THE PERFORMANCE OF RESIDENTIAL ACTIVE COLLECT/PASSIVE STORE SOLAR SPACE-HEATING SYSTEMS

by

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Twenty nine residential active collect/passive store (AC/PS) systems of three different designs have been analyzed to determine their performance. Each house natural gas meter was monitored for approximately one year on a weekly basis. The solar energy systems were enabled and disabled on alternating weeks to minimize the effect of weather patterns on the analysis.

A model of the house energy gains and losses was developed to assist in the analysis of the data. The major system energy gain and loss paths were taken into account. These include infiltration, house skin losses, basement losses, internal gains, passive solar gains, the base load, and the active system gains and losses. The infiltration rate, which is assumed to be constant, and the house skin losses are combined into one term which is a function of the difference between the house and the ambient temperatures. The passive gains for each house are assumed to be a linear function of the average radiation on four vertical surfaces facing north, south, east and west. The basement losses are assumed to be a linear function of the difference between the house and ground temperatures. The internal gains from people, DHW losses, and cooking were estimated using typical values. Electrical meter data was interpolated to give estimated use for each week and added to the internal gains. The base natural gas load due to gas DHW, dryers and/or stoves is estimated by averaging the gas use during the summer months.

The active system parameters consist of collector gain ($A_c F_R \tau\alpha$) and loss ($A_c F_R U_L$) terms. It was found that the predicted solar fraction does not change for a wide range of

values of the collector gain term, as long as the corresponding value of the collector loss term is determined by the least-squares analysis. In order to minimize the number of variables in the regression, the collector gain term is estimated for each system from laboratory test results.

To account for thermal capacitance effects, two versions of the model were created: one with zero thermal mass, and one with infinite thermal mass. The thermal energy stored by the infinite capacitance model was set to zero at 8AM every day, resulting in a 24-hour infinite capacitance model. It is assumed that the results from these two models bracket the results that would be obtained using the actual house thermal mass.

Using hourly weather data measured at a site that is between 50 and 100 miles from the houses, a nonlinear regression analysis was done to find three house parameters (the skin loss/infiltration term, the basement loss term and the passive gain term), and one active system parameter (the collector loss term). This analysis was performed twice for each system, once for the zero capacitance model and once for the infinite capacitance model. Base fuel use, internal gains, the collector gain term and the furnace efficiency were estimated and used as input values to the model.

After all the house and active system parameters had been determined, they were used in combination with weather data for a Madison, WI typical meteorological year to predict the performance of each system for typical weather conditions. The predicted solar fractions varied between 0 and 24%, and if the two best sets of results are discounted the maximum predicted solar fraction drops to 14%. The expected solar fractions reported by the system owners ranged from 30 to 70%.

ACKNOWLEDGEMENTS

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NOMENCLATURE

Note: symbols which appear only once in the text and are defined locally are not defined here.

A	area of a surface
B	internal gains [Btu/hr]
base	refers to the non-heating appliance fuel use of a house
bsmt	basement
c	collector
coll	collector
C_p	specific heat
E	energy
F	fuel use
F_R	the collector heat removal factor
g	ground
G	the irradiance on the horizontal
h	enthalpy, a convection heat transfer coefficient
i	inlet
I	radiation
inf	infiltration, the infinite capacitance model
k	constant which relates the passive gain to the house in question to the radiation incident on the "typical house".
L	loss, leak
NAC	Normalized Annual Consumption
Q	energy flow rate

R	thermal resistance [hr-ft^2-F/Btu], the ratio of radiation on the surface in question to radiation on the horizontal
o	overall
skin	the exterior surface of a building
T	temperature
u	useful
U	conductance
z	refers to the zero capacitance model

GREEK

α	absorptance
η	efficiency (of furnace unless indicated otherwise)
Ω	measured fuel use
τ	transmittance

SUBSCRIPTS

amb	ambient
bal	balance, refers to the balance temperature of a building
e	effective
h	house
p	passive solar
T	tilted surface
wd	window
wl	wall

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Between May 1978 and June 1986 the State of Wisconsin offered energy tax credits and direct refunds, under certain restrictions, to home-owners who purchased solar energy systems. 11,171 systems were subsidized by these tax credits and refunds at a total cost of approximately 10.3 million dollars to the state. In September 1985 the Wisconsin Division of State Energy, prompted by a need for realistic performance information on these solar systems, initiated a study of the performance of one of the most common types of solar systems that had been installed under the program, the active collect/passive store (AC/PS) system. This system type was chosen because it had not been carefully studied before, and because the Division of State Energy was interested in determining whether the manufacturers' performance claims were reasonable. The objective of the Division's initiative was to a) decide whether performance calculation methods for AC/PS systems in the solar program were adequate and b) help assess overall policy implications of the program. The study was jointly funded by the Wisconsin Department of Administration (using funds from the United States Department of Energy State Energy Conservation Program) and the Wisconsin Electric Power Company, and carried out at the Solar Energy Laboratory of the University of Wisconsin-Madison. This thesis is a description of the theory, methods, results and conclusions of that study.

1.2 DESCRIPTION OF ACTIVE COLLECT/PASSIVE STORE SYSTEM

Active collect/passive store systems absorb solar radiation in collectors, deliver the collected energy directly to the heated space, and store excess thermal energy in the building mass. They are different from other active systems in that they have no water tank or rock-bed for energy storage. The indoor temperature is allowed to rise whenever

the active solar gain causes the total building energy gain to exceed the instantaneous space-heating load. When the solar energy is insufficient to meet the building load, the indoor temperature drops and energy is released from the building mass to the occupied space. All of the AC/PS systems under investigation in this study use air as a working fluid. A schematic of a typical AC/PS system on a house is presented in Fig. 1.2.1.

The energy storage capacity of an AC/PS system is limited by the maximum acceptable indoor air temperature. As the temperature approaches an uncomfortable level, energy from the collector must be dumped to the surroundings to avoid overheating of the occupied space.

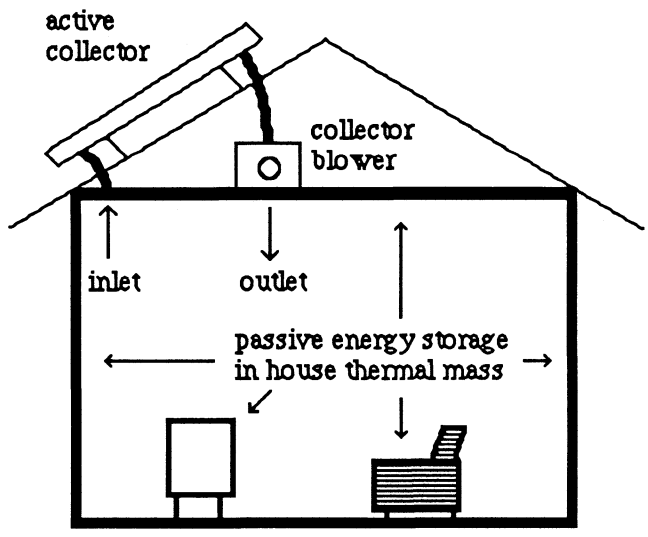


FIGURE 1.2.1 SCHEMATIC OF AC/PS SYSTEM ON HOUSE

The advantages of this type of system are that it reduces the number of air-handling and control components required, eliminates the cost of an active storage component (which can be a significant percentage of the total system cost), and occupies less space in

a building than a system with active storage. The disadvantage is that the energy storage potential is limited by the thermal mass of the house and the maximum allowable temperature variation.

Active collect/passive store systems are particularly suited for retrofit applications, since only minimal changes must be made to the original building design, and for applications in which the solar energy system is not expected to meet a high percentage of the space-heating load. This type of system is the simplest active solar space-heating option available and has the potential to be relatively inexpensive, and therefore attractive to home-owners who like the idea of heating with solar energy but have limited financial resources.

1.3 OBJECTIVES

The purpose of this project is to characterize the performance of three brands of AC/PS systems. A computer model of a house and AC/PS system has been created to predict the performance of each of the 29 systems in the study based on measured fuel usage and weather data. The results include a comparison of the manufacturer's predicted performance to the actual performance and suggestions for the performance optimization of AC/PS systems.

1.4 LITERATURE REVIEW

Only one source of information on AC/PS systems was found in a review of the literature. In his 1983 thesis, Brian Evans presents a design method for this type of system. His work also includes descriptions of AC/PS simulation models and of the theoretical limits to AC/PS performance. No information was found in the literature on the measured performance of this type of system.

A report by Lof and Karaki (1984) draws general conclusions about the installed performance of many types of active solar systems: "systems in routine residential and

commercial use have not performed as well as expected, nor as well as systems in research and development sites. The differences are mainly due to the soundness of design, the quality of the installation, and the extent of maintenance required and performed."

The data in Lof and Karaki's report on space heating systems in the National Solar Data Network (NSDN) reveal much poorer performance by typical residential and commercial systems than was obtained at the Colorado State University solar community. They conclude that "differences between the several types of well designed and installed systems are considerably less than the differences in systems of the same type but of good and poor quality."

There has been a concerted solar energy research and development effort by the European Economic Community (EEC). A 1982 report by Ferraro, which was a result of EEC efforts to determine the performance of existing systems, describes the performance of space-heating active solar systems in occupied buildings. These systems are located between 38 and 57 degrees north, in regions that experience a wide variety of climates. The energy contribution ranged from 126 to 1,288 MJ/m^2yr, with an average value of 571 MJ/m^2yr. They did not specify the system parameters or control strategies. They conclude that ducting should be as short as possible and well insulated. Their measurements indicated that losses were often 2-3 times larger than the manufacturer's information indicated.

In an analysis of National Solar Data Network data, Vitro Laboratories studied the performance of sixteen solar space heating systems (Rossi, 1982). Many of the systems yielded less than 50% of the predicted performance. The author attributes the poor performance to a) unconventional design strategies, b) poor construction, c) control anomalies, and d) large losses from storage vessels.

The measured performance information found in the literature review is of questionable worth for the purposes of this study, since none of it pertains to systems with

passive storage. However, a considerable amount of performance data was found which can be compared to that of the systems in the research project, keeping in mind that all of the systems surveyed have active storage and many have solar domestic hot water heating (SDHW).

One of the goals of this literature review is to examine methods similar to the one developed in this study for determining the effectiveness of energy conservation retrofits to houses. Researchers at Princeton University have developed a simple model for determining the Normalized Annual Consumption (NAC) of houses and multi-family dwellings for periods before and after energy conservation strategies have been implemented. The NAC is the predicted annual fuel use of the building in question under typical weather conditions. The Princeton Scorekeeping Method (PRISM) is a statistical procedure for calculating the effects of changes in building parameters or usage on energy consumption (Fels,1986). It is similar to the method developed for the present analysis in that it uses measured fuel use and weather data in a regression analysis to find coefficients which represent building parameters. Both methods are based on assumptions about the factors that determine building heating loads, albeit not the same assumptions.

The PRISM model uses three parameters: the base-level fuel consumption, which is an indication of the non-heating appliance load (DHW, stove, dryer) for the fuel in question; the house balance temperature, which is the ambient temperature below which the furnace must operate to maintain the house at the set temperature; and the heating slope, which is the house heat-loss coefficient divided by the furnace efficiency. This choice of parameters is based on the approximation that fuel use is constant at ambient temperatures above the balance temperature, and that it is a linear function of the difference between the balance and ambient temperatures below the balance temperature.

In equation form, the PRISM model is as follows:

$$f = \alpha + \frac{(UA)}{\eta}(T_{bal} - T_{amb,daily})^{+} + \varepsilon \qquad (1.5.1)$$

where: f = fuel consumption per day

α = daily base-level appliance load, which is assumed constant throughout the year. Some of this energy contributes to internal gains, and therefore decreases the balance temperature.

UA = conductance-area product

η = furnace efficiency

T_{bal} = balance temperature. The ambient temperature below which the furnace must operate to maintain the heated space at the set temperature.

$T_{amb,daily}$ = the mean daily ambient temperature, defined as the average of the maximum and minimum hourly temperatures measured on the day in question.

ε = the difference between the measured and predicted fuel use for the period, an error term which is assumed to be random.

(The "+" indicates that the term in parentheses should be set equal to zero if it is negative.)

Fuel meter readings and ambient temperatures are used in a linear regression analysis to determine the model parameters (α, T_{bal}, and UA/η). The calculation is done on a meter-reading period basis; daily average fuel use is calculated by dividing the fuel use for the period by the number of days in the period. The mean daily ambient temperature is available from most weather stations, and is used to calculate the heating degree-days for the period to a variable balance temperature. Using the daily fuel use and average daily heating degree-day data in combination with a guessed balance temperature, the best values for the base appliance load and the heating slope are found by an ordinary least-squares regression technique.

A guessed value for the balance temperature is used because it allows the degree days for the period to be treated as input data. If the balance temperature were found by the regression analysis, the regression equation would be nonlinear in the parameters, i.e. the fuel use would have to be set equal to zero for negative values of the (T_{bal} - $T_{amb,daily}$) term. A nonlinear regression analysis requires significantly more computational effort, since it is an iterative process rather than one which allows direct calculation of the solution, and it requires parameter starting values which are fairly close to the actual values. Therefore a linear regression analysis is preferable to a nonlinear one if the choice is available.

The process described above is repeated for various values of the balance temperature using Newton's method to minimize the residual sum of squares with respect to the balance temperature. The values for the base appliance load and the heating slope that correspond to the balance temperature which results in the lowest sum of squares are then used in the calculation of the NAC.

The NAC is an index of fuel consumption for the house. It is calculated as follows:

$$NAC = 365\alpha + \frac{(UA)}{\eta} DD_H(T_{bal}) \qquad (1.5.2)$$

where: $DD_H(T_{bal})$ = long-term average annual heating degree days to base T_{bal}

The NAC prediction typically has an associated standard error of 3% (the specially-derived method for calculating this standard error is described in Goldberg, 1982). The effective house parameters are less well determined. Nevertheless, work has been done to interpret changes in these parameters as changes in actual house parameters (Goldberg, 1986).

There are more factors that affect a house space-heating load than are accounted for in the PRISM model. Among these are passive solar gains and basement skin losses (for further explanation of these effects, refer to Chapter 2). In addition, while developing this study it was decided that a model for predicting the performance of AC/PS systems should explicitly include a solar radiation-driven component. Therefore, a different model with its own inherent advantages and limitations has been developed.

1.5 SUMMARY OF ANALYTIC METHOD

Residential active solar system performance is difficult to determine. There are no simple methods for measuring energy transfer from the system to the house without modifying the system or affecting the homeowner's control strategy and thereby prejudicing the results of the analysis. Instead of attempting to measure energy flows in the systems under investigation or calculate their fuel use from engineering theory, a model has been created which represents the major energy flow paths in a typical house and AC/PS system. The model coefficients for a particular house are found by a nonlinear regression of fuel use against the model forcing functions, i.e. weather variables.

The gas meters are monitored at each site while enabling and disabling the active systems for alternating 1-week periods. This strategy is used in order to minimize the effect of systematic errors on the prediction of AC/PS system performance. It is hoped that the enable/disable method will cancel out fuel-use factors which are not accounted for in the model, such as seasonal variation in the base fuel use. The method of enabling and disabling the systems is described in section 3.2.

Refer to Figure 1.5.1 for a graphic representation of the model inputs and outputs. The hourly weather data include temperature, passive gain radiation, and radiation on the collector. The weekly fuel use data refers to the readings taken from the natural gas meters at each site. The system energy parameters describe the system fuel use as a function of weather conditions.

The parameters found in the regression analysis were used with Typical Meteorological Year (TMY) weather data to predict the annual active solar energy gain which can be expected from each system under typical weather conditions (SOLMET). For a complete description of the theory behind the model, refer to Chapters 2 and 3.

1.6 OVERVIEW OF REMAINING CHAPTERS

Chapter 2 is a description of all the important system energy flow paths and how they were dealt with in the model, as well as a discussion of some of the fuel use factors not in the model. Identifying and understanding these energy flow paths was the first step in creating the model. The various versions of the model that were used and justifications for their choice are presented in Chapter 3. The system sites and the methods used in fuel meter data collection are described in Chapter 4. Chapter 5 covers the choice of weather data sources for the analysis and the weather data processing that was done at the Solar Energy Laboratory. Chapters 6 and 7 present the results and comparisons of actual to predicted performance, and the conclusions and recommendations, respectively.

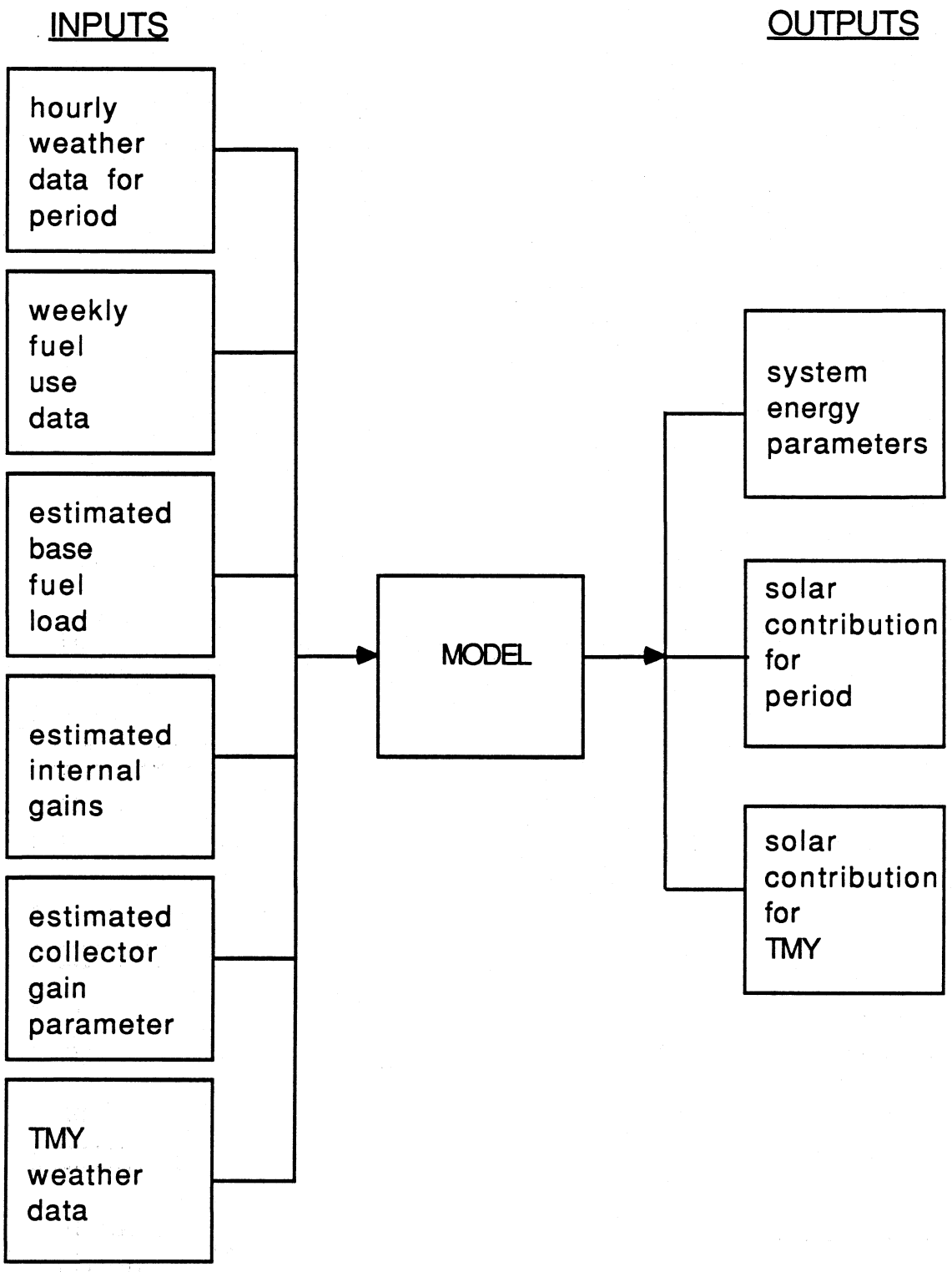


FIGURE 1.5.1 MODEL INPUTS AND OUTPUTS

CHAPTER 2 HOUSE AND ACTIVE SYSTEM ENERGY FLOW PATHS

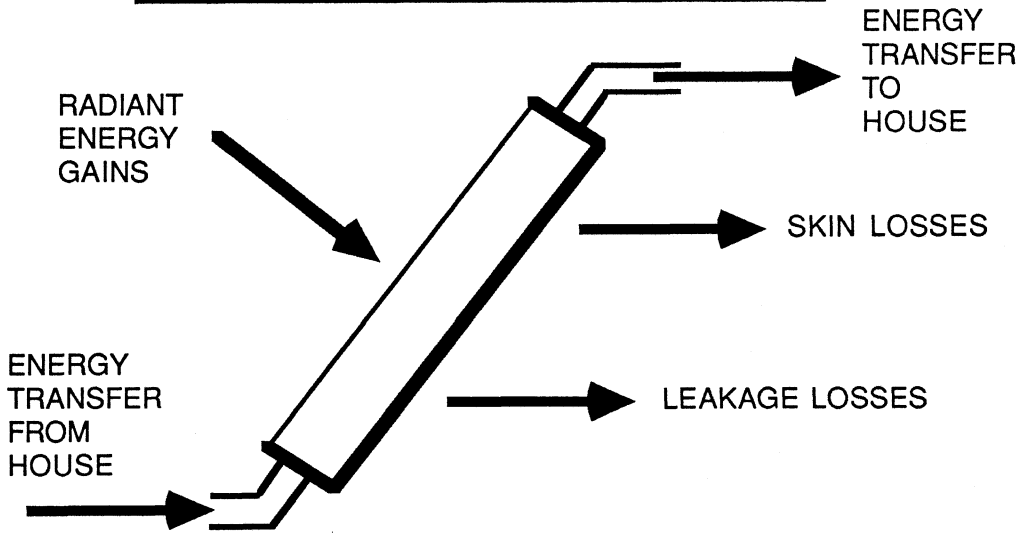
There are many mechanisms for house energy gains and losses. In order to create a reasonably simple model of energy use, the important energy flow paths (those that account for a significant percentage of the total load) must be identified. The less important energy flow paths are assumed to be negligible or to result in random errors in the fuel use predictions.

A schematic of the major energy flow paths for an AC/PS house is presented in Fig. 2.0.1, which is divided into two parts: the basic house and the active system. During periods when the active system is disabled, only the basic house energy flows apply. During the enabled periods, the basic house energy flows apply continually and the active system energy flows apply when the collector blower is operating. All of the flow paths depicted appear in the model equations for fuel use. There are arrows showing energy transfer both from and to the house because the collector contribution to the house space-heating load is the net energy added to the air flowing through the active system. All of these energy flows and the ways in which they were incorporated into the model are described in the following paragraphs. Energy storage is not dealt with in this chapter; all of the energy flows are based on a zero energy storage model. The 24-hour infinite storage method used to account for house thermal energy storage is described in Sec. 3.2.

2.1 BASIC HOUSE ENERGY FLOW PATHS

The basic house is the energy equivalent of the house before the AC/PS retrofit was done. The method developed for this analysis makes it convenient to separate the house into basic house and active solar collector parts, as shown in Fig. 2.0.1.

ACTIVE SYSTEM ENERGY FLOWS



BASIC HOUSE ENERGY FLOWS

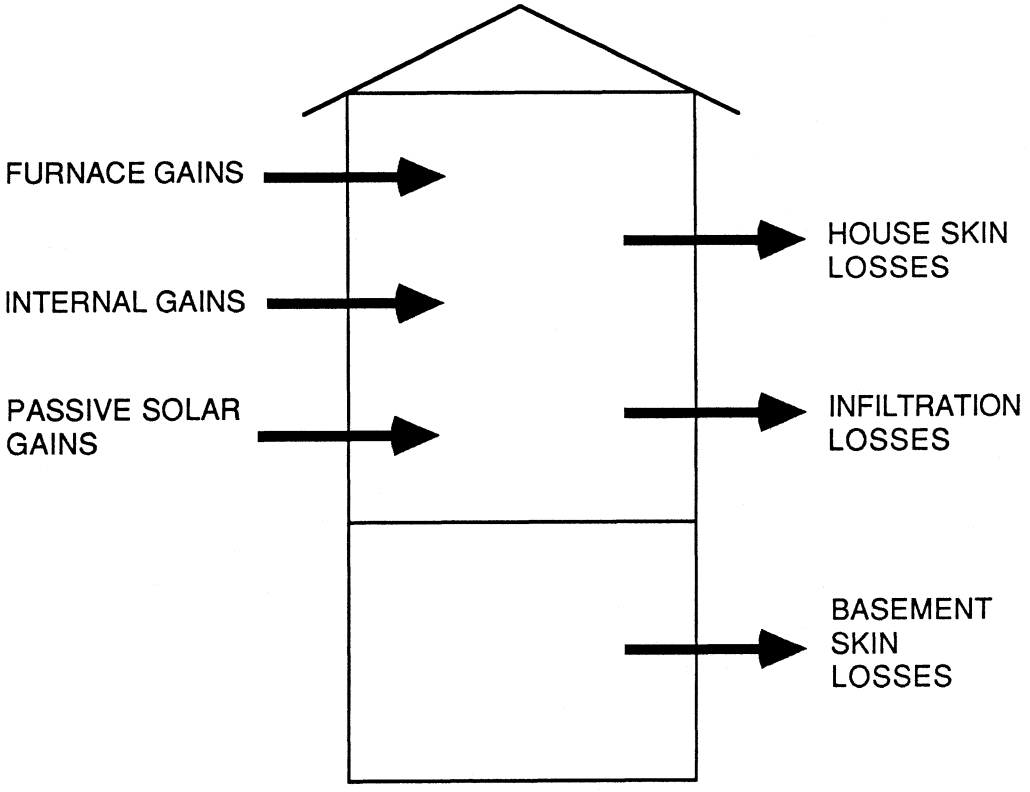


FIGURE 2.0.1 IMPORTANT AC/PS HOUSE ENERGY FLOWS

2.1.1 FURNACE GAINS

All of the houses in the present study have natural gas furnaces. Fig. 2.1.1 depicts the furnace energy flows into the heated space and up the chimney. In this work, the furnace efficiency is defined as the difference between the energy transferred from the furnace heat exchanger to the conditioned air and the incremental increase in infiltration losses caused by a high furnace temperature during furnace operation, divided by the higher heating value of the fuel. The furnace-induced increase in infiltration is over and above a base rate of flue infiltration which is assumed to be constant and included in the infiltration term. The systematic error introduced by a varying flue infiltration rate per unit of net energy delivered, which is a result of seasonal changes in the furnace cycling rate, is described in Sec. 2.3.2. The net energy delivered by a furnace is:

$$E_{delivered,net} = \eta \, E_{HHV,\ sp.\ hting} \qquad (2.1.1)$$

where: η = furnace efficiency

$E_{HHV,\ sp.\ hting}$ = higher heating value of natural gas used for space heating, defined as the total energy released when the fuel is burned and the water vapor is condensed out of the combustion products

2.1.2 INTERNAL GAINS

Internal gains are defined here as non-solar sources of energy that reduce the furnace space-heating load. The four sources of internal gains are domestic hot water heating (DHW), cooking, people, and electricity. A portion of the energy for DHW and all of the energy for natural gas energy cooking, both of which are shown in Fig 2.1.1, contribute to the internal gain term.

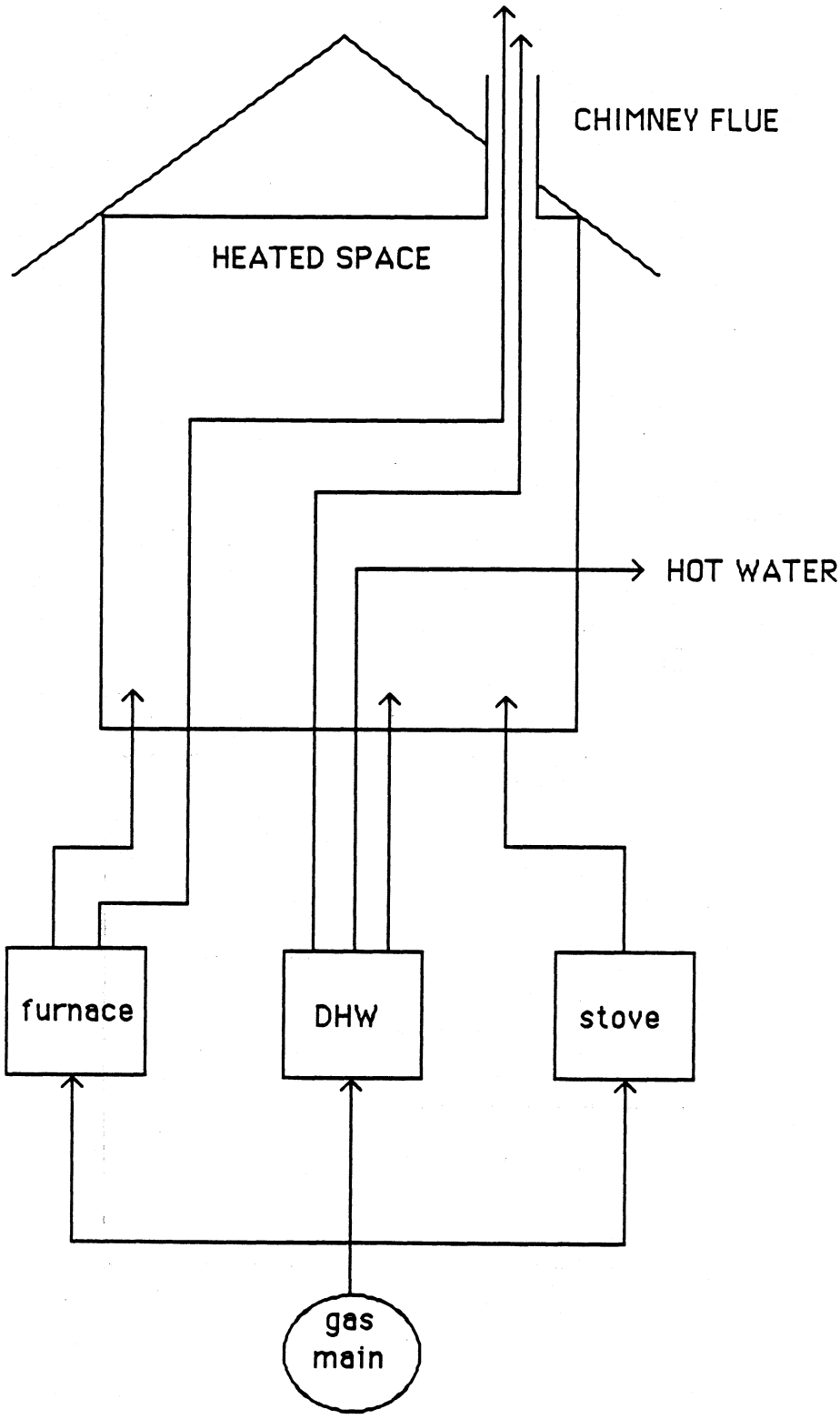


FIGURE 2.1.1 RESIDENTIAL NATURAL GAS ENERGY FLOWS

Fig. 2.1.1 depicts the various paths that natural gas energy takes as it is released and enters the house, and also those paths that lead directly to the ambient without off-setting any of the space-heating load. DHW energy use can be divided into three categories: chimney losses, tank and pipe losses, and drain losses. The latter refers to the energy that is lost when hot water goes down the drain. Drain losses and chimney losses have no effect on the space-heating load; only the tank and pipe losses contribute to the internal gain term. However, since the pipe losses are relatively small and difficult to estimate, only the tank losses are considered in the model internal gain calculation. The DHW tank specifications for each house in the study are not available, so typical tank parameters were assumed and the estimated tank losses calculated as follows:

Assume:	insulation:	$R = 4$ (hr-ft^2-F)/Btu
	surface area:	$A = 30$ ft^2
	water set temperature:	$T_{tank} = 140$ F
	tank is in heated bsmt:	$T_{bsmt} = 60$ F

$$Q_{tank\ loss} = \frac{A\,(T_{tank} - T_{bsmt})}{R} \qquad (2.1.2)$$

$$= 30 * (140 - 60) / 4$$

$$= 600 \text{ Btu / hr}$$

Each house is assumed to have a DHW tank that reduces the furnace space-heating load by a constant 600 Btu/hr. If the water heater is in an unheated part of the house, for example an uninsulated basement closet, the tank losses may not affect the space-heating load. Given the constraints of this study, however, this method of dealing with tank losses must suffice.

The houses in the study have either electric or gas stoves. In both cases virtually all of the cooking energy offsets the space-heating load, as shown in Fig. 2.1.1 for gas stoves. A small fraction of the cooking energy causes chemical changes in the food; this energy does not reduce the space-heating load. The model is based on the assumption that all the cooking energy is transformed into thermal energy. Electric stove cooking energy consumption appears in the electrical use data and is treated in the same way as the rest of the electrical use. Gas stove cooking energy consumption is more problematic. Since no data are available for the houses in the study, it is assumed that all the gas stoves use the same amount of energy as the one described in a report by Macriss and Elkins. The oven and range together used 85.4 therms/year. (A therm is 10^5 Btu. It is a convenient unit of energy to use in house energy analysis because gas meters are read in units of CCF, hundreds of cubic feet of natural gas. 100 cubic feet of natural gas has a typical higher heating value of 1003 Btu/ft^3 (Mitchell, 1983, p.133). Therefore the meter readings of gas volume use can be directly translated into energy use if the higher heating value is rounded to 1000 Btu/ft^3.) The gas dryer, which some of the houses in the study have as well, used 33.8 therms/year. It is assumed that the cooking energy acts as a constant gain to the heated space, and that the drying energy is lost to the outdoors. For a discussion of the seasonal dependence of house non-heating energy use (DHW, cooking, and electricity) refer to Fels et al, 1986, p.139.

People transfer energy to their surroundings by sensible and latent heating; however, only the sensible heating serves to offset the space-heating load because indoor moisture levels are generally not high enough to cause condensation of the moisture added to the air by latent heating. A reasonable estimate of human sensible energy loss is 250 Btu/person-hr (Mitchell, 1983, p.47). The model is based on the assumption that 2 people occupy each house 24 hours/day.

The model internal gain calculation is based on the assumption that all of the electrical energy consumed reduces the space-heating load by an equivalent amount, i.e. it is all converted to thermal energy within the house. This is not completely true, some of the energy used for lighting is radiated through windows for example, but it is a convenient assumption and justifiable since the error involved is small relative to the total electrical load.

In order to account for changes in electrical use with time, the monthly electrical use data were interpolated to estimate the values which correspond to the fuel data periods. These estimated weekly electrical use data were then used as input values in the regression calculation.

All of the internal gain terms are estimated, either from measurements or from typical values, and used in the model as input values. They are represented in the model equation by the letter B:

B = DHW losses to the heated space + cooking energy + sensible losses from people to the heated space + total electrical energy use

2.1.3 PASSIVE SOLAR GAINS

In the context of this study, passive solar refers to solar energy gains through the house windows and to the house walls. This section is a description of how those gains are dealt with in the model.

The energy gain through a window can be calculated as follows:

$$Q_{wd} = (\tau\alpha)_e A_{wd} R G \qquad (2.1.3.1)$$

where: $(\tau\alpha)_e$ = the instantaneous effective window-room transmittance-absorptance product

A_{wd} = window area

R = the ratio of radiation on the window in question to radiation on the horizontal

G = the irradiance on the horizontal

The difficulty in creating a general passive solar parameter for a variety of houses is that each house has different window areas, orientations and types. Thus all the terms in Eq. 2.1.3.1 except the irradiance are dependent on which house and which wall of that particular house are under investigation. R and $(\tau\ \alpha)_e$ are also functions of time, which further complicates the analysis.

For an n-walled house, the passive gain for an hour (the period for which weather data are available) is:

$$E_{hourly} = I \sum_{i=1}^{n} (R_i\ \overline{(\tau\alpha)}_{e,i}\ A_{wd,i}) \qquad (2.1.3.2)$$

where:

$\overline{(\tau\alpha)}_{e,i}$ = the average effective transmittance-absorptance product for the windows in wall i

I = solar radiation on the horizontal during one hour

Solar gains occur at exterior wall surfaces as well as through windows. Radiant energy is absorbed by wall surfaces, thereby raising the temperature of the surface. Since the rise in wall temperature is not accounted for in the model skin loss calculation (see the following section), the concomitant reduction in skin losses can be treated as a solar gain. A derivation of the net solar gain to the heated space which results from insolation on the house walls follows (refer to Fig. 2.1.3.1):

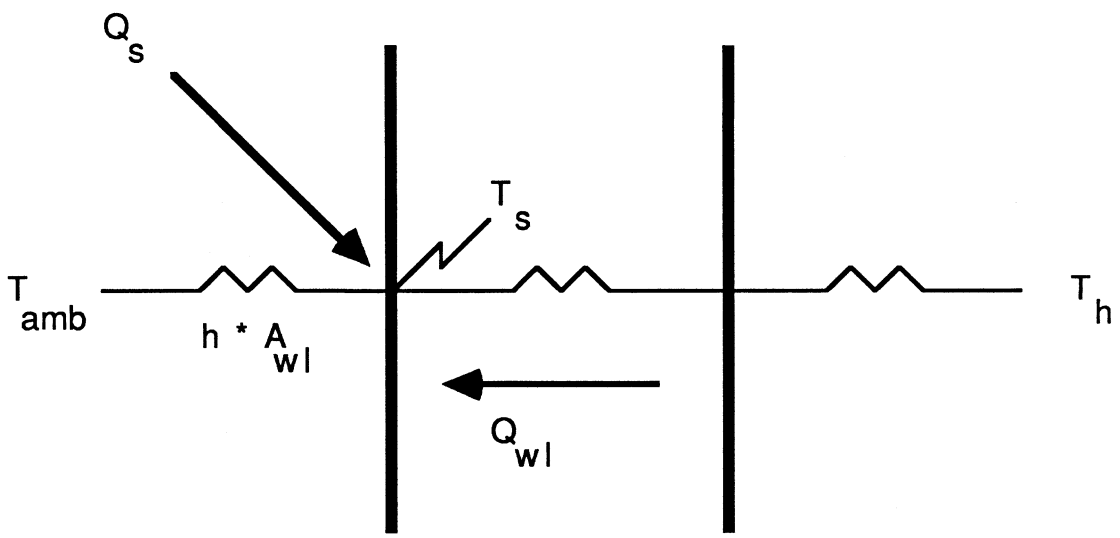


FIGURE 2.1.3.1 PASSIVE SOLAR WALL GAINS

$$Q_{wl} = - Q_s + h\,A_{wl}\,(T_s - T_{amb}) \equiv h\,A_{wl}\,(T_s - T_{solair}) \quad (2.1.3.3)$$

therefore:

$$T_{solair} = T_{amb} + \frac{Q_s}{h\,A_{wl}} \quad (2.1.3.4)$$

$$Q_{wl,\text{with solar}} = UA_{wl}\,(T_h - T_{solair}) \quad (2.1.3.5)$$

$$Q_{wl,w/out\ solar} = UA_{wl}\,(T_h - T_{amb}) \qquad (2.1.3.6)$$

where: Q_{wl} = the net energy transfer through the wall

Q_s = the decrease in energy transfer through the wall due to absorbed solar radiation

h = the convection heat transfer coefficient from the exterior wall to the ambient air

U = the overall thermal resistance through the wall

T_s = the temperature at the exterior surface of the wall

T_{solair} = the ambient temperature which, if there were no incident solar radiation, would result in the same rate of energy transfer through the wall as occurs when there is radiation incident on the wall

The net solar gain is:

$$Q_{solar,net} = UA_{wl}\,(T_h - T_{amb}) - UA_{wl}\,(T_h - T_{solair}) \qquad (2.1.3.7)$$

$$= UA_{wl}\,(T_{solair} - T_{amb}) \qquad (2.1.3.8)$$

$$= Q_s \frac{U}{h} \qquad (2.1.3.9)$$

since: $$Q_s = I\,R\,\alpha\,A_{wl} \qquad (2.1.3.10)$$

where: $\alpha =$ the absorptance of the house wall

$$Q_{solar,net} = I\,R\,\alpha\,A_{wl}\frac{U}{h} \qquad (2.1.3.11)$$

For all the walls of the house, the net solar gain is:

$$Q_{solar,net,total} = I\sum_{i=1}^{n} R_i\,\alpha_i\,A_{wl,i}\,\frac{U_i}{h_i} \qquad (2.1.3.12)$$

In order to allow for a simplified analysis of the total passive solar gain to the windows and walls of each house, it was decided to choose a representative house configuration with an assumed combination of vertical surface orientations. This representative configuration will be referred to in this discussion as the "typical house". The window and wall passive gain to each house is approximated in the model as the radiation incident on the typical house multiplied by a constant factor, k, which is unique to that house.

$$E_{hourly} = k\,I_p \qquad (2.1.3.13)$$

where: I_p = the hourly radiation incident on the surfaces of the typical house

$$k = \frac{I\left[\sum_{i=1}^{n} R_i\ \overline{(\tau\alpha)}_i\ A_{wd,i} + \sum_{j=1}^{m} R_j\ \alpha_j\ A_{wl,j}\ \frac{U_j}{h_j}\right]}{I_p} \qquad (2.1.3.14)$$

As a means of determining the optimum typical house, i.e. the combination of surface areas and orientations which results in the most linear relationships between the passive gains to the houses in the study and the radiation incident on the typical house, it was necessary to determine how the k-value would vary over the heating season for a variety of house designs. This was accomplished by computer modeling of different houses using F-LOAD, a building design program developed by F-CHART Software that allows the user to specify house parameters which are then used to calculate the energy performance of the house. Four model houses were created with F-LOAD and used to determine the typical house which would subsequently be part of the regression analysis. The four F-LOAD houses have the following characteristics:

1. F-LOAD default house with window area adjusted to 100 ft^2 (see Appendix A for parameter list).

2. F-LOAD default house with 100 ft^2 of windows only on the south side.

3. F-LOAD default house with house orientation changed +45° and 25 ft^2 of window on each of its four sides.

4. F-LOAD default house with 50 ft^2 of windows on the east and 50 ft^2 of windows on the west walls.

For each house, the program outputs passive gain data on a monthly basis. Only December through April data were used, since those months correspond to the southern Wisconsin heating season.

Eight typical house configurations were chosen for trial, beginning with the simplest surface orientation for which radiation data are available- the horizontal:

1. horizontal
2. vertical, 0° azimuth angle
3. vertical, 15° azimuth angle
4. vertical, 30° azimuth angle
5. vertical, 45° azimuth angle
6. vertical, 90° azimuth angle
7. four surfaces oriented north, south, east and west
8. three surfaces oriented south, east and west

A monthly k-value for each F-LOAD house and typical house combination was calculated by dividing the F-LOAD house monthly passive gains by the total monthly irradiation on the typical house in question. Each F-LOAD house has a window area of 100 ft^2. The typical houses also have areas of 100 ft^2 equally distributed over their surfaces to make the k-values more meaningful.

A sample set of monthly k-values for house 3 is presented in Table 2.1.3.1. These values were calculated by dividing each monthly passive gain calculated by F-LOAD for house 3 by the monthly radiation incident on each typical house. The best

typical house is the one which has the least variation in its monthly k-value over the year. For house 3 the best typical house is the one which has four surfaces of equal area oriented north, south, east, and west.

TABLE 2.1.3.1 PASSIVE SOLAR K-VALUES FOR HOUSE 3

	TYPICAL HOUSE MODEL							
month	hor	V0	V15	V30	V45	V90	N,S E,W	S,E W
OCT	0.41	0.35	0.36	0.38	0.41	0.65	0.95	0.80
NOV	0.46	0.32	0.33	0.35	0.39	0.68	0.95	0.80
DEC	0.51	0.31	0.31	0.34	0.39	0.73	0.97	0.81
JAN	0.51	0.30	0.31	0.34	0.38	0.74	0.95	0.79
FEB	0.44	0.33	0.34	0.36	0.39	0.63	0.94	0.79
MAR	0.37	0.40	0.41	0.41	0.43	0.58	0.98	0.84
APR	0.34	0.54	0.53	0.50	0.48	0.57	1.03	0.90
MAX	0.51	0.54	0.53	0.50	0.48	0.74	1.03	0.90
MIN	0.34	0.30	0.31	0.34	0.38	0.57	0.94	0.79
% DIFF:	33	44	42	32	21	23	9	12

The same analysis was done for the other three house types listed. The percent differences between the minimum and maximum k-values calculated for each possible house/surface combination are presented in Table 2.1.3.2.

TABLE 2.1.3.2 K-VALUE PERCENT DIFFERENCES FOR EACH COMBINATION OF FLOAD HOUSE AND TYPICAL HOUSE MODEL

		TYPICAL HOUSE MODEL						
house	hor	V0	V15	V30	V45	V90	N,S E,W	S,E W
1	54	23	18	8	8	44	24	19
2	39	39	38	27	15	28	0	5
3	33	44	42	32	21	23	9	12
4	12	58	57	51	43	6	32	34
Σ	138	164	155	118	87	101	66	70

The percent differences are summed on the bottom line of Table 2.1.3.2 to show how appropriate each surface model is for the four houses considered. The single-surface models are distinctly worse than the two multiple-surface models for the purposes of this study. There is very little difference between the sums of percent differences for the 3- and 4-surface models. The 4-surface model was chosen since it has a slightly lower sum of percent differences.

The choice of the typical house model described in the previous paragraph determines the way the passive gain variable is calculated for use in the regression analysis. Since the best model is one that has equal surface areas facing north, east, south, and west, the average of the total radiation per unit area incident on those four surfaces is used as the passive gain variable. Thus, the model is based on the assumption that the passive gain to every house in the study is a linear function of the average radiation per unit area on north-, east,- south-, and west-facing surfaces.

All of the basic house gain terms have been described; the following paragraphs cover the basic house loss terms.

2.1.4 HOUSE SKIN LOSSES

The major mode of energy loss for a typical house is by energy transfer through the skin. The word skin refers to the exposed surfaces of the house: the exterior walls and ceiling. The ceiling is considered the exterior surface rather than the roof because most of the thermal resistance is located there, and because standard construction methods call for a ventilated attic.

The electrical analogy to energy transfer is useful in explaining the concept of an overall conductance-area product, on which the calculation of skin losses is usually based. Energy is transferred through the skin of a house by a network of conduction, convection and radiation paths. These paths can be thought of as thermal resistances to energy flow. The potential that drives the flow is the temperature difference across the resistances.

In order to simplify the skin loss concept, all of the thermal resistances involved, which are interconnected in series and in parallel, are lumped into one overall resistance. The skin losses are then calculated as:

$$Q_{skin} = \frac{A\,(T_h - T_{amb})}{R_{overall}} \qquad (2.1.4.1)$$

Mitchell (1983, p.35), presents a derivation of the overall thermal resistance. Skin loss coefficients are generally spoken of as conductance values rather than resistance values, in which case Eq. 2.1.4.1 becomes:

$$Q_{skin} = (\,UA\,)_o\,(T_h - T_{amb}) \qquad (2.1.4.2)$$

and the first term in parentheses is the overall conductance-area product. In the model the skin losses are represented by a constant term multiplied by the temperature difference in Eq. 2.1.4.2.

The owners of the systems under investigation were asked in a letter survey what their normal and setback thermostat settings are. These thermostat settings are used as the house temperatures in the analysis. The model is based on the assumption that the furnace thermostats are at the normal settings from 7AM to 11PM, and at the setback settings from 11PM to 7AM every day. A diagram of the assumed thermostat control strategy is shown in Fig. 2.1.4.1. Although not all of the homeowners involved in the study use a control strategy that is exactly like the one depicted in the diagram, in general the strategies they reported using were similar.

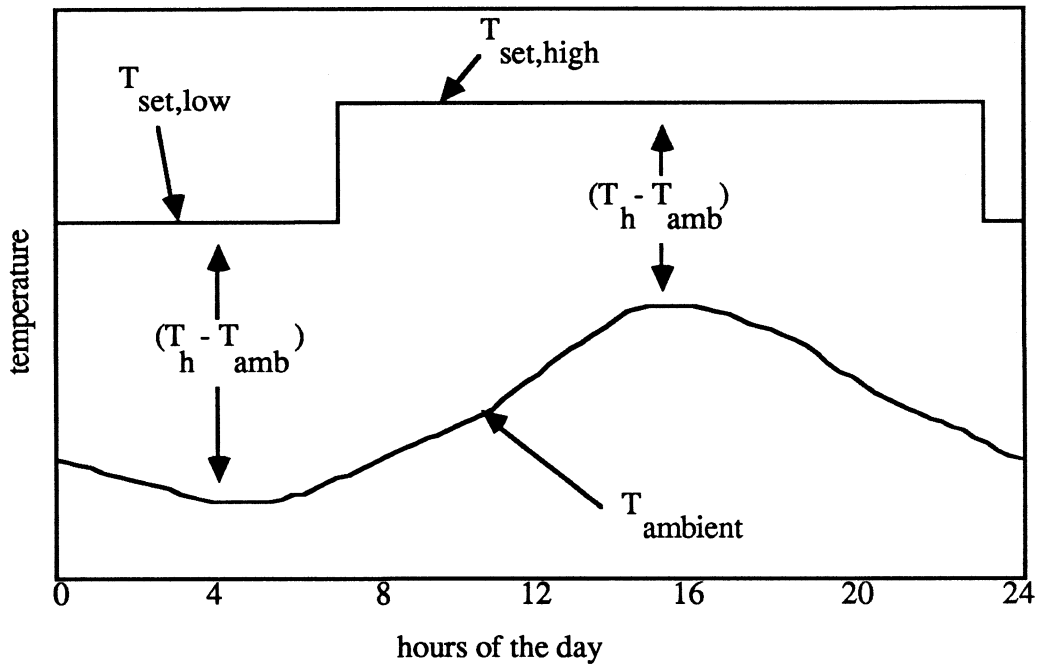


FIGURE 2.1.4 DIAGRAM OF THE THERMOSTAT SETBACK TEMPERATURES

One of the terms in the overall conductance is the convection heat transfer coefficient between the exterior wall surface and the ambient air. It is determined in part by the wind speed and direction at the surface. In order to include wind-induced skin loss effects in the analysis, much more site-dependent weather and system information would be required than is available. Therefore the effect of changes in wind speed and direction on skin losses is neglected.

The other conductances are assumed to be constant over the course of the study for both the active system enabled and disabled periods. This assumption precludes thermosiphoning or collector infiltration during the disabled periods; these effects are accounted for by the collector gain term during the enabled periods. The active system inlet and outlet registers were sealed with plastic covers during the disabled periods, which is assumed to have eliminated any active system losses during those times.

2.1.5 INFILTRATION

Infiltration is a process by which ambient air enters a house, replacing air which is at the house temperature. It increases the space-heating load because the ambient air must be warmed to the house temperature. The energy required per unit time is:

$$Q_{inf} = \dot{m}_{inf} (h_h - h_{amb}) \qquad (2.1.5.1)$$

where: h_h = the enthalpy of the house air

h_{amb} = the enthalpy of the ambient air

Assuming constant specific heat, this equation can be written:

$$Q_{inf} = \dot{m}_{inf} C_p (T_h - T_{amb}) \qquad (2.1.5.2)$$

The air flow rate, $\dot{m}_{inf}$, is a function of the total cross-sectional area of cracks and openings in the house skin, and of the pressure difference between the inside and outside of the house. This pressure difference varies with location on the house and is the result of buoyancy forces (the warm house air is less dense than the cold ambient air) and wind effects. The infiltration which occurs as a result of ambient air entering the active solar system is dealt with in the equation describing active system performance, which is presented in section 2.2.3.

The model is based on the assumption that the house infiltration flow rate is constant; changes in wind speed and direction, and in buoyancy forces are not taken into account.

2.1.6 BASEMENT LOSSES

The basement losses are similar to the house skin losses in that they are a function of the difference between two temperatures, the house and the ground temperatures. They are different in that, at a given time, the ground temperature is not uniform over the surface in question; it is a function of the distance from the surface, of the soil conductivity, and of the soil moisture content at each point on the exterior surface of the basement wall and floor.

In order to simplify the analysis, it is assumed that the losses are a linear function of the difference between the house temperature and an effective ground temperature:

$$Q_{bsmt} = UA_{bsmt} (T_h - T_g) \qquad (2.1.6.1)$$

If the basement is heated, the basement loss coefficient is the effective overall conductance-area product for the basement. If the basement is unheated, the loss

coefficient also includes the effects of the thermal resistance between the house floor and the basement walls, and losses from the furnace, ductwork and other energy sources located in the basement. The results of a survey of the homeowners involved in the study indicate that most basement temperatures are within ten degrees Fahrenheit of the daytime house temperature.

The effective ground temperature is dependent on the recent average ambient temperature history and on the deep ground temperature. The deep ground temperature can be approximated as the annual average ambient temperature (45° for Madison, WI). Yard et al (1984) show in their report on basement energy loss that the effective ground temperatures for basement walls and floors have a phase lag with respect to the ambient temperature when the temperatures are plotted against time. Since the regression analysis is done for weekly fuel data, it was decided to use a constant effective ground temperature for each week. The weekly effective ground temperature is calculated as the average of the average ambient temperature for a certain number of weeks preceding the week in question, and the deep ground temperature.

$$T_g = \frac{\sum_{i=1}^{n} \frac{(T_{amb,weekly,i})}{n} + T_{amb,\ yearly}}{2} \qquad (2.1.6.2)$$

The number of weeks (n) of ambient temperature to use in the calculation was found by doing a series of analyses with different numbers of weeks on one of the houses in the study. The results appear in Table 2.1.6. The sum of squares refers to the sum of the squares of the differences between the measured and predicted weekly fuel uses.

TABLE 2.1.6 EFFECT ON THE SUM OF SQUARES OF USING VARIOUS NUMBERS OF WEEKS IN THE CALCULATION OF THE EFFECTIVE GROUND TEMPERATURE

	NUMBER OF WEEKS				
	3	4	5	6	7
SUM OF SQUARES: (therms^2)	35.4	33.6	31.2	31.0	31.4

The sums of squares for the analyses decrease with increasing number of weeks until the sixth week, then begin to increase. The 5-week calculation was chosen for use in the regression analyses because its sum of squares is lower than that of the 4-week calculation, and insignificantly higher than that of the 6-week calculation.

If effective ground temperatures were measured for each house at a given time they would be found to vary considerably. This is because the effective ground temperature is a strong function of the depth of the basement, its dimensions, and the soil conductivity in the area. The use of a single ground temperature algorithm for all the houses in the study is justified on the grounds that the regression analysis will find the best combination of house and basement UA-values to describe the skin loss characteristics of the house. For example, if houses A and B are identical except that A is located in an area with much lower soil conductivity than the area that B is in, the basement UA-value of house A found by the regression analysis should be lower than that of house B.

A plot of weekly average ambient temperature and weekly average ground temperature appears in Fig. 2.1.6.1. The ground temperature was found using the 5-week calculation. It has a shape similar to a sine-curve with a phase lag, which is in agreement with the theory of Yard et al.

All of the energy flows associated with the basic house have now been described.

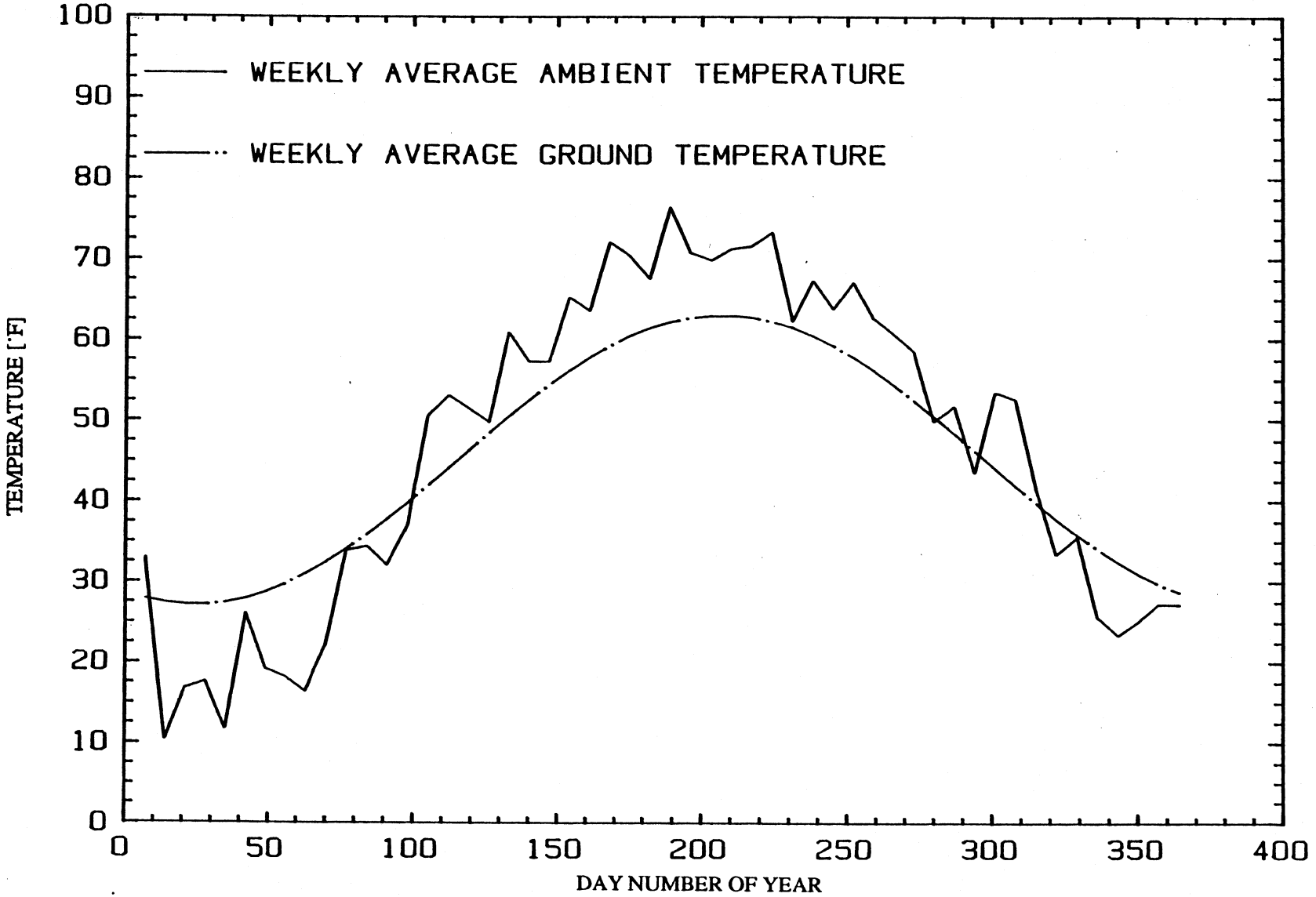


FIG. 2.1.6.1 WEEKLY AVERAGE TEMPERATURES FOR A MADISON TMY

2.2 ACTIVE SOLAR ENERGY FLOW PATHS

The active solar energy flow paths, depicted in Fig. 2.0.1, are those associated with the solar collector and ductwork. The model is based on the assumption that the blower is activated as soon as the collector gains exceed its losses. This is referred to as the ideal controller assumption. The actual system controllers differ from the model in that they have deadbands built into them to prevent excessive cycling of the blower. However, only a small error is introduced by assuming an ideal controller because relatively small amounts of energy are available at times when an ideal controller would be on and a controller with deadband would be off.

2.2.1 SOLAR GAINS

Collector solar gains occur whenever there is radiation incident on the collector surface. The hourly active gain is:

$$E_{hourly,coll} = \overline{(\tau\alpha)}_{e,coll} \; A_{coll} \, R_{coll} \; I \qquad (2.2.1.1)$$

The performance parameters A_c, $F_R(\tau\alpha)_e$, and $F_R U_L$ of the three brands of collectors in the study were measured by independent engineering firms (see Table 4.1.1). However, only the collector area measurement is useful in this investigation; the collector mass flow rates and leakage rates of the in situ systems are likely to differ significantly from those of the test systems, which means that their $F_R(\tau\alpha)_e$, and $F_R U_L$ values are likely to be different.

2.2.2 COLLECTOR SKIN LOSSES

The collector loses energy to its surroundings by radiation and convection when it is at temperatures higher than the ambient. These skin losses are difficult to calculate directly since the collector plate temperature is a function of insolation, which changes constantly, and of distance along the plate. To simplify the calculation, a collector heat removal factor (F_R) is defined as the ratio between the useful energy gain of the collector, and the useful energy that would be contributed if the entire collector plate were at the inlet temperature (see Duffie and Beckman (1980), p.223).

$$F_R = \frac{\dot{m}\, C_p\, (T_{out} - T_{in})}{A_c\, [(\tau\alpha)_e\, R\, I - U_L (T_i - T_{amb})]} \qquad (2.2.2.1)$$

The collector heat removal factor is useful in characterizing a particular collector design, since it is essentially constant as long as the ratio of collector mass flow rate to collector area is not changed. Defining the heat removal factor in this way allows the useful energy gain from the collector to be calculated as:

$$Q_u = A_c\, F_R\, [\, (\tau\alpha)_e\, R\, I - U_L (T_i - T_{amb})\,] \qquad (2.2.2.2)$$

This is the Hottel-Whillier collector equation, and includes both the collector solar gain and loss terms.

Skin losses from the inlet and outlet ducts are often significant, particularly since air systems have conduits with relatively large surface areas. These losses can be accounted for in the regression analysis by writing the collector equation with modified values of $(\tau\alpha)_e$ and U_L:

$$Q_u = A_c F_R [(\tau\alpha)'_e R I - U'_L (T_i - T_{amb})] \qquad (2.2.2.3)$$

Refer to Duffie and Beckman (1980), p.356, for the derivation. This is particularly convenient for the type of analysis used in this investigation, since changes in the collector parameters due to duct skin losses are reflected by a slightly altered regression loss coefficient. Therefore it is not necessary to separate the collector performance from the duct effects to accurately model the active system performance.

2.2.3 LEAKAGE IN DUCTS AND COLLECTORS

All of the solar systems under investigation use air as the working fluid and have blowers located at the ends of the collector outlet ducts. Air systems traditionally have significant leakage problems, which makes it necessary to account for leakage in the analysis, since leakage affects performance. The location of the blower means that the collector systems operate below ambient pressure, and any leaks will be into the systems.

There are three potential collector leak locations: along the inlet duct, along the collector, and along the outlet duct. See Fig. 2.2.3.1, in which the basic house infiltration, the potential collector leaks, and the increased infiltration which would result from collector leakage are depicted.

The following discussion of the three types of leaks shows that the effect of a leak or combination of leaks can be accounted for by the Hottel-Whillier Equation with modified values of the gain term and/or the loss term. Therefore, the Hottel-Whillier Equation can be used in the regression analysis model to describe the performance of the active system. Since the active system parameters, $A_c F_R (\tau\alpha)_e$ and $A_c F_R U_L$, are determined by minimizing the sum of squares of the residuals in the regression analysis, any changes to those parameters due to leakage will be reflected in the values found by the regression analysis.

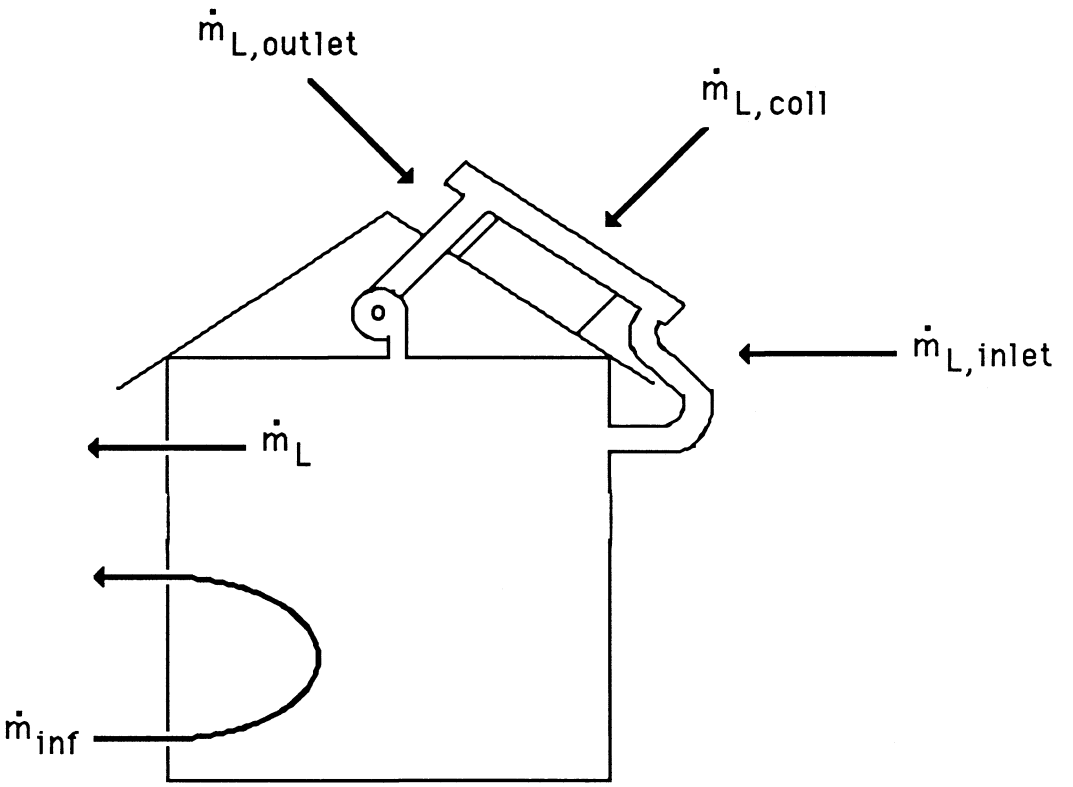


FIGURE 2.2.3.1 POTENTIAL LEAK LOCATIONS IN ACTIVE SOLAR SYSTEM

Inlet duct leakage results in a) lower losses due to reduced plate temperatures, b) lower outlet temperatures, c) higher efficiency as a result of decreased losses (this does not mean higher overall performance), and d) fewer operating hours. The collector equation includes the inlet temperature, which would change appreciably if inlet leaks

occurred. The change in the inlet temperature can be derived as follows:

$$\dot{m}_{in}\, h_{in} = (\dot{m}_{in} - \dot{m}_L) h_h + \dot{m}_L h_{amb} \qquad (2.2.3.1)$$

where: $\dot{m}_L$ = the leakage mass flow rate into the inlet duct

Assuming constant specific heats:

$$\dot{m}_{in}\, C_p\, T_{in} = (\dot{m}_{in} - \dot{m}_L)\, C_p\, T_h + \dot{m}_L\, C_p\, T_{amb} \qquad (2.2.3.2)$$

$$T_{in} = \frac{\dot{m}_{in}\, T_h + \dot{m}_L\, (T_{amb} - T_h)}{\dot{m}_{in}} \qquad (2.2.3.3)$$

$$= T_h + \frac{\dot{m}_L\, (T_{amb} - T_h)}{\dot{m}_{in}} \qquad (2.2.3.4)$$

Therefore:

$$(T_{in} - T_{amb}) = T_h + \frac{\dot{m}_L (T_{amb} - T_h)}{\dot{m}_{in}} - T_{amb} \qquad (2.2.3.5)$$

$$= \left(1 - \frac{\dot{m}_L}{\dot{m}_{in}}\right)(T_h - T_{amb}) \qquad (2.2.3.6)$$

performance: inlet duct leaks improve collector efficiency by lowering the inlet temperature, while outlet duct leaks reduce collector efficiency by decreasing the flow rate through the collector which results in higher plate temperatures and losses, other factors being equal.

TABLE 2.2.3 ANNUAL AC/PS SYSTEM SOLAR FRACTIONS FOR VARIOUS 50% LEAKAGE SCENARIOS (MODELED USING FCHART)

LEAK LOCATION	SOLAR FRACTION (ANNUAL)
NONE	0.45
INLET	0.36
OUTLET	0.26
BOTH	0.33

2.3 DISCUSSION OF FUEL-USE FACTORS NOT INCLUDED IN MODEL

There is no limit to the number of factors which affect residential natural gas use. The goal in developing a model of that use, therefore, is to balance the need for accuracy in the model against the need for simplicity. The PRISM model, described in the literature review of Chapter 1, is a powerful tool because of its simplicity. The model developed for the present analysis is considerably more complicated, yet still omits many factors which effect fuel use, such as occupant behavior, seasonal changes in furnace efficiency, night insulation, and the solar domestic water heating which is included on nine of the AC/PS systems in the study. These are described in the following paragraphs. The simplifications inherent in the fuel-use factors which have been accounted for in the model are discussed in Sections 2.1 and 2.2.

Since the collector inlet temperature can be approximated as the house temperature for the case of no inlet duct leak, the only change in the collector equation due to an inlet duct leak is the addition of a constant multiplication factor to the loss term. This effect would show up in the regression results as a modified $A_c F_R U_L$ term.

If leaks occur along the collector the effects can be modeled as modified gain and loss terms in the collector equation. For the derivation of the modified terms, refer to Close and Yusoff (1978).

Leaks along the outlet duct cause a change in the collector heat removal factor, since they result in a decreased collector mass flow rate. Otherwise, they can simply be considered as increased infiltration which occurs when the blower is operating. Collector infiltration is included in the collector loss term, since both skin losses and infiltration are assumed to be linear functions of the difference between the house and ambient temperatures.

All three leak scenarios can be modeled by modified collector performance coefficients in the regression model. Therefore the collector equation presented in section 2.2.2, with an infiltration term added to the collector loss coefficient ($U_L + C_p * \dot{m}_L$), is used as the basis for determining the total active system performance in the model.

FCHART, a solar energy system design program developed at the University of Wisconsin-Madison Solar Energy Laboratory, was used to determine the theoretical effect of leakage in the inlet and outlet ducts of an AC/PS system. The FCHART method is a correlation of the results of many hundreds of thermal performance simulations of solar heating systems. The program does not allow for taking into account the effects of leakage in the collector. The default parameters for a flat-plate collector were used, except for the leakage rate which was set at 50%. The results appear in Table 2.2.3.

The system with inlet duct leakage did substantially better than the one with outlet duct leakage. This can be explained by considering the effect of leak location on collector

2.3.1 THE EFFECT OF OCCUPANT BEHAVIOR ON FUEL USE

No attempt was made in the development of the model to account for the effect on fuel use of seasonal variation in human behavior or differences in human behavior between sites. By neglecting this aspect of fuel use, the implicit assumption is made that the effects are either constant over the period of the study, and therefore reflected in the model parameters found by the regression analysis, or random, resulting in errors which do not change the final results of the investigation.

Examples of human behavior which change fuel use are: opening and closing of doors, using different set temperatures at different times of the year, and occupancy level changes which effect the base-fuel load. It is expected that occupant behavior effects could range from being negligible for a given house to being on the same order of magnitude as the active solar contribution, which would result in large 95% confidence intervals for the predicted energy saved due to the active solar system.

2.3.2 SEASONAL CHANGES IN FURNACE EFFICIENCY

The final result desired in this analysis of the performance of AC/PS systems is the amount of energy saved by using the systems. On an annual basis, the energy saved is an inverse function of the average furnace efficiency:

$$E_{saved,annual} = \frac{\text{annual solar contribution}}{\eta} \qquad (2.3.2)$$

Traditional combustion furnaces operate at a steady-state efficiency of approximately 80%. In normal operation, however, they cycle on and off since the steady-state output is higher than the load under all but the most severe weather conditions. Over an entire heating season, a furnace operates about 10% of the time (Mitchell, 1983, p.147).

Cycling affects the furnace efficiency because the elevated temperature of the furnace just before and just after blower operation causes increased thermosiphoning up the flue. Therefore there is a loss associated with a furnace cycle that is independent of the amount of energy delivered during that cycle. The higher the cycling rate, the greater the effect is on the furnace efficiency. In the spring and fall, when the ambient temperature is often relatively close to the house balance temperature, the cycling rate per unit of energy delivered is high and a lower furnace efficiency results. In contrast, during the colder winter months the furnace operates for much longer periods of time and the cycling rate per unit of energy delivered is much lower.

The variation in furnace efficiency over the course of a heating season has a lower bound of zero and an upper bound of ten to twenty percent. Since the relationship between furnace efficiency and predicted energy saved is an inverse linear one (see Eq. 2.3.1), and the systems under investigation are expected to yield solar fractions of 10-20%, changes in furnace efficiency could have an effect on the ability of the model to predict energy savings due to the active solar system accurately.

2.3.3 THE EFFECT OF NIGHT INSULATION ON FUEL USE

One of the most common ways of reducing the heating requirements of a house is to insulate the windows at night. Windows can account for a significant percentage of the house skin losses and are relatively easy to insulate using window quilts, curtains or blinds. The effect of window insulation is to reduce the house overall conductance-area product (UA), which is the most important fuel-use parameter in the model.

It is not known how many of the houses in the study have night insulation. If enough night insulation were used to significantly change the UA-value, it is hypothesized that the regression analysis would find an average UA-value for the house, and the confidence intervals for all the parameters would be wider. All the parameters would be effected because they are highly correlated, and because the skin losses account

for such a high percentage of the total load. Since the confidence interval for the predicted energy savings is calculated using the parameter confidence intervals, the predicted energy saved would also have wide confidence intervals.

2.3.4 THE EFFECT OF SDHW SYSTEMS ON FUEL USE

Nine of the twenty nine systems in the study have solar domestic hot water heating (SDHW) as part of their active solar systems. Eight of them are General Solar systems located in Kenosha, and the ninth is an EMG system in Jefferson County. Two of the General Solar systems have preheat tank pumps that have been disconnected, which means they can be treated as if they did not have any SDHW. The enable/disable control strategy of the EMG system (house 28) was not continued during the summer, so it is assumed to have water heating performance similar to the other SDHW systems and omitted from the following discussion of the SDHW systems. This assumption is justified on the grounds that, although the EMG system has 130 ft^2 of collector area as opposed to 92 ft^2 for all the General Solar SDHW systems, its collector is mounted vertically and therefore receives less radiation per square foot than the General Solar systems. The EMG systems also have significantly higher measured leakage rates than the General Solar systems (refer to Section 4.2).

For this investigation, the SDHW systems have been characterized as follows:

1. The solar energy used for water heating is transferred to a water preheat tank which is located between the water mains and the gas- or electric-fired residential water heater .

2. Energy from the active solar system is transferred from the collector to the preheat tank by an air-to-water heat exchanger mounted in the active system air duct. There is a pump in the preheat tank that circulates the water.

3. SDHW system does not operate until the space-heating load has been met.

4. The control system includes a freeze-protection strategy which energizes the pump to circulate water from the preheat tank through the heat exchanger when it is in danger of freezing.

Assumptions 3 and 4 in the preceding list are the only questionable ones. The actual control of an active solar system often deviates considerably from the intended strategy due to problems with the control hardware. A schematic of the type of SDHW system used in these houses is presented in Figure 2.3.4.1.

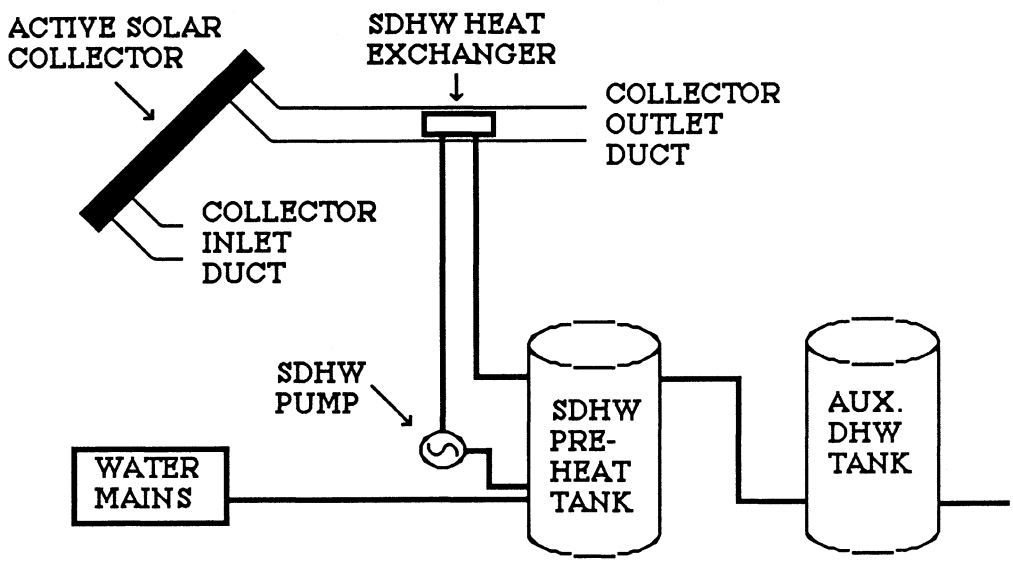


FIGURE 2.3.4.1 SCHEMATIC OF AN SDHW SYSTEM

In order to assess the effects of the SDHW systems in the study, the weekly summer season fuel use of each of them was plotted against time. The summer season is defined as that period during which either a) the furnace is turned off, or b) there is negligible space-heating load. Since the enable/disable strategy and weekly fuel readings were continued throughout the summer for those systems with SDHW, plotting the fuel use reveals the extent to which the enabled systems reduced the base fuel load. This was done for all nine systems.

House 6 showed the greatest average difference (2.5 therms/week) between fuel use during the enabled and disabled periods. A plot of summer season fuel use versus time for that house appears in Fig. 2.3.4.2. The two disabled fuel reading points in the middle of the summer occurred because nobody was available to turn the system on during that week. The differences between enabled and disabled period fuel uses range from five therms per week in the middle of the summer season to one therm per week at the beginning and end of the summer season. This house was chosen to demonstrate that the SDHW effect on fuel use during the space-heating season is negligible because it showed the greatest difference between enabled and disabled period fuel use during the summer, and therefore its performance represents an upper limit on the reduction in fuel use which would occur due to SDHW system operation during the space-heating season.

It is reasonable to assume that the effect of the SDHW system on fuel use would be lower at other times of the year than during the summer season for three reasons: a) there is less solar radiation available during the space-heating season than during the summer, b) the collector losses increase as the average ambient temperature decreases, and c) the space-heating load must be met before any of the energy absorbed in the collector can be delivered to the water heating system. A conservative estimate of the energy that would be saved by the SDHW system during a week just before or after the summer season, when the effect would be largest due to relatively low space-heating loads and relatively high insolation rates and ambient temperatures, is 50% of the savings

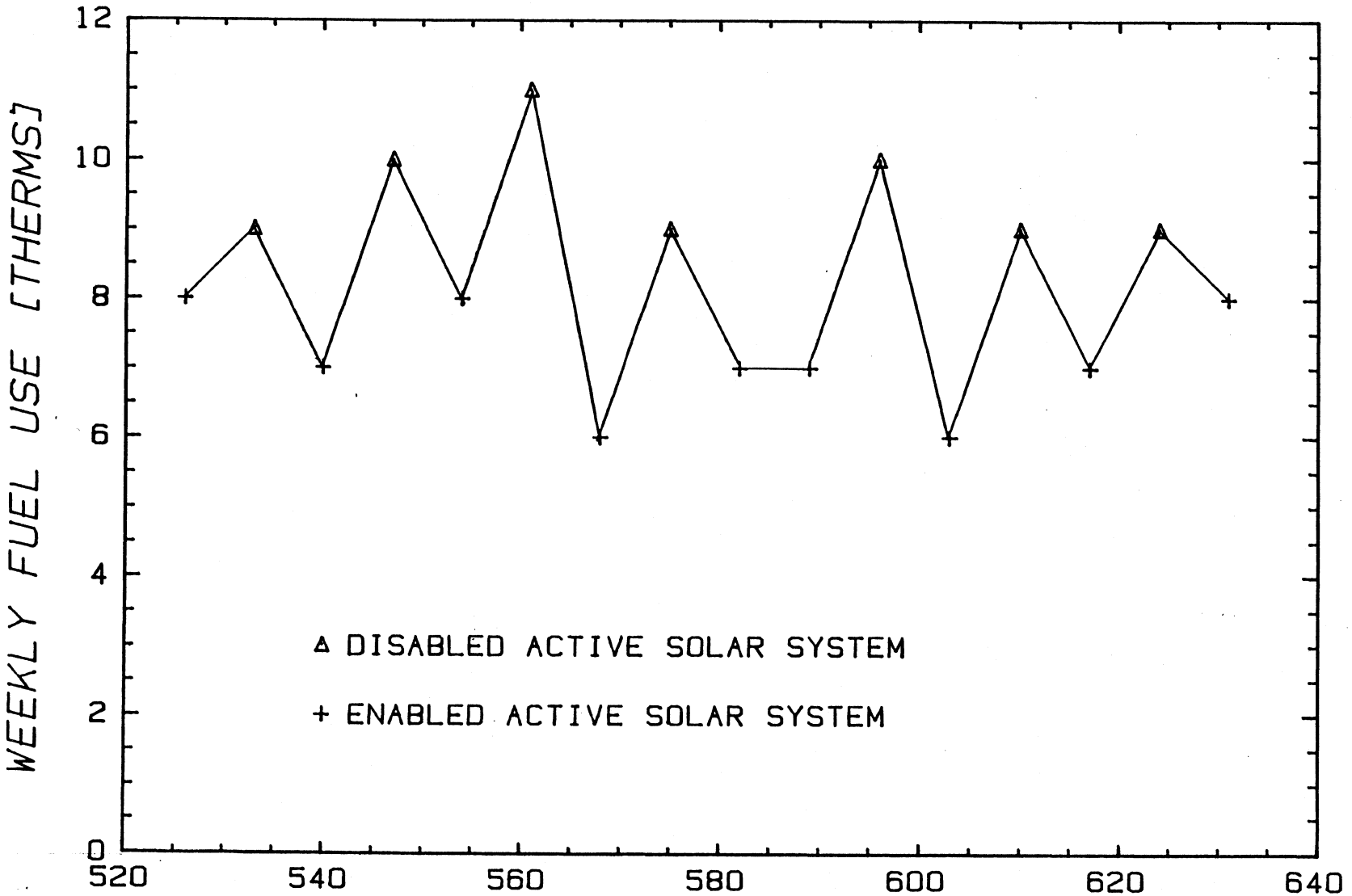


FIG. 2.3.4.2 SUMMER SEASON WEEKLY FUEL USE OF HOUSE #6

which occurred at the beginning and end of the summer season: 0.5 therms per week. This value represents 4-5% of the total fuel use during those weeks, and is considerably less than the typical variation in weekly fuel use due to random effects. The root mean square residual between the predicted and measured weekly fuel use values for the infinite storage version of the analysis of house 6 is 3.4 therms per week, which is seven times the estimated effect of the SDHW system. Therefore it is concluded that the SDHW systems in the study have a negligible effect on fuel use and can be neglected in the AC/PS system analyses. If they do significantly change fuel use, the regression analyses will find the best fit of measured versus predicted fuel use, and the effect of the SDHW systems will be reflected in slightly altered house performance parameters and predicted fuel savings values.

As mentioned in the list of SDHW system characteristics, it is assumed that the systems are designed so that the SDHW pump will circulate water from the preheat tank to the SDHW heat exchanger if it is in danger of freezing. This would effect fuel use, since the energy transferred from the tank to the heat exchanger, and ultimately to the surroundings, would have to be replaced by energy supplied by the DHW tank. Even in the case of an electric DHW tank the accuracy of the model would be brought into question, since it is assumed that all electricity use, except a constant amount deducted for water heating losses from electric DHW tanks, contributes to the internal gains. One of the General Solar system owners has noticed that his SDHW pump runs often during the coldest times of the year. The effects of this control strategy could have significant effects on the measured weekly fuel use, and therefore on the results of the regression analysis. Nevertheless, the possibility of significant fuel use due to the SDHW freeze-protection system is neglected in the model simply because not enough is known about the SDHW system control and operation.

The effect of the General Solar SDHW systems on summer season fuel use is summarized in Table 2.3.4:

TABLE 2.3.4 SDHW SYSTEM CONTRIBUTIONS DURING THE SUMMER SEASON

HOUSE NUMBER	COLLECTOR AREA [ft^2]	AVERAGE DIFFERENCE* [therms/week]	MAXIMUM DIFFERENCE* [therms/week]
1	92	2.2	4
2	92	0.3	4
4	92	1.8	3
5	92	0.1	3
6	92	2.5	5
10	92	0.2	2

* refers to the differences between enabled and disabled period fuel use values

The poor performance of these SDHW systems can be attributed to their significant collector/air duct leakage rates, and the low effectiveness which characterizes the type of heat exchanger commonly used for this application.

All of the major house and active system energy flow paths and the ways in which they are taken into account in the computer model have been described in this chapter. The theory of house energy use presented in this chapter serves as a base for the development of the fuel use equations described in the following chapter.

CHAPTER 3 DEVELOPMENT OF MODEL EQUATIONS

In order to predict the performance of AC/PS systems, the theory described in Chapter 2 was used to create a computer model of each house and active system combination. The model allows the determination, by a regression analysis, of the system energy parameters. These parameters, which characterize the house in question, can then be used to predict the system fuel consumption for a typical meteorological year (TMY) and the fuel savings due to the active solar contribution. The following paragraphs describe the development of the model equations.

3.1 ZERO CAPACITANCE MODEL

The houses under investigation have varying amounts of thermal mass. Energy is stored in the thermal mass of a house when the ambient temperature exceeds the house balance temperature. The balance temperature is determined in part by the internal and active solar gains, which are the sources of the energy that is stored. In order to simplify the analysis and avoid trying to estimate the thermal mass of each house, two models were created: one based on the assumption of zero energy storage capacity and the other based on the assumption of infinite energy storage capacity over a 24-hour period. The zero capacity version of the model is described in this section, and the infinite capacity version is described in the following section as a modification of the zero capacity case.

The active system is enabled and disabled on alternating weeks to separate the performance of the basic house from that of the active system. There is a model for each mode of operation. For the disabled mode, the factors that determine fuel use are:

1. house skin losses
2. infiltration

3. basement losses
4. internal gains
5. passive gains
6. base load
7. furnace efficiency

which are described in detail in Chapter 2. The corresponding equation is:

$$\Omega_Z = \frac{1}{\eta}\sum_{1}^{n}[(UA+C_p\dot{m}_{inf})(T_h-T_{amb})+UA_{bsmt}(T_h-T_g) - B - kI_P]^{+} + \sum_{1}^{n}F_{base} \quad (3.1.1)$$

where: Ω_Z = the fuel use predicted by the zero capacity model for the period of n hours

F_{base} = the base fuel use in Btu/hr

The summation is of the hourly values over the period in question. The periods are generally one week, which corresponds to 168 hours, although occasionally the meter readings were taken at different times of the day resulting in varying numbers of hours per period.

The terms inside the brackets of Eq. 3.1.1 are those that determine the space-heating load. The plus sign means that the space-heating load is set equal to zero whenever the terms inside the brackets sum to less than zero. This reflects the nonlinearity of the equation: in the model, the dependent variable (fuel use) is a nonlinear function of the forcing functions (base use, internal gains, and weather variables). When the ambient temperature exceeds the house balance temperature, fuel use is no longer

affected by changes in the forcing functions, with the possible exception of the base use. The method used to analyze this nonlinear equation is described in Section 3.4.

Depending on the types of non-heating appliances in the house, the base fuel use is determined by the DHW fuel use, the stove and oven fuel use, and/or the clothes dryer fuel use. At times when the ambient temperature exceeds the balance temperature the base fuel use is the only non-zero term. For houses without gas appliances other than the furnace, the base fuel use is always zero and their fuel use is zero when the ambient exceeds the balance temperature.

There are times during the heating season when some of the energy used by the appliances appears twice in Eq. 3.1.1, in the internal gains term [B] as well as in the base fuel use [F_{base}]. This is because the internal gains from gas appliances reduce the space-heating load. For example, the furnace will operate less than it otherwise would during periods when the stove is on. However, this does not mean that fuel use is unaffected by stove operation. There is a change in the fuel use when part of the space-heating load is being met by energy transfer from a gas stove because the energy obtained from burning gas in the furnace is less than the energy obtained from the stove by a factor of $1/\eta$.

The difference between the equations for the disabled and enabled periods is the addition of the active system gain and loss parameters. They too are nonlinear in the parameters and appear inside the brackets of the part of the disabled equation that is governed by the "+" sign. When the active system is operating it reduces the balance temperature of the system. The equation for fuel use during the enabled periods is:

$$\Omega_z = \frac{1}{\eta} \sum_{1}^{n} [(UA + C_p \dot{m}_{inf})(T_h - T_{amb}) + UA_{bsmt}(T_h - T_g) - B - k I_P -$$

$$(A_c F_R \tau \alpha I_T - (A_c F_R U_L + C_p \dot{m}_L)(T_h - T_{amb}))^{+}]^{+} + \sum_{1}^{n} F_{base} \qquad (3.1.2)$$

At times when the net energy available from the collector to the house is less than zero, the collector has no effect on fuel use and equation 3.1.2 simplifies to equation 3.1.1.

3.2 INFINITE CAPACITANCE MODEL

In the infinite energy storage capacity case, excess energy is accumulated from 8AM one day to 8AM the following day, and used to offset the space-heating load that occurs during the same period. If the excess energy exceeds the space-heating load for the period, the remaining energy is dumped. The model is otherwise identical to the zero capacity model. The model equation for the infinite storage case which applies during the disabled period is:

$$\Omega_i = \frac{1}{\eta} \sum_{days=1}^{m} \left[\sum_{i=1}^{24} \left[(UA + C_p \dot{m}_{inf})(T_h - T_{amb}) + UA_{bsmt}(T_h - T_g) - B - k\, I_P \right] \right]^+$$

$$+ \sum_{1}^{n} F_{base} \qquad (3.2.1)$$

The infinite storage model equation for the enabled period is:

$$\Omega_i = \frac{1}{\eta} \sum_{days=1}^{m} \left[\sum_{i=1}^{24} \left[(UA + C_p \dot{m}_{inf})(T_h - T_{amb}) + UA_{bsmt}(T_h - T_g) - B - k\, I_P - \right.\right.$$

$$\left.\left. (A_c F_R \tau \alpha I_T - (A_c F_R U_L + C_p \dot{m}_L)(T_h - T_{amb}))^+ \right] \right]^+ + \sum_{1}^{n} F_{base} \qquad (3.2.2)$$

The summation inside the large brackets is of the 24 hours in the period between 8AM on day m and 8AM on day m+1. The first summation in the equation is over the m days in the period. The summation of the base fuel use values is the same as in the zero-capacity equations; it is over the n hours in the period.

The usefulness of this method of dealing with thermal capacitance depends on the relative magnitude of its effect; if the energy storage capacity of a house has a great effect on the performance of the active solar system, the predicted active solar contributions using the two methods described above would differ significantly. In this case, the predicted active solar contribution of the actual house would remain undetermined, although it should still be bracketed by the predictions from the two versions of the model. However, under the assumption that the actual house performance is bracketed by the performances of the 24-hour infinite and zero energy storage models, the prediction of actual house performance is well-determined when the two models predict similar active solar contributions.

3.3 THE REGRESSION SUBROUTINE

NREG77, the Fortran 77 subroutine used to perform the regression analyses, was developed at the Madison Academic Computing Center, Madison, WI (Lin, 1982). It is designed to find the best parameter fit to a nonlinear mathematical model by minimizing the sum of squares of the residuals. In the present study, the residuals are the differences between the measured and predicted fuel use for each period:

$$\text{Sum of Squares} = \sum_{i=1}^{p} (\text{Fuel Use}_{\text{pred.}} - \text{Fuel Use}_{\text{meas.}})^2 \qquad (3.3.1)$$

where: p = the number of gas meter readings

The predicted values are found using the equations described in sections 3.1 and 3.2. It is the nature of nonlinear regression that the initial values of the model parameters must be input to the regression routine. Each successive set of parameters is then calculated using the Marquardt method. The Jacobian matrix of first partial derivatives,

$$J_{i,j} = \frac{\partial R_i(\theta)}{\partial \theta_j} \qquad (3.3.2)$$

where: $R_i(\theta)$ = the residual vector

θ = the parameter vector

which is required in the Marquardt method, is calculated in the NREG77 routine by a forward difference approximation.

Three termination criteria were set for the regression routine:

1. Termination occurs when both the actual and predicted reductions in the sum of squares are at most 10^{-8}.

2. Termination occurs when the relative error of parameters between two consecutive iterates is at most 10^{-8}.

3. Termination occurs when the number of iterations reaches 1200 (this termination criterion was never reached).

The NREG77 output includes 95% confidence intervals for each model parameter θ_i. For lack of statistical methods that apply to nonlinear models, the confidence intervals for the linear model case are used. They are defined as:

$$C.I. = \theta_i +/- 2e_i$$

where: e_i = the asymptotic standard error for the ith parameter

$$e_i = \sqrt{\frac{b_{i,i}\ s}{(N-p)}} \qquad (3.3.3)$$

where: $b_{i,i}$ = the matrix $(J^T*J)^{-1}$

s = the sum of squares

N = the number of observations

p = the number of parameters

3.4 CALCULATION OF THE SOLAR CONTRIBUTION CONFIDENCE INTERVAL

Based on the parameter 95% confidence intervals supplied by NREG77, Drs. Beckman and Klein of the Solar Energy Lab created a method for calculating the 95% confidence intervals for the predicted TMY solar contribution. The calculation involves fixing one of the four model parameters at its lower 95% confidence interval limit, and then running the regression analysis while allowing the three remaining parameters to vary. A solar contribution associated with that parameter being at its lower confidence limit is found. Then the analysis is repeated with the same parameter fixed at its upper limit. By performing 8 analyses, each time with one of the parameters fixed at one of its confidence limits and allowing the other three to vary, 8 solar contributions are

calculated. The 95% confidence interval for the predicted solar contribution is then determined as follows:

$$C.I._{SC} = +/- \ 0.5 * \sqrt{\frac{\sum_{i=1}^{4} (SC_{i,high} - SC_{i,low})^2}{4}} \qquad (3.3.4)$$

where: $SC_{i,high}$ = the predicted solar contribution using a fixed value of the upper 95% confidence interval limit for parameter i in place of parameter i

$SC_{i,low}$ = the predicted solar contribution using a fixed value of the lower 95% confidence interval limit for parameter i in place of parameter i

This method for calculating the solar contribution 95% confidence intervals was chosen because, by allowing the other parameters to vary while one is fixed at its confidence interval limit, it implicitly accounts for the fact that some of the model parameters are highly correlated, i.e. they are interdependent. For example, since the house skin loss and basement loss coefficients are functions of similar variables (the ambient temperature and the ground temperature have the same period on a long-term basis, and only a small phase angle difference between their curves), the regression analysis cannot completely separate the effect of changes in the house skin loss coefficient on fuel use from the effect of changes in the basement loss coefficient. In addition, Wisconsin's coldest winter weather is characterized by winds from the north which are associated with high radiation levels and low ambient temperatures. Thus there is also a correlation between radiation, the forcing function for passive solar gains, and ambient temperature, the forcing function for house skin losses.

The large parameter confidence intervals which characterize the results obtained from the regression analyses reflect the wide variety of parameter values for which the analysis yields approximately the same predicted solar contribution. In terms of the least squares calculation, this is due to the shallow slope of the partial derivative of the residual sum of squares with respect to any of the parameters in the region of the minimum sum of squares value. By allowing the other parameters to vary while one parameter is set at its confidence interval limit the effect of the high level of correlation between the parameters is removed from the calculation, and the resulting confidence interval on the solar contribution prediction is much smaller than it would be if the correlation between parameters were ignored.

3.5 ADAPTATION OF THE MODEL TO THE REGRESSION ANALYSIS

The original regression model included eight output parameters:

$$PAR.1 = \frac{1}{\eta}(UA + C_p\dot{m}_{inf})$$ [house skin loss + infiltration]

$$PAR.2 = \frac{1}{\eta} UA_{bsmt}$$ [basement losses]

$$PAR.3 = \frac{k\ R}{\eta}$$ [passive gain]

$$PAR.4 = \frac{1}{\eta}(A_c F_R U_{L,on} + C_p\dot{m}_{L,on})$$ [coll. loss, enabled]

$$PAR.5 = \frac{1}{\eta}\,(A_c F_R U_{L,off} + C_p \dot{m}_{L,off}) \qquad \text{[coll. loss, disabled]}$$

$$PAR.6 = \frac{1}{\eta}\,A_c F_R\,\tau\,\alpha \qquad \text{[coll. gain]}$$

$$PAR.7 = \frac{B}{\eta} \qquad \text{[internal gains]}$$

$$PAR.8 = \sum_{i=1}^{n} F_{base,i} \qquad \text{[base fuel use]}$$

The regression analysis using these eight parameters resulted in a close fit between the measured and predicted weekly fuel use values for the systems analyzed. However, the 95% confidence intervals for the individual parameters were very wide. After several attempts to perform the regression analyses, which were stymied by the inability of the regression routine to calculate confidence intervals for such highly correlated parameters, it was determined that changes would have to be made in the regression model to allow a more accurate determination of the parameters.

To remedy the situation, it was decided to estimate parameters 6, 7, and 8, and eliminate parameter 5. The decision to eliminate 5, which accounted for reverse thermosiphon and leakage losses in the active system during disabled periods, followed a

series of trial regression runs which showed that the active system losses during the disabled period were so small as to have absolutely no effect on the results of the analysis. This parameter was not left in the model to see if it would be more significant in other runs because the corresponding confidence interval was so wide that it caused divide-by-zero errors in the confidence interval calculation. It is reasonable to assume that the plastic covers used on the active system registers during the disabled periods were effective in preventing significant losses during those times.

Parameter 6, the collector gain coefficient, was estimated by dividing the $A_cF_R\tau\alpha$ value reported in an ASHRAE 93-77 test by a guessed furnace efficiency of 65%. This simplification of the model was tested by running the analysis with a range of collector gain coefficient values. A sample set of results appears in Table 3.5.1.

TABLE 3.5.1 RESULTS FROM A SET OF INFINITE CAPACITANCE ANALYSES ON HOUSE 21 USING A RANGE OF $(A_cF_R\tau\alpha)/\eta$ VALUES

$(A_cF_R\tau\alpha)/\eta$ [ft^2]	SUM OF SQUARES [therms^2]	$(A_cF_RU_L+C_p\dot{m}_L)/\eta$ [Btu/hrF]	SOLAR FRACTION [%]
0	46.2	112	0.0
25	32.1	5	8.2
50	32.4	76	9.9
75	32.8	177	11.3
100	39.4	334	11.7
125	42.6	494	11.6
150	46.4	720	10.9

For a wide range of collector gain terms (excluding zero) the predicted solar fraction varies little: the minimum and maximum values are less than 2% apart. By minimizing the squares of the residuals, the regression analysis finds the best collector

loss term for the collector gain term chosen. The relationship between the collector loss and gain terms is depicted in Figure 3.5.1.

Parameter 7, the internal gains divided by the furnace efficiency, was estimated as described in section 2.1.2. Parameter 8, the base fuel load, was estimated from the average fuel use during the summer months, when the furnace was not operating.

After these changes were made in the regression analysis, the confidence intervals decreased, and the problems with divide-by-zero errors were eliminated. However, it is still necessary to constrain the passive gain coefficient to values greater than or equal to zero. This is a result of the high level of correlation between some of the parameters and/or of variables that effect fuel use that are not taken into account in the model, for example the effect of human behavior on fuel use. The passive gain coefficient is the only coefficient in the model that had to be constrained. Those analyses in which the passive gain coefficient bumped up against this constraint have parameter #2 values of zero or almost zero (refer to Fig. 6.2.1, 6.3.1 and Fig. 6.4.1).

One of the factors which determines the significance of the results of a nonlinear regression analysis is the choice of initial parameter values. Unless the initial values of the parameters are relatively close to their actual values, the analysis may return a set of results that does not correspond to the absolute minimum sum of squares. This is due to the presence of relative minima on the sum of squares plane which satisfy the termination criteria of the analysis. There is no way of determining whether a minimum sum of squares point is a relative or absolute minimum, except by performing the analysis for all possible starting values of the parameters. Fortunately, in this analysis it is possible to guess the important parameter values to within an order of magnitude with considerable confidence. The systems that did not yield reasonable results on the first try were reanalyzed using adjusted values of the input parameters: the collector gain term, the internal gains, and the base fuel use.

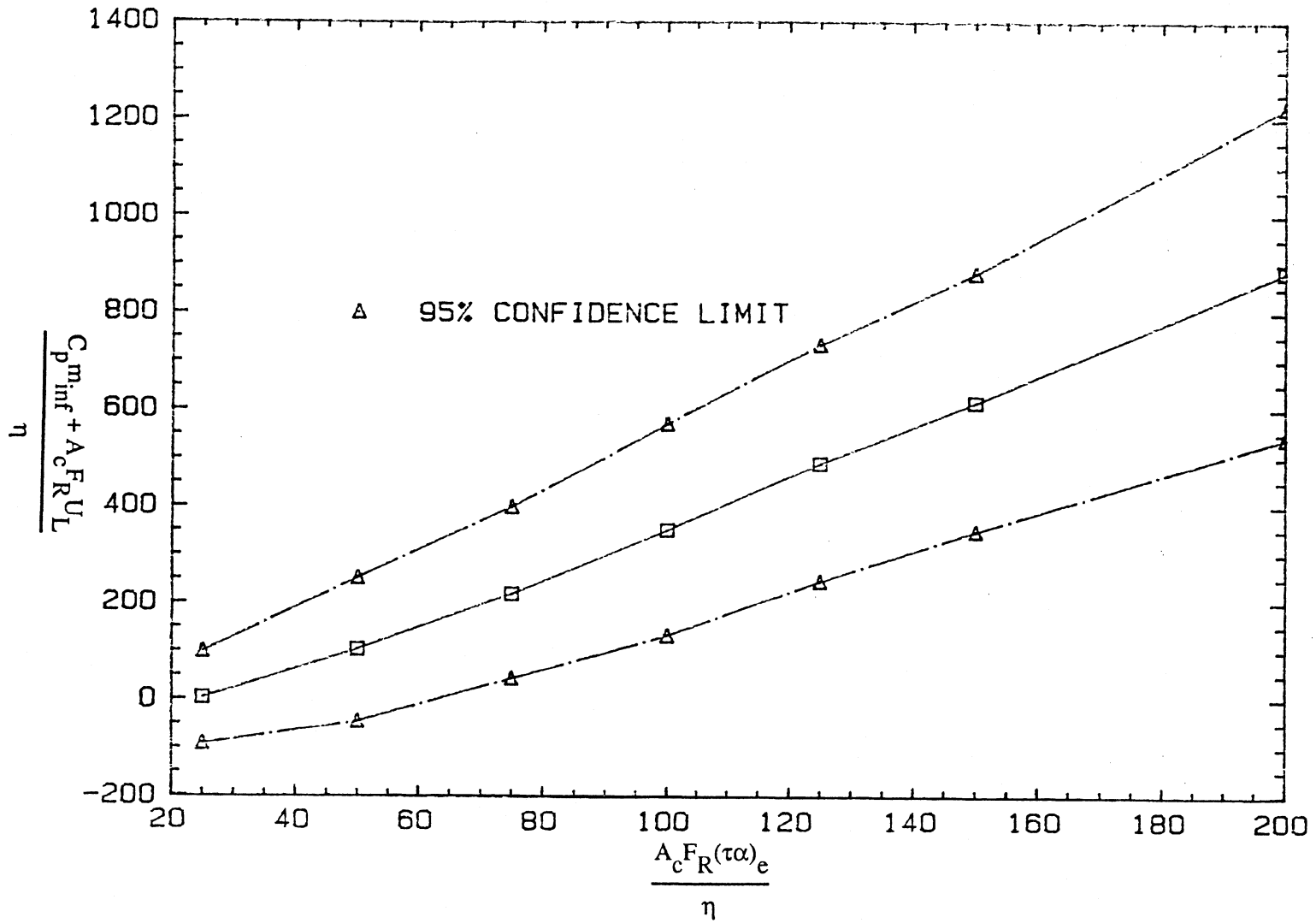


FIGURE 3.5.1 COLLECTOR PERFORMANCE LINE

HOUSE #21, MOR-FLO, INFINITE STORAGE MODEL

CHAPTER 4 EXPERIMENTAL SITES AND DATA COLLECTION

There are 29 systems from three manufacturers under investigation. The three brands of AC/PS systems (EMG, Mor-Flo, And General Solar) were chosen because they are among the most common types of AC/PS solar systems in southern Wisconsin, and because the Division of State Energy has information on the locations of many of these particular systems in its Renewable Energy Incentive Program records. The original plan was to have ten systems of each type in the study, however one of the General Solar systems was later found to be unsuitable, leaving ten EMG systems, ten Mor-Flo systems, and nine General Solar systems.

4.1 DESCRIPTION OF ACTIVE SYSTEMS

The Mor-Flo and General Solar active systems are of similar design. They are units of 2 or 3 preassembled collector panels mounted on the house roof at an angle to the horizontal of approximately 57 degrees, and with an azimuth angle of approximately 0 degrees.

The EMG active systems are mounted vertically on a south-facing wall. The EMG collectors consist of 2'x2' modular glass cover and trim systems over black mesh absorbers, with foam sheet insulation behind the absorbers. They are insulated on the backs of the absorber plates, which has the added benefit of decreasing skin losses through the wall. The vertical orientation results in reduced direct solar gain throughout the year, however the lower direct gain during the heating season is largely offset by reflected diffuse radiation if there is a snowfield located in front of the collector (Kerr, p.13-1, 1977). The reduced solar gains in summer are an advantage since they result in lower collector stagnation temperatures.

The Mor-Flo and General Solar collectors are assembled in the factory. The EMG collectors, however, are assembled on site. This is necessary since the EMG systems are

mounted on a house wall and each collector must be custom-designed for the wall in question. Many of them are mounted around windows. In general, the EMG systems require shorter ducting since they are located closer to the conditioned space. Table 4.1.1 presents the characteristics of these systems as reported in the manufacturers literature.

TABLE 4.1.1 ACTIVE SOLAR SYSTEM PARAMETERS

	Mor-Flo	General Solar	EMG
$\frac{\text{gross area}}{\text{modular unit}}$ [ft^2]	34	31	4
total gross areas [ft2]	68-102	61-92	100-286
max. operating temp [F]	450°	500°	220°
cover	single, low-iron tempered glass	double, poly-carbonate	single, tempered glass
absorber coating	selective black nickel	Columbia Solar Black	black exterior enamel
$F_R(\tau\alpha)_n$	0.618	0.526	0.580
$F_R U_L$ [Btu/(ft^2*hr)]	0.853	1.02	1.38

Note: in each case the collector parameter values were measured by an independent engineering laboratory in an ASHRAE 93-77 test.

4.2 INITIAL SITE INSPECTIONS

The systems in the study were chosen by writing to homeowners in southeastern Wisconsin who had received financial incentives for purchasing one of the three brands under investigation. Only customers of Wisconsin Electric Power Company and Wisconsin Natural Gas were allowed to apply. The participants had to have natural gas furnaces, not use wood for heating, and agree to allow someone into their homes on a weekly basis to enable and disable the active systems.

All of the systems chosen were inspected before the data collection was started. Notes were made on collector shading, collector tilt and azimuth angles, number of panels, and ducting configurations. Flow rates into and out of the active system registers were measured using a flowhood, which is a calibrated manifold that fits over the register opening. All of the systems have blowers at the collector outlets. The results of the flow measurement tests are presented in figures 4.2.1-3. When a system appears twice in a graph it is because two sets of flow measurements were made, once before and once after cleaning the air filter. The average percent difference between inlet and outlet flow rates of the EMG Mor-Flo and General Solar systems was 41, 33 and 25%, respectively. A calibration test of the flowhood used to measure the inlet and outlet flow rates appears in Appendix B.

Problems with some of the systems were noticed during the inspections. One of the Mor-Flo systems was not operational because it had been wired incorrectly. Whenever the collector thermostat closed the blower switch, it caused a short circuit and tripped a circuit breaker. The problem was corrected by the investigators before the beginning of the study. The flowhood test revealed an 80% leakage rate in one of the General Solar systems. An air filter at the inlet to the system was cleaned, which reduced the leakage somewhat. In general, however, the goal has been to allow the systems to operate without any effect of having been chosen for this study, since the purpose of the investigation is to determine the normal performance of installed systems.

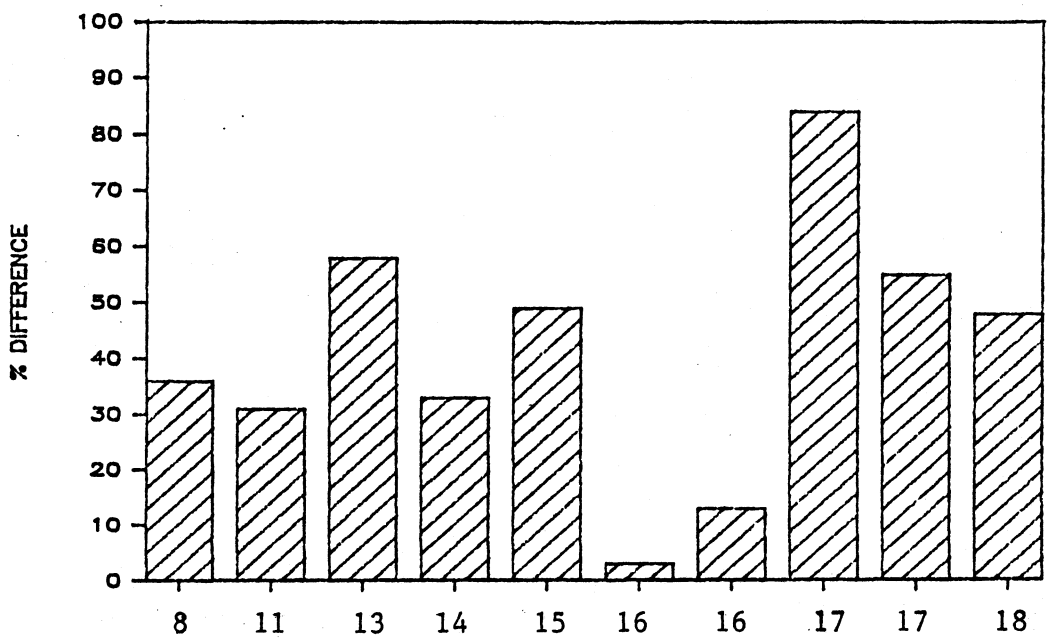


FIGURE 4.2.1 PERCENT DIFFERENCE BETWEEN INLET AND OUTLET REGISTER FLOW RATES- EMG SYSTEMS

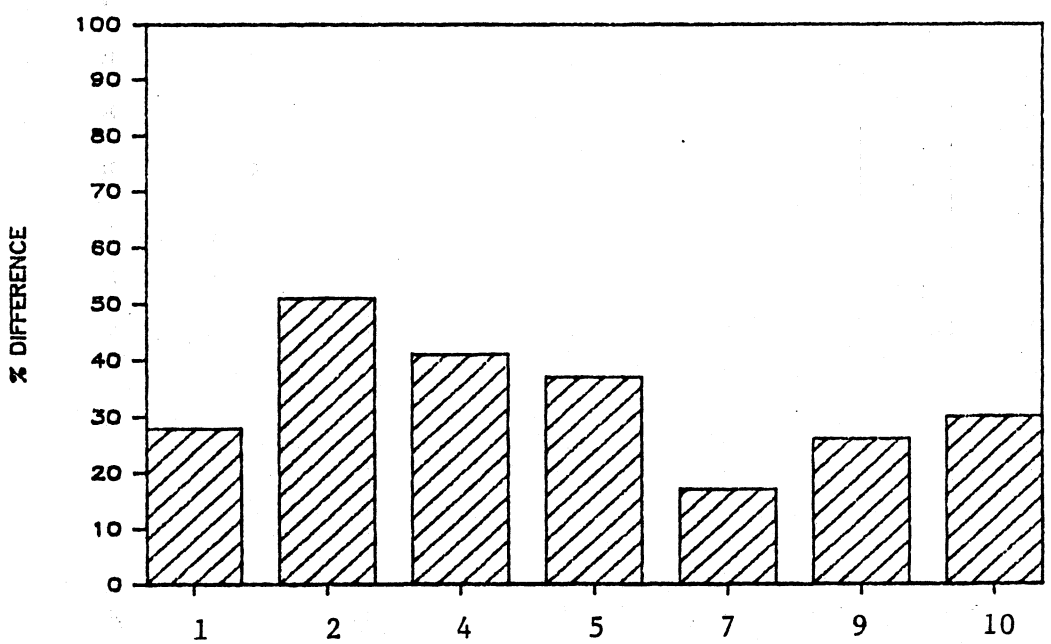


FIGURE 4.2.2 PERCENT DIFFERENCE BETWEEN INLET AND OUTLET REGISTER FLOW RATES- GENERAL SOLAR SYSTEMS

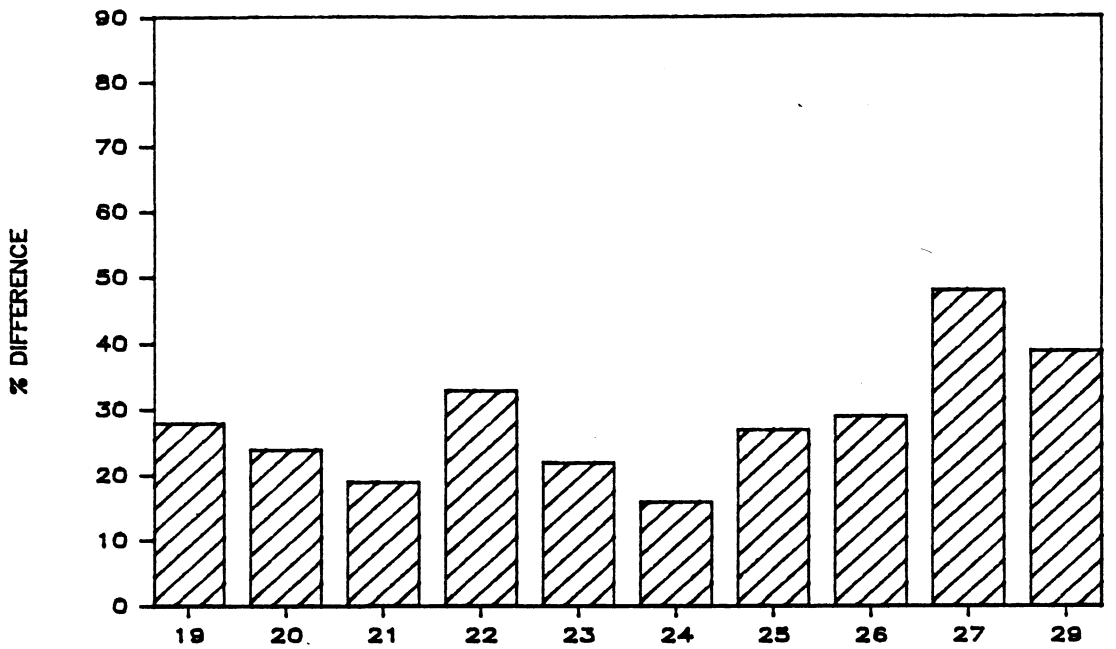


FIGURE 4.2.3 PERCENT DIFFERENCE BETWEEN INLET AND OUTLET REGISTER FLOW RATES- MOR-FLO SYSTEMS

4.3 METHOD FOR ENABLING AND DISABLING THE ACTIVE SYSTEMS

The method developed for this study calls for the active systems to be enabled and disabled on a weekly basis. The enabled periods correspond to normal active system operation, and the disabled periods correspond to basic house operation, i.e. no active system effect on fuel use.

The active systems were disabled by sealing the active system duct registers and either turning down the thermostats which control the active solar systems below the minimum furnace thermostat setting or by using a switch installed for this purpose. Sealing the ducts was accomplished using pieces of plastic sheet with self-adhesive magnetic strips around the edge which allowed quick attachment to the steel registers. Turning the thermostat down ensured that the blower motor would not operate, and

sealing the registers prevented thermosiphoning and leakage through the collector. It is assumed that the active systems were effectively isolated from the houses by this method. All of the active systems were turned off during the summer except for those which include SDHW, which were monitored weekly and enabled and disabled as they had been during the space-heating season.

4.4 FUEL METER DATA COLLECTION

The Jefferson County fuel meter readings were taken by investigators from the Wisconsin Division of State Energy; those in Waukesha and Kenosha were taken by employees of Wisconsin Natural Gas Company, which is cooperating in this research. In general fuel data collection consisted of reading the house natural gas meters, turning the active system thermostat up or down depending on whether the system was to be enabled or disabled the following week, and installing or removing the active system register covers. In a few homes, the owners agreed to perform active system enable/disable routines themselves, while investigators read the meters. This resulted in questionable data for at least one system. This was done during a weekly visit to each system in the study. The enable/disable routine was stopped during the summer months, after the house furnaces had been turned off, except for the systems which have SDHW. It was restarted in the fall before the furnaces were turned on, however only those meter reading periods during which the furnaces were on are included in the regression analysis.

CHAPTER 5 WEATHER DATA

The method developed for this analysis calls for the use of hourly radiation and temperature data in the regression analysis. This is one of the ways in which this method differs from others, for example the PRISM method, since they generally use daily mean temperature data which are available from many more sources than the hourly values.

5.1 JUSTIFICATION FOR USE OF HOURLY WEATHER DATA

Hourly values of radiation data were required rather than daily values because passive and active solar gains, which are parameters in the model, are not distributed evenly over a day. There are periods at the beginning and end of the heating season when the space-heating loads of the houses in the study are met entirely by internal, passive, and active gains. During these times, part of the gains may be dumped to avoid overheating. Daily radiation data would be insufficient to determine how much energy should be dumped and how much is used to offset the furnace space-heating load. Hourly radiation values are sufficient for these calculations to the accuracy required in this study.

Daily mean temperature values, which are the average of the daily maximum and minimum temperatures and are used in the PRISM method of residential energy use analysis, are good approximations of the daily average temperature. Nevertheless, as in the case of radiation data, there are times of the year when an analysis using daily average temperatures would indicate a load, whereas the load is actually met by energy that is stored during hours when the ambient temperature exceeds the balance temperature. When the thermostat set temperature is decreased in the late evening, which is the most common control strategy, the energy stored in the building mass is released to the heated space and eliminates the need for auxiliary heating. In addition, using daily temperature values prevents the inclusion of the night setback temperature in the model, which is an important factor in space-heating fuel use.

5.2 SOURCES OF WEATHER DATA

Hourly radiation data is available from two locations in southeastern Wisconsin: Janesville and Arlington. Both of these sources are automatic weather stations operated by the State Climatologist, Dr. Douglas Clark. Hourly temperature data is available from several locations, including Arlington and Janesville.

The 29 systems in the study are distributed as follows: 12 in Jefferson County, 7 in Waukesha, and 10 in Kenosha. A map of these locations is presented in Fig. 5.2.1.

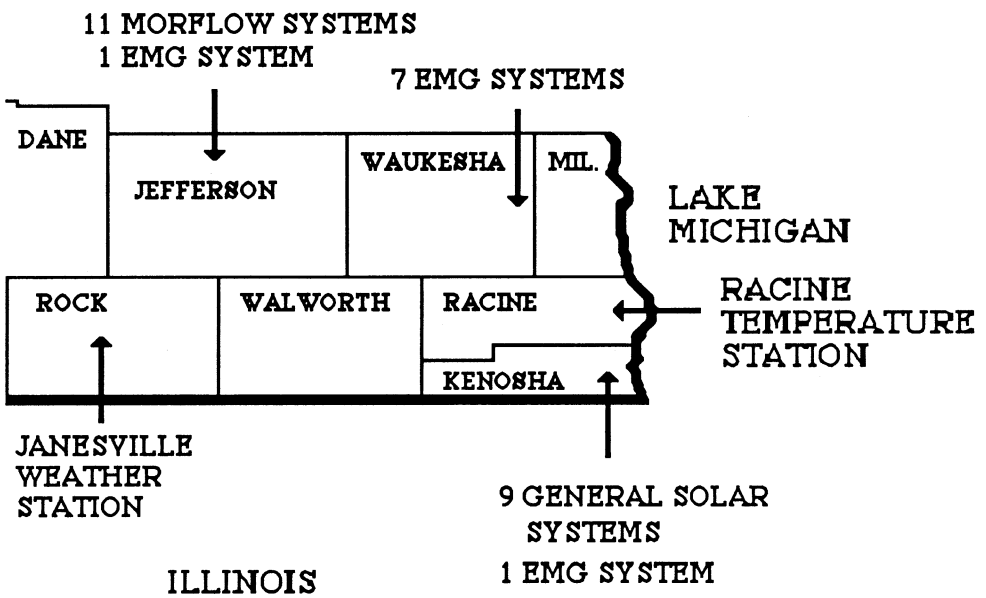


FIG 5.2.1 MAP OF SYSTEM AND WEATHER STATION LOCATIONS

The systems are situated roughly 20-60 miles from Janesville, and 30-100 miles from Arlington. In addition to proximity, there are several reasons for choosing Janesville over Arlington as a weather data source. Long-term average constant monthly temperature lines for southeastern Wisconsin run from the northeast to the southwest during the months of October through March, which is essentially all of the space-heating season

(Wisconsin Weather, pp.6-11, 1975). This characteristic means that Janesville temperatures are in general closer to those at the system sites than Arlington temperatures are.

The seasonal patterns of average daily solar radiation are not as regular as those for temperature, however the variation from one location in southeastern Wisconsin to another is small. For example, the average daily solar radiation on all of the sites in the study in January of 1985 was between 0.18 and 0.20 kWh/m^2 (Diak and Weickmann, Fig.29b, 1985).

For these reasons, and because no better (i.e. closer) sources of hourly weather data are available, Arlington radiation data were used for all of the system analyses. Temperature data from Arlington were used for the systems in Jefferson County and Waukesha, while the systems in Kenosha were analyzed using hourly Racine temperature data. This change was made because the Kenosha systems are all within 5 miles of Lake Michigan, where the temperature gradient is often relatively steep (Wisconsin Weather, pp.4-12, 1975). The Racine weather station is approximately the same distance from the lake as the Kenosha sites and less than 20 miles to the north, so its temperature data are more appropriate for use in the analysis of those systems than the Arlington temperature data. No radiation data are available from Racine, therefore Arlington radiation data were used for the Kenosha system analyses.

5.3 PROCESSING THE WEATHER DATA

The Arlington temperature and radiation data were obtained from the State Climatologist's office on floppy disks and transferred to the Solar Lab computer for processing. Plots of the daily average temperature at the Janesville and Racine stations appear in Fig. 5.3.1. The only change necessary for the temperature data was from degrees Celsius to degrees Fahrenheit, however the radiation data required more complex processing. Three sets of hourly radiation values for 1 Dec. 1985 through 22 Jan. 1987 were required: the average radiation incident on vertical north-, south-, east-, and west-

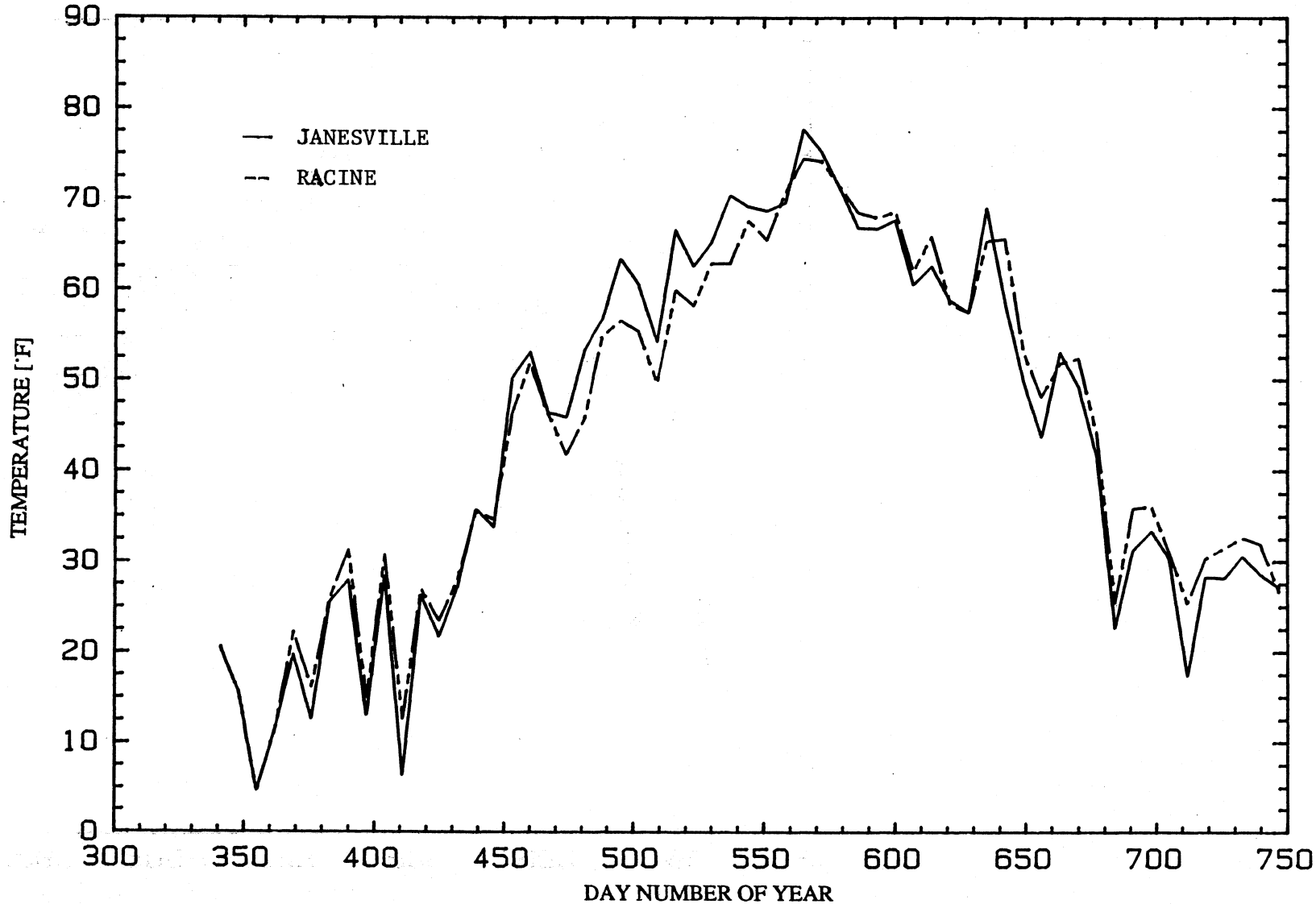


FIG. 5.3.1 WEEKLY AVG AMBIENT TEMPERATURES FROM TWO LOCATIONS

facing surfaces, the radiation incident on a surface mounted at 57° to the horizontal with a 0° azimuth angle, and the radiation incident on a vertical surface with a 0° azimuth angle. The first set of data is for use in the passive solar gain calculation; the second and third sets are for the calculations of active solar gain by collectors mounted at 57° and 90°, respectively.

The transformation of the State Climatologist's hourly horizontal radiation data into the sets of data described in the last paragraph was accomplished using TRNSYS, a modular program developed at the Solar Energy Laboratory for modeling many different types of systems (TRNSYS, 1983). One of the TRNSYS modules is a radiation processor, which was created to estimate radiation on a tilted surface given horizontal radiation data. It interpolates the data, performs a series of calculations related to the position of the sun, and estimates the radiation on up to four surfaces. Plots of the daily average values of the three sets of radiation data for a Madison, WI typical meteorological year are presented in figures 5.3.2, 5.3.3 and 5.3.4.

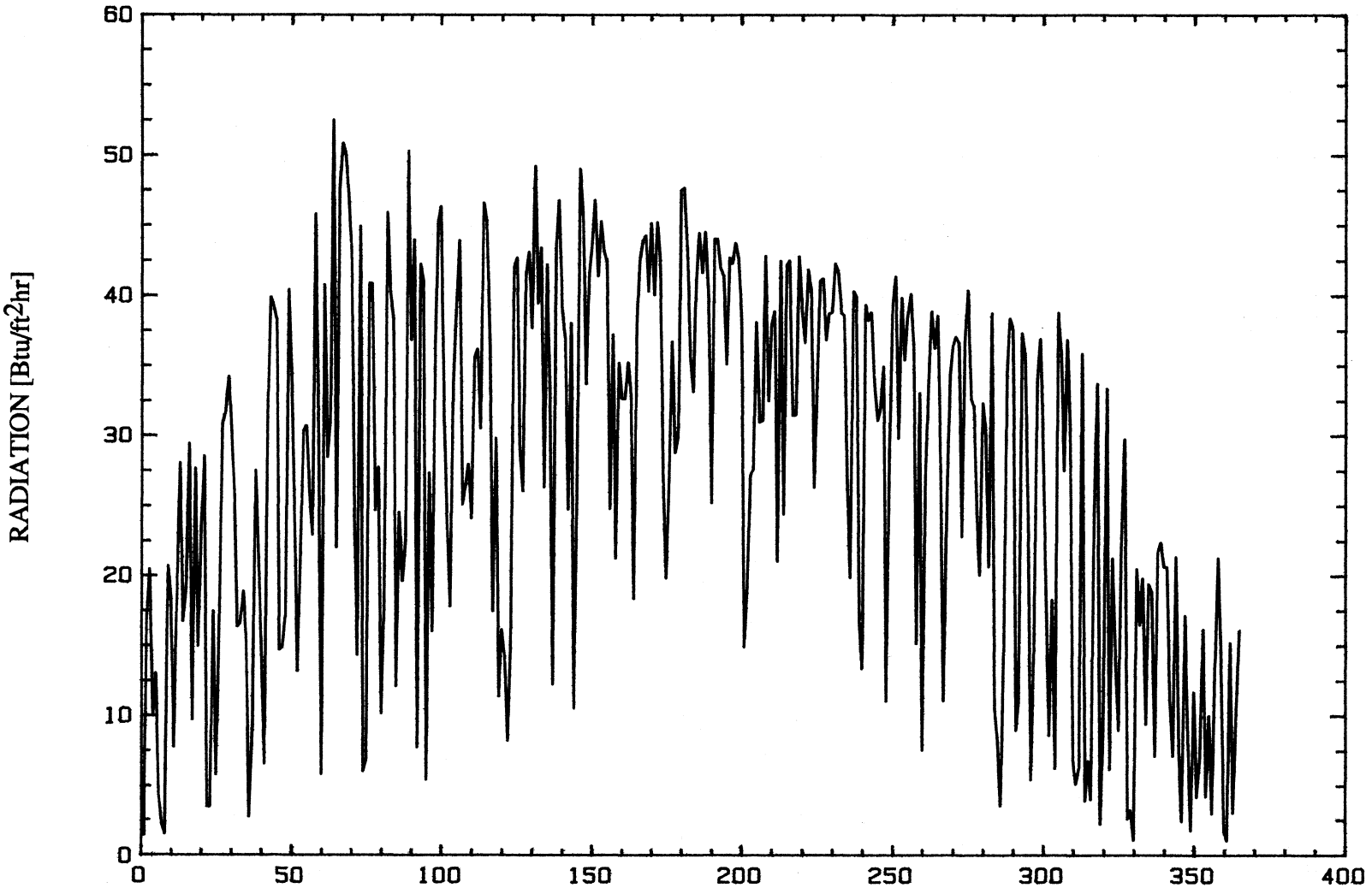


FIG 5.3.2 DAILY AVERAGE MADISON TMY PASSIVE GAIN RADIATION

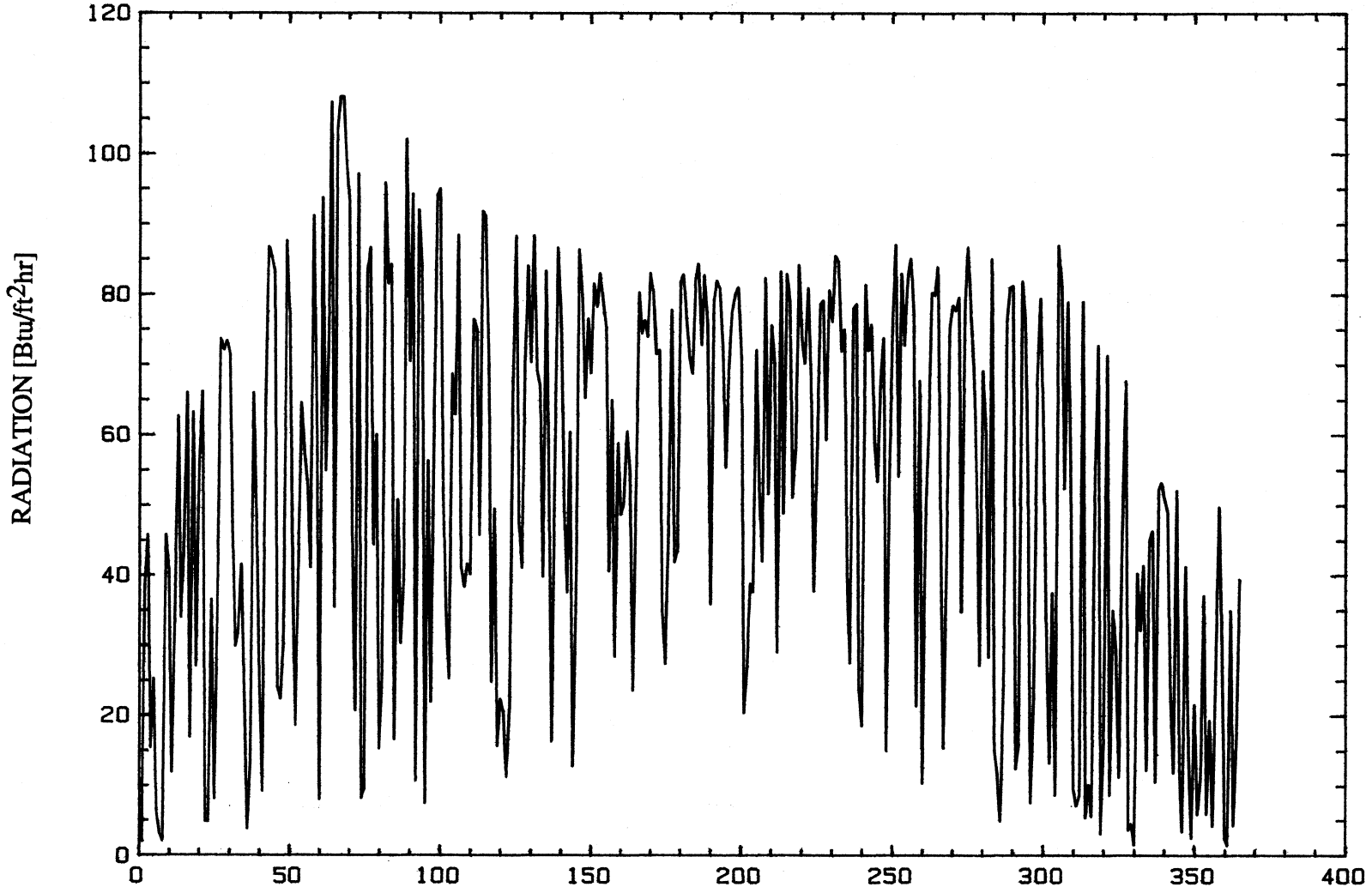


FIG 5.3.3 DAILY AVERAGE MADISON TMY RADIATION ON 57° COLLECTOR

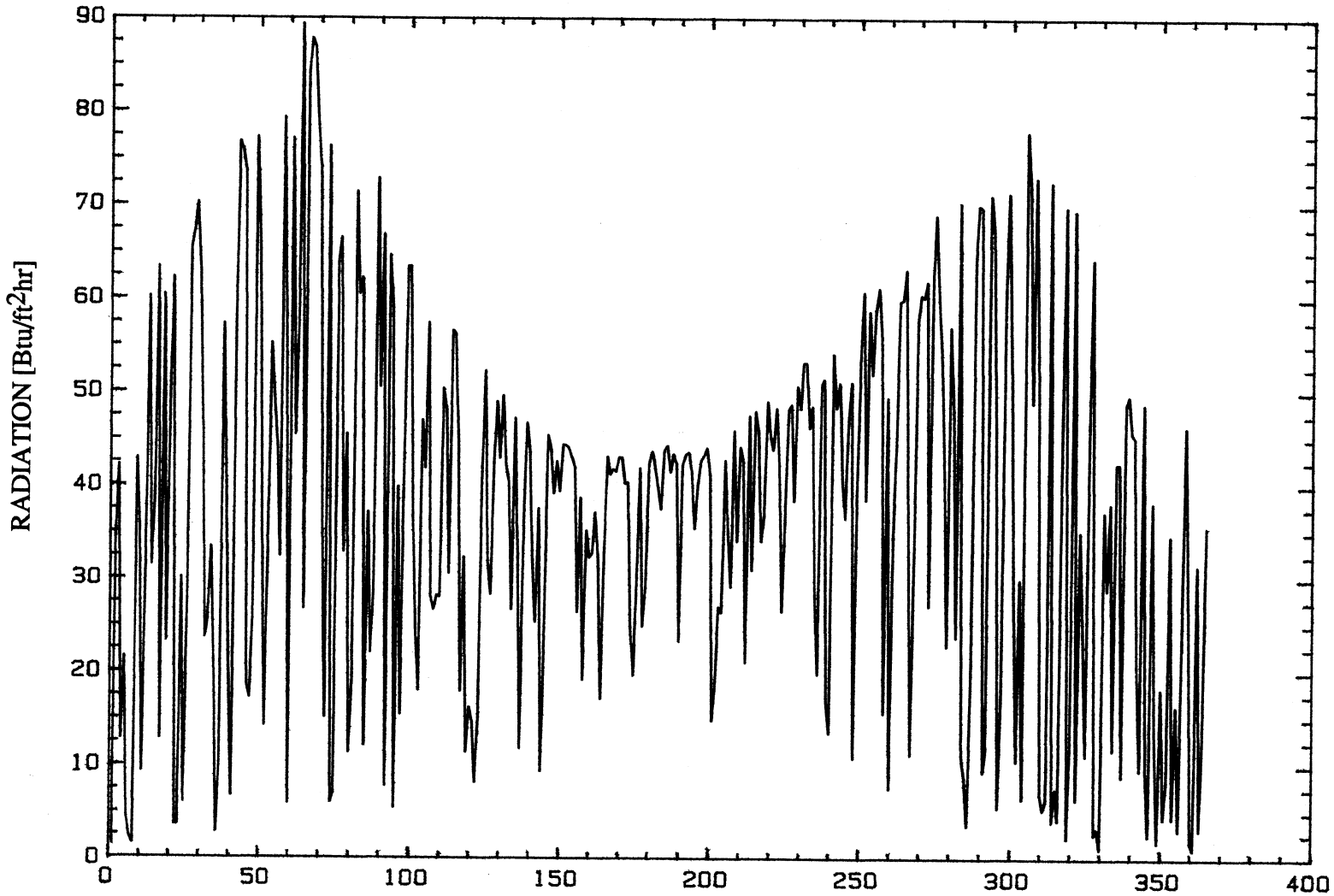


FIG 5.3.4 DAILY AVERAGE MADISON TMY RADIATION ON 90° COLLECTOR

CHAPTER 6 DISCUSSION OF THE RESULTS

The twenty nine AC/PS systems in the study were analyzed by a nonlinear regression technique which incorporates the fuel use equations described in Chapter 3. Measured fuel use values were regressed against the forcing functions (hourly weather parameters) to determine a set of performance coefficients for each house. These coefficients were then used to predict the fuel savings due to the active system operation at each house during a typical meteorological year (TMY). The following is a presentation and discussion of those results.

6.1 INTRODUCTION

The predicted fuel energy savings for the Mor-Flo, EMG, and General Solar systems are presented in tabular and bar graph form in the following sections. All the predicted fuel savings results are normalized to a square foot basis. There are two sets of results for each house: that of the zero storage model and that of the infinite storage model. The associated performance parameters are presented with each fuel saving prediction, as well as a predicted TMY solar fraction. The solar fractions are defined as the percentage of the total space-heating load that is met by the active solar systems. The 95% confidence limits that are listed with the energy saved and solar fraction results were calculated using the algorithm described in Sec. 3.4.

It is important to note that the predicted fuel savings are not equivalent to the active solar contributions. They are the active solar contributions divided by the house furnace efficiency:

$$\text{fuel savings} = \frac{\text{active solar contribution}}{\eta} \qquad (6.1.1)$$

Since the house furnace efficiencies are not known, the active solar contributions cannot be calculated, which means that the active systems in the study cannot be compared to each other directly. Nevertheless, they can be compared to some extent, since furnace efficiencies vary over a limited range. Typical seasonal furnace efficiencies for non-condensing furnaces vary from 40% to 75%.

The 95% confidence intervals presented with these results are based on several premises that are known to be false:

1. *The errors in the weekly predicted fuel use values are random.* This is not true because of the many factors that affect fuel use which were not taken into account in the fuel use model, and therefore result in systematic errors. Some of these were discussed in Sec. 2.3.

2. *The model coefficients are independent.* In fact, all of the coefficients are correlated. An explanation of the high level of correlation between the model coefficients appears in Sec. 3.3.

3. *The model is linear in the parameters.* This is a nonlinear model because the space-heating fuel use goes to zero when the ambient temperature exceeds the balance temperature.

Therefore the confidence intervals should be considered as indicators of relative reliability, and even those results which have large confidence intervals should not be discounted completely. The 95% confidence intervals and the specially-derived way in which they are calculated were chosen for use in this analysis for lack of a better method of reporting the accuracy of the results. Interpretations of the predicted fuel use results for each type of system in the study appear in the following sections.

6.2 THE MOR-FLO SYSTEM RESULTS

The results of the Mor-Flo system analyses are presented in Table 6.2. A bar graph of the predicted fuel savings appears in Fig. 6.2. The first bar on the bar graph, labelled "F", is an FCHART prediction of the annual energy contribution that a Mor-Flo system should deliver divided by a typical furnace efficiency of 0.65. It is included as a reference to which the predicted system performances can be compared. Measured Mor-Flo system performance parameters, such as $F_R\tau\alpha$ and $F_R U_L$, were input to the FCHART collector modeling program, along with some assumptions about the collector system duct losses and leakage rates, to calculate a predicted value for the solar energy delivered. The input parameter lists for the FCHART program analyses of all three of the brands of AC/PS systems under investigation appear in Appendix D.

The largest predicted fuel savings among the Mor-Flo systems was for house 23, however, it does not necessarily follow that the active system on that house achieved the highest performance. That particular house is an old farmhouse, and has the highest measured space-heating load of any of the houses in the study. It probably has very low insulation R-values, and high infiltration rates. Nevertheless, it should have reasonable space-heating fuel use, since there are only two occupants and part of the house is closed off during the space-heating season . The reported thermostat settings are 68°F for both daytime and setback temperatures.

One possible explanation for both the high space-heating fuel use and the high predicted fuel savings due to solar in house 23 is that the house furnace efficiency is very low. The predicted fuel savings are approximately twice what the savings estimated by FCHART are. This could be accounted for by a furnace efficiency of 30-40%. Such low efficiencies are uncommon for natural gas furnaces, but not impossible. They can be caused by bad fuel-to-air ratios, clogged heat exchangers, leaky ductwork, faulty controls, dirty filters, or a combination of these factors.

All of the other Mor-Flo predictions of fuel savings are sufficiently close to the FCHART prediction that the differences could be due to collector leakage effects, which

TABLE 6.2 MORFLO SYSTEM RESULTS

SYS #	STORAGE TYPE	PAR.1	PAR.2	PAR.3	PAR.4	TMY ENERGY SAVED [kBtu/ft^{2}yr]	TMY SOLAR FRACTION [%]
19	ZERO	624	-43	297	183	85 +/- 44	6.8 +/- 3.5
	INF	596	-53	345	211	105 +/- 43	8.2 +/- 3.4
20	ZERO	583	-162	-69	-17	38 +/- 22	9.8 +/- 5.7
	INF	602	-129	-104	6	46 +/- 91	13.1 +/- 25.9
21	ZERO	314	-21	128	199	40 +/- 17	10.7 +/- 4.5
	INF	301	-14	133	77	49 +/- 26	13.5 +/- 7.3
22	ZERO	435	-26	210	259	34 +/-66	3.6 +/- 7.2
	INF	428	-10	228	299	46 +/- 53	4.9 +/- 5.5
23	ZERO	875	-12	216	42	228 +/- 110	9.8 +/- 4.8
	INF	853	-3	188	13	234 +/- 143	10.7 +/- 6.5
24	ZERO	530	-12	283	250	69 +/- 38	7.3 +/- 4.1
	INF	524	-7	251	207	78 +/- 43	8.8 +/- 4.8
25	ZERO	812	-24	264	90	118 +/- 23	9.9 +/- 1.9
	INF	774	-3	305	134	135+/- 506	11.1 +/- 42
26	ZERO	482	-97	81	138	40 +/- 54	4.1 +/- 5.7
	INF	456	-128	142	115	60 +/- 57	6.3 +/- 6.1
27	ZERO	620	0	101	61	99 +/- 3291	11.0 +/- 365.
	INF	599	0	132	85	115 +/- 62	12.7 +/- 6.9
29	ZERO	747	-158	82	201	38 +/- 23	4.6 +/- 2.8
	INF	700	-43	81	139	65 +/- 37	7.8 +/- 4.4

Par.1=	$(UA + C_p{*}m_{inf})/\eta$	house skin loss	[Btu/hr·F]
Par.2 =	$-k/\eta$	passive gain	[(Btu/hr)/(modelBtu/ft^{2}hr)]
Par.3 =	UA_{bsmt}/η	basement skin loss	[Btu/hr·F]
Par.4 =	$(A_c F_R U_{L,on} + C_p m_L)/\eta$	active solar loss	[Btu/hr·F]

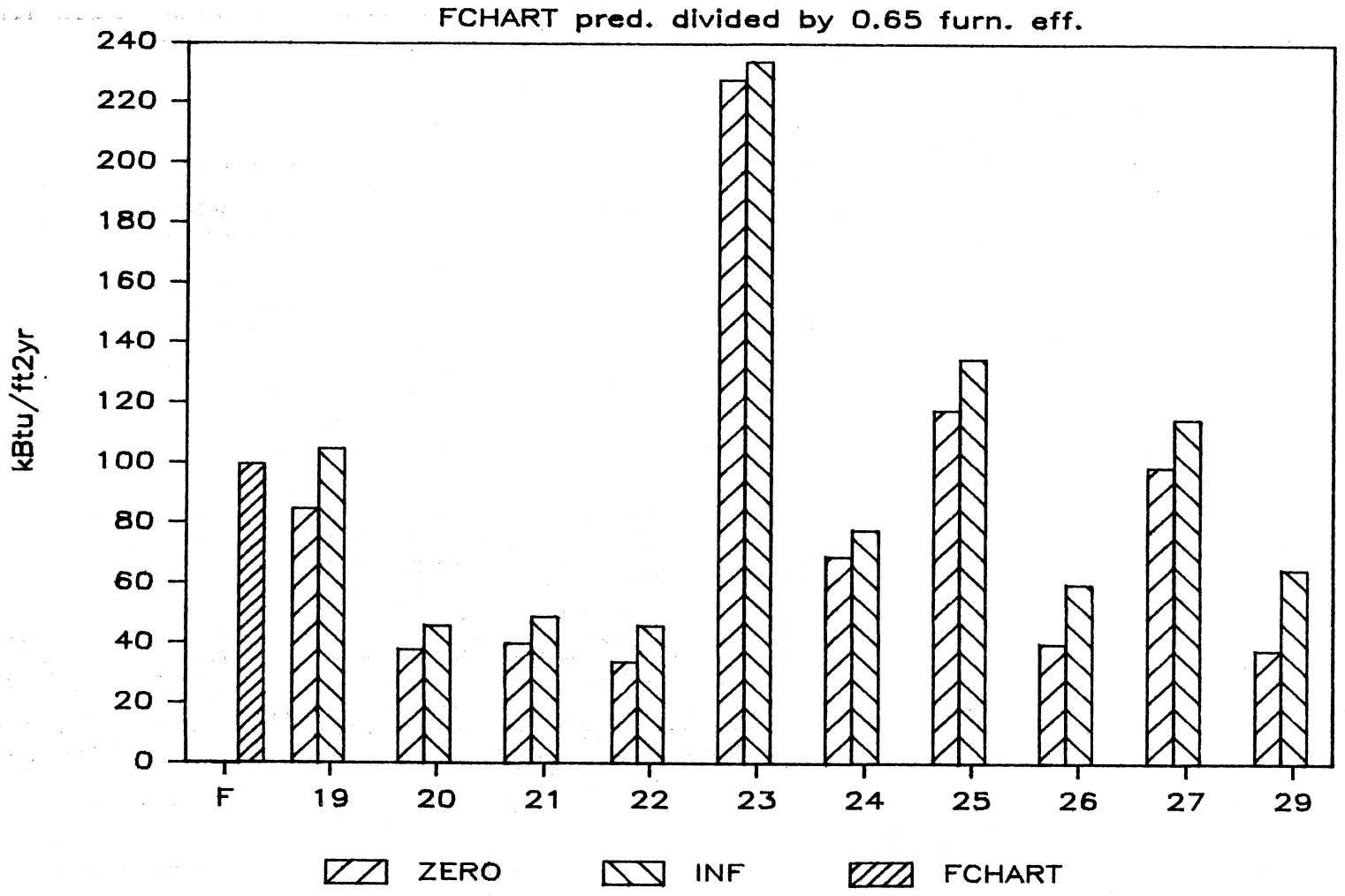


FIG. 6.2 PREDICTED FUEL SAVINGS - MORFLO SYSTEMS

are suspected to be significant (refer to Figures 4.2.1,2,3 and Table 2.2.3), and small variations in house furnace efficiencies. The predicted TMY solar fractions for Mor-Flo systems vary from 3.9% to 13.5%. These values are not useful for comparison between individual systems because they depend on the total space-heating load, which can vary considerably between houses.

Although it is not true for the two other brands of collector investigated, all of the Mor-Flo analyses resulted in a smaller fuel savings prediction from the zero capacitance model than from the infinite capacitance model. This effect agrees with what would intuitively be expected from the two different models, since it is expected that the performance of an average house would be more closely approximated by the infinite capacity model than the zero capacity model. It is not possible, however, to conclude from this reasoning that the infinite capacity analyses result in more accurate prediction of active system performance than the zero capacity analyses. The many fuel-use factors that were not included in the model make that type of assumption difficult to justify. The Mor-Flo zero capacity results actually have smaller confidence intervals, in general, than the infinite capacity results.

6.3 THE EMG SYSTEM RESULTS

Numerical values of the EMG results are in Table 6.3. A bar graph of the predicted fuel savings appears in Fig. 6.3. The maximum predicted fuel savings for these systems is 97 kBtu/ft^{2}yr (house 28), which is considerably smaller than the maximum for the Mor-Flo systems (234 kBtu/ft^{2}yr, house 23) or the General Solar systems (189 kBtu/ft^{2}yr, house 1). This is explainable at least in part by considering the design differences between the systems. The Mor-Flo and General Solar systems have relatively small collector areas (60-90 ft^2) and are mounted at 57° to the horizontal. The EMG systems, on the other hand, are larger (100-240 ft^2) and mounted at 90° to the horizontal. Both of these factors put the EMG systems at a disadvantage when compared to the other system types on a square foot basis. The size difference has a negative effect because

TABLE 6.3 EMG SYSTEM RESULTS

SYS #	STORAGE TYPE	PAR.1	PAR.2	PAR.3	PAR.4	TMY ENERGY SAVED [kBtu/ft^{2}yr]	TMY SOLAR FRACTION [%]
8	ZERO	744	-72	30	293	35 +/- 76	5.0 +/- 11.1
	INF	716	-40	43	459	31 +/- 66	4.5 +/- 9.7
11	ZERO	523	-249	290	-24	62 +/- 24	13.5 +/- 5.1
	INF	394	-48	258	375	68 +/- 35	17.4 +/- 9.0
12	ZERO	399	-81	269	234	28 +/- 49	4.9 +/- 8.7
	INF	361	-76	321	303	31 +/- 47	5.5 +/- 8.4
13	ZERO	602	-43	252	394	42 +/- 28	8.2 +/- 5.5
	INF	562	-52	321	567	50 +/- 26	9.7 +/- 5.1
14	ZERO	680	-187	296	1235	4 +/- 331	0.9 +/- 74.
	INF	605	-71	336	1757	11 +/- 232	2.4 +/- 51.
15	ZERO	953	-28	11	71	67 +/- 55	9.4 +/- 7.8
	INF	901	-8	43	131	68 +/- 71	9.8 +/- 10.3
16	ZERO	339	0	193	175	31 +/- 189	8.4 +/- 52.
	INF	324	0	214	225	34 +/- 208	9.3 +/- 57.
17	ZERO	422	-16	79	81	52 +/- 15	19.7 +/- 5.6
	INF	395	-3	78	234	58 +/- 70	24.3 +/- 29.3
18	ZERO	817	-20	253	640	10 +/- 1015	0.6 +/- 67.
	INF	807	-115	180	735	2 +/- 620	0.1 +/- 49
28*	ZERO	566	-45	253	102	79 +/- 297	9.5 +/- 35.7
	INF	553	-75	298	110	97 +/- 116	11.5 +/- 13.9

* system with SDHW

Par.1= $(UA + C_p{*}m_{inf})/h$	house skin loss	[Btu/hr·F]
Par.2 = $-k/h$	passive gain	[(Btu/hr)/(modelBtu/ft^{2}hr)]
Par.3 = UA_{bsmt}/h	basement skin loss	[Btu/hr·F]
Par.4 = $(A_c F_R U_{L,on} + C_p m_L)/h$	active solar loss	[Btu/hr·F]

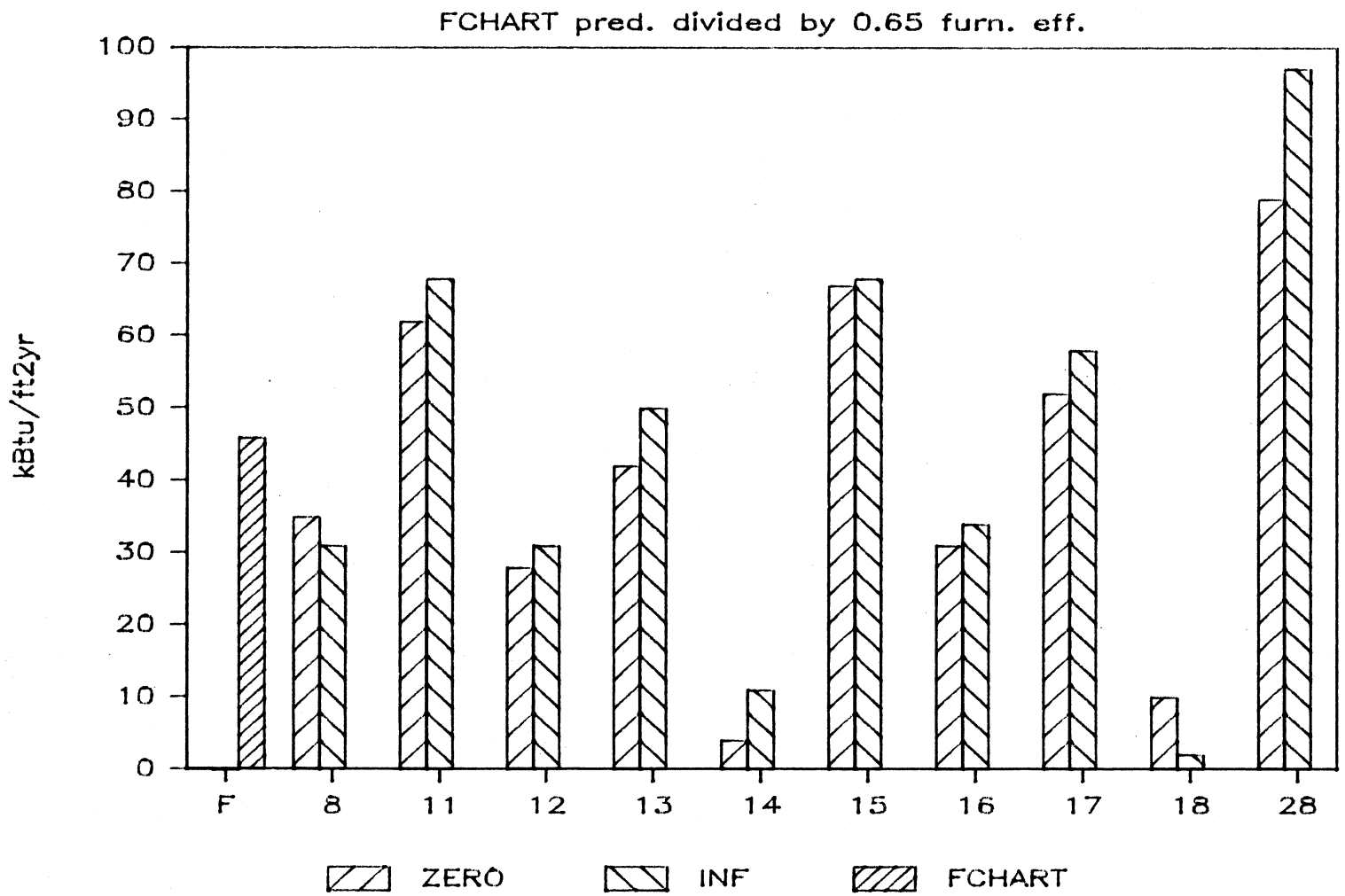


FIG. 6.3 PREDICTED FUEL SAVINGS - EMG SYSTEMS

collector performance is usually less than linearly proportional to collector size in the size ranges of these collectors, and the orientation has a negative effect because it results in lower rates of incident radiation.

The EMG system with the highest predicted performance, which is significantly higher than that of any of the other EMG systems, is the active system on house 28. This is the only EMG system which included SDHW. It is also the only SDHW system that was not analyzed as the other systems with SDHW were (refer to Sec. 2.3.4) because the enable/disable control strategy was not continued into the summer season. The General Solar systems which have SDHW systems provided such poor water-heating performance that the model was not changed to account for their effect on fuel use. For lack of information on its summer season performance, the same assumption was extended to the SDHW system of house 28.

There are several possible explanations for the high performance of system 28. It could be a result of a particularly low furnace efficiency and/or of SDHW effects which were not taken into account in the model. The furnace efficiency effect was described in Sec. 6.2 with reference to house 23.

It is possible that, because of hardware or control system differences, the EMG SDHW system performed better than the General Solar SDHW systems. This would be surprising in light of the fact that the General Solar systems are mounted at 57° to the horizontal, while the EMG systems are mounted at 90° to the horizontal, which means that the General Solar systems receive significantly more incident solar radiation per unit area during the early fall and late spring when heating-season SDHW effects would be greatest. During those periods there is no snow on the ground, which is supposed to augment the winter season performance of the EMG systems by reflecting radiation.

The confidence intervals on the predicted savings for house 28 are relatively large, which could be a logical consequence of the effect of a reasonably good SDHW system that was not taken into account in the models used to analyze the system. The confidence interval for the infinite storage prediction is less than one half as large as that of the zero

storage prediction, which is in agreement with the idea that the infinite storage version could account for at least a portion of the fuel saved by an SDHW system by attributing the decrease in fuel use to thermal storage effects.

The two EMG systems which have the lowest predicted fuel savings due to active solar are those on houses 14 and 18. The associated confidence intervals are also the widest of all the EMG results. A possible explanation for this combination of low predicted performance and high confidence intervals is that these active systems actually have a negative effect on fuel use. One of the shortcomings of the model is that it cannot predict negative active system performance; instead, the predicted performance approaches zero, as it does for both of these houses. Negative active system performance could be the result of very high leakage into the active system, and/or control anomalies. Some of the systems in the study appear to have significant leakage, and control problems have plagued the solar energy industry since its inception.

Another possible explanation for this type of results is that the system was enabled and disabled, but not according to the strategy noted. This is more likely in the case of house 18, since the homeowners, rather than the person monitoring the gas meter, had responsibility for enabling and disabling the active system. In the case of one of the General Solar systems it was possible to ascertain that the active system was running during disabled periods because there was a timer attached to the active system blower, however houses 14 and 18 did not have blower timers.

The remaining EMG houses have predicted performances sufficiently close to the FCHART prediction that the differences can be explained as collector leakage effects and variations in furnace efficiency. System 17 yielded predicted performance values that are close to the FCHART prediction, yet the predicted TMY solar fractions (19% and 24%) are the highest of all the systems in the study. This is a result of the low fuel use of this house. During the ten and a half months that fuel consumption was monitored, only 575 therms were used, despite the fact that the house has a gas stove, a gas water heater, and a gas dryer. The estimated solar fractions of the EMG systems range from 0% to 24%.

The EMG results show the same tendency of lower performance predictions by the zero storage model than by the infinite storage model that the Mor-Flo results did, however houses 8 and 18 did not conform to the pattern.

6.4 THE GENERAL SOLAR SYSTEM RESULTS

The General Solar results are presented in Table 6.4.1 and Fig. 6.4. These analyses were the most problematic of the three sets. The 95% confidence intervals on the results are high, the residual sums of squares are high, the correlation coefficients for the predicted versus measured plots are low, and the model routine would not even produce output for the zero capacity analysis of house 3 and the infinite capacity of house 7 because the parameter confidence intervals were so wide that they caused divide-by-zero errors. There are several possible explanations. The most obvious is that the assumption that the SDHW systems do not affect fuel use during the space-heating season is a bad one, however, on closer inspection this does not appear to be true. The three systems that yielded what appear to be reliable results are systems 1,4, and 9. Systems 1 and 4 are two of the four General Solar systems that showed significant SDHW fuel use effects during the summer season. System 9 has no SDHW, however neither does system 3, which is one of the systems for which no results were obtained. These results actually substantiate the claim that the General Solar SDHW subsystems have no significant effect on space-heating season fuel use.

A second possible explanation is that the weather data used for the General Solar analyses did not accurately reflect conditions at the system sites. The radiation data were measured at Janesville, which is 66 miles west of the General Solar sites in Kenosha. Moreover, the level of radiation incident on these systems is certain to be strongly affected by their proximity to Lake Michigan, which is only a few miles away. The lake causes steep east-west temperature gradients in this part of Wisconsin as well. Hourly temperature data from Racine, which is 11 miles north of Kenosha, were used in hopes

TABLE 6.4 GENERAL SOLAR SYSTEM SPACE-HEATING RESULTS

SYS #	STORAGE TYPE	PAR.1	PAR.2	PAR.3	PAR.4	TMY ENERGY SAVED [kBtu/ft^{2}yr]	TMY SOLAR FRACTION [%]
1*	ZERO	553	-8	177	-19	180 +/- 164	11.5 +/- 10.5
	INF	538	-2	192	-17	189 +/- 179	12.1 +/- 11.4
2*	ZERO	691	-52	143	691	4 +/- 642	0.3 +/- 52.5
	INF	669	-32	158	2060	0 +/- 960	0.0 +/- 79.0
3*	ZERO	no reasonable results					
	INF	955	-87	-173	148	66 +/- 295	5.3 +/- 23.6
4*	ZERO	761	-43	3	44	100 +/- 75	9.6 +/- 7.1
	INF	715	-42	63	120	89 +/- 138	8.5 +/- 13.2
5*	ZERO	538	-40	214	1334	0 +/- 964	0.0 +/- 98.9
	INF	527	-43	232	1046	3 +/- 507	0.3 +/- 52.2
6*	ZERO	854	-164	201	567	3 +/- 1342	0.2 +/- 94.8
	INF	790	-48	253	155	86 +/- 213	5.8 +/- 14.5
7*	ZERO	549	-92	171	669	0 +/- 875	0.0 +/- 63.6
	INF	no reasonable results					
9	ZERO	612	-713	70	-17	39 +/- 108	4.7 +/- 12.8
	INF	463	-64	55	24	51 +/- 141	7.2 +/- 20.0
10*	ZERO	565	-121	137	479	3 +/- 372	0.4 +/- 50.
	INF	509	-76	193	479	11 +/- 128	1.5 +/- 17.2

* systems with SDHW (reduction in fuel use due to SDHW reported in TABLE 2.3.4)

Par.1=	$(UA + C_p{*}m_{inf})/\eta$	house skin loss	[Btu/hr·F]
Par.2 =	$-k/\eta$	passive gain	[(Btu/hr)/(modelBtu/ft^{2}hr)]
Par.3 =	UA_{bsmt}/η	basement skin loss	[Btu/hr·F]
Par.4 =	$(A_c F_R U_{L,on} + C_p m_L)/\eta$	active solar loss	[Btu/hr·F]

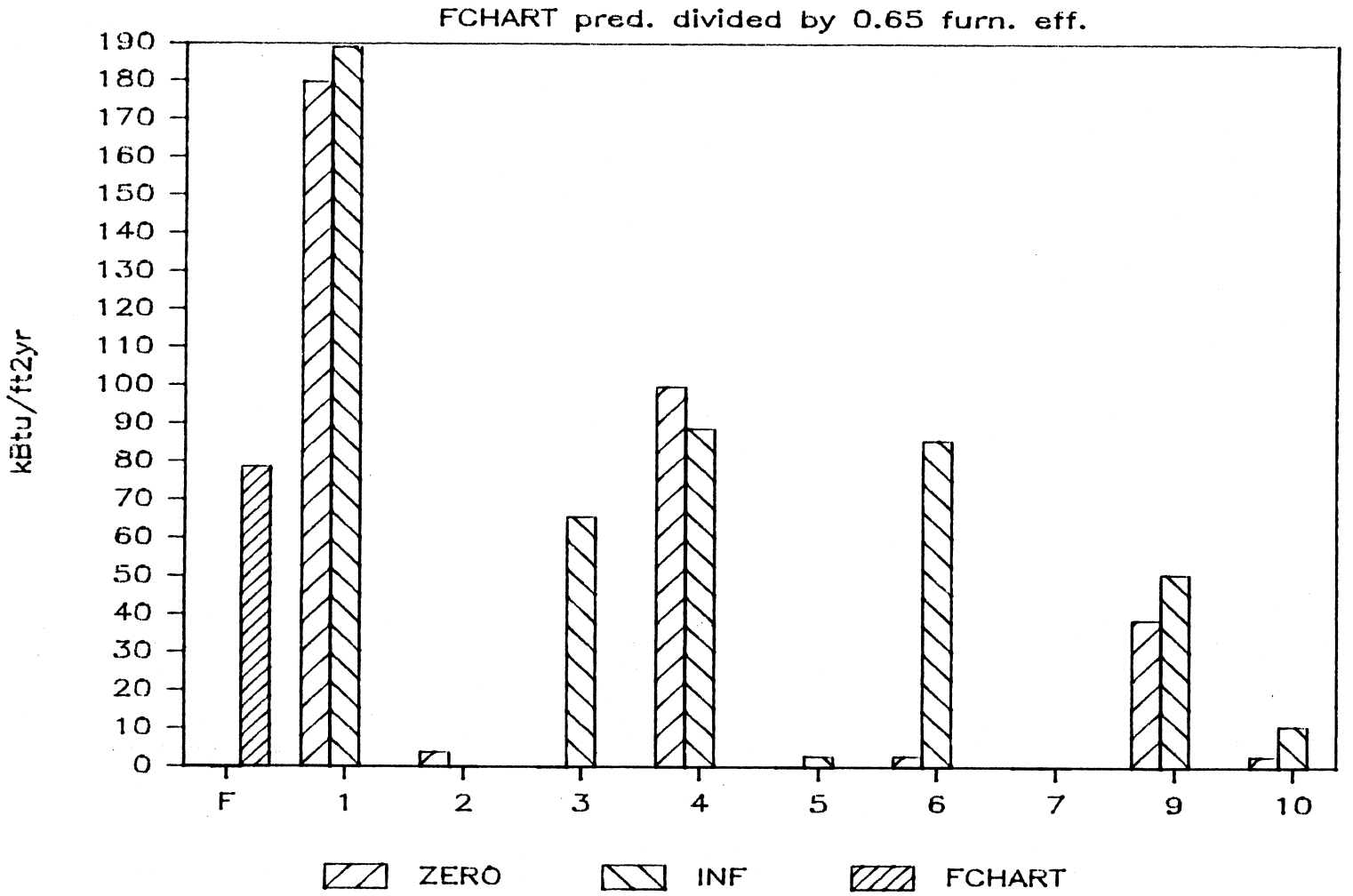


FIG. 6.4 PREDICTED FUEL SAVINGS - GENERAL SOLAR SYSTEMS

of mitigating the temperature gradient effects on the accuracy of the results, however a single set of temperature data is probably insufficient to represent conditions at sites which are located at a range of distances from the lake. No conclusions have been drawn about the extent of the weather data effects on these results.

A final possible explanation is that problems with the raw gas meter data caused the poor results. This is the most likely reason, since many problems have been noticed with the raw data and more are suspected. For example, the data sheets for house 6 include a column in which the active system blower timer readings were recorded. These data indicate that the active system blower operated during all the meter periods from the beginning of the study on 12 Feb. 1987 through 13 May 1987. The only reasonable explanation is that the active system was not disabled when it should have been. Nevertheless, the system was analyzed as if it had been operated under the prescribed control strategy. The resulting large confidence intervals on the fuel savings predictions and poor agreement between the zero and infinite capacity predictions for this system are not surprising.

The raw data were collected in three sets: data from Jefferson County (10 Mor-Flo and 2 EMG systems), data from Waukesha (7 EMG systems), and data from Kenosha (9 General Solar and one EMG system). The fewest problems were encountered with data from Jefferson County, and the most with data from Kenosha. The most common problem with the raw data was bad meter readings. This is difficult to diagnose at times, since the measured fuel use is expected to vary considerably due to unknown factors, however there are several instances in which it is obvious which lead to the suspicion that it occurred in many other General Solar data sets.

Table 6.4.2 presents an example of what appears to be a bad meter reading. The weekly average difference between the house set temperature and the ambient temperature is included in the table since it is the strongest forcing function for space-heating fuel use. The fuel use values should be an approximately linear function of the weekly average temperature difference. In this case the opposite appears to be true: the lowest measured

fuel use occurs during the week of the highest weekly average temperature difference. Then, the following week, the highest measured fuel use occurs during the week of the lowest weekly average temperature. The effect is not a result of active solar system operation because the system was disabled during the low fuel use week and enabled during the high fuel use week. This pattern of an unusually low fuel use value followed by an unusually high one, or vice versa, occurs in many of the General Solar data files. It is interpreted as an indication of a bad gas meter reading which results in gas use during one period being attributed to gas use during the following or previous period.

TABLE 6.4.2 EXAMPLE OF A BAD DATA READING FROM HOUSE 4

DATE	Weekly Avg. $T_{h,j} - T_{amb}$ [°F]	Measured Fuel Use [therms/week]	Active Solar System Operation
5/6/87	16.3	12	enabled
5/13/87	12.8	17	disabled
5/20//87	14.4	20	enabled
5/27/87	17.7	8	disabled
6/3/87	6.6	25	enabled

In the above example, the indications of a bad meter reading are very clear, however, when the same problem occurs during colder weather such a diagnosis is more difficult because the level of fuel use is much higher. It is hypothesized that most of the problems encountered in the General Solar analyses can be attributed to bad gas meter readings.

All of the gas meters used in the study were of the dial type. Readings are taken from a row of dials, the needles of which rotate in alternating directions. It would be an easy mistake to err in reading one of these meters, particularly as the needle approaches a digit.

Systems 4 and 9, which are the only systems besides system 1 that yielded reasonable results, have predicted energy savings values similar to that of the FCHART prediction for the General Solar systems. The discrepancy between their results and the

FCHART prediction can be attributed to leakage rate differences and small variations in furnace efficiency. The General Solar predicted solar fractions range from 0 to 12%.

6.5 CORRELATION COEFFICIENTS FOR THE WEEKLY PREDICTED VERSUS MEASURED FUEL USE VALUES

One indication of whether a model is appropriate is how well the predicted and measured values agree. The r^2 correlation coefficient is a measure of this agreement. It is calculated using the following equation:

$$r^2 = \frac{\left[n\sum(xy) - \sum(x)\sum(y)\right]^2}{\left[n\sum x^2 - (\sum x)^2\right] * \left[n\sum y^2 - (\sum y)^2\right]} \qquad (6.5.1)$$

where: n = the number of measured or predicted values

x = the measured weekly fuel use values

y = the predicted weekly fuel use values

The best value for r^2 is one. The further an r^2 value is from one, the less agreement there is between the measured and predicted fuel use values. Table 6.5.1 presents the correlation coefficients for all of the analyses done, both the zero and infinite capacity runs for each house.

The correlation coefficients are all high, indicating good agreement between the predicted and measured fuel use values. This is not a surprising result; fitting a four-parameter model to a set of data should result in high correlation coefficients unless the data is a strong function of a variable that is not taken into account in the model.

The average correlation coefficients for each brand of system appear at the bottom of Table 6.5.1. The Mor-Flo systems, which yielded the highest average correlation coefficient, were also the systems located closest to the weather station in Janesville and

TABLE 6.5.1 CORRELATION COEFFICIENTS FOR ALL ANALYSES

VERSION	#	Mor-Flo	#	EMG	#	GENERAL SOLAR
zero	19	0.988	8	0.938	1	0.943
infinite		0.990		0.938		0.946
zero	20	0.865	11	0.932	2	0.937
infinite		0.872		0.933		0.951
zero	21	0.963	12	0.967	3	0.925
infinite		0.967		0.967		0.921
zero	22	0.985	13	0.979	4	0.964
infinite		0.984		0.977		0.967
zero	23	0.987	14	0.963	5	0.924
infinite		0.986		0.958		0.926
zero	24	0.982	15	0.958	6	0.959
infinite		0.982		0.957		0.967
zero	25	0.986	16	0.957	7	0.950
infinite		0.981		0.956		no results
zero	26	0.974	17	0.954	9	0.935
infinite		0.974		0.942		0.936
zero	27	0.988	18	0.968	10	0.935
infinite		0.988		0.972		0.942
zero	29	0.990	28	0.937		
infinite	29	0.988	28	0.946		
AVERAGE:		0.979		0.955		0.943

the systems which gave the best overall performance. It is hypothesized that the high correlation coefficient is a result of both of these factors. Since they are the forcing functions which drive the model, accurate weather data are crucial to the analysis. The magnitude of the solar energy contribution to the space-heating load is important because the regression routine cannot separate small solar energy contributions from systematic errors in the analysis.

Plots of predicted versus measured fuel use values for those systems with the highest and lowest correlation coefficients are presented in Figures 6.5.1 and 6.5.2, respectively. Both of these are Mor-Flo systems. The most obvious difference between the two sets of points is that the maximum rate of weekly fuel use for the system with a high correlation coefficient is approximately twice as large as the maximum rate for the system with a low correlation coefficient. This may be the result of systematic errors of approximately the same magnitude in both sets of data. Such errors would affect the results for a system with low space-heating fuel use to a much greater extent than those of a system with high space-heating fuel use.

6.6 BREAK-EVEN SYSTEM COST CALCULATION

The criterion upon which residential solar energy systems are ultimately judged is their economic value to the homeowner. Therefore, in order to allow an approximate economic assessment of the usefulness of the three brands of AC/PS systems under investigation, the break-even system cost of each has been calculated based on the active solar contribution which was determined using FCHART. The FCHART predictions were performed using TMY data for Madison, WI. Solar system performance is strongly weather dependent, and these results do not apply to other locations which have weather patterns significantly different from those of Madison. The economic analysis was done only for space-heating systems, to allow a simple comparison of the predictions and because little is known about the SDHW systems.

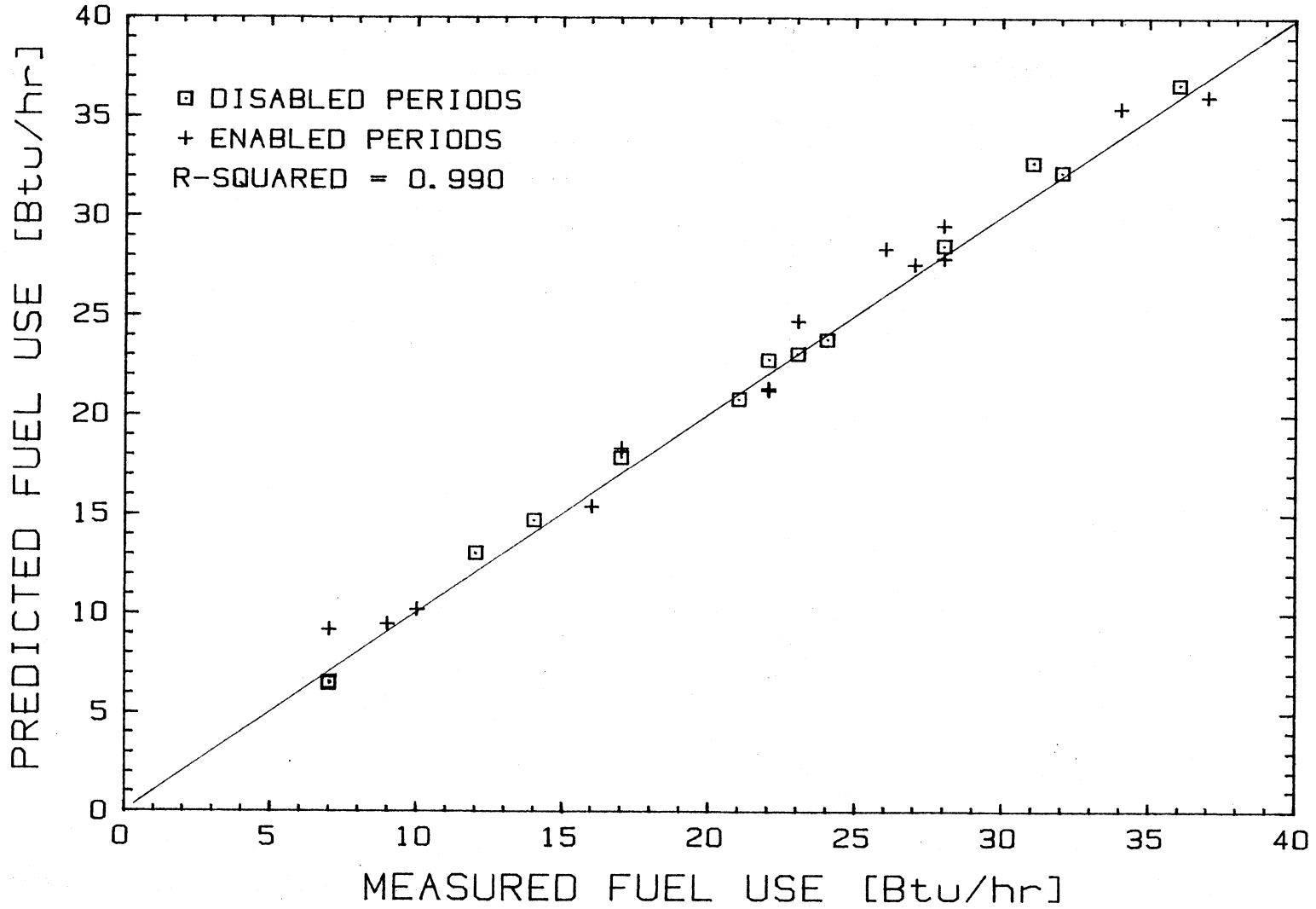


FIG 6.5.1 PREDICTED VS MEASURED FUEL USE - SYSTEM 29 ZERO CAP

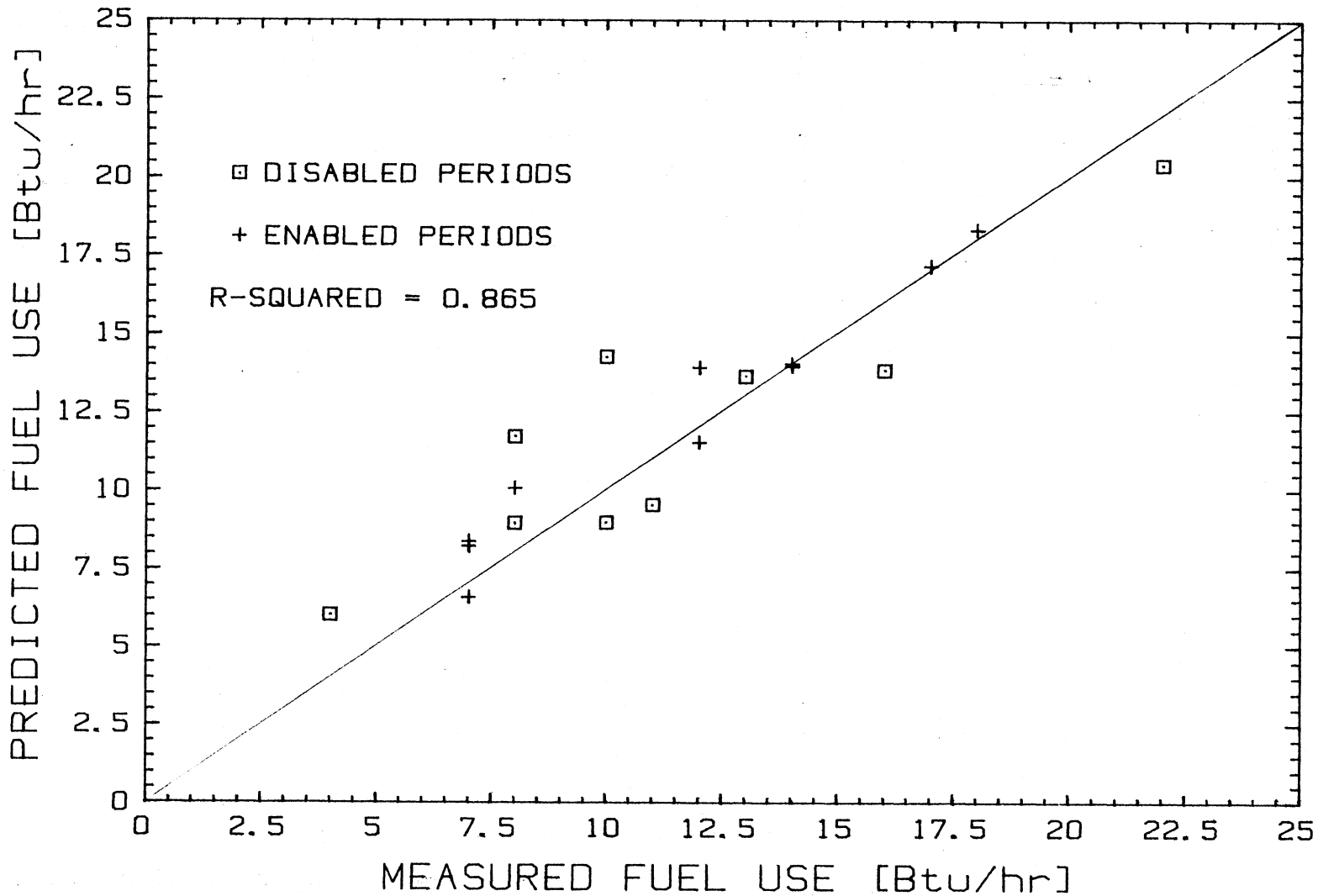


FIG 6.5.2 PREDICTED VS MEASURED FUEL USE - SYSTEM 20 ZERO CAP

Duffie and Beckman (p.399) present a method for calculating the life-cycle savings of a solar energy system. The equation used is:

$$LCS = P_1 C_{f1} LF - P_2(C_A A + C_E) \; * \qquad (6.6.1)$$

* This equation does not include the cost of blower or pumping energy, which should be small compared to the total savings

where: LCS =the life-cycle savings

P_1 = the ratio of the life cycle fuel cost savings to the first year fuel cost savings

C_{f1} = the first period's unit energy cost delivered from the fuel

LF = the energy saved

P_2 = the ratio of the life cycle expenditures incurred because of the additional capital investment to the initial investment

C_A = the total collector area-dependent costs

A = the collector area

C_E = the total cost of the equipment which is independent of collector area

The break-even cost of a system is calculated by setting the life-cycle savings to zero and solving for the system cost.

$$C_A A + C_E = \frac{P_1 C_{f1} LF}{P_2} \qquad (6.6.2)$$

The calculation is done for a collector size of $100ft^2$ for each system to allow comparison and because this is a reasonable size for space-heating systems in Wisconsin.

P_1 is calculated as follows:

$$P_1 = PWF(n,f,d) = \frac{1}{(d - f)} \left[1 - \left(\frac{1 + f}{1 + d}\right)^n \right] \qquad (6.6.3)$$

where: PWF = the present worth factor

n = the term of the economic analysis (the life of the system)

f = the fuel inflation rate

d = the market discount rate

It is assumed for this analysis that the life of these systems is fifteen years (n=15), the fuel inflation rate is eight percent (f=0.08), and the market discount rate is five percent (d=0.05). Therefore P_1 is equal to 17.5.

P_2 depends on the amount of down payment, rate of payments on the principal, tax deductions for interest payments, property tax, maintenance costs, salvage value, and tax credits. These factors can vary considerably between systems, so the simplest case was chosen for this calculation. The following assumptions are made:

1. The system is paid for in full on the date of purchase.
2. There is no property tax.
3. There are no maintenance costs.
4. The salvage value after 15 years is zero.

Under these assumptions, P_2 is unity.

The approximate cost of residential natural gas in southern Wisconsin is \$0.62/therm. This value must be divided by the house furnace efficiency to calculate the delivered energy cost of the fuel. A seasonal furnace efficiency of 65% is assumed (C_{f1} = \$0.62/0.65 = \$0.95/therm).

The solar energy contribution (LF) predicted by FCHART and the associated break-even cost of each of the three system types are presented in Table 6.6.1:

TABLE 6.6.1 FCHART PREDICTED SOLAR ENERGY CONTRIBUTION AND BREAK-EVEN COST

System	Predicted Energy Delivered (therms/100ft^{2}year)	Break-even Cost (dollars)
Mor-Flo	65	1081
EMG	30	499
General Solar	55	914

The EMG system results are low in part because their collectors are mounted vertically, and therefore receive less incident radiation than the other collector types which are mounted at 57° to the horizontal. This effect is offset to some extent by the larger collector areas of the EMG systems. The Mor-Flo and General Solar systems have collector areas of either 60 or 90 ft^2, and the EMG system collector areas range from 100 to 240 ft^2.

These break-even costs are all considerably less than the installed systems actually cost. The calculations were not repeated for the case of electric resistance space-heating, which would approximately double the break-even cost. None of the houses in the study are equipped with electric resistance heating.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

The performance of three brands of residential active collect/passive store (AC/PS) solar energy systems has been analyzed. The 29 systems, located in southeastern Wisconsin, were monitored for approximately one year. A computer model of the houses and AC/PS systems has been created, based on heat transfer theory and empirical observations, which was used in a nonlinear regression analysis to characterize the fuel use performance. The expected fuel savings for a typical meteorological year (TMY) were then calculated using the results of the regression analysis and TMY weather data. The following conclusions were drawn from the results of this work:

1. These solar energy systems performed less well than expected by the homeowners and less well than had been suggested by the manufacturer's and salespeople. Anecdotal reports from the homeowners indicate that they expected solar fractions of 30-70%. None of the system analyses resulted in predicted solar fractions of greater than 25%, and if the two best of the twenty nine systems are not included the maximum predicted solar fraction drops to 14%. The two high predicted solar fractions are the result of unusually low space-heating loads rather than high collector performance. The estimated break-even cost for each of the system types, based on a $100ft^2$ collector area and collector parameters which were supplied by the manufacturers, is less than $1,100 (this does not include the effect of solar domestic water heating (SDHW), which was incorporated in nine of the twenty nine systems).

2. These systems are not economically viable at present energy prices for natural gas space-heating applications in southeastern Wisconsin. This appears to be particularly true for the EMG systems, which pay an added penalty in decreased incident radiation due to their vertical orientation and suffer from higher leakage rates, possibly due to on-site assembly of the collector.

3. Although direct comparison of active system results is difficult because the house furnace efficiencies are not known, the Mor-Flo systems seem to perform better, in general, than the EMG or General Solar systems. None of the Mor-Flo system energy savings predictions approached zero, as was true in some cases for the other two systems. This result is corroborated by both the FCHART prediction and the collector performance parameters reported by the manufacturers. The Mor-Flo collector gain parameter ($F_R\tau\alpha$) is higher than those of the other two brands, and its collector loss parameter (F_RU_L) is lower.

4. There appears to be good agreement between the FCHART program for estimating annual active system performance and the method developed for this work. The fuel savings predicted in the regression analysis of the systems in the study which yielded reliable results are reasonably close to those predicted by FCHART. The differences are attributed to furnace efficiency effects and, in one case, to SDHW effects.

5. The computer model and analytic method created for the purposes of this research appear, under certain conditions, to be useful means of determining the installed performance of residential active solar energy systems. The prerequisites for meaningful results are: a consistent and well-documented monitoring and active system control strategy, accurate hourly weather data obtained from a station close to the system location, reliable fuel use data, and some knowledge of occupant behavior (vacation periods, thermostat set temperatures, changes in auxiliary heating control strategy).

6. It is not possible to separate the effects of active system solar performance from random variations in residential fuel use if the active system performance is below a certain threshold. Some of the systems that have been investigated in this work appear to operate below that level. The height of the threshold depends on the

magnitude of the fuel use factors which are not accounted for in the model, and therefore varies from system to system. A rough estimate is 5-10% of the space-heating load.

A study of the type described in this thesis is usually stopped for lack of time before all the useful information available is extracted. That is true in the present case. The following recommendations include suggestions for application of the knowledge gleaned from this work and for continued development of the computer model and method created for this analysis.

1. A collector system modelling program should be used to estimate the installed performance of any residential active solar energy system before it is subsidized by a government agency. Factors affecting performance such as leakage and duct losses should be included in the analysis. The results should include predicted payback periods and life-cycle-savings estimates.

2. If a group or groups of active solar systems are investigated by this method, they should be screened for homogeneity. The inclusion of SDHW systems in two of the groups studied made accurate determination of active system performance difficult. The dispersed locations of the systems added uncertainty to the analysis, particularly for the systems in Kenosha which are located relatively far from the source of radiation data in Janesville and close to Lake Michigan, which has a strong effect on the weather of neighboring regions.

3. If the house and active system model developed for this work is to be used in another such application, it should be modified to allow the predicted active system performance to be negative.

4. Not enough was known about the designs and control strategies of these systems. Although it is suspected that many of them were not operating as intended by the manufacturer, more information would still have been helpful in the development of the active system part of the model. Another study should include a closer inspection of the system designs.

5. The method of reading and transferring gas meter data to computer files should be simplified and made foolproof. If possible, fuel use should be monitored electronically. Simple methods for checking fuel use data should be used. For example, a fuel use per degree-day calculation could be performed at every reading to check for large deviations which might indicate a bad reading. If readings are taken manually, one person should take all the readings.

6. A minimum of one full heating season of data should be used in any analysis of this kind. Many fuel use factors are seasonally dependent, such as basement losses and appliance fuel use, and their effects are important in the characterization of a house and active solar system. The number of data points is also important in terms of the regression analysis. It was found that in most cases a minimum of 18-20 measured fuel use readings were required to ensure that the regression routine would complete a run without bombing because of divide-by-zero errors in the parameter confidence interval calculations.

7. The active system blower timers which were installed on some of the systems were useful as checks of the enable/disable control strategy, and for gaining an impression of the active system operation. Timers are good monitoring instruments because they do not require changes in the system configuration and do not affect its performance. Any future studies of this type should include blower timers on all the active systems.

APPENDIX A

FLOAD HOUSE PARAMETERS

04-02-1987
DEFAULT

```
** BASIC BUILDING **
1  CITY LOCATION................   127
2  REFERENCE ANGLE WRT SOUTH.....   0            DEG
3  HEATED AIR VOLUME.............   11355        FT3
4  CONSTR QUAL (0 TO 3 OR NEG)...   1
5  NUMBER OF EXTERIOR WALLS......   8
6  SET ALL EXTERIOR WALL R-VALUES   16.4         FT2-HR-F/BTU
7  SET ALL WINDOW DAY R-VALUES...   2.2          FT2-HR-F/BTU
8  SET ALL WINDOW NIGHT R-VALUES.   2.7          FT2-HR-F/BTU
9  STORAGE CAP (0 TO 3 OR NEG)...   1
10 OUTPUT 1=SUMMARY TO 4=DETAILED   3
11 GRAPHIC OUTPUT? 1=Y 2=N.......   2

** WALL 1 **
1  ORIENTATION WRT TO REFERENCE..   0            DEG
2  GROSS WALL AREA...............   306          FT2
3  EXTERIOR WALL R-VALUE.........   16.4         FT2-HR-F/BTU
4  WINDOW AREA...................   63.7         FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   21           FT2
9  DOOR R-VALUE..................   2.56         FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   90           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 2 **
1  ORIENTATION WRT TO REFERENCE..   90           DEG
2  GROSS WALL AREA...............   194          FT2
3  EXTERIOR WALL R-VALUE.........   16.4         FT2-HR-F/BTU
4  WINDOW AREA...................   0            FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   0            FT2
9  DOOR R-VALUE..................   2            FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   90           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 3 **
1  ORIENTATION WRT TO REFERENCE..   180          DEG
```

```
2  GROSS WALL AREA...............   306          FT2
3  EXTERIOR WALL R-VALUE.........   16.4         FT2-HR-F/BTU
4  WINDOW AREA...................   18.3         FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   42           FT2
9  DOOR R-VALUE..................   2.1          FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   90           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 4 **
1  ORIENTATION WRT TO REFERENCE..   270          DEG
2  GROSS WALL AREA...............   194          FT2
3  EXTERIOR WALL R-VALUE.........   16.4         FT2-HR-F/BTU
4  WINDOW AREA...................   0            FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   0            FT2
9  DOOR R-VALUE..................   2            FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   90           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 5 **
1  ORIENTATION WRT TO REFERENCE..   0            DEG
2  GROSS WALL AREA...............   67           FT2
3  EXTERIOR WALL R-VALUE.........   19           FT2-HR-F/BTU
4  WINDOW AREA...................   0            FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   0            FT2
9  DOOR R-VALUE..................   2            FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   0            DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 6 **
1  ORIENTATION WRT TO REFERENCE..   0            DEG
2  GROSS WALL AREA...............   153          FT2
3  EXTERIOR WALL R-VALUE.........   9.100001     FT2-HR-F/BTU
4  WINDOW AREA...................   9            FT2
5  WINDOW DAYTIME R-VALUE........   1.8          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   1.8          FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0            %
8  DOOR AREA.....................   0            FT2
9  DOOR R-VALUE..................   2            FT2-HR-F/BTU
```

```
10 WINDOW TILT FROM HORIZONTAL...   0           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 7 **
1  ORIENTATION WRT TO REFERENCE..   270         DEG
2  GROSS WALL AREA...............   188         FT2
3  EXTERIOR WALL R-VALUE.........   9.100001    FT2-HR-F/BTU
4  WINDOW AREA...................   0           FT2
5  WINDOW DAYTIME R-VALUE........   2.2         FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.7         FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0           %
8  DOOR AREA.....................   0           FT2
9  DOOR R-VALUE..................   2           FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   0           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** WALL 8 **
1  ORIENTATION WRT TO REFERENCE..   180         DEG
2  GROSS WALL AREA...............   153         FT2
3  EXTERIOR WALL R-VALUE.........   9.100001    FT2-HR-F/BTU
4  WINDOW AREA...................   9           FT2
5  WINDOW DAYTIME R-VALUE........   1.8         FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   1.8         FT2-HR-F/BTU
7  WINDOW % OF TIME SHADED.......   0           %
8  DOOR AREA.....................   0           FT2
9  DOOR R-VALUE..................   2           FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   0           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** ROOF-FLOOR-BASEMENT-GARAGE **
1  TOTAL CEILING AREA............   1013        FT2
2  CEILING R-VALUE...............   26.3        FT2-HR-F/BTU
3  1=SLAB,2=CRAWLSP,3=FULL,4=COMB   1
4  TYPE 1:DUCTS IN SLAB? 1=Y 2=N.   2
5  TYPE 1:PERIMETER OF SLAB......   63          FT
6  TYPE 1:R-VALUE OF EDGE INSUL..   5           FT2-HR-F/BTU
7  TYPE 2:FLOOR AREA OVER CRAWL..   0           FT2
8  TYPE 2:FLOOR R-VALUE..........   2           FT2-HR-F/BTU
9  TYPE 3:BASEMT HEATED? 1=Y 2=N.   2
10 TYPE 3:FLOOR AREA OVER BASEMT.   0           FT2
11 TYPE 3:BUILDING FLOOR R-VALUE.   2           FT2-HR-F/BTU
12 TYPE 3:BASEMENT WALL AREA.....   0           FT2
13 TYPE 3:BSMT INSUL WALL R-VALUE   0           FT2-HR-F/BTU
14 NUMBER OF CAR GARAGE (0 TO 3).   2
15 WALL AREA COMMON TO GARAGE....   188         FT2
16 R-VAL OF WALL COMMON TO GARAGE   19          FT2-HR-F/BTU
17 FLOOR AREA COMMON TO GARAGE...   480         FT2
```

```
18 R-VAL OF FLOOR COMMON TO GAR..   12          FT2-HR-F/BTU
19 R-VAL OF GARAGE EXTERIOR WALLS   2           FT2-HR-F/BTU
20 DUCTS IN UNHEATED SPC 1=Y 2=N.   2
21 PITCHED ROOF ATTIC? 1=Y 2=N...   1
22 ROOF SOLAR ABSORPTIVITY.......   .4

** INTERNAL SPACE **
1  ANNUAL ELECTRICAL CONSUMPTION.   8000        KW-HR
2  AVERAGE NUMBER OF OCCUPANTS...   4
3  HEATING LOAD CALC (1=Y 2=N)...   1
4    DAYTIME THERMOSTAT SETTING..   72          F
5    NIGHTTIME THERMOSTAT SETTING   68          F
6    EQUIPMENT FILE NAME....... FURNACE
7  COOLING LOAD CALC (1=Y 2=N)...   2
8    DAYTIME THERMOSTAT SETTING..   78          F
9    NIGHTTIME THERMOSTAT SETTING   78          F
10   ROOM RELATIVE HUMIDITY......   40          %
11   VENTILATION (1=Y 2=N).......   1
12   MOISTURE GENERATION.........   .5          LBM/HR
13   EQUIPMENT FILE NAME....... AIRCOND
14 HOURS FOR NIGHT SETTING.......   8           HOURS
15 ALLOWABLE TEMPERATURE SWING...   9           F
16 VENTILATION HX EFFECTIVENESS..   0           %
17 VENTILATION HX FLOWRATE.......   0           CFM
18 DHW CALCULATION (1=Y 2=N).....   2
19   DHW LOSS TO SPACE (1=Y 2=N).   2
20   DHW(1=EL;2=NG;3=OIL;4=OTHER)   1
21   WATER HEATER EFFICIENCY.....   100         %
22   AVERAGE DAILY HOT WATER USE.   80          GALLONS
23   HOT WATER SET TEMPERATURE...   140         F
24   R-VALUE OF TANK INSULATION..   2           FT2-HR-F/BTU
25   HOT WATER TANK VOLUME.......   40          GALLONS

** ECONOMICS **
1  ECON ANALYSIS DETAIL (0 TO 4).   0

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MADISON         WI           04-02-1987

DEFAULT
```

EQUIPMENT FILE TITLES

HEATING: TYPICAL GAS FURNACE

*** HEATING ENERGY (MMBTU) ***

ALL WALLS

MONTH	WALL	WINDOW	DOOR	SOLAR
JAN	4.32	1.72	1.13	1.33
FEB	3.65	1.46	0.95	1.53
MAR	3.25	1.31	0.85	1.77
APR	1.97	0.80	0.52	1.67
MAY	1.19	0.49	0.31	1.81
JUN	0.44	0.18	0.12	1.83
JUL	0.23	0.09	0.06	1.91
AUG	0.30	0.12	0.08	1.93
SEP	0.87	0.35	0.23	1.79
OCT	1.68	0.67	0.44	1.77
NOV	2.80	1.12	0.73	1.12
DEC	3.92	1.56	1.02	0.98
YR	24.62	9.88	6.43	19.45

MONTH	ROOF	BSMT	INFIL	GARAGE
JAN	1.54	1.26	2.45	1.84
FEB	1.30	1.07	2.02	1.56
MAR	1.16	0.95	1.64	1.39
APR	0.70	0.58	0.84	0.84
MAY	0.43	0.35	0.43	0.51
JUN	0.16	0.11	0.13	0.19
JUL	0.08	0.01	0.06	0.10
AUG	0.11	0.05	0.08	0.13
SEP	0.31	0.25	0.29	0.37
OCT	0.60	0.49	0.67	0.72
NOV	1.00	0.82	1.35	1.19
DEC	1.40	1.14	2.13	1.67
YR	8.78	7.06	12.10	10.49

MONTH	(ENV)	GAIN	EXCESS	AUX
JAN	13.00	3.38	0.12	9.74
FEB	10.95	3.54	0.09	7.51
MAR	9.60	4.34	0.11	5.36
APR	5.68	4.57	0.34	1.44
MAY	3.36	5.17	1.81	0.00
JUN	1.22	5.37	4.15	0.00
JUL	0.62	5.67	5.05	0.00

AUG	0.82	5.58	4.75	0.00
SEP	2.42	5.00	2.58	0.00
OCT	4.77	4.72	0.70	0.75
NOV	8.18	3.49	0.12	4.81
DEC	11.70	3.09	0.12	8.73
YR	72.31	53.92	19.95	38.35

*** DESIGN VALUES ***
DESIGN HEATING LOAD = 31100 BTU/HR
LOSS/(AREA-DD) = 5.4 BTU/FT2-F-DAY

*** PURCHASED ENERGY (MMBTU) ***

HEATING MONTH	AUX	DEL	SHORT	PURCH
JAN	9.74	9.74	0.00	12.99
FEB	7.51	7.51	0.00	10.01
MAR	5.36	5.36	0.00	7.15
APR	1.44	1.44	0.00	1.92
MAY	0.00	0.00	0.00	0.00
JUN	0.00	0.00	0.00	0.00
JUL	0.00	0.00	0.00	0.00
AUG	0.00	0.00	0.00	0.00
SEP	0.00	0.00	0.00	0.00
OCT	0.75	0.75	0.00	1.00
NOV	4.81	4.81	0.00	6.41
DEC	8.73	8.73	0.00	11.64
YR	38.35	38.35	0.00	51.13

APPENDIX B

FLOWHOOD CALIBRATION RESULTS

TEST OF FLOWHOOD TO DETERMINE LEVEL OF AGREEMENT BETWEEN INLET AND OUTLET FLOW RATE MEASUREMENTS*

Run	Blower RPM	Inlet Flowrate [cfm]	Outlet Flowrate [cfm]
1	420	1475	1500
2	422	1490	1510
3	422	1500	1500
4	422	1495	1500
5	422	1490	1505
6	540	1150	1150
7	540	1150	1150
8	540	1150	1150
9	540	1145	1140
10	540	1150	1150

* This instrument was used to measure the flowrates at the inlet and outlet registers of the active systems during the initial system inspections. The leakage rates were so high (average=40%) that the reliability of the flowhood was suspected. However, the flowhood measures both inlet and outlet flow rates very accurately, as evidenced by these test data. These measurements were made on the small wind tunnel in the Mechanical Engineering Energy Lab at the University of Wisconsin-Madison on 27 May 1986.

APPENDIX C

FCHART PARAMETER SETS

```
04-02-1987
MORFLO

** FLAT PLATE COLLECTOR **
1  NUMBER OF COLLECTOR PANELS....  3
2  COLLECTOR PANEL AREA..........  34          FT2
3  FR*UL (TEST SLOPE)............  .85         BTU/HR-FT2-F
4  FR*TAU*ALPHA (TEST INTERCEPT).  .62
5  COLLECTOR SLOPE...............  57          DEG
6  COLLECTOR AZIMUTH (SOUTH=0)...  0           DEG
7  INCIDENCE ANGLE MOD TYPE(8-10)  8
8    NUMBER OF GLAZINGS..........  2
9    INC ANGLE MODIFIER CONSTANT.  .255
10   INC ANGLE MODIFIER VALUE(S).
  1   .999   .998   .995   .981   .953   .882
  .7   .35   0
11 COLLECTOR FLOWRATE/AREA.......  37          LB/HR-FT2
12 COLLECTOR FLUID SPECIFIC HEAT.  .24         BTU/LB-F
13 MODIFY TEST VALUES (1=Y,2=N)..  2
14   TEST COLLECTOR FLOWRATE/AREA  9           LB/HR-FT2
15   TEST FLUID SPECIFIC HEAT....  .24         BTU/LB-F

** ACTIVE - BUILDING STORAGE SYSTEM **
1  CITY CALL NUMBER..............  127
2  BUILDING UA...................  400         BTU/HR-F
3  BUILDING STORAGE CAPACITY.....  12900       BTU/F
4  LOW THERMOSTAT SET TEMPERATURE  68          F
5  DAILY INTERNAL GENERATION.....  86000       BTU/DAY
6  ALLOWABLE TEMPERATURE SWING...  10          F
7  FUEL (1=EL,2=NG,3=OIL,4=OTHER)  2
8  EFFICIENCY OF FUEL USAGE......  70          %
9  DUCT LOSSES (1=Y,2=N).........  1
10   INLET DUCT UA...............  19          BTU/HR-F
11   OUTLET DUCT UA..............  19          BTU/HR-F
12   PERCENT DUCT LEAK RATE......  15          %
13   LEAK LOC (1=IN,2=OUT,3=BOTH)  3
14 DOMESTIC HOT WATER (1=Y,2=N)..  2
15   DAILY HOT WATER USAGE.......  80          GALLONS
16   WATER SET TEMPERATURE.......  140         F
17   ENVIRONMENT TEMPERATURE.....  68          F
18   UA OF AUX STORAGE TANK......  7.6         BTU/HR-F
19   HX WATER FLOWRATE...........  2000        LB/HR
20   AIR/WATER HX EFFECTIVENESS..  .5

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  0
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```

MORFLO

** ACTIVE - BUILDING STORAGE SYSTEM **
** FLAT PLATE COLLECTOR **

	SOLAR MMBTU	HEAT MMBTU	DHW MMBTU	AUX MMBTU	F
JAN	2.9	12.5	0.0	12.4	0.01
FEB	3.4	10.4	0.0	10.1	0.03
MAR	4.2	8.6	0.0	8.1	0.06
APR	4.1	4.1	0.0	3.2	0.22
MAY	4.6	1.6	0.0	0.1	0.92
JUN	4.6	0.3	0.0	0.0	1.00
JUL	4.9	0.1	0.0	0.0	1.00
AUG	4.9	0.2	0.0	0.0	1.00
SEP	4.4	0.9	0.0	0.0	1.00
OCT	4.0	3.0	0.0	1.8	0.40
NOV	2.4	7.0	0.0	6.7	0.05
DEC	2.1	11.1	0.0	10.9	0.01
YR	46.6	59.9	0.0	53.4	0.11

```
04-02-1987
EMG

** FLAT PLATE COLLECTOR **
1  NUMBER OF COLLECTOR PANELS....  1
2  COLLECTOR PANEL AREA..........  100          FT2
3  FR*UL (TEST SLOPE)............  1.38         BTU/HR-FT2-F
4  FR*TAU*ALPHA (TEST INTERCEPT).  .58
5  COLLECTOR SLOPE...............  90           DEG
6  COLLECTOR AZIMUTH (SOUTH=0)...  0            DEG
7  INCIDENCE ANGLE MOD TYPE(8-10)  8
8    NUMBER OF GLAZINGS..........  1
9    INC ANGLE MODIFIER CONSTANT.  .12
10   INC ANGLE MODIFIER VALUE(S).
  1   .999   .998   .995   .981   .953   .882
  .7   .35   0
11 COLLECTOR FLOWRATE/AREA.......  37           LB/HR-FT2
12 COLLECTOR FLUID SPECIFIC HEAT.  .24          BTU/LB-F
13 MODIFY TEST VALUES (1=Y,2=N)..  2
14   TEST COLLECTOR FLOWRATE/AREA  9            LB/HR-FT2
15   TEST FLUID SPECIFIC HEAT....  .24          BTU/LB-F

** ACTIVE - BUILDING STORAGE SYSTEM **
1  CITY CALL NUMBER..............  127
2  BUILDING UA...................  400          BTU/HR-F
3  BUILDING STORAGE CAPACITY.....  12900        BTU/F
4  LOW THERMOSTAT SET TEMPERATURE  68           F
5  DAILY INTERNAL GENERATION.....  86000        BTU/DAY
6  ALLOWABLE TEMPERATURE SWING...  10           F
7  FUEL (1=EL,2=NG,3=OIL,4=OTHER)  2
8  EFFICIENCY OF FUEL USAGE......  70           %
9  DUCT LOSSES (1=Y,2=N).........  1
10   INLET DUCT UA...............  19           BTU/HR-F
11   OUTLET DUCT UA..............  19           BTU/HR-F
12   PERCENT DUCT LEAK RATE......  15           %
13   LEAK LOC (1=IN,2=OUT,3=BOTH)  3
14 DOMESTIC HOT WATER (1=Y,2=N)..  2
15   DAILY HOT WATER USAGE.......  80           GALLONS
16   WATER SET TEMPERATURE.......  140          F
17   ENVIRONMENT TEMPERATURE.....  68           F
18   UA OF AUX STORAGE TANK......  7.6          BTU/HR-F
19   HX WATER FLOWRATE...........  2000         LB/HR
20   AIR/WATER HX EFFECTIVENESS..  .5

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  0
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EMG

** ACTIVE - BUILDING STORAGE SYSTEM **
** FLAT PLATE COLLECTOR **

	SOLAR MMBTU	HEAT MMBTU	DHW MMBTU	AUX MMBTU	F
JAN	2.6	12.5	0.0	12.5	0.00
FEB	2.9	10.4	0.0	10.4	0.00
MAR	3.2	8.6	0.0	8.6	0.00
APR	2.7	4.1	0.0	4.0	0.03
MAY	2.7	1.6	0.0	1.3	0.22
JUN	2.6	0.3	0.0	0.0	1.00
JUL	2.8	0.1	0.0	0.0	1.00
AUG	3.1	0.2	0.0	0.0	1.00
SEP	3.1	0.9	0.0	0.0	1.00
OCT	3.3	3.0	0.0	2.4	0.20
NOV	2.1	7.0	0.0	7.0	0.01
DEC	1.9	11.1	0.0	11.1	0.00
YR	32.9	59.9	0.0	57.2	0.05

```
04-02-1987
GENSOL

** FLAT PLATE COLLECTOR **
1  NUMBER OF COLLECTOR PANELS....  3
2  COLLECTOR PANEL AREA..........  34          FT2
3  FR*UL (TEST SLOPE)............  1.02        BTU/HR-FT2-F
4  FR*TAU*ALPHA (TEST INTERCEPT).  .53
5  COLLECTOR SLOPE...............  57          DEG
6  COLLECTOR AZIMUTH (SOUTH=0)...  0           DEG
7  INCIDENCE ANGLE MOD TYPE(8-10)  8
8    NUMBER OF GLAZINGS..........  1
9    INC ANGLE MODIFIER CONSTANT.  .063
10   INC ANGLE MODIFIER VALUE(S).
  1   .999   .998   .995   .981   .953   .882
  .7   .35   0
11 COLLECTOR FLOWRATE/AREA.......  37          LB/HR-FT2
12 COLLECTOR FLUID SPECIFIC HEAT.  .24         BTU/LB-F
13 MODIFY TEST VALUES (1=Y,2=N)..  2
14   TEST COLLECTOR FLOWRATE/AREA  9           LB/HR-FT2
15   TEST FLUID SPECIFIC HEAT....  .24         BTU/LB-F

** ACTIVE - BUILDING STORAGE SYSTEM **
1  CITY CALL NUMBER..............  127
2  BUILDING UA...................  400         BTU/HR-F
3  BUILDING STORAGE CAPACITY.....  12900       BTU/F
4  LOW THERMOSTAT SET TEMPERATURE  68          F
5  DAILY INTERNAL GENERATION.....  86000       BTU/DAY
6  ALLOWABLE TEMPERATURE SWING...  10          F
7  FUEL (1=EL,2=NG,3=OIL,4=OTHER)  2
8  EFFICIENCY OF FUEL USAGE......  70          %
9  DUCT LOSSES (1=Y,2=N).........  1
10   INLET DUCT UA...............  19          BTU/HR-F
11   OUTLET DUCT UA..............  19          BTU/HR-F
12   PERCENT DUCT LEAK RATE......  15          %
13   LEAK LOC (1=IN,2=OUT,3=BOTH)  3
14 DOMESTIC HOT WATER (1=Y,2=N)..  1
15   DAILY HOT WATER USAGE.......  80          GALLONS
16   WATER SET TEMPERATURE.......  140         F
17   ENVIRONMENT TEMPERATURE.....  68          F
18   UA OF AUX STORAGE TANK......  7.6         BTU/HR-F
19   HX WATER FLOWRATE...........  2000        LB/HR
20   AIR/WATER HX EFFECTIVENESS..  .5

*** ECONOMICS ***
1  ECON ANALYSIS DETAIL (0 TO 4).  0
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GENSOL

** ACTIVE - BUILDING STORAGE SYSTEM **
** FLAT PLATE COLLECTOR **

	SOLAR MMBTU	HEAT MMBTU	DHW MMBTU	AUX MMBTU	F
JAN	2.9	12.5	2.4	14.9	0.00
FEB	3.4	10.4	2.2	12.5	0.01
MAR	4.2	8.6	2.4	10.7	0.03
APR	4.1	4.1	2.3	5.8	0.10
MAY	4.6	1.6	2.4	2.8	0.30
JUN	4.6	0.3	2.3	2.3	0.12
JUL	4.9	0.1	2.3	2.3	0.08
AUG	4.9	0.2	2.3	2.3	0.10
SEP	4.4	0.9	2.3	2.3	0.29
OCT	4.0	3.0	2.4	4.5	0.17
NOV	2.4	7.0	2.3	9.2	0.02
DEC	2.1	11.1	2.4	13.4	0.00
YR	46.6	59.9	27.9	82.7	0.06

APPENDIX D

MODEL COMPUTER CODE

(Note: this code was used in conjunction with NREG77, a nonlinear regression subroutine, to perform the zero capacitance analyses described in this work. The code used for the infinite capacitance analyses is not presented.)

```
*****************************************************************
*        SYSTEM MODEL- ZERO STORAGE VERSION
*                    - INTERNAL GAINS ARE INPUT VALUES
*                    - FURNACE TURNED OFF IN SUMMER MONTHS
*
* THIS PROGRAM CALCULATES THE COEFFICIENTS OF A HOUSE HEATING-
* FUEL CONSUMPTION MODEL USING NREG77

*
*  NOTE:  1) "NO" IS A POSITIVE INTEGER VARIABLE SET TO THE NUMBER
                      OF  OBSERVATIONS

*
*              2) "NP" IS A POSITIVE INTEGER VARIABLE SET TO THE
                  NUMBER OF VARIABLES

*
*****************************************************************
*
C
      IMPLICIT DOUBLE PRECISION (A-Z)
      INTEGER J,M,N,INFO,SYSTEM,MAXMOD,LS,NO,
*                     NP,I,K,FIXEDP,PREVFXDP
      INTEGER FLAG,IOTA(4),NPRT(4),IOPT(4)
C
      DOUBLE PRECISION Y(50),TH(5),R(50),TOL(3),S(500),COLLHR(60)
      DOUBLE PRECISION TGR(64),TGROUND(60),E(5),AUX(60),ATDIFBAR(60)
      DOUBLE PRECISION ARADBAR(60),HOUR(60),ACTIVE(60),DUMP(60)
      DOUBLE PRECISION INTGAINS(60),DELP(4),P(4),C(4),XDELP(4)
 C
      REAL XDATE,XTIME,XRAD,XTAMB,XRADTILT
C
      CHARACTER*15 NAME
      CHARACTER*15 TYPE
      CHARACTER*6 DATE
C
      COMMON AUX,ATDIFBAR,ARADBAR,HOUR,COLLHR,TGR,
      *TGROUND,TDAY,
     *TNIGHT,FDHWFC,ACFRTA,ACTIVE,DUMP,LOSSENON,PASSGN,
     *ACFRUL,INTGAINS,PPLDHWCK,ESTACFRTAN,FIXEDP,P,PREVFXDP
      EXTERNAL MODEL,SOLFRAC,TMY,RMS,COST,PRINT,NREG77
C
      COMMON /STAT/ DELP
C
      DATA IOPT/0,0,1,0/
      DATA NPRT/1,0,1,0/
      DATA TOL/1.E-4,1.E-4,0/
      LS=500
      SUMCOLHR=0.
      FLAG=0
      TOTFLUSE=0
      EPSMOD=1.E-8
      MAXMOD=1200
      FIXEDP=0
      PREVFXDP=10
```

```
C
C ASSIGN FIRST FIVE GROUND TEMPERATURES
C
      TGR(1)=42
      TGR(2)=43
      TGR(3)=37
      TGR(4)=39
      TGR(5)=12
C
C  DEFINE INITIAL COEFFICIENT VALUES
C
      TH(1)=500
      TH(2)=10
      TH(3)=150
      TH(4)=200
      E(1)=TH(1)
      E(2)=-TH(2)*TH(2)
      E(3)=TH(3)
      E(4)=TH(4)
C
C  READ INPUT PARAMETERS
C
      READ(2,163) NAME,TYPE
      READ(2,*) NO,NP
      READ(2,*) FDHWFC,ACFRTA,ESTACFRTAN,ACFRUL,PPLDHWCK
      READ(2,*) TDAY,TNIGHT
163   FORMAT(T1,2A12)
C
C       ASSIGN THE Y ARRAY- MEASURED FUEL USE VALUES IN THERMS
C
        DO 9 J=1,NO
8         CONTINUE
          READ(2,*) ENDDT,ENDHR,AUXDATA,ELECDATA,SYSTEM
          IF(SYSTEM.LT.0) GOTO 8
          Y(J)=AUXDATA
9       CONTINUE
C
      REWIND 2
      READ(2,163) NAME,TYPE
      READ(2,*) NO,NP
      READ(2,*) FDHWFC,ACFRTA,ESTACFRTAN,ACFRUL,PPLDHWCK
      READ(2,*) TDAY,TNIGHT
C
C  CALL THE REGRESSION SUBROUTINE "NREG77" (REFER TO THE NREG MANUAL)
C
      CALL NREG77(NO,NP,TH,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
C
C  CALL THE SUBROUTINE WHICH PRINTS OUT THE WEEKLY
C   INTERMEDIATE RESULTS
C
      CALL PRINT(NAME,TYPE,TH,E)
C
C  CALL THE SUBROUTINE WHICH CALCULATES THE SOLAR FRACTION
C  FOR THE
```

```
C  PERIOD OVER WHICH DATA WERE MEASURED
C
      CALL SOLFRAC(TH)
C
C  CALL THE SUBROUTINE WHICH DOES THE TMY CALCULATION
C
      CALL TMY(TH)
C
C  CALCULATE THE 95% CONFIDENCE INTERVAL FOR THE PREDICTED
C  ENERGY SAVED AND SOLAR FRACTION
C
      DO 162 I=1,4
        XDELP(I)=DELP(I)
162   CONTINUE
      NPRT(3)=0
      FIXEDP=1
      P(1)=TH(2)
      P(2)=TH(3)
      P(3)=TH(4)
      P(4)=TH(1)+XDELP(1)
      C(1)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(2)=P(1)
      C(3)=P(2)
      C(4)=P(3)
      CALL TMY(C)
      P(1)=TH(2)
      P(2)=TH(3)
      P(3)=TH(4)
      P(4)=TH(1)-XDELP(1)
      C(1)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(2)=P(1)
      C(3)=P(2)
      C(4)=P(3)
      CALL TMY(C)
C
      FIXEDP=2
      P(1)=TH(1)
      P(2)=TH(3)
      P(3)=TH(4)
      P(4)=TH(2)+XDELP(2)
      C(2)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(3)=P(2)
      C(4)=P(3)
      CALL TMY(C)
      P(1)=TH(1)
      P(2)=TH(3)
      P(3)=TH(4)
      P(4)=TH(2)-XDELP(2)
```

```
      C(2)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(3)=P(2)
      C(4)=P(3)
      CALL TMY(C)
C
      FIXEDP=3
      P(1)=TH(1)
      P(2)=TH(2)
      P(3)=TH(4)
      P(4)=TH(3)+XDELP(3)
      C(3)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(2)=P(2)
      C(4)=P(3)
      CALL TMY(C)
      P(4)=TH(3)-XDELP(3)
      P(1)=TH(1)
      P(2)=TH(2)
      P(3)=TH(4)
      C(3)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(2)=P(2)
      C(4)=P(3)
      CALL TMY(C)
C
      FIXEDP=4
      P(1)=TH(1)
      P(2)=TH(2)
      P(3)=TH(3)
      P(4)=TH(4)+XDELP(4)
      C(4)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(2)=P(2)
      C(3)=P(3)
      CALL TMY(C)
      P(1)=TH(1)
      P(2)=TH(2)
      P(3)=TH(3)
      P(4)=TH(4)-XDELP(4)
      C(4)=P(4)
      CALL NREG77(NO,3,P,Y,MODEL,JACOB,EPSMOD,IOPT,TOL,MAXMOD,
     *NPRT,INFO,S,LS)
      C(1)=P(1)
      C(2)=P(2)
      C(3)=P(3)
      CALL TMY(C)
```

```
      STOP
      END
*********************************************************************
* THIS SUBROUTINE IS CALLED BY NREG77.  IT
* CALCULATES A SET OF FUEL CONSUMPTION VALUES FOR A GIVEN SET
* OF PARAMETERS, AND RETURNS THE VALUES TO NREG77.

*********************************************************************
*
      SUBROUTINE MODEL(NO,NP,Y,THP,R)
      IMPLICIT DOUBLE PRECISION (A-Z)
C
      CHARACTER*15 NAME
      CHARACTER*15 TYPE
C
      INTEGER NO,NP,SYSTEM,PREVFXDP
      INTEGER I,J,H,FIXEDP
C
      DOUBLE PRECISION AUX(60),ATDIFBAR(60),ARADBAR(60),HOUR(60)
      DOUBLE PRECISION TGR(64),TGROUND(60),COLLHR(60),DUMP(60),P(4)
      DOUBLE PRECISION Y(NO),TH(4),R(NO),ACTIVE(60),INTGAINS(60),
     *THP(4)
C
      REAL XDATE,XTIME,XRAD,XTAMB,XRADTILT
C
     COMMON AUX,ATDIFBAR,ARADBAR,HOUR,COLLHR,TGR,TGROUND,
    *TDAY,TNIGHT,FDHWFC,ACFRTA,ACTIVE,DUMP,LOSSENON,PASSGN,
     *ACFRUL,INTGAINS,PPLDHWCK,ESTACFRTAN,FIXEDP,P,PREVFXDP
C
      DO 125 I=1,NP
        P(I)=THP(I)
125   CONTINUE
      RES=0
C
      IF(FIXEDP.EQ.0.OR.FIXEDP.EQ.4) THEN
      TH(1)=P(1)
      TH(2)=P(2)
      TH(3)=P(3)
      TH(4)=P(4)
      ENDIF
C
      IF(FIXEDP.EQ.1) THEN
      TH(1)=P(4)
      TH(2)=P(1)
      TH(3)=P(2)
      TH(4)=P(3)
      ENDIF
C
      IF(FIXEDP.EQ.2) THEN
      TH(1)=P(1)
      TH(2)=P(4)
      TH(3)=P(2)
      TH(4)=P(3)
      ENDIF
C
```

```
      IF(FIXEDP.EQ.3) THEN
      TH(1)=P(1)
      TH(2)=P(2)
      TH(3)=P(4)
      TH(4)=P(3)
      ENDIF
C
      TANNAVG=45.1
      I=0
      H=0
      EFF=0.65
      PASSGN=-TH(2)*TH(2)
      LOSSENON=TH(4)
C
130   CONTINUE
C
C  READ DATA FOR PERIOD UNDER CONSIDERATION
C
      READ(2,*,END=160) ENDDT,ENDHR,AUXDATA,ELECDATA,SYSTEM
C
      H=H+1
      J=0
      TAVG=0
      IF(SYSTEM.GE.0) GOTO 131
132   CONTINUE
      J=J+1
      READ(1) XDATE,XTIME,XRAD,XTAMB,XRADTILT
      DATE=XDATE
      TIME=XTIME
      TAVG=TAVG+XTAMB
      IF(DATE.EQ.ENDDT.AND.TIME.EQ.ENDHR) THEN
      TGR(H+5)=TAVG/J
      GOTO 130
      ENDIF
      GOTO 132
131   CONTINUE
      I=I+1
      COLLHR(I)=0.
      ACTIVE(I)=0.
      XS=0
C
C  CONVERT AUXDATA FROM THERMS TO BTU
      AUXDATA=AUXDATA*1.E5
C  CONVERT ELECTRICAL DATA FROM WATTS TO BTU/HR
      ELECDATA=ELECDATA*3.413
C  INTERNAL GAINS = ELECTRICAL USE + PEOPLE + DHW TANK LOSSES + c C
COOKING
      INTGAINS(I)=(-ELECDATA-PPLDHWCK)/EFF
C
C  CALCULATE GROUND TEMPERATURE
C
      TGRAVG=(TGR(H+4)+TGR(H+3)+TGR(H+2)+TGR(H+1)+TGR(H))/5
      TGROUND(I)=(TGRAVG+TANNAVG)/2
C
      AUXCALC=0.
```

```
      RADBAR=0.
      TDIFBAR=0.
      TAVG=0.
      J=0
140   CONTINUE
      READ(1) XDATE,XTIME,XRAD,XTAMB,XRADTILT
      DATE=XDATE
      TIME=XTIME
      RAD=XRAD
      TAMB=XTAMB
      RADTILT=XRADTILT
C
C  SET HOUSE TEMPERATURES
C
      THOUSE=TDAY
C
      IF(TIME.LT.7.OR.TIME.GT.23.) THOUSE=TNIGHT
C
      J=J+1
C
C  CALCULATE HOURLY AUX AND ADD TO PREVIOUS TOTAL
C
C  IF "SYSTEM"=1, ACTIVE SOLAR SYSTEM IS ENABLED
C  IF "SYSTEM'=0, ACTIVE SOLAR SYSTEM IS DISABLED
C
      BASICHS=TH(1)*(THOUSE-
TAMB)+INTGAINS(I)+PASSGN*RAD+TH(3)*(THOUSE-
     *TGROUND(I))
      IF(SYSTEM.EQ.1) GOTO 200
      IF(BASICHS.LT.0.) THEN
      XS=XS-BASICHS
      BASICHS=0.
      ENDIF
      AUXCALC=AUXCALC+BASICHS
      GOTO 210
200   CONTINUE
C
C  IF COLLECTOR BALANCE (COLLBAL) IS POSITIVE, IDEAL CONTROLLER
C  TURNS
C  BLOWER ON
C
      COLLBAL=ESTACFRTAN*RADTILT-LOSSENON*(THOUSE-TAMB)
      IF(THOUSE.LT.TAMB) COLLBAL=0.
      BALENOFF=BASICHS
      IF(BALENOFF.GT.0.AND.COLLBAL.GT.0.) GOTO 220
      IF(BALENOFF.LT.0) THEN
      XS=XS-BALENOFF
      BALENOFF=0.
      ENDIF
      AUXCALC=AUXCALC+BALENOFF
      GOTO 210
220   CONTINUE
      BALENON=BASICHS-COLLBAL
      CNTRBUTN=COLLBAL
      IF(BALENON.LT.0.) THEN
```

```
      XS=XS-BALENON
      BALENON=0.
      ENDIF
      AUXCALC=AUXCALC+BALENON
      COLLHR(I)=COLLHR(I)+1.
      ACTIVE(I)=ACTIVE(I)-CNTRBUTN
210   CONTINUE
      TDIFBAR=TDIFBAR+(THOUSE-TAMB)
      RADBAR=RADBAR+RAD
      TAVG=TAVG+TAMB
      IF(DATE.EQ.ENDDT.AND.TIME.EQ.ENDHR) THEN
      AUXCALC=AUXCALC+FDHWFC*J
      R(I)=(AUXCALC-AUXDATA)*1.E-5
      RES=RES+R(I)*R(I)
      AUX(I)=AUXCALC/J
      ATDIFBAR(I)=TDIFBAR/J
      TGR(H+5)=TAVG/J
      ARADBAR(I)=RADBAR/J
      HOUR(I)=J
      ACTIVE(I)=ACTIVE(I)/J
      DUMP(I)=XS
      GO TO 130
      ENDIF
      GO TO 140
160   CONTINUE
162   FORMAT(8F5.1)
      REWIND 2
      REWIND 1
      READ(2,163) NAME,TYPE
      READ(2,*) XNO,XNP
      READ(2,*) FDHWFC,ACFRTA,ESTACFRTAN,ACFRUL,PPLDHWCK
      READ(2,*) TDAY,TNIGHT
163   FORMAT(T1,2A12)
      RETURN
      END
C
*********************************************************************
* THIS SUBROUTINE CALCULATES THE SOLAR FRACTION FOR THE ENTIRE
* WEATHER DATA FILE TIME PERIOD USING THE MODEL COEFFICIENTS
* FOUND IN THE REGRESSION ANALYSIS.

*********************************************************************
    SUBROUTINE SOLFRAC(C)
      IMPLICIT DOUBLE PRECISION (A-Z)
C
      CHARACTER*15 NAME
      CHARACTER*15 TYPE
C
      INTEGER M,N,SYSTEM,PREVFXDP
      INTEGER I,J,FIXEDP
C
      DOUBLE PRECISION AUX(60),ATDIFBAR(60),ARADBAR(60),HOUR(60)
      DOUBLE PRECISION TGR(64),TGROUND(60),COLLHR(60),ACTIVE(60)
      DOUBLE PRECISION Y(60),C(5),DUMP(60),INTGAINS(60),P(4)
C
```

```
      REAL XDATE,XTIME,XRAD,XTAMB,XRADTILT
C
      COMMON AUX,ATDIFBAR,ARADBAR,HOUR,COLLHR,TGR,TGROUND,
     *TDAY,TNIGHT,FDHWFC,ACFRTA,ACTIVE,DUMP,LOSSENON,PASSGN,
     *ACFRUL,INTGAINS,PPLDHWCK,ESTACFRTAN,FIXEDP,P,PREVFXDP
C
      REWIND 1
      REWIND 2
      READ(2,163) NAME,TYPE
163   FORMAT(T1,2A10)
      READ(2,*) M,N
      READ(2,*) FDHWFC,ACFRTA,ESTACFRTAN,ACFRUL,PPLDHWCK
      READ(2,*) TDAY,TNIGHT
      I=0
      AUXEN=0.
      AUXDIS=0.
      COLLHRS=0.
      TOTFDFC=0.
      XSEN=0.
      XSDIS=0.
340   CONTINUE
      I=I+1
      READ(2,*,END=350) ENDDT,ENDHR,AUXDATA,ELECDATA,SYSTEM
C
      IF(SYSTEM.GE.0) GOTO 1131
      I=I-1
1132   CONTINUE
      READ(1) XDATE,XTIME,XRAD,XTAMB,XRADTILT
      DATE=XDATE
      TIME=XTIME
      IF(DATE.EQ.ENDDT.AND.TIME.EQ.ENDHR) GOTO 340
      GOTO 1132
1131   CONTINUE
      READ(1) XDATE,XTIME,XRAD,XTAMB,XRADTILT
      DATE=XDATE
      TIME=XTIME
      RAD=XRAD
      TAMB=XTAMB
      RADTILT=XRADTILT
C
C  SET HOUSE TEMPERATURES
C
      THOUSE=TDAY
C
      IF(TIME.LT.7.OR.TIME.GT.23.) THOUSE=TNIGHT
C
C  CALCULATE HOURLY AUX AND ADD TO PREVIOUS TOTAL
C
      BASICHS=C(1)*(THOUSE-TAMB)+INTGAINS(I)+PASSGN*RAD+C(3)*
     *(THOUSE-TGROUND(I))
      BASICHSDIS=BASICHS
      IF(BASICHS.LT.0.) THEN
      XSDIS=XSDIS-BASICHS
      BASICHSDIS=0.
      ENDIF
```

```
      AUXDIS=AUXDIS+BASICHSDIS
C
C  IF COLLECTOR BALANCE (COLLBAL) IS POSITIVE, IDEAL CONTROLLER
C  TURNS
C  BLOWER ON
C
      COLLBAL=ESTACFRTAN*RADTILT-LOSSENON*(THOUSE-TAMB)
      IF(THOUSE.LT.TAMB) COLLBAL=0.
      BALENOFF=BASICHS
      IF(BALENOFF.GT.0.AND.COLLBAL.GT.0.) GOTO 320
      IF(BALENOFF.LT.0) THEN
      XSEN=XSEN-BALENOFF
      BALENOFF=0.
      ENDIF
      AUXEN=AUXEN+BALENOFF
      GOTO 310
320   CONTINUE
      BALENON=BASICHS-COLLBAL
      IF(BALENON.LT.0.) THEN
      XSEN=XSEN-BALENON
      BALENON=0.
      ENDIF
      AUXEN=AUXEN+BALENON
      COLLHRS=COLLHRS+1.
310   CONTINUE
      IF(DATE.EQ.ENDDT.AND.TIME.EQ.ENDHR) THEN
      TOTFDFC=TOTFDFC+FDHWFC*HOUR(I)
      GOTO 340
      ENDIF
      GOTO 1131
350   CONTINUE
C
C  CONVERT AUX. VALUES FROM BTUs TO THERMs
C
      SOLARFRC=(AUXDIS-AUXEN)/(AUXDIS)*100.
      AUXDIS=(AUXDIS+TOTFDFC)/1.E5
      AUXEN=(AUXEN+TOTFDFC)/1.E5
      AUXDIFF=AUXDIS-AUXEN
      WRITE(6,300) AUXDIS,AUXEN,AUXDIFF,SOLARFRC,COLLHRS
300   FORMAT(/,/,1X,'FUEL USE WITHOUT ACTIVE SOLAR=',F8.1,
     *'  [THERMS]',/,
     */,4X,'FUEL USE WITH ACTIVE SOLAR=',F8.1,'  [THERMS]',
     */,/,12X,'PREDICTED ENERGY SAVED=',F8.1,'  [THERMS]',
     */,/,16X,'SOLAR FRACTION=',F8.1,' %',/,/,' HOURS OF
     *COLLECTOR OPERATION FOR CONTINUALLY ENABLED SYSTEM:',F6.0)
      RETURN
      END
*********************************************************************
*
*  THIS SUBROUTINE CALCULATES THE ACTIVE SOLAR ENERGY
*  CONTRIBUTION AND
* THE SOLAR FRACTION FOR A MADISON TYPICAL
* METEOROLOGICAL YEAR
*********************************************************************
    SUBROUTINE TMY(C)
```

```
      IMPLICIT DOUBLE PRECISION (A-Z)
C
      CHARACTER*15 NAME
      CHARACTER*15 TYPE
C
      INTEGER M,N,SYSTEM,PREVFXDP
      INTEGER I,J,FIXEDP
C
      DOUBLE PRECISION AUX(60),ATDIFBAR(60),ARADBAR(60),HOUR(60)
      DOUBLE PRECISION TGR(64),TGROUND(60),COLLHR(60),ACTIVE(60)
      DOUBLE PRECISION Y(60),C(5),DUMP(60),INTGAINS(60),P(4)
      DOUBLE PRECISION SEPLSMNS(4)
C
      REAL XDATE,XTIME,XRAD,XTAMB,XRADTILT,XTGR
C
      COMMON AUX,ATDIFBAR,ARADBAR,HOUR,COLLHR,TGR,TGROUND,
     *TDAY,TNIGHT,FDHWFC,ACFRTA,ACTIVE,DUMP,LOSSENON,PASSGN,
     *ACFRUL,INTGAINS,PPLDHWCK,ESTACFRTAN,FIXEDP,P,PREVFXDP
C
      COMMON /TMYHRS/ COLLHRS
      REWIND 1
      REWIND 2
      REWIND 3
C
      AUXEN=0.
      AUXDIS=0.
      TOTFDFC=0.
      COLLHRS=0.
      READ(2,5163) NAME,TYPE
5163   FORMAT(T1,2A10)
      READ(2,*) M,N
      READ(2,*) FDHWFC,ACFRTA,ESTACFRTAN,ACFRUL,PPLDHWCK
      READ(2,*) TDAY,TNIGHT
      XSEN=0.
      XSDIS=0.
      INTGNS=-7000.
5340  CONTINUE
      READ(3,END=5350) XDATE,XTIME,XRAD,XTAMB,XRADTILT,XTGR
      IF(XDATE.GT.120.AND.XDATE.LT.274) GOTO 5340
      DATE=XDATE
      TIME=XTIME
      RAD=XRAD
      TAMB=XTAMB
      RADTILT=XRADTILT
      TGRND=XTGR
C
C  SET HOUSE TEMPERATURES
C
      THOUSE=TDAY
C
      IF(TIME.LT.7.OR.TIME.GT.23.) THOUSE=TNIGHT
C
C  CALCULATE HOURLY AUX AND ADD TO PREVIOUS TOTAL
C
      BASICHS=C(1)*(THOUSE-TAMB)+INTGNS+PASSGN*RAD+C(3)*(THOUSE-
```

```
     *TGRND)
      BASICHSDIS=BASICHS
      IF(BASICHS.LT.0.) THEN
      XSDIS=XSDIS-BASICHS
      BASICHSDIS=0.
      ENDIF
      AUXDIS=AUXDIS+BASICHSDIS
C
C  IF COLLECTOR BALANCE (COLLBAL) IS POSITIVE, IDEAL CONTROLLER
C  TURNS
C  BLOWER ON
C
      COLLBAL=ESTACFRTAN*RADTILT-LOSSENON*(THOUSE-TAMB)
      IF(THOUSE.LT.TAMB) COLLBAL=0.
      BALENOFF=BASICHS
      IF(BALENOFF.GT.0.AND.COLLBAL.GT.0.) GOTO 5320
      IF(BALENOFF.LT.0) THEN
      XSEN=XSEN-BALENOFF
      BALENOFF=0.
      ENDIF
      AUXEN=AUXEN+BALENOFF
      GOTO 5310
5320   CONTINUE
      BALENON=BASICHS-COLLBAL
      IF(BALENON.LT.0.) THEN
      XSEN=XSEN-BALENON
      BALENON=0.
      ENDIF
      AUXEN=AUXEN+BALENON
      COLLHRS=COLLHRS+1.
5310   CONTINUE
      GOTO 5340
5350   CONTINUE
C
C  CONVERT AUX. VALUES FROM BTUs TO THERMs
C
      TOTFDFC=FDHWFC*5088
      SOLARFRC=(AUXDIS-AUXEN)/(AUXDIS)*100.
      AUXDIS=(AUXDIS+TOTFDFC)/1.E5
      AUXEN=(AUXEN+TOTFDFC)/1.E5
      AUXDIFF=AUXDIS-AUXEN
C
      WRITE(6,5300) AUXDIS,AUXEN,AUXDIFF,SOLARFRC,COLLHRS
5300  FORMAT(/,/,20X,'******** RESULTS USING WEATHER DATA FOR A
TYPICAL
     * METEOROLOGICAL YEAR ********',/,/,1X,
     *'TMY FUEL USE WITHOUT ACTIVE SOLAR=',F8.1,'  [THERMS]',/,
     */,4X,'TMY FUEL USE WITH ACTIVE SOLAR=',F8.1,'  [THERMS]',
     */,/,12X,'TMY ENERGY SAVED=',F8.1,'  [THERMS]',
     */,/,16X,'TMY SOLAR FRACTION=',F8.1,' %',/,/,'  TMY HOURS OF
     *COLLECTOR OPERATION FOR CONTINUALLY ENABLED SYSTEM:',F6.0)
C
C  CALCULATE ROOT MEAN SQUARE OF PREDICTED ENERGY SAVED
C
      IF(FIXEDP.EQ.0) THEN
```

```
      AUXDIFF0=AUXDIFF
      SOLARFRC0=SOLARFRC
      ENDIF
C
      IF(PREVFXDP.EQ.FIXEDP) THEN
      SEPLSMNS(FIXEDP)=(AUXDIFF-PREVAUXDIFF)/2.
      ENDIF
C
      IF(PREVFXDP.EQ.4) CALL RMS(AUXDIFF0,SOLARFRC0,SEPLSMNS)
      PREVFXDP=FIXEDP
      PREVAUXDIFF=AUXDIFF
      RETURN
      END
*****************************************************************
*  THIS SUBROUTINE CALCULATES THE 95% CONFIDENCE INTERVAL FOR THE
PREDICTED ENERGY SAVED AND SOLAR FRACTION
*****************************************************************
      SUBROUTINE RMS(AUXDIFF0,SOLARFRC0,SEPLSMNS)
      IMPLICIT DOUBLE PRECISION (A-Z)
      INTEGER I
      DOUBLE PRECISION SEPLSMNS(4)
C
      SUM=0.
        DO 165 I=1,4
          SUM=SUM+SEPLSMNS(I)**2
165     CONTINUE
      DELTAES=SQRT(SUM)
      DELTASF=SOLARFRC0*DELTAES/AUXDIFF0
      WRITE(6,170) AUXDIFF0,DELTAES,SOLARFRC0,DELTASF
170   FORMAT(/,5X,'PREDICTED FUEL ENERGY SAVED IS',F7.1,' THERMS PLUS
     * OR MINUS',F6.1,/,5X,'PREDICTED SOLAR FRACTION IS',F6.1,
     *'  PLUS OR MINUS',F6.1)
      CALL COST(AUXDIFF0,DELTAES)
      RETURN
      END
*****************************************************************
* THIS SUBROUTINE PRINTS OUT THE REGRESSION RESULTS ON A
* BTU/HOUR BASIS *
*****************************************************************
C
      SUBROUTINE PRINT(NAME,TYPE,TH,E)
C
      IMPLICIT DOUBLE PRECISION (A-Z)
      INTEGER J,M,N,INFO,SYSTEM,MAXMOD,LS,NO,NP,I,K,FIXEDP,
     *PREVFXDP
      INTEGER FLAG,IOTA(4),NPRT(4),IOPT(4)
      DOUBLE PRECISION Y(50),TH(5),R(50),TOL(3),S(500),COLLHR(60)
      DOUBLE PRECISION TGR(64),TGROUND(60),E(5),AUX(60),ATDIFBAR(60)
      DOUBLE PRECISION ARADBAR(60),HOUR(60),ACTIVE(60),DUMP(60)
      DOUBLE PRECISION INTGAINS(60),DELP(4),P(4),C(4),XDELP(4)
      CHARACTER*15 NAME
      CHARACTER*15 TYPE
      CHARACTER*6 DATE
      COMMON AUX,ATDIFBAR,ARADBAR,HOUR,COLLHR,TGR,TGROUND,
     *TDAY,TNIGHT,FDHWFC,ACFRTA,ACTIVE,DUMP,LOSSENON,PASSGN,
```

```
     *ACFRUL,INTGAINS,PPLDHWCK,ESTACFRTAN,FIXEDP,P,PREVFXDP
C
      WRITE(6,508)
508   FORMAT(5X,'************* ZERO STORAGE VERSION OF HOUSE
     *SPACE-HEATING MODEL  ***************'/)
      CALL IDATE(I,J,K)
      WRITE(6,510) NAME,TYPE,I,J,K
510   FORMAT(/,1X,'SYSTEM OWNER: ',A10,5X,'SYSTEM TYPE: ',A10,5X,
     *'DATE OF EXECUTION:  'I2,'/',I2,'/',I2)
      WRITE(6,512)
512   FORMAT(/,/,1X,'PERIOD 0=DIS END  # OF  TH-TA PASS COLL  TGROUND
     *  MEAS.   CALC.   DIFF.   SKIN    BSMT    PASSIVE ACTIVE
     *  INTRNL  DUMPED',/,1X,'ENDING 1=EN  DATE HOURS',7X,'RAD
     *  HOURS'
     *,10X,'AUX.    AUX.',12X,'LOSSES  LOSSES  GAINS   GAINS
     * GNS/n   EXCESS',/,25X,'[F]  [B/H-F2]      [F]   [--------------
     *---------------BTU/HOUR-------------------------------]'
     *,/)
      I=0.
18    CONTINUE
      READ(2,*,END=19) ENDDT,ENDHR,AUXDATA,ELECDATA,SYSTEM
      IF(SYSTEM.LT.0) THEN
      IF(SYSTEM.LT.-1) THEN
      IF(FLAG.EQ.0) WRITE(6,26)
26    FORMAT(/,6X,'*************************************************
     *   FURNACE TURNED OFF  ****************************************
     **********',/)
      FLAG=1
      ENDIF
      GOTO 18
      ENDIF
      I=I+1.
      DATE='JAN,87'
         IF(ENDDT.LE.730) DATE='DEC,86'
         IF(ENDDT.LE.699) DATE='NOV,86'
         IF(ENDDT.LE.669) DATE='OCT,86'
         IF(ENDDT.LE.638) DATE='SEP,86'
         IF(ENDDT.LE.608) DATE='AUG,86'
         IF(ENDDT.LE.577) DATE='JUL,86'
         IF(ENDDT.LE.546) DATE='JUN,86'
         IF(ENDDT.LE.516) DATE='MAY,86'
         IF(ENDDT.LE.485) DATE='APR,86'
         IF(ENDDT.LE.455) DATE='MAR,86'
         IF(ENDDT.LE.424) DATE='FEB,86'
         IF(ENDDT.LE.396) DATE='JAN,86'
         IF(ENDDT.LE.365) DATE='DEC,85'
      TOTFLUSE=TOTFLUSE+AUXDATA
      AUXDATA=AUXDATA*1.E5/HOUR(I)
      DIFF=AUXDATA-AUX(I)
      SKIN=TH(1)*ATDIFBAR(I)
      BSMT=TH(3)*((.67*TDAY+.33*TNIGHT)-TGROUND(I))
      PASSIVE=PASSGN*ARADBAR(I)
      SUMCOLHR=SUMCOLHR+COLLHR(I)
      DUMP(I)=DUMP(I)/HOUR(I)
159   CONTINUE
```

```
      WRITE(7,*) AUXDATA,AUX(I),SYSTEM
      WRITE(6,161) DATE,SYSTEM,ENDDT,HOUR(I),ATDIFBAR(I),ARADBAR(I),
     *COLLHR(I),TGROUND(I),AUXDATA,AUX(I),DIFF,SKIN,BSMT,
     *PASSIVE,ACTIVE(I),INTGAINS(I),DUMP(I)
161   FORMAT(1X,A6,I4,2X,2F5.0,F6.1,F7.1,F5.0,F7.1,1X,2F8.0,7F8.0)
      GO TO 18
19    CONTINUE
      WRITE(6,25) TDAY,TNIGHT,SUMCOLHR,TOTFLUSE
25    FORMAT(/,5X,'DAY TEMP=',F5.0,'   NIGHT TEMP=',F5.0,
     *5X,'CALC HOURS OF COLL OPERATION:',F6.0,5X,'TOTAL MEAS. FUEL
USE'
     *,F6.0,'  THERMS')
      WRITE(6,20) FDHWFC,ESTACFRTAN,ACFRTA,ACFRUL,PPLDHWCK,TH(1),E(1),
     *PASSGN,E(2),TH(3),E(3),LOSSENON,E(4)
20    FORMAT(/,/,5X,'INPUT PARAMETERS:',/,/,5X,'[Fdhw+Fc]=',15X,F10.2,
     *2X,'BTU/HR',/,/,5X,'[ACFRTAhouse/n]=',9X,F10.2,2X,'FT2',
     */,/,5X,'[AcFRTAtest]=',12X,F10.2,2X,'FT2',/,/,5X,
     *'[ACFRULtest]=',12X,F10.2,2X,'BTU/HR-F',/,/,5X,'[PEOPLE +
     * DHW TANK LOSSES',/,5X,'+ COOKING]=',14X,F10.2,2X,'BTU/HR',
     *4X,' A FURNACE EFFICIENCY OF 65% WAS ASSUMED FOR THE
     *INTERNAL
     * GAINS CALCULATION',
C
     */,/,5X,'OUTPUT PARAMETERS:',42X,'TYPICAL VALUES',
     */,/,1X,'1.  [(UA+CpMinf)/n]=',9X,F10.2,2X,'BTU/HR-F'
     *,18X,F8.0,/,/,1X,'2.  [-k/n]=',18X,F10.2,2X,'(BTU/HR)/(MODELBTU/
     *HR-FT2)',F8.0,2X,'(CONSTRAINED BELOW 0)',
     */,/,1X,'3.  [UA/n]bsmt=',14X,F10.2,2X,'BTU/HR-F',18X,F8.0,
     *2X,'Tground CALCULATION USES 5 WEEKS OF Tamb,weekly DATA',
     */,/,1X,'4.  [(CpM.L,on+
     *AcFRULon)/n]=',F11.2,2X,'BTU/HR-F',18X,F8.0)
      RETURN
      END
*************************************************************
* THIS SUBROUTINE CALCULATES THE BREAKEVEN COST OF THE ACTIVE *
* SYSTEM BASED ON ESTIMATED ECONOMIC INDICATORS               *
*************************************************************
C
      SUBROUTINE COST(AUXDIFF0,DELTAES)
C
      IMPLICIT DOUBLE PRECISION (A-Z)
      COMMON /TMYHRS/ COLLHRS
C  EXPECTED LIFE OF SYSTEM:
      LIFE=15
C  FUEL INFLATION RATE:
      FUELRATE=0.083
C  DISCOUNT RATE:
      DISCRATE=0.05
C  $/THERM:
      THERMCOST=0.62
C
C  PRESENT WORTH FACTOR CALCULATION:
      IF(FUELRATE.EQ.DISCRATE) THEN
      PWF=LIFE/(1+DISCRATE)
      GOTO 20
```

```
      ENDIF
C
      A=((1+FUELRATE)/(1+DISCRATE))**LIFE
      B=1/(DISCRATE-FUELRATE)
      PWF=B*(1-A)
20    CONTINUE
C
C  BREAKEVEN COST CALCULATION        BRKCOST=THERMCOST*AUXDIFF0*PWF
      DIFF=THERMCOST*DELTAES*PWF
C
      WRITE(6,10) LIFE,FUELRATE*100,DISCRATE*100,BRKCOST,DIFF
10    FORMAT(/,/,5X,'BASED ON:',/,5X,'EXPECTED LIFE=',F5.1,/,5X,
     *'FUEL INFLATION RATE=',F5.1,' %',/,5X,'MARKET DISCOUNT RATE=',
     *F5.1,' %',/,5X,'THE PREDICTED BREAK-EVEN COST OF THIS SYSTEM IS
     *',F6.0,' DOLLARS PLUS OR MINUS',F5.0,' DOLLARS')
C
      RETURN
      END
```

APPENDIX E

MODEL INPUT DATA FILES

The terminology used in this appendix is defined as follows:

Number of observations:	the number of gas meter readings that were used in the zero and infinite capacitance analyses of this particular house. Does not include summer season readings.
Estimated base fuel use:	the base fuel use used in the analyses. It was estimated by taking the average of the summer season fuel use.
Measured gain coefficient:	the collector $A_c F_R \tau\alpha$ value reported by the manufacturers.
Estimated gain coefficient: efficiency	the estimated value which was input to the model
Measured loss coefficient:	the collector $A_c F_R U_L$ value reported by the manufacturers
Estimated internal gains:	the estimated energy added to the heated space by people, DHW losses and cooking. In some cases this value has been adjusted heuristically to improve the results.
Date:	the number of the last day of the period for which fuel use is reported. 1 January 1985 is day 1.
Time:	the time of day at which the meter was read.
Fuel:	measured fuel use for the period.
System:	1 refers to enabled periods, 0 to disabled periods, -1 to vacation or problem periods, and -2 to the summer season.

SYSTEM NUMBER=1

HOMEOWNER: HAGEN SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 27.
EST. BASE FUEL USE: 5567. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 40. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 1500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
408.	13.	0.	-1.	610.	16.	8.	-2.
414.	10.	43.	0.	617.	9.	12.	-2.
421.	10.	43.	1.	624.	9.	9.	-2.
427.	9.	45.	0.	631.	9.	9.	-2.
435.	9.	41.	1.	638.	9.	9.	-2.
442.	9.	35.	0.	645.	9.	16.	-2.
449.	9.	36.	1.	652.	9.	18.	-1.
456.	8.	27.	0.	659.	9.	24.	0.
463.	9.	20.	1.	666.	9.	15.	1.
470.	9.	30.	0.	673.	9.	22.	0.
477.	9.	24.	1.	680.	9.	25.	1.
484.	9.	18.	-1.	687.	9.	43.	0.
491.	9.	17.	1.	694.	9.	35.	1.
498.	9.	18.	0.	701.	9.	36.	0.
505.	9.	16.	1.	708.	9.	40.	1.
512.	9.	16.	-1.	715.	9.	50.	0.
519.	9.	13.	-2.	722.	9.	39.	1.
526.	9.	14.	-2.	729.	9.	41.	0.
533.	9.	13.	-2.	736.	9.	40.	1.
540.	9.	10.	-2.	743.	9.	44.	0.
547.	9.	9.	-2.	750.	9.	45.	1.
554.	9.	11.	-2.	0.	0.	0.	0.
561.	11.	8.	-2.	0.	0.	0.	0.
568.	9.	11.	-2.	0.	0.	0.	0.
575.	15.	6.	-2.	0.	0.	0.	0.
589.	9.	13.	-2.	0.	0.	0.	0.
596.	9.	7.	-2.	0.	0.	0.	0.
603.	9.	10.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=2

HOMEOWNER: GVANWIE SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 30.
EST. BASE FUEL USE: 4802. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 1476. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	9.	0.	-1.	610.	17.	10.	-2.
407.	9.	57.	1.	617.	8.	9.	-2.
414.	9.	63.	0.	624.	16.	11.	-2.
421.	9.	50.	1.	631.	9.	10.	-2.
427.	8.	48.	0.	638.	9.	12.	-2.
435.	8.	49.	1.	645.	8.	19.	1.
442.	9.	41.	0.	652.	9.	23.	0.
449.	8.	40.	1.	659.	8.	26.	1.
456.	8.	21.	0.	666.	8.	19.	0.
463.	8.	27.	1.	673.	8.	23.	1.
470.	8.	37.	0.	680.	8.	35.	0.
477.	8.	32.	1.	687.	8.	48.	1.
484.	8.	20.	0.	694.	8.	47.	0.
491.	8.	12.	1.	701.	8.	42.	1.
498.	8.	17.	0.	708.	8.	46.	0.
505.	8.	20.	1.	715.	8.	39.	-1.
512.	8.	8.	-1.	722.	8.	47.	0.
519.	8.	25.	-1.	729.	8.	47.	1.
526.	8.	14.	-2.	736.	8.	46.	0.
533.	8.	9.	-2.	743.	8.	49.	1.
540.	8.	8.	-2.	750.	8.	51.	0.
547.	8.	7.	-2.	0.	0.	0.	0.
554.	8.	8.	-2.	0.	0.	0.	0.
561.	12.	7.	-2.	0.	0.	0.	0.
568.	9.	8.	-2.	0.	0.	0.	0.
589.	8.	19.	-1.	0.	0.	0.	0.
596.	8.	8.	-2.	0.	0.	0.	0.
603.	8.	7.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=3

HOMEOWNER: HEAL SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 28.
EST. BASE FUEL USE: 6372. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 1686. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	9.	0.	-1.	603.	8.	11.	-2.
407.	9.	61.	0.	610.	17.	13.	-2.
414.	9.	65.	1.	617.	9.	13.	-2.
421.	9.	52.	0.	624.	17.	12.	-2.
427.	9.	48.	1.	631.	9.	9.	-2.
435.	9.	51.	0.	638.	9.	12.	-2.
442.	9.	37.	1.	645.	9.	15.	-2.
449.	9.	44.	0.	652.	9.	23.	1.
456.	8.	7.	-1.	659.	9.	28.	0.
463.	8.	15.	-1.	666.	9.	11.	1.
470.	9.	29.	-1.	673.	8.	24.	0.
477.	9.	30.	1.	680.	8.	32.	1.
484.	9.	15.	0.	687.	9.	54.	0.
491.	9.	18.	1.	694.	9.	47.	1.
498.	9.	14.	0.	701.	8.	44.	0.
505.	9.	20.	1.	708.	9.	48.	1.
512.	9.	16.	0.	715.	9.	61.	0.
519.	8.	15.	-2.	722.	8.	40.	1.
526.	9.	12.	-2.	729.	9.	40.	0.
533.	9.	11.	-2.	736.	9.	45.	1.
540.	9.	11.	-2.	743.	9.	50.	0.
547.	9.	10.	-2.	750.	9.	51.	1.
554.	8.	9.	-2.	0.	0.	0.	0.
561.	12.	11.	-2.	0.	0.	0.	0.
568.	9.	9.	-2.	0.	0.	0.	0.
575.	16.	9.	-2.	0.	0.	0.	0.
589.	9.	19.	-2.	0.	0.	0.	0.
596.	9.	11.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=4

HOMEOWNER: JVANWIE SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 35.
EST. BASE FUEL USE: 5249. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	8.	0.	-1.	603.	8.	8.	-2.
407.	8.	56.	0.	610.	17.	13.	-2.
414.	8.	57.	1.	617.	8.	8.	1.
421.	8.	49.	0.	624.	16.	15.	0.
427.	8.	41.	1.	631.	8.	9.	1.
435.	8.	49.	0.	638.	9.	11.	0.
442.	8.	33.	1.	645.	8.	13.	1.
449.	8.	38.	0.	652.	8.	18.	0.
456.	8.	14.	1.	659.	8.	17.	1.
463.	8.	20.	0.	666.	8.	15.	0.
470.	8.	26.	1.	673.	8.	19.	1.
477.	8.	28.	0.	680.	8.	30.	0.
484.	8.	14.	1.	687.	8.	40.	1.
491.	8.	15.	0.	694.	8.	37.	0.
498.	8.	12.	1.	701.	8.	31.	1.
505.	8.	12.	0.	708.	8.	42.	0.
512.	8.	13.	1.	715.	8.	53.	1.
519.	8.	14.	0.	722.	8.	47.	-1.
526.	8.	11.	-2.	729.	8.	30.	-1.
533.	8.	10.	-2.	736.	8.	40.	0.
540.	8.	9.	-2.	743.	8.	44.	1.
547.	8.	9.	-2.	750.	8.	47.	0.
554.	8.	8.	-2.	0.	0.	0.	0.
561.	17.	10.	-2.	0.	0.	0.	0.
568.	8.	7.	-2.	0.	0.	0.	0.
575.	16.	10.	-2.	0.	0.	0.	0.
589.	8.	16.	-2.	0.	0.	0.	0.
596.	8.	10.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=5

HOMEOWNER: OGREN SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 26.
EST. BASE FUEL USE: 5125. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	8.	0.	-1.	603.	8.	8.	-2.
407.	8.	54.	1.	610.	16.	9.	-2.
414.	8.	56.	0.	617.	8.	10.	-2.
421.	8.	47.	1.	624.	16.	10.	-2.
427.	8.	45.	0.	631.	8.	8.	-2.
435.	8.	45.	1.	638.	9.	8.	-2.
442.	8.	39.	0.	645.	8.	17.	-2.
449.	8.	39.	1.	652.	8.	17.	1.
456.	8.	20.	0.	659.	8.	22.	0.
463.	8.	22.	1.	666.	8.	15.	1.
470.	8.	35.	0.	673.	8.	20.	0.
477.	8.	32.	1.	680.	8.	27.	1.
484.	8.	18.	-2.	687.	8.	39.	0.
491.	8.	13.	-2.	694.	8.	40.	1.
498.	8.	14.	-2.	701.	8.	37.	0.
505.	8.	14.	-2.	708.	8.	39.	1.
512.	8.	13.	-2.	715.	8.	54.	0.
519.	8.	10.	-2.	722.	8.	41.	1.
526.	8.	10.	-2.	729.	8.	43.	0.
533.	8.	9.	-2.	736.	8.	44.	1.
540.	8.	9.	-2.	743.	8.	47.	0.
547.	8.	9.	-2.	750.	8.	47.	1.
554.	8.	9.	-2.	0.	0.	0.	0.
561.	12.	8.	-2.	0.	0.	0.	0.
568.	8.	8.	-2.	0.	0.	0.	0.
575.	16.	7.	-2.	0.	0.	0.	0.
589.	8.	16.	-2.	0.	0.	0.	0.
596.	8.	7.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=6

HOMEOWNER: AMMENDOLA SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 5238. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
408.	13.	0.	-1.	610.	16.	9.	-2.
414.	9.	59.	1.	617.	17.	7.	-2.
421.	9.	61.	1.	624.	16.	9.	-2.
427.	9.	55.	1.	631.	17.	8.	-2.
435.	9.	58.	1.	638.	17.	10.	-2.
442.	9.	45.	1.	645.	17.	11.	-2.
449.	9.	41.	1.	652.	16.	20.	0.
456.	9.	21.	1.	659.	17.	22.	1.
463.	9.	27.	1.	666.	16.	17.	0.
470.	9.	33.	1.	673.	18.	24.	1.
477.	9.	26.	1.	680.	16.	39.	0.
484.	9.	25.	1.	687.	17.	51.	1.
491.	9.	18.	1.	694.	16.	50.	0.
498.	9.	12.	1.	701.	17.	45.	1.
505.	9.	23.	0.	708.	16.	52.	0.
512.	9.	12.	-2.	715.	17.	61.	1.
519.	9.	12.	-2.	722.	17.	55.	0.
526.	9.	8.	-2.	729.	16.	51.	1.
533.	9.	9.	-2.	736.	17.	51.	0.
540.	9.	7.	-2.	743.	16.	55.	1.
547.	9.	10.	-2.	750.	17.	57.	0.
554.	9.	8.	-2.	0.	0.	0.	0.
561.	11.	11.	-2.	0.	0.	0.	0.
568.	9.	6.	-2.	0.	0.	0.	0.
575.	16.	9.	-2.	0.	0.	0.	0.
589.	9.	14.	-2.	0.	0.	0.	0.
596.	9.	10.	-2.	0.	0.	0.	0.
603.	9.	6.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=7

HOMEOWNER: BRUENNING SYSTEM TYPE:GENERAL SOLAR

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 3827. BTU/HR
MEAS. GAIN COEFF: 32. FT2
EST. GAIN COEFF/EFF: 50. FT2
MEAS. LOSS COEFF: 63. BTU/HR-F
EST. INTERNAL GAINS: 1100. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	10.	0.	-1.	603.	9.	6.	-2.
407.	9.	48.	1.	610.	16.	7.	-2.
414.	9.	53.	0.	617.	9.	5.	-2.
421.	9.	43.	1.	624.	16.	5.	-2.
428.	16.	42.	0.	631.	9.	6.	-2.
435.	16.	39.	1.	638.	9.	6.	-2.
442.	9.	31.	0.	645.	9.	8.	-2.
449.	9.	32.	1.	652.	9.	11.	-2.
456.	9.	12.	0.	659.	9.	13.	0.
463.	9.	19.	1.	666.	9.	10.	1.
470.	9.	27.	0.	673.	9.	16.	0.
477.	9.	23.	1.	680.	9.	21.	1.
484.	9.	13.	0.	687.	9.	33.	0.
491.	9.	12.	1.	694.	9.	30.	1.
498.	9.	9.	0.	701.	9.	26.	0.
505.	9.	11.	1.	708.	9.	33.	1.
512.	9.	11.	-2.	715.	9.	42.	0.
519.	9.	6.	-2.	722.	9.	36.	1.
526.	9.	8.	-2.	729.	9.	36.	0.
533.	9.	6.	-2.	736.	9.	36.	1.
540.	9.	6.	-2.	743.	9.	39.	0.
547.	9.	4.	-2.	750.	9.	37.	1.
554.	9.	5.	-2.	0.	0.	0.	0.
561.	11.	6.	-2.	0.	0.	0.	0.
568.	9.	3.	-2.	0.	0.	0.	0.
575.	15.	5.	-2.	0.	0.	0.	0.
589.	9.	12.	-2.	0.	0.	0.	0.
596.	9.	5.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=8

HOMEOWNER: HUFF SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 1468. BTU/HR
MEAS. GAIN COEFF: 83. FT2
EST. GAIN COEFF/EFF: 127. FT2
MEAS. LOSS COEFF: 197. BTU/HR-F
EST. INTERNAL GAINS: -1483. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
413.	17.	0.	-1.	617.	17.	6.	-2.
421.	17.	51.	0.	624.	17.	2.	-2.
428.	16.	45.	1.	631.	17.	2.	-2.
435.	16.	47.	0.	638.	17.	2.	-2.
442.	17.	37.	1.	645.	17.	12.	-2.
449.	16.	39.	0.	652.	16.	15.	0.
456.	17.	13.	-1.	659.	17.	16.	1.
463.	16.	21.	-1.	666.	16.	13.	0.
470.	17.	30.	1.	673.	17.	25.	1.
477.	17.	29.	0.	680.	16.	31.	0.
484.	16.	17.	1.	687.	17.	42.	1.
491.	17.	12.	0.	694.	16.	41.	0.
498.	16.	12.	1.	701.	17.	39.	1.
505.	16.	14.	0.	708.	16.	44.	0.
512.	17.	13.	1.	715.	17.	53.	1.
519.	16.	13.	0.	722.	17.	43.	0.
526.	17.	9.	1.	729.	16.	43.	1.
533.	16.	7.	-2.	736.	17.	47.	0.
540.	17.	4.	-2.	743.	16.	40.	1.
547.	16.	3.	-2.	750.	17.	46.	0.
554.	17.	2.	-2.	0.	0.	0.	0.
561.	17.	2.	-2.	0.	0.	0.	0.
568.	16.	1.	-2.	0.	0.	0.	0.
575.	16.	1.	-2.	0.	0.	0.	0.
589.	17.	4.	-2.	0.	0.	0.	0.
596.	16.	2.	-2.	0.	0.	0.	0.
603.	18.	1.	-2.	0.	0.	0.	0.
610.	17.	5.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=9

HOMEOWNER: ELLERSTON SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 1441. BTU/HR
MEAS. GAIN COEFF: 32. FT2
EST. GAIN COEFF/EFF: 50. FT2
MEAS. LOSS COEFF: 63. BTU/HR-F
EST. INTERNAL GAINS: 0. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	16.	0.	-1.	603.	17.	2.	-2.
407.	16.	29.	0.	610.	16.	3.	-2.
414.	17.	31.	1.	617.	17.	2.	-2.
421.	16.	25.	0.	624.	15.	3.	-2.
428.	16.	23.	1.	631.	16.	3.	-2.
435.	16.	24.	0.	638.	16.	2.	-2.
442.	16.	19.	1.	645.	16.	2.	-2.
449.	16.	19.	0.	652.	16.	9.	-2.
456.	16.	7.	1.	659.	16.	9.	1.
463.	16.	10.	0.	666.	16.	7.	0.
470.	16.	14.	1.	673.	16.	11.	1.
477.	16.	15.	0.	680.	16.	14.	0.
484.	16.	5.	1.	687.	16.	26.	1.
491.	16.	7.	0.	694.	16.	22.	0.
498.	16.	5.	1.	701.	16.	21.	1.
505.	16.	6.	0.	708.	16.	24.	0.
512.	16.	6.	-2.	715.	16.	32.	1.
519.	16.	4.	-2.	722.	16.	25.	0.
526.	16.	2.	-2.	729.	16.	25.	1.
533.	16.	2.	-2.	736.	16.	26.	0.
540.	17.	3.	-2.	743.	16.	27.	1.
547.	16.	3.	-2.	750.	16.	28.	0.
554.	17.	2.	-2.	0.	0.	0.	0.
561.	16.	2.	-2.	0.	0.	0.	0.
568.	16.	3.	-2.	0.	0.	0.	0.
575.	15.	2.	-2.	0.	0.	0.	0.
589.	17.	3.	-2.	0.	0.	0.	0.
596.	15.	3.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=10

HOMEOWNER: DAVIS SYSTEM TYPE: GENERAL SOLAR

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 2636. BTU/HR
MEAS. GAIN COEFF: 48. FT2
EST. GAIN COEFF/EFF: 74. FT2
MEAS. LOSS COEFF: 94. BTU/HR-F
EST. INTERNAL GAINS: -500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
400.	16.	0.	-1.	603.	17.	4.	-2.
407.	16.	37.	1.	610.	16.	3.	-2.
414.	17.	40.	0.	617.	17.	4.	-2.
421.	16.	28.	1.	624.	15.	4.	-2.
428.	16.	29.	0.	631.	16.	3.	-2.
435.	16.	27.	1.	638.	16.	4.	-2.
442.	16.	25.	0.	645.	16.	5.	-2.
449.	16.	24.	1.	652.	16.	7.	-2.
456.	16.	8.	0.	659.	16.	8.	0.
463.	16.	13.	1.	666.	16.	7.	1.
470.	17.	19.	0.	673.	16.	11.	0.
477.	16.	15.	1.	680.	16.	14.	1.
484.	16.	12.	0.	687.	16.	28.	0.
491.	17.	10.	1.	694.	16.	21.	1.
498.	16.	8.	0.	701.	16.	23.	0.
505.	16.	8.	1.	708.	16.	25.	1.
512.	16.	10.	-2.	715.	16.	35.	0.
519.	16.	6.	-2.	722.	16.	27.	1.
526.	16.	6.	-2.	729.	16.	26.	0.
533.	16.	5.	-2.	736.	16.	29.	1.
540.	17.	4.	-2.	743.	17.	30.	0.
547.	16.	5.	-2.	750.	16.	30.	1.
554.	17.	4.	-2.	0.	0.	0.	0.
561.	16.	3.	-2.	0.	0.	0.	0.
568.	16.	3.	-2.	0.	0.	0.	0.
575.	15.	2.	-2.	0.	0.	0.	0.
589.	17.	8.	-2.	0.	0.	0.	0.
596.	15.	3.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=11

HOMEOWNER: PINGEL SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 27.
EST. BASE FUEL USE: 3571. BTU/HR
MEAS. GAIN COEFF: 100. FT2
EST. GAIN COEFF/EFF: 180. FT2
MEAS. LOSS COEFF: 239. BTU/HR-F
EST. INTERNAL GAINS: 0. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	9.	0.	-1.	588.	15.	5.	-2.
400.	9.	32.	0.	595.	14.	5.	-2.
407.	9.	37.	1.	602.	14.	5.	-2.
414.	9.	44.	0.	610.	14.	7.	-2.
421.	9.	31.	1.	616.	15.	8.	-2.
428.	9.	31.	0.	623.	15.	6.	-2.
435.	8.	31.	1.	630.	15.	7.	-2.
441.	15.	24.	0.	637.	15.	7.	-2.
448.	15.	25.	1.	644.	15.	8.	-2.
455.	15.	14.	0.	651.	15.	10.	1.
462.	14.	16.	1.	658.	15.	16.	1.
469.	15.	19.	0.	665.	15.	13.	0.
476.	15.	18.	1.	672.	15.	10.	1.
483.	15.	12.	-2.	679.	15.	21.	0.
490.	15.	11.	-2.	686.	15.	24.	1.
497.	15.	10.	-2.	693.	16.	34.	0.
504.	15.	10.	-2.	700.	16.	21.	1.
512.	15.	9.	-2.	707.	16.	31.	0.
519.	15.	9.	-2.	714.	15.	31.	1.
525.	15.	7.	-2.	721.	14.	38.	0.
532.	15.	8.	-2.	728.	14.	32.	1.
539.	16.	7.	-2.	735.	13.	29.	0.
546.	15.	7.	-2.	742.	16.	34.	1.
553.	15.	7.	-2.	749.	16.	34.	0.
560.	15.	6.	-2.	0.	0.	0.	0.
567.	14.	4.	-2.	0.	0.	0.	0.
574.	17.	5.	-2.	0.	0.	0.	0.
581.	13.	4.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=12

HOMEOWNER: TEICHERT SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 28.
EST. BASE FUEL USE: 3108. BTU/HR
MEAS. GAIN COEFF: 71. FT2
EST. GAIN COEFF/EFF: 100. FT2
MEAS. LOSS COEFF: 170. BTU/HR-F
EST. INTERNAL GAINS: 2000. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	11.	0.	-1.	588.	15.	5.	-2.
399.	13.	27.	1.	595.	14.	5.	-2.
406.	13.	36.	0.	602.	14.	4.	-2.
413.	13.	38.	1.	610.	15.	4.	-2.
420.	13.	30.	0.	616.	14.	3.	-2.
427.	13.	29.	1.	623.	14.	3.	-2.
434.	13.	31.	0.	630.	16.	4.	-2.
441.	13.	28.	1.	638.	15.	4.	-2.
448.	13.	26.	0.	644.	16.	4.	-2.
455.	13.	11.	1.	651.	15.	6.	-2.
462.	13.	11.	0.	658.	16.	11.	1.
469.	13.	15.	1.	665.	15.	7.	0.
476.	14.	14.	0.	672.	16.	8.	1.
484.	13.	12.	1.	680.	14.	16.	0.
491.	13.	7.	0.	686.	17.	11.	-1.
498.	13.	6.	1.	693.	16.	33.	-1.
504.	13.	7.	0.	700.	14.	19.	1.
512.	13.	7.	-2.	707.	15.	29.	0.
518.	13.	5.	-2.	714.	16.	33.	1.
525.	13.	4.	-2.	721.	16.	28.	0.
532.	14.	5.	-2.	729.	16.	33.	1.
539.	14.	5.	-2.	735.	15.	24.	0.
546.	14.	6.	-2.	742.	15.	28.	1.
553.	14.	5.	-2.	749.	15.	30.	0.
560.	15.	6.	-2.	0.	0.	0.	0.
567.	14.	4.	-2.	0.	0.	0.	0.
575.	16.	5.	-2.	0.	0.	0.	0.
581.	13.	5.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=13

HOMEOWNER: BERG SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 31.
EST. BASE FUEL USE: 5357. BTU/HR
MEAS. GAIN COEFF: 124. FT2
EST. GAIN COEFF/EFF: 191. FT2
MEAS. LOSS COEFF: 295. BTU/HR-F
EST. INTERNAL GAINS: 3000. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	14.	0.	-1.	588.	15.	9.	-2.
399.	14.	36.	1.	595.	15.	8.	-2.
406.	15.	52.	0.	602.	15.	8.	-2.
413.	15.	57.	1.	610.	15.	9.	-2.
420.	16.	48.	0.	616.	14.	8.	-2.
427.	15.	42.	1.	623.	14.	9.	-2.
434.	14.	48.	0.	630.	17.	9.	-2.
441.	14.	39.	1.	638.	16.	11.	-2.
448.	15.	40.	0.	644.	16.	10.	0.
455.	12.	16.	1.	651.	15.	13.	1.
462.	15.	19.	0.	658.	15.	19.	0.
469.	14.	21.	1.	665.	15.	12.	1.
476.	15.	23.	0.	672.	16.	18.	0.
483.	14.	16.	1.	680.	13.	27.	1.
490.	14.	15.	0.	686.	16.	38.	0.
497.	14.	12.	1.	693.	16.	35.	1.
504.	13.	12.	0.	700.	14.	31.	0.
512.	14.	16.	1.	707.	17.	43.	1.
518.	14.	8.	-2.	714.	16.	53.	0.
525.	14.	10.	-2.	721.	16.	40.	1.
532.	14.	9.	-2.	729.	16.	43.	-1.
539.	14.	10.	-2.	735.	16.	24.	-1.
546.	13.	7.	-2.	742.	13.	43.	0.
553.	14.	8.	-2.	749.	15.	40.	1.
560.	15.	8.	-2.	0.	0.	0.	0.
567.	15.	8.	-2.	0.	0.	0.	0.
575.	15.	8.	-2.	0.	0.	0.	0.
581.	14.	8.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=14

HOMEOWNER: WERRA SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 28.
EST. BASE FUEL USE: 3542. BTU/HR
MEAS. GAIN COEFF: 166. FT2
EST. GAIN COEFF/EFF: 255. FT2
MEAS. LOSS COEFF: 395. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	11.	0.	-1.	588.	15.	4.	-2.
399.	15.	46.	1.	595.	15.	6.	-2.
406.	16.	58.	1.	602.	15.	5.	-2.
413.	15.	66.	0.	610.	16.	6.	-2.
420.	16.	50.	1.	616.	14.	5.	-2.
427.	16.	48.	0.	623.	15.	6.	-2.
434.	15.	50.	1.	630.	16.	6.	-2.
441.	15.	46.	0.	637.	15.	6.	-2.
448.	15.	41.	1.	644.	17.	6.	-2.
455.	16.	18.	0.	651.	16.	8.	-2.
462.	15.	18.	-1.	658.	16.	22.	0.
469.	15.	27.	0.	665.	15.	12.	1.
476.	15.	30.	1.	672.	16.	18.	0.
483.	16.	14.	0.	680.	14.	31.	1.
490.	15.	17.	1.	686.	17.	31.	0.
497.	16.	10.	0.	693.	16.	38.	1.
504.	16.	11.	1.	700.	14.	39.	0.
512.	16.	14.	0.	707.	16.	47.	1.
518.	16.	8.	-2.	714.	15.	58.	0.
525.	13.	9.	-2.	721.	12.	37.	1.
532.	15.	8.	-2.	729.	16.	61.	0.
539.	15.	6.	-2.	735.	16.	43.	1.
546.	15.	5.	-2.	742.	13.	28.	-1.
553.	15.	6.	-2.	749.	15.	48.	-1.
560.	15.	5.	-2.	0.	0.	0.	0.
567.	14.	5.	-2.	0.	0.	0.	0.
574.	16.	5.	-2.	0.	0.	0.	0.
581.	14.	6.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=15

HOMEOWNER: KRUEGER SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 33.
EST. BASE FUEL USE: 5052. BTU/HR
MEAS. GAIN COEFF: 113. FT2
EST. GAIN COEFF/EFF: 120. FT2
MEAS. LOSS COEFF: 270. BTU/HR-F
EST. INTERNAL GAINS: 1686. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	11.	0.	-1.	588.	15.	7.	-2.
399.	15.	50.	1.	595.	15.	6.	-2.
406.	16.	63.	0.	602.	15.	7.	-2.
413.	16.	73.	1.	610.	17.	12.	-2.
420.	16.	63.	0.	616.	13.	10.	1.
427.	16.	47.	1.	623.	16.	10.	0.
434.	15.	53.	0.	630.	16.	10.	1.
441.	14.	45.	1.	637.	16.	9.	0.
448.	16.	48.	0.	644.	17.	13.	1.
455.	15.	16.	1.	651.	16.	19.	0.
462.	15.	24.	0.	658.	17.	29.	1.
469.	14.	28.	1.	665.	16.	15.	0.
476.	16.	29.	0.	672.	17.	25.	1.
483.	16.	15.	1.	679.	14.	46.	0.
490.	14.	17.	-2.	686.	17.	50.	1.
497.	16.	9.	-2.	693.	17.	55.	0.
504.	16.	7.	-2.	700.	15.	56.	1.
512.	16.	17.	-2.	707.	16.	50.	0.
518.	16.	8.	-2.	714.	16.	72.	1.
525.	14.	9.	-2.	721.	11.	50.	0.
532.	15.	8.	-2.	729.	16.	61.	1.
539.	15.	8.	-2.	735.	16.	43.	0.
546.	16.	7.	-2.	742.	14.	58.	1.
553.	15.	7.	-2.	749.	16.	55.	0.
560.	16.	7.	-2.	0.	0.	0.	0.
567.	15.	6.	-2.	0.	0.	0.	0.
575.	16.	6.	-2.	0.	0.	0.	0.
581.	15.	6.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=16

HOMEOWNER: BUTT SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 28.
EST. BASE FUEL USE: 1554. BTU/HR
MEAS. GAIN COEFF: 77. FT2
EST. GAIN COEFF/EFF: 80. FT2
MEAS. LOSS COEFF: 182. BTU/HR-F
EST. INTERNAL GAINS: 500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	10.	0.	-1.	588.	15.	3.	-2.
399.	14.	21.	1.	595.	15.	2.	-2.
406.	14.	31.	0.	602.	14.	2.	-2.
413.	13.	31.	1.	610.	15.	3.	-2.
420.	14.	25.	0.	616.	14.	2.	-2.
427.	13.	20.	1.	623.	14.	3.	-2.
434.	13.	23.	0.	630.	16.	2.	-2.
441.	13.	23.	1.	637.	15.	3.	-2.
448.	13.	24.	0.	644.	16.	3.	-2.
455.	14.	7.	1.	651.	16.	4.	-2.
462.	14.	11.	0.	658.	16.	7.	1.
469.	14.	9.	1.	665.	15.	4.	0.
476.	15.	12.	0.	672.	16.	7.	1.
483.	13.	6.	1.	679.	13.	11.	0.
490.	13.	7.	0.	686.	17.	19.	1.
497.	13.	4.	-2.	693.	16.	17.	0.
504.	13.	4.	-2.	700.	14.	14.	1.
512.	14.	5.	-2.	707.	16.	21.	0.
518.	14.	4.	-2.	714.	16.	28.	1.
525.	14.	3.	-2.	721.	16.	19.	0.
532.	14.	3.	-2.	729.	16.	24.	1.
539.	14.	3.	-2.	735.	16.	19.	0.
546.	13.	2.	-1.	742.	13.	22.	1.
553.	14.	3.	-1.	749.	15.	21.	0.
560.	15.	3.	-2.	0.	0.	0.	0.
567.	14.	3.	-2.	0.	0.	0.	0.
574.	16.	2.	-2.	0.	0.	0.	0.
581.	13.	2.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=17

HOMEOWNER: RUTLEY SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 24.
EST. BASE FUEL USE: 3695. BTU/HR
MEAS. GAIN COEFF: 93. FT2
EST. GAIN COEFF/EFF: 140. FT2
MEAS. LOSS COEFF: 221. BTU/HR-F
EST. INTERNAL GAINS: -1000. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
394.	12.	0.	-1.	588.	16.	4.	-1.
399.	16.	21.	1.	595.	14.	6.	-2.
406.	15.	31.	0.	602.	14.	8.	-2.
413.	15.	32.	1.	610.	16.	9.	-2.
420.	15.	27.	0.	616.	14.	7.	-2.
427.	15.	20.	1.	623.	14.	7.	-2.
434.	15.	27.	0.	630.	16.	6.	-2.
441.	15.	20.	1.	637.	16.	7.	-2.
448.	15.	24.	0.	644.	16.	8.	-2.
455.	15.	9.	1.	651.	16.	8.	-2.
462.	15.	10.	0.	658.	16.	13.	-2.
469.	15.	12.	1.	665.	15.	5.	-1.
476.	16.	14.	0.	672.	16.	8.	-1.
483.	15.	10.	1.	679.	16.	14.	1.
490.	16.	8.	-2.	686.	15.	26.	0.
497.	15.	7.	-2.	693.	16.	21.	1.
504.	15.	7.	-2.	700.	16.	22.	0.
512.	15.	8.	-2.	707.	16.	26.	1.
519.	15.	6.	-2.	714.	16.	34.	0.
525.	15.	6.	-2.	721.	13.	21.	1.
532.	15.	5.	-2.	728.	13.	25.	0.
536.	16.	3.	-2.	735.	14.	24.	1.
546.	16.	3.	-1.	742.	15.	25.	0.
553.	15.	5.	-1.	749.	16.	24.	1.
560.	15.	6.	-2.	0.	0.	0.	0.
567.	15.	6.	-2.	0.	0.	0.	0.
574.	16.	5.	-2.	0.	0.	0.	0.
581.	14.	4.	-1.	0.	0.	0.	0.

SYSTEM NUMBER=18

HOMEOWNER: MCALISTER SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 0. BTU/HR
MEAS. GAIN COEFF: 58. FT2
EST. GAIN COEFF/EFF: 89. FT2
MEAS. LOSS COEFF: 138. BTU/HR-F
EST. INTERNAL GAINS: 2300. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	7.	0.	-1.	547.	8.	0.	-2.
351.	7.	-28.	-1.	554.	8.	0.	-2.
358.	7.	67.	0.	561.	8.	0.	-2.
365.	7.	80.	1.	568.	9.	0.	-2.
372.	7.	66.	0.	575.	8.	0.	-2.
379.	9.	68.	1.	582.	9.	0.	-2.
386.	7.	53.	0.	589.	10.	0.	-2.
393.	7.	64.	1.	596.	9.	0.	-2.
400.	7.	60.	0.	603.	9.	0.	-2.
407.	7.	59.	1.	610.	9.	0.	-2.
414.	7.	68.	0.	617.	8.	0.	-2.
421.	7.	53.	1.	624.	8.	0.	-2.
428.	7.	54.	0.	631.	8.	0.	-2.
435.	7.	58.	1.	638.	8.	0.	-2.
442.	7.	39.	0.	645.	7.	0.	-2.
449.	7.	46.	-1.	652.	7.	32.	-2.
456.	7.	15.	-1.	659.	7.	21.	0.
463.	7.	28.	-1.	666.	7.	14.	1.
470.	7.	28.	1.	673.	7.	22.	0.
477.	7.	27.	0.	680.	7.	31.	1.
484.	7.	11.	1.	687.	7.	57.	0.
491.	7.	11.	0.	694.	7.	49.	1.
498.	7.	2.	1.	701.	7.	41.	0.
505.	8.	3.	0.	708.	7.	56.	1.
512.	9.	3.	1.	715.	7.	64.	0.
519.	10.	2.	-2.	0.	0.	0.	0.
533.	8.	0.	-2.	0.	0.	0.	0.
540.	9.	0.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=19

HOMEOWNER: RUPNOW SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 34.
EST. BASE FUEL USE: 2302. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 98. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	11.	0.	-1.	540.	10.	4.	-2.
351.	9.	61.	1.	547.	11.	4.	-2.
358.	9.	77.	0.	554.	9.	3.	-2.
365.	9.	77.	1.	561.	10.	4.	-2.
372.	9.	67.	0.	568.	10.	3.	-2.
379.	9.	63.	1.	575.	10.	4.	-2.
386.	9.	56.	0.	582.	11.	3.	-2.
393.	9.	60.	1.	589.	11.	3.	-2.
400.	9.	64.	0.	596.	10.	4.	-2.
407.	9.	61.	1.	603.	10.	4.	-2.
414.	9.	71.	0.	610.	10.	3.	-2.
421.	9.	54.	1.	617.	10.	5.	-2.
428.	9.	56.	0.	624.	10.	8.	-2.
435.	9.	54.	1.	631.	8.	8.	-2.
442.	9.	50.	0.	638.	9.	4.	1.
449.	10.	43.	1.	645.	9.	21.	0.
456.	10.	22.	0.	652.	9.	20.	1.
463.	9.	24.	1.	659.	9.	24.	0.
470.	9.	36.	0.	666.	9.	16.	1.
477.	10.	27.	1.	673.	9.	26.	0.
484.	9.	14.	0.	680.	9.	28.	1.
491.	9.	10.	1.	687.	9.	51.	0.
498.	9.	10.	0.	694.	9.	42.	1.
505.	9.	11.	-2.	701.	9.	43.	0.
512.	10.	9.	-2.	708.	9.	49.	1.
519.	11.	5.	-2.	715.	9.	61.	0.
526.	10.	3.	-2.	0.	0.	0.	0.
533.	9.	6.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=20

HOMEOWNER: VOELTNER SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 19.
EST. BASE FUEL USE: 0. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 80. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 1000. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	8.	0.	-1.	540.	9.	0.	-2.
351.	8.	27.	1.	547.	9.	0.	-2.
358.	8.	30.	1.	554.	9.	0.	-2.
365.	8.	37.	0.	561.	9.	0.	-2.
372.	8.	24.	1.	568.	9.	0.	-2.
379.	8.	27.	0.	575.	9.	0.	-2.
386.	8.	13.	1.	582.	9.	0.	-2.
393.	8.	22.	0.	589.	10.	0.	-2.
400.	8.	21.	1.	596.	9.	0.	-2.
407.	8.	18.	0.	603.	10.	0.	-2.
414.	8.	21.	1.	610.	9.	0.	-2.
421.	8.	15.	0.	617.	9.	0.	-2.
428.	8.	13.	1.	624.	8.	0.	-2.
435.	8.	18.	0.	631.	8.	0.	-2.
442.	8.	15.	-2.	638.	8.	0.	-2.
449.	8.	0.	-2.	645.	8.	0.	-2.
456.	8.	0.	-2.	652.	8.	0.	-2.
463.	8.	0.	-2.	659.	8.	0.	-2.
470.	8.	0.	-2.	666.	8.	0.	-2.
477.	8.	1.	-2.	673.	8.	3.	-2.
484.	8.	0.	-2.	680.	8.	8.	0.
491.	8.	0.	-2.	687.	8.	15.	1.
498.	8.	0.	-2.	694.	8.	15.	0.
505.	8.	0.	-2.	701.	8.	12.	1.
512.	9.	0.	-2.	708.	8.	19.	0.
519.	10.	1.	-2.	715.	8.	24.	1.
526.	9.	0.	-2.	0.	0.	0.	0.
533.	10.	0.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=21

HOMEOWNER: LIVANGOOD SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 27.
EST. BASE FUEL USE: 1548. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 50. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 700. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	9.	0.	-1.	540.	10.	3.	-2.
351.	8.	23.	1.	547.	9.	3.	-2.
358.	8.	29.	0.	554.	9.	3.	-2.
365.	8.	29.	1.	561.	9.	2.	-2.
372.	8.	25.	0.	568.	9.	2.	-2.
379.	8.	23.	1.	575.	9.	3.	-2.
386.	8.	21.	0.	582.	10.	2.	-2.
393.	8.	21.	1.	589.	10.	3.	-2.
400.	8.	26.	0.	596.	9.	3.	-2.
407.	8.	22.	1.	603.	10.	2.	-2.
414.	8.	28.	0.	610.	9.	2.	-2.
421.	8.	21.	1.	617.	9.	3.	-2.
428.	8.	21.	0.	624.	8.	2.	-2.
435.	8.	21.	1.	631.	8.	3.	-2.
442.	8.	17.	0.	638.	8.	2.	-2.
449.	8.	14.	1.	645.	8.	3.	-2.
456.	8.	5.	0.	652.	8.	4.	-2.
463.	8.	6.	1.	659.	8.	6.	0.
470.	8.	11.	0.	666.	8.	5.	1.
477.	8.	7.	-2.	673.	8.	5.	0.
484.	8.	3.	-2.	680.	8.	8.	1.
491.	8.	4.	-2.	687.	8.	20.	0.
498.	8.	3.	-2.	694.	8.	16.	1.
505.	8.	3.	-2.	701.	8.	17.	0.
512.	9.	3.	-2.	708.	8.	19.	1.
519.	11.	3.	-2.	715.	8.	26.	0.
526.	9.	3.	-2.	0.	0.	0.	0.
533.	9.	2.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=22

HOMEOWNER: LECHNER SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 33.
EST. BASE FUEL USE: 3512. BTU/HR
MEAS. GAIN COEFF: 42. FT2
EST. GAIN COEFF/EFF: 65. FT2
MEAS. LOSS COEFF: 58. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	8.	0.	-1.	540.	10.	6.	-2.
351.	8.	39.	1.	547.	9.	8.	-2.
358.	8.	45.	1.	554.	9.	6.	-2.
365.	8.	47.	0.	561.	9.	7.	-2.
372.	8.	38.	1.	568.	9.	6.	-2.
379.	8.	42.	0.	575.	9.	5.	-2.
386.	8.	32.	1.	582.	9.	6.	-2.
393.	8.	40.	0.	589.	10.	5.	-2.
400.	8.	40.	1.	596.	9.	5.	-2.
407.	8.	36.	0.	603.	9.	5.	-2.
414.	8.	42.	1.	610.	9.	7.	-2.
421.	8.	33.	0.	617.	9.	6.	-2.
428.	8.	29.	1.	624.	8.	7.	-2.
435.	8.	31.	0.	631.	8.	6.	0.
442.	7.	23.	1.	638.	8.	7.	1.
449.	8.	26.	0.	645.	8.	8.	0.
456.	8.	11.	1.	652.	8.	11.	1.
463.	8.	13.	1.	659.	8.	12.	0.
470.	8.	17.	1.	666.	7.	8.	1.
477.	8.	14.	0.	673.	8.	14.	0.
484.	8.	9.	1.	680.	8.	19.	1.
491.	8.	10.	-2.	687.	8.	30.	0.
498.	8.	7.	-2.	694.	8.	26.	1.
505.	8.	8.	-2.	701.	8.	25.	0.
512.	9.	7.	-2.	708.	8.	31.	1.
519.	10.	7.	-2.	715.	8.	40.	0.
526.	9.	5.	-1.	0.	0.	0.	0.
533.	9.	4.	-1.	0.	0.	0.	0.

SYSTEM NUMBER=23

HOMEOWNER: KOEPSELL SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 500. BTU/HR
MEAS. GAIN COEFF: 42. FT2
EST. GAIN COEFF/EFF: 80. FT2
MEAS. LOSS COEFF: 58. BTU/HR-F
EST. INTERNAL GAINS: 1000. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	9.	0.	-1.	540.	10.	7.	-2.
351.	9.	68.	1.	547.	9.	8.	-2.
358.	9.	84.	1.	554.	9.	7.	-2.
365.	8.	96.	0.	561.	9.	8.	-2.
372.	8.	76.	1.	568.	9.	6.	-2.
379.	8.	80.	0.	575.	9.	6.	-2.
386.	8.	61.	1.	582.	10.	6.	-2.
393.	8.	77.	0.	589.	10.	7.	-2.
400.	8.	74.	1.	596.	9.	7.	-2.
407.	8.	77.	0.	603.	10.	7.	-2.
414.	8.	77.	1.	610.	9.	8.	-2.
421.	8.	67.	0.	617.	9.	7.	-2.
428.	8.	56.	1.	624.	8.	7.	-2.
435.	8.	66.	0.	631.	8.	7.	-2.
442.	8.	51.	1.	638.	8.	8.	-2.
449.	8.	57.	0.	645.	8.	7.	-2.
456.	8.	16.	1.	652.	8.	19.	-2.
463.	8.	30.	0.	659.	8.	24.	1.
470.	8.	35.	1.	666.	8.	15.	0.
477.	8.	30.	0.	673.	8.	23.	1.
484.	8.	12.	1.	680.	8.	40.	0.
491.	8.	15.	0.	687.	9.	55.	1.
498.	8.	10.	-2.	694.	8.	51.	0.
505.	9.	11.	-2.	701.	8.	49.	1.
512.	10.	9.	-2.	708.	8.	57.	0.
519.	11.	8.	-2.	0.	0.	0.	0.
526.	10.	7.	-2.	0.	0.	0.	0.
533.	9.	7.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=24

HOMEOWNER: POTTER SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 31.
EST. BASE FUEL USE: 6115. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 80. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 800. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	1.	0.	-1.	540.	11.	9.	-2.
351.	12.	51.	1.	547.	12.	10.	-2.
358.	11.	62.	0.	554.	10.	10.	-2.
365.	10.	66.	1.	561.	10.	11.	-2.
372.	10.	58.	0.	568.	10.	9.	-2.
379.	10.	52.	1.	575.	10.	9.	-2.
386.	10.	46.	0.	582.	11.	8.	-2.
393.	10.	51.	1.	589.	11.	9.	-2.
400.	10.	55.	0.	596.	10.	10.	-2.
407.	10.	50.	1.	603.	11.	11.	-2.
414.	10.	61.	0.	610.	10.	10.	-2.
421.	10.	49.	1.	617.	10.	8.	-2.
428.	10.	47.	0.	624.	10.	10.	-2.
435.	10.	47.	1.	631.	9.	11.	-2.
442.	10.	38.	0.	638.	10.	9.	-2.
449.	10.	35.	1.	645.	10.	16.	-2.
456.	10.	19.	0.	652.	10.	18.	1.
463.	10.	21.	1.	659.	10.	14.	1.
470.	10.	30.	0.	666.	10.	14.	0.
477.	10.	24.	1.	673.	10.	22.	1.
484.	11.	15.	0.	680.	10.	29.	0.
491.	10.	14.	1.	687.	10.	40.	1.
498.	10.	11.	-2.	694.	10.	37.	0.
505.	10.	12.	-2.	701.	10.	35.	1.
512.	11.	11.	-2.	708.	10.	39.	0.
519.	12.	11.	-2.	715.	10.	50.	1.
526.	10.	8.	-2.	0.	0.	0.	0.
533.	10.	13.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=25

HOMEOWNER: BIEBERITZ SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 4762. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 60. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
351.	10.	0.	-1.	547.	11.	7.	-2.
358.	10.	68.	1.	554.	10.	6.	-2.
365.	9.	74.	0.	561.	10.	6.	-2.
372.	10.	64.	1.	568.	10.	6.	-2.
379.	9.	61.	0.	575.	10.	6.	-2.
386.	9.	47.	1.	582.	11.	6.	-2.
393.	9.	59.	0.	589.	11.	5.	-2.
400.	10.	57.	1.	596.	10.	7.	-2.
407.	9.	62.	0.	603.	11.	6.	-2.
414.	9.	59.	1.	610.	10.	7.	-2.
421.	9.	53.	0.	617.	10.	6.	-2.
428.	10.	42.	1.	624.	10.	8.	-2.
435.	10.	50.	0.	631.	9.	9.	-2.
442.	9.	36.	1.	638.	9.	7.	-2.
449.	10.	39.	0.	645.	9.	12.	-2.
456.	10.	16.	1.	652.	9.	19.	0.
463.	10.	20.	0.	659.	9.	24.	1.
470.	9.	23.	1.	666.	9.	15.	0.
477.	10.	26.	0.	673.	9.	18.	1.
484.	10.	10.	1.	680.	9.	30.	0.
491.	10.	12.	-2.	687.	10.	42.	1.
498.	9.	10.	-2.	694.	9.	40.	0.
505.	9.	12.	-2.	701.	9.	34.	1.
512.	10.	12.	-2.	708.	9.	46.	0.
519.	12.	8.	-2.	715.	10.	57.	1.
526.	10.	15.	-2.	0.	0.	0.	0.
533.	9.	-2.	-2.	0.	0.	0.	0.
540.	10.	7.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=26

HOMEOWNER: MACHGAN SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 0. BTU/HR
MEAS. GAIN COEFF: 42. FT2
EST. GAIN COEFF/EFF: 65. FT2
MEAS. LOSS COEFF: 58. BTU/HR-F
EST. INTERNAL GAINS: -1693. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	12.	0.	-1.	540.	11.	1.	-2.
351.	11.	42.	1.	547.	11.	0.	-2.
358.	10.	48.	0.	554.	10.	0.	-2.
365.	10.	48.	1.	561.	10.	0.	-2.
372.	10.	42.	0.	568.	10.	0.	-2.
379.	10.	40.	1.	575.	10.	0.	-2.
386.	10.	37.	0.	582.	11.	0.	-2.
393.	10.	36.	1.	589.	11.	0.	-2.
400.	10.	40.	0.	596.	10.	0.	-2.
407.	9.	38.	1.	603.	11.	0.	-2.
414.	10.	46.	0.	610.	10.	0.	-2.
421.	10.	34.	1.	617.	10.	1.	-2.
428.	10.	35.	0.	624.	10.	3.	-2.
435.	10.	33.	1.	631.	9.	11.	-2.
442.	10.	30.	0.	638.	9.	0.	-2.
449.	10.	22.	1.	645.	10.	7.	-2.
456.	10.	9.	0.	652.	10.	13.	0.
463.	10.	11.	1.	659.	10.	14.	0.
470.	10.	22.	0.	666.	9.	9.	1.
477.	10.	13.	1.	673.	10.	15.	0.
484.	10.	5.	-2.	680.	10.	16.	1.
491.	10.	3.	-2.	687.	10.	31.	0.
498.	10.	0.	-2.	694.	10.	28.	1.
505.	9.	4.	-2.	701.	9.	26.	0.
512.	11.	1.	-2.	708.	10.	31.	1.
519.	12.	2.	-2.	715.	10.	39.	0.
526.	10.	0.	-2.	0.	0.	0.	0.
533.	10.	1.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=27

HOMEOWNER: WAGIE SYSTEM TYPE:MOR-FLO

NUMBER OF OBSERVATIONS: 31.
EST. BASE FUEL USE: 3203. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 80. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 500. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	12.	0.	-1.	540.	10.	4.	-2.
351.	11.	49.	1.	547.	11.	6.	-2.
358.	10.	58.	1.	554.	10.	4.	-2.
365.	10.	62.	0.	561.	10.	4.	-2.
372.	10.	54.	1.	568.	10.	5.	-2.
379.	10.	53.	0.	575.	10.	4.	-2.
386.	10.	41.	1.	582.	11.	4.	-2.
393.	9.	51.	0.	589.	11.	3.	-2.
400.	10.	49.	1.	596.	10.	5.	-2.
407.	9.	49.	0.	603.	11.	4.	-2.
414.	10.	50.	1.	610.	10.	4.	-2.
421.	10.	46.	0.	617.	10.	5.	-2.
428.	10.	38.	1.	624.	10.	6.	-2.
435.	10.	43.	0.	631.	9.	5.	-2.
442.	10.	33.	1.	638.	9.	4.	-2.
449.	10.	38.	0.	645.	9.	12.	-2.
456.	10.	10.	1.	652.	9.	16.	1.
463.	10.	21.	0.	659.	9.	21.	0.
470.	10.	22.	1.	666.	9.	14.	1.
477.	10.	24.	0.	673.	10.	22.	0.
484.	10.	12.	1.	680.	10.	25.	1.
491.	10.	13.	0.	687.	10.	42.	0.
498.	9.	9.	-2.	694.	10.	35.	1.
505.	9.	10.	-2.	701.	9.	33.	0.
512.	10.	7.	-2.	708.	10.	40.	1.
519.	12.	8.	-2.	715.	10.	59.	0.
526.	10.	7.	-2.	0.	0.	0.	0.
533.	10.	5.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=28

HOMEOWNER: SCHULTZ SYSTEM TYPE: EMG

NUMBER OF OBSERVATIONS: 29.
EST. BASE FUEL USE: 4897. BTU/HR
MEAS. GAIN COEFF: 75. FT2
EST. GAIN COEFF/EFF: 116. FT2
MEAS. LOSS COEFF: 178. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	1.	0.	-1.	540.	11.	7.	-2.
351.	12.	50.	1.	547.	11.	8.	-2.
358.	11.	58.	1.	554.	10.	7.	-2.
365.	10.	64.	0.	561.	10.	8.	-2.
372.	10.	55.	1.	568.	10.	7.	-2.
379.	10.	53.	0.	575.	10.	7.	-2.
386.	10.	42.	1.	582.	11.	7.	-2.
393.	10.	52.	0.	589.	11.	5.	-2.
400.	10.	52.	1.	596.	10.	8.	-2.
407.	10.	53.	0.	603.	11.	6.	-2.
414.	10.	56.	1.	610.	10.	9.	-2.
421.	10.	58.	0.	617.	10.	7.	-2.
428.	10.	31.	1.	624.	10.	8.	-2.
435.	10.	48.	0.	631.	9.	8.	-2.
442.	10.	34.	1.	638.	10.	7.	-2.
449.	10.	41.	0.	645.	10.	23.	-2.
456.	10.	25.	1.	652.	10.	5.	-2.
463.	10.	18.	0.	659.	10.	13.	1.
470.	10.	25.	1.	666.	9.	13.	0.
477.	10.	24.	0.	673.	10.	18.	1.
484.	10.	13.	1.	680.	10.	25.	0.
491.	10.	11.	-2.	687.	10.	37.	1.
498.	10.	9.	-2.	694.	10.	36.	0.
505.	9.	13.	-2.	701.	10.	32.	1.
512.	11.	12.	-2.	708.	10.	40.	0.
519.	12.	9.	-2.	715.	10.	48.	1.
526.	10.	9.	-2.	0.	0.	0.	0.
533.	10.	9.	-2.	0.	0.	0.	0.

SYSTEM NUMBER=29

HOMEOWNER:REYNOLDS SYSTEM TYPE: MOR-FLO

NUMBER OF OBSERVATIONS: 27.
EST. BASE FUEL USE: 3214. BTU/HR
MEAS. GAIN COEFF: 63. FT2
EST. GAIN COEFF/EFF: 50. FT2
MEAS. LOSS COEFF: 87. BTU/HR-F
EST. INTERNAL GAINS: 890. BTU/HR

DATE	TIME	FUEL	SYS	DATE	TIME	FUEL	SYS
345.	12.	0.	-1.	540.	10.	7.	-2.
351.	10.	49.	1.	547.	11.	6.	-2.
358.	10.	61.	0.	554.	10.	5.	-2.
365.	10.	63.	1.	561.	10.	5.	-2.
372.	10.	53.	0.	568.	10.	5.	-2.
379.	10.	48.	1.	575.	10.	6.	-2.
386.	9.	41.	0.	582.	11.	5.	-2.
393.	9.	46.	1.	589.	11.	5.	-2.
400.	10.	49.	0.	596.	10.	5.	-2.
407.	9.	45.	1.	603.	11.	5.	-2.
414.	10.	55.	0.	610.	10.	6.	-2.
421.	10.	40.	1.	617.	10.	6.	-2.
428.	10.	37.	0.	624.	10.	5.	-2.
435.	10.	38.	1.	631.	9.	7.	-2.
442.	10.	29.	0.	638.	9.	5.	-2.
449.	10.	27.	1.	645.	9.	9.	-2.
456.	10.	13.	0.	652.	9.	15.	-2.
463.	10.	13.	1.	659.	9.	16.	1.
470.	10.	21.	0.	666.	9.	12.	0.
477.	10.	14.	-2.	673.	10.	17.	1.
484.	10.	5.	-2.	680.	10.	25.	0.
491.	10.	5.	-2.	687.	10.	38.	1.
498.	9.	6.	-2.	694.	10.	36.	0.
505.	9.	8.	-2.	701.	10.	29.	1.
512.	10.	7.	-2.	708.	10.	40.	0.
519.	12.	8.	-2.	715.	10.	48.	1.
526.	10.	7.	-2.	0.	0.	0.	0.
533.	10.	8.	-2.	0.	0.	0.	0.

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