

**HUMAN FACTORS IN RESIDENTIAL ENERGY EFFICIENCY: EXPLORATORY STUDY  
IN AN ENERGY TEST FACILITY**

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**Abstract**

*Implementing residential energy efficient strategies frequently affects the occupants by involving human factors of thermal comfort and user convenience (time, physical effort, or attention). This paper presents an analysis of human factors and measured energy savings resulting from the use of selected energy efficient strategies in residential heating while families lived in a residential test facility. Seven volunteer families lived separately in the test facility for six-week periods and trial tested five heating strategies for one week each. Human factors and energy consumption data were collected for each strategy. The heating strategies were (1) closing off bedroom vents and doors, (2) setting the thermostat at 65° F, (3) using a sunspace, (4) using a woodstove, and (5) combining the use of the sunspace and woodstove. After each family used all five strategies, the adult male and female family members ranked the strategies according to perceived demands of time, physical effort, attention and to perceived general convenience of use. They also ranked their perceived thermal comfort. The participants' evaluation of strategy use indicated a trade-off of convenience (time, physical effort, and attention) for thermal comfort and energy savings. Rankings indicated that reported convenience was inversely related to perceived thermal comfort and energy savings. The most convenient strategy (i.e., setting the thermostat at 65° F) produced lower perceived thermal comfort and energy savings than did the least convenient strategy (i.e., combining the use of the sunspace and woodstove). Results are discussed relative to the advantages and limitations of using a test facility in studying residential energy use.*

**Introduction**

Although considerable progress has been made since the 1970s in reducing residential energy consumption, vigorous initiatives are necessary in the 1990s for wise use of available resources in a globally-endangered environment (National Academy of Sciences, 1991). Space heating is the largest single energy use source in residences and has received particular attention in efforts to improve energy efficiency. Specifically, households have improved energy efficiency in space heating either by making changes to the structure (such as adding insulation, storm doors and windows), by using alternative systems (such as woodstoves and sunspaces), or by implementing energy-related practices (such as practicing thermostat management and closing off unused rooms).

Regardless of which approach a household may choose to improve energy efficiency in space heating, user involvement and the changes in habits and routines often required to implement energy efficient strategies are important factors affecting energy savings. Residential energy studies have primarily assessed savings that can result from strategy use and have often overlooked occupant-related behavior involved in producing those energy savings. Moreover, efforts to measure energy consumption will be incomplete if user response to energy use is left unobserved (Stern, 1984).

Because many strategies require some human interaction (i.e., opening and closing doors and windows as well as adjusting thermostats), the interaction of the user with the activity can greatly influence whether a particular strategy or set of strategies will achieve the desired energy efficiency. Even in homes which are structurally energy efficient and which

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contain energy efficient systems, research indicates that energy savings are highly dependent on the energy use habits and routines of residents (Seligman, Darley, & Becker, 1978; Socolow, 1978; Stern, 1985; Weihi & Gladhart, 1990).

Other research describing user involvement or demands placed on the user in the operation of residential energy systems, or energy efficient strategies, has dwelled on the tasks, decisions, and knowledge involved in the use of the system/strategy (Case & DeJonge, 1982; Kempton, Harris, Keith & Weihi, 1985). Specifically, lack of knowledge and misconceptions in operating systems has been found to influence the efficient operation of the space conditioning system (Kempton, 1984; Weihi & Gladhart, 1990).

As a household implements energy efficient strategies, requirements are often made on human factors including time, physical effort, and attention. Human factors in energy efficient strategies have been studied primarily from the occupant's satisfaction with the thermal environment. Most notable has been the establishment of standards for the thermal environment by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 1981a). Further, thermal comfort has been identified as a major variable influencing an individual's practice of energy efficiency (Socolow, 1978).

This paper reports results from a study that examined both energy savings and human factors involved in using selected energy efficient strategies in residential space heating. The reported results are drawn from a comprehensive investigation<sup>1</sup> of lifestyle issues and energy use (Turner, Gruber, & Klett, 1988). The objectives of the study reported in this paper were (1) to study selected energy efficient strategies in space heating relative to user involvement in strategy use, and (2) to compare the relative energy savings of the particular strategies. Specifically, the research questions for this paper were the following:

1. What is the relative importance of the human factors of thermal comfort and convenience (time, physical effort, and attention) in implementing each heating strategy?
2. What are the energy savings associated with using each heating strategy?

## **Methodology**

### ***Research Design***

The study was conducted in a residential test facility in which seven families lived separately for six-week periods and trial tested selected energy efficient strategies in space heating. The study of energy use by individual households versus examining household data at the group level has been recommended as a way to better understand residential energy use behavior (McDougall, Claxton, Ritchie, & Anderson, 1981). The use of a residential test facility approach provided an opportunity to study and collect detailed data on a small number of households in a semi-controlled environment. Other research efforts have used either a laboratory approach in which individuals occupied test chambers for short periods of time and responded to environmental conditions (ASHRAE, 1981b), or a field study approach in which families were observed in limited ways in their own home environment (Winnett, Hatcher, Fort, Leckliter, Love, Riley, & Fishback, 1982).

The first week of the six-week residency served as a baseline period. During the baseline week, each family was encouraged to select comfortable temperature settings controlled by a heating thermostat located on each floor. The baseline period was used to establish the family's baseline energy consumption as well as to provide an opportunity to become familiar with the house and data collection procedures. After the baseline week, each family trial tested five heating conservation strategies. Each strategy was used separately for one week.

The residency time periods occurred in the late Fall to early Spring (November through April) during 1983 to 1986. The selected time periods coincided with the months of heaviest demand for heating as determined by degree day<sup>2</sup> and other climatic data established for the region of North Carolina in which the test facility is located (Burby & Marsden, 1980; Goswami, Klett, Raiford, & Stefanakos, 1979). Specific time periods of occupancy appear in Table 1.

### **Residential Test Facility**

The residential test facility was Garrett House, a pre-World War II two-story brick house located on the campus of North Carolina Agricultural and Technical State University, Greensboro, North Carolina. The house was retro-fitted with appropriate insulation and storm windows/doors and was rated as an energy efficient structure by the local utility company. A passive sunspace and other energy conserving features also were added to the residence. The primary heating source for the test facility was a gas furnace that was centrally controlled by separate thermostats located on each floor. The house contains 2770 sq. ft. floor area based on inside dimensions; a floor plan of the house is shown in Figure 1.

The features of the house that were utilized in the testing of energy efficient strategies were: (1) the vents and doors to the bedrooms, (2) the woodstove, and (3) the attached passive sunspace. Below is a brief description of some of the pertinent details of these features.

**Bedroom Doors and Vents.** The bedrooms were located on the second floor. The bedroom doors could be shut and opened easily by the participants but the heating vents could be opened or closed only by removing the vent covers. The vents were located in the center of the bedroom ceilings and were closed only for the week that involved the heating strategy of closing bedroom vents. The vents were opened and closed at the appropriate times by the project staff.

**Woodstove.** An Efel® woodstove was installed in the living room fireplace. Heat produced by the woodstove was distributed to the adjacent family room and to the upstairs area through natural convection.

**Sunspace.** A sunspace located on the south side of the house served as a solar collector to provide space heating for the house. The system provided heat to the residence by two means: (1) two sets of French doors which opened into the living room allowed heat transfer directly into the downstairs living space, and (2) a thermostatically-controlled blower delivered warm air from the sunspace to both the upstairs and downstairs when the sunspace temperature reached 80°F.

### **Data Collection Methods**

**User Evaluation.** Questionnaires administered at the beginning and end of the period of each family's residency in the test facility were used to collect the user evaluation data. The adult male and female participants ranked the five heating strategies according to his or her perception of time involved, physical effort required, attention demanded, and general convenience in implementing the strategies. The adult participants also ranked the strategies according to their thermal comfort experienced during the strategy use. Because a separate question concerning user acceptability was not included in the original questionnaire design, an overall measure of user acceptability was created by averaging the rankings of user convenience and thermal comfort for each strategy.

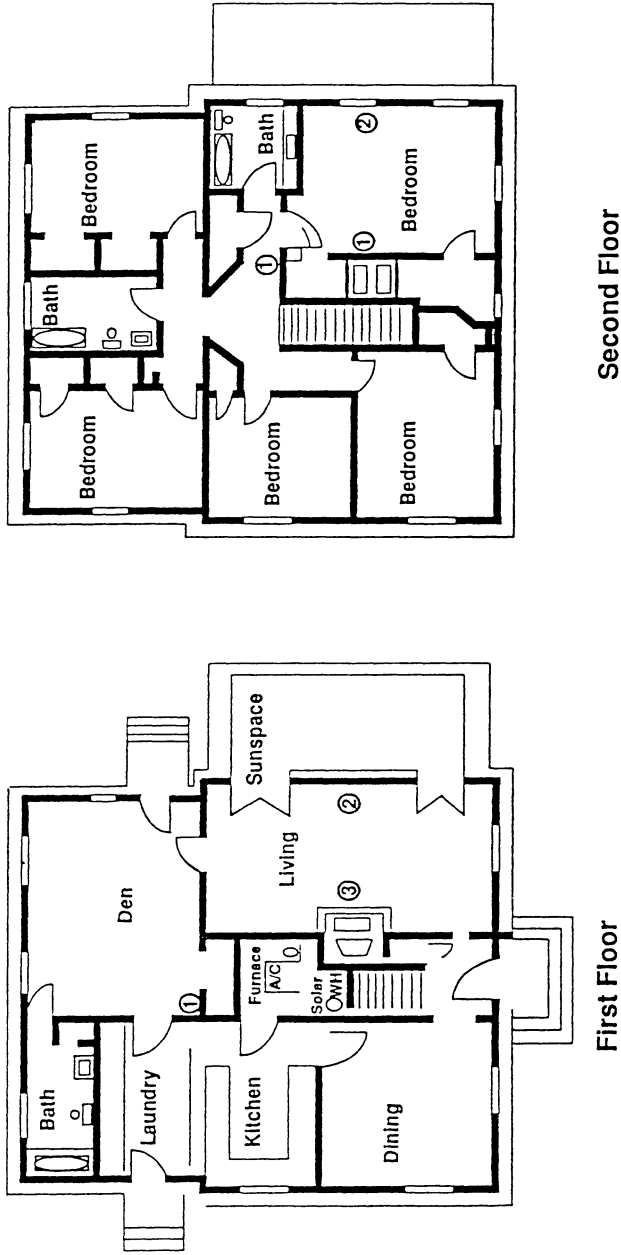
A ranking of "1" indicated the lowest demand for the human factors of time, physical effort, and attention. For the convenience ranking, "1" was the most convenient; for thermal comfort, "1" indicated the most comfortable. For acceptability, "1" was the most acceptable.

**Energy Consumption.** Energy consumption by strategy was based on the gas consumption of the heating furnace and the number of degree days during the week the strategy was used by each family. Specifically, the energy usage for the week was divided by the number of degree days that occurred during the week. The use of degree days was an attempt to control for differences in energy demand due to weather conditions and to allow a comparison of energy consumption across the weeks of use by a family.

Energy savings data indicated the relative impact of a strategy in offsetting the energy consumption of the central heating system as measured during each family's baseline period. The family's baseline energy consumption was defined as the amount of natural gas used per degree day during the initial (baseline) week when the participants set the thermostat at their preferred temperature. Energy savings for each strategy was determined by comparing energy use during the week of strategy use. Energy consumption across the families for each of the five heating strategies provided a means to determine the range and average percent savings achieved through strategy use.

Figure 1. Floor plan of Garrett House.

# Floor Plan of Garrett House



- Key: ① Thermostat  
② Warm Air Vents from Sunspace  
③ Woodstove

### **Participant Selection**

The seven volunteer families were selected on two primary characteristics: family size and age(s) of children. Selection on the basis of these characteristics insured inclusion of families of various sizes and stages in the life cycle. Although it was anticipated in the planning stage of the study that these characteristics would impact energy consumption, subsequent analyses did not reveal a trend in the relationship between the energy data and family characteristics (Turner, 1985). The seven participating families had a family size ranging from two persons to five persons (husband, wife, and up to three children). The ages of the children varied from preschool to teen-age. All families included a married husband and wife which allowed assessment of two adult respondents, as well as comparisons of male and female responses. Major demographic characteristics and residency periods appear in Table 1.

The participating families were recruited through public service television messages and through contacts with project personnel and other participating families. The selection panel consisted of the first author and a senior colleague from the Department of Human Environment and Family Sciences, North Carolina Agricultural and Technical State University. Families involved with the project were neither staff, employees, nor relatives of the project personnel. Four of the seven were employees of the University; the remaining three families were not affiliated with the University. All families lived within a 20 mile radius of the University.

Because the study was designed to evaluate each family's reactions to selected energy efficient strategies, participation in the study required families to move into the test facility for the six-week participation period and to use the test house as their primary place of residence (i.e., sleep, eat, entertain). The families were encouraged to continue their usual home, social, and work activities. The families were responsible for personal expenses, but did receive a stipend of \$400.

### **Procedures For Trial Use of Strategies**

The selected energy efficient strategies in space heating represented strategies that either could be implemented with limited monetary requirements or could feasibly be added to most residential structures. The five heating strategies tested were closing off bedroom doors and vents, setting the thermostat at 65°F, and using a sunspace and woodstove (both singly and in combination). During the weeks that the sunspace and woodstove were used, either alone or in combination, the thermostat was set at 65°F. Following the baseline week, the strategies were tested for one-week periods. For four of the families, the use of the sunspace alone preceded the use of the woodstove alone. This was done to investigate any ordering effects when the strategies were introduced. No apparent ordering effects were found. The order of testing the strategies was the following:

- Week 1: Baseline energy consumption data and preferred thermostat settings were obtained. No strategies were introduced.
- Week 2: The central heating thermostats were kept at the family's preferred temperature setting. Heat inlets in the bedrooms were closed by project staff and the doors to these bedrooms were kept closed by the participants during the day when the rooms were not in use.
- Week 3: The central heating thermostats were kept at 65°F and the restrictions on bedroom heat inlets and doors were withdrawn. Heat inlets were opened by project staff.
- Week 4: The heating thermostats were kept at 65°F and use of the sunspace as a heat source was introduced.
- Week 5: The heating thermostats were kept at 65°F, use of the sunspace continued, and use of the woodstove was added.
- Week 6: The heating thermostats were kept at 65°F, use of the sunspace was discontinued, and use of the woodstove continued.

At the beginning of each week, families were given written instructions on strategy use; when appropriate, demonstrations also were given. The families were asked to use the strat-

Table 1. Demographic characteristics of the families.

Family	1	2	3	4	5	6	7
Family Size	3	4	5	4	2	4	2
Sex/Age of Children	F 4 yrs M 4 yrs	F 7 yrs M 4 yrs	F 12 yrs M 5 yrs M 2 yrs	M 6 yrs M 8 mos	---	F 6 yrs M 4 yrs	---
Age of Adult (yrs.)							
Husband	42	35	40	36	70	25	31
Wife	37	38	44	36	69	25	34
Education							
Husband	College Grad.	Post-Graduate	Vocation Sch.	High Sch. Grad.	College Grad.	High Sch. Grad.	Post-Graduate
Wife	Post-Graduate	Post-Graduate	High Sch. Grad.	College Grad.	College Grad.	High Sch. Grad.	High Sch. Grad.
Employment Status							
Husband	Full-time	Full-time	Full-time	Full-time	Retired	Full-time	Full-time
Wife	Full-time	Full-time	Full-time	Full-time	Retired	Disability Leave	Coll. Student
Employment Type							
Husband	Technical	Professional	Operator	Technical	---	Sales	Professional
Wife	Professional	Professional	Clerical	Clerical	---	Protective Serv.	---
Family Income	\$15,000-19,999	\$35,000-39,999	\$20,000-24,999	\$25,000-29,999	\$15,000-19,999	\$30,000-34,999	\$30,000-34,999
Date of Residence	Mid-February to Mid-April, 1983	Late October to Mid-December 1983	Early January to Late February, 1984	Early December, 1984, to Mid-January, 1985	Late January to Mid-March, 1985	Early November to Late December, 1985	Early January to Late February, 1986

egies as instructed but were not asked nor encouraged to try to save or reduce energy consumption.

## Results

### ***Human Factors***

Composite rankings of the human factors involved in the use of five heating strategies are presented in Table 2. The strategy that was ranked the least time intensive of the strategies was setting the thermostat at 65°F. Two strategies ranked as the most time intensive: closing the bedroom vents/doors and using the sunspace alone. The strategy considered to require the least amount of physical effort was setting the thermostat at 65°F, and the strategy requiring the most effort was combining the use of the sunspace and the woodstove. The strategy requiring the least amount of attention was setting the thermostat at 65°F; the strategy requiring the most attention was using the sunspace in combination with the woodstove.

When asked to rank the strategies in overall convenience, the participants selected setting the thermostat at 65°F as the most convenient and using the sunspace and woodstove in combination as the least convenient. This overall convenience ranking paralleled the ranking when the separate scores for time, physical effort, and attention were combined. The similarity of the two rankings suggests that the three separate factors of time, physical effort, and attention represented independent dimensions that the families used to evaluate the ease in strategy use.

### ***Perceived Thermal Comfort***

The couples ranked the strategy of using the sunspace and woodstove together as producing the most thermal comfort (see Table 3). The strategy of using the woodstove alone was ranked second in terms of thermal comfort, followed by closing bedroom vents/doors, and then by using the sunspace alone. The strategy ranked as least comfortable was setting the thermostat at 65°F without the availability of a supplemental heat source.

### ***Acceptability***

The results indicate that using the space in combination with the woodstove was the most acceptable strategy to the families (see Table 3). The strategy considered the least acceptable was setting the thermostat at 65°F with no use of supplemental heating sources.

### ***Energy Savings***

When the energy consumption resulting from each family's use of each strategy was compared with that particular family's baseline consumption level, the average savings resulting from the use of the strategies ranged from 28% to 70% (see Table 4). The greatest energy savings was achieved with the combined use of the sunspace and woodstove (70%). This highest level of energy savings was followed closely by the strategies that used the sunspace alone (63%) and the strategy that used the woodstove alone (59%). Next in savings achieved was the strategy of setting the thermostat at 65°F (43%). The strategy contributing least to the energy savings involved closing the bedroom doors and vents (28%).

The project staff assumed that each family would select thermostat settings above 65°F during the baseline period; all but Family 2 did. Instead, this family kept the heating thermostats on 55°F. As a result, use of the heating system during the baseline period was minimal, and more energy was used during the strategy use weeks (when the heating thermostats were set at 65°F) than during the baseline period.

## Discussion

The findings indicate that the human factors of time, physical effort and attention, general convenience, and thermal comfort varied with strategy use, with no one strategy being both the most convenient to use or producing the most thermally-acceptable environment. The rankings indicate that reported convenience was inversely related to perceived thermal comfort and energy savings. While contributing to the understanding of the variability of convenience, thermal comfort and energy savings in strategy use, the study also raises some

Table 2. Rankings of human factors: User demands and convenience.

Family Adult Participant	1		2		3		4		5		6		7		Avg Rank	Rank Order
	M	F	M	F	M	F	M	F	M	F	M	F	M	F		
Strategies																
Close bedroom vent/doors	4	4	3	2	5	3	5	4	4	2	3	2	2	2	3.2	4.5
Set thermostat at 65°F	5	5	1	1	1	5	2	5	5	1	1	1	1	1	2.5	1
Sunspace/Set thermostat at 65°F	3	3	2	3	4	4	3	3	3	3	4	3	4	3	3.2	4.5
Sunspace/Woodstove/Thermostat 65°F	1	1	5	5	3	1	4	1	1	5	2	5	5	5	3.1	3
Woodstove/Set Thermostat at 65°F	2	2	4	4	2	2	1	2	2	4	5	4	3	4	2.9	2
Physical Effort <sup>b</sup>																
Close bedroom vent/doors	4	2	3	2	2	2	2	2	2	2	2	2	3	2	2.3	2
Set thermostat at 65°F	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1.3	1
Sunspace/Set thermostat at 65°F	3	3	2	3	3	3	3	3	3	3	3	3	4	3	3.0	3
Sunspace/Woodstove/Thermostat 65°F	1	4	5	5	4	5	5	5	5	5	4	5	5	5	4.5	5
Woodstove/Set Thermostat at 65°F	2	5	4	4	5	4	4	4	4	4	5	4	2	4	3.9	4
Attention <sup>c</sup>																
Close bedroom vent/doors	4	2	3	2	4	5	4	2	3	5	N/A	2	3	2	2.9	3
Set thermostat at 65°F	5	1	1	1	1	1	2	1	1	1	N/A	1	1	1	1.3	1
Sunspace/Set thermostat at 65°F	2	4	2	3	3	2	3	3	2	3	N/A	3	4	3	2.6	2
Sunspace/Woodstove/Thermostat 65°F	1	5	5	5	2	4	5	5	5	4	N/A	5	5	5	4.0	5
Woodstove/Set Thermostat at 65°F	3	3	4	4	5	3	1	4	4	2	N/A	4	2	4	3.1	4
Convenience <sup>d</sup>																
Close bedroom vent/doors	2	2	4	3	5	5	1	1	4	2	4	4	2	2	2.9	2
Set thermostat at 65°F	1	1	1	1	1	1	5	2	5	1	5	5	1	1	2.2	1
Sunspace/Set thermostat at 65°F	3	3	2	2	2	2	3	3	2	3	3	3	4	3	2.7	3
Sunspace/Woodstove/Thermostat 65°F	5	5	5	5	3	4	2	5	3	5	1	1	5	5	3.9	5
Woodstove/Set Thermostat at 65°F	4	4	3	4	4	4	4	4	1	4	2	2	3	4	3.3	4

<sup>a</sup>Rankings ranged from 1 to 5, with 1 requiring the least amount of time.

<sup>b</sup>Rankings ranged from 1 to 5 with 1 requiring the least physical effort.

<sup>c</sup>Rankings ranged from 1 to 5, with 1 requiring the least amount of attention. N/A = Data were not provided by respondent.

<sup>d</sup>Rankings ranged from 1 to 5 with 1 being the most convenient.

important questions concerning variability among households, as well as the appropriateness of using a test facility in studying energy use.

#### ***Variation Among Families***

Variability in energy consumption as a function of human factors consideration was well demonstrated in this study. Despite efforts to control residential environmental variables (use of a test facility) and weather environmental variables (heating degree days adjustment), the results show that individual family variations were the norm even for strategies that required little user effort to implement.

#### ***Varied Response to Human Factors***

The families had varying experiences as indicated by the wide range in scores for almost all the strategies on the separate operational demands of time, physical effort, and attention, as well as thermal comfort (see Tables 2 and 3). The findings parallel results by Weihl and Gladhart (1990), indicating that behavior is complex within households, and varies greatly across households.

This variation in evaluation of the strategies in operational demands and thermal comfort suggests that when households are deciding on possible adoption of energy conservation strategies, consideration needs to be given to evaluating user involvement required in the use of strategies, as well as to the resulting energy consumption. Thus, it is important to consider both the convenience factors involving time, physical effort, and attention, as well as the experience of thermal comfort.

#### ***Variation in Energy Consumption***

Despite the fact that many of the usual variables were controlled, (the same structure was used, energy consumption was based on degree days for comparison, and the same energy efficient strategies were tested), the results showed considerable variation in energy consumption. Although it was anticipated that family size and type would impact energy consumption, subsequent trend analysis did not indicate such a relationship. The variation in energy consumption found was primarily due to variations in each family's specific use of the strategies and the use of the structure. Previous analysis of the energy data did indicate a trend relationship between previous experience in the use of the woodstove and energy savings resulting from its use. Specifically, greater prior experience with woodstove use resulted in greater savings from its use (Turner & Gruber, 1988). Previous participant experience level was similar for the other heating strategies.

#### ***Importance of Thermal Comfort***

Perceived thermal comfort was more important to the participants than convenience in strategy use. When the comfort rankings were combined with the convenience rankings to create a strategy acceptability measure, those strategies with the highest comfort rankings also had higher acceptability rankings. Acceptability of user involvement depended on whether the involvement ultimately produced a thermally-acceptable environment. This finding supports previous research that identified thermal comfort as a major variable affecting energy consumption. Previous research has shown that thermal comfort is sometimes more important than saving energy (Socolow, 1978).

#### ***Importance of Options***

The strategies that had options to alter the thermal environment were related to user acceptability. The availability of some form of instant relief from unsatisfactory room temperatures was an important factor in the acceptability of the energy efficient heating strategies in this study. The heating strategies which involved supplemental heat sources (sunspace or woodstove) were rated as most acceptable to families. This may be partially due to the fact that the participants could go to a warm spot if they became thermally uncomfortable. This trend in the data points to the importance of heating strategies that can promote thermal comfort while also contributing to the goal of energy savings.

#### ***Using a Test Facility for Studying Energy Use Behavior***

This study represented a unique opportunity to go beyond a simulation or a controlled laboratory assessment of energy use behavior. By using actual families in a real home, it

Table 3. Rankings of human factors: Thermal comfort and acceptability.

Family Adult Respondent	1		2		3		4		5		6		7		Avg Rank	Rank Order
	M	F	M	F	M	F	M	F	M	F	M	F	M	F		
Strategies																
Close bedroom vent/doors	1	1	5	4	5	2	1	2	4	4	4	4	3	1	2.9	3
Set thermostat at 65°F	5	5	4	5	4	5	5	5	5	5	5	5	5	5	4.9	5
Sunspace/Set thermostat at 65°F	4	4	3	3	3	3	3	3	3	3	3	3	2	4	3.1	4
Sunspace/Woodstove/Thermostat 65°F	2	2	1	1	1	1	2	1	1	1	1	1	1	2	1.3	1
Woodstove/Set Thermostat at 65°F	3	3	2	2	2	4	4	4	2	2	2	2	4	3	2.8	2
Acceptability <sup>b,c</sup>																
Close bedroom vent/doors	1.5	1.5	4.5	3.5	5	3.5	1	1.5	4	3	4	4	2.5	1.5	2.9	2.5
Set thermostat at 65°F	3	3	2.5	3	2.5	3	5	3.5	5	3	5	5	3	3	3.5	5
Sunspace/Set thermostat at 65°F	3.5	3.5	2.5	2.5	2.5	2.5	3	3	2.5	3	3	3	3	3.5	2.9	2.5
Sunspace/Woodstove/Thermostat 65°F	3.5	3.5	3	3	2	2.5	2	3	2	3	1	1	3	3.5	2.6	1
Woodstove/Set Thermostat at 65°F	3.5	3.5	2.5	3	3	3.5	4	4	1.5	3	2	2	3.5	3.5	3.0	4

<sup>a</sup>Rankings ranged from 1 to 5, with 1 being the most comfortable.

<sup>b</sup>Rankings ranged from 1 to 5, with 1 being most acceptable.

<sup>c</sup>Rankings represent an average of the Convenience and Comfort rankings.

Table 4. Energy consumption savings for the heating strategies for each week compared against baseline.

Family	1		2		3		4		5		6		7		Avg Rank Savings Order															
	CFG	DD	CFG	DD	CFG	DD	CFG	DD	CFG	DD	CFG	DD	CFG	DD																
Baseline	3125	107	29.2	...	25	70	0.4	...	5225	174	30.0	...	4625	163	28.4	...	6625	207	32.0	...	1625	60	27.0	...	5625	161	36.2	...		
Bedroom Vents	1325	72	18.4	37%	425	76	5.6	...	4825	156	31.6	-5%	1825	103	17.7	38%	6225	199	31.3	2%	125	30	4.2	84%	3925	120	32.7	10%	28%	5
Set 65° F	1325	91.4	14.5	50%	2225	136	16.4	...	2725	167	16.3	46%	1325	115	11.5	60%	4525	187	24.2	24%	725	64	11.4	58%	6325	219	28.9	20%	43%	4
Sunspace	1725	130	13.3	54%	925	98	9.4	...	225	95	2.4	92%	1225	87	14.0	51%	525	80	6.6	79%	425	45	9.4	65%	2225	100	22.3	38%	63%	2
Combination	1125	113	10.0	66%	1225	128	9.7	...	25	56	0.4	99%	2925	178	16.4	42%	225	62	3.6	89%	325	105	3.1	89%	4325	191	22.6	38%	70%	1
Woodstove	825	65	12.7	57%	925	110	8.4	...	2125	180	11.8	61%	3025	202	15.0	47%	1225	133	9.2	71%	2225	190	11.7	57%	1125	83	13.6	62%	59%	3
Average Use for All Strategies			13.8	53%			9.9	...			12.5	58%			14.9	47%			15.0	53%			7.0	74%			24.0	34%	53%	

CFG = Cubic ft. of natural gas

DD = Degree day

CFGDD = Cubic ft. of natural gas/degree day

SVGS = Percent of natural gas used per strategy in relation to amount used during the baseline week

... = Savings were greater than 100% because family #2's preferred temperature was below the minimum selected for comparison

was possible to study the practicality of the strategies and how their use was affected by the families. The study represents the only known completed study in which families implemented energy efficient strategies while living in a test facility with extensive behavioral and energy consumption monitoring.

**Advantages.** Unlike a pure laboratory setting where the focus of a study is likely only to concentrate on the acceptability of controlled room temperatures, such as in the ASHRAE studies (ASHRAE, 1981a), this study provided a more realistic and dynamic situation of people evaluating the comfort of the environment in which they were living and having some impact (in terms of operation of the strategies) on the comfort level of that environment. The test facility also allowed greater monitoring and control of the building variables than is possible in field studies of persons living in their own homes.

**Limitations.** The obvious limitations include the fact that the families were volunteers, that the number of participating families was small, and that only selected space heating strategies were tested. However, none of the limitations challenge the accuracy or meaningfulness of the data. The limitations are included to alert the reader to recognize the limitations on the representativeness and generality of the findings.

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 efficient efforts and the results should be helpful in directing future inferential studies. The results, therefore, cannot necessarily be generalized directly to a larger population. Instead, the families' experiences provide greater understanding of the human factors involved in the implementation of heating energy efficient strategies. Also, although the study was completed in the 1980s, there are no known reasons why the findings are not currently applicable or do not assist in expanding current knowledge and understanding of occupant energy efficient behavior.

One important aspect to the study design that should be emphasized is that because the families had freedom to come and go and to move about the house, evaluations across families were not likely based on the same amount of time in the house or in the same rooms. Consequently, for some families, evaluation of some of the strategies may have been based on a much more limited exposure relative to other families. Variation in exposure assists in explaining some variations in perception of user involvement. Also, while no restrictions were placed on what families could wear or what activities they could engage in while in the home, this may have affected their resulting comfort and reaction to operational demands of the strategies.

Another limiting factor not under the control of the project was varying weather conditions. Although the heating demands resulting from the varying weather were somewhat controlled by the use of degree days, mild weather was experienced by some families for some strategy weeks. This mild weather resulted in either low reliance on the strategy (such as use of the woodstove) or produced less awareness of its comfort-producing capacity (such as the heating thermostat set at 65°F).

Another limitation was the amount of time (one week) each family had for using and implementing each of the strategies. A week may be an inadequate period of time to evaluate all or even most of the possible concerns and problems that might arise with the use of a particular strategy. Due to the nature of the study, the strategies were introduced one at a time and used only one at a time (except for the combination of woodstove and sunspace). The use of one strategy at a time was somewhat artificial, but necessary. Under normal family living conditions, it is likely that families would use several conservation strategies depending on what options were available to them.

#### **Recommendations for Further Study,**

Although this study examined the responses of families in their use of the energy efficient strategies, especially in their assessment of the operational demands and of thermal comfort, the study did not concentrate on a detailed description of their other day-to-day activities in the use of the home energy systems. An example of this is that the families were not asked to indicate daily how often they added wood to the woodstove, or exactly when they opened and closed sunspace and bedroom doors. This information would be useful in

determining the exact impact of their individual actions. Research is needed that delineates individual user behavior that result in energy savings.

Although this study examined selected energy efficient strategies, additional study is needed on the acceptability and energy saving aspects of supplemental sources of heating residences, such as portable heaters. This is important because not all homeowners can afford or will prefer to have woodstoves or sunspaces added to their residences. Also, renters have limited choices of space heating alternatives.

Obviously, all strategies will not meet the individual needs of all households. Some households may benefit more than other households from a given strategy, primarily due to lifestyle pattern including the time of day at home, flexibility of schedule, and tolerance for inconvenience in implementing strategies. This latter group includes such activities as taking time to open and close window coverings to take advantage of the direction of the sun, and raising/closing windows according to outside temperature and the "sunny" side of the house. A systematic way to match families with strategies could assist in promoting optimal results from strategy use.

### References

- ASHRAE (1981 a). *ANSI/ASHRAE Standard 55-1981. Thermal environmental conditions for human occupancy*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- ASHRAE (1981 b). *Handbook of fundamentals*. New York: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- Burby, R. J., & Marsden, M. E. (Eds.) (1980). *Energy and housing: Consumer and builder perspectives*. Cambridge, MA: Oelgeschlager Gunn & Hain, Publishers, Inc.
- Case, D. F. & DeJonge, J. (1982). *Integrated design research for household energy conservation: Clothing, interior, and design*. Report to the National Endowment for the Arts (Research Project No. NEA-12-4252-042) by the University of Tennessee, Knoxville.
- Goswami, D. Y., Klett, D. E., Raiford, M. T., & Stefanakos, E. K. (1979). *Solar radiation design data for North Carolina, handbook*. Energy Division, North Carolina Department of Commerce.
- Kempton, W. (1984). Two theories used for home heat control. In B. M. Morrison & W. Kempton (Eds.), *Families and energy: Cooing with uncertainty* (pp. 643-656). Institute for Family and World Study, College of Human Ecology, East Lansing: Michigan State University.
- Kempton, W., Harris, C. K., Keith, J. G., & Weihl, J. S. (1985). Do consumers know "what works" in energy conservation? *Marriage and Family Review*, 9, 115-133.
- McDougall, G. H. G., Claxton, J. O., Ritchie, J. R. B., & Anderson, C. D. (1981). Consumer energy research: A review. *Journal of Consumer Research*, 8, 343-354.
- National Academy of Sciences (1991). *Policy implications of greenhouse warming*. Washington: National Academy Press.
- Seligman, C., Darley, J. M., & Becker, L. J. (1978). Behavioral approaches to residential energy conservation. *Energy and Building*, 1, 325-337.
- Socolow, R. H. (1978). *Saving energy in the home: Princeton's experiment at Twin Rivers*. Cambridge, MA: Ballinger.
- Stern, P.C. (1984). Saving energy: The human dimension. *Technology Review*, 16-25, 62.
- Stern, P.C. (1985). *Energy efficiency in buildings*. Committee on Behavioral and Social Aspects of Energy Consumption and Production, Commission on Behavioral and Social Sciences and Education, National Research Council. Washington, DC: National Academy Press.
- Turner, C. S. (1985). Perceived thermal comfort and energy conservation strategies. (Doctoral Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia). *Dissertation Abstracts International*, 46, (2642-B).

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- Turner, C. S. & Gruber, K. J. (1988, June). *Use factors influencing household energy consumption*. Paper presented at the Annual Meeting of the American Home Economics Association, Baltimore, Maryland.
- Turner, C. S., Gruber, K. J., & Klett, D. E. (1988). *The effect of energy conservation strategies on lifestyle* (Research Bulletin Series T-140). Greensboro, North Carolina: Agricultural Research Program, North Carolina Agricultural and Technical State University.
- Weihl, J. S. & Gladhardt, P. M. (1990). Occupant behavior monitoring and successful energy conservation: Findings and implications of behavioral monitoring. *Proceedings of the 1990 Summer Study on Energy Efficiency in Buildings, Volume II*. American Council for an Energy-Efficient Economy: Monterey, California.
- Winett, R. A., Hatcher, J., Fort, T. R., Leckliter, I., Love, S. Q., Riley, A. W., & Fishback, J. F. (1982). The effects of videotape modeling and feedback on residential electricity consumption, temperature and humidity, comfort and clothing work: Winter and summer. *Journal of Applied Behavior Analysis*, 15, 381-2.

#### Footnotes

<sup>1</sup> The heating strategy data reported in this paper are the result of a study entitled *The Effect of Home Energy Conservation Strategies on Lifestyle*, funded by the United States Department of Agriculture, Cooperative State Research Service, Project Number: NCX-046-5-80-170-1, and completed at North Carolina Agriculture and Technical State University, Greensboro, North Carolina, in the Agricultural Research Program, Housing Research. The four-year research effort (1982-1986) explored lifestyle factors and energy use through an intensive study of fifteen families who live separately in a residential test facility either during winter months or summer months. Nine families participated in the winter months phase of the study; six participated during the summer months. This paper reports data on seven families who participated in the winter months and whose involvement provided data on energy consumption as well as convenience and thermal comfort factors.

<sup>2</sup> A degree day is defined as the difference in Fahrenheit temperatures between 65°F and the average temperature-for a particular day. Degree days are used to estimate heating requirements (ASHRAE, 1981b).