PREDICTING THE SEASONAL PERFORMANCE FACTOR OF RESIDENTIAL AIR-SOURCE HEAT PUMPS IN OKLAHOMA

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PREFACE

The purpose of this study was to develop a simplified technique for estimating the seasonal heating efficiency of residential air-source heat pumps in Oklahoma.

The author wishes to express his appreciation to his major adviser, Dr. George W. A. Mahoney, for his guidance and assistance throughout this study. Appreciation is also extended to the other committee members, Dr. James E. Garton and Dr. Raymond L. Huhnke, for their valuable assistance in the preparation of this manuscript.

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CHAPTER I

INTRODUCTION

Approximately 200,000 homeowners in Oklahoma currently heat their homes with either L.P. gas or electric resistance furnaces. In either case, cost of home heating has become extremely high. In the interest of economics, many of these homeowners are looking at alternate home heating methods. Various alternatives considered are supplemental wood heat, solar heat, wind energy systems, water-source heat pumps, and air-source heat pumps. Of these, the electric air-source heat pump is the alternative most often chosen by homeowners in Oklahoma.

One of the primary difficulties associated with air-source heat pumps is evaluation of seasonal efficiency. To determine economic benefits of air-source heat pumps over other alternatives, seasonal efficiency must be estimated. Because the heat pump fulfills a dual role of both heating and cooling, sizing is typically based on cooling load of the structure. While the unit is sized to meet cooling requirements, it does not have adequate capacity to meet all heating requirements. Therefore, it is necessary to provide supplemental heat to the structure during low temperature outdoor conditions. Supplemental heating requirements are determined by graphical procedures as illustrated in Figure 1. The load line represents calculated structural heating requirements as a function of outdoor temperature. It is approximated by a linear function that passes through the design heat-loss rate (DL) at outdoor design temperature (DT) and the temperature at which the structure requires no external heat. Likewise, the output curve represents heat pump heating capacity as a function of outdoor temperature. At the temperature where the two curves intersect, the heat pump has sufficient capacity to meet all structural heating requirements. This temperature is normally defined as balance point temperature (BP). At outside temperatures above balance point, heat pump heating capacity exceeds structural heating demand. As temperature increases above balance point, efficiency is increased while run time is decreased. However, at outdoor temperatures below balance point temperature heat pump efficiency decreases and capacity is not sufficient to meet heating demand. It is in this region of operation that supplemental heat must be supplied. Typically, supplemental heat is supplied by electric resistance strip heaters which have a seasonal efficiency of 1.0. Thus, overall system efficiency below balance point temperature is reduced. Figure 2 contains long term average temperature bin data for central Oklahoma. From the distribution, it can be seen that a significant number of hours occur in the temperature bins between -4°C (25°F)

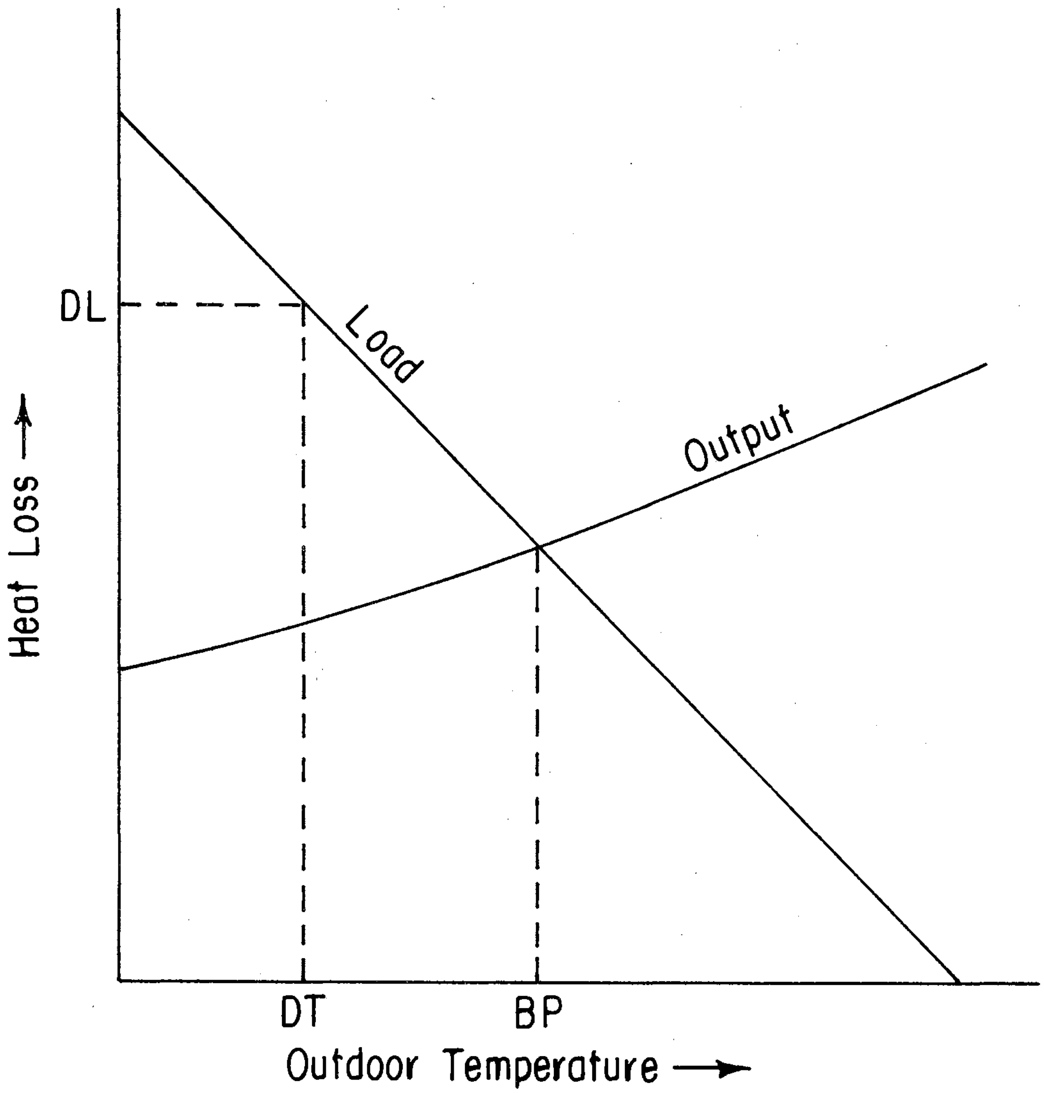

Figure 1. Heat Pump Output and Heat Loss Rate of Structure vs. Outdoor Temperature

and 4°C (40°F). Typically, balance point temperatures are in this range. In the example of Figure 1, balance point temperature was approximately 2.2°C (36°F). From the temperature distribution, there are approximately 1,065 hours where temperatures are below this balance point. If balance point temperatures in Figure 1 were lowered to -1°C (30°F), only 615 hours of temperatures below balance point would be encountered. Obviously, as balance point temperature is decreased, hours with temperature below balance point also decrease. In each of these cases, supplemental heating requirements and heat pump efficiency is different. Thus, for a given location, seasonal performance varies as a function of balance point temperature.

To maximize seasonal efficiency for a given heat pump system, balance point temperature should be minimized. Several methods of reducing balance point temperature exist. One method is illustrated in Figure 3. For a given structure, if heat pump heating capacity is increased, balance point temperature is lowered. With the load line fixed in Figure 3, output performance is increased and a lower balance point temperature results. The major problem with this method of lowering balance point is that changing heating capacity also changes cooling capacity. An increase in cooling capacity above that calculated for design conditions results in lowered efficiency during cooling. Also,

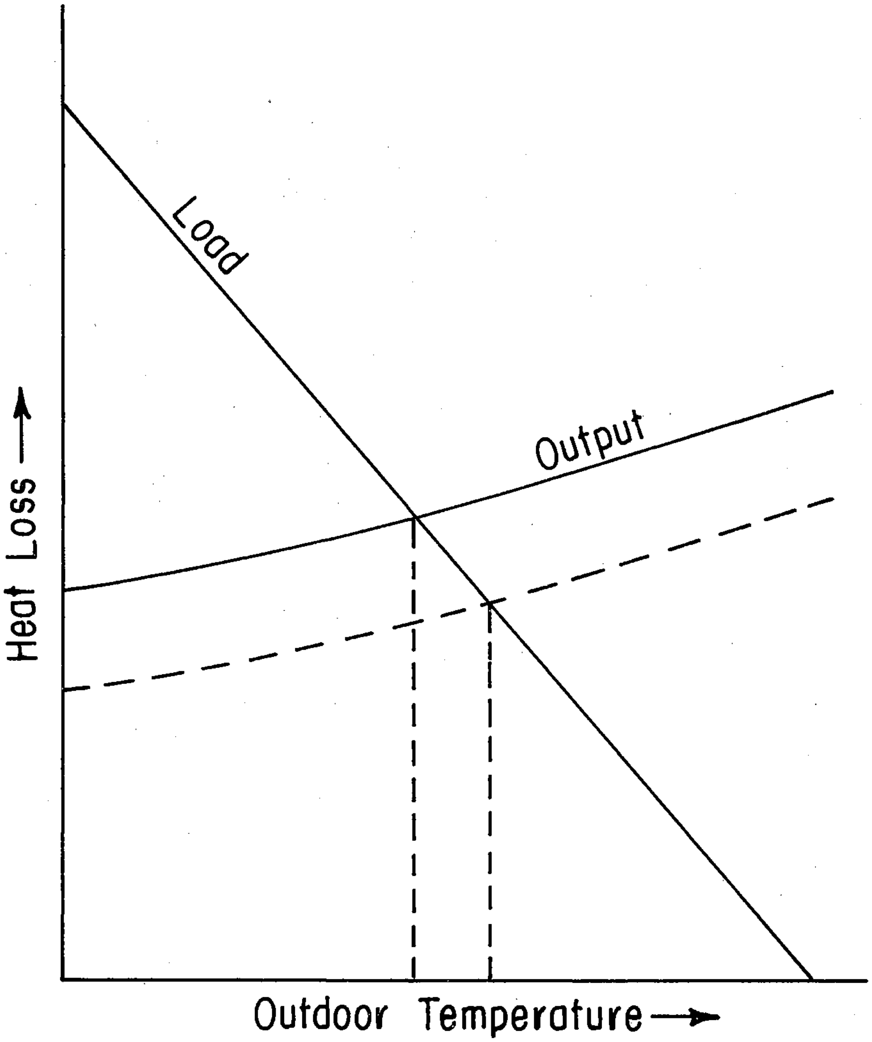

Figure 3. Variation in Balance Point Temperature with Change in Heat Pump Capacity

with increased size, initial unit cost is increased. Therefore, in Oklahoma, it is not recommended to increase unit size beyond that required for cooling.

Other methods of lowering balance point temperature primarily involve changing the design heat loss rate of the structure itself. If design heat loss rate of the structure is lowered, heat requirements are decreased and, thus, balance point temperature is lowered. It is possible for structures to have identical cooling loads and yet have distinctly different heating loads. The heat loss rate curves in Figure 4 represent three actual homes in Oklahoma. While each home has identical cooling requirements, the load curves indicate significantly different balance point temperatures.

A term which has proven useful in expressing heating requirements of a structure is heating-cooling load ratio (HCLR). Heating-cooling load ratio is defined as the ratio of design heating load to design cooling load. Homes in Oklahoma generally have heating-cooling load ratios in the range of 1 to 2. Typically, homes with low heating-cooling load ratios are more energy efficient and have lower balance point temperatures for a given heat pump. This is illustrated in Figure 4. The home with an HCLR of 1.1 has a much lower balance point temperature than does the home with a HCLR of 1.9. Therefore, it appears that balance point temperature is a function of HCLR.

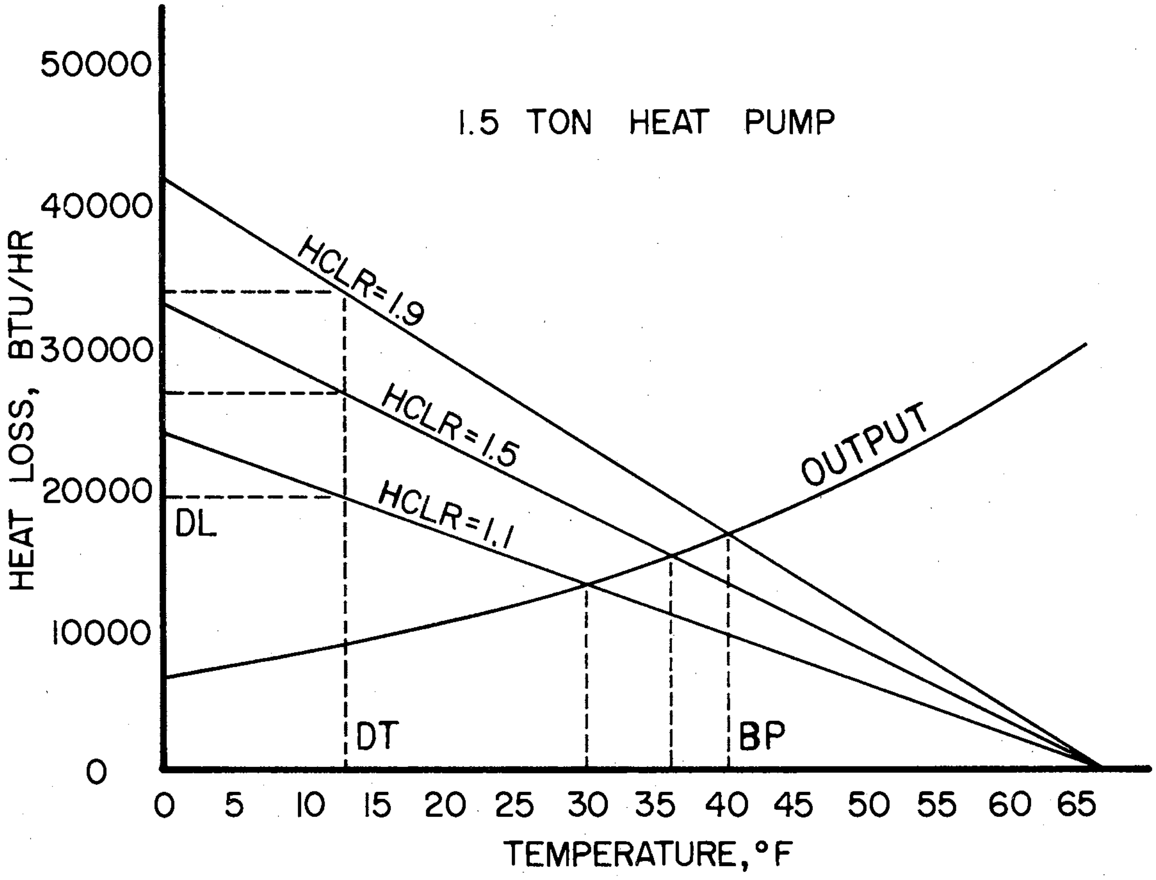

Figure 4. Variation in Balance Point Temperature with Different Structural Heating Loads

From the above discussion, it can be seen that seasonal performance of an air-source heat pump is primarily a function of balance point temperature for a given geographical location.

While this is generally known, very little work has been done to determine a specific relationship between seasonal performance of a heat pump and system balance point temperature. The purpose of this research is to establish a useful relationship that can be used to improve simplified SPF estimating techniques.

Objectives of Study

1. Collect and assemble manufacturer's heat pump performance data for a variety of residential air-source heat pumps.

2. Assemble weather data to represent the broad range of climate in Oklahoma.

3. Develop a computerized technique to model heat pump performance under representative Oklahoma conditions.

4. Develop procedures for predicting the seasonal performance factor of residential air-source heat pumps in Oklahoma.

CHAPTER II

LITERATURE REVIEW

Seasonal efficiency of an air-source heat pump is normally referred to as the seasonal performance factor. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)(1) define seasonal performance factor (SPF) as shown in equation 1.

$$\mathrm{SPF} = \frac{q_h}{q_t} \qquad (1)$$

where:

q_h = Total useful heat output including allowances for loss of capacity during defrost cycles.

q_t = Heat equivalent of the total energy input required to operate the system, including auxiliaries, such as fans.

Therefore, determination of SPF requires total heat output and total energy input of the system on an annual basis. This is usually accomplished by employing a bin method of energy calculation as described by ASHRAE (2). The bin method requires hourly weather data as well as system characteristics. The system is typically modeled as a linear function of the design heat loss rate versus outdoor dry bulb temperatures in 2.8°C (5°F) wide bins.

Cane (3) outlined a modified bin method for estimating annual heating requirements of air-source heat pumps. This method emphasizes accounting for extraneous heat gains due to solar radiation. A significant improvement over the ASHRAE bin method for estimating seasonal heating energy consumption was reported. However, calculated seasonal performance factor was identical for both methods.

New testing and rating procedures for seasonal performance of heat pumps have been proposed by Didion and Kelly (4). These new procedures would require testing and rating heat pumps at part load operation to account for cyclic effects. This would provide a means of estimating SPF with a very simple bin method.

Since bin methods require numerous calculations and a large data base, there are several methods in use for simplified estimates of seasonal performance factor.

The Department of Energy Model Audit (5) recommends use of the values in Table I for evaluating SPF.

A simple regression of SPF on heating degree days (DD) yields the following equation with a correlation coefficient of -0.997.

$$SPF = 2.258 - .000143 * DD \tag{2}$$

where:

DD = Heating Degree Days (65°F Base)

Ferh (6) developed equation 3 from manufacturer's heat pump data for use in a computerized home energy audit.

TABLE I

SEASONAL PERFORMANCE FACTOR VS. DEGREE DAYS FROM DEPARTMENT OF ENERGY MODEL AUDIT

Annual Heating Degree Days (65°F base)	SPF
500	2.2
1000	2.1
2000	2.0
3000	1.8
4000	1.7
5000	1.5
6000	1.4
7000	1.3
8000	1.1

$$Y = 2.643 - .000143 * x \qquad (3)$$

where:

Y = Average seasonal heat pump coefficient of performance

x = Heating degree days (65°F base)

Good results were reported using this equation.

Public Service Company of Oklahoma developed equation 4 for use in their service areas (7).

$$SPF = 2.579 - .00015 * DD \qquad (4)$$

This equation was developed by normalizing SPF to a value of 2.0 at 3860 degree days.

In a study done for the Electric Power Research institute (EPRI), Westinghouse Electric Corp. (8) instrumented 120 heat pump heated test homes at 12 locations across the U.S. Energy consumption, indoor and outdoor temperature data were collected during the winters of 1975-76 and 1976-77. Heating degree days ranged from 300 to 8000 (65°F base) at these locations. An alternate heating mode was used in this study. It involved using a timer to bypass the heat pump on alternate days, thereby causing any heating requirement to be provided entirely by the auxiliary resistance heaters. This allowed a direct comparison of electric resistance versus heat pump heating under very similar external conditions. A statistical analysis of the data obtained resulted in the development of equation 5.

$$SPF = 2.3 - .00015 * DD \qquad (5)$$

where:

DD = Heating degree days in the six months, October through March (65°F base)

In a similar study for Empire State Electric Energy Research Institute Inc. (ESEERCO)(9), Westinghouse found equation 5 to consistently overpredict SPF. A modified bin method was developed which was reported to yield much better estimates of SPF.

Jones (10) reported significant error in using equations involving SPF as a linear function of heating degree days only. He theorized that more parameters are needed to accurately estimate SPF.

CHAPTER III

DATA COLLECTION AND ASSEMBLY

Heat pump performance data were collected from 8 heat pump manufacturers. Performance data were assembled for heat pumps with rated design capacities from 5,000 to 18,000 watts (18,000 Btu/hr to 60,000 Btu/hr). Data consisted of output capacity and energy input as functions of outdoor temperature. In general,heat pump data is reported for temperature bins of 2.8°C (5°F) increments. However, in many cases these bins were not compatible with normal weather data temperature bins. In these instances, the heat pump data were plotted so that input and output values at the appropriate temperature could be obtained. For those manufacturers who report only compressor power input,the data were adjusted in accordance with the Air Conditioning and Refrigeration Institute (11) standard 240-77. This standard is as follows:

a) Cooling capacity is decreased by 365 Watts (1,250 Btu/hr) per 0.472 m^3/s (1,000 cfm).

b) Heating capacity is increased by 365 Watts (1,250 Btu/hr) per 0.472 m^3/s (1,000 cfm).

c) Total power input for both heating and cooling is increased by 365 Watts per 0.472 m^3/s (1,000 cfm).

When it could not be determined whether total power input or compressor only input was reported,the data were rejected. Output capacity for both heating and cooling was adjusted for a standard airflow rate of 450 cfm. In total, data for 134 heat pumps were assembled. These data are contained in Appendix A.

Weather data were assembled for 10 locations as shown in Figure 5 (12). Since detailed temperature data are not generally available for all locations in Oklahoma, four locations were chosen outside the state. These four locations serve to bracket the temperature data on all four sides of the state. The 10 locations are representative of various climatic regions within the state. The data consisted of average temperature bins in 2.8°C (5°F) bins. These data are listed in Appendix B.

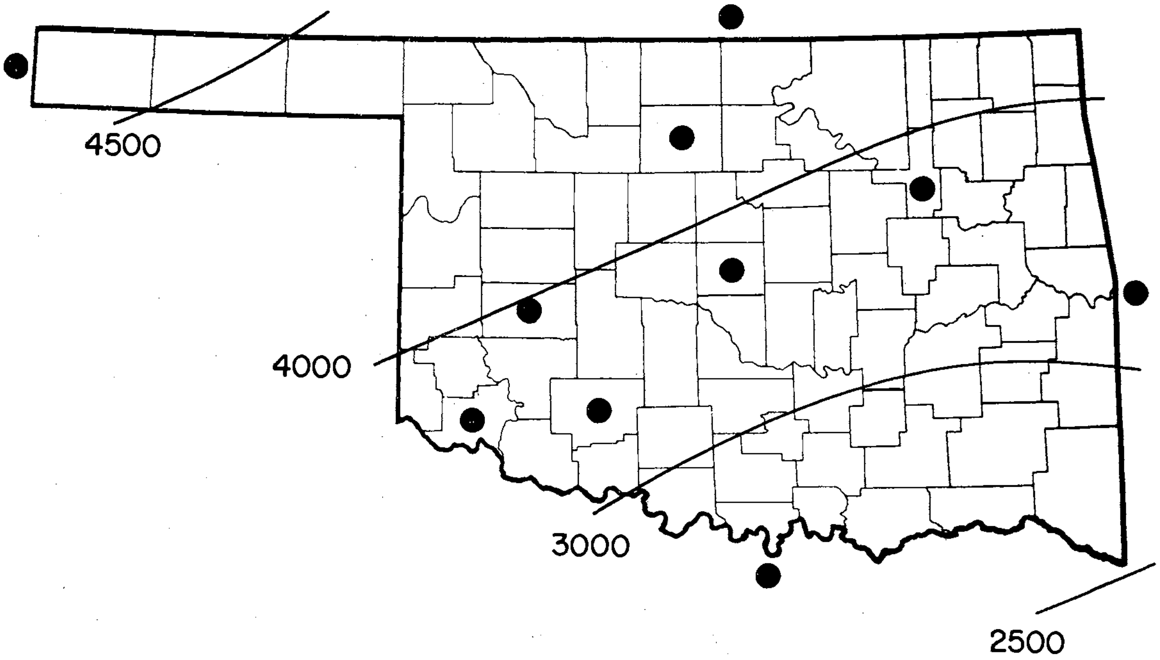

Figure 5. Heating Degree Days and Locations Used in Analysis

CHAPTER IV

MODEL DEVELOPMENT AND CALCULATION PROCEDURES

Each of the 134 heat pumps in the study had a unique size based on total cooling capacity. For each unique heat pump, 11 heat loss rate curves were calculated using HCLR values of 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, and 2.0. By combining the 11 heat-loss rate curves and the heat pump performance curve, 11 balance point temperatures were derived. In total, 1,474 individual heat pump system curves were developed (134 heat pumps * 11 heat loss rate curves/heat pump = 1,474 system curves).

Each of the 1,474 system curves was modeled against weather bin data at the 10 locations. Thus, 14,740 total systems were analyzed to determine heat pump energy input, energy output, and seasonal performance. A typical system is shown in Figure 6.

Total energy output of the system was determined from the heat loss rate curve and temperature bin data for each system. The heat loss rate curve defines heating energy requirements of the structure at various outdoor temperatures. Temperature bin data provides the number of hours

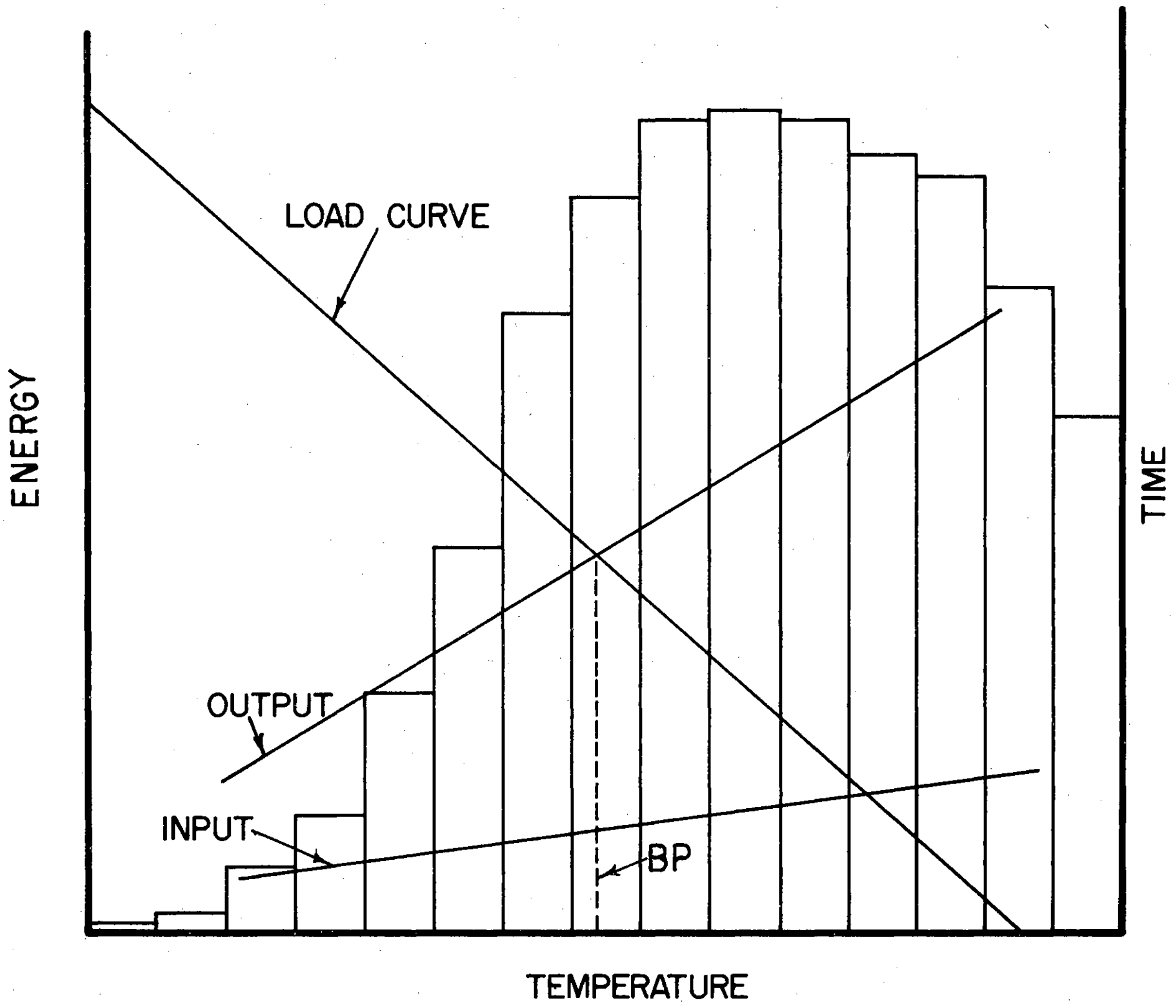

Figure 6. Typical System Used to Evaluate Input, Output and Seasonal Performance of a System

per heating season that a certain temperature is experienced. Heat requirements at the midpoint of each temperature bin were determined. The product of midpoint heat requirement and number of hours in the appropriate temperature bin summed over the entire heating season yielded total seasonal heating requirement.

$$SER = \sum_{j=1}^{n} (HL_j)(HR_j) \tag{6}$$

where:

SER = Seasonal energy requirement

n = Number of bins

j = Bin number

HR = Number of hours in bin_j

HL = Heat loss rate at midpoint of bin_j

Input energy is the sum of total heat pump input energy and total supplemental input energy. The basic equation for calculation of input energy is as follows.

$$TEI = \sum_{j=1}^{n} (RT_j * HR_j * HPEI_j + SH_j) \tag{7}$$

where:

TEI = Total energy inputs

RT = Run time ratio in bin $_j$

SH = Supplemental energy input in bin_j

HPEI = Heat pump energy input in bin $_j$

Run time was calculated as the ratio of structural heat loss rate to heat pump output capacity for each temperature bin. For temperature bins below balance point temperature, this ratio is greater than 1.0. Therefore, the heat pump was assumed to run 100% of the time at temperatures below balance point temperature. At temperatures above balance point temperatures, the heat pump has excess capacity and therefore does not run 100% of the time. The run time ratio is an estimation of the percent of hours within each temperature bin above balance point temperature that the heat pump operates. Heat pump energy input values were calculated from input performance data at the midpoint of each temperature bin.

Energy input for supplemental heat was calculated by subtracting heat requirements from heat pump capacity at the midpoint of each temperature bin below balance point temperature. The product of this value and the number of hours in each temperature bin represented total supplemental energy input.

$$SH = \sum_{j=1}^{n} (HL_j - OC_j) * HR_j \qquad (8)$$

where:

OC = Heat pump output at midpoint of bin_j

Total energy inputs for all heat pump systems were adjusted for time demand defrost cycles of 3 1/2 minutes out of 90 minutes for temperature bins below 3°C (37°F).

This was accomplished by assuming a hot gas defrost cycle for all heat pumps. Therefore, during defrost, total energy supplied by the system was calculated as the sum of total heat loss rate plus heat pump energy input for each bin. No corrections for cyclic losses were made in total energy input.

By knowing values of total energy output and input, a seasonal performance factor for each heat pump was calculated.

$$SPF = \frac{SER}{TEI} \tag{9}$$

The following values were then written to a data file for statistical processing:

1. Balance point temperature.
2. Total energy requirement of structure.
3. Total heat pump system energy inputs.
4. Coefficients of performance at -8.3°C (17°F) and 8.3°C (47°F).
5. Calculated seasonal performance factor.
6. Heating-cooling load ratio.

A copy of the Fortran program used to model the systems is contained in Appendix C.

CHAPTER IV

RESULTS AND CONCLUSIONS

Balance point temperature was correlated to heating-cooling load ratio independent of location using the general linear models procedures of the Statistical Analysis System (SAS)(13). A summary of these statistics is contained in Table II. Figure 7 contains a plot of balance point temperature as a function of HCLR.

From the graph, it appears that balance point temperature can be estimated from the heating-cooling load ratio. This relationship is stated mathematically in equation 10.

$$BP = 11.21 \text{ Ln } (HCLR) - 2.63 \qquad (10)$$

where:

BP = Balance point temperature, °C

$$BP = 20.01 \text{ Ln } (HCLR) + 27.27 \qquad (10A)$$

where:

BP = Balance point temperature, °F

Seasonal performance factor was correlated with balance point temperature using SAS, and good correlation

TABLE II

STATISTICAL SUMMARY FOR EQUATION 10

BALANCE POINT TEMPERATURE AS A FUNCTION OF LN(HCLR)

DEPENDENT VARIABLE:BPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	279816.47641155	279816.47641155	99999.99	0.0000	0.937019	3.2348
ERROR	14738	18807.75534104	1.27614027				
TOTAL	14739	298624.23175259					

SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE IV SS	F VALUE	PR > F
LN(HCLR)	1	279816.47641155	99999.99	0.0000	279816.47641155	99999.99	0.0000

PARAMETER	ESTIMATE	T FOR H0:=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	27.27213390	1450.50	0.0001	0.01880194
LN(HCLR)	20.01158564	468.26	0.0001	0.04273602

STD DEV : 1.12966379 BPT MEAN : 34.92265943

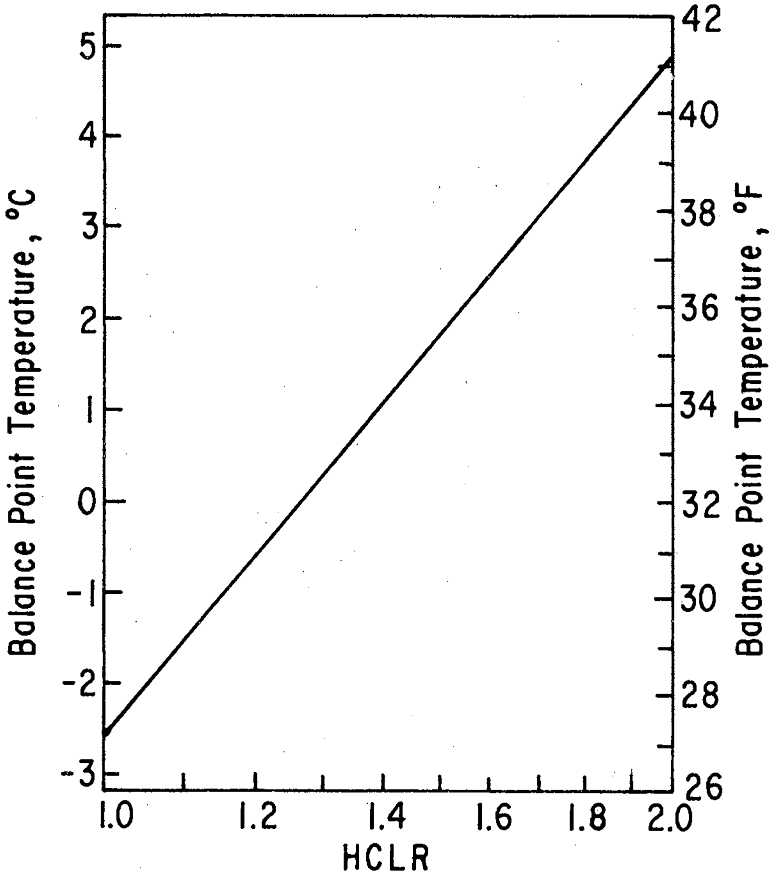

Figure 7. Semi-Logarithmic Plot of Relationship Between Balance Point Temperature and Heating-Cooling Load Ratio for Oklahoma

resulted at each independent location. However, to determine a general correlation that could be used throughout the state, a variable to account for climatological influence was required. Outdoor design temperature was found to best describe climatological effects. The EPRI study by Westinghouse found seasonal heating degree days to be highly correlated to outdoor design temperature. Since seasonal heating degree days are readily available for most locations, climatological influence was indicated with seasonal heating degree days. In addition to balance point temperature and seasonal heating degree days, the addition of heat pump coefficients of performance at -8.3°C (17°F) and 8.3° (47°F) was found to significantly improve prediction of SPF. These are the values of coefficient of performance reported by heat pump manufacturers for publication in the ARI manual (3). A statistical summary of these data are contained in Table III. Average COP values for the 134 heat pumps used in this study are 1.92 at 17°F and 2.71 at 47°F. The resulting prediction equation for SPF is shown in equation 11.

$$\begin{aligned} SPF = 2.325 - .028\ (BP) + 0.256\ (COP17) + \\ 0.298\ (COP47) - 0.00019\ (DD) \end{aligned} \qquad (11)$$

where:

DD = Seasonal heating degree days (65°F base)

Because balance point temperature can be predicted from HCLR as shown in equation 10, and SPF is a function of

TABLE III

STATISTICAL SUMMARY FOR EQUATION 11

SEASONAL PERFORMANCE FACTOR USING CALCULATED BALANCE POINT TEMPERATURE (CBPT)

DEPENDENT VARIABLE:SPF

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	4	666.55736776	166.63934194	35133.66	0.0000	0.905101	3.5751
ERROR	14735	69.88826591	0.00474301				
TOTAL	14739	736.44563366					

SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE IV SS	F VALUE	PR > F
CBPT	1	253.12573265	53368.15	0.0001	226.76847989	47811.08	0.0001
DD	1	176.85020389	37286.48	0.0001	176.85020388	37286.48	0.0001
COP17	1	213.81764649	45080.57	0.0001	17.34220911	3656.37	0.0001
COP47	1	22.76378473	4799.44	0.0001	22.76378473	4799.44	0.0001

PARAMETER	ESTIMATE	T FOR H0:=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	2.30510946	264.58	0.0001	0.00871247
CBPT	-0.02775787	-218.66	0.0001	0.00012695
DD	-0.00019191	-193.10	0.0001	0.00000099
COP17	0.25483799	60.47	0.0001	0.00421443
COP47	0.29517375	69.28	0.0001	0.00426072

STD DEV : 0.06886952 BPT MEAN : 1.92635007

balance point temperature, a general relationship can be derived for SPF in terms of HCLR.

Substituting equation 10 into 11 yields the following equation for SPF as a function of HCLR.

$$SPF = 1.554 - 0.565\ (\ln HCLR) + 0.256\ (COP17) + 0.298\ (COP47) - 0.0019\ (DD) \qquad (12)$$

Since equations 10 and 11 both have a functional relationship with heat pump output, some auto-correlation was anticipated. To determine the extent of auto-correlation, a least squares regression was performed on the data using equation 10 to predict HCLR. This analysis indicated that SPF was more highly correlated to COP17 than equation 12 provides. Therefore, equation 13 was selected as best fit to the data.

$$SPF = 1.57 + 0.552\ (\ln HCLR) + 0.367\ (COP17) + 0.213\ (COP47) - 0.00019\ (DD) \qquad (13)$$

Table IV contains a statistical summary of the development of equation 13.

Using mean values of 1.92 and 2.71 for COP17 and COP47 in equation 13 yields a simplified equation involving HCLR and DD only.

$$SPF = 2.854 - 0.552\ (\ln HCLR) - 0.00019\ (DD) \qquad (14)$$

However, as mentioned previously, prediction accuracy is diminished considerably with this equation. The

TABLE IV

STATISTICAL SUMMARY FOR EQUATION 12

SEASONAL PERFORMANCE FACTOR USING PREDICTED BALANCE POINT TEMPERATURE (PBPT)

DEPENDENT VARIABLE:SPF

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	4	652.56550130	163.14137533	28658.61	0.0001	0.886101	3.9167
ERROR	14735	83.88013236	0.00569258				
TOTAL	14739	736.44563366					

SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE IV SS	F VALUE	PR > F
PBPT	1	212.77661343	37377.90	0.0001	212.77661344	37377.90	0.0001
DD	1	176.85020389	31066.81	0.0001	176.85020388	37286.48	0.0001
COP17	1	251.16851542	44122.11	0.0001	35.99685420	6323.47	0.0001
COP47	1	11.77016856	2067.63	0.0001	11.77016856	2067.63	0.0001

PARAMETER	ESTIMATE	T FOR H0:=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	2.31478464	264.58	0.0001	0.00964885
PBPT	-0.02757562	-193.33	0.0001	0.00014263
DD	-0.00019191	-176.26	0.0001	0.00000109
COP17	0.36453974	79.52	0.0001	0.00458424
COP47	0.21138952	45.47	0.0001	0.00464886

STD DEV : 0.07544917 BPT MEAN : 1.92635007

correlation coefficient for equation 14 is 0.73 vs. 0.94 for equation 13.

Values of SPF calculated from equations 2, 3, 4, 5 and 14 are contained in Table V. These values were calculated for heating degree days from 1000 to 5000. this range of heating degree days would represent the total range of heating degree days for Oklahoma. A comparison of the data in Table V indicates that equation 14 encompasses the range of predicted SPF's from equations 2, 3, 4 and 5. This suggests that prediction equations involving only degree days are accurate over a very narrow range of balance point temperatures. For the range of balance point temperatures used in this study, equations 2-5 yielded correlation coefficients less than 0.5.

Summary and Conclusions

Results of this study reinforce the idea that the seasonal performance of air-source heat pumps is primarily dependent upon system balance point temperature and seasonal heating degree days. However, this study also reveals that SPF is significantly affected by the COP values at 8.3°C (17°F) and 8.3°C (47°F). Since heat pumps operate as a Carnot cycle, they are therefore very sensitive to evaporator and condensor temperatures. These COP values are a good indicator of this sensitivity and provide a measure of performance about the system balance point temperature.

TABLE V

COMPARISON OF SPF FROM EQUATIONS 2, 3, 4, 5, AND 12

DD	2	3	4	5	14		
					HCLR		
					1.0	1.5	2.0
1000	2.12	2.50	2.43	2.15	2.66	2.44	2.28
2000	1.97	2.36	2.28	2.00	2.47	2.25	2.09
3000	1.83	2.21	2.13	1.85	2.28	2.06	1.90
4000	1.69	2.07	1.98	1.70	2.09	1.87	1.71
5000	1.54	1.93	1.83	1.55	1.90	1.68	1.52

An empirical method of estimating system balance point as a function of the structural heating-cooling load ratio was developed. In most cases, it is more convenient to determine the HCLR than balance point temperature. Therefore, a relationship of seasonal performance factor as a function of heating-cooling load ratio was derived.

Use of the empirical relationships developed in this study will provide a better estimate of air-source heat pump performance with very little additional input data. SPF prediction equations based on heating degree days only are accurate over a very narrow range of balance point temperatures. An example of the use of equation 10 and 14 is included in Appendix D.

Seasonal performance factors predicted from the relationships developed in this study are considerably different from those predicted by methods currently employed. However, the results obtained by this study have not been tested for accuracy against actual residential energy consumption data.

Suggestions for Future Work

1. Field test the validity of the procedures developed in this study.

2. Compare the results of the model used in this study to a more sophisticated model, such as the transfer function method, to determine the feasibility of using simplified methods to model air-source heat pumps.

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APPENDIXES

APPENDIX A

HEAT PUMP DATA

The heat pump data for the 134 heat pumps used in this study are contained in Table VI.

Definition of the data is as follows:

1. Temp = Outdoor dry bulb temperature, °F.
2. Btu/h = Heat pump capacity in Btu/hour.
3. Watts = Total power input to heat pump in watts.

The values at 99°F are for the cooling mode, all others are heating.

TABLE VI

HEAT PUMP DATA

	AMANA											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	23052	2926	23048	3062	28448	4180	33788	5720	33776	5848	45848	7392
72	31313	3163	28875	2863	37500	3713	49125	5225	39500	3850	63250	6925
67	29750	3080	27900	2840	36000	3650	46900	5120	37600	3760	60000	6700
62	28300	3000	27100	2820	34500	3600	44800	5020	36250	3700	56860	6480
57	26900	2920	26200	2800	33100	3540	42500	4910	34600	3640	53580	6250
52	25300	2850	25100	2780	31600	3490	40200	4810	32800	3580	50320	6010
47	23500	2750	24000	2750	30000	3400	38000	4700	30000	3400	47000	5800
42	21900	2710	22400	2680	28300	3380	35900	4590	28600	3350	43570	5590
37	20000	2660	21100	2640	26500	3310	33800	4480	26100	3300	40280	5360
32	17800	2600	18300	2600	24500	3260	31500	4360	24000	3280	37080	5140
27	15800	2550	15900	2550	22500	3210	29100	4250	21900	3200	33820	4925
22	14000	2500	13800	2490	20400	3150	26900	4120	19900	3130	30440	4715
17	12500	2400	12000	2400	18500	3100	24500	4000	18000	3100	27000	4500
12	11500	2370	11300	2370	16700	3030	22100	3890	16600	3010	23220	4275
7	10800	2340	10600	2345	15000	2980	19900	3770	15000	2950	19500	4030
2	10000	2300	9800	2330	13300	2910	17500	3640	13400	2900	15600	3790
-2	9280	2268	8920	2298	11940	2870	15580	3544	12080	2844	0	0
-7	8540	2220	7740	2250	10080	2804	13020	3424	10270	2766	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI (Continued)

	AMANA							
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	55684	9460	33776	5848	45760	7228	55000	9300
72	73875	8288	47000	4888	64250	7175	75500	8300
67	70500	8070	45000	4830	61000	6900	72000	8060
62	67480	7875	43000	4790	58270	6730	69200	7870
57	63720	7650	41000	4730	55410	6500	66200	7655
52	59980	7435	39000	4690	52360	6280	63050	7440
47	57000	7200	37000	4600	48000	5800	58000	7100
42	52715	6985	34900	4530	45750	5720	55680	6950
37	48600	6770	32900	4440	42570	5550	52500	6745
32	44600	6535	30700	4340	38860	5305	47700	6500
27	40300	6295	28500	4220	35120	5050	42500	6250
22	36150	6048	26300	4110	31875	4855	38250	6075
17	32000	5800	24500	4000	29000	4700	34000	5900
12	27680	5580	22000	3920	23320	4330	26700	5430
7	24000	5300	19700	3850	19200	4130	20200	5190
2	19000	5050	17300	3770	15200	3930	14200	4900
−2	0	0	15460	3698	0	0	0	0
−7	0	0	13160	3600	0	0	0	0
−12	0	0	0	0	0	0	0	0

TABLE VI (Continued)

	BRYANT											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	19900	2490	20400	2540	20860	2490	26140	3530	26280	3590	27740	3690
72	30333	2800	30833	2967	31100	2900	41400	4033	41000	3933	41500	3867
67	28467	2700	28967	2833	29200	2800	39000	3867	38600	3767	39100	3733
62	26600	2600	27100	2700	27300	2700	36600	3700	36200	3600	36700	3600
57	24800	2500	25300	2500	25400	2600	34300	3600	34000	3500	34400	3500
52	22900	2400	23400	2400	23500	2500	31900	3400	31500	3300	32000	3400
47	21000	2300	21500	2300	21600	2400	29400	3200	29000	3100	29500	3200
42	18800	2200	19300	2200	19400	2300	26100	3100	25700	3000	26000	3100
37	16600	2100	17000	2100	17200	2200	24000	3000	23600	2900	23800	3000
32	14500	2000	14900	2100	15000	2100	21500	2900	21000	2800	21200	2900
27	12900	1900	13400	2000	13500	2000	19600	2800	19100	2700	19300	2800
22	11800	1800	12300	1900	12400	1900	18400	2700	17900	2600	17900	2700
17	10700	1700	11200	1800	11300	1800	17000	2600	16500	2500	16500	2600
12	9500	1600	10000	1700	10100	1700	15500	2500	15000	2400	15000	2500
7	8300	1600	8800	1600	8900	1700	13700	2400	13500	2300	13500	2400
2	7000	1500	7500	1500	7600	1600	12200	2300	12000	2200	11800	2300
−2	6280	1420	6540	1500	6640	1520	11080	2220	10800	2120	10360	2140
−7	5140	1320	5340	1420	5360	1420	9440	2120	9220	2020	8640	2020
−12	3940	1220	4140	1320	4140	1320	7820	2020	7620	1920	7420	1920

TABLE VI (Continued)

	BRYANT											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	31580	4280	32080	4280	32540	4280	33040	4320	38240	5120	39200	5320
72	53200	4767	53200	4767	53300	4767	53300	4767	59867	5400	63333	6167
67	49800	4633	49800	4633	49900	4633	49900	4633	56233	5200	58867	5833
62	46400	4500	46400	4500	46500	4500	46500	4500	52600	5000	54400	5500
57	43000	4400	43000	4400	43100	4400	43100	4400	49100	4800	48400	4900
52	40000	4200	40000	4200	40100	4200	40100	4200	45500	4600	44800	4700
47	36200	4100	36200	4100	36300	4100	36300	4100	41700	4400	41000	4500
42	33200	3800	33100	3800	33300	3800	33300	3800	37600	4200	35800	4300
37	31000	3700	30800	3700	31000	3700	31000	3700	33700	4100	31900	4100
32	26400	3500	26200	3500	26000	3500	26000	3500	29800	3900	28000	4000
27	24100	3400	23800	3400	23600	3400	23600	3400	27200	3800	25500	3900
22	22500	3300	22100	3300	22000	3300	22000	3300	25400	3600	23500	3700
17	20700	3100	20200	3100	20200	3100	20200	3100	23500	3500	21500	3600
12	18800	3100	18300	3000	18300	3100	18300	3100	21500	3300	19500	3400
7	17000	2900	16500	2900	16500	2900	16500	2900	19500	3200	17500	3200
2	15100	2800	14600	2800	14600	2800	14600	2800	17400	3100	15400	3100
-2	13580	2640	13080	2640	13080	2720	13080	2720	15800	2940	13880	3020
-7	11680	2520	11180	2520	11180	2540	11180	2540	13720	2820	11980	2920
-12	9780	2340	9280	2340	9280	2340	9280	2340	11700	2640	9920	2740

TABLE VI (Continued)

	BRYANT											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	44220	5970	45180	5920	46140	5920	54400	7620	56360	7720	19900	2540
72	71100	6733	70500	6833	72167	6667	87333	8100	88333	8200	30733	2900
67	66800	6467	66300	6567	67833	6433	82167	7800	83167	7900	28867	2800
62	62500	6200	62100	6300	63500	6200	77000	7500	78000	7600	27000	2700
57	58400	5900	58100	6000	59300	6000	71900	7200	72900	7300	25200	2600
52	54200	5600	54000	5700	55000	5700	67000	6900	68000	7000	23300	2500
47	49600	5400	49500	5500	50500	5500	61500	6600	62500	6700	21400	2400
42	44800	5100	44800	5200	45800	5200	55700	6400	56700	6500	18800	2200
37	40200	4800	40500	4900	41500	5000	50100	6100	51100	6200	17000	2200
32	35600	4600	36200	4700	37200	4800	44600	5900	45600	6000	14900	2100
27	32500	4400	33100	4500	34100	5000	40800	5600	41800	5700	13400	2000
22	30400	4200	31200	4400	32200	4500	38100	5400	39100	5500	12300	1900
17	28100	4000	29100	4200	30100	4300	35200	5200	36200	5300	11200	1800
12	25800	3900	26600	4000	27300	4100	32100	5000	33100	5000	10000	1700
7	23500	3700	24300	3800	24800	3800	29000	4700	30000	4800	8800	1700
2	21100	3500	21800	3600	22000	3700	25700	4500	26700	4500	7500	1600
-2	19260	3340	19800	3440	19840	3540	23140	4340	24140	4340	6540	1520
-7	16880	3220	17380	3320	17380	3340	19860	4140	20860	4140	5340	1420
-12	14480	3040	14980	3140	14980	3140	16640	3940	17640	3940	4140	1320

TABLE VI (Continued)

	BRYANT											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	20400	2590	20860	2490	26140	3430	26280	3640	31580	4230	38240	5120
72	31100	3067	31200	2967	41000	3867	41300	3867	52700	4767	65833	6167
67	29200	2933	29300	2833	38600	3733	38900	3733	49300	4633	61067	5833
62	27300	2800	27400	2700	36200	3600	36500	3600	45900	4500	56300	5500
57	25400	2600	25500	2500	34000	3500	34200	3500	42500	4400	49300	4900
52	23500	2500	23600	2400	31500	3400	31800	3400	39500	4200	45700	4700
47	21600	2400	21700	2300	29000	3200	29300	3200	35700	4100	42000	4500
42	19400	2300	19500	2200	25700	3100	25900	3100	32700	3800	37700	4300
37	17200	2200	17300	2100	23600	3000	23700	2900	30500	3700	33700	4100
32	15000	2200	15200	2100	21000	2900	21100	2900	25900	3500	29700	4000
27	13500	2100	13900	2000	19100	2800	19200	2700	23600	3400	27000	3900
22	12400	2000	12900	1900	17900	2700	17900	2600	22000	3300	25000	3700
17	11300	1900	11800	1800	16500	2600	16500	2500	20200	3100	22500	3600
12	10100	1800	10500	1700	15000	2500	15000	2400	18300	3000	21000	3400
7	8900	1700	9300	1600	13500	2400	13500	2300	16500	2900	19000	3200
2	7600	1600	7900	1500	12000	2300	12000	2200	14600	2800	16900	3100
-2	6640	1600	6940	1500	10800	2140	10800	2120	13080	2640	15300	3020
-7	5360	1520	5660	1420	9220	2020	9220	2020	11180	2520	13220	2920
-12	4140	1420	4440	1320	7620	1920	7620	1920	9280	2340	11200	2740

TABLE VI (Continued)

			BRYANT			
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	39200	5320	46140	6120	20400	2540
72	65333	6167	70667	6833	31600	3067
67	60867	5833	66433	6567	29700	2933
62	56400	5500	62200	6300	27800	2800
57	51000	4900	58200	6000	25900	2600
52	46500	4700	54100	5700	24000	2500
47	43000	4500	49500	5500	22100	2400
42	38000	4300	44800	5200	19900	2300
37	32100	4100	40400	5000	17600	2200
32	28400	4000	35900	4700	15400	2200
27	25500	3900	32800	4500	13900	2100
22	23500	3700	30800	4300	12800	2100
17	21500	3600	28600	4100	11700	1900
12	19500	3400	26300	4000	10400	1800
7	17500	3200	24000	3700	9100	1700
2	15400	3100	21600	3600	7700	1600
-2	13880	3020	19760	3440	6740	1600
-7	11980	2920	17380	3240	5460	1520
-12	9920	2740	14980	3040	4240	1420

TABLE VI (Continued)

	CARRIER											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	15180	2248	18600	2606	23360	3806	25880	3964	28200	4522	30460	4572
72	24563	2250	33125	2225	38500	3750	42375	3838	47000	4450	48188	4438
67	22950	2200	30700	2200	36000	3640	39700	3770	44200	4340	45350	4370
62	21200	2200	27700	2200	33500	3540	36700	3720	41200	4240	42600	4320
57	19600	2170	25150	2170	31000	3440	34000	3640	38350	4140	39850	4240
52	18100	2120	22900	2120	28500	3340	31500	3540	35600	4040	37100	4140
47	16500	2000	21000	2100	26000	3200	29000	3500	33000	3900	34000	4100
42	14357	1857	17071	1886	22429	2986	24000	3000	29429	3757	30429	3814
37	12750	1770	14750	1770	19950	2840	20950	2800	26500	3640	27650	3640
32	11500	1720	13500	1720	18200	2740	19200	2800	24000	3540	25400	3540
27	10400	1700	12250	1700	16450	2670	17450	2740	21800	3440	23150	3470
22	9400	1700	11000	1700	14700	2620	15700	2640	19800	3340	20900	3420
17	8500	1700	10000	1700	13500	2600	14500	2600	18000	3300	19000	3200
12	7429	1629	9000	1629	12071	2529	12714	2457	15857	3157	16857	3129
7	6550	1600	8120	1570	10600	2470	11100	2370	13950	3040	14800	3040
2	5800	1600	7320	1520	9100	2420	9600	2320	12200	2940	12800	2940
-2	5320	1528	6584	1462	8020	2356	8520	2256	10680	2836	11320	2836
-7	4800	1390	5600	1378	6750	2260	7250	2160	8700	2690	9550	2690
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI (Continued)

	CARRIER											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	35040	5680	36640	5680	41560	6380	44720	6512	48560	6416	52800	7760
72	56375	5425	59625	5450	65500	6188	70438	6000	0	0	96188	7843
67	52900	5340	55900	5300	61600	6010	66150	5880	0	0	89350	7574
62	49400	5240	52400	5300	57600	5860	61400	5680	0	0	79100	7064
57	45900	5170	48900	5240	53750	5710	57100	5540	59910	6120	72000	6770
52	42400	5120	45400	5140	50000	5560	53100	5440	55260	5820	67000	6620
47	39000	5000	41000	4700	46000	5300	49000	5400	51000	5600	62000	6500
42	33643	4571	34929	4343	38857	4800	42571	4971	46929	5314	54143	5957
37	29850	4370	30850	4140	34350	4540	38200	4740	42570	5080	48600	5659
32	27100	4320	28100	4040	31600	4440	35200	4640	38020	4880	44600	5524
27	24650	4240	25650	3970	29000	4280	32350	4570	34310	4680	40600	5368
22	22400	4140	23400	3920	26500	4080	29600	4520	31160	4480	36600	5198
17	20500	3900	21500	3800	24500	4000	27000	4500	27700	4200	32000	5100
12	18000	3829	19000	3657	21643	3929	24500	4500	25700	4057	29500	5071
7	15800	3710	16800	3510	19300	3840	22150	4500	23310	3880	26400	4994
2	13800	3560	14800	3360	17300	3740	19900	4500	20660	3680	22900	4884
-2	12200	3416	13200	3192	15700	3636	18100	4476	18804	3544	20220	4741
-7	10200	3220	11200	2950	13700	3490	15850	4430	16660	3390	16950	4525
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI (Continued)

				CARRIER				
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	55040	7760	57120	7936	39120	6380	45120	5912
72	95938	7980	0	0	63938	6350	75625	6089
67	89350	7724	0	0	59950	6180	70700	5891
62	79100	7264	0	0	55700	5980	65200	5676
57	71700	6981	75040	7320	51600	5810	60000	5488
52	66200	6816	68940	7020	47600	5660	55000	5318
47	63000	6700	65000	6800	44000	5500	51000	5100
42	53357	6057	58929	6443	37214	5429	43143	4614
37	47400	5758	53050	6180	32850	5370	38200	4393
32	43900	5688	47300	5980	30100	5320	35200	4348
27	40250	5582	42900	5750	27650	5240	32200	4270
22	36500	5452	39400	5500	25400	5140	29200	4170
17	33500	5200	36100	5300	23500	5000	26500	4000
12	29929	5143	32457	5229	21000	4786	23643	3964
7	26550	5072	29380	5080	18650	4550	20850	3872
2	23300	4992	26680	4880	16400	4300	18100	3742
-2	20700	4866	24712	4744	14600	4124	15900	3624
-7	17450	4666	22380	4590	12350	3920	13150	3466
-12	0	0	0	0	0	0	0	0

TABLE VI (Continued)

	FEDDERS											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	17600	1600	23480	2140	29360	2340	37000	4280	41120	4620	45000	4780
72	21875	1325	30375	2350	37375	2825	49000	4200	56750	5000	60625	5225
67	20900	1300	29000	2300	35700	2700	46800	4100	54200	4900	57900	5100
62	20000	1250	27700	2250	34150	2550	44750	4000	51800	4800	55350	5000
57	19100	1200	26400	2200	32600	2400	42700	3900	49400	4700	52800	4900
52	18050	1200	24950	2150	30800	2300	40350	3800	46700	4600	49900	4750
47	17000	1200	23500	2100	29000	2200	38000	3700	44000	4500	47000	4600
42	16300	1355	22150	2050	27350	2150	35850	3650	41500	4400	44350	4450
37	15600	1510	20800	2000	25700	2100	33700	3600	39000	4300	41700	4300
32	14350	1305	19400	1900	24000	2050	31450	3500	36400	4150	38900	4150
27	13100	1100	18000	1800	22300	2000	29200	3400	33800	4000	36100	4000
22	11800	1100	15500	1700	21150	1950	26350	3200	30400	3850	32050	3850
17	10500	1100	13000	1600	20000	1900	23500	3000	27000	3700	28000	3700
12	9850	1050	12850	1550	17800	1900	22000	2950	25350	3650	26650	3650
7	9200	1000	12700	1500	15600	1900	20500	2900	23700	3600	25300	3600
2	8150	950	11250	1450	13850	1850	18150	2850	21000	3550	22450	3550
-2	7310	910	10090	1410	12450	1810	16270	2810	18840	3510	20170	3510
-7	6260	900	8640	1360	10660	1760	13960	2720	16140	3420	17280	3460
-12	5210	900	7190	1310	8860	1710	11660	2620	13440	3320	14380	3410

TABLE VI (Continued)

GENERAL ELECTRIC

Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	28240	4180	28960	4270	29440	4080	30260	3980	30860	3875	32560	5120
72	33900	4000	34200	4000	34800	3900	37500	4100	38300	4100	40600	4800
67	33700	3900	34000	3900	34600	3800	37300	4100	38100	4000	40400	4800
62	33300	3800	33600	3800	34200	3700	36800	4000	37600	3900	39900	4700
57	32400	3700	32700	3700	33300	3600	35900	3800	36600	3800	38900	4500
52	31000	3600	34200	3600	31800	3500	34300	3700	35000	3600	37100	4400
47	29200	3500	29400	3400	30000	3400	32300	3600	33000	3500	35000	4200
42	27300	3400	27500	3300	28100	3300	30000	3400	30700	3400	32700	4100
37	25100	3200	25300	3200	25900	3200	27400	3300	28300	3300	30100	4000
32	22900	3100	23100	3100	23700	3100	24700	3200	25700	3100	27500	3800
27	20700	3000	20800	3000	21500	3000	22100	3000	23200	3000	24800	3700
22	18600	2900	18800	2900	19500	2900	19600	2900	20800	2900	22400	3600
17	16600	2800	16800	2800	17500	2800	17200	2800	18500	2800	20000	3500
12	14900	2700	14900	2700	15600	2700	15300	2700	16300	2600	17900	3300
7	13300	2600	13300	2500	13800	2600	13600	2600	14400	2500	15900	3200
2	11800	2500	11800	2400	12200	2500	12000	2500	12600	2400	14100	3000
-2	10680	2420	10680	2320	11000	2420	10800	2420	11240	2320	12820	2920
-7	9440	2320	9440	2220	9660	2320	9540	2320	9700	2220	11300	2820
-12	8480	2220	8400	2200	8520	2220	8500	2220	8440	2120	10120	2720

TABLE VI (Continued)

	GENERAL ELECTRIC											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	33760	5170	33960	4030	34280	5150	34380	4130	34680	4505	35780	4530
72	39800	4500	40500	3600	40600	4600	40700	3600	44600	4800	45800	4600
67	39600	4400	40300	3500	40400	4500	40500	3500	44400	4700	45500	4600
62	39100	4300	39800	3400	39900	4400	40000	3400	43900	4600	44000	4400
57	38100	4200	38700	3300	38900	4300	39000	3300	42700	4400	43800	4300
52	36400	4100	37000	3200	37100	4100	37200	3200	40800	4300	41800	4200
47	34300	3900	34900	3100	35000	4000	35100	3100	38500	4100	39400	4000
42	32000	3800	32300	3000	32700	3800	32500	3000	35900	4000	36800	3900
37	29400	3700	29600	2900	30100	3700	29700	2900	33000	3900	33900	3800
32	26700	3500	26700	2800	27500	3600	26800	2800	30100	3700	30800	3600
27	24100	3400	23800	2700	24800	3500	24000	2700	27100	3600	27800	3500
22	21600	3300	21100	2600	22400	3300	21200	2600	24400	3500	25000	3400
17	19200	3200	18500	2500	20000	3200	18600	2500	21700	3300	22300	3300
12	17100	3000	16300	2400	17800	3100	16400	2400	19200	3200	19700	3100
7	15200	2900	14300	2300	15700	3000	14500	2300	16900	3100	17300	3000
2	13500	2800	12500	2300	13900	2800	12600	2200	14700	2900	15100	2900
-2	12220	2720	11140	2220	12460	2720	11240	2120	13100	2820	13500	2820
-7	10780	2620	9680	2120	10900	2620	9780	2020	11340	2720	11660	2640
-12	9620	2520	8440	2020	9560	2520	8540	2000	9800	2620	10100	2520

TABLE VI (Continued)

GENERAL ELECTRIC

Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	37900	4730	41300	6165	40500	4960	43820	6360	46020	6435	46740	6635
72	44000	4400	54700	6500	47400	4400	53300	6300	55200	5700	57100	5600
67	43800	4300	54400	6400	47200	4300	53000	6200	54900	5600	56800	5500
62	43300	4200	53700	6200	46600	4200	52400	6000	54200	5500	56200	5400
57	42100	4100	52300	6000	45400	4100	51000	5800	52800	5300	54700	5200
52	40200	3900	50000	5800	43300	4000	48700	5600	50400	5100	52200	5000
47	38000	3800	47100	5600	40900	3800	45900	5400	47600	4900	49300	4900
42	35400	3700	43300	5400	37900	3700	42600	5200	44100	4800	46000	4700
37	32600	3600	39300	5200	34700	3600	38900	5000	40300	4600	42400	4600
32	29700	3500	35100	4900	31400	3500	35200	4900	36400	4500	38800	4500
27	26800	3400	30900	4700	28100	3400	31400	4700	32500	4300	35100	4400
22	24000	3300	26900	4500	25000	3300	27800	4500	28900	4100	31600	4200
17	21400	3200	23100	4300	22000	3200	24400	4300	25300	4000	28300	4100
12	18900	3000	20700	4100	19500	3000	21700	4100	22500	3800	25200	4000
7	16500	2900	18500	4000	17100	2900	19300	4000	20000	3700	22400	3900
2	14400	2800	16600	3800	15000	2800	17100	3800	17700	3500	19800	3700
−2	12800	2720	15240	3720	13400	2640	15500	3720	15940	3420	17880	3620
−7	10960	2620	13700	3620	11640	2520	13660	3540	14060	3240	15720	3520
−12	9400	2520	12520	3440	10180	2420	12180	3420	12500	3120	13940	3420

TABLE VI (Continued)

	GENERAL ELECTRIC											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	46920	6560	47200	6160	47400	6100	48200	6260	49100	6180	49200	7230
72	56300	6000	69900	6100	69900	6000	71000	6100	72100	5900	68500	7000
67	56000	5800	67700	6000	67700	5800	68800	6000	69900	5800	66400	6800
62	55300	5700	64800	5800	64800	5700	65800	5800	66800	5600	63500	6600
57	53800	5500	60700	5600	60700	5500	61700	5600	62600	5400	59500	6300
52	51400	5300	55700	5300	55700	5200	56600	5300	57500	5200	54600	6100
47	48500	5100	51000	5100	51000	5000	51800	5100	54600	4900	50000	5800
42	45000	4900	46800	4900	46800	4800	47600	4900	48300	4700	46000	5600
37	41100	4700	42700	4700	42700	4600	43400	4700	44100	4500	42100	5400
32	37100	4600	38600	4500	38600	4400	39200	4500	39800	4300	38100	5200
27	33100	4400	34800	4300	34800	4200	35400	4300	35900	4100	34500	5000
22	29400	4200	31300	4100	31300	4000	31800	4100	32300	4000	31100	4800
17	25800	4000	28000	3900	28100	3800	28400	3900	28900	3800	28000	4700
12	22900	3800	24600	3700	24700	3600	25100	3800	25400	3600	24800	4400
7	20400	3700	21400	3500	21600	3500	21900	3600	22100	3400	21900	4200
2	18000	3500	18600	3400	18800	3300	19100	3500	19200	3300	19200	4000
-2	16240	3420	16520	3240	16720	3220	17020	3340	17040	3140	17280	3840
-7	14280	3320	14080	3120	14440	3120	0	0	14580	3020	15120	3640
-12	12700	3220	12160	3020	12560	3020	0	0	12500	2920	13340	3520

TABLE VI (Continued)

GENERAL ELECTRIC

Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	50200	7340	50400	7300	51200	7310	56120	8160	56120	8090	57040	8060
72	69600	6900	68500	6700	69600	6800	84900	8300	83600	8300	84900	8100
67	67500	6700	66400	6500	67500	6700	82300	8100	81000	8100	82300	7900
62	64500	6500	63500	6300	64500	6500	78700	7900	77500	7900	78700	7700
57	60500	6300	59500	6100	60500	6200	73800	7600	72600	7600	73800	7400
52	55500	6000	54600	5800	55500	6000	67800	7200	66700	7200	67800	7100
47	50800	5700	50000	5600	50800	5700	62000	6900	61000	6900	62000	6800
42	46700	5500	46000	5400	46700	5500	57600	6600	56200	6600	57200	6500
37	42700	5300	42100	5200	42700	5300	53200	6400	51400	6300	52400	6300
32	38700	5100	38100	5000	38700	5100	48900	6100	46700	6000	47600	6100
27	35100	4900	34500	4800	35100	4900	45000	5900	42300	5700	43300	5800
22	31600	4700	31100	4600	31600	4700	41300	5600	38200	5400	39200	5600
17	28400	4600	28100	4400	28400	4600	38000	5400	34500	5100	35500	5400
12	25200	4300	24900	4200	25200	4300	33500	5100	30500	4900	31400	5100
7	22100	4100	21900	4000	22200	4100	29300	4900	26800	4600	27500	4900
2	19400	3900	19300	3800	19500	3900	25400	4600	23400	4400	24100	4700
−2	17400	3740	17300	3640	17580	3740	22520	4440	20920	4320	21540	4540
−7	15140	3540	15120	3520	15340	3620	19240	4240	18140	4140	18580	4340
−12	13260	3340	13340	3340	13540	3440	16520	4120	15840	4020	16240	4140

TABLE VI (Continued)

GENERAL ELECTRIC

Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	58040	8060	60040	8060	33360	5130	33880	5120	47400	6180	51200	7500
72	84900	8100	87700	7500	40600	4900	40200	4600	71000	6000	70700	6600
67	82300	7900	85000	7300	40400	4800	40000	4500	68800	5900	68500	6500
62	78700	7600	81300	7100	39900	4700	39500	4400	65800	5700	65500	6300
57	73800	7300	76200	6800	38900	4500	38500	4300	61700	5500	61400	6000
52	67800	7000	70000	6500	37100	4400	36700	4100	56600	5300	56400	5800
47	62000	6700	64000	6200	35000	4200	34700	4000	51800	5000	51600	5500
42	57200	6400	59100	6000	32700	4100	32300	3900	47933	4833	47800	5300
37	52400	6200	54200	5800	30100	4000	29800	3700	44067	4667	44100	5200
32	47600	6000	49300	5600	27500	3800	27200	3600	40200	4500	40400	5000
27	43300	5700	44900	5400	24800	3700	24600	3500	36700	4400	37000	4800
22	39200	5500	40800	5300	22400	3600	22100	3400	33400	4300	33800	4700
17	35500	5300	37000	5100	20000	3500	19800	3200	30500	4100	31000	4600
12	31300	5000	32400	4800	17800	3300	17600	3100	26700	3900	27300	4300
7	27400	4800	28100	4600	15900	3200	15600	3000	23200	3700	24000	4100
2	23900	4500	24200	4300	14000	3000	13800	2900	20100	3500	21000	3900
-2	21260	4340	21320	4140	12720	2920	12440	2820	17700	3340	18680	3740
-7	18280	4140	17960	3940	11200	2820	10900	2720	14940	3220	16100	3540
-12	15780	4020	15220	3740	9940	2640	9640	2620	12640	3040	13920	3340

TABLE VI (Continued)

	LENNOX											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	22735	2969	23435	3059	27820	3771	28220	3851	30580	3548	32880	3508
72	35572	3346	36238	3293	42827	3770	42827	3818	46973	3843	46973	3843
67	33458	3170	34092	3119	40433	3635	40433	3682	44007	3673	44007	3673
62	31345	2993	31945	2946	38040	3501	38040	3546	41040	3503	41040	3503
57	29225	2798	29825	2753	35620	3364	35620	3406	38000	3320	38000	3320
52	27165	2618	27705	2576	33260	3226	33260	3266	34940	3148	34940	3148
47	25005	2463	25505	2426	30860	3098	30860	3138	32140	2993	32140	2993
42	22805	2321	23245	2286	28520	2966	28520	3003	29300	2848	29300	2848
37	20965	2199	21365	2164	26220	2832	26220	2867	26240	2688	26180	2688
32	19545	2101	19945	2069	24160	2702	24160	2734	23740	2545	23580	2524
27	18005	2023	18345	1993	22200	2584	22200	2614	21880	2456	21620	2385
22	16425	1947	16725	1917	20260	2483	20260	2513	20420	2382	20120	2290
17	14985	1879	15285	1852	18360	2391	18360	2418	19240	2320	18940	2230
12	13465	1813	13705	1788	16460	2298	16460	2323	17600	2243	17360	2177
7	11985	1752	12185	1727	14500	2203	14500	2228	15960	2145	15760	2110
2	10585	1691	10785	1666	13280	2117	13280	2142	14380	2033	14300	2017
-2	9513	1641	9713	1616	12528	2043	12528	2066	12732	1944	12716	1938
-7	8349	1581	8501	1558	11556	1950	11556	1970	10864	1831	10864	1830
-12	7517	1519	7625	1498	10544	1857	10544	1877	9540	1707	9540	1707

TABLE VI (Continued)

	LENNOX											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	33530	3705	34030	3687	34790	4456	35090	4506	46450	5960	47310	6157
72	50130	3898	50130	3848	54182	4670	54263	4607	71257	6324	71257	6324
67	47430	3758	47430	3710	51271	4503	51337	4444	67643	6115	67643	6115
62	44730	3618	44730	3573	48361	4337	48410	4282	64030	5905	64030	5905
57	41950	3467	41950	3425	45338	4160	45310	4111	60390	5713	60390	5713
52	39230	3333	39230	3293	42350	4000	42310	3958	56790	5501	56790	5501
47	36630	3198	36630	3161	39630	3838	39630	3795	53190	5276	53190	5276
42	34150	3062	34210	3027	36910	3674	36970	3692	49530	5037	49530	5046
37	31510	2938	31790	2903	34350	3559	34630	3613	45890	4818	46010	4851
32	28890	2815	29350	2783	31710	3432	32170	3485	42470	4635	42850	4689
27	26390	2684	26830	2663	28850	3277	29350	3329	38870	4424	39670	4508
22	23830	2546	24230	2540	26070	3116	26510	3166	35790	4189	36790	4289
17	21470	2400	21990	2430	23610	2999	24070	3058	32890	3981	33890	4081
12	19090	2274	19630	2318	20950	2872	21450	2931	29430	3773	30430	3873
7	16890	2164	17390	2198	18470	2717	18970	2769	25910	3538	26910	3638
2	14650	2054	15030	2075	15850	2559	16350	2609	22330	3299	23330	3399
-2	13066	1980	13238	1994	14106	2388	14366	2503	19322	3053	20082	3153
-7	11406	1888	11430	1899	12358	2207	12398	2283	16154	2778	16454	2830
-12	9986	1771	9986	1776	10846	2046	10846	2045	13262	2602	13302	2610

TABLE VI (Continued)

	RHEEM											
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	17530	2562	23843	3339	28124	3976	28725	3926	35240	5278	42120	5920
72	21563	2400	30563	3038	37500	4013	37500	3950	45875	5450	52000	5494
67	20850	2350	29350	2980	36200	3900	36200	3840	44300	5250	50200	5365
62	20312	2300	28349	2923	35258	3805	35258	3751	43056	5041	49000	5210
57	19550	2250	27050	2865	33600	3690	33600	3640	41100	4850	47100	5090
52	18789	2200	25772	2807	32437	3574	32437	3526	39655	4631	44900	4970
47	18000	2150	24500	2750	31000	3450	31000	3400	38000	4450	43000	4850
42	16808	2100	22698	2690	28495	3306	28495	3259	35217	4259	39600	4700
37	15700	2050	21250	2630	26500	3160	26500	3120	33000	4080	35800	4550
32	14537	2000	19387	2574	23925	3028	23925	2979	30250	3919	33600	4430
27	13150	1850	17200	2515	21000	2920	21000	2860	27300	3750	30600	4300
22	12143	1900	16101	2457	19222	2766	19222	2714	25264	3605	27800	4170
17	11000	1850	14500	2400	17000	2600	17000	2550	22500	3400	25500	4050
12	9591	1800	13098	2342	14880	2548	14880	2495	20769	3308	22800	3920
7	8800	1750	12250	2285	13300	2500	13300	2450	19600	3750	20900	3810
2	7649	1700	10641	2227	11392	2339	11392	2348	17272	3023	19500	3700
−2	6850	1660	9728	2181	10278	2348	10278	2310	16094	2885	18700	3620
−7	0	0	0	0	0	0	0	0	0	0	0	0
−12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI (Continued)

						RHEEM						
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	46800	6944	47800	6644	58800	8400	17530	2662	35240	5082	42120	5720
72	57500	6075	58500	5775	73500	7588	21563	2450	45875	5300	52000	5244
67	55800	5980	56800	5680	71400	7450	20850	2400	44300	5100	50200	5125
62	54900	5920	55900	5610	71100	7360	20312	2350	43056	4912	49000	5010
57	53200	5820	54200	5510	69500	7230	19550	2300	41100	4750	47100	4890
52	50900	5700	51900	5390	66700	7080	18789	2250	39655	4515	44900	4770
47	49000	5600	50000	5300	63000	6900	18000	2200	38000	4300	43000	4650
42	45200	5410	46200	5110	58900	6710	16800	2150	35217	4134	39600	4500
37	40900	5200	41900	4900	54500	6500	15700	2100	33000	3950	35800	4350
32	38400	5070	39400	4790	49500	6290	14537	2050	30250	3777	33600	4230
27	34900	4890	35900	4620	44700	6080	13150	2000	27300	3600	30600	4100
22	31400	4710	32400	4450	40100	5880	12143	1950	25264	3450	27800	3970
17	28500	4550	29500	4300	36000	5700	11000	1900	22500	3300	25500	3850
12	25100	4360	26100	4110	32700	5540	9791	1850	20769	3160	22800	3720
7	22400	4190	23400	3950	30400	5410	8800	1800	19600	3050	20900	3610
2	20100	4040	21100	3800	29100	5310	7649	1750	17272	2914	19500	3500
-2	18740	3928	19740	3688	29260	5262	6850	1710	16094	2823	18700	3420
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI (Continued)

	RHEEM							
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	46800	6844	58800	8200	42120	5520	42120	5920
72	57500	5975	73500	7388	52000	5044	52000	5494
67	55800	5880	71400	7250	50200	4925	50200	5365
62	54900	5810	71100	7150	49000	4810	49000	5210
57	53200	5720	69500	7030	47100	4690	47100	5090
52	50900	5600	66700	6880	44900	4570	44900	4970
47	49000	5500	63000	6700	43000	4450	43000	4850
42	45200	5320	58900	6530	39600	4300	39600	4700
37	40900	5125	54500	6350	35800	4150	35800	4550
32	38400	5000	49500	6150	33600	4030	33600	4430
27	34900	4830	44700	5960	30600	3900	30600	4300
22	31400	4660	40100	5770	27800	3770	27800	4170
17	28500	4500	36000	5600	25500	3650	25500	4050
12	25100	4310	32700	5450	22800	3520	22800	3920
7	22400	4150	30400	5320	20900	3410	20900	3810
2	20100	4000	29100	5220	19500	3300	19500	3700
−2	18740	3880	29260	5164	18700	3220	18700	3620
−7	0	0	0	0	0	0	0	0
−12	0	0	0	0	0	0	0	0

TABLE VI (Continued)

WESTINGHOUSE

Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	17420	2754	21420	3304	27880	4196	28290	4194	33180	5172	34600	4920
72	21200	2460	26000	3000	39800	4140	42100	4160	46000	4750	54000	5500
67	20900	2430	25600	2920	38000	4000	40000	4040	43200	4650	52000	5250
62	20600	2400	25000	2830	36300	3860	38100	3910	41000	4570	49000	5100
57	20100	2350	24200	2750	34500	3740	36000	3780	39000	4480	47000	4900
52	19500	2320	23500	2660	32800	3620	34000	3660	37500	4390	44000	4700
47	18500	2260	22500	2600	30500	3500	32000	3550	36500	4300	41000	4550
42	17800	2200	21400	2520	28200	3410	29970	3410	34000	4170	39000	4400
37	16500	2130	20000	2450	26000	3320	27700	3300	31500	4040	36000	4200
32	14800	2070	18300	2390	23800	3230	25500	3170	29200	3880	33000	4000
27	13200	2010	16400	2340	21500	3140	23500	3060	27000	3700	30000	3900
22	11600	1960	14200	2290	19300	3060	21500	2960	24000	3540	27000	3650
17	10000	1900	12500	2250	17000	2950	19600	2850	21000	3400	25000	3450
12	9200	1860	11000	2180	15200	2910	17700	2760	19000	3270	22000	3350
7	8100	1810	9400	2120	13200	2860	16000	2660	17400	3180	19000	3250
2	7200	1780	8500	2050	12000	2800	14400	2550	17000	3110	17000	3100
-2	0	0	0	0	0	0	13280	2470	0	0	15400	3020
-7	0	0	0	0	0	0	11880	2370	0	0	14200	2880
-12	0	0	0	0	0	0	10880	2262	0	0	13200	2810

TABLE VI (Continued)

	WESTINGHOUSE									
Temp	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts	Btu/h	Watts
99	39940	6216	46960	7198	48840	6820	57580	8330	58540	8760
72	49500	5400	58200	6150	73000	6900	88000	8200	69000	7540
67	49100	5370	57500	6110	70000	6700	82000	7800	68000	7450
62	48900	5340	56100	6080	66200	6480	77000	7450	66600	7360
57	48400	5290	55000	6000	63000	6220	72000	7100	64500	7230
52	47000	5220	52900	5920	59200	6000	67500	6800	62000	7050
47	45000	5100	51000	5800	56000	5800	63000	6500	58500	6800
42	42000	5000	48400	5660	52000	5520	58000	6200	54700	6620
37	38800	4870	45300	5500	48650	5295	54000	5900	50000	6370
32	35600	4720	41400	5350	45300	5070	50000	5650	45100	6250
27	32200	4560	38400	5150	41900	4820	46000	5400	39800	5900
22	29100	4400	34500	4970	38100	4600	42000	5200	36000	5680
17	26000	4250	30900	4750	35000	4400	38000	5000	33000	5410
12	23000	4100	27100	4570	31200	4110	35000	4760	29200	5270
7	20000	3950	24900	4380	27900	3900	32000	4580	27000	5100
2	17900	3800	22000	4190	24200	3670	29000	4400	25000	4900
-2	0	0	0	0	21440	3482	26760	4272	0	0
-7	0	0	0	0	17990	3247	24440	4096	0	0
-12	0	0	0	0	14660	3024	22400	3932	0	0

APPENDIX B

WEATHER DATA

The weather data used in this study are contained in Table VII.

Temp = Outdoor dry bulb temperature, °F

Values in the table are the long term average number of hours in each temperature bin by month.

TABLE VII

WEATHER DATA

ALTUS,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	1	5	5	0	0	0	0
102	0	0	0	0	2	8	37	28	4	0	0	0
97	0	0	0	1	7	40	86	60	17	0	0	0
92	0	0	5	7	23	73	100	92	40	8	0	0
87	0	0	4	18	55	98	108	108	60	22	0	0
82	0	1	10	34	82	122	134	125	87	37	3	0
77	1	3	16	56	98	125	142	150	113	55	15	0
72	5	8	27	75	127	125	105	127	141	79	26	5
67	12	15	49	102	133	87	23	40	115	107	46	13
62	21	31	60	118	115	33	4	9	79	122	63	27
57	37	47	79	114	60	7	0	2	44	125	84	49
52	48	63	88	90	27	1	0	0	16	94	105	70
47	76	85	105	58	10	0	0	0	2	58	121	101
42	99	104	114	30	3	0	0	0	0	28	104	114
37	105	103	87	13	0	0	0	0	0	8	86	123
32	118	86	63	5	0	0	0	0	0	2	44	121
27	85	70	27	2	0	0	0	0	0	0	16	72
22	62	39	9	0	0	0	0	0	0	0	6	34
17	40	10	4	0	0	0	0	0	0	0	1	11
12	21	2	2	0	0	0	0	0	0	0	0	4
7	11	1	0	0	0	0	0	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0	0	0	0
-2	1	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	2	2	2

TABLE VII (Continued)

CLINTON,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	0	1	0	0	0	0
102	0	0	0	0	0	1	12	15	0	0	0	0
97	0	0	0	0	2	12	51	49	9	0	0	0
92	0	0	0	3	16	39	93	80	31	1	0	0
87	0	0	2	15	47	81	102	103	56	16	0	0
82	0	1	4	29	75	106	137	133	75	32	0	0
77	0	2	10	50	103	145	161	154	116	51	3	0
72	3	7	20	75	140	144	141	136	143	79	19	0
67	6	13	40	101	142	122	53	60	122	118	45	6
62	14	20	55	110	102	55	4	10	89	131	63	16
57	27	40	74	105	73	6	0	3	49	130	82	35
52	47	52	86	95	32	1	0	0	22	105	107	61
47	68	74	101	75	9	0	0	0	8	52	114	89
42	99	94	101	38	3	0	0	0	0	22	104	112
37	105	107	102	21	0	0	0	0	0	6	86	115
32	107	90	68	3	0	0	0	0	0	1	53	126
27	94	75	40	0	0	0	0	0	0	0	28	86
22	59	54	24	0	0	0	0	0	0	0	11	52
17	43	25	8	0	0	0	0	0	0	0	4	30
12	34	13	5	0	0	0	0	0	0	0	1	12
7	20	3	3	0	0	0	0	0	0	0	0	4
2	15	0	1	0	0	0	0	0	0	0	0	0
-2	3	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

ENID,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	1	6	6	0	0	0	0
102	0	0	0	0	0	11	27	28	3	0	0	0
97	0	0	0	0	4	38	62	57	23	1	0	0
92	0	0	0	2	16	65	90	89	40	7	0	0
87	0	0	1	10	36	88	104	103	58	20	0	0
82	0	0	5	22	58	114	128	124	80	33	1	0
77	0	2	9	31	87	135	153	149	110	53	7	1
72	2	6	21	56	116	121	125	120	134	77	20	2
67	8	14	33	81	141	86	40	51	111	102	37	8
62	20	31	54	99	139	43	8	11	86	116	51	20
57	31	47	70	117	83	12	1	3	52	120	80	38
52	48	66	93	99	45	5	0	1	19	98	91	60
47	61	84	105	87	13	0	0	0	3	68	115	95
42	94	98	110	66	6	0	0	0	0	28	105	115
37	105	98	96	35	1	0	0	0	0	14	84	135
32	116	99	80	11	0	0	0	0	0	5	61	123
27	89	61	44	4	0	0	0	0	0	1	41	71
22	72	35	14	0	0	0	0	0	0	0	21	42
17	48	22	6	0	0	0	0	0	0	0	4	21
12	31	7	1	0	0	0	0	0	0	0	1	9
7	11	1	0	0	0	0	0	0	0	0	0	3
2	4	0	0	0	0	0	0	0	0	0	0	1
-2	1	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

FORT SILL,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	2	3	0	0	0	0
102	0	0	0	0	0	4	26	22	2	0	0	0
97	0	0	0	0	3	27	78	58	12	0	0	0
92	0	0	1	3	14	67	103	90	37	6	0	0
87	0	0	4	13	45	100	110	104	62	17	0	0
82	0	1	9	30	79	122	139	128	87	40	2	0
77	0	3	17	55	105	140	154	156	121	50	14	1
72	5	7	31	84	139	132	100	133	140	91	32	4
67	11	17	48	118	140	84	26	40	120	111	48	13
62	25	32	66	126	117	35	4	9	77	127	73	32
57	37	49	81	110	62	9	1	2	40	118	85	56
52	53	66	97	86	29	1	0	0	17	86	112	77
47	79	88	103	51	11	0	0	0	3	62	111	107
42	104	109	106	27	2	0	0	0	0	28	108	113
37	112	104	87	13	0	0	0	0	0	7	78	125
32	112	86	56	5	0	0	0	0	0	1	36	107
27	85	62	23	1	0	0	0	0	0	1	13	62
22	53	33	8	0	0	0	0	0	0	0	5	32
17	37	10	4	0	0	0	0	0	0	0	0	9
12	16	2	1	0	0	0	0	0	0	0	0	6
7	11	0	0	0	0	0	0	0	0	0	0	1
2	2	0	0	0	0	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

TULSA,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	5	6	0	0	0	0
102	0	0	0	0	0	3	15	25	3	0	0	0
97	0	0	0	0	0	20	58	47	17	0	0	0
92	0	0	0	1	7	64	96	91	47	6	0	0
87	0	0	1	7	37	101	116	118	65	19	0	0
82	0	1	5	26	75	129	146	137	87	39	1	0
77	0	2	12	49	111	148	152	157	121	56	10	2
72	6	7	29	74	127	127	111	109	139	87	33	5
67	19	20	40	100	145	82	36	41	113	110	47	11
62	26	37	54	109	116	34	9	13	71	125	52	26
57	39	55	76	106	73	12	1	3	39	112	77	53
52	53	77	94	93	36	2	0	0	16	87	99	73
47	69	87	118	81	11	0	0	0	2	55	111	100
42	90	99	107	49	4	0	0	0	0	30	92	129
37	117	96	83	20	1	0	0	0	0	11	82	118
32	116	76	71	5	0	0	0	0	0	4	62	101
27	82	55	26	3	0	0	0	0	0	1	36	68
22	65	35	15	0	0	0	0	0	0	0	16	34
17	36	17	5	0	0	0	0	0	0	0	4	15
12	16	5	3	0	0	0	0	0	0	0	1	8
7	6	2	2	0	0	0	0	0	0	0	0	3
2	1	0	0	0	0	0	0	0	0	0	0	0
−2	1	0	0	0	0	0	0	0	0	0	0	0
−7	0	0	0	0	0	0	0	0	0	0	0	0
−12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

OKLAHOMA CITY,OKLAHOMA

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	0	1	0	0	0	0
102	0	0	0	0	0	0	9	8	1	0	0	0
97	0	0	0	0	0	4	51	32	7	0	0	0
92	0	0	0	1	4	42	91	74	25	3	0	0
87	0	0	1	7	28	88	103	106	49	11	0	0
82	0	1	4	21	71	127	142	130	77	30	0	0
77	0	1	12	47	104	151	171	164	123	49	7	0
72	1	5	24	84	144	156	123	152	145	84	29	1
67	7	13	41	112	148	98	42	60	122	115	52	9
62	22	22	65	123	115	39	8	13	96	128	71	27
57	32	42	74	111	74	12	1	3	49	120	87	49
52	55	62	93	89	37	1	0	0	19	99	101	71
47	69	83	99	65	14	0	0	0	4	62	111	101
42	94	105	107	37	3	0	0	0	1	31	100	114
37	103	102	90	16	0	0	0	0	0	9	91	126
32	119	92	77	4	0	0	0	0	0	2	45	107
27	91	70	36	3	0	0	0	0	0	1	19	62
22	61	49	12	0	0	0	0	0	0	0	8	44
17	42	19	4	0	0	0	0	0	0	0	1	19
12	30	5	4	0	0	0	0	0	0	0	0	10
7	12	1	1	0	0	0	0	0	0	0	0	2
2	8	0	0	0	0	0	0	0	0	0	0	1
-2	1	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

FORT SMITH,ARKANSAS

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	3	4	0	0	0	0
102	0	0	0	0	0	4	17	20	2	0	0	0
97	0	0	0	0	1	28	54	41	15	1	0	0
92	0	0	0	1	18	71	94	89	43	6	0	0
87	0	0	1	12	58	91	103	102	62	23	0	0
82	0	1	8	35	83	112	124	114	79	45	3	0
77	2	3	18	59	105	130	170	162	111	59	20	1
72	9	12	33	78	121	147	139	140	153	85	34	7
67	21	21	48	100	146	96	33	55	121	109	43	15
62	23	35	66	114	108	31	6	16	73	126	57	24
57	36	51	82	106	61	9	1	2	42	106	86	47
52	54	81	104	94	27	2	0	0	17	79	106	69
47	82	96	117	62	11	0	0	0	3	57	106	93
42	99	109	108	40	3	0	0	0	0	29	93	118
37	121	98	79	16	1	0	0	0	0	15	79	135
32	120	91	51	4	0	0	0	0	0	4	50	104
27	82	48	22	1	0	0	0	0	0	1	29	70
22	46	15	6	0	0	0	0	0	0	0	13	34
17	27	6	2	0	0	0	0	0	0	0	3	15
12	11	1	0	0	0	0	0	0	0	0	0	6
7	8	0	0	0	0	0	0	0	0	0	0	3
2	1	0	0	0	0	0	0	0	0	0	0	0
-2	1	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

WICHITA, KANSAS

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	0	1	0	0	0	0
102	0	0	0	0	0	1	14	11	0	0	0	0
97	0	0	0	0	1	10	42	26	4	0	0	0
92	0	0	0	0	6	37	71	61	16	2	0	0
87	0	0	0	3	26	70	96	96	37	10	0	0
82	0	0	3	14	51	107	132	125	63	24	0	0
77	0	0	8	31	85	124	155	146	104	45	1	0
72	0	1	18	56	121	143	134	139	135	70	12	0
67	2	6	27	86	129	129	72	93	130	96	33	1
62	7	11	43	105	129	69	21	37	103	113	51	13
57	13	25	57	113	89	25	5	8	75	115	64	27
52	29	39	76	104	67	4	0	1	35	114	91	43
47	48	57	83	90	27	0	0	0	14	83	109	68
42	72	89	100	65	9	0	0	0	2	51	116	101
37	100	100	108	34	2	0	0	0	0	16	112	120
32	115	107	108	16	0	0	0	0	0	6	75	135
27	109	87	61	4	0	0	0	0	0	2	36	92
22	90	72	30	0	0	0	0	0	0	0	14	65
17	60	49	14	0	0	0	0	0	0	0	6	36
12	50	19	4	0	0	0	0	0	0	0	2	26
7	28	7	3	0	0	0	0	0	0	0	0	8
2	14	2	1	0	0	0	0	0	0	0	0	6
-2	6	0	0	0	0	0	0	0	0	0	0	1
-7	1	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VII (Continued)

CLAYTON,NEW MEXICO

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	0	0	0	0	7	0
102	0	0	0	0	0	0	0	0	0	0	2	0
97	0	0	0	0	0	5	5	3	0	0	0	0
92	0	0	0	0	1	36	31	22	4	0	0	0
87	0	0	0	1	11	66	71	69	26	3	0	0
82	0	0	0	6	38	76	89	98	53	21	0	0
77	1	1	0	24	50	81	106	92	66	40	2	0
72	3	3	13	31	71	93	109	114	67	56	6	2
67	8	12	27	48	86	105	151	127	86	64	18	7
62	14	30	32	58	94	111	138	131	131	78	37	22
57	27	37	49	79	111	81	43	73	148	114	45	28
52	48	54	66	90	126	37	1	12	85	127	57	49
47	67	75	83	111	81	25	0	3	38	106	88	69
42	84	88	85	99	53	4	0	0	12	73	100	93
37	104	102	112	85	20	0	0	0	4	42	106	124
32	99	94	83	53	1	0	0	0	0	16	88	113
27	89	78	89	25	1	0	0	0	0	4	74	98
22	68	45	57	8	0	0	0	0	0	0	46	56
17	50	31	29	2	0	0	0	0	0	0	30	44
12	30	12	15	0	0	0	0	0	0	0	15	18
7	21	4	4	0	0	0	0	0	0	0	5	18
2	17	4	0	0	0	0	0	0	0	0	3	3
-2	9	0	0	0	0	0	0	0	0	0	0	0
-7	5	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	2	0	0

TABLE VII (Continued)

SHERMAN,TEXAS

Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
107	0	0	0	0	0	0	0	1	0	0	0	0
102	0	0	0	0	0	0	12	17	0	0	0	0
97	0	0	0	0	1	12	68	61	12	0	0	0
92	0	0	0	0	9	62	110	101	40	7	0	0
87	0	0	1	5	44	106	126	128	71	16	0	0
82	0	1	7	25	97	140	166	158	103	45	2	0
77	1	3	18	63	133	166	170	161	148	77	18	2
72	6	10	36	118	166	142	79	96	160	120	45	7
67	22	22	66	143	145	66	13	17	109	139	71	29
62	38	45	94	132	89	21	1	3	49	125	101	56
57	48	67	91	105	38	4	0	0	23	101	98	75
52	77	82	110	64	18	1	0	0	4	70	120	90
47	95	108	108	37	3	0	0	0	1	31	106	119
42	107	112	95	17	1	0	0	0	0	11	79	120
37	117	92	62	5	0	0	0	0	0	1	49	110
32	98	75	37	2	0	0	0	0	0	1	24	72
27	62	38	13	0	0	0	0	0	0	0	8	38
22	34	13	4	0	0	0	0	0	0	0	1	15
17	21	3	1	0	0	0	0	0	0	0	0	5
12	12	0	0	0	0	0	0	0	0	0	0	1
7	5	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX C

LISTING OF HEAT PUMP MODEL PROGRAM

The following computer program is written in Fortran IV for an IBM 370/168 computing system. All equations, constants, and data contained in the computer program are in the English system of units.

FORTRAN PROGRAM

```
C     HPUMP -- ANALYSIS OF HEAT PUMP OPERATION
C
      COMMON /HPUMP/ AHM(18),AHT(18),AHB(18),AHW(18)
      COMMON /EXTRA/ DQ,QM,QB,HCLR,BPT,DCL
      COMMON /WETHR/ AWL(18),AWT(18),AWH(18)
C
C     *** WEATHER LOOP
C
      DO 10 I=1,10
C
C     *** READ WEATHER DATA
C
         READ (11,20) (AWL(II),AWT(II),AWH(II),II=1,18)
20       FORMAT (A4,2F10.0)
C
C     *** PRINT WEATHER LOCATION
C
         WRITE (6,32) AWL(1)
32       FORMAT (2X,A4)
C
C     *** HEAT PUMP LOOP
C
         DO 30 J=1,136
C
C     *** READ HEAT PUMP DATA
C
         READ(12,40)DCL,(AHM(II),AHT(II),AHB(II),AHW(II),II=1,18)
40          FORMAT (2X,7X,F7.0,/,(A2,3F7.0))
C
C     *** HEATING/COOLING LOAD RATIO LOOP
C
            DO 50 K=1,11
               HCLR=FLOAT(K)/10.+0.9
C
C     *** CALL BALPT SUBROUTINE
C
               CALL BALPT
C
C     *** CALL OCALC SUBROUTINE
C
               CALL OCALC
C
C     *** END HCLR LOOP
C
50          CONTINUE
C
```

```
C      *** END HEAT PUMP LOOP
C
30        CONTINUE
C
C      *** REWIND HEAT PUMP FILE
C
          REWIND 12
C
C      *** END WEATHER LOOP
C
10     CONTINUE
C
C      *** FIN
C
       STOP
       END
C
C**********************************************************
C
       SUBROUTINE BALPT
C
C      SUBROUTINE BALPT -- CALCULATES BALANCE POINT TEMPERATURE
C
       COMMON /HPUMP/ AHM(18),AHT(18),AHB(18),AHW(18)
       COMMON /EXTRA/ DQ,QM,QB,HCLR,BPT,DCL
       COMMON /WETHR/ AWL(18),AWT(18),AWH(18)
C
C      *** DETERMINE DESIGN HEAT LOAD AND EQU OF HEAT LOAD LINE
C
       DQ=DCL*HCLR
       DT=13.0
       BQ=0.0
       BT=67.0
       QM=(BQ-DQ)/(BT-DT)
       QB=DQ-QM*DT
C
C      *** ESTIMATE BALANCE POINT
C
       DO 20 J=1,18
          Q=QM*AHT(J)+QB
          IF (AHB(J).LT.Q.AND.AHB(J).NE.0.0) GOTO 30
20     CONTINUE
C
C      *** DETERMINE EQU OF HEAT PUMP LINE ABOUT BALANCE POINT
C
30     HBL=AHB(J)
       HBH=AHB(J-1)
       HTL=AHT(J)
       HTH=AHT(J-1)
       HM=(HBH-HBL)/(HTH-HTL)
```

```
      HB=HBH-HM*HTH
C
C     *** DETERMINE EXACT BALANCE POINT
C
      BPT=(HB-QB)/(QM-HM)
C
C     *** FIN
C
      RETURN
      END
C
C************************************************************
C
      SUBROUTINE OCALC
C
C     SUBROUTINE OCALC -- CALCULATES OUTPUT VARIABLES
C
      COMMON /HPUMP/ AHM(18),AHT(18),AHB(18),AHW(18)
      COMMON /EXTRA/ DQ,QM,QB,HCLR,BPT,DCL
      COMMON /WETHR/ AWL(18),AWT(18),AWH(18)
C
C     *** CALCULATE OUTPUT VARIABLES
C
      TPDF=0.0
      TPRQ=0.0
      TPHP=0.0
      TPER=0.0
      DO 41 J=1,18
        Q=QM*AWT(J)+QB
        TF=1.0
        IF (AWT(J).GT.67.0) TF=0.0
        PDF=0.0
        IF (AWT(J).LT.37.0)
     &   PDF=TF*((3.5/90.)*AWH(J)*((DQ/3413.)+(AHW(J)/1000.)))
        RT=0.0
        IF (AWT(J).GE.BPT.AND.AHB(J).NE.0.0)
     &   RT=Q/AHB(J)
        PHP=0.0
        IF (AWT(J).GE.BPT)
     &   PHP=TF*(AHW(J)*AWH(J)*RT/1000.+PDF)
        PER=0.0
        IF (AWT(J).LT.BPT)
     &   PER=TF*((Q-AHB(J))*AWH(J)/3413.)
        IF (AWT(J).LT.BPT)
     &   PHP=TF*((AHW(J)/1000.)*AWH(J)+PER+PDF)
        PRQ=TF*(Q*AWH(J)/3413.)
        TPRQ=TPRQ+PRQ
        TPDF=TPDF+PDF
        TPHP=TPHP+PHP
        TPER=TPER+PER
```

```
01560          IF (INT(AWT(J)).EQ.17) COP17=AHB(J)/3.413/AHW(J)
01570          IF (INT(AWT(J)).EQ.47) COP47=AHB(J)/3.413/AHW(J)
01580 41    CONTINUE
01590       COPT=TPRQ/TPHP
01600 C
01610 C     *** PRINT OUT RESULTS
01620 C
01630       WRITE (10,1234)
01640      & AWL(1),AHM(1),HCLR,COP17,COP47,COPT,BPT,TPER,TPDF,TPHP
01650 1234  FORMAT(A4,A2,2X,8F8.1)
01660 C
01670 C     *** FIN
01680 C
01690       RETURN
01700       END
```

APPENDIX D

SAMPLE CALCULATIONS

Data used in the sample calculations were obtained from homes in Oklahoma. These data were collected for energy auditing purposes. Heating and cooling loads were calculated using the model described by Jones (10). Values for COP17 and COP47 were calculated from data contained in Appendix A.

The procedures for estimating SPF are as follows:

1. Calculate heating and cooling loads to determine HCLR.

2. Select heat pump based on cooling load from step 1.

3. Obtain COP values for 17 and 47°F from ARI (11) manual. These values may be calculated from input and output data if available.

4. Substitute values obtained steps 1 and 3 along with the appropriate degree day value into equation 13.

TABLE VIII

SAMPLE CALCULATIONS

Home No.	Cooling Load Btu/hr	Heating Load Btu/hr	HCLR	Balance Point Temp., °F	COP17	COP47	DD	SPF
1.	40,920	52,580	1.28	32.2	1.84	2.59	3300	2.03
2.	37,495	60,100	1.60	36.7	1.83	2.73	4000	1.80
3.	22,850	25,570	1.12	29.5	1.63	2.54	3750	1.93
4.	19,200	40,885	2.13	42.4	1.63	2.54	4050	1.52
5.	33,990	35,700	1.05	28.2	2.12	2.64	3300	2.26

VITA

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