EXPERIMENTAL MEASUREMENTS OF HEATING SEASON ENERGY SAVINGS FROM VARIOUS RETROFIT TECHNIQUES IN THREE UNOCCUPIED HOUSES

W.P. Levins

ABSTRACT

A group of three houses in Karns, a suburb of Knoxville, Tennessee, were used as a test facility to conduct a series of retrofit heating experiments during the 1984/85 heating season. The three houses were 1200-ft^2 (111 m^2), unoccupied, ranch-style houses with crawl spaces heated with 2-ton, single-package heat pumps. The houses proved to be quite well matched both thermally and with regard to infiltration. House 1 was used as a control house to which the other two were compared.

After conducting calibration runs in both the resistance and heat pump heating modes, the houses were operated for several weeks in a zoning mode--house 2 had two bedrooms zoned off and house 3 had three bedrooms zoned off, first with resistance heat and then with heat pump heating. Savings on the order of 10% to 20% were measured for the existing weather conditions during these tests.

Programmable thermostats were then installed in each house and night setback experiments (0 F, 5 F, and 10 F from 10 p.m. until 7 a.m.) (0 C, 2.8 C, and 5.6 C) were conducted in the resistance mode. The relatively mild weather existing during this series of tests did not allow the full 10 F setback to be attained at all times, yet savings on the order of 20% were measured.

Night setback and zoning were then combined, and savings on the order of 28% to 40% were measured. The weather was again relatively mild during these tests.

The results of the testing are believed to be accurate, but only so far as the existing weather conditions were concerned. Simple empirical modeling of the weather effects on the house loads was done, but it is recommended that the data obtained be used as the input to a more elaborate modeling effort in order to predict the seasonal effects of the retrofit measures.

INTRODUCTION

Since the energy conservation movement began in the 1970s as a result of the Arab oil embargo, many potential energy-saving devices and operational strategies have emerged. Most of these devices and/or strategies do save energy, but the question has always persisted as to how much energy is actually saved and how cost effective are the various measures. Although the question seems rather easy to answer, it has turned out to be quite difficult to do so.

In an attempt to better quantify the effects of some of the retrofit measures available to the residential consumer, the Energy Division of the Oak Ridge National Laboratory (ORNL) under the sponsorship of the U.S. Department of Energy (DOE) Division of Buildings and Community Systems set out in May of 1984 to experimentally measure the effects of the more promising energy efficient retrofit strategies. Some previous analytical work had been done (Potter and Karnitz 1985; McLain n.d.) at ORNL to determine the most promising retrofits available to the customer and what effect these retrofits might have on electric

W.P. Levins is with the Energy Division of Oak Ridge National Laboratory, Oak Ridge, TN.

utility demand. These studies showed that zoning, night setback, and a combination of zoning with night setback showed the most potential to save energy.

One of the first things decided about the experimental study was that the effects of occupant life-style should not be included because of the wide range of variability it would impose on the results. The effect of the retrofit would be determined, but the interaction between occupant life-style and the retrofit would not be determined. Another important decision was that measurements would be made at a location that contained a control house as well as the house on which the retrofit was made. It was felt that these two procedures would demonstrate the actual energy-savings benefit of a retrofit free of any masking from either the occupants or the external conditions.

DESCRIPTION OF THE TEST SITE

A facility in the Karns community, a suburb of the city of Knoxville, TN, was in the process of phasing out a test program involving the coupling of heat pumps with the crawl space area. The facility consisted of three single-family 1200-ft^2 ranch-style houses with crawl spaces heated and cooled with heat pumps. The houses were already well instrumented, and measured data had shown them to be quite similar from a thermal viewpoint. Figure 1 is a photograph of the three houses.

Figure 2 depicts the floor plan of one of the Karns houses and Table 1 lists some of the specifics for each room. The heat pump used to heat and cool each house is a single-package unit nominally rated at 24,000 Btu/h (two tons or 7 kW) cooling at 95 F (35 C) outdoor air temperature and 27,000 Btu/h (8 kW) heating at 47 F (8.3 C) outdoor air temperature. Ten kW of backup resistance heaters are also available to either augment the heat pumps in cold weather or to operate by themselves to heat the house.

The houses are adjacent to each other, each facing generally north. The conditioned space is over a crawl space extending under the entire floor.

The houses were built by the same contractor using standard construction methods. Only minor exterior cosmetic differences exist, so that they would fit aesthetically into the neighborhood. The houses are insulated according to recommendations provided by the Knoxville Utilities Board: R-11 in all exterior walls, R-19 in the floor, and R-30 in the ceiling. Each house has the same make and model two-ton, single-package residential heat pump. Ductwork is located in the crawl space and insulated to R-7.6.

The surroundings for the three Karns houses are very similar. The recently graded flat lots are devoid of trees or shrubbery, and there are no large buildings in the area. The houses have very little shielding.

Knoxville has a moderate temperature range with cool winters and warm summers. The heating degree-days for the year (4004) are much greater than cooling degree-days (864), and the wind speed is moderate. The relative humidity for the area is about average for the southeast region but above average for the country as a whole.

DESCRIPTION OF DATA ANALYSIS AND RESULTS

As received from the data acquisition system, the data were on floppy disks in American Standard Code for Information Interchange (ASCII) format files. A microcomputer was used to analyze and reduce the data. Software was written to create hourly files from the data if desired, make plots of the raw data, make plots of derived values, make new data files suitable for statistical analyses, etc. All plots and tables are able to be printed out on a printer. Since there were many different experiments carried out during the course of this work, the overall results of the work are presented in Table 2. This table will be referred to in the remainder of the paper, and the interpretation of the results will be discussed with some backup detailed data to support the conclusions. It is very easy to misinterpret the results shown in Table 2, so the reader is advised to read the whole paper before forming any of his or her own conclusions.

DESCRIPTION OF THE DATA ACQUISITION SYSTEM

Figure 3 is a photocopy of the data acquisition system used to collect the data at each Karns house. The data logger receives conditioned power from an AC line conditioner. An uninterruptible power supply was added to the system and located between the power line conditioner and the data logger. The data acquisition had originally used a tape cassette system to store the gathered data, but a microcomputer replaced the tape drive and also changed the manner in which the data logger was used. The data logger was only used to linearize thermocouple readings and a few of the analog voltage readings and transmit the information to the microcomputer over an RS-232 serial port. The data collection process was software-driven by the microcomputer, which was then able to massage the data into the desired format and store the results on floppy disks for later analysis.

In general, the data collected included the temperatures and humidity within the house, the outside temperature, wind speed and direction, total horizontal plane insolation, attic temperatures and humidity, crawl space temperature and humidity, outside earth temperatures, power consumed by the house and the HVAC system in its various modes of operation, and the heat delivered by the HVAC system. In all, there were 50 channels of data scanned on a 30-s interval by the data logger and sent to the microcomputer for preliminary analysis and storage.

DESCRIPTION OF EXPERIMENTS

Resistance Heating Calibration and Results

The first task to be done at the Karns test facility was to calibrate the houses to determine the heating load of each. Since each house had a heat pump for an HVAC (heating--ventilating-air conditioning) system, the houses were run on resistance heat for a period of approximately three weeks to determine their load profiles. Figure 4 shows the results for house 1 for a typical one-week period, December 20-26, 1984. The main thing to notice from this plot of hourly house loads vs outdoor temperature is that the curve fit has a rather poor R^2 (goodness of fit) value. Plots from the other houses showed that the slopes and intercepts of the houses are quite similar to each other for each period but quite different from one period to the next. This trend was quite evident throughout the testing and presents a strong argument in favor of having a control house with which to compare test houses during the course of an experiment.

The variation in slope of the curves was no doubt caused by the changes in the weather during the test periods, as the period from December 26 to January 1 was rather warm compared to the other two weeks. It is strongly believed that the poor R^2 value of each fit was caused mostly by the thermal capacity of the house and by the cycling of the thermostat, and aided somewhat by variations in insolation and infiltration rates. The results of a multiple linear regression analysis for house 1 for the period of December 20-26, 1984, are typical of such an analysis, which relates the house load to outdoor temperature, insolation, wind speed, indoor temperature, and internal loads. Table 3 contains the results of the analysis. When the values of the R^2 for the simpler plot of Figure 4 are compared to that of Table 3, it is seen that the multiple linear regression increases the R^2 from 0.69 to 0.77, but it still leaves a great deal of unexplained variability in the data.

House 3 was undergoing some indoor air quality measurements during the period December 20, 1984-January 7, 1985, so it had to be calibrated against house 1 in the following weeks. Table 2 contains the reduced data for the testing. With respect to the resistance heating calibration testing, if house 1 were assigned a relative value of 1.000, house 2 had a value of 1.033 and house 3 a value of 0.988. These values show that the houses do indeed have very similar heating load characteristics.

Heat Pump Heating Calibration and Results

The houses were run on their heat pumps over the period January 18-28, 1985, in order to "calibrate" the heat pumps and compare the house loads with the heat pumps. Once again, if house 1 were assigned a relative value of 1.000 for this period, house 2 had a value of 1.038, and house 3 had a value of 0.988. These values are in quite good agreement with those of the resistance-heating calibration runs and again confirm the assumption that the houses are thermally quite similar. Also, the COP values of the heat pumps were quite similar for each period, as listed in Table 2.

Infiltration Measurements

In addition to the thermal testing of the houses, many measurements of the infiltration rates of the three houses were made by the author as well as by the ORNL Health and Safety Research Division. The consensus on a semiquantitative basis is that the houses behave quite similarly so far as infiltration is concerned. Measurements were made by the author using sulphur hexafluoride as the tracer-gas with the decay method. The concentration of the tracer gas was monitored with a tracer gas analyzer. Of particular note in these measurements was the fact that the infiltration rate of the houses increased significantly when the central HVAC fan was operating. Figure 5 illustrates this fact by showing the results of some of the experimental data. Two obvious explanations of this loss are that either the house is being overly pressurized by the fan or the ductwork is somewhat leaky, or both.

Tests made on the houses with a micromanometer showed no significant difference in the inside-outside pressure difference when the fan was running or not. This suggests that the ductwork, located in the crawl space, is leaky. Since the flow rate through the fan is on the order of 1000 cfm, a quick calculation shows that about 50 cfm, or 5% of the air, would have to be leaking. Air temperature measurements in the crawl space do not show more than a 0.2 F temperature rise maximum between the the on-off cycles. The fan effect will be pursued further in the fall of 1985 by the ORNL Health and Safety Research Division.

DESCRIPTION AND RESULTS OF RETROFIT EXPERIMENTS

Zoning with Resistance Heating

The first series of retrofit experiments involved the zoning or closing off of two bedrooms in house 2. The forced air outlets in bedroom 2 and bedroom 3 in house 2 were taped shut with a reinforced aluminum duct tape, the bedroom doors closed, and towels stuffed under each door to further seal each room. This method was chosen because it is probably the way a typical consumer would do it.

The results of the aforementioned analytical study by Potter and Karnitz (1985) had shown that zoning could save an appreciable amount of energy. The volume of the two closed-off bedrooms at Karns amounted to about 20% of the house volume. (Three closed-off bedrooms amount to about 40% of the house volume.) The resistance zoning experiment lasted from January 7 to January 18, 1985, and only involved house 2 with the two closed-off bedrooms (house 3 was undergoing some additional calibration). Figure 6 is a plot showing how the temperatures of the zoned-off bedrooms floated compared to the house thermostat temperature and the outside temperature. There was about a 15 F difference between the zoned-off bedroom and the rest of the house. The relative energy measurements showed that compared to the 1.000 value given house 1, house number 2 has a value of 0.859. Since house 2 has a normal heating load of 1.033 times that of house 1, the actual relative value of house 2 is 0.859/1.033 or 0.832. Refer to Table 2 for the data.

These results show that zoning can save a noticable amount of energy in resistance heating, but the results cannot be applied to the entire heating season. The results show that for the given weather conditions, a 17% reduction in energy was obtained. In order to predict the savings over an entire season, a predictive model is necessary. More will be said about predictive models later in the paper.

Zoning with Heat Pump Heating

The heat pump zoning tests were conducted in the same manner as those described for zoning with resistance heating. All three houses were used during this phase of the testing, which lasted from January 28 to February 13, 1985. Table 2 shows the normalized relative values of the data--house 2 has a value of 0.903, and house 3 is 0.818. Once again it should be kept in mind that the measured savings apply only to the monitored period, and should not be extrapolated to a yearly savings value without applying some analysis with a predictive model.

These results appear to be linearly dependent with volume, as house 2 had 20% of its volume zoned off and house 3 had 40% of its volume zoned off. If one compares the relative efficiencies (COPs) of the heat pumps in the three houses for this experiment against those obtained in the heat pump calibration experiments (Table 2), one can conclude that increased zoning does indeed lower the heat pump efficiency. However, since the weather conditions were different during the two tests, such judgments are strictly qualitative---even though the data show a clear trend. One would normally expect cycling losses to increase with a decrease in cycle run time.

Night Setback with Resistance Heating

New "smart" thermostats were installed in all three houses following the heat pump zoning tests. They contain a microprocessor that allows two user-settable periods of setback per day and also allows weekends to be skipped if desired. The thermostat also lets the user set the amount of desired setback during the periods.

The thermostats were set up so that house 1 operated with no setback, house 2 had a 5 F setback, and house 3 had a 10 F setback. Only one setback period was programmed into the thermostats in houses 2 and 3--it started the setback period at 10 p.m. and started to recover at 7 a.m., with full recovery being reached by 9 a.m. Figure 7 is a plot of the house temperature in each house along with the outside temperature for the period February 22-March 1, 1985. This time period was fairly warm and as a result the full 10 F setback was only attained for house 3 for two of seven days. The 5 F degree setback was attained on five of the seven days for house 2.

Table 4 shows the average hourly loads for the three houses for the whole seven-day period as well as for the two-day period in which all the setbacks were actually attained. Based on the seven-day period, the 10 F setback in house 3 showed an energy usage of 0.82 relative to the zero setback of house 1, while the 5 F setback of house 2 showed a relative energy usage of 0.78. House 3 appears to be using more energy than house 2! Perhaps the occasional occupancy of House 2 by the reseachers coupled with the mild weather contributed to the difference. No other explanation is offered at present.

Based on the cold two-day period, the 10 F setback showed a relative energy usage of 0.73, while that of the 5 F setback was 0.76. Once again, these numbers show that energy savings are to be had by a retrofit technique, but some serious modeling of the residence and the weather must be done in order to ascertain the actual savings. Note that the above results have been normalized for the differences in the heating loads between the three houses.

One factor, which is very important to electrical utilities, is the effect of a retrofit measure on the peak electrical demand. The maximum hourly demand with no setback was 3700 watt-hours, that with 5 F setback was 5400 watt-hours, and that with 10 F setback was 7100 watt-hours. Thermostat setback does indeed increase the demand of a residence, while it decreases the total purchased electrical energy. This situation is one most utilities do not favor. Widespread use of thermostat setback with resistance heating during extremely cold weather might well tax the capacity of a utility with a high percentage of residential customers in its supply network.

Resistance Heating with Both Zoning and Setback

Since both zoning and night setback showed energy savings during the testing, a combination of the two methods was tried. Table 2 contains the results of these tests. The data obtained from this testing were somewhat confusing, as it showed that house 2, which had only two bedrooms zoned off and a 5 F setback, used less energy than house 3 which had three bedrooms zoned off and a 10 F setback. It was only natural to assume that house 3 should have had the greater energy savings. The explanation of the result was quite logical, once it was figured out.

If one refers back to Figure 2, the floor plan of the house, one will notice that the two bedrooms zoned off in house 2 were bedrooms 2 and 3, both north-facing bedrooms. House 3 had all bedrooms zoned off; including bedroom 1, which was a south-facing bedroom. More important than the location of the bedroom, however, was the fact that the data acquisition system was located in bedroom 1. The main source of the approximately 500-W internal load of each house was the data acquisition system. Therefore, one would assume that the internal loads in bedroom 1 would not be distributed throughout the house and would also raise the temperature of bedroom 1 above that of bedrooms 2 and 3.

Figure 8 confirms the results of our logic. It is a plot of the temperatures of the three zoned-off bedrooms, as well as the thermostat (which is the same as the nonzoned portion of the house). The temperatures of bedrooms 2 and 3 are well below that of the thermostat, while the temperature of bedroom 1 is considerably above that of the thermostat. Figure 8 very dramatically shows how the internal loads can impact on the temperatures of the various sections of the house, which, in turn impact on the house HVAC load.

House 2 showed an energy use of 0.595 on a normalized basis relative to house 1. House 3 showed an energy use of 0.692 relative to house 1. The situation in house 3 is obviously not optimized for the greatest possible savings and, therefore, should not be considered as valid data for comparison purposes so far as house 2 is concerned. House 3 does show, however, what might possibly happen in a given situation in an occupied house if the wrong doors are either opened or closed for whatever reason.

Heat Pump Heating with Both Zoning and Setback

An attempt was made to determine the combined effects of zoning and setback on the houses in the heat pump mode. House 2 had two bedrooms zoned off as before, and house 3 also had all three bedrooms zoned off in the same manner as before. Obviously the reason for the relatively poor performance of house 3 had not yet been determined, else the test would not have been run in the same manner. Yet another gremlin managed to sneak into this set of tests, which were started on Friday morning, March 8, 1985. On that evening, the power surged on and off several times in the course of a minute and managed to open the circuit breaker supplying the power to the heat pump in house 2, thus shutting it off for the weekend. The weather turned relatively mild on Sunday night so that when the houses were checked on Monday afternoon, everything looked all right. The weather turned cooler again Monday, and on Tuesday the problem was discovered and the circuit breaker reset. Still believing that the results for house 3 might be valid, the testing continued without the inclusion of house 2. Needless to say, optimized data were not obtained for these tests. The unoptimized test results showed that house 3 had an energy use of 0.719 on a normalized basis. Although the savings are biased on the low side, they are still substantial when compared to either zoning or setback on an individual basis.

DISCUSSION OF EXPERIMENTAL RESULTS

Figure 9 is a bar graph representing the relative normalized energy use of the three Karns houses as tabulated in Table 2. There is no doubt that the savings depicted in Figure 9 are actual measurements of savings, but the question remains as just how do these short--term experimental measurements apply to season-long savings because of the differences in ambient weather conditions that a structure will undergo during the course of a heating season. Figure 10, a plot of the normalized average hourly energy usage of each house for all the experiments, illustrates this fact somewhat better than Figure 9. It is obvious from this plot that the setback and setback/zoning combination tests were conducted in relatively mild weather compared to the rest of the testing.

The shortcomings of the data from house 3 during the zoning experiments, when the bulk of the internal loads were contained in a zoned-off bedroom during relatively mild weather, have already been recognized, and yet savings were still registered in this mode. As mentioned earlier, the best way to use the measured data is in the form of input to a computer modeling program, which, in turn, can be used to predict the season-long expected savings from a given retrofit.

A simple empirical modeling technique, that of multiple linear regression, was discussed somewhat earlier in this report and Table 3 showed the results of such an excursion. The model assumes that the dependent variable is the house hourly heating load expressed in inch-pound units of Btu/h. The independent variables were chosen to be the outdoor temperature in degrees Fahrenheit, the insolation (solar radiation) in Btu/h·ft^2, the wind speed in mph, the house inside (thermostat) temperature in degrees Fahrenheit, and the house internal electrical loads in kWh/h.

Figure 11 shows the results of using an empirical multiple linear regression model as described above for house 2 for the week of January 1-7, 1985, to predict the heating loads of house 2 for the same period. Table 5 shows the results of using predictive equations from each of three periods to predict the load for all three periods in tabular form and also includes differences and the average period temperatures for the sake of comparison. Figure 12 shows the data from Table 5 in a bar graph format.

The important thing to note from this exercise is that the predicted hourly loads are not very close to the measured hourly loads in almost all cases, but that the integrated loads for each period can be fairly well predicted if the data from that period, or another period in which the weather was similar, are used to obtain the predictive equation. The predicted loads for the second period (December 26, 1984-January 1, 1985) do not agree very well with the measured loads when periods 1 or 3 are used to make the prediction. Likewise, period 2 does not predict the results of periods 1 or 3 very well. The differences between the three time periods is that the second period was warm, relative to the first and third periods. This situation is very similar to that of using polynomial curve fits to predict values outside of the range of the data used to derive the curve fit.

The preceding discussion is not meant to convince the reader that an empirical model is the best method to use in predicting the energy consumption of a structure based on some measured energy history, but it is meant to illustrate that a proper model can predict energy usage quite accurately. The better predictive models are those that are accurate and require a minimum of monitored data input. Once again, such a model should be used in conjunction with the measurements made in this work to better predict the annual savings of retrofit measures. As an aside, modeling the effect of life-style on the retrofit benefit is also needed.

REFERENCES

Potter, M.C. and Karnitz, M.A. 1985. The influence of building parameters on space conditioning in small residential buildings. ORNL/CON-156, November.

McLain, H. (in press). Appropriate conservation measures for single-family buildings in hot, humid climates. ORNL/CON report.

ACKNOWLEDGMENT

Research sponsored by the Office of Buildings and Community Systems, U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

TABLE 1

Measured Inside Dimensions of Karns House 2

Room Location	Length (ft)	Width (ft)	Height (ft)	Area (ft^2)	Volume (ft^3)	Windows Area (ft^2)	Windows Facing (azm)[a]	Insulation Wall (R)	Insulation Ceil (R)	Insulation Floor (R)
Bedroom #1 (SBB)	15.63	10.96	7.92	171.2	1355.5	16.04	South	11	32	19
SBB Bathroom	7.00	4.92	7.92	34.4	272.4	0.00	-	11	32	19
SBB Closet	8.21	1.83	7.92	15.0	119.1	0.00	-	11	32	19
Bedroom #2 (NBB)	9.75	10.96	7.92	106.8	845.9	14.25	North	11	32	19
NBB Closet	4.96	3.13	7.92	15.5	122.7	0.00	-	11	32	19
Bedroom #3 (NCB)	9.75	9.63	7.92	93.8	743.0	14.25	North	11	32	19
NCB Closet	4.94	1.88	7.92	9.3	73.3	0.00	-	11	32	19
Great Room (GR)	25.58	19.27	7.92	493.0	3903.0	30.48	North	11	32	19
Kitchen	10.33	3.00	7.92	31.0	245.4	35.94	South	11	32	19
Kitchen Closet	4.96	4.96	7.92	24.6	194.6	0.00	-	11	32	19
Hallway + Closet	17.92	3.04	7.92	54.5	431.5	0.00	-	11	32	19
Main Bathroom	8.17	4.88	7.92	39.8	315.2	0.00	-	11	32	19
TOTALS				1089.0	8621.6	110.96				
Garage	23.23	11.63	8.25	270.0	2227.8					

[a]Azimuth

TABLE 2

Listing of Karns Normalized Heating Experimental Data

		Normalized Relative Energy			HVAC System COP		
Operating Mode	Hours	House 1	House 2	House 3	House 1	House 2	House 3
Res-Calibrate	421	1.000	1.033	----	1.000	1.000	-----
Res-Calibrate	119	1.000	-----	0.988	1.000	-----	1.000
Res-Zoned	261	1.000	0.832	-----	1.000	1.000	-----
HP-Calibrate	238	1.000	1.038	0.998	1.342	1.436	1.427
HP Zoned	376	1.000	0.903	0.818	1.764	1.796	1.683
Res-Setback	166	1.000	0.781	0.822	1.000	1.000	1.000
Res-SB-Zoned	168	1.000	0.595	0.692	1.000	1.000	1.000
HP-SB-Zoned	167	1.000	----	0.719	1.968	-----	1.996

Note: All relative energy data are relative to House #1
Normalized data = Raw data/Calibration (Res or HP)

TABLE 3

Sample Multiple Linear Regression

House #1 Standard Resistance Heat December 20-26, 1984

Dependent Variable = Btu

Independent Variables	Regression Coefficients	Std Error of Coeffs	t-Score	Probability	Beta
ODTemp	-292.6072	20.0837	-14.57	1.000	-0.788
Insol	-31.1100	4.9733	-6.26	1.000	-0.347
WindSp	16.9932	66.8870	0.25	0.200	0.014
T'stat	427.1347	384.5072	1.11	0.731	0.060
IntLoad	0.2361	0.8051	0.29	0.230	0.012
Intercept	-11301.7191				

R-Squared	=	0.7748	Durbin-Watson	=	1.0731
Adjusted R-squared	=	0.7680	No. of Data Points	=	137
Multiple Correlation	=	0.8802	No. of Points Used	=	137
Std Error of Estimate	=	1952.2210			

Analysis of Variance

	Degs of Freedom	Sum of Squares	Mean Squared	F Value	F Probability
Regression	5	1717562000	343512400	90	1.0000
Residual	131	499263000	3811168		
Total	136	2216824673			

TABLE 4

Effect of Setback (10 p.m. - 7 a.m.) on House Load While on Resistance Heat

				Load Relative to House 1	
Start-End Date	House #	Setback	Avg kWh/h	Raw Data	Normalized Data
2/22 - 3/01/85	1	0 F	648.17	1.000	1.000
	2	5 F	523.43	0.807	0.781
	3	10 F	526.90	0.812	0.822
2/27 - 3/01/85	1	0 F	1380.0	1.000	1.000
	2	5 F	1086.6	0.787	0.762
	3	10 F	1003.8	0.727	0.736

Note: Houses did not always attain setback in first period.

TABLE 5

Comparison of Multiple Linear Regression Empirical Modeling

		Energy Use (Btu)			
Period No. (Start-End)	Predicted From Period	Measured	Predicted	Difference	% Diff
Period No. 1	1	724,402	732,289	7,887	1.08
(12/20-26)	2	724,402	661,071	-63,331	-9.58
T(avg)=46 F	3	724,402	712,435	-11,967	-1.68
Period No. 2	1	245,097	324,531	79,434	24.48
(12/26-1/01)	2	245,097	258,610	13,513	5.22
T(avg)=58 F	3	245,097	277,566	32,469	11.70
Period No. 3	1	1,095,945	1,092,899	-3,046	-0.28
(1/01-07)	2	1,095,945	961,588	-134,357	-13.97
T(avg)=39 F	3	1,095,945	1,098,758	2,813	0.26

Figure 1. Karns houses test facility

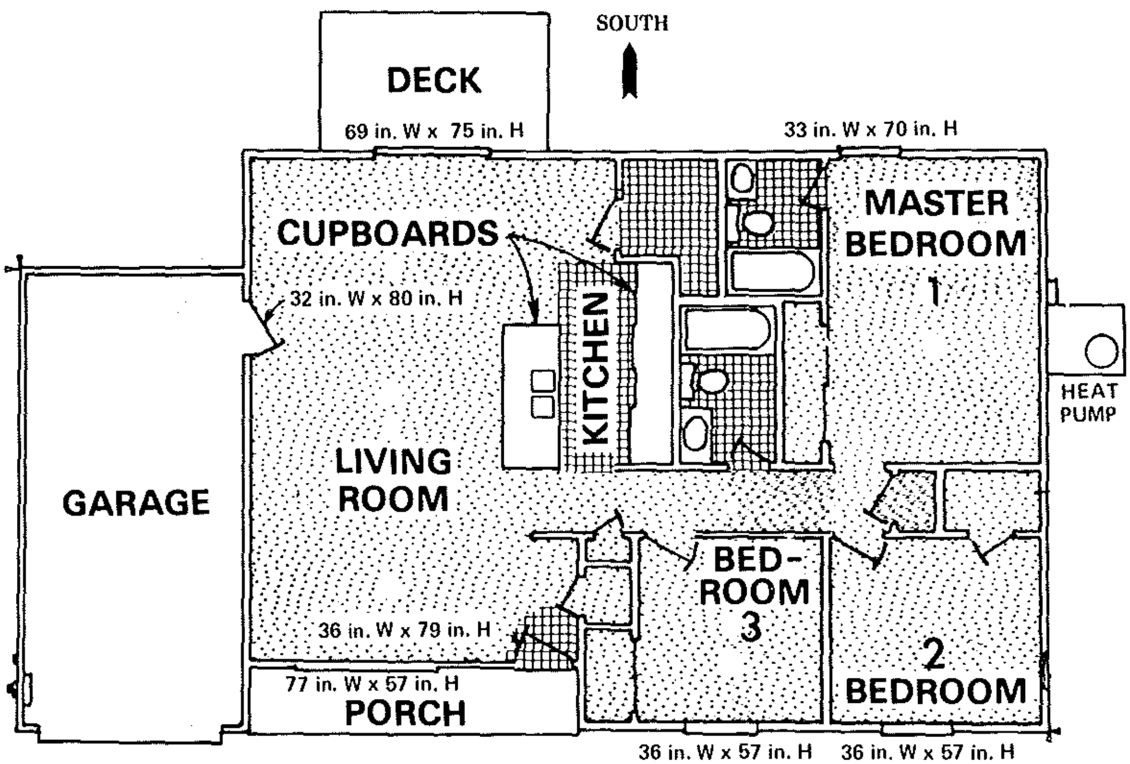

Figure 2. Floor plan of Karns houses

Figure 3. Data acquisition system

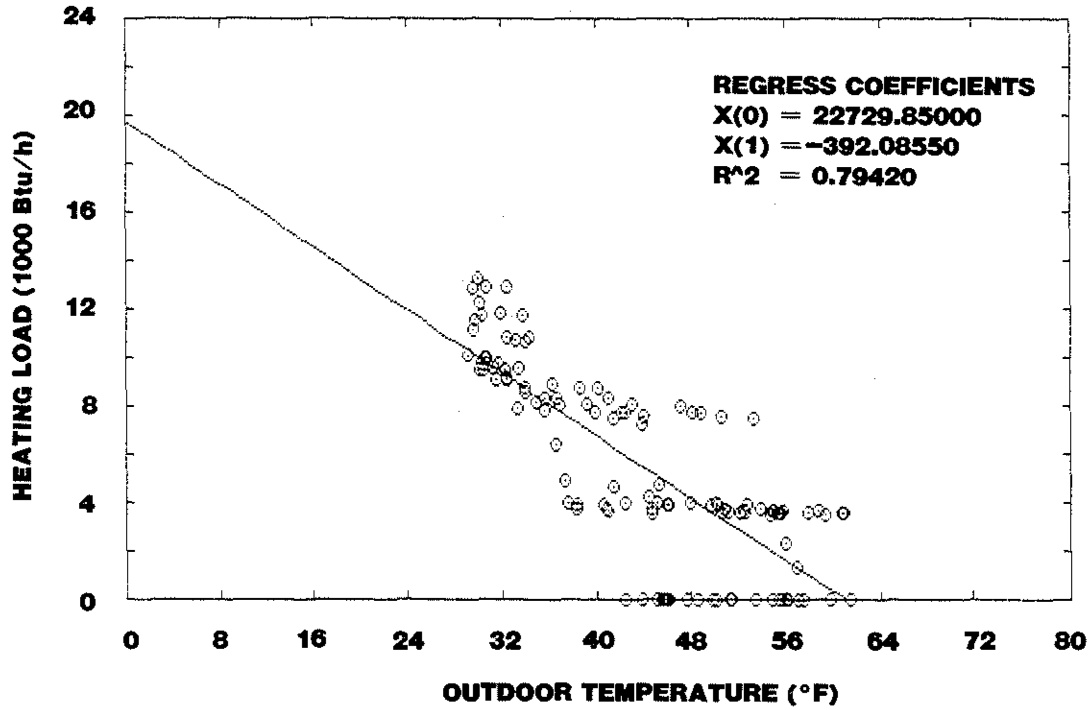

Figure 4. House 1 (resistance) heating load vs. outdoor temperature, January 1 - 7, 1985

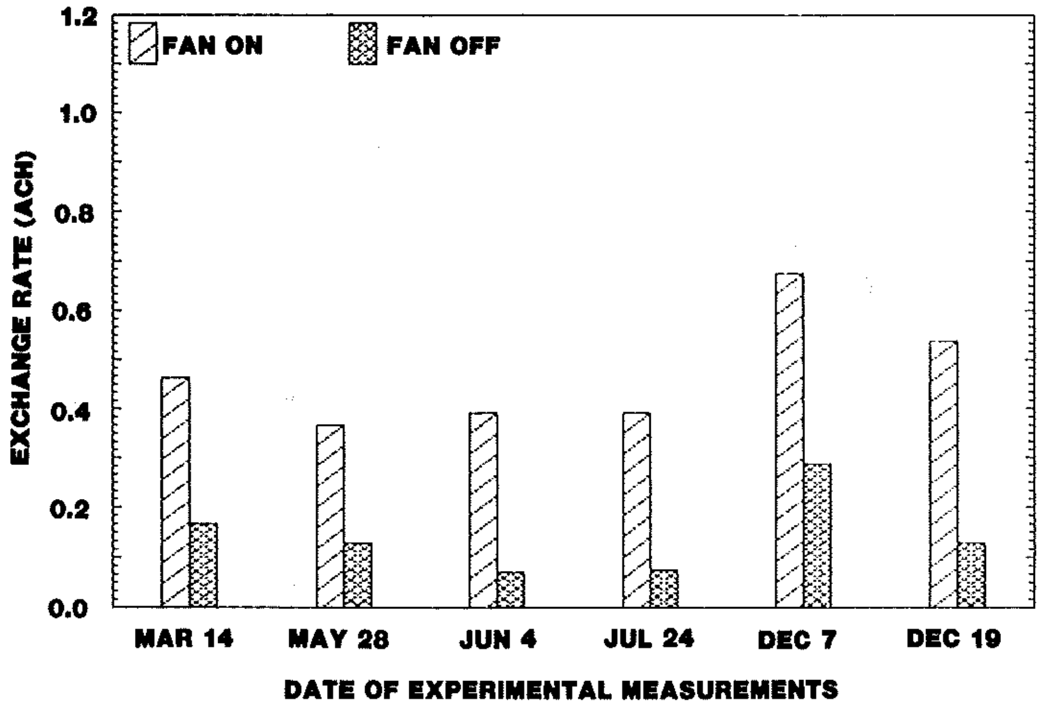

Figure 5. Effect of HVAC fan on house infiltration rate

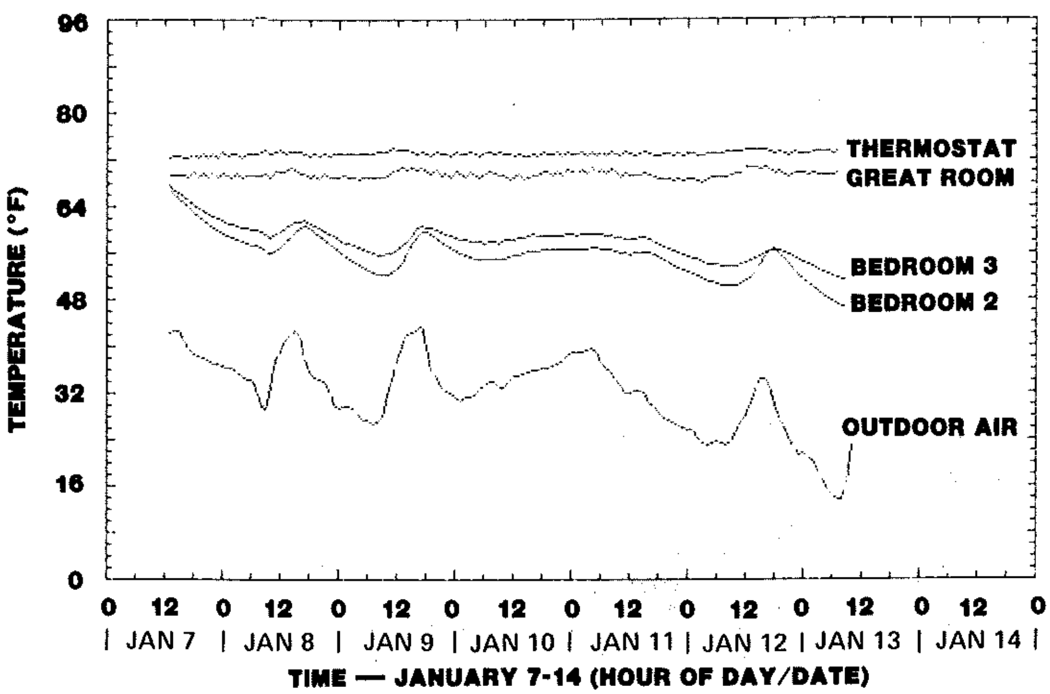

Figure 6. Effect of zoning on house temperatures

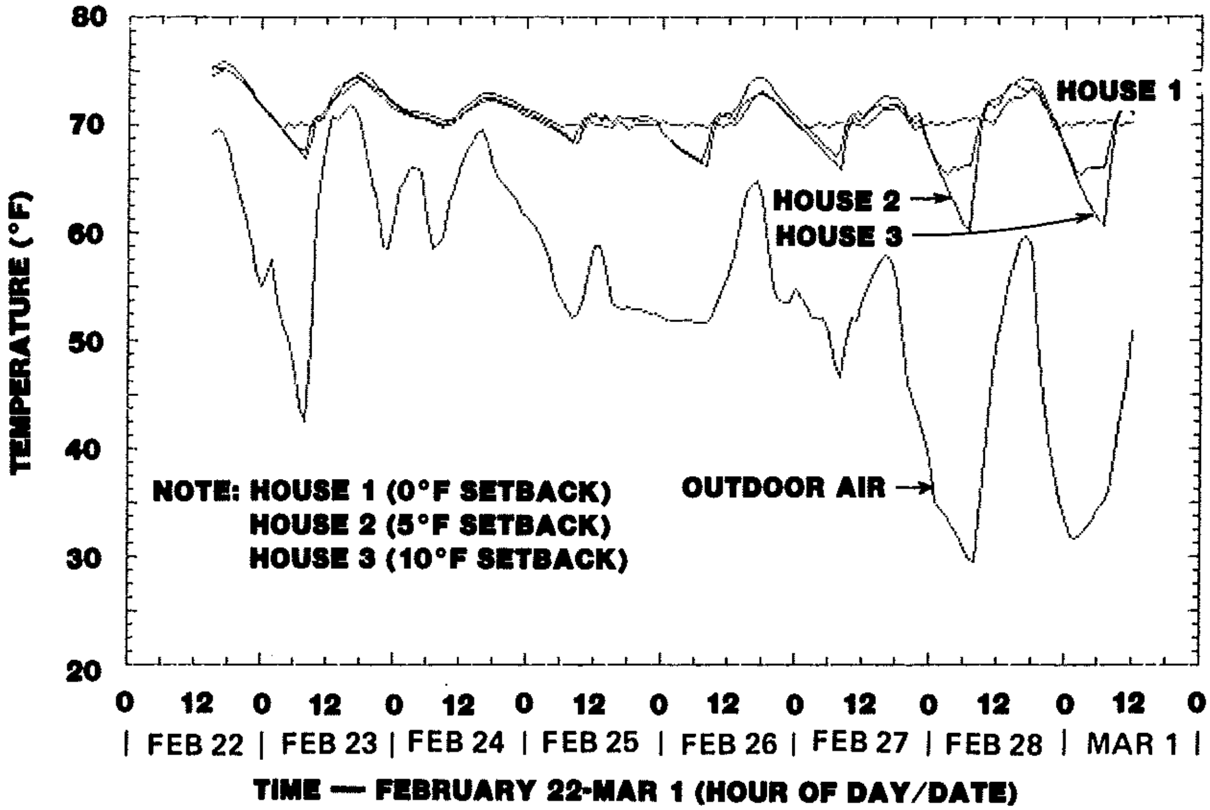

Figure 7. Effect of night setback on house temperatures

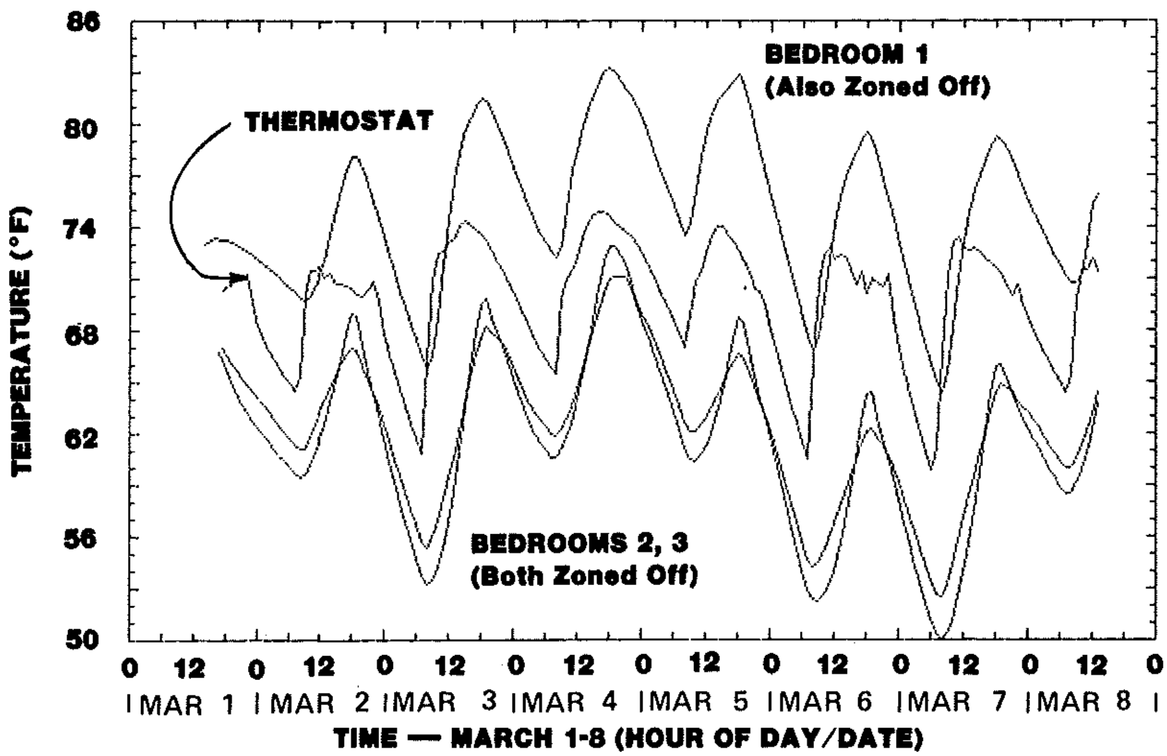

Figure 8. House 3, effect of zoning three bedrooms and 10 F setback on house temperature

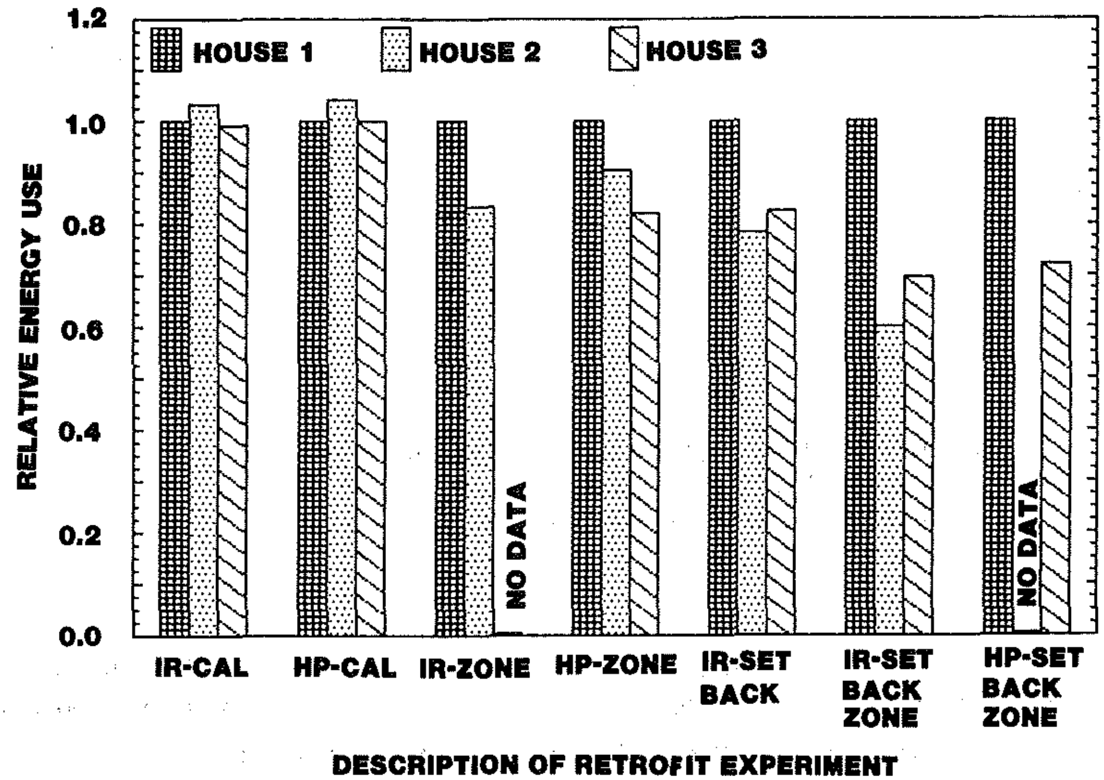

Figure 9. Relative results of normalized heating experiments at Karns

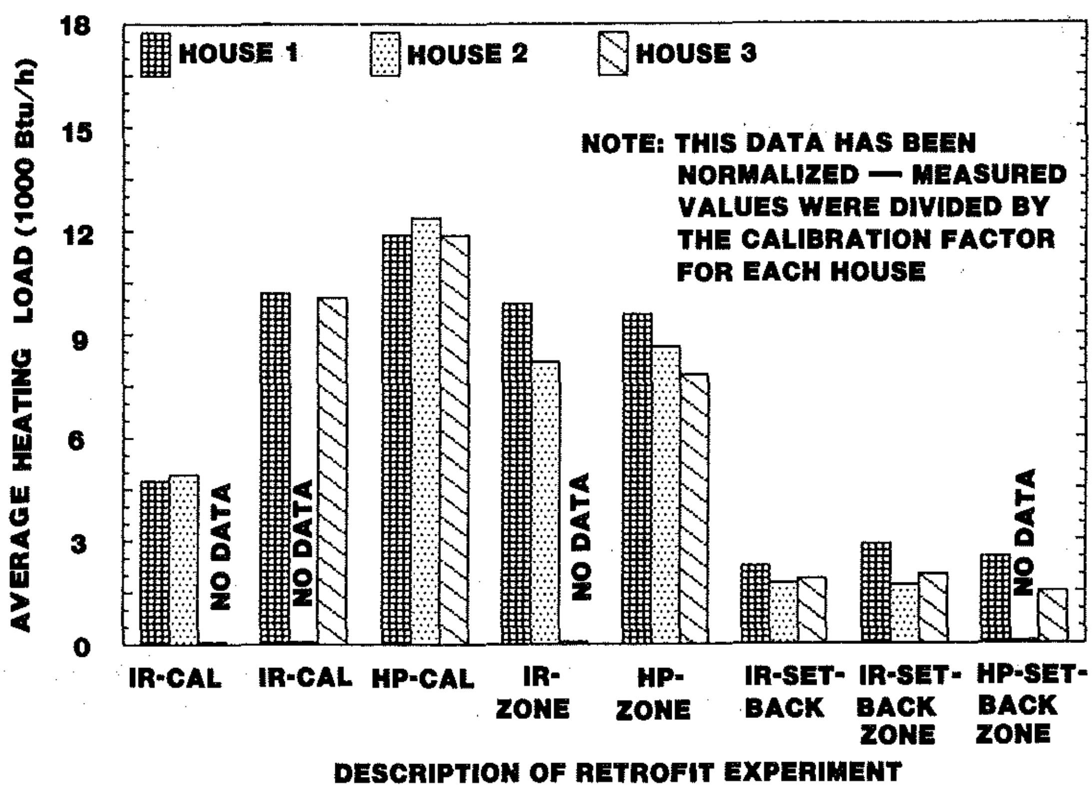

Figure 10. Results of normalized heating experiments at Karns

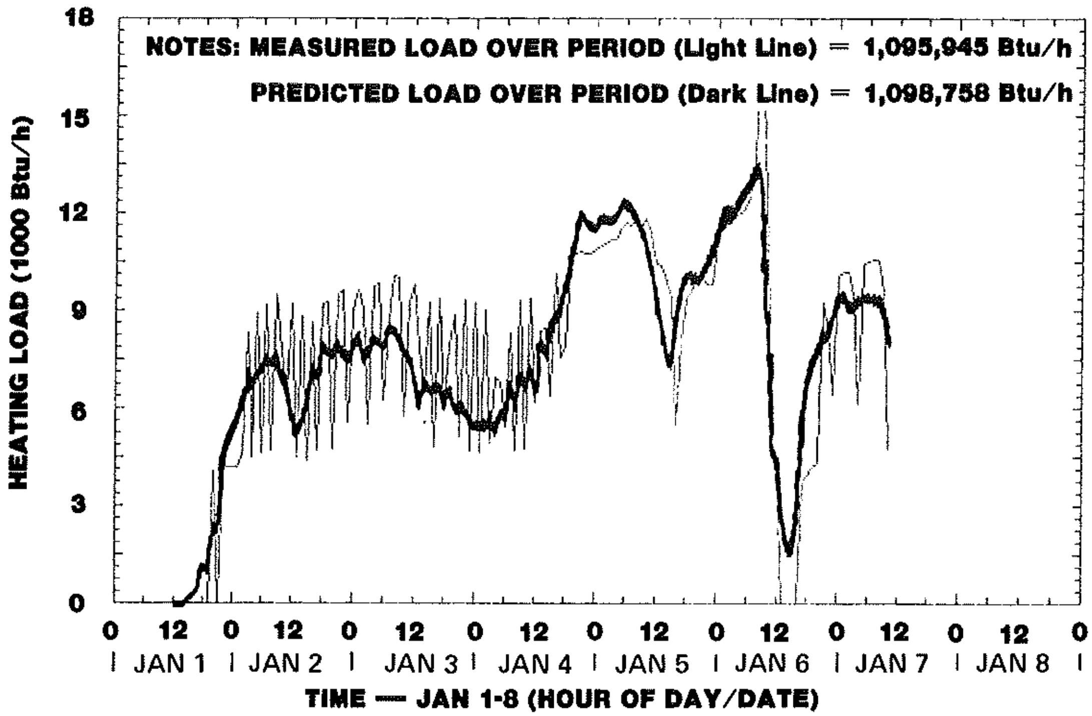

Figure 11. Results of multiple linear regression modeling

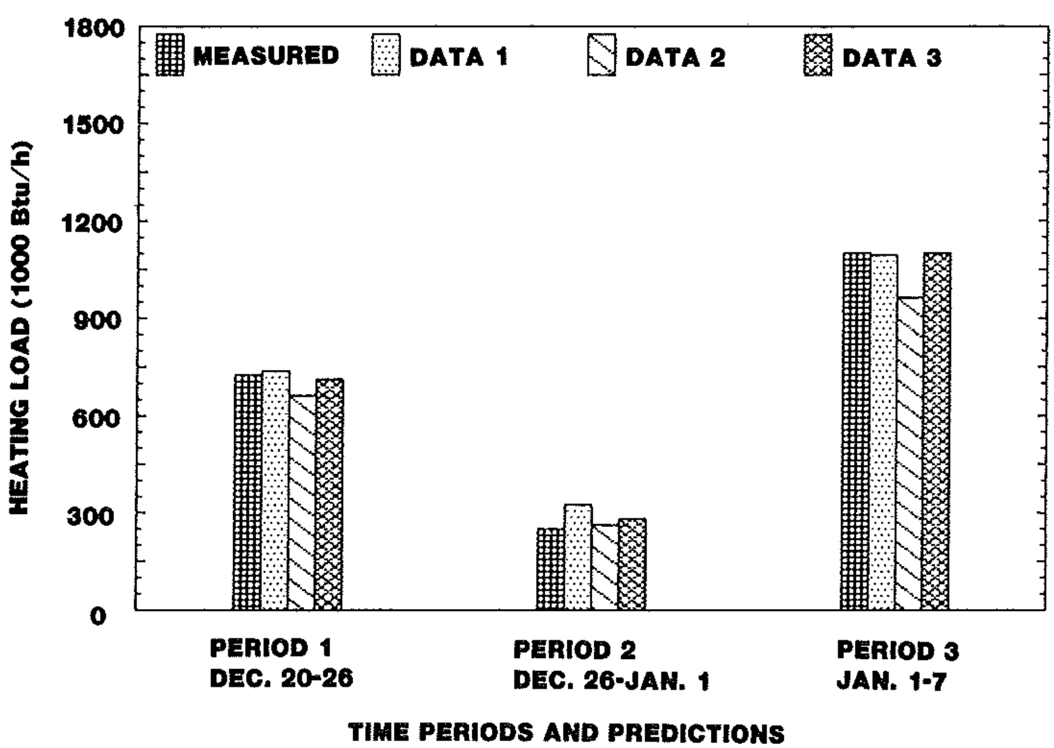

Figure 12. Comparative results of multiple regression modeling