EXHIBIT NO. ___(JAD-8)
DOCKET NO. UE-060266/UG-060267
2006 PSE GENERAL RATE CASE
WITNESS: JEFFREY A. DUBIN

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY, INC.,** **Respondent.**	**Docket No. UE-060266** **Docket No. UG-060267**

THIRD EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED REBUTTAL TESTIMONY OF JEFFREY A. DUBIN ON BEHALF OF PUGET SOUND ENERGY, INC.

AUGUST 23, 2006

BEFORE THE WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

Docket Nos. UE-060266 & UG-060267
Puget Sound Energy, Inc.'s
2006 General Rate Case

WUTC STAFF DATA REQUEST NO. 016

WUTC STAFF DATA REQUEST NO. 016:

Re: Regarding Exhibit No.___(JAD-1T), at pages 23-26

Please explain, and provide supporting documentation, to show why statistical analysis alone can be used to establish base or balance point temperature. Please explain, and provide supporting documentation, if non-statistical analysis was used to justify the use of different base or balance point temperature.

First Supplemental Response:

Attached as Attachment A to Puget Sound Energy, Inc.'s ("PSE") First Supplemental Response to WUTC Staff Data Request No. 016, please find the results of a study based on PSE survey data indicating that balance point temperatures lower than 65 degrees Fahrenheit are likely for customers within PSE's service territory. This study provides non-statistical support for the use of base temperatures lower than 65 degrees Fahrenheit in PSE's weather adjustment equations. This study also supports and expands the justifications discussed in the prefiled direct testimony of Mr. Jeffrey A. Dubin, Exhibit No. ___(JAD-1T), and in PSE's Response to WUTC Data Request Nos. 014, 015 and 016.

Date of First Supplemental Response: May 24, 2006
Person who Prepared the Response: Villamor Gamponia
Witness Knowledgeable About the Response: Jeffrey A. Dubin

Attachment A to PSE's First Supplemental Response to WUTC Staff Data Request No. 016

Analysis of Puget Sound Energy Residential Appliance Saturation Survey – Engineering Analysis of Balance Point Temperature Differentials

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I. Introduction

The purpose of this analysis is to determine the likely range of balance point temperatures in single-family residential structures in the Puget Sound Energy, Inc. (PSE) service area. No additional heating is required when outdoor temperatures are higher than the balance point. Thermostat setting and the insulation properties of the residential shell determine the balance point temperature.[1]

The heat gain from occupants and appliances in a well insulated dwelling may lower the balance point temperature significantly below the thermostat set point. If, for instance, customers set their thermostats at 65 degrees in the winter, then it is possible that no extra energy (electricity or natural gas, etc.) will be required to achieve the 65 degree thermostat setting until outside temperatures drop to 45 to 55 degrees depending on the dwelling and its occupants. A base temperature of 65 degrees used for heating-degree-day measurement would tend to over-estimate the amount of likely energy requirement for heating in such a situation. My weather

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[1] For additional discussion of balance point temperatures and the use of engineering thermal models, see Margaret Fels, “PRISM: An Introduction”, Energy and Buildings, Volume 9, 1986, pp. 5-18. Huang, Ritschard, Bull, and Chang (1987) report balance point temperatures from 56 degrees F to 65 degrees F depending on the thermal integrity of typical dwellings. Their analysis is similar to the analysis reported here and is based on the DOE-2 energy simulation program. See J. Huang, "Climatic Indicators for Estimating Residential Heating and Cooling Loads," ASHRAE Transactions, Vol. 93, 1987, pp. 72-111.

normalization analysis does not assume any balance point temperatures or thermostat settings because it uses alternative base temperature measurements in a regression analysis[2]. This analysis established the non-linear empirical relationship between temperature conditions and load. However, the present analysis demonstrates the theoretical and empirical link between temperatures below 65 degrees and heating load based on survey evidence and engineering analysis.

To accomplish these goals, I analyzed PSE's RAS 2004 survey. RAS is an acronym for Residential Appliance Saturation. The RAS survey samples individual gas and electric customers on the PSE system and contains detailed information on over 5000 households. I adapted an energy thermal model published in Dubin (1985)[3] to work with the PSE survey. I used information on single-family residence square footage, presence or absence of insulation, the types of storm or glazed windows in the home, and other factors available in the survey as inputs to my model. These factors and matched weather information permitted me to make an engineering prediction of space heating load for each month that would likely occur for each household. The energy load model quantifies the differences between energy used for houses of different sizes. I used this information to calculate the implied balance point temperatures for each dwelling.[4] Balance point temperatures are the external temperatures at which a given household would begin to need space heating in order to maintain an assumed comfort level.

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[2] Prefiled Direct Testimony of Jeffrey A. Dubin December 2005.

[3] Jeffrey A. Dubin, Consumer Durable Choice and the Demand for Electricity, Elsevier Publishers, New York: New York, 1985.

II. RAS Survey

Puget Sound Energy (PSE) performed a mail survey of its residential and gas customers in 2004. This survey is the most recent of several previous surveys conducted of PSE's residential customers (1981, 1983, 1986, 1989, 1992, and 1998). The RAS survey was designed to collect detailed and representative data on appliance holdings and customer characteristics. The survey was conducted using a mail survey instrument. The 2004 RAS Survey instrument is attached to this report as Appendix A. The RAS provides information on whether the customer is a gas, electric, or combined customer of PSE. It provides basic information on housing tenure (owning or renting the dwelling and its type), as well as structural characteristics of the dwelling. These physical traits include: square footage, number of floors, and the presence of weatherization (ceiling insulation, wall insulation, duct insulation, weather strip doors, and glazed or storm windows). The survey also provides information on the use of fuels for heating and cooking, type of heating system (gas, electric, oil), and presence of air-conditioning. The RAS also captures information on water heat fuel types and the number of electricity using appliances (stove-top cooking, ovens, clothes dryers and so on). Finally, the survey captures various socio-demographic characteristics, such as education levels, income levels, employment status, and number of household members.

The target population for the survey was all residential customers. Billing recodes established the sampling frame, which was then sampled based on systematic sampling. To insure that all customers would be represented, dwelling type and sorting schedule were used to sort the target population. Following systematic sampling, PSE achieved a sample that was proportionately stratified by dwelling type and billing schedule.

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[4] Balance point temperatures also depend on thermostat settings as I discuss below.

My review of previously conducted RAS surveys suggested that a large enough initial population was sampled in 2004 to achieve a high degree of reliability[5]. The resulting surveys were keypunched and verified. The final survey results were assembled into a SAS database of 5,316 respondents. A sample weighting factor was present to allow extrapolation to population levels. For instance, the 5,316 survey respondents represented 259,205 Gas customers, 552,795 electric customers and 260,400 combined customers for a total of 813,195 electric and 519,605 gas customers in 2004.

I extracted an ASCII data file and record layout rasfinal.sts from the file rasfinal.sas7bdat using Stat-Transfer. I took additional information from the survey instrument and from the file rass formats.sas, which provided value labels for some of the variables contained in the survey. I used SST (Statistical Software Tool 3.0) to read the raw data and prepare it for analysis. The codes in rasfinal.cmd read the ASCII to create an SST saveset. The output from this program, rasfinal.log, is in Appendix B. I further used the program jad.cmd (output of the command file, jad.log, is presented in Appendix B) to process and recode the data. Rasfinal.log has a complete listing of factors contained in the survey, as well as several recoded factors. In processing the raw data for analysis, I determined that there were 2,657 electric customers and 1,286 combined customers in the final RAS survey or 3,943 electric customers in 2004. Over 78 percent of these customers lived in single-family dwellings. I ultimately selected the single-family electric customers for further analysis. These customers constitute 3,089 sampled individuals.

Several factors are necessary inputs to the Dubin-McFadden thermal model. They include (i) house square footage, (ii) number of storm windows, (iii) number of non-storm windows, (iv) presence of wall insulation, (v) inches of attic insulation, (vi) number of rooms,

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[5] For instance, detailed information from the 1992 PSE RAS survey found that nearly 70% of customers responded to the survey. This response rate is exceptionally high for a mail survey

(vii) number of floors, (viii) weather conditions for system design (summer outdoor daily temperature range, summer degree dry bulb and winter degree design temperature), (ix) normal heating and cooling degree days for estimated system coefficients of performance and (x) heating and cooling degrees days for a test period. To produce these factors, I needed to recode the RAS survey information to eliminate missing values and to check or recode the data for consistency and rationality. The thermal model also post-processes the information to check the values of all key factors.

For instance, I combined household members by age group to create a total number of household members. I further assumed that households with greater than 7 members had exactly 7 members to “top-code” the small number of cases of implausibly large households. I similarly assigned average values to households with missing data or non-response on this factor. The number of household member for which imputation was done was 169, or 5.5 percent, of the 3,089 survey respondents.

Similarly, I recoded the factors for the presence of wall and ceiling insulations. I assumed 12 inches of ceiling insulation for homes with this characteristic. Because dwelling vintage or information about when insulation was upgraded in order to determine the amount of attic insulation was not available, I did not use either piece of information in the analysis. Instead I used the information that insulation had been added to the residence either before or after the current resident had moved in.

To determine the number of rooms in the residence, I combined information on the number of heated rooms and the number of bathrooms; I top-coded heated-rooms above ten to ten.[6] I then assigned average values to those entries with missing information. I recoded the categorical value for dwellings into a continuous measure, and recoded missing data as discussed above. The number of heated rooms was missing in 835, or 27 percent, of the 3,089 surveyed responses. The number of bathrooms was missing in 658, or 21 percent, of the survey respondents. After recoding missing data, there were, on average, approximately 6.96 heated rooms in the dwellings and 2.26 bathrooms.

I also assigned mean values to houses with missing square footage using the continuously reported square footage variable, the categorical square footage when available, or final based on average imputation when it was available. Square footage was imputed in 333 cases (10.8 percent).

An important factor missing from the RAS survey was the number of windows. Using a sample of 7 homes from the ASHRAE Fundamentals (1982), I ran regressions for the number of windows and floors, square footage, and number of rooms. I found a high correlation (R-squared 81 percent) for a simple regression where the number of windows was determined by the number of floors and the home's square footage. The result was then used to impute the number of windows for RAS respondents. The file, winavg.log, in Appendix C contains the regression outcomes. Next, I used the observed information on percent of double-pane and stormed windows to calculate a percentage of stormed or double-paned windows. I used the combination of percentage and total number of windows to impute a value for the number of stormed and non-stormed windows. Because the thermal model requires a distribution of small, medium and large windows, I assumed that all windows were medium sized.

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[6] The number of rooms in the dwelling (number of heated rooms plus number of bathrooms) is only used to determine heating system transmission losses related to the length of piping or ducting used in the heating system. It does not affect the balance point temperature differential.

Using "county of residence," I matched information on normal degree days with a base of 65 degrees in the thermal modeling. Based on matched billing information, I also matched actual heating and cooling degree information and kwh consumption for the three years, 2001-2003. Actual heating and cooling degree days were combined with billing data from PSE's survey contractor using the weather station closest to the address of the survey respondent. For the year 2003, I found that the degree of correlation between cooling degree days measured at the county level and the cooling degree days measured at the closest weather station was quite high (correlation = 0.88). However, the heating degree day correlation was low (correlation = 0.36). SST file county2.log in Appendix C processes the county level normal heating and cooling degree day information. County3.log presented in Appendix C processes the 2003 actual annual heating and cooling degree days at the county level.

Summer design weather conditions and winter design weather were taken from ASHRAE (2005) for Washington state based on the closest weather station for each recorded county of residence. The SST file used for processing this information was weather.cmd and the output from this analysis was weather.log. It is available in Appendix C. Finally, I assumed a winter thermostat setting of 70 degrees and a summer thermostat setting of 75 degrees. As discussed below, these values do not affect the balance point temperature differential. However, they do affect the predicted space and cooling heat load.

I finally restricted the sample to the 2,875 cases for which the survey contractor could ascertain the monthly heating and cooling degree information in 2003. I found that in the full sample of electric and gas customers, 23.1 percent claimed to use electricity for primary heating.

III. Thermal Model Analysis

The Dubin-McFadden thermal model is in Chapter 2 of Dubin (1985), I have reproduced a copy of this chapter in Appendix D. The approach used in the Dubin-McFadden model was to construct an engineering thermal model that is simple enough to use with typical residential survey data. Such data is often much less complete than one would obtain using a detailed energy audit. For the reason mentioned above, the thermal model makes simplifying assumptions when some data is not available. The model assumes operating characteristics of dwellings that are not coded in typical survey data. The model has been successfully applied in several contexts. For example, the thermal model was adapted in Dubin (1985) for analyzing the Pacific Northwest Survey administered under the Bonneville Power Administration. The Dubin-McFadden model also uses summary weather measures, such as temperature means and extremes or heating and cooling degree days measured as alternative base temperatures to fit empirical temperature distributions. These measures are then used to forecast loads.

The basic approach follows ASHRAE engineering principles and conceptualizes the residence as a box with walls of varying thermal resistances to heat conduction. One insight of the modeling analysis is that the temperature load relationship is non-linear. As outside temperature declines, the marginal energy load necessary to maintain an interior temperature is non-constant. This fundamental observation is due to air-infiltration. As the difference between indoor and outdoor temperatures increases, the rate of exchange of the air volume in the house due to infiltration also increases. Each air exchange brings unheated air into the dwelling. That air must be heated to maintain the indoor temperature. This mechanism creates a multiplicative affect where the energy required to maintain a given indoor temperature increases as measured by the product of air infiltration and temperature differential. Because indoor and outdoor temperatures are proportional to temperature differential, a quadratic relationship exists between indoor and outdoor temperatures and temperature differential.

The quadratic approximation that Dubin-McFadden derived was:

$Q(t_o) = w_0 + w_1 * (t_i - t_o) + w_2 * (t_i - t_o)^2$

where t_o is the outdoor temperature and t_i is the interior temperature. The constants, w_0, w_1, and w_2, are functions of the dwelling's thermal characteristics. They are dependent on the size of the dwelling and its insulation levels, among other factors. The formula provides an estimate of BTU's lost per hour due to the temperature differential.

The presence of sensible heat gain due to occupants and appliances causes the constant, $w_{0,}$ to be negative in the above expression. Provided that w_0 is negative, there is a balance temperature, $t_{b.}$ Heat is not required for temperature above this level. After all, the load function $Q(t_o)$ is quadratic in t_o, negative at the point t_i, zero at the point t_b, and decreasing in the range $[t_b, t_i]$. Heating is not required until temperatures fall below the balance temperature, t_b. For further discussion see Dubin (1985, p. 52, equation (43)). The thermal load function is illustrated in Figure 1.[7]

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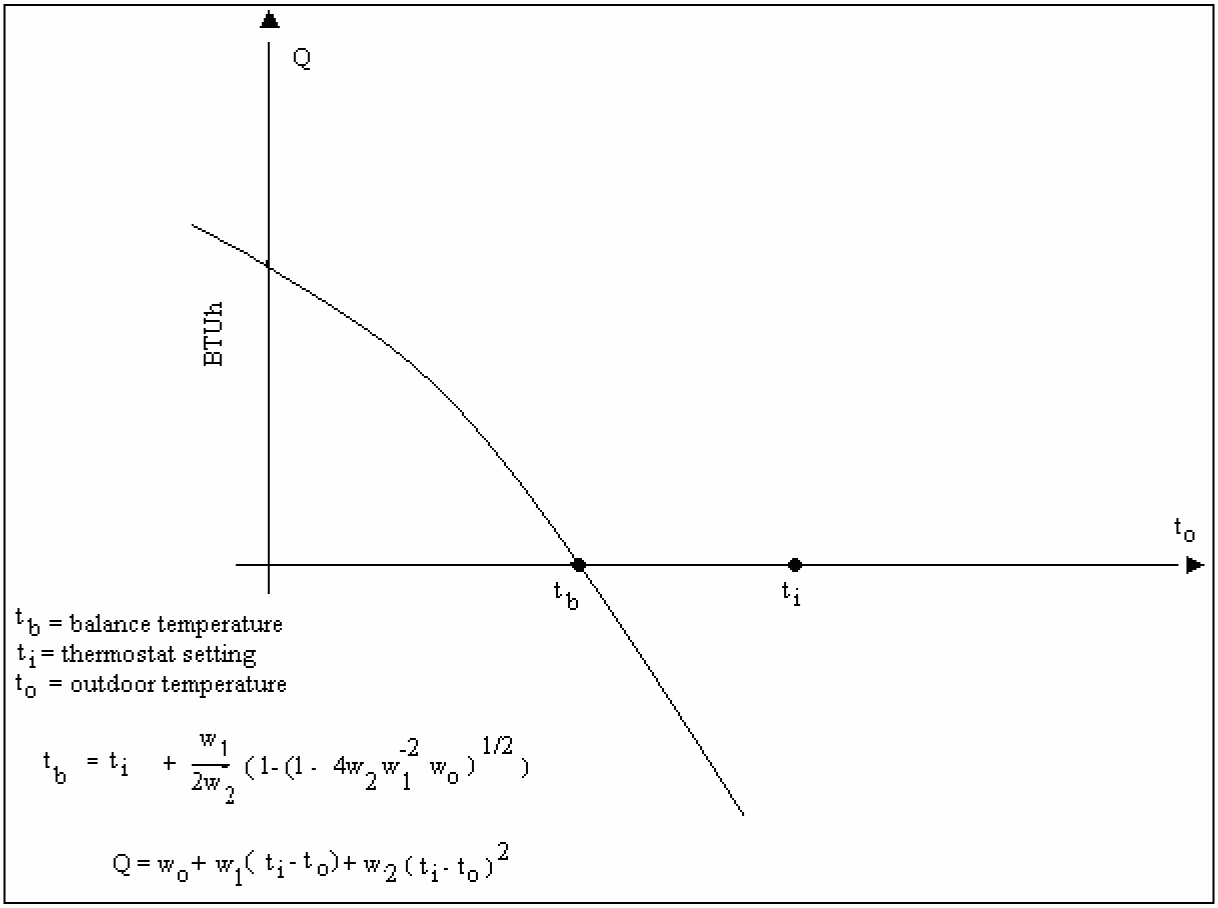
[7] Inspection of the formula for the balance point temperature differential shows that it is unchanged up to multiplicative scale changes in the thermal load function. Thus inaccuracies in the thermal load function, if present, do not affect the calculation of balance point temperature differentials reported below.

Figure 1: Thermal Load Function



The thermal model is shown in Appendix E. It is in the form of a computer program written in C, which has been modified to accommodate the RAS survey information. As described above, the inputs to this model consist of the design temperature information, monthly normal heating and cooling degree days, heating and cooling degree days by location of residence for the three years 2001-2003 on a monthly basis and the factors taken from the RAS survey described above. These considerations include: square footage, windows, insulation levels, and number of residents. The model processes data inputs for each of the 2,875 households for every month from 2001 through 2003. The output from the model consists of an estimated balance point temperature differential (the difference between the estimated balance point temperature and the assumed indoor thermostat setting). The results also contain the estimated space heat energy loads for each of the 36 months, assuming that space heat is produced using the efficiency of an all electric space heating system.

To illustrate the methodology, I provide the detailed characteristics for two households from the survey.[8] These are the first and fifth households from the subset 2,875 analyzed by the thermal model. Both households reside in King County where the summer outdoor daily temperature range is 18.2 degrees F, the summer design dry bulb temperature is 84.9 degrees F and the winter design temperature is 28.4 degrees F.[9] Each household has two family members. Neither has wall insulation. Both households have stormed or double-paned windows. The first household has 8 heated rooms, 1 floor, 1,290 square feet, and 11 windows. The second household has 5 heated rooms, 2 floors, 322 square feet, and 15 windows. The first house does not have attic insulation while the second house does have attic insulation (assumed to be 12 inches). The thermal coefficients (w0, w1, and w2) respectively are estimated to be -3719.0, 682.4, and 1.291 for house number 1 and -3719.0, 312.3, and 0.329 for house number 5. The estimated balance temperature differentials are -5.39 and -11.76 degrees F for the households respectively.

The mean balance point temperature was -8.1 degrees for all electric sample of households. The standard deviation of this differential was 3.8 degrees. These calculations are presented in the reg.log shown in Appendix F. They are based on the SST program reg.cmd. Balance point temperatures corresponding to different thermostat settings are easily derived. The mathematics show that the balance point estimate decline one degree for each one degree change in the thermostat setting. Hence, at a thermostat setting of 60 degrees for the interior

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[8] These households are selected to illustrate a range of dwelling sizes and are not meant to be representative of all households in the survey.

temperature, the balance point temperature would be roughly 52 degrees. At a thermostat setting of 65 degrees the balance point temperature would be 57 degrees on average.

I show a histogram of balance point temperatures, assuming a 65 degree F thermostat setting, in Appendix F. This distribution has a “fat tail” with many values below the average. Assuming that the thermostat is set at 65 degree (a 15 degree balance point temperature differential), about 5 percent of the sample has a balance point of 50 degrees or less. However, my analysis of thermostat settings on the PSE system reveals that many customers set their thermostat at levels lower than 65 degrees. I have analyzed survey data taken from roughly 400 PSE customers during the last twelve months.[10] Monthly self-reported thermostat information is available by month for each month from April 2005 through March 2006. My analysis of this information reveals a seasonal pattern in average thermostat settings wherein lower thermostat levels are set during summer months. The survey also collected thermostat settings for living and sleeping areas in the home and for three time-periods: day, evening, and night. I found clear variation in thermostat settings by time of day, somewhat less variation in the sleeping versus living area of the home. For instance, average evening thermostat settings are 64.9 degrees in the sleeping area and 66.6 degrees in the living area. By contrast, average nightly thermostat settings are closer to 63.3 degrees. In Appendix F, I show the histogram of thermostat settings. Over 40 percent of the sample has thermostat settings lower than 65 degrees while over 10 percent of the

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[9] Design temperatures are from American Society of Heating, Refrigerating and Air-Conditioning, 2005 Fundamentals, Chapter F28, Climatic Design Information. Design temperatures affect system design capacities but do not affect the estimated balance point temperature differential.

[10] PSE devotes a significant portion of its web page (www.pse.com) to energy efficiency. PSE customers can conduct a free energy self-audit through an online survey. This produces a report with specific and customized energy efficiency recommendations. The thermostat data was collected as part of the online survey process.

sample reported thermostat settings less than 55 degrees.[11] As the RAS survey and the web thermostat surveys are independent and as thermostat settings and balance point temperature differentials may reasonably be assumed to be independent, there are a significant number of customers whose true balance point temperature is quite low.[12] In these households, energy load for heating would not be triggered until the outdoor temperature becomes fairly cold. The relevant measure on a daily basis of such events is based on heating degree days for bases lower than 65 degrees. A single measurement of heating degree days with base 65 does not capture this information. The weather normalization analysis I conducted demonstrates that non-linearity between load and temperature is adequately captured using a measurement at base 45 degrees in conjunction with a measurement of heating degree days at 65 degrees.

V. Conclusions

The engineering thermal modeling approach to electric loads in the PSE service territory shows that balance point temperatures may be as low as 45 to 50 degrees for some households. This finding demonstrates that base temperatures of 65 degrees used in weather normalization regression models are not likely to capture the load temperature relationship for a significant number of dwellings. Regression techniques using splines or other non-parametric methods exploring curvature in the load-temperature relationship should rely on multiple base temperature measures of degrees days. The Dubin-McFadden engineering thermal model shows

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[11] These results are similar to those obtained from the EIA 2001 Residential Energy Consumption Survey (RECS). The public use micro data file: http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html contains 481 survey respondents in the Pacific region which includes Washington State. I find that thermostat settings range from 45 to 80 degrees with an average of 64 degrees F. Roughly 4 percent of respondents set their thermostats lower than 50 and roughly one-third set their thermostats lower than 60 degrees.

considerable promise in forecasting space heating load. Applied to the RAS data, the model yields practical implications and demonstrates that energy load on the PSE system is not best measured by heating degrees days base 65 degrees because balance point temperatures are significantly lower than comfort levels for a significant fraction of the PSE customer class.

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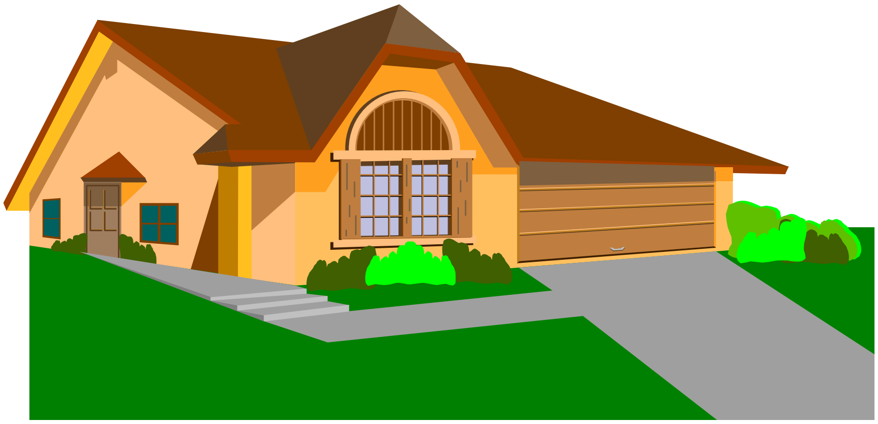
[12] For instance, roughly 5 percent of customers have balance point temperature differentials of 15 degrees or more while roughly one third of customers set their thermostats under 60 degrees. Thus there are at least 1.5 percent of customers whose balance point temperature is 45 degrees or lower.

Appendix A

PSE
PUGET
SOUND
ENERGY

←



Residential Energy Study

This study is being conducted by Puget Sound Energy to better understand your energy needs. Please help us by taking the time to answer the questions in this booklet. If you wish to comment on a question, please feel free to use the space provided in the margins. You are encouraged to answer every question is this booklet. However, if there is a question to which you would rather not respond, feel free to omit your answer and continue.

Please answer the questions in this booklet for the address shown below.

ID number

Service Address

Service City

Please answer these questions for the address shown on the cover of this booklet.

You are encouraged to answer every question is this booklet. However, if there is a question to which you would rather not respond, feel free to omit your answer and continue.

Circle the number for the most appropriate answer.

THIS RESIDENCE

1. Do you own or rent this residence?

   1 Own or buying
   2 Rent or lease ⇨*Answer 1A below*
   3 Other (*Please describe*)
   4 Don't know

   1A. Do you pay the heating bills for this residence, or does your landlord pay them?

   1 We pay the bills to heat our home
   2 We pay for some heating (e.g., portable heaters) and our landlord pays for some.
   3 Our landlord pays for all of our heat (included as part of our rent)
   4 Other (*Please describe*) ________________________
   5 Don't know

2. How long have you lived in this residence?

   1 1 year or less
   2 2-5 years
   3 6-10 years
   4 11-20 years
   5 More than 20 years
   6 Don't know

3. Which of the following best describes how this residence is occupied?

   1 Year-round, full-time
   2 Seasonal or part-time use
   3 Don't know

4. Which of the following best describes this residence?

   1 Single family detached house (on a separate lot) not connected to other living units
   2 A unit in a condominium or apartment (2 or more attached units) ⇨ *Answer 4A below*

3 Row or townhouse (Adjacent walls to another residence with no units above or below.) ⇨*Answer 4A below*
4 Mobile home or house trailer
5 Other (*Please describe*) ______________________________
6 Don't know

4A. How many living units or apartments are in the building where this residence is located? Please answer only for the building which contains this residence. Do not consider other buildings which may exist in the complex.

1 2 units
2 3 units
3 4 units
4 5 or more units
5 Don't know

5. How many levels or stories are there in this residence? *Do not* include an unfinished attic or basement or other floors not used for living space. (*For a townhouse or multi-family building with two or more living units*, answer only for the portion of the building where this residence is located.) *Please circle only one number.*

1 One story
2 One and a half stories
3 Split-level or two stories
4 Two and a half stories
7 Other (*Please describe*)
5 Tri-level or three stories
6 More than three stories
8 Don't know

6. What is the approximate square footage of *heated* floor space in this residence?

______ Heated square feet 0 Don't know

If you don't know the actual *heated* floor space, please indicate below the appropriate category.

1 Less than 500 square feet
2 501 to 1000 square feet
3 1001 to 1500 square feet
4 1501 to 2000 square feet
5 2001 to 2500 square feet
6 2501 to 3000 square feet
7 More than 3000 square feet
8 Don't know

10. About what year was this residence built?

01 Before 1980
02 1980 to 1985
03 1986 to 1990
04 1991 to 1995
05 1996 to 2000
06 2001
07 2002
08 2003
09 2004
10 Don't know

11. Have there been any additions to this residence *within the last five years* that have increased the *heated floor space*?

    1 Yes ⇨ *Answer 11A below*
    2 No
    3 Don't know

11A. How much heated floor space was added to this residence in the last five years?

______ Square feet added 0 Don't know

NATURAL GAS SERVICE

1. Do you have natural gas service at this residence?
   1 Yes → *Answer 1A below*
   2 No
   3 Don't know

1A. Was natural gas service in this residence at the time it was built or was it added at a later time?
   1 In residence at the time it was built
   2 Added at a later time
   3 Don't know

2. Is natural gas service available in this neighborhood (do any of your close neighbors have natural gas service)?
   1 Yes
   2 No
   3 Don't know

HOME HEATING

1. Does the main heating system serve only this residence or does it serve more than one residence? The main heating system is the one that is used the most.

- ☐ Heating system serves only this residence
- ☐ Heating system serves more than residence → Skip to the WATER HEATING SECTION
- ☐ This residence has no heating system → Skip to the WATER HEATING SECTION
- ☐ Don't know → Skip to the WATER HEATING SECTION

3. What is the main heating system that is used to heat the home? The main heating system is the one that is used the most.

4. What other heating system(s) do you use to heat your home?

	Q3. Main System	**Q4. Additional System(s)**
Type of Heating System(s)	**Circle the number for the ONE system used most at this residence.**	**Circle the number for ALL other heating systems that are used at this residence.**
Natural Gas Heating		
Central forced air furnace	1	1
Natural gas fireplace	17	17
Other natural gas system	3	3
Electric Heating		
Baseboard, wall heaters (without fans), or ceiling cables	4	4
Wall heaters with fans	5	5
Central forced air furnace	6	6
Heat pump	7	7
Portable heaters	8	8
Other electric system	9	9
Oil Heating:		
Central forced air furnace	10	10
Other oil system	12	12
Bottled Gas Heat: propane, butane, or kerosene		
Central forced air	13	13
Portable heaters	14	14
Other Fuels		
Wood stove	15	15
Wood fireplace	16	16
Solar	18	18
Other System (please describe): ______________________________	19	19

3. Approximately how old is the *main* heating system (the one used most often)?

1 1 year OR LESS→ *Answer 3A below*
3 2 to 5 years
4 6 to 10 years
5 11 to 20 years
6 More than 20 years
7 Don't know

3A. Was the *main* heating system for this residence replaced in 2003?

1 Yes → *Answer 3A1 below*
2 No
3 Don't know

3A1. What was the primary source of heat before the replacement? (C*heck one box only.*)

01 Electric baseboards
02 Electric wall heaters
03 Electric forced air furnace or boiler
04 Heat pump
05 Natural gas forced air furnace or boiler
06 Propane or bottled gas furnace or boiler
07 Oil forced air furnace or boiler
08 Only have wood heating device(s)
09 Other (*Please describe*) ____________
10 None
11 Don't know

2. Have you had a service professional repair or perform routine maintenance on your main heating system within the last two years?

1 Yes, repair work was performed within the past two years
2 Yes, routine maintenance was performed within the past two years
3 Yes, repair work **AND** routine maintenance was performed within the past two years
4 No
5 Don't know

5. What type of temperature control is on the main heating system (the one used most often)?

   01 Regular thermostat(s) with temperature settings
   02 Clock or programmable thermostat(s)
   03 Dial control without temperature settings
   04 Simple on/off switch or no temperature control
   05 Other [specify: ____________________________________]

6. Which of the following statements best describes how the main heating system is used?

   01 The thermostat(s) is kept at a constant setting or temperature
   02 The thermostat setting changes based on the time of day or night
   03 The heater is turned on only when someone is cold
   04 We rarely use this heating system

WATER HEATING

1. Does the water heater, or the source of the hot water, serve only this residence or does it serve more than one residence?
   - ☐ Water heater(s) serves only this residence
   - ☐ Water heater serves more than residence → Skip to the APPLIANCE SECTION
   - ☐ This residence has no hot water → Skip to the APPLIANCE SECTION
   - ☐ Don't know → Skip to the APPLIANCE SECTION

2. How many water heaters are at this residence?
   - ☐ One
   - ☐ Two
   - ☐ Three or more

The following questions refer to the *primary* or *main* water heater (the one that is used the most).

3. What type of fuel or energy is used to heat the water used in this residence?

☐ Electricity
☐ Natural gas
☐ Propane or bottled gas (LP, propane, butane)
☐ Other [describe: ____]
☐ Don't know

4. Approximately how old is your main water heater?

1 1 year OR LESS→ *Answer 4A below*
☐ 2 to 5 years old
☐ 6 to 10 years old
☐ 11 to 20 years old
☐ More than 20 years old
☐ Don't know

4A. Was the *primary water heater f*or this residence replaced in 2003?

1 Yes → *Answer 4A1 below*
2 No
3 Don't know

4A1. What type of water heater was replaced? (C*heck one box only.*)

12 Electric
13 Natural gas
14 Propane or bottled gas furnace or boiler
15 Other (*Please describe*) ____________
16 Don't know

5. Where is your main water heater located?

☐ In a heated area (including a heated basement)
☐ In an unheated area (such as a garage, utility room, or unheated basement)
☐ Don't Know

6. Which of the following items do you have for your main water heater?

   Water heater wrap or insulation blanket on the outside of the water heater
   ☐ Water heater pipe wrap
   ☐ Water heater timer
   ☐ None of these

Please continue to answer these questions for the address shown on the cover of this booklet.

APPLIANCES AND OTHER EQUIPMENT

1. For the following appliances or household equipment, please indicate what fuel or energy source is used at this residence. (Please circle only one answer for each. Do not count appliances or equipment shared by other residences.)

	Don't Have	**Electricity**	**Natural Gas**	**Propane**	**Other**	**Don't Know**
Stove-top cooking*	0	1	2	3	4	5
Conventional oven*	0	1	2	3	4	5
Clothes dryer	0	1	2	3	4	5
Private hot tub or spa	0	1	2	3	4	5
Private swimming pool	0	1	2	3	4	5

**If this residence has a conventional range (i.e., combination cook-top and oven), please answer for both of these appliances*

2. Approximately how old are the following appliances? (Please circle only one answer for each. Do not count appliances or equipment shared by other residences.)

	Don't Have	**1 year or less**	**2 to 5 years**	**6 to 10 years**	**11 to 20 years**	**More than 20 years**	**Don't Know**
Stove-top cooking*	0	1	2	3	4	5	6
Conventional oven*	0	1	2	3	4	5	6
Clothes dryer	0	1	2	3	4	5	6
Private hot tub or spa	0	1	2	3	4	5	6
Private swimming pool	0	1	2	3	4	5	6

**If this residence has a conventional range (i.e., combination cook-top and oven), please answer for both of these appliances*

3. How many of each of the following appliances or household equipment are there in use in this residence? (Please respond for each appliance listed below. If none, please enter "0" or none)

4. Approximately how old is your primary unit? (Please respond for each appliance listed below.)

Appliance/Equipment Type	Q3.. How many installed?	Q4.. Approximately how old is your primary unit?
Dishwasher		
Microwave oven		
Refrigerator		
Separate freezer		
On-demand hot water dispenser		
Central air conditioner		
Room air conditioner		
Electric Blankets		
Televisions		
Video cassette recorders (VCRs) or DVD players		
Home office equipment (Fax, photo copier, etc.)		
Personal computers		
Home stereo systems		

7. Do any of the appliances or equipment in this residence have the ENERGY STAR label on them?

☐ Yes → Please list: ....______________________________
...._____________________________

☐ No

☐ Don't know

4. Is there a back-up generator at this residence?
   1 Yes
   2 No
   3 Don't know

7. Is there a home office at this residence from which a business is operated?
   1 Yes
   2 No
   3 Don't know

WEATHERIZATION/EFFICIENT EQUIPMENT AND LIGHTING

In this section, we are gathering information about changes you may have made to you home. Please consider all work you have done ***with or without assistance*** from a contractor or other service personnel.

1. Which of the following energy conservation measures do you have in this residence? If you do have an item, please indicated whether or not it was already there when you moved in, or was something that was done after you moved in.

	Yes, was done…		**No, was never done**	**Don't know**
	…before I moved in	**…after I moved in**		
1. Ceiling or attic insulation	1	2	3	4
2. Wall or floor insulation	1	2	3	4
3. Heating duct insulation	1	2	3	4
4. Caulk or weatherstrip doors or windows	1	2	3	4
5. Low-flow showerheads	1	2	3	4
6. Energy efficient windows	1	2	3	4

2. Compact fluorescent bulbs (CFLs) are small screw-in fluorescent bulbs that fit in regular light bulb sockets. CFLs look different than standard incandescent bulbs. They are often made out of thin tubes of glass bent into loops. Sometimes, they are enclosed in a globe for use in ceiling fans or bathroom vanities. Without any rebates or discounts, compact fluorescent bulbs typically cost from $2 to $13, while regular incandescent bulbs usually cost from $1 to $1.50. Do you have any compact fluorescent bulbs, or CFLs, in your home?

1 Yes → *Answer 2A*
2 No
3 Don't know

2A. Where are your Compact fluorescent bulbs located? Please indicate the number of CFLs installed in the…

_____Bathroom
_____Bedroom
_____Closet
_____Dining room
_____Family room
_____Garage
_____Hallway/entryway
_____Kitchen
_____Living room
_____Home office
_____Utility room
_____Other [Specify:____________________]
_____Other [Specify:____________________]

_____Outdoors

3. Approximately what percentage of this residence's windows are double or triple-pane?

1 All (100%)→ *Answer 3A*
2 Most (75%) → *Answer 3A*
3 Some (50%) → *Answer 3A*
4 Few (25%) → *Answer 3A*
5 None
6 Don't know

3A. Approximately how old are the double or triple-pane windows in this residence?

1 1 year or less
2 2-5 years
3 6-10 years
4 11-20 years
5 more than 20 years
6 Don't know

4. Approximately what percentage of this residence's windows are equipped with storm windows?

1 All (100%)
2 Most (75%)
3 Some (50%)
4 Few (25%)
5 None
6 Don't know

HOUSEHOLD CHARACTERISTICS

To assist us in analyzing the information gathered in this study, your answers to the following questions will be especially helpful. Please be assured that all of your answers will be confidential and used only to summarize statistics for large groups of customers.

1. Please indicate how many people who usually live in this residence at least six months of the year are in each of the age groups shown below. (If you have none, please enter “0”.)

Number of Persons

______ Under 6 years old
______ 6 to 18 years old
______ 19 to 64 years old
______ 65 years and older

Please answer the following questions for the primary wage earner, or the person considered to be the head of the household.

4. What is the highest level of schooling completed by the head of the household?

1 8th grade or less
2 High school graduate/GED
3 Business/technical school
4 Some college (or 2-year degree)
5 Graduated college (4-year degree)
6 Some graduate work
7 Graduate degree
8 Don’t know

5. What is the employment status of the head of the household?

1 Employed full-time
2 Employed part-time
3 Not employed
4 Self-employed
5 Don’t know

6. What is the age of the head of the household?

______ Years
0 Don't know

2. Which of the following categories includes the total yearly income before taxes for the entire household in 1997?

01 Less than $20,000	07 $70,000 - $79,999
02 $20,000 - $29,999	08 $80,000 - $89,999
03 $30,000 - $39,999	09 $90,000 - $99,999
04 $40,000 - $49,999	10 $100,000 - $149,999
05 $50,000 - $59,999	11 $150,000 or more
06 $60,000 - $69,999	12 Don't know

8. PSE plans to collect more detailed information and is conducting short follow-up telephone interviews on a small sample of homes. Would you be interested in participating in a follow-up telephone interview?

☐ Yes
☐ No

9. PSE plans to collect more detailed information on energy efficient equipment, and is conducting in-persons audits at a small sample of homes. The audits are conducted by professionals, and are simply conducted to look at the presence of energy efficient equipment in households. Participants in the study will also receive [incentive] Would you be interested in participating in this study?

☐ Yes
☐ No

11. If you indicated 'Yes' to either of the above questions, what is the best number to reach you?

(_______) __________-________________

12. When is the best time to have someone call you to conduct an interview or schedule an appointment?

1. Morning
2. Afternoon
3. Evenings
4. Weekends

Exhibit No. ___(JAD-8)

Thank you very much for your cooperation and assistance!

Appendix B

rasfinal.log

```
SST Spool File:  rasfinal.log
Thu Mar 30 09:23:46 2006

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   scanid      20-23       \
   ownrent     24-25       \
   payht       26-27       \
   occres      28-29       \
   dwltype     30-31       \
   units       32-33       \
   dwlstr      34-35       \
   sqftact     36-40       \
   sqftcat     41-42       \
   heatroom    43-44       \
   bathroom    45-46       \
   builtyr     47-48       \
   addition    49-50       \
   addsqft     51-54       \
   ngserv      55-56       \
   ngtime      57-58       \
   ngavail     59-60       \
   heatserv    61-62       \
   prihtsys    63-64       \
   htngcnt     65-66       \
   htngfp      67-68       \
   htngoth     69-70       \
   htelbsb     71-72       \
   htelwht     73-74       \
   htelcrh     75-76       \
   htelchp     77-78       \
   htelpth     79-80       \
   hteloth     81-82       \
   htolcnt     83-84       \
   htoloth     85-86       \
   htbgcnt     87-88       \
   htbgpth     89-90       \
   htwdws      91-92       \
   htwdfp      93-94       \
   htslr       95-96       \
   htotsys     97-98       \
   htsysage    99-100      \
   htrepl03    101-102     \
   heatrepl    103-104     \
   repair      105-106     \
   htctlbev    107-108     \
   heatuse     109-110     \
   whsystyp    111-112     \
   whsysnum    113-114     \
   whfuel      115-116     \
   whage       117-118     \
   whrepl03    119-120     \
   whrepl      121-122     \
   whloc       123-124     \
   whwrap      125-126     \
   whpwrap     127-128     \
   whtimer     129-130     \
   whnone      131-132     \
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   ckovtyp     135-136     \
   drytyp      137-138     \
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pltyp       141-142     \
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ckovage     145-146     \
dryage      147-148     \
sphtage     149-150     \
poolage     151-152     \
dishwn      153-154     \
microwvn    155-156     \
refrn       157-158     \
freezern    159-160     \
hwdispn     161-162     \
centacn     163-164     \
roomacn     165-166     \
elblnktn    167-168     \
tvn         169-170     \
vcrdvdn     171-172     \
offeqpn     173-174     \
pcn         175-176     \
stereon     177-178     \
dishwa      179-180     \
microwva    181-182     \
refra       183-184     \
freezera    185-186     \
hwdispa     187-188     \
centaca     189-190     \
roomaca     191-192     \
elblnkta    193-194     \
tva         195-196     \
vcrdvda     197-198     \
offeqpa     199-200     \
pca         201-202     \
stereoa     203-204     \
enrgystr    205-206     \
genrator    207-208     \
homeoffc    209-210     \
ceilins     211-212     \
wallins     213-214     \
htdctins    215-216     \
drwinins    217-218     \
showerhd    219-220     \
eewindws    221-222     \
cfl         223-224     \
cflbthn     225-226     \
cflbedn     227-228     \
cflclstn    229-230     \
cflfamrn    231-232     \
cflgrgen    233-234     \
cflhalln    235-236     \
cflktchn    237-238     \
cfllvrmn    239-240     \
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cfloutn     243-244     \
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nr6_18      258         \
nr19_64     259-260     \
nr65ovr     261         \
educ        262-263     \
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agenr       268-269     \
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followup    272         \
audits      273         \
phone       274-283     \
besttime    284         \
batchno     285-287     \
nr0_6a      288         \
nr6_18a     289         \
nr19_64a    290         \
nrovr65a    291         \
dwltypex    292         \
custx       293         \
county1     294         \
county2     295         \
numres      296-297     \
name        298-343 (s) \
mailadd     344-378 (s) \
mailcity    379-395 (s) \
mailst      396-397 (s) \
mailzip     398-402 (s) \
address     403-441 (s) \
city        442-458 (s) \
zip         459-463 (s) \
pscounty    464-465 (s) \
ps_egi      466-469 (s) \
ps_dwl      470-472 (s) \
ownrntot    473         \
payhtot     474-475     \
occresot    476         \
dwltypot    477-478     \
dwlstrot    479         \
htothr      480         \
htnr        481         \
htprfp      482         \
htpellet    483         \
htrad       484         \
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htflrepo    486-487     \
httempct    488-489     \
whfuelot    490-491     \
whrepot     492         \
whlocot     493-494     \
esac        495-496     \
escd        497-498     \
espc        499-500     \
ecmntr      501-502     \
ecdishw     503-504     \
ecdry       505-506     \
ecdvd       507-508     \
ecfrzr      509-510     \
ecfrnc      511-512     \
ecmicrow    513-514     \
ecprint     515-516     \
ecrefr      517-518     \
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rmacnact    557-558     \
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pcncat      567-568     \
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refracat    609-610     \
fzracat     611-612     \
hwdspact    613-614     \
centact     615-616     \
rmacact     617-618     \
blnktact    619-620     \
tvacat      621-622     \
vcrdvact    623-624     \
offeqact    625-626     \
pcacat      627-628     \
streoact    629-630     \
agecat      631-632     \
kwh2001     633-637     \
kwh2002     638-642     \
kwh2003     643-647     \
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bathsqr     668-685     \
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   cflbed      760-761     \
   cflclst     762-763     \
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   cflgarag    766-767     \
   cflhall     768-769     \
   cflktch     770-771     \
   cflliv      772-773     \
   pcflhoff    774-775     \
   cflout3     776-777     \
   cflutil     778-779     \
   cflot1      780-781     \
   cflot2      782-783     \
   pcflindr    784-785     \
   pcflbath    786-804     \
   pcflbed     805-823     \
   pcflclst    824-842     \
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   pcflhall    862-880     \
   pcflktch    881-899     \
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label var[hwdispa     ] lab[{AGE PRIM ONDEMAND H20 DISPENSER -A Q4}]
label var[centaca     ] lab[{AGE OF PRIM CENTRAL AC - A Q4}        ]
label var[roomaca     ] lab[{AGE OF PRIM ROOM AIR CONDITIONER-A Q4}]
label var[elblnkta    ] lab[{AGE OF PRIM ELECTRIC BLANKET - A Q4}  ]
label var[tva         ] lab[{AGE OF PRIM TELEVISION - A Q4}        ]
label var[vcrdvda     ] lab[{AGE OF PRIM VCR OR DVD PLAYER - A Q4} ]
label var[offeqpa     ] lab[{AGE OF PRIM HOME OFFICE EQUIP - A Q4} ]
label var[pca         ] lab[{AGE OF PRIM PERSONAL COMPUTER - A Q4} ]
label var[stereoa     ] lab[{AGE OF PRIM HOME STEREO SYSTEM - A Q4}]
label var[enrgystr    ] lab[{ANY APPL ENERGY STAR - A Q5}          ]
label var[genrator    ] lab[{BACK UP GENERATOR - A Q6}             ]
label var[homeoffc    ] lab[{HOME OFFICE AT RESIDENCE - A Q7}      ]
```

```
label var[ceilins    ] lab[{WHEN CEILING INSULATION INSTALLED-C Q1}]
label var[wallins    ] lab[{WHEN WALL INSULATION INSTALLED - C Q1}]
label var[htdctins   ] lab[{WHEN HEAT DUCT INS INSTALLED - C Q1}  ]
label var[drwinins   ] lab[{WHEN WEATHERSTRIP INSTALLED - C Q1}   ]
label var[showerhd   ] lab[{WHEN LOWFLOW SHOWER HD INSTALLED-C Q1}]
label var[eewindws   ] lab[{WHEN EFFICIENT WINDOWS INSTALLED-C Q1}]
label var[cfl        ] lab[{HAS CFLS - C Q2}                      ]
label var[cflbthn    ] lab[{N OF CFLS IN BATHROOM - C Q2a}        ]
label var[cflbedn    ] lab[{N OF CFLS IN BEDROOM - C Q2a}         ]
label var[cflclstn   ] lab[{N OF CFLS IN CLOSET - C Q2a}          ]
label var[cflfamrn   ] lab[{N OF CFLS IN FAMILY ROOM - C Q2a}     ]
label var[cflgrgen   ] lab[{N OF CFLS IN GARAGE - C Q2a}          ]
label var[cflhalln   ] lab[{N OF CFLS IN HALLWAY - C Q2a}         ]
label var[cflktchn   ] lab[{N OF CFLS IN KITCHEN - C Q2a}         ]
label var[cfllvrmn   ] lab[{N OF CFLS IN LIVING ROOM - C Q2a}     ]
label var[cflhoffn   ] lab[{N OF CFLS IN HOME OFFICE EQUIP-C Q2a} ]
label var[cfloutn    ] lab[{N OF CFLS IN OUTDOORS - C Q2a}        ]
label var[cflutiln   ] lab[{N OF CFLS IN UTILITY ROOM - C Q2a}    ]
label var[cfloth1n   ] lab[{N OF CFLS IN OTHER 1 - C Q2a}         ]
label var[cfloth2n   ] lab[{N OF CFLS IN OTHER 2 - C Q2a}         ]
label var[dblpane    ] lab[{PCNT OF DBL PANE WINDOWS - C Q3}      ]
label var[dblpanea   ] lab[{AGE OF DBLE PANE WINDOWS - C Q3a}     ]
label var[pctstrmw   ] lab[{PCNT OF WINDOWS THAT ARE STORM - C Q4}]
label var[nr0_6      ] lab[{N OF PEOPLE UNDER 6 YRS OLD - D Q1}   ]
label var[nr6_18     ] lab[{N OF PEOPLE BTWN 6 AND 18 - D Q1}     ]
label var[nr19_64    ] lab[{N OF PEOPLE BTWN 19 AND 64 - D Q1}    ]
label var[nr65ovr    ] lab[{N OF PEOPLE OLDER 65 YRS OLD - D Q1}  ]
label var[educ       ] lab[{HIGHEST EDUC BY HEAD OF HOUSE - D Q2} ]
label var[empstat    ] lab[{EMP STATUS OF HEAD OF HOUSE - D Q3}   ]
label var[age        ] lab[{AGE OF HEAD OF HOUSEHOLD - D Q4}      ]
label var[agenr      ] lab[{AGE OF HEAD OF HOUSEHOLD - D Q4}      ]
label var[income     ] lab[{YEARLY INCOME 2003 - D Q5}            ]
label var[followup   ] lab[{FOLLOW UP INTERVIEW - D Q6}           ]
label var[audits     ] lab[{FOLLOW UP AUDIT - D Q7}               ]
label var[phone      ] lab[{BEST PHONE NUMBER - D Q8}             ]
label var[besttime   ] lab[{BEST TIME TO REACJ - D Q9}            ]
label var[batchno    ] lab[{Survey Id}                            ]
label var[nr0_6a     ] lab[{N IN HOUSEHOLD UNDER 6 ANY- D Q1}     ]
label var[nr6_18a    ] lab[{N IN HOUSEHOLD 6-18 ANY- D Q1}        ]
label var[nr19_64a   ] lab[{N IN HOUSEHOLD 19-64 ANY- D Q1}       ]
label var[nrovr65a   ] lab[{N IN HOUSEHOLD OVER 65 ANY- D Q1}     ]
label var[dwltypex   ] lab[{PSE DWELLING TYPE (1=SF,2,3=MF,4=MH)} ]
label var[custx      ] lab[{CUST TYPE (1=GAS,2=ELECTRIC,3=COMBO)} ]
label var[county1    ] lab[{FIRST DIGIT OF COUNTY}                ]
label var[county2    ] lab[{SECOND DIGIT OF COUNTY}               ]
label var[numres     ] lab[{TOTAL NUMBER OF OCCUPANTS}            ]
label var[name       ] lab[{PSE: CUSTOMER NAME}                   ]
label var[mailadd    ] lab[{PSE: MAILING ADDRESS}                 ]
label var[mailcity   ] lab[{PSE: MAILING CITY}                    ]
label var[mailst     ] lab[{PSE: MAILING STREET}                  ]
label var[mailzip    ] lab[{PSE: MAILING ZIP}                     ]
label var[address    ] lab[{PSE: RESIDENCE ADDRESS}               ]
label var[city       ] lab[{PSE: RESIDENCE CITY}                  ]
label var[zip        ] lab[{PSE: RESIDENCE ZIP}                   ]
label var[pscounty   ] lab[{PSE: RESIDENCE COUNTY}                ]
label var[ps_egi     ] lab[{PSE: ELECTRIC GAS INDICATOR}          ]
label var[ps_dwl     ] lab[{PSE: DWELLING TYPE}                   ]
label var[ownrntot   ] lab[{OWN OR RENT: OTHER - R Q1}            ]
label var[payhtot    ] lab[{PAY BILL: OTHER - R Q1a}              ]
label var[occresot   ] lab[{OCCUPANT SEASONS: OTHER - R Q3}       ]
label var[dwltypot   ] lab[{DWELLING TYPE: OTHER - R Q4}          ]
label var[dwlstrot   ] lab[{DWELLING STORIES: OTHER - R Q5}       ]
label var[htothr     ] lab[{HEATSYS: OTHER - H Q2}                ]
label var[htnr       ] lab[{HEATSYS: DON'T KNOW - H Q2}           ]
```

```
label var[htprfp      ] lab[{HEATSYS: PROPANE STOVE - H Q2}        ]
label var[htpellet    ] lab[{HEATSYS: PELLET STOVE - H Q2}         ]
label var[htrad       ] lab[{HEATSYS: RADIANT FLOOR HEAT - H Q2}   ]
label var[hthwrad     ] lab[{HEATSYS: READIANT HOT WATER - H Q2}   ]
label var[htflrepo    ] lab[{PRIOR HEATING SYSTEM: OTHER - H Q4b}  ]
label var[httempct    ] lab[{TEMP CONTROL: OTHER - H Q6}           ]
label var[whfuelot    ] lab[{WATER HTR FUEL: OTHER - W Q3}         ]
label var[whrepot     ] lab[{WATER HTR REPLACED: OTHER - W Q4b}    ]
label var[whlocot     ] lab[{WATER HTR LOCATION: OTHER - W Q5}     ]
label var[esac        ] lab[{HAS ENERGY STR AIR CONDITION - A Q5}  ]
label var[escd        ] lab[{HAS ENERGY STR CD PLAYER - A Q5}      ]
label var[espc        ] lab[{HAS ENERGY STR COMPUTER - A Q5}       ]
label var[ecmntr      ] lab[{HAS ENERGY STR COMPUTER MONITOR-A Q5} ]
label var[ecdishw     ] lab[{HAS ENERGY STR DISHWASHER - A Q5}     ]
label var[ecdry       ] lab[{HAS ENERGY STR DRYER - A Q5}          ]
label var[ecdvd       ] lab[{HAS ENERGY STR DVD PLAYER - A Q5}     ]
label var[ecfrzr      ] lab[{HAS ENERGY STR FREEZER - A Q5}        ]
label var[ecfrnc      ] lab[{HAS ENERGY STR FURNACE - A Q5}        ]
label var[ecmicrow    ] lab[{HAS ENERGY STR MICROWAVE - A Q5}      ]
label var[ecprint     ] lab[{HAS ENERGY STR PRINTER - A Q5}        ]
label var[ecrefr      ] lab[{HAS ENERGY STR REFRIGERATOR - A Q5}   ]
label var[ecstereo    ] lab[{HAS ENERGY STR STEREO - A Q5}         ]
label var[ecstove     ] lab[{HAS ENERGY STR STOVE - A Q5}          ]
label var[ectv        ] lab[{HAS ENERGY STR TV - A Q5}             ]
label var[ecvcr       ] lab[{HAS ENERGY STR VCR - A Q5}            ]
label var[ecwash      ] lab[{HAS ENERGY STR WASHING MACHINE- A Q5} ]
label var[ecwh        ] lab[{HAS ENERGY STR WATER HEATER - A Q5}   ]
label var[ecoth       ] lab[{HAS ENERGY STR OTHER - A Q5}          ]
label var[cfloth1     ] lab[{OTHER LOCATION WITH CFL - C Q2a}      ]
label var[cfloth2     ] lab[{OTHER LOCATION WITH CFL - C Q2a}      ]
label var[cfl1oth     ] lab[{OTHER LOCATION WITH CFL - C Q2a}      ]
label var[cfl2oth     ] lab[{OTHER LOCATION WITH CFL - C Q2a}      ]
label var[cflbasem    ] lab[{CFL IN BASEMENT - C Q2a}              ]
label var[cfldine     ] lab[{CFL IN DINING ROOM - C Q2a}           ]
label var[cfllamp     ] lab[{CFL IN LAMPS - C Q2a}                 ]
label var[cflout      ] lab[{CFL OUTSIDE - C Q2a}                  ]
label var[adsqftct    ] lab[{ADDED HEATED SQUARE FOOTAGE - R Q10a} ]
label var[dwncat      ] lab[{N OF DISHWASHERS - A Q3}              ]
label var[mwvncat     ] lab[{N OF MICROWAVES INSTALLED - A Q3}     ]
label var[refrncat    ] lab[{N OF REFRIGERATORS INSTALLED - A Q3}  ]
label var[fzrncat     ] lab[{N OF SEPARATE FREEZERS INSTALLED-A Q3}]
label var[hwdnact     ] lab[{N OF ONDEMAND H20 DISPENSERS  - A Q3} ]
label var[centnact    ] lab[{N OF CENTRAL AIR CONDITIONERS - A Q3} ]
label var[rmacnact    ] lab[{N OF ROOM ACs INSTALLED - A Q3}       ]
label var[blnktnct    ] lab[{N OF ELECTRIC BLANKETS - A Q3}        ]
label var[tvncat      ] lab[{N OF TELEVISIONS - A Q3}              ]
label var[vcrdvnct    ] lab[{N OF VCR OR DVD PLAYER - A Q3}        ]
label var[offeqnct    ] lab[{N OF HOME OFFICE EQUIP - A Q3}        ]
label var[pcncat      ] lab[{N OF PERSONAL COMPUTERS - A Q3}       ]
label var[sternct     ] lab[{N OF HOME STEREO SYSTEM - A Q3}       ]
label var[cflbtnct    ] lab[{N OF CFLS IN BATHROOM - C Q2a}        ]
label var[cflbdnct    ] lab[{N OF CFLS IN BEDROOM - C Q2a}         ]
label var[cflclnct    ] lab[{N OF CFLS IN CLOSET - C Q2a}          ]
label var[cflfrnct    ] lab[{N OF CFLS IN FAMILY ROOM - C Q2a}     ]
label var[cflganct    ] lab[{N OF CFLS IN GARAGE - C Q2a}          ]
label var[cflhlnct    ] lab[{N OF CFLS IN HALLWAY - C Q2a}         ]
label var[cflktnct    ] lab[{N OF CFLS IN KITCHEN - C Q2a}         ]
label var[cfllvnct    ] lab[{N OF CFLS IN LIVING ROOM - C Q2a}     ]
label var[cflofnct    ] lab[{N OF CFLS IN HOME OFFICE EQUIP-C Q2a} ]
label var[cfoutnct    ] lab[{N OF CFLS IN OUTDOORS - C Q2a}        ]
label var[cflutnct    ] lab[{N OF CFLS IN UTILITY ROOM - C Q2a}    ]
label var[cflo1nct    ] lab[{N OF CFLS IN OTHER 1 - C Q2a}         ]
label var[cflo2nct    ] lab[{N OF CFLS IN OTHER 2 - C Q2a}         ]
label var[nr0_6cat    ] lab[{N OF PEOPLE UNDER 6 YRS OLD - D Q1}   ]
```

```
label var[nr618cat   ] lab[{N OF PEOPLE BTWN 6 AND 18 - D Q1}     ]
label var[n1964ct    ] lab[{N OF PEOPLE BTWN 19 AND 64 - D Q1}    ]
label var[n65ovrct   ] lab[{N OF PEOPLE OLDER 65 YRS OLD - D Q1}  ]
label var[dwacat     ] lab[{AGE OF PRIM DISHWASHERS - A Q4}       ]
label var[mwvacat    ] lab[{AGE OF PRIM MICROWAVE - A Q4}         ]
label var[refracat   ] lab[{AGE OF PRIM REFRIGERATOR - A Q4}      ]
label var[fzracat    ] lab[{AGE OF PRIM SEPARATE FREEZER - A Q4}  ]
label var[hwdspact   ] lab[{AGE PRIM ONDEMAND H20 DISPENSER-A Q4} ]
label var[centact    ] lab[{AGE OF PRIM CENTRAL AC - A Q4}        ]
label var[rmacact    ] lab[{N OF ROOM AC INSTALLED - A Q3}        ]
label var[blnktact   ] lab[{AGE OF PRIM ELECTRIC BLANKET - A Q4}  ]
label var[tvacat     ] lab[{AGE OF PRIM TELEVISION - A Q4}        ]
label var[vcrdvact   ] lab[{AGE OF PRIM VCR OR DVD PLAYER - A Q4} ]
label var[offeqact   ] lab[{AGE OF PRIM HOME OFFICE EQUIP - A Q4} ]
label var[pcacat     ] lab[{AGE OF PRIM PERSONAL COMPUTER - A Q4} ]
label var[streoact   ] lab[{AGE OF PRIM HOME STEREO SYSTEM - A Q4}]
label var[agecat     ] lab[{AGE OF HEAD OF HOUSEHOLD - D Q4}      ]
label var[kwh2001    ] lab[{PSE ANNUAL 2001 KWH}                  ]
label var[kwh2002    ] lab[{PSE ANNUAL 2002 KWH}                  ]
label var[kwh2003    ] lab[{PSE ANNUAL 2003 KWH}                  ]
label var[yrresnum   ] lab[{NUMBER OF YEARS IN RESIDENCE}         ]
label var[roomsq     ] lab[{ROOMS PER SQUARE FOOTAGE}             ]
label var[bathsqr    ] lab[{BATHS PER SQUARE FOOTAGE}             ]
label var[yrs_res    ] lab[{YEARS LIVED IN RESIDENCE}             ]
label var[counter    ] lab[{NUMBER OF MISSING KEY VARIABLES}      ]
label var[nrescat    ] lab[{N OF PEOPLE IN HOUSEHOLD - D Q1}      ]
label var[dwlnew     ] lab[{Dwelling Type}                        ]
label var[housetyp   ] lab[{Housetype}                            ]
label var[custtyp    ] lab[{Custtyp}                              ]
label var[county     ] lab[{County}                               ]
label var[weight     ] lab[{CASE WEIGHT}                          ]
label var[relwt      ] lab[{RELATIVE WEIGHT}                      ]
label var[resp1_a    ] lab[{1 IF IN FINAL SAMPLE}                 ]
label var[cflbath    ] lab[{NUMBER OF CFLS IN BATHROOM- CLEANED}  ]
label var[cflbed     ] lab[{NUMBER OF CFLS IN BEDROOM - CLEANED}  ]
label var[cflclst    ] lab[{NUMBER OF CFLS IN CLOSETS - CLEANED}  ]
label var[cflfam     ] lab[{NUMBER OF CFLS IN FAMILY ROOM-CLEANED}]
label var[cflgarag   ] lab[{NUMBER OF CFLS IN GARAGE - CLEANED}   ]
label var[cflhall    ] lab[{NUMBER OF CFLS IN HALLS - CLEANED}    ]
label var[cflktch    ] lab[{NUMBER OF CFLS IN KITCHENS - CLEANED} ]
label var[cflliv     ] lab[{NUMBER OF CFLS IN LIVING ROOM-CLEANED}]
label var[pcflhoff   ] lab[{NUMBER OF CFLS IN HOME OFFICE-CLEANED}]
label var[cflout3    ] lab[{NUMBER OF CFLS OUTDOORS - CLEANED}    ]
label var[cflutil    ] lab[{NUMBER OF CFLS IN UTILITY ROOM-CLEANED}]
label var[cflot1     ] lab[{NUMBER OF CFLS IN OTHER RESP 1-CLEANED}]
label var[cflot2     ] lab[{NUMBER OF CFLS IN OTHER RESP 2-CLEANED}]
label var[pcflindr   ] lab[{Number of CFLs Indoors}               ]
label var[pcflbath   ] lab[{PERCENT OF CFLS - BATHROOMS}          ]
label var[pcflbed    ] lab[{PERCENT OF CFLS - BEDROOMS}           ]
label var[pcflclst   ] lab[{PERCENT OF CFLS - CLOSETS}            ]
label var[pcflfam    ] lab[{PERCENT OF CFLS - FAMILY ROOM}        ]
label var[pcflhall   ] lab[{PERCENT OF CFLS - HALLS}              ]
label var[pcflktch   ] lab[{PERCENT OF CFLS - KITCHEN}            ]
label var[pcflliv    ] lab[{PERCENT OF CFLS - LIVING ROOM}        ]
label var[pcflhof2   ] lab[{PERCENT OF CFLS - HOME OFFICE}        ]
label var[pcflutil   ] lab[{PERCENT OF CFLS - UTILITY ROOM}       ]
label var[pcfloth1   ] lab[{PERCENT OF CFLS - OTHER RESP 1}       ]
label var[pcfloth2   ] lab[{PERCENT OF CFLS - OTHER RESP 2}       ]

save file[rasfinal]

quit mem
Memory release complete
```

```
SST Spool File:  jad.log

load file[rasfinal]
set case_num = obsno

match file[ebill1] key[id]
Warning: 1652 observations not matched

freq var[pscounty]


pscounty    {PSE: RESIDENCE COUNTY}
5316 valid observations

                     17          19          27          34          15
                      0           1           2           3           4
             ----------  ----------  ----------  ----------  ----------
Count              1231         263         843         472         242
Percent           23.16        4.95       15.86        8.88        4.55


                     16          18          29          37          21
                      5           6           7           8           9
             ----------  ----------  ----------  ----------  ----------
Count               266         670         220         222         242
Percent            5.00       12.60        4.14        4.18        4.55


                     31
                     10
             ----------
Count               645
Percent           12.13

recode var[pscounty] map[0=17 1=19 2=27 3=34 4=15 5=16 6=18 7=29 8=37 9=21
10=31]
freq var[pscounty]


pscounty    {PSE: RESIDENCE COUNTY}
5316 valid observations


                     15          16          17          18          19
             ----------  ----------  ----------  ----------  ----------
Count               242         266        1231         670         263
Percent            4.55        5.00       23.16       12.60        4.95



                     21          27          29          31          34
             ----------  ----------  ----------  ----------  ----------
Count               242         843         220         645         472
Percent            4.55       15.86        4.14       12.13        8.88



                     37
             ----------
Count               222
Percent            4.18
```

```
freq var[custx]


custx    {CUST TYPE (1=GAS,2=ELECTRIC,3=COMBO)}
5316 valid observations

                    1           2           3
            ----------  ----------  ----------
Count             1373        2657        1286
Percent          25.83       49.98       24.19

calc sum(weight,custx==1)
      2.59205e+005
calc sum(weight,custx==2)
      5.52795e+005
calc sum(weight,custx==3)
      2.60400e+005
calc sum(weight)
      1.07240e+006
set eleccust = (custx == 2) || (custx == 3)

freq var[dwltype]


dwltype    {DWELLING TYPE - R Q4}
5316 valid observations

                    1           2           3           4           5
            ----------  ----------  ----------  ----------  ----------
Count             4288         472         154         276          82
Percent          80.66        8.88        2.90        5.19        1.54


                   97          98
            ----------  ----------
Count                5          39
Percent           0.09        0.73

range if[dwltype==1 & eleccust] rp # Single-family dwellings and ELEC only

set sumths = 75

recode var[sqftcat] map[(97,98)=md]
set sqftc = (sqftcat == 1) * 500 + \
          (sqftcat == 2) * 750 + \
          (sqftcat == 3) *1250 + \
          (sqftcat == 4) *1750 + \
          (sqftcat == 5) *2250 + \
          (sqftcat == 6) *2750 + \
          (sqftcat == 7) *3000
freq var[sqftcat]


sqftcat    {SQUARE FOOTAGE OF HOME - R Q6}
2756 valid observations

                    1           2           3           4           5
            ----------  ----------  ----------  ----------  ----------
Count               69         265         631         769         492
Percent           2.50        9.62       22.90       27.90       17.85


                    6           7
            ----------  ----------
```

```
Count              298         232
Percent          10.81        8.42


recode var[sqftact] map[99999=md]

set sfe = !miss(sqftact) ? sqftact : (!miss(sqftc) ? sqftc : 0)
freq var[(sfe==0)]


(sfe==0)
3089 valid observations

                    0           1
            ----------  ----------
Count             2756         333
Percent          89.22       10.78

recode var[sfe] map[0=$(mean(sfe))]
cova var[sfe]

Variable:      sfe

Mean                    1.88727e+003 Standard deviation      8.34803e+002
Minimum                 2.52000e+002 Skewness                1.71896
Maximum                 8.97500e+003 Kurtosis               10.60412
Valid observations      3089


set nhsldmem = nr0_6 + nr6_18 + nr19_64 + nr65ovr
recode var[nhsldmem] map[(7 thru hi)=7]
freq var[nhsldmem]


nhsldmem
3089 valid observations

                    0           1           2           3           4
            ----------  ----------  ----------  ----------  ----------
Count              169         403        1302         511         463
Percent           5.47       13.05       42.15       16.54       14.99


                    5           6           7
            ----------  ----------  ----------
Count              151          48          42
Percent           4.89        1.55        1.36

recode var[nhsldmem] map[0=$( mean(nhsldmem) )]
freq var[nhsldmem]


nhsldmem
3089 valid observations

                    1           2      2.5021           3           4
            ----------  ----------  ----------  ----------  ----------
Count              403        1302         169         511         463
Percent          13.05       42.15        5.47       16.54       14.99


                    5           6           7
            ----------  ----------  ----------
Count              151          48          42
```

```
Percent          4.89        1.55        1.36


rem Recode wall and Ceiling insulation so that it is yes if was \
    done before or after resident moved in
freq var[wallins]


wallins    {WHEN WALL INSULATION INSTALLED - C Q1}
3089 valid observations

                    1           2           3          97          98
             ----------  ----------  ----------  ----------  ----------
Count            1962         349         228         395         155
Percent         63.52       11.30        7.38       12.79        5.02

recode var[wallins] map[(97,98,99)=0]
set hinwall = (wallins == 1) | (wallins==2)
freq var[hinwall]


hinwall
3089 valid observations

                    0           1
             ----------  ----------
Count             778        2311
Percent         25.19       74.81


freq var[ceilins]


ceilins    {WHEN CEILING INSULATION INSTALLED - C Q
3089 valid observations

                    1           2           3          97          98
             ----------  ----------  ----------  ----------  ----------
Count            2105         451         155         281          97
Percent         68.15       14.60        5.02        9.10        3.14

recode var[ceilins] map[(97,98,99)=0]
set insat1 = 12 * ((ceilins==1)|(ceilins==2))
freq var[insat1]


insat1
3089 valid observations

                    0          12
             ----------  ----------
Count             533        2556
Percent         17.25       82.75


freq var[bathroom]


bathroom    {NUMBER OF BATHROOMS - R Q8}
3089 valid observations

                    1           2           3           4           5
             ----------  ----------  ----------  ----------  ----------
Count               7         415         977         821         211
```

```
Percent          0.23        13.43        31.63        26.58         6.83


                   98
           ----------
Count             658
Percent         21.30

recode var[bathroom] map[0=99,1=0,2=1,3=2,4=3,5=4]  # J227 PSE Questionaire
Layout.doc
recode var[bathroom] map[(97,98,99)=md]
recode var[bathroom] map[(5 thru hi) = 5]
recode var[bathroom] map[md=$( mean(bathroom) )]
set bathroom = floor(bathroom+0.5)
cova var[bathroom]

Variable: bathroom     {NUMBER OF BATHROOMS - R Q8}

Mean                    2.26352      Standard deviation      0.78306
Minimum                 0.00000      Skewness                0.32671
Maximum                 4.00000      Kurtosis                2.93553
Valid observations      3089


freq var[heatroom]


heatroom    {NUMBER OF HEATED ROOMS - R Q7}
3089 valid observations

                    1            2            3            4            5
           ----------   ----------   ----------   ----------   ----------
Count              10           27           87          179          340
Percent          0.32         0.87         2.82         5.79        11.01


                    6            7            8            9           10
           ----------   ----------   ----------   ----------   ----------
Count             472          392          360          181          123
Percent         15.28        12.69        11.65         5.86         3.98


                   11           12           13           14           15
           ----------   ----------   ----------   ----------   ----------
Count              46           20            6            4            4
Percent          1.49         0.65         0.19         0.13         0.13


                   16           19           98
           ----------   ----------   ----------
Count               2            1          835
Percent          0.06         0.03        27.03

recode var[heatroom] map[(97,98,99)=md]
cova var[heatroom]

Variable: heatroom     {NUMBER OF HEATED ROOMS - R Q7}

Mean                    6.67569      Standard deviation      2.11035
Minimum                 1.00000      Skewness                0.43363
Maximum                19.00000      Kurtosis                4.09770
Valid observations     2254

reg dep[heatroom] ind[(1) sfe] coef[bhr]
```

```
********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:  heatroom

Independent        Estimated            Standard               t-
 Variable         Coefficient             Error             Statistic

      (1)           3.27800              0.10652             30.77368
      sfe           1.94899e-003         5.74711e-005        33.91253


Number of Observations              2254
R-squared                              0.33805
Corrected R-squared                    0.33775
Sum of Squared Residuals               6.64198e+003
Standard Error of the Regression       1.71737
Durbin-Watson Statistic                1.93360
Mean of Dependent Variable             6.67569

set hroom = floor((bhr[1] + bhr[2]*sfe) + 0.5)
cova var[hroom]

Variable:    hroom

Mean                     7.07252      Standard deviation      1.63191
Minimum                  4.00000      Skewness                1.56470
Maximum                 21.00000      Kurtosis               10.10877
Valid observations       3089

set heatroom = (!miss(heatroom) ? heatroom : hroom)
recode var[heatroom] map[(12 thru hi) = 12]
cova var[heatroom]

Variable: heatroom     {NUMBER OF HEATED ROOMS - R Q7}

Mean                     6.96698      Standard deviation      2.04045
Minimum                  1.00000      Skewness                0.18984
Maximum                 12.00000      Kurtosis                3.11481
Valid observations       3089

recode var[heatroom] map[md=$( mean(heatroom) )]
set heatroom = floor(heatroom+0.5)
cova var[heatroom]

Variable: heatroom     {NUMBER OF HEATED ROOMS - R Q7}

Mean                     6.96698      Standard deviation      2.04045
Minimum                  1.00000      Skewness                0.18984
Maximum                 12.00000      Kurtosis                3.11481
Valid observations       3089


set nrooms = heatroom + bathroom
cova var[heatroom bathroom nrooms]

Variable: heatroom     {NUMBER OF HEATED ROOMS - R Q7}

Mean                     6.96698      Standard deviation      2.04045
Minimum                  1.00000      Skewness                0.18984
Maximum                 12.00000      Kurtosis                3.11481
Valid observations       3089
```

```
Variable: bathroom     {NUMBER OF BATHROOMS - R Q8}

Mean                    2.26352      Standard deviation      0.78306
Minimum                 0.00000      Skewness                0.32671
Maximum                 4.00000      Kurtosis                2.93553
Valid observations      3089

Variable:   nrooms

Mean                    9.23050      Standard deviation      2.41607
Minimum                 2.00000      Skewness               -6.28123e-002
Maximum                16.00000      Kurtosis                2.89499
Valid observations      3089


freq var[dwlstr]


dwlstr    {N STORIES IN BLDG - R Q5}
3089 valid observations

                        1           2           3           4           5
             ----------  ----------  ----------  ----------  ----------
Count                1284         220        1285          68         200
Percent             41.57        7.12       41.60        2.20        6.47


                        6           7          97          98
             ----------  ----------  ----------  ----------
Count                   9          10           2          11
Percent              0.29        0.32        0.06        0.36

recode var[dwlstr] map[(97,98,99)=0]
set floors = (dwlstr==1)*1 + (dwlstr==2)*1.5 + (dwlstr==3)*2 + (dwlstr==4)*2.5
+ \
           (dwlstr==5)*3 + (dwlstr==6)*3 + (dwlstr==7)*0
freq var[floors]


floors
3089 valid observations

                        0           1         1.5           2         2.5
             ----------  ----------  ----------  ----------  ----------
Count                  23        1284         220        1285          68
Percent              0.74       41.57        7.12       41.60        2.20


                        3
             ----------
Count                 209
Percent              6.77

recode var[floors] map[0=$(mean(floors))]
freq var[floors]


floors
3089 valid observations

                        1         1.5      1.6125           2         2.5
             ----------  ----------  ----------  ----------  ----------
Count                1284         220          23        1285          68
Percent             41.57        7.12        0.74       41.60        2.20
```

```
                   3
            ----------
Count             209
Percent          6.77


freq var[pscounty]


pscounty    {PSE: RESIDENCE COUNTY}
3089 valid observations


                  15          16          17          18          19
            ----------  ----------  ----------  ----------  ----------
Count             195         219         800         528         202
Percent          6.31        7.09       25.90       17.09        6.54



                  27          29          34          37
            ----------  ----------  ----------  ----------
Count             438         181         371         155
Percent         14.18        5.86       12.01        5.02

match file[county2] by[co_indx] key[pscounty]  # match normals
match file[county3] by[co_indx] key[pscounty]  # match 2003 actuals

set hdd03 = cdd03 = kwh03 = 0
foreach(j ; {25-36}) {
set hdd03 += hdd${j}
set cdd03 += cdd${j}
set kwh03 += kwh${j}
}

set hdd_03 = cdd_03 = 0
foreach(j ; {1-12}) {
set hdd_03 += hdd3_${j}
set cdd_03 += cdd3_${j}
}

cova var[hdd_03 hdd03] cov

Variable:   hdd_03

Mean                    4.61350e+003 Standard deviation      4.56778e+002
Minimum                 4.04378e+003 Skewness                1.32116
Maximum                 5.86865e+003 Kurtosis                4.45074
Valid observations      2875

Variable:    hdd03

Mean                    4.85333e+003 Standard deviation      4.27145e+002
Minimum                 4.21545e+003 Skewness               -0.41649
Maximum                 5.67235e+003 Kurtosis                1.69215
Valid observations      2875

Correlation and Covariance matrix

               hdd_03             hdd03
  hdd_03      2.08573e+005       6.92280e+004
   hdd03      0.35494            1.82389e+005
```

```
cova var[cdd_03 cdd03] cov

Variable:   cdd_03

Mean                     2.30316e+002 Standard deviation      1.17546e+002
Minimum                 84.00000      Skewness                0.83659
Maximum                  5.45500e+002 Kurtosis                3.95119
Valid observations       2875

Variable:    cdd03

Mean                     2.37476e+002 Standard deviation      2.13801e+002
Minimum                 40.00000      Skewness                2.19794
Maximum                  9.91700e+002 Kurtosis                8.20554
Valid observations       2875

Correlation and Covariance matrix

               cdd_03             cdd03
  cdd_03      1.38122e+004      2.16171e+004
   cdd03      0.86046           4.56951e+004

cova var[kwh2003 kwh03] cov

Variable:  kwh2003     {PSE ANNUAL 2003 KWH}

Mean                     1.13763e+004 Standard deviation      7.47000e+003
Minimum                  0.00000      Skewness                1.61226
Maximum                  7.99130e+004 Kurtosis                8.54331
Valid observations       2875

Variable:    kwh03

Mean                     1.13763e+004 Standard deviation      7.47000e+003
Minimum                  0.00000      Skewness                1.61226
Maximum                  7.99130e+004 Kurtosis                8.54331
Valid observations       2875

Correlation and Covariance matrix

              kwh2003            kwh03
 kwh2003      5.57816e+007      5.57816e+007
   kwh03      1.00000           5.57816e+007


freq var[custx]


custx    {CUST TYPE (1=GAS,2=ELECTRIC,3=COMBO)}
3089 valid observations

                    2           3
            ----------  ----------
Count            1917        1172
Percent         62.06       37.94


rem set win = floor( (2.66 + 8.33 * floors) + 0.5 )
set win = floor( 1.9423 + 6.385*floors + 0.002173*sfe + 0.5)

freq var[dblpane pctstrmw]
```

```
dblpane    {PCNT OF DBL PANE WINDOWS - C Q3}
3089 valid observations

                   1           2           3           4           5
            ----------  ----------  ----------  ----------  ----------
Count           2074         301         100         135         306
Percent        67.14        9.74        3.24        4.37        9.91


                  97          98
            ----------  ----------
Count            123          50
Percent         3.98        1.62


pctstrmw    {PCNT OF WINDOWS THAT ARE STORM - C Q4}
3089 valid observations

                   1           2           3           4           5
            ----------  ----------  ----------  ----------  ----------
Count            290         113          59          86        2077
Percent         9.39        3.66        1.91        2.78       67.24


                  97          98
            ----------  ----------
Count            345         119
Percent        11.17        3.85

recode var[dblpane] map[(97,98,99)=0]
set pctdp  = (dblpane==1)*1.00 + (dblpane==2)*0.75 + (dblpane==3)*0.5 + \
             (dblpane==4)*0.25 + (dblpane==5)*0.00 + (dblpane==6)*0.00

recode var[pctstrmw] map[(97,98,99)=0]
set pctstm = (pctstrmw==1)*1.00 + (pctstrmw==2)*0.75 + (pctstrmw==3)*0.5 + \
             (pctstrmw==4)*0.25 + (pctstrmw==5)*0.00 + (pctstrmw==6)*0.00


set pct = vmax(pctdp,pctstm)

set lwinds = 0
set mwinds = win
set swinds = 0

set nlwind = 0
set nmwind = win * pct
set nswind = 0

set winths = 70

match file[weather] by[co_indx] key[pscounty]  # match design termperatures
rename var[sddr] to[sddb]

range if[!miss(hdd25)] rp
list

---- Variables ----
addition  2875  Thu Mar 30 09:23:47 2006 {ADDITIONS TO HOME - R Q10}
address   2875  Thu Mar 30 09:23:47 2006 {PSE: RESIDENCE ADDRESS}
addsqft   2875  Thu Mar 30 09:23:47 2006 {ADDED HEATED SQUARE FOOTAGE- R Q10a}
adsqftct  2875  Thu Mar 30 09:23:47 2006 {ADDED HEATED SQUARE FOOTAGE- R Q10a}
age       2875  Thu Mar 30 09:23:47 2006 {AGE OF HEAD OF HOUSEHOLD - D Q4}
agecat    2875  Thu Mar 30 09:23:47 2006 {AGE OF HEAD OF HOUSEHOLD - D Q4}
agenr     2875  Thu Mar 30 09:23:47 2006 {AGE OF HEAD OF HOUSEHOLD - D Q4}
```

```
audits     2875  Thu Mar 30 09:23:47 2006 {FOLLOW UP AUDIT - D Q7}
batchno    2875  Thu Mar 30 09:23:47 2006 {Survey Id}
bathroom   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF BATHROOMS - R Q8}
bathsqr    2875  Thu Mar 30 09:23:47 2006 {BATHS PER SQUARE FOOTAGE}
besttime   2875  Thu Mar 30 09:23:47 2006 {BEST TIME TO REACJ - D Q9}
blnktact   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM ELECTRIC BLANKET - A Q4}
blnktnct   2875  Thu Mar 30 09:23:47 2006 {N OF ELECTRIC BLANKETS - A Q3}
builtyr    2875  Thu Mar 30 09:23:47 2006 {YEAR HOME WAS BUILT - R Q9}
case_num   2875  Fri Apr 28 12:34:55 2006
cdd03      2875  Fri Apr 28 12:34:57 2006
cdd1       2875  Fri Apr 28 12:34:55 2006
cdd10      2875  Fri Apr 28 12:34:55 2006
cdd11      2875  Fri Apr 28 12:34:55 2006
cdd12      2875  Fri Apr 28 12:34:55 2006
cdd13      2875  Fri Apr 28 12:34:55 2006
cdd14      2875  Fri Apr 28 12:34:55 2006
cdd15      2875  Fri Apr 28 12:34:55 2006
cdd16      2875  Fri Apr 28 12:34:55 2006
cdd17      2875  Fri Apr 28 12:34:55 2006
cdd18      2875  Fri Apr 28 12:34:55 2006
cdd19      2875  Fri Apr 28 12:34:55 2006
cdd2       2875  Fri Apr 28 12:34:55 2006
cdd20      2875  Fri Apr 28 12:34:55 2006
cdd21      2875  Fri Apr 28 12:34:55 2006
cdd22      2875  Fri Apr 28 12:34:55 2006
cdd23      2875  Fri Apr 28 12:34:55 2006
cdd24      2875  Fri Apr 28 12:34:55 2006
cdd25      2875  Fri Apr 28 12:34:55 2006
cdd26      2875  Fri Apr 28 12:34:55 2006
cdd27      2875  Fri Apr 28 12:34:55 2006
cdd28      2875  Fri Apr 28 12:34:55 2006
cdd29      2875  Fri Apr 28 12:34:55 2006
cdd3       2875  Fri Apr 28 12:34:55 2006
cdd30      2875  Fri Apr 28 12:34:55 2006
cdd31      2875  Fri Apr 28 12:34:55 2006
cdd32      2875  Fri Apr 28 12:34:55 2006
cdd33      2875  Fri Apr 28 12:34:55 2006
cdd34      2875  Fri Apr 28 12:34:55 2006
cdd35      2875  Fri Apr 28 12:34:55 2006
cdd36      2875  Fri Apr 28 12:34:55 2006
cdd3_1     2875  Fri Apr 28 12:34:57 2006
cdd3_10    2875  Fri Apr 28 12:34:57 2006
cdd3_11    2875  Fri Apr 28 12:34:57 2006
cdd3_12    2875  Fri Apr 28 12:34:57 2006
cdd3_2     2875  Fri Apr 28 12:34:57 2006
cdd3_3     2875  Fri Apr 28 12:34:57 2006
cdd3_4     2875  Fri Apr 28 12:34:57 2006
cdd3_5     2875  Fri Apr 28 12:34:57 2006
cdd3_6     2875  Fri Apr 28 12:34:57 2006
cdd3_7     2875  Fri Apr 28 12:34:57 2006
cdd3_8     2875  Fri Apr 28 12:34:57 2006
cdd3_9     2875  Fri Apr 28 12:34:57 2006
cdd4       2875  Fri Apr 28 12:34:55 2006
cdd5       2875  Fri Apr 28 12:34:55 2006
cdd6       2875  Fri Apr 28 12:34:55 2006
cdd7       2875  Fri Apr 28 12:34:55 2006
cdd8       2875  Fri Apr 28 12:34:55 2006
cdd9       2875  Fri Apr 28 12:34:55 2006
cdd_03     2875  Fri Apr 28 12:34:57 2006
ceilins    2875  Thu Mar 30 09:23:47 2006 {WHEN CEILING INSULATION INSTALLED- C
centaca    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM CENTRAL AC - A Q4}
centacn    2875  Thu Mar 30 09:23:47 2006 {N OF CENTRAL AIR CONDITIONERS- A Q3}
centact    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM CENTRAL AC - A Q4}
centnact   2875  Thu Mar 30 09:23:47 2006 {N OF CENTRAL AIR CONDITIONER - A Q3}
```

```
cfl       2875  Thu Mar 30 09:23:47 2006 {HAS CFLS - C Q2}
cfl1oth   2875  Thu Mar 30 09:23:47 2006 {OTHER LOCATION WITH CFL - C Q2a}
cfl2oth   2875  Thu Mar 30 09:23:47 2006 {OTHER LOCATION WITH CFL - C Q2a}
cflbasem  2875  Thu Mar 30 09:23:47 2006 {CFL IN BASEMENT - C Q2a}
cflbath   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN BATHROOM- CLEANED}
cflbdnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN BEDROOM - C Q2a}
cflbed    2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN BEDROOM - CLEANED}
cflbedn   2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN BEDROOM - C Q2a}
cflbthn   2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN BATHROOM - C Q2a}
cflbtnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN BATHROOM - C Q2a}
cflclnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN CLOSET - C Q2a}
cflclst   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN CLOSETS - CLEANED}
cflclstn  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN CLOSET - C Q2a}
cfldine   2875  Thu Mar 30 09:23:47 2006 {CFL IN DINING ROOM - C Q2a}
cflfam    2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN FAMILY ROOM- CLEAN
cflfamrn  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN FAMILY ROOM - C Q2a}
cflfrnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN FAMILY ROOM - C Q2a}
cflganct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN GARAGE - C Q2a}
cflgarag  2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN GARAGE - CLEANED}
cflgrgen  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN GARAGE - C Q2a}
cflhall   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN HALLS - CLEANED}
cflhalln  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN HALLWAY - C Q2a}
cflhlnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN HALLWAY - C Q2a}
cflhoffn  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN HOME OFFICE EQUIP- C Q2
cflktch   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN KITCHENS- CLEANED}
cflktchn  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN KITCHEN - C Q2a}
cflktnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN KITCHEN - C Q2a}
cfllamp   2875  Thu Mar 30 09:23:47 2006 {CFL IN LAMPS - C Q2a}
cflliv    2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN LIVING ROOM- CLEAN
cfllvnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN LIVING ROOM - C Q2a}
cfllvrmn  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN LIVING ROOM - C Q2a}
cflo1nct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OTHER 1 - C Q2a}
cflo2nct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OTHER 2 - C Q2a}
cflofnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN HOME OFFICE EQUIP- C Q2
cflot1    2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN OTHER RESP 1- CLEA
cflot2    2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN OTHER RESP 2- CLEA
cfloth1   2875  Thu Mar 30 09:23:47 2006 {OTHER LOCATION WITH CFL - C Q2a}
cfloth1n  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OTHER 1 - C Q2a}
cfloth2   2875  Thu Mar 30 09:23:47 2006 {OTHER LOCATION WITH CFL - C Q2a}
cfloth2n  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OTHER 2 - C Q2a}
cflout    2875  Thu Mar 30 09:23:47 2006 {CFL OUTSIDE - C Q2a}
cflout3   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS OUTDOORS - CLEANED}
cfloutn   2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OUTDOORS - C Q2a}
cflutil   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN UTILITY ROOM- CLEA
cflutiln  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN UTILITY ROOM - C Q2a}
cflutnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN UTILITY ROOM - C Q2a}
cfoutnct  2875  Thu Mar 30 09:23:47 2006 {N OF CFLS IN OUTDOORS - C Q2a}
city      2875  Thu Mar 30 09:23:47 2006 {PSE: RESIDENCE CITY}
ckovage   2875  Thu Mar 30 09:23:47 2006 {CONVENTIONAL OVEN  AGE  - A Q2}
ckovtyp   2875  Thu Mar 30 09:23:47 2006 {CONVENTIONAL OVEN FUEL - A Q1}
ckrnage   2875  Thu Mar 30 09:23:47 2006 {STOVETOP COOKING EQUIP AGE- A Q2}
ckrntyp   2875  Thu Mar 30 09:23:47 2006 {STOVETOP COOKING FUEL - A Q1}
co_indx   2875  Fri Apr 28 12:34:57 2006 county index
counter   2875  Thu Mar 30 09:23:47 2006 {NUMBER OF MISSING KEY VARIABLES}
county    2875  Thu Mar 30 09:23:47 2006 {County}
county1   2875  Thu Mar 30 09:23:47 2006 {FIRST DIGIT OF COUNTY}
county2   2875  Thu Mar 30 09:23:47 2006 {SECOND DIGIT OF COUNTY}
county4   2875  Thu Mar 30 09:23:47 2006 {COUNTY CODE}
custtyp   2875  Thu Mar 30 09:23:47 2006 {Custtyp}
custx     2875  Thu Mar 30 09:23:47 2006 {CUST TYPE
(1=GAS,2=ELECTRIC,3=COMBO)}
dblpane   2875  Thu Mar 30 09:23:47 2006 {PCNT OF DBL PANE WINDOWS - C Q3}
dblpanea  2875  Thu Mar 30 09:23:47 2006 {AGE OF DBLE PANE WINDOWS - C Q3a}
dishwa    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM DISHWASHERS - A Q4}
```

```
dishwn    2875  Thu Mar 30 09:23:47 2006 {N OF DISHWASHERS - A Q3}
drwinins  2875  Thu Mar 30 09:23:47 2006 {WHEN WEATHERSTRIP INSTALLED - C Q1}
dryage    2875  Thu Mar 30 09:23:47 2006 {CLOTHES DRYER AGE  - A Q2}
drytyp    2875  Thu Mar 30 09:23:47 2006 {CLOTHES DRYER FUEL - A Q1}
dwacat    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM DISHWASHERS - A Q4}
dwlnew    2875  Thu Mar 30 09:23:47 2006 {Dwelling Type}
dwlstr    2875  Thu Mar 30 09:23:47 2006 {N STORIES IN BLDG - R Q5}
dwlstrot  2875  Thu Mar 30 09:23:47 2006 {DWELLING STORIES: OTHER - R Q5}
dwltype   2875  Thu Mar 30 09:23:47 2006 {DWELLING TYPE - R Q4}
dwltypex  2875  Thu Mar 30 09:23:47 2006 {PSE DWELLING TYPE (1=SF,2,3=MF, 4=MH
dwltypot  2875  Thu Mar 30 09:23:47 2006 {DWELLING TYPE: OTHER - R Q4}
dwncat    2875  Thu Mar 30 09:23:47 2006 {N OF DISHWASHERS - A Q3}
ecdishw   2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR DISHWASHER - A Q5}
ecdry     2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR DRYER - A Q5}
ecdvd     2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR DVD PLAYER - A Q5}
ecfrnc    2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR FURNACE - A Q5}
ecfrzr    2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR FREEZER - A Q5}
ecmicrow  2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR MICROWAVE - A Q5}
ecmntr    2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR COMPUTER MONITOR- A Q
ecoth     2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR OTHER - A Q5}
ecprint   2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR PRINTER - A Q5}
ecrefr    2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR REFRIGERATOR - A Q5}
ecstereo  2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR STEREO - A Q5}
ecstove   2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR STOVE - A Q5}
ectv      2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR TV - A Q5}
ecvcr     2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR VCR - A Q5}
ecwash    2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR WASHING MACHINE- A Q5
ecwh      2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR WATER HEATER - A Q5}
educ      2875  Thu Mar 30 09:23:47 2006 {HIGHEST EDUC BY HEAD OF HOUSE- D Q2}
eewindws  2875  Thu Mar 30 09:23:47 2006 {WHEN EFFICIENT WINDOWS INSTALLED - C
elblnkta  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM ELECTRIC BLANKET - A Q4}
elblnktn  2875  Thu Mar 30 09:23:47 2006 {N OF ELECTRIC BLANKETS - A Q3}
eleccust  2875  Fri Apr 28 12:34:56 2006
empstat   2875  Thu Mar 30 09:23:47 2006 {EMP STATUS OF HEAD OF HOUSE - D Q3}
enrgystr  2875  Thu Mar 30 09:23:47 2006 {ANY APPL ENERGY STAR - A Q5}
esac      2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR AIR CONDITION - A Q5}
escd      2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR CD PLAYER - A Q5}
espc      2875  Thu Mar 30 09:23:47 2006 {HAS ENERGY STR COMPUTER - A Q5}
floors    2875  Fri Apr 28 12:34:57 2006
followup  2875  Thu Mar 30 09:23:47 2006 {FOLLOW UP INTERVIEW - D Q6}
freezera  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM SEPARATE FREEZER - A Q4}
freezern  2875  Thu Mar 30 09:23:47 2006 {N OF SEPARATE FREEZERS INSTALLED - A
fzracat   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM SEPARATE FREEZER - A Q4}
fzrncat   2875  Thu Mar 30 09:23:47 2006 {N OF SEPARATE FREEZERS INSTALLED - A
genrator  2875  Thu Mar 30 09:23:47 2006 {BACK UP GENERATOR - A Q6}
hdd03     2875  Fri Apr 28 12:34:57 2006
hdd1      2875  Fri Apr 28 12:34:55 2006
hdd10     2875  Fri Apr 28 12:34:55 2006
hdd11     2875  Fri Apr 28 12:34:55 2006
hdd12     2875  Fri Apr 28 12:34:55 2006
hdd13     2875  Fri Apr 28 12:34:55 2006
hdd14     2875  Fri Apr 28 12:34:55 2006
hdd15     2875  Fri Apr 28 12:34:55 2006
hdd16     2875  Fri Apr 28 12:34:55 2006
hdd17     2875  Fri Apr 28 12:34:55 2006
hdd18     2875  Fri Apr 28 12:34:55 2006
hdd19     2875  Fri Apr 28 12:34:55 2006
hdd2      2875  Fri Apr 28 12:34:55 2006
hdd20     2875  Fri Apr 28 12:34:55 2006
hdd21     2875  Fri Apr 28 12:34:55 2006
hdd22     2875  Fri Apr 28 12:34:55 2006
hdd23     2875  Fri Apr 28 12:34:55 2006
hdd24     2875  Fri Apr 28 12:34:55 2006
hdd25     2875  Fri Apr 28 12:34:55 2006
```

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hdd26     2875  Fri Apr 28 12:34:55 2006
hdd27     2875  Fri Apr 28 12:34:55 2006
hdd28     2875  Fri Apr 28 12:34:55 2006
hdd29     2875  Fri Apr 28 12:34:55 2006
hdd3      2875  Fri Apr 28 12:34:55 2006
hdd30     2875  Fri Apr 28 12:34:55 2006
hdd31     2875  Fri Apr 28 12:34:55 2006
hdd32     2875  Fri Apr 28 12:34:55 2006
hdd33     2875  Fri Apr 28 12:34:55 2006
hdd34     2875  Fri Apr 28 12:34:55 2006
hdd35     2875  Fri Apr 28 12:34:55 2006
hdd36     2875  Fri Apr 28 12:34:55 2006
hdd3_1    2875  Fri Apr 28 12:34:57 2006
hdd3_10   2875  Fri Apr 28 12:34:57 2006
hdd3_11   2875  Fri Apr 28 12:34:57 2006
hdd3_12   2875  Fri Apr 28 12:34:57 2006
hdd3_2    2875  Fri Apr 28 12:34:57 2006
hdd3_3    2875  Fri Apr 28 12:34:57 2006
hdd3_4    2875  Fri Apr 28 12:34:57 2006
hdd3_5    2875  Fri Apr 28 12:34:57 2006
hdd3_6    2875  Fri Apr 28 12:34:57 2006
hdd3_7    2875  Fri Apr 28 12:34:57 2006
hdd3_8    2875  Fri Apr 28 12:34:57 2006
hdd3_9    2875  Fri Apr 28 12:34:57 2006
hdd4      2875  Fri Apr 28 12:34:55 2006
hdd5      2875  Fri Apr 28 12:34:55 2006
hdd6      2875  Fri Apr 28 12:34:55 2006
hdd7      2875  Fri Apr 28 12:34:55 2006
hdd8      2875  Fri Apr 28 12:34:55 2006
hdd9      2875  Fri Apr 28 12:34:55 2006
hdd_03    2875  Fri Apr 28 12:34:57 2006
heatrepl  2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEM PRIOR TO 2003 - H
Q4b}
heatroom  2875  Thu Mar 30 09:23:47 2006 {NUMBER OF HEATED ROOMS - R Q7}
heatserv  2875  Thu Mar 30 09:23:47 2006 {HEATING SYS SERVICE TYPE - H Q1}
heatuse   2875  Thu Mar 30 09:23:47 2006 {HEATING SYS CONTROL BEHAVIOR - H Q7}
hinwall   2875  Fri Apr 28 12:34:56 2006
homeoffc  2875  Thu Mar 30 09:23:47 2006 {HOME OFFICE AT RESIDENCE - A Q7}
housetyp  2875  Thu Mar 30 09:23:47 2006 {Housetype}
hroom     2875  Fri Apr 28 12:34:57 2006
htbgcnt   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htbgpth   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htctlbev  2875  Thu Mar 30 09:23:47 2006 {TMP CONTROL ON HEATING SYSTEM- H Q6}
htdctins  2875  Thu Mar 30 09:23:47 2006 {WHEN HEAT DUCT INS INSTALLED - C Q1}
htelbsb   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htelchp   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htelcrh   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
hteloth   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htelpth   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htelwht   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htflrepo  2875  Thu Mar 30 09:23:47 2006 {PRIOR HEATING SYSTEM: OTHER - H Q4b}
hthwrad   2875  Thu Mar 30 09:23:47 2006 {HEATSYS: READIANT HOT WATER - H Q2}
htngcnt   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htngfp    2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htngoth   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htnr      2875  Thu Mar 30 09:23:47 2006 {HEATSYS: DON'T KNOW - H Q2}
htolcnt   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htoloth   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htothr    2875  Thu Mar 30 09:23:47 2006 {HEATSYS: OTHER - H Q2}
htotsys   2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htpellet  2875  Thu Mar 30 09:23:47 2006 {HEATSYS: PELLET STOVE - H Q2}
htprfp    2875  Thu Mar 30 09:23:47 2006 {HEATSYS: PROPANE STOVE - H Q2}
htrad     2875  Thu Mar 30 09:23:47 2006 {HEATSYS: RADIANT FLOOR HEAT - H Q2}
htrepl03  2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEM REPLACED IN 2003- H Q
```

```
htslr     2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htsysage  2875  Thu Mar 30 09:23:47 2006 {AGE OF HEATING SYSTEM - H Q4}
httempct  2875  Thu Mar 30 09:23:47 2006 {TEMP CONTROL: OTHER - H Q6}
htwdfp    2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
htwdws    2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEMS USED AT HOME - H Q3}
hwdispa   2875  Thu Mar 30 09:23:47 2006 {AGE PRIM ONDEMAND H20 DISPENSER- A Q
hwdispn   2875  Thu Mar 30 09:23:47 2006 {N OF ONDEMAND H20 DISPENSERS - A Q3}
hwdnact   2875  Thu Mar 30 09:23:47 2006 {N OF ONDEMAND H20 DISPENSERS - A Q3}
hwdspact  2875  Thu Mar 30 09:23:47 2006 {AGE PRIM ONDEMAND H20 DISPENSER- A Q
id        2875  Thu Mar 30 09:23:47 2006 {ID NUMBER}
income    2875  Thu Mar 30 09:23:47 2006 {YEARLY INCOME 2003 - D Q5}
insat1    2875  Fri Apr 28 12:34:56 2006
kwh03     2875  Fri Apr 28 12:34:57 2006
kwh1      2875  Fri Apr 28 12:34:55 2006
kwh10     2875  Fri Apr 28 12:34:55 2006
kwh11     2875  Fri Apr 28 12:34:55 2006
kwh12     2875  Fri Apr 28 12:34:55 2006
kwh13     2875  Fri Apr 28 12:34:55 2006
kwh14     2875  Fri Apr 28 12:34:55 2006
kwh15     2875  Fri Apr 28 12:34:55 2006
kwh16     2875  Fri Apr 28 12:34:55 2006
kwh17     2875  Fri Apr 28 12:34:55 2006
kwh18     2875  Fri Apr 28 12:34:55 2006
kwh19     2875  Fri Apr 28 12:34:55 2006
kwh2      2875  Fri Apr 28 12:34:55 2006
kwh20     2875  Fri Apr 28 12:34:55 2006
kwh2001   2875  Thu Mar 30 09:23:47 2006 {PSE ANNUAL 2001 KWH}
kwh2002   2875  Thu Mar 30 09:23:47 2006 {PSE ANNUAL 2002 KWH}
kwh2003   2875  Thu Mar 30 09:23:47 2006 {PSE ANNUAL 2003 KWH}
kwh21     2875  Fri Apr 28 12:34:55 2006
kwh22     2875  Fri Apr 28 12:34:55 2006
kwh23     2875  Fri Apr 28 12:34:55 2006
kwh24     2875  Fri Apr 28 12:34:55 2006
kwh25     2875  Fri Apr 28 12:34:55 2006
kwh26     2875  Fri Apr 28 12:34:55 2006
kwh27     2875  Fri Apr 28 12:34:55 2006
kwh28     2875  Fri Apr 28 12:34:55 2006
kwh29     2875  Fri Apr 28 12:34:55 2006
kwh3      2875  Fri Apr 28 12:34:55 2006
kwh30     2875  Fri Apr 28 12:34:55 2006
kwh31     2875  Fri Apr 28 12:34:55 2006
kwh32     2875  Fri Apr 28 12:34:55 2006
kwh33     2875  Fri Apr 28 12:34:55 2006
kwh34     2875  Fri Apr 28 12:34:55 2006
kwh35     2875  Fri Apr 28 12:34:55 2006
kwh36     2875  Fri Apr 28 12:34:55 2006
kwh4      2875  Fri Apr 28 12:34:55 2006
kwh5      2875  Fri Apr 28 12:34:55 2006
kwh6      2875  Fri Apr 28 12:34:55 2006
kwh7      2875  Fri Apr 28 12:34:55 2006
kwh8      2875  Fri Apr 28 12:34:55 2006
kwh9      2875  Fri Apr 28 12:34:55 2006
lwinds    2875  Fri Apr 28 12:34:57 2006
mailadd   2875  Thu Mar 30 09:23:47 2006 {PSE: MAILING ADDRESS}
mailcity  2875  Thu Mar 30 09:23:47 2006 {PSE: MAILING CITY}
mailst    2875  Thu Mar 30 09:23:47 2006 {PSE: MAILING STREET}
mailzip   2875  Thu Mar 30 09:23:47 2006 {PSE: MAILING ZIP}
microwva  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM MICROWAVE - A Q4}
microwvn  2875  Thu Mar 30 09:23:47 2006 {N OF MICROWAVES INSTALLED - A Q3}
mwinds    2875  Fri Apr 28 12:34:57 2006
mwvacat   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM MICROWAVE - A Q4}
mwvncat   2875  Thu Mar 30 09:23:47 2006 {N OF MICROWAVES INSTALLED - A Q3}
n1964ct   2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE BTWN 19 AND 64 - D Q1}
n65ovrct  2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE OLDER 65 YRS OLD - D Q1}
```

```
n_cdd1    2875  Fri Apr 28 12:34:57 2006 Jan normal cooling days
n_cdd10   2875  Fri Apr 28 12:34:57 2006 Oct normal cooling days
n_cdd11   2875  Fri Apr 28 12:34:57 2006 Nov normal cooling days
n_cdd12   2875  Fri Apr 28 12:34:57 2006 Dec normal cooling days
n_cdd2    2875  Fri Apr 28 12:34:57 2006 Feb normal cooling days
n_cdd3    2875  Fri Apr 28 12:34:57 2006 Mar normal cooling days
n_cdd4    2875  Fri Apr 28 12:34:57 2006 Apr normal cooling days
n_cdd5    2875  Fri Apr 28 12:34:57 2006 May normal cooling days
n_cdd6    2875  Fri Apr 28 12:34:57 2006 Jun normal cooling days
n_cdd7    2875  Fri Apr 28 12:34:57 2006 Jul normal cooling days
n_cdd8    2875  Fri Apr 28 12:34:57 2006 Aug normal cooling days
n_cdd9    2875  Fri Apr 28 12:34:57 2006 Sep normal cooling days
n_hdd1    2875  Fri Apr 28 12:34:57 2006 Jan normal heating day
n_hdd10   2875  Fri Apr 28 12:34:57 2006 Oct normal heating day
n_hdd11   2875  Fri Apr 28 12:34:57 2006 Nov normal heating day
n_hdd12   2875  Fri Apr 28 12:34:57 2006 Dec normal heating day
n_hdd2    2875  Fri Apr 28 12:34:57 2006 Feb normal heating day
n_hdd3    2875  Fri Apr 28 12:34:57 2006 Mar normal heating day
n_hdd4    2875  Fri Apr 28 12:34:57 2006 Apr normal heating day
n_hdd5    2875  Fri Apr 28 12:34:57 2006 May normal heating day
n_hdd6    2875  Fri Apr 28 12:34:57 2006 Jun normal heating day
n_hdd7    2875  Fri Apr 28 12:34:57 2006 Jul normal heating day
n_hdd8    2875  Fri Apr 28 12:34:57 2006 Aug normal heating day
n_hdd9    2875  Fri Apr 28 12:34:57 2006 Sep normal heating day
name      2875  Thu Mar 30 09:23:47 2006 {PSE: CUSTOMER NAME}
ngavail   2875  Thu Mar 30 09:23:47 2006 {NATURAL GAS SERVICE AVAILABLE - N
Q2}
ngserv    2875  Thu Mar 30 09:23:47 2006 {HAS NATURAL GAS SERVICE - N Q1}
ngtime    2875  Thu Mar 30 09:23:47 2006 {NATURAL GAS BUILT IN OR ADDED - N
Q1a
nhsldmem  2875  Fri Apr 28 12:34:56 2006
nlwind    2875  Fri Apr 28 12:34:57 2006
nmwind    2875  Fri Apr 28 12:34:57 2006
nr0_6     2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE UNDER 6 YRS OLD - D Q1}
nr0_6a    2875  Thu Mar 30 09:23:47 2006 {N IN HOUSEHOLD UNDER 6 ANY- D Q1}
nr0_6cat  2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE UNDER 6 YRS OLD - D Q1}
nr19_64   2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE BTWN 19 AND 64 - D Q1}
nr19_64a  2875  Thu Mar 30 09:23:47 2006 {N IN HOUSEHOLD 19-64 ANY- D Q1}
nr618cat  2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE BTWN 6 AND 18 - D Q1}
nr65ovr   2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE OLDER 65 YRS OLD - D Q1}
nr6_18    2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE BTWN 6 AND 18 - D Q1}
nr6_18a   2875  Thu Mar 30 09:23:47 2006 {N IN HOUSEHOLD 6-18 ANY- D Q1}
nrescat   2875  Thu Mar 30 09:23:47 2006 {N OF PEOPLE IN HOUSEHOLD - D Q1}
nrooms    2875  Fri Apr 28 12:34:57 2006
nrovr65a  2875  Thu Mar 30 09:23:47 2006 {N IN HOUSEHOLD OVER 65 ANY- D Q1}
nswind    2875  Fri Apr 28 12:34:57 2006
numres    2875  Thu Mar 30 09:23:47 2006 {TOTAL NUMBER OF OCCUPANTS}
occres    2875  Thu Mar 30 09:23:47 2006 {LIVES IN RESIDENCE: YEAR ROUND- R Q3
occresot  2875  Thu Mar 30 09:23:47 2006 {OCCUPANT SEASONS: OTHER - R Q3}
offeqact  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM HOME OFFICE EQUIP- A Q4}
offeqnct  2875  Thu Mar 30 09:23:47 2006 {N OF HOME OFFICE EQUIP - A Q3}
offeqpa   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM HOME OFFICE EQUIP- A Q4}
offeqpn   2875  Thu Mar 30 09:23:47 2006 {N OF HOME OFFICE EQUIP - A Q3}
ownrent   2875  Thu Mar 30 09:23:47 2006 {OCCUPIED BY OWNER OR RENTER - R Q1}
ownrntot  2875  Thu Mar 30 09:23:47 2006 {OWN OR RENT: OTHER - R Q1}
payht     2875  Thu Mar 30 09:23:47 2006 {PAY FOR  SYSTEM - R Q1a}
payhtot   2875  Thu Mar 30 09:23:47 2006 {PAY BILL: OTHER - R Q1a}
pca       2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM PERSONAL COMPUTER- A Q4}
pcacat    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM PERSONAL COMPUTER- A Q4}
pcflbath  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - BATHROOMS}
pcflbed   2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - BEDROOMS}
pcflclst  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - CLOSETS}
pcflfam   2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - FAMILY ROOM}
pcflhall  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - HALLS}
```

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pcflhof2  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - HOME OFFICE}
pcflhoff  2875  Thu Mar 30 09:23:47 2006 {NUMBER OF CFLS IN HOME OFFICE -
CLEAN
pcflindr  2875  Thu Mar 30 09:23:47 2006 {Number of CFLs Indoors}
pcflktch  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - KITCHEN}
pcflliv   2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - LIVING ROOM}
pcfloth1  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - OTHER RESP 1}
pcfloth2  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - OTHER RESP 2}
pcflutil  2875  Thu Mar 30 09:23:47 2006 {PERCENT OF CFLS - UTILITY ROOM}
pcn       2875  Thu Mar 30 09:23:47 2006 {N OF PERSONAL COMPUTERS - A Q3}
pcncat    2875  Thu Mar 30 09:23:47 2006 {N OF PERSONAL COMPUTERS - A Q3}
pct       2875  Fri Apr 28 12:34:57 2006
pctdp     2875  Fri Apr 28 12:34:57 2006
pctstm    2875  Fri Apr 28 12:34:57 2006
pctstrmw  2875  Thu Mar 30 09:23:47 2006 {PCNT OF WINDOWS THAT ARE STORM - C
Q4
phone     2875  Thu Mar 30 09:23:47 2006 {BEST PHONE NUMBER - D Q8}
pltyp     2875  Thu Mar 30 09:23:47 2006 {SWIMMING POOL FUEL - A Q1}
poolage   2875  Thu Mar 30 09:23:47 2006 {SWIMMING POOL AGE  - A Q2}
prihtsys  2875  Thu Mar 30 09:23:47 2006 {PRIMARY HEATING SYSTEM - H Q2}
ps_dwl    2875  Thu Mar 30 09:23:47 2006 {PSE: DWELLING TYPE}
ps_egi    2875  Thu Mar 30 09:23:47 2006 {PSE: ELECTRIC GAS INDICATOR}
pscounty  2875  Thu Mar 30 09:23:47 2006 {PSE: RESIDENCE COUNTY}
refra     2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM REFRIGERATOR - A Q4}
refracat  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM REFRIGERATOR - A Q4}
refrn     2875  Thu Mar 30 09:23:47 2006 {N OF REFRIGERATORS INSTALLED - A Q3}
refrncat  2875  Thu Mar 30 09:23:47 2006 {N OF REFRIGERATORS INSTALLED - A Q3}
relwt     2875  Thu Mar 30 09:23:47 2006 {RELATIVE WEIGHT}
repair    2875  Thu Mar 30 09:23:47 2006 {HEATING SYSTEM MAINT SINCE 2003 - H
Q
resp1_a   2875  Thu Mar 30 09:23:47 2006 {1 IF IN FINAL SAMPLE}
rmacact   2875  Thu Mar 30 09:23:47 2006 {N OF ROOM AC INSTALLED - A Q3}
rmacnact  2875  Thu Mar 30 09:23:47 2006 {N OF ROOM ACs INSTALLED - A Q3}
roomaca   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM ROOM AIR CONDITIONER - A
roomacn   2875  Thu Mar 30 09:23:47 2006 {N OF ROOM AC INSTALLED - A Q3}
roomsq    2875  Thu Mar 30 09:23:47 2006 {ROOMS PER SQUARE FOOTAGE}
sampleid  2875  Thu Mar 30 09:23:47 2006 {SAMPLE ID}
scanid    2875  Thu Mar 30 09:23:47 2006 {SCAN ID}
sddb      2875  Fri Apr 28 12:34:57 2006 SummerDesign Dry Bulb
sfe       2875  Fri Apr 28 12:34:56 2006
showerhd  2875  Thu Mar 30 09:23:47 2006 {WHEN LOWFLOW SHOWER HD INSTALLED - C
sodr      2875  Fri Apr 28 12:34:57 2006 Daily Range
sphtage   2875  Thu Mar 30 09:23:47 2006 {HOT TUB AGE  - A Q2}
sphtf     2875  Thu Mar 30 09:23:47 2006 {HOT TUB FUEL - A Q1}
sqftact   2875  Thu Mar 30 09:23:47 2006 {SQUARE FOOTAGE OF HOME - R Q6}
sqftc     2875  Fri Apr 28 12:34:56 2006
sqftcat   2875  Thu Mar 30 09:23:47 2006 {SQUARE FOOTAGE OF HOME - R Q6}
stereoa   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM HOME STEREO SYSTEM- A Q4
stereon   2875  Thu Mar 30 09:23:47 2006 {N OF HOME STEREO SYSTEM - A Q3}
sternct   2875  Thu Mar 30 09:23:47 2006 {N OF HOME STEREO SYSTEM - A Q3}
streoact  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM HOME STEREO SYSTEM- A Q4
sumths    2875  Fri Apr 28 12:34:56 2006
swinds    2875  Fri Apr 28 12:34:57 2006
tva       2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM TELEVISION - A Q4}
tvacat    2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM TELEVISION - A Q4}
tvn       2875  Thu Mar 30 09:23:47 2006 {N OF TELEVISIONS - A Q3}
tvncat    2875  Thu Mar 30 09:23:47 2006 {N OF TELEVISIONS - A Q3}
units     2875  Thu Mar 30 09:23:47 2006 {N UNITS IN BLDG - R Q4a}
vcrdvact  2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM VCR OR DVD PLAYER- A Q4}
vcrdvda   2875  Thu Mar 30 09:23:47 2006 {AGE OF PRIM VCR OR DVD PLAYER- A Q4}
vcrdvdn   2875  Thu Mar 30 09:23:47 2006 {N OF VCR OR DVD PLAYER - A Q3}
vcrdvnct  2875  Thu Mar 30 09:23:47 2006 {N OF VCR OR DVD PLAYER - A Q3}
w99t      2875  Fri Apr 28 12:34:57 2006 Winter Desing Dry Bulb
wallins   2875  Thu Mar 30 09:23:47 2006 {WHEN WALL INSULATION INSTALLED- C Q1
```

```
weight    2875  Thu Mar 30 09:23:47 2006 {CASE WEIGHT}
whage     2875  Thu Mar 30 09:23:47 2006 {WATER HTR AGE - W Q4}
whfuel    2875  Thu Mar 30 09:23:47 2006 {WATER HTR FUEL TYPE - W Q3}
whfuelot  2875  Thu Mar 30 09:23:47 2006 {WATER HTR FUEL: OTHER - W Q3}
whloc     2875  Thu Mar 30 09:23:47 2006 {WATER HTR LOCATION - W Q5}
whlocot   2875  Thu Mar 30 09:23:47 2006 {WATER HTR LOCATION: OTHER - W Q5}
whnone    2875  Thu Mar 30 09:23:47 2006 {WATER HTR ITEMS - W Q6}
whpwrap   2875  Thu Mar 30 09:23:47 2006 {WATER HTR ITEMS - W Q6}
whrepl    2875  Thu Mar 30 09:23:47 2006 {PRI WATER HEATER - W Q4b}
whrepl03  2875  Thu Mar 30 09:23:47 2006 {WATER HTR REPLACED IN 2003 - W Q4a}
whrepot   2875  Thu Mar 30 09:23:47 2006 {WATER HTR REPLACED: OTHER - W Q4b}
whsysnum  2875  Thu Mar 30 09:23:47 2006 {N OF WATER HTRS - W Q2}
whsystyp  2875  Thu Mar 30 09:23:47 2006 {WATER HTR SERVICE TYPE - W Q1}
whtimer   2875  Thu Mar 30 09:23:47 2006 {WATER HTR ITEMS - W Q6}
whwrap    2875  Thu Mar 30 09:23:47 2006 {WATER HTR ITEMS - W Q6}
win       2875  Fri Apr 28 12:34:57 2006
winths    2875  Fri Apr 28 12:34:57 2006
yrresnum  2875  Thu Mar 30 09:23:47 2006 {NUMBER OF YEARS IN RESIDENCE}
yrs_res   2875  Thu Mar 30 09:23:47 2006 {YEARS LIVED IN RESIDENCE}
zip       2875  Thu Mar 30 09:23:47 2006 {PSE: RESIDENCE ZIP}

---- Matrices ----
bhr       2, 1  Fri Apr 28 12:34:57 2006
save file[jad]

write file[jad.dat] var[sodr sddb w99t \
n_hdd{1-12} n_cdd{1-12} hdd{1-36} cdd{1-36} \
sumths nhsldmem \
hinwall insat1 nrooms floors sfe lwinds mwinds swinds \
nlwind nmwind nswind winths case_num] # fmt[114(e15.8,5x)]

print var[sodr sddb w99t \
n_hdd{1-12} n_cdd{1-12} hdd{1-36} cdd{1-36} \
sumths nhsldmem \
hinwall insat1 nrooms floors sfe lwinds mwinds swinds \
nlwind nmwind nswind winths case_num] obs[1,5]

  Obsno          sodr              sddb              w99t
     1:      18.20000          84.90000          28.40000
     5:      18.20000          84.90000          28.40000

  Obsno        n_hdd1            n_hdd2            n_hdd3
     1:       7.53000e+002      7.52000e+002      6.18000e+002
     5:       7.53000e+002      7.52000e+002      6.18000e+002

  Obsno        n_hdd4            n_hdd5            n_hdd6
     1:       5.94000e+002      4.48000e+002      2.85000e+002
     5:       5.94000e+002      4.48000e+002      2.85000e+002

  Obsno        n_hdd7            n_hdd8            n_hdd9
     1:       1.44000e+002     48.00000          40.00000
     5:       1.44000e+002     48.00000          40.00000

  Obsno       n_hdd10           n_hdd11           n_hdd12
     1:       1.35000e+002      3.64000e+002      5.75000e+002
     5:       1.35000e+002      3.64000e+002      5.75000e+002

  Obsno        n_cdd1            n_cdd2            n_cdd3
     1:       0.00000           0.00000           0.00000
     5:       0.00000           0.00000           0.00000
  Obsno        n_cdd4            n_cdd5            n_cdd6
     1:       0.00000           0.00000           4.00000
     5:       0.00000           0.00000           4.00000
```

```
Obsno        n_cdd7            n_cdd8            n_cdd9
   1:      10.00000          56.00000          77.00000
   5:      10.00000          56.00000          77.00000

Obsno       n_cdd10           n_cdd11           n_cdd12
   1:      27.00000           0.00000           0.00000
   5:      27.00000           0.00000           0.00000

Obsno          hdd1              hdd2              hdd3
   1:       7.06300e+002      6.88900e+002      6.19200e+002
   5:       7.15200e+002      7.07700e+002      6.41400e+002

Obsno          hdd4              hdd5              hdd6
   1:       5.30600e+002      3.37300e+002      2.42900e+002
   5:       5.45200e+002      3.90200e+002      3.00300e+002

Obsno          hdd7              hdd8              hdd9
   1:       1.14600e+002     70.20000           1.73000e+002
   5:       1.91950e+002     85.30000           1.89400e+002

Obsno         hdd10             hdd11             hdd12
   1:       4.44300e+002      5.48200e+002      7.24400e+002
   5:       4.53100e+002      5.24200e+002      7.24800e+002

Obsno         hdd13             hdd14             hdd15
   1:       7.37400e+002      6.50400e+002      7.28900e+002
   5:       7.37800e+002      6.36900e+002      7.44100e+002

Obsno         hdd16             hdd17             hdd18
   1:       5.08400e+002      3.91800e+002      1.57925e+002
   5:       5.29200e+002      4.45100e+002      2.01775e+002

Obsno         hdd19             hdd20             hdd21
   1:      73.20000          71.20000           1.48600e+002
   5:       1.38800e+002      1.15500e+002      2.18350e+002

Obsno         hdd22             hdd23             hdd24
   1:       4.29100e+002      5.45600e+002      6.78400e+002
   5:       4.90500e+002      5.54800e+002      6.99300e+002

Obsno         hdd25             hdd26             hdd27
   1:       6.02300e+002      6.51000e+002      5.80800e+002
   5:       6.19650e+002      6.71100e+002      6.06400e+002

Obsno         hdd28             hdd29             hdd30
   1:       5.04300e+002      3.41600e+002      1.30500e+002
   5:       5.30700e+002      3.91500e+002      1.72500e+002

Obsno         hdd31             hdd32             hdd33
   1:      29.00000          29.90000           1.23700e+002
   5:      77.20000          72.50000           1.56700e+002

Obsno         hdd34             hdd35             hdd36
   1:       3.32700e+002      6.73800e+002      7.15200e+002
   5:       3.62100e+002      7.17200e+002      7.37300e+002

Obsno          cdd1              cdd2              cdd3
   1:       0.00000           0.00000           0.00000
   5:       0.00000           0.00000           0.00000

Obsno          cdd4              cdd5              cdd6
   1:       0.00000           8.10000           3.40000
   5:       0.00000           1.00000           0.00000
```

```
    Obsno           cdd7              cdd8              cdd9
       1:       12.20000          30.50000           0.40000
       5:        0.00000          14.50000           0.20000

    Obsno          cdd10             cdd11             cdd12
       1:        0.00000           0.00000           0.00000
       5:        0.00000           0.00000           0.00000

    Obsno          cdd13             cdd14             cdd15
       1:        0.00000           0.00000           0.00000
       5:        0.00000           0.00000           0.00000

    Obsno          cdd16             cdd17             cdd18
       1:        0.00000           0.00000          24.30000
       5:        0.00000           0.00000           8.40000

    Obsno          cdd19             cdd20             cdd21
       1:       54.00000          52.30000           4.80000
       5:       16.40000          24.30000           0.00000

    Obsno          cdd22             cdd23             cdd24
       1:        0.00000           0.00000           0.00000
       5:        0.00000           0.00000           0.00000

    Obsno          cdd25             cdd26             cdd27
       1:        0.00000           0.00000           0.00000
       5:        0.00000           0.00000           0.00000

    Obsno          cdd28             cdd29             cdd30
       1:        0.00000           0.10000          62.80000
       5:        0.00000           0.00000          25.90000

    Obsno          cdd31             cdd32             cdd33
       1:       93.10000          44.30000          30.70000
       5:       42.50000           6.20000          14.80000

    Obsno          cdd34             cdd35             cdd36
       1:        0.00000           0.00000           0.00000
       5:        0.00000           0.00000           0.00000

    Obsno         sumths           nhsldmem          hinwall
       1:       75.00000           2.00000           0.00000
       5:       75.00000           2.00000           0.00000

    Obsno         insat1            nrooms            floors
       1:        0.00000           8.00000           1.00000
       5:       12.00000           6.00000           2.00000

    Obsno            sfe            lwinds            mwinds
       1:        1.29000e+003      0.00000          11.00000
       5:        3.22000e+002      0.00000          15.00000

    Obsno         swinds            nlwind            nmwind
       1:        0.00000           0.00000          11.00000
       5:        0.00000           0.00000          15.00000

    Obsno         nswind            winths          case_num
       1:        0.00000          70.00000          11.00000
       5:        0.00000          70.00000          55.00000
quit mem
Memory release complete
```

Appendix C

```
SST Spool File:  winavg.log

load file [winavg] dbase

reg dep[wind] ind[(1) sqft]

********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:      wind

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error               Statistic

      (1)           8.13629                3.23307               2.51658
     sqft           3.98637e-003           1.75880e-003          2.26653


Number of Observations                   7
R-squared                                0.50677
Corrected R-squared                      0.40812
Sum of Squared Residuals                83.70891
Standard Error of the Regression         4.09167
Durbin-Watson Statistic                  1.85635
Mean of Dependent Variable              14.57143

reg dep[wind] ind[(1) sqft room flr]


********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:      wind

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error               Statistic

      (1)           1.21906                4.86290               0.25068
     sqft           1.69202e-003           2.60635e-003          0.64919
     room           0.31186                1.33321               0.23392
      flr           5.90656                3.50477               1.68529


Number of Observations                   7
R-squared                                0.81702
Corrected R-squared                      0.63405
Sum of Squared Residuals                31.05369
Standard Error of the Regression         3.21733
Durbin-Watson Statistic                  1.22536
Mean of Dependent Variable              14.57143

reg dep[wind] ind[(1) room]


********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:      wind

Independent        Estimated              Standard                t-
 Variable         Coefficient              Error               Statistic

      (1)           1.27143                4.67083               0.27221
     room           1.90000                0.63987               2.96937
```

```
Number of Observations                 7
R-squared                              0.63813
Corrected R-squared                    0.56576
Sum of Squared Residuals              61.41429
Standard Error of the Regression       3.50469
Durbin-Watson Statistic                1.95704
Mean of Dependent Variable            14.57143

reg dep[wind] ind[(1) flr]


********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:      wind

Independent       Estimated             Standard              t-
 Variable        Coefficient             Error             Statistic

      (1)          2.66667               3.67575              0.72548
      flr          8.33333               2.43128              3.42755


Number of Observations                 7
R-squared                              0.70146
Corrected R-squared                    0.64175
Sum of Squared Residuals              50.66667
Standard Error of the Regression       3.18329
Durbin-Watson Statistic                0.66228
Mean of Dependent Variable            14.57143

reg dep[wind] ind[(1) flr sqft]


********* ORDINARY LEAST SQUARES ESTIMATION *********

Dependent Variable:      wind

Independent       Estimated             Standard              t-
 Variable        Coefficient             Error             Statistic

      (1)          1.94235               3.27990              0.59220
      flr          6.38493               2.48734              2.56697
     sqft          2.17294e-003          1.39988e-003         1.55223


Number of Observations                 7
R-squared                              0.81369
Corrected R-squared                    0.72053
Sum of Squared Residuals              31.62008
Standard Error of the Regression       2.81159
Durbin-Watson Statistic                1.23718
Mean of Dependent Variable            14.57143


quit
```

county2.log

```
SST Spool File:  county2.log
Tue Apr 25 12:45:59 2006

load file[county2.dbf] dbase
recode var[*] map[-999=md]

label var   [co_indx]   lab   [county index]
label var   [n_hdd1 ]   lab   [Jan normal heating day]
label var   [n_hdd2 ]   lab   [Feb normal heating day]
label var   [n_hdd3 ]   lab   [Mar normal heating day]
label var   [n_hdd4 ]   lab   [Apr normal heating day]
label var   [n_hdd5 ]   lab   [May normal heating day]
label var   [n_hdd6 ]   lab   [Jun normal heating day]
label var   [n_hdd7 ]   lab   [Jul normal heating day]
label var   [n_hdd8 ]   lab   [Aug normal heating day]
label var   [n_hdd9 ]   lab   [Sep normal heating day]
label var   [n_hdd10]   lab   [Oct normal heating day]
label var   [n_hdd11]   lab   [Nov normal heating day]
label var   [n_hdd12]   lab   [Dec normal heating day]
label var   [n_cdd1 ]   lab   [Jan normal cooling days]
label var   [n_cdd2 ]   lab   [Feb normal cooling days]
label var   [n_cdd3 ]   lab   [Mar normal cooling days]
label var   [n_cdd4 ]   lab   [Apr normal cooling days]
label var   [n_cdd5 ]   lab   [May normal cooling days]
label var   [n_cdd6 ]   lab   [Jun normal cooling days]
label var   [n_cdd7 ]   lab   [Jul normal cooling days]
label var   [n_cdd8 ]   lab   [Aug normal cooling days]
label var   [n_cdd9 ]   lab   [Sep normal cooling days]
label var   [n_cdd10]   lab   [Oct normal cooling days]
label var   [n_cdd11]   lab   [Nov normal cooling days]
label var   [n_cdd12]   lab   [Dec normal cooling days]
label var   [co_indx]   val   [15 island 16 jefferso 17 king 18 kitsap \
19 kittitas 21 lewis 27 pierce 29 skagit 31 snohomis 34 thurston 37 whatcom]

freq var[co_indx]

co_indx    county index
11 valid observations

               island   jefferso       king     kitsap   kittitas
                   15         16         17         18         19
           ---------- ---------- ---------- ---------- ----------
Count               1          1          1          1          1
Percent          9.09       9.09       9.09       9.09       9.09


                lewis     pierce     skagit   snohomis   thurston
                   21         27         29         31         34
           ---------- ---------- ---------- ---------- ----------
Count               1          1          1          1          1
Percent          9.09       9.09       9.09       9.09       9.09


              whatcom
                   37
           ----------
Count               1
Percent          9.09


save file[county2.sav]

quit mem
```

Exhibit No. ___(JAD-8)

```
Memory release complete
```

```
county3.log
SST Spool File:  county3.log
Tue Apr 25 12:46:03 2006

load file[county3] dbase # 2003 HDD/CDD for Washington Counties in RASFINAL

list
---- Variables ----
cdd1        11  Tue Apr 25 12:46:03 2006
cdd10       11  Tue Apr 25 12:46:03 2006
cdd11       11  Tue Apr 25 12:46:03 2006
cdd12       11  Tue Apr 25 12:46:03 2006
cdd2        11  Tue Apr 25 12:46:03 2006
cdd3        11  Tue Apr 25 12:46:03 2006
cdd4        11  Tue Apr 25 12:46:03 2006
cdd5        11  Tue Apr 25 12:46:03 2006
cdd6        11  Tue Apr 25 12:46:03 2006
cdd7        11  Tue Apr 25 12:46:03 2006
cdd8        11  Tue Apr 25 12:46:03 2006
cdd9        11  Tue Apr 25 12:46:03 2006
co_indx     11  Tue Apr 25 12:46:03 2006
hdd1        11  Tue Apr 25 12:46:03 2006
hdd10       11  Tue Apr 25 12:46:03 2006
hdd11       11  Tue Apr 25 12:46:03 2006
hdd12       11  Tue Apr 25 12:46:03 2006
hdd2        11  Tue Apr 25 12:46:03 2006
hdd3        11  Tue Apr 25 12:46:03 2006
hdd4        11  Tue Apr 25 12:46:03 2006
hdd5        11  Tue Apr 25 12:46:03 2006
hdd6        11  Tue Apr 25 12:46:03 2006
hdd7        11  Tue Apr 25 12:46:03 2006
hdd8        11  Tue Apr 25 12:46:03 2006
hdd9        11  Tue Apr 25 12:46:03 2006


foreach(j ; {1-12} ) {
rename var[hdd${j} cdd${j}] to[hdd3_${j} cdd3_${j}]
}

list
---- Variables ----
cdd3_1      11  Tue Apr 25 12:46:03 2006
cdd3_10     11  Tue Apr 25 12:46:03 2006
cdd3_11     11  Tue Apr 25 12:46:03 2006
cdd3_12     11  Tue Apr 25 12:46:03 2006
cdd3_2      11  Tue Apr 25 12:46:03 2006
cdd3_3      11  Tue Apr 25 12:46:03 2006
cdd3_4      11  Tue Apr 25 12:46:03 2006
cdd3_5      11  Tue Apr 25 12:46:03 2006
cdd3_6      11  Tue Apr 25 12:46:03 2006
cdd3_7      11  Tue Apr 25 12:46:03 2006
cdd3_8      11  Tue Apr 25 12:46:03 2006
cdd3_9      11  Tue Apr 25 12:46:03 2006
co_indx     11  Tue Apr 25 12:46:03 2006
hdd3_1      11  Tue Apr 25 12:46:03 2006
hdd3_10     11  Tue Apr 25 12:46:03 2006
hdd3_11     11  Tue Apr 25 12:46:03 2006
hdd3_12     11  Tue Apr 25 12:46:03 2006
hdd3_2      11  Tue Apr 25 12:46:03 2006
hdd3_3      11  Tue Apr 25 12:46:03 2006
hdd3_4      11  Tue Apr 25 12:46:03 2006
hdd3_5      11  Tue Apr 25 12:46:03 2006
hdd3_6      11  Tue Apr 25 12:46:03 2006
hdd3_7      11  Tue Apr 25 12:46:03 2006
```

```
hdd3_8       11  Tue Apr 25 12:46:03 2006
hdd3_9       11  Tue Apr 25 12:46:03 2006

save file[county3]

quit mem
Memory release complete
```

weather.log

```
SST Spool File:  weather.log
Tue Apr 25 12:46:24 2006

load file [weather.dbf] dbase

label var   [co_indx  ] lab   [County Index Number]
label var   [sodr     ] lab   [Daily Range]
label var   [sddr     ] lab   [SummerDesign Dry Bulb ]
label var   [w99t     ] lab   [Winter Desing Dry Bulb]

save file[weather.sav]

quit mem
Memory release complete
```

Appendix D

Appendix E

Thermal Model

```
#include "stdio.h"
#include "stdlib.h"

void main(argc, argv)
int argc;
char **argv;
{
int     i;
float   w0g,w0i,w1,w2,s0,s1,s2,copg,copo,cophp,copac,sheatp,sheatd,sheatn;
float   shuce,shucg,shuco,shude,shudg,shudo,shupe,shupg,shupo,shuchp;
float   dshuce,dshucg,dshuco,dshude,dshudg,dshudo,acheat;
float   dshupe,dshupg,dshupo,dshuchp,shuec,dshuec,acuec,dacuec;
float   hdda,cdda;

int     N, j, y, k;

float   dtp[3];
float   hdd[36], n_hdd[12]; /* Assumes three years of heating degree day data
*/
float   cdd[36], n_cdd[12]; /* Assumes three years of cooling degree day data
*/
float   hse[14];
float   sumths;
float   winths;
float   **X;
float   xlamc_out, xlamh_out;
float   case_num;
float   shuec_out[36];

FILE *fpin;
FILE *fpout;
extern FILE *fopen();

/* NUMBER OF DAYS IN EACH CALANDER MONTH */
static  float   xdays[] = { 31.,28.,31.,30.,31.,
                            30.,31.,31.,30.,31.,30.,31. };

if (argc != 4) {
      printf("Usage: thermal N file_name_in file_name_out\n");
      exit(1);
}

N = atoi( argv[1] );

if((fpin = fopen(argv[2],"r"))==NULL) {
      printf("unable to open input file %s\n",argv[2]);
      exit(1);
      }

if((fpout = fopen(argv[3],"w"))==NULL) {
      printf("unable to open output file %s\n",argv[3]);
      exit(1);
      }


X = (float **)calloc( 114, sizeof(float *) );
if (X == NULL) {printf("could not allocate array X\n"); exit(1);}

for ( j = 0; j < 114; j++ ) {
      X[j] = (float *)calloc(N, sizeof(float));
      if( X[j] == NULL ) {printf("could not allocate array X[%d] of size
%d\n", j, N); exit(1);}
      }
```

```
for(i = 0; i < N; i++) {
      for(j = 0; j < 114; j++)
            {
            if (fscanf(fpin,"%f",&(X[j][i])) != 1) {
                  printf("Error: reading observation %d\n",i+1);
                  exit(1);
                  }
            }
      }

for( i = 0; i < N; i++ ) {

      for(j = 0; j< 3; j++)  dtp[j]   = X[ 0+j][i];
      for(j = 0; j<12; j++)  n_hdd[j] = X[ 3+j][i];   /* normal monthly hdd */

      for(j = 0; j<12; j++)  n_cdd[j] = X[ 15+j][i];  /* normal monthly cdd */
      for(j = 0; j<36; j++)  hdd[j]   = X[ 27+j][i];  /* 2001-2003 monthly hdd
*/
      for(j = 0; j<36; j++)  cdd[j]   = X[ 63+j][i];  /* 2001-2003 monthly cdd
*/
      for(j = 0; j<14; j++)  hse[j]   = X[ 99+j][i];
    case_num = X[113][i];


/* PASADENA, CALIFORNIA */
/*static  float   dtp[] = { 29.,95.,32. };
static  float   hdd[] = { 418.,332.,342.,241.,141.,48.,2.,
                          2.,13.,77.,241.,385. };
static  float   cdd[] = { 2.,2.,4.,7.,27.,89.,
                  218.,228.,165.,55.,9.,2. };

/* TEST CASE #1  1510 ONTARIO AVE.
static  float   hse[] = { 75.,2.,0.,4.,3.,1.,
                  1650.,4.,10.,1.,0.,0.,0.,70. };*/

sumths = *(hse);
winths = *(hse+13);

/* Design Conditions */
building(n_hdd,n_cdd,hse,dtp,&w0g,&w0i,&w1,&w2,&s0,&s1,&s2,
         &copg,&copo,&cophp,&copac,&sheatp,&sheatd,&sheatn,
         &acheat,&hdda,&cdda);

for (y=0; y<3; y++) {
      for (j=0; j<12; ++j) {
      k = y*12 + j;
    therm(sumths,winths,w0g,w0i,w1,w2,s0,s1,s2,*(hdd+k),

*(cdd+k),*(xdays+j),&shuec,&dshuec,&acuec,&dacuec,&xlamc_out,&xlamh_out);
      shuec_out[k] = shuec;

    /*hvac(shuec,dshuec,&acuec,&dacuec,copg,copo,
         cophp,copac,sheatp,sheatd,sheatn,
         &shuce,&shucg,&shuco,&shude,&shudg,&shudo,
         &shupe,&shupg,&shupo,&shuchp,
         &dshuce,&dshucg,&dshuco,&dshude,&dshudg,&dshudo,
         &dshupe,&dshupg,&dshupo,&dshuchp);*/
      }
}

fprintf(fpout,"%4d %8.0f %15.8f", i+1, case_num, xlamh_out);
for (y=0; y<3; y++) {
      for (j=0; j<12; ++j) {
```

```
      k = y*12 + j;
    fprintf(fpout," %15.8f", shuec_out[k]);
      }
}

fprintf(fpout,"\n");
}
fclose(fpin);
fclose(fpout);
}

building(hdd,cdd,hse,dtp,w0g,w0i,w1,w2,s0,s1,s2,
         copg,copo,cophp,copac,sheatp,sheatd,sheatn,
         acheat,hdda,cdda)

float   *hdd,*cdd,*hse,*dtp,*hdda,*cdda;
float   *w0g,*w0i,*w1,*w2,*s0,*s1,*s2,*acheat;
float   *copg,*copo,*cophp,*copac,*sheatp,*sheatd,*sheatn;
{

extern  float   min1(),max1();
extern  double  pow(),exp();
int     i;

float   sflwinds,sfmwinds,sfswinds,sflstrm,sfmstrm,sfsstrm;
float   sfwi,sfstrm,sfnstrm,sflnstrm,sfceil,sfwall,beta,b,vol,reg,duct;
float   pipe,rinsceil,rinswall,sdtempd,wdtempd,reswall,resceilw,ueff1;
float   ueff2,zglass,zglasrw,infil1,infil2,intern;
float   radhlf,radelf,tight;

float   sodr=dtp[0];      /*summer outdoor daily temp range     */
float   sddb=dtp[1];      /*summer design temperature           */
float   w99t=dtp[2];      /*winter design temperature           */

float   sumths=  hse[ 0]; /*summer thermostat setting           */
float   nhsldmem=hse[ 1]; /*total number of residents           */
float   hinwall= hse[ 2]; /*have ext wall insul                 */
float   insat1=  hse[ 3]; /*inches of attic insul.              */
float   nrooms=  hse[ 4]; /*number of rooms in living space     */
float   floors=  hse[ 5]; /*total number of floors              */
float   sfe=     hse[ 6]; /*square feet of dwelling             */
float   lwinds=  hse[ 7]; /*number of large windows             */
float   mwinds=  hse[ 8]; /*number of medium windows            */
float   swinds=  hse[ 9]; /*number of small windows             */
float   nlwind=  hse[10]; /*number large storm win              */
float   nmwind=  hse[11]; /*number medium storm win             */
float   nswind=  hse[12]; /*number small storm win              */
float   winths=  hse[13]; /*winter thermostat setting           */

/*annual heating and cooling degree days*/

*hdda = *cdda =0.;
for (i=0; i<12; ++i)
        {
        *hdda += *(hdd+i);
        *cdda += *(cdd+i);
        }

/*transformations and redefinitions */

insat1 = min1( 17., max1( 0., insat1 ) );      /*inches attic insulation*/
sflwinds=45.*lwinds;
sfmwinds=25.*mwinds;
sfswinds=8. *swinds;
```

```
sflstrm= 45.*nlwind;
sfmstrm= 25.*nmwind;
sfsstrm= 8.*nswind;
sfwi=sflwinds+sfmwinds+sfswinds;
sfstrm=sflstrm+sfmstrm+sfsstrm;
sfnstrm =max1( 0., (sfwi-sfstrm) );
sflnstrm=max1( 0., (sflwinds-sflstrm) );

/*ceiling and wall square feet from regressions on typical houses*/

sfceil=.96*pow((double) floors,-.815)*pow((double) sfe,1.006); /*sf ceiling*/
sfceil=min1(10000.,max1(100.,sfceil)); /*square feet ceiling*/
sfwall=19.1*pow( (double) floors,.92)*pow( (double) sfe,.57);
sfwall=min1(4000.,max1(320.,sfwall));
beta=(sfwi/sfwall);
b=max1(.03,min1(.7,beta));
sfwi=b*sfwall;           /*number of square feet of all windows*/
sfwall *=(1.-b);         /*sf wall excluding windows*/
b=max1(beta/b,1.);
sflstrm  /=b;   /*square feet of large storm windows,doors*/
sflnstrm /=b;   /*square feet of large non-storm windows*/
sfstrm   /=b;   /*square feet of stormed windows*/
sfnstrm  /=b;   /*square feet of non-stormed windows*/

/*cubic feet*/

vol=8.94*pow((double) floors,.8)*pow((double) sfceil,.98);
vol=min1(90000.,max1(800.,vol));                /*volume in cubic feet      */

/*pipe, duct, and chimney*/

reg=2.55+1.07*nrooms+.003*sfe;                  /*number registers          */
duct=3.89*reg+.067*sfe;                         /*lf duct                   */
pipe=0.142* pow( (double) sfe,1.03);            /*lf pipe                   */

/*insulation r-values*/

rinsceil=max1(.85,3.*insat1);                         /* ceiling insulation r-
value */
/* rinswall=max1(.94,(1.+.001* *hdda)*hinwall);*/     /* wall insulation r-
value    */
rinswall=max1(.94,19*hinwall);                                      /* wall
insulation r-value    */

tight=1;

sdtempd=sddb-sumths;
wdtempd=winths-w99t;

/*resistences*/

reswall=(2.85+rinswall)/(.9394+.0138*rinswall);
resceilw=3.834+.943*rinsceil;
ueff1=(0.3769+0.00636*rinsceil)/(2.097+0.608*rinsceil);
ueff2=(0.17389+0.00293*rinsceil)/(2.097+0.608*rinsceil);
zglass=((sflstrm/1.32)+(sflnstrm/.88));
zglasrw=(sfstrm-sflstrm)/2.78+(sfnstrm-sflnstrm)/.98;
infil1=tight*(1.14-.28*(sfstrm)/sfwi);
infil2=.00833*infil1;
infil1=.575*infil1;
intern= 3083 + 318.0 * nhsldmem; /* sensible heat gain Anderson (1973) */

/*heat loss and gain coefficients*/
```

```
*w0g=sfceil*(3.88 -0.0299*w99t);
*w0i = - intern;
*w1=(sfwall/reswall)+(sfceil/resceilw)+zglasrw
    +zglass+.018*vol*infil1;
*w2=.018*vol*infil2;

*s0=(sfwall/reswall)*(26.27+0.3196*sodr);
*s0 +=  sfceil*ueff1*(25.35+0.2820*sodr);
*s0= ( *s0 + intern + 30*(sfwi-sflstrm) + 27*sflstrm )*1.25;
*s1=1.0050*(sfwall/reswall) + sfceil*ueff1*0.9958 + sfceil*ueff2;
*s1 = ( *s1 +  0.8*(sfwi-sflstrm) + 0.6*sflstrm + 0.007423*vol )*1.25;
*s2=0.00015*vol*1.25;

/*design capacities*/

*sheatn=(*w0g+wdtempd*(*w1+wdtempd* *w2))/1000.;
*sheatp= *sheatn+.01128*pipe;
*sheatd= *sheatn+.0249*duct;
*acheat=(*s0+sdtempd*(*s1+sdtempd* *s2))/1000.;

/* cooling uec calculation */
*s0 = (sfwall/reswall)*(362.1-0.9638*sodr)/24;
*s0 +=  sfceil*ueff1*(355.6- 1.032*sodr)/24;
*s0 = (*s0  +  intern + 30*(sfwi-sflstrm) + 27*sflstrm)*1.25;
*s1 = 22.67*(sfwall/reswall)/24 + sfceil*ueff1*22.66/24 + sfceil*ueff2/24;
*s1 = (*s1 + 0.8*(sfwi-sflstrm)+0.6*sflstrm+0.007423*vol)*1.25;
*s2 = 0.00015*vol*1.25;

/* necessary size of distribution system */

radhlf= *sheatn / .645;
radelf= *sheatn / .6394;

 /*seasonal heating efficiencies*/

*copg=.46+.0146* *hdda/365.;
*copo=.404+.013* *hdda/365.;
*cophp=1.94 + 1040.25/ *hdda + 350.4/ *cdda;
*cophp +=  - .000126* *hdda - .000222* *cdda;
*copac= 3.44 + 271.56/ *hdda + 448.95/ *cdda;
*copac +=  - .0000986* *hdda - .0001041* *cdda;

}

therm(sumths,winths,w0g,w0i,w1,w2,s0,s1,s2,hdd,cdd,
        xdays,shuec,dshuec,acuec,dacuec,xlamc_out,xlamh_out)
float   sumths,winths;
float   w0g,w0i,w1,w2,s0,s1,s2,hdd,cdd,xdays;
float   *shuec,*dshuec,*acuec,*dacuec;
float   *xlamc_out, *xlamh_out;
{

extern  double  sqrt(), exp();
extern  float   max1(), min1();
float   xlamc,s0a,s1a,s2a,xlamh,w0a,w1a,w2a,apar,bpar,w0;
float   xxlamh,ph,xxlamc,pc,tmean,xd;
float   toler=1.e-4;
int     hmeth,cmeth;

/* calculate summer thermal coeffiecients */

xlamc=sqrt( (double) (1.-4.*s2*min1(s0,0.)/(s1*s1)) );
xlamc=s1*(1.-xlamc)/(2.*s2);
*xlamc_out = xlamc;
```

```
s0a=max1(s0,0.);
s1a= (s1 + 2.*s2*(-1.0*xlamc))*(-1.0);
s2a=s2;

/*calculate heating uec.  first a balance inside-outside temperature */
/*differential  lam  is calculated.  this quantity is independent of */
/*the thermostat setting.  then w1 and w0 coeffieients are redefined */
/*so heat gives the average of  q  over the temperature distribution */
/*up to the balance temperature.  note that the energy cost of a one */
/*degree thermostat increase is simple to compute because balance    */
/*temperature rises one degree, balance differential is unchanged.   */

/*calculate winter thermal coeffiecients                             */
/*do not include heat loss to ground                                 */

w0 = w0i;
xlamh=sqrt( (double) (1.-4.*w2*min1( w0 ,0.)/(w1*w1)) );
xlamh=w1*(1.-xlamh)/(2.*w2);
*xlamh_out = xlamh;
w0a=max1( w0 ,0.);
w1a= (w1 + 2.*w2*(-1.0*xlamh));
w2a=w2;

hdd /=xdays;
cdd /=xdays;

/* choose calculation mode; 1-normal 0-mean  */

hmeth=cmeth=1;

if ((hdd!=0.0) && (cdd!=0.0))   /*  estimate temperature distribution */
        {
        coef(hdd,cdd,&apar,&bpar);
        /*  check estimated temperature distribution through bpar */
        if (bpar != 1.0)           /* calculate xlamh,xlamc,ph,pc */
                {
                /* heating */
                xxlamh=apar+bpar*( winths + xlamh);
                ph=1.0/(1.0+exp( (double) -xxlamh));
                if ( (ph <= toler) || ( (1.0 - ph) <= toler ) ) hmeth=0;
                /* cooling */
                xxlamc=apar+bpar*( sumths - xlamc);
                pc=1.0/(1.0+exp( (double) -xxlamc));
                if ((pc <= toler ) || ( (1.0 - pc ) <= toler ) ) cmeth=0;
                }
        }
else    {
        hmeth=cmeth=0;
        }

/* calculate mean temperature */

if (hdd<cdd) { tmean=65.+cdd; } else { tmean=65.-hdd; }
if ( (hmeth) || (cmeth) ) tmean= - apar/bpar;

/* go to correct method */

if (hmeth && cmeth)
        {
        heat1(xxlamh,w0a,w1a,w2a,bpar,shuec,dshuec);
        acc1(xxlamc,s0a,s1a,s2a,apar,bpar,sumths,acuec,dacuec);
        }
else    if (hmeth && !(cmeth))
        {
```

```
        heat1(xxlamh,w0a,w1a,w2a,bpar,shuec,dshuec);
        acc2(cdd,acuec,dacuec);
        }
else    if (!(hmeth) && cmeth)
        {
        heat2(w0,w1,w2,winths,tmean,shuec,dshuec);
        acc1(xxlamc,s0a,s1a,s2a,apar,bpar,sumths,acuec,dacuec);
        }
else    {
        heat2(w0,w1,w2,winths,tmean,shuec,dshuec);
        acc2(cdd,acuec,dacuec);
        }

xd=xdays*24.0/1000.;
*shuec  *= xd;
*dshuec *= xd;
*acuec  *= xd;
*dacuec *= xd;
}

coef(h65,c65,a,b)
float   h65,c65,*a,*b;
{
float btop,bbot,g;
int     i;
extern  double  log(),exp();

btop=1.;
bbot=0.;
*b=1.;
for (i=1; i<=30; ++i)
        {
        g=1. - exp( (double) - *b * h65) - exp( (double) - *b * c65);
        if ( (g==0.) || ((btop-bbot)<.0001) ) break;
        if (g<0.) {bbot= *b;} else {btop= *b;}
        *b = (btop+bbot)/2.;
        }
*b = (btop+bbot)/2.;
*a = *b * (h65-65.)+log( (double) (1.-exp( (double) - *b * h65 )) );
return;
}

float   gamma(rrr)
float   rrr;
{
float   temp1,temp2,ggg;
extern  float   max1();
extern  double  exp();

temp1=max1(0.,rrr);
temp2=exp( (double) -temp1);
ggg=temp2*.00643169  *(exp( (double) 5.*rrr)-1.);
ggg=temp2*(-.03401569*(exp( (double) 4.*rrr)-1.)+ggg);
ggg=temp2*(.09649159 *(exp( (double) 3.*rrr)-1.)+ggg);
ggg=temp2*(-.24595448*(exp( (double) 2.*rrr)-1.)+ggg);
ggg=temp2*(.99949556 *(exp( (double)    rrr)-1.)+ggg);
ggg=(temp1*temp1/2.)+.82246703+ggg;
return(ggg);
}


float   heat(rrr1,c0,c1,c2,bpar)
float   rrr1,c0,c1,c2,bpar;
{
```

```
extern  double  exp(),log();
extern  float   gamma();
float   hhh;

hhh =  c0/(1.0+exp( (double) -rrr1));
hhh += c1*(log( (double) 1.0+exp( (double) rrr1)))/bpar;
hhh += 2.0*c2*gamma(rrr1)/(bpar*bpar);
return(hhh);
}


heat1(xxlamh,w0a,w1a,w2a,bpar,shuec,dshuec)
float   xxlamh,w0a,w1a,w2a,bpar,*shuec,*dshuec;
{
extern  float   heat();
*shuec  = heat(xxlamh,w0a,w1a,w2a,bpar);
xxlamh  +=bpar;
*dshuec = heat(xxlamh,w0a,w1a,w2a,bpar) - *shuec;
return;
}

heat2(w0,w1,w2,winths,tmean,shuec,dshuec)
float   *shuec,*dshuec,w0,w1,w2,winths,tmean;
{
extern  float   max1();
*shuec  = max1((w0 + w1*( winths-tmean) +
          w2*(winths-tmean)*(winths-tmean)),0.0);
*dshuec = max1((w0 + w1*(winths+1.-tmean) +
          w2*(winths+1.-tmean)*(winths+1.-tmean)),0.0) - *shuec;
return;
}

acc1(xxlamc,s0a,s1a,s2a,apar,bpar,sumths,acuec,dacuec)
float   xxlamc,s0a,s1a,s2a,apar,bpar,sumths,*acuec,*dacuec;
{
extern  double  pow();
*acuec =  s0a+s1a*( sumths - (-1.*apar/bpar))+
          s2a* pow( sumths - (- apar/bpar) , 2. );
*acuec += s2a*(3.289868)/(bpar*bpar) - heat(xxlamc,s0a,s1a,s2a,bpar);
xxlamc += -bpar;
*dacuec = s0a+s1a*( sumths -1. - (-1.*apar/bpar))+
          s2a* pow( sumths -1. - (-1.*apar/bpar),2.);
*dacuec += s2a*(3.289868)/(bpar*bpar) - heat(xxlamc,s0a,s1a,s2a,bpar)
           - *acuec;
return;
}

acc2(cdd,acuec,dacuec)
float   *acuec, *dacuec, cdd;
{
if (cdd==0.0) {*acuec=0.0;}  else { *acuec= -99.;}
*dacuec=0.;
return;
}

hvac(shuec,dshuec,acuec,dacuec,copg,copo,cophp,copac,sheatp,sheatd,sheatn,
     shuce,shucg,shuco,shude,shudg,shudo,shupe,shupg,shupo,shuchp,
     dshuce,dshucg,dshuco,dshude,dshudg,dshudo,dshupe,dshupg,dshupo,dshuchp)

float   shuec,dshuec,*acuec,*dacuec,copg,copo,cophp,copac,sheatp;
float   sheatd,sheatn;
float   *shuce,*shucg,*shuco,*shude,*shudg,*shudo,*shupe;
float   *shupg,*shupo,*shuchp;
float   *dshuce,*dshucg,*dshuco,*dshude,*dshudg,*dshudo,*dshupe;
```

```
float   *dshupg,*dshupo,*dshuchp;

{
*shuce=shuec;
*shucg=shuec/copg;
*shuco=shuec/copo;

*shude= *shuce * sheatd/sheatn;
*shudg= *shucg * sheatd/sheatn;
*shudo= *shuco * sheatd/sheatn;

*shupe = *shuce * sheatp/sheatn;
*shupg = *shucg * sheatp/sheatn;
*shupo = *shuco * sheatp/sheatn;

*shuchp=(shuec/cophp);
*acuec /= copac;

*dshuce=dshuec;
*dshucg=dshuec/copg;
*dshuco=dshuec/copo;

*dshude = *dshuce * sheatd/sheatn;
*dshudg = *dshucg * sheatd/sheatn;
*dshudo = *dshuco * sheatd/sheatn;

*dshupe = *dshuce * sheatp/sheatn;
*dshupg = *dshucg * sheatp/sheatn;
*dshupo = *dshuco * sheatp/sheatn;

*dshuchp=dshuec/cophp;
*dacuec /= copac;
}

float   min1(x,y)
float   x,y;
{
return(x>=y ? y : x);
}

float   max1(x,y)
float   x,y;
{
return(x>=y ? x : y);
}

output121(fp,i,j,xlamc_out, xlamh_out,
                sheatp,sheatd,sheatn,acheat,
                shuce,shucg,shuco,shude,shudg,shudo,
                  shupe,shupg,shupo,dshuce,dshucg,
                  dshuco,dshude,dshudg,dshudo,dshupe,dshupg,dshupo,
                  shuchp,dshuchp,acuec,dacuec)
FILE    *fp;
int     i,j;
float   xlamc_out, xlamh_out;
float   sheatp,sheatd,sheatn,acheat;
float   shuce,shucg,shuco,shude,shudg,shudo,shupe,shupg,shupo;
float   dshuce,dshucg,dshuco,dshude,dshudg,dshudo;
float   dshupe,dshupg,dshupo;
float   shuchp,dshuchp,acuec,dacuec;
{
/* CASE NUMBER, MONTH NUMBER,
BALANCE TEMP Cool, Heat,
CAPACITY UTILIZATION non-central duct, duct, hot-water, air-cond (BTUS's Hour)
```

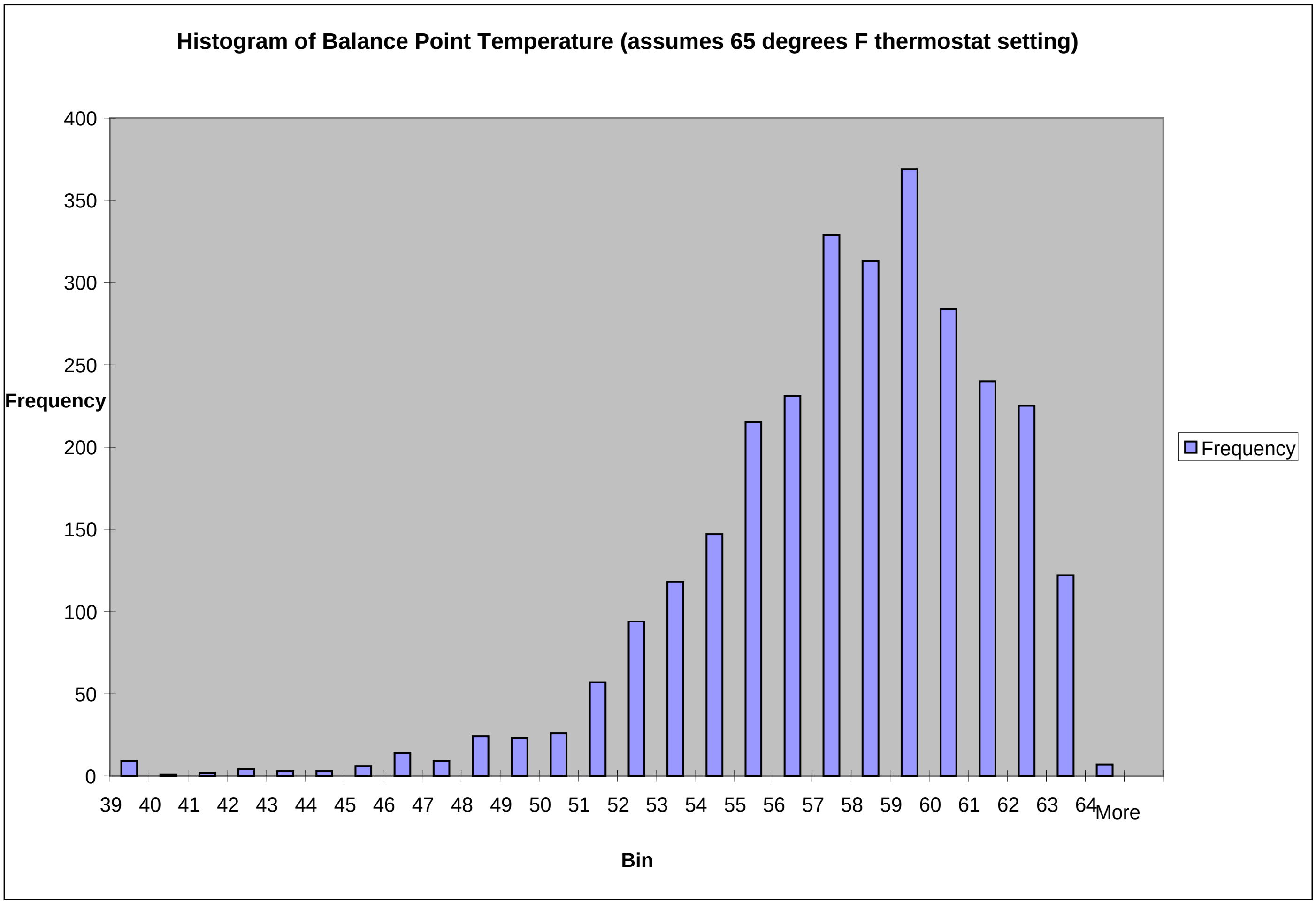
```
NON-CENTRAL SYSTEMS elec, gas, oil,
CENTRAL DUCT SYSTEMS elec, gas, oil,
HOT-WATER DELIVARY elec, gas, oil,
HEAT-PUMP SYSTEM,
AIR-CONDITIONING */

fprintf(fp,"%4d %4d %15.8f %15.8f ", i+1,j+1,xlamc_out,xlamh_out);

fprintf(fp,"%15.8f %15.8f %15.8f %15.8f \
            %15.8f %15.8f %15.8f %15.8f %15.8f %15.8f \
            %15.8f %15.8f %15.8f %15.8f %15.8f %15.8f \
            %15.8f %15.8f %15.8f %15.8f %15.8f %15.8f \
            %15.8f %15.8f %15.8f %15.8f",
            sheatn,sheatd,sheatp,acheat,
            shuce,dshuce,shucg,dshucg,shuco,dshuco,
            shude,dshude,shudg,dshudg,shudo,dshudo,
            shupe,dshupe,shupg,dshupg,shupo,dshupo,
            shuchp,dshuchp,acuec,dacuec);

fprintf(fp,"\n");
}
```

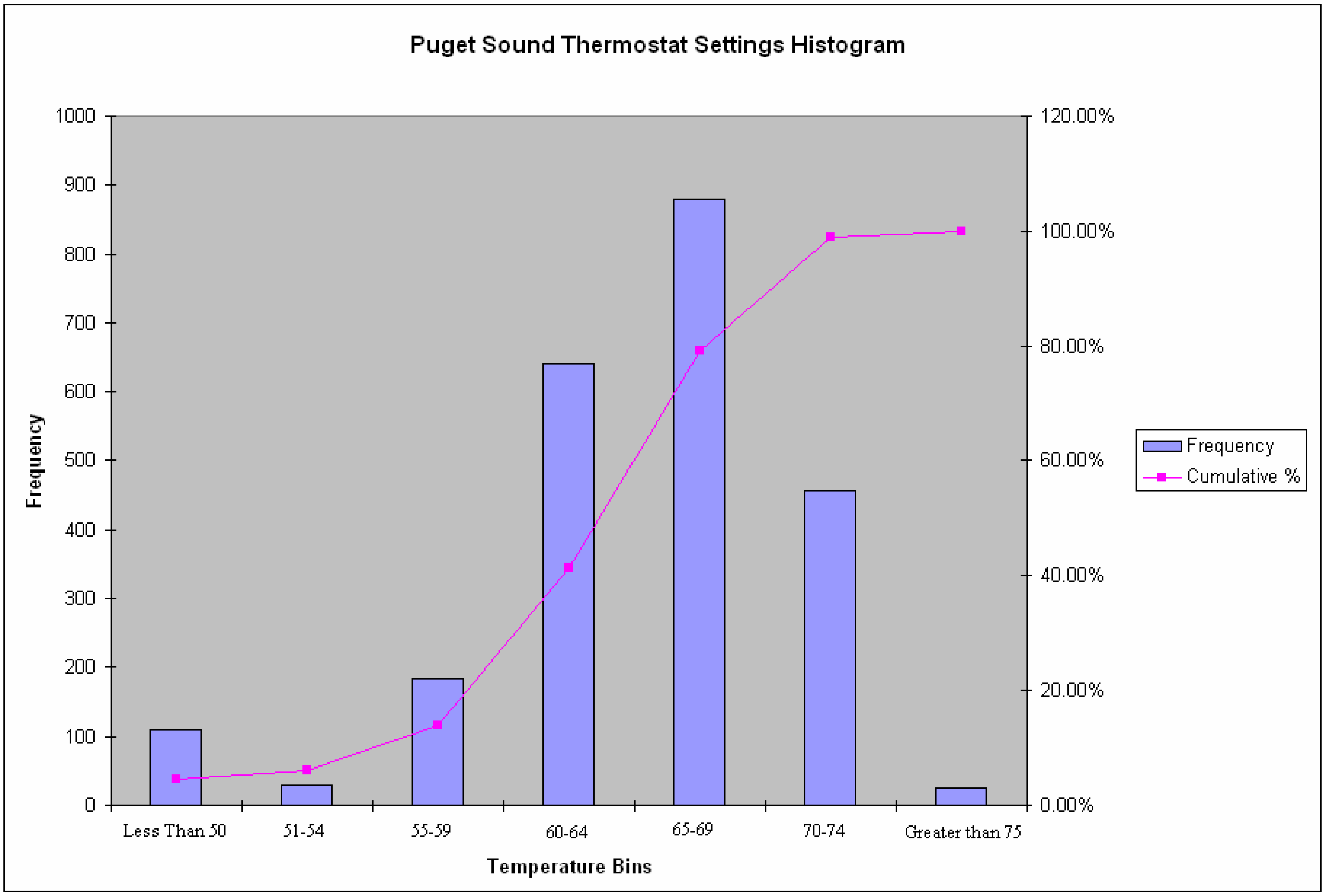
Appendix F

Reg.log

```
SST Spool File:  reg.log


read to[case case_num xlamh shuce{1-36}] file[jad.out]

cova var[xlamh]

Variable:    xlamh

Mean                    -8.11150      Standard deviation
3.80298
Minimum                -39.75851      Skewness                -
1.35748
Maximum                 -1.64159      Kurtosis
7.35549
Valid observations      2875


save file[reg.sav] var[case case_num shuce{1-36} xlamh]
save file[reg.dbf] var[case case_num shuce{1-36} xlamh] dbase

match file[jad] key[case_num] var[weight]
calc sum(xlamh*weight)/sum(weight)
     -7.86989

quit
```

Histogram


Histogram of Balance Point Temperature (assumes 65 degrees F thermostat setting)
Frequency
400
350
300
250
200
150
100
50
0
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
More
Bin
Frequency


Puget Sound Thermostat Settings Histogram
Frequency
1000
900
800
700
600
500
400
300
200
100
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
Less Than 50
51-54
55-59
60-64
65-69
70-74
Greater than 75
Temperature Bins
Frequency
Cumulative %

CHAPTER 2

A heating and cooling load model for single-family detached dwellings[1]

2.1. Introduction

The National Interim Energy Consumption Survey (NIECS) and the Pacific Northwest Residential Energy Survey (PNW) are clustered, random samples of households interviewed between 1978 and 1980. These surveys were designed to report household equipment holdings and energy consumption by fuel, as well as selected household and dwelling characteristics. To study the economic determinants of equipment and usage behavior, it is necessary first to describe the economic environment in which behavior is determined. This chapter carries out the construction of heating-ventilating-air conditioning (HVAC) physical characteristics and costs for alternative systems available to single-family, owner-occupied households.

The approach of this chapter is to construct a very simple thermal model of representative dwellings with characteristics corresponding to those available in typical energy survey data. This model is used to estimate heating and cooling capacity requirements, energy usage, and physical characteristics for households in the NIECS and PNW surveys. Cost data from Means (1981) are then used to estimate the capital and operating costs of 19 alternative HVAC configurations for the actual thermal integrity of the building shell and for two alternative thermal standards.

---

[1] This chapter revises and extends a coauthored draft with Daniel McFadden entitled "A Thermal Model for Single-Family Owner-Occupied Detached Dwellings in the National Interim Energy Consumption Survey," M.I.T. Energy Laboratory Discussion paper No. 25, MIT-EL 82-040WP. Our research was supported in part by NSF Grant No. 80-16043-DAR, Department of Energy, under Contract No. EX-76-A-01-2295, Task Order 67, and the Environmental Quality Laboratory of the California Institute of Technology. We wish to acknowledge a substantial contribution to this research by Thomas Cowing, who provided weather and location data for NIECS households, and to Jean Yates-Rimpo, who provided assistance with the Pacific Northwest data.

2.2. Thermal modeling principles

Heating and cooling system design capacities of a dwelling are determined by the rates of heat transfer between the interior and exterior under extreme weather conditions. Conduction and infiltration are the dominant modes of transfer in winter; radiation is important in summer. Heating capacity calculations normally assume steady-state thermal conditions, while cooling calculations take account of inertial (flywheel) effects.

The approach to capacity calculation adopted here follows engineering practice, as detailed in ASHRAE (1977, 1978, 1979), Anderson (1973), Khashab (1977), and Streeter (1966). Application of these principles to the NIECS and PNW households requires a number of assumptions and model simplifications due to incomplete data on dwelling characteristics.

A dwelling may be pictured as a box with walls of varying thermal resistances to conduction of heat, as depicted in Figure 2.1.

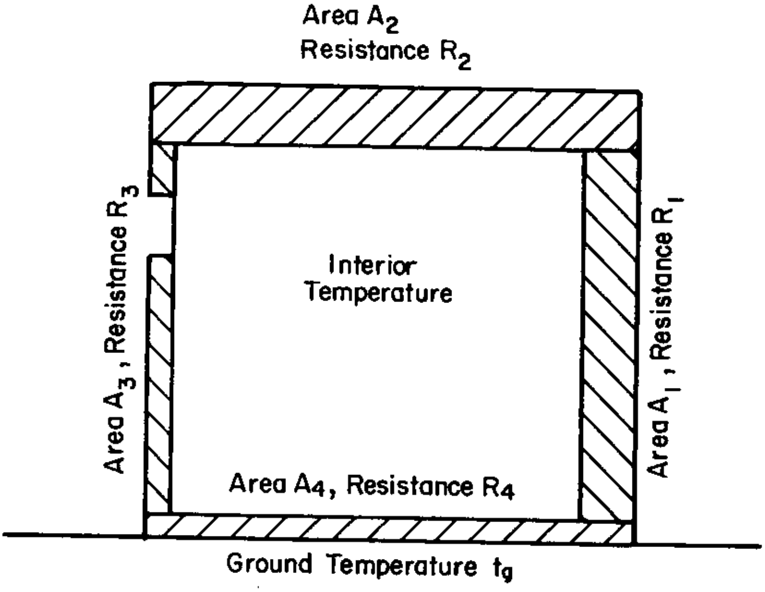


Figure 2.1

The net heat loss by conduction from the dwelling in Btuh is the sum of the losses through each area, which equals the area times the temperature differential divided by the resistance (measured in ft^2 × °F / Btuh):

$$\begin{aligned}\begin{array}{c}\text{Net conduction}\\ \text{heat loss}\end{array} &= \frac{A_1\,(T_i-T_e)}{R_1} + \frac{A_2\,(T_i-T_e)}{R_2} \\ &\quad + \frac{A_3\,(T_i-T_e)}{R_3} + \frac{A_4\,(T_i-T_g)}{R_4}\end{aligned} \tag{1}$$

This formula omits boundary effects due to the exterior temperature gradient near the ground surface and at the interface of surfaces with different resistances. In practice, these effects are usually small and can be neglected. When a correction is required, it can be calculated using elementary circuit theory. The method is illustrated in Figure 2.2 for the example of a wall in a heated basement that has an exterior temperature gradient. The wall can be represented by a network of nodes connected by conductors with resistances equal to the thermal resistances of the intervening material. The precision of the calculation is improved by increasing the number of nodes. In the example, R_1 and R_2 are resistances of wall material from the dwelling interior to the wall center and from the wall center to the exterior, while R_7 is a resistance to vertical conduction. Heat flow along a link equals the temperature difference between the link nodes times the cross-sectional area represented by the link, divided by the resistance of the link. In thermal equilibrium, net heat flow into an interior node is zero. These conditions plus the interior and exterior temperatures define a system of linear equations in the node temperatures and link heat flows. In the example, these equations are:

$$\begin{bmatrix} R_1^{-1}+\lambda R_7^{-1}+R_2^{-1} & -\lambda R_7^{-1} & 0 \\ -\lambda R_7^{-1} & R_3^{-1}+R_4^{-1}+\lambda R_7^{-1}+\lambda R_8^{-1} & -\lambda R_8^{-1} \\ 0 & -\lambda R_8^{-1} & R_5^{-1}+R_6^{-1}+\lambda R_8^{-1} \end{bmatrix}$$

$$\times \begin{bmatrix} T_i-T_1' \\ T_i-T_2' \\ T_i-T_3' \end{bmatrix} = \begin{bmatrix} R_2^{-1}(T_i-T_1) \\ R_4^{-1}\,(T_i-T_2) \\ R_6^{-1}(T_i-T_3) \end{bmatrix} \tag{2}$$

where the cross-sectional areas associated with R_1 and R_6 are assumed to equal 1 and the cross-sectional areas associated with R_7 and R_8 are assumed to equal λ. Then:

$$H = \frac{1}{3}\,(\text{wall area})\left(\frac{T_i - T_1'}{R_1} + \frac{T_i - T_2'}{R_3} + \frac{T_i - T_3'}{R_5}\right) \tag{3}$$

is the heat loss through the wall.

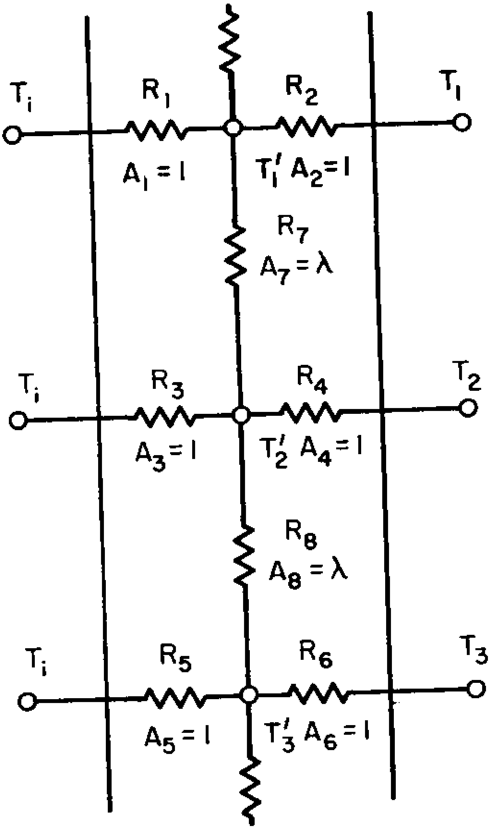


Figure 2.2

ASHRAE (1977, Chap. 22) provides data on the resistances of various construction materials. These permit calculation of resistances of standard construction. The NIECS/PNW data do not indicate type of wall construction, whether the roof is pitched, whether there is a basement, or whether walls and roof are light or dark. For purposes of estimating design capacities, we therefore make the following assumptions:

1. Exterior walls are of standard frame construction with exterior wood siding.
2. The dwelling has a pitched roof with an unheated attic with natural ventilation.
3. There is an *unheated* basement that is primarily below grade.
4. Roof and walls are dark in color.

It should be noted that variations in construction will cause substantial variations in the thermal performance of dwellings. Hence, the model developed here should not be expected to predict precisely dwelling-to-dwelling variations in thermal performance, even for dwellings satisfying the four assumptions above. On the other hand, construction standards tend to compensate for differences in resistance usually arising in dwellings that do not fit these assumptions. For example, construction standards for flat roofs generally call for insulation between roofing and sheathing, which offsets the loss of resistance provided by an attic. Similarly, masonry walls with lower resistance than frame walls are normally more heavily insulated, as are slab floors in comparison with construction over an unheated basement. Consequently, we do not expect resistance calculations based on the assumptions above to be systematically biased for alternative types of construction. Table 2.1 gives the resistance of standard frame exterior wall construction. Table 2.2 gives the resistance of ceiling and roof for flat and pitched roofs. A later analysis incorporating the effects of solar radiation will combine these resistances into a single, effective ceiling-roof resistance. Table 2.3 gives the resistance of glass, excluding radiation effects. Table 2.4 gives floor resistance.

Table 2.1

Exterior wall resistance

Material	R-value
Outside Surface (15 mph windspeed)[1]	0.17
Wood Siding	0.87
Building Paper	0.06
Sheathing (0.5 plywood)	0.62
Air Space (framing)[2]	0.94 (4.38)
Gypsum Wallboard	0.45
Inside Surface	0.68
Resistance of portion of wall with framing (10 for 16 o.c. framing)	7.23
Resistance of portion of wall without framing or insulation	3.79
Resistance of portion of wall with insulation (R-value = I)	2.85 + I
Average resistance of wall without insulation[3]	3.98
Average resistance of wall with insulation (R-value = I)[3]	$\dfrac{12.85 + I}{0.9394 + 0.0138I}$

[1] Surface resistance decreases with wind speed. The ASHRAE design standard is 15 mph winter windspeed and 7.5 mph summer windspeed, the latter giving a surface resistance of 0.25.

[2] Standard 2" × 4" framing is assumed, giving an air space of 3.75 . Without insulation the R-value of the air space is 0.94. At typical insulation R-value of 3.0/inch, the R-value of light insulation (1.5) is 4.5, and of heavy insulation (3.5) is 10.5. The R-value of the wood framing members is 1.17 per inch.

[3] The average resistance of the wall satisfies:

$$R^{-1}_{average} = R^{-1}_{framing} \binom{proportion}{framing} + R^{-1}_{other} \binom{proportion}{other}.$$

Source: ASHRAE (1977), 22.13-22.22, particularly Tables 4A,G,I,K.

Table 2.2

Ceiling and roof resistance

Flat Roof and Ceiling	Heating R-value	Cooling R-value
Outside Surface (15 mph winter, 7.5 mph summer)	0.17	0.25
Roofing	0.33	0.33
Roof Insulation	1.39	1.39
Plywood Deck	0.78	0.78
Air Space[1](framing)	0.85 (6.73)	1.23 (6.73)
Gypsum Wallboard	0.45	0.45
Inside Surface	0.61	0.76
Resistance without insulation in air space[2]	4.85	5.47
Resistance with insulation (R-value = I) in air space[3]	$\frac{3.73 + I}{0.936 + .01I}$	$\frac{3.96 + I}{0.937 + 0.1I}$
Pitched Roof and Ceiling Roof		
Outside Surface (15 mph winter, 7.5 mph summer)	0.17	0.25
Roofing	0.44	0.44
Building Paper	0.06	0.06
Plywood Deck (5/8)	0.78	0.78
Inside Roof Surface	0.62	0.76
Framing[1]	5.84	5.84
Roof resistance[2]	2.24	2.47

[1] Framing is assumed to be 2" × 6", 16" o.d., giving 10 percent of total area.

[2] The formula is:

$$R^{-1}_{average} = R^{-1}_{framing} + 0.9\, R^{-1}_{other}$$

The contribution of open framing to resistance is negligible.

Source: ASHRAE (1977), 22.13-22.22.

Table 2.2 (cont.)

Ceiling and roof resistance

Attic Wall		
Outside Surface	0.17	0.25
Wood Siding	0.87	0.87
Building Paper	0.06	0.06
Sheathing	0.62	0.62
Inside Wall Surface	0.68	0.68
Framing[1]	4.38	4.38
	------	------
Wall Resistance[2]	2.57	2.65
Ceiling		
Upper Surface	0.61	0.76
Insulation (framing)[1]	I (4.48)	I (4.38)
Gypsum Board	0.45	0.45
Inside Surface	0.61	0.76
Ceiling Resistance	$1.67 + I$	$1.97 + I$
	$0.9276 + 0.0165I$	$0.9310 + 0.0157I$

[1] Insulation fills the air space.
[2] Framing is assumed to be 2" × 4", 16" o.d., giving 10 percent of total area.
Source: ASHRAE (1977), 22.13-22.22.

Table 2.3

Resistance of windows

Material	Heating R-value	Cooling R-value
Single Glazed (no storm)[1]	.98	1.05
Double Glazed (storm)[1]	2.78	—
Sliding Glass Door, Single Glazed	.88	.94
Sliding Glass Door, Double Glazed	1.32	1.43

[1] Assume wood sash, 80 percent glass.
Source: ASHRAE (1977), 22.24.

Table 2.4

Resistance of floor

Material	Heating R-value	Cooling R-value
Top Surface	.61	.76
Tile	.05	.05
Felt Pad	.06	.06
Plywood	.78	.78
Subfloor	.94	.94
Insulation (R-7)	7.00	7.00
Bottom Surface	.61	.76
Total Resistance[1]	10.05	10.35

[1] The resistance of a slab floor is similar after adjustment for additional insulation. Winter ground temperatures below the frost level are approximately:

$$t_g = 36 + 0.3\ t_e$$

where t_e is design temperature. Basement wall losses due to the temperature gradient above the frost line are neglected. Slab edge losses with insulation are assumed comparable to unheated basement losses. Net heat transfer through the floor in summer is neglected.

Source: ASHRAE (1977, 22.20, Table 4G, and 24.4).

2.2.1. Winter heating load

The combined resistance of ceiling, attic, and roof is calculated as follows: In winter, thermal equilibrium requires:

$$0 = -\frac{A_r}{R_r}(t_a - t_e) - \frac{A_w}{R_w}(t_a - t_e) + \frac{A_c}{R_c}(t_i - t_a) \tag{4}$$

where t_a is attic temperature, A_c, A_r, A_w are ceiling, roof, and attic wall areas, and R_c, R_r, R_w are resistances. Then:

$$t_i - t_a = \frac{\left(\frac{A_r}{R_r} + \frac{A_w}{R_w}\right)(t_i - t_e)}{\left[\frac{A_c}{R_c} + \frac{A_r}{R_r} + \frac{A_w}{R_w}\right]} \tag{5}$$

so the net ceiling heat flux is:

$$\frac{Q}{A_c} = \frac{\left(\frac{A_r}{A_c}\frac{1}{R_r} + \frac{A_w}{A_c}\frac{1}{R_w}\right)}{\left(1 + \frac{A_r}{A_c}\frac{R_c}{R_r} + \frac{A_w}{A_c}\frac{R_c}{R_w}\right)}(t_i - t_e) = \frac{t_i - t_e}{R_{eff}} \tag{6}$$

For a sample of six representative dwellings with pitched roofs, the average value of A_r/A_c is 1.12 and the average value of A_w/A_c is 0.08. These are used along with the resistances in Table 2.2 to calculate the effective winter ceiling resistance for a dwelling with an attic:

$$R_{eff} = \frac{\left\{1 + 1.12\frac{R_c}{R_r} + 0.08\frac{R_c}{R_w}\right\}}{\left\{1.12\frac{1}{R_r} + 0.08\frac{1}{R_w}\right\}} = \frac{3.416 + 1.031\ I}{0.9276 + 0.0165\ I} \tag{7}$$

A first order Taylor's expansion of (7) about $I = 3$ gives the approximation:

$$R_{eff} \doteq 3.834 + 0.943\ I \tag{8}$$

For comparison, the resistance of a flat roof and ceiling is approximately:

$$R \doteq 4.064 + 0.960\ I \tag{9}$$

Typical values are:

I	.85	3	6	9
R_{eff}	4.56	6.66	9.35	11.80
approx R_{eff}	4.63	6.66	9.50	12.32
R	4.83	6.95	9.74	12.37
approx R	4.88	6.95	9.83	12.71

On the basis of this comparison, we choose (8) as an adequate approximation of the resistance of all roofs, pitched or flat.

Infiltration is a function of the integrity of the dwelling shell and pressure differentials created by wind, stack effects, and temperature differences. A common method of calculating infiltration effects is to determine the number of air changes per hour in the dwelling K . Then the heat transfer is:

$$\text{Net infiltration heat loss} = 0.018\, KV\, (t_i - t_e) \tag{10}$$

where V is the volume of the dwelling (ft^3), 0.018 equals the Btu's required to heat 1 cu. ft. of air by 1 °F, and $t_i - t_e$ is the temperature differential (ASHRAE, 1977. 24.6).

Air changes per hour in most dwellings are in the range $0.5 \leqslant K \leqslant 1.5$ for heating and $1 \leqslant K \leqslant 2$ for cooling. Dwellings with $K < 0.5$ are "stuffy" and $K \geqslant 2$ are "drafty." Experimental measurements by Achenback and Coblentz (1963) give an air change rate:

$$K = 0.25 + 0.02165\,(\text{wind velocity}) + 0.00833\,|t_i - t_e| \tag{11}$$

for an average dwelling. Detailed calculations by Anderson (1973) permit a calculation of the effect of integrity of the shell on this rate. For tight construction, with storm doors and windows, the rate is reduced 14 percent; for loose construction, it is increased 14 percent. Therefore, we multiply the value of K in (11) by a factor:

$$1.14 - 0.28\,(\text{proportion of window area stormed}) \tag{12}$$

An additional factor entering thermal calculations is the heat generated internally by occupants and appliances. ASHRAE (1977, 25.17, 25.41) design standards typically assume each occupant generates 225 Btuh in normal activity, while lighting and appliances generate 1200 Btuh. Anderson reports a higher internal load from lighting and appliances of 3083 Btuh, and an effective load-per-occupant of 318 Btuh due to the daily pattern of occupancy. For purposes of calculating design capacity, we use the ASHRAE standards. We follow the usual practice of including internal load in the calculation of air conditioner capacity requirements, but excluding it in heating capacity requirements. The winter heat transfer calculations may now be summarized in Table 2.5.

Table 2.5

Summary of winter heating capacity calculation

Design Btuh is the sum of the following components:

1. Wall losses:
(Exterior wall area surrounding heated space, excluding windows)

$$\times \frac{0.9394 + 0.0138\, I_w}{2.85 + I_w} \cdot (75 - t_e)$$

2. Ceiling losses:

$$\begin{bmatrix}\text{ceiling}\\ \text{area}\end{bmatrix} \cdot (3.834 + 0.943\, I_c)^{-1} \cdot (75 - t_e)$$

3. Floor losses:

$$\begin{bmatrix}\text{ceiling}\\ \text{area}\end{bmatrix} \cdot [75 - (36 + 0.3\, t_e)]/10.05$$

4. Window losses:

$$\left(\frac{A_{ws}}{2.78} + \frac{A_{wn}}{0.98} + \frac{A_{sds}}{1.32} + \frac{A_{sdn}}{0.88}\right) \cdot (75 - t_e)$$

5. Infiltration losses:

$$1.14 - \frac{0.28\,(A_{ws} + A_{sds})}{(A_{ws} + A_{wn} + A_{sds} + A_{sdn})}$$

$$\times\ [0.25 + 0.02165(15) + 0.00833(75 - t_e)]$$

$$\times\ (0.018)\, V\, (75 - t_e)$$

I_w	R-value of wall insulation (0.94 for air gap if no insulation)
I_c	R-value of ceiling insulation
t_i=75	interior design temperature (°F)
t_e	exterior winter design temperature (°F)
A_{ws}	area of stormed windows (ft^2)
A_{wn}	area of non-stormed windows (ft^2)
A_{sds}	area of stormed sliding glass doors (ft^2)
A_{sdn}	area of non-stormed sliding glass doors (ft^2)
V	volume of conditioned space (ft^3)

2.2.2. Summer cooling load

The rate of instantaneous heat gain during the summer is classified by the mode in which heat enters the residence. Heat gain occurs in the form of: (1) solar radiation through transparent surfaces; (2) heat conduction through interior partitions, ceilings, and floors; (3) heat conduction through exterior walls and roof; (4) heat generated within the space by occupants and equipment; (5) energy transfer as a result of ventilation and infiltration of outdoor air; and (6) all miscellaneous heat gains.

Precise calculation of the effects of solar radiation on air conditioning requirements necessitates measurement of the angle of incidence of radiation on each surface of the shell, degree of shading, and reflectance of the surface over the day. Heat flux into the surface satisfies (ASHRAE, 1977, 25.4):

$$(\text{Btuh per ft}^2) = \alpha I_r + (t_o - t_i)/R - \xi\rho \tag{13}$$

where:

t_o outdoor air temperature, °F

α absorptance of surface for solar radiation

I_r solar radiation incident on surface (Btuh/ft^2)

R resistance of surface to radiation and convection heat transfer

ξ emittance of surface

ρ correction for difference between sky and black-body radiation spectrum

The value of I_r will be a function of latitude, time of day, and the orientation of the surface. ASHRAE converts this equation to a *sol-air temperature equivalent*:

$$t_{sa} = t_o + R\ (\alpha I_r - \xi\rho) \tag{14}$$

so that:

$$(\text{Btuh per ft}^2) = (t_{sa} - t_i)/R \tag{15}$$

The temperature t_{sa} is the outdoor temperature that, in the absence of radiation exchanges, gives the same rate of heat entry into the incident surface as exists under standard conditions. The calculation of heat gain combines transient thermal properties of building materials and sol-air equivalent temperatures by the transfer function method (ASHRAE, 1977, 25.27). The rate of instantaneous heat gain will not, however, generally determine instantaneous cooling load. Radiant energy is first absorbed by surfaces that enclose the space. As these surfaces become warmer than the space air, heat is transferred into the room by convection. A transfer function method is used to convert instantaneous heat gain into cooling load.

For hour-by-hour calculation, ASHRAE provides values of the thermal transfer coefficients for roofs and walls under a variety of constructions indexed by weight and average conductivity (ASHRAE, 1977, 25.28, Table 26, and 25.29, Table 27). In Table 2.6 we estimate roof density and weight for the roof materials assumed in Table 2.2. To approximate the conditions maintained in Table 2.2, we examine ASHRAE roofs #22 and #25 with weight of 8 lbs./ft^3 and conductances 0.109 and 0.170 respectively.

Table 2.6

Roof densities and weights

Flat Ceiling and Roof:	Thickness	Density (lbs./ft^3)
Roofing	.375"	70.
Roof Insulation	–	--
Plywood Deck	.625"	34.
Airspace (framing)	5.75"	0.(32)
Wallboard	.5"	50.

Density of section with wood-framing:
$(.375 \times 70 + .625 \times 34 + 5.75 \times 32 + .5 \times 50)/7.25 = 35.37$

Density of section without framing:
$(.375 \times 70 + .625 \times 34 + .5 \times 50)/7.25 = 10$

Average density: (assume framing is 10 percent of material)
$(.10 \times 35.379 + .09 \times 10) = 12.54$ lbs./ft^3

Weight:

Consider a 1 ft^2 section of ceiling. Thickness is (7.25/12) ft., which implies a volume of 0.60417 ft^3. Average weight is 7.8 lbs./ft^2

Density and weight for a pitched roof are 9.06 lbs./ft^3 and 6.47 lbs./ft^2 respectively.

The transfer function method for calculation of instantaneous heat gain through roofs and exterior walls assumes constant indoor temperature and represents outdoor conditions by sol-air equivalent temperatures. Heat gain (at hour h) arising through a roof or wall is:

$$q(h)/A = B(L)t_{sa}(h) - D(L)q(h)/A - t_iC \tag{16}$$

where:

A = indoor surface area of a roof or wall, ft^2

$q(h)$ = heat gain, Btuh/ft^2

h = solar hour

$t_{sa}(h)$ = sol−air temperature at hour h, °F

t_i = indoor temperature, °F

$B(L), D(L)$ = lag-polynomials of the transfer function

Table 2.7 presents the transfer function polynomials for ASHRAE roofs #22 and #25. Note that (16) implies:

$$[\, I + D(L) \,] \cdot q(h)/A = B(L)t_{sa}(h) - t_iC \tag{17}$$

In the calculation of $q(h)/A$, initial conditions may be arbitrary provided the polynomial $(I + D(L))$ is invertible. This condition in turn requires that the characteristic equation $F(X) = 1 + d_1X + d_2X^2 + d_3X^3$ have roots that lie within the unit circle in the complex plane. It may be verified that the roofs (and walls) considered in our analysis satisfy this property by direct solution of the cubic equation. The driving function $t_{sa}(h)$ is assumed periodic (with a one-day period) so that calculation of $q(h)/A$ simply requires repeating successive 24-hour cycles in (16) to allow the effect of initial conditions to become negligible.

Table 2.7

Transfer function polynomials for ASHRAE roofs #22 and #25

$B(L) = b_0 + b_1 L + b_2 L^2 + b_3 L^3$

$D(L) = d_0 + d_1 L + d_2 L^2 + d_3 L^3$

Roof #22:	n=0	n=1	n=2	n=3	U	C
b	0.0012	0.0180	0.0150	0.0011		
d	0.0000	-0.8098	0.1357	-0.0007	0.109	0.0353
Roof #25:	**n=0**	**n=1**	**n=2**	**n=3**	U	C
b	0.0043	0.0385	0.0202	0.0007		
d	0.0000	-0.7314	0.1061	-0.0003	0.170	0.0637

U — conductance
C — indoor temperature
L — lag operator

The hourly cycle for $t_{sa}(h)$ will depend on roof and/or wall orientation and the daily cycle of outdoor temperatures. Outdoor temperature will itself follow a pattern determined by the average temperature and daily range of temperatures. Table 2.8 presents the percentages of the daily range used in the calculation of the daily temperature cycle.

Table 2.8

Percentage of the daily range

Time, Hour	Percent	Time, Hour	Percent
1	87	13	11
2	92	14	3
3	96	15	0
4	99	16	3
5	100	17	10
6	98	18	21
7	93	19	34
8	84	20	47
9	71	21	58
10	56	22	68
11	39	23	76
12	23	24	82

Application: temperature at hour h = (maximum temperature) - (percentage) (temperature range) = (daily average temperature) + (0.5-percentage) (temperature range).
Source: (ASHRAE, 1977, 25.4, Table 3).

ASHRAE (1977, 25.2, Table 2) provides sol-air temperatures for roofs and walls on a day with maximum temperature of 95°F and daily range of temperatures equal to 21°F. We assume that the difference between sol-air temperatures and outdoor temperatures remains constant independent of the daily mean and range of temperatures. Table 2.9 presents the sol-air temperature differences.

Table 2.9

Sol-air temperature differences

Time	Temp. Difference	Time	Temp. Difference
1	0.0	13	25.4
2	0.0	14	28.3
3	0.0	15	30.4
4	0.0	16	29.2
5	0.0	17	26.4
6	17.6	18	17.6
7	26.4	19	0.0
8	29.2	20	0.0
9	30.4	21	0.0
10	28.3	22	0.0
11	25.4	23	0.0
12	23.4	24	0.0

Assume dark-colored surfaces averaged over orientations in the proportions: N—10 percent; S—15 percent; NE, E, SE, SW, W, NW—12.5 percent.
Source: (ASHRAE, 25.5, Table 2).

To determine cooling load for varied materials and weather conditions, we generate hourly heat flux values when average temperature varies between 70° and 110° (in increments of 5°), daily temperature range varies between 10° and 30° (in increments of 10°), and inside temperature varies between 68° and 84° (in increments of 2°). A convergence criteria for the heat flux profile is suggested by equation (17) evaluated at mean values:

$$[\, I + D(L)\,] \cdot \bar{q}/A = B(L)\,\bar{t}_{sa} - t_i\, C \tag{18}$$

which implies:

$$(1 + d_1 + d_2 + d_3)(\bar{q}/A) = (b_0 + b_1 + b_2 + b_3)\,\bar{t}_{sa} - t_i\, C \tag{19}$$

where $\bar{q}$ and $\bar{t}_{sa}$ are average values of $q(h)$ and $t_{sa}(h)$ respectively. From (19) we see that:

$$\bar{q}/A = \frac{(b_0 + b_1 + b_2 + b_3)}{(1 + d_1 + d_2 + d_3)}\,\bar{t}_{sa} - \frac{C}{(1 + d_1 + d_2 + d_3)}\,t_i \qquad (20)$$

It is easy to check that the coefficients used in the transfer function method satisfy $C = b_0 + b_1 + b_2 + b_3$ and that conductance U satisfies:

$$U = (b_0 + b_1 + b_2 + b_3)/(1 + d_1 + d_2 + d_3) \qquad (21)$$

Thus convergence of the heat flux profile is accomplished when the sample average of a 24-hour predicted heat flux profile is approximately $U(\bar{t}_{sa} - t_i)$.

Having determined an estimated hourly heat flux profile, we may use the transfer function method to determine hourly cooling load:

$$Q(h)/A = v_0 q(h)/A + v_1 q(h-1)/A - w_1 Q(h-1)/A \qquad (22)$$

where:

$Q(h)$ = cooling load at hour h (Btuh/ft^2)

v_0, v_1, w_1 = coefficients of the room transfer function

The values of v_0, v_1, and w_1 were determined under the assumptions of (1) low room air circulation; (2) 2" wood floor; and (3) frame exterior wall (ASHRAE, 1977, 25.35 - 25.36, Tables 30 and 31). Iterating the stationary heat flux profile until convergence provides hourly cooling loads. Daily cooling load attributable to a surface is then approximately the sum of positive cooling loads arising from that surface over the course of a day. This relationship is only approximate, because the cooling load transfer function applies to the total of all sources of heat flux rather than to the sum of all source cooling loads.

To illustrate the calculation, we present in Table 2.10 the daily profile of outdoor and sol-air temperatures as well as instantaneous heat flux and cooling loads for ASHRAE roof #22 on a day with mean 85°, range 21°, and inside temperature of 75°.

Table 2.10
Output from thermal transfer function calculation for a typical day[1]

Hour	Outside Temp.	Sol-Air Temp. Difference (Sol-Air - outside)	Sol-Air Temp.	Cooling Load Temp.Diff.[2]	Heat Flux
1	77.23	0.00	77.23	13.88	0.91
2	76.18	0.00	76.18	11.65	0.67
3	75.34	0.00	75.34	9.76	0.48
4	74.71	0.00	74.71	8.11	0.32
5	74.50	0.00	74.50	6.69	0.20
6	74.92	17.60	92.52	5.63	0.12
7	75.97	26.40	102.37	6.97	0.41
8	77.86	29.20	107.06	11.09	1.11
9	80.59	30.40	110.99	16.03	1.89
10	83.74	28.30	112.04	20.66	2.59
11	87.31	25.40	112.71	24.50	3.13
12	99.67	23.40	114.07	27.43	3.50
13	93.19	25.40	118.59	29.76	3.78
14	94.87	28.30	123.17	32.14	4.05
15	95.50	30.40	125.90	34.97	4.40
16	94.87	29.20	124.07	37.94	4.76
17	93.40	26.40	119.80	40.27	5.01
18	91.09	17.60	108.69	41.23	5.06
19	88.36	0.00	88.36	39.98	4.77
20	85.63	0.00	85.63	35.39	3.98
21	83.32	0.00	83.32	29.32	3.02
22	81.22	0.00	81.22	24.09	2.24
23	79.54	0.00	79.54	19.93	1.66
24	78.28	0.00	78.28	16.60	1.23

[1] Mean temperature 85°F, temperature range 21°F, inside temperature 75°F, ASHRAE roof #22 with U = 0.109.

[2] Total cooling load temperature difference = 544. Btu/ft^2.

To summarize the relationship of cooling load to standard weather inputs, we have calculated total and maximal cooling load temperature differences for two roofs and four walls over the ranges of temperatures specified above.[2] Each test surface generates 243 observations, which are

---

[2] A FORTRAN program that implements the thermal transfer function calculations is reproduced in Dubin and McFadden (1983).

used to estimate summary regression formulae. The regression results presented in Table 2.11 are used below in the calculation of daily cooling load and cooling load capacity.

Table 2.11

Summary of regression results

Structure	(Mean-Inside) Temperature	Temperature Range	Constant
Dependent variable is Total Cooling Load Temperature Difference[1]			
1	22.66	-1.032	355.6
2	22.71	-1.012	358.4
3	22.67	-0.9638	362.1
4	22.49	-0.9535	359.5
5	22.58	-0.9526	361.5
6	22.48	-0.9357	360.9
Dependent variable is Maximum Cooling Load Temperature Difference[2]			
1	0.9958	0.2820	25.35
2	1.0010	0.2988	25.55
3	1.0050	0.3196	26.27
4	0.9972	0.3206	26.12
5	1.0020	0.3256	26.30
6	0.9990	0.3300	26.29

[1] Daily cooling load temperature difference = $\alpha_{temp\Delta}$ (mean - inside temperature) + α_{range}(range) + α.

[2] Maximum cooling load temperature difference = $\alpha_{temp\Delta}$ (mean - inside temperature) + α_{range}(range) + α.

Number of observations = 243
All coefficients are significant: R^2's range from 0.9944 to 1.0.

Structure

1. Roof #22, 1" wood, 2" insulation $U = 0.109$
2. Roof #25, 1" wood, 1" insulation $U = 0.170$
3. Exterior frame wall #36, 3" insulation $U = 0.081$
4. Exterior frame wall #37, 2" insulation $U = 0.112$
5. Exterior frame wall #38, 1" insulation $U = 0.178$
6. Exterior frame wall #39, no insulation $U = 0.438$

Noting the similarity in the regression results, we assume that ASHRAE roof #22 and exterior wall #37 provide adequate approximations for cooling load determination. These relationships must be modified for differences in actual levels of thermal resistance.

In the case of a pitched roof, we can calculate an effective cooling resistance for the combined ceiling and roof by using the ceiling and roof resistances given in Table 2.2 and the definition of average heat flux. It is necessary to account for the effective resistance contributed by natural ventilation of the attic. Assume the ASHRAE (1977, 22.23, Table 6, and 24.2) design standard of 0.1 cubic feet per minute per square foot of ceiling area for ventilation, assume the effective cross section of the roof for solar radiation equals the area of ceiling, and neglect the effect of radiation on attic walls. Then thermal equilibrium evaluated at mean values requires:

$$\frac{A_c}{R_r}(\bar{t}_{sa} - t) + (\frac{A_r}{R_r} + \frac{A_w}{R_w})(t-t_a) \tag{23}$$

$$+ (0.018)(.1)(60)A_c(t-t_a) = \frac{A_c}{R_c}(t_a - t_i)$$

where $\bar{t}_{sa}$ is average sol-air temperature, t_a is attic temperature, and t is daily mean temperature. Then:

$$t_a - t_i = \frac{\frac{A_c}{R_r}(\bar{t}_{sa} - t) + \left[\frac{A_r}{R_r} + \frac{A_w}{R_w} + 0.108A_c\right](t - t_i)}{\left[\frac{A_c}{R_c} + \frac{A_r}{R_r} + \frac{A_w}{R_w} + 0.108A_c\right]} \tag{24}$$

and net ceiling heat flux is:

$$\bar{q}/A_c = \frac{\frac{1}{R_r}(\bar{t}_{sa} - t) + \left[\frac{A_r}{A_c}\frac{1}{R_r} + \frac{A_w}{A_c}\frac{1}{R_w} + 0.108\right](t - t_i)}{1 + \left[\frac{A_r}{A_c}\frac{1}{R_r} + \frac{A_w}{A_c}\frac{1}{R_w} + 0.108\right]R_c} \tag{25}$$

The values in Table 2.2 and the ratios $A_r/A_c = 1.12$ and $A_w/A_c = 0.08$ imply:

$$\bar{q}/A_c = \left[\frac{0.9310 + 0.0157I}{2.097 + 0.608I}\right] \cdot [0.40485(\bar{t}_{sa} - t) + 0.59163(t - t_i)] \tag{26}$$

We may then define:

$$\bar{q}/A_c = U_1^{effective} \cdot (\bar{t}_{sa} - t_i) + U_2^{effective} \cdot (t - t_i) \tag{27}$$

where:

$$U_1^{effective} = \left[\frac{0.3769 + 0.00636I}{2.097 + 0.608I}\right] \tag{28}$$

$$U_2^{effective} = \left[\frac{0.17389 + 0.00293I}{2.097 + 0.608I}\right]$$

From (22) and the values of v_0, v_1, and w_1, we note that average cooling load and average heat flux satisfy $\bar{Q}/A_c = \bar{q}/A_c$. If effective resistance in the attic is approximately uniform over the day, then:

$$\bar{Q}_{attic}/A_c = U_1^{effective} \cdot \left[{}^{\text{total cooling load}}_{\text{temperature difference}}\right] + U_2^{effective} \cdot 24 \tag{29}$$

For a flat roof we use the resistance values given in Table 2.2 to obtain:

$$\bar{Q}_{flat}/A_c = \left[\frac{0.937 + 0.1I}{3.96 + I}\right] \cdot \left[{}^{\text{total cooling load}}_{\text{temperature difference}}\right] \tag{30}$$

Typical values of the ceiling cooling load are given in Table 2.12 for $t_i = 75°\text{F}$.

Table 2.12

Summer cooling load

Daily Mean	Daily Range	R-Value of Attic Insulation	Pitched[1] Roof Q/A_c	Flat Roof[2] Q/A_c
79.00	12.00	0.00	85.94	102.66
75.00	20.00	0.00	60.20	79.26
84.00	12.00	0.00	116.25	129.47
80.00	20.00	0.00	90.52	106.07
89.00	12.00	0.00	146.57	156.27
85.00	20.00	0.00	120.83	132.87
80.00	30.00	0.00	88.66	103.62
94.00	12.00	0.00	176.88	183.08
90.00	20.00	0.00	151.15	159.68
85.00	30.00	0.00	118.98	130.43
79.00	12.00	10.00	25.76	60.20
75.00	20.00	10.00	18.04	46.48
94.00	12.00	10.00	53.01	107.36
90.00	20.00	10.00	43.30	93.64
85.00	30.00	10.00	35.66	76.49
79.00	12.00	20.00	16.91	53.18
75.00	20.00	20.00	11.84	41.06
94.00	12.00	20.00	34.79	94.85
90.00	20.00	20.00	29.73	82.72
85.00	30.00	20.00	23.40	67.57

[1] Q/A_c is total cooling for 24-hour period in Btu's.
[2] Q/A_c is total cooling for 24-hour period in Btu's.
Internal temperature is 75°F.

For total cooling load temperature difference, we use the regression estimates for roof #22:

$$\left[{}^{\text{total cooling load}}_{\text{temperature difference}}\right] = 22.66 \cdot (t-t_i) - 1.032 \cdot t_r + 355.6 \qquad (31)$$

We assume the pitched roof formula (29) to be consistent with our assumptions in the heating load calculation.

For design cooling load arising from window gains, sol-air temperature equivalents are given as a function of glazing, orientation, and covering. For windows with draperies, Venetian blinds, or half-drawn roller shades, the formula (ASHRAE, 1977, 25.40, Table 36) is:

$$[\text{Btuh/ft}^2] = -a + bt_e \qquad (32)$$

where $b = 0.8$ for single glazed and $b = 0.6$ for double glazed (stormed) windows, t_e = design temperature, and a has the following values:

Orientation	*Single Glazed*	*Double Glazed*	*Prop.*
N	52	39	.10
NE and NW	33	21	.25
E and W	16	6	.25
SE and SW	24	13	.25
S	43	30	.15
average	30	18	--

The average above is calculated by assuming that square footage of window space in a characteristic dwelling is distributed in the proportions given in the last column.

For the purpose of cooling load calculations, we assume that the window gain effect is essentially uniform over the day so that:

$$[\text{Btuh/ft}^2] = -a + bt \tag{33}$$

The summer heat gain calculation is summarized in Tables 2.13 and 2.14 for daily cooling load and design capacity. The calculations differ in two ways. Wall gains and ceiling gains use total cooling load temperature difference in the daily cooling load calculation and use maximal cooling load temperature difference in the capacity calculation. The second difference concerns the treatment of mean versus design temperatures in the calculation of window and infiltration gains. Cooling load calculations use daily mean temperature under the assumption that relevant gains are uniform due to the thermal flywheel effect. Capacity calculations use design temperature to determine maximal load. Tables 2.15 and 2.16 consider additional allowances for transmission losses in forced hot water and hot air systems.

2.3. Benchmark energy consumption levels

Implicit in the thermal calculations for heating and cooling system design capacities are energy consumption levels under the benchmark behavioral assumptions used. These consumption levels can be

Table 2.13

Summary of summer cooling calculation—daily load

Btu's-per-day is the sum of the following components:

---

1. **Wall gains:**

(exterior wall area surrounding conditioned space, excluding windows)

$$\times \frac{0.9394 + 0.138\ I_w}{2.85 + I_w} \times (22.67 \cdot (t - t_i) - 0.9638 \cdot t_r + 362.1)$$

2. **Ceiling gains (assume pitched roof):**

$$\begin{bmatrix}\text{ceiling}\\ \text{area}\end{bmatrix} \times \frac{(0.3769 + 0.00636 \cdot I_c)}{(2.097 + 0.608 \cdot I_c)} \times (22.66 \cdot (t - t_i) - 1.032 \cdot t_r + 355.6)$$

$$+ \frac{(0.17389 + 0.00293 \cdot I_c)}{(2.097 + 0.608 \cdot I_c)}\ (t - t_i) \cdot 24$$

3. **Window gains (assuming storms removed on windows):**

$$(A_{ws} + A_{wn} + A_{sdn}) \cdot (0.8t - 30) \cdot 24 + A_{sds} \cdot (0.6t - 18) \cdot 24$$

4. **Internal load (sensible):**

$$[1200 + 225\ (\text{number of occupants})] \cdot 24$$

5. **Infiltration gains:**

$$24 \cdot 0.018 \cdot V \cdot (t - t_i) \cdot [0.25 + 0.02165\ (7.5) + 0.00833(t - t_i)]$$

The sum of 1-5 is increased by 25 percent to account for latent heat load (dehumidification) (ASHRAE, 1977, 25.41).

---

t	mean temperature (°F)
t_r	temperature range (°F)
I_W	R-value of wall insulation
I_C	R-value of ceiling insulation
V	Volume of conditioned space

calculated as a function of weather and time to give benchmark HVAC load curves, or can be summed up over the season to give annual HVAC consumption. This section provides the formulae for these calculations.

Consider first the treatment of temperatures through time. When seasonal, monthly, or hourly temperatures are available, they can be used directly in the calculations described below. It is convenient, however,

Table 2.14

Summary of summer cooling calculation—design capacity

Btu's-per-hour at design conditions is the sum of the following components:

---

1. Wall gains:

(exterior wall area surrounding conditioned space, excluding windows)

$$\times \frac{0.9394 + 0.138\ I_w}{2.85 + I_w} \times 0.319\ t_r + 1.0050\ \Delta t_e + 26.27$$

2. Ceiling gains (assumed pitched roof):

$$\begin{bmatrix}\text{ceiling}\\ \text{area}\end{bmatrix} \times \frac{(0.3769 + 0.00636 \cdot I_{c)}}{(2.097 + 0.608 \cdot I_{c)}} \times (0.2820\ t_r + 0.0058\ \Delta t_e + 25.35)$$

$$+ \frac{(0.17389 + 0.00293 \cdot I_{c)}}{(2.097 + 0.608 \cdot I_{c)}} \cdot \Delta t_e$$

3. Window gains (assuming storms removed on windows):

$$(A_{ws} + A_{wn} + A_{sdn}) \cdot (0.8t_e - 30) + A_{sds} \cdot (0.6t_e - 18)$$

4. Internal load (sensible):

[1200 + 225 (number of occupants)]

5. Infiltration gains:

$$0.018\ V \cdot \Delta t_e \cdot [0.25 + 0.02165(7.5) + 0.00833\ (\Delta t_e)]$$

The sum of 1-5 is increased by 25 percent to account for latent heat load (dehumidification) (ASHRAE, 1977, 25.41). $\Delta t_e = t_e - t_i$ where t_e = summer design minimum temperature (°F).

---

for seasonal or annual calculations to use several simple approximations to temperature patterns over time. Let $F(t)$ denote the cumulative distribution function of daily mean temperatures. Then average heating degree-days per day over the year, to base temperature τ, satisfies:

$$HD_\tau = \int_{t_0}^{t_1} \max(0, \tau - t) F'(t)\, dt = \int_{t_0}^{\tau} F(t)\, dt \tag{34}$$

where t_0 and t_1 are extreme possible temperatures. Similarly, average cooling degree-days per day to base temperature τ satisfies:

Table 2.15

Hot water system pipe transmission losses

Assume 2.5" black iron pipe with outside diameter of 2.88", 2" insulation with an R-value of 6, delivery temperature 120°, return temperature 80°, basement temperature 40°.

The formula for loss is:

$$\text{Btuh} = \frac{(t_w - t_b)(2\,\pi\, r_s\, L)}{r_s\,(\ln \frac{r_s}{r_o})\, I + R_s}$$

with:

t_w	water temperature
t_b	basement temperature
r_o	outside radius of pipe (ft.) = 1.44/12
r_s	outside radius of pipe + insulation (ft.) = 3.44/12
I	R-value of insulation (per ft.) = 36
R_s	surface resistance = 0.6
L	length of pipe

Delivery loss:

$$\text{Btuh} = \frac{80\,(2\pi \cdot 0.287 \cdot L/2)}{0.287 \cdot \ln \left[\frac{3.44}{1.44}\right] \cdot 36 + 0.6} = 7.52L$$

Return loss:

$$\text{Btuh} = \frac{40\,(2\pi \cdot 0.287 \cdot L/2)}{0.287 \cdot \ln \left[\frac{3.44}{1.44}\right] \cdot 36 + 0.6} = 3.76L$$

Total loss: Btuh = $11.28L$

Source: ASHRAE (1977) 22.7-22.9, 22.26, and 22.27

$$CD_\tau = \int_{t_0}^{t_1} \max(0,\, t-\tau) F'(t)\, dt = \int_{\tau}^{t_1} [1-F(t)]\, dt \tag{35}$$

Approximate $F(t)$ by a logistic cumulative distribution function:

$$F(t) = (1 + e^{-a-bt})^{-1} \tag{36}$$

Table 2.16

Heating duct transmission losses

Assume 600 fpm velocity, 4" x 10" ducts, 2" insulation with R-value of 6, average air temperature in delivery duct 120°, basement temperature 40°.

The formula for loss is:

$$\text{Btuh} = PL\ (t_d - t_b)/I$$

where:

P	perimeter (ft.)
L	length (ft.)
t_d	average duct temperature (°F)
t_b	basement temperature (°F)
I	R-value of insulation

Assuming 80 percent of ducting is for delivery and neglecting return heat loss, the total loss is:

$$\text{Btuh} = (2.33)(.8)\ L\ (80)/6 = 24.9L$$

Source: ASHRAE (1977), Chap. 30.

Then:

$$HD_\tau = \frac{1}{b} \ln\left(1 + e^{a+b\tau}\right) \tag{37}$$

$$CD_\tau = \frac{1}{b} \ln\left(1 + e^{-a-b\tau}\right) \tag{38}$$

If HD_{65} and CD_{65} are given, then the parameters a and b can be determined by solving:

$$1 = e^{-b \cdot CD_{65}} + e^{-b \cdot HD_{65}} \tag{39}$$

$$a = b(HD_{65} - CD_{65} - 65) \tag{40}$$

Then HD_τ and CD_τ can be calculated for other bases. The value of b is quickly calculated by iteratively splitting the interval containing the solution, starting from:

$$\ln 2 \,/\, \max(HD_{65}, CD_{65}) \leqslant b \leqslant \ln 2 \,/\, \min(CD_{65}, HD_{65}) \tag{41}$$

Note that $F(t)$ has mean $-a/b$, variance $\pi^2/3b^2$, and a 95 percent temperature range $t_{high}-t_{low} = 2.9444/b$. For the NIECS data, national average values are $b = .1218$ and $a = -6.870$, implying annual mean temperature 56.4, standard deviation 14.9, and 95 percent temperature range 24.2, or $32.2 \leqslant t \leqslant 80.6$. These match the actual distribution of mean daily temperatures for average U.S. locations quite well.

2.3.1. Heating load calculation

Space heat capacity as a function of ambient temperature and thermostat setting may be interpreted as a measure of average hourly consumption of delivered energy over a day with the specified temperatures. Therefore, benchmark consumption levels can be calculated from the capacity models by replacing design temperatures with the seasonal pattern of daily mean temperatures. Delivered energy per hour on a winter day with mean ambient temperature t and thermostat setting τ is, from Table 2.6:

$$\begin{aligned} Q = {} & [A_w U_w + A_c U_c + A_{win} U_{win}](\tau - t) + A_c U_f(\tau - t_g) \\ & + \theta V[.01035 + .00015\,(\tau - t)](\tau - t) - \text{INTERNAL} \end{aligned} \tag{42}$$

The notation is:

A_w, A_c, A_{win}	wall, ceiling, and window areas
U_w, U_c, U_{win}, U_f	average conductivities of wall, ceiling, and floor
θ	window infiltration loss factor
V	volume
t_g	ground temperature, *assumed constant throughout the winter*
INTERNAL	internal load from occupants and appliances

In this formula, no attempt is made to correct for the effect of the nonlinearity in infiltration with temperature difference over the daily temperature cycle. For typical daily temperature ranges, this correction is negligible at the level of precision of the overall calculation. Rewrite (42) in the form:

$$Q = w_0 + w_1(\tau - t) + w_2(\tau - t)^2 \tag{43}$$

with:

$$w_0 = A_c U_f(\tau - t_g) - \text{INTERNAL}$$

$$w_1 = A_w U_w + A_c U_c + A_{win}\, U_{win} + .01035\theta V$$

$$w_2 = .00015\theta V$$

Then the annual average delivered heat (Btuh) is given by:

$$Q_{seas} = \int_{t_0}^{\tau} \max(Q(t), 0) F'(t)\, dt \tag{44}$$

If $w_0 < 0$, then there is a balance temperature $t_b < \tau$ above which heat is not required:

$$t_b = \tau + \frac{w_1}{2w_2}\left[1 - (1 - 4w_2 w_1^{-2} \min(w_0, 0))^{1/2}\right]$$

Then (44) can be rewritten:

$$Q_{seas} = \int_{t_0}^{t_b} \left[w_0' + w_1'(t_b-t) + w_2'(t_b-t)^2\right] F'(t)\, dt$$

$$= w_0' F(t_b) + w_1' \int_{t_0}^{t_b} F(t)\, dt + 2w_2' \int_{t_0}^{t_b} (t_b-t) F(t)\, dt$$

where:

$$w_0' = w_0 + w_1(\tau-t_b) + w_2(\tau-t_b)^2 = 0$$

$$w_1' = w_1 + 2w_2(\tau-t_b)$$

$$w_2' = w_2$$

Using integration by parts,

$$\int_{t_0}^{t_b} (t_b-t) F'(t)\, dt = \int_{t_0}^{t_b} F(t)\, dt$$

$$\int_{t_0}^{t_b} (t_b-t)^2 F'(t)\, dt = 2 \int_{t_0}^{t_b} (t_b-t) F(t)\, dt$$

Using the approximation (36) to the seasonal temperature distribution yields:

$$F(\tau) = (1 + e^{-a-b\tau})^{-1} \tag{45}$$

$$\int_{t_0}^{\tau} F(t)\, dt = \frac{1}{b} \ln\,(1 + e^{a+b\tau}) \tag{46}$$

$$2 \int_{t_0}^{\tau} (\tau-t) F(t)\, dt = \frac{2}{b} \int_{t_0}^{\tau} \ln\,(1 + e^{a+bt})\, dt \tag{47}$$

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$$= 2\,\gamma(a+b\tau)/b^2$$

where:

$$\gamma(\lambda) = \int_{-\infty}^{\lambda} \ln(1 + e^s)\, ds = \int_0^{e^\lambda} \ln(1 + x)\, \frac{dx}{x} \tag{48}$$

Note that for $0 \leqslant x \leqslant 1$:

$$\ln(1 + x) = \sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{k}\, x^k \tag{49}$$

Also, with error at most 10^{-5} for $0 \leqslant x \leqslant 1$:

$$\frac{\ln(1 + x)}{x} \doteq a_1 + a_2 x + a_3 x^2 + a_4 x^3 + a_5 x^4 \tag{50}$$

with:

$a_1 = .99949556$ $a_4 = -.13606275$
$a_2 = .49190896$ $a_5 = .03215845$
$a_3 = .28947478$

Then:

$$\gamma(0) = \int_0^1 \ln(1 + x)\, \frac{dx}{x} = \sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{k} \int_0^1 x^{k-1}\, dx \tag{51}$$

$$= \sum_{k=1}^{\infty} (-1)^{k-1}/k^2 = \pi^2/12$$

and for $\lambda < 0$, with error at most 10^{-5}:

$$\gamma(\lambda) = \int_0^1 \ln(1 + x)\, \frac{dx}{x} - \int_{e^\lambda}^0 \ln(1 + x)\, \frac{dx}{x} \tag{52}$$

$$= \frac{\pi^2}{12} - \sum_{k=1}^{5} a_k \int_{e^{\lambda}}^{1} x^{k-1}\, dx$$

$$= \frac{\pi^2}{12} + \sum_{k=1}^{5} \frac{a_k}{k} (e^{k\lambda} - 1)$$

For $\lambda > 0$, with error at most 10^{-5}:

$$\gamma(\lambda) = \int_{-\infty}^{0} \ln (1 + e^s)\, ds + \int_{0}^{\lambda} \ln (1 + e^s)\, ds \tag{53}$$

$$= \frac{\pi^2}{12} + \int_{0}^{\lambda} s\, ds + \int_{0}^{\lambda} \ln (1 + e^{-s})\, ds$$

$$= \frac{\pi^2}{12} + \frac{\lambda^2}{2} + \int_{e^{-\lambda}}^{1} \ln (1 + x) \frac{dx}{x}$$

$$\doteq \frac{\pi^2}{12} + \frac{\lambda^2}{2} + \sum_{k=1}^{5} \frac{a_k}{k} (1 - e^{-k\lambda})$$

Defining $\alpha = \max(\lambda, 0)$, $\beta = e^{-\alpha}$, $\delta = e^{\lambda}$, and $c_k = a_k/k$, all cases can be combined in the formula:

$$\gamma(\lambda) \doteq \frac{\pi^2}{12} + \frac{\alpha^2}{2} + \sum_{k=1}^{5} c_k\, \beta^k(\delta^k - 1) \tag{54}$$

We summarize the annual average delivered heat per hour as:

$$\begin{aligned} Q_{seas} = {} & w_0/(1 + e^{-a-b\tau}) + (w_1/b) \ln (1 + e^{a+b\tau}) \\ & + (2w_2/b^2)\, \gamma(a+b\tau) \qquad \text{for } w_0 \geqslant 0 \end{aligned}$$

$$Q_{seas} = (w_1'/b) \ln (1 + e^{a+bt_b})$$

$$+ (2w_2'/b^2)\,\gamma(a+bt_b) \qquad \text{for } w_0 < 0$$

2.3.2. *Cooling load calculation*

Delivered energy per hour on a summer day with mean ambient temperature t and thermostat setting τ is, from Table 2.13:[3]

$$Q = S_0 + S_1(t-\tau) + S_2(t-\tau)^2$$

where:

$$\begin{aligned} S_0 = [\,&(A_w U_w(362.1 - 0.9638 \cdot t_r) \\ &+ A_c U_1^{eff}(355.6 - 1.032 \cdot t_r))/24 \\ &+ (A_{ws} + A_{wn} + A_{sdn})(0.8\tau - 30) \\ &+ A_{sds}(0.6\tau - 18) + \text{INTERNAL}\,] \cdot 1.25 \end{aligned}$$

$$\begin{aligned} S_1 = [\,&(A_w U_w \cdot 22.67 + A_c U_1^{eff} \cdot 22.66 \\ &+ A_c U_2^{eff} \cdot 24)/24 + (A_{ws} + A_{wn} + A_{sdn})(0.8) \\ &+ A_{sds}(0.6) + 0.00742 \cdot V\,] \cdot 1.25 \end{aligned}$$

$$S_2 = (0.00015 \cdot V) \cdot 1.25$$

---

[3] Notation is given in Tables 2.13 and 2.14.

Then annual average delivered cooling (Btuh) is given by:

$$Q^{AC}_{seas} = \int_{\tau}^{t_1} \max(Q(t), 0)F'(t)\, dt \tag{55}$$

If $S_0 < 0$, then there is a balance temperature $t_b > \tau$ below which cooling is not required:

$$t_b = \tau - \frac{S_1}{2S_2}[1 - (1 - 4S_2 S_1^{-2} \min(S_0, 0))^{1/2}]$$

Then (55) can be rewritten:

$$Q^{AC}_{seas} = \int_{t_b}^{t_1} [S_0{}' + S_1{}'(t - t_b) + S_2{}'(t - t_b)^2]F'(t)\, dt \tag{56}$$

where:

$$S_0' = S_0 + S_1(t_b - \tau) + S_2(t_b - \tau)^2 = 0$$

$$S_1' = S_1 + 2S_2(t_b - \tau)$$

$$S_2' = S_2$$

Note that we may relate the integral in (56) to the form evaluated in the heating load calculation because:

$$\int_{t_b}^{t_1} [S_0' + S_1'(t - t_b) + S_2'(t - t_b)^2]F'(t)\, dt$$

$$= \int_{t_0}^{t_1} [S_0' - S_2'(t_b - t) + S_2'(t_b - t)^2]F'(t)\, dt$$

$$- \int_{t_0}^{t_b} [S_0' - S_1'(t_b - t) + S_2'(t_b - t)^2]F'(t)\, dt$$

$$= S_0' - S_1'(t_b - \mu) + S_2'[(t_b - \mu)^2 + var(t)]$$

$$- \int_{t_0}^{t_b} [S_0' - S_1'(t_b - t) + S_2'(t_b - t)^2]F'(t)\, dt$$

where $\mu = -a/b$ and $var(t) = \pi^2/3b^2$. The cases $S_0 < 0$ and $S_0 \geqslant 0$ imply:

$$S_0' = \begin{cases} 0 & S_0 < 0 \\ S_0 & S_0 \geqslant 0 \end{cases}$$

$$S_1' = \begin{cases} S_1 + 2S_2(t_b - \tau) & S_0 < 0 \\ S_1 & S_0 \geqslant 0 \end{cases}$$

$$S_2' = S_2$$

Duct losses for air conditioning are ignored, so the expression for Q_{seas}^{AC} gives gross air conditioner output. For duct and pipe systems, additional furnace output is required to offset transmission losses. These losses can be divided into a component due to conduction losses from the delivery system and a component due to heat gains and losses of the delivery system under cyclic operation. The first component is to a close approximation proportional to heat delivered, and the coefficient of proportionality can be obtained from the calculation of capacity requirements for non-central and central systems. Thus:

$$Q_D = Q_{seas} \cdot \mathrm{SHEATD/SHEATN} \tag{57}$$

$$Q_P = Q_{seas} \cdot \mathrm{SHEATP/SHEATN} \tag{58}$$

where SHEATN, SHEATD, and SHEATP are capacities of non-central, duct, and pipe systems respectively, and Q_D and Q_P are seasonal furnace outputs net of cyclic losses.

Seasonal efficiencies of heating equipment depend on climate, through cyclic heat loss. Empirical seasonal efficiencies of heating equipment, or *coefficients of performance*, can be obtained from ASHRAE. Distribution cyclic heat losses are small relative to the furnace losses and will be ignored. The coefficients for gas, oil, electric resistance (baseboard), and heat pump are respectively:

$$COP_G = .46 + .0146 \cdot HD_{65} \tag{59}$$

$$COP_O = .404 + .0130 \cdot HD_{65} \tag{60}$$

$$COP_E = 1.0 \tag{61}$$

$$COP_{HP} = 1.94 + \frac{2.85}{HD_{65}} + \frac{.96}{CD_{65}} - .046\ HD_{65} - .081\ CD_{65} \tag{62}$$

The efficiency loss in central electric resistance units is relatively small, and is ignored. For air conditioning, the coefficient of performance is approximately:

$$COP_{AC} = 3.44 + \frac{.744}{HD_{65}} + \frac{1.23}{CD_{65}} - .036\ HD_{65} - .038\ CD_{65} \tag{63}$$

The approximations in equations (62) and (63) are discussed in the Appendix to this chapter.

The base technological calculations of seasonal energy consumption can now be summarized. Take, for example, a gas-fired forced-air system. Energy input in MBH over the year is 8.76 Q_D/COP_G. Similarly, an electric baseboard system requires an input of 8.76 Q_{seas}/COP_E, while an air conditioner requires 8.76 Q^{AC}_{seas}/COP_{AC}. Multiplied by marginal fuel prices, these figures give the technologically based operating costs of alternative systems.

These calculations are carried out for specified winter and summer thermostat settings. Repeating the calculations for a 1-degree change in the thermostat setting and taking differences yield an overall calculation of the seasonal price of comfort. In carrying out these "price" calculations, we ignore the very small change in w_0 induced by the thermostat change.

The seasonal calculations just completed can also be applied to time periods within a season, such as billing periods. The temperature distribution $F(t)$ should then be that applicable for the period in question. The logistic approximation used for the seasonal temperature distribution requires some modification for use in billing periods.

A more accurate temperature distribution can be obtained using degree-day calculations for alternative bases. Let H_υ , C_υ denote heating and cooling degree-days (per day) to base υ; then:

$$H_\upsilon = \frac{1}{b} \ln\left(1+e^{b(\upsilon-\mu)}\right) = \upsilon-\mu + \frac{1}{b} \ln\left(1+e^{-b(\upsilon-\mu)}\right)$$

$$= \max(0, \upsilon-\mu) + \frac{1}{b} \ln\left(1+e^{-b|\upsilon-\mu|}\right)$$

$$C_\upsilon = \int_\upsilon^\infty (t-\upsilon)F'(t)\, dt = \frac{1}{b} \ln\left(1+e^{-b(\upsilon-\mu)}\right)$$

$$= \max(0, \mu-\upsilon) + \frac{1}{b} \ln\left(1+e^{-b|\upsilon-\mu|}\right)$$

Note that $C_\upsilon - H_\upsilon = \int_{-\infty}^{+\infty} (t-\upsilon)F'(t)\, dt = \mu-\upsilon$. For a base $\tau \geqslant \upsilon$, one has:

$$(\tau-\upsilon)F(\upsilon) \leqslant H_\tau - H_\upsilon = \int_\upsilon^\tau F(t)\, dt \leqslant (\tau-\upsilon)F(\tau)$$

$$(\tau-\upsilon)[1-F(\tau)] \leqslant C_\upsilon - C_\tau = \int_\upsilon^\tau [1-F(t)]\, dt \leqslant (\tau-\upsilon)[1-F(\upsilon)]$$

Given C_υ, H_τ for $\tau \geqslant \upsilon$, consider the function:

$$G(b) = (1 - e^{-bH_\tau}) \cdot (1 - e^{-bC_\upsilon}) \cdot e^{b(\upsilon - \tau + H_\tau + C_\upsilon)} - 1$$

derived by eliminating μ from the equations for H_τ and C_υ. This function has $G(0) < 0$ and $G'(0) > 0$. If $G(1) > 1$, then a unique solution can be obtained by successive interpolation, with the consistent value:

$$\mu = \upsilon + C_\upsilon + \frac{1}{b} \ln (1 - e^{-bC_\upsilon})$$

On the other hand, if $G(1) < 1$, as will be the case if C_υ or H_τ is sufficiently small, then the temperature distribution has little mass in the range of υ and τ, where balance temperatures are attained. Outside this range, marginal heating and cooling requirements are linear in the temperature differential, except for small stack and ground effects in heating, which can be neglected. Hence, in this case it is a good approximation to assume that mean temperature for the period under study is concentrated at $\mu = \upsilon + C_\upsilon - H_\upsilon$, and set $Q_{AC} = Q(\mu)$, with an analogous procedure for heating.

2.4. Characteristics of single-family dwellings

The thermal calculations in the preceding sections require information on wall, window, and ceiling areas, volume, and feet of pipe or ducting for central heating systems. The NIECS/PNW data do not provide this level of detail, but do provide (incomplete) information on square footage and numbers of rooms, floors, and windows. To fill this gap, we have sampled seven typical dwellings, and from their detailed characteristics obtained relationships between the required variables and those observed in NIECS/PNW. Table 2.17 lists the measured characteristics.

A series of regressions on these seven observations provide a link from variables in NIECS/PNW to structural characteristics, as follows:

1) ln (wall area including windows) = 2.96 + 0.92 ln (no. floors) + 0.57 ln (ceiling area) ; $\bar{R}^2 = 0.99$ $\sigma^2 = 19$

2) ln (ceiling area) = -0.04 + 0.815 ln (no. floors) + 1.006 ln (house sq. ft.) ; $\bar{R}^2 = 0.996$ $\sigma^2 = 0.007$

Table 2.17

Characteristics of typical dwellings

	Dwelling						
Variable	1	2	3	4	5	6	7
Floors	1	2	1	1	2	1	2
Rooms	5	9	4	5	9	9	8
Baths	1	2	1	1	3	3	2.5
Bedrooms	3	7	2	3	4	4	4
Sq. ft.	768	1404	576	1024	3128	2552	1848
Sq. ft. largest room	315	275	153	227	271	433	293
Ceiling area	768	864	576	1024	1888	2552	924
Roof area	810	1222	607	1109	1990	2552	974
Attic wall area	96	81	96	0	171	0	0
Wall area excl. windows	851	1396	736	931	2472	1532	1552
Number picture windows	0	0	0	0	6	0	1
Sq.ft. picture windows	0	0	0	0	248	0	24
Number sliding glass doors	0	0	0	0	6	2	2
Sq.ft. sliding glass doors	0	0	0	0	308	140	77
Number other windows	10	16	8	11	7	13	20
Sq.ft. other windows	45	60	32	94	66	128	314
Volume	6144	10656	4608	8192	27232	22491	15246
Hot air system:							
registers	11	15	9	9	21	20	20
ft. duct	92	114	81	104	292	251	226
Hot water system:							
radiator	6	10	5	5	12	14	14
ft. pipe	160	230	128	144	564	530	344

3) $\ln(\text{volume}) = 2.19 + 0.80 \ln(\text{no. floors}) + 0.98 \ln(\text{ceiling area})$; $\bar{R}^2 = 0.98 \quad \sigma^2 = 0.01$

Average area per picture window = 38.9; average area per other window = 8.7; average area per sliding glass door = 52.5.

4) $(\text{average roof area} / \text{ceiling area}) = 1.12$; $\sigma^2 = 0.15$

5) (average attic wall area / ceiling area)= 0.08 ; $\sigma^2 = 0.07$

6) number of registers = 2.55 + 1.07 (rooms) + .003 (house square feet) ; $\overline{R}^2 = 0.97$ $\sigma^2 = 4.52$

7) feet of duct = 3.89 (number of registers) + 0.067 (house square feet) ; $\overline{R}^2 = 0.99$ $\sigma^2 = 427$

8) ln (feet of hot water pipe) = -1.95 + 1.03 ln (house square feet) ; $\overline{R}^2 = 0.99$ $\sigma^2 = 0.02$

9) number of radiators = 1.04 (number of rooms) + 0.0014 (house square feet) ; $\overline{R}^2 = 364$ $\sigma^2 = 0.96$

We use these equations to estimate structural characteristics of the NIECS/PNW dwellings, except that for hot water systems, we assume baseboard radiators rather than conventional radiators, and use the ASHRAE design standard that 1 linear foot of baseboard radiator is required per 645 Btuh designed capacity of the heating system.

The proportion of window area to total wall area in the typical houses ranges from 0.04 to 0.27. We shall assume that for the NIECS/PNW houses, this proportion is bounded between 0.03 and 0.7, and use these bounds if the regression predicts a more extreme value.

The NIECS/PNW data report square footage of the dwelling as estimated by the respondent. There is evidence in the NIECS data, however, that these responses are subject to error. Therefore, we regress reported square footage on several variables that we believe to be measured more accurately, and use the predicted values from this equation in our analysis. The method was to remove the accurately measured square footage of the largest room from the reported total square feet, predict the square footage of the remainder of the dwelling, and then add back in the largest room square footage. The estimated equation is given in Table 2.18. Some average characteristics of the NIECS/PNW dwellings are given in Table 2.19.

Typical house 7 is taken from ASHRAE (1977, 24.7-24.9), which calculates its heating system capacity to be 114 MBtuh for a Syracuse, N.Y. location with a design temperature of -10°F when there is no wall or attic insulation. The thermal program developed here, using the same inputs as are provided for the NIECS/PNW households, and the design temperature for this location, yields a capacity of 131 MBtuh. The thermal program yields a central air conditioning capacity of 65 MBtuh for this

Table 2.18

Regression of log square feet per room (for rooms other than the largest) for NIECS households

Variable	Region 1	Region 2	Region 3	Region 4
Baths	.149 (.071)	.118 (.045)	.184 (.043)	.124 (.053)
Floors	.011 (.062)	.055 (.037)	.067 (.048)	.131 (.052)
Income (000)	.0039 (.0033)	.0039 (.0019)	.0036 (.0020)	.0032 (.0021)
Year Built (1930-1978)	.0020 (.0024)	.0026 (.0014)	.0002 (.0015)	.0037 (.0018)
Largest Room L-shaped	-.081 (.143)	-.002 (.085)	-.15 (.07)	-.07 (.07)
No. Doors	-.007 (.036)	.032 (.027)	.029 (.022)	.019 (.025)
No. Windows	.0043 (.0057)	.0058 (.0033)	.0025 (.0041)	.0060 (.0036)
Log No. Rooms	-.377 (.171)	-.317 (.103)	-.592 (.101)	-.577 (.112)
Heating Degree-Days (1000)	.078 (.082)	-.011 (.038)	-.059 (.060)	.010 (.018)
Cooling Degree-Days (1000)	-.134 (.291)	.247 (.109)	-.035 (.098)	-.056 (.069)
Value of House (1000)	.0015 (.0012)	.0020 (.0005)	.0016 (.0009)	.0018 (.0008)
SMSA Dummy	.034 (.074)	-.46 (.49)	-.16 (.05)	-.04 (.08)
Urban Area Dummy	-.091 (.068)	.19 (.49)	.078 (.042)	-.027 (.080)
Constant	5.30 (.70)	4.88 (.35)	6.06 (.44)	5.68 (.25)
$\bar{R}^2$	.16	.17	.17	.22
Observations	230	494	432	253

house under the Syracuse summer design temperature of 90 with a daily range of 20. The corresponding ASHRAE calculation using actual characteristics of the shell gives an air conditioning capacity of 44 MBtuh.

Table 2.19

Selected characteristics of NIECS/PNW households

Variable	NIECS Mean (estimated)	Typical House Mean	PNW Mean (estimated)
Floors	1.42	1.43	1.29
Rooms	6.06	7.00	5.97
Baths	1.49	1.93	1.17
Square feet	1572 (1553)[1]	1614	1513
Volume	11400	13510	11930
No. Windows	13.0	14.6	10.43
Window Area	(179.4)	219.4	(246.9)
Wall Area Exc. Windows	(1506)	1353	(1341)
Ceiling Area	(1175)	1228	(1292)
Feet Duct	(151.0)	166	(156.1)
Feet Pipe	(265.6)	300	(273.9)
Space Heat Cap. Net of Distribution Losses, MBtuh	(45.5)	—	(46.7)
Central AC Capacity, MBtuh	(34.71)	—	(28.6)
Proportion with Attic Insul. Average R-value Attic	81.9 (17.41)	—	81.0 (20.28)
Average R-value Wall	(7.03)	—	(8.93)

[1] Correlation .94 between observed and estimated.

The usage calculations in Section 2.3 applied to the NIECS and PNW households imply the coefficients of performance and usages in Table 2.20. Note that these are averages over all dwellings of the performance of the specified equipment *if* it were installed in every dwelling, *not* the performance of equipment actually installed.

To test the sensitivity of the thermal model, we have calculated capacity and usage under two alternative levels of building thermal characteristics. The first alternative is an uninsulated dwelling without storm windows or double glazing. The second alternative is the ASHRAE 90-75 voluntary thermal standard for new construction. Under this standard, all windows are stormed or double glazed, walls and ceiling are insulated, heating and cooling system capacities are reduced, and tight construction is used to reduce infiltration. The ASHRAE standards vary by region, as presented in Table 2.21. Table 2.22 summarizes the

Table 2.20

Energy usage characteristics of NIECS/PNW dwellings

	NIECS		PNW	
	Mean	SD	Mean	SD
Coefficients of Performance				
Gas	.64	.08	.70	.05
Oil	.57	.07	.62	.05
Heat Pump	2.3	2.4	3.2	2.7
Air Conditioner	4.0	3.1		
Energy Consumption[1]				
Electric resistance	99420	51800	130800	60610
Gas	151300	71310	186700	87070
Oil	171600	80800	211600	98700
Heat Pump	54600	32800	47960	27390
Air Conditioner	6976	5780	1200	1234
Energy Price of Comfort[2]				
Electric Resistance	4726	2120	5351	2614
Gas	7446	3455	7723	3978
Oil	8447	3922	8753	4511
Heat Pump	2523	1249	1918	1046
Air Conditioner	684	540	155	130

[1] In 10^3 Btu's, net of distribution losses.
[2] In 10^3 Btu's, per degree thermostat setting, net of distribution losses.

differences in capacities and energy consumption under these alternatives, for dwellings built since 1970.

Note that observed thermal performance achieves a substantial fraction of that achievable under the ASHRAE 90-75 standards. In electric resistance heating, for example, 81 percent of the potential conservation is achieved. Substantial conservation is still attainable, however, from the ASHRAE standard: for electric resistance heating, electricity consumption could have been reduced 29 percent relative to actual construction, with comparable reductions for other heating systems. Table 2.23 gives the sample average capital costs (in 1981 prices) of the thermal improvements and heating system for the observed construction since 1970 and for the ASHRAE standards.

These costs are taken from an equipment and construction costing program described in Cowing-Dubin-McFadden (1982). Note first that for electric baseboard resistance heating and heat pumps, the savings in equipment cost from reduced design capacity requirements and downsizing more than offset the added cost of meeting the ASHRAE

Table 2.21

Thermal characteristics by region

	Region 1 Northeast	Region 2 North Central	Region 3 South	Region 4 West
R-value ceiling insulation	17.14	17.14	19.5	19.5
R-value wall insulation	15.44	15.44	9.45	9.45
Reduction in heating design temp. differential	12	14	12	14
Reduction in cooling design temp. differential	7	6	6	5

standards, even before the reduction in life-cycle costs from reduced operating cost is taken into account. On the other hand, for gas forced-air systems, there is an average increment in capital cost of $486.70 required to meet the ASHRAE standards and reduce energy consumption by 28,790,000 Btu's/year. At an average gas price of $3.54 per 10^6 Btu's, the operating cost savings is approximately $102/year.

Ignoring the effects of finite dwelling and equipment life, the real rate of return to adoption of the ASHRAE standards is 21 percent. Because this rate exceeds the real interest rate for most consumers who are free of credit constraints, it appears that improvement of thermal performance to meet the ASHRAE standard should in fact benefit most consumers and may be adopted voluntarily if consumers are fully appraised of the life-cycle costs. This conclusion is subject to a caveat that a comparison is being made between actual and standard thermal levels for gas forced-air heat, irrespective of the type of heat actually chosen. In fact, actual insulation levels are higher for electrically heated homes than for homes heated by other fuels, as should be expected when thermal performance is adjusted to minimize life-cycle cost. This will tend to lead the preceding calculation to overstate the benefit attainable from imposing standards on electrically heated homes, and understate the benefit for homes using other fuels. A more careful behavioral analysis of joint choice of heating fuel and thermal shell performance will be reported separately.

We conclude this chapter with a few comments on the uses and limitations of the thermal and costing models we have developed. First, it is *not* our objective to construct a detailed thermal model suitable for

Table 2.22

Sensitivity of HVAC system to thermal characteristics (NIECS)[1]

	Observed Dwelling	Uninsulated Dwelling	ASHRAE 90-75 Standards
Air Conditioning			
Capacity[2]	34.08	57.56	23.53
Energy Consumption (1000 Btu's)	6883	10060	5590
Electric Resistance Heat			
Capacity[3]	47.20	85.02	29.63
Energy Consumption[4]	107500	195200	86920
Gas Forced-Air			
Capacity[2]	51.86	89.28	33.89
Energy Consumption[4]	106400	287000	128300
Oil Forced-Air			
Capacity[2]	51.86	89.28	33.89
Energy Consumption[4]	181190	325400	145500
Heat Pump			
Capacity[2]	51.86	89.28	33.89
Energy Consumption[4]	57710	104600	46560

[1] Houses built after 1970.
[2] Capacity for forced-air central system in MBtuh.
[3] Capacity of non-central baseboard system in MBtuh.
[4] Annual energy consumption in 10^3 Btu's, including distribution losses.

Table 2.23

Costs of thermal improvements

	Observed Dwellings	ASHRAE Standard
(1) Insulation cost	790.30	1,136.00
(2) Storm/Double glazing cost	263.20	444.60
(3) Electric resistance capital cost	1,942.40	1,386.00
(4) Total (1) + (2) + (3)	2,995.90	2,966.60
(5) Gas forced-air capital cost	2,392.30	2,351.90
(6) Total (1) + (2) + (5)	3,445.80	3,932.50
(7) Heat pump capital cost	9,293.00	5,274.00
(8) Total (1) + (2) + (7)	10,346.50	6,854.60

engineering new dwellings or carrying out energy audits for existing structures, and it would be a mistake to try to use the model for these purposes. The data requirements for such modeling are greater by an order of magnitude than the structural information in the NIECS or

PNW data sets. Second, it *is* our objective to utilize the data available from NIECS/PNW to approximate thermal requirements across a statistical sample in a way that explained most of the technologically determined scale of capacity and usage. The outputs of the thermal model can then be used as inputs to an analysis of choice behavior, with econometric models explaining behavioral deviations from the engineering base.

The thermal and costing models we have developed appear to give a much more satisfactory basis for pricing out alternative HVAC systems than one could achieve using simple formulae for cost per square foot or cost per square foot degree-day. Further, the implied energy consumption under alternative weather conditions should be adequate for indexing the expected operating costs of alternative systems.

We see several advantages to combining the simple engineering thermal model we have developed and a behavioral analysis of consumer response. We can avoid the problems of a pure econometric approach that "burns degrees of freedom" to explain usage variations that are technically determined. We also avoid a pure engineering model that fails to account for economic behavioral response. In addition, the use of the thermal model as an input to the behavioral analysis allows one to calculate readily the technical *and* behavioral response of households to energy policies. This permits a logically consistent and complete method for translating policy affecting voluntary or mandatory building standards into technical consequences in terms of capital cost and energy requirements, modified by consumers' behavioral responses to these consequences.

2.5. Appendix: Seasonal heating and cooling efficiencies of air conditioners and heat pumps

The coefficient of performance of air conditioners and heat pumps in the cooling mode from ASHRAE graphs is approximately:

$$COP = 1/(.235 + .0051\ (t-\tau))$$

where t is daily mean ambient temperatures and τ is thermostat setting. As a basis for a seasonal efficiency calculation, consider a typical residence in which the average cooling load over a day in the cooling season (defined by $t > \tau = 75$) is 17900 + 791 (t-75) Btuh. The energy output per hour for cooling, averaged over the year, is:

$$Q_{out} = \int_{75}^{t_1} [17900 + 791\,(t-75)]F'(t)\,dt$$

where $F(t)$ is the distribution of daily mean temperatures. The corresponding energy input is:

$$Q_{in} = \int_{75}^{t_1} [17900 + 791(t-75)]\,\frac{F'(t)}{COP}\,dt$$

$$= \int_{75}^{t_1} [17900 + 791(t-75)]$$

$$\cdot\ [.235 + .0051(t-75)]F'(t)\,dt$$

Using the approximation to the annual distribution of mean temperatures given by (36), we compute these expressions at representative locations in each of the seven AIA weather zones in the United States, and compute the seasonal efficiency Q_{out}/Q_{in}. These values are then fitted empirically as a function of daily average heating and cooling degree-days. The empirical function is accurate to within 1 percent.

In the heating mode, the COP of heat pumps is approximately constant, with value 3.25, over the range where the unit is operational. Below an ambient mean temperature of 40°F, however, build-up of frost on the outdoor coil prevents operation, and backup heating is required. The usual system has electric resistance heating for extreme weather. We analyze this system. This method could be applied with obvious modifications to oil or gas backup units.

The energy output per hour for heating, averaged over the year, is:

$$Q_{out} = \int_{t_0}^{\tau} [800(\tau-t) - 1600]F'(t)\,dt$$

where τ is the thermostat setting and $800(\tau-t)-1600$ is the average heating load in Btuh over a day in the heating season (defined by $t < \tau$). If the input for days with $t < 40$ is provided by resistance heating, then:

$$Q_{in} = \int_{t_0}^{40} [800(\tau - t) - 1600]F'(t)\,dt$$

$$+ \frac{1}{3.25} \int_{40}^{\tau} [800(\tau - t) - 1600]F'(t)\,dt$$

$$= \frac{1}{3.25} \Big(2.25 \int_{t_0}^{40} [800(\tau - t) - 1600]F'(t)\,dt$$

$$+ \int_{t_0}^{\tau} [800(\tau - t) - 1600]F'(t)\,dt \Big)$$

We compute Q_{out}/Q_{in} at representative locations in the seven AIA weather zones, using the approximation (36) to the temperature distribution. The resulting efficiencies are then approximated empirically as functions of heating and cooling degrees per day. The reported efficiencies are for a thermostat setting of 65 degrees. The empirical formula is accurate to within 4 percent.