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Effects of Home Weatherization on Occupant Comfort: First Report of A Field Study

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EFFECTS OF HOME WEATHERIZATION ON OCCUPANT COMFORT: FIRST REPORT OF A FIELD STUDY

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

This study reports preliminary examination of data testing the hypothesis that, when existing residences are treated with weatherization retrofitting measures intended primarily to save fuel, house occupants are likely to report improvement in wintertime comfort. Data were gathered through questionnaire-guided interviews with individuals in 108 experimental houses and 37 control houses. These houses, at nine sites representing a range of U.S. climates, were part of a three-year National Weatherization Demonstration, sponsored by the Community Services Administration and planned and managed by researchers at the Center for Building Technology of the National Bureau of Standards. The experimental houses had been weatherized to determine how much their fuel usage could be reduced by cost-effective retrofitting. The control houses had not been weatherized in the demonstration. Interview topics included: thermostat setting patterns, impressions of comparative comfort, amounts of clothing worn, and specific comfort and temperature ratings for the house as a whole and for individual rooms in the house. Preliminary examination of the data has focussed on: 1) a composite "comfort change" index, comprised of: indicators derived from thermostat setting practices in unusually cold weather, impressions of change in comfort-related attributes of the indoor environment, amounts of clothing worn in winter, and comfort ratings of the house and of individual rooms, 2) the specific comfort ratings, and 3) the specific temperature ratings. The results present strong indications of support for the hypothesis.

ACKNOWLEDGMENTS

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SI CONVERSION UNITS

In view of the present accepted practice for building technology in this country, common U.S. units of measurement were used throughout the report. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the International System of Units (SI) in 1960, the table below is presented to facilitate conversion to SI units. Readers interested in making further use of the coherent system of SI units are referred to: NBS SP 330, 1977 Edition, The International System of Units; and ASTM E621-78, Standard Practice for the Use of Metric (SI) Units in Building Design and Construction.

Table of Conversion Factors to SI Units

To Convert From	To	Multiply By
Btu	J (joule)	1.056×10^3
F degree	K (kelvin)	0.556
R-value $(Btu/(ft^2 \cdot hr \cdot °F))^{-1}$	$(W/m^2 \cdot k)^{-1}$	1.761×10^{-1}
°F	°C	0.556, after subtracting 32.

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1. BACKGROUND AND STATEMENT OF THE PROBLEM

The United States has entered a time of energy transition and potential crisis. Modern industrial societies have been designed and adapted to depend for their energy needs largely on fossil fuels. While the consequent demand for and consumption of such fuels has grown apace in recent decades, it is now increasingly recognized that these sources of energy are "capital goods," and the earth has only a finite endowment. This situation mandates efforts to: 1) reduce the rates of consumption of depleting fuels, and 2) shift to the use of renewable forms of energy supplies. The time pressures attending this necessary transition are compounded for the United States by our current heavy dependence on petroleum supplies from foreign nations. Thus, while pursuing the development of economical technologies to utilize non-depleting forms of energy, the United States must also reduce its present rate of energy consumption.

In even a temperate climate such as that of the United States, a significant fraction of the energy used goes to maintaining healthful and satisfying indoor environment conditions, in particular maintaining desired indoor air temperatures in winter. Roughly 16 percent of our energy consumption occurs in our houses (Clark & Hastings, 1979, p.4). By far the largest segment of the 16 percent is used to maintain the comfort conditions of the air in dwellings--principally temperature and relative humidity. This largest segment of residential energy consumption can be further broken down into 1) space heating (its largest component), 2) air conditioning (still only about three percent of the residential total), and 3) ventilation (an insignificant fraction in residences, covering power attic ventilators and fans and air conditioners used for ventilating purposes).

Thus, space heating of homes consumes, by recent estimates, 11 percent of total U.S. energy (70 percent of overall residential consumption) (Clark and Hastings, 1979). Within the residential one-sixth of our total energy usage, space heating seems clearly the highest priority area for efforts to reduce present energy consumption levels.

The amount of energy used to maintain wintertime indoor temperatures is a function, principally, of the amount of heat lost through the building shell. (It is also affected by the efficiency of the space heating equipment). The rate of heat loss is principally a function of 1) the shell area, 2) the (average) thermal resistance of the shell, and 3) the temperature difference across the shell ($\Delta T = T_{indoor} - T_{outdoor}$). When designing new buildings, one can give attention to minimizing the shell area for a building of given enclosed space. However, for most existing residences--which include the houses in which most people will be living next year and five- even twenty-years hence, the only feasible ways to reduce energy usage are increasing the thermal resistance of the building shell and reducing the ΔT across the shell. (This presupposes the continued use of conventional, fuel-consuming space heating equipment.)

Both approaches have been addressed in the last few years in this country. Twice since 1973, Americans have been urged, in the interest of reducing the Nation's demand for imported oil, to lower their wintertime thermostat settings: to 68°F in 1973, and then to 65°F in 1979 (Smith, 1979, p. 431). Also, many programs and incentives have been established to help and encourage residents to improve the heat conserving properties of their dwellings.

This study is concerned with the implications for occupant comfort of reducing space heating energy consumption in residences.

The single most important environmental parameter affecting human comfort (as discussed below) is air temperature. To significantly lower wintertime thermostat settings is to directly and deleteriously affect this human comfort parameter. Moreover, there is a 50-year documented trend of gradually rising preferred indoor temperatures in the U.S. (Nevins, McNall, & Stolwijk, 1974, p. 42). This trend may or may not be necessary or desirable; nevertheless, it needs to be considered before invoking "instant" energy conservation measures contrary to it. There <u>are</u> ways for occupants to compensate for a lower ambient air temperature and maintain thermal comfort, namely: to wear more or heavier clothes and/or to be more physically active. However, both of these compensations are behavioral choices that may or may not be acceptable to--or practical for--occupants, in which cases people are likely to set their heating thermostat at 70° or 72°F (or even higher, for reasons discussed below), rather than being uncomfortable during cold weather.

The other approach to reducing space heating energy consumption, which is increasing the thermal resistance of the building, is accomplished through weatherization retrofitting of the building. This may involve installing new or additional insulation in attics and walls, adding storm windows, caulking and weatherstripping around windows and doors to minimize infiltration of cold air/exfiltration of heated air, or improving the efficiency of the heating system. This work can require a financial outlay up to several thousand dollars for a typical house in the more northerly areas of the United States; however, based on typical present-day fuel costs, such expenditures for weatherization can be expected to be recouped in saved fuel costs within a few years. Moreover, there are reasons to expect that this approach to reducing energy consumption will also maintain and probably improve the level of wintertime thermal comfort felt by occupants in their house <u>without any behavioral modifications on their part</u>. In fact, in some cases weatherization retrofitting is likely to have the effect of inducing residents to voluntarily lower thermostat settings in order to <u>maintain</u> thermal comfort (i.e., avoid overheating)--for reasons that are discussed below. This consequence would bring about even greater fuel savings than those directly attributable to the increased heat flow resistance of the building shell.

The Community Services Administration sponsored (under an Interagency Agreement signed in March, 1978), and the National Bureau of Standards carried out, from mid-1977 to late 1980, a national "optimal weatherization demonstration." The principal goal of the demonstration was to find out how much reduction in fuel consumption could be achieved by installing cost-effective weatherization in various types of houses in different climate zones of the United States (Crenshaw, Clark, Grot & Chapman, 1978). The approach was to: 1) establish the pre-weatherization rates of fuel usage of the experimental houses; 2) carry out all weatherization work which a cost/benefit analysis had shown to be economically effective in the climates and with the fuel costs of the different sites; 3) measure the post-weatherization fuel consumption of the houses; and 4) compare the measured and projected savings in fuel costs with the measured costs of the weatherization work. Data collected in the project, in addition to fuel consumption and air infiltration measurements, included weekly representative temperature readings on each occupied floor of project houses, and monthly detailed measurements of the temperature variations within the dwellings. In addition, data were obtained on certain occupant activities and attitudes affecting energy consumption in the houses.

The present paper reports the first phase of study of the comfort-related data from the CSA Weatherization Demonstration--namely, development of an appropriate questionnaire and a plan to administer it, and analysis of the questionnaire data. The author hopes eventually to be able to compare the occupants' reports about the wintertime comfort in their houses before and after weatherization with the temperature measurements recorded over the same time period. The goal of the analysis is to determine whether changes in comfort are related to changes in the measured temperature variation in the houses brought about by weatherization. The first step in this analysis, described and reported in this paper, is to see if reported comfort is related to whether a house was weatherized or not.

2. OVERVIEW OF THE STUDY

2.1 GOAL OF THE RESEARCH

The overall objective of this study was to measure the comfort impressions of residents of houses before and after the houses were weatherized, and to compare the measures. A second objective was to compare the comfort impression measures with the temperature stratification measurements of the houses.

2.2 THEORY CONTEXT

The feelings or impressions of thermal comfort experienced by an occupant of an indoor space, while essentially subjective in nature, are clearly influenced by certain physical parameters of the indoor environment. First among these is obviously the temperature of the air. Air at temperatures within some range will be felt by a person to be "comfortable", while outside of that range it is felt to be "uncomfortable"--"too cold", or "too warm." However, even considering just the relation of dry-bulb air temperature to occupant comfort, the matter is more complex. It cannot be assumed that the temperature of all of the air in a space is uniform; that is, the temperatures may 1) feel uniformly comfortable, 2) feel uniformly uncomfortable, or 3) be so varying from place to place in the space as to feel more or less uncomfortable.

People's feelings of thermal comfort are affected by another environmental parameter: the radiant temperatures of the solid surfaces surrounding them (i.e., walls, windows, ceiling, floor). Since the temperatures of these various surfaces likely differ at any given time, their effect is generally dealt with in terms of the "mean [average] radiant temperature" (MRT) of the surrounding surfaces. To the extent that this temperature is lower than the dry-bulb air temperature in the space, the MRT has a relatively larger effect on an occupant's feelings of "comfort" than does the air temperature.

A third environmental parameter that influences comfort impressions is relative air movement. Particularly if the dry-bulb air temperature is on the low side of the "comfortable" range, movement of the air past the body at greater than some fairly low rate will exacerbate the effects of the low air temperature, and increase a person's "uncomfortableness." In an indoor space, such as a dwelling, such excessive air movement may result from wind-induced leakage around loose-fitting windows or doors, convection currents of cold air flowing down from windows, or even walls, or air flows generated by the heating system.

The fourth environmental parameter that can affect people's comfort feelings is relative humidity (or water vapor pressure) in the ambient air. Ordinarily this factor only comes into play in warm situations, when the relative humidity is high enough to interfere with the evaporation of sweat.

All of these comfort-influencing environmental parameters can be directly affected by one or more of the building retrofits or treatments that are applied under the subject of "building weatherization." Weatherization has generally been carried out in the interest of reducing the heating energy consumption of the building--or of saving energy. However, the CSA weatherization demonstration offered an opportunity to obtain data with which to try to determine whether weatherization of a house might also result in improved occupant comfort in winter.

2.3 METHODS

The CSA Weatherization Demonstration was a three year (1977-1980) study, conducted in or near 12 U. S. cities, and intended primarily to ascertain how much reduction in fuel consumption could be obtained by "optimal" weatherization of houses occupied by low-income people (Crenshaw et al., 1978). It also sought to learn something of the effectiveness of broad categories of retrofitting: "conduction" (i.e., increasing the thermal resistance of the building shell by adding insulation, storm windows), "infiltration" (i.e., reducing infiltration/exfiltration by means of caulking, weatherstripping), and "mechanical systems" (i.e., improving the efficiency of the heat producing and distributing systems in houses). In all, some 240 houses at the 12 sites were studied in the demonstration. The "before weatherization" rate of fuel consumption of the houses was established by analyzing two years of archival fuel delivery records (utility billing records for gas or electricity, delivery records for oil, bottled gas or kerosene). A cost-effective set of weatherization retrofits was determined for each house, using "cost/benefit" economic analysis. The weatherization work was either done by local Community Action Agency (CAA) weatherization crews in the site areas, or contracted out by the agencies. The site agencies progressed at varying rates, so that weatherization work began as early as fall, 1978, in some cities, and was completed as late as January 1980, in others.

To permit "compressing" the post-weatherization data collection period, meters were installed in the houses, for recording and reporting of: furnace fuel consumption, furnace run-time, furnace on-off cycles, water heater fuel consumption, and hot water consumption. Local CAA personnel read these meters, as well as the total house electric and gas (utility) meters, and thermometers installed near the center of each floor of the houses, weekly, and forwarded the data to the research staff at the National Bureau of Standards for review and analysis.

Field personnel measured and recorded other data monthly over the period of the demonstration study: The infiltration rate of each house was measured, using a tracer gas-decay method. Of particular relevance to hoped-for future extension of the present study, an interior temperature profile of each house, called a "temperature stratification test," was recorded monthly. Each test comprised a number of sets of temperature readings, obtained in different areas of the house with a quick-responding, electronic digital thermometer. Thus, a number of rather detailed descriptions of temperature variation within each house was recorded once a month over two heating seasons. Finally, to obtain data for the present comfort study, the field personnel conducted a questionnaire-guided interview of a responsible member of each household.

3. LITERATURE REVIEW

3.1 GENERAL THERMAL COMFORT/DISCOMFORT

The implications of indoor temperatures for occupants have been recognized for over a century. In a History and Art of Warming and Ventilating Buildings, published in 1845, W. Bernon addressed the issue:

> "Leaving Foulkner and his disciples [climatologists of that time] in possession of their dogma, that governments may stamp the manners but it is the air they breath which molds the form, temper, and genius of the people, we may go with it so far with the ingenious enthusiast as to admit that warmth exerts a considerable influence on our physical, if not also our mental condition. The formation and regulation of artificial climate will then assume the character of an art for developing and expanding the mind and the body, for preserving health and for prolonging life" (quoted in Nevins, McNall & Stolwijk (1974)).

Bernon concludes with the prescient statement, "The skillful practice of the art [of formation and regulation of artificial climate] as a means of saving fuel will become essential, not to the well being, only, but to the existence of many comunities." (Emphasis added.)

Human thermal comfort, as a field and as a topic for extensive experimental efforts, can be traced to the work of Houghton and Yaglou in the United States. Beginning in 1923, these investigators mapped out the combinations of ambient dry bulb temperature and relative humidity which resulted in reports of "feelings of equal warmth" by subjects. To briefly review the physical, physiological, and psychological bases of human thermal comfort:

The human body is a heat engine, key components of which (e.g., the brain, other internal organs) can survive and function properly only within fairly narrow temperature limits. The body's manner of maintaining correct internal temperature is to generate a surplus of heat, appropriately regulating the dissipation of excess heat to its surroundings.

A sitting, resting adult breathes in 15 to 20 cubic feet of air per hour. Metabolic processes utilizing the oxygen in the air produce about 400 Btu (422 kilojoules) of heat that must be dissipated. A thermally comfortable adult wearing ordinary clothes, sitting in a room in which the air is practically still, with a dry bulb temperature of 60°F (15.6°C) and relative humidity of 50 percent, loses the 400 Btu as follows: about 46 percent by radiation to the solid surroundings, about 30 percent by convection, and 24 percent by evaporation from the lungs and skin (Angus, 1968). The maximum mechanical efficiency of the human body is roughly 20 percent--so that when substantial amounts of metabolic energy are being converted into physical or mental work, four-fifths of the total energy produced is still excess heat that must be dissipated.

The physiological mechanisms for controlling the rate of heat loss to the environment are sweating and vasoconstriction. When insufficient heat is being dissipated, sweating commences, to increase the rate of heat loss, primarily through the heat of vaporization necessary for evaporating the sweat from the skin. When heat is being lost at too rapid a rate, the veins near the body surface constrict, reducing the amount of blood flowing through them, and consequently the rate of transfer of heat from the interior of the body to the skin. Using these regulating mechanisms, the human "thermoregulatory system is quite effective and the heat balance [of generation in vs. loss from the body] can therefore be maintained within wide limits of the environmental variables, corresponding to wide limits of the physiological parameters [skin temperature and sweat secretion]" (Fanger, 1970, pp. 37-38). Physiologically, "thermal comfort" is that condition in which the body does not have to exercise either regulatory mechanism in order to maintain the heat balance. Thus, Fanger continues: "This [satisfying of the body's heat balance over wide ranges of environmental variables] is...far from being a sufficient condition for thermal comfort...there is only a narrow interval [of the environmental variables] which will create thermal comfort" (Fanger, 1970, p. 38).

One line of the work started by Houghton and Yaglou, to characterize the environmental and other variables affecting human thermal comfort and to ascertain the limits within which comfort can be found, culminated in the classic work of Fanger (1970), cited above. Fanger worked out in considerable detail an equation expressing the body's heat balance, and used it to generate curves and tables with which levels of human thermal sensation can be accurately predicted from environmental and personal variables. Such predictions can be made in two different forms: 1) those combinations of the variables which will produce "optimal thermal comfort," and 2) the "predicted mean vote" (on a seven-point scale, with thermal neutrality as center point--discussed below) of a group of people experiencing the specified set of conditions.

Fanger identified six variables as materially affecting feelings of thermal comfort. They can be divided into two groups: Two are personal factors: 1) activity level (heat production in the body), and 2) thermal resistance of the clothing worn (expressed in a derived unit called "clo"). The other four factors are environmental: 3) air (dry bulb) temperature, 4) mean radiant temperature of surrounding solid surfaces, 5) relative air velocity, and 6) water vapor pressure in the ambient air. The four environmental factors are the physical parameters which can affect the rates of heat transfer from a body by radiation, convection, and evaporation.

Other authors have listed additional factors affecting the range of environmental conditions that will be found acceptable, for example: "personal: age, sex, body composition, body build, diurnal variation, metabolic rate, state of acclimation; behavioral: meal pattern, clothing worn, thermal antecedents, physical activity antecedents, mental concentration; environmental: distractions (noise, vibrations, odors), lighting, decor. Synergistic as well as inhibitory interactions are not only possible but probable." (Buskirk & Loomis, nd, p. 2). Nevertheless, Fanger's six factors are the only ones that have been systematically studied, and they have been shown in many studies with "standardized" conditions to quite adequately explain human thermal sensations. The other variables affect the minimum predicted percentage of dissatisfied (PPD), calculated by Fanger as five percent at the optimal combinations of his six variables.

So far in this paper, "thermal comfort" has been equated with "thermal neutrality," in the sense of absence of physiological regulatory effort. The psychological counterpart to this concept would imply the absence of sensations of either warmth or coolness, or, "... that [a person] does not know whether he would prefer a higher or lower ambient temperature," (Olesen, Mortensen, Thorshauge, & Berg-Munch, 1980, 1st page). This shift from defining thermal comfort physiologically in terms of the net physical heat balance of the body to defining it psychologically in terms of expressed mental attitude is explicitly recognized in recent thermal comfort work. Furthermore, "... physiologists have recognized that sensations of comfort and of temperature may have different physiological and physical bases, and each type should be considered separately. In the ASHRAE Comfort Standard 55-66 thermal comfort is defined 'as that <u>state of mind</u> which expresses satisfaction with the thermal environment.'" (ASHRAE, 1978, p. 138, emphasis added.) The discussion continues: "Unfortunately, very little practical research has been reported to date that specifically answers this ASHRAE definition ... the majority of our current predictive charts are based on comfort defined as a sensation 'that is neither slightly warm or slightly cool'" (ASHRAE, 1978, p. 138). In consonance with this newer understanding, the present study asked respondents to report both their temperature sensation and their impressions of comfort.

Relative humidity is more likely to affect comfort impressions in hot than in relatively cool environments, so is unlikely to be a factor in wintertime comfort. It is true that installing a vapor barrier in a house in conjunction with insulating the house could result in a noticeably higher indoor relative humidity. (Relative humidity was reported as part of the weekly data in the present study, so the records can be examined for any occurrences of excessive humidity.)

As summarized by McIntyre (1978a, pp. 4, 7): "By comfort we mean a state of satisfaction, i.e., a person is comfortable if he says he is comfortable. [Furthermore] thermal comfort is not an exact concept, nor does it occur at an exact temperature. A person may be comfortable over a range of temperatures and if the temperature is changed so that it moves outside this range, the onset of discomfort is not sudden... A person's reaction to a temperature which is less than perfect will depend very much on his expectations, personality, and what else he is doing at the time." A loose relationship is still assumed between thermal sensation and comfort feelings: "The generally accepted convention is to treat thermal discomfort in terms of the scale of warmth sensation, and the comfort range taken to be the three central categories of the seven-point scales" (usually: "slightly warm," "neutral," "slightly cool") (McIntyre, 1978a, p. 7). However, two recently reported experiments, one conducted at Capenhurst, England, in winter and the other at New Haven in summer, found that subjects stating that they were "comfortable" (the neutral point on the widely-used scales) nevertheless "would like to be warmer" in the winter experiment and "would like to be cooler" in the summer one (McIntyre, 1978b, 5th page). McIntyre reasonably observes: "The explanation probably lies in the connotations of the words 'warm' and 'cool.' In a cold climate people want to be 'warm;' they do not dream of a room somewhere which is thermally neutral. Conversely, in a hot climate..." (McIntyre, 1978b, 5th page).

To summarize: 1) "Thermal comfort" is a function of the physical heat balance state of the "heat engine" human body. 2) It was long defined and studied as a special condition of thermal neutrality--maintenance of the heat balance without the noticeable intervention of the physiological thermoregulatory system. 3) As such, it is governed by four environmental parameters: air temperature, (mean) radiant temperature, relative air movement, and water vapor pressure or relative humidity. 4) It is now considered in a somewhat altered light as an aspect of (mental) satisfaction, linked in some way with the sensation of temperature or heat/cold.

3.2 EFFECT OF MEAN RADIANT TEMPERATURE

In the words of Nevins & McNall (1972, p. 33): "... dry bulb temperature is usually the major factor in determining the thermal exchange of the human body, ... in most environmental control systems, the dry bulb temperature is the controlled variable, and it is the most commonly used single variable employed to estimate or classify the thermal environment." However, heat does "flow" by radiation from surfaces with higher radiant temperatures to surfaces with lower radiant temperatures. Since the human body is dissipating as much as one-third or more of its excess heat by radiation to the solid surroundings, even under typically "comfortable" conditions, the average or mean radiant temperature (MRT) of those surrounding surfaces is likely to have significant effects on the body's heat balance.

A common assumption is that the temperature of the surfaces in a room is the same as the temperature of the air with which they are in contact, and most thermal comfort studies in environmental chambers have been carried out with such a relationship. However, in the "real world," such a relationship often does not prevail in houses (or office buildings) during cold weather. As Nevins and McNall (1972, p. 33) state: "Thermal radiation exchange or the mean radiant temperature is determined by the inside surface temperatures of the space, which in turn are dictated normally by the outdoor conditions, the construction of the building, window areas, solar load, etc." To the extent that the indoor surface temperatures do differ from indoor air temperatures in cold weather, they are almost always lower.

Consider a cross section of an exterior building component--a wall, or a pane of glass--in winter. There exists a thermal gradient across any such component: on the inside is air at some value close to the indoor air temperature. On the outside is air at the prevailing outdoor temperature--anywhere from 20 to 50 (or more) F degrees lower. At various points across the building shell component, temperatures between the two described extremes occur. The difference between any two adjacent temperatures as one traverses the building component is a function of the thermal resistance between the two points. It is important to understand what happens at the surface where air meets solid material. Stagnant air exhibits a relatively high resistance to heat flow. On the indoor side of the component, there is likely to be slight air movement, consequently a fairly thick layer of stagnant air, and a relatively high thermal resistance "between" the room air and the surface. Thus, the surface may be significantly colder than the indoor air (Smith, 1979, p. 473). On the outdoor side, air currents may well be stronger, the stagnant layer thinner, and consequent thermal resistance smaller--and the temperature of the outside surface almost the same as the outside air temperature. Single pane glass has very low resistance to heat flow (R 1.0)--thus the inside surfaces of single-glazed windows are, in cold weather, areas of quite low radiant temperature, lowering the MRT of the inner surfaces of a room.

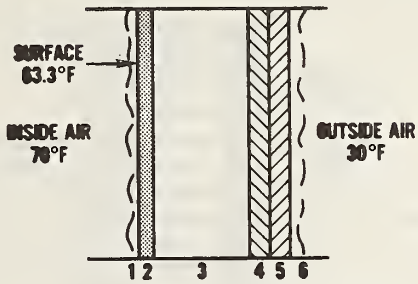
What is the consequence of the MRT being significantly lower than the air temperature in a space? Since the human body in this situation will lose more heat by radiation to the surrounding surfaces, to maintain its heat balance it <u>must</u> lose less by convection (and evaporation). In other words, to maintain thermal comfort, a depressed MRT must be compensated by a raised air temperature. Fanger's calculations, confirmed by studies reported by Nevins and McNall (1972, p. 34), show that, for persons wearing light to medium clothing, dry bulb air temperature may have to be raised as much as 1°F for a 1°F drop in MRT to maintain thermal comfort. Any step which adds to the thermal resistance of the building shell, such as adding insulation to a wall, adding storm windows or triple glazing to a window, will increase the total resistance vis-a-vis that of the inside stagnant air layer, and as a consequence raise the temperature of the inner surface of the shell component for a given prevailing outside temperature and wind condition.

Consider two examples:

1) A typical uninsulated wood frame wall in a house at the Allentown, Pennsylvania, demonstration site has an R-value of 4.3 (see figure 1, next page). If an occupant tries to maintain an indoor air temperature for comfort of 70°F and the outdoor temperature is 30°F, the inner surface of an exterior wall would be at about 64°F. The amount of radiation loss of a body is dependent on the particular surfaces to which it is "exposed." Thus, for a standing or even a seated person, the bulk of the radiation loss is to the walls, and the temperatures of the walls have the largest effect on the mean radiant temperature experienced by an occupant of the room. Consequently, a single wall surface at 64°F could have the effect of lowering the mean radiant temperature of a room by 1 to 1.5 F degrees (assuming one wall is, effectively, approximately one fifth of the surface to which the body is exposed---the effect could be even more, depending on how close the person is to the wall). For a corner room with two exterior walls, the MRT could be lowered to 67.5 or 68°F. The air temperature in these two rooms would have to be raised as much as 1.5 and 2.5 F degrees, respectively, to maintain comfort for a sedentary, lightly to moderately clothed individual.

2) Solid masonry (two layers of 4 inch brick) walls, common in the demonstration houses in St. Louis and Allentown, have a typical

Figure 1. Temperatures across an uninsulated wall in cold weather



	R-VALUE	% TOTAL
1 STILL AIR	0.61	17
2 PLASTER	0.32	
3 STUDS	1.13	
4 SHEATHING	0.78	83
5 SIDING	0.63	
6 STILL AIR	0.17	
TOTAL	3.64	100%

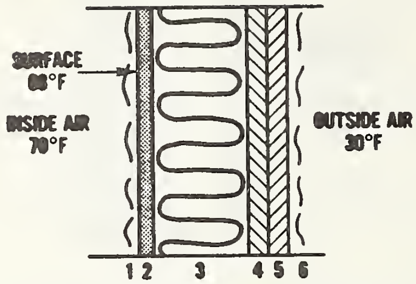
R-value of 3.3. With this type of wall, and the indoor and outdoor conditions described in the first example, the MRT experienced in the above two rooms (i.e., non-corner, or corner) could typically be 68.5 and 67°F, respectively. These conditions would require increases of air temperature of as much as 1.5 and 3 F degrees, respectively, to maintain thermal comfort for typical occupants.

Note that, with the same prevailing air temperature conditions, the inner surface temperature of a single-glazed window would be about 56°F! Thus, large, single-glazed window areas can cause significant lowering of the MRT in a room.

Occupants of houses with uninsulated walls and substantial areas of single-glazed windows are quite likely to seek needed increases in interior air temperature in cold weather by raising the furnace thermostat setting, thereby raising the ΔT across the building thermal envelope, increasing the envelope heat loss, and increasing furnace fuel consumption.

If insulation equivalent to R-13 is added to the exterior walls in either of these two examples (one inch of rigid foam board applied to the inside or outside of masonry walls, or five inches of cellulose blown into frame walls), the deficiency of MRT below air temperature would be reduced to less than 0.9 F degrees in the most extreme case (see figure 2, next page). As a consequence, the uniformity of thermal comfort conditions in the rooms would be improved, and the need for raising the air temperature would be significantly reduced.

Figure 2. Temperatures across an insulated wall in cold weather



	R-VALUE	% TOTAL
1 STILL AIR	0.61	4
2 PLASTER	0.32	96
3 STUDS & INSULATION	12.00	
4 SHEATHING	0.78	
5 SIDING	0.63	
6 STILL AIR	0.17	
TOTAL	14.50	100%

Berglund (1977, pp. 117-118), reviewing the state-of-the-art of measuring the four environmental properties affecting thermal comfort, states: "... measurement of thermal radiation in the built environment is still elusive to the HVAC [heating, ventilating and air conditioning] engineer and has been often overlooked or neglected because accurate measurement is difficult and time consuming." In the present field study, although the MRT in the houses has not been measured, some inferences about the effects of MRT are made, based on 1) the known thermal resistance characteristics of the building walls and windows, and 2) the measured (air) temperature variation throughout the houses.

3.3 BEHAVIORAL THERMOREGULATION AND THERMAL ADAPTATION

I have briefly described the physiological mechanisms of thermoregulation and quoted Fanger's observation that the body's modification of vasoconstriction and sweat rate can maintain a proper internal temperature over a rather wide range of the pertinent environmental parameters. However, we know that people survive and function in an even wider range of environments. The means by which we succeed in doing this is behavioral temperature regulation motivated by thermal discomfort (Hardy, 1971, p. 50). This motivation is a reason that people build buildings, move to the sheltered side of a building on a windy winter day, drill for oil, put on or take off a sweater or long stockings, open or close windows or shades, and turn up or down a thermostat. The objective is not only to ensure maintenance of correct internal body temperature, but also, to minimize physiological regulatory stress--ergo discomfort, by affecting the environment at the body surface.

The important point for the present study: this, most powerful, loop for regulation of body temperature will affect--interfere with, to a degree--"measurements" made by people (comfort ratings) of a built environment. People can adjust to lower indoor temperatures by wearing more clothes, or even by being more active and energetic.

3.4 SCALES

Since the present study required recording occupants' reports of their impressions of comfort--and temperature--in their houses in winter, appropriate scales for recording such impressions had to be identified.

In recognition of the distinction between temperature sensation and comfort sensation, ASHRAE studies and other researches make use of two scales for subjects to rate their environments. The rating scales commonly used in comfort studies in this country are: the "ASHRAE" seven-point scale of warmth, or temperature, sensation (McIntyre, 1976, p. 4) and the four-point scale of comfort-discomfort sensation developed and used at the John B. Pierce Foundation. McIntyre has carried out an extensive evaluation of seven-point scales of warmth (McIntyre, 1976). The author observes: "It is clearly a category scale. The categories can be unambiguously ordered, and are usually presented ordered and numbered. It is therefore an ordinal scale. This is enough to perform non-parametric statistics. However, ... a goal of comfort work is to be able to predict the comfort of people, and to do this it is necessary to be able to work in terms of the parameters of the distribution of votes" (McIntyre, 1976, p. 10). Using the data from a number of comfort experiments that have employed the seven-point scales, McIntyre finds that "there is nothing to suggest that the category widths vary systematically, and no reason to suppose that we are not dealing with an equal interval scale [with the obvious exceptions of the end categories]."

To get a measure of the within-subjects reliability of the seven-point warmth scale, McIntyre analyzed data from several experiments in which the subjects were exposed to identical environmental conditions over a six hour exposure or at intervals of from one to three weeks. From the results of these studies, McIntyre obtained average standard deviations of 1.0 scale units for between-sessions vote variation and 0.8 for within-session. In one experiment several scales were used, mostly seven-point semantic differential-type scales. "In general, scales of warmth had a mean difference [between subjects] of about one interval, while evaluative scales (e.g., comfort) had a mean difference of about two intervals."

To study the variation of votes across temperatures, McIntyre performed regression analyses of data from several experiments in environmental chambers, including 1296 observations recorded at Kansas State University and at Fanger's laboratory in Denmark. For mean temperatures ranging from 22.6°C (72.7°F) to 25.6°C (78.1°F) the between-subjects standard deviations ranged from 0.8 K (1.44 F degrees) to 1.5 K (2.7 F degrees). He was able to calculate within-subjects standard deviations for two of the studies. These were 0.6 K (1.1 F degrees) and 1.2 K (2.2 F degrees), respectively. Elsewhere McIntyre (1978b, 5th, 6th pages) has presented figures for the variation of warmth votes (seven-point scale) with temperature as "a consistent value of 0.33 scale units per degree K" for environmental chamber studies, and 0.23 su/K for field studies. He suggests the "variation (noise) in the scales must reflect some spontaneous variation in sensation." Furthermore, Rohles (1980, 6th page) found, by plotting data from an earlier study of 1600 subjects in terms of mean vote against standard deviation of the vote, that "the variability of the responses is highest around the temperatures judged to be comfortable...."

In the present study I faced a measurement problem. One must conclude about the scales and the (physiological) instrument used for measurement of comfort ratings in this study: 1) The seven-point warmth scale is a reasonably uniform category scale (with the exception of the end categories). However, 2) even in "standard" condition environmental chamber studies, the warmth scale is somewhat unstable for between-sessions comparison. 3) Virtually no data exist as to the stability and uniformity of the five-point comfort scale used. (The results presented in section 4.5 offer indirect evidence that this problem was not as serious as feared.)

3.5 FIELD STUDIES OF THERMAL COMFORT

More than 30 field studies of thermal comfort have been carried out in various parts of the world in the last 40 years. These are reviewed and compared by Humphreys (1975). Many of these studies, "have two purposes: to find a way of describing the thermal environment which correlates well with human response, ... and to define the range of conditions found to be pleasant or tolerable by the population concerned." In the field studies, the respondents continue their usual normal activities in their usual surroundings, but are asked to report or record their subjective impressions from time to time. "Usually in field studies no attempt is made to control the environmental conditions... In this way the studies gain in realism but lose some of the advantages of planned experimental designs. It would generally be true to say that they are not so much experiments as surveys accompanied by measurements" (Humphreys, 1975, 2nd page).

As to the measurements, "There is a wide variation among the studies in the completeness with which the thermal environment has been measured." In view of the relative simplicity of its measurement, air temperature is often the only parameter recorded, "but... there has usually been no attempt to shield the thermometer from radiation, so its readings would [be] affected to some extent by the mean radiant temperature of the surrounding surfaces" (Humphreys, 1975, 3rd page).

Although relative humidity can have an effect on comfort in certain situations, it has been shown to have no noticeable effect at levels and in combination with temperatures ordinarily found in houses--i.e., as long as sweat can freely evaporate from the skin. Wet and dry bulb thermometer readings were recorded as part of the weekly data from the houses in the present study, and can be checked for extreme values that might lead to discomfort. Air velocity, particularly in houses heated by circulating air systems or relatively leaky unweatherized houses, may well be an unmeasured parameter in the present study that does affect comfort perceptions. Humphreys suggests that air temperature alone is a satisfactory descriptor of the environment as long as air velocity is "very slight (≤0.2 m/s [0.7 ft/s])." This rate could be exceeded in local situations in houses.

The amount of clothing worn by respondents in field studies is usually not controlled, but is often recorded. (In present study the questions about clothing are addressed to possible changes in the amount of clothing typically worn.)

In seeking comfort ratings from respondents, the questions may refer "to the thermal state of the room, ... [or] to the thermal state of the respondent." The distinction, although subtle, does occur in common speech: "Is it hot in here, or is it just me?" (Humphreys, 1975, 5th page). (In the present study, the respondents are asked to ascribe comfort and temperature ratings to the spaces in the house.)

Comparing the findings of field studies to those from environmental chamber experiments, Humphreys observes, "Because they are free to continue their normal activity in their normal clothing and surroundings the respondents' assessments are likely to be reliable descriptions of their feelings in daily life, and not merely transient impressions of unfamiliar environments." (Humphreys, 1975, 5th page).

The knotty problem involved in conducting a field study such as the present one is clearly the reliability of the measurement judgments and the consequent validity of the comparisons of comfort ratings. None of the field studies reviewed by Humphreys appears to have involved the recording of comfort and thermal impressions several months or even a year and a half after the time in question, as does the present study.

Humphreys (1975, 11th page) presents a "category width" data, based on the seven-point rating of warmth, from two wintertime studies. One involved people engaged in "sedentary light industry" and the other involved school students, ages 11 to 16 engaged in their school lessons. The mean "0" (central) category width from the latter study was 2.9 K (5.2 F degrees) and the widths of the "-1" and "+1" ("slightly cool" and "slightly warm", respectively) categories were 4.2 K (7.6 F degrees) and 3.1 K (5.6 F degrees), respectively. Combining the mean category widths obtained from all studies which used a seven category scale, Humphreys obtained overall mean widths for the -1, 0, and +1 categories, respectively, of: 3.8 K (6.8 F degrees), 4.7 K (8.5 F degrees), and 3.7 K (6.7 F degrees). Of course, all of these figures include "between subjects" variation. These data, however, do give some crude indication of the sensitivity of the seven-point warmth scale to differences in dry bulb temperature, around its midpoint.

Some lessons can be drawn from the few studies of longer duration. Several involved obtaining impressions daily, weekly, or monthly over an entire year. One study gathered daily responses over a year, and "obtained the lowest regression coefficient [of rating to temperature], and the widest categories, of all the studies of adult subjects which used seven-category scales. This finding suggests that the response to the shorter term variations of temperature which occur from day to day has been 'diluted' by a much smaller response to seasonal variation" (Humphreys, 1975, 18th page). It is clear from these studies that, "the ability of respondents to adjust to their normal thermal environment has a profound effect upon their sensations of warmth" (Humphreys, 1975, 18th page). When Humphreys compares the regression coefficients obtained from the field studies with those typically obtained in climate chamber experiments, where the subject has no opportunity to adjust his clothing or level of activity to suit the environment, the values for field studies are found to be much lower (see table 1). These data suggest that, "even during intervals of hours rather than days, people's adjustment to the variations of temperature has a significant effect on their comfort".

Table 1

Regression Coefficients of Scale Unit to K Obtained from Various Types of Comfort Studies

Sampling	Regression coefficient/K
Climate chamber, standard clothing/activity	0.32
Field study--observations over some days or weeks, little seasonal drift of temperature	0.23
Field study--one observation per day, over whole year	0.16
Field study--one observation per week, over whole year; little daily variation of temperature	0.10
Field study--monthly means of responses over 15 months	0.05

(Humphreys, 1975, 18th page).

3.6 EFFECTS OF RECALL AND MEMORY FACTORS IN OBTAINING SURVEY DATA

The comfort- and temperature-impression data for the present study were obtained by means of retrospective questions incorporated in an interview questionnaire. Thus, they are subject to temporal and other effects on memory and recall. During the development of this study, question was raised about the possibility of obtaining valid, useable data about wintertime comfort feelings in one's own house one or two years earlier. The question is a legitimate one, and was addressed by exploring the pertinent literature.

Cannell and Kahn (1968) discuss the effects of memory on successfully obtaining information through interviewing:

> "Three broad concepts seem to comprise much of the available research and advice, and to summarize well the conditions for successful interviewing. These are accessibility of the required data to the respondent, cognition or understanding by the respondent..., and motivation of the respondent to take the [responding] role and fulfill its requirements," (p. 535) (emphasis in the original); and, "These are not independent factors; they [are]... a set of interrelated conditions for attaining adequate measurement by means of interviewing..."

The principal concern in the present study is with accessibility. "One aspect of accessibility has to do with memory decay or forgetting. The respondent may once have had the requested information readily available, but it has now receded from easy recollection or may be completely unavailable." (Cannnell & Kahn, 1968, p. 541) However, "'remembered,' 'forgotten,' and 'never known' should not be regarded as absolute categories. 'Forgotten' material can often be recalled with sufficient effort... there is a powerful interaction between memory and motivation." (Cannell & Kahn, 1968, p. 543).

"There is general agreement among students and practitioners of interviewing that the respondent's motivation or willingness to report is the most important issue in the accuracy of interview data, and that the context of the material sought has a major effect on respondent motivation" (Cannell & Kahn, 1968, p. 545, emphasis added). The fact that the questionnaire in the present study is focused on matters concerning weatherization, energy conservation and closely related comfort should help motivate respondents who have been closely involved with a weatherization demonstration for three years.

Quoting again from Cannell and Kahn: "Our problem ..., as far as accessibility is concerned, is to bring the relevant events to the consciousness of the respondent." Virtually all references to memory factors found in the literature refer to recollection of "events," not of impressions--affects. Thus, there is a dearth of direct evidence on the questions of concern to this study. Remembering "how you felt" would seem to be rather different in implications for "accuracy" than "When did you _____?" or "How often did you _____?" The authors continue, "... the material which a respondent is likely to find acccessible to him will be a complex function of elapsed time since the event, current cues... and the significance of the event in his life." (Cannell & Kahn, 1968, p. 560)

Seymour Sudman and Norman Bradburn have published an extensive study of response effects (average error rates) in surveys (Sudman & Bradburn, 1974). The authors calculated, from published studies, response effects for various factors which may affect the accuracy of responses to survey questions. In establishing a model for the understanding and analysis of response effects, Sudman and Bradburn identified three types of variables as potential causes of such effects: 1) task structure, 2) degree to which the task engages problems of self-presentation for the respondent, and 3) salience of the required information. Task structure involves matters of open- versus closed-ended questions, use of cards or other stimuli for aided-recall or to minimize interviewer or respondent interpretation of questions, and self- versus interviewer-administration. The authors suggest that "conditions of high structure tend toward the maximal adaptation of the task to the commonalities among respondents and to reduce sources of variation." (Sudman & Bradburn, 1974, pp. 8-9) (The questionnaire in the present study is highly structured).

Problems of self-presentation arise primarily from questions posing some threat to the respondent, those evoking some socially-desirable response, or those to which the respondent does not know the answer but wishes to appear knowledgeable and cooperative. The questionnaire in the present study does not involve questions of the first two types; as protection against response effects from lack of knowledge, the respondent was urged to feel free to state when he did not know or recall the requested information, because "the researchers realize that it may be hard for you to remember your impressions from that long ago."

Sudman and Bradburn consider the saliency, or importance to the respondent, of the requested information as a significant influence on response effects. It seems a reasonable assumption that their comfort is salient to most people.

Throughout their paper, these authors distinguish two types of survey data: 1) information about behavior (which can, in principal, be verified against records) and 2) information about attitudes or "psychological states" (to which the term accuracy does not apply) (Sudman & Bradburn, 1974, pp. 6-7). In the present questionnaire, there are behavioral items about thermostat settings, use of rooms in one's house in winter, or amount of clothes worn. There are attitudinal questions about temperature sensations and comfort. There exists a differentiation between the reporting of the two kinds of information. An additional factor affecting a person's recall of attitudinal matters is the "clarity of the respondent's state relevant to the issue"--"the extent to which the respondent has a well-formulated attitude or idea about the question he is asked..." (Sudman & Bradburn, 1974, p. 12). The literature of human thermal comfort research stretching over the last 50 years shows that this particular concern is not a problem for the present study: People do know what is meant and how they feel when asked, "How warm or cold are you?", or "How comfortable are you?"

Factors associated with differential memory affect both types of data. The four factors Sudman and Bradburn treat as affecting any recall of information are 1) recency, 2) importance, 3) complexity, and 4) affect or "repression." The last two are not involved significantly with any of the responses sought by the questionnaire used in this study. As to importance, I presume wintertime comfort and related behaviors to be fairly important to most people. Winter environments do not always and automatically stay within comfort limits, and, by its very nature, the discomfort experienced when those limits are exceeded is strongly conducive to behavioral and other responses on the part of the individual.

The factor, of these four, most pertinent to the present study is recency. These authors, as do Cannell and Kahn, emphasize that none of the factors is fixed and unchangeable, but that, "The formulation of the questions, however, plays an important role because it... can radically affect the perceived saliency of the requested information." (Sudman & Bradburn, 1974, p. 13) This advice was an important guide in the development of my questionnaire.

According to Worcester (1972), "What little research has been done on [long-term recall]... suggests that memory is fairly accurate where behavior is regular... much less accurate for the occasional departure from regularity... or for the informant whose behavior follows no regular pattern" (p. 74). For this reason, respondents in my study were asked, "Is the thermostat generally at the same setting each day in winter?"

Thus, the pertinent literature on memory effects in interview data indicates that recollection of information is a dynamic, not a static function. What is known suggests that: 1) Some respondents would not remember requested information from an earlier time period. 2) Some respondents would be able to provide valid and useful information. 3) The size of the latter group could be increased by properly phrasing and introducing questions. 4) Appropriate questions in the questionnaire can provide some indication as to the group to which a respondent belongs. (In the 145 cases analyzed for this report, approximately 80 percent of the respondents stated they were "very sure" or "moderately sure" of the comfort and temperature ratings they reported for the earlier winter.)

4. THE PRESENT STUDY

4.1 RESPONDENTS

The total of 240 experimental and control houses are distributed among 12 sites (with a control group of three to six houses at each site). The site areas represent a range of inhabited climates in the United States, from Fargo, ND, St. Paul/Minneapolis, and Portland, ME, to Oakland, CA, Atlanta, and Charleston, SC. (Unfortunately, no questionnaire data were received from Portland, and those from St. Paul/Minneapolis and Chicago required too much "cleaning up" to have been included in this report.)

Since the demonstration was sponsored by the Community Services Administration, participating households had to meet the Federal government's "low income" guidelines. People are in the "low income" category for various reasons. In some of the demonstration homes, the head of household is retired and living on Social Security--and consequently in the low income category. Some cases represent female-headed households. Although direct data relevant to the reasons for the household being in the low income category was not collected, the distribution of the ages of respondents to the questionnaire suggests that perhaps the "retired" households predominate. (See table 2.) Most, but not all, respondents were the head of the household.

Table 2

Distribution of Respondent Ages

<20	20-29	30-39	40-49	50-59	60-69	70-79	80-89	?
2	6	8	20	25	31	36	15	2

Houses for the demonstration were obtained thusly: 1) Candidate houses were proposed by local Community Action agencies, usually from their existing list of households that had applied for weatherization assistance. 2) Two year fuel consumption records for all proposed houses were run through a "balance point" analysis--a regression analysis of fuel consumption against degree days (a standard measure of the coldness of winter weather). To ensure valid "baseline" pre-weatherization fuel consumption, a minimum correlation coefficient (R^2) of 0.9 was used as a selection criterion. 3) From the resulting set of qualified households/houses, the experimental and control groups were selected as follows: the experimental group was to consist of "cells" of a minimum of five houses--each "cell" being characterized by a building type/construction type combination, e.g., "one-story detached, frame" or "two-story attached, solid masonry." This arrangement was predicated on our expectation that differences between the thermal performance of the different types might necessitate analyzing them separately regarding fuel usage.

Houses that ended up as control houses tended to be: 1) houses of a type too few at a particular site to constitute a "cell", 2) houses irregular in shape (e.g., "L"-shaped), thus more difficult to analyze thermally, and 3) houses whose owners did not want extensive weatherization (e.g., wall insulation retrofitting). For purposes of the energy conservation study, control houses were instrumented, weekly readings collected and all other testing and measuring done to the house, but no weatherization work was done on the houses. Note that control group houses were not obtained from a common pool of subjects by random selection. However, careful examination of the process by which experimental and control houses were picked did not identify any factors likely to cause systematic differential biasing of comfort impressions due to a household being in the control group.

4.2 EXPERIMENTAL DESIGN

To study the effects of weatherization of occupied houses on the comfort and temperature sensation reactions of the occupants before and after the weatherization work, a field study was conducted. The occupants were used as the "instruments" to assess the comfort of the houses.

With data available both from houses that were weatherized ("experimental") and ones that were not ("control"), the study was cast in the form of a "nonequivalent control group design" (Campbell & Stanley, 1963, pp. 47-50). The key characteristic of this design is that the experimental and control cases are not drawn from a common pool by random selection, consequently the control cases cannot automatically be assumed to be equivalent to the others. Two particular issues are important in relating the present study to the model: 1) How the control group was selected (discussed above), and 2) How the pre- and post-test measures were obtained. The comfort and temperature ratings and the relevant behavioral data, for both pre- and post-test situations, were obtained by means of retrospective questioning using a survey instrument. This is clearly a weak link in the study. The alternative--obtaining comfort assessments before the weatherization work was done, and then again afterward--might well be affected by even greater problems of shift in the subjective standard against which respondents judged comfort levels. (T. Cook and D. Campbell (1976) discuss this as an "instrumentation" problem.) In the present approach of employing retrospective questions, respondents could be asked during a single interview to make both comparative judgements ("Have you noticed any change in the comfort in your house over the last two winters?") and absolute judgements ("How would you rate the comfort of your house this past winter?", and, later in the questionnaire, "How would you rate the comfort of your house in winter a year ago?"). Then one can compare the responses on the two types of questions for congruence.

In the context of the body of theory and practice of field studies of thermal comfort discussed earlier, this study asked respondents to do something different than has been done before: to make integrated, retrospective evaluations of the overall comfort and temperature characteristics in their house and in individual rooms in their house. It asked respondents to report their environmental comfort impressions at two times separated by a year (or two). Legitimate questions can be raised as to whether these are reasonable expectations to place on people.

Concerning the possible threats to internal validity of this field study design, Campbell and Stanley state that we can regard it as controlling the main effects of history, maturation, testing, and instrumentation, assuming "the experimental and the control groups are [similar] in their recruitment" (Campbell & Stanley, 1963, p. 48). From the above description of sample selection, it is evident that the two groups were chosen from a common pool, and it is only the process of selection of experimental versus control houses, itself, that could have introduced a bias.

In this review of validity threats, we are considering the "pre-post" comfort ratings as the critical measure in question. For houses in the control group due to lack of five cases for a "cell," it is impossible to hypothesize a bias due to interaction of selection with another factor. For irregular-shaped houses, the degree of interior temperature variation would be expected to be relatively higher than in those with a regular, rectangular shape (because of the higher exterior wall-to-volume ratio). However, this--again--should not affect the "pre-post" comparison of comfort impressions. In this regard, each house serves as its own control. For households rejecting extensive weatherization work, it is also difficult to hypothesize an effect on "pre-post" comparisons.

Although one phase of the analysis seeks to evaluate the combined (mean) pre and post measures, it does seem implausible that these would be subject to a statistical regression artifact. The method used for selecting control versus experimental houses from the common pool does not appear to offer any basis for supposing that "pre" scores of either group would be systematically biased. (The mean "pre" comfort and temperature ratings of the two groups, as calculated, bore out this expectation.)

Although control households received a 50 percent fuel subsidy for two heating seasons, promised "normal" weatherization of their houses was postponed from its originally-scheduled summer 1979 date (due to the necessary extension of the measurement period). This delay caused unhappiness on the part of some control house homeowners, and could result in "resentful demoralization of respondents receiving less desirable treatments." (Cook & Campbell, 1976, p. 228) This would seem more likely to cause total lack of cooperation with the survey effort than to bias "pre-post" measures.

Some problem of "imitation of the treatment has occurred." Some control households have, on their own, installed storm windows or carried out other low-level weatherization of their dwellings. (This is, of course, also a threat to the basic fuel consumption comparisons of the demonstration.) Active steps were taken to make sure that such conditions are recorded, so that data about them will be available when the results are interpreted.

Since the houses in a site area are scattered geographically, with no pattern to experimental and control houses, local history can only be expected to have a random effect on outcomes.

Ideally, one would combine the pre-test comfort ratings of experimental and control houses, verify that the control group is equivalent, and then show post-test stability of control houses and improvement in experimental houses. Because of climate differences, house differences, individual differences, and the "noise" in the measuring instrument, I was doubtful that this approach could be expected to produce clearcut results. Furthermore, some of the relevant test items had pre-post comparison "built into" them. Thus, I planned to carry out the analysis for this stage of the study on a house-by-house basis, by constructing a composite comfort change "index" for each house. Assuming the measuring "instrument" used (retrospective reporting of behavior and feelings) is reasonably stable, control houses should exhibit a relatively small value for the composite index and experimental houses a rather larger value. However, it has been possible, as discussed below, to demonstrate significant shifts in the mean comfort and temperature ratings of the samples.

4.3 INSTRUMENT

Earlier I alluded to the occupants/respondents as instruments being used for "measuring" the comfort conditions of a house during two winters, separated by one or two years. In a stricter sense, what I have endeavored to "measure" is respondents' perceptions or feelings of wintertime comfort--and the instrument is a complex comprised of: 1) the respondents' recollections of comfort-related perceptions and behaviors, 2) the questionnaire used to prompt and direct the effort to elicit information about the perceptions and behavior, and 3) the interview situation, including the interviewer and the setting.

The first part of this complex was discussed in section 3.6, "Effects of recall and memory factors in obtaining survey data." The second and third parts remain, to be considered here.

The questionnaire developed for this study, which appears as appendix B, was designed to serve a somewhat larger purpose than just the comfort investigation. To help in evaluating and interpreting the fuel usage measurements, we needed to obtain background information about the occupants of the houses over the demonstration measurement period--concerning the demographics of the household, the possible non-occupancy of the house at times during the last three years, and thermostat setting patterns. However, most of the items did pertain, directly or indirectly, to the comfort investigation. In order to seek as rich descriptions of the respondents' comfort impressions as could be obtained, I asked them to provide, if they were able, individual comfort (and temperature) ratings for the various rooms of the house. To simplify the recording and processing of this data, copies of floor diagrams were used. These diagrams had already been provided to the research staff as part of the temperature stratification test data. (Furthermore, these diagrams will permit me to link the two sets of data--comfort ratings for rooms and for specific, particularly uncomfortable places, and the temperature stratification readings--for future efforts to try to determine the degree to which one can be "mapped" onto the other.) Note the questions concerning verifying the correctness of the diagrams (Q. 28 and Q. 43), nonuse of any rooms in winter and reasons therefore (Q. 29 and Q. 44), comments about any rooms rated "uncomfortable" (Q. 34 and Q. 48), and locations and ratings of any particularly uncomfortable places (Q. 35 and Q. 49).

Questions 33, 36, 47, and 50 asked respondents to record room comfort and temperature ratings directly on the floor diagrams. I hoped that this technique would prove helpful to respondents in relating their recollections to the specific areas of their house, and to focus respondents' attention on the thermal states of the rooms, in contrast to their purely personal thermal states.

The questionnaire incorporated the two rating scales commonly used in comfort studies in this country for respondents to report their comfort and temperature impressions: The "ASHRAE" seven-point scale of warmth sensation, and a slightly modified version of the comfort/discomfort sensation scale used by the John B. Pierce Foundation. I extended the latter scale by the addition of a point labelled "5-Very Comfortable" beyond the original terminus of the scale, "4-Comfortable."

In addition to the comfort- and temperature-rating data, the questionnaire sought other pertinent information: Thermostat setting practices (Q. 11-20) would serve as a possible indicator of activity along one path of behavioral thermoregulation (as discussed above). Respondents were asked whether they "have noticed any change in the wintertime comfort of your house over the last three winters;" if so, they were asked to give ratings on scales of change of several attributes that may be related to comfort (Q. 24). Considering that another avenue for behavioral thermoregulation is changing the amount of clothing worn, I sought data that would permit a rough indication of any changes over the period of the demonstration in amounts of clothing worn (Q. 55-57, and 59, 60). Finally, since amount of bodily activity affects the thermal balance of the body, hence feelings of thermal comfort, questions were included about any unusual activities employed to keep warm at times of cold weather (Q. 58 and Q. 61). I took considerable care to design the questionnaire so that it could be used for both experimental and control houses identically, except for occasional "skips," and to avoid using possibly biasing references to the "treatment" (i.e., weatherization).

4.4 PROCEDURE

The CSA Weatherization Demonstration commenced in the summer of 1977. Solicitations of proposed demonstration houses were sent out to the Community Action agencies in the selected cities, data on proposed houses were received, and during the fall of 1977 the fuel data records were analyzed to identify those houses for which pre-weatherization fuel usage could be confidently determined. By the spring of 1978, the CAA's at most sites had been notified of the houses accepted for the demonstration, and had been sent lists of weatherization retrofit options to be installed in each house. The project plan envisaged that weatherization work be completed by the fall of 1978, and that the winter of 1978-79 would be the "post-weatherization" measurement period. However, problems with getting funds out to the sites and subsequent delays in getting the weatherization work accomplished pushed back the schedule by as much as a year at some sites--with the retrofit work not being completed until the summer, or even the fall, of 1979.

It was important to minimize the required recall period for questionnaire items referring to the pre-weatherization wintertime, in the interest of minimizing the problems of recall and memory. Consequently, the reference dates for these items were related to the actual time schedule followed at each site--even to individual houses, where that was necessary. Thus, some refer back to the "winter of 1978-79" and some had to refer back to the earlier period of "winter 1977-78."

The questionnaire was drafted in early 1980, and a preliminary version sent, with a cover letter of instructions, to several site agencies for pilot testing. This resulted in changes in the final version. In retrospect of the entire interviewing effort, while some needed changes should have been identified by more extensive pilot testing, they were few and relatively minor. The draft questionnaire was submitted to the Office of Management and Budget for clearance--a requirement for all data-collection forms going out from Federal agencies to ten or more respondents. The OMB review process also resulted in improvement of the questionnaire--and the study as a whole--regarding taking cognizance of, and attempting to control for, recall and memory factors affecting the retrospective data. I pre-labelled the final questionnaires with site identification and house numbers (since those for experimental and control houses differed slightly--questions applying only to experimental houses were blanked out in the questionnaires for control houses). I placed two copies of the floor plan(s) for a house--labelled "This Past Winter" and "Winter 1978-79" (or "Winter 1977-78", as appropriate)--in the questionnaire for that house--so that they could be handed by the interviewer to the respondent for recording room comfort and temperature ratings. The ratings scales--for "comfort" and for "temperature"--were printed, as reproduced at the end of the questionnaire in appendix B, on front and back sides of a five by eight inch card, to be handed to the respondent for perusal while the ratings were being recorded on the floor diagrams. The questionnaires, together with a cover letter and some additional instructions (reproduced as appendix A of this report) were sent out to the field agencies, and the interviews were conducted in June, 1980. Telephone contact with the interviewers, to deal with problems that came up in the course of interviewing, was frequent during this period

Once the completed questionnaires were received back, the data was coded by the author. In view of the size and nature of the data set for each house, and the likelihood of wanting to use SPSS (Statistical Package for the Social Sciences) at some point in the analysis of the data, SPSS-compatible formating was used. In order to accomodate possible lists of unused rooms, of rooms rated "C3" or less, and the ratings data for up to 12 rooms, seven 80-column cards were required for each "case."

A contractor keypunched the data from standard 80-column coding sheets. Once the data file was in computer disk form, all subsequent processing has been accomplished with a Perkin-Elmer Interdata 7/32 maxi-minicomputer (located at the Center for Building Technology of the National Bureau of

Standards), except that the analysis of the mean comfort and temperature ratings was done on the Bureau's UNIVAC 1108.

I wrote two programs needed for processing and analyzing the data, in Interdata FORTRAN VII. First, a program was created to read (most of) the data items in the file, and print out the data for each house in a two-page format for "at a glance" perusal. This printout served two purposes: 1) It serves as a "reference book" of the questionnaire data from the houses as various parts of the larger demonstration analysis process are being accomplished. (When analysis of post-weatherization fuel usage data for a house turns up a point of unusually low consumption in January, 1980, reference to this listing may quickly show that the occupants were away and the house was unoccupied for three weeks of that month.) 2) The listing also served as a valuable and efficient medium for "proofing" and correcting the data file. The data listings were proofread against the questionnaires themselves, thus at one step verifying both the coding (which required considerable "cleaning up," due to issues not resolved, or identified, until part way through the coding process) and the keypunching (which had introduced a few errors).

A sample of output from this program (called QUSTEDIT) is included as appendix C of this report. As can be seen, some data items were "decoded" for easier checking (for example, name of interviewer), some codes were printed as part of the listing (thermostat setting changes, clothing change), while yet others were printed verbatim (e.g., most "8"s for "NA"). The program performed some counting or calculation: counting up the number of rooms listed as unused or described as "uncomfortable" ("C3" or less) (to facilitate checking the collating process described below), and calculating the length of the interview. All data pertaining to specific rooms were collated and listed in a table at the end of the house record. These included, for each winter time: 1) rooms listed as unused, 2) rooms described as uncomfortable, and 3) particularly uncomfortable places identified in rooms. The data in the table read as follows: room identification (pre-edited to match room identifications used in temperature stratification data--initial digit identifies floor); "1" (or some specific code for reason) if the room was generally unused this past winter; the comfort and temperature ratings for the room this past winter; two columns under "P.U." listing: the number of particularly uncomfortable places identified in a room and the (compass) orientation of specific, particularly uncomfortable places; the "C" and "T" ratings of such places; a code for rooms described as uncomfortable; followed by eight more columns for the similar data for the earlier winter.

After verifying and correcting the data, I wrote a program for analyzing the data. The creation of this program, called QUSTANAL, started with the use of the "tried and proven" READ statements of the QUSTEDIT program. (Proofing the data had verified that these statements were, in fact, reading the correct columns for each variable. Actually, I modified the READ statements for QUSTANAL so as not to read and store data unneeded in the analysis; but, working from the already-used commands contributed significantly to ease and accuracy of design of the "read" portion of the analysis program.) Program QUSTANAL has progressed through several versions, as will become evident in the following section.

4.5 DISCUSSION AND PRELIMINARY RESULTS

Analysis of questionnaire data from the nine sites strongly suggests that many residents are likely to notice a definite difference in the wintertime comfort of their houses after weatherization of the dwellings, in contrast to residents of houses that are not weatherized.

What data has been analyzed? Completed questionnaires were received and the data keypunched, edited and analyzed, from nine sites: Atlanta; Charleston, SC; Colorado Springs; Easton/Allentown/Bethlehem; Fargo; Oakland; St. Louis; Tacoma; and Washington (Hughesville, MD). The data set comprises 145 questionnaires.

Are all of these questionnaires included in the analysis results reported below? In view of the above-discussed concern about recollection of data, cases were disregarded if respondents stated they were less than "moderately sure" (i.e., "somewhat unsure" or lower) about any of the comfort ratings (or the temperature ratings, depending on the particular analysis that was run). Although the precise numbers vary, again depending on the particular analysis, roughly 20 percent of the 145 cases were eliminated due to this criterion. When each of the three analyses discussed below was conducted, a few additional cases had to be disregarded for one or more of the following reasons, as appropriate: 1) inadequate comfort ratings for comparison; 2) inadequate temperature ratings for comparison; or, 3) insufficient data to compute at least four of the possible five indicator components, in the case of the Composite Comfort Change index. Of the remaining cases in each analysis, approximately 75 percent were experimental (weatherized) houses and 25 percent control houses.

Exactly what weatherization retrofitting was done to the "treated houses" included in this analysis? This paper reports only "gross" analysis across the entire nine-site sample. Because of the cost/benefit criterion applied to the selection of retrofit options for installation in the demonstration, more retrofit work tended to be prescribed for houses in the more northerly or colder locations. On the other hand, some prescribed retrofits were not installed, either because the house already had them (e.g., storm windows, or adequate attic insulation) or due to some problem in the field. Consequently, there was considerable variation in the amount of weatherization work applied to houses. Table 3, (next page) shows, for the 112 cases that constitute the basis for the results reported below: 1) the number of control and experiment houses, 2) the percentage of experimental houses that received various retrofits to the building shell, and 3) the 30-year average degree day figures, a comparative measure of the normal amount of "coldness" over a year. It can be seen (last column of the table) that more than 90 percent of these houses received attic insulation, a little less than half wall insulation, a little more than half storm windows, and fractions ranging from one-quarter to almost nine-tenths received various infiltration-reducing work.

Table 3

Severity of Winter Weather & Options Installed, by Site

SITE:	CHA	OAK	ATL	WAS	STL	TAC	ABE	CSP	FAR	ALL
30-yr. avg. Degree Days	1904	2909	3095	4211	4750	5185	5827	6473	9271	---
	(Numbers of houses)									
CONTROL	4	3	4	4	3	1	1	3	4	27
WEATHERIZED	14	6	7	6	21	2	8	12	6	82
	(Percent of weatherized houses)									
OPTIONS INSTALLED:										
INFILTRATION:										
Replace Broken Glass	64	67	0	0	0	100	88	92	0	40
Reset Glazing	43	17	14	18	0	50	63	50	0	26
Replace Threshold	100	100	14	0	0	0	0	100	0	40
Seal Cracks/Holes	100	33	14	0	0	0	13	67	0	32
Weatherstrip Windows	93	0	29	18	0	0	63	50	100	40
Caulk Windows	100	0	43	100	86	100	13	100	83	74
Weatherstrip Doors	93	100	57	100	86	100	63	100	100	88
Caulk Doors	100	0	57	100	0	100	25	100	83	55
W/S Attic Hatch	79	0	29	0	0	50	63	50	100	38
CONDUCTION:										
Install Storm Windows	7	0	71	100	90	100	0	92	0	54
Install Triple Glazing	0	0	29	0	0	0	0	0	100	10
Install Storm Doors	0	0	0	50	0	0	0	0	0	4
Insulate Attic	93	100	100	100	95	100	63	100	100	94
Insulate Walls	0	0	29	83	43	100	50	83	100	46
Insulate Basement Walls/Slab/Crawl Space	64	0	71	67	43	100	0	75	100	54

Site Identifiers:

ABE - Allentown/Easton/Bethlehem, PA
ATL - Atlanta
CHA - Charleston, SC
CSP - Colorado Springs, CO
FAR - Fargo, ND

OAK - Oakland, CA
STL - St. Louis, MO
TAC - Tacoma, WA
WAS - Washington (Hughesville, MD)

What analyses have been carried out and what results obtained for these 112 houses? A Composite Comfort Change index has been constructed, and analyzed. Mean comfort ratings have been calculated for experimental and for control houses, as have mean temperature ratings, and these have been analyzed.

4.5.1 Composite Comfort Change Index

Since some of the data items relating to before-after comfort comparison had comparison built into them, and in light of the theoretical construct of "comfort" discussed earlier, the first analysis approach used was to construct a Composite Comfort Change index (CCCI) for each house. This index comprised five components, or indicators. These were derived as follows:

1 - "Thermostat" indicator: If the thermostat was formerly set higher during particularly cold weather, but was not so changed this past winter (i.e., 1977-80), suggesting lessened occupant reaction to lowered mean radiant temperature caused by cold walls or to drafts, this was taken as an indicator of changed (i.e., improved) comfort. If the house did not have a thermostat, this component was classified as "missing." (An option in QUSTANAL permits using any lowering of the usual thermostat setting over the course of the demonstration as indication of improved comfort. However, since the reason for lowering the thermostat was not recorded and this could be purely a response to conservation appeals or economy desires, rather than any reaction to weatherization, this is too loose a criterion, and was not used in the final analysis runs). For the 109 cases that "passed" the above-described criteria for inclusion in this analysis, the frequency distribution of this component was as shown in table 4.

Table 4

Frequency Distribution of "Thermostat" Indicator (%(N))

	Improvement	No Improvement	Missing
Experimental	32(25)	40(31)	27(21)
Control	0(0)	50(13)	50(13)

To turn around the interpretation of this particular set of data, for a moment, from that of an indication of improved thermal comfort in the house to that of a direct measure of reduced propensity to "turn up" the thermostat in unusually cold weather, hence reduced fuel consumption: we can observe that 45 percent of the households in experimental houses that have thermostats appear to have exhibited this energy-saving response to weatherization, while none of the control houses made such a change.

2 - "Noticed difference" indicator: This was computed from question 24 ("...have [you] noted any change in the wintertime comfort of your house....") and the related scales on the following page of the questionnaire. If question 24 was answered "yes" and at least two of three scales ("cooler-warmer", "more-less drafty", and "more-less uniform temperatures") were rated near the scale ends ("6" or "7" for the first two, "2" or "1" for "uniform temperatures"), this was taken as a indication of improved comfort. The distribution of this indicator is shown in table 5.

Table 5

Frequency Distribution of "Noticed Difference" Indicator (%(N))

	Improvement	No Improvement	Missing
Experimental	91(70)	9(7)	0(0)
Control	19(5)	81(21)	0(0)

3 - "Clothing change" component" This was generated by a weighted combination of the question about overall clothing levels (Q. 55) and the questions about frequency of sweater or "extra" wrap wearing. A "yes" on the first question was taken to indicate improved comfort. A "no", combined with a net reduction in frequency of sweater wearing of at least four units on the scale was also so interpreted.

Table 6

Frequency Distribution of "Clothing Change" Indicator (%(N))

	Improvement	No Improvement	Missing
Experimental	39(30)	61(47)	0(0)
Control	12(3)	88(23)	0(0)

The last two components incorporate the comfort ratings ascribed 1) to the whole house, and 2) to individual rooms. For these two items, the difference criterion is specified ($\geq$ d.c.) when an analysis run is made. Only if the "post" rating exceeds the "pre" rating by at least the specified amount is improved comfort indicated. The analysis has been run using criteria of one and two scale units.

4 - "Overall comfort rating" component: This is derived from the overall house "C" ratings -- Q. 27 and Q. 42.

Table 7

Frequency Distribution of "Overall Comfort Rating" Indicator (%(N))

	Improvement	No Improvement	Missing
with "comfort criterion" = 1:			
Experimental	86(66)	13(10)	1(1)
Control	35(9)	62(16)	4(1)
with "comfort criterion" = 2:			
Experimental	56(43)	43(33)	1(1)
Control	15(4)	81(21)	4(1)

In light of the "fuzziness" of this scale, as discussed earlier, use of the stricter criterion of two scale units is probably preferable. However, as can be observed from these frequency distributions, that analysis approach is less effective for distinguishing experimental houses, although more so for control houses.

5 - "Average comfort rating" component: For this indicator, the individual comfort ratings of the rooms were combined in a simple, unweighted average.

Table 8

Frequency Distribution of "Average Comfort Rating" Indicator (%(N))

	Improvement	No Improvement	Missing
with "comfort criterion" = 1:			
Experimental	58(45)	40(31)	1(1)
Control	15(4)	85(22)	0(0)
with "comfort criterion" = 2:			
Experimental	23(18)	75(58)	1(1)
Control	4(1)	96(25)	0(0)

The CCCI was constructed on the rationale of a "summated score" as discussed in Research Methods in Social Relations (Selltiz, Wrightsman, & Cook, 1976, pp. 417-418). Since each of the data points which are incorporated into the index components are, according to established human comfort theory, positively related to people's perceptions of thermal comfort, it seemed plausible that, the more one's feelings of wintertime comfort have improved, the more of these items to which one would be likely to respond positively. The individual indicators were set to "1" (improvement in comfort impression indicated) or "0" (no change indicated), and the results summed to generate the CCCI for each house. (If an indicator was missing or presented some other problem, it was set to "9", and disregarded in computing the house score.)

Since houses that do not have thermostats would have a possible total score of four, rather than five, I used the proportion of the summated score to the possible total as the score for analysis. I set a minimum requirement of four of the indicators being available, so the possible scores were the various fractions with 5 or 4 as denominator.

Analyzing the data set with a "comfort criterion" of one scale unit produced the distribution of CCCI scores shown in table 9. Since this is an ordinal, but not an equal-interval scale, the mode has been selected as the appropriate statistic for describing the central tendency of the scores, as suggested by Siegal (1956, p. 25).

Table 9

Frequency Distributions of "Composite Comfort Change Index" Scores (N)

Score	Experimental	Control
1.00	19	1
0.80	14	0
0.75	6	2
0.60	10	1
0.50	6	0
0.40	13	2
0.25	2	1
0.20	4	3
0.00	3	16
Modal Values:	1.00	0.

This set of distributions was analyzed for the strength of indications of differences between the experimental and the control house sets by using the χ^2 Test for Two Independent Samples (Siegal, 1956, p. 104-111). In order to meet the requirement for this test of minimizing the number of cells with expected frequencies of less than five, the scores were grouped into five sets (0.0 - 0.20; 0.21 - 0.40; 0.41 - 0.60; 0.61 - 0.80; and 0.81 - 1.00). The calculated value of χ^2 was 44.59. With four degrees of freedom, as in this case, the critical value of χ^2 for p=0.001 is 18.46. Thus, difference between scores for the population of experimental houses and those for the population of control houses is very strongly indicated.

Since the above test with five rows says nothing about the direction of differences, I then re-ran the test with the scores simply dichotomized above and below 0.50. This analysis produced a calculated χ^2 of 19.2. The critical value of χ^2 with one degree of freedom at p=0.001 is 10.8. Thus, it appears highly likely that houses that get weatherized will score significantly higher on the "Composite Comfort change" index than non-weatherized control houses.

4.5.2 Comfort Ratings

As indicated above, the questionnaire sought two sets of comfort ratings (on the five-point scale, shown at the end of the questionnaire in appendix B) -- "before" and "after" ratings for 1) the whole house, and 2) for each room ordinarily used in winter. Means were calculated for experimental and control houses for each of these.

Looking first at the "overall house" (i.e., integer) comfort ratings, I obained the following mean scores (on the one to five scale):

Table 10

Means of Overall House Comfort Ratings

(Number of cases in parentheses)

	"PRE"	"POST"
Experimental	2.74 (76)	4.38 (77)
Control	2.85 (26)	3.20 (25)

I have not yet been able to run a house-by-house correlation of the average of room "C" ratings ("pre" and "post") against the house overall "C" rating. However, taking the mean of the room ratings as a "house average 'C' rating", the mean house averages for the two groups exhibit a pattern quite similar to that for the overall "C" ratings:

Table 11

Means of House Average Comfort Ratings

(Number of cases in parentheses)

	"PRE"	"POST"
Experimental	2.99 (76)	4.17 (76)
Control	2.98 (26)	3.26 (26)

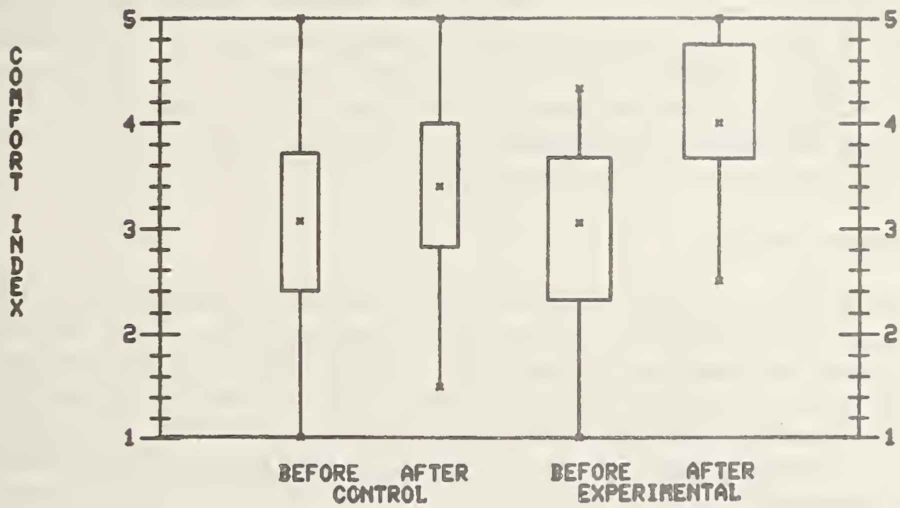
Since the "house average" comfort ratings represent a relatively "finer" scale of comfort measurement of the house, I chose to analyze these only. Four different techniques have been used to analyze these "house average" comfort ratings:

1. Analysis of variance. In keeping with the nature of the "nonequivalent control group design" (discussed on pages 21-23, above), a one-way analysis of variance was first run on all of the "pre" ratings, to ascertain that all of the houses did, in fact, come from a common population, as regards house winter-time comfort ratings. With the one factor being "experimental" or "control", the F statistic calculated at 0.0036, which value lies at the 4.802 percent point of the F distribution in this case. Thus, the difference between "pre" ratings for experimental and for control houses is not significant.

Then a similar one-way analysis of variance was run on all of the "post" house average comfort ratings. In this analysis, the F statistic calculated out at 30.0173. This value lies at the 100.000 percent point of the F distribution. Thus, the difference between comfort ratings of weatherized and of control houses can be said to be significant at the 99.9% probability level.

2. Box plots. The differences in the distributions of "pre" and "post" comfort ratings for both control and experimental houses are shown by the box plots in figure 3 (next page). "Before" refers to the "earlier winter" (i.e., 1978/79, or 1977/78) and "after"--the winter of 1979/80. In these plots, the box indicates the 25th to the 75th percentile of the distribution, the outlying points are the maximum and minimum values, and the enclosed point is the median of the distribution. It can be seen that, while there was some upward shift of the comfort ratings in control houses, the "slippage" appears minor. On the other hand, in the experimental houses, the middle 50 percent of the ratings after weatherization lies entirely above the middle 50 percent of the ratings before weatherization; further, the minimum reported comfort rating "after" falls above the 25th percentile of the "before" distribution, and the maximum "before" rating lies below the 75th percentile of the "after" ratings.

Figure 3. Box plots of distributions of "house average" comfort ratings



3. Kruskal-Wallis test. To further assess the significance of these shifts, or "slippages", Kruskal-Wallis "H" statistics were calculated for the distributions. This is a non-parametric test of the hypothesis that two samples came from the same population. The two samples (e.g., control house "before" ratings and control house "after" ratings) are first tagged as to the sample in which they occurred. The two samples are then combined into a single set, ranked, and weighted rank sums computed for the two original sets. The two rank sums are compared to derive the H static, which is closer to 1.0 the more likely the two samples were taken from the same population.

For control house "before" and "after" average house comfort ratings, the H* statistic (H, corrected for the existence of ties among the ratings) was 1.030802. The probability of exceeding this value if the populations are indeed identical is 0.31265--that is, a higher value would occur by chance in almost one case out of three. Thus, we can infer that the apparent shift is, indeed, insignificant.

For the experimental house "before" and "after" house average comfort ratings, H* was computed as 67.86064. The probability of exceeding this value if these two samples were from an identical population is 0.0000, indicating that the "before" and "after" comfort impressions that were reported in the experimental houses are strongly differentiated, and in the direction of improved comfort, as indicated by the box plots.

4. Youden plots. Each of the above analyses has dealt with the various distributions, overall. None has given any information about house-by-house relationships between "post" and "pre" comfort ratings. To fill this gap in the analysis, the Youden plots shown in figures 4 and 5 were prepared. In these, the "after" rating for each house is plotted against the "before" rating for that house. We would expect that ratings for control houses would tend to remain unchanged; thus, points for these houses would lie on the diagonal of the graph. Figure 4 shows this to be generally so. For houses with higher comfort ratings after weatherization, the points should lie below (strictly, to the right of) the diagonal, and again figure 5 indicates this to be generally true for the experimental houses.

4.5.3 Temperature Ratings

In light of the earlier-discussed distinction between comfort sensation and temperature sensation, and with a view to the expected parallelism between them, I also asked respondents to ascribe temperature ratings for the "before" and "after" periods to the individual rooms in their house. These were reported on the standard ASHRAE seven-point scale of warmth having "4" as center point: "neutral--neither warm nor cool" (as printed at the end of the questionnaire in appendix B). The calculated means of house averages of these ratings are shown in table 12 (p. 37).

Figure 4. Youden plot of control "house average" comfort ratings

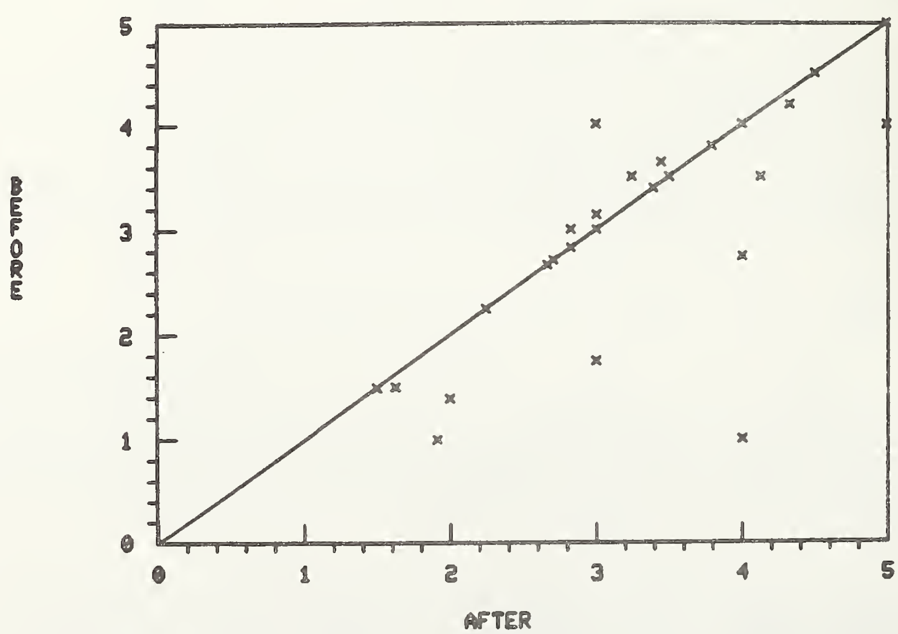


Figure 5. Youden plot of experimental "house average" comfort ratings

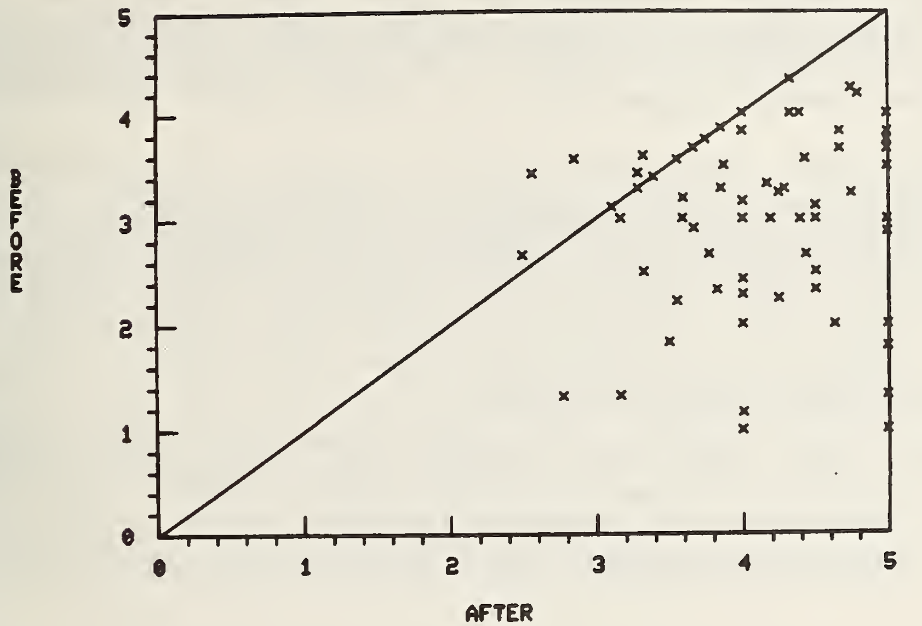


Table 12

Means of House Average Temperature Ratings

(Number of cases in parentheses)

	"PRE"	"POST"
Experimental	3.38 (74)	4.78 (76)
Control	3.22 (26)	3.39 (26)

Although I have not had the opportunity to compare (correlate) the house average temperature ratings with the house average comfort ratings, I have carried out the same analyses on them as on the comfort ratings.

1. Analysis of variance. For the one-way analysis of variance of all "before" temperature ratings, the one factor being "experimental" or "control", the F statistic calculated at 0.60839. This value lies at 56.280 percent, well within the body of the distribution of the F statistic. Thus, the difference between the means of "pre" ratings for control and for experimental houses is not significant. The one-way analysis of variance of all "post" temperature ratings resulted in an F value of 25.5752. This value lies beyond the 99.970 point of

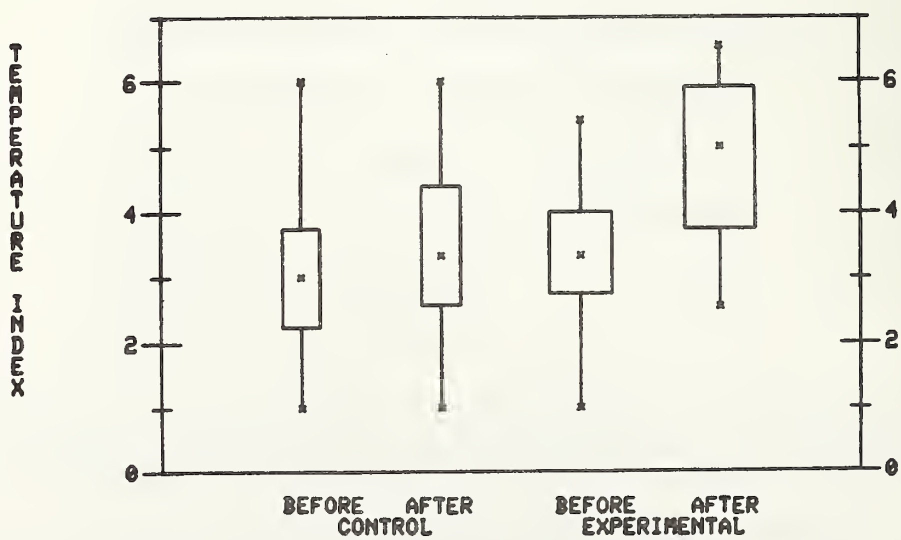
the F distribution. Something had caused a shift in the ratings of the experimental (and/or the control) houses such that they could no longer have come from the same population.

2. Box plots. Again, the distributions show some upward shift in the ratings from control houses, but the improvement in reported warmth in the weatherized hosues is much more marked (figure 6).

3. Kruskal-Wallis test. The Kruskal-Wallis H* statistic for control house "before" and "after" house average temperature ratings was 1.40115. The probability of exceeding this value if the populations are identical is 0.23934—thus, the two samples can be inferred to be identical. For the "before" and "after" temperature ratings reported in the experimental houses, H* was computed to be 42.05735. This value is significant at better than the 0.99 level, suggesting that occupants of houses that have been weatherized are highly likely to report feeling warmer in winter.

4. Youden plots. Again, these plots show that, for control houses (figure 7, next page) the temperature ratings tended to be about the same "after" as "before", while occupants of the experimental houses tended to report them as "warmer" (e.g., higher rating numbers) after weatherization than before (figure 8).

Figure 6. Box plots of distributions of "house average" temperature ratings



A brief comment is in order on the "slippage" in the mean values for control houses. These shifts are consistently upward for the three sets of ratings data reported above--for both comfort and temperature ratings. I cannot explain this manifestation. Do people tend to recall earlier winters as colder, more severe, more uncomfortable? This is one possible explanation. The question may be deserving of further study.

4.6 CONCLUSION

Although further analysis remains to be conducted on even this questionnaire data, the study has obtained very encouraging indications that many people are likely to notice an improvement in wintertime comfort of their houses after weatherization.

I am hopeful that there will be opportunity to round out the research by studying the relationships between the comfort impressions recorded in this survey data and the physical measurements of wintertime temperature stratification that were also recorded in the houses.

Figure 7. Youden plot of control "house average" temperature ratings

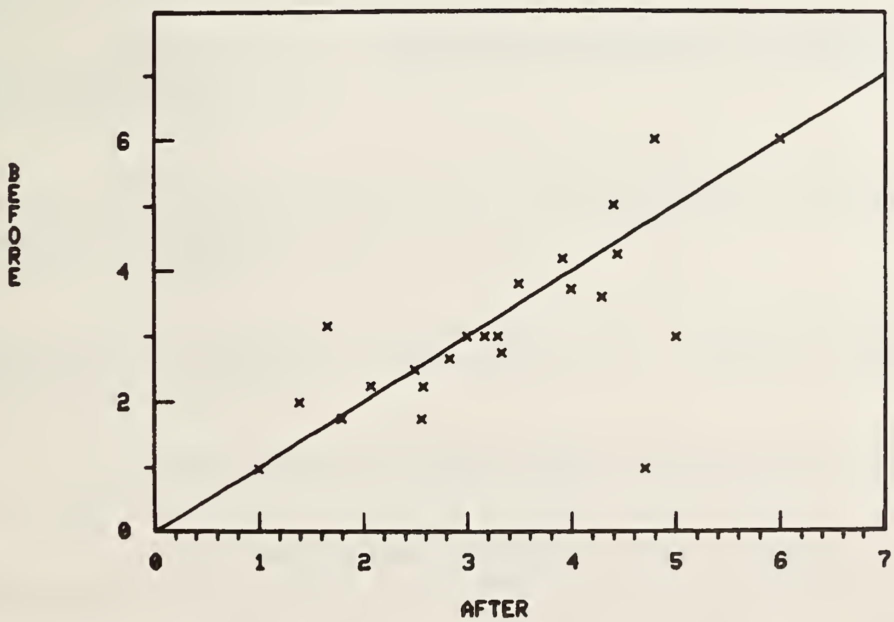
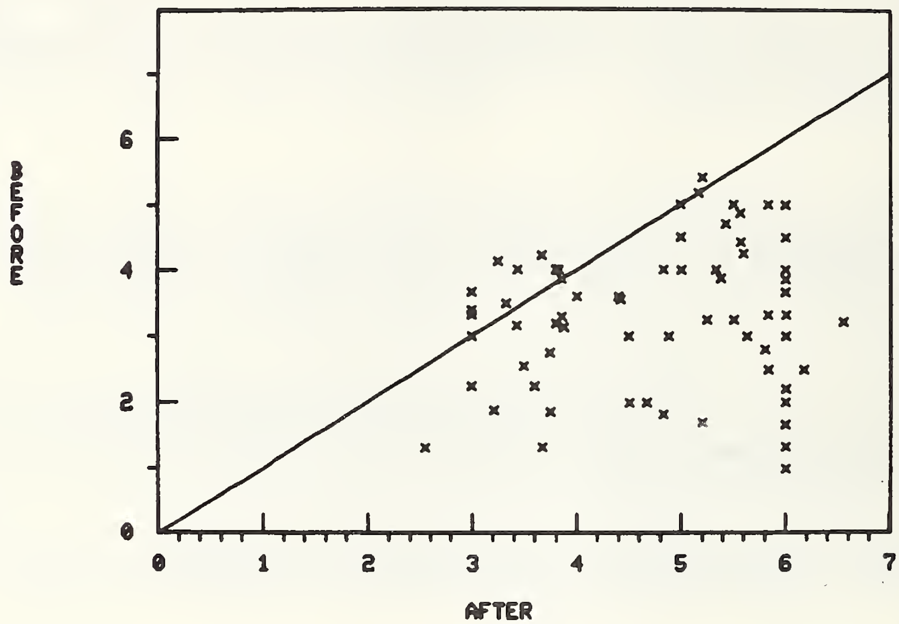


Figure 8. Youden plot of experimental "house average" temperature ratings



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APPENDIX A

Cover Letter and Instructions Sent to Interviewers

May 20, 1980

Dear

I direct your attention to the CSA Weatherization Demonstration Project Plan, specifically the section "Recording of Occupancy Characteristics" on page 53. The enclosed questionnaire is the mechanism we will be using to collect the needed data about energy-affecting occupant activities and attitudes.

Thanks to your conscientious efforts as Project Coordinators, we now have considerable data about the physical aspects of energy consumption and weatherization for most of the houses in the CSA Demonstration. Because things that occupants do also affect the energy consumption of their households, we need to "fill a gap" by carefully documenting, over the whole measurement period of the Demonstration, certain attributes and attitudes of the households.

Attached to this letter you will find one copy of the CSA Weatherization Demonstration Occupant Activities and Attitudes Questionnaire, so that you can read it over and become familiar with it. It is not necessary for you to reproduce it. Within a few days you will receive from Roy Clark a complete set of questionnaires for your Sample and Control houses. These will be pre-numbered for specific houses, and pre-marked with information where needed. Each questionnaire will also have attached to it two copies of the house floor plans that you provided with the temperature stratification measurements: one labelled "This Past Winter" and one labelled "Winter of 1978-79." As you will see from reading the questionnaire, these are to be used for recording "comfort" and "temperature" ratings of the spaces in a house, and are to be returned to NBS as part of the completed questionnaires.

We believe that it would probably be best for the Project Coordinator to do the interviewing and complete the questionnaires at most sites. However, if the "meter reader" is acquainted, and has good rapport, with household members, he/she may be satisfactory for the job. The Project Coordinator should consult Roy Clark before such a decision is made. In any case, it is important for consistency and accuracy of data that all interviewing be done by the same Project person.

The person who is going to do the interviewing (as well as the Project Coordinator, if different) should read the questionnaire, and note any questions he/she has about it. Please call Roy Clark as soon as you are ready to go over in detail the administration of the questionnaire.

Trial runs indicate that an interview of 30 to 45 minutes length should be sufficient for completing a questionnaire. Although it will require some adjustment of your "weekly readings" schedule, I suggest that you work the interviews into that schedule. Since it is important to have an uninterrupted half hour to sit down with the householders and obtain the answers to the questions, it is probably not a good idea to try to combine interviewing with the monthly air bag/temperature stratification testing.

I must emphasize that completed questionnaires are the property of the CSA and the NBS, and must be forwarded to Richard Crenshaw at the NBS. They are not to be copied at a local agency, since the confidentiality of the data is being guaranteed by the NBS.

Roy looks forward to talking with you soon about this important and exciting part of the CSA Weatherization Demonstration. Thank you for your conscientious consideration of this matter.

Sincerely,

Richard Crenshaw

RICHARD CRENSHAW, Project Manager
Architectural Research Group
Environmental Design Research Division
Center for Building Technology, NEL

Enclosure

Dear

Please Note--

There are many factors that can affect the accuracy of the information that people give in interviews. Some important ones are: the way an interviewer reads a question, a desire on the part of a respondent to be helpful and say something even where he or she does not know or does not remember the information, distractions during the interview, or the fact that something asked about may have happened too long ago or have been too unimportant to the respondent to now be accurately remembered. Since bad data is much worse than no data (because it actively misleads us), I urge you to be very careful, in conducting the interviews, to minimize these possible causes of data inaccuracy.

Read each statement and question to the respondent exactly as it is written in the Questionnaire. (This is important also for obtaining consistent data from respondents: every respondent must be answering exactly the same questions for the answers to be a valid set of data.) It is also important to follow exactly the instructions printed in the Questionnaire. You should always be completely accepting of "don't remember" responses. Do not urge or prompt respondents to come up with answers beyond the prompts that are written in the Questionnaire as a statement or question to be read to the respondent.

If, in conducting any interview, you should encounter any uncertainty about what some question (or instruction) means, please call me about it as soom as you have the opportunity. That way, we can clear up the confusion before you do many more interviews.

To lighten your load a little, note that where the instructions tell you to skip a question, it is not necessary to write anything in the skipped question. On page 3, you need fill in data only as directed by the instructions. If all present occupants are the same as those living in the house when it became a part of the Demonstration, you will end up with no entries in Columns 4, 5, and 6 of the Table. Notice that the first line of the Table is intended for information about the respondent.

When you come to the comfort rating questions (beginning on page 9), please note two things: First, you are to go through the two series of questions about individual rooms for one floor at a time (this has to do with multi-floor houses). First, go through questions 28 through 36 for the first floor (which should be the lowest occupied floor in the house, whatever that is called), and then go back and start again with question 28 for the next floor up. The same instruction applies for questions 43 through 50. Second, please be ready to give respondents any help they need in making any needed changes to the floor plans and in getting the rating numbers recorded in the right places on the plans. Note that, as directed by the instructions in the Questionnaire, the only C-numbers and T-numbers that should have circles around them are those rating particularly uncomfortable places in the house.

When you finish an interview, please slip the floor diagram sheet in between pages of the Questionnaire so that I will receive it right along with the other data in the questionnaire. Also, please send the completed questionnaires on to me a few at a time as you get them completed. I prefer that you not wait and send them all to me in one package.

Thank you very much for your careful attention to these matters.

Roy E. Clark
Research Analyst
Center for Building Technology
National Bureau of Standards

APPENDIX B

Questionnaire

CSA WEATHERIZATION DEMONSTRATION

OCCUPANT ACTIVITIES AND ATTITUDES QUESTIONNAIRE

Form Approved
O.M.B. No. 116-S80004

CITY ID ________

PROJECT
HOUSE NO. ________

DATE ________

TIME IS NOW ________

NOTE: Items in square brackets [LIKE THIS] are instructions to the Interviewer, not to be read to the Respondent.

Where a square box is provided for an answer, simply mark "X" in the correct box.

[BEGIN—READ TO THE RESPONDENT] Your cooperation with the CSA Optimum Weatherization Demonstration has been very valuable to the Nation in this time of energy concern. Your letting us study your house, install meters and read them weekly, conduct other tests and measurements, and weatherize your house where appropriate has made it possible for us to begin to get a good idea of how much energy can be saved in houses like yours across the United States by optimum weatherization, and how much that weatherization would cost.

Specifically, we know the following things about your house: How much fuel or energy it used in a typical year before the Demonstration and how much it now uses in a typical year; and in the case of Sample houses, what was done to weatherize the house, how much that weatherization cost, and what problems were encountered in weatherizing a house of this type in this area.

This information gives us a pretty good idea of how much energy savings can be achieved by specific weatherization modifications. However, to get a better idea of the energy savings figures, we also need some information about your household.

Other energy consumption studies have found that the way people use their house has definite effects on the amount of energy consumed. For example, some people prefer warmer temperatures than others, so they use more energy to keep the inside air warmer in winter. Households with children tend to use doors to the outside much more often than households with just adults. In cold weather this lets in more cold air that needs to be warmed and this means more energy for heating.

It is important that the researchers at the National Bureau of Standards know whether there have been changes that may affect the energy consumption of your household during the time that we have been measuring your fuel use from utility bills and meters. They also want to know about your feelings of comfort in your house in cold weather.

The information that you give us will be identified by project house number, so that the researchers can use it to better understand the energy consumption data from your house. However, to protect your privacy, neither your name or your street address will be used in connection with the data.

We hope that you are willing to spend 30 to 45 minutes answering some questions about your household and your house. Your cooperation is needed and will be very much appreciated.

[IF RESPONDENT IS NOT WILLING TO COOPERATE, PLEASE RECORD REASON GIVEN.]

____

____

____

1. Are you the Head of Household here? NO [2] YES [1] → GO TO Q. 3

2. [IF NO, ASK:] What is your relationship to the Head of Household? ______________________

3. What year did you begin living in this house? ______________________

[GO ON TO NEXT PAGE.]

Your house became a part of the CSA Optimum Weatherization Demonstration

in 1977
[OR IN] _____. Some of these questions will refer back to that time and others will refer to the recent past--that is, to this past winter.

4. Who was living in this house in the Spring of 1977? [FILL IN INFORMATION IN COLUMN 1 OF TABLE BELOW. FILL IN SEX OF EACH OCCUPANT IN COLUMN 2.]

1 OCCUPANT	2 SEX	3 1977 AGE	4 LEFT WHEN?	5 ARRIVED WHEN?	6 PRESENT AGE
Respondent					

What were their ages at that time--that is, the Spring of 1977? [ENTER IN COLUMN 3 OF THE TABLE.]

If any of these people are no longer living here, please tell me which ones, and when they left the household. [ENTER INFORMATION IN COLUMN 4.]

If any people have been added to the household since Spring 1977, please tell me who they are. [ENTER INFORMATION IN COLUMN 1, ABOVE.] For these new members of the household, please tell me their Sex, When they became members of the household, and their present Age. [ENTER INFORMATION IN COLUMNS 2, 5, AND 6 OF THE TABLE.]

[GO ON TO NEXT PAGE.]

As I said earlier, some of these questions refer back to the winter time 1 or 2 years ago. The researchers understand that some people can more easily remember their experiences of several years back than others. If you feel unsure about the answers to any of the questions that I ask you, please feel free to tell me that you do not recall the information.

5. In the winter of 1976-77, just before your house became a part of the CSA Optimum Weatherization Demonstration, was there usually someone in the house during the daytime on weekdays?

   YES [1]   NO [2] → GO TO Q. 7

6. [IF YES, ASK:] Was the person or were the people usually in the house

   ALL DAY [ ]   or, WHAT PART OF THE DAY ____________

7. Has the weekday daytime use of the house in winter changed since that time?

   YES [1]   NO [2] → GO TO Q. 9

8. [IF YES, ASK:] How and when has it changed? ________________

   ____

   ____

9. Were there times in the past 3 years when you were away and the house was unoccupied for a week or more at a time?

   YES [1]   NO [2] → GO TO Q. 11 (NEXT PAGE)

10. [IF YES, ASK:] When were those times?

YEAR	MONTH	FOR HOW LONG?
____	____	____________
____	____	____________
____	____	____________
____	____	____________

11. Does your house have a thermostat that controls the main heater or furnace? YES [1] NO [2] → GO TO Q. 22 (PAGE 8)

[QUESTIONS FOR HOUSES HAVING THERMOSTATS:]

12. Is the thermostat generally at the same temperature setting each day in winter? YES [1] NO [2] → GO TO Q. 14

13. Has the daytime thermostat setting you use been changed since the beginning of winter 1976? YES [1] NO [2] → GO TO Q. 14

[IF YES, ASK:] When was that? What change?

MONTH	YEAR	
____	____	________________
____	____	________________
____	____	________________

14. Back in the winter of 1976-77, was the thermostat usually set differently at night? YES [1] NO [2] → GO TO Q. 15 CANNOT RECALL [3]

[IF YES, ASK:] How different? HIGHER [3] LOWER [4]

How much? 2° [5] 4° [6] 6° [7] 8° [8] 10° [9]

15. [IF THE HOUSE WAS USUALLY UNOCCUPIED DURING AT LEAST PART OF THE DAY— Q. 5, PAGE 5 ABOVE—ASK:] Was the thermostat usually turned down when no one was at home during the day? YES [1] NO [2]

16. Now please think about times of unusually cold weather back in 1976-77. At such times, in comparison with usual winter weather, was the thermostat usually set LOWER [4] HIGHER [8] THE SAME [5]

[IF LOWER OR HIGHER, ASK:] About how much?

2° [5] 4° [6] 6° [7] 8° [8] 10° [9] DO NOT RECALL [3]

17. During this past winter, was the thermostat usually set differently at night than during the daytime? YES [1] NO [2] → GO TO Q. 18

[IF YES, ASK:] How different? HIGHER [3] LOWER [4]

How much? 2° [5] 4° [6] 6° [7] 8° [8] 10° [9]

18. [IF THE HOUSE WAS USUALLY UNOCCUPIED DURING AT LEAST PART OF THE DAY THIS PAST WINTER (Q. 5, 7—PAGE 5 ABOVE), ASK:] How about this past winter--was the thermostat usually turned down when no one was at home during the day? YES [1] NO [2]

19. What about particularly cold spells this past winter--was the thermostat usually set LOWER [4] THE SAME [5] HIGHER [3] than during usual winter weather.

20. So, the thermostat settings usually used this past winter were

DAYTIME _____ °F NIGHTTIME: SAME AS DAYTIME [05] [OR] _____ °F

21. Does your house have a clock thermostat to control the furnace or heater?

YES [1] NO [2] → GO TO Q. 24 (PAGE 9)

[IF YES, ASK:] When was the clock thermostat installed?

MONTH _____ YEAR _____ CANNOT RECALL [3]

Have you changed the day or night settings since the clock thermostat was installed? YES [1] NO [2] → GO TO Q. 24 (PAGE 9)

[IF YES, ASK:] When was that? What change?

MONTH	YEAR	

[NOW GO TO Q. 24 (PAGE 9).]

[QUESTIONS FOR HOUSES WITHOUT THERMOSTATS:]

22. [IF THE HOUSE WAS USUALLY UNOCCUPIED DURING AT LEAST PART OF THE DAY IN WINTER 1976-77 (Q. 5—PAGE 5 ABOVE), ASK:] Back in the winter of 1976-77, was the beater or furnace usually turned off when no one was at home in the daytime: YES [1] NO [2]

23. [IF THE HOUSE WAS USUALLY UNOCCUPIED DURING AT LEAST PART OF THE DAY THIS PAST WINTER (Q. 5 AND 7—PAGE 5 ABOVE), ASK:] How about this past winter--was the heater or furnace usually turned off when no one was at home in the daytime? YES [1] NO [2]

[GO ON TO NEXT PAGE.]

24. The next several questions have to do with how comfortable your house feels in winter. We realize that wintertime comfort in a house is affected by many things--such as how severe the winter weather is, the thermostat setting, how efficiently the heating system is operating, how warmly we are dressed, and how physically active we are in the house. The researchers would like to know whether you have noticed any change in the wintertime comfort of your house over the last three winters--that is, since about the time your house became a part of the Weatherization Demonstration?

YES [1] NO [2] → GO TO Q. 25 (PAGE 11)

[IF YES, HAND RESPONDENT CARD LABELLED "CHANGE IN HOUSE CHARACTERISTICS OVER THE PAST THREE WINTERS", AND SAY:] This card lists some characteristics of a house that may be related to comfort. Each one has a scale from 1 to 7. Would you think about the change in your feelings of comfort in your house over the past three years, and tell me which number shows how much you feel each characteristic has changed. If you feel a characteristic has not changed at all, use the number "4". If you feel the characteristic is not related to comfort, please tell me that. [WAIT--MARK "X" OVER THE PROPER NUMBERS ON THE NEXT PAGE.]

Change in house characteristics over the past three winters:

	MUCH			NO CHANGE			MUCH		NOT RELATED TO COMFORT
COOLER	1	2	3	4	5	6	7	WARMER	8
MORE HUMID	1	2	3	4	5	6	7	LESS HUMID	8
MORE DRAFTY	1	2	3	4	5	6	7	LESS DRAFTY	8
MORE UNIFORM TEMPERATURES	1	2	3	4	5	6	7	LESS UNIFORM TEMPERATURES	8

25. [FOR SAMPLE HOUSES, ONLY, ASK:] Do you feel that weatherization work done on your house is in any way related to any change in the comfort of the house in winter? YES [1] NO [2] → GO TO Q. 26

[IF YES, ASK:] In what way? ________________________________

____

____

____

26. [FOR ALL HOUSES, SAY:] For the next several questions I would like you to think about your feelings of comfort this past winter. First, what is your recollection of the weather this past winter? Would you say it was

MUCH COLDER THAN NORMAL	[4]
SOMEWHAT COLDER THAN NORMAL	[5]
ABOUT NORMAL	[6]
SOMEWHAT MILDER THAN NORMAL	[7]
MUCH MILDER THAN NORMAL	[8]

27. Now I would like you to tell me how it felt in your house this past winter. [HAND RESPONDENT CARD WITH RATING SCALES, WITH COMFORT/DISCOMFORT SCALE FACING UP.] This is for describing your feelings of the comfort of a room or a place in a room. For example, if you felt that a room was Moderately Comfortable in the winter, you would rate it C4. [PAUSE.]

How comfortable, overall, would you say your house was this past winter--what C-number best describes your overall feelings of comfort in the house?

C____

[GO ON TO NEXT PAGE.]

[HAND RESPONDENT THE FLOOR PLAN LABELLED "THIS PAST WINTER".]

28. Now please look at the [AS APPROPRIATE] FIRST
SECOND
or THIRD FLOOR PLAN of your house labelled "This Past Winter". Does that plan correctly show all of the rooms on that floor of your house?

FIRST FLOOR: NO [2] YES [1] → GO TO Q. 29

SECOND FLOOR: NO [2] YES [1] → GO TO Q. 29

THIRD FLOOR: NO [2] YES [1] → GO TO Q. 29

[IF NO, SAY:] Then please draw in any missing rooms.

[WAIT.]

29. Do you usually keep any of these rooms closed off and not used in winter?

FIRST FLOOR: YES [1] NO [2] → GO TO Q. 30

SECOND FLOOR: YES [1] NO [2] → GO TO Q. 30

THIRD FLOOR: YES [1] NO [2] → GO TO Q. 30

[IF YES, SAY:] Please write "NO" in each of the usually closed-off rooms.

[WAIT.] Would you tell me why each is unused?

ROOM	WHY UNUSED

[IF ALL ROOMS ON A FLOOR ARE UNUSED IN WINTER, GO TO Q. 37 (PAGE 15)]

30. Now I want you to think about times when family members were at home during the daytime this past winter, and about the rooms that were generally used daytimes. Please draw a line or lines around these rooms on the plan. [WAIT.]

31. Do you have some recollections of how comfortable the various rooms in your house felt this past winter?

YES [1] NO [2] → GO TO Q. 39 (PAGE 16)

32. Did you notice feelings of different temperatures in different rooms of your house this past winter? YES [1] NO [2]

33. You probably have noticed that we have been taking many temperature readings throughout your house each month--that is the Temperature Stratification Test described in the yellow booklet about the Demonstration.

[HOLD UP COPY OF "THE WEATHERIZATION DEMONSTRATION RESEARCH PROGRAM AND YOU".]

The researchers at the National Bureau of Standards would like to know how comfortable you feel in the different rooms of your house in winter, so that they can determine how your comfort is affected by the varying temperatures throughout the house.

We would like you to record your impressions of the comfort of the various rooms of your house this past winter on the floor plan. Think for a moment about each room. If you have a clear recollection of how comfortable it usually felt, look at the COMFORT/DISCOMFORT RATING SCALE, see what C-number best represents your feeling about the room, and write the C-number right on the plan in that room. [WAIT.]

34. Have you rated any of the rooms C3 or less?

FIRST FLOOR: YES [1] NO [2] → GO TO Q. 35

SECOND FLOOR: YES [1] NO [2] → GO TO Q. 35

THIRD FLOOR: YES [1] NO [2] → GO TO Q. 35

[IF YES, SAY:] Please describe what is uncomfortable about each of the rooms you have rated C3 or less:

ROOM	WHAT IS UNCOMFORTABLE ABOUT IT

35. In the rooms for which you have given comfort ratings, are there any particular places that, during normal winter weather, felt rather more uncomfortable than your overall comfort rating for that room:

FIRST FLOOR: YES [1] NO [2] → GO TO Q. 36 (NEXT PAGE)

SECOND FLOOR: YES [1] NO [2] → GO TO Q. 36

THIRD FLOOR: YES [1] NO [2] → GO TO Q. 36

[IF YES, SAY:] Please write C-number ratings for those places on the plan. If there is not space on the plan right at a particular place for the C-number, draw a large dot at the place on the plan, and write the C-number just outside the plan close to the dot. Please draw circles around these C-numbers to identify them to the researchers as representing particularly uncomfortable places. [WAIT.]

36. Now please turn over the card and look at the WARM/COLD RATING SCALE. This is used to describe how warm or cold a place feels. For example, if you felt a room was Slightly Cool, you would use T3 to describe it. [PAUSE.]

Now, wherever you can recall how the temperature of a room or place in a room felt last winter, write beside the C-number on the floor plan the T-number that best describes how the temperature of that place feels in winter. Remember that C-numbers with circles around them represent particularly uncomfortable places. If you can recall how the temperature felt at any of those places, write the appropriate T-number beside the C-number and draw a circle around it. [WAIT.]

[IF THE HOUSE HAS AN OCCUPIED SECOND (OR THIRD) FLOOR, SAY:] Now I would like you to record the same kind of ratings for any rooms on the second [or third] floor in which family members spent any appreciable amount of time daytimes this past winter. [GO BACK TO Q. 28 (PAGE 12)]

[OTHERWISE, GO ON TO NEXT QUESTION, BELOW.]

37. To help the researchers in analyzing the Comfort Ratings you have given for the various rooms in your house, would you say how sure you feel about those ratings?

VERY SURE [3] MODERATELY SURE [4] SOMEWHAT UNSURE [5] UNSURE [6]

38. How about the Temperature Ratings—how sure do you feel about them?

VERY SURE [3] MODERATELY SURE [4] SOMEWHAT UNSURE [5] UNSURE [6]

39. Is there anything you would like to add about the comfort of your house this past winter? ______________________________

____

____

____

[FOR CONTROL HOUSES, SAY:] For the next several questions I want you to try to think back to winter time the year before this--that is, the period of about November 1978 to February 1979. [GO TO Q. 41]

40. [FOR SAMPLE HOUSES, ASK:] Can you recall when the Demonstration weatherization work--such as caulking, weatherstripping, insulating--was started on your house? YES [1] NO [2]

[IF YES, ASK:] When was that: YEAR ______ MONTH ______

[CONTINUE.] For the next several questions I want you to try to think back to winter time before your house was weatherized.

[IF NO DATE GIVEN ABOVE, SAY:] That is, the early part of winter 1978-79

[OR] ______________________.

41. For comparison, the researchers would like to know how you felt about the comfort of your house back then. First, what is your recollection of the weather at that time--would you say it was

MUCH COLDER THAN NORMAL	4
SOMEWHAT COLDER THAN NORMAL	5
ABOUT NORMAL	6
SOMEWHAT MILDER THAN NORMAL	7
MUCH MILDER THAN NORMAL	8
DO NOT RECALL	3

42. Now please look at the COMFORT/DISCOMFORT RATING SCALE. How comfortable, overall, would you say your house was back at this earlier time we are now thinking about? What C-number would best describe your overall feelings of comfort in winter back then? C______

43. Please turn over the sheet with the floor diagram on it, and look at the [AS APPROPRIATE] FIRST
SECOND
or THIRD FLOOR PLAN of your house labelled "Winter 1978-79".

→ Does that plan correctly show all of the rooms on that floor of your house as they were back in 1978-79?

FIRST FLOOR: NO [1] YES [2] → GO TO Q. 44

SECOND FLOOR: NO [1] YES [2] → GO TO Q. 44

THIRD FLOOR: NO [1] YES [2] → GO TO Q. 44

[IF NO, SAY:] Then please draw in any corrections needed on this plan. [WAIT.]

44. Did you usually keep any of these rooms closed off and not used in winter back in the earlier time ?

FIRST FLOOR: YES [1] NO [2] → GO TO Q. 45

SECOND FLOOR: YES [1] NO [2] → GO TO Q. 45

THIRD FLOOR: YES [1] NO [2] → GO TO Q. 45

[IF YES, SAY:] Then please write "NO" in each of the rooms that were usually closed off in winter. [WAIT.] Would you tell me why each was unused?

ROOM	WHY UNUSED

[IF ALL ROOMS ON A FLOOR WERE UNUSED IN WINTER, GO TO Q. 51 (PAGE 20)]

45. Now I want you to think about times when family members were at home during the daytime back at this earlier time, and about the rooms that were generally used daytimes. Please draw a line or lines around these rooms on the plan. [WAIT.]

46. The researchers realize that it may be hard for you to remember your impressions from that long ago. For the next several questions about your comfort feelings back in the earlier winter time, please just give your best recollection, or say if you cannot recall at all. Do you recall noticing different feelings of comfort in different rooms of your house back at the earlier winter time? YES [1] NO [2] → GO TO Q. 53 (PAGE 20)

47. Then we would like you to record your recollections of the feelings of comfort of the various rooms of your house at this earlier time. Do it just as you did before. Think for a moment about how each room felt in winter back at the earlier time. If you have a clear recollection of how comfortable it usually felt, look at the COMFORT/DISCOMFORT RATING SCALE, see what C-number best represents your recollection of your feeling in that room, and write the C-number right on the plan in that room. [WAIT.]

[THEN GO ON TO NEXT PAGE.]

48. Have you rated any of the rooms C3 or less?

FIRST FLOOR: YES [1] NO [2] → GO TO Q. 49

SECOND FLOOR: YES [1] NO [2] → GO TO Q. 49

THIRD FLOOR: YES [1] NO [2] → GO TO Q. 49

[IF YES, SAY:] Please describe what was uncomfortable about each of the rooms you have rated C3 or less.

ROOM	WHAT WAS UNCOMFORTABLE ABOUT IT

49. In the rooms for which you have given comfort ratings, were there any particular places that, during normal winter weather, felt rather more uncomfortable than your overall comfort rating for that room:

FIRST FLOOR: YES [1] NO [2] → GO ON TO Q. 50 (NEXT PAGE)

SECOND FLOOR: YES [1] NO [2] → GO ON TO Q. 50

THIRD FLOOR: YES [1] NO [2] → GO ON TO Q. 50

[IF YES, SAY:] Please write C-number ratings for those places on the plan as you did before. Draw circles around these special C-number ratings, and place them outside the plan with a dot inside at the place, if necessary.

[WAIT—THEN GO ON TO NEXT PAGE.]

50. Now please turn over the card and look at the WARM/COLD RATING SCALE. Wherever you can recall how the <u>temperature</u> of a room or place in a room felt at the earlier winter time, write beside the C-number on the floor plan the T-number that best describes how the temperature of that place felt in winter. Again remember that C-numbers with circles around them represent particularly uncomfortable places. If you can recall how the temperature felt at any of those places, write the appropriate T-number beside the C-number and draw a circle around it. [WAIT.]

[IF THE HOUSE HAS AN OCCUPIED SECOND (OR THIRD) FLOOR, SAY:] Now I would like you to record ratings for any rooms on the second [or third] floor in which family members spent any appreciable amount of time daytimes back in the earlier winter. Please look at the [AS APPROPRIATE] FIRST
SECOND
or THIRD FLOOR PLAN

of your house labelled "Winter 1978-79". [GO BACK TO SECOND PART OF Q. 43 (PAGE 17)]

51. How sure do you feel about the Comfort Ratings you have given for the winter time in 1978 or 1979?

VERY SURE [4] MODERATELY SURE [5] SOMEWHAT UNSURE [6] UNSURE [7]

52. How about the Temperature Ratings--how sure do you feel about them:

VERY SURE [4] MODERATELY SURE [5] SOMEWHAT UNSURE [6] UNSURE [7]

53. Is there anything you would like to add about the comfort of your house back in the earlier winter time? ______________________________

____

____

____

54. How important would you say the wintertime comfort of your house is to you?

VERY IMPORTANT [4] MODERATELY IMPORTANT [5] SLIGHTLY IMPORTANT [6]
NOT IMPORTANT [7]

55. The clothing we wear strongly affects how warm or cool we feel. Please think for a moment about the clothes you usually wore at home this past winter. [WAIT.] Now try to recall the clothes you usually wore at home back in the winter of ________. Comparing the clothes you usually wore at those two times, would you say that, during this past winter, you usually wore

MORE OR HEAVIER CLOTHING [4]
ABOUT THE SAME AMOUNT OF CLOTHING [5]
LESS OR LIGHTER CLOTHING [6]
DO NOT KNOW [3]

56. During this past winter how often did you wear a sweater or other "extra" wrap in the house during daytimes?

ALL THE TIME [1] USUALLY [2] SOMETIMES [3] RARELY [4] NEVER [5]

57. What about during the evenings--how often did you wear a sweater or other "extra" wrap this past winter?

ALL THE TIME [1] USUALLY [2] SOMETIMES [3] RARELY [4] NEVER [5]

58. During this past winter were there any ways, other than adjusting the heater setting or the clothing you wore, that you used to get warm or keep warm--like, for example, doing exercises, or rubbing your hands together?

YES [1] NO [2] → GO TO Q. 59

[IF YES, SAY:] You do not need to answer this, but if you would care to tell me what those ways of getting warm or keeping warm were, the researchers would be interested to know: ______________________

____

____

59. Now please think back to the winter time in _____. How often did you wear a sweater or other "extra" wrap in the house daytimes back then?

ALL THE TIME [1] USUALLY [2] SOMETIMES [3] RARELY [4] NEVER [5]

60. How about during the evenings back then?

ALL THE TIME [1] USUALLY [2] SOMETIMES [3] RARELY [4] NEVER [5]

61. During the earlier winter time, were there any ways, other than adjusting the heater setting or the clothes you wore, that you used to get warm or keep warm?

YES [1] NO [2] → GO TO Q. 62

[IF YES, SAY:] Again, you do not need to answer this, but if you care to tell me what those ways were, I will record them: ______________________

____

____

62. Does your house have a fireplace or wood burning stove?

FIREPLACE [1] → GO TO Q. 64 (NEXT PAGE)

WOOD STOVE [2] → GO TO Q. 63

NO [3] → GO TO Q. 65 (NEXT PAGE)

63. When did you get the wood stove? YEAR ______ MONTH ______

64. How often do you have a fire in the fireplace or wood stove during cold weather?

EVERY DAY [1]   SEVERAL TIMES A WEEK [2]   ONCE A WEEK [3]   LESS OFTEN [4]

65. Do you usually leave any windows open, even a crack, for fresh air in cold weather?   YES [1]   NO [2]

[IF YES, ASK:]   About how many? ______

Thank you very much for taking the time to answer these questions. We really appreciate your cooperation.

TIME IS NOW ________

INTERVIEW CONDUCTED BY ______________

[INTERVIEWER: REMEMBER TO PICK UP:

1- FLOOR PLAN SHEET;

2- CARD WITH RATING SCALES;

3- CARD WITH "CHANGE IN HOUSE CHARACTERISTICS . . . ."]

COMFORT/DISCOMFORT RATING SCALE

- C5 — VERY COMFORTABLE
- C4 — MODERATELY COMFORTABLE
- C3 — SLIGHTLY UNCOMFORTABLE
- C2 — UNCOMFORTABLE
- C1 — VERY UNCOMFORTABLE

WARM/COLD (TEMPERATURE) RATING SCALE

- T7 — HOT
- T6 — WARM
- T5 — SLIGHTLY WARM
- T4 — NEUTRAL: NEITHER WARM NOR COLD
- T3 — SLIGHTLY COOL
- T2 — COOL
- T1 — COLD

APPENDIX C

Sample of Output of Program QUSTEDIT

CSA Weatherization Demonstration Questionnaire' Data

Generally: 8 = "NA"; 0 = blank; 1 = "YES"; 2 = "NO"

CASE NO. 134 SITE: STL HOUSE NO. 70 Category: S

Interview Date: 6/24/80 Begin Time: 10:35 Q.20: 0
Respondent H. of H.: 1 Relationship: 0 Year moved in: 1955

OCCUPANTS:

Sex	77 Age	Left	Arrived	80 Age
M	56	NA	NA	59
F	50	NA	NA	53
M	17	Fb 80	NA	20
M	20	19 78	NA	23
M	10	NA	NA	13
-				
-				
-				
-				

Day OCCUPANCY: 1 All Day? 1 Changed: 2 (How?) 0 ("9"=NOTE!)
Unoccupied? 2

YEAR	MONTH	How many days?
88	NA	88
88	NA	88
88	NA	88
88	NA	88

THERMOSTAT: Have: 1 ("3"=FAULTY) Same each day: 1
Changed since 1976: 1

MONTH	YEAR	CHANGE ("2"=DN;"3"=UP;"4"=?;"5"=BOTH)
0	79	2
0	0	0

In unusually cold weather: ("3"=HIGHER; "4"=LOWER; "5"=SAME)
1976-77 3 4 Deg.
1979-80 5
Usual settings last winter: Day: 70 Night: 70
("33" = INDETERMINATE/FAULTY; "40" = "OFF")
NOTICED DIFFERENCES: 1
("1")Cooler("4")Warmer("7"): 7 ("9" =NOT RELATED TO COMFORT)
More - Less Humid: 6
More - Less Drafty: 7
More - Less Uniform Temps.: 1

Believe weatherization work related to comfort: 1 (How?): 1

Recollection of winter weather: ("4"<COLDER-"6"-MILDER>"8") OVERALL "C"
1979/80: 7 ("2"=NOT RECALL; 5
Earlier winter: 4 "9"=NA) 3
Recall feelings of: COMFORT: 1 TEMPERATURE: 2

```
                          LAST WINTER                        EARLIER WINTER
                          1st flr. 2nd flr. 3rd flr. 1st flr. 2nd flr. 3rd flr.
                          -------  -------  -------  -------  -------  -------
Floor Plan Correct:         1        1        1        2        2        2
Rooms unused:               2        2        1        2        2        1
Rooms "C3" or less:         2        2        2        1        1        2
Partic. uncomf. places:  2           2        2        2        1        2

SURENESS OF RATINGS -  "C"    "T"      "To add??"    ("2"=NOTE!;
  ("1"-VERY;..."4"-UNSURE)                         "3"=NON-COMFORT)
  1979/80:              1      1          1
  Earlier winter:       1      1          0

Recall when weath. began?   1     YEAR:  1979    MONTH:
"Before" date in questions:  78/9
ACTUAL WEATH. DATE:               YEAR:  1979    MONTH:  J1
Recall different feelings of comfort from earlier winter    1
Importance wintertime comfort: 4  ("4"-VERY; "5"-MODERATE; "6"-SLIGHT; "7"-NOT)

CLOTHING CHANGE:  6   ("4"-MORE; "5"-SAME; "6"-LESS)
             1979/80:  Day   Night Activ.   Earlier:  Day   Night Activ.
Wore sweater:           4      4                       1      1
  ("1"-ALL TIME;..."5"-NEVER)
Activities to keep warm:           2  8                               2  8

"Other" heat source:         3
("1"-FIREPLACE; "2"-WOOD STOVE; "3"-"NO"; "4"-COAL STOVE)
When got:  88/88    How often use:  8  ("1"=DAILY;"2"=SEV./WK.;"3"=1/WK.;
Windows open in cold weather:  2    How many:  8                 "5"=NEVER)

INTERVIEWER: TWilliams  (STL)         END TIME: 11:10    LENGTH:  35 MINS.

  Last winter: Unused  C3 or less   Earlier winter: Unused  C3 or less
No. of rooms:     1        0                           1        2

ROOM DATA: Last Winter                  Earlier Winter
Room Unusd "C" "T" P.U.:"C" "T" C3or> Unusd "C" "T" P.U.:"C" "T" C3or>
 1LR        5   6                            3   3
 1DR        5   6                            3   3
 1KT        5   6                            3   3
 1W1        5   6                            3   3
 2B1        5   6                            3   3
 2B2        5   6                            3   3   1 5  2
 2W2        5   6                            3   3
 2B3        5   6                            3   3
 2B4        5   6                            3   3

"ENTER" YEAR: 1977
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5. AUTHOR(S)

Roy E. Clark

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This study reports preliminary examination of data testing the hypothesis that, when existing residences are treated with weatherization retrofitting measures intended primarily to save fuel, house occupants are likely to report improvement in wintertime comfort. Data were obtained through questionnaire-guided interviews with individuals in 108 experimental houses and 37 control houses. These houses, at nine sites representing a range of U. S. climates, were part of a three-year National Weatherization Demonstration, sponsored by the Community Services Administration and planned and managed by researchers at the Center for Building Technology of the National Bureau of Standards. The experimental houses had been weatherized to determine how much their fuel usage could be reduced by cost-effective retrofitting. The control houses had not been weatherized in the demonstration. Interview topics included: thermostat setting patterns, impressions of comparative comfort, amounts of clothing worn, and specific comfort and temperature ratings for the house as a whole and for individual rooms in the house. Preliminary examination of the data has focussed on: 1) a composite "comfort change" index, comprised of indicators derived from thermostat setting practices in unusually cold weather, impressions of change in comfort-related attributes of the indoor environment, amounts of clothing worn in winter, and comfort ratings, 2) the specific comfort ratings, and 3) the temperature ratings. The results presented offer strong indications of support for the hypothesis.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Community Services Administration; field study; occupant comfort; Optimal Weatherization Demonstration; thermal comfort; thermostat setting practices; weatherization; weatherization and thermal comfort

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