Statistical Evaluation of Pacific Northwest Residential Energy Consumption Survey Weather Data

J. J. Tawil

February 1986

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SUMMARY

This report contains the results of a task in the Customer System Efficiency Improvement (CSEI) Assessment Project. The project is being conducted by the Pacific Northwest Laboratory (PNL) for the Office of Conservation, Bonneville Power Administration (BPA). The principal objective of the CSEI project is to assess the potential for conservation in the power systems of BPA's customers. The CSEI project complements ongoing BPA assessment work on the conservation potential in the residential, commercial, agricultural and industrial sectors and in BPA's own electric power transmission and generation system.

The current report addresses an issue relating to energy consumption and conservation in the residential sector. BPA has obtained two meteorological data bases for use with its 1983 Pacific Northwest Residential Energy Survey (PNWRES). One data base consists of temperature data from weather stations; these have been aggregated to form a second data base that covers the National Oceanographic and Atmospheric Administration (NOAA) climatic divisions. As compared to the corresponding climatic division data, the weather station data can generally be expected to more closely approximate the microclimate around a dwelling unit. However, acquiring and processing the weather station data represents a significant additional cost to BPA.

At BPA's request, Pacific Northwest Laboratory has produced a household energy use model for both electricity and natural gas. The primary objective of this study was to use this model to determine whether the statistically estimated parameters of the model significantly differ when the two different meteorological data bases are used.

Three major tasks were performed to accomplish this objective. First, the household energy use model was produced. This model consists of five components: 1) a space heating model, 2) a space cooling model, 3) an appliance and lighting model, 4) a water heating model, and 5) a consumer response model. The literature was reviewed to identify suitable relationships for these components.

The second major task was to edit the 1983 PNWRES data. This involved substantial editing of existing variables, defining and creating new variables, and merging the billing and meteorological data with the basic household survey data.

Alternative specifications of the energy use model were evaluated through regression analysis. The final model specification was tested statistically to determine whether results using the climatic division degree-day data were significantly different from the results using the weather station degree-day data. Tests were conducted on both the full edited PNWRES sample and on a restricted sample consisting only of households living in a zip code area containing a weather station.

The test results offer little evidence that weather station data is more precise than the more aggregate climatic division data.

CONTENTS

SUMMARY	iii
1.0 INTRODUCTION	1
2.0 ENERGY USE SUBMODELS	3
2.1 SPACE HEATING MODEL	4
2.2 SPACE COOLING MODEL	7
2.3 APPLIANCE AND LIGHTING MODEL	9
2.4 WATER HEATING MODEL	12
2.5 CONSUMER RESPONSE MODEL	12
3.0 DEFINITION AND DESCRIPTION OF VARIABLES	14
3.1 SPACE HEATING MODEL	15
3.2 SPACE COOLING MODEL	21
3.3 APPLIANCE AND LIGHTING MODEL	21
3.4 WATER HEATING MODEL	22
3.5 CONSUMER RESPONSE	22
3.6 OTHER VARIABLES	24
4.0 CREATING THE PNWRES SUBSAMPLE	25
5.0 ESTIMATION RESULTS	29
5.1 REGRESSION RESULTS	30
5.2 TEST OF EQUIVALENCE OF WEATHER DATA	41
REFERENCES	R-1
APPENDIX A	A-1
ACKNOWLEDGMENTS	Ack.1

TABLES

1	Additional Exclusions from Data Set	27
2	Regression Variables	31
3	Electricity Consumption: Meteorological Stations, Full Sample .	33
4	Natural Gas Consumption: Meteorological Stations, Full Sample .	34
5	Electricity Consumption: Climate Zones, Full Sample . . .	35
6	Natural Gas Consumption: Climate Zones, Full Sample . . .	36
7	Electricity Consumption: Meteorological Stations, Restricted Sample	38
8	Natural Gas Consumption: Meteorological Stations, Restricted Sample	39
9	Electricity Consumption: Climate Zones, Restricted Sample . .	40
10	Natural Gas Consumption: Climate Zones, Restricted Sample . .	42
11	Pooled Regression: Electricity, Full Sample	43
12	Pooled Regression: Natural Gas, Full Sample	44
13	Pooled Regression: Electricity, Restricted Sample	45
14	Pooled Regression: Natural Gas, Restricted Sample	46

1.0 INTRODUCTION

The 1983 Pacific Northwest Residential Energy Consumption Survey (PNWRES) data base and complementary billing and meteorological data bases have been recently released by the Bonneville Power Administration (BPA). These are currently being used to develop relationships relating to energy use in residential housing. To evaluate the importance of ambient temperature on residential energy use, BPA has obtained two meteorological data sets. One set consists of heating and cooling degree days taken directly from meteorological stations located in the Pacific Northwest. The second set consists of the same weather station data, grouped and averaged to produce heating and cooling degree days for each of the National Oceanographic and Atmospheric Administration (NOAA) climatic divisions. NOAA collects and compiles these data annually for its climatic divisions. There are up to 10 climatic divisions in each state, with 36 in the four states of the Pacific Northwest.

An important question for BPA concerns the extent to which the weather station data provide PNWRES users with a valuable research tool that extends beyond the usefulness of the NOAA data. The potential advantage of using the weather station data is that it more closely approximates the microclimate surrounding each respondent's dwelling, than do the more aggregate NOAA data. However, to provide the weather station data to PNWRES users, BPA must first acquire the raw weather station data, adjust it for missing values, assign each respondent to a weather station, and provide the finalized data to users. This represents a significant effort on the part of BPA.

By comparing the performance of the two data sets in explaining residential energy use, Pacific Northwest Laboratory (PNL) has evaluated the potential benefit to PNWRES users of receiving the weather station data in addition to the NOAA climatic division data. The performance criteria were conventional statistical tests. The steps that were taken in this research effort are described below.

First, a residential energy use model was specified. The purpose of the energy use model was to account for total household energy use by the individual energy-using components. The model was used as a vehicle for comparing the two meteorological data sets. The energy use model is specified in Chapter

2 and consists of several submodels, including a space heating submodel, a space cooling submodel, an appliance and lighting submodel, a water heating submodel, and a consumer response submodel.

The variables used in the submodels are defined and qualified in Chapter 3. The discussion in this chapter includes reporting how certain survey responses were handled, how new variables were defined, and the assumptions that were made.

In the next step, the PNWRES data were edited to provide an appropriate sample to be analyzed. For example, all respondents not using electricity or natural gas as the primary fuel for space heating were excluded. The editing procedures are described in Chapter 4.

In Chapter 5 regression equations for explaining residential energy use are specified, and the results of this statistical analysis are reported. This chapter also contains an assessment of the extent to which the weather station data set provides a useful research tool in addition to the NOAA climatic division data set.

Finally, the methodology used to produce the meteorological station data is discussed in Appendix A.

2.0 ENERGY USE SUBMODELS

In this section we discuss the five submodels that comprise the energy use model to be estimated in Chapter 4. The model that will be estimated is

$$CE = a_0 + a_1 SH + a_2 SC + a_3 AP + a_4 WH + a_5 CR$$

where CE = household consumption of electricity (natural gas)

SH = design space heating requirements of the housing unit

SC = design space cooling requirements of the housing unit

AP = electricity (natural gas) consumption of appliances

WH = electricity (natural gas) consumption for water heating

CR = consumer response submodel.

The constants $a_0, \dots, a_5$ are parameters to be estimated. Values for SH, SC and WH are computed independently in the space heating, space cooling and water heating submodels, respectively. SH and SC depend on the physical characteristics of the dwelling and on the heating and cooling equipment installed. WH depends on the number occupying the dwelling and on the fuel used to heat water. In the appliance and lighting submodel, the term AP is expanded to identify individual appliances. The variables in these first four submodels depend on the physical characteristics of the dwelling and the types of energy-using equipment. In the fifth submodel, the consumer response submodel, the way consumers use their electrical and natural gas equipment is considered. The amount of energy consumed is hypothesized to depend on consumers' response to the price of energy and to their household income level.

All of the variables except energy price and income are measured in average Btu/hr; price and income are measured in dollars. The model is estimated for electricity and natural gas, for meteorological station data and for climate zone data, and for a subset of the sample in which only households with a weather station within their zip code area are included. The space heating, space cooling, appliance, water heating, and consumer response models are described in the remainder of this section.

2.1 SPACE HEATING MODEL

The space heating model is based largely on the heating and cooling load model in Dubin & McFadden (1983); this model will be referred to as the D&M model in this report. The D&M model is a thermal model designed to use the survey data in the National Interim Energy Consumption Survey (NIECS) and the 1979 PNWRES. We have adapted it here for use with the 1983 PNWRES. The model requires as input certain physical characteristics of the housing unit and the type of heating and cooling equipment used. From these, the model provides estimates of the annual design energy requirements of the housing unit. A major feature of the model is that it is specified so as not to depend on the base used for computing heating and cooling degree days.

The variables used by the D&M heating model are defined in the following section, and the model itself is specified. For information regarding the derivation of the model and other details, the reader is referred to the D&M report.

2.1.1 Variables Used by the Model

The variables used in the space heating model are described below. Several of the variables are not contained in the 1983 PNWRES and had to be developed indirectly. The derivation of all the variables used in the model is addressed in Chapter 3.

WA = exterior wall area excluding windows and sliding glass doors
CA = ceiling area, equals roof area measured in a horizontal plane
WSA = multi-glazed and storm window area
WNA = single-glazed window area
SSA = multi-glazed sliding glass door area
SNA = single-glazed sliding glass door area
V = volume of conditioned space
T = mean daily ambient temperature
TAUW = winter design temperature - 70° assumed
TG = ground temperature
N = number of occupants
INTRNL = internal load
IW = R-Value, walls
IC = R-Value, ceilings
AX, BX = solution parameters to Equations 39 and 40 in D&M.

The D&M heat load model is specified as a quadratic equation in the variable Δt , the difference between the building design temperature and the ambient temperature:

$$QSEAS = W_0 + W_1 \Delta t + W_2 \Delta t^2$$

where QSEAS is the annual average energy consumption level for space heating under benchmark assumptions about internal load, thermostat setting and appliance use. The coefficients W_0 , W_1 and W_2 are defined by the following relationships:

Let

$$W_0 = CA \left(\frac{75 - (36 + 0.3T)}{10.05} \right) (TAUW - TG) - INTRNL$$

$$W_1 = WA \left(\frac{0.9394 + 0.0138IW}{2.85 + IW} \right) + CA \left(\frac{1}{3.834 + 0.943TC} \right) + \frac{WSA}{2.78} + \frac{WNA}{0.98} + \frac{SSA}{1.32} + \frac{SNA}{0.88} + 0.01035 \theta V$$

and $W_2 = 0.00015 \theta V$

where $\theta = 1.14 - \frac{0.28 (WSA + SSA)}{WSA + WNA + SSA + SNA}$

and the other variables are as defined above. Now, define the function $r(\delta)$ as follows:

$$r(\delta) = \frac{\pi^2}{12} + \frac{\alpha^2}{2} + \sum_{K=1}^5 C_K \beta^K (\delta^K - 1)$$

where $\alpha = \max(\lambda, 0)$

$$\beta = e^{-\alpha}$$

$$\delta = e^{\lambda}$$

and $C_K = a_K/K$ with $a_1 = 0.99949556$

$$a_2 = 0.49190896$$

$$a_3 = 0.28947478$$

$$a_4 = 0.13606275$$

$$a_5 = 0.03215845$$

Also, define the balance temperature, TBALW, as

$$TBALW = TAUW + \frac{W1}{2W2} (1 - (1 - 4*W2*W1^{-2} \min(W0,0))^{0.5})$$

The balance temperature is the temperature above which no heating is required.

If $W0 \geq 0$, then the annual average delivered heat per hour, QSEAS, is given by

$$QSEAS = \frac{W0}{1 + e^{-AX-BX*TAUW}} + \frac{W1*\ln(1+e^{AX+BX*TAUW})}{BX} + \frac{2W2}{BX^2} \tau(Ax+BX*TAUW)$$

If $W0 < 0$, then QSEAS is given by

$$QSEAS = \frac{W1'}{BX} \ln(1 + e^{AX+BX*TBALW}) + \frac{2W2'}{BX^2} \tau(Ax+BX*TBALW)$$

where $W1' = W1 + 2*W2(TAUW-TBALW)$

and $W2' = W2$

The delivered energy requirements for natural gas furnaces and heat pumps need to be adjusted to reflect the thermal efficiency of these units. The coefficient of performance for a natural gas furnace, COPNG, is assumed to be

$$COPNG = 0.46 + 0.0146*HD65$$

where HD65 is the number of annual heating degree days to the base 65°F.

(This is Equation 59 in O&M.) The coefficient of performance for a heat pump, COPHP, is assumed to be

$$COPHP = HDTB / (HD40 + (HDTB-HD40)/3.25)$$

where HDTB and HD40 are the number of annual heating degree days using, respectively, the balance temperature and 40°F as the base. The relationship for COPHP is from data provided by Kathleen Hudson of Cambridge Systematics in Berkeley, CA.

Energy input in MBtu over the annual period is given by

$$8.76 * QSEAS / COP_{xx}$$

where COP_{xx} is the coefficient of performance for the relevant system. Measured in average Btu/hr, the above relation is

$$SH = QSEAS / COP_{xx}$$

2.2 SPACE COOLING MODEL

The space cooling model is also from Dubin & McFadden (1983) and is essentially the same as the space heating model described above. For information regarding the derivation of the cooling load model and other details, the reader is referred to the D&M report.

2.2.1 Variables Used in the Cooling Load Model

The following additional variables are used in the space cooling model:

TR = mean daily temperature range

TAUS = summer design temperature - 75° assumed

Let

$$UF = (TAUS - (36. + 0.3 * T)) / 10.05$$

$$UW = (0.9394 + 0.0138 * IW) / (2.85 + IW)$$

$$UCW = 1.0 / (3.834 + 0.943 * IC)$$

$$UCS1 = (0.3769 + 0.00636 * IC) / (2.097 + 0.608 * IC)$$

and $UCS2 = (0.17389 + 0.00293 * IC) / (2.097 + 0.608 * IC)$

Then

$$SO = \left(WA * UW * (362.1 - 0.9638 * TR) + \frac{CA * UCS1 * (355.6 - 1.032 * TR)}{24.} + \right. \\ \left. (WSA + WNA + SNA) * (0.8 * TAUS - 30.0) + SSA * (0.6 * TAUS - 18.0) + \right. \\ \left. 1000 * INTRNL \right) 1.25$$

$$S1 = \left(\frac{WA*UW*22.67 + CA*UCS1*22.66 + CA*USC2*24.0}{24.0} + (WSA + WNA + SNA)*0.8 + SSA*0.6 + 0.00742*V \right) 1.25$$

$$S2 = 0.00015*V*1.25$$

and the other variables are as defined above. Also, define the summer balance temperature, TBALS, as

$$TBALS = TAUS + \frac{S1}{2S2} (1 - (1 - 4*S2*S1^{-2} \min(S0,0))^{0.5})$$

The summer balance temperature is the temperature below which no cooling is required. Finally, define

$$S0' = S0 + S1*(TBALS - TAUS) + S2*(TBALS - TAUS)^2 = 0$$

$$S1' = S1 + 2.0*S2*(TBALS - TAUS)$$

$$S2' = S2$$

Then, if $S0 \geq 0$, the annual average delivered energy per hour, QAC, is given by

$$QAC = \frac{S0}{1 + e^{-AX-BX*TAUS}} + \frac{S1*\ln(1 + e^{AX+BX*TAUS})}{BX} + \frac{2S2}{BX^2} \Gamma(AX+BX*TAUS)$$

If $S0 < 0$, then QAC is given by

$$QSEAS = \frac{S1'}{BX} \ln(1 + e^{AX+BX*TBALS}) + \frac{2S2'}{BX^2} \Gamma(AX+BX*TBALS)$$

The delivered energy requirements need to be adjusted to reflect the thermal efficiency of air conditioning units. For an air conditioner, the coefficient of performance, COPAC, is assumed to be

$$COPAC = 3.44 + \frac{0.744}{HD65} + \frac{1.23}{CD65} - 0.036*HD65 - 0.038*CD65$$

where HD65 and CD65 are the number of respective annual heating and cooling degree days to the base 65°F. (This is Equation 63 in D&M.)

Energy input in MBtu for space cooling over the annual period is given by

$$8.76*QAC/COPAC$$

Measured in average Btu/hr, the above relation is

$$SC = QAC/COPAC$$

2.3 APPLIANCE AND LIGHTING MODEL

The appliance and lighting model is based on an empirical analysis conducted on the 1980 Residential Energy Consumption Survey (RECS) by Latta (1983). The RECS data are from a national survey. Latta's analysis consists of regression equations estimated for single-family detached housing units, mobile homes, single-family attached units, and units in small and large apartment buildings. Gas and electric consumption were separately considered. In the Latta model, energy consumption is computed as the sum of four components: 1) space heating, 2) space cooling, 3) hot water and 4) lighting and appliances. This model differs from ours in two respects: 1) our model is based on design energy use for both heating and cooling, while the corresponding variables in Latta's model are for actual energy use; and 2) Latta's model does not include energy price and household income, our consumer response variables.

We use Latta's estimated appliance and lighting model, described below, to compute the internal load--variable INTRNL--in the space heating and cooling submodels described in Section 1.1. However, to estimate the effects of appliances on energy consumption, we include individual major appliances in our estimated model. The energy used by lighting and minor appliances is assumed to be estimated primarily by the intercept term. Because Latta's appliance equation is used to compute our internal load variable, we devote the remainder of this section to a description of Latta's appliance and lighting submodel.

Energy consumption by appliances was considered in two components: electrical energy consumption, EAPLOAD; and natural gas consumption, GAPLOAD. EAPLOAD and GAPLOAD are estimated as follows:

Let ADULTS = the number of occupants 13 years old and above

VINTAG = the age of the housing unit

PSTRM = percent of window and sliding glass door area that is insulated or has storm windows

HEATED = total square feet of conditioned area

NFRIG = number of manually defrosted refrigerators in use
 NFFFRG = number of automatically defrosting refrigerators in use
 VAR282 = number of freezers in use
 VAR262 = number of ovens in use
 VAR289 = 1, indicates washing machine
 VAR290 = 1, indicates electric dryer
 VAR291 = 1, indicates gas dryer
 VAR318 = number of occupants
 TVCOL = the number of color television sets in use
 TVBLK = the number of black and white television sets in use
 CFA = 1, indicates a central warm air or forced air furnace
 GOV = the number of natural gas ovens

Then $EAPLOAD = 2614.8 + 1088.6*ADULTS + 399.6*VINTAG - 19,28*PSTRM +$
 $1.098*HEATED + 2455.6*NFRIG + 2863.3*NFFFRG +$
 $3953.5*VAR282 + 929.71*VAR262 - 4330.5*VAR289 +$
 $1734.7*VAR289*VAR318 + 3409.5*VAR290 + 836.17*TVBLK +$
 $2055.4*TVCOL + 1155.6*CFA$

and $GAPLOAD = 930.*GOV + 3400.*VAR291$

The above relationships are taken from Latta (1983; pp. 31-2). Latta also has terms for swimming pools, heated pools and wringer-type washing machines. Our sample excludes the few individuals who heat their swimming pools with electricity or natural gas (see Chapter 4). With regard to wringer-type washing machines, the 1983 PNWRES does not identify these separately; however, they are presumed to be sufficiently rare so as not to affect the results.

The appliance and lighting equations give energy consumption in MBtu for a one-year period. To convert MBtu to hourly load in Btu--the units used in the space heating and cooling models--we multiply EAPLOAD and GAPLOAD by $1.0/(8.760)$.

Latta provides adjustment factors for dwelling units other than single-family detached (Latta 1983; p. 83). The coefficients for mobile homes, single-family attached, units in small apartment buildings, and units in large apartment buildings are +0.1491, -0.1639, -0.1545 and -0.1734, respectively, for electric appliances and lighting. Unfortunately, the PNWRES building type

classification does not correspond exactly to that of the RECS survey; the former uses multi-family attached/detached, while the latter uses units in small/large apartment buildings. However, Latta's coefficient for the single-family attached is close to and nearly midway between the coefficients for apartments. The coefficient for single-family attached was therefore used to adjust all dwelling types except mobile homes. Thus, the electric lighting and appliance energy consumption equation in its general form is:

$$\text{EAPLOAD}' = (1.0 + 0.1491*\text{MOB} - 0.1639*(\text{SFA1}+\text{SFA2}+\text{MFD}+\text{MFA1}+\text{MFA2}+\text{MF5})) * \\ \text{EAPLOAD}*(1.0/8.76) \quad (\text{Btu/hr})$$

where MOB = 1, indicates mobile home
 SFA1 = 1, indicates single-family, attached one side
 SFA2 = 1, indicates single-family, attached two sides
 MFA1 = 1, indicates multi-family, attached one side
 MFA2 = 1, indicates multi-family, attached two sides
 MFD = 1, indicates multi-family detached
 MF5 = 1, indicates multi-family with 5 or more units

The method used by Latta to adjust the estimates of natural gas consumption for dwelling type does not permit the adjustment to be made for gas appliances only. Therefore, we arbitrarily used the adjustment factor for electric appliances and lighting to make the adjustment for natural gas. Thus,

$$\text{GAPLOAD}' = (1.0 + 0.1491*\text{MOB} - 0.1639*(\text{SFA1}+\text{SFA2}+\text{MFD}+\text{MFA1}+\text{MFA2}+\text{MF5})) * \\ \text{GAPLOAD}*(1.0/8.76) \quad (\text{Btu/hr})$$

As already noted, the estimated coefficients from Latta's appliance and lighting model are used only to compute internal loads in the space heating and cooling models. To estimate electricity and natural gas consumed by appliances and lighting from the 1983 PNWRES data, we used in our estimating equation essentially the same variables used by Latta. The coefficients for these variables were determined from a regression.

2.4 WATER HEATING MODEL

The water heating submodel is also based on Latta's analysis of the RECS data. The estimated relationship for electric water heating for single-family detached units is

$$EWH = 3966.7 + 2156.9*VAR318 + 3337.8*TEENS + 4903.6*VAR292$$

where EWH = annual consumption of electricity, in MBtu, to heat water

VAR318 = number of occupants

TEENS = number of teenagers in the household

VAR292 = 1, indicates an electric dishwasher

After making adjustments for building type and converting the energy units into hourly Btu, the equation becomes

$$ELCONWH = \frac{(1 - 0.4084*MOB - 0.1639*(SFA1+SFA2+MFD+MFA1+MFA2+MF5))*EWH}{8.76}$$

where WH = hourly Btu consumed in heating water, and the other variables are as previously defined.

2.5 CONSUMER RESPONSE MODEL

Energy users will adjust their consumption of energy based on their preference for comfort, their income and the price of energy. Since the energy crisis of 1974, methods of conserving household energy have become widely known. Commonly adopted conservation measures and strategies include altering thermostat settings, closing off rooms in winter, including conservation measures in new building construction, reducing temperature settings on hot water heaters, installing hot water savers on showers and appliances, and using energy-efficient appliances.

The effect on energy consumption of such conservation responses can be evaluated through multiple regression analysis. In the current model, we measure some of these responses with energy price and household income variables. The following discussion considers which of the conservation responses are measurable by these variables.

The nature of multiple regression analysis is to explain variations in the dependent variable through the presence of independent or explanatory variables. In the model that we have been describing, some conservation-related measures are considered explicitly, while others are not. For example, the amount of roof insulation and the number of refrigerators in use are explicitly considered while thermostat settings and the energy efficiency of the refrigerators are not. If a conservation measure is not considered explicitly, its influence on variations in the dependent variable must be "explained" by other variables in the model or must be absorbed into the the disturbance term. The energy price and household income variables have been included in the model to "explain" the influence on energy consumption of those conservation measures not explicitly included.

From the above explanation, it should be clear which conservation measures have an explicit effect on the dependent variable and which have an effect through the energy price and household income variables. One measure--closing off rooms to conserve fuel during winter--deserves further elaboration. The D&M space heating and cooling models assume that all of the living space included in the model is conditioned. To the extent that unheated areas have been included in the reported square footage variable (Variable 473), variations in household energy usage from closing off rooms will be "explained" by the energy price and income variables. Whether such areas have been included is not altogether clear. Instructions to the interviewer were: "[i]n general, [to] measure all parts of the housing unit which are used as year-round living quarters." However, the computed areas are based on interviewer-constructed "floor plans," and it seems likely that these may have been based on exterior walls. Also, interviewers were instructed to include basements if at least some portion was heated; and attics were to be excluded only if they were both unheated and unfinished (PNWRES 1983).

Other conservation measures for which variations in household energy usage are "explained" by the energy price and income variables include lowered thermostat settings in winter and reduced use of air conditioning in summer, increased appliance efficiency, reduced temperatures for heating water, reduced lighting, and hot water saving devices.

In the following section, we describe and qualify the variables that are used in the submodels described in this section.

3.0 DEFINITION AND DESCRIPTION OF VARIABLES

In this section we define the variables used in each of the five energy use submodels. When appropriate, we discuss any qualifications or assumptions that have been applied. Variables that are taken from the 1983 PNWRES are indicated with the variable number following the letter V. For example, V250 refers to variable 250, as denoted in PNWRES (1983). Many of the variables required for estimating the energy use submodels are not in the PNWRES data and therefore had to be derived indirectly. This required defining and using additional variables. The format for presenting this information is as follows: the variables used directly in the energy use submodels are recorded at the left margin and their description is underlined. Additional variables that are needed to define these and that have not been previously defined are indented.

3.1 SPACE HEATING MODEL

The space heating model is used to estimate the design heating requirements of the housing unit. Consequently, "nonphysical" factors that affect space heating usage, such as the interior thermostat setting, are excluded from the estimate. The variables used by the space heating model are described below and in Section 3.6.

WA Exterior Wall Area Excluding Windows and Sliding Glass Doors

The following variables are used to estimate WA:

WDA = total square footage of windows and sliding glass doors

WDA is estimated with the following relationship:

$$WDA = -34.493364 + 3.558968 * \text{SQRT}(V473) + 81.43361 * V147$$

V473 = square footage of housing unit used for year-round living

V147 = number of sliding glass doors

The above relationship was statistically estimated by running a regression using the measurement data from 7 "typical" dwelling units documented in Dubin & McFadden (1983; Table 17). This estimating procedure was used because the 1983 PNWRES reported no information on window area and comparable information was not readily available from other sources.

SDAT = total sliding glass door area

$$SDAT = 53 * V147 \quad (\text{square feet})$$

In seven "typical" dwellings where several measurements were taken, the average for sliding glass doors was found to be 53 sq. ft. (Dubin & McFadden 1983; Table 17).

WAX = exterior wall area, including doors and windows

$$WA = WAX - WDA - SDAT. \quad (\text{square feet})$$

SSA Sliding Glass Door Area, Insulated or Stormed

$$SSA = 53 * V148 \quad (\text{square feet})$$

V148 = number of insulated sliding glass doors

SSN Sliding Glass Door Area, Single-Glazed

$$SSN = SDAT - SSA \quad (\text{square feet})$$

WSA Stormed Window Area

Let IGF = fraction of windows having insulated/thermopane glass (V153)

SWF = fraction of windows having storm windows (V154)

PLF = fraction of windows having plastic covers (V155)

The above variables were evaluated from the survey responses. The responses and the assigned values are:

"None" = 0.0
"Less than 10%" = 0.05
"10-39%" = 0.25
"40-59%" = 0.50
"60-89%" = 0.75
"90-100%" = 1.0.

$$\text{Then } WSA = (IGF + SWF + PLF) * WDA \quad (\text{square feet})$$

The sum of IGF, SWF and PLF was restricted not to exceed 1.0. Note also that windows with insulating measure "other" (V156) were excluded from this calculation.

WNA Nonstormed Window Area

$$WNA = WDA - WSA - SSA - SSN \quad (\text{square feet})$$

CA Ceiling Area

Let V469 = square feet of conditioned space on floor 1

V470 = square feet of conditioned space on floor 2

V471 = square feet of conditioned space on floor 3

$$\text{Then } CA = \text{Max } (V469, V470, V471) \quad (\text{square feet})$$

The ceiling area variable is used to compute the heat loss through the roof. Since the relevant area was not directly reported, it was assumed to consist of the largest of the areas comprising each floor, excluding the basement. Normally, this would be the first floor area, but if, for example, the second floor extended over an unheated garage or carport, then the second floor area could be larger than the first floor area and therefore would be taken as the ceiling area. If none of variables 469 through 472 were reported but total square feet was reported in V473, then CA was computed by dividing variable V473 by FLRS, where FLRS is based on V408 and is defined as follows:

A default value of 1 was given to the number of floors used as living quarters. This default value was assigned to any respondent not reporting the number of floors or levels. In addition, a response of more than 3 floors was assigned the value 4; a split level with two levels was counted as 1 floor; a split level with 3 levels was counted as 1-1/2 floors; and a split level with more than 3 levels was counted as 2 floors.

V Volume of Conditioned Space

$$V = 8 * V473 \quad (\text{cubic feet})$$

Eight-foot ceilings are assumed.

T Mean Ambient Daily Temperature

AX, BX = the coefficients estimated for the Dubin-McFadden thermal efficiency model (Dubin & McFadden 1983; Equations 39 & 4D)

$$T = -AX/BX \quad (\text{degrees F})$$

AX and BX were computed from the heating and cooling degree day data with base 65°F. Four pairs of these values were generated for each member of the sample as follows: 1) station data, natural gas; 2) station data, electricity; 3) climatic division data, natural gas; and 4) climatic division data, electricity. The values were obtained by using a computer routine to solve a pair of nonlinear equations for these parameters.

TAUW Winter Design Temperature

Assumed to equal 70. (degrees F)

TG Ground Temperature

$$TG = T - (18 * ORE + 18 * WAS + 19 * IDA + 20 * MON) \quad (\text{degrees F})$$

(Based on ASHRAE 1977)

The ground temperature affects the heat loss through basement walls and the flooring on the ground floor. The coefficients of the dummy variables ORE, WAS, IDA and MON represent the annual ranges in ground temperature at a depth of 4 inches.

V318 Number of Occupants

INTRNL Internal Load

The internal load is made up of heat energy from lighting, appliances, building occupants, and solar gain. The internal load calculation for lighting and appliances is based on Latta (1983) and is discussed in Sections 2.3 and 3.3.

In calculating internal load, we assume that, with the exception of energy used for heating water, all energy used by appliances and lighting ultimately becomes heat energy and contributes to the internal load. To assume that none of the energy used in heating water contributes to the internal load may cause the internal load to be understated. However, adding all of the energy used by clothes dryers to internal load will tend to overstate the internal load because much of the heat from these appliances may be vented outdoors.

EAPLOAD' = electricity consumption of lighting and of appliances using electricity (Btu/hr). The computation of EAPLOAD' was defined in Section 2.3; also, see Section 3.3.

GAPLOAD' = natural gas consumption of appliances (Btu/hr). The computation of GAPLOAD was described in Section 2.3; also, see Section 3.3.

SDL = solar gain (Btu/hr).

Solar gain was estimated using the following relationship developed by Kathleen Hudson of Cambridge Systematic, Berkeley, CA.

PCTCLR = the fraction of the daytime hours in which the weather is clear. PCTCLR value is 0.6 for Montana, 0.5 for Idaho and 0.4 for Washington and Oregon.

$$PCTCLR = 0.6*MON + 0.5*IDA + 0.4*WAS + 0.4*ORE$$

WAS = Washington (dummy variable) (V2)

Eastern and Western Washington were aggregated into a single variable.

ORE = Oregon (dummy variable) (V2)

Eastern and Western Oregon were aggregated into a single variable.

IDA = Idaho (dummy variable) (V2)

MDN = Montana (dummy variable) (V2)

SHDG = shading factor for insulated/stormed glass

$$SHDG = 0.9$$

$$SOL = 1000.*PCTCLR*SHDG*(WSA+SSA)/(24*WDA) \quad (\text{Btu/hr})$$

$$INTRNL = (EAPLOAD' + GAPLOAD') + 225*V318 + SOL \quad (\text{Btu/hr})$$

I_wR-Value, Walls

The 1983 PNWRES does not directly inquire about the amount of insulation in the walls; however, it does contain two questions that can be used to construct an estimate. V131 asks for the percentage of the outside walls that contain insulation; V49 relates to the respondent's perception of the energy efficiency of his home. Values for I_w were constructed based on responses to these two variables as follows:

R-Values, Walls

Perc. of Walls Insulated	Potential Improvement in Energy Efficiency of Home			
	None	A Little	Moderate	A Lot
None	3	3	3	3
1-10	7	7	5	5
10-39	8	8	7	7
40-59	9	9	9	8
60-89	10	10	9	9
90-100	11	11	10	9
Don't Know	11	10	9	7

The entries in the above table are based on judgment. A default value of R-11 was used for responses not falling in any of the above categories. Besides using frequency information on the two variables noted, information from the following table was also factored in. The information is based on surveys of new-home builders in the Pacific states for the years indicated.

Exterior Wall Insulation, Single-Family Detached
Pacific States, Selected Years
(percent of units with R-value)

R-Value	1975-6	1974	1973*
R0	0.2	6.0	2.5
R3	---	9.6	0.5
R7	0.4	15.1	20.9
R11	87.5	69.2	70.4
R13	8.9	---	---
R19	3.0	0.0	---

*Based on a mix of dwelling types in the Western Region.

Source: (OTA 1979)

I_cR-Value, Ceilings

Although the 1983 PNWRES does not directly inquire about the amount of insulation in the ceilings, it does contain two questions that can be used to construct an estimate for the amount of ceiling insulation.

V133 asks for the percentage of the ceiling that contains insulation, and V49 relates to the respondent's perception of the energy efficiency of his home. Values for I_c were constructed based on responses to these two variables as follows:

R-Values, Ceilings

Percent of Ceilings Insulated	Potential Improvement in Energy Efficiency of Home			
	None	A Little	Moderate	A Lot
None	9	9	0	0
1-10%	11	11	9	9
10-39%	13	13	11	11
40-59%	13	13	13	13
60-89%	18	18	18	18
90-100%	19	19	19	19
Don't Know	19	13	11	9

The entries in the above table are based on judgment. A default value of R-13 was used for responses not falling in any of the above categories. Besides using frequency information on the two variables noted, information from the following table was also factored in. The information is based on surveys of new-home builders in the Pacific states for the years indicated.

Exterior Ceiling Insulation, Single-Family Detached Pacific States, Selected Years (percent of units with R-value)

R-Value	1975-6	1974	1973*
None	0.7	4.8	3.0
R7	0.3	---	0.2
R9	---	4.5	17.0
R11	2.5	16.3	11.5
R13	12.8	28.2	38.5
R18	---	4.4	1.2
R19	80.9	41.6	16.8
R22	0.9	0.1	---
R30	0.8	---	---
R31	0.3	---	---
> R31	0.4	---	---

*Based on a mix of dwelling types in the Western Region.

Source: (OTA 1979)

V289 = 1 indicates washing machine; 0 otherwise
 V290 = 1 indicates electric clothes dryer; 0 otherwise
 TVCOL = the number of color television sets
 TV1 = 1 if television #1 is a color television; 0 otherwise (V255)
 TV2 = 1 if television #2 is a color television; 0 otherwise (V256)
 TVCOL = TV1 + TV2
 TVBLK = the number of black and white television sets
 V254 = the number of television sets in use
 TVBLK = V254 - TVCOL
 CFA = 1 indicates a central warm air or forced air furnace;
 0 otherwise (V158 or V159)
 GOV = the number of natural gas ovens
 GOV1 = 1 if oven #1 uses natural gas; 0 otherwise (V263)
 GOV2 = 1 if oven #2 uses natural gas; 0 otherwise (V264)
 GOV = GOV1 + GOV2
 V291 = 1 indicates gas clothes dryer; 0 otherwise (V291)

3.4 WATER HEATING MODEL

The following variables were used in estimating the water heating model.

VAR318 Number of Residents

TEENS Number of Teenagers in Household

This variable was evaluated from variables V321 through V358 as follows:

If the exact age of the householder was given and the person was between the ages of 13 and 19, that person was included in the TEENS count. If an exact age was not given but the person was in age category 3, that person was included in the TEENS count.

V292 Electric Dishwasher is Present

This variable equals 1 if an electric dishwasher is present, and 0 otherwise.

3.5 CONSUMER RESPONSE MODEL

The purpose of the consumer response submodel is to account for consumer adjustments in energy consumption which are not directly traceable to variables included explicitly in the model. We account for these adjustments with two

variables: energy price and household income. Our hypothesis is that, other things remaining equal, higher energy prices will cause more energy users to take actions to reduce energy consumption; and, other things remaining equal, higher household incomes will result in higher energy consumption. Energy price and household income are defined as follows:

EPRICE Price of Electricity

ECON = Electricity consumption in the 6th through 17th billing periods; this most closely approximates the 1982 calendar year. (kWhs)

ECOST = Electricity cost in the 6th through 17th billing periods. (dollars)

EPRICE = ECOST / ECON (dollars/kWh)

The observation was excluded if $EPRICE \geq \$0.10$ because reported electricity costs may include costs other than for electricity consumption.

GCON = Natural gas consumption in the 6th through 17th billing periods. (therms)

GCOST = Natural gas cost in the 6th through 17th billing periods. (dollars)

GPRICE = GCOST / GCON (dollars/therm)

NVAR364 Household Annual Income

This variable was evaluated from variable V364 and value was assigned as follows:

under \$ 5,000,	NVAR364 = \$ 4,000
\$ 5,000-\$ 7,999,	NVAR364 = \$ 6,500
\$ 8,000-\$ 9,999,	NVAR364 = \$ 9,000
\$10,000-\$11,999,	NVAR364 = \$11,000
\$12,000-\$13,999,	NVAR364 = \$13,000
\$14,000-\$15,999,	NVAR364 = \$15,000
\$16,000-\$17,999,	NVAR364 = \$17,000
\$18,000-\$19,999,	NVAR364 = \$19,000
\$20,000-\$24,999,	NVAR364 = \$22,500
\$25,000-\$29,999,	NVAR364 = \$27,500
\$30,000-\$34,999,	NVAR364 = \$32,500
\$35,000-\$39,999,	NVAR364 = \$37,500
\$40,000-\$49,999,	NVAR364 = \$45,000

- (a) Bill Monroe, a statistical analyst at Electronic Data Systems, provided the basis for selecting \$0.10 as the cutoff point. He took the maximum prices reported for all billing periods and found that approximately 95% of these were under \$0.10 per kWh.

\$50,000-\$59,999, NVAR364 = \$55,000
\$60,000-\$74,999, NVAR364 = \$67,500
\$75,000 or over, NVAR364 = \$90,000.

3.6 OTHER VARIABLES

In addition to the variables defined in Sections 2.1 and 2.2, adjustment factors F1 and F2 are defined for use in the space heating and cooling models. The adjustment factors are used in processing attached building units. If a building unit is attached, we assume that there is no heat loss through the common wall(s). For a building with five or more units, we assume that there is no heat loss through two walls, the ceiling and the floor.

The factors F1 and F2 are used to reduce the wall, ceiling and floor areas accordingly. For a single- or multi-family unit that is attached on one side, the wall area is decreased by 25%. For a single- or multi-family unit attached on two sides, the wall area is decreased by 50%. For a unit in a building with five or more units, the wall area is decreased by 50% and the effective area of the floor and ceiling is zero square feet. An assumption implicit in the above procedure is that the attached unit is square; i.e., the common wall is the same size as each exterior wall.

4.0 CREATING THE PNWRES SUBSAMPLE

This section describes the measures that were taken to obtain an appropriate subsample from the full PNWRES data set. The objective here was to construct a data set that met the following two criteria: 1) it should contain variables that can adequately explain residential energy consumption, and 2) it should lead to a clear statistical test of the incremental value of using the weather station data over the more aggregate climate division data. To meet the second requirement, the proportion of variance explained by at least one of the weather variables must be high relative to the unexplained variance. This can be accomplished by reducing the unexplained variance to the extent practicable.

Consider the following example, which illustrates measures that were taken to reduce the unexplained variance. To account for electricity use among households that heat a swimming pool with electricity, we could use a dummy variable for swimming pool ownership. Alternatively, we could exclude these households entirely from the sample. The latter course results in exclusion of a relatively few households. However, it is also likely to significantly reduce the unexplained variance, since the included variables are not expected to account for much of the variation in the amount of electricity consumed in heating a pool. As long as excluding the variable would not favor the specification with one weather variable over the specification with the other weather variable, such exclusions will not affect the validity of the test. In short, the objective is to obtain a good test of the incremental value of the weather station data rather than to explain energy consumption among the widest range of energy consumers.

The original PNWRES sample consisted of 4,703 observations on residential housing units that were individually metered to measure their consumption of electricity and natural gas. Meteorology data (heating and cooling degree days) were unavailable for 634 of these observations; after these were excluded, 4,069 observations remained. The next step in creating a relevant subsample was to exclude respondents not using electricity or natural gas most of the time for purposes of space heating. After this group was excluded, a subsample of 2,329 households remained.

From the remaining subsample we next eliminated respondents from additional categories in accordance with the criteria discussed above. These additional eliminations are presented in Table 1, which shows the PNWRES variable number, the description of the variable being excluded, the reason for excluding the variable, and the number of respondents among the 2,329 households falling into the restricted category. The numbers in the last column may be mutually inclusive.

The reasons for excluding some of the variables requires some elaboration. The design energy use of an unconventional residence, such as a houseboat, is difficult to characterize, particularly if the survey data do not indicate what makes the residence unconventional. Thus, unconventional residences were removed from the sample. We also removed respondents who might have moved into their residences between December 1981 and January 1983, the period of analysis. It was unlikely that they were in residence during all of their first billing period, which would affect their use of appliances and hot water. After the exclusions indicated in Table 1 were made, 1,604 households remained in the sample.

Some additional screening of variables was performed before regressions were run on the statistical model. Respondents who did not report their household income (V364) were excluded, as were those for which there were no heating degree days reported within the 12-month sample period selected for this study. (Respondents with no heating degree days reported within the 20-month period covered by the 1983 PNWRES had been excluded earlier.) Additionally, respondents who did not know the percentage of their basement that was heated during the heating months were assumed to have an unheated basement.

TABLE 1. Additional Exclusions from Data Set

PNWRES Variable Number	Description	Reason for Excluding	Number in Category
5	Not a mobile home, SF Residence or building with 2 or more units	Unconventional residence	9
7	Not a mobile home or building with 5 or more units, not de- tached, not attached on 1 or 2 sides.	Unconventional residence	42
20,21	First moved into residence after 12/81	Cannot adjust for appliance use in first billing period	432
164, 166	Fuel type used most of time for space heating was changed since 9/81	To reduce unexplained variance	75
297, 300	Swimming pool heated with electricity or natural gas	To reduce unexplained variance	16
316	Utility bills include charges for electricity not relating to living quarters	To reduce unexplained variance	133
317	Utility bills include charges for natural gas not relating to living quarters	To reduce unexplained variance	134
366, 368	Electricity used for water heating or space heating included in rent	To reduce unexplained variance	24
376, 378	Natural gas used for water heating or space heating included in rent	To reduce unexplained variance	17

5.0 ESTIMATION RESULTS

As discussed in Chapter 2.0, we are estimating a statistical relationship of the form

$$CE = a_0 + a_1 SH + a_2 SC + a_3 AP + a_4 WH + a_5 CR + e$$

where CE = household consumption of electricity (natural gas)

SH = design space heating requirements of the housing unit

SC = design space cooling requirements of the housing unit

AP = electricity (natural gas) consumption of appliances

WH = electricity (natural gas) consumption for water heating

CR = consumer response submodel.

The constants $a_0, \dots, a_5$ are parameters to be estimated and e is a stochastic disturbance term distributed $N(0, \sigma^2)$, with zero covariances. SH, SC and WH are independent variables that are computed within the submodels. As discussed earlier, SH and SC are based on engineering computations, and WH is computed by applying the PNWRES data to variables used in a statistical relationship estimated on the RECS data by Latta (1983). SC is computed only for dwelling units with central air conditioning, an evaporative swamp cooler, or a heat pump. Room air conditioners were considered with other appliances. AP is expanded to include individual appliances and CR is expanded to include the two consumer response variables, energy price and household income.

All of the variables except price and income are measured in average Btu/hr; price and income are measured in dollars. The model is estimated for electricity and natural gas, and for meteorological station data and climatic division data. In addition, the model is estimated for a subset of the sample (referred to below as the restricted sample) that includes only households with a weather station located within their zip code area.

The purpose of the restricted sample is to construct a more stringent test for the climatic division data. By restricting the sample to households with a weather station within their zip code area, we almost certainly reduce the average distance between the housing units and their corresponding weather stations. This means that the weather station data should more closely approxi-

mate the microclimate around the housing unit, compared with the data from the unrestricted sample. On the other hand, there is no reason to believe that the restricted sample will perform better than the unrestricted sample when the climatic division data are used. The test will be for the climatic division data to perform as well as the station data with the restricted sample. If for this restricted sample we cannot reject the null hypothesis that the climatic division data perform as well as the station data, then the case is even stronger that we should not reject the null hypothesis for the unrestricted sample.

5.1 REGRESSION RESULTS

All of the variables discussed previously were included in an initial regression on a subsample (99 observations) to establish which variables were likely to be of significance in explaining electricity and natural gas consumption. The number of independent variables was reduced according to the following criteria: 1) variables that should be included on theoretical grounds were included, even if their coefficients were not statistically different from zero; and 2) if any one of a set of dummy variables was retained, then all of the dummy variables in the set were retained regardless of significance.

Equation specifications with natural logarithms of the energy price and income variables did not measurably improve the statistical significance of the regression, and so the simple linear model was retained. Because the space heating, space cooling, water heating, and appliance and lighting components of the model are additive in their simple form, logarithmic transformations were not evaluated. The dependent and independent variables used in the regressions are identified in Table 2 for convenience.

The dummy variables MOB, SFA1, SFA2, MFA1, MFA2, MFD and MF5 have already been incorporated into the space heating, space cooling and water heating submodels. Therefore, their presence in a regression equation should be interpreted as affecting only the appliance and lighting variable and the consumer response variables. The variables TALE and TALG, which give the number of months of billing data reported for each respondent, are used to adjust appliance and water heater use. The space heating and space cooling models do not need to be adjusted since heating and cooling degree days are

TABLE 2. Regression Variables

<u>Dependent Variables</u>	
BVAR01 - Electricity Consumption	BVAR03 - Natural Gas Consumption
<u>Independent Variables</u>	
QSAV - Design Space Htg Rqrmts.	MOB - Mobile Home
QASAV - Design Space Cool Rqrmts.	SFA1 - S.F. Attached 1 Side
NFRIG - No. of Manual Defrost Refr.	SFA2 - S.F. Attached 2 Sides
NFFFRIG - No. of Frost Free Refr.	MFA1 - M.F. Attached 1 Side
VAR282 - No. of Freezers	MFA2 - M.F. Attached 2 Sides
VAR289 - Washing Machine	MFD - M.F. Detached
VAR290 - Elec. Clothes Dryer	MF5 - M.F., 5 or More Units
VAR291 - Gas Clothes Dryer	VAR306 - Woodworking Equipment
TVCOL - No. of Color Televisions	VAR314 - Elec. Well Water Pump
ELCONHW - Elec. Hot Water Heater Cons.	RMAC - No. of Room Air Conditioner
EPRICE - Dollars per Kwh of Elec.	VAR203 - Away from Home for 1 Week +
NVAR364 - Annual Household Income	IDA - Resident in Idaho
GCONHW - N.G. Hot Water Heater Cons.	ORE - Resident in Oregon
VAR140 - Extent Basement Heated	WAS - Resident in Washington
NVAR157 - Heat with Elec(=0); N.G.(=1)	TALE - Months Billed, Electricity
VAR189 - Number of Cords of Wood Brnd	TALG - Months Billed, Natural Gas
GPRICE - Dollars per Therm of N.G.	

reported only for months in which billing data are also reported. In the regression results, several variable names begin with the letter I. This indicates that the original variable has been adjusted by multiplying it by TALE/12 or TALG/12, for electric and gas appliances, respectively.

The regression results are reported in Tables 3 through 10, followed by a discussion of the statistical test of the null hypothesis that the regressions using meteorological station data are not statistically different from regressions using climatic division data.

Table 3 presents the results for the electricity consumption regression run on the full sample with meteorological station data. All of the variables except QASAV, TNFRIG, TNFFRIG, TVAR289, TVAR290, SFA2, MFA2, MFD and VAR203 are significant at the 95% confidence level or better, and QASAV, TNFFRIG, MFA2 and MFD are significant at a 90% confidence level. All of the coefficients have the expected sign except SFA1, MFD, and TRMAC. (The signs of SFA1 and MFD are expected to be negative because these types of housing units, relative to single-family detached, are likely to be smaller and have smaller major appliances.) SFA1 is statistically significant, and the reason for the positive coefficient is not clear. The elasticity of electricity consumption with respect to the price of electricity is, at the mean values of the variables, equal to -0.22, and the elasticity with respect to income is 0.06.

Table 4 presents the results for the natural gas consumption regression run on the full sample with meteorological station data. All of the variables except TGOV, MOB, SFA2, MFA1, MFD, and MF5 are significant at the 95% confidence level or better, and only the last four are not significant at a 90% confidence level. All of the coefficients have the expected sign except TGOV, SFA1, MFA2, and MF5. TGOV is significant at the 90% confidence level, and SFA1 and MFA2 are highly significant. The elasticity of natural gas consumption with respect to the price of natural gas is, at the mean values of the variables, equal to -0.11, and the elasticity with respect to income is 0.14.

Table 5 presents the results for the electricity consumption regression run on the full sample with climatic division data. All of the variables except QASAV, TNFRIG, TVAR289, TVAR290, SFA2, MFA2, MFD and VAR203 are significant at the 95% confidence level or better, while MFA2 is significant at the 90% confidence level. All of the coefficients have the expected sign except SFA1, MFD and TRMAC; both SFA1 and TRMAC are statistically significant. The elasticity of electricity consumption with respect to the price of electricity is, at the mean values of the variables, equal to -0.23, and the elasticity with respect to income is 0.06.

Table 6 presents the results for the natural gas consumption regression run on the full sample with climatic division data. All of the variables except TGOV, MOB, SFA2, MFA1, MFD, MF5, and TVAR291 are significant at the 95%

TABLE 3. Electricity Consumption: Meteorological Stations, Full Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	8887131448	386397019	58.572	0.0001
ERROR	1204	7942685412	6596915		
C TOTAL	1227	16829816859			
ROOT MSE		2508.446	R-SQUARE	0.5281	
DEP MEAN		7483.747	ADJ R-SQ	0.5190	
C.V.		34.32032			

DEP VARIABLE: BVAR01

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	5005.532	414.678	12.071	0.0001
QSAV	1	0.1762652	0.02213285	7.964	0.0001
QASAV	1	0.8318528	0.4458707	1.866	0.0623
TNFRIG	1	72.66588	211.9321	0.343	0.7318
TNFFRIG	1	378.2199	226.9381	1.667	0.0958
TVAR282	1	388.4712	124.761	3.114	0.0019
TVAR289	1	194.9454	379.7999	0.513	0.6078
TVAR290	1	311.4436	325.2396	0.958	0.3385
TTVCOL	1	451.4257	142.3932	3.170	0.0016
TELCONHW	1	1.40679	0.1234366	11.397	0.0001
EPRICE	1	-53107.9	7613.04	-6.976	0.0001
BVAR364	1	0.02217453	0.004762092	4.656	0.0001
NOB	1	914.6966	224.2457	4.079	0.0001
SFA1	1	839.1414	367.2123	2.285	0.0225
SFA2	1	-726.892	870.3285	-0.835	0.4038
MFA1	1	-986.94	450.4728	-2.191	0.0287
MFA2	1	-1376.02	830.174	-1.658	0.0977
MFD	1	2625.228	1498.413	1.752	0.0800
MFS	1	-1714.82	438.5577	-3.910	0.0001
TVAR306	1	603.3564	194.4392	3.103	0.0020
TVAR314	1	605.0913	220.4345	2.745	0.0061
NVAR157	1	-4229.27	251.3594	-16.826	0.0001
TRAC	1	-401.808	169.7538	-2.367	0.0181
VAF203	1	-110.679	89.88149	-1.231	0.2184

TABLE 4. Natural Gas Consumption: Meteorological Stations, Full Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	27272654648	1435402876	288.782	0.0001
ERROR	1208	6004421372	4970547		
C TOTAL	1227	33277076020			
ROOT MSE		2229.472	R-SQUARE	0.8196	
DEP MEAN		2008.658	ADJ R-SQ	0.8167	
C.V.		110.9931			

DEP VARIABLE: BVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > t
INTERCEP	1	879.5578	263.8736	3.333	0.0009
QSAV	1	0.1512378	0.0191891	7.881	0.0001
TGUV	1	-993.419	549.3538	-1.808	0.0708
TGCCNH6	1	1958.204	152.0458	12.879	0.0001
BVAR364	1	0.01394324	0.003920966	3.556	0.0004
ADB	1	328.4317	182.0123	1.804	0.0714
SFA1	1	1213.428	316.294	3.836	0.0001
SFA2	1	-66.1031	751.209	-0.088	0.9299
WFA1	1	-122.762	385.5962	-0.318	0.7503
WFA2	1	3982.693	715.1615	5.569	0.0001
WFD	1	-105.416	1293.386	-0.082	0.9351
WFS	1	313.0198	352.8683	0.887	0.3752
IDA	1	-2125.56	256.1078	-8.299	0.0001
NAS	1	-1701.93	229.7407	-7.408	0.0001
URE	1	-1578.8	238.9175	-6.608	0.0001
VAR140	1	107.434	41.71857	2.575	0.0101
VAR189	1	-241.585	53.20837	-4.540	0.0001
NVAR157	1	10970.43	618.07	17.750	0.0001
GPRICE	1	-2221.4	877.7792	-2.531	0.0115
IVAR291	1	2179.933	901.9763	2.417	0.0158

TABLE 5. Electricity Consumption: Climate Zones, Full Sample

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	9513371462	413624846	61.244	0.0001
ERROR	1250	8442192575	6753754		
C TOTAL	1273	17955564037			
ROOT MSE		2598.799	R-SQUARE	0.5298	
DEP MEAN		7529.16	ADJ R-SQ	0.5212	
C.V.		34.51645			

DEP VARIABLE: BVAR01

35

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
INTERCEP	1	5302.279	423.4965	12.520	0.0001
OSAV	1	0.1589509	0.02141869	7.421	0.0001
QASAV	1	0.814133	0.589929	1.380	0.1678
TNERIG	1	128.0025	209.6269	0.611	0.5416
TNEFFRIG	1	486.9761	223.4595	2.179	0.0295
TVAR282	1	399.0833	123.2426	3.238	0.0012
TVAR289	1	161.0677	381.7405	0.422	0.6731
TVAR290	1	307.6231	325.9624	0.944	0.3455
TTVCOL	1	431.4311	140.7224	3.066	0.0022
TELCDNHW	1	1.366162	0.1213779	11.255	0.0001
EPRICE	1	-56183.8	7642.061	-7.352	0.0001
NVAR364	1	0.02358608	0.004679433	5.040	0.0001
MOE	1	806.9647	225.0637	3.585	0.0003
SFA1	1	748.2654	371.1485	2.016	0.0440
SFA2	1	-892.756	880.7222	-1.014	0.3109
MFA1	1	-983.439	453.7772	-2.167	0.0304
MFA2	1	-1398.25	840.0066	-1.665	0.0982
MFB	1	2469.242	1516.166	1.629	0.1036
MFS	1	-1789.55	425.7727	-4.203	0.0001
TVAR306	1	532.9794	190.9498	2.791	0.0053
TVAR314	1	495.5568	221.7267	2.235	0.0256
NVAR157	1	-4404.71	243.0974	-18.119	0.0001
TRMAC	1	-473.07	166.2082	-2.846	0.0045
VAR203	1	-112.446	90.44385	-1.243	0.2140

TABLE 6. Natural Gas Consumption: Climate Zones, Full Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	30026091684	1580320615	305.254	0.0001
ERROR	1254	6492052318	5177075		
C TOTAL	1273	36518144002			
ROOT MSE		2275.319	R-SQUARE	0.8222	
DEP MEAN		2193.421	ADJ R-SQ	0.8195	
C.V.		103.7338			

DEP VARIABLE: BVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	953.3972	265.3934	3.592	0.0003
QSAV	1	0.1472976	0.01862137	7.910	0.0001
TGOV	1	-1053.23	552.5476	-1.906	0.0569
TGCONHW	1	1636.217	143.9604	11.366	0.0001
NVAR364	1	0.01405289	0.003894915	3.608	0.0003
MOB	1	347.4318	185.0447	1.878	0.0607
SFA1	1	1248.739	322.3118	3.874	0.0001
SFA2	1	-52.9643	766.594	-0.069	0.9449
MFA1	1	-140.841	393.0167	-0.358	0.7201
MFA2	1	3905.078	729.0018	5.357	0.0001
MFD	1	-169.374	1319.922	-0.128	0.8979
MFS	1	328.751	342.8682	0.959	0.3378
IDA	1	-2206.38	260.9506	-8.455	0.0001
WAS	1	-1849.48	228.4775	-8.095	0.0001
GRE	1	-1659.89	243.432	-6.819	0.0001
VAR140	1	105.7773	40.83585	2.590	0.0097
VAR189	1	-230.45	53.37578	-4.317	0.0001
NVAR157	1	11330.27	613.1629	18.478	0.0001
GPRTCE	1	-2173.32	895.0117	-2.428	0.0153
TVAR291	1	1360.59	806.0313	1.713	0.0870

confidence level or better, and TGOV, MOB and TVAR291 are significant at a 90% confidence level. All of the coefficients have the expected sign except TGOV, SFA1, MFA2, and MF5. TGOV is significant at the 90% confidence level, and SFA and MFA2 are highly significant. The elasticity of natural gas consumption with respect to the price of natural gas is, at the mean values of the variables, equal to -0.11, and the elasticity with respect to income is 0.13.

Table 7 presents the results for the electricity consumption regression run on the restricted sample with meteorological station data. All of the variables except TNFRIG, TVAR290, SFA1, SFA2, MFA1, MFA2, MFD and TRMAC are significant at the 95% confidence level or better; of the exceptions, TNFRIG and TRMAC are significant at the 90% confidence level. All of the coefficients have the expected sign except SFA1 and RMAC. The elasticity of electricity consumption with respect to the price of electricity is, at the mean values of the variables, equal to -0.20, and the elasticity with respect to income is 0.04.

Table 8 presents the results for the natural gas consumption regression run on the restricted sample with meteorological station data. All of the variables except TGOV, MOB, SFA2, MFA1, MFD, MF5, VAR140, GPRICE and TVAR291 are significant at the 95% confidence level or better; none of these are significant at a 90% confidence level. All of the coefficients have the expected sign except TGOV, SFA1, MFA2 and MF5; SFA1 and MFA2 are highly significant. The elasticity of natural gas consumption with respect to the price of natural gas is, at the mean values of the variables, equal to -0.04, although the price coefficient is not significant; and the elasticity with respect to income is 0.15.

Table 9 presents the results for the electricity consumption regression run on the full sample with climatic division data. All of the variables except TNFRIG, TVAR290, MOB, SFA1, SFA2, MFA1, MFA2, MFD and TRMAC are significant at the 95% confidence level or better, and TNFRIG, MOB, MFA2 and TRMAC are significant at the 90% confidence level. All of the coefficients have the expected sign except SFA1 and TRMAC, neither of which is statistically significant. The elasticity of electricity consumption with respect to the price of electricity is, at the mean values of the variables, equal to -0.21, and the elasticity with respect to income is 0.05.

TABLE 7. Electricity Consumption: Meteorological Stations, Restricted Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	5956852071	258993568	48.802	0.0001
ERROR	665	3529158667	5307006		
C TOTAL	688	9486010738			
ROOT MSE		2303.694	R-SQUARE	0.6280	
DEP MEAN		7226.241	ADJ R-SQ	0.6151	
C.V.		31.87956			

DEP VARIABLE: BVAR01

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	3211.684	555.9841	5.777	0.0001
QSAV	1	0.1258895	0.02905156	4.333	0.0001
GASAV	1	1.497761	0.4969396	3.014	0.0027
TNERIG	1	425.412	256.8716	1.656	0.0982
TNEFFRIG	1	911.6522	268.2492	3.399	0.0007
TVAR282	1	402.2191	140.4265	2.864	0.0043
TVAR289	1	904.7859	448.5641	2.017	0.0441
TVAR290	1	283.1486	374.3984	0.756	0.4498
TTVCOL	1	833.6929	172.5244	4.832	0.0001
TELCONHW	1	1.514084	0.1494569	10.131	0.0001
EPRICE	1	-47125.2	8985.698	-5.244	0.0001
BVAR364	1	0.01493699	0.005745222	2.600	0.0095
MOB	1	619.8856	300.8316	2.061	0.0397
SFA1	1	270.0403	444.0508	0.608	0.5433
SFA2	1	-177.836	793.4565	-0.224	0.8227
BFA1	1	-679.436	523.2054	-1.299	0.1945
BFA2	1	-1253.32	965.8706	-1.298	0.1949
BFD	1	-635.64	1649.501	-0.385	0.7001
MF5	1	-1171.77	507.5192	-2.309	0.0213
TVAR306	1	742.8127	234.7207	3.165	0.0016
TVAR314	1	672.5166	285.7637	2.353	0.0189
QVAR157	1	-3629.55	288.4123	-12.585	0.0001
TRHAC	1	-322.396	192.675	-1.673	0.0947
VAR203	1	-326.273	142.2477	-2.294	0.0221

TABLE 8. Natural Gas Consumption: Meteorological Stations, Restricted Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	18525363635	975019139	143.526	0.0001
ERROR	669	4544743320	6793338		
C TOTAL	688	23070106955			
ROOT MSE		2606.403	R-SQUARE	0.8030	
DEP MEAN		2425.559	ADJ R-SQ	0.7974	
C.V.		107.4558			

DEP VARIABLE: BVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	1770.654	414.8586	4.268	0.0001
GSAY	1	0.1760213	0.03262522	5.395	0.0001
TGUV	1	-644.429	726.2569	-0.887	0.3752
TGCONHW	1	2319.088	250.3595	9.263	0.0001
NVAR364	1	0.01751425	0.006055095	2.892	0.0039
MOB	1	162.8361	320.8607	0.508	0.6120
SFA1	1	1990.441	495.9799	4.013	0.0001
SFA2	1	-234.413	884.7013	-0.265	0.7911
MFA1	1	-243.406	581.951	-0.418	0.6759
MFA2	1	4405.877	1088.269	4.049	0.0001
AFU	1	-479.879	1857.055	-0.258	0.7962
AFS	1	129.6898	528.0766	0.246	0.8061
IDA	1	-3051.22	377.5237	-8.082	0.0001
WAS	1	-2674.03	369.0255	-7.246	0.0001
DRF	1	-2556.63	365.8938	-6.987	0.0001
VAR140	1	80.26682	58.519	1.372	0.1706
VAR189	1	-355.037	81.56734	-4.353	0.0001
NVAR157	1	9587.469	914.7235	10.481	0.0001
SPRICE	1	-930.931	1298.584	-0.717	0.4737
TVAR291	1	350.5705	1253.281	0.280	0.7798

TABLE 9. Electricity Consumption: Climate Zones, Restricted Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	6174099322	268439101	51.006	0.0001
ERROR	700	3684021695	5262888		
C TOTAL	723	9858121017			
ROOT MSE		2294.099	R-SQUARE	0.6263	
DEP MEAN		7102.992	ADJ R-SQ	0.6140	
C.V.		32.29764			

PARAMETER ESTIMATES

DEP VARIABLE: BVAR01

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	3572.299	538.2781	6.637	0.0001
QSAV	1	0.0855932	0.02600327	3.292	0.0010
QASAV	1	1.638007	0.6240171	2.625	0.0089
INFRIG	1	444.7459	249.4357	1.783	0.0756
INFEFRIG	1	930.108	260.6157	3.569	0.0004
TVAR282	1	418.1093	136.264	3.068	0.0022
TVAR289	1	886.0648	438.8235	2.019	0.0438
TVAR290	1	259.6664	366.5942	0.708	0.4770
TTVCOL	1	814.1411	167.9099	4.849	0.0001
TELCOMHW	1	1.426165	0.1433589	9.948	0.0001
PRICE	1	-48742.3	8842.716	-5.512	0.0001
BVAR364	1	0.01790972	0.005510061	3.250	0.0012
MOB	1	567.6698	299.08	1.898	0.0581
SFA1	1	284.1967	441.4249	0.644	0.5199
SFA2	1	-325.595	788.9184	-0.413	0.6799
IFA1	1	-597.793	516.8635	-1.157	0.2478
IFA2	1	-1585.73	889.6629	-1.782	0.0752
IFD	1	-739.064	1641.777	-0.450	0.6527
IF5	1	-1200.23	469.1284	-2.558	0.0107
PVAR306	1	094.9226	225.4153	0.418	0.6721
PVAR314	1	654.4306	282.3358	2.318	0.0207
PVAR157	1	-3706.7	267.4628	-13.859	0.0001
PRMAC	1	-311.773	183.5936	-1.698	0.0899
VAR203	1	-342.53	139.6311	-2.453	0.0144

Table 10 presents the results for the natural gas consumption regression run on the restricted sample with climatic division data. All of the variables except TGOV, MOB, SFA2, MFA1, MFD, MF5, VAR140, GPRICE and TVAR291 are significant at the 95% confidence level or better; none of these exceptions are significant at a 90% confidence level. All of the coefficients have the expected sign except TGOV, SFA1, MFA2, and MF5; SFA1 and MFA2 are highly significant. The elasticity of natural gas consumption with respect to the price of natural gas is, at the mean values of the variables, equal to -0.09, and the elasticity with respect to income is 0.14.

5.2 TEST OF EQUIVALENCE OF WEATHER DATA

A test procedure described in Rao and Miller (1971; p.148ff), was used to determine if the regression based on weather station data was statistically equivalent to the regression based on climatic zone data. The null hypothesis, H_n , was that the two regressions were equivalent. The test statistic is

$$F = \frac{(RSS(H_n) - RSS(H_a))/R}{RSS(H_a) / (N - K)}$$

where $RSS(H_a)$ and $RSS(H_n)$ are the residual sum of squares under the alternative and null hypotheses, respectively; R is the number of restrictions imposed on the parameters, N is the number of observations in the sample, and K is the number of parameters estimated, including the intercept term.

$RSS(H_n)$ is obtained by running the regression on the pooled sample (climatic division data and weather station data). These regression results are presented for electricity consumption in Table 11 for the full sample and in Table 13 for the restricted sample. The corresponding regression results for natural gas are presented in Tables 12 and 14. $RSS(H_a)$ is computed by adding the RSS for the separate regressions based on climatic division data and on weather station data. For the full sample test for electricity, we add the RSS from Tables 3 and 5. Applying the test, we have

TABLE 10. Natural Gas Consumption: Climate Zones, Restricted Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	20906336187	1100333484	151.726	0.0001
ERROR	704	5105478064	7252100		
C TOTAL	723	26011814251			
ROOT MSE		2692.972	R-SQUARE	0.8037	
DEP MEAN		2773.752	ADJ R-SQ	0.7984	
C.V.		97.08771			

DEP VARIABLE: HVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
INTERCEP	1	1856.064	413.2291	4.492	0.0001
QSAV	1	0.1894173	0.03029351	6.253	0.0001
PGOV	1	-851.704	739.3312	-1.152	0.2497
PGCONHW	1	1691.948	225.7605	7.494	0.0001
NVAR364	1	0.01783879	0.00604543	2.951	0.0033
MOR	1	200.5757	332.4697	0.603	0.5465
SFA1	1	2032.872	511.4177	3.975	0.0001
SFA2	1	-205.206	913.7514	-0.225	0.8224
MFA1	1	-346.604	599.3674	-0.578	0.5633
MFA2	1	3811.239	1038.832	3.669	0.0003
MFD	1	-546.028	1917.942	-0.311	0.7561
MFS	1	244.1904	499.8702	0.489	0.6253
IDA	1	-3226.97	387.978	-8.317	0.0001
WAS	1	-2938.2	358.1068	-8.205	0.0001
ORE	1	-2731.88	375.1121	-7.283	0.0001
VAR140	1	80.82472	56.43516	1.383	0.1671
VAR189	1	-351.429	83.43801	-4.212	0.0001
VAR157	1	10636.43	906.6558	11.731	0.0001
GPRICE	1	-1808.55	1335.083	-1.355	0.1760
VAR291	1	112.0993	1089.361	0.103	0.9181

TABLE 11. Pooled Regression: Electricity, Full Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	18391060037	799611306	120.852	0.0001
ERROR	2476	16395610432	6616469		
C TOTAL	2501	34786670469			
ROOT MSE		2572.25	R-SQUARE	0.5287	
DEP MEAN		7506.871	ADJ R-SQ	0.5243	
C.V.		34.26527			

DEP VARIABLE: BVAR01

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	5148.659	294.9535	17.456	0.0001
GSAV	1	0.1674642	0.01530244	10.944	0.0001
QASAV	1	0.7995565	0.3530921	2.264	0.0236
TNFRIG	1	103.39	148.335	0.697	0.4859
TNFFRIG	1	437.333	158.4519	2.760	0.0058
IVAR282	1	394.3729	87.27258	4.519	0.0001
IVAR289	1	179.9644	268.0371	0.671	0.5020
IVAR290	1	308.9379	229.198	1.348	0.1778
ITVCUL	1	441.4034	99.62902	4.430	0.0001
TPLCONHW	1	1385.797	86.10316	16.095	0.0001
EPRICE	1	-54590.7	5365.425	-10.175	0.0001
NVAR364	1	0.02295191	0.003321646	6.910	0.0001
MOB	1	861.7381	158.1036	5.450	0.0001
SFA1	1	793.744	259.8826	3.054	0.0023
SFA2	1	-810.644	616.3561	-1.315	0.1886
MEA1	1	-984.167	318.2479	-3.092	0.0020
MEA2	1	-1386.27	587.6078	-2.358	0.0184
MFL	1	2547.64	1061.115	2.401	0.0164
MFS	1	-1751.7	303.7964	-5.766	0.0001
IVAR306	1	566.0585	135.5862	4.175	0.0001
IVAR314	1	548.6858	155.6074	3.526	0.0004
IVAR157	1	-4323.18	173.7843	-24.877	0.0001
TRNAC	1	-439.705	116.0785	-3.724	0.0002
VAR203	1	-111.369	63.46035	-1.755	0.0794

TABLE 12. Pooled Regression: Natural Gas, Full Sample

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	57303450901	3015971100	598.224	0.0001
ERROR	2482	12513114652	5041545		
C TOTAL	2501	69816565553			
ROOT MSE		2245.339	R-SQUARE	0.8208	
DEP MEAN		2102.738	ADJ R-SQ	0.8194	
C.V.		106.7817			

DEP VARIABLE: HVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PPROB > T
INTERCEP	1	917.662	186.3563	4.924	0.0001
CSAV	1	0.1495097	0.01329167	11.248	0.0001
TGDV	1	-1020.42	388.0161	-2.630	0.0086
TGCDNH	1	1784.377	104.0683	17.146	0.0001
NVAR364	1	0.01399049	0.002753968	5.083	0.0001
406	1	338.5064	129.3575	2.617	0.0089
SFA1	1	1231.945	225.0473	5.474	0.0001
SFA2	1	-58.8246	534.9383	-0.110	0.9124
MFA1	1	-131.956	274.4028	-0.461	0.6306
MFA2	1	3940.349	508.9398	7.742	0.0001
MFD	1	-138.49	921.0396	-0.150	0.8805
MFS	1	319.2661	244.957	1.303	0.1926
JDA	1	-2168.5	182.2192	-11.901	0.0001
MAS	1	-1779.52	161.2367	-11.037	0.0001
JRE	1	-1622.04	169.8929	-9.547	0.0001
VAR140	1	106.047	29.07372	3.648	0.0003
VAR169	1	-235.731	37.55906	-6.276	0.0001
NVAR157	1	11166.73	433.2735	25.773	0.0001
GERICE	1	-2202.76	624.4288	-3.528	0.0004
TVAR291	1	1707	597.9656	2.855	0.0043

TABLE 13. Pooled Regression: Electricity, Restricted Sample

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	23	12126147813	527223818	101.382	0.0001
ERROR	1389	7223346648	5200394		
C TOTAL	1412	19349494461			
ROOT MSE		2280.437	R-SQUARE	0.6267	
DEP MEAN		7163.09	ADJ R-SQ	0.6205	
C.V.		31.83594			

DEP VARIABLE: BVAR01

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	3400.296	383.351	8.870	0.0001
USAV	1	0.1033026	0.01917184	5.388	0.0001
QASAV	1	1.547813	0.3834963	4.036	0.0001
TNFRIG	1	435.3032	177.4526	2.453	0.0143
TUEFRIG	1	923.5165	185.3573	4.982	0.0001
TVAR282	1	411.4316	96.97423	4.243	0.0001
TVAR289	1	899.023	311.0715	2.890	0.0039
TVAR290	1	268.8406	259.778	1.035	0.3009
TTVCOL	1	823.8223	119.3474	6.903	0.0001
TELCONHW	1	1463.216	102.4843	14.277	0.0001
EPRTCE	1	-47726.1	6244.477	-7.643	0.0001
NVAR364	1	0.01655978	0.00394311	4.200	0.0001
MOB	1	588.347	210.2888	2.798	0.0052
SFA1	1	278.8348	310.5006	0.898	0.3693
SFA2	1	-256.707	554.9231	-0.463	0.6437
MFA1	1	-636.595	364.5778	-1.746	0.0810
MFA2	1	-1431.23	649.0422	-2.205	0.0276
IFL	1	-692.418	1154.272	-0.600	0.5487
IFS	1	-1184.27	341.0129	-3.473	0.0005
TVAR306	1	718.9564	161.2301	4.459	0.0001
TVAR314	1	665.8865	199.1741	3.343	0.0009
NVAR157	1	-3677.13	194.2531	-18.930	0.0001
PRMAC	1	-318.072	131.563	-2.418	0.0157
VAR203	1	-336.455	98.78176	-3.406	0.0007

TABLE 14. Pooled Regression: Natural Gas, Restricted Sample

ANALYSIS OF VARIANCE					
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	19	39445654559	2076087082	298.788	0.0001
ERROR	1393	9679067826	6948362		
C TOTAL	1412	49124722385			
ROOT MSE		2635.975	R-SQUARE	0.8030	
DEP MEAN		2603.968	ADJ R-SQ	0.8003	
C.V.		101.2292			

DEP VARIABLE: BVAR03

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	1813.863	290.3778	6.247	0.0001
OSAV	1	0.184644	0.02196487	8.406	0.0001
TGOV	1	-760.685	514.7939	-1.478	0.1397
TGCOHHW	1	1958.798	166.2511	11.782	0.0001
BVAR364	1	0.0177633	0.004254314	4.175	0.0001
BOH	1	183.4396	229.7537	0.798	0.4248
SFA1	1	2009.376	354.2115	5.673	0.0001
SFA2	1	-219.102	632.5264	-0.346	0.7291
MFA1	1	-301.02	415.4319	-0.725	0.4688
MFA2	1	4083.519	746.6786	5.469	0.0001
MFD	1	-539.321	1327.692	-0.406	0.6847
MFS	1	187.1646	360.4479	0.519	0.6037
IDA	1	-3149.92	269.1455	-11.703	0.0001
WAS	1	-2816.52	254.2064	-11.080	0.0001
ORE	1	-2650.97	260.1408	-10.191	0.0001
VAR140	1	79.96544	41.11812	1.945	0.0520
VAR189	1	-354.206	58.01877	-6.105	0.0001
QVAR157	1	10184.98	638.5194	15.951	0.0001
GPRICE	1	-1431.42	925.4146	-1.547	0.1221
IVAR291	1	161.2027	814.939	0.198	0.8432

$$F = \frac{(16,395,610,432 - 16,384,877,987)/23}{16,384,877,987 / (2501 - 47)}$$

$$= 0.07$$

The remaining test results are as follows:

Full sample, natural gas: $F = 0.17$

Restricted sample, electricity: $F = 0.08$

Restricted sample, natural gas: $F = 0.22$

The critical value F_c at a 95% confidence level is no less than 1.50 for all of these tests. Therefore, the null hypothesis is accepted in all cases.

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APPENDIX A

CONSTRUCTION OF DEGREE DAYS ESTIMATES
FOR THE 1983 PACIFIC NORTHWEST
RESIDENTIAL ENERGY CONSUMPTION SURVEY
(PNWRES-83)

SUMMARY

The 1983 Pacific Northwest Residential Energy Consumption Survey (PNWRES-83), sponsored by the Bonneville Power Administration, was conducted in the summer of 1983. Data on housing and appliance characteristics were collected from households in the Pacific Northwest region. Billing data from each consenting household's utility as well as demographic, economic and attitudinal information were also collected. Pacific Northwest Laboratory contracted with the Bonneville Power Administration (BPA) to construct indicators of climatic conditions (heating and cooling degree days) for the respondents in PNWRES who signed billing waivers. These indicators were constructed by assigning survey respondents to both:

- o National Oceanic and Atmospheric Administration (NOAA) climatic divisions; and
- o weather stations located in the proximity of their residence.

This document presents a description of the procedures used to construct these data sets.

1.0 INTRODUCTION

The Pacific Northwest Residential Energy Consumption Survey was conducted in the summer of 1983 to collect data on the residential energy sector. PNWRES has been an on-going data collection effort at BPA and was first administered in 1979. The survey data have been of substantial importance to BPA, the Northwest Power Planning Council, and the region's utilities in supporting load forecasting, conservation assessment, evaluation, and program planning.

The PNWRES surveys contain information on the physical characteristics of the residence (including square footage, presence of appliances, etc.) and attitudinal, economic, and demographic descriptions of the occupants of the residence. Billing histories for electricity and natural gas consumption are also provided.

However, since weather significantly affects energy consumption in the residential sector, indicators of the climatic conditions which prevailed over the period for which energy consumption data are provided are quite useful. A common indicator of climatic conditions is degree days. Heating and cooling degree days were constructed for the 1979 PNWRES survey--BPA thought it desirable to provide comparable metrics for the 1983 survey.

This appendix describes how the degree day estimates were constructed.

In the 1979 dataset, degree day estimates were provided for a temperature base of 65° F. The geographic resolution of the temperature data was National Oceanic and Atmospheric Administration climatic divisions (Figures A.1-A.4).

The choice of a proper base for construction of degree day estimates is, in part, dependent on the characteristics of the particular site examined. In constructing the degree day estimates for the 1983 dataset, therefore, we choose to provide several bases for degree days. Heating degree day bases included 55° F, 60° F, 65° F, and 70° F, while cooling degree bases were 65° F, 70° F, 75° F, and 80° F. Because NOAA climatic divisions represent aggregations of reporting weather stations, degree day estimates were constructed at two levels of geographic aggregation: 1) NOAA climatic divisions, and 2) station level.

Consistency with the 1979 dataset has been maintained by providing estimates for climatic divisions at the 65⁰ F base.

GEOGRAPHIC ASSIGNMENT

In order to construct the climatic indicators, each PENWRES respondent had to be assigned to a particular climatic division and weather station. In both cases, the finest resolution that was practical for determining the location of a residence was the zipcode of the respondent.

The first step in constructing the indicators was to assign each unique zipcode to a specific NOAA climatic division. This was done by manually cross-referencing the city name of the zipcode with a map of NOAA climatic divisions (see Figures A.1-A.4). Because the original data set provided to PNL had a number of zipcodes missing, a revised dataset was supplied in January of 1985.

Subsequent to assigning the zipcodes to NOAA climatic divisions, each zipcode was then assigned to a specific weather station by a PNL meteorologist using euclidean distance and elevation measures. Each assignment was reviewed for appropriateness and consistency by a Senior Research Scientist.^(a)

Many of the weather stations have a significant number of missing data values. In instances where the primary station had one or more periods of missing data, the professional judgment of the PNL meteorologist was applied to reassign the zipcode to a secondary station for those periods.

The final geographic assignment step was to merge the datafile containing billing periods (or dates on which the consumption data were recorded) with the files containing the assignment of zipcodes to climatic divisions and weather stations. This step resulted in the following four files:

(a) The assignment of station numbers involved the concatenation of a unique NOAA station number and the assigned climatological division. Station identification numbers provided by NOAA on the temperature data tape include the climate identification number. The assignment, therefore, served as a check that the proper climate division assignment had been made.

- o for each observation with reported electricity consumption, the electricity billing dates and weather station assignment,
- o for each observation with reported electricity consumption, the electricity billing dates and climatic division assignment,
- o for each observation with reported natural gas consumption, the electricity billing dates and weather station assignment, and
- o for each observation with reported natural gas consumption, the electricity billing dates and climatic division assignment.

The next step was to create the degree-day estimates.

CONSTRUCTION OF DEGREE DAY ESTIMATES

An average temperature was computed for each respondent for each billing period, according to the following formula:

$$\text{AVG. TEMP} = (\text{MAX T} + \text{MIN T})/2$$

where MAX T and MIN T are the maximum and minimum temperatures recorded for each day during the billing period. Heating degree days (HDD) were computed as the maximum of (BASE - AVG. TEMP, 0), while cooling degree days (CDD) were computed as the maximum of (AVG. TEMP - BASE, 0). Finally, heating and cooling degree days for each billing period were computed as the sum of the HDDs and CDDs, respectively, for each day in the billing period; i.e.,

$$\text{BILLING PERIOD DD} = \text{SUM(DAILY DD)}$$

The computations resulted in the four data files describe above.

In the files relating to electricity consumption, there were 43 cases with unrecoverable problems. These cases were eliminated. In addition, if a faulty or inconsistent date was recorded in the billing data file, the date was suppressed by creating a single billing period from the two consecutive periods containing the faulty date.

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Jack Tawil

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