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OCCUPANT/DWELLING DISPOSITION FACTORS
AS PREDICTORS OF RESIDENTIAL ENERGY CONSUMPTION

by

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INTRODUCTION

For several years there has been a national effort to reduce energy consumption in all sectors. This thesis focuses on energy conservation efforts in the residential sector. There are principally two reasons for the residential sector focus.

1. Twenty five percent of all energies consumed in the United States are used for space heating and cooling and for domestic water heating in homes.¹
2. Much of the energy used in today's homes is wasted. For example, results from experiments in townhouses at Twin Rivers, New Jersey demonstrated that using ordinary structural retrofitting techniques it was possible to attain a two-thirds reduction in space heating fuel use at a very reasonable cost.²

Currently, monitoring of progress in residential energy conservation is primarily managed through the use of energy audits. These audits are used to gather information for two distinctly different energy-related applications. The first is when a physical inventory is desirable as a basis upon which to make decisions concerning home remodeling to conserve energy. The second application is when basic empirical information is gathered for the purpose of making inferences and testing hypotheses about appropriate community or national energy policies.

It is, of course, the quality of the evaluation audit and the facility with which the audit is interpreted that determines the usefulness of audit results. For the purposes of physical inventory, structure-based audits are appropriate and have been highly refined both in their content and in their application. However, for the purpose of prediction, audits currently in use are often inadequate since they

¹ Robert Stobaugh and Daniel Yergin, eds. Energy Future, (Random House, 1979), p.123.

² Frank W. Sinden, "A Two-Thirds Reduction in the Space Heat Requirement of a Twin Rivers Townhouse," Saving Energy in the Home, ed. Robert H. Socolow (Ballinger Publishing Co., 1978), pp.63-100.

frequently measure only structural attributes and none of the occupant-related attributes of an occupied dwelling. This is a significant concern since it has been shown that structure-based characteristics are not necessarily the primary causes of energy use variance in a home.³ Predicting home energy consumption/conservation using structure-based audits presents at least two significant problems.

1. **Assumptions are made that each energy conservation feature is fully used.** In practice, the degree of utilization is determined by the occupant's behavior. For example, storm windows left open are not effective.
2. **Assumptions are made that no other changes occur as a result of the presence of a new energy conservation feature.** In fact, once a feature is installed, the occupant may change his/her behavior for the better or for the worse in the home or in another sector.⁴ The net effect is unpredictable using current audits and may neutralize or double the energy savings possible with the feature installed. An example of changing behaviors is the family who, after having bought a 'solar' home, feel they have done their conservation duty and become less careful about turning off unused lights.

The limited research to date, which will be discussed in the next chapter, indicates that a multidimensional approach is essential for measuring and predicting the potential for energy conservation in the residential sector. Researchers in each of the studies cited agree that some mix of energy-related attitudinal, demographic, behavioral, and structural variables will be required for a predictive auditing tool.

This thesis adopts the suggested multidimensional approach and investigates in a community setting the relation between occupant dispositions (attitudes, demographics, and actions), and physical features (such as insulation levels, infiltration control, etc.) as they effect energy consumption.

³ Robert C. Sonderegger, "Movers and Stayers, The Resident's Contribution to Variance Across Houses in Energy Consumption for Space Heating," Saving Energy in the Home, ed. Robert H. Socolow (Ballinger Publishing Co., 1978), pp. 207-229.

⁴ Jan Hamrin, "Energy-Saving Homes: Don't Bet on Technology Alone," Psychology Today, (Apr. 1979), p. 32.

Specifically, this thesis discusses:

1. the process used to single out five structural and occupant characteristics of occupied single family dwellings in Marysville, Kansas which are primary contributors to variance in metered energy consumption, and;
2. the strong ability of those characteristics to predict the the variance in metered energy consumption.

The result is that a mix of occupant and structural variables is shown to improve the ability to predict metered energy consumption in dwellings.

CHAPTER 1 - LITERATURE REVIEW

National Surveys

Many national surveys have been conducted to gather basic empirical data concerning residential energy use. These studies are discussed in detail in the report of the Monitor Project (Beck, Doctors, and Hammond, 1980). In general, the national studies focus primarily on three issues.

1. Individuals' beliefs about the reality of and the need for energy conservation.
2. Individuals' belief about who, if anybody, is responsible for the energy crisis.
3. Individuals' self-reports of conservation behaviors (the bias in self-reports in these early studies is not quantified).

According to the Monitor Project, Americans are able to sustain a belief in the need to conserve energy only so long as crisis situations are perceived to exist; opinions as to who is responsible for energy crises vary with the crisis situation; and self-reports of conservation behaviors rise during crisis periods, and fall during non-crisis periods.

These national studies are useful as background but are still too general to provide specific guidance in the selection of variables for the thesis research.

Surprisingly little research exists which examines specific relationships between attitudinal, demographic, behavioral, and structural variables affecting energy use in occupied dwellings. There are perhaps only three studies which specifically attempt to use a few behavior-based predictor variables to predict either self-reports of conservation activities or measured energy use. The following is a discussion of those three studies as well other research in relation to the Marysville study.

The Movers and Stayers Study

In 1976, Robert Sondregger determined in townhouses in New Jersey that the effect of the homeowner was more the cause of variance in an occupied dwelling's energy consumption than was the house's structure. The study did not look at specific structure or occupant attributes which might be affecting energy use, but took instead a more general look at why there was so much variation in energy consumption across seemingly identical houses. The report suggests that the significance of the results is in their guidance of public policy. That is, "to concentrate attention on the residents, clarifying by research and subsequent publicity the kinds of actions that have energy penalties and savings and their magnitudes".⁵

Attitudes, Behaviors and Energy Consumption

Seligman, Darley and Becker (1978) isolated behavioral attributes related to electricity use for air conditioning which could account for the observed variance in summer electricity use. The results of their investigation (also carried out at Twin Rivers, New Jersey) showed that

"1. homeowners' attitudes toward energy can be conceptualized into a few basic factors, and 2. that these attitudinal factors can predict actual energy consumption. Homeowners perceived their use of energy according to their judgement of the effect of energy conservation on their personal comfort and health, the effort required to conserve and the monetary payoff for doing so, the ability of the individual to have an impact on the energy problem, and their belief that the crisis is legitimate. Together, these factors were capable of explaining a total of fifty percent of the variance in actual electric consumption. Examined singly, the comfort and health factor, the high effort, low payoff factor, and the role of the individual factor were significant predictors of energy use. The comfort and health factor emerged as the best single predictor of consumption accounting for a greater percentage of consumption variance than any other factor.

A second survey of sixty-nine couples was conducted in September 1976 in the same community to attempt to confirm the general results of the

⁵ op. cit., Sondregger, p.208.

first survey. The results of the second survey showed that the same factors reemerged and that together they again accounted for a significant portion of the variance. However, in the second survey the comfort and health factors were the only statistically significant predictors of actual energy consumption."⁶

The Marysville study adopted several of the questions used at Twin Rivers and added to them similar questions which were modified to measure attitudes about wintertime energy use for heating. These are discussed in detail in chapter 2. The results in Marysville clearly support the importance of the health and well being factor, especially as it relates to summertime cooling. In addition, a measure of the belief in the crisis was significant enough to be included among the five most important predictor variables in the Marysville study. However, belief in the crisis was overshadowed by demographic variables of family income and average age of home occupants and the summertime health and well being factor.

The Monitor Project

The report of the Monitor Project (Beck, Doctors, Hammond, 1980) in Allegheny County, Pennsylvania describes the Project's efforts to predict self-reports of conservation activities in several areas using demographic, situational, attitudinal, and perceptual predictor variables. Of particular interest to the Marysville study was their research in the area of general conservation.

Attitude Variables

The Monitor Project measured attitudinal predictor variables of political confidence, political trust, sophistication, energy conservation, general conservation, energy pessimism, cost consciousness, and non materialism. Of these, cost consciousness, sophistication, concern, and non materialism were eventually determined to be the best predictor variables.

⁶ Clive Seligman, John M. Darley, and Lawrence J. Becker, "Behavioral Approaches to Residential Energy Conservation", Saving Energy in the Home, Robert H. Socolow (Balingier Publishing Co., 1978), p.241.

The strongest predictor of energy use in the Marysville study is the education of the head of the household. This result would seem to support the Monitor Report's findings concerning the importance of sophistication (of thinking about energy), and the ability to evaluate economic options (cost consciousness). Presumably, those with more education are more likely and better able to evaluate cost-related energy decisions. The Marysville study also identified the importance of home occupants' concern or belief in the existence of an energy problem. Non materialism, identified in the Monitor Study, was not measured in the Marysville study.

Activities Variables

Activities measured in the Monitor Study were the addition of attic, roof and wall insulation, weatherstripping, storm windows, shutting off heat in unused rooms, lower thermostat settings at night, and setting thermostat at sixty-eight degrees or less during the day. In the Monitor Study, a score developed from these measures was used as the dependent variable for the study. How each of these variables, in conjunction with attitudinal, demographic and structural variables affected actual energy use in a home was not measured.

The Marysville project measured each of the activity variables measured by the Monitor Study. Of these, only activities of adding attic, roof and wall insulation emerged as sufficiently strong predictors of energy use. Of the combined attitudinal, demographic, activity and structural variables, the activities variables were the least successful predictors of energy use.

Demographic Variables

The Monitor Study measured demographic variables of sex, education, income, age, race, and income decline. In another study, Newman and Day (1975) have placed particular emphasis on the importance of race. They suggest that race (white, black and hispanics are the divisions commonly used) may have a great deal to do with energy consumption, because of its relation to income, education, and housing stock type and quality.

The 1980 National Census data for the City of Marysville, shows less than one percent of the households as being black or hispanic.⁷ For this reason, the effect of race on energy

⁷ U.S. Bureau of the Census, 1980 Census of the Population,

consumption was not measured in the Marysville study.

Income decline, as defined by the Monitor Study, has to do with the phenomena that people who expect energy prices to outstrip their ability to pay for energy are more likely to undertake energy conservation activities. The Marysville study did not address this issue specifically, although the general effects of income, education, and the belief in an ongoing energy problem are measured. As has been mentioned, education and belief in the crisis were identified as being very important predictor variables in the Marysville study.

Other Research

Though there are many audits which measure structural variables, the State of Kansas currently uses the Audit For Conservation Today (ACT) (Phil Dubach, 1981). ACT is a revised version of the federally mandated Residential Conservation Service (RCS) (U.S. Department of Energy, 1980) audit. ACT measures approximately ninety physical variables such as building skin construction techniques and insulation levels. Questions such as 'number of home occupants' which appear to measure behavioral data, are used to estimate physical parameters such as quantity of energy consumed to heat water, or amount of air infiltration from opening doors.

Perhaps the most important finding of the research at Twin Rivers (Sondregger 1978) was that the majority of explained variance between actual and expected energy use in a group of townhouses was caused by the occupants, not by the structure. They found that the effect of the occupants was overwhelming to the degree that they could not predict the energy use of the living unit from one occupant to the next.

"In a sample of twenty eight identical townhouses, variation in energy consumption was found to be as great as two to one. Since these houses are identical in floor plan, position in the interior of a townhouse row, builder, construction materials, and climate, it is likely that most of the consumption variance is due to the different behavior of the people in the houses. Finally, even after houses had been successfully retrofitted (with twenty to twenty five percent savings), the variance in energy consumption among the houses remained almost the same as it was before the retrofits took

place, and the rank order hardly changed."⁸

Structure-based, thermal simulation audits (such as the ACT) require a relatively high commitment of time and effort. Although these audits presumably portray accurately the theoretical performance of a building in the absence of variance produced by occupant actions, the previously mentioned research provides evidence that structure-based thermal analysis procedures will not predict (better than chance) the actual performance of occupied dwellings.

For this reason, and because of limited time and financial resources, a modified form of the National Association of Realtors (NAR) energy features auditing method was adopted for the thesis research (National Association of Realtors, 1980).

The National Association of Realtors uses one of the few energy audits which recognize the effects of the home occupant on energy use. Because NAR recognizes that a homeowner's lifestyle affects fuel consumption tremendously, they recommend use of an audit which compares measured energy use per square foot with the expected energy use given the number of 'energy features' in that home. Energy features are recommended according to the climate zone in which the home is located. If the home's utility bills are either lower or higher than one would expect given the number of energy features present, then the Realtor assumes the unpredictability was caused either by the previous owner's energy use behavior or by some unknown factors in the building's structure. In either case, the Realtor is cautioned not to make any promises about the utility bills to the prospective home buyer. Energy features include essentially any building feature which may reduce the quantity of energy a home uses. For example, thermal resistance insulation, storm doors and windows, vent dampers, zoned heating and cooling systems, clock thermostats, water flow controllers and other similar features are common 'energy features'.

For the thesis research, energy features in quantities appropriate to Marysville were determined using NAR guidelines before fieldwork began. Homes in the sample were rated by observing the features present and the degree to which they conformed to the standards set forth (see appendix D). This approach allowed for representation of physical features in the analysis without spending unavailable and possibly unwarranted time collecting the data.

⁸ Seligman, Darley, and Becker, op. cit., p.232.

In 1981, a national survey commissioned by Gardens For All and conducted by the Gallup Organization entitled, The Impact of Home and Community Food Gardening on America, found that the a very good predictor of energy conservation actions was gardening.⁹ The Marysville study measured whether or not dwelling occupants had had a garden during the year previous to this study; whether gardening, indoors or out, was a regular activity; and the types of plants grown. None of these measures proved to be a significant contributor to the prediction of energy use in the dwelling.

⁹ Bruce Butterfield, ed., The Impact of Home and Community Food Gardening on America, (Gardens For All, 1981), pp.24-26.

CHAPTER 2 - RESEARCH DESIGN

Sampling Method

In October of 1982, a stratified (by dwelling age) random sample of 5% (67) of the homes in Marysville, Kansas was selected from the Marshall County assessor's records of dwellings in Marysville. Marysville was chosen for two reasons.

1. Because of the availability of upper level undergraduate and graduate architectural, planning and landscape architecture students enrolled in a joint design studio at Kansas State University for the purpose of studying the uses of energy and the potential for greater energy independence in Marysville. These students, plus Marysville residents, were used to gather the data for the study.

2. Manageable size. The 1980 census shows 3670 residents in 1340 households.¹⁰ Five percent of 1340 households required a sample of sixty seven households. This was deemed to be manageable during the six to eight weeks available.

Sampling of homes was stratified by the year of the home's original construction in order to control for dwelling age; initially thought to be a major determinant of energy consumption. Results of the study indicate that the original construction date had very little to do with the present condition of a home and therefore is not likely to be a significant predictor of dwelling energy use.

During October and November of 1982, students from the design studio as well as volunteers from Marysville were trained as interviewers and auditors before being sent into the community to collect data on energy related structural, attitude and demographic variables. Respondents were told that the project was a uses-of-energy survey and that the survey would require approximately thirty to forty-five minutes of their time. If the respondent indicated he/she would not allow her/himself to be interviewed, then a replacement was chosen from a list of extra, randomly chosen homes. Care was taken to replace with homes from the same

¹⁰ U.S. Bureau of the Census, op. cit., p. 122.

age group. If, after three contacts, no one was found at home, then the home was similarly replaced. Contacts were made between the hours of eight in the morning and seven in the evening. Eventually, because of time constraints, respondents were contacted in only fifty six of the homes. This resulted in a four percent sample being taken.

Research Instruments

Respondents were limited to the head of the household or the spouse. Four individual research instruments were used.

1. **Face to face interviews** containing one hundred and four questions about the dwelling type, occupant demographics, own/rent status, value of the home, heating and cooling uses and fuels, occupant activities related to general weatherization, occupant's participation in activities correlated to energy conservation activities (ie: gardening), and occupant's willingness to participate in further energy related studies (see Appendix A).

2. At the conclusion of the interview, respondents were asked to authorize the release of **fuel use data** by the local utility (see Appendix B). Metered natural gas and electricity data for the thirteen months previous to and including November 1982 were collected.

3. Before leaving the home, interviewers left one or two **attitudes-about-energy surveys** for the head and, if living in the household, spouse to complete (see Appendix C). They were told to complete the forms independently during the next few days; they would be picked up by an audit team within one week.

The energy attitudes survey consisted of eighteen statements about energy use representing eight conceptual areas. Items 'a' through 'f' are concepts identified by the Twin Rivers study (Seligman, Darley & Becker, 1978). Item 'g' is a modified form of item 'a'. Item 'h' is an entirely new concept introduced in the Marysville study.

a. Perceptions of the effect of summer energy conservation on the health and well-being of the occupants. (ex: How essential is it to your personal health and well being for the house to be airconditioned in the summer?)

b. Belief in the reality of the energy problem. (ex: The energy crisis certainly doesn't warrant all the attention given to it in the last few years.)

c. Perceived returns for the inconvenience of conserving energy. (ex: Trying to save a few pennies a day conserving energy is just not worth it.)

d. The morality of energy consumption/conservation. (ex: It is immoral to consume any more energy than I absolutely need.)

e. The individual's faith in technology's ability to solve the problem. (ex: American technology in the past has come to grips with all major crises and it will no doubt soon discover a solution to the energy problem.)

f. The role of the individual in energy conservation. (ex: Consumers have the right to use as much energy as they want and can pay for.)

g. Perceptions of the effect of winter energy conservation on the health and well-being of the occupants. (ex: While others may be willing to set their thermostat lower in the winter, my own need for a very warm house is high.)

h. Belief in the immediacy of the problem. (ex: To what degree do you think it possible that, for whatever reason, your supply of heating fuel may be cut off in the near future?)

Responses to the questions were made on a seven point scale much like that used in the Twin Rivers study (Seligman, Darley and Becker, 1978). Questions were randomly ordered on the survey except for the measures of family income and education. Respondents were allowed to mark boxes themselves indicating their income and level of education rather than provide this information to an interviewer. It was felt that by gathering this potentially sensitive information in this way, a higher response rate might be achieved by providing a greater sense of privacy.

4. The fourth instrument was a **physical audit** performed by teams separately chosen and trained because of their prior experience with energy auditing and building construction (see Appendix D). Before the data gathering began, a windshield survey of Marysville indicated that the residential building stock was generally homogenous in size, construction and form. In addition, research in other localities had indicated that detailed building features, if possible to classify at all, were probably not as important in predicting energy consumption as were occupant attitude and demographic variables (see Chapter 2, section Other Research for a discussion of this assumption). These issues, combined with time and personnel constraints, lead to use of the 'energy feature' auditing method. In addition to the energy features audit, a solar access evaluation was performed although this information was not used in the research reported in this thesis.

Internal Validity

The study of behavioral effects in residential energy consumption is still very young. Standardized testing instruments and procedures, like those which exist in some other fields of study, have not been developed for these studies. In the absence of broadly accepted testing instruments and procedures, the Marysville study chose to draw procedures and measures from the few research examples available and either use them as they stand or with slight modification. However, combining the various procedures to measure observed energy use does not appear to have precedent and therefore can only be evaluated in this instance by the face validity of the procedures, internal measures of validity, and the believability of the results.

Face Validity of the Procedures

The introduction and the literature review provide a discussion of the rationale used to arrive at the approach of combining structural, demographic, attitudinal and activity variables as predictors of observed energy use in an occupied dwelling.

Internal Measure of Validity

A common test of internal validity is the analysis of the content of measures which tend to vary similarly. If variables are measuring something other than that which they were designed to measure, they tend not to cluster with identifiable common themes. Analysis of variables which cluster together in the Marysville study show that clusters do indeed have common themes. These are discussed in the next chapter.

Face Validity of the Results

The results of this research can be compared to other studies only partially; that is, important energy-related attitudes identified in the Marysville study can be compared with those identified in the Twin Rivers (Seligman, Darley, and Becker, 1979) studies, but the combined predictive potential of attitudinal, behavioral, structural and demographic variables has only been tested in the Marysville study.

Overall, results of the Marysville study compare favorably with those of both the Twin Rivers research and the Mo-

nitor Project. A discussion of those comparisons may be found in Chapter 1 - Literature Review.

External Validity

As is often the case, the choice of this research design presented both advantages and disadvantages.

The chief advantage was the reduction of variables in the study because it was not necessary to modify the analysis of dwellings to account for multiple unit buildings, widely differing construction methods and materials, or diverse plantings and vegetation. Similarly, the lack of racial diversity, and the lack of a widely divergent social and cultural makeup within the city allowed a simplified analysis which may not be possible in a more urbanized context.

Ironically, the homogenous structural and demographic character of Marysville which allowed a simplified analysis, also requires that the generalizability of the study be limited to cities of a size and character similar to Marysville. However, one must remember that although there is no other study with which to compare the predictive ability of the mixed variables as they were used in the Marysville study, the importance of the individual attitudinal, behavioral and demographic characteristics identified agree very well with those identified in other studies.

CHAPTER 3 - OBSERVATIONS

Overview

As has been previously discussed, the purpose of the Marysville study is two-fold. First, it identifies a few measures of structural, attitudinal, demographic, and behavioral attributes of occupied single family dwellings which have been shown to be related to energy use in homes. Second, it tests the combined ability of a few of those measures to predict reliably the observed energy use in an occupied dwelling.

The hypothesis is that just a few of the many measures currently known to effect energy use in occupied dwellings are responsible for most of the variance in the observed energy use. If this is true, it should be possible to first identify those primary variables and then quantify their effects. The goal of these actions would be the development of a 'short form' energy audit with greatly enhanced usefulness as a predictive tool.

Initially, it was determined that factor analysis would be used to identify dimensions or groupings of variables which were similar enough to be characterized and tested in combination as predictors of variance in the dependent variable **metered energy consumption**. Unfortunately, the parametric factor analysis available on Kansas State University's Statistical Analysis System requires more observations than were available in this study. Alternatively, an item analysis procedure was used to arrive at groupings of strongly associated variables.¹¹ These groupings were then tested (using nonparametric analysis procedures) in combination with pivotal variables as predictors of metered energy consumption using a multivariate regression procedure. The result is a five variable regression model which predicts through independent and interactive effects approximately fifty eight percent of the variance in metered energy consumption.

¹¹ Earl R. Babbie, The Practice of Social Research, 2nd Ed., (Wadsworth Publishing Co., Inc., 1979) pp.407-408.

Correlation Analysis

The sample selected for the Marysville study is a small sized sample and the variables of interest in the study are measured using nominal or ordinal scales. For these reasons, the nonparametric Spearman Correlation procedure was used to get an initial fix on the associations among the fifty-eight variables in the data set (see Appendix E).¹² Variables with no correlation coefficients greater than .45 were deleted and another Spearman procedure was performed on the remaining forty one variables (also see Appendix E). This reduction process had the effect of condensing variance and strengthening the significance of correlations.

A correllogram (Figure 1) represents the association of the variables after the second procedure by graphically illustrating the orthogonal connections, strengths, and direct or inverse relationships of the variables remaining in this study. The correllogram clearly shows five clusters of variables. These are the summer health and well being, winter health and well being, number of occupants, ages and rights, and the insulation clusters. In addition, it shows pivotal variables which seem to connect the clusters. These are the average age of all the dwelling occupants (Avgall), the average age of the children in the dwelling (Avgchld), the household income (v_130), the education of the head of the household (v_131), attitudes about the morality of energy conservation (v_122), and a measure of the perceived returns for the bother of conserving (v_129). Several variables which were only associated weakly with one other variable were deleted for clarity from the correllogram.

¹² Sidney Seigel, Nonparametric Statistics for the Behavioral Sciences, (McGraw-Hill Book Company, Inc.), pp.18-20, 202-213.

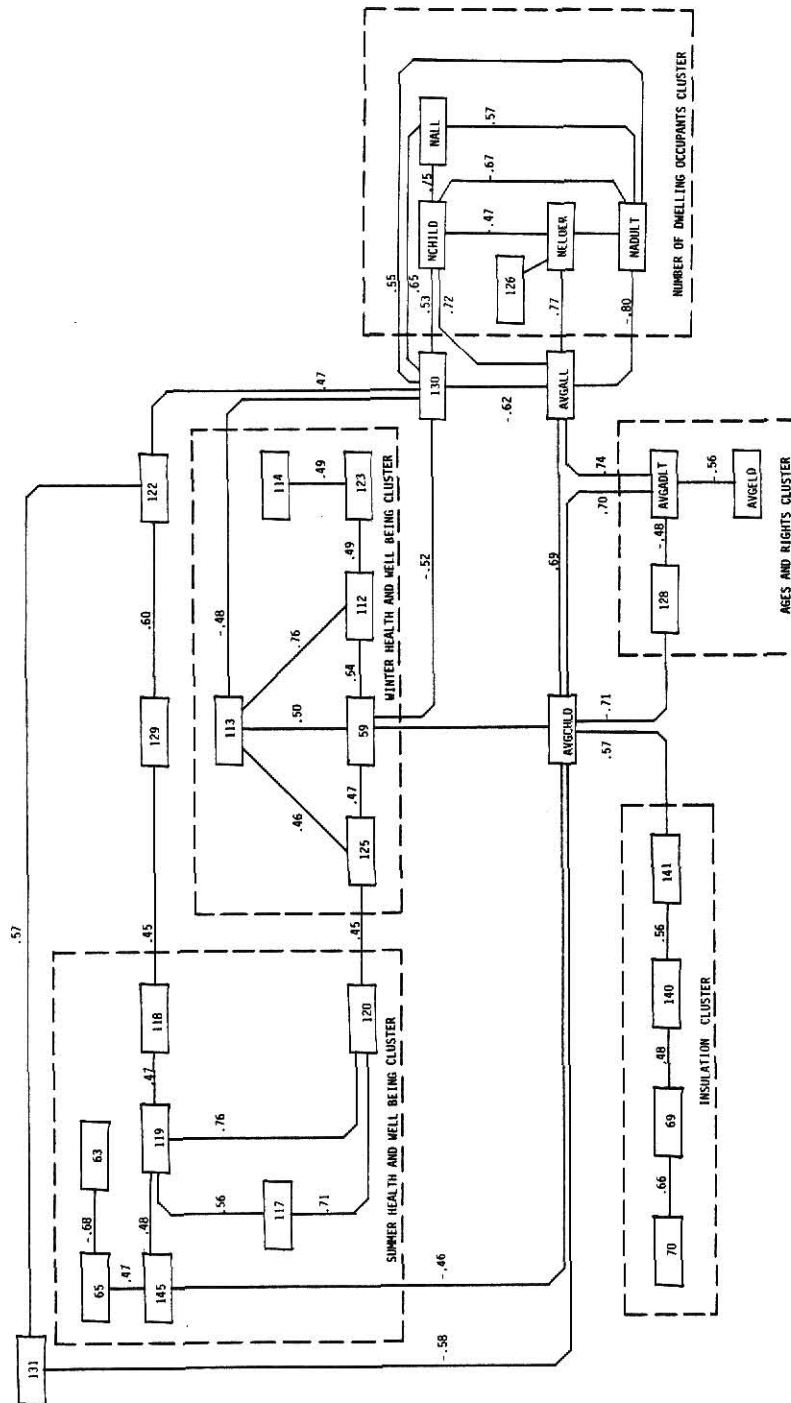


Figure 1: Correllogram

To identify the variables within each cluster which are most strongly associated with the cluster as a whole, a variable for each cluster was created which is the sum of the raw scores for each variable within that cluster. The variable created, therefore, represented the total variance of that cluster. By again using a Spearman Correlation procedure to compare the variance of each measure within a cluster with the total variance of that cluster, a measure of the strength of the association between the individual variables and total cluster was achieved. These associations are reported in Tables 1 through 5.

Summer Health and Well Being Cluster

Table 1 is composed of airconditioning variables, principally those concerned with the perceived effect of airconditioning energy consumption/conservation on the occupant's health and well-being.

TABLE 1			
Correlation of Cluster Variables With Total Cluster Variance - Summer Health and Well Being			
Rank	Variable	Corr. Coefficient	Signif. ¹
1	High need for being cool in summer.	.87428	.0001
2	Difficult to fall asleep in summer without aircon.	.84609	.0001
3	Essentialness to personal health and well being of aircon.	.72057	.0001
4	Not worth it to sweat some in summer to save a little energy.	.65613	.0001
5	Presence of central airconditioning.	.44490	.0025
6	Presence of extra glazing or storms.	.33993	.0395
7	Presence of window airconditioner.	-.22760	.1373
¹ Prob > R under Ho : Rho = 0			

Winter Health and Well Being Cluster

Table 2 is composed similarly to Table 1 though the variables measure heating values and the perceived effect of consumption/conservation of heating energy on the occupants health and well being.

TABLE 2			
Correlation of Cluster Variables With Total Cluster Variance - Winter Health and Well Being			
Rank	Variable	Corr. Coefficient	Signif. ¹
1	Degree of discomfort if 68 deg. maintained through winter.	.77818	.0001
2	Energy crisis is due to real worldwide shortages of fuels.	.70714	.0001
3	Effect to health and well being if 68 deg. maintained thru winter.	.70728	.0001
4	High need for very warm house.	.64137	.0001
5	How much has overconsumption contributed to energy problems.	.43067	.0087
6	Thermostat setting in winter.	.31770	.0356
¹ Prob > R under Ho : Rho = 0			

Total Number of Dwelling Occupants

Table 3 is composed of five variables. The first variable is a measure of the occupant's belief that the energy crisis does or does not warrant all the attention given to it in the last few years. The other four variables are measures of the number of children (age 1 to 17), the number of adults (age 18 to 59), the number of elderly (age 60 and older), and the total number of dwelling occupants (children + adults + elderly). The number of people in the household and the belief in the crisis relation is a difficult association to explain. Perhaps younger families (which have more people in the home) have a different perspective on the reality of the crisis than do older households (which tend to have fewer occupants).

TABLE 3

Correlation of Cluster Variables with Total Cluster
Variance - Number of Dwelling Occupants Cluster

Rank	Variable	Corr. Coefficient	Signif. ¹
1	Energy doesn't war- rant all the attention given to it.	.60903	.0001
2	Number of children in the dwelling.	.56595	.0001
3	Total number of dwelling occupants.	.53684	.0001
4	Number of adults in the dwelling.	.24012	.1121
5	Number of elderly in the dwelling.	.02760	.8572

¹Prob > |R| under H₀ : Rho = 0

Ages and Rights Cluster

Table 4 is composed of three variables. Two variables measure the average ages of adults and elderly, and the third measures occupants belief that consumers have the right to use as much energy as they want and can pay for. On the surface this is another difficult association to explain. Perhaps older people, because of their concern with their health and their experiences with availability and cost of fuels, feel differently than young people about having all the fuel they want and can pay for.

TABLE 4

Correlation of Cluster Variables With Total Cluster
Variance - Ages and Rights Cluster

Rank	Variable	Corr. Coefficient	Signif. ¹
1	Average age of adults in dwelling.	.87301	.0001
2	Average age of elderly in dwelling.	.65041	.0001
3	Consumers have right to use as much energy as want & can pay for.	-.19882	.2381

¹Prob > |R| under Ho : Rho = 0

Insulation Cluster

Table 5 is composed of two variables which measure the presence of wall and attic insulation, and two variables which measure actions taken by the occupants to install attic and wall insulation.

TABLE 5			
Correlation of Cluster Variables With Total Cluster Variance - Insulation Cluster			
Rank	Variable	Corr. Coefficient	Signif. ¹
1	Presence of wall ins.	.81402	.0001
2	Presence of attic ins.	.77162	.0001
3	Action taken by occupant to add attic insulation.	.59880	.0001
4	Action taken by occupant to add wall insulation.	.57285	.0001
¹ Prob > R under Ho : Rho = 0			

Data Reduction

Remember that the goal is to test the ability of just a few variables to predict a large portion of the dependent variable. To reduce the total number of variables under consideration, only two or three of the variables in each cluster were retained. This was a somewhat subjective process guided by the strength (as reported in Tables 1 through 5) of the association of each variable with the cluster in which it appears. Retained variables are reported in Table 7, which details the content of the final regression model. After the variables to be retained in each cluster were chosen, a new value for the total variance of each cluster was calculated by summing the raw scores of the retained variables. This value was used in the regression procedure as the regressor variable representing each cluster.

Regression Analysis

The final step in the analysis was to test the ability of the variables identified to predict variance in the dependent variable observed energy use. Eight independent variables have been identified.

1. The variance of the retained variables in the summer health and well being cluster.
2. The variance of the retained variables in the winter health and well being cluster.
3. The variance of the retained variables in the number of dwelling occupants cluster.
4. The variance of the retained variables in the ages and rights cluster.
5. The variance of the retained variables in the insulation cluster.
6. The average age of all the dwelling occupants.
7. The family income.
8. The education level of the head of household.

The average age of the children, which appears on the correlogram as a pivotal variable with many associations to other variables, could not be tested because of an insufficient number of households with children in the sample.

A Stepwise Maximum R^2 Improvement procedure was used to determine the portion of total variance (in BTU's) of the dependent variable **observed energy use** which is explained by each of the independent variables.¹³

Stepwise is most helpful for exploratory analysis when one wants to determine which of many variables should be included in a regression model. MaxR is a method of model selection implemented in the Stepwise procedure. MaxR is a forward selection with pair switching method.¹⁴

"Unlike other selection techniques, the MaxR method does not settle on a single model. Instead, it tries to find the best one-variable model, the best two-variable model, and so forth, although it is not guaranteed to find the model with the largest R^2 for each size. The MaxR method begins by finding the one-variable

¹³ Fred N. Kerlinger and Elazar J. Pedhazur, Multiple Regression in Behavioral Research, (New York University: Holt, Rinehart and Winston, Inc., Publishing Co., 1973) pp. 290-295.

¹⁴ See Hocking, R.R. (1976), "The Analysis and Selection of Variables in Linear Regression," *Biometrics*, pp. 32, 1-50.

model producing the highest R^2 . Then another variable, the one that yields the greatest increase in R^2 , is added. Once the two-variable model is obtained, each of the variables in the model is compared to each variable not in the model. For each comparison, MaxR determines if removing one variable and replacing it with the other variable increases R^2 . After comparing all possible switches, the one that produces the largest increase in R^2 is made. Comparisons begin again, and the process continues until MaxR finds that no switch could increase R^2 . The two-variable model thus achieved is considered the 'best' two-variable model the technique can find. Another variable is then added to the model, and the comparing- and-switching process is repeated to find the 'best' three-variable model, and so forth".¹⁵

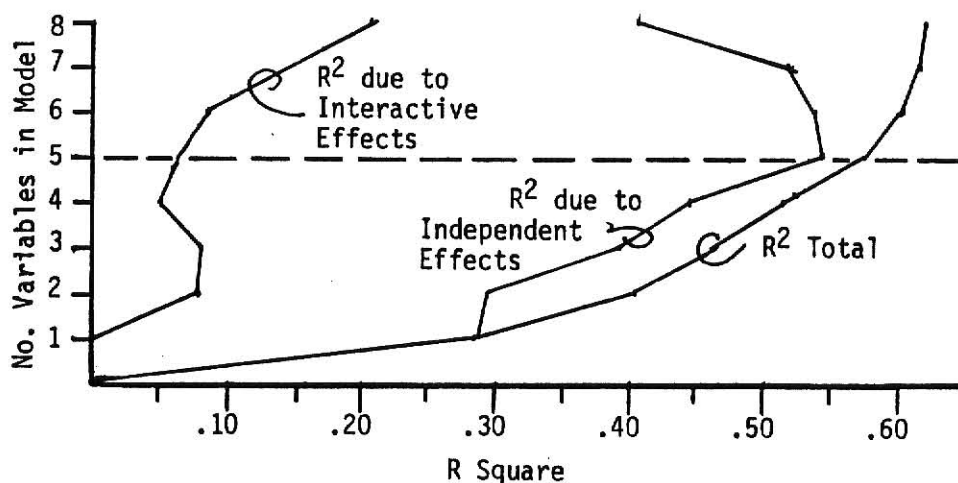
Ideally, the R^2 contribution of each independent variable in a regression model should be independent of the contribution from each of the other variables in the model. In actuality, this rarely occurs. A portion of the contribution to the total R^2 of the model is a result of interactive effects between variables.

Table 6 illustrates the relation between R^2 total, R^2 contribution due to independent effects, and R^2 contribution due to interactive effects between variables. Table 6 serves to make clear the preferability of the five variable model by showing that the five variable model exhibits the maximum improvement in total R^2 , maximum independent R^2 , and the minimum R^2 due to interactive effects. The five variable model identified predicts approximately fifty eight percent ($R^2 = .5758$, $\text{Prob}>F = .0109$) of the variance in total energy use. The independent contribution of all five variables totals 55% ($R^2 = .5506$) with interactive effects between variables accounting for 3% ($R^2 = .0252$) of the variance in the dependent variable.

TABLE 6

Number of Variables in Model vs R^2 Total, R^2 Independent, and R^2 Interactive

Graph of Tabular Data



Tabular Data

Number Vars. in Model	R^2 Interactive effects	R^2 Independent effects	R^2 Total	Prob>F
1	0	.286	.286	.0103
2	.1069	.2954	.4020	.0075
3	.0737	.3948	.4685	.0086
4	.0739	.4474	.5213	.0104
5	.0525	.5506	.5758	.0109
6	.0624	.5418	.6042	.0164
7	.0886	.5297	.6183	.0291
8	.2091	.4135	.6226	.0553

Table 7 shows the composition of the five variable regression model.

TABLE 7

Content of the Five Variable Regression Model

Rank	Variable	Independent R Square
1.	Income (Var.#130)	.2182
2.	Average age of all dwelling occupants. (Vars.#3-11)	.1521
3.	Summer health and well being cluster.	.0868
	a. High need for being cool in summer. (Var.#120)	
	b. Difficult to fall asleep in summer. (Var.#119)	
4.	Number of dwelling occupants cluster.	.0642
	a. Total number of dwelling occupants. (Var.#3-11)	
	b. Number of children in dwelling. (Vars.#5-8)	
	c. Energy doesn't warrant all the attention given to it. (Var.#126)	
5.	Insulation cluster	.0293
	a. Presence of wall insul. (Var.#141)	
	b. Presence of attic insul. (Var.#140)	
Independent contribution to R ²		= .5506
Interactive contribution to R ²		= .0252
Total R ²		= .5758
Prob>F		= .0109

CHAPTER 4 - CONCLUSION

The analysis shows that in this community setting it was possible first to identify five predictor variables from physical, attitude, behavior, and demographic dimensions of dwelling energy use and then to reliably predict fifty-eight percent of the observed energy consumption in occupied dwellings using those predictor variables.

In order by the ability to explain variance in observed energy use, the variables identified and tested were:

1. household income; the greater the income, the greater the energy use.
2. average age of dwelling occupants; the older the occupants, the greater the energy use.
3. attitudes about the effect of summertime energy conservation on occupants health and well-being; the more occupants felt the need to be cool in the summer the greater the energy use.
4. number of dwelling occupants; dwellings with more occupants tended to use more energy than those with fewer occupants.
5. the insulation level in the walls and the attic; houses with greater levels of insulation in the walls and attic tended to use less energy than dwellings with lesser insulation.

In Chapter 1, several relationships are discussed between the research reported in this thesis and that reported in previous studies. That discussion, and the unusually strong ability of only five predictor variables to predict energy use, suggest guidelines for the future development of predictive residential energy use models.

1. All of the variables currently being collected in residential audits are probably not necessary if the purpose of an audit is prediction of energy use. It appears that summary measures which represent several dimensions with one variable are the more successful predictors.

For example, the average age of the occupants was, in this study, the second most powerful predictor of energy

use. Directly represented by this measure are the number and ages of all the occupants of the dwelling. Indirectly represented are the energy-related actions which people of varying ages are likely to take and the impact of many or few people taking those actions. Clearly, many different dimensions of energy use can be classified as age-related. Three of these are: that babies and old or sedentary people require higher temperatures for metabolic reasons; young children have less knowledge of the effects of opening and closing outside doors, turning off unused lights and appliances, running hot water excessively and other energy consuming actions; if all other factors were equal, a home with more people living in it would probably use more energy than a home with fewer people living in it. These three dimensions of the number and ages of dwelling occupants represent very different concepts and would require different approaches if one were interested in controlling them as a means of affecting energy conservation in a dwelling. However, for the purpose of prediction, the single variable **average age of dwelling occupants** provides a convenient and useful handle with which to describe multiple dimensions affecting energy use. This supports the initial hypothesis which suggested that probably only a few of the many variables currently being collected are necessary for the purpose of predicting energy use in occupied dwellings.

2. Although the previous discussion suggests the existence of causal relationships, readers should be reminded that no part of this analysis establishes causal relationships between variables. Indeed, the research effort required in order to establish causal relationships in a predictive model is probably not called for. It seems to be enough to know that the variance of one variable is usually associated in a predictable way with the variance of another variable or group of variables.

3. As was discussed in the introduction to the thesis, the environment in which a dwelling is located, the physical characteristics of a dwelling and the occupant-related parameters for the use of the dwelling interact to determine the energy use of the dwelling. In the Marysville Project, the first four 'best' predictors of energy use were occupant-related measures. It is even possible that the fifth measure, presence of attic and wall insulation, is more a measure of occupant intervention than it is a structure-related measure of the physical effect of varying resistance to heat flux.

These results lead to the conclusion that the structure-related variables in the study were either inconsistently measured, or were not significant enough to have more of an impact on energy use prediction than were the occupant-related measures. If the second supposition is supported, the effect on future research is dramatic.

Under the second hypothesis, the definition of different building types would be much broader than it now is and would require fewer building type classifications. Within these broad building types a few energy-related occupant characteristics could be used as the primary predictors of energy use.

4. This thesis identifies some of those energy-related occupant characteristics. However, these variables are not endowed with any type of scaling mechanism. An example of the lack of a scaling mechanism is that although it has been shown that age and number of occupants is of primary importance, one cannot tell precisely what, for example, will be the incremental difference in energy use between two occupied dwellings which are equal to each other in all respects except for having differing average ages of occupants. The lack of a scaling mechanism is primarily the result of a small sample size which would not allow the use of more powerful statistics.

5. Future research should use larger and more diverse samples and employ more powerful statistics to focus on a procedure for quantifying the effects which the occupants introduce. The results discussed above suggest that future studies should be extended to include a wider range of building types; including, for example, single family homes built after energy became a prominent concern, duplexes, low-rise and high-rise apartments, and owned or rented townhouses and condominiums.

6. Longitudinal studies which examine changing energy use characteristics through varying political, social and economic time periods will also be necessary. These studies can provide tests of the sensitivity and long-term accuracy of measures of occupant-induced energy consumption variance.

In conclusion, there is every reason to be confident that a few measures of occupant-induced energy consumption variance could be used in combination with broad energy-related environmental and structural variables to arrive at more useful predictions of expected energy consumption in occupied dwellings.

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Appendix A
INTERVIEW INSTRUMENT

MARYSVILLE RESIDENTIAL ENERGY AUDIT
INSTRUMENT #1 - QUESTIONNAIRE

INTERVIEW ID

V-1 & V-ID

DATE

INTERVIEWER ID

TIME

I. Dwelling Type

V-2	1	Single family detached
	2	Duplex (choose unit 'A' or lowest number)
	3	Mobile/Modular
	4	Single family unit - Multiple occupancy
	5	Apartment house (three or more units)
	6	Other explain(_____)

NOTE: INTERVIEW ONLY THE FIRST THREE(3) TYPES OF UNITS.
IF UNIT IS ONE OF LAST THREE(3) TYPES, STOP HERE. PICK
A NEW UNIT FROM THE RESERVE LIST AND START AGAIN WITH A
NEW INSTRUMENT.

→ I would like to begin by explaining the parts of this survey and what will be involved with each part. First of all, your house was chosen at random to be included in a sample of the homes in Marysville. There will be 3 parts to this survey requiring 2 visits by our investigators. The first part is an interview which we can do now or sometime in the next couple of days at your convenience. It will take about 30 minutes to complete. The second part is a questionnaire which we will leave for the head of the household and, if applicable, the spouse to independently fill out. These should take about 15 minutes to complete. The third part will consist of some measurements of the house to be taken at the time the questionnaire(s) are picked up.

You do not have to take part in this survey. If you choose not to be involved, there will be no obligation to do so. Participation is entirely voluntary. You may, if you wish, terminate the interview at any time for any reason. This is not a test. There are no right or wrong answers, and your responses will be kept entirely confidential.

In keeping with the KSU Human Subjects Research Policy, I would like for you to sign this statement to show that I have read it to you, that you understand it, and that you agree to be interviewed.

****NOTE - INTERVIEW ONLY HEAD OF HOUSEHOLD OR SPOUSE****

I would like to begin by asking who lives here. I would like to know their relation to the head of the household, their age, if they work and in what kind of job.

Job Classifications	1. N.A.	6. Professional
	2. Unemployed	7. Management
	3. Retired	8. Clerical
	4. Disabled/Unable	9. Agricultural
	5. Housewife	10. Labor/Manual
		11. Other

Dwelling occupants by
relation to Head of
Household.

	Age	Sex		Job Class	Respondent?	
		M	F		N	Y
1. Head of Household <u>V-3</u>		☐ <u>V-12</u>	☐ <u>2</u>	<u>V-21</u>	☐ <u>V-30</u>	☐ <u>2</u>
2. Spouse <u>V-4</u>		☐ <u>V-13</u>	☐ <u>2</u>	<u>V-22</u>	☐ <u>V-31</u>	☐ <u>2</u>
3. Child 1 <u>V-5</u>		☐ <u>V-14</u>	☐ <u>2</u>	<u>V-23</u>		
4. Child 2 <u>V-6</u>		☐ <u>V-15</u>	☐ <u>2</u>	<u>V-24</u>		
5. Child 3 <u>V-7</u>		☐ <u>V-16</u>	☐ <u>2</u>	<u>V-25</u>		
6. Child 4 <u>V-8</u>		☐ <u>V-17</u>	☐ <u>2</u>	<u>V-26</u>		
7. Other <u>V-9</u>		☐ <u>V-18</u>	☐ <u>2</u>	<u>V-27</u>		
8. Other <u>V-10</u>		☐ <u>V-19</u>	☐ <u>2</u>	<u>V-28</u>		
9. Other <u>V-11</u>		☐ <u>V-20</u>	☐ <u>2</u>	<u>V-29</u>		

(HAND RESPONDENT CARD # 1)

40. From the categories on this card, when would you say this house was built?

- V-32
- | | |
|----------------------------|-------------|
| ☐ 1 | Don't know |
| ☐ 2 | 1982-1960 |
| ☐ 3 | 1959-1940 |
| ☐ 4 | 1939-1920 |
| ☐ 5 | 1919-1900 |
| ☐ 6 | 1899-1880 |
| ☐ 7 | before 1880 |

V-32A - Actual year built
from County Assessors
Records. - same
scale as V-32.

Do you own this home, pay rent, or what? V-33

☐ 1 owns or
is buying

☐ 2 rents

☐ 3 neither owns nor rents

How is that? _____

(go to 44)

(HAND RESPONDENT CARD # 2)

Could you tell me the group on this card that
would indicate about how much rent you pay a
month, not including utilities.

V-34

- ☐ 1 Under \$100
- ☐ 2 100-149
- ☐ 3 150-199
- ☐ 4 200-249
- ☐ 5 250-299
- ☐ 6 300-349
- ☐ 7 350-399
- ☐ 8 400-449
- ☐ 9 450-500
- ☐ 10 500 and more

(go to 44)

(HAND RESPONDENT CARD # 3)

Could you tell me the group on this card that would indicate what the present
value of this home is. What would it bring if you sold it today.

V-35

- ☐ 1 Below 40,000
- ☐ 2 40,000-49,999
- ☐ 3 50,000-59,999
- ☐ 4 60,000-69,999
- ☐ 5 70,000-79,999
- ☐ 6 80,000-89,999
- ☐ 7 90,000-99,999
- ☐ 8 100,000-109,999
- ☐ 9 110,000-119,999
- ☐ 10 120,000 and above

(go to 44)

The next few questions are about the types of energy used in this home and what they are used for.

ENERGY USE

=====

	none	D.K.	nat. gas	elect.	L.P.	oil	Wood	Solar	Other
44. What energy source do you use most for heating this home? V-36	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
45. Which, if any, secondary energy source is used for heating this home? V-37	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

(PROBE OR LOOK)

(FOR ANY RESPONSE OTHER THAN "WOOD", GO TO NEXT PAGE)

WOOD CONTINGENCY

46. Estimate how many cords of wood you used last winter. V-37A

V-38	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
	>1	1-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6 & more

47. What do you do most? (READ RESPONSES)

V-39	☐ 1	☒ 2	☐ 3	☐ 4	<u>V-37B</u>
	buy your wood	get it free	cut your own	or do you do something else (what is that)	

Please answer yes or no as to whether or not you use the following types of wood burners in this home.

48. Fireplace without glass doors V-46	☒ 2 yes	☐ 1 no	V-37C
49. Fireplace with glass doors V-41	☒ 2 yes	☐ 1 no	V-37D
50. New type, air tight woodstove V-42	☒ 2 yes	☐ 1 no	V-37E
51. Old type woodstove V-43	☒ 2 yes	☐ 1 no	V-37F
52. Any other? V-44	☒ 2 yes	☐ 1 no	V-37G

Please explain _____

53. What energy source do you use most for water heating? V-45
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar | Other |
|------|------|-----------|--------|------|-----|------|-------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
54. Which, if any, secondary energy source do you use for water heating? V-46 (PROBE OR LOOK)
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar | Other |
|------|------|-----------|--------|------|-----|------|-------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

55. What energy source do you use most for clothes drying at home? V-47
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar (Clothesline) | Other |
|------|------|-----------|--------|------|-----|------|---------------------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
56. Which, if any, secondary energy source do you use for clothes drying at home? V-48 (PROBE OR LOOK)
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar (Clothesline) | Other |
|------|------|-----------|--------|------|-----|------|---------------------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
57. Do you have an outside clothes line available to you? V-49
- | yes | no |
|-----|----|
| 2 | 1 |

58. Which energy source do you use most for cooking in the home? V-50
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar | Other |
|------|------|-----------|--------|------|-----|------|-------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
59. Which, if any, secondary energy source do you use for cooking in the home? V-51 (PROBE OR LOOK)
- | none | D.K. | nat. gas. | elect. | L.P. | oil | wood | Solar | Other |
|------|------|-----------|--------|------|-----|------|-------|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Please answer 'yes' or 'no' to indicate whether or not you regularly use the following appliances.

- | | yes | no | |
|----------|-----|----|--------------------------------|
| V-52 60. | 2 | 1 | Crock Pot |
| V-53 61. | 2 | 1 | Microwave oven |
| V-54 62. | 2 | 1 | Convection oven |
| V-55 63. | 2 | 1 | Electric roaster |
| V-56 64. | 2 | 1 | Automatic electric coffeemaker |
| V-57 65. | 2 | 1 | Other - What is that? _____ |

=====
 66. Do you have a thermostat or some other mechanical means of controlling the temperature of this home during the winter?

☐ 2 yes ☐ 1 V-58
 no (go to 70)

(HAND RESPONDENT CARD # 4)

67. From the categories on this card, where during the daytime in the winter is the thermostat set?

V-59 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8
 below 50 50-54 55-59 60-64 65-69 70-74 75-80 80+

68. Do you set back your thermostat at night in the winter?

☐ 2 yes ☐ 1 V-60
 no (go to 70)

(HAND RESPONDENT CARD # 5)

69. From the categories on this card, to what temperature do you set your thermostat back?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 V-61
 below 50 50-54 55-59 60-64 65-69 70-74 75-79 80 and above

=====
 70. Do you use any method for summer cooling such as airconditioners, whole house fans, or the like?

☐ 2 yes ☐ 1 V-62
 no (go to 77)

Please answer 'yes' or 'no' to whether or not you use these methods of summertime cooling?

71. Window airconditioner

☐ 2 yes ☐ 1 V-63
 no (go to 73)

72. How many window airconditioners do you use?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 V-64
 1 2 3 4 5 more than 5

☐ yes ☐ no
 73. Central airconditioner ☐ 2 ☐ 1 V-65
 74. Swamp Cooler ☐ 2 ☐ 1 V-66
 75. Whole house fan ☐ 2 ☐ 1 V-67
 76. Window, floor or ceiling fans ☐ 2 ☐ 1 V-68

Please answer 'yes' or 'no' to indicate whether or not in the last few years or in the months since you have lived here, you have added to or changed any of the features listed below.

7. Attic Insulation ☐ no ☒ yes V-69
(please explain)
78. Wall Insulation ☐ no ☒ yes V-70
(please explain)
79. Caulking ☐ no ☒ yes V-71
(please explain)
80. Weatherstripping around doors and windows ☐ no ☒ yes V-72
(please explain)
81. Storm doors ☐ no ☒ yes V-73
(please explain)
82. Storm windows ☐ no ☒ yes V-74
(please explain)
83. Regularly installed plastic on the windows ☐ no ☒ yes V-75
(please explain)
84. Room additions ☐ no ☒ yes V-76
(please explain)
85. Any solar options ☐ no ☒ yes V-77
(please explain)

86. Because of its relation to energy use, could you tell me if there have been any periods of more than 2 weeks in the past 12 months, or in the months you have lived here, when the house has been nearly or completely unoccupied?

- ☐ no ☒ yes V-78
(please explain)

87. For the same reasons, could you tell me if in the last 12 months, or in the months you have lived here, have you had extra people come to stay with you for more than 2 weeks at a time?

- ☐ no ☒ yes V-79
(please explain)

The next few questions deal with plant growing activities in and around this home. I will be using the word 'garden' in a general sense to mean any or all plant growing activities; (including vegetable gardening, flower gardening, etc.)

GARDENING

88. Did you have a garden this year?

no yes
V-80 ☐ 1 ☐ 2
↓
(go to 106)

- ☐ 1 Like Fresh Produce
☐ 2 Enjoyment - Recreation
☐ 3 Economics

☐ 4 get outside
89. Could you tell me why? (WRITE AS NEARLY AS POSSIBLE A VERBATIM RESPONSE) ☐ 5 something to do
V-81 ☐ 6 all others

90. In this or in previous homes, how many years have you had a garden
☐ 1 ☐ 2 ☐ 3 V-82
1-5yr. 6-10yr. more than 10 years
91. In season, about what percent of the household needs does the garden provide.
V-83 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
0-24% 25-49% 50-74% 75-99% 100+%
These questions are about categories of plants grown in your yard and in your garden. Answer 'yes' for the ones you grow, and 'no' for the ones you do not.
yes no
92. Annual vegetables? ☐ 2 ☐ 1 V-84
93. Perennial vegetables? ☐ 2 ☐ 1 V-85
94. Perennial flowers outside? ☐ 2 ☐ 1 V-86
95. Annual flowers outside? ☐ 2 ☐ 1 V-87
96. Fruit trees? ☐ 2 ☐ 1 V-88
97. Nut trees? ☐ 2 ☐ 1 V-89
98. Berry Bushes? ☐ 2 ☐ 1 V-90
99. Indoor plants and flowers? ☐ 2 ☐ 1 V-91

V-92 ☐ no ☒ yes

go to 112

V-93 101. ☐ no ☒ yes

V-94 102. ☐ no ☒ yes

V-95 103. ☐ no ☒ yes

V-96 104. ☐ no ☒ yes

Indicate with a 'yes' or 'no' whether or not you regularly use the following preservation methods.

canning

freezing

drying

other - what is that? _____

V-97 105.

Compared to other people you know who preserve food, would you say you preserve much more, more, the same as, less, or much less than they do?

☐ much more ☒ more ☐ the same as ☐ less ☒ much less

Could you tell me why you don't have a garden? (MARK 'YES' ON THE ONES THAT ARE MENTIONED, AND 'NO' ON THE ONES WHICH ARE NOT MENTIONED.)

112. As a result of the information gathered from this research project, future studies which involve more detailed measurements may be undertaken using homes such as yours. If such a study were undertaken, would you be interested in being involved?

☒

yes

☐

no

V-104

=====
(THIS ENDS THE INTERVIEW)

REMEMBER TO DO THE FOLLOWING:

1. Ask the respondent to fill out and sign the fuel release form.

DONE

2. Explain the survey forms and leave 1 or 2 for the head of household and/or spouse to fill out INDEPENDENTLY.

DONE

3. Make an appointment for the Measurements Team to pick up the surveys, answer any questions about the surveys, and to do their physical features and solar suitability assessments.

APPOINTMENT TIME/S

4. Thank them for their time and cooperation.

Appendix B
FUEL USE RELEASE FORM

ID. NO _____

THE MARYSVILLE ENERGY PROJECT
UTILITY INFORMATION RELEASE FORM

Please enter the following information from your last utility bill:

NAME OF UTILITY COMPANY _____

YOUR NAME, as shown on bill _____

YOUR ADDRESS, as shown on bill _____

YOUR ACCOUNT NUMBER, as shown on bill _____

I hereby give my permission to my utility company to give the Marysville Energy Project, which has been endorsed by the Marysville PRIDE Committee, and the Marysville Chamber of Commerce, information on the last thirteen months useage of electricity, natural gas or other fuels.

I have read and signed this release form on the _____ day of _____, 1982.

V-ID

V-OCTG	V-OOTE
V-SEPG	V-SEPE
V-AUGG	V-AUGE
V-JULG	V-JULE
V-JUNG	V-JUNE
V-MAYG	V-MAYE
V-APRG	V-APRE
V-MARG	V-MARE
V-FEBG	V-FEBE
V-JANG	V-JANE
V-DECG	V-DECE
V-NOVG	V-NOVE
V-OCTG	V-OBIE

SIGNATURE

Appendix C
ENERGY ATTITUDES SURVEY

MARYSVILLE RESIDENTIAL ENERGY AUDIT
INSTRUMENT #2

INTERVIEW ID ☐ ☐ V-110 or V-ID DATE: October ☐ ☐

WHICH ONE ARE YOU? (MARK ONE) ☐ Head of Household

V-111 & V-111A ☐ Spouse

Through your response to these questions we would like to know how you truly feel about the statements provided. This is not a test. There are no right or wrong answers, and your responses will be kept entirely confidential.

INSTRUCTIONS: Mark with an 'X' the box which, by it's position on the scale, best represents your opinion.

1. To what degree would you be uncomfortable if you kept the temperature of you house at 68 degrees through the winter?
not very
uncomfortable ☐ ☐ ☐ ☐ ☐ ☐ ☐ uncomfortable

V-112 & 112A

2. Do you feel that your health and well being would be much better, much worse, or somewhere in between if you adjusted the temperature of your home to maintain 68 degrees throughout the winter?

much better ☐ ☐ ☐ ☐ ☐ ☐ ☐ much worse

V-113 & 113A

3. To what degree would you say overconsumption by individuals has contributed to this country's energy problem?

very much ☐ ☐ ☐ ☐ ☐ ☐ ☐ not very much

V-114 & 114A

4. To what degree do you think it possible that the cost of home fuel may rise to the point where you won't be able to afford it?

very possible ☐ ☐ ☐ ☐ ☐ ☐ ☐ not very possible

V-115 & 115A

5. To what degree do you think it possible that, for whatever reason, your supply of heating fuel may be cut off in the near future?

very possible ☐ ☐ ☐ ☐ ☐ ☐ ☐ not very possible

V-116 & 116A

6. How essential is it to your personal health and well being for the house to be airconditioned in the summer?

not very
essential ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 very essential

V-117 & 117A

=====

INSTRUCTIONS: Please indicate how strongly you agree or disagree with the following statements.

=====

7. It's just not worth it to sweat some in the summer to save a little energy.

strongly
disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-118 & 118A

8. I find it very difficult to fall asleep in the summer without an airconditioner on at night.

strongly
disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-119 & 119A

9. While others might tolerate turning off the airconditioner in the summer, my own need for being cool is high.

strongly
disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-120 & 120A

10. Turning off the airconditioner and opening the windows every time it gets a little cooler outside is just not worth the trouble.

strongly
disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-121 & 121A

11. It is immoral to consume any more energy than I absolutely need.

strongly
disagree ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 strongly agree

V-122 & 122A

12. The energy crisis is largely due to real worldwide shortages of fuels needed to produce energy.

strongly
disagree ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 strongly agree

V-123 & 123A

13. The energy crisis is largely due to profiteering by those who control the world's energy resources.

strongly
disagree ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 strongly agree

V-124 & 124A

14. While others may be willing to set their thermostat lower in the winter, my own need for a very warm house is high.

strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-125 & 125A

15. The energy crisis certainly doesn't warrant all the attention given to it in the last few years.

strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-126 & 126A

16. American technology in the past has come to grips with all major crises and it will no doubt soon discover a solution to the energy problem.

strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-127 & 127A

17. Consumers have the right to use as much energy as they want and can pay for.

strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-128 & 128A

18. Trying to save a few pennies a day conserving energy is just not worth it.

strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 strongly agree

V-129 & 129A

=====

19. Within these categories, could you tell me about what your combined family income (before taxes) was last year? (Responses will be kept entirely confidential)

- ☐ 1 less than \$5,000
- ☐ 2 \$5,000-\$9,999
- ☐ 3 \$10,000-\$14,999
- ☐ 4 \$15,000-\$19,999
- ☐ 5 \$20,000-\$24,999
- ☐ 6 \$25,000-\$29,999
- ☐ 7 \$30,000 and above

V-130 & 130A

20. What was the last level of formal education you completed?

- ☐ 1 Never attended school
- ☐ 2 Grade school
- ☐ 3 Junior high school
- ☐ 4 High school
- ☐ 5 Vocational training
- ☐ 6 College - Bachelor Degree
- ☐ 7 College - Masters Degree
- ☐ 8 College - Doctorate

V-131 & 131A

Appendix D

**STRUCTURAL ENERGY FEATURES AND SOLAR ACCESS
EVALUATION**

ID# _____

V-139 or V-110
ID# of address _____ address _____**STRUCTURAL FEATURES**

Indicate in the space below the degree to which the features of this house meet the standards indicated in the last column.

	Percent of Standard					NA	Standard	
	0	25	50	75	100			
Attic Insulation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ R-38	V-140
Wall Insulation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ R-11	V-141
Crawlspace Insulation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ R-11	V-142
Floor Insulation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ R-19	V-143
Sill Area Insulation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ R-19	V-144
Double/Triple glazed or Storm Windows	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ all	V-145
Storm Doors	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ all	V-146
Caulking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ all	V-147
Weatherstripping	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ all	V-148
Plastic on Windows	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ .	☐ all	V-149

=====

Answer 'yes' or 'no' to whether or not these features are present in this home.

	NA	yes	no	
Heat Pump	☐ .	☐ 2	☐ 1	V-150
Duct and Pipe Insulation	☐ .	☐ 2	☐ 1	V-151
Hot Water Tank Insulation	☐ .	☐ 2	☐ 1	V-152
Solar Greenhouses, or extra windows for solar gain	☐ .	☐ 2	☐ 1	V-153
Active Solar Domestic Water Heating	☐ .	☐ 2	☐ 1	V-154
"Breadbox" Solar Water Heating	☐ .	☐ 2	☐ 1	V-155
Active Solar Space Heating	☐ .	☐ 2	☐ 1	V-156

STRUCTURAL FEATURES

Indicate in the space below the most appropriate answers for the features of this residence.

FRAME	SIDING MATERIALS
☐ 1 wood studs	☐ 1 wood, shingle, metal, vinyl, asbestos, or masonite siding
☐ 2 conc./masonry V-157	☐ 2 1/2 stone/brick and 1/2 wood
☐ 3 steel studs	☐ 3 all stone or all brick V-158
☐ 4 other _____	☐ 4 stucco/cement

SOLAR SUITABILITY ASSESSMENT

When using the compass, do not stand near any metal objects or heavy electrical lines. Either of these can cause the compass to give an improper reading.

When using the compass, remember that TRUE SOUTH is 8 degrees west of magnetic south which the compass reads.

The calibration markings on the compass are in 2 degree increments.

- Sketches should contain the following:
1. basic shape and orientation of the residence
 2. any south walls, windows, and doors
 3. basic plan of the roof
 4. any pertinent information about the site and surroundings

The shading calculator sketches should have noted on them deciduous trees on the site, deciduous trees off the site, coniferous trees on the site, coniferous trees off the site, and any other obstructions.

A SPECIAL WORD OF CAUTION please be careful with the compasses, any compass either lost or broken will be paid for by the group that compass was assigned to.

To determine 10 - 2 winter on the "SHADE CALCULATOR" USE below the Sept/March line.
To determine 10 - 2 summer on the "SHADE CALCULATOR" USE above the Sept/March line.

SOLAR SUITABILITY ASSESSMENT FOR WALLS

INDICATE IN THE SPACE BELOW THE BEST ANSWER IN EACH SECTION, THEN FOLLOW THE ARROWS TO THE NEXT SECTION.

SKETCHES

AREAS (WALLS)-

1	less than 10 ft ²	wash-out go to roof
2	10 - 32	
3	33 - 64	
4	65 - 96	
5	97 - 120	
6	121 - 160	
7	161 - 192	
8	193 - 224	
9	225 + ft ²	

V-159

OBSTRUCTION V-162

1	Conifer
2	Deciduous
3	Wall/Fence
4	Building

wash-out
go to roof

ACCESS TO SUN V-161

1	No Access
2	10-2 winter only
3	10-2 summer only
4	10-2 anytime

wash-out
go to roof

V-160 ORIENTATION

1	0 - 15° E or W of South
2	16 - 30° E or W of South
3	31 - 45° E or W of South
4	46 - 60° E or W of South
5	61 - 75° E or W of South
6	76 - 90° E or W of South

RESIDENCE FT² →

V-164

LIST AREAS OF ROOMS NOT USED IN WINTER

--	--	--	--

Total Area of Rooms not used in winter V-165

NOTES

PERCENTAGE ACCESS

1	less than 40%
2	40 - 54%
3	55 - 69%
4	70 - 84%
5	85 - 100%

V-163

SOLAR SUITABILITY ASSESSMENT FOR ROOFS

INDICATE IN THE SPACE BELOW THE BEST ANSWER IN EACH SECTION, THEN FOLLOW THE ARROWS TO THE NEXT SECTION.

SKETCHES

AREAS (ROOFS) V-166

1	less than 10 ft ²	
2	10 - 32	
3	33 - 64	
4	65 - 96	
5	97 - 120	
6	121 - 160	
7	161 - 192	
8	193 - 224	
9	225 + ft ²	

wash-out
go to yard

OBSTRUCTION V-169

1	Conifer
2	Deciduous
3	Wall/Fence
4	Building

wash-out
go to yard

ACCESS TO SUN V-168

1	No Access
2	10-2 winter only
3	10-2 summer only
4	10-2 anytime

wash-out
go to yard

ORIENTATION V-167

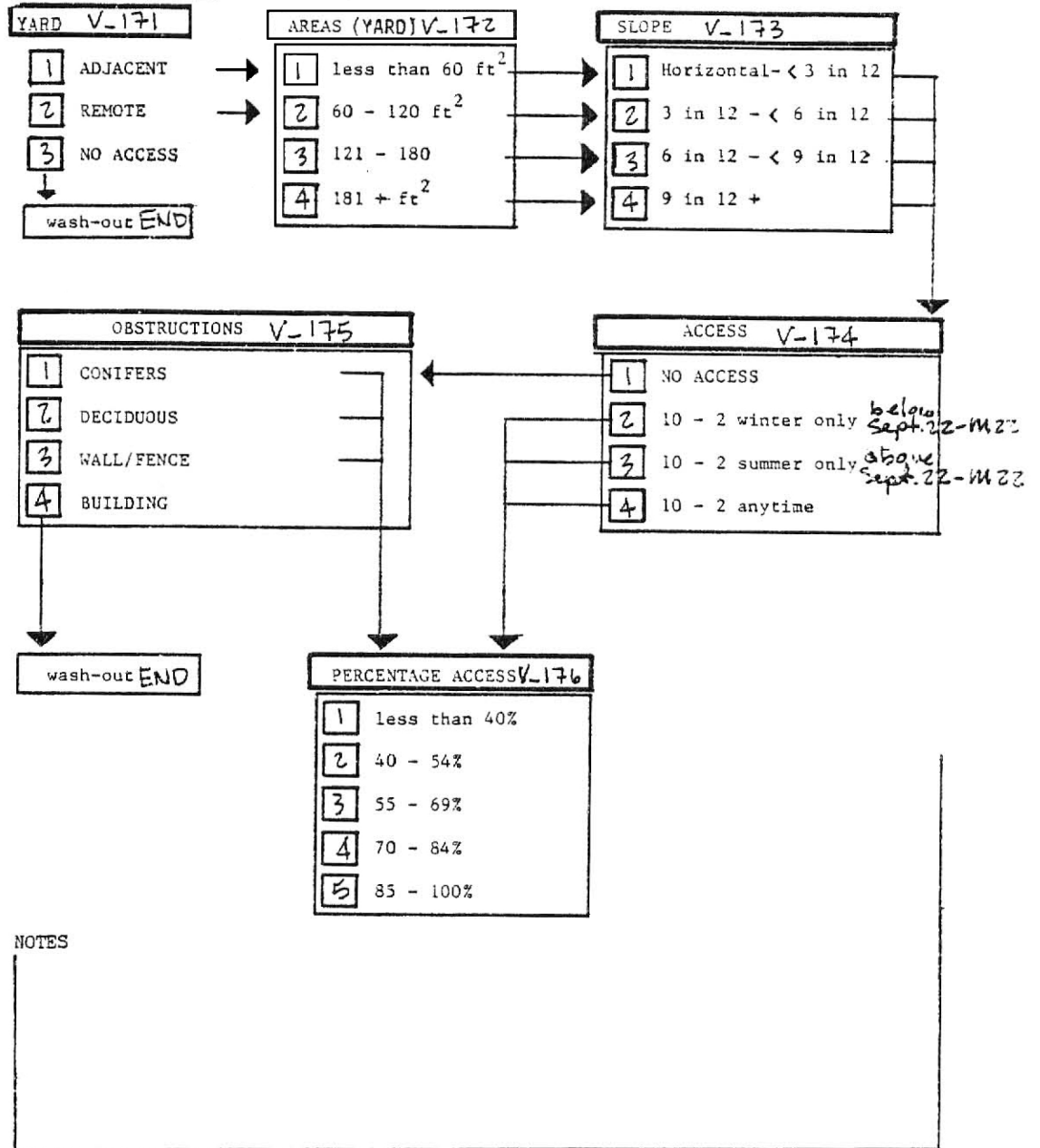
1	0 - 15° E or W of South
2	16 - 30° E or W of South
3	31 - 45° E or W of South
4	46 - 60° E or W of South
5	61 - 75° E or W of South
6	76 - 90° E or W of South

NOTES

PERCENTAGE ACCESS V-170

1	less than 40%
2	40 - 54%
3	55 - 69%
4	70 - 84%
5	85 - 100%

SOLAR SUITABILITY ASSESSMENT FOR THE YARD



Appendix E

**VARIABLES INCLUDED IN SPEARMAN CORRELATION
PROCEDURES**

Variable name	Variable Description	Retained for 2nd Spear- man Proc.
Nelder	Number of elderly (age 60+) dwelling occupants.	x
Avgelder	Average age of elderly dwelling occupants.	x
Nadult	Number of adult (age 18-59) dwelling occupants.	x
Avgadlt	Average age of adult dwelling occupants.	x
Nchild	Number of children (age 0-17) in dwelling.	x
Avgchld	Average of children in dwelling.	x
Nall	Total number of dwelling occupants.	x
Avgall	Average age of dwelling occupants.	x
2	Dwelling type.	
21	Job class of head of household.	
32a	Year dwelling was built.	
33	Own/rent status.	
33b	Value of dwelling.	
36	Winter space heating fuel type.	
45	Water heating fuel type.	
59	Winter day thermostat setting.	x
60	Winter night thermostat setting.	
63	Use of window-type airconditioner.	
65	Use of central airconditioner.	x
69	Actions to add or change attic ins..	x
70	Actions to add or change wall ins..	x
71	Actions to add or change caulking.	x
72	Actions to add or change wtherstrip'g	x
73	Actions to add or change storm doors.	x
78	Dwelling unoccupied > two weeks.	
79	Extra occupants > two weeks.	
80	Did occupant garden.	
104	Willingness to be involved with further energy-related studies.	
112	Degree of discomfort if 68 deg. maintained throughout winter.	x
113	Effect to health if 68 deg. maintained throughout winter.	x
114	Belief that overconsumption has contributed to energy problem.	x
115	Belief that home heating fuel will become unaffordable.	x
116	Belief that heating fuel supply may be cut off.	
117	Essentialness to personal health and well being of summertime aircon.	x
118	Perceived return for the bother of saving summer aircon. energy.	x

Variables included in Spearman Corr. Procedures
(cont.)

Variable name	Variable Description	Retained for 2nd Spear- man Proc.
119	Difficulty of falling asleep in summer without aircon.	x
120	Degree of perceived high need for being cool in summer.	x
121	Worth of turning off aircon. when it gets cooler outside.	x
122	Morality of consuming more energy than is absolutely needed.	x
123	Energy crisis largely due to real worldwide shortages of fuels.	x
124	Energy crisis largely due to profit- eering.	
125	Degree of need for a very warm house in winter.	x
126	Energy crisis doesn't warrant attention given to it.	x
127	Faith in American technology.	x
128	Consumers have right to use as much energy as they want and can pay for.	x
129	Trying to save a few pennies a day conserving energy is not worth it.	x
130	Combined family income.	x
131	Last level of formal education.	x
140	Percent of standard - attic insul..	x
141	Percent of standard - wall insul..	x
145	Percent of standard - multi glazings.	x
146	Percent of standard - storm doors.	x
147	Percent of standard - caulking.	
148	Percent of standard - weatherstripping.	
164	Square feet of floor area in dwelling.	x
165	Square feet of floor area closed off in winter.	x
Totuse	Total energy supplied to dwelling.	x
Total	Sum of the raw values of the previous variables.	x

OCCUPANT/DWELLING DISPOSITION FACTORS
AS PREDICTORS OF RESIDENTIAL ENERGY CONSUMPTION

by

ALAN ROBERT EDGAR

B. Arch., Kansas State University, 1978

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF ARCHITECTURE

Department of Architecture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

ABSTRACT

Recent research has indicated that the structure-based audits used to predict the progress and status of energy conservation efforts in the residential sector may be seriously flawed. By failing to provide sufficient measures of aggregate human factors effecting energy use in occupied dwellings, they may provide an innacurate and misleading picture of the use of energy in homes, as well as the actions which are most productive for affecting energy conservation in homes.

In order to better understand the interaction between dwellings and dwelling occupants, detailed information about fifty-seven occupied, single-family, detached dwellings in the city of Marysville, Kansas was gathered during October and November of 1982 by graduate and upper level undergraduate students from Kansas State University and by Marysville residents using four survey and interview instruments.

This thesis uses an item analysis and a Stepwise Maximum R^2 Improvement proceedure to identify five measures of structural, behavioral, attitudinal and demographic variables which reliably predict a large portion (fifty-eight percent) of the variance in observed annual energy consumption in homes in Marysville, Kansas.

The measures identified and the portion of observed annual energy consumption which the measures independently explain were: household income, 22%; average age of the dwelling occupants, 15%; occupant perceptions of the effect of summer energy conservation on individual health and well being, 9%; number of dwelling occupants, 6%; and the level of insulation in the attic and walls, 3%. In addition, the measures explain 3% of the variance in the dependent variable through interactive effects between measures.

Though this appears to be the first testing of structural, behavioral, attitudinal, and demographic dimensions used in combination to predict energy use, the important concepts identified within each dimension are consistent with those identified in similar previous research.