However, since the 1974 oil embargo that brought decreased availability and increased costs of fossil fuels, greater attention has been placed on developing ways to reduce energy needs to heat residences. This need to conserve energy has also led to the consideration of the acceptability of the thermal environment under conditions produced by the various methods of energy conservation in residential heating.

Development of Standards for Occupant Thermal Comfort

This section describes the various indices and the research methods used to establish guidelines or standards for occupant thermal comfort.

General considerations. First, it is important to realize that the temperatures a person or society designates as comfortable is a dynamic assessment (Winett et al., 1982). The temperature criteria for thermal comfort rose steadily between 1920 and 1960. Nevins (1961) surveyed temperature requirements over a 60-year period and found that a temperature range of 65 to 70°F was acceptable in 1900, but by 1960, the temperature range that was recommended for comfort was 75 to 80°F--both ranges being given for 40 percent relative humidity.

The reasons for this gradual increase in temperatures for thermal comfort are linked to changes in society: (1) the reduction in the weight of clothing (and thus to some extent its ability to insulate); (2) the ease with which heating could be achieved (with the availability of fossil fuels); (3) changes in living habits; and (4) changes in the way buildings are built (ASHRAE, 1981a; Heerwagen et al., 1978; Rohles, 1981; Winett et al., 1981). Regardless of the precise reason, it is important to recognize that a person's feeling of comfort is directly related to his ability to respond to the various environmental conditions that impact on his physiological state. As described in the previous section, six factors determine a person's physiological response to the building environment. The main environmental factors are the ambient air and mean radiant temperatures, the relative humidity, and the relative air velocity. The main personal factors are the thermal resistance of the person's clothing and the activity level of the individual. Almost all of the recent research on human comfort recognizes these six factors as those determining the individual's physiological responses to the building environment.

Early indices for thermal comfort (1920's - 1950's). Since the 1920's, a succession of at least a dozen indices, equations, and envelopes or zones have been developed for predicting thermal comfort (Givoni, 1976; Heerwagen et al., 1978; Hill, Kusanda, Liu & Powell, 1975; Newburgh, 1968). The first of these indices was developed by the work of Houghten and Yaglou (1923) in the 1920's and continued into the early 1960's (Heerwagen et al., 1978). Most of these efforts to describe human comfort were organized around the development of a series of thermal indices which could be used to predict physiological responses to varying conditions in the environment. Givoni (1976) has compared the various indices and determined that they differ in at least four major areas: (1) the specific environmental and personal factors and physiological responses that are addressed, (2) the way in which these factors and responses are weighed for relative importance and whether or how the factors and responses affect each other, (3) the range of environmental conditions in which the various indices are applicable, and (4) the manner in which the various indices are expressed.

Three major works (Since 1960's). Beginning with the 1960's, these former indices of human comfort have been somewhat replaced with the use of thermal envelopes (comfort zones) such as those used to develop the ASHRAE Standard 55-81 (1981a). Three major research efforts since the early 1960's have occurred from which specific recommendations about comfort conditions have been advanced. A description of these three research efforts and their results are presented below.

The first major research effort was begun by Nevins, Rohles, Springer, and Feyerherm (1966) at Kansas State in 1963. The researchers first identified a comfort zone based on dry bulb temperatures and relative humidity scales by determining how test subjects evaluated the environmental conditions when the ambient air temperature and the relative humidity were varied. The respondents evaluated the environmental conditions on a seven-point rating scale ranging from "cold" to "hot" with "comfortable" at the median point. This research actually was not centered on the issue of thermal comfort as much as on the thermal sensations. Later work, as reported by Rohles (1970), led to the development of a "Model Comfort Envelope."

The research at Kansas State University used environmentally controlled chambers which small groups occupied for certain periods of time and individually responded to perceived comfort levels. In the initial work by Nevins (1961), 720 college students (equally divided by gender) participated. In the work by Rohles (1970), these 720 students plus 880 more, for a total of 1600, participated.

The results of Nevins' work was a modified Psychometric Chart entitled "Baseline Comfort Chart" which showed the humidity and temperatures that the respondents found to be "slightly cool," "comfortable" and "slightly warm." A rise in humidity shifted the perception of comfort to the left or down several degrees. With the additional data from Rohles (1970), a "Modal Comfort Chart" was derived. The Modal Comfort Chart is determined by an envelope overlaid on the lines showing the "slightly cool," "comfortable" and "slightly warm." The envelope signifies the zone in which the test subjects were comfortable.

The second main effort in comfort research was led by Fanger (1972) at the Technical University of Denmark. Fanger began his work by attempting to relate the environmental and personal factors that affect the maintenance of comfort with the body's mechanisms by which heat is gained or lost. As a result, he developed a comprehensive "Comfort Equation" with which can be calculated whether an individual will be comfortable when exposed to a set of environmental conditions under clothing insulation levels and specific metabolic (activity) rates. From the comprehensive equation he developed nomographs in which combinations of several environmental and personal factors are compared. These nomographs were called "comfort diagrams" and were intended to be used in general practice without having to use the quite complex Comfort Equation.

Fanger used this comfort equation and his "Comfort Envelope" to evaluate the predicted comfort of specific room climates. He used a rating scale similar to the one established by Nevins (1961) and Rohles (1970) to develop the concept of a "Predicted Mean Vote." Using research on active subjects, Fanger determined that the predicted mean vote (PMV) was a factor of the six environmental and personal factors to which the subjects were exposed. An equation was developed that could be used to determine the predicted mean vote when the six variables were known (Heerwagen et al., 1978).

Fanger also developed the idea of "Predicted Percentage of Dissatisfaction" (PPD) of people who will be uncomfortable when they experience some set of environmental and personal conditions. The predicted percentage of dissatisfied (PPD) is directly related to the predicted mean vote (PMV) and an equation relating the two was developed by Hill et al. (1975).

The value of Fanger's work is that it presents a way to calculate, by computer, whether the occupants of a space will be comfortable when exposed to any set of environmental conditions when clothed in a specific manner and when engaged in a specific activity. Thus, this is a design aid to evaluate a building prior to its construction (Heerwagen et al., 1978). Hill et al. (1975) reported that one difficulty in using Fanger's PMV and PPD ratings is that their predicted lines of relatively small and larger discomfort do not match those found by Nevins and Rohles who established comfort guidelines for a larger sample of test subjects. However, the two research efforts do agree closely in the area that is considered comfortable.

The third major research effort in defining comfort zones was the work by Gagge, Stolwijk and Nishi (1971) at the John B. Pierce Foundation Laboratory in New Haven, Connecticut. Primarily the researchers developed a version of the old thermal index "Effective Temperature" (ET), originally developed in the 1920's by Houghten and Yaglou (1923). The "New Effective Temperature"* is based on the human body's various heat exchange mechanisms. The "New Effective Temperature" (designated as ET*) is similar to Fanger's Comfort Equation but is argued to be more accurate as it includes exchange effects due to vasoregulation (Heerwagen et al., 1978). The ET* scale, like the Comfort Equation, can be used to predict the comfort level when varying environmental conditions exist with specific clothing and activity levels of the occupants.

Effective temperature (ET) is "the uniform temperature of a radiantly black enclosure at 50 percent 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, 1981a).

Current Thermal Comfort Standards of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)

The current comfort standard, ASHRAE Standard 55-81, is a revision of the ASHRAE Standard 55-74 and incorporates research and experience gained since the 1974 revision. The operative temperatures[a] for thermal acceptability for sedentary or slightly active persons are given for winter and summer. The winter operative temperature range for clo value[b] of 0.9 for 80 percent thermal acceptability is 68 to 74.5°F with an optimal operative temperature of 71°F. The summer operative temperature range for a clo value of 0.5 is 73 to 79°F with an optimal operative temperature of 76°F. These standards are developed for slow air movement (0.15 m/s [30fpm]) and 50 percent relative humidity. The principal additions or new features include the following: winter and summer comfort temperature ranges based on current seasonal clothing habits in the United States; limits on the thermal nonuniformities in the space such as drafts, temperature variation, and radiant asymmetry which can cause local discomfort; temperature adjustments for activity and allowance in summer of higher temperature if air movement is correspondingly increased.

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[a] Operative temperature is "the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. Operative temperature is numerically the average, weighted by respective heat transfer coefficients (h_c and h_r), of the air (t_a) and mean radiant temperatures. At air speeds of 0.4 m/s (80 fpm) or less and $\bar{t}_r$ less than 50°C (120°F), operative temperature is approximately the simple average of the air and mean radiant temperatures and equal to the adjusted dry bulb temperature (ASHRAE, 1981a).

[b] Clo value is "the numerical representation of a clothing ensemble's thermal resistance, 1 Clo = 0.155 M^2K/W (0.88 $ft.^2hF/BTM$), (ASHRAE, 1981a).

Studies of Thermal Comfort and Energy Conservation

Gagge and Nevins (1976) completed a study at the Pierce Foundation Laboratory for the Federal Energy Administration (FEA) to determine if a specific set of new comfort standards were reasonable and what observations the researchers would make about the occupant acceptability of the guidelines. The new guidelines were established in response to the energy situation in 1974 by the FEA and were different from the ASHRAE Standard 55-74. The temperatures of the FEA were 68 to 70°F for winter and 78 to 80°F for summer (with a possible 80 to 82°F being examined at the time for possible implementation later).

The results of the FEA-sponsored study were that while the conditions set forth with the ASHRAE Standard 55-74 were revalidated as optimal for comfort, the researchers reported that variations from the standard were acceptable. The acceptability criterion was that 80 percent of those persons subjected to the temperatures would find them comfortable. An upper limit on the temperature was set at 78 to 80°F with relative humidity up to 70 percent as long as lighter clothing was worn (clothing rated at 0.4 clo or less). An even higher temperature range of 80 to 82°F can be made acceptable if one of the following exists: (1) the clo value is maintained at 0.3 or 0.4; (2) the relative air velocity is kept at 50 to 100 fpm range, and/or (3) the relative humidity is kept at 40 percent or less. The lower temperature range of 68 to 70°F was found to be acceptable (to 80 percent or more of the subjects) if the clo values of the clothing worn ranged from 0.8 to 1.2 clo and was evenly distributed over the body and drafts around the neck and body were avoided.

A gender difference in response to the extreme temperature ranges was observed in the FEA study. Men appeared to be more sensitive to temperatures on the upper region of the range, whereas women, particularly those young in age, seemed more sensitive at the lower range. In both cases, these sensitivities were overcome by relying on the above identified aids. The primary conclusion from the study was that except for hospital patients, there appeared to be no serious health hazard for individuals when exposed to temperatures in the range of 68 to 80°F (winter and summer).

From a series of field studies using residents living in their own homes as subjects and focusing on perceived thermal comfort, energy conservation and related variables, Winett and his research colleagues at Virginia Polytechnic Institute and State University have concluded that the comfort ranges used by ASHRAE are too narrow and that ASHRAE approaches comfort as a "static" versus a "dynamic" assessment (Winett, 1983; Winett & Ester, 1982; Winett et al., 1983; Winett et al., 1982; Winett et al., 1981; Winett et al., 1979; Winett & Neale, 1979). They reported that people can adapt to temperatures outside the ranges set by ASHRAE. Further, the researchers raised some external validity questions concerning the laboratory testing of standards including the short-term nature of the experience, lack of a true behavior measure of comfort (such as adjusting the thermostat), and the general artificiality of the research setting. They further concluded that people can be quite comfortable using devices and strategies that use very little energy such as automatic set-back thermostats as well as portable room heaters and fans.

Godbey and Davis (1982) used thermal comfort as one of several criteria to evaluate homes that use the solar greenhouse to offset heating costs. They specifically studied the importance of humidity and temperatures in providing a comfortable environment in a solar greenhouse residence. They used a solar greenhouse residence designed by Clemson University and the USDA-Rural Housing Research Unit (RHRU). The house had 24 thermocouples that recorded temperatures every hour. The minimum temperature in the house was kept at 64.4^oF which the occupants (one family) said was comfortable. This temperature was about four degrees lower than the recommended minimum by ASHRAE. The researchers partially explained the comfort with this lower temperature by the design of the house. The outside walls were buffered from the extreme outside ambient temperatures by the solar greenhouse design. Since there were no cold surfaces to which the body could lose heat by radiation, the occupants felt more comfortable.

In a study funded by the National Endowment for the Arts, Case and DeJonge (1982) studied fifteen families in homes with a solar greenhouse, a woodstove, or a combination of the two for home heating. The researchers' purpose was to integrate clothing, interior design, and basic housing design into a systems approach to home heating. They found that temperature swings occurred in all the homes and sometimes caused discomfort for the residents. However, overall, the residents reported that even at lower temperatures, the homes were more comfortable than conventional homes. The researchers concluded that the response was due to the extra wall and ceiling insulation as well as higher levels of weather tightness intentionally designed into these homes.

Summary

A succession of three conceptual frameworks for perceived thermal comfort are presented. The first framework is a generalized idea of the two major components of environmental and human factors that influence perceived thermal comfort. A second framework identifies the specific concepts derived from the generalized framework. The environmental factors include structural aspects of buildings as well as environmental conditions such as room temperatures and air velocity. The human factors include personal factors such as the insulating quality of the clothing worn but also the psychological factors of preferred temperatures and personal control. This framework is different from previous ones used to study perceived thermal comfort in that psychological factors are incorporated. The third framework includes the concepts measured in this study. It includes the energy conservation strategies as independent variables as well as air temperature, relative humidity, clothing worn, preferred temperature, and personal control.

Research relating personal control and perception of comfort suggests the influence of personal control on perceived thermal comfort. Subjects with greater personal control reported less discomfort with electric shock (Staub et al., 1971; Geer & Maisel, 1972; Gatchel, 1980; Phares, 1976). Further, Darley (1978) found persons who had control over the heating thermostat through an override feature tolerated lower thermostat settings.

The temperatures a person or society designates as comfortable is a dynamic assessment (Winett et al., 1982). The temperature criteria for thermal comfort rose from a range of 65 to 70°F in 1900 to a range of 75 to 80°F in 1960 (Nevins, 1961). Reasons for this change are based on the reduced amount of clothing worn, the easy availability of fuel sources to heat spaces, changes in living habits, and changes in the ways buildings are built (ASHRAE, 1981a; Heerwagen et al., 1978; Rohles, 1981; Winett et al., 1981).

Since the 1920's a succession of at least a dozen indices, equations, and envelopes or zones have been developed for predicting thermal comfort in occupied structures (Givoni, 1976; Heerwagen et al., 1978; Hill, Kusanda, Liu & Powell, 1975; Newburgh, 1968). Because the early indices were less satisfactory than desired, use of them as predictors of human comfort has declined (Heerwagen et al., 1978). However, three major works since the 1960's have contributed heavily to the development of the current thermal standards established by the American Society of the Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Nevins et al., 1966; Fanger, 1972; Gagge et al., 1971). The current ASHRAE comfort standard, ASHRAE 55-81, prescribes a temperature range of 68 to 74.5°F for winter with an optimal temperature of 71°F, with the insulating value of the clothing worn of 0.9 clo, and with a relative humidity of 50 percent.

Recent research indicates that persons can be comfortable outside the comfort range set by ASHRAE. Gagge and Nevins (1976) completed a study to determine if the comfort standards for public buildings established by the Federal Energy Administration (FEA) were reasonable. The temperature range of 68 to 70°F for winter was found to be acceptable to 80 percent of the subjects with clo values of the clothing worn between 0.8 and 1.2 clo. Also, from a series of field studies using residents living in their own homes as subjects, Winett and his colleagues concluded that the comfort ranges used by ASHRAE are too narrow and that people can adapt to temperatures outside the ranges set by ASHRAE (Winett, 1983; Winett & Ester, 1982; Winett et al., 1983; Winett et al., 1982; Winett et al., 1981; Winett et al., 1979; Winett & Neale, 1979). Similar results were obtained by Godbey and Davis (1982) when occupants of a solar greenhouse test house residence reported comfort at 64.4°F.

Finally, sacrifice in thermal comfort appears not to be required to save energy in residential heating conservation strategies. Low-energy using strategies such as the use of portable heaters and automatic setbacks have been found to produce acceptable levels of thermal comfort (Winett, 1983; Winett & Ester, 1982; Winett et al., 1983; Winett et al., 1982; Winett et al., 1981; Winett et al., 1979; Winett & Neale, 1979).

In the following chapter, the research design for the study is presented. Specifically, the definitions and measurement of the major variables are described in detail.

CHAPTER III

METHODOLOGY

The purpose of this study was to complete a detailed descriptive analysis of five families and the reactions of the husbands and wives to the thermal environment while each family lived in an energy test house and employed strategies with varying levels of personal control to reduce energy consumption in residential heating. In addition, the data were analyzed for trends that appeared to exist between perceived thermal comfort and selected variables including the level of personal control over the temperatures when using the strategies. Specifically, the investigation addressed the following research questions:

1. When selected energy conservation strategies in residential heating are employed, what is the impact of their use in the following areas?
    a. variables influencing the physiological response
    b. perceived thermal comfort
    c. energy consumption
2. Does the level of personal control the respondent has over the strategies appear to affect the level of perceived thermal comfort?
3. What relationship exists between the perceived thermal comfort and the amount of energy saved?

4. How similar are the respondents' anticipated ratings of comfort to the actual ratings of comfort?
5. What patterns or trends appear to exist between perceived thermal comfort and related variables including the family's preferred temperature and the demographic and energy-related characteristics of the family?

The methodology used in completing this study is presented in this chapter beginning with a section on the source of the data. Then, the research design is described in terms of the family participants, a description of the energy test house used in the study, the energy conservation strategies tested, the definition and measurement of perceived thermal comfort and related variables, and the data analysis.

Source of Data

The source of data was a residential energy study currently underway at the North Carolina Agricultural and Technical State University, in Greensboro, North Carolina, entitled "The Effect of Home Energy Conservation Strategies on Lifestyle." The four-year research project began in 1982 and is funded by the United States Department of Agriculture (Turner et al., 1983). Garrett House, an energy test house located on the campus, is being used to study the energy consumption as well as the behavioral aspects of selected conservation strategies. Fifteen families will live separately in the house for periods of either four or six weeks and implement selected energy conservation strategies in the areas of space heating/cooling and hot water consumption. A description of the project appears in Appendix A.

Research Design

Five families each lived for six weeks in Garrett House and employed five energy conservation strategies in residential heating. The residence periods of the five families occurred during the winter months from November through April of the years 1983 and 1984. After the initial baseline week, the selected strategies were tested for one week each. At daily and weekly intervals, the perceived thermal comfort of the ten participants was analyzed in relation to room temperature, humidity, clothing worn, preferred room temperatures, personal control over the temperatures, and energy consumption of the central heating system. Below, details of the research design are presented including the selection of the families, a description of the energy test house, the energy conservation strategies tested, definition and measurement of perceived thermal comfort and the other dependent variables, and the data analysis.

Participating Families

The five participating families were selected by a panel from a list of families that volunteered to participate in the project. Applications were accepted from persons who either saw television public service interviews with the project personnel or heard about the project otherwise. The panel consisted of the investigator and two faculty members at North Carolina Agricultural State University involved in the project that provided the data. The families were selected on the basis of two main characteristics--family size and ages of children. The family size ranged from two persons (a couple) to five persons (husband, wife, and three children). The ages of the children varied from preschool to teenage and the family type was married husband and wife. The involvement of couples allowed assessment of two adult respondents as well as comparisons of male and female responses. A stipend of $400 was given to each family to offset any extra costs incurred from living in the house, such as extra travel to employment or day care, and all utilities in Garrett house were provided at no cost to the families.

Description of the Energy Test House (Garrett House)

Garrett House, the energy test house used in this investigation, is described in detail in Appendix A. Two energy conservation features of the test house were used in this investigation--a passive solar greenhouse and a freestanding woodstove vented into an existing fireplace. The floor plan in Figure 4 shows the placement of these items and details of each are presented.

The passive solar greenhouse was designed to replace an existing covered porch on the south side of the house. The greenhouse is 9 feet by 20 feet and was constructed from pressure treated pine 4x4's and a double walled polycarbonate glazing (Tufak - Twinwall® by Rhomn and Haas). The glazing material was chosen for its excellent impact resistance, an important consideration for a campus structure. The greenhouse is 100 percent glazed to maximize solar gain and minimize complexity and cost. Its main function is that of a solar collector to provide space heating for the house. It was not designed as an energy self-sufficient growing environment for plants. As a solar collector it performs well, delivering an estimated average 13 million BTU's to the house annually or about 25 percent of the total space heating requirement.

Heat is transferred from the greenhouse into the living area by opening two sets of French doors to the greenhouse during times when the occupants are at home and by a thermostatically controlled blower that

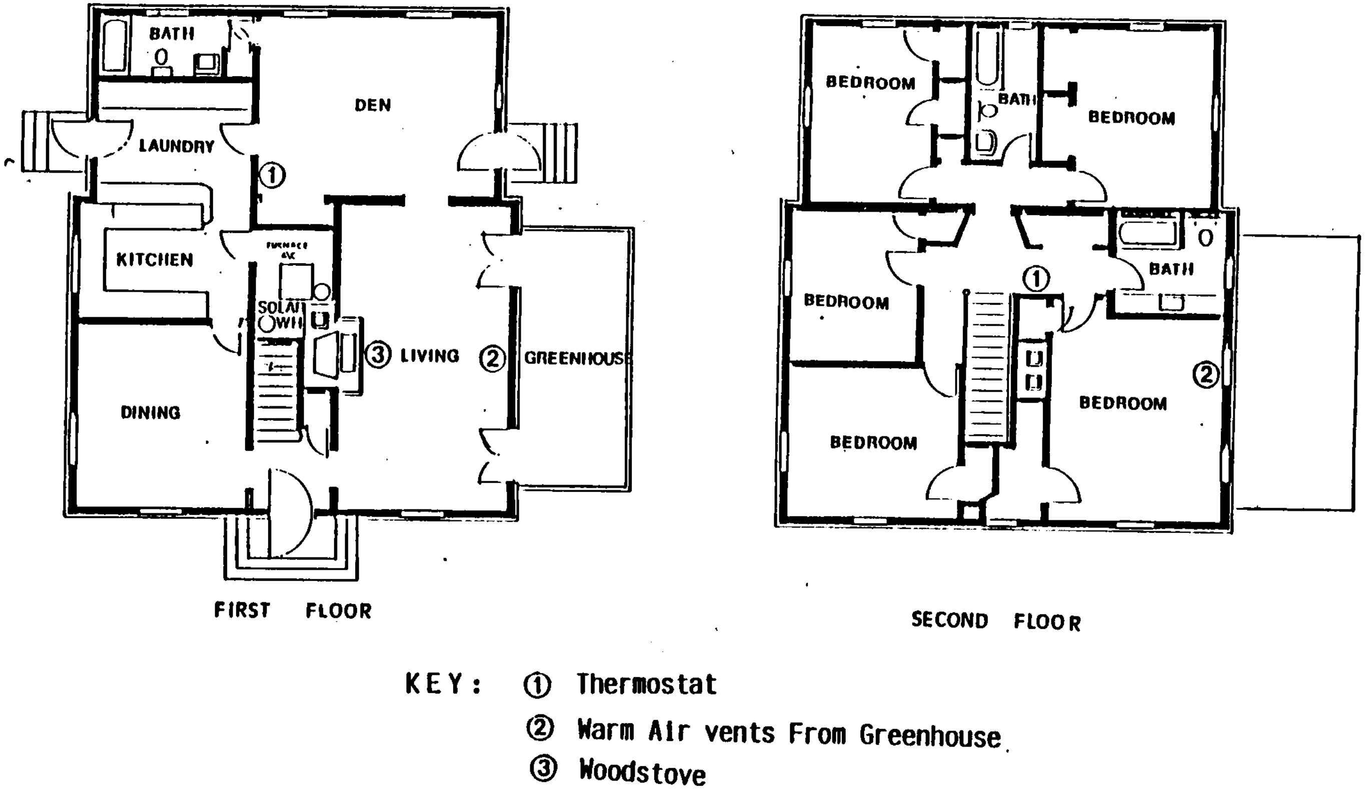


Figure 4

Floor Plan of Garrett House

delivers warm air from the greenhouse to both the upstairs and downstairs. The blower begins operation when the greenhouse temperature reaches $80^{\circ}F$.

The house had a fireplace in the living room. However, for the project, the fireplace opening was closed and a woodstove was placed on the hearth in front of the fireplace. The temperature of the top surface of the stove is monitored by a thermocouple connected to the data acquisition system. This temperature provides information about when the stove is in use and the relative intensity of the fire.

Independent Variables: Energy Conservation Strategies

The five energy conservation strategies in residential heating served as independent variables in the investigation. During the six weeks that each family lived in the house, the first week served as a baseline period. During the baseline period, families were instructed to set the thermostat at temperature levels that they found to be comfortable. In the following weeks, strategies were added one at a time and were tested for a one-week period. The conservation strategies used during this six-week period are listed below:

Week 1: The baseline data were obtained establishing a family norm. No strategies were introduced.

Week 2: The central heating thermostat was kept at the family's norm level, but heat inlets in the bedrooms were closed and the doors to these bedrooms were kept closed by the resident during the daytime when not in use.

Week 3: The central heating thermostat was kept at $65^{\circ}F$ and the restriction on bedroom heat inlets and doors were withdrawn.

Week 4: The heating thermostat was kept at $65^{\circ}F$ and use of the greenhouse as a heat source was introduced.

Week 5: The heating thermostat was kept at 65°F, use of the greenhouse continued, and use of the woodstove was added.

Week 6: The heating thermostat was kept at 65°F, use of the greenhouse was discontinued, and use of the woodstove continued.

At the beginning of each strategy, a list of instructions and information was given to the family. When appropriate, demonstrations also were given. It is important to note that the families did not have the responsibilities of cutting wood or cleaning out the woodstove. A description of the procedures used in the investiagion and the instructions given to the family appear in Appendix B.

The ordering of the treatments (use of the conservation strategies) was designed to permit measurement and comparison of the contributions of the strategies to the energy used in space heating. Therefore, little variation in the ordering of the treatments was possible. However, to analyze an ordering effect, three families used the strategies in the order listed above while two families used the strategies in a different order.

Dependent Variables: Energy Consumption, Perceived Thermal Comfort, and Related Variables

Two broad categories of dependent variables existed for this study One was the actual energy consumption of the central heating system resulting from the use of the various energy conservation strategies. The methods used to monitor and determine energy consumption are described in this section. Primarily, the data were collected by a computer located in the energy test house.

The other set of dependent variables in the study pertained to perceived thermal comfort, variables influencing the thermal physiological responses, and certain psychological variables. These data were collected primarily through the use of questionnaires and various response forms described in the following sections. The physiological variables included the room temperatures, the activity level of the respondents, clothing worn, air velocity, and relative humidity. The psychological factors include the level of personal control over the temperatures and one's preferred room temperature. In addition, the respondents' attitudes toward energy were assessed. Energy conservation practices and activities used by each family in their own home were used to develop three energy indexes for each family.

Demographic and Behavioral Response Instruments

Four sets of questionnaires were used to collect the demographic and behavioral data. The questionnaires were developed both by adapting some questions developed for other research projects and by generating items specifically for this investigation. The four questionnaires are described below while the specific questions used in this study appear in Appendix C.

Energy Information Questionnaire. This extensive ten page questionnaire was completed by both the husbands and the wives both before and after the live-in experience in Garrett House. Questionnaire items were utilized to describe the demographic characteristics of the families, to develop the Energy Conservation Indexes of the energy-related activities and practices of the families, to describe attitudes toward energy conservation, and to compare the similarity of the rankings of the anticipated and the actual thermal comfort.

Weekly Questionnaires. Immediately after the completion of the weekly use of each strategy, each husband and wife completed a questionnaire specifically related to the strategy. These questions sought their response in terms of perceived thermal comfort for each room in the house, convenience, attention demanded, and the time and human effort required. The only item used from the weekly questionnaires was the perceived thermal comfort.

Daily activity log. The Daily Activity Log was designed to determine the performer, time, and location of selected activities which either impact on or are affected by energy consumption. The only item from the daily log used in this investigation was the section used to determine the daily occupancy rate, the average number of hours daily the house was occupied by at least one family member.

Daily thermal comfort and clothing worn. This questionnaire was adapted from a form developed by the American Society of Heating, Air-Conditioning and Refrigerating Engineer for measuring responses to perceived thermal comfort and the insulating quality of the clothing worn (ASHRAE, 1981a; 1981b). The comfort score is a rating on a seven-point Likert-type scale. The insulating quality of the clothing worn is determined by the "clo value" of items indicated on a clothing checklist. Each husband and wife completed the form between 7 and 10 p.m. daily, after being engaged in sedentary activity for one hour.

Definition and Measurement of Major Variables

The major variables used in this investigation are listed below along with a definition and dscription of how each was measured or controlled.

Activity level. The activity level refers to the bodily movements of the person that contribute to metabolic heat production. In this study, the activity level was sedentary or slightly active when the daily comfort and clo values were assessed. The two adult respondents in

Families 4 and 5 were asked to complete the daily questionnaire referring to clothing and thermal comfort between the hours of 7 and 10 p.m. and be sedentary for at least one hour before completing the forms. If the respondents were not in the home during the 7 to 10 p.m. time period, forms were not completed. The forms were based on research by ASHRAE (1981a; 1981b).

Air velocity. The air velocity refers to the air movement in the house. The average air movement recommended by ASHRAE should not exceed 0.5 m/s (30 fpm) (ASHRAE, 1981a). As the air movement in Garrett House did not exceed this level, the air velocity was controlled in this study.

Anticipated/actual rankings of thermal comfort. The rankings of anticipated thermal comfort of the energy conservation strategies were completed by the respondents before participating in the research project. The rankings of actual thermal comfort that resulted from using the conservation strategies were obtained after the families had completed the live-in experience. The questions that asked the participants to rank the strategies appear in the Energy Information Questionnaire.

Attitude toward Energy. Three questions on the Energy Information Questionnaire administered before the respondents moved into Garrett House were used to assess the ten participants' attitudes toward the part consumers play in energy conservation. Two questions dealt with the extent to which various reasons or groups contributed to the energy situation. The responses were obtained from a five-point Likert-type scale range from "totally" with a score of "1" to "not at all" with a score of "5". The other question focused on whether using less energy in homes would make any significant difference in the overall energy situation. The responses options to this question were "yes," "no," and "don't know."

Clothing worn. The insulating quality of the clothing worn was determined from the "clo values" of items on a clothing checklist that each participant completed daily between 7 and 10 p.m. "Clo value" is defined as a "numerical representation of a clothing ensemble's thermal resistance, 1 clo = 0.155mk/w (0.88 ft. hf/BTU)." The measurement of the clo values and the clothing checklists were developed by ASHRAE (1981a; 1981b). Clo values were determined for the husbands and wives in only two families as this measurement was added later in the study. Clothing from the husbands and wives in the remaining three families was assessed weekly to determine whether clothing was added or removed in response to the room temperatures.

Daily occupancy rate. The daily occupancy rate is a concept that represents the actual number of hours in a 24-hour day that the house was occupied by at least one person. The information was collected by a log completed daily by an adult designated by the family.

Demographic characteristics. The demographic characteristics of the family included the number of persons in the family, age(s) of the children (if any), family income, and the education, employment status, and employment types of the husbands and wives. The family size ranged from two persons (a couple) to five persons (husband, wife, and three children). The ages of the children varied from preschool to teenage. The family income was the total annual income of the husband and wife and was reported as either "$20,000 or above" or "below $20,000." The employment status was either "full time or part-time" or "other." The employment type was based on the Classified Index of Industries and Occupations, developed by the U. S. Department of the Census. All of these data were collected with the Energy Information Questionnaire administered to the respondents before participating in the research project.

Energy conservation indexes. Three energy conservation indexes were used to describe the family's energy conservation activities in their own home. The responses were obtained from an Energy Conservation Questionnaire administered to the family before they moved into Garrett House. The adults in each family indicated on two lists of activities which ones they had completed or practiced in their home. One list included changes to the structure itself and were later categorized as major and minor technical changes, based on the expense involved in making the changes. The major technical changes included such items as "added insulation" and "added woodstove." The other list contained behavioral items such as "closing off rooms" and "lowered thermostat in winter."

Energy consumption. The amount of natural gas used during the baseline week and during the weeks that the individual strategies in residential heating were employed was the measure of energy consumption. During the various weeks, the energy consumption was measured by cubic feet of gas used per degree day. The calculations were completed using the gas meter readings and the actual number of degree days during the week. A degree day is one degree Fahrenheit difference between $65^{o}F$ and the average outside temperature for a day and is used to measure heat requirements. This study concentrated on determining the impact of selected conservation strategies in offsetting the heating demands of the central natural gas furnace; however, if total energy consumption were addressed, consideration would be given to the amount of wood burned as well as to the electricity used to run the furnace fan.

Energy-related characteristics. The energy-related characteristics of the family were obtained from the Energy Information Questionnaire and included the following items: description of the heating source/system in their own home, attitude toward energy, energy conservation indexes, anticipated rankings of thermal comfort, family preferred temperature, and the daily occupancy rate. Except for the heating source/system, the characteristics are described under separate headings in this section of major variables.

Family preferred temperature. The family preferred temperature is the average whole house temperature for the baseline period, week 1, and was obtained by averaging the daily average whole house temperatures. The temperature was obtained from temperature sensors located in each room that are connected to the computer in the house and were read every 10 seconds. The average was recorded on tape on an hourly basis.

Length of stay. The length of stay refers to length of time a person remained in the interior environment. At the time the daily clothing and thermal comfort questionnaires were completed, the person had been in the environment for at least one hour.

Personal control. Personal control is defined as the level of control the person had over the energy conservation strategies that produced the room temperatures in the energy test house. The energy conservation strategies were ranked from "1" (most control) to "5" (least control), by the ten respondents after they had completed the entire experiment. A composite ranking of the ten respondents was used as the measure of personal control.

Perceived thermal comfort. Thermal comfort is "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 1981a). The perceived thermal comfort of the husbands and wives was measured by three distinct methods: (1) a weekly rating of thermal comfort which was compelted immediately at the end of the week that a strategy was used. The score is an overall rating covering a whole week and is an average of each person's rating from "1" (low) to "7" (high) for each room in the house; (2) a final ranking of the comfort level accompanying each of the strategies in relation to each other after all strategies had been used for one week each; and (3) a daily rating of thermal comfort with the temperatures between the hours of 7 and 10 p.m. daily (for Families 4 and 5).

Relative humidity. Relative humidity, the moisture level in the air, is defined as "the ratio of the mol fraction of water vapor present in the air to the mol fraction of water vapor present in saturated air at the same temperature and barometric pressure" (ASHRAE, 1981a). The relative humidity that is given along with the ASHRAE recommended temperatures is 50 percent. For this study, relative humidity was measured by the humidity sensor located in the den of Garrett House and connected to the computer in the house.

Room temperatures. The room temperatures include those for the living room, kitchen, den and master bedroom that were listed separately but were also averaged daily to give a whole house average. Temperature sensors located in each room and connected to the computer were used to determine the daily and weekly average temperatures for the whole house. The daily and weekly high and low temperatures were also reported. In addition, the daily and weekly temperatures were reported for the period from 7 to 10 p.m., which is the time during which the clo values and the thermal comfort responses from Families 4 and 5 were obtained. All temperatures were read every 10 seconds and were averaged and recorded on an hourly basis by the computer.

Development of Testable Hypotheses

Using data collected when each of the five families lived in Garrett House, the conceptual framework in Figure 3 was examined to determine if the concepts included and their arrangement appeared to be appropriate. The research questions listed in Chapter I directed the analysis of relationships, trends, or patterns that may exist among the variables. From this analysis, testable hypotheses were developed to give direction to further study and inferential research.

Data Analysis

The data were analyzed by descriptive statistical techniques. The results are reported in frequencies and percentages as well as in charts.

CHAPTER IV

MAJOR FINDINGS AND TRENDS OBSERVED

The purpose of this study was to examine closely five families and the responses of the husbands and wives to the thermal environment while each family lived in an energy test house and implemented selected energy conservation strategies in residential heating. The conservation strategies had varying levels of personal control and included closing off bedroom vents/doors, the setting of the thermostat at $65^{\circ}F$, and the addition of supplemental heat from a solar greenhouse and a woodstove. The project of which this study is a part is described in Appendix A. A description of the strategies and how they were implemented appears in Appendix B.

The findings and trends observed for perceived thermal comfort, energy consumption, and related variables when the families used the conservation strategies are reported in this chapter. A description of the demographic and energy related characteristics of the five families is presented first. Then, selected family characteristics are examined in relation to the baseline and general data while the families lived in Garrett House. Next, the environmental conditions, the perceived thermal comfort, and the energy savings resulting from the use of the strategies are reported. Finally, the relationships between perceived thermal comfort and selected variables are examined.

Description of the Family Participants

Demographic Characteristics

The five families who lived for six weeks in the residential energy test house ranged in size from two to five persons and the children's ages varied from two to fourteen years (Table 1). The ages of the adults ranged from 32 to 42 years for the males and from 33 to 44 years for the females. The educational levels of the adult family participants ranged from high school to doctoral degrees. In three of the families, both spouses had either college or post-graduate degrees while in the remaining two families, both males had vocational school training and the females had high school diplomas.

In four of the families, both adults were employed full time. In the fifth family, the male was employed full time while the wife was not gainfully employed. The employment types of the participating families fell into the categories of professional, machine operator, sales and clerical. Three families had professional types of employment including university teaching, physical therapy, and social science research. The family income categories ranged from \$15,000 - \$19,000 to \$50,000 and over, with no two families falling into the same income range.

Energy Related Characteristics

Heating fuel and equipment in own home. All participating families lived in single-family dwellings in which they used various fuels and equipment for space heating (Table 2). In fact, none of the five families used the same type of fuel and several families used a combination of fuels. The primary heating equipment used in three homes was a forced air furnace (Families 1, 2, and 4) while in two families the major heating equipment used was the woodstove (Families 3 and 5).

Table 1

Demographic Characteristics of the Family

	Family				
Characteristics	1	2	3	4	5
Family Size	2	3	4	5	5
Sex/age(s) of children	-	F 4 yrs.	F 7 yrs. M 4 yrs.	F 12 yrs. M 5 yrs. M 2 yrs.	F 14 yrs. M 12 yrs. M 2 yrs.
Age of Adult					
Male	37	42	35	40	32
Female	36	37	38	44	33
Education					
Male	Post-Graduate	College Graduate	Post-Graduate	Vocational High School	Vocational School
Female	Post-Graduate	Post-Graduate	Post-Graduate	High School Graduate	High School Graduate
Employment Status					
Male	Full time	Full time	Full time	Full time	Full time
Female	Full time	Full time	Full time	Full time	None
Employment Type					
Male	Professional	Technical	Professional	Operator	Sales
Female	Professional	Professional	Professional	Clerical	--
Family Income	50,000 +	15,000-19,999	35,000-39,999	20,000-24,999	25,000-29,000

Table 2

Energy-Related Characteristics of the Families in Their Own Homes (Energy Sources and Systems)

Characteristics	Family 1	Family 2	Family 3	Family 4	Family 5
Energy Sources Used to Heat House	Electricity	Oil	Wood (major) Oil Electricity	Gas	Wood (major) Electricity
Heating Systems Used	Forced Air Furnace	Forced Air Furnace	Woodstove Forced Air Furnace Portable Heaters	Forced Air Furnace	Woodstove Forced Air Furnace

<u>Energy conservation indexes</u>. All the families had made some technical and behavioral modifications to save energy (Table 3). The technical modifications were changes made to the house structure or equipment. The technical modifications were divided on the basis of the cost into the categories of major and minor modifications, with the major ones involving a greater outlay of money than the minor ones. The behavioral modifications involved changes in the manner in which the family members used the house or its equipment. The technical (both major and minor) and behavioral modifications can be used as separate indexes of the families' level of energy conserving activity.

When asked what major technical changes had been made to save energy, the family responses fell into two categories--no major changes (Families 1 and 4) and two changes each (Families 2, 3, and 5) (Table 3). Family 2 had added insulation and storm windows/doors. Families 3 and 5 had added a woodstove and storm windows/doors.

The number of minor changes made to save energy ranged from 0 to 6 (Table 3). The items reported most frequently were "weather stripping/ caulking," "reduced wattage of bulbs" and "had the furnace cleaned/ adjusted." The items least frequently mentioned were "insulated water heaters" and "installed flow-restricting showerheads." Family 2 made the most changes (six) followed by Family 4 (five changes), Family 3 (four changes) and Family 1 (three changes). Family 5 reported having made no minor changes to their home to save energy.

When asked what behavioral modifications they had made in the last year to save energy, the responses ranged from one to five (Table 3). The most frequent responses were "lowered thermostat in the winter" and

Table 3

Energy Conservation Indexes
(Modifications Made in Own Home)

Index	Family				
	1	2	3	4	5
Technical Modifications					
Major					
Insulation		X			
Storm Windows/Doors		X	X		X
Woodstove			X		X
Total	0	2	2	0	2
Minor					
Weather Stripping/Caulking	X	X	X	X	
Reduced Wattage of Bulbs	X	X		X	
Furnace Cleaned/Adjusted	X	X		X	
Added Portable Heater		X	X		
Blocked Cracks Under Doors		X	X		
Covered Windows with Plastic			X	X	
Insulated Water Heater				X	
Installed Flow-Rest. Showerheads		X			
Total	3	6	4	5	0
Behavioral Modifications					
Lowered Thermostat in Winter	X	X	X	X	
Closed Window Drapes	X				
Reduced No. of Lights Used		X	X	X	
Used Cold Water Wash/Rinse Clothes Wash		X	X	X	X
Lower Hot Water Thermostat			X	X	
Closed Off Rooms			X		
Total	2	3	5	4	1

"used cold water wash/rinse in clothes washing" followed by "reduced the number of lights used." One family reported that they "closed off rooms." Family 3 had made the most changes in behavior to save energy (five changes) followed by Family 4 (four changes), Family 2 (three changes), Family 1 (two changes), and Family 5 (one change).

Overall, the five families' scores on the three indexes of energy conservation activity level varied, with some families displaying more activities in certain areas. Families 2, 3, and 5 were active in the major technical changes made while Families 2, 3, and 4 were most active in the minor technical modifications as well as in the behavioral changes.

Energy Conservation Attitudes

The respondents in all the five families held similar attitudes toward consumers and energy conservation (Table 4). When responding to statements on the causes of the energy situation, both spouses in all of the five families reported that they believe that wasteful consumption of energy and a society of high energy using consumers have contributed "totally" to the energy problem. Further, all respondents reported that they believe that using less energy in homes throughout the country will make a significant difference in the overall energy situation.

General and Baseline Data on Families While in Garrett House

To provide background for analyzing the results when the energy conservation strategies were used, general and baseline data are presented on the families while they lived in Garrett House. These data include the dates of occupancy, the average daily occupancy rate while living in Garrett House, and the preferred average whole house temperature and energy consumption during the baseline period of the first week.

Table 4

Respondents' Attitudes Toward

Energy Conservation

Question	Answer	
	"Totally"	
	N	%
To what extent does wasteful consumption of energy contribute to the energy problem?	10	100
To what extent is the following statement responsible for the energy problem? USA is a society of high energy consumers.	10	100
	"Yes"	
	N	%
Do you think using less energy in homes throughout the country will make any significant difference in the overall energy situation?	10	100

Dates of Occupancy

The months of the year selected for testing the energy conservation strategies in home heating in Garrett House were November through April. The selection was based on the results of an energy study concerning the normal monthly average temperatures and heating needs of North Carolina (Burby and Marsden, 1980). Families 1 and 4 lived in Garrett House during similar periods from early January to mid-February in 1983 and 1984, respectively, while Families 2 and 5 lived in Garrett House during similar dates from mid-February to early April in 1983 and 1984, respectively (Table 5). Family 3 lived in the test house during the warmest period from early November to mid-December, 1983.

Daily Occupancy Rate

The daily occupancy rate, the average number of hours daily that the house was occupied by at least one family member, was based on the total six-week period of residence by each family. The daily occupancy rate ranged from 14 to 22 hours, or from 54 to 92 percent, and increased with family size. It is noted that for sizes of two, three, and four persons (Families 1, 2, and 3), the daily occupancy rate increased by one hour as the family size increased by one member. However, for the five member families (Families 4 and 5), the daily occupancy rate increased six hours (Family 5) and seven hours (Family 4) over the three member family. The employment and work hours seemed to have influenced the daily occupancy rate as one adult in Family 5 was unemployed and one adult in Family 4 worked third shift and slept through most of the day.

Table 5

General and Baseline Information on Families

While Living in Garrett House

	Families				
	1	2	3	4	5
Date of Occupancy	January-- Mid-Feb 1983	Mid-Feb --April 1983	Nov- Mid-Dec. 1983	January- Mid-Feb. 1984	Mid-Feb --April 1984
Daily Occupancy Rate During Total Time in House (Hours/ percent)	13 hrs 54 %	14 hrs 58 %	15 hrs 63 %	22 hrs 92 %	21 hrs 88 %
Preferred Room Temp. During Baseline (°F)	72.7	70.3	67.9	71.6	72.2
Energy Consumption Per Degree Day (Cu.ft.)	35.6	32.7	5.7	32.1	31.6

Preferred Room Temperature During the Baseline Period

During the baseline period of the first week, the families were instructed to set the thermostat on temperatures found to be comfortable. The temperatures selected by the families to be comfortable ranged from a low of 67.9°F by Family 3 to a high of 72.7°F by Family 1. Families 2, 4, and 5 selected temperatures of 70.3°F, 71.6°F, and 72.2°F, respectively. The range from 67.9 to 72.7°F is more narrow but very similar to the 68 to 74.5°F established by ASHRAE.

Energy Consumption During the Baseline Period

The energy consumption during the baseline period for the five families is reported both by the consumption of natural gas in cubic feet and by the gas consumption controlled for degree day. Except for Family 3, the families used relatively the same level of energy in the baseline period.

Family 3 is dramatically different from the other families in the level of consumption during the baseline period, using only about 20 percent as much gas as the next highest family. The low level of energy consumption by Family 3 during the baseline period is partially a function of the handling of the thermostat by the family, the warm outside temperatures, and the internal heat generation of appliances. The family set the heating thermostat at 55°F and, at times, turned off the heating system while they were away. This was the procedure they used in their own home and, as instructed, used Garrett House as they did their own home. Also, during this baseline period, the heating needs or degree days were low. During this time, the average whole house temperature stayed around 67°F which may have been due to the warm outside temperature as well as to the internal heat generation of appliances. As a result of the combination of these factors the furnace seldom ran during the baseline period.

Selected Family Characteristics as Related to Preferred Room Temperature and Energy Consumption During the Baseline Period

The family characteristics of size, daily occupancy rate, and the scores on the energy indexes were examined in relation to the family's preferred whole house temperature and the level of energy consumption during the baseline period of the experiment. Tables were examined to observe trends that may exist among the variables. A trend was noted if a relationship existed in three of the five family cases.

First, the preferred room temperatures and the energy consumption during the baseline period appear to be positively related. When the preferred temperature and energy consumption of the five families are ranked from low to high, three families occupy the same ranked position on the two variables (Table 6). Family 3 not only selected the lowest preferred room temperature but also used the least amount of energy during the baseline period. Also, Family 1 selected the highest room temperature and used the most energy during the baseline period. Family 4 ranked third in both preferred room temperature and energy consumption.

Although family size and the daily occupancy rate appear to be directly related, the two variables appear not to be related to the energy consumption or preferred room temperatures during the baseline period. Although family size and percentage of time the house is occupied may affect other areas of energy consumption such as hot water demands and use of appliances, these two family variables appear not to be related to energy consumption in space heating.

Table 6

Ranked Comparisons of the Families' Preferred Room Temperature and Energy Consumption During the Baseline Period and Scores on the Three Energy Indexes

Rank	Families (1-5)				
			Energy Indexes		
	Preferred Room Temperature (Baseline)	Energy Consumption (Baseline)	Major Technical Modifications	Minor Technical Modifications	Behavioral Modifications
1 (high)	1	1	2, 3 & 5	2	3
2	5	2	4, 1	4	4
3	4	4		3	2
4	2	5		1	1
5 (low)	3	3		5	5

A relationship does appear to exist among the baseline preferred room temperatures and the scores on two of the energy indexes of the families (Table 6). Families 2, 3, and 4 ranked high in both the minor technical changes and behavioral changes made to save energy and also ranked in the top three positions in terms of lower preferred room temperature during the baseline period.

Results From Using Strategies

The findings for each family when they used the energy conservation strategies are presented in the following areas: (1) environmental conditions of room temperatures and humidity, (2) perceived thermal comfort and clothing worn, and (3) energy consumption of the gas heating system. The data presented in each area are described briefly below.

The environmental conditions reported include the room temperatures and the indoor relative humidity. The room temperatures are presented in several measures: (1) the weekly average whole house temperature which is the average of the daily hourly temperatures for every room in the house. Both the high and the low average whole house temperatures for the week are presented to determine the extent of variations in the temperatures, (2) weekly average room temperatures are reported for the living room and the master bedroom as these two rooms could be affected differently by the use of the strategies, and (3) the weekly whole house temperatures between 7 and 10 p.m. are reported also for Families 4 and 5 because the spouses in these two families reported the daily thermal comfort responses during this time period.

The perceived thermal comfort is presented for both the male and female spouses. A whole house comfort rating ranging from "1" to "7," with "1" being the most comfortable, was obtained when the spouses individually responded in Likert-type questions at the end of the week and rated each room in the house in terms of thermal comfort. The ratings by each spouse for each room were averaged to obtain the spouse's individual score. The scores of each spouse for the living room and the master bedroom were also reported. For Families 4 and 5, daily comfort scores were also reported.

The clothing worn is reported in two ways. For Families 1, 2, and 3, the spouses reported at the end of the week whether or not clothing was added during the use of the particular strategy. For Families 4 and 5, daily clo values for each spouse were obtained which were averaged for a weekly score.

The energy consumption reported is the actual gas consumption of the furnace system adjusted for degree days. In addition, to allow for comparisons across strategies, a percentage savings over the baseline usage is reported.

Before proceeding to the results, explanation is given for the reported instances of missing data. During the first two weeks of Family 1's stay in Garrett House, the humidity sensor malfunctioned and caused a loss of data. The missing data for Family 4 were the comfort ratings for the separate rooms in the house for one week which the respondents did not provide on a questionnaire. In the cases of Families 3 and 5, two weeks of data were not collected due to an undetected instantaneous power failure which caused a loss of the data acquisition program in the computer, and which went undetected for two weeks. This problem of possible data loss caused by a brief power failure was solved by the installation of a battery back-up system for the computer.

Family 1

Environmental conditions. The average room temperature of 72.3°F for the whole house selected during the week that the bedroom vents/doors were closed was almost the same as the 72.7°F selected by the family during the baseline period (Table 7). When the thermostat was set at 65°F, the whole house temperature dropped to 65.3°F, which was the lowest temperature experienced by Family 1 when using the strategies. When the thermostat was set at 65°F and supplemental heat sources were added, the temperature remained around 65°F when only the greenhouse was used (65.8°F), when both the greenhouse and woodstove were used in combination (65.5°F) and when the woodstove alone was used (66.2°F). A graph of the weekly average whole house temperatures also is presented (Figure 5).

Large temperature swings were not observed when any of the strategies were used by Family 1. The average low and the average high temperature differences ranged from 2.2 to 4.2°F.

The average weekly temperatures in the living room and the master bedroom were higher than the whole house temperature throughout the experience of Family 1. When the strategies were used, the two rooms were warmest during the week that the bedroom vents/doors were closed. During the weeks that the thermostat was set at 65°F and during the weeks that the thermostat was set at 65°F with supplemental heat sources available, the temperature ranged from 66.7 to 68.3°F in the living room and

Table 7

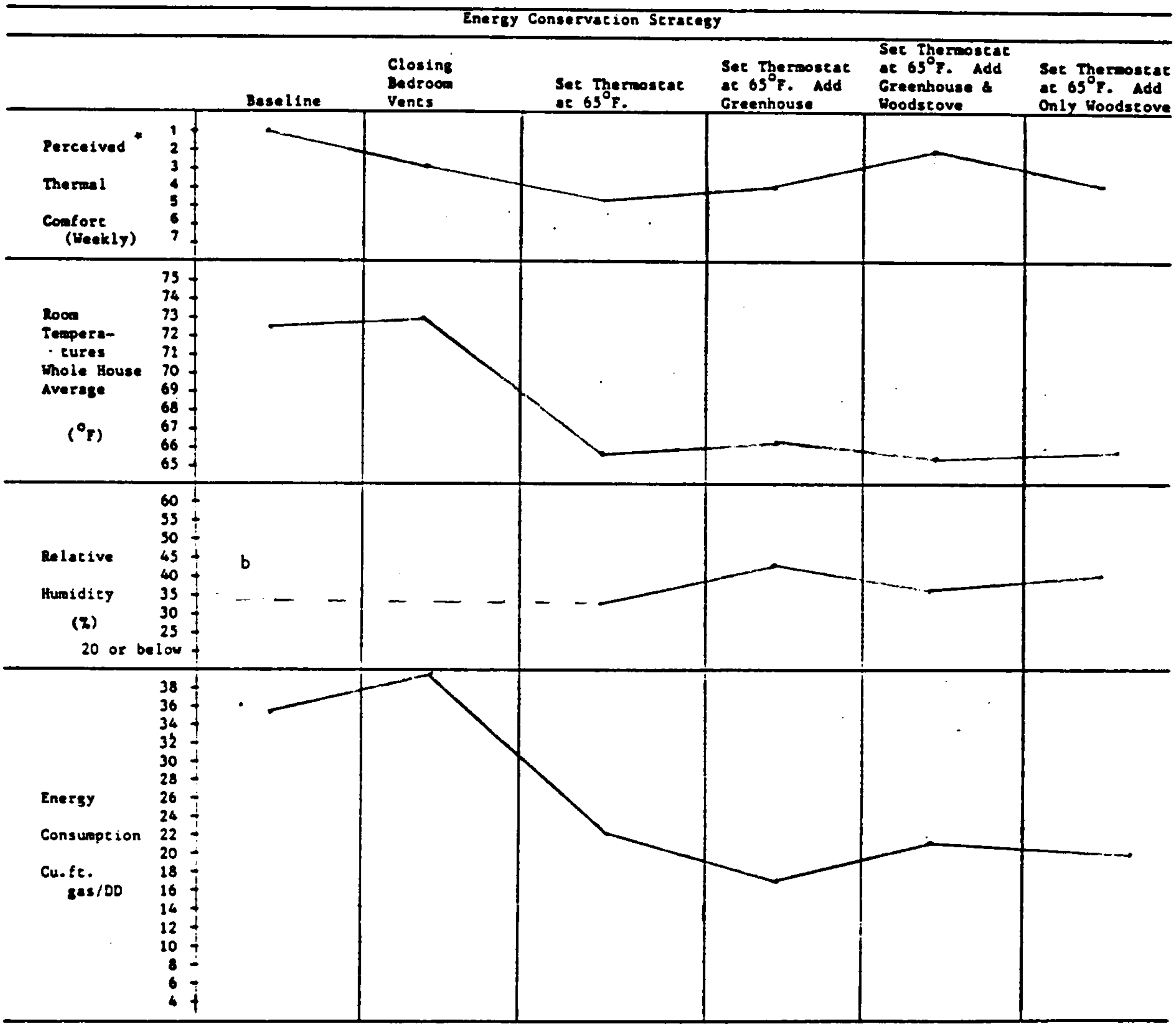
Results from USING STRATEGIES: Room Temperatures, Humidity, Perceived Thermal Comfort, Clothing Worn and Energy Consumption for

FAMILY 1

	Strategies					
	Baseline	Closing Bedroom Vents	Set Thermostat at 65°F	Set Thermostat at 65°F; Add Greenhouse	Set Thermostat Add Greenhouse and Woodstove	Set Thermostat at 65°F; Add Woodstove
Room (°F)						
Temperatures						
Whole House	72.7	72.3	65.3	66.8	65.6	66.2
Low	71.5	70.3	63.4	64.8	64.7	64.7
High	73.6	74.5	67.1	69.0	66.9	67.7
Living Room	74.8	74.7	66.9	67.4	68.0	66.7
Master Bdr.	73.2	73.8	67.0	68.3	66.8	67.2
Relative Humidity (%)	b	b	33.3	46.4	37.1	40.1
Perceived Thermal Comf.[a]						
Whole House						
Male	1	3	5	3.4	3	4
Female	1	3	5	5.6	2.2	4
Living Room						
Male	1	3	6	3	4	4
Female	1	3	6	2	3	2
Master Bdrm						
Male	1	3	7	2	4	4
Female	1	3	5	4	3	4
Clothing		No change	Added Clothing	Added Clothing	Added Clothing	Added Clothing
Energy Consumption Cu.ft.gas/DD	35.6	40.7	23.5	17.2	22.7	20.0
Savings over Baseline		-14%	34%	52%	36%	44%

[a] Comfort scale ranged from 1 - 7, with 1 being the most comfortable.

[b] Data not available due to equipment malfunction.



[a] 1 = high, 7 = low

[b] Dotted line represents missing data due to equipment malfunction.

Figure 5

Results from Using Strategies: Perceived Thermal Comfort, Temperatures, Humidity, and Energy Consumption

Family 1

the master bedroom. The living room was warmest when both the greenhouse and the woodstove were used, and the master bedroom was warmest when the greenhouse alone was used. It is noted that the greenhouse was especially effective during the first week of its usage primarily because of the intense sunshine during that particular week. The relative humidity remained near 50 percent throughout the experiment of Family 1.

Perceived thermal comfort. The male and female adult family members responded similarly to the whole house temperature in terms of perceived thermal comfort. Beginning with a high comfort level of "1" during the baseline period, the reported thermal comfort dropped to "3" during the week when the bedroom vents were closed and the doors were to be kept closed except when occupied. The perceived thermal comfort dropped even further to "5" when the thermostat was set at 65°F. In fact, this was the lowest thermal comfort reported by the family. Greater comfort was reported when the thermostat was kept at 65°F but various supplemental sources of heat were added. The male spouse expressed similar comfort levels during the week of the combined use of the greenhouse and the woodstove and during the week when the greenhouse alone was used as a supplemental heat source. The female spouse reported the greatest comfort level with the whole house temperature when the combination of the woodstove and greenhouse was used (2.2) and her lowest comfort level was for the week when the greenhouse alone was used (5.6).

When the comfort levels of the two individual rooms--the living room and the master bedroom--were examined, it was observed that the couple reported the same level of comfort of "3" for both rooms as for the whole house temperatures when the strategy of closing the bedroom vents/doors was used. However, in the use of the remaining strategies, the expressed thermal comfort with the temperatures in the individual rooms is different from the expressed thermal comfort with the temperatures in the whole house. In the case of the strategy of setting the thermostat at 65°F with no available supplemental heat sources, the respondents reported in three of the four instances less comfort with the temperatures in the individual rooms than with the temperatures of the whole house. In fact, both spouses expressed the lowest comfort level in the living room and the master bedroom when this strategy was used. Also, when the combination of both the greenhouse and the woodstove was used, both spouses reported less comfort with the temperatures in the living room and the master bedroom than with the temperatures for the whole house. On the other hand, the comfort levels were reversed when the greenhouse alone was used as a supplemental heat source in that both spouses expressed higher levels of comfort with the temperatures in both the living room and the master bedroom than with the temperatures for the whole house.

The reactions to the temperatures in terms of perceived thermal comfort presented above can be partially explained by the weather conditions and also by how frequently the woodstove was used. During the week that the greenhouse was used alone as a supplemental heat source, the solar radiation was intense and thus the heat collected by the greenhouse increased the temperatures and comfort levels in both the living room and the master bedroom over that of the whole house temperature. The residents used the greenhouse by opening the double French doors and excitedly reported the warmer temperatures. However, as will be explained in the next section, Family 1 used the woodstove only a few times during the two-week period that the woodstove was available for use.

In terms of clothing worn during the strategies, the couple reported that they both added clothing such as boots and coats when the thermostat was dropped to 65°F and throughout the remainder of the experiment. The actual clo value of the clothing worn is not known as the measurement of the clo value was added later in the experiment.

Energy consumption. To determine the energy savings achieved as a result of using the strategies, the gas usage is reported in cubic feet of gas used per degree day (Table 7). During the baseline period, 35.6 cubic feet of gas was used per degree day. When compared to the baseline period, the greatest energy savings achieved as a result of using the strategies was 52 percent during the week when the thermostat was set at 65°F and the greenhouse was added as a supplemental heat source. The strategy of using the woodstove alone as a supplemental heat source produced the next highest energy savings of 44 percent, followed by 36 percent when both the woodstove and the greenhouse were used and by 34 percent when the thermostat was set at 65°F. During the week that the bedroom vents and doors were closed, more energy was used than during the baseline week for a negative savings of 14 percent.

The negative savings of 14 percent during the week that the bedroom vents and doors were closed is partially explained by the fact that the resident could set the thermostat at any level found to be comfortable. Since the master bedroom overall temperature during the week was actually higher than the master bedroom temperatures during the baseline period, the thermostat may have been set higher by the residents to compensate for the possible coolness in the bedrooms caused by the closed vents.

Although it was expected that less energy would be used when both the greenhouse and woodstove were used, the greatest energy savings occurred when the greenhouse alone was used. This is partially explained by the weather conditions and by the way the family members used the woodstove. During the week that the greenhouse was used, the solar radiation was great due to intense sunshine. The greenhouse temperature during the day stayed around 100°F and this heat was being transferred into the living room and master bedroom by use of a thermostatically controlled fan. During the week of the combined usage of the greenhouse and the woodstove, the greenhouse did not contribute heavily to the heating needs because of the cloudy weather. Also, the woodstove actually was used only three days because about midweek the husband became ill and had to have an emergency intestinal operation. As a result, during the week of the combined usage of the greenhouse and the woodstove, less attention was given to the greenhouse and to the woodstove operation as only one spouse was in the house to monitor the strategies. Also, the woodstove was used two days during the week that the woodstove alone was available for use.

Differences in the use of the woodstove also might be explained by some other characteristics of the family. The woodstove needs attention to obtain the maximum effect of its use, yet neither spouse had ever used a woodstove. Although the couple received a demonstration and instruction, time was needed to develop the experience base from which to get the most heat from the strategy.

Family 2

Environmental conditions. The average whole house temperatures during the week that the bedroom vents/doors were closed remained at

70.4°F which was similar to the 70.3°F selected as comfortable during the baseline period (Table 8). When the thermostat was set at 65°F with no other heat source available, the temperature dropped to 65.3°F. Then when the supplemental heat source of the greenhouse was added, the temperature remained about the same with a reading of 65.7°F. When the woodstove was in use, either alone or in combination with the greenhouse, the temperature remained at 67.8°F. The temperature information is also presented in chart form (Figure 6).

As with Family 1, no great swings in temperatures were observed during the use of the strategies. The difference between the average low and the average high temperatures ranged from 2.5 to 3.9°F.

The weekly average temperatures in the living room and the master bedroom were warmer than the whole house temperature throughout the experience for Family 2. The highest temperatures in both rooms were achieved during the week that the bedroom vents/doors were closed. Next, the living room and the master bedroom were warmest when both the greenhouse and the woodstove were used in combination. The coolest temperatures were experienced during the week that the thermostat was set at 65°F. The relative humidity ranged from 38 to 67 percent throughout the experience of Family 2.

<u>Perceived thermal comfort</u>. The two adult respondents reported similar scores of perceived thermal comfort when the various energy conservation strategies were employed. Both found the highest level of comfort when the bedroom vents/doors were closed with a score of "2" for the male and "1" for the female (Table 8). Both registered their lowest comfort score, a score of "4," when the thermostat was dropped to 65°F. Both respondents reported scores from "3" to "3.8" for the

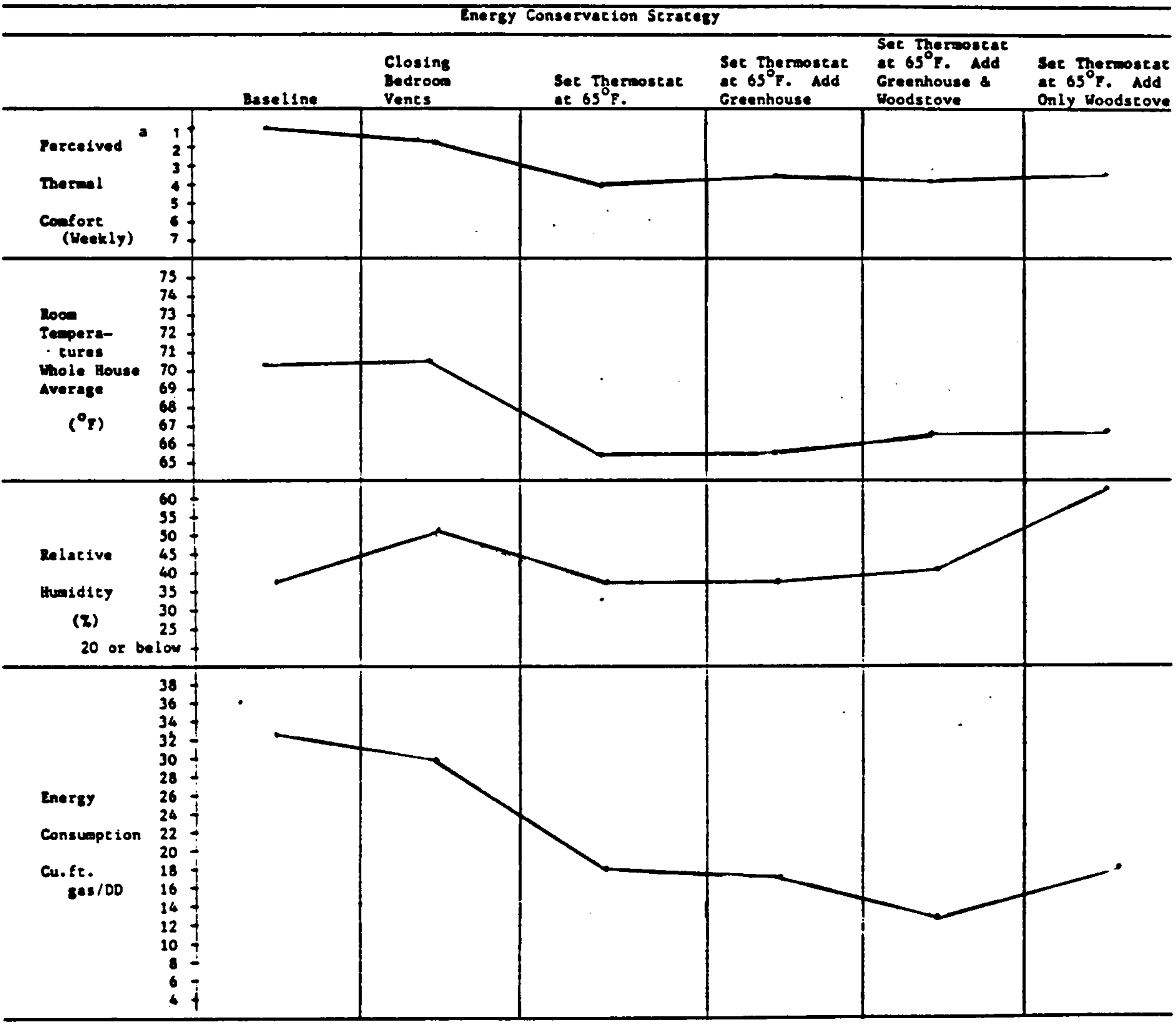
Table 8

Results from USING STRATEGIES: Room Temperatures, Humidity, Perceived Thermal Comfort, Clothing Worn and Energy Consumption For

FAMILY 2

		Strategies				
	Baseline	Closing Bedroom Vents	Set Thermostat at 65°F	Set Thermostat at 65°F; Add Greenhouse	Set Thermostat Add Greenhouse and Woodstove	Set Thermostat at 65°F; Add Woodstove
Room Temperatures(°F)						
Whole House	70.3	70.4	65.3	65.7	67.8	67.8
Low	71.1	69.1	64.0	64.0	66.4	67.0
High	72.5	71.6	66.8	67.1	70.3	70.1
Living Room	71.7	70.5	65.8	66.4	70.1	67.9
Master Bedroom	72.1	71.4	66.1	66.4	69.8	68.4
Relative Humidity (%)	38.1	52.8	35.3	36.0	40.3	67.7
Perceived Thermal Comfort[a]						
Whole House						
Male	1	2	4	3.3	3.8	3.1
Female	1	1	4	3	3.8	3.5
Living Room						
Male	1	2	4	3	3	1
Female	1	1	4	3	4	1
Master Bedroom						
Male	1	2	4	3	3	4
Female	1	1	4	3	4	4
Clothing		No change	Added Clothing	Added Clothing	Added Clothing	Added Clothing
Energy Consumption						
Cu.ft.gas/DD	32.7	30.9	18.6	17.4	13.8	18.5
Savings over Baseline		6%	43%	47%	58%	43%

[a] Comfort scale ranged from 1 - 7, with 1 being the most comfortable.



ᵃ1=high, 7=low.

Figure 6

Results from Using Strategies: Perceived Thermal Comfort, Temperatures, Humidity, and Energy Consumption

Family 2

strategies that added supplemental heat--the greenhouse alone, a combination of both the greenhouse and the woodstove, and the woodstove alone.

When the thermal comfort responses to the living room and the master bedroom temperatures were examined, it was noted that although the temperatures in the master bedroom dropped slightly from the baseline during the week that the bedroom vents/doors were closed, the couple reported no loss in thermal comfort. When the greenhouse was in use either alone or with the woodstove, the master bedroom comfort level improved for the male spouse. The master bedroom comfort was higher for the female spouse when the greenhouse alone was available as a supplemental heat source. When the greenhouse was no longer available for use, the comfort in the master bedroom for both respondents dropped. Also, when the woodstove was used alone as a heat source, the couple reported a rise in the comfort level for the living room.

The clothing worn during the use of the strategies is described by the clothing items added when the thermostat was set at 65°F and also when the supplemental heat sources were used. The exact clo value of the added items is not known as the collection of this data was added later in the research project.

Energy consumption. The average energy consumption during the baseline period was 32.7 cubic feet of gas per degree day (Table 8). Using the baseline period as a comparison, an energy savings of six percent occurred when the strategy of closing the bedroom doors and vents was used. When the thermostat was set at 65°F and when the woodstove alone was used, a savings of 43 percent occurred in each instance. A saving of 47 percent was achieved with the use of the greenhouse. The largest energy savings of 58 percent occurred with the combined use of the greenhouse and the woodstove.

An analysis of the activities of Family 2 confirms that the woodstove was in full use during the two weeks that it was used as a supplemental heat source. The greenhouse was particularly helpful as a heat source during the two weeks that it was in use because of the intense sunlight available at the time.

Family 3.

Environmental conditions. During the experience of Family 3, the whole house temperatures remained in a narrow range varying from 67.4 to 70.1°F (Table 9) (Figure 7). The temperature was lowest when the thermostat was set at 65°F (67.4°F) with no supplemental heat sources available and highest during the use of the strategy in which the thermostat was set at 65°F with the greenhouse available as the only supplemental heat source (70.1°F). Temperature swings were noticed especially during the week that the thermostat was set 65°F and the greenhouse was the only available supplemental heat source. That week a difference of 10°F occurred between the low whole house average temperature and the high whole house average temperature. During the other strategies on which data are available, the temperature difference between the low and high average whole house temperatures are only 4.0 and 4.1°F. It is noted that the temperatures in the master bedroom and the living room during the strategy of the greenhouse usage increased over the temperatures that resulted when the other strategies were used. Also, the relative humidity remained around 50 percent throughout the experiment for Family 3.

Table 9

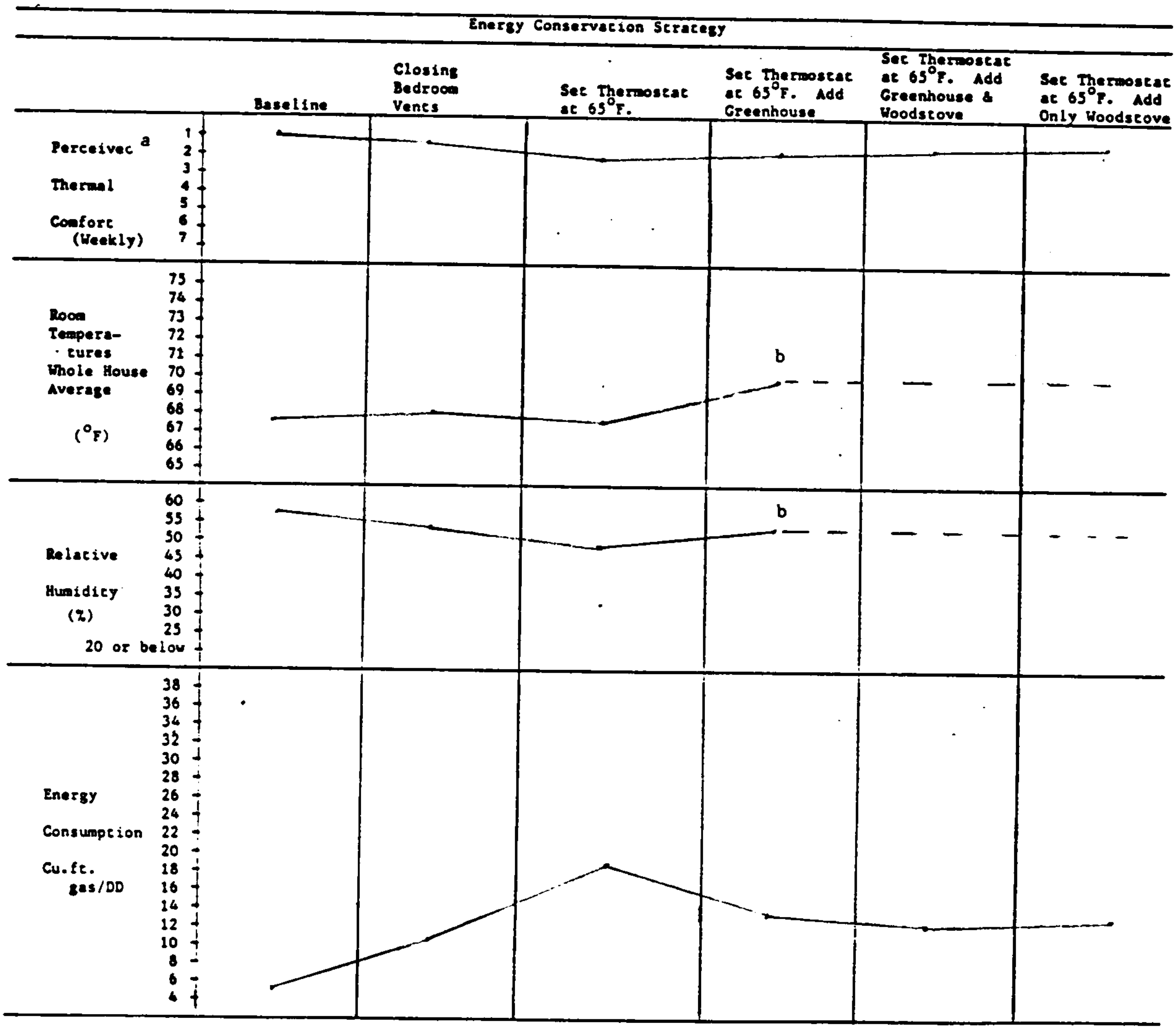
Results from USING STRATEGIES: Room Temperatures, Humidity, Perceived Thermal Comfort, Clothing Worn and Energy Consumption For

FAMILY 3

	Strategies					
	Baseline	Closing Bedroom Vents	Set Thermostat at 65°F	Set Thermostat at 65°F; Add Greenhouse	Set Thermostat Add Greenhouse and Woodstove	Set Thermostat at 65°F; Add Woodstove
Room Temperatures(°F)						
Whole House	67.9	68.6	67.4	70.1	—[b]	—[b]
Low	68.9	66.7	65.2	62.8	—	—
High	70.1	70.7	69.3	73.51	—	—
Living Room	67.8	69.1	68.8	71.3	—	—
Master Bedroom	69.4	69.4	67.4	69.7	—	—
Relative Humidity (%)	58.9	56.7	47.5	54.5	—[b]	—[b]
Perceived Thermal Confort[a]						
Whole House						
Male	1	1	2.9	2	1.9	1.9
Female	1	1.5	2.3	2	1.8	1.9
Living Room						
Male	1	1	3	2	1	2
Female	1	1	b	2	2	2
Master Bedroom						
Male	1	1	3	2	2	2
Female	1	2	2	2	2	2
Clothing		Added Clothing	Added Clothing	No change	No change	No change
Energy Consumption						
Cu.ft.gas/DD	5.7	10.6	19.8	13.3	12.5	12.2
Savings over Baseline		-86%	-247%	-133%	119%	-114%

[a] Comfort scale ranged from 1 - 7, with 1 being the most comfortable.

[b] Data not available due to power failure.



[a] 1 = high, 7 = low

[b] Dotted lines represent missing data due to power failure.

Figure 7

Results from Using Strategies: Perceived Thermal Comfort, Temperatures, Humidity, and Energy Consumption

Family 3

Perceived thermal comfort. The perceived thermal comfort of the two respondents for the whole house temperature stayed in the narrow range from "1" to "2.9" on the seven point comfort scale. The highest rating of comfort reported occurred during the strategy when the bedroom vents and doors were closed. The next highest comfort was reported for the strategy that combined the use of the woodstove and the greenhouse and also for the strategy that used the woodstove alone as the only supplemental heat source. Both of these latter two strategies received an overall rating by both spouses of "1.9." The third highest in terms of perceived thermal comfort was the strategy that used the greenhouse alone as a supplemental heat source. The least thermal comfort was expressed during the week that the thermostat was set at 65°F with no supplemental heat source available. Although there were differences in the comfort ratings of the respondents, it is important to realize that the range of differences was "1" to "2.9" on the seven point scale--the couple remained quite comfortable throughout the experiment. Also, it is noted that both spouses reported a high level of "1" in perceived thermal comfort for the living room during the week that the combination of both the greenhouse and woodstove was employed.

Both spouses reported that clothing was added during the week that the strategies of closing the bedroom vents/doors and setting the thermostat at 65°F were used. They reported no additional clothing was added during the last three strategies. The actual clo value of the added clothing items is not known as the measurement of clo value was added later in the experiment.

Energy consumption. The energy consumption pattern of Family 3 requires special explanation. The energy used during the baseline period was less than the energy used during the remaining weeks when the energy conservation strategies were being tested. This is partially explained by the thermostat settings of 55°F by the family in the baseline period and by the fact that they were accustomed to lower temperatures in their own home than experienced in Garrett House. Thus, when analyzing their energy consumption pattern in terms of percentage savings, the percentage is a negative figure. However, the strategies can be analyzed to determine which ones used the least energy per degree day.

The strategy that used the least energy, 10.6 cubic feet per degree day, was closing the bedroom vents and doors. The strategy that used the most energy, 19.8 cubic feet of gas per degree day, was setting the thermostat at 65°F. The remaining strategies produced savings in the following order: use of the woodstove as the only supplemental heat source (12.2 cubic feet of gas per degree day), combined use of the woodstove and the greenhouse (12.5 cubic feet of gas per degree day), and the use of the greenhouse only as a supplemental heat source (13.3 cubic feet of gas per degree day).

In analyzing why closing the bedroom vents/doors would save the most energy, again it is related to temperature selection by the family. During this particular week as well as during the baseline week, the family was instructed to set the thermostat where they found it to be comfortable. They selected the 55°F setting during this week which would produce greater savings than when the thermostat was set at 65°F during the remaining treatment weeks.

Family 4

Environmental conditions. During the week that the bedroom vents/ doors were closed and when the family was allowed to set the thermostat, the family selected a temperature of 72°F for the average whole house temperature, which was slightly higher than the 71.6°F selected during the baseline period (Table 10) (Figure 8). The highest average whole house room temperature of 73.3°F was experienced with the strategy using a combination of the greenhouse and the woodstove. The temperature was 72.2°F when the greenhouse was used alone as a supplemental heat source. The lowest temperatures resulted when the thermostat was set at 65°F (67.6°F) with no supplemental heat source available and when the woodstove only was used (67.5°F). The average low and average high whole house temperatures ranged from 4.1 to 5.9°F. The relative humidity ranged from 35.4 to 51.0 percent throughout the experiment with Family 4.

The average temperatures in the living room and the master bedroom were warmer than the average whole house temperatures during the use of all the strategies except for the week when the thermostat was set at 65°F and the greenhouse alone was available as a supplemental heat source (the temperature dropped about 0.5°F).

During the week that the greenhouse alone was used as a supplemental heat source, the cloudy weather limited the amount of heat available from the greenhouse. During the week that the greenhouse was used in combination with the woodstove, the more intense sunlight contributed to the warmest room temperatures experienced in the master bedroom.

The average whole house temperature from 7 to 10 p.m. is reported because additional comfort scores are linked to this time period. In

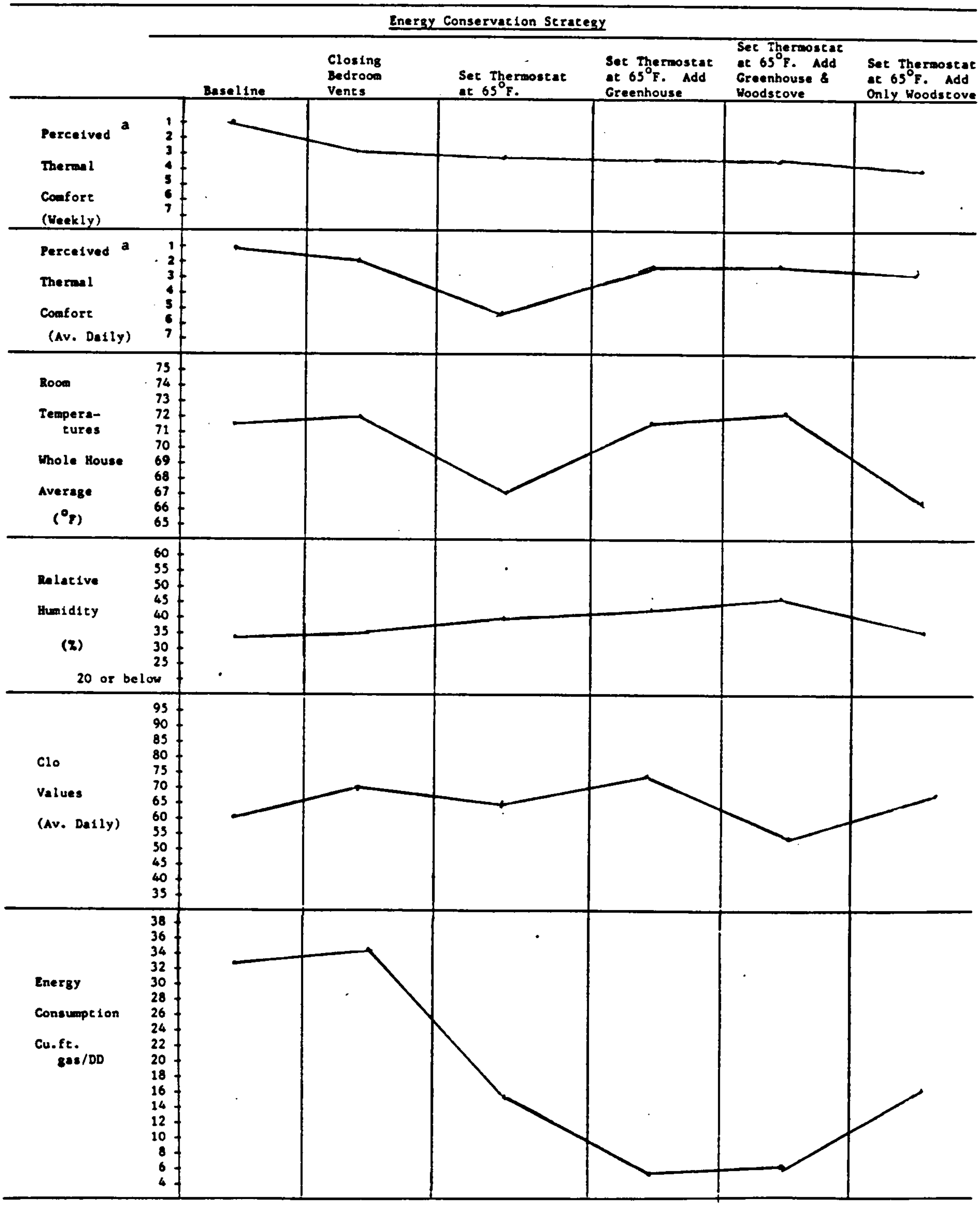
Table 10

Results From USING STRATEGIES: Room Temperatures, Humidity, Perceived Thermal Comfort, Clothing Worn and Energy Consumption For FAMILY 4

	Strategies					
	Baseline	Closing Bedroom Vents	Set Thermostat at 65°F	Set Thermostat at 65°F; Add Greenhouse	Set Thermostat Add Greenhouse and Woodstove	Set Thermostat at 65°F; Add Woodstove
Room Temperatures(°F)						
Whole House	71.6	72.1	67.6	72.2	73.3	67.5
Low	68.9	69.4	65.7	69.2	70.2	65.7
High	75.5	75.1	69.8	75.1	75.8	71.4
Living Room	73.1	73.0	66.8	71.7	72.3	70.3
Master Bedroom	73.1	73.5	68.9	71.6	74.8	69.2
Whole Hs.7-10p.m	73.3	74.4	68.5	73.6	74.7	69.9
Relative Humidity (%)	34.1	35.4	40.6	43.9	51.0	36.8
Perceived Thermal Comfort[a]						
Whole House						
Male	1	2.7	2.9	4.6	3.6	4.0
Female	1	3.3	4.9	2.7	2.9	4.0
Living Room						
Male	1	2	3	4	3	—[b]
Female	1	1	5	2	1	—
Master Bedroom						
Male	1	3	2	4	3	—
Female	1	3	5	3	3	—
Daily Score						
Male	1	4	5	2.3	3	4
Female	1	1.3	5.7	1.4	1	1.6
Clo Values						
Male	0.71	0.91	0.72	0.72	0.46	0.75
Female	0.65	0.58	0.63	0.82	0.56	0.63
Energy Consumption						
Cu.ft.gas/DD	32.1	34.1	15.4	5.1	5.8	16.0
Savings over Baseline		-5.6%	52%	84%	82%	50.0%

[a] Comfort scale ranged from 1 - 7, with 1 being the most comfortable.

[b] Data not available.



^{a}1 = high, 7 = low

Figure 8

Results from Using Strategies: Perceived Thermal Comfort,

Temperatures, Humidity, and Energy Consumption

Family 4

all strategies, the average room temperature between 7 and 10 p.m. was warmer than the average whole house temperature. The difference ranged from 0.9°F during the week when the thermostat was set at 65°F to 2.4° when the woodstove alone was used as a supplemental heat source.

Perceived thermal comfort. The perceived thermal comfort, reported for the average whole house temperature by the two respondents in Family 4, during the entire experience ranged from "1" (high) to "4.9" (low) on the seven-point comfort scale (Table 10) (Figure 5). The male spouse reported the highest thermal comfort with the whole house temperature during the use of the strategy that closed the bedroom vents and doors, while the female spouse reported her highest thermal comfort rating during the week that the greenhouse was the only available supplemental heat source. The male spouse reported his lowest comfort rating during the week when only the greenhouse was used as a supplemental heat source while the female reported her least comfort during the week that the thermostat was set at 65°F.

When the comfort ratings for the living room and for the master bedroom were examined, it was observed that both spouses found the master bedroom to be slightly more comfortable than the whole house temperature when the greenhouse was used as a supplemental heat source, as the extra heat being blown into the master bedroom added to the comfort of the room. Also, when the woodstove was used, the living room received higher ratings than the whole house temperatures.

Additional perceived thermal comfort ratings were secured on a daily basis from the adult members of Family 4 The daily comfort ratings were completed during the hours of 7 to 10 p.m.; therefore, the temperatures on which the daily evaluations were based on the whole house temperatures from 7 to 10 p.m., which were slightly warmer than the whole house temperatures for a complete day.

The male spouse reported less thermal comfort using the strategies during this period from 7 to 10 p.m. than did the female spouse. Both spouses reported the least thermal comfort when the thermostat was set at 65°F. The female reported a high level of comfort during this 7 to 10 p.m. period under all the other strategies.

In analyzing the perceived thermal comfort of the adult family members when using the strategies, the daily comfort scores, the whole house temperature from 7 to 10 p.m. and the clothing worn were examined. During the use of the strategies that closed the bedroom vents/doors, the strategy that used the greenhouse alone and the strategy that used a combination of the greenhouse and the woodstove, the whole house temperatures from 7 to 10 p.m. ranged from 73.3 to 74.7°F. During this time, the female spouse reported a daily level of comfort ranging from "1" to "1.4" with clothing worn on a range from 0.58 to 0.82 clo. The male spouse reported a comfort level of "2.3" to "4" with a clo value ranging from 0.46 to 0.91.

With the two remaining strategies, the setting of the thermostat at 65°F and using the woodstove as the only supplemental heat source, the whole house temperatures from 7 to 10 p.m. were 68.5°F and 69.9°F respectively. These were the lowest temperatures experienced by the family while living in the house. The male spouse reported his least comfort, a score of "5" and a clo value of 0.72 when the thermostat was set at 65°F. Also, the male reported a low comfort score of "4" and a clo value of 0.72 when the woodstove was the only supplemental heat source. The female spouse reported scores similar to the male during the week that the thermostat was set at 65°F--her lowest comfort score of "5.7" and a clo value of 0.63. For the week that the woodstove was the only supplemental heat source, she reported a comfort score of "1,6" and a clo value of 0.63.

A summary analysis of the daily perceived thermal comfort is that the adult respondents found the temperatures from 68.5°F to 74.7°F to be comfortable with less clothing than anticipated from the predictions of the ASHRAE Standards. The ASHRAE Standard research reported that 80 percent of the people were comfortable with clo values around 0.90 between the temperatures of 68 to 72°F. The higher temperatures during three strategies may help explain why these respondents were comfortable with less clothing. But the family reported comfort with the same basic clothing during the weeks that the temperatures remained just below 68°F.

Energy consumption. The greatest energy savings occurred when the greenhouse only was used which produced an 84 percent savings over the baseline week. The strategy of setting the thermostat at 65°F and the use of the woodstove only produced energy savings of 52 percent and 50 percent, respectively. During the week the strategy of closing the bedroom vents/doors was used, actually more energy was used for a negative savings of 5.6 percent. The outdoor temperatures were higher that week so the resident may have turned up the thermostat to offset the temperature deficit in the bedrooms.

Family 5

Environmental conditions. During the weeks for which the temperature data were available, the average whole house temperature ranged from 71.8 to 71.9°F (Table 11)(Figure 9). The lowest temperature of 71.8°F was

Table 11

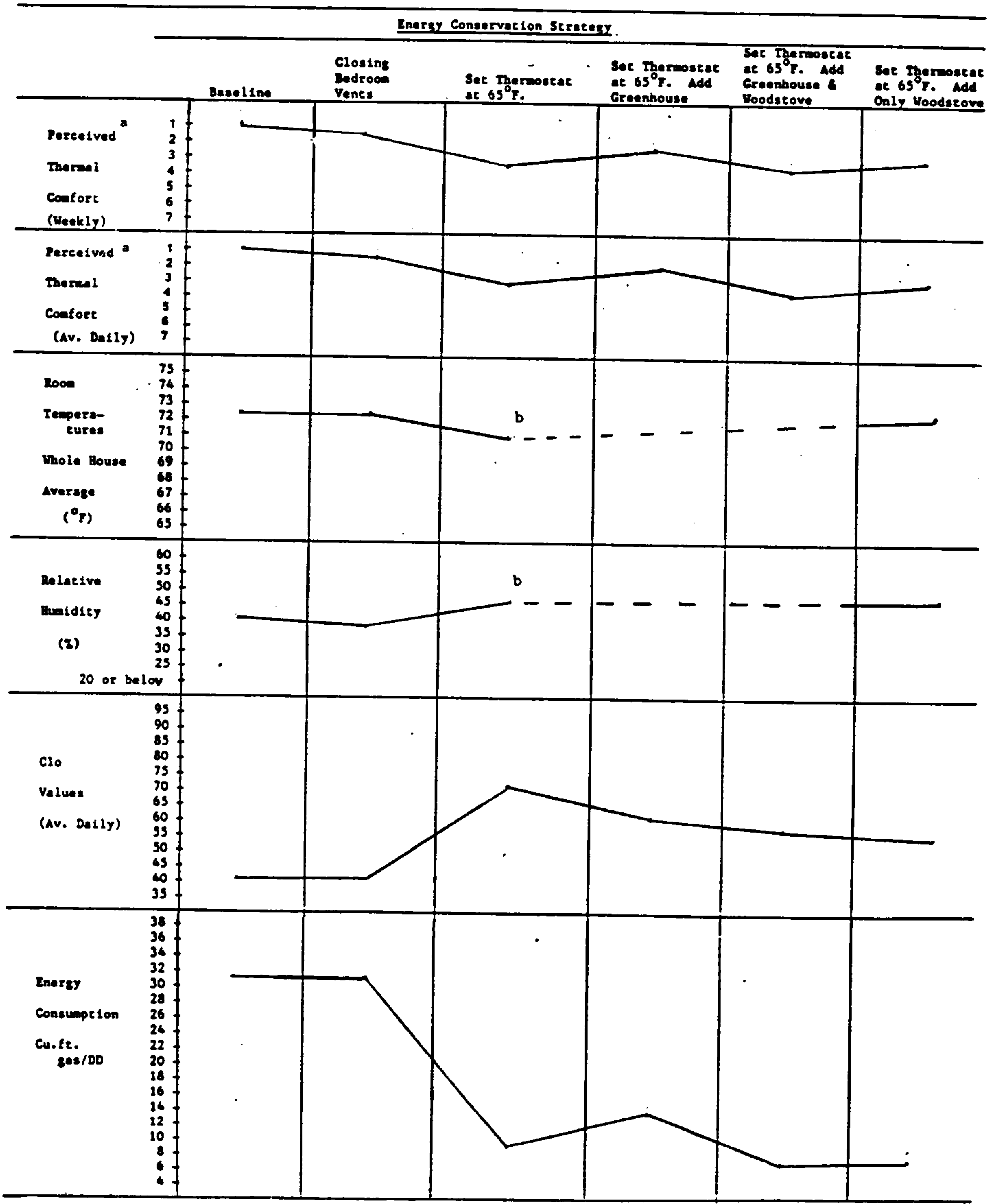
Results from USING STRATEGIES: Room Temperatures, Humidity, Perceived Thermal Comfort, Clothing Worn and Energy Consumption For

FAMILY 5

	Baseline	Closing Bedroom Vents	Set Thermostat at 65 F	Set Thermostat at 65°F; Add Greenhouse	Set Thermostat Add Greenhouse and Woodstove	Set Thermostat at 65°F; Add Woodstove
Room Temperatures(°F)						
Whole House	72.2	72.4	71.8	—[b]	—[b]	72.9
Low	69.4	72.2	70.4	—	—	70.8
High	75.5	77.0	73.3	—	—	75.9
Living Room	72.7	72.6	69.2	—	—	71.5
Master Bedroom	73.3	73.9	72.3	—	—	73.0
Whole Hs.7-10p.m	73.7	76.2	71.1	—	—	72.8
Relative Humidity (%)	40.0	34.5	53.0	—[b]	—[b]	54.6
Perceived Thermal Comfort[a]						
Whole House						
Male	1	1.3	3.8	1.6	4.4	4.1
Female	1	1.3	5.1	3.1	4.3	3.8
Living Room						
Male	1	1	4	1	2	2
Female	1	1	5	2	1	1
Master Bedroom						
Male	1	1	3	2	5	4
Female	1	1	4	3.5	5	3
Daily Score						
Male	1	1	2.4	2.0	1.3	2.5
Female	1	1	2.3	2.0	1	1.8
Clo Values						
Male	0.41	0.40	0.79	0.55	0.57	0.53
Female	0.38	0.41	0.65	0.70	0.63	0.55
Energy Consumption						
Cu.ft.gas/DD	31.6	31.2	8.2	14.0	5.5	7.2
Savings over Baseline		1%	74%	56%	83%	77%

[a] Comfort scale ranged from 1 - 7, with 1 being the most comfortable.

[b] Data not available due to power failure.



[a] 1 = high, 7 = low

[b] Dotted lines represent missing data due to power failure.

Figure 9

Results from Using Strategies: Perceived Thermal Comfort, Temperatures, Humidity, and Energy Consumption

Family 5

experienced when the thermostat was set at 65°F with no available heat sources while the highest temperature occured during the strategy when the thermostat was set at 65°F and the woodstove was available as a supplemental heat source. The average low temperature and average high temperature ranged from 2.9 to 5.1°F. The relative humidity remained in the range of 34.5 to 54.6 percent throughout the experiment with Family 5.

When the average temperatures of the living room and the master bedroom were examined in relation to the whole house temperatures, it was observed that the average temperatures in the master bedroom ranged from 72.3 to 73.9°F and in all strategies were higher than the average temperatures in the whole house throughout the experiment for Family 5. However, in two of the three strategies for which temperature data were available, the living room temperatures were cooler than the whole house temperatures. When the strategy of setting the thermostat at 65°F with no supplemental heat sources available was used, the living room temperature was 69.2°F as compared with the average whole house temperature of 71.8°F. When the thermostat was set at 65°F and the woodstove was used, the average living room temperature was 71.5°F as compared with the average whole house temperature of 72.9°F.

Differences were found when the average whole house temperatures were compared with the average whole house temperatures in the specific time period from 7 to 10 p.m. In the strategy when the bedroom vents/doors were closed, the average whole house temperature in the 7 to 10 p.m. time segment was higher than the average whole house temperature by 3.8°F. Under the remaining two strategies--the setting of the therstat at 65°F with no supplemental heat sources available and during the strategy of setting the thermostat at 65°F with the woodstove available as a supplemental heat source--the temperature differences between the whole house temperature and the whole house temperature in the time period from 7-10 p.m. were relatively the same with only a difference of .7°F and .1°F.

Perceived thermal comfort. Both spouses reported the highest level of thermal comfort with the whole house temperatures during the week that the bedroom vents/doors were closed, with "1.3" on the seven point scale. Next in terms of thermal comfort was the strategy with the greenhouse as the only source of supplemental heat with "1.6" and "3.1" levels of comfort for the male and female, respectively.

The highest thermal comfort of "1" for the living room and master bedroom was expressed for the strategy of closing the bedroom vents/doors. The lowest thermal comfort in the living room was reported when the thermostat was set at 65°F with no supplemental heat sources available. Both the husband and wife expressed the greatest loss of thermal of comfort in the master bedroom during the strategy that combined the use of the greenhouse and the woodstove.

Additional perceived thermal comfort ratings were secured from Family 5 on a daily basis between the hours of 7 and 10 p.m. The whole house temperature from 7 to 10 p.m. was warmer than the whole house temperature for the complete day both during the baseline week and when the strategies were employed.

Both spouses reported high levels of comfort during all the strategies during the 7 to 10 p.m. period. The comfort range was from "1" to "2.5" on the seven-point comfort rating scale. During this 7-10 p.m. time period, both spouses reported the greatest thermal comfort during the strategies that used a combination of the woodstove and the greenhouse as supplemental heat sources. The male expressed the greatest loss of comfort with the strategy of using the woodstove only while the female spouse reported the greatest comfort loss during the week that the thermostat was set at 65°F. It is important to note that little difference was shown in the rating given to the strategies by respondents in Family 5.

The analysis of the perceived thermal comfort of the adult family members when using the strategies includes the daily comfort scores, the clothing worn, and the whole house temperatures when the forms were completed. Due to the lack of available data from power failure as previously described, the analysis will not include these last two strategies of the greenhouse alone as a supplemental heat source and the combined use of the greenhouse and the woodstove.

When the strategy of closing the bedroom vents/doors was employed, the whole house temperature during the 7 to 10 p.m. period was 76.2°F, the highest temperature level achieved during the use of the strategies. Both spouses reported a comfort level of "1" and wore clothing having clo values of 0.40 and 0.41.

When the thermostat setting was dropped to 65°F, the perceived thermal comfort of the male spouse dropped to "2.4" and the clothing worn had a clo value of 0.79. Also, the perceived thermal comfort to the female spouse dropped to "2.3" with the clothing worn having a clo value of 0.65. During this time, the temperature of the whole house between 7 and 10 p.m. was 71.1°F.

During the week that the woodstove was the only supplemental heat source, the average whole house temperature between 7 and 10 p.m. was 72.8°F. The male spouse expressed a comfort rating of "2.5" which was almost the same as for the strategy in which the thermostat was set at

65°F, while the female expressed a comfort level of "1.8." The clo values of the clothing worn by the male and female were 0.53 and 0.55, respectively.

A summary analysis of the daily perceived thermal comfort of Family 5 is that high levels of thermal comfort were reported by the respondents for the temperatures produced by the strategies ranging from 71.1 to 76.2°F. This was expected as predicted by the ASHRAE Standards. The noticeable difference is that clo value of the clothing worn by the respondents was less than expected from the ASHRAE Standards.

Energy consumption. The greatest energy savings occurred when the combination of the woodstove and greenhouse were used together, which produced an energy savings of 83 percent over the baseline period. The strategies of using the woodstove alone as a supplemental heat source and the strategy of setting the thermostat at 65°F produced energy savings of 77 percent and 74 percent, respectively. The least energy savings occurred with the strategy of closing the bedroom vents/doors which produced a savings of one percent.

Perceptions of Thermal Comfort, Personal Control, Personal Effort, and Energy Savings

Following their experience in Garrett House, the spouses in the five families were asked to rank the energy conservation strategies according to the thermal comfort, personal control over the temperatures, and personal effort involved. Composite rankings of the ten responses appear in Table 12 along with rankings of the energy savings and room temperatures achieved during each strategy. The data were used to examine the relationship between the perceived thermal comfort and

Table 12

Rankings of Energy Conservation Strategies:

(1) Perceived Thermal Comfort, Personal Control and Personal Effort by Participants and

(2) Actual Energy Savings and Resulting Room Temperatures

Rank	Rankings by Family Participants			Rankings of Computer Data	
	Perceived Thermal Comfort	Personal Control	Personal Effort	Energy Savings	Resulting Room Temperatures (Whole Hs.Av.)
1(High)	Comb.	Comb.	Comb.	Comb.	CLRB
2	WDST.	WDST	WDST	GH	GH
3	CLBR	CLBR	GH	WDST	COMB
4	GH	GH	CLBR	65°F	65°F
5 (Low)	65°F	65°F	65°F	CLRB	WDST

Key: Comb. = Combination of Woodstove and Greenhouse
WDST = Woodstove Only
CLBR = Closing off Bedroom Vents/Doors
GH = Greenhouse Only
65°F = Setting of Thermostat at 65°G

personal control as well as to determine if a sacrifice in thermal comfort was necessary to achieve greater energy savings.

A parallel appears to exist between the level of personal control and the level of perceived thermal comfort as reported by the subjects after their experience in Garrett House (Table 11). The ranking of the personal control by the ten participants appears to have had more influence on the perceived thermal comfort than the actual whole house temperatures achieved when the strategies were employed. The ranked order of the temperatures does not parallel the ranked order of perceived thermal comfort. The psychological factor of personal control appears to impact strongly on the perceived thermal comfort of the participants. The personal control variable may be impacting not only on the thermal comfort but also may be involved in explaining why Family 4 and Family 5 reported high levels of comfort in the range of temperatures recommended by the ASHRAE Standard but the families did so with clothing of less insulative value.

For this experiment, it appears that a loss of perceived thermal comfort was not required to save energy. In fact, a high level of comfort was expressed when the strategies that contributed to the highest savings were used. Of the three strategies that produced the most energy savings, only the greenhouse required a loss in comfort while the use of the woodstove either alone or in combination with the greenhouse achieved a higher ranking of comfort and energy savings.

Beyond the top position of the combined use of the woodstove and the greenhouse which yielded both the most thermal comfort and the greatest energy savings, little agreement exists between the resulting thermal comfort and the amount of energy saved from using a given strategy. Two strategies produced more comfort than energy savings--the woodstove only and closing the bedroom vents/doors. The other two strategies, the greenhouse and the setting of the thermostat at 65°F, ranked higher in energy savings than in perceived thermal comfort. It does appear, however, that a trade-off in personal effort versus thermal comfort is needed to assure energy savings when using the strategies tested in this investigation.

Impact of the Difference Between Preferred and Actual Room Temperatures on Thermal Comfort

A psychological variable included in the conceptual framework for this study is the temperature norm or preferred temperature of the family. This norm is represented by the whole house temperature during the baseline period of the first week in the experiment when the residents were instructed to set the thermostat at a point found to be comfortable. According to the normative deficit theory of Morris and Winter (1978), the greater the difference between the preferred and actual conditions, the greater the dissatisfaction. In the case of perceived thermal comfort, which is assumed to be a measure of satisfaction with the thermal environment, a person would be expected to express a higher level of discomfort as the difference between the desired and actual conditions increases.

The data used in this analysis of the relationship between the temperature deficit and the thermal comfort are presented in Table 13. The temperature deficit was obtained from the difference between the baseline temperature (norm) and the temperature of the strategy that produced the lowest temperatures (the strategy of setting the thermostat at 65°F with no supplemental heat sources available). The

Table 13

Comparison of Room Temperature

Deficit and Perceived Thermal Comfort

Ranking of Temperature Deficit		Room Temperatures Deficit (°F)[a]	Av. of Spouses Weekly Ratings of Perceived Thermal Comfort[b]
1 (High)	Family 1	7.4	5
2	Family 2	5.0	4
3	Family 4	3.7	3.6
4	Family 3	0.5	2.6
5	Family 5	0.3	4.4

[a] Difference between baseline temperature and lowest temperature experienced in Garrett House.

[b] Scores ranged from 1 (high) to 7 (low).

perceived thermal comfort was obtained by averaging the responses of the spouses in each family to the weekly rating of each strategy obtained immediately after the use of the strategy.

The conclusion is that the temperature deficit between the preferred and the achieved actual whole house temperature does appear to be related to the perceived thermal comfort ratings given by the ten participants. In four of the five families (Families 1, 2, 4 and 3, in that order), as the temperature deficit decreased, the perceived thermal comfort also decreased. Thus the data do not disagree with Morris and Winter's deficit theory. These findings would suggest that if families do decide to save energy by decreasing the temperature in their homes, it would be better for them to gradually change over time to allow for adjustment to the deficit temperatures.

Similarity Between Anticipated and Actually Experienced Thermal Comfort

To assess how accurately persons can predict the achieved thermal comfort of a given energy conservation strategy, the participants' rankings of thermal comfort of the strategies both before and after the experience were compared. The rankings by the ten participants used in this analysis appear in Table 14.

Six (60 percent) of the ten respondents were accurate in their projected anticipated thermal comfort and then actually experienced thermal comfort that resulted from using the strategies. This ability to accurately assess the thermal comfort was evenly balanced between the males and the females with three persons in each category. In four of the five families participating in the project, there was agreement between the male and female spouses on the final rankings of thermal comfort achieved when using the strategies.

Table 14

Similarity Between Participants' Rankings of Thermal Comfort Anticipated and Actually Experienced

Family	Rankings		
	Similar of Before/After		Similar Actually Experienced Comfort of Spouses
	Male	Female	
1	No	Yes	Yes
2	No	No	Yes
3	Yes	Yes	Yes
4	Yes	No	No
5	Yes	Yes	Yes

CHAPTER V

DISCUSSION AND IMPLICATIONS

The purpose of this study was to complete a detailed descriptive analysis of five families and the reactions of the husbands and wives to the thermal environment while each family lived in an energy test house and employed strategies with varying levels of personal control to reduce energy consumption in residential heating. In the following discussion the results of using the strategies, the relationships between selected variables, and the methodology used in measuring perceived thermal comfort are interpreted. The final section contains a summary of implications for educators, policymakers, and researchers.

Family Characteristics, Thermal Comfort and Energy Conservation

Family size and daily occupancy rate did not appear to be related to the preferred temperature and level of energy conservation. The daily occupancy rate and the actual time of day of the occupancy may have been related to the comfort levels achieved with the strategies but the time of day of occupancy was not part of this study. An example is being home during the day to take advantage of the greenhouse temperature. This topic is being studied more fully in a project underway at the North Carolina Agricultural & Technical State University from which the data for this project were secured.

The Energy Conservation Indexes appear to be related to the preferred room temperatures and the level of energy consumption. The families that scored highest on the Indexes also selected the lower preferred room temperatures and used less energy in the baseline period. The relationship between the Indexes and these variables merits further exploration as possible predictors of energy conservers. The Energy Conservation Indexes need expansion, refinement, further development, and testing for reliability and validity if they are to be used in inferential research.

An implication for persons promoting energy conservation is that energy conservation strategies should be examined along dimensions other than just energy savings to determine how a strategy is evaluated by the potential user. Such dimensions include not only thermal comfort but also the convenience in using the strategies in time, personal effort and attention.

Thermal Comfort and Energy Conservation Strategies

When the energy conservation strategies were employed by the five families, the strategies in which supplemental heat sources were used and the thermostat was set at $65^{\circ}F$ were reported as contributing to the highest levels of thermal comfort. The use of the woodstove, used either alone or in combination with the greenhouse, ranked highest in thermal comfort. All participants reported that they experienced the lowest comfort levels with the strategy that set the thermostat at $65^{\circ}F$ with no other available heat sources.

In analyzing the thermal comfort ratings of the strategies, the impact of the strategies on the temperatures in different rooms was examined. The strategy of setting the thermostat at $65^{\circ}F$ with no supplemental heat sources brought colder temperatures all over the house - there was no "warm spot" available. All residents reported this strategy lowest in thermal comfort. When the thermostat was set at the family's own discretion but the bedroom vents and doors were closed, the bedroom temperatures dropped slightly. When the greenhouse was used, either alone or in combination with the woodstove, the living room and master bedroom temperatures increased slightly. When the woodstove was used, either alone or in combination with the greenhouse, the temperature in the living room increased substantially. Apparently the availability of certain rooms with higher temperatures was a factor in determining the thermal comfort ratings of the subjects.

An implication of the fact that certain strategies may affect the room temperatures differently throughout the house is that the placement of the supplemental heat source in relation to the most frequently used rooms should be an important consideration. The strategy may not only impact differently on the temperatures in various rooms but could produce varying results in different houses depending upon the design of the house and site orientation with respect to prevailing winds.

When the thermal comfort and the energy savings were compared for the strategies, it appeared that a sacrifice in thermal comfort was not a requirement to save energy but, in fact, the strategy that saved the most energy also was the most comfortable (combined use of the greenhouse and the woodstove as supplemental heat sources). Instead, it was learned that a trade-off in personal effort versus thermal comfort may be necessary to reduce energy consumption.

Personal Control and Thermal Comfort

As proposed in the conceptual framework, personal control appears to be a variable that affects the perception of thermal comfort. When the residents ranked the strategies on personal control and on thermal comfort after they had used all the strategies, the rankings were almost identical. However, the rankings of the actual temperatures obtained when using the strategies were not in order of the thermal comfort reported.

Personal control in the setting of comfortable temperatures needs to be considered by persons studying the impact of the thermal environment on the occupants. The studies in electric shock in which the respondents could control the amount of shock showed that those in control expressed less discomfort to the levels of shock than did those who had no control (Staub, Tursky & Schwartz, 1971; Geer & Maisel, 1972; Gatchel, 1980; Phares, 1976). It may be that when the occupants of homes (or offices) can adjust the temperatures at will they may be able to endure lower temperatures with less discomfort. Also, as stressed by Winett and his colleagues (Winett, 1983; Winett & Ester, 1983; Winett et al, 1983; Winett et al, 1982; Winett et al, 1981; Winett et al, 1979; Winett & Neale, 1979), the perceived thermal comfort is a dynamic assessment that changes over time. Having control over the temperature may contribute to a person's adjustment to lower temperatures over time.

Analysis of Ordering Effect

Because the order of the use of the energy conservation strategies in residential heating was designed to measure in an additive manner the contribution to the space heating needs, little opportunity existed to vary the order in which the strategies were used by the families. However, the first three families (Families 1, 2, and 3) used the strategies in the order presented in Chapter III. Two strategies were switched in placement for the last two families (Families 4 and 5) when the woodstove alone was used as a supplemental heat source during the fourth week while the greenhouse alone was used during the last week.

A composite listing of the average of the male and female responses for each family in perceived thermal comfort is presented in Table 15 and are used in an analysis of a treatment effect. When the greenhouse was used alone or when the woodstove was used alone, the responses of Families 4 and 5 differed little from those of Families 1, 2, and 3 in the levels of comfort expressed with the strategies. The data did not indicate a difference due to the ordering of the treatments.

Different Measures of Thermal Comfort

The perceived thermal comfort of the ten subjects was measured by three distinct methods:

(1) a weekly rating of thermal comfort which was completed immediately at the end of the week that a strategy was used. The score is an overall rating of temperatures covering a whole week and is an average for each person of the rating from "1" to "7" given to the various rooms in the house;

(2) a final ranking of comfort level accompanying each of the strategies in relation to each other after all strategies had been used for one week each; and

(3) a daily rating of the thermal comfort between the hours of 7 and 10 p.m. daily (for Families 4 and 5).

The daily rating of thermal comfort, a response to temperatures during a specific time of day (7 to 10 p.m.), was expected to be different from the weekly rating and the final ranking of the strategies since the temperature conditions may also have been different. In

Table 15

Composite of Weekly Perceived Thermal Comfort by Strategy

Family	Av. of Male & Female Weekly Comfort Rating[a]/Strategy				
	Closing Bedroom Vents/Doors	Set Thermostat at 65°F.	Set Thermostat at 65°F. Add Greenhouse	Set Thermostat at 65°F Add Greenhouse and Woodstove	Set Thermostat at 65°F. Add Woodstove
Family 1	3.0	5.0	4.5	2.6	4.0
Family 2	1.5	4.0	3.2	3.8	3.3
Family 3	1.3	2.6	2.0	1.9	1.9
Family 4	3.0	3.9	3.7	3.8	4.0
Family 5	1.3	4.5	2.4	4.4	4.0

[a] Comfort Scores ranged from 1 to 7, with 1 being the most comfortable.

fact, the results show that the reported thermal comfort and temperatures were higher during the 7 to 10 p.m. period than during the whole 24-hour day.

However, a closer analysis is needed to interpret the discrepancy between the weekly rating and the final ranking of the strategies in terms of thermal comfort. When the weekly ratings of the strategies by the ten participants are combined and ranked according to the sum of scores, the resulting ranking is different from the final rankings given to the strategies immediately after experiencing the completion of the use of all the strategies. Why does this difference exist and how are these differences analyzed in light of the results?

The differences may exist because the respondents were responding to different types of questions. On the one hand, with the weekly response, the subject was using a rating from "1" to "7" and was rating each room in the house according to this scale. On the other hand, when the respondent completed the ranking, he was forced to place in order the strategies after using all of them. This response was interpreted as an overall reflective choice among the strategies. Further study is needed to determine if and why perceptions over time may change and how this change can best be measured.

The choice of which measure of thermal comfort to use in the analysis process depended on the question being answered. The weekly response was used to analyze the reactions to the actual temperatures when the strategies were used. The final rankings were used to determine the subjects' ranking of the strategies along other dimensions such as personal control and personal effort.

Perceived Thermal Comfort Measured In A Residential Setting

One contribution of this investigation to the development of thermal standards for the human environment is the use of a residential setting for measuring perceived thermal comfort under varying conditions. The testing laboratory was a house that was highly instrumented to measure the temperature in every room in the house every ten seconds and then average it hourly. Also the respondents actually moved into this test house for six weeks. Various responses to room temperatures were measured including clothing added (clo values were obtained from two families). Other variables which impact on the perception of thermal comfort were either controlled for or monitored such as the relative humidity and air velocity.

The average temperatures in the house for each strategy ranged from 67.2 to 71.1^{0}F. This range of temperatures is lower than the range of temperatures from 68 to 74^{o}F with 72^{o}F specified as optimal given by ASHRAE as the recommended range in which 80 percent of the occupants would be comfortable. The participants in the study reported high levels of comfort with the temperatures. Also, when the clo values were also assessed, two of the couples (Families 4 and 5) experienced high levels of comfort with temperatures between 7 and 10 p.m. that ranged from 69.8 to 75.3^{o}F but with lower clo values than recommended by ASHRAE.

The findings of this study are similar to those of Winett and his colleagues (1983) in that the participants reported higher levels of comfort with lower temperatures than recommended by ASHRAE. This experience with five case studies indicates that further study is needed to determine if standards based on laboratory testing that uses chambers occupied by people for short time periods are appropriate for the development of thermal standards in residential settings.

Conceptual Framework and Testable Hypotheses

The data collected from the participating families support the inclusion of all variables in the conceptual framework developed for this study (Figure 3). However, it is important to emphasize that researchers examining perceived thermal comfort should use the conceptual framework (Figure 2) which includes _all_ variables influencing perceived thermal comfort, including those controlled in this investigation. When attempting to explain the perception of thermal comfort, it appears appropriate not only to include the environmental factors of room temperatures and humidity and the personal factors of clothing worn and activity level but also to include some psychological variables. Personal control may be appropriate to explain some variation in responses to the environmental conditions that are not explained otherwise. Further, the preferred room temperature (or norm) may prove helpful in assisting families in adjusting to changing temperatures over time.

As a result of the study, several hypotheses are listed below for further investigation in inferential studies:

1. The level of personal control over an energy conservation strategy affects the perception of thermal comfort.
2. The difference between the preferred room temperature and the actual temperatures is indirectly related to perceived thermal comfort.

3. A sacrifice in thermal comfort is not required to save energy in residential heating.
4. A sacrifice in lifestyle dimensions such as personal effort is related to energy conservation.
5. Energy Indexes can be used to predict the level of energy consumption of families.
6. Strategies that use supplemental or direct heat sources versus a whole house heating system can contribute not only to thermal comfort but to energy savings.

Implications

The results of this investigation have implications for professionals who are involved not only in promoting residential energy conservation but also are committed to providing an acceptable thermal environment. These professionals include educators, policymakers, and researchers. The following suggestions and recommendations are concerned with the methodology used in setting standards for the thermal environment as well as the relationship of selected variables to perceived thermal comfort.

For Educators

Educators with the Cooperative Extension Service as well as with utility companies and educational institutions are in a position of encouraging energy conservation in the residential sector through direct contact with families. Although the results need to be tested in a broader study involving more subjects, it appears that greater emphasis needs to be placed on the use of heating conservation strategies that will produce "warm spots" in the home. This may be in the form of portable space heaters, greenhouses, or woodstoves. The use of supplemental heat sources apparently can reduce the overall energy consumption of fossil fuels but yet contribute to high levels of thermal comfort.

For Policymakers

Persons in the position of setting policy to promote energy conservation in the residential sector need to consider lifestyle variables in the planning process. From this study, it appears that thermal comfort does not have to be sacrificed to save energy. Instead there may be a trade-off along other lifestyle dimensions such as personal effort. The relationship between the Energy Behavior Index and the lower preferred temperatures and levels of energy consumption indicate that existing incentives to encourage the residential sector to engage in energy conservation activities should be continued and that further study is needed to develop incentives to save energy.

For Researchers

The engineers involved in the development of the ASHRAE Standards for occupied dwellings should consider use of various methods of testing since this research and previous research that used actual residences indicate that persons experience comfort at temperatures lower in winter than those reported by Laboratory tests (Winett et al., 1983). More testing in the residential setting is suggested as well as comparative studies of several methodologies.

In these studies, attention should also be directed at involving the subjects in the establishment of the temperatures at comfortable settings. In the ASHRAE studies, the subjects were not involved in setting the thermostat. The lack of personal control in the process may be one of the reasons that ASHRAE reported higher temperature zones for comfort. Giving groups of subjects various levels of control in setting the thermostat is one way to test the impact of personal control on the perception of thermal comfort.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this investigation was to complete a detailed descriptive analysis of five families and the reactions of the husbands and wives to the thermal environment while each family lived for six weeks in an energy test house and employed strategies with varying levels of personal control to reduce energy consumption in residential heating. The general objectives of the study were (1) to describe the thermal environment, the residents' perceived thermal comfort, and the level of energy consumption that result from the use of selected energy conservation strategies in home heating, (2) to determine if a sacrifice in thermal comfort is required to save energy, and (3) to describe trends or patterns that may exist between perceived thermal comfort and related variables including the resulting room temperatures, level of personal control, anticipated ratings of thermal comfort, energy consumption, clothing, and selected demographic and energy-related characteristics of the family participants.

The methodology of using a residential setting was offered as an alternative to that of laboratory chambers that people occupied for varying time periods as in the development of the thermal standards for dwellings by the American Association Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1981a). It was also an alternative to using various homes in field studies in that variations due to structural differences were eliminated by residents occupying a single dwelling. The use of one dwelling in which extra data collection equipment was installed also increased the types of measurements that could be obtained in the house.

The test site was Garrett House located on the campus of North Carolina Agricultural and Technical State University and built in 1939. The house is an energy efficient dwelling after attention to additional insulation, storm windows/doors, caulking, etc. The house has a porch converted to a passive solar greenhouse, a free-standing woodstove, and a gas furnace heating system.

The data acquisition system installed in the test house used a Commodore 4032 CBM microcomputer which monitored 37 channels of data including room temperatures, humidity and electric power consumption. The data channels for the temperatures and humidity were scanned every 10 seconds and averaged hourly while the power consumption was summed on an hourly basis. The thermal comfort and behavioral responses for the ten project participants were obtained through daily logs and by weekly and periodic questionnaires.

During the six week residence of each family, the following energy conservation strategies in residential heating were tested to determine the perceived thermal comfort of the 10 adult respondents and the actual energy consumption while the strategies were employed:

Week 1: The baseline data were obtained establishing a family norm. No strategies were introduced.

Week 2: The central heating thermostat was kept at the family's norm level but heat inlets in the bedrooms were closed at all times and the doors to these bedrooms were kept closed during the daytime when not in use.

Week 3: The central heating thermostat was kept at 65°F and the restriction on heat inlets and doors was withdrawn.

Week 4: The heating thermostat was kept at 65°F and the use of the greenhouse as a heat source was introduced.

Week 5: The heating thermostat was kept at 65°F, use of the greenhouse continued and use of the woodstove was added.

Week 6: The heating thermostat was kept at 65°F, use of greenhouse was discontinued, and use of the woodstove continued.

A conceptual framework containing the variables impacting on perceived thermal comfort was examined to determine the appropriateness of the variables included. The framework included environmental factors (temperature and humidity), personal factors (clothing worn and activity level), and psychological factors (preferred room temperature or norm, and personal control). The psychological factors have not been considered in previous efforts to develop standards for thermal environment. The results of the study confirm the appropriateness of the variables included in the framework.

The major findings of the investigations give guidance and suggestions for further research:

1. The participants preferred the conservation strategies that added supplemental heat to the home.
2. A sacrifice in thermal comfort is not required to save energy.
3. A trade-off in personal effort rather than thermal comfort may be necessary to save energy.

4. The Energy Conservation Indexes seem to be related to the preferred room temperatures and the level of energy consumption.
5. Personal control appears to influence the perception of thermal comfort.
6. An indirect relationship appears to exist between the difference in preferred and actual room temperatures and the level of expressed thermal comfort.

Conclusions

1. The use of a residential setting to measure thermal comfort under varying environmental conditions can be successfully accomplished and can contribute to the development of thermal standards for occupied dwellings.
2. Psychological variables such as personal control should be considered and tested by persons involved in development of standards for the thermal environment.
3. The ability and experience of the persons to use a strategy can affect the achieved energy saving benefits of the strategy. One week may not be enough time to adequately learn how to use the strategy.
4. Personal preference in the amount of personal effort a person is willing or able to give will impact on the decision on whether to use certain strategies.
5. Heating strategies that can produce a direct source of heat or at least some warmer areas were rated highest by the project participants. Supplemental heat sources that warm small areas should

be encouraged as not only a comfort measure but also as a measure to conserve energy used in the central heating system.

6. Weather can play an important role in the effectiveness of the solar greenhouse as a heat source.

Recommendations for Further Study

1. Additional energy conservation strategies in residential heating need exploration. Thermostat setbacks and the use of portable heating are two methods needing further study not only in energy use but also in user acceptability.
2. The Energy Conservation Indexes need further development to be reliable and valid instruments to predict energy consumption behavior.
3. A methodological study comparing the results of using both residences and laboratory chambers needs to be explored. The laboratory studies omit some important variables that apparently influence perceptions. One such variable is personal control.
4. Conservation strategies for summer cooling should be examined along with the dimensions explored in this study.

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APPENDICES

APPENDIX A

"The Effect of Home Energy Conservation Strategies on Lifestyle"

Project Description

The research project entitled "The Effect of Home Energy Conservation Strategies on Lifestyle" began in 1982 on the campus of North Carolina Agricultural and Technical State University. The four-year project was funded by the Cooperative State Research Service of the United States Department of Agriculture and its main thrust has been to investigate the effect of home energy conservation strategies on lifestyle. A multidisciplinary team for the disciplines of Home Economics, Mechanical Engineering and Psychology have been monitored by families while they live separately in an energy test home and employ energy conservation strategies in the areas of space heating/cooling and hot water usage.

Objectives

The three main objectives of the residential energy study are the following:

1. To measure and compare the energy consumption of selected conservation strategies in space heating/cooling and hot water heating.
2. To identify and compare the lifestyle changes associated with the use of selected energy conservation strategies including thermal comfort, use of space, convenience and demands in time, attention and human effort.
3. To develop an Index of Consumer Acceptability of Strategies by combining the consumption and lifestyle data.

Methodology and Research Design

The exploratory study is designed to obtain an in-depth knowledge of human behavior and consumption patterns related to specific energy conservation strategies. The research is based on the premise that behavioral and attitudinal responses to unfamiliar life situations can be analyzed with greater reliability if the subject actually experiences such situations rather than simply responds to hypothetical circumstances (Turner et al., 1983). A distinct advantage of the methodology is that the residential structure is held constant and extensive monitoring can be accomplished to determine energy consumption as well as the environmental conditions such as temperatures. Also, a fine-grained study of the participants is made possible by day-by-day monitoring. Although the findings cannot necessarily be generalized to the population as a whole, they can serve as a major link in directing and strengthening future inferential studies of family energy conservation behavior.

The research design involves having 15 families reside in Garrett House, the energy test house, over the three-year live-in phase of the project. Nine families will participate in the winter treatment while six families will be involved in the summer treatment. The length of residence for the winter treatment is six weeks while the summer residence is four weeks. The length of residence depends on the number of strategies employed during the treatment.

Garrett House was constructed on the campus of North Carolina Agricultural State University in 1939 and contains 2570 square feet of living space. The two-story, brick veneer Colonial structure was rated an energy-efficient structure by Duke Power, the local electric utility company, after insulation was added to the walls, floors and ceilings, and storm windows and weather stripping were installed. The house also has a solar greenhouse, a freestanding woodstove and solar hot water system.

The family participants are selected by a panel on the basis of two main characteristics--family size and age of children. The family size ranges from two persons (a couple) to five persons (husband, wife and three children). The ages of the children vary from preschool to teenage. The family type is a married husband and wife. The involvement of married couples allows analysis of two adults and also allows comparison of male and female responses.

The family characteristics are viewed as situational factors which define the parameters of consumption and conservation patterns. In this study, unlike a sample survey, families are not selected to allow random distribution of characteristics. Due to limited resources and the restricted number of families which can participate in the study, families are selected on the basis of the two characteristics mentioned above. Thus, the family characteristics are considered as defining the situations in which consumption, conservation and responses to change take place and these situations vary in a non-random manner.

The energy conservation strategies serve as independent variables and focus on space heating/cooling and on hot water consumption, which constitute the major energy users in the home. Following are the <u>winter</u> strategies:

Week 1: The baseline data are obtained establishing a family norm. No strategies are introduced.

Week 2: The central heating thermostat is kept at the family's norm level but heat inlets in the bedrooms are closed and the doors to these bedrooms are kept closed during the daytime when not in use.

Week 3: The central heating thermostat is kept at 65°F and the restriction on heat inlets in the bedrooms is withdrawn.

Week 4: The heating thermostat is kept at 65°F and the use of the greenhouse as a heat source is introduced.

Week 5: The heating thermostat is kept at 65°F, use of the greenhouse continues and use of the woodstove is added.

Week 6: The heating thermostat is kept at 65°F, use of greenhouse is discontinued, and use of the woodstove continues.

Following are the summer strategies:

Week 1: Baseline data are obtained establishing a family norm. No strategies are added.

Week 2: Air-conditioning thermostat is set at 80°F.

Week 3: Air-conditioning is turned off and the family uses only the attic fan.

Week 4: Air-conditioning thermostat is set at 80°F and is used between 2 p.m. and 8 p.m. The attic fan is available for use at other times.

As mentioned above, the first week serves as a baseline for energy consumption as well as for general household activity. During this first week, the families follow their own norm of consumption patterns. After the first week, the conservation strategies are each employed for one week.

It may be noted that specific conservation strategies are used alone or in combination in the various strategies thus allowing analysis of a wider range of permutations of conservation behavioral patterns. For instance, the greenhouse and woodstove are used singly for one week each as well as together for another week. Such variations in the independent variables follow the same sequence for some families but is varied slightly for others. Comparative analysis of different strategies will be in terms of a norm of family consumption patterns to be developed from the baseline data collected in the homes of the families and during the first week of stay in the Garrett House when no conservation strategy is used.

In addition to the above strategies pertaining to space heating and cooling, two additional strategies for use of hot water are employed. First, water flow-restricting showerheads are installed. Second, water temperature and quantity are controlled in the use of clothes washing.

At the beginning of each strategy period, a list of instructions or information is given to the family. When appropriate, demonstrations are also given.

Two broad categories of dependent variables exist for this study. One is the actual energy consumption resulting from the use of the various energy conservation strategies. The methods used to monitor and determine energy consumption are described in a subsequent section.

The other set of dependent variables in the study pertain to lifestyle changes resulting from the use of the conservation strategies. These changes relate to the dimensions of lifestyle including the patterns of family activities such as space use as well as responses in terms of thermal comfort, convenience, and demands on attention, time and human energy. These data are collected by a daily activity log and questionnaires.

The daily activity log is designed to determine the performer, time and location of selected activities. The activities either impact on or are affected by energy consumption. In addition, the adult family members complete a weekly questionnaire concerning the particular strategy employed each week. A questionnaire on energy consumption behavior, attitudes and demographic information is also administered prior to participation on the project. A questionnaire on attitudinal concerns is completed by each adult family member immediately completing the live-in experience. Further, a follow-up questionnaire is administered a year after each family participated in the project.

The basic unit of analysis of consumption patterns, conservation behavior and changes in patterns of family living was one full day. This approach yielded sufficient observations to develop discernable patterns of consumption, conservation and changes in life style associated with the various conservation strategies.

Data Acquisition System

The data acquisition system installed in Garrett House is based on a Commodore 4032 CBM microcomputer. In its present configuration the system is capable of monitoring 48 channels of analog data input. For this project, 37 channels of data are being monitored including room temperatures, humidity, hot water consumption, electric power consumption, weather conditions and run times of several appliances.

All data channels are scanned every 10 seconds. The temperature, humidity and windspeed readings are averaged while the solar radiation, hot water consumption, power consumption and appliance run times are integrated to give totals. At one hour intervals, the averages and integrated values are outputed to a cassette tape. A cassette holds three weeks worth of hourly data. The stored data is later transferred from the cassettes to the University's main frame computer for data reduction analysis. The raw data are also transferred to a 9-track magnetic tape for permanent storage and easy retrieval.

The data acquisition system consists of the microcomputer, a Techtran Data Cassette Unit and an analog input module (homemade and incorporating A/D conversion, channel multiplexing, etc.) The system collects the information from the sensors for temperature, humidity, wind speed, solar radiation and water as well as from the sensor signal processing circuitry.

The data gathered by the computer system along with manual daily readings of natural gas consumption and total household water consumption are used to determine the energy savings realized from each of the conservation strategies employed as outlined in the previous section. The actual measured energy consumption is compared with predicted energy consumption on a daily basis to determine an estimated savings. The predicted energy consumption is obtained through the use of a computer model for calculating heat loss/heat gain based on daily inside and outside average temperatures, wind speed and solar radiation. The computer model is validated for each resident family against measured energy consumption for the first week baseline period during which no conservation strategies were employed.

APPENDIX B

Description of Energy Conservation Strategies in Home Heating

Description of Energy Conservation Strategies in Home Heating Being Tested in Garrett House North Carolina A&T State University

STRATEGY	DESCRIPTION	
Strategy I Thermostat Set by Resident; Bedroom Heat Inlets and Doors Closed.	**Thermostat** The thermostat is selected & adjusted by the **resident** to levels found to be comfortable.	**Bedroom Heat Inlets** The bedroom heat inlets are closed by the project personnel at the beginning of the use of the strategy and then later opened by the project personnel when the strategy is no longer in use. The resident cannot open or close the vents during this time. Bedroom Doors The resident is asked to keep the bedroom doors closed when the bedrooms are **not** in use.
Strategy II **Thermostat Set at 65°F.**	**Thermostat** The thermostat is set at 65 F by the **project personnel** and a locked thermoguard is placed over the thermostat. The resident does not have access to the key.	

STRATEGY	DESCRIPTION	
Strategy III	**Thermostat**	**Greenhouse**
Thermostat Set at 65°F. Use of Greenhouse.	Same as for Strategy II	The resident is given the following instruction for use of the greenhouse: "When at home, open the double french doors to the greenhouse when the temperature in the GH is above 80°F as indicated on the large dial thermometer. Close the doors in the evening when the temperature drops below 80°F. If you will be away from the house for a period of time, you can leave the doors open if you think the sun will continue to shine until you return. If you will be returning after dark or the weather forecast is calling for increasing cloudiness, it is best to close the doors before leaving. During the period that the greenhouse is being used as a supplemental heat source, the blower will be activated so that some heat will be delivered to the house through the blower system whenever the greenhouse is warm even if the doors are closed."

STRATEGY	DESCRIPTION	
Strategy IV **Thermostat Set at 65°F; Greenhouse and Woodstove** Are Used.	**Thermostat** Same as for **Strategy II**	**Greenhouse** Same as for Strategy III **Woodstove** The resident is given the following instructions for the use of the woodstove: "Load the stove through end door. Use wadded-up newspaper and kindling to start fire. Place newspaper in stove. Place several pieces of kindling on newspaper. Place one small log on kindling. Make sure draft vents are fully open. Light paper with match. Let fire become established then add more logs and adjust draft to desired burn rate. Load stove fully before going to bed and reduce draft for a slow burn. If a good bed of coals is present in the morning, just add logs and open draft to get fire going good. After fire is going good, the draft can be reduced for a long, slow burn. It is easier to keep the fire going than to relight it. Place spark guard rug in front of woodstove."
Strategy V **Thermostat Set at 65°F;** Use of Woodstove.	**Thermostat** Same as for **Strategy II**	**Woodstove** Same as for **Strategy IV.**

APPENDIX C

Questionnaire Items and Daily Activity Log

CODE___________________

DATE_________________

ENERGY INFORMATION QUESTIONNAIRE

1. Family Composition

Please fill in the information about each member of your household in the following chart. Household consists of your entire family, including your children not living with you, any adopted children and any other relatives living with you.

FAMILY MEMBER	AGE	SEX	LIVING W/YOU	
			YES	NO
HEAD OF HOUSEHOLD				
SPOUSE				
CHILD #1				
CHILD #2				
CHILD #3				
CHILD #4				
Other relatives (specify relationship to head of household)				

2. RACE: Please check (✓) the category applicable to you.

___ White
___ Black
___ Spanish
___ Other (specify)___________________

3. Education: Please check (✓) the appropriate categories.

EDUCATION	HEAD OF HOUSEHOLD	SPOUSE
Less than high school		
High School		
4 years of college		
Graduate or Professional		
Vocational/Technical (Please specify)		

4. Gross Family Income Per Year: Four our purposes gross family income means total yearly income before taxes or other deductions, combined income of all amily members and from all other sources. Please check the category applicable to your family.

___ Less than $15,000
___ $15,000 - 19,999
___ $20,000 - 24,999
___ $25,000 - 29,999
___ $30,000 - 34,999
___ $35,000 - 39,999
___ $40,000 - 44,999
___ $45,000 - 49,999
___ $50,000 - or more

CODE________________

DATE________________

5. Heating/Cooling

a. How do you heat your home?

___oil forced air system
___oil hot water system
___gas forced air system
___gas hot water system
___electirc forced air
___ electric baseboard
___ electric radiant
wood
other (please explain____________________

b. Do you sometimes use portable space heaters?

yes ___
no ___

c. How do you cool your home?

___no cooling provision
___ central AC (electric)
___ central AC (gas)
___ individual air conditiong
___attic fan
___attic fan in combination w/
air conditioners ___
room units ___
central system ___
___other (Please explain)______________

d. Do you sometimes use portable fans?

yes ___
no ___

6. How do you heat your hot water?

___oil
___ gas electricity
___solar

7. Is your oven:

___ gas
___ electric

9. Which of the following statements best reflects your feelings about energy crisis. You may check more than one of these statements if applicable.

___energy is present temporary problem which will be resolved in due time

___ energy is a real problem here and now

___ energy is not an immediate problem in our society

___ energy is a definite potential problem for the future

___ energy is highly exaggerated by the media

___ the energy problem is used as a political scapegoat for covering other serious problems in our society.

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10. To what extent do the following contribute to the present energy problem: (circle the appropriate answer)

	totally	considerably	somewhat	a little	not at all
general shortage of conventional fuel	1	2	3	4	5
wasteful consumption of energy	1	2	3	4	5
rising standard of living and associated energy use increases	1	2	3	4	5
slow development of alternate energy sources	1	2	3	4	5

11. To what extent are the following responsible for the present energy problem:

federal and state government policies and actions	1	2	3	4	5
profit motvies of large corporations that produce and distribute fuels	1	2	3	4	5
USA is a society of high energy consumers.	1	2	3	4	5
actions of foreign government and monopolies	1	2	3	4	5

12. What is your guess of the number of years before we will run out of an adequate supply of the following conventional fuels. Circle the number closest to your guess.

Coal	10	20	50	80	100	200	500	1000	Never
Oil	10	20	50	80	100	200	500	1000	Never
Natural Gas	10	20	50	80	100	200	500	1000	Never

13. Of the total energy consumed in our country what proportion (approximate percentage) do you think is used in homes (for all purposes including heating, air conditioning, water heating, appliances, etc., but not including gasoline used in cars).

approximately____ %

14. Do you think using less energy (say 25% less) in homes throughout the country will make any significant difference in the overall energy situation.

yes__ no__ don't know___

15. Since we live in Greensboro, with a relatively mild climate, do you think conserving energy in our homes here will make any significant difference in the overall energy situation.

yes___ no___ don't know___

CODE________________ DATE______________

16. Check any changes made to your home to save energy or reduce utility costs.

	Which of the checked items saved the most energy? Rank with I saving the most energy.	Which of the checked items cost the most to install? Rank with I having the highest cost.
added or increased insulation		
added storm windows/doors or double pane windows		
added woodstove		
added portable heated		
reduced wattage of lightbulbs		
weather stripped and caulked		
covered windows with plastic		
installed attic fan		
added insulation to water heater		
added solar hot water system		
converted porch/added greenhouse		
had furnace or heater cleaned or adjusted		
blocked cracks under doors		
installed flow restricting showerhead		
other (please specify)		

(4)

CODE____________________

DATE____________________

17. Check any of the following that you did to save energy in the last year.

		regularly	only sometimes	check if cause inconvenience		
				a lot	somewhat	no much at all
____	used woodstove	1	2	1	2	3
____	reduced lights used	1	2	1	2	3
____	lowered thermostat in winter	1	2	1	2	3
____	raised thermostat in summer	1	2	1	2	3
____	used appliances more efficiently	1	2	1	2	3
____	lowered water heat thermostat	1	2	1	2	3
____	closed off rooms	1	2	1	2	3
____	used attic fan instead of AC	1	2	1	2	3
____	closed window drapes	1	2	1	2	3
____	used cold water wash and/or rinse for clothes washing	1	2	1	2	3

18. Please rank order of the following energy users in the home according to your estimate of the relative share each one consumes of your total yearly utility expenses. Please a 1 next to the highest energy user and a 2 by the next highest and so on.

hot water heating ______

space heating ______

space cooling ______

lighting ______

cooking and baking ______

regrigerator ______

freezer ______

dishwasher ______

clothes washer ______
clothes dryer ______
all other appliances ______

(5)

CODE____________________

DATE____________________

19. Below is a list of the major energy using activities in a typical home. Using activities in a typical home, how would you rate energy usage for each activity in your home----less than average, average, or more than average. Circle one level of activity.

	much less	less	somewhat less	average	somewhat more	more	much more
hot water heating	1	2	3	4	5	6	7
space heating	1	2	3	4	5	6	7
space cooling	1	2	3	4	5	6	7
lighting	1	2	3	4	5	6	7
cooking and baking	1	2	3	4	5	6	7
refrigerator	1	2	3	4	5	6	7
freezer	1	2	3	4	5	6	7
dishwasher	1	2	3	4	5	6	7
clothes washer	1	2	3	4	5	6	7
clothes dryer	1	2	3	4	5	6	7
all other appliances	1	2	3	4	5	6	7

20. If you decided to save energy in your home and you had to reorganize some of the activities listed below, which one would you change and home much would you change them? Indicate by circling the new levels for each activity listed below.

	much less	less	somewhat less	average	somewhat more	more	much more
hot water heating	1	2	3	4	5	6	7
space heating	1	2	3	4	5	6	7
space cooling	1	2	3	4	5	6	7
lighting	1	2	3	4	5	6	7
cooling and baking	1	2	3	4	5	6	7
freezer	1	2	3	4	5	6	7
dishwasher	1	2	3	4	5	6	7
clothes washer	1	2	3	4	5	6	7
clothes dryer	1	2	3	4	5	6	7
all other appliances	1	2	3	4	5	6	7

(6)

CODE________________

DATE________________

21. Which of the following energy-saving techniques for home heating do you think will save the most energy? Rank them 1-5, 1 saving the most energy.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied.

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

22. Which of the following energy-saving techniques for home heating do you think overall will be the most convenient to use? (convenient in terms of requireing time, attention and/or human energy to accomplish.) Rank 1-5, 1 beign the most convenient.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

23. Which of the following energy techniques do you think would be most time-intensive? (Requiring time to accomplish.) Rank 1-5, 1 being most time-intensive.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied___

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

CODE____________________DATE______________

24. Which of the following energy saving techniques would be most demanding in terms of requiring attention (requiring person to remember to do certain things, etc.) Rank 1-5, 1 requiring the most attention.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

25. Which of the following energy saving techniques would be most human-energy intensive? (requires work on the part of the individual to accomplish). Rank 1-5, 1 being the most human-energy intensive.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

26. Which of the following energy saving techniques for home heating do you think will be most comfortable? Rank 1-5, 1 being most comfortable.

___ close warm air inlets of the bedrooms and keep bedroom doors closed when not occupied

___ drop heat thermostat setting to 65° F

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions

___ drop heat thermostat setting to 65°F and use greenhouse to help heat house; open and close doors to greenhouse according to certain instructions and use woodstove

___ drop heat thermostat setting to 65°F and use woodstove

27. Which of the following energy saving techniques do you think will save the most energy? Rank them 1-3, 1 saving the most energy.

___ set air conditioning thermostat at 80°F

___ use only attic fan

___ combine use of air conditioning (thermostat set at 80°F) between 2-8 pm: use attic fan at other times

(8)

28. Which of the following energy-saving techniques do you think will save the most energy? Rank them 1-5, 1 saving the most energy.

____a. Set air-conditioning thermostat at 80°f

____b. Use only attic fan

____c. Combine use of air- conditioning (thermostat set at 80°F) between 2-8 p.m. and use attic fan at other times.

29. Which of the following energy-saving techniques do you think overall will be most convenient to use? (Convenient in terms of requiring time,, attention and/or human energy to accomplish.) Rank 1-5, 1 being the most convenient.

____a. Set air-conditioning thermostat at 80°F

____b. Use only attic fan

____c. Combine use of air conditioning (thermostat set at 80°F) between 2-8 p.m. and use attic fan at other times.

30. Which of the following energy-saving techniques do you think would be most time-intensive? (Requiring time to accomplish.) Rank 1-5, 1 being the most time-intensive.

____a. Set air-conditioning thermostat at 80°F

____b. Use attic fan only

____c. Combine use of air conditioning (thermostat set at 80°F) between 2-8 p.m. and use attic fan at other times

31. Which of the following energy-saving techniques would be most demanding in terms of requiring attention. (Requiring persons to remember to do certain things, etc.) Rank 1-5, 1 requiring the most attention.

____a. Set air-conditioning thermostat at 80°F

____b. Use only attic fan

____c. Combine use of air-conditioning (thermostat set at 80°F) between 2-8 p.m. and use attic fan at other times.

32. Which of the following energy-saving techniques would be most human energy intensive (requires work on the part of the individual to accomplish). Rank 1-5, 1 being the most human-energy intensive.

____a. Set air-conditioning thermostat at 80°F

____b. Use only attic fan

____c. Combine use of air-conditioning (thermostat set at 80°F) between 2-8 p.m. and attic fan at other times.

33. Which of the following energy-saving techniques do you think will be most comfortable? Rank 1-5, 1 being the most comfortable.

____a. Set air-conditioning thermostat at 80°f

____b. Use attic fan

____c. Combine use of air-conditioning (thermostat set at 80°F) with attic fan at other times.

34. Overall, which of the following energy-saving techniques will be most acceptable to do on a regular basis in a person's own home? Rank them 1-3, 1 being the highest.

___ a. Set air-conditioning thermostat at 80°F

___ b. Use only attic fan

___ c. Combine use of air conditioning (thermostat set at 80°F) at certain times with attic fan at other times

35. Which do you think would save the most energy in hot water usage? Rank them 1-4, 1 being the highest.

___ a. Install flow restricting showerheads.

___ b. Use cold wash/cold rinse in clothes washer when possible.

___ c. Use water level selections or only run full loads in clothes washer.

___ d. Run only full loads in dishwasher.

36. Which do you think would be the most acceptable way to save energy in hot water usage? Rank 1 to 4, 1 being most acceptable.

___ a. Install flow restricting showerheads.

___ b. Use cold wash/ cold rinse in clothes washer when possible.

___ c. Use water level selections or only run full loads in clothes washer.

___ d. Run only full loads in dishwasher.

37. What factors do you think would most influence your decision to adopt an energy conservation method? Rank each with 1 being the most important.

___ Comfort

___ Aesthetics

___ Convenience in using

___ Time required to use

___ Human-energy required to use

___ Attention-demanded to use

___ Possible monetary savings from use

___ Possible energy savings from use

___ Size of initial investment

___ Extent of structure modification required

WEEKLY COMFORT QUESTION

Describe the overall temperature in each room this week by circling the appropriate number:

	COMFORTABLE				UNCOMFORTABLE		
Living Room	1	2	3	4	5	6	7
Dining Room	1	2	3	4	5	6	7
Kitchen	1	2	3	4	5	6	7
Family Room	1	2	3	4	5	6	7
Bedroom 1 (Master)	1	2	3	4	5	6	7
Bedroom 2 (child)	1	2	3	4	5	6	7
Bedroom 3 (child)	1	2	3	4	5	6	7
Bedroom 4	1	2	3	4	5	6	7

DAILY THERMAL COMFORT AND CLOTHING WORN

NAME________________________________

DATE________________________________

Please complete this form daily at the designated time:________________

Indicate the exact time form was completed:____________________________

THERMAL ENVIRONMENT AND COMFORT

The purpose of this response sheet is to assess how you feel now about the thermal environment of the dwelling in which you live. Please complete the form <u>during the designated item,</u> but be sure to wait at least an hour after strenuous activity before completing the form. The adult members of the family should complete the forms.

<u>QUESTIONS</u>

1. Circle the number of the phrase that best describes <u>how you feel now</u>. (Thermal Sensation)

Neutral	Slightly Cool	Cool	Slightly Cold	Cold	Very Cold	Extremely Cold
1	2	3	4	5	6	7

2. Circle the number that best describes <u>how you feel now.</u> (Thermal Comfort)

Comfortable						Uncomfortable
1	2	3	4	5	6	7

Date____________________

MEN'S CLOTHING CHECKLIST

Please check off, in the far right hand column, the articles of clothing you have on now. We realize that this list is not exhaustive, so if you have on an article of clothing that does not exactly match a listed item, please check the item that is most similar.

Description	Fabric Contruction	Typical Fiber Content	CLO	✓
Underwear				
Briefs	knit	cotton	0.05	___
Sleeveless undershirt	knit	cotton	0.08	___
Short-sleeve undershirt	knit	cotton	0.09	___
Long Underwear/tops	knit		0.25	___
Long underwear/bottoms	knit		0.25	___
Long thermal underwear				
Tops	waffle knit		0.35	___
Bottoms	waffle knit		0.35	___
Socks				
Light socks	knit		0.03	___
Heavy socks	knit		0.04	___
Light knee-high socks	knit		0.06	___
Heavy knee high socks	knit		0.08	___
Shoes				
Low shoes			0.04	___
High shoes			0.15	___
Knee-high boots			0.30	___
Shirts				
Short sleeve woven	plain weave	cotton	0.19	___
Short sleeve light knit	knit	cotton	0.22	___
Short sleeve heavy knit	knit	orlon/acrylic	0.25	___
Long sleeve woven	plain weave	poly/cotton blend	0.29	___
Long sleeve light knit	knit	cotton	0.14	___
Long sleeve heavy knit	knit	wool	0.37	___
Pants				
Light trousers	plain weave	polyester	0.26	___
Jeans	twill weave	cotton	0.26	___
Heavy trousers	twill weave	wool	0.32	___
Sweaters				
Sleeveless sweater	knit	orlon	0.17	___
Long sleeve sweater	knit	wool blend	0.37	___

MEN'S CLOTHING CHECKLIST

page two

Sport Coats & Vests

Light vest	weave		0.20	___
Heavy vest	weave		0.30	___
Light sport coat	twill weave	dacron/polyester	0.35	___
Heavy sport coat	twill weave	wool	0.49	___

Miscellaneous

Coveralls	twill weave	nylon/cotton	0.55	___

Date____________

WOMEN'S CLOTHING CHECKLIST

Please check off, in the far right hand column, the articles of clothing you have on now. We realize that the list is not exhaustive, so if you have on an article of clothing that does not exactly match a listed item, please check the item that is most similiar.

Description	Fabric Construction	Typical Fiber Content	CLO	✓
Underwear				
Bra		cotton	0.02	
Panties		acetate	0.02	
Girdle		nylon-lycra	0.04	
Half Slip		nylon	0.13	
Full Slip		nylon	0.19	
Long Underwear				
Tops	knit		0.25	
Bottoms	knit		0.25	
Long Thermal Underwear				
Tops	waffle knit		0.35	
Bottoms	waffle knit		0.35	
Socks and Hosiery				
Pantyhose		nylon	0.01	
Tights	knit		0.25	
Light socks	knit		0.03	
Heavy socks	knit		0.04	
Light knee-high socks	knit		0.06	
Heavy knee-high socks	knit		0.08	
Shoes				
Low shoes			0.03	
High shoes (6-9")			0.15	
Knee-high fashion boots			0.25	
Knee-high boots, leather lined			0.30	
Blouses				
Short sleeve	plain weave	rayon	0.17	
Light long sleeve	plain weave	poly/cotton	0.20	
Heavy long sleeve	plain weave	poly/cotton	0.29	
Heavy long sleeve	plain weave	wool	0.37	

Pants				
Light pants	knit	polyester	0.26	______
Heavy pants	twill	wool	0.44	______
Jeans	Twill	cotton	0.26	______
Dresses and Skirts				
Light skirt or dress	knit	cotton	0.17	______
Heavy skirt	twill weave	wool	0.22	______
Sweaters				
Sleeveless sweater	knit	wool	0.17	______
Long sleeve sweater	knit	wool	0.37	______
Blazers and Vests				
Light vest	weave		0.20	______
Heavy vest	weave		0.30	______
Light blazer	weave	polyester	0.31	
Heavy blazer	weave	wool	0.43	______
Miscellaneous				
Light shawl	knit		0.30	______
Heavy shawl	knit		0.40	______
Coveralls	twill	nylon/cotton	0.55	______

DAILY ACTIVITY LOG

page three

CODE________
DATE________
DAY OF WEEK________

Daily Activity Log

ACTIVITY	PERSON(S)						VISITORS			AM											TIME									PM				ROOM												
	HRS	[illegible]	1	2	3	all	1	2	3	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	LR	DR	K	O	BR1	BR2	BR3	BR4	BR5	[illegible]	[illegible]	[illegible]	[illegible]
CLOTHES WASHER:																																														
DISHWASHER:																																														
BATHING:																																														
PEOPLE/HOUSE/HOURS																																														

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