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USER'S MANUAL FOR
HEAT-PUMP SEASONAL-PERFORMANCE MODEL (SPM)
WITH SELECTED PARAMETRIC EXAMPLES

Topical Report Task 3

CONSUMER PRODUCTS MINIMUM ENERGY
EFFICIENCY STANDARDS PROGRAM

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1. INTRODUCTION

The Seasonal Performance Model (SPM) was developed to provide an accurate source of seasonal energy consumption and cost predictions for the evaluation of heat pump design options. The program uses steady state heat pump performance data obtained from manufacturer's or Computer Simulation Model (CSM) (Reference 1) runs. The SPM can be used to determine the cost effectiveness of energy efficiency improvements to heat pumps (using inputs of efficiency and manufacturing cost obtained from CSM and manufacturing cost analysis respectively) by generating seasonal energy consumption and life cycle costs for each alternative input.

The SPM was originally developed in two forms (as documented in Reference 2), a cooling model for central air conditioners and heat pumps and a heating model for heat pumps. Both models use double bin hour (temperature and humidity) weather data as a basis for calculations. The original models have undergone many modifications to improve the accuracy of predictions and to increase flexibility for use in parametric evaluations. The current SPM is a combined version of the former independent models and is capable of evaluating heating, cooling or annual energy consumption of a heat pump.

1.1 SPM METHODOLOGY

The current SPM is based on the Central Air Conditioner SPM (CACSPM), and the Heat Pump (heating) SPM (HPSPM), (from Reference 3), previously developed at SAI for the DOE. Reference 2 describes at length the theory and validation of the basic models. A variety of changes have been made to these models to improve their accuracy and flexibility including:

- o Combining the heating and cooling models to provide annual performance data.
- o Adding an improved thermostat model which accounts for the interaction between cyclic degradation and equipment on time.
- o Adding a defrost control system selection and energy consumption calculation package.

- o Providing for input specification of heat pump rating point data.
- o Providing for input specification of building area.
- o Increasing the number of weather sites available for evaluation.

Sections 2 and 3 of this report further describe these improvements.

A general flow chart for the cooling and heating SPM is given in Figure 1-1. The method for calculating the equipment operating parameters for the heating and cooling seasons are quite similar.

The heating model uses double bin (six humidity bins per temperature bin) load hour data in the defrost region (17 to 42F) and single bin data for all other temperatures. The double binning is necessary to calculate heat pump integrated performance and related defrost parameters. This, combined with heating load calculations (described in detail in References 3 and 4), is used to determine equipment "on-time" and cyclic losses via the thermostat models.

For cooling operation the latent equipment capacity and load must be considered as well as the sensible cooling requirements. The equipment sensible to latent capacity ratio and the latent load, are dependent upon the indoor humidity. The SPM iterates to determine the indoor humidity that satisfies both an enthalpy balance and a moisture balance for each bin (temperature and humidity). Due to this iteration and accuracy requirements, the cooling model requires about three times more central processing unit time than the heating model.

1.2 CAPABILITIES AND LIMITATIONS OF THE SPM

The SPM provides an accurate and flexible vehicle for investigation of many parameters effecting heat pump performance. Through parametric studies utilizing the SPM and supporting cost and manufacturing data, significant insights can be gained for purposes such as energy efficiency standards development, test procedure evaluation, and component design.

Figure 1-1. SPM Flowchart

Figure 1-1 (Cont'd). SPM Flowchart

The SPM is designed to allow multiple runs to be made for each job submission. The parameters that may be varied for each of the runs are limited to the weather site and the defrost control system specification. Variations in all other input parameters must be made thru individual SPM initializations.

The user should be aware that the model does not contain safeguards against erroneous input specifications. The results of specifying undefined input values is unknown.

Section 2 of this report is intended to provide insights to the theory and construction of the major options. Sections 3 and 4 will provide the prospective user with a more thorough understanding of the available options and output variables of the SPM. Specific investigations made using the SPM are described in Section 5 and provide examples of the possible applications of the model.

2. IMPROVEMENTS AND APPLICATIONS OF OPTIONS

The following subsections of this report describe the more significant modifications made in development of the cooling and heating SPM beyond the capability documented in References 2 and 5. Included in these discussions are the supporting theories and sources used in this development. Introductions to the potential applications of the resulting SPM user options are also given.

2.1 WEATHER FILES

The number of available SPM weather sites has been expanded from 12 to 14 with the addition of Louisville, Kentucky and Cincinnati, Ohio in order to provide climates with high defrost energy consumption. A complete list of available sites is given in Section 3.

Both cooling and heating weather data are based on a combination of NOAA 5 and 10 year summaries (Reference 6) and AFM 88-8 Engineering Weather Data (Reference 7). These sources are combined using data base processors to provide four input files to the SPM. This manipulation is further described in References 5 and 8. Three of the resulting input files represent different length heating seasons, the fourth contains double bin cooling data for each site. The available heating seasons are six month, annual or SAI estimated (six to nine months). Weather data options are further described in Section 3.

By using weather data based on the same source data for all sites and utilizing a consistent method of manipulation for input file compilation, the resulting SPM output data can provide direct site to site comparisons.

2.2 HEAT PUMP DATA

The previous heat pump heating SPM's (Reference 2 and 5) utilized "performance map" input files which contained heating capacity, energy input and defrost data for each temperature and humidity bin in the heating region as described in Reference 9. These input files were generated line by line

using manufacturers data and calculations from auxiliary defrost models. The current cooling and heating SPM eliminates this input file requirement by internally generating the performance map. Only the capacity and efficiency (COP) at the 17 and 47F rating points, and a defrost control system selection are required as input to the model. A performance map is then generated by using linear steady state heat pump capacity and energy input vs. temperature relationships. This state point data is then input to the defrost model (see Section 2.3).

The complex relationships of cooling capacity and energy input to source and sink temperature and humidity, do not permit a similar approximation of linear cooling performance relationships (as is used for heating performance). To permit calculation of heat pump cooling capacities and efficiencies, cooling performance maps coded into the model are scaled proportionately to match the 95F rating point data that is required as input. The performance maps that are so scaled are for a GE BWB936A condensing unit and a BWV936G air handler (34000 Btu/hr, EER 7.0 at 95F) as described in Reference 2. The SPM is not currently capable of changing the slopes of these performance curves.

2.3 DEFROST PERFORMANCE

The SPM uses a time-step integration algorithm to calculate performance for frost and defrost conditions. The heat output, electrical consumption, COP, time to defrost and time between defrosts are calculated for each temperature/humidity bin. The equations, and test documentation for the simulation are contained in Reference 10.

2.3.1 Defrosting Phenomena and Control Systems

At outdoor coil surface temperatures, below 32F when the humidity is high, frost will begin to accumulate on the coil. The frost accumulates in two phases: a slow build-up in the primary phase, followed by a rapid build-up in the secondary phase. The accumulation of frost in the second phase reduces the heat transfer of the outdoor coil which in turn reduces the performance of the heat pump.

The heat pump defrost control system initiates a defrost by reversing the heat pump (switches to the cooling mode) resulting in melting of the frost on the outdoor coil. At the end of the defrost cycle, the control system returns the heat pump to the heating mode.

Heat pump defrost control systems are broadly divided into two categories: timed and demand. In timed defrost systems the defrost cycle is initiated by a timer, whereas demand systems initiate defrost based on sensing the need to defrost. There are several variations on these two types of control schemes. Timed defrosts have the disadvantage of initiating defrost cycles when they are not needed, but have the advantages of low first cost and high reliability. Demand defrost systems have the advantage of defrosting only as required but are higher in first cost and historically lower in reliability.

All defrost control systems also include ambient air temperature sensors to signal the presence of frosting conditions. Heat pump defrost control systems are activated at air temperatures below about 42F and above about 17F. Air temperatures outside this range cannot cause frost to accumulate, therefore the defrost system is deactivated.

Eight defrost control systems are modeled in the SPM. Each is discussed below.

Peak: The first system modeled is peak performance (i.e., no defrost). This is included to serve as a benchmark against which other control schemes can be judged.

Timed: The timed defrost scheme defrosts at a fixed time interval, usually 45 or 90 minutes, depending on load climate conditions.

Timed, Outdoor Coil: This control system uses an extra temperature sensor on the outdoor coil to activate the timer. When the outdoor coil is below 32F, defrost cycles are initiated at fixed time intervals.

VITT: Variable interval time-temperature control systems vary the time between defrost as a function of outdoor air temperature. Since frost accumulates more rapidly at lower air temperatures than at higher air temperatures, this control system increases the frequency of defrosting as outdoor air temperatures decrease.

Demand-Temperature: Temperature sensors monitor the outdoor air and coil temperatures. When the difference exceeds a preset limit (usually 16 or 17F) a defrost cycle is initiated.

Demand-Pressure: A pressure sensor across the outdoor coil is used to initiate defrost. As the coil frosts up, the air pressure drop across the outdoor coil increases, when this pressure drop reaches a preset level a defrost cycle is initiated (see Reference 10).

Optimum Defrost, Maximum Heat Output: A defrost cycle is initiated as soon as frost accumulation causes a decline in the heat output from the steady state value. This results in the maximum heat output possible during frosting conditions.

Optimum Defrost, Maximum COP: A defrost cycle is initiated as soon as frost accumulation causes a decline in COP from the steady state COP. This results in the maximum COP possible during frosting conditions.

The last two control systems are included to serve as benchmarks of the optimum control systems. The difference between defrosting to maximize heat output or to maximize COP is small.

2.3.2 The Defrost Algorithm

The defrost algorithm is a time-step simulation of the frost accumulation and defrosting phenomena. Figure 2-1 presents the relationships of the subroutines used in the simulation, and their major function. The major routines of interest are HPDEF and DEFRST. The other routines perform secondary calculations.

Figure 2-1. Relationship of Routines in Defrost Simulation

HPDEF duplicates the defrost control system by deciding whether or not to initiate a defrost cycle. The first step in the procedure is to calculate the outdoor coil condition. Using correlations from Reference 9 the difference between the outdoor air and coil temperature is calculated:

$$\Delta T_{\text{coil-air}} = 10.41 - 0.086 (T_{\text{indoor air}} - T_{\text{outdoor air}}) \quad (1)$$

By subtracting out the outdoor air temperature, the outdoor coil temperature is determined:

$$T_{\text{outdoor coil}} = T_{\text{outdoor air}} - \Delta T_{\text{coil-air}} \quad (2)$$

The routine HUMID is then called to obtain the specific humidity of the ambient outdoor air, and the specific humidity of the air very near the outdoor coil surface (over ice). A series of logic checks are then made to determine the response of the selected control system; a flag is set to indicate the outcome in one of three ways: no defrost, defrost with no frost accumulation, and defrost with frost accumulation. Once the flag is set, the routine DEFRST is called.

DEFRST performs the defrost simulation. If the flag was set to no defrost, DEFRST sets the heat output, electric consumption, and COP to the steady state values. If the flag was set to defrost with no frost accumulation, DEFRST performs a one step integration. If the flag was set to defrost with frost accumulation, DEFRST begins a time-step solution. The time-step solution is based on the work of Reference 10. Before beginning the time step, Equation 3 is used to calculate the transition time between the primary and secondary frost accumulation phases:

$$\text{Time}_{\text{transition}} = 0.82 (\text{SPH}_{\text{air}} - \text{SPH}_{\text{coil}})^{-0.6} \quad (3)$$

where: SPH is the specific humidity.

The slopes of the frost accumulation correlations are then calculated:

$$\text{Slope}_{\text{primary}} = 0.0852 * (\text{SPH}_{\text{air}} - \text{SPH}_{\text{coil}})^{0.12}, \quad (4)$$

$$\text{Slope}_{\text{secondary}} = 4.51 * (\text{SPH}_{\text{air}} - \text{SPH}_{\text{coil}})^{0.86}. \quad (5)$$

The transition time from Equation 3 is used in Equation 6 to obtain the outdoor air-coil temperature difference and the transition point:

$$\Delta T_{\text{transition}} = \Delta T_{\text{coil-air}} * e^{(\text{Slope}_{\text{primary}} * \text{Time}_{\text{transition}})} \quad (6)$$

At this point the time-step is begun. The temperature difference between the outdoor air and outdoor coil is calculated. Using the slopes of Equation 4, the temperature difference during the primary phase is calculated:

$$\Delta T_{\text{primary}} = \Delta T_{\text{coil-air}} * e^{(\text{Slope}_{\text{primary}} * \text{Time})}, \quad (7)$$

where $\Delta T_{\text{coil-air}}$ is from Equation 1.

The correlation for the outdoor air-coil temperature difference during the secondary phase is:

$$\Delta T_{\text{secondary}} = \Delta T_{\text{coil-air}} + (\Delta T_{\text{transition}} - \Delta T_{\text{coil-air}}) * e^{(\text{Slope}_{\text{secondary}} * (\text{Time} - \text{Time}_{\text{transition}}))} \quad (8)$$

This temperature difference is used to calculate the instantaneous heat output and electric consumption using subroutine HEAT. These instantaneous values are summed in routine SUM. DEFRST then performs a series of logic tests to determine if it is time to terminate the defrost cycle. If it is, control is returned to HPDEF, if it is not, time is incremented and another 'step' is taken.

The subroutines HUMID, TIMED, HEAT, SUM, FRENCH and PARAB are used to perform secondary calculations. HUMID returns the specific humidity of air at an input temperature and relative humidity. A flag is set for whether the air is over water or ice. HUMID is based on Reference 11.

TIMED loads the times between defrosts for VITT defrost control systems. TIMED contains constants for three VITT systems: GE, Honeywell, and Ranco. (Reference 9)

HEAT calculates the steady-state heat output, electric consumption and COP of the heat pump based on the correlation of Reference 10. HEAT uses the table look-up routine FRENCH (and PARAB) to find the heat output and electric consumption versus the temperature difference between the indoor air temperature and the outdoor coil temperature.

SUM is an integration routine. The instantaneous values of heat output, electric consumption, and COP are integrated with respect to time during the simulation. SUM also calculates the defrost time, heat output, and energy using the following correlations (see Reference 10).

$$\text{Time}_{\text{defrost}} = 0.025 + 0.052 * T_{\text{ratio}} \quad (9)$$

where T_{ratio} is:

$$\frac{\Delta T - \Delta T_{\text{coil-air}}}{\Delta T_{\text{demand}} - \Delta T_{\text{coil-air}}}$$

$\Delta T_{\text{coil-air}}$ is from Equation 1, ΔT is from Equation 7 or 8 depending on the time, and ΔT_{demand} is the temperature at which demand defrost should be initiated. ΔT_{demand} for temperature sensors is set to 16F. For pressure sensor systems it is set to:

$$\Delta T_{\text{demand}} = 9.1 + 0.2 * T_{\text{outdoor air}} \quad (11)$$

The heat output (in Btu/h) is:

$$Q_{\text{defrost}} = 4862 * 0.025 - 533.0 * T_{\text{ratio}} \quad (12)$$

and the energy (input in watts) is:

$$E_{\text{defrost}} = 2800.0 * \text{Time} \quad (13)$$

2.3.3 Inputs for Defrost Calculations

Defrost calculations are included in the SPM by setting the variable IDEFT to any value between 1 and 7. If set to 0, defrost calculations are not performed. The value of IDEFT is determined by the type of control system desired as listed in Table 2-1. If IDEFT is set to 4 or 5, the input variable IDFMOD is utilized. Table 2-2 outlines the options for IDFMOD.

Table 2-2. Options for IDFMOD

<u>IDFMOD</u>	<u>Description</u>
1	FITT defrost (interval = TDFBAS)
2	GE-VITT programmed control
3	Honeywell VITT programmed control
4	Ranco VITT programmed control

When IDFMOD is equal to 1 the input variable TDFBAS is used as the base time between defrosts.

In addition to IDEFT, IDFMOD, and TDFBAS, Table 2-3 summarizes the five variables in the defrost routines which are set to constants but which the user might wish to vary. The user may access these by changing FORTRAN statements in the subroutine HPDEF.

Table 2-1. Defrost Control Options for IDEFT

IDEFT	DESCRIPTION OF CONTROL SCHEME	NOTES
1	Peak performance of heat pump with no defrosting	
2	Demand defrost-cycle initiated by pressure drop across outdoor coil	
3	Demand defrost-cycle initiated by difference between outdoor coil temperature and outdoor air temperature	Default is 16F
4	Timed defrost-cycle initiated by timer and deactivated by outdoor air temperature. (Defrosts only when outdoor air temperature is less than 45F and more than 15F.)	IDFMOD and TDFBAS are utilized
5	Timed defrost-cycle initiated by timer and deactivated by outdoor coil temperature. (Coil must be below 32F to defrost.)	IDFMOD and TDFBAS are utilized
6	Optimum defrost - cycle initiated by decline in heat pump heat output	
7	Optimum defrost - cycle initiated by decline in COP	

Table 2-3. Key Constraints in SPM

VARIABLE	DEFINITION	VALUE IN SPM
DTIME	Time step for integration (time between steps-hours).	0.015
SETT	Temperature difference that initiates defrost in temperature demand control systems (degrees F)	16.0
TDEACT	Temperature below which defrost cycles are initiated (F)	45
TMIN	Minimum defrost cycle time (hours)	0.025
TMAX	Maximum time between defrost cycles (hours)	12.0

2.3.4 Results

The defrost routines produce results which agree with the experimental data of Reference 8 obtained from two different heat pumps.

2.4 CYCLIC PERFORMANCE

The cooling and heating SPM contains four thermostat models for simulation of steady state equipment cycle rate. All thermostat models utilize the time constant method for calculation of cyclic losses as described in Reference 2. The available thermostat models are:

1. "Old" - Cycle rate is determined as a function of outdoor dry-bulb temperature (Reference 2).
2. "New" - Cycle rate is calculated as a parabolic function of estimated heat pump on-time (Reference 5).
3. "ITT" - Cycle rate is calculated iteratively as a parabolic function of actual heat pump on-time, including changes in on-time due to cyclic and defrost losses.
4. "RAC" - The room air conditioner thermostat, to be used for cooling only SPM simulations. This thermostat model is sensitive to indoor dry-bulb temperature only (no anticipator circuit). (Reference 2).

The third "iterative" model was added to provide an exact solution for cycle rate and the resulting seasonal or annual number of cycles. This allows the sensitivity of these outputs to parameters such as equipment time constant, peak cycle rate or heat pump sizing to be evaluated. The following discussion develops this thermostat model in comparison to the "NEW" thermostat model (presented in Reference 5) for the heating mode. It should be noted that some reduction in CPU time can be achieved using the "NEW" model when exact cycle rate predictions are not required.

Figure 2-2 illustrates the ideal thermostat response curve that was used in the "NEW" thermostat. The algorithm for this curve is:

Figure 2-2. "NEW" Thermostat Model (From Reference 5)

$$\text{CYCLE RATE (cyc/hr)} = \text{MAXIMUM RATE} \times (1 - (\text{POT} - 50)^2 / 2500) \quad (14)$$

where POT = percent heat pump on time.

The estimated percent on time (POT_E) in the heating mode is computed using the following equation to account for cyclic losses:

$$\text{POT}_E = \left[\frac{\text{hourly load}}{\text{steady state capacity}} + \frac{\text{Tau}_{\text{on}} \times \text{Ideal Cycle Rate}}{60} \right] \times 100 \quad (15)$$

where: Tau_{on} = Start-up time constant (min).

Ideal Cycle Rate = Cycles per hour calculated using the ideal on-time (load/capacity) and Equation 14.

The estimated heat pump cycle rate is then calculated using the results of Equation 15 in Equation 14. This cycle rate is then used to calculate the cyclic losses using the time constant method as described in Reference 2. The actual on-time is also determined. Note that this on-time may not agree with the value last input to the thermostat model.

Reference 12 shows that the parabolic thermostat model, as used in the "NEW" thermostat, can be used to calculate the related cycle times by the following equations:

$$t_{\text{cycle}} \text{ (hr)} = \frac{1}{\text{cycle rate}} \quad (16)$$

$$t_{\text{on/cycle}} = \frac{1}{2 \times \text{cycle rate}} \times \left[1 \pm \left(1 - \frac{\text{cycle rate}}{\text{peak cycle rate}} \right)^{1/2} \right] \quad (17)$$

$$t_{\text{off/cycle}} = t_{\text{cycle}} - t_{\text{on/cycle}} \quad (18)$$

The thermostat "ITT" uses these times as input constraints to a cyclic degradation model (Figure 2-3).

Figure 2-3. Time Constant Heat Pump Cyclic Degradation

The actual heat pump output is then calculated using the following algorithms:

During on time,

$$\text{HP output}_{\text{on}} (\text{Btu}) = \text{cap}_{\text{ss}} \times \left(T_{\text{on/cyc}} - \text{Tau}_{\text{on}} \left(1 - e^{-\left(\frac{T_{\text{on/cyc}}}{\text{Tau}_{\text{on}}} \right)} \right) \right) \quad (19)$$

where: cap_{ss} = heat pump steady state capacity.

During off-time (continuous fan operation only);

$$\text{HP output}_{\text{off}} (\text{Btu}) = \text{cap}_{\text{ton}} \times \text{Tau}_{\text{off}} \left(1 - e^{-\left(\frac{T_{\text{off/cyc}}}{\text{Tau}_{\text{off}}} \right)} \right) \quad (20)$$

where: τ_{off} = shutdown time constant

cap_{ton} = capacity at end of on-time

$$= \text{cap}_{\text{ss}} \times \left(1 - e^{\left(\frac{-T_{\text{on/c}}}{\tau_{\text{on}}} \right)} \right) \quad (21)$$

For autofan mode:

$$\text{HP output total (Btu/hr)} = \text{HP output}_{\text{on}} \times \text{cycle rate}, \quad (22a)$$

and for continuous fan mode:

$$\text{HP output total (BTU/hr)} = (\text{HP output}_{\text{on}} + \text{HP output}_{\text{off}}) \times \text{cycle rate}. \quad (22b)$$

The actual average equipment heat pump on time can now be calculated:

$$\text{POT}_a = \frac{\text{HP output total}}{\text{Capacity}_{\text{ss}}} \times 100 \quad (23)$$

This is used to calculate a corrected percent on time which is fed back to the thermostat model. This sequence of calculations is continued until the input and output on-times agree.

Table 2-4 contains results of the heating SPM for thermostats "NEW" and "ITT" both with and without cyclic degradation for three locations. The major differences between the two models are:

- o The average cycle rate for the "NEW" thermostat is independent of cyclic degradation losses. For the "ITT" model, degradation has a noticeable effect on cycle rate. This is especially true for moderate climates (e.g., Dallas) where the average heat pump percent on-time is low. (The average percent on-time for the "ITT" model with degradation in Dallas was 38.4% compared to 70.5% in Minneapolis.)
- o Figure 2-4 shows cycle rate as a function of outdoor temperature as calculated using these two thermostats and the ideal (w/o degradation) values. Both thermostats yield a shifting of the parabola to the right due to the increase in on time from cyclic losses. The "ITT" thermostat generally yields a higher cycle rate than the "NEW" model, and shows a significant dependence on the equipment time constant τ .

Table 2-4. Heating SPM Thermostat Comparison

		COMPRESSOR		SPF	AVERAGE CYCLE RATE
		HOURS	# CYCLES		
W/O DEGRADATION					
<u>Minneapolis</u>					
	NEW	3457	5901	5.34	1.16
	ITT	3457	5867	5.34	1.16
<u>Kansas City</u>					
	NEW	2103	6614	6.66	1.68
	ITT	2103	6512	6.66	1.66
<u>Dallas</u>					
	NEW	807	4682	8.01	2.00
	ITT	807	4458	8.01	1.90
W/ CYCLIC DEGRADATION					
<u>Minneapolis</u>					
	NEW	3574	5901	5.23	1.16
	ITT 1.2	3574	5962	5.23	1.18
	ITT 3.0	3743	6040	5.08	1.19
<u>Kansas City</u>					
	NEW	2234	6614	6.33	1.68
	ITT 1.2	2235	6679	6.33	1.70
	ITT 3.0	2426	6829	5.90	1.74
<u>Dallas</u>					
	NEW	900	4682	7.19	2.00
	ITT 1.2	900	4732	7.19	2.02
	ITT 3.0	1043	5065	6.21	2.16

HEATING SPM, RHO - 40 %

LEGEND
□ = 'NEW' T-STAT
○ = W/O DEG. (ITT)
△ = TAU=1.2 (ITT)
+ = TAU=3.0 (ITT)

Figure 2-4. Effect of Cyclic Degradation on Cycle Rate

For these reasons it is recommended that the "ITT" thermostat be used in evaluations of cyclic losses due to its greater sensitivity to cyclic degradation parameters, compared to the other thermostat models.

2.5 HEAT PUMP SIZING

It has been suggested that proper heat pump selection (or space conditioning equipment selection) should be based upon life cycle cost projections for the system being considered. Such projections applied to heat pump selection require accurate and comparable estimates of energy use to be provided as input to an economic model. Due to cyclic losses and supplementary heating requirements, the size of the heat pump can have a large effect on energy use and therefore life cycle cost. A basic life cycle cost calculation subroutine was added to the SPM so that the effect of these parameters could be assessed.

This subroutine incorporates simple equipment cost algorithms which should be refined using manufacturing analysis of heat pump costs if any life cycle cost evaluations are to be performed for purposes of determining cost effective design improvements and equipment sizing.

Use of the life cycle cost calculation subroutine for Minneapolis, Dallas and Kansas City showed that the smallest unit meeting the cooling requirements had the lowest life cycle costs for Dallas and Kansas City. An optimum was reached for Minneapolis at a size 1 to 1-1/2 tons above the cooling requirement. This was due to the large quantities of supplementary heat required in the heating mode below the balance point for smaller units.

Due to the dynamics of latent cooling loads and capacities the SPM is not capable of accurately predicting actual indoor relative humidity. When substantially oversized heat pumps (for cooling) are suggested (the analysis implied oversizing up to 80% in Minneapolis) the heat pump duty factor for moderate cooling dry bulb temperatures may become so small that the steady state solutions for indoor relative humidity computed using the SPM are not practically realized. This lack of humidity control may result in an unacceptable compromise of occupant comfort to minimize life cycle cost.

3. INPUT DATA

Figure 3-1 contains a sample listing of the input deck required for the cooling and heating SPM. (It is the base case for the analyses included in Section 5 of this report). The variable names are given following the input values, on each line for easy reference. All input's are free format (formatted by comma's only), although the input values must comply with the standard FORTRAN variable type punctuation (single quoted alpha numerics, no decimal in integers).

The program has not been protected against erroneous input values.

The following list presents the definitions and explanations of the input parameters:

NCASES = Number of cases to be analyzed where each product model/site combination is a case.

ISTSZ = Number of cases per set. A heating summary listing is provided after each "ISTSZ" case. If ISTSZ = 0, or ISTSZ is equal or greater than NCASES, the subset summaries are considered inappropriate and are therefore not provided.

IMODE = 1 Cooling calculations only.
= 2 Heating calculations only.
= 3 Cooling and heating calculations are made.

IAF = 0 Continuous fan operation.
1 Autofan operative.

ICYCLE = 0 No cyclic degradation.
1 Cyclic degradation.

NOTE: When ICYCLE is activated IAF=0 implies that the residual heat of the equipment is recovered. IAF=1 implies that the residual heat of the equipment is lost.

IECON = 1 Life cycle cost and related economics are calculated.
= 0 No economics are evaluated.

ISPEED = 1 Single speed heat pump mode.
= 2 Dual speed heat pump (for future use only).

IWEAT = "ANN" for 12-month weather data (for heating).
= "SIX" for 6-month weather data (for heating).
= "EST" for SAI estimated heating season, which varies by site.

NOTE: This switch does not apply to cooling calculations.

IRSARE = 1 The load is scaled to the given area "RESARI".
= 0 The building is sized according to heat pump capacity.

RESARI = Floor area of the residence (used when IRSARE=1).

TIDBC = Indoor dry bulb thermostat set point temperature, cooling.

TIDBH = Indoor dry bulb thermostat set point temperature, heating.

TIDBBN = Nominal indoor dry bulb temp. (for cooling dry bulb bin calculations only).

TMINS = Minimum outdoor dry bulb temperature to be considered for solar hours.

TMIND = Minimum outdoor dry bulb temperature to be considered for dark hours.

ANACHC = Design load air change rate (air changes per hour), cooling.

ANACHH = Design load air change rate, heating.

QIIPSF = Internal heat gain rate (Btu/hour/sq.ft.).

EOSIZE = Equipment oversize factor. This oversizing factor is used in the load model to determine the magnitude of cooling design load based on the 95F rating point capacity of the heat pump. A temperature correction is applied in the program to correct for other than 95F cooling design temperatures.

SHSF = Supplementary Heater Scale Factor. Set SHSF equal to zero to eliminate tempering heat.

TSNAM = 'OLD' Old thermostat which is based on outdoor dry-bulb temperature.
= 'NEW' New thermostat which is based on percent on-time.
= 'ITT' Iterative percent on-time thermostat with degradation effects.
= 'RAC' Room air conditioner thermostat, to be used for cooling runs only.

CYCMAX = Maximum cycle rate (CYC/HR) for the 'NEW' (or 'ITT') thermostat.
 TAU = Equipment time constant (TAUON = TAUOFF) in min.
 RHOBAS = Base relative humidities to represent the cooling bins, 0-29%, 30-49%, 50-69%, 70-79%, 80-89%, 90-100%.
 CALCRP = Rating Point Cooling Capacity at 95F (Btu)
 EERLRP = Rating Point EER at 95F.
 CAHLRP = Rating Point Heating Capacity at 47F (Btu)
 COHLRP = Rating Point COP at 47F.
 CALLRP = Rating Point Heating Capacity at 17F (Btu)
 POLLRP = Rating Point COP at 17F.

The following switches require a "Y" or "N" as input unless otherwise noted.

IPRNTA = Print out an initial summary of the runs (and input) being made.
 IPRNTB = Printout end of run summaries of seasonal performance results.
 IPRNTC = Printout a listing of the load components for each bin.
 IPRNTD = Print out a listing of the cooling solar hour results for each bin.
 IPRNTE = Print out a listing of the cooling dark hour results for each bin.
 IPRNTF = Product information printout. Note - 'PO' = production information printout.
 IPRNTG = Dry-bulb-bin (NBS) printout. Note - 'CO' = Dry-bulb-bin printout only. Applies to cooling only.
 IPRNTH = Weather data statistics printout. Note - 'WO' = Weather P/O only. Applies to cooling only.
 IPRNTI = Tempering heat detail printout. Note: 'TO' = tempering heat printout only (heating).
 IPRNTJ = 'Y' if you only want summaries of results (heating).

The following are inputs for economic calculations:

RFI = Interest rate on loan (%/year).
RDSC = Discount Rate (%/year).
REE = Electricity escalation rate (%/year).
ECKWH = Electricity cost (\$/kWh).
HPLIFE = Heat pump life (years).
WRNTY = Length of heat pump warranty (years).
SVGWOD = Salvage value of system without ducts.
SVGWD = Salvage value of system including ducts.

The run by run inputs are as follows. note that there must be as many lines included contained these values as were specified by NCASES (the first variable in this deck).

ISITEM = Site number, referring to weather file reference numbers.

= 1 Minneapolis
= 2 Chicago
= 3 Boston
= 4 Seattle
= 5 Kansas City
= 6 Philadelphia
= 7 Sacramento
= 8 Las Vegas
= 9 Dallas
= 10 Los Angeles
= 11 New Orleans
= 12 Miami
= 13 Louisville
= 14 Cincinnati

IDEFT = Defrost type for defrost calculation subroutine:

= 0 Do not call defrost calculation subroutine.
= 1 Peak, no defrost cycle (yields same results as '0').
= 2 Demand defrost cycle, pressure differential sensor.
= 3 Demand defrost cycle, temperature sensors.
= 4 Timed defrost cycle with deactivation by outdoor air temperature.

- = 5 Timed defrost cycle with deactivation by outdoor coil temperature.
 - = 6 Optimum defrost cycle, maximum heat output.
 - = 7 Optimum defrost cycle, maximum COP.
- IDFMODE = Selector for type of timed defrost control (applies to timed controls only).
- = 1 Time between defrosts = TDFBAS.
 - = 2 GE programmed control.
 - = 3 Honeywell programmed control.
 - = 4 Ranco programmed control.
- TDFBAS = Base time for timed defrost options (applies to timed control only). (Min)


```

03, 03, 3, NCASES, ISTSZ, IMODE
1, 1, 1, 1, IAF, ICYCLE, IECON, ISPEED
'EST', 1, IWEAT, IRSARE
75., 70., 80., 65., 65., TIDBC, TIDBH, TIDBBN, TMIN, TMIND
0.5, 1.0, 3.5, 1500., 1.475, 1.0, ANACHC, ANACHH, QIIPSF, RESARI, EOSIZE, SHSF
'ITT', 3.0, 1.2, TSNAM, CYCMAX, TAU
25., 40., 60., 75., 84., 92., RHO BASES.
24000., 7.80, CACLRP, EERLRP (CAP 8 EER AT 95 F)
24000., 2.70, CAHLRP, COHLRP (CAP 8 COP AT 47 F)
14400., 2.00, CALLRP, COLLRP (CAP 8 COP AT 17 F)
5, 5, 6, ITTY, IREAD, IWRITE
'Y', IPRNTA: RUN SUMMARY LISTING.
'Y', IPRNTB: COMPRESSED (SUMMARY) SP RESULTS LISTING.
'Y', IPRNTC: LOAD COMPONENT LISTING.
'Y', IPRNTD: SOLAR HOURS INFO LISTING.
'Y', IPRNTE: DARK HOURS INFO PRINTOUT.
'Y', IPRNTF: PRODUCT INFO PRINTOUT. NOTE: "PO" = PROD P/O ONLY.
'N', IPRNTG: DRY-BULB-BIN (NBS) PRINTOUT. NOTE: "CO" = COMPRESSED P/O ONLY.
'Y', IPRNTH: WEATHER DATA STATISTICS PRINTOUT. NOTE: "WO" = WEA P/O ONLY.
'Y', IPRNTI: TEMPERING HEAT DETAIL P/O. "TO"=T.H. P/O ONLY (HEATING).
'N', IPRNTJ: "Y" IF YOU ONLY WANT SUMMARIES OF RESULTS (HEATING).
10.0, 10.0, 10.0, 0.060, RFI, RDSC, REE, ECKWH
10.0, 1.0, HPLIFE, WRNTY
50.0, 050.0, SVGWOD, SVGWD
1, 3, 1, 90., ISITE, IDEFT, IDFMOD, TDFBAS
5, 3, 1, 90., ISITE, IDEFT, IDFMOD, TDFBAS
9, 3, 1, 90., ISITE, IDEFT, IDFMOD, TDFBAS

```

Figure 3-1. Sample SPM Input File

4. SAMPLE OUTPUT

The following is a page by page description of the output listing presented as Figure 4-1 at the end of this section. Generally the listing should be found self explanatory. In addition to the page and run number, the model mode (cooling or heating) is noted in the upper right corner of each page for clarification.

Cover Sheet - This reflects the input data for all runs in the set and is self explanatory.

COOLING MODEL OUTPUT

Page 1 - Cooling Weather Statistics. Here the double bin hour matrices are given as read by the program from the input data base for the particular site.

Page 2 - Product and Site Data. This sheet contains the equipment and site design data, and resulting design load calculations for the run.

The heat pump or building is sized according to the heat pump cooling capacity and the cooling design conditions. The variables are:

TODH = Heating design temperature (F).

TODC = Cooling design temperature in (F).

RANGE = The range in daily temperature per Manual J. There are three possible ranges: low, medium, and high.

RESVOL = Volume of the building.

RESAREA = Area of the building.

Cooling Scale Factors - These are coefficients calculated in the program reflecting the change in heat pump size required to force the coded cooling capacity and power data (see Section 2.2) to fit the 95F design values given as input.

Design Load Results:

QH9560 = Heating load calculated using a 95F cooling design temperature and a 60F heating design temperature (used in calculated QHDL).

QHDL = Heating design load.

QCSDL = Total cooling design sensible load.

DOE - Heating load and output. These calculations are based on DOE test procedures.

A complete description of these calculations are given in Reference 9.

Page 3 - Solar Hour Results, Equipment Data. The variables in the heading of the table are defined in the explanation of the input file (Section 3). The table contains the equipment side results as calculated with the SPM for the solar bin hours. Some of the pertinent input variables are repeated for convenience. Output variable (left to right) definitions are as follows:

I = Cooling bin number.

TODB = Outdoor dry bulb temperature.

RHO = Outdoor relative humidity.

TIDB = Indoor dry bulb temperature (thermostat setting).

TIWB = Indoor wet bulb temperature as calculated by satisfying both indoor enthalpy and latent heat balance equations.

RHI = Indoor relative humidity.

CAPACITY = Equipment latent, sensible and total cooling capacities.
 SENS. RATIO = The ratio of sensible to total equipment cooling capacities.
 HETOT = Equipment input power.
 FREQ. = Actual cycle rate as calculated in the thermostat model.
 ON-TIME/ CYC = The ideal and actual (includes cyclic losses) equipment on-time in minutes per cycle.
 PCT. ON-TIME = The equipment duty factor (percent) corresponding to the given on-times and cycle rate for ideal and actual conditions.
 COOLING HOURS = The total bin hours read from the weather data file.
 COMP HRS = The actual number of compressor operating hours for the bin.
 BNACH = The actual infiltration rate.

Page 4 - Solar Hour Results, Load Data. This contains the load data corresponding to the equipment data of page 3. The variables that have not been defined previously are described (left to right) below. The units are Btu/hr unless otherwise noted.

QSUN = Total radiation load.
 QCONDNET = Net conduction load.
 SENS TOT = Total sensible load.
 INTERNAL = The sensible, latent and total internal cooling loads.
 SENS TOT & INTERNAL = Summation of SENS TOT and total internal loads (columns 6 and 9).
 Q INFILTRATION = The latent and total infiltration loads.
 QTOT = Total cooling load (summation of columns 10 and 12).

Pages 5 and 6 - Dark Hour Results. These tables contain dark hour equipment and load data and follow identical formats to those of pages 3 and 4.

Pages 7, 8, and 9 - Aggregated Results. These three pages contain the seasonal results for solar, dark and total cooling hours, respectively. The three tables follow similar formats. Where a bin appears during both solar and dark hours the values given in the total cooling hour tables are maximums.

KBTU-COOL = The total cooling supplied for the bin (Btu x 1000).

KWH-TOT = The total energy input to the equipment (kWh).

EER = The ratio of KBTU-COOL to KWH-TOT.

HR(RH>65) = The number of cooling hours where the indoor relative humidity is greater than 65%.

PW = The actual equipment on-time per cycle (pulse width).

DF = The equipment duty factor (percent).

Note that the number of compressor cycles is given in the footnotes.

Page 10 - Heat Pump Heating Performance Data. The data listed on the heat pump performance map are as follows:

I = Bin number. There are 47 bins from -8F to 72F in dry-bulb temperature. The heating load is negative for the example presented for temperature bins above 52F, and therefore the listing starts with bin 5.

TODB = Outdoor dry-bulb temperature (F) for the bin.

RHO = Outdoor relative humidity for the bin in percent. The binning structure is disaggregated by relative humidity only for outdoor dry-bulb temperatures between 15 and 45F.

TOTCAP = Total capacity in Btu/h.

TOTPWR = Total power in Watts.

COP = Coefficient of performance.
D-D = Time between defrosts in minutes.
DUR = Duration of defrost in minutes.

"-" in the "Defrost Times" columns stands for not applicable. The heat pump does not defrost in these bins.

The "Peak Values" are the values at that time after defrost when the capacity reaches an instantaneous peak. The "Integrated Values" are average values over a defrost to defrost cycle. If the conditions are such that the heat pump does not defrost, the peak and integrated values are identical.

The "Defrost Performance Factors" are the ratio of "Integrated Values" to "Peak Values".

The compressor operating hour weighted average values of the defrost performance factors are a measure of the seasonal effect of defrosts on the heat pump alone. The example heat pump operates at 3.1% lesser efficiency in Minneapolis than would be the case if defrosting was not necessary and the heat pump could operate at peak, clear coil capacity at all times.

Page 11 - The equipment data given on page 2 is repeated here for convenience.

Page 12 - Heating Load Data. The column headings of this table have the following meanings:

I = Bin number. There are 47 bins from -8F to 72F. This table is set to start with bin 3, because negative heating loads are expected for all sites and all load assumptions for outdoor dry-bulb temperatures above 62F.
TODB = Outdoor dry-bulb temperature (F) for the bin.

RHO	= Outdoor relative humidity for the bin in percent. The binning structure is disaggregated by relative humidity only for outdoor dry-bulb temperatures between 15 and 45F.
HEATING-HRS	= Seasonal hours for which the bin conditions occur. The number of hours depends on the site and the weather data base selected.
NACH	= Actual air changeover rate in air changes per hour.
QINF	= Infiltration load component in Btu/h.
QTRAN	= Transmission load component in Btu/h.
QII	= Internal heat load (negative for heat gain) in Btu/h.
QTOTAL	= Sum of QINF, QTRAN, and QII.
TOTAL/BIN	= Heat requirement for the bin in kBtu.

The footnote variables are as follows:

QIIPSF	= Input value of internal heat gain in Btu/h/ft ² .
ZLTEMP	= The dry-bulb temperature in °F for which QTOTAL is zero.

Page 13 - The design load components of page 2 are repeated here for convenience.

Page 14 - Seasonal Performance Data. The table headings have the following definitions:

I	= Bin number. There are 47 bins from -8F to 72F. This table starts with the first bin for which there is a heating load and ends with the bin below which there are no more heating hours.
TODB	= Outdoor dry-bulb temperature (F) for the bin.

RHO	= Outdoor relative humidity for the bin in percent. The binning structure is disaggregated by relative humidity only for outdoor dry-bulb temperatures between 15 and 45F.
HRS	= Seasonal hours for which the bin conditions occur. The number of hours depends on the site and the weather data base selected.
CPHRS	= Compressor operating hours.
HTLOAD	= Total heating load in Btu/h.
HP-CAP	= Heat pump integrated capacity in Btu/h.
SH-CAP	= Supplementary heater capacity in Btu/h. When HP-CAP is greater than HTLOAD, SH-CAP is the capacity of the first stage of supplementary heat. When HP-CAP is less than HTLOAD, SH-CAP is the difference between HTLOAD and HP-CAP.
HP-KBTU	= The heat output of the heat pump in kBtu.
SH-KBTU	= The heat output of the supplementary heaters in kBtu. When HP-CAP is greater than HTLOAD, SH-KBTU is tempering heat. Otherwise SH-KBTU is the balance of the bin heat requirement beyond that which the heat pump alone can satisfy.
HP-KWH	= The heat pump energy consumption in kWh.
TOT-KWH	= Sum of SH-KBTU and HP-KWH (in kWh).
COP	= The heat pump only COP, which equals $HP-KBTU/HP-KWH/3.413$.
IPCT-ON	= "Ideal" percent on-time in percent. The percent on-time if there were no cyclic degradation, which equals $100 \times HT-LOAD/HP-CAP$.
APCT-ON	= "Actual" percent on-time in percent. The percent on-time which includes the effects of cyclic degradation if ICYCLE equals 1.
FCY	= The ON/OFF cycle rate in cycles/hr.
PW-I	= "Ideal" pulse width or duration of the "on" period of each cycle in minutes if there were no cyclic degradation. It equals $60 \times IPCT-ON/FCY/100$.

PW-ACT = "Actual" pulse width or duration of the "on" period of each cycle in minutes which includes the effects of cyclic degradation if ICYCLE equals 1.

The differences between the ideal and actual pulse widths and on-times reflect the effects of cyclic degradation. The 600 minute entries in the PW-I and PW-ACT columns are meaningless default values; the heat pump never turns off so the pulse width is indeterminant.

The TOTALS are self-explanatory, but the AVERAGES are not. The averages are calculated as follows:

$$\begin{aligned} \text{HT-LOAD(AVG)} &= \frac{\text{TOT OUT (KBTU)}}{\text{HRS (TOTAL)}} \\ \text{HP-CAP(AVG)} &= \frac{\text{HP-KBTU (TOTAL)}}{\text{CPHRS (TOTAL)}} \\ \text{COP(AVG)} &= \frac{\text{HP-KBTU (TOTAL)}}{3.413 \times \text{HP-KWH(TOTAL)}} \\ \text{APCT-ON(AVG)} &= \frac{\text{CPHRS(TOTAL)} \times 100}{\text{HRS (TOTAL)}} \\ \text{FCY(AVG)} &= \frac{\# \text{ COMP CYCLES}}{\text{HRS (TOTAL)}} \end{aligned}$$

and

$$\text{PW-ACT(AVG)} = \frac{60 \times \text{APCT-ON(AVG)}}{100 \times \text{FCY(AVG)}}$$

Several of the averages could be deceiving, because continuous operation below the balance point temperature distorts the results. It might be noted, however, that there is self-consistency between the average HP-CAP and COP.

The summary variables have the following definitions:

TOTOUT	=	Total seasonal heat delivered by the system in kBtu.
TOTIN	=	Total seasonal energy consumption of the system in kWh.
SYSTEM COP	=	Coefficient of performance of the system, which equals $TOTOUT/3.413/ TOTIN$.
# COMP CYCLES	=	Number of compressor cycles, which equals the sum over the bins of $FCY \times HRS$.
# DEFROST CYCLES	=	Number of defrost cycles. The number in front of the parenthesis is the total. The number in parentheses is the number that occurs above the balance point temperature.
TBPNOM	=	"Nominal" balance point temperature (F). Part load operation does not occur in any bin with a dry-bulb temperature less than TBPNOM.
TBPDY	=	Dry coil balance point temperature (F). TBPDY is calculated by linear interpolation of dry coil capacity, i.e., capacity in the 20% relative humidity bins.
TBPDES	=	The balance point temperature (F) that results from design heating load calculations. Since design loads are invariably greater than operating loads, TBPDES is invariably greater than TBPDY.
S1KW	=	The capacity of the first stage of supplementary heat in kW. The tempering heater capacity is S1KW.
ZLTEMP	=	The zero load temperature or structure heat balance temperature (F). ZLTEMP is calculated by linear interpolation. TODB for the first bin listed is always the highest bin temperature that is less than ZLTEMP.
DEGDYS(ABOVE)	=	Heating degree days for the hourly weather data presented for a base temperature of 65F, which equals the sum of $HRS \times (65-TODB)/24$.

DEGDYS(NOAA)	= Annual heating degree days as published by NOAA in the five and ten year summaries for the site listed for a base temperature of 65F.
EQFLH(ABOVE)	= Equivalent full load hours for the hourly weather data presented, which equals $DEGDYS(ABOVE) \times 24 / (65 - TODH)$.
EQFLH(NOAA)	= Equivalent full load hours corresponding to the NOAA degree days, which equals $DEGDYS(NOAA) \times 24 / (65 - TODH)$.
DOEHLH	= DOE Heating Load Hours as estimated from the DOE Heating Load Hour map for the site listed.
DOERGN	= The DOE Region number for the site listed as estimated from the DOE Heating Load Hour map.
Seasonal Performance Factor	= Ratio of total output (Btu) to total input (watts).

Page 16 - Seasonal Performance Data (Cont.). The compressor hour weighted defrost performance factors show the overall degradation (from ideal) due to defrost for the given heat pump/site combination. The output lost to the defrost cycles is the heat supplied to the outdoor coil for defrosting. This value is then used to calculate the percentage loss with respect to heat pump output and system total output. Following the defrost data, the site, equipment, and load design data from page 2 are repeated.

Page 17 - Tempering Heat Details. The column headings have the following meanings:

I	= Bin number. There are 47 bins from -8F to 72F. This table starts with bin 7 because defrosts do not occur for outdoor dry-bulb temperatures of 47F or higher. The table ends with the TODB below which the heat pump is on 100% of the time.
TODB	= Outdoor dry-bulb temperature for the bin in °F.
RHO	= Outdoor relative humidity for the bin in percent.

CPHRS	=	Compressor "on" hours for the bin.
TIM(D-D)	=	Interval between defrosts in minutes.
#DEF	=	Number of defrost cycles in the bin, which <u>approximately</u> equals $60 \times \text{CPHRS} / \text{TIM(D-D)}$.
TIM(DUR)	=	Duration of the time in defrost for each cycle in minutes.
TH-ON	=	Total "on" time of the tempering heaters for the bin in hours, which equals $\#DEF \times \text{TIM(DUR)} / 60$.
TH-CAP	=	Capacity of the tempering heaters in Btu/h.
TH-OUT	=	Heat output of the tempering heaters in kBtu, which equals $\text{TH-ON} \times \text{TH-CAP} / 1000$.
TH-IN	=	Electricity input to the tempering heaters in kWh, which equals $\text{TH-OUT} / 3.413$.
DELTIM (MIN/CYC)	=	The reduction of the time in minutes that the heat pump is "on" during each cycle as compared to the time that it would be ON if TH-CAP were zero.

The treatment of tempering heater effects starts with a set of calculations that assume that TH-CAP is zero. The effects of tempering heat are included by adjusting the results of the first set of calculations. A complete discussion of the tempering heat calculation method is given in Reference 9.

Page 18 - Life Cycle Costs. A summary of annual heating and cooling input energy requirements is given at the top of this page. The economic input parameters are next stated as read from the input file.

The algorithms presented in the program are only to provide general costing figures for qualitative investigations of the effect of heat pump sizing on life-cycle cost or similar relationships. It was intended however, that the life cycle cost calculations should be detailed sufficiently so that accurate costing and economic figures could be incorporated into the model.

The program computes the present worth of the life cycle costs of the heat pump equipment, including capital costs, maintenance costs, energy costs and salvage value. The present worth of each of these life cycle cost elements is included as well as the percent of the total.

Page 19 - Cooling Results Summary. Here the totals and averages given at the bottom of page 9 are repeated to provide convenient run by run comparisons. The total and averages of the values for all runs in this set are also given.

Page 20 - Heating Results Summary. Similar to page 19 but for heating hours. The more common results are tabulated and averages are given for the set of runs.

Page 21 - Life Cycle Cost Summary. The economic input values are repeated here for easy reference. The electric consumption and total life cycle costs are tabulated for all runs and the average values are presented.

SAMPLE COOLING AND HEATING SPM OUTPUT

***** COOLING & HEATING

DATE 1-Jun-82 AT 13:24: 59.4

THE NUMBER OF RUNS IN THE SET IS:

1

DATA THAT ARE CONSTANT FOR THE SET OF RUNS:

THE HEAT PUMP 95 DEG-F RATING POINT, CAPACITY IS:
EER IS:

24000. BTU/HOUR
7.80

THE INDOOR TEMPERATURE SETTING IS (DEG-F):

COOLING, 75.00
HEATING, 70.00

THE MINIMUM TEMPERATURES (DEG-F) ALLOWED FOR COOLING OPERATION ARE:

DAYTIME, 65.00
NIGHTTIME, 65.00

THE COOLING OUTDOOR RELATIVE HUMIDITY BASES ARE (%):

25.00 40.00 60.00 75.00 84.00 92.00

THE DESIGN LOAD AIR CHANGE OVER RATES (ACH/D) ARE:

COOLING, 0.50
HEATING, 1.00

THE INTERNAL HEAT GAIN IS (BTU/H/FT**2):

3.50

THE EQUIPMENT OVERSIZE FACTOR IS:

1.47

THE TYPE OF THERMOSTAT IS:

ITT , (ITERATIVE PARAB W/ DEGRADATION)
PEAK CYCLE RATE IS 3.00

THE SUPPLEMENTARY HEATER CAPACITY SCALE FACTOR IS:

1.00 (0 = NO TEMPERING HEAT)

THE HEATING SEASON IS:

SAI-S ESTIMATE (6-11 MONTHS DEPENDING ON SITE).

THE OPTIONS SELECTED FOR THIS SET OF RUNS ARE:

"AUTOFAN" OPERATION.
CYCLIC DEGRADATION INCLUDED IN CALCULATIONS.
THE FLOOR AREA IS FIXED AT 1500.0 SQUARE FEET.
LIFE CYCLE COSTS ARE CALCULATED.

THE COMPRESSOR TYPE IS:

SINGLE SPEED.

THE SET OF RUN INPUTS IS AS FOLLOWS:

RUN #	SITE #	SITE NAME	DEFROST CONTROL DESCRIPTION (MODEL, TIMER)
1	1	MINN	(3) DEMAND, TEMPERATURE SENSORS , (0)

Figure 4-1. SPM Sample Output (Title Page)

***** COOLING WEATHER DATA/STATISTICS *****

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT

(ANNUAL MINUS JUN-AUG)

TODB	***** TOTAL HOURS FOR SPECIFIED RH *****						TOTALS
	25%	40%	60%	75%	84%	92%	
67.0	30.0	109.0	59.3	0.0	0.0	0.0	690.1
72.0	25.1	145.6	201.6	104.7	94.5	48.6	620.1
77.0	26.6	150.1	177.0	72.0	36.4	5.6	467.7
82.0	18.2	124.5	118.7	28.7	5.2	0.0	295.3
87.0	8.4	52.0	64.1	21.1	0.9	0.2	146.7
92.0	4.0	31.4	18.2	0.1	0.0	0.0	53.7
97.0	1.3	5.4	1.4	0.0	0.0	0.0	8.1
102.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
107.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
112.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS:	113.6	629.1	770.4	347.5	263.7	157.6	2281.9
AVERAGE RH:							60.0

TODB	***** SOLAR HOURS FOR SPECIFIED RH *****						TOTALS
	25%	40%	60%	75%	84%	92%	
67.0	30.0	109.0	59.3	0.0	0.0	0.0	198.4
72.0	25.1	144.0	92.4	0.0	0.0	0.0	261.5
77.0	26.6	147.6	78.1	0.0	0.0	0.0	252.3
82.0	18.2	123.6	59.1	0.0	0.0	0.0	200.9
87.0	8.4	51.6	42.0	13.6	0.0	0.0	115.6
92.0	4.0	31.4	12.2	0.0	0.0	0.0	47.6
97.0	1.3	5.4	1.4	0.0	0.0	0.0	8.1
102.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
107.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
112.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS:	113.6	612.9	344.6	13.6	0.0	0.0	1084.6
AVERAGE RH:							45.2

TODB	***** DARK HOURS FOR SPECIFIED RH *****						TOTALS
	25%	40%	60%	75%	84%	92%	
67.0	0.0	0.0	0.0	0.0	0.0	0.0	491.7
72.0	0.0	1.6	109.2	104.7	94.5	48.6	358.6
77.0	0.0	2.5	98.9	72.0	36.4	5.6	215.4
82.0	0.0	0.9	59.6	28.7	5.2	0.0	94.4
87.0	0.0	0.4	22.1	7.5	0.9	0.2	31.1
92.0	0.0	0.0	6.0	0.1	0.0	0.0	6.1
97.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
102.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
107.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
112.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS:	0.0	16.2	425.8	333.9	263.7	157.6	1197.3
AVERAGE RH:							73.4

Figure 4-1 (Cont'd). SPM Sample Output (Page 1 of 21)

***** PRODUCT AND SITE DATA *****

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

FOR THIS SITE:	TODH:	-10.0 DEG-F;	TODC:	90.0 DEG-F.
			RANGE:	MED
RATED CAPACITIES:	@ 47 DEG-F:	24000.0 BTU/H;	@ 95 DEG-F:	24000.0 BTU/H.
	@ 17 DEG-F:	14400.0 BTU/H.		
RATED POWERS FOR :	@ 47 DEG-F:	2604.4 WATTS;	@ 95 DEG-F:	3076.9 WATTS.
	@ 17 DEG-F:	2109.6 WATTS.		
RATED EFFICIENCIES :	@ 47 DEG-F:	2.70 (COP);	@ 95 DEG-F:	7.80 BTU/WH.
	@ 17 DEG-F:	2.00 (COP).		
MISC. EQUIPMENT DATA:	TIME CONST. (TAU)	1.20 MINUTES.		
SCALE FACTORS:	INDOOR FAN PWR:	307.7 WATTS.	OUTDOOR FAN PWR:	246.2 WATTS.
	COOLING CAPACITY	0.7059		
	COOLING POWER	0.6344		
DESIGN LOAD RESULTS:	QH9560:	35702.5 BTU/H.	QCSDL:	15521.5 BTU/H.
	QHDL:	47603.3 BTU/H;		
	BUILDING VOLUME:	12000. CUBIC FEET		
	FLOOR AREA:	1500. SQUARE FEET		
DOE AVERAGE HEATING LOADS @ TODH:	I-IV & VI:	34650.0 BTU/H;		
	V:	29568.0 BTU/H.		
DOE AVG HEATING OUTPUT:	I-IV & VI:	87824.7 KBTU/Y;		
	V:	74943.8 KBTU/Y.		

EER @ 82 DEG-F (EERB) = 9.52 SEER = 8.33

Figure 4-1 (Cont'd). SPM Sample Output (Page 2 of 21)

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

--- EQUIPMENT DATA ---

I	TODB	RHO	TIDB	TIWB	RHI	--CAPACITY (BTU/H)--			SENS. RATIO	HETOT (WATTS)	FREQ. (CYC/H)	ON-TIME/CYC.		PCT.-ON-TIME		COOLING HRS	COMP HRS	BNACH (ACH/H)
						LATENT	SENS	TOTAL				IDEAL	ACT	IDEAL	ACT			
1	67.	25.	75.	56.6	30.2	1.	23126.	23126.	100.0	2185.	2.169	6.21	6.55	19.4	23.7	30.00	7.10	0.404
2	67.	40.	75.	59.0	37.9	1466.	21330.	22796.	93.6	2223.	2.073	6.11	6.43	18.1	22.2	109.04	24.21	0.404
3	67.	60.	75.	61.6	46.6	4535.	18961.	23496.	80.7	2264.	1.904	5.96	6.23	16.1	19.8	59.35	11.74	0.404
7	72.	25.	75.	58.0	34.5	95.	22238.	22333.	99.6	2286.	2.776	7.23	7.85	30.8	36.3	25.10	9.12	0.364
8	72.	40.	75.	59.8	39.4	1944.	20808.	22752.	91.5	2310.	2.746	7.14	7.74	30.0	35.4	144.03	51.05	0.364
9	72.	60.	75.	61.6	46.7	4477.	18367.	23344.	80.8	2343.	2.698	7.02	7.59	28.8	34.1	92.37	31.52	0.364
13	77.	25.	75.	58.4	35.9	522.	21746.	22267.	97.7	2372.	2.995	8.63	9.62	42.0	48.0	26.60	12.78	0.356
14	77.	40.	75.	59.8	40.5	2242.	20429.	22671.	90.1	2394.	2.994	8.59	9.58	41.8	47.8	147.57	70.54	0.356
15	77.	60.	75.	61.7	47.1	4548.	18675.	23223.	80.4	2425.	2.992	8.54	9.51	41.4	47.4	78.15	37.06	0.356
19	82.	25.	75.	58.7	36.8	787.	21383.	22169.	96.5	2455.	2.891	10.81	12.35	53.8	59.5	18.20	10.83	0.396
20	82.	40.	75.	60.1	41.7	2585.	20020.	22606.	88.6	2479.	2.875	10.98	12.57	54.5	60.2	123.62	74.44	0.396
21	82.	60.	75.	62.1	48.3	4932.	10248.	23180.	78.7	2510.	2.851	11.22	12.87	55.4	61.1	59.11	36.14	0.396
25	87.	25.	75.	59.1	38.1	1064.	20919.	21983.	95.2	2560.	2.446	14.99	17.53	66.6	71.5	8.40	6.00	0.436
26	87.	40.	75.	60.6	43.3	2965.	19498.	22463.	86.8	2585.	2.355	15.89	18.64	68.5	73.2	51.64	37.79	0.436
27	87.	60.	75.	62.6	50.2	5385.	17689.	23074.	76.7	2616.	2.215	17.37	20.47	71.2	75.6	42.00	31.74	0.436
28	87.	75.	75.	64.1	55.4	7108.	16415.	23523.	69.8	2640.	2.101	18.69	22.09	73.2	77.4	13.56	10.49	0.436
31	92.	25.	75.	59.6	40.0	1320.	20302.	21622.	93.9	2671.	1.594	26.51	31.71	81.1	84.2	4.00	3.37	0.476
32	92.	40.	75.	61.3	45.5	3334.	18818.	22152.	84.9	2697.	1.342	32.42	38.96	84.6	87.2	31.37	27.34	0.476
33	92.	60.	75.	63.3	52.7	5839.	16977.	22816.	74.4	2729.	0.959	47.20	57.06	89.4	91.2	12.22	11.15	0.476
37	97.	25.	75.	60.3	42.1	1605.	19573.	21178.	92.4	2747.	0.232	208.18	254.00	97.6	98.0	1.30	1.27	0.516
38	97.	40.	75.	62.0	47.9	3732.	18028.	21760.	82.9	2777.	0.000	600.00	600.00	103.0	100.0	5.40	5.40	0.516
39	97.	60.	75.	64.1	55.5	6317.	16166.	22483.	71.9	2816.	0.000	600.00	600.00	110.6	100.0	1.40	1.40	0.516
44	102.	40.	75.	62.7	50.4	4152.	17146.	21299.	80.5	2891.	0.000	600.00	600.00	124.5	100.0	0.20	0.20	0.556

Figure 4-1 (Cont'd). SPM Sample Output (Page 3 of 21)

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

--- LOAD DATA ---

I	TODB	RHO	QSUN	QCOND NET	SENS TOT	----- INTERNAL -----			SENS TOT + INTERNAL	Q INFILTRATION		QTOT	SENSIBLE RATIO
						SENSIBLE	LATENT	TOTAL		LATENT	TOTAL		
1	67.0	25.0	5049.	-1329.	3720.	1500.	795.	2295.	6015.	-795.	-1523.	4492.	100.0
2	67.0	40.0	4423.	-1329.	3094.	1500.	795.	2295.	5359.	-529.	-1251.	4138.	93.6
3	67.0	60.0	3589.	-1329.	2260.	1500.	795.	2295.	4555.	-67.	-778.	3777.	80.7
7	72.0	25.0	5153.	461.	5614.	1500.	795.	2295.	7909.	-766.	-1028.	6882.	99.6
8	72.0	40.0	4527.	461.	4988.	1500.	795.	2295.	7233.	-212.	-458.	6826.	91.5
9	72.0	60.0	3693.	461.	4154.	1500.	795.	2295.	6449.	493.	268.	6717.	80.8
13	77.0	25.0	5258.	2251.	7508.	1500.	795.	2295.	9833.	-576.	-439.	9364.	97.7
14	77.0	40.0	4632.	2251.	6882.	1500.	795.	2295.	9177.	143.	303.	9480.	90.1
15	77.0	60.0	3797.	2251.	6048.	1500.	795.	2295.	8333.	1090.	1282.	9625.	80.4
19	82.0	25.0	5362.	4040.	9402.	1500.	795.	2295.	11607.	-372.	221.	11918.	96.5
20	82.0	40.0	4736.	4040.	8776.	1500.	795.	2295.	11671.	614.	1242.	12314.	88.6
21	82.0	60.0	3901.	4040.	7942.	1500.	795.	2295.	10237.	1940.	2616.	12853.	78.7
25	87.0	25.0	5466.	5830.	11296.	1500.	795.	2295.	13591.	-86.	1055.	14647.	95.2
26	87.0	40.0	4840.	5830.	10670.	1500.	795.	2295.	12935.	1237.	2429.	15394.	86.8
27	87.0	60.0	4006.	5830.	9836.	1500.	795.	2295.	12131.	3039.	4301.	16432.	76.7
28	87.0	75.0	3380.	5830.	9210.	1500.	795.	2295.	11505.	4411.	5725.	17230.	69.8
31	92.0	25.0	5571.	7620.	13190.	1500.	795.	2295.	15435.	276.	2058.	17543.	93.9
32	92.0	40.0	4945.	7620.	12564.	1500.	795.	2295.	14359.	2025.	3878.	18738.	85.0
33	92.0	60.0	4110.	7620.	11730.	1500.	795.	2295.	14025.	4425.	6376.	20401.	74.4
37	97.0	25.0	5675.	9409.	15084.	1500.	795.	2295.	17379.	772.	3290.	20669.	92.4
38	97.0	40.0	5049.	9409.	14458.	1500.	795.	2295.	16753.	3051.	5667.	22421.	82.8
39	97.0	60.0	4214.	9409.	13624.	1500.	795.	2295.	15919.	6190.	8942.	24860.	71.9
44	102.0	40.0	5153.	11199.	16352.	1500.	795.	2295.	18647.	4374.	7860.	26507.	80.5

COOLING DESIGN LOAD COMPONENTS:

SUN: 4909. WINDOW CONDUCTION: 957. WALL CONDUCTION: 4010. CEILING CONDUCTION: 1937.

SENSIBLE INFILTRATION: 1620. TOTAL SENSIBLE: 15522.

Figure 4-1 (Cont'd). SPM Sample Output (Page 4 of 21)

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

--- EQUIPMENT DATA ---

I	TODB	RHO	TIDB	TIWB	RHI	--CAPACITY (BTU/H)--			SENS. RATIO	HETOT (WATTS)	FREQ. (CYC/H)	ON-TIME/CYC.		PCT.-ON-TIME		COOLING HRS	COMP HRS	BNACH (ACH/H)
						LATENT	SENS	TOTAL				IDEAL	ACT	IDEAL	ACT			
8	72.	40.	75.	60.8	43.8	3485.	19627.	23112.	84.9	2330.	1.163	5.47	5.61	8.6	10.9	1.57	0.17	0.364
9	72.	60.	75.	64.6	57.4	7968.	16211.	24179.	67.0	2391.	1.017	5.40	5.52	7.4	9.3	109.23	10.21	0.364
10	72.	75.	75.	67.7	69.2	11437.	13607.	25043.	54.3	2441.	0.859	5.33	5.42	6.1	7.8	104.70	8.12	0.364
11	72.	84.	75.	69.8	77.7	13640.	11988.	25628.	46.8	2474.	0.714	5.26	5.34	5.0	6.4	94.50	6.00	0.364
12	72.	92.	75.	72.1	87.0	15145.	11100.	26245.	42.3	2509.	0.522	5.18	5.24	3.6	4.6	48.60	2.21	0.364
14	77.	40.	75.	60.8	44.0	3489.	19480.	22970.	84.8	2410.	2.245	6.29	6.66	20.5	24.9	2.53	0.63	0.356
15	77.	60.	75.	63.7	54.1	6899.	16895.	23795.	71.0	2456.	2.266	6.31	6.69	20.8	25.3	98.05	24.98	0.356
16	77.	75.	75.	65.9	62.0	9352.	15057.	24409.	61.7	2490.	2.278	6.33	6.71	21.0	25.5	72.00	18.34	0.356
17	77.	84.	75.	67.1	66.9	10794.	13979.	24773.	56.4	2511.	2.284	6.34	6.72	21.1	25.6	36.40	9.31	0.356
18	77.	92.	75.	68.3	71.5	12043.	13069.	25112.	52.0	2529.	2.283	6.33	6.72	21.1	25.5	5.60	1.43	0.356
20	82.	40.	75.	61.0	44.6	3634.	19228.	22062.	84.1	2493.	2.848	7.47	8.16	33.1	38.7	0.88	0.34	0.396
21	82.	60.	75.	63.6	53.8	6735.	16894.	23630.	71.5	2534.	2.896	7.68	8.43	34.9	40.7	59.59	24.25	0.396
22	82.	75.	75.	65.5	60.6	8886.	15295.	24180.	63.3	2564.	2.927	7.85	8.65	36.3	42.2	28.70	12.11	0.396
23	82.	84.	75.	66.6	64.7	10122.	14375.	24497.	58.7	2581.	2.943	7.96	8.79	37.2	43.1	5.20	2.24	0.396
26	87.	40.	75.	61.4	45.9	3898.	18800.	22698.	82.8	2597.	2.990	9.42	10.61	46.9	52.9	0.36	0.19	0.436
27	87.	60.	75.	63.9	54.7	6883.	16581.	23464.	70.7	2636.	2.950	10.11	11.48	50.6	56.5	22.10	12.48	0.436
28	87.	75.	75.	65.6	61.1	8913.	15087.	24000.	62.9	2664.	2.899	10.73	12.25	53.4	59.2	7.54	4.46	0.436
29	87.	84.	75.	66.6	64.8	10050.	14250.	24300.	58.6	2680.	2.858	11.16	12.78	55.2	60.9	0.90	0.55	0.436
30	87.	92.	75.	67.5	68.2	11020.	13547.	24567.	55.1	2693.	2.817	11.55	13.28	56.7	62.3	0.20	0.12	0.436
32	92.	40.	75.	62.0	47.9	4187.	18190.	22376.	81.3	2708.	2.623	13.34	15.49	62.5	67.7	0.03	0.02	0.476
33	92.	60.	75.	64.4	56.6	7139.	16034.	23173.	69.2	2746.	2.363	15.81	18.54	68.4	73.0	5.93	4.37	0.476
34	92.	75.	75.	66.1	62.8	9106.	14600.	23714.	61.6	2773.	2.115	18.52	21.89	73.0	77.2	0.10	0.08	0.476

Figure 4-1 (Cont'd). SPM Sample Output (Page 5 of 21)

C8HSPM82-1, COOLING RUN 1, PAGE 6
***** DARK HOUR PER HOUR ANALYSIS RESULTS *****

. --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=171 TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

--- LOAD DATA ---

I	TODE	RHO	QSUN	QCOND NET	SENS TOT	----- INTERNAL -----			SENS TOT +INTERNAL	Q INFILTRATION		QTOT	SENSIBLE RATIO
						SENSIBLE	LATENT	TOTAL		LATENT	TOTAL		
8	72.0	40.0	1523.	-1074.	449.	1500.	795.	2295.	2744.	-494.	-748.	1996.	84.9
9	72.0	60.0	1022.	-1074.	-52.	1500.	795.	2295.	2243.	-207.	-453.	1790.	67.1
10	72.0	75.0	647.	-1074.	-427.	1500.	795.	2295.	1868.	-95.	-339.	1529.	54.2
11	72.0	84.0	421.	-1074.	-652.	1500.	795.	2295.	1643.	-116.	-362.	1281.	47.0
12	72.0	92.0	221.	-1074.	-853.	1500.	795.	2295.	1442.	-256.	-507.	935.	42.4
14	77.0	40.0	1627.	716.	2343.	1500.	795.	2295.	4638.	-80.	74.	4712.	84.8
15	77.0	60.0	1127.	716.	1843.	1500.	795.	2295.	4130.	640.	818.	4955.	71.0
16	77.0	75.0	751.	716.	1467.	1500.	795.	2295.	3762.	1167.	1363.	5125.	61.7
17	77.0	84.0	526.	716.	1242.	1500.	795.	2295.	3537.	1480.	1686.	5223.	56.4
18	77.0	92.0	325.	716.	1041.	1500.	795.	2295.	3336.	1740.	1955.	5291.	52.1
20	82.0	40.0	1732.	2506.	4237.	1500.	795.	2295.	6532.	406.	1028.	7560.	84.1
21	82.0	60.0	1231.	2506.	3737.	1500.	795.	2295.	6032.	1557.	2221.	8253.	71.5
22	82.0	75.0	855.	2506.	3361.	1500.	795.	2295.	5656.	2435.	3131.	8787.	63.2
23	82.0	84.0	630.	2506.	3136.	1500.	795.	2295.	5431.	2972.	3637.	9118.	58.7
26	87.0	40.0	1836.	4295.	6131.	1500.	795.	2295.	8426.	1033.	2219.	10645.	82.8
27	87.0	60.0	1335.	4295.	5631.	1500.	795.	2295.	7926.	2685.	3936.	11861.	70.7
28	87.0	75.0	960.	4295.	5255.	1500.	795.	2295.	7550.	3962.	5262.	12812.	62.9
29	87.0	84.0	734.	4295.	5030.	1500.	795.	2295.	7325.	4752.	6082.	13407.	58.6
30	87.0	92.0	534.	4295.	4829.	1500.	795.	2295.	7124.	5454.	6812.	13936.	55.2
32	92.0	40.0	1940.	6085.	8025.	1500.	795.	2295.	10320.	1822.	3669.	13990.	81.3
33	92.0	60.0	1440.	6085.	7525.	1500.	795.	2295.	9820.	4035.	6026.	15845.	69.2
34	92.0	75.0	1064.	6085.	7149.	1500.	795.	2295.	9444.	5853.	7866.	17310.	61.6

Figure 4-1 (Cont'd). SPM Sample Output (Page 6 of 21)

***** SOLAR HOUR AGGREGATED RESULTS *****

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

	TODB	RH	CHRS	KBTU-COOL	KWH-TOT	EER	SENS-RAT	RHI	HR(RH>65)	CPHRS	FCY	PW	DF(%)
1	67.0	25.0	30.09	135.	16.	8.68	100.0	30.2	0.00	7.10	2.17	6.55	23.7
2	67.0	40.0	109.04	451.	54.	8.38	93.6	37.9	0.00	24.21	2.07	6.43	22.2
3	67.0	60.0	59.35	224.	27.	8.43	80.7	46.6	0.00	11.74	1.90	6.23	19.8
7	72.0	25.0	25.10	173.	21.	8.29	99.6	34.5	0.00	9.12	2.78	7.85	36.3
8	72.0	40.0	144.03	983.	118.	8.34	91.5	39.4	0.00	51.05	2.75	7.74	35.4
9	72.0	60.0	92.37	620.	74.	8.40	80.8	46.7	0.00	31.52	2.70	7.59	34.1
13	77.0	25.0	26.60	249.	30.	8.22	97.7	35.9	0.00	12.78	3.00	9.62	48.0
14	77.0	40.0	147.57	1399.	169.	8.28	90.1	40.5	0.00	70.54	2.99	9.58	47.8
15	77.0	60.0	78.15	752.	90.	8.37	80.4	47.1	0.00	37.06	2.99	9.51	47.4
19	82.0	25.0	18.20	217.	27.	8.15	96.5	36.8	0.00	10.83	2.89	12.35	59.5
20	82.0	40.0	123.62	1522.	185.	8.25	88.6	41.7	0.00	74.44	2.87	12.57	60.2
21	82.0	60.0	59.11	760.	91.	8.38	78.7	48.3	0.00	36.14	2.85	12.87	61.1
25	87.0	25.0	8.40	123.	15.	8.01	95.2	38.1	0.00	6.00	2.45	17.53	71.5
26	87.0	40.0	51.64	795.	98.	8.14	86.8	43.3	0.00	37.79	2.36	18.64	73.2
27	87.0	60.0	42.00	690.	83.	8.31	76.7	50.2	0.00	31.74	2.22	20.47	75.6
28	87.0	75.0	13.56	234.	28.	8.44	69.8	55.4	0.00	10.49	2.10	22.09	77.4
31	92.0	25.0	4.00	70.	9.	7.80	93.9	40.0	0.00	3.37	1.59	31.71	84.2
32	92.0	40.0	31.37	588.	74.	7.97	84.9	45.5	0.00	27.34	1.34	38.96	87.2
33	92.0	60.0	12.22	249.	30.	8.19	74.4	52.7	0.00	11.15	0.96	57.06	91.2
37	97.0	25.0	1.30	27.	4.	7.68	92.4	42.1	0.00	1.27	0.23	254.00	98.0
38	97.0	40.0	5.40	121.	15.	8.07	82.9	47.9	0.00	5.40	0.00	600.00	100.0
39	97.0	60.0	1.40	35.	4.	8.83	71.9	55.5	0.00	1.40	0.00	600.00	100.0
44	102.0	40.0	0.20	5.	1.	9.17	80.5	50.4	0.00	0.20	0.00	600.00	100.0

TOTALS 1084.63 10422. 1259. 0.00 512.70

AVERAGES	45.5 (45.2)		8.28	86.1	43.3 (42.4)		2.56	11.08	47.3
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(RH AVERAGES WITH BRACKETS ARE LOAD HOUR WEIGHTED, THOSE WITHOUT ARE COMPRESSOR HOUR WEIGHTED.)

NUMBER OF COMPRESSOR CYCLES = 1296. MAXIMUM INDOOR RH IS 55.5 %, AND OCCURS IN BIN 39.

EER @ B2 DEG-F (EERB) = 9.52 SEER = 8.33

Figure 4-1 (Cont'd). SPM Sample Output (Page 7 of 21)

***** DARK HOUR AGGREGATED RESULTS *****

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT= ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

	TODB	RH	CHRS	KBTU-COOL	KWH-TOT	EER	SENS-RAT	RUH	HR(RH>65)	CPHRS	FCY	PW	DF(%)
1	72.0	40.0	1.57	3.	0.	7.88	84.9	43.8	0.00	0.17	1.16	5.61	10.9
8	72.0	60.0	109.23	195.	24.	8.00	67.0	57.4	0.00	10.21	1.02	5.52	9.3
9	72.0	75.0	104.70	160.	20.	8.09	54.3	69.2	104.70	8.12	0.86	5.43	7.8
10	72.0	84.0	94.50	121.	15.	8.13	46.8	77.7	94.50	6.00	0.71	5.34	6.4
11	72.0	92.0	48.60	45.	6.	8.18	42.3	87.0	48.60	2.21	0.52	5.24	4.6
12	77.0	40.0	2.53	12.	2.	7.84	84.8	44.0	0.00	0.63	2.24	6.66	24.9
13	77.0	60.0	98.85	490.	61.	7.98	71.0	54.1	0.00	24.98	2.27	6.69	25.3
14	77.0	75.0	72.00	369.	46.	8.08	61.7	62.0	0.00	18.34	2.28	6.71	25.5
15	77.0	84.0	36.40	190.	23.	8.13	56.4	66.9	36.40	9.31	2.28	6.72	25.6
16	77.0	92.0	5.60	30.	4.	8.18	52.0	71.5	5.60	1.43	2.28	6.72	25.5
17	82.0	40.0	0.88	7.	1.	7.83	84.1	44.6	0.00	0.34	2.85	8.16	38.7
18	82.0	60.0	59.59	492.	61.	8.00	71.5	53.8	0.00	24.25	2.90	8.43	40.7
19	82.0	75.0	28.70	252.	31.	8.13	63.3	60.6	0.00	12.11	2.93	8.65	42.2
20	82.0	84.0	5.20	47.	6.	8.20	58.7	64.7	0.00	2.24	2.94	8.79	43.1
21	87.0	40.0	0.36	4.	0.	7.75	82.8	45.9	0.00	0.19	2.99	10.61	52.9
22	87.0	60.0	22.10	262.	33.	7.97	70.7	54.7	0.00	12.48	2.95	11.48	56.5
23	87.0	75.0	7.54	97.	12.	8.13	62.9	61.1	0.00	4.46	2.90	12.25	59.2
24	87.0	84.0	0.90	12.	1.	8.22	58.6	64.8	0.00	0.55	2.86	12.78	60.9
25	87.0	92.0	0.20	3.	0.	8.30	55.1	68.2	0.20	0.12	2.82	13.28	62.3
26	92.0	40.0	0.03	0.	0.	0.00	81.3	47.9	0.00	0.02	2.62	15.49	67.7
27	92.0	60.0	5.98	95.	12.	7.90	69.2	56.6	0.00	4.37	2.36	18.54	73.0
28	92.0	75.0	0.10	2.	0.	8.09	61.6	62.8	0.00	0.08	2.12	21.89	77.2
29													
30													
31													
32													
33													
34													
TOTALS			705.56	2887.	359.				290.00	142.61			
AVERAGES	68.2					8.04	64.9	59.7			1.65	7.34	20.2
	(71.5)							(64.3)					

(RH AVERAGES WITH BRACKETS ARE LOAD HOUR WEIGHTED, THOSE WITHOUT ARE COMPRESSOR HOUR WEIGHTED.)

NUMBER OF COMPRESSOR CYCLES = 323. MAXIMUM INDOOR RH IS 87.0 %, AND OCCURS IN BIN 12.

EER @ 82 DEG-F (EERB) = 9.52 SEER = 8.33

Figure 4-1 (Cont'd). SPM Sample Output (Page 8 of 21)

1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=17T TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

	TODB	RH	CHRS	KBTU-COOL	KWH-TOT	EER	SENS-RAT	RHI	HR(RH>65)	CPHRS	FCY	PW	DF(%)
1	67.0	25.0	30.00	135.	16.	8.68	100.0	30.2	0.00	7.10	2.17	6.55	23.7
2	67.0	40.0	109.04	451.	54.	8.38	93.6	37.9	0.00	24.21	2.07	6.43	22.2
3	67.0	60.0	59.35	224.	27.	8.43	80.7	46.6	0.00	11.74	1.90	6.23	19.8
7	72.0	25.0	25.10	173.	21.	8.29	99.6	34.5	0.00	9.12	2.78	7.85	36.3
8	72.0	40.0	145.60	986.	118.	8.33	91.4	39.5	0.00	51.22	2.73	7.74	35.2
9	72.0	60.0	201.60	816.	98.	8.30	77.5	49.3	0.00	41.73	1.79	6.95	20.7
10	72.0	75.0	104.70	160.	20.	8.09	54.3	69.2	104.70	8.12	0.86	5.42	7.8
11	72.0	81.0	94.50	121.	15.	8.13	46.8	77.7	94.50	6.00	0.71	5.34	6.4
12	72.0	92.0	48.60	45.	6.	8.18	42.3	87.0	48.60	2.21	0.52	5.24	4.6
13	77.0	25.0	26.60	249.	30.	8.22	97.7	35.9	0.00	12.78	3.00	9.62	48.0
14	77.0	40.0	150.10	1411.	170.	8.28	90.1	40.5	0.00	71.17	2.98	9.54	47.4
15	77.0	60.0	177.00	1242.	151.	8.21	76.7	49.9	0.00	62.04	2.59	8.13	35.1
16	77.0	75.0	72.00	369.	46.	8.08	61.7	62.0	0.00	18.34	2.28	6.71	25.5
17	77.0	84.0	36.40	190.	23.	8.13	56.4	66.9	36.40	9.31	2.28	6.72	25.6
18	77.0	92.0	5.60	30.	4.	8.18	52.0	71.5	5.60	1.43	2.28	6.72	25.5
19	82.0	25.0	18.20	217.	27.	8.15	96.5	36.8	0.00	10.83	2.89	12.35	59.5
20	82.0	40.0	124.50	1529.	185.	8.25	88.5	41.7	0.00	74.78	2.87	12.54	60.1
21	82.0	60.0	110.70	1252.	152.	8.23	75.9	50.5	0.00	60.39	2.87	10.62	50.9
22	82.0	75.0	28.70	252.	31.	8.13	63.3	60.6	0.00	12.11	2.93	8.65	42.2
23	82.0	84.0	5.20	47.	6.	8.20	58.7	64.7	0.00	2.24	2.94	8.79	43.1
25	87.0	25.0	8.40	123.	15.	8.01	95.2	38.1	0.00	6.00	2.45	17.53	71.5
26	87.0	40.0	52.00	799.	98.	8.14	86.8	43.3	0.00	37.98	2.36	18.57	73.0
27	87.0	60.0	64.10	952.	116.	8.21	75.0	51.4	0.00	44.22	2.47	16.77	69.0
28	87.0	75.0	21.10	330.	40.	8.34	67.8	57.1	0.00	14.95	2.39	17.82	70.9
29	87.0	84.0	0.90	12.	1.	8.22	58.6	64.8	0.00	0.55	2.86	12.78	60.9
30	87.0	92.0	0.20	3.	0.	8.30	55.1	68.2	0.20	0.12	2.82	13.28	62.3
31	92.0	25.0	4.00	70.	9.	7.80	93.9	40.0	0.00	3.37	1.59	31.71	84.2
32	92.0	40.0	31.40	588.	74.	7.97	84.9	45.5	0.00	27.36	1.34	38.92	87.1
33	92.0	60.0	18.20	344.	42.	8.11	73.0	53.8	0.00	15.52	1.42	36.01	85.3
34	92.0	75.0	0.10	2.	0.	8.09	61.6	62.8	0.00	0.08	2.12	21.89	77.2
37	97.0	25.0	1.30	27.	4.	7.68	92.4	42.1	0.00	1.27	0.23	254.00	98.0
38	97.0	40.0	5.40	121.	15.	8.07	82.9	47.9	0.00	5.40	0.00	600.00	100.0
39	97.0	60.0	1.40	35.	4.	8.83	71.9	55.5	0.00	1.40	0.00	600.00	100.0
44	102.0	40.0	0.20	5.	1.	9.17	80.5	50.4	0.00	0.20	0.00	600.00	100.0
TOTALS			1790.19	13309.	1618.				290.00	655.31			
AVERAGES	50.5 (55.6)					8.22	81.5	46.9 (51.0)			2.20	9.98	36.6

(RH AVERAGES WITH BRACKETS ARE LOAD HOUR WEIGHTED, THOSE WITHOUT ARE COMPRESSOR HOUR WEIGHTED.)

NUMBER OF COMPRESSOR CYCLES = 1620. MAXIMUM INDOOR RH IS 87.0 %, AND OCCURS IN BIN 12. ACTUAL SEER = 8.224

EER @ 82 DEG-F (EERB) = 9.52 SEER = 8.33

Figure 4-1 (Cont'd). SPM Sample Output (Page 9 of 21)

***** HEAT PUMP PERFORMANCE DATA AS MODELED *****

DEFROST DESCRIPTION: --- DEMAND, TEMPERATURE SENSORS

I	TODB	RHO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			*	DEFROST TIMES (MINUTES)	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP		D-D	DUR
5	52.0	ALL	25600.	2687.	2.79	1.000	1.000	1.000	25600.	2687.	2.79	-	-	
6	47.0	ALL	24000.	2604.	2.70	1.000	1.000	1.000	24000.	2604.	2.70	-	-	
7	42.0	20.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
8	42.0	40.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
9	42.0	60.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
10	42.0	75.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
11	42.0	85.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
12	42.0	95.0	22400.	2522.	2.60	1.000	1.000	1.000	22400.	2522.	2.60	-	-	
13	37.0	20.0	20800.	2439.	2.50	1.000	1.000	1.000	20800.	2439.	2.50	-	-	
14	37.0	40.0	20800.	2439.	2.50	1.000	1.000	1.000	20800.	2439.	2.50	-	-	
15	37.0	60.0	20800.	2439.	2.50	1.000	1.000	1.000	20800.	2439.	2.50	-	-	
16	37.0	75.0	18881.	2353.	2.35	0.908	0.965	0.941	20800.	2439.	2.50	288.72	4.62	
17	37.0	85.0	18467.	2352.	2.30	0.888	0.964	0.921	20800.	2439.	2.50	126.72	4.62	
18	37.0	95.0	18020.	2342.	2.25	0.867	0.960	0.903	20800.	2439.	2.50	92.74	4.84	
19	32.0	20.0	19200.	2357.	2.39	1.000	1.000	1.000	19200.	2357.	2.39	-	-	
20	32.0	40.0	19200.	2357.	2.39	1.000	1.000	1.000	19200.	2357.	2.39	-	-	
21	32.0	60.0	19200.	2357.	2.39	1.000	1.000	1.000	19200.	2357.	2.39	-	-	
22	32.0	75.0	17465.	2276.	2.25	0.910	0.966	0.942	19200.	2357.	2.39	329.25	4.65	
23	32.0	85.0	17134.	2277.	2.20	0.892	0.966	0.924	19200.	2357.	2.39	145.71	4.71	
24	32.0	95.0	16818.	2272.	2.17	0.876	0.964	0.909	19200.	2357.	2.39	105.26	4.76	
25	27.0	20.0	17600.	2275.	2.27	1.000	1.000	1.000	17600.	2275.	2.27	-	-	
26	27.0	40.0	17600.	2275.	2.27	1.000	1.000	1.000	17600.	2275.	2.27	-	-	
27	27.0	60.0	17600.	2275.	2.27	1.000	1.000	1.000	17600.	2275.	2.27	-	-	
28	27.0	75.0	16000.	2197.	2.14	0.914	0.966	0.946	17600.	2275.	2.27	472.32	4.62	
29	27.0	85.0	15855.	2203.	2.11	0.901	0.968	0.930	17600.	2275.	2.27	178.11	4.71	
30	27.0	95.0	15620.	2201.	2.08	0.887	0.968	0.917	17600.	2275.	2.27	124.97	4.67	
31	22.0	20.0	16000.	2192.	2.14	1.000	1.000	1.000	16000.	2192.	2.14	-	-	
32	22.0	40.0	16000.	2192.	2.14	1.000	1.000	1.000	16000.	2192.	2.14	-	-	
33	22.0	60.0	16000.	2192.	2.14	1.000	1.000	1.000	16000.	2192.	2.14	-	-	
34	22.0	75.0	14712.	2119.	2.03	0.919	0.967	0.951	16000.	2192.	2.14	720.21	4.11	
35	22.0	85.0	14545.	2127.	2.00	0.909	0.970	0.937	16000.	2192.	2.14	219.42	4.62	
36	22.0	95.0	14355.	2127.	1.98	0.897	0.970	0.925	16000.	2192.	2.14	150.14	4.64	
37	17.0	20.0	14400.	2110.	2.00	1.000	1.000	1.000	14400.	2110.	2.00	-	-	
38	17.0	40.0	14400.	2110.	2.00	1.000	1.000	1.000	14400.	2110.	2.00	-	-	
39	17.0	60.0	14400.	2110.	2.00	1.000	1.000	1.000	14400.	2110.	2.00	-	-	
40	17.0	75.0	13603.	2063.	1.93	0.945	0.970	0.966	14400.	2110.	2.00	720.43	2.53	
41	17.0	85.0	13134.	2051.	1.88	0.912	0.972	0.938	14400.	2110.	2.00	276.14	4.64	
42	17.0	95.0	13002.	2052.	1.86	0.903	0.973	0.928	14400.	2110.	2.00	182.53	4.63	
43	12.0	ALL	12300.	2027.	1.85	1.000	1.000	1.000	12800.	2027.	1.85	-	-	
44	7.0	ALL	11200.	1945.	1.69	1.000	1.000	1.000	11200.	1945.	1.69	-	-	
45	2.0	ALL	9600.	1862.	1.51	1.000	1.000	1.000	9600.	1862.	1.51	-	-	
46	-3.0	ALL	8000.	1780.	1.32	1.000	1.000	1.000	8000.	1780.	1.32	-	-	
47	-8.0	ALL	6400.	1697.	1.10	1.000	1.000	1.000	6400.	1697.	1.10	-	-	

MINN CPHS WEIGHTED AVERAGE VALUES: 0.955 0.985 0.969 DOE DEGRADATION COEFFICIENT (CD) AT 47F= .223

ALL DATA ARE FOR TIDB = 70.0 DEG-F.

RATED CAPACITIES:	@ 47 DEG-F:	24000.0 BTU/H;	@ 95 DEG-F:	24000.0 BTU/H.
	@ 17 DEG-F:	14400.0 BTU/H.		
RATED POWERS FOR :	@ 47 DEG-F:	2604.4 WATTS;	@ 95 DEG-F:	3076.9 WATTS.
	@ 17 DEG-F:	2109.6 WATTS.		
RATED EFFICIENCIES :	@ 47 DEG-F:	2.70 (COP);	@ 95 DEG-F:	7.80 BTU/WH.
	@ 17 DEG-F:	2.00 (COP).		
			SENS COOLING RATIO	73.8 %
MISC. EQUIPMENT DATA:	TIME CONST. (TAU)	1.20 MINUTES.		
	INDOOR FAN PWR:	307.7 WATTS.	OUTDOOR FAN PWR:	246.2 WATTS.
SCALE FACTORS:	COOLING CAPACITY	0.7059		
	COOLING POWER	0.6344		

Figure 4-1 (Cont'd). SPM Sample Output (Page 11 of 21)

SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT

(ANNUAL MINUS JUN-AUG)

I	TODB	RHO	HEATING-HRS BIN	ACG	NACH	QINF -----	QTRAN (BTU/HOUR)	QII -----	QTOTAL -----	TOTAL/BIN (KBTU)
3	62.0	ALL	373.	373.	0.431	745.	1214.	-5250.	-3291.	0.
4	57.0	ALL	451.	451.	0.460	1291.	3237.	-5250.	-722.	0.
5	52.0	ALL	478.	478.	0.489	1980.	5260.	-5250.	1910.	913.
6	47.0	ALL	468.	468.	0.517	2571.	7283.	-5250.	4604.	2155.
7	42.0	20.0	3.		0.546	3304.	9306.	-5250.	7361.	22.
8	42.0	40.0	61.		0.546	3304.	9306.	-5250.	7361.	449.
9	42.0	60.0	171.		0.546	3304.	9306.	-5250.	7361.	1259.
10	42.0	75.0	102.		0.546	3304.	9306.	-5250.	7361.	751.
11	42.0	85.0	89.		0.546	3304.	9306.	-5250.	7361.	656.
12	42.0	95.0	75.		0.546	3304.	9306.	-5250.	7361.	551.
				501.						
13	37.0	20.0	0.		0.575	4100.	11330.	-5250.	10180.	2.
14	37.0	40.0	37.		0.575	4100.	11330.	-5250.	10180.	377.
15	37.0	60.0	167.		0.575	4100.	11330.	-5250.	10180.	1698.
16	37.0	75.0	137.		0.575	4100.	11330.	-5250.	10180.	1395.
17	37.0	85.0	126.		0.575	4100.	11330.	-5250.	10180.	1283.
18	37.0	95.0	93.		0.575	4100.	11330.	-5250.	10180.	947.
				560.						
19	32.0	20.0	0.		0.604	4958.	13353.	-5250.	13061.	0.
20	32.0	40.0	20.		0.604	4958.	13353.	-5250.	13061.	261.
21	32.0	60.0	152.		0.604	4958.	13353.	-5250.	13061.	1985.
22	32.0	75.0	150.		0.604	4958.	13353.	-5250.	13061.	1959.
23	32.0	85.0	159.		0.604	4958.	13353.	-5250.	13061.	2077.
24	32.0	95.0	151.		0.604	4958.	13353.	-5250.	13061.	1972.
				632.						
25	27.0	20.0	0.		0.633	5879.	15376.	-5250.	16004.	0.
26	27.0	40.0	15.		0.633	5879.	15376.	-5250.	16004.	240.
27	27.0	60.0	135.		0.633	5879.	15376.	-5250.	16004.	2161.
28	27.0	75.0	158.		0.633	5879.	15376.	-5250.	16004.	2529.
29	27.0	85.0	180.		0.633	5879.	15376.	-5250.	16004.	2881.
30	27.0	95.0	122.		0.633	5879.	15376.	-5250.	16004.	1953.
				610.						
31	22.0	20.0	0.		0.662	6861.	17399.	-5250.	19010.	0.
32	22.0	40.0	13.		0.662	6861.	17399.	-5250.	19010.	247.
33	22.0	60.0	109.		0.662	6861.	17399.	-5250.	19010.	2072.
34	22.0	75.0	133.		0.662	6861.	17399.	-5250.	19010.	2528.
35	22.0	85.0	176.		0.662	6861.	17399.	-5250.	19010.	3346.
36	22.0	95.0	85.		0.662	6861.	17399.	-5250.	19010.	1616.
				516.						
37	17.0	20.0	0.		0.691	7906.	19422.	-5250.	22078.	0.
38	17.0	40.0	14.		0.691	7906.	19422.	-5250.	22078.	309.
39	17.0	60.0	108.		0.691	7906.	19422.	-5250.	22078.	2384.
40	17.0	75.0	119.		0.691	7906.	19422.	-5250.	22078.	2627.
41	17.0	85.0	109.		0.691	7906.	19422.	-5250.	22078.	2407.
42	17.0	95.0	34.		0.691	7906.	19422.	-5250.	22078.	751.
				384.						
43	12.0	ALL	311.	311.	0.719	9014.	21445.	-5250.	25209.	7840.
44	7.0	ALL	246.	246.	0.748	10183.	23468.	-5250.	28402.	6987.
45	2.0	ALL	186.	186.	0.777	11415.	25492.	-5250.	31657.	5888.
46	-3.0	ALL	119.	119.	0.806	12710.	27515.	-5250.	34975.	4162.
47	-8.0	ALL	62.	62.	0.835	14067.	29538.	-5250.	38354.	2378.
TOTALS:			5073.	5073.						76015.

QIIPSF: 3.50

ZLTEMP: 55.63

COOLING DESIGN LOAD COMPONENTS:

SUN: 4909. WINDOW CONDUCTION: 957. WALL CONDUCTION: 4010. CEILING CONDUCTION: 1937.

SENSIBLE INFILTRATION: 1620. TOTAL SENSIBLE: 15522.

HEATING DESIGN LOAD COMPONENTS:

COOLING REFERENCE FOR 95 DEG-F COOLING DESIGN TEMP: 17851.

HEATING REFERENCE FOR 95 DEG-F COOLING DESIGN TEMP
& 60 DEG-F HEATING DESIGN DELTA TEMP: 35702.

HEATING TOTAL FOR ACTUAL CONDITIONS: 47603.

Figure 4-1 (Cont'd). SPM Sample Output (Page 13 of 21)

***** SEASONAL PERFORMANCE DATA *****

DEFROST DESCRIPTION: --- DEMAND, TEMPERATURE SENSORS
 SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

I	TODB	RHO	HRS	CPHRS	HT-LOAD	HP-CAP	SH-CAP	HP-KBTU	SH-KBTU	HP-KWH	TOT-KWH	COP	IPCT-ON	APCT-ON	FCY	PW-I	PW-ACT
5	52.0	ALL	478.0	45.1	1910.	25600.	0.	913.	0.	121.	121.	2.21	7.5	9.4	1.025	5.40	5.52
6	47.0	ALL	460.0	109.5	4604.	24000.	0.	2155.	0.	285.	285.	2.21	19.2	23.4	2.151	6.19	6.53
7	42.0	20.0	3.0	1.2	7361.	22400.	0.	22.	0.	3.	3.	2.22	32.9	38.5	2.842	7.45	8.13
8	42.0	40.0	61.0	23.5	7361.	22400.	0.	449.	0.	59.	59.	2.22	32.9	38.5	2.842	7.45	8.13
9	42.0	60.0	171.0	65.9	7361.	22400.	0.	1259.	0.	166.	166.	2.22	32.9	38.5	2.842	7.45	8.13
10	42.0	75.0	102.0	39.3	7361.	22400.	0.	751.	0.	99.	99.	2.22	32.9	38.5	2.842	7.45	8.13
11	42.0	85.0	89.1	34.3	7361.	22400.	0.	656.	0.	87.	87.	2.22	32.9	38.5	2.842	7.45	8.13
12	42.0	95.0	74.8	28.8	7361.	22400.	0.	551.	0.	73.	73.	2.22	32.9	38.5	2.842	7.45	8.13
13	37.0	20.0	0.2	0.1	10180.	20800.	0.	2.	0.	0.	0.	2.23	48.9	54.9	2.971	9.79	11.10
14	37.0	40.0	37.0	20.3	10180.	20800.	0.	377.	0.	50.	50.	2.23	48.9	54.9	2.971	9.79	11.10
15	37.0	60.0	166.8	91.6	10180.	20800.	0.	1690.	0.	224.	224.	2.23	48.9	54.9	2.971	9.79	11.10
16	37.0	75.0	137.0	80.6	10180.	18881.	16187.	1373.	21.	190.	196.	2.12	51.4	58.9	2.808	10.68	12.23
17	37.0	85.0	126.0	74.2	10180.	18467.	16187.	1237.	45.	175.	180.	2.08	51.2	58.9	2.859	10.73	12.36
18	37.0	95.0	93.0	55.0	10180.	18028.	16187.	898.	49.	129.	143.	2.04	51.2	59.2	2.824	10.87	12.57
20	32.0	40.0	26.0	14.5	13061.	19200.	0.	261.	0.	34.	34.	2.23	68.0	72.7	2.380	15.64	18.33
21	32.0	60.0	152.0	110.5	13061.	19200.	0.	1985.	0.	261.	261.	2.23	68.0	72.7	2.380	15.64	18.33
22	32.0	75.0	150.0	116.5	13061.	17465.	16187.	1932.	27.	265.	273.	2.13	65.4	77.7	2.010	19.52	23.19
23	32.0	85.0	159.0	123.3	13061.	17134.	16187.	2010.	67.	281.	300.	2.10	64.9	77.5	1.921	20.27	24.22
24	32.0	95.0	151.0	117.3	13061.	16818.	16187.	1882.	90.	267.	293.	2.07	64.7	77.7	1.830	21.22	25.48
26	27.0	40.0	15.0	13.9	16004.	17600.	0.	240.	0.	32.	32.	2.23	90.9	92.5	0.831	55.15	66.79
27	27.0	60.0	135.0	124.9	16004.	17600.	0.	2161.	0.	284.	284.	2.23	90.9	92.5	0.831	55.15	66.79
28	27.0	75.0	158.0	150.0	16004.	16080.	0.	2529.	0.	347.	347.	2.13	99.5	100.0	0.000	600.00	600.00
29	27.0	85.0	180.0	180.0	16004.	15855.	150.	2854.	27.	396.	404.	2.11	100.9	100.0	0.000	600.00	600.00
30	27.0	95.0	122.0	122.0	16004.	15620.	385.	1906.	47.	269.	282.	2.08	102.5	100.0	0.000	600.00	600.00
32	22.0	40.0	13.0	13.0	19010.	16000.	3010.	208.	39.	28.	40.	2.14	118.8	100.0	0.000	600.00	600.00
33	22.0	60.0	109.0	109.0	19010.	16000.	3010.	1744.	328.	239.	335.	2.14	118.8	100.0	0.000	600.00	600.00
34	22.0	75.0	133.0	133.0	19010.	14712.	4299.	1957.	572.	282.	449.	2.03	129.2	100.0	0.000	600.00	600.00
35	22.0	85.0	176.0	176.0	19010.	14545.	4466.	2560.	786.	374.	605.	2.00	130.7	100.0	0.000	600.00	600.00
36	22.0	95.0	85.0	85.0	19010.	14355.	4655.	1220.	396.	181.	297.	1.98	132.4	100.0	0.000	600.00	600.00
38	17.0	40.0	14.0	14.0	22078.	14400.	7678.	202.	107.	30.	61.	2.00	153.3	100.0	0.000	600.00	600.00
39	17.0	60.0	108.0	108.0	22078.	14400.	7678.	1555.	829.	228.	471.	2.00	153.3	100.0	0.000	600.00	600.00
40	17.0	75.0	119.0	119.0	22078.	13603.	8475.	1619.	1009.	245.	541.	1.93	162.3	100.0	0.000	600.00	600.00
41	17.0	85.0	109.0	109.0	22078.	13134.	8944.	1432.	975.	224.	509.	1.88	168.1	100.0	0.000	600.00	600.00
42	17.0	95.0	34.0	34.0	22078.	13002.	9077.	442.	309.	70.	160.	1.86	169.8	100.0	0.000	600.00	600.00
43	12.0	ALL	311.0	311.0	25209.	12800.	12409.	3981.	3859.	630.	1761.	1.85	196.9	100.0	0.000	600.00	600.00
44	7.0	ALL	246.0	246.0	28402.	11200.	17202.	2755.	4232.	478.	1718.	1.69	253.6	100.0	0.000	600.00	600.00
45	2.0	ALL	136.0	186.0	31657.	9600.	22057.	1786.	4103.	346.	1548.	1.51	329.8	100.0	0.000	600.00	600.00
46	-3.0	ALL	119.0	119.0	34975.	8000.	26975.	952.	3210.	212.	1152.	1.32	437.2	100.0	0.000	600.00	600.00
47	-8.0	ALL	62.0	62.0	38354.	6400.	31954.	397.	1981.	105.	686.	1.10	599.3	100.0	0.000	600.00	600.00
TOTALS			5072.9	3574.5				52908.	23106.	7767.							
AVERAGES					14984.	15497.						2.00		70.5	1.175		35.97

Figure 4-1 (Cont'd). SPM Sample Output (Page 14 of 21)

C8HSPMB2-1, HEATING RUN 1, PAGE 15

***** SEASONAL PERFORMANCE DATA (CONT.) *****

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DEFROST DESCRIPTION:  --- DEMAND, TEMPERATURE SENSORS
SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT      (ANNUAL MINUS JUN-AUG)

ICYCLE =  :   IAF = 1   TIDB = 70.0   NACH (DESIGN) = 1.00   QIIPSF = 3.50   TSTAT: 1TT   SHSF = 1.00   ISPEED = 1

TOT OUT (KBTU): 76015.   TOT IN (KWH): 14538.   SYSTEM COP: 1.53   # COMP CYCLES: 5961
TBPNOB = 25.00          TBPDRY = 25.27          TBPDES = 38.04          # DEFROST CYCLES: 491( 234)
SIKW = 4.7429          DEGDYS(ABOVE): 7921.      EQFLH(ABOVE): 2535.     DOERGN: V
ZLTEMP: 55.63          DEGDYS(NOAA): 8159.        EQFLH(NOAA): 2611.     DOEHLH: 2750.
SEASONAL PERFORMANCE FACTOR = 5.229
  
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Figure 4-1 (Cont'd). SPM Sample Output (Page 15 of 21)

DEFROST DESCRIPTION: --- DEMAND, TEMPERATURE SENSORS
 SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

THE DEFROST PERFORMANCE FACTORS (COMPRESSOR HOUR WEIGHTED) ARE:

CAPACITY:	0.955	(-4.5 %)
AVERAGE POWER:	0.985	(-1.5 %)
COP:	0.969	(-3.1 %)

THE HP HEAT OUTPUT LOST TO THE DEFROST CYCLES IS: 2777. KBTU.

THE LOST OUTPUT CORRESPONDS TO THE FOLLOWING PERCENTAGES:

5.25 % OF TOTAL ACTUAL HP OUTPUT;
 3.65 % OF TOTAL ACTUAL SYSTEM OUTPUT.

FOR THIS SITE:	TODH:	-10.0 DEG-F;	TODC:	90.0 DEG-F.
			RANGE:	MED
RATED CAPACITIES:	@ 47 DEG-F:	24000.0 BTU/H;	@ 95 DEG-F:	24000.0 BTU/H.
	@ 17 DEG-F:	14400.0 BTU/H.		
RATED POWERS FOR :	@ 47 DEG-F:	2604.4 WATTS;	@ 95 DEG-F:	3076.9 WATTS.
	@ 17 DEG-F:	2109.6 WATTS.		
RATED EFFICIENCIES :	@ 47 DEG-F:	2.70 (COP);	@ 95 DEG-F:	7.80 BTU/WH.
	@ 17 DEG-F:	2.00 (COP).		
			SENS COOLING RATIO	73.8 %
MISC. EQUIPMENT DATA:	TIME CONST. (TAU)	1.20 MINUTES.		
	INDOOR FAN PWR:	307.7 WATTS.	OUTDOOR FAN PWR:	246.2 WATTS.
SCALE FACTORS:	COOLING CAPACITY	0.7059		
	COOLING POWER	0.6344		
DESIGN LOAD RESULTS:	QH9560:	35702.5 BTU/H.	QCSDL:	15521.5 BTU/H.
	QHD1:	47603.3 BTU/H;		
	BUILDING VOLUME:	12000. CUBIC FEET		
	FLOOR AREA:	1500. SQUARE FEET		
DOE AVERAGE HEATING LOADS @ TODH:	I-IV & VI:	34650.0 BTU/H;		
	V:	29568.0 BTU/H.		
DOE AVG HEATING OUTPUT:	I-IV & VI:	87824.7 KBTU/Y;		
	V:	74943.8 KBTU/Y.		

Figure 4-1 (Cont'd). SPM Sample Output (Page 16 of 21)

***** TEMPERING HEAT DETAILS *****

DEFROST DESCRIPTION: --- DEMAND, TEMPERATURE SENSORS
 SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

I	TODB	RHO	CPERS	TIM(D-D)	# DEF	TIM(DUR)	TH-ON (HRS)	TH-CAP (BTU/H)	TH-OUT (KBTU)	TH-IN (KWH)	DELTIM (MIN/CYC)
7	42.0	20.0	1.16	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
8	42.0	40.0	23.50	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
9	42.0	60.0	65.86	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
10	42.0	75.0	39.29	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
11	42.0	85.0	34.32	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
12	42.0	95.0	28.81	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
13	37.0	20.0	0.11	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
14	37.0	40.0	20.33	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
15	37.0	60.0	91.64	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
16	37.0	75.0	80.64	288.72	16.99	4.62	1.31	16187.	21.	6.	0.170
17	37.0	85.0	74.20	126.72	36.29	4.62	2.79	16187.	45.	13.	0.403
18	37.0	95.0	55.04	92.74	37.36	4.84	3.02	16187.	49.	14.	0.613
19	32.0	20.0	0.00	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
20	32.0	40.0	14.55	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
21	32.0	60.0	110.55	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
22	32.0	75.0	116.53	329.25	21.52	4.65	1.67	16187.	27.	8.	0.308
23	32.0	85.0	123.29	145.71	52.37	4.71	4.11	16187.	67.	20.	0.763
24	32.0	95.0	117.32	105.26	69.92	4.76	5.55	16187.	90.	26.	1.159
25	27.0	20.0	0.00	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
26	27.0	40.0	13.68	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
27	27.0	60.0	124.89	7.E+05	0.00	0.00	0.00	0.	0.	0.	0.000
28	27.0	75.0	158.00	472.32	0.00	4.62	0.00	0.	0.	0.	0.000

TOTALS: 234.45 299. 87.

TEMPERING HEAT CALCULATIONS ARE MADE ONLY FOR TODB > 25.0. BECAUSE BELOW THIS TEMPERATURE THE HP IS ALWAYS ON.

THE TEMPERING HEAT STRIP HEATER CAPACITY IS: 4.7429 KW, OR 16187. BTU/H.

THE TEMPERING HEAT CAPACITY IS BASED ON THE FOLLOWING RESULTS:

DESIGN LOAD @ TODH = -10.0 DEG-F IS: 47603.
 HP CAPACITY @ TODH = -10.0 DEG-F IS: 5760.

WHICH, FOR A SH SCALE FACTOR = 1.00, RESULTS IN
 A TOTAL SUPPLEMENTARY HEATER CAPACITY OF:

41843. BTU/H, OR 12.2600 KW.

THE TEMPERING HEATER (I.E. 1ST STAGE) PERCENT OF TOTAL
 FOR THE CALCULATED DESIGN BALANCE POINT
 TEMPERATURE OF 38.04 DEG-F IS:

39. % 38.6859 %

WHICH RESULTS IN THE FOLLOWING HEATER CAPACITY:

16187. BTU/H, OR 4.7429 KW.

***** LIFE CYCLE COSTS *****

DEFROST DESCRIPTION: --- DEMAND, TEMPERATURE SENSORS
 SITE: 1 --- MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT (ANNUAL MINUS JUN-AUG)

	ANNUAL ENERGY USAGE (KWH)	PERCENT OF TOTAL
COOLING	1618.4	10.02
HEATING (HEAT PUMP)	7767.4	48.08
RESISTANCE HEAT	6770.1	41.90
TOTAL	16155.9	-----

INTEREST RATE (LOAN)	10.00 %	ELECTRIC RATE	0.060 \$/KWH
DISCOUNT RATE	10.00 %	WARRANTY DURATION	1.00 YEARS
ELECTRICITY ESCALATION RATE	10.00 %	EQUIPMENT LIFE	10.00 YEARS
		SALVAGE VALUE W/O DUCTS	50.00 \$
		SALVAGE VALUE W/ DUCTS	50.00 \$

SYSTEM COST, W/O DUCTS	1891.80 \$
, W/ DUCTS	2891.80 \$
MAINTENANCE COST	56.50 \$/YEAR

	LIFE CYCLE COST	----- PERCENT OF TOTAL -----	
		W/O DUCTS	W/ DUCTS
CAPITAL (INC SLVG), W/O DUCTS	1872.52	15.79	-----
, W/ DUCTS	2872.52	-----	22.33
MAINTENANCE	295.80	2.49	2.30
ELECTRICITY	9693.57	81.72	75.37
TOTAL, W/O DUCTS	11861.90		
, W/ DUCTS	12861.90		

Figure 4-1 (Cont'd). SPM Sample Output (Page 18 of 21)

C8HSPM82-1, GENERAL RUN 1, PAGE 19

***** TOTAL COOLING HOUR AGGREGATED RESULTS *****

IAF= 1 ICYCLE= 1 NACH= 0.50 T-STAT=ITT TIDB= 75. TEMP-MIN-S= 65. TEMP-MIN-D= 65.

SITE	RHO	CHRS	KBTUH-COOL	KWH-TOT	EER	SENS-RAT	RHI	HR(RH>65)	CPHRS	FCY	PW	DF(%)

1 MINN												
TOTALS		1790.19	13309.	1618.				290.00	655.31			
AVERAGES	50.5 (55.6)				8.22	81.5	46.9 (51.0)			2.20	9.98	36.6

NUMBER OF COMPRESSOR CYCLES = 1620. ACTUAL SEER = 8.224												

NCASES = 1

AVG OF TOTALS		1790.19	13309.	1618.				290.00	655.31			
AVG OF AVGS	50.5 (55.6)				8.22	81.5	46.9 (51.0)			2.20	9.98	36.6
(RH AVERAGES WITH BRACKETS ARE LOAD HOUR WEIGHTED, THOSE WITHOUT ARE COMPRESSOR HOUR WEIGHTED.)												

EER @ 82 DEG-F (EERB) = 9.52 SEER = 8.33

Figure 4-1 (Cont'd). SPM Sample Output (Page 19 of 21)

C8HSPM82-1, GENERAL RUN 1, PAGE 20

***** SEASONAL PERFORMANCE DATA SUMMARY, HEATING *****

ICYCLE = . IAF = 1 TIDB = 70.0 NACH (DESIGN) = 1.00 QIIPSF = 3.50 TSTAT: ITT SHSF= 1.00 ISPEED = 1

SITE #	TOTOUT	TOTIN	HPIN	SYSCOP	#CPCYC	#DEFCYC	TBPNOM	TBPDY	TBPDES	S1KW	ZLTEMP	CPIRS
1	76015.	14538.	7767.	1.53	5962.	492.	25.00	25.27	38.04	4.7429	55.63	3574.
AVGS:	76015.	14538.	7767.	1.53	5962.	492.	25.00	25.27	38.04	4.7429	55.63	3574.

4-33

Figure 4-1 (Cont'd). SPM Sample Output (Page 20 of 21)

***** LIFE CYCLE COST SUMMARY *****

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*****
INTEREST RATE (LOAN)      10.00 %      ELECTRIC RATE      0.060 $/KWH
DISCOUNT RATE           10.00 %      WARRANTY DURATION  1.00 YEARS
ELECTRICITY ESCALATION RATE 10.00 %      EQUIPMENT LIFE    10.00 YEARS
                                SALVAGE VALUE W/O DUCTS  50.00 $
                                SALVAGE VALUE W/ DUCTS   50.00 $
*****

```

```

*****
RUN #   SITE #   ----- KWH -----   HP SIZE   - LIFE CYCLE COST -
              COOLING  HEATING  STRIP HEAT  TOTAL   (TONS)   W/O DUCTS  W/ DUCTS
-----
4-34  1         1         1618.    7767.    6770.    16156.    2.00    11861.90  12861.90
-----
AVERAGES:         1618.    7767.    6770.    16156.    2.00    11861.90  12861.90
*****

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Figure 4-1 (Cont'd). SPM Sample Output (Page 21 of 21)

5. SELECTED SPM APPLICATIONS AND INVESTIGATIONS

This section provides examples of possible applications and areas of investigation for which the SPM can be used. These studies are also for the purpose of supporting the theories used in developing the model, expanding the description of the input parameters and to providing insight for determining reasonable input values.

The base case input is listed in Section 3 of this report, i.e., a medium efficiency two ton heat pump for a 1500 ft² residence with construction characteristics as specified in Reference 2.

5.1 EFFECTS OF DEGRADATION ON HEAT PUMP EFFICIENCY

The purpose of this section is to provide a description of the SPM's treatment of defrost and cyclic losses and their effects on heat pump and system performance. This discussion is generally limited to heating mode operation, this will be assumed unless otherwise noted.

As discussed in Sections 2.2 and 3.0 the heating mode rating point capacity and efficiency at 47 and 17F is required as input to the program. These points are then used in the model to generate linear ideal capacity and power vs. temperature curves. In the defrost region (17 to 42F) these peak values are used as input to the defrost model (Section 2.3) which calculates the effective (integrated) capacity and input power for each bin. The resulting (integrated) COP as a function of outdoor temperature is shown in Figure 5-1 for three relative humidities using the temperature controlled demand defrost model (base case). The 20% RH curve represents peak heat pump performance (no defrost occurs). The non-linear appearance of this curve is due to the different slopes of the capacity and power curves used in calculating COP. Tempering heat is not included in the calculation. As expected, the greatest defrost losses are shown to occur in the warmer portion of the defrost region since for a given relative humidity, the specific humidity increases with increasing dry bulb temperature.

Cyclic degradation losses are modeled using the time constant method as described in Section 2.4. A base case value for the equipment time-constant τ of 1.2 minutes was selected following a survey of values used by other investigators. The results of this survey are given in Table 5-1. (The actual value that should be used for τ when modeling specific systems is dependent upon the equipment selected and the length of the installed refrigerant lines; and is best determined experimentally.) Figure 5-2 shows the effect of including cyclic degradation for a range of time-constants on heat pump COP. The effect of cyclic losses for lightly loaded equipment having a large time constant are dramatic.

The combined effects of cyclic and defrost losses are displayed in Figure 5-3. The peak heat pump COP occurs in the defrost region near the balance point (approximately 25F) during low outdoor relative humidity conditions. The limiting effect of cyclic degradation during low equipment percent on-times can be seen as COP decreases as outdoor temperature increases above the defrost region.

Figure 5-4 includes backup (resistance) heating requirements, including tempering heat, with defrost and cyclic losses for the base case. The most obvious change in system COP occurs below the heat pump balance point. Significant changes in COP also can be seen in the defrost region above the balance point. These are due to tempering heat requirements during defrost.

During cooling mode operation, cyclic losses also have an effect similar to that of heating on actual heat pump efficiency. Figure 5-5 contains a plot of cooling EER vs. outdoor temperature for a range of equipment time constants. Again, lightly loaded equipment having large time constants can be seen to have the most severe losses. The plot does not contain points above the cooling balance point temperature because the indoor temperature will no longer be constant at these outdoor temperatures.

A parametric examination of various thermostat characteristics and their effect on cyclic rate was conducted by Lamb and Tree in Reference 15 using a closed-loop feedback model containing a parabolic curve of on-time vs. cycle rate (as is used in the SPM). A summary of the variables investigated and the resulting ranges of peak cycle rate are given in Table 5.2. It can be seen that by varying the thermostat control band (temperature difference between setpoint and cutoff) alone, the peak cycle rate can range from 1.3 to 4.2 cycles per hour (for a base value of 3.0). The effect of combining variations in more than one of these parameters is likely to increase this range even further. Contractor and user preferences, variations in equipment, and differences in equipment/load sizing will effect the actual peak cycle rate for a particular installation so that it could easily be anywhere within this range.

Goldschmidt (Reference 13) shows that for a reasonable minimum equipment on-time (5 min) the peak cycle rate (cycle rate at 50% load) for a parabolic thermostat curve is 3 cycles per hour and that this is in agreement with both the NEMA thermostat method of test (Reference 16) and the DOE test procedure (Reference 17).

The actual peak cycle rate has a virtually linear effect on the seasonal number of heat pump cycles. Figures 5-6 and 5-7 show this for cooling and heating seasons respectively, at three locations, as determined using the SPM. A similar, more significant effect is the decrease in seasonal efficiency due to greater cyclic losses as the peak cycle rate is increased. Figures 5-8 and 5-9 illustrate this effect. Notice that for both Dallas in the cooling season and Minneapolis in the heating season, the detrimental effect on efficiency of increasing the peak cycle rate is less severe. This is due to the high equipment load factors seen at these locations for the respective seasons.

5.3 HEAT PUMP RATING POINT DATA PARAMETRIC STUDY

A parametric sensitivity study was made to investigate the effect on seasonal performance of rating point data as input to the SPM. Determination of the heat pump heating capacity and input power as a function of temperature allows studies of individual changes in these rating point parameters to be made yielding useful qualitative insights of their effects on seasonal performance. The results of this investigation can be used in optimization of heat pump sizing and selection for particular conditions.

The ARI Directory (Reference 18) was used to provide a source of rating point data for a variety of unitary, air source, split system heat pumps (only DOE covered products were considered). Listing for two to three ton systems available from a number of manufacturers were examined. Twenty two systems were selected to represent the mean and extremes of rating point efficiencies, capacities and the relationship between capacities and efficiencies at different rating points. Table 5-3 contains a listing of the rating point data for the selected units.

It should be noted that the rating point SEER as listed in the directory can be shown to be approximately equal to the EER at 95F that is required as input to the SPM. The following serves as verification of this statement:

As developed by Thomas et.al., (Reference 12) concerning the DOE rating point test method using the default value for the degradation coefficient ($C_D = .25$),

$$PLF (.5) = .875 \quad (24)$$

where: PFL is the part load factor.

The definition of SEER is given as:

$$SEER = PLF (.5) \times EER_B \quad (25)$$

Thomas develops the following relationship between rating point EER's:

$$EER_A = (.82 \text{ to } .88) \times EER_B \quad (26)$$

The lower limit of the coefficient of EER_B was determined from theory while the upper limit was calculated from experimental data. Combining equations 5-1 through 5-3 the following relationship is developed:

$$EER_A = (.94 \text{ to } 1.01) \times SEER \quad (27a)$$

or

$$SEER \approx EER_A \quad (27b)$$

Therefore for the purposes of this investigation SEER and EER_A will be used interchangeably.

Three additional parameters were defined to allow examination and quantification of the ranges and combinations of heat pump rating point (RP) data. Their definitions are:

$$\text{Capacity Ratio} = \frac{\text{RP Cooling Capacity @ 95F}}{\text{RP Heating Capacity @ 47F}}$$

$$\text{Normalized Heating Capacity Slope} = \frac{\text{RP Capacity @ 47F} - \text{RP Capacity @ 17F}}{30F \times \text{RP Capacity @ 47F}}$$

$$\text{Heating COP Slope} = \frac{\text{COP @ 47F} - \text{COP @ 17F}}{30F}$$

The values of these parameters for the selected units are included in Table 5-3. From the range of data indicated, values for each of the parameters were chosen to represent reasonable high and low limits. These were then used to generate parametric variations in base case input data for the SPM (Table 5-4). In addition to the parametric variations, two sets of rating point data were developed to be representative of the general trends seen for low and high efficiency systems. (The base case is intended to be an average unit.) Table 5-4 also contains the RP data used for these heat pumps.

The results of the SPM calculations are given in Figure 5-10 as normalized heating SPF for each case at three locations. In all locations the sensitivity to COP slope was greatest. As expected heating seasonal efficiency in locations having more severe heating seasons were more sensitive to the variations in parameters. The HSPF in Dallas appears to be relatively insensitive to individual variations in input values.

Included in Figure 5-10 are the results of the simulations using the "low and "high" efficiency heat pump rating point data. A scale change of 2.5 was required in plotting the data which indicates the compound effects of multiple parameter changes. A reverse in location sensitivity is observed from that of the individual parameter cases. This is due to the general increase in the slope of the COP with increasing system efficiency causing the increase in seasonal efficiency to be battered by the severity of the climate.

Figure 5-11 contains a similar plot for annual electric usage. The effect of parametric variations show the same trends as for heating SPF. The addition of cooling requirements shows that in Dallas annual performance is virtually insensitive to the parameters studied due to the relative magnitudes of the cooling and heating seasons.

Table 5-1. Summary of Time Constants for Heat Pumps

SOURCE	TIME CONSTANT, Tau
Goldschmidt, et al., 1981 (Reference 13)	Less than 2 minutes
Thomas, S.B., et al., 1980 (Reference 12)	.611, .952 and 1.287
Wilden, M.W., 1978 (Reference 14)	Approximately 1 minute
Science Applications, Inc. 1980 (Reference 10)	1.1 to 2.8 minutes

Table 5-2. Effect of Thermostat Parameters on Cycle Rate
(from G. Lamb, D. Tree, Reference 15)

PARAMETER	RANGE	BASE VALUE	EFFECTIVE RELATIONSHIP TO CYCLE RATE	MAGNITUDE OF EFFECT	RESULTING RANGE OF PEAK CYCLE RATE (cyc/hr)
Switch Differential (SD) (Control Band)	1-3 F	1.5 F	Inverse	Largest effect relative to its range	1.3-4.2
Anticipator Temper- ature Rise (K_a)	1-3 F	2 F	Direct	Large effect, manually adjust- able	1.8-4.2
Bimetal Element Time Constant (τ_e)	3-10 min.	5 min.	Inverse	Large effect over extremes of range	1.8-4.2
Anticipator Time Constant (τ_a)	0-3 min.	1.5 min.	Inverse	Relatively small effect	1.6-3.5
Building/Equipment Time Constant (τ_p)	0-15 min.	0 min.	Inverse	Little effect for $\tau_p > 5$ min.	2.3-3
Equipment Gain (K_p)	4-16 F/hr	10 F/hr	Direct	Smallest effect of parameters	2.8-3.2

Table 5-3. Selected Heat Pump Rating Point Data (Reference 18)

ITEM NUMBER	MANUFAC- TURER	95 F		47 F		17 F		CAPACITY RATIO	NORMALIZED HEATING CAPACITY SLOPE	HEATING COP SLOPE	COMMENTS
		CAPACITY (Btu/hr)	SEER	CAPACITY (Btu/hr)	COP	CAPACITY (Btu/hr)	COP				
1.	A	23800	7.90	22400	2.50	12600	1.75	1.06	.0146	.0250	
2.		25800	7.55	28600	2.65	16900	1.95	.90	.0136	.0233	
3.		28200	7.60	31000	2.70	18000	1.95	.91	.0140	.0250	
4.	B	27400	8.00	30200	2.65	17900	1.95	.91	.0136	.0233	High Efficiency Line
5.		27600	8.05	29600	2.50	17500	1.75	.93	.0136	.0250	" " "
6.		24200	6.45	26000	2.35	14800	1.65	.93	.0144	.0233	Standard Line
7.		29000	6.60	32200	2.45	19400	1.80	.90	.0133	.0217	" "
8.	C	23800	7.90	22400	2.50	12600	1.75	1.06	.0146	.0250	Large Selection Listed
9.		28800	7.80	31000	2.80	17900	2.00	.93	.0141	.0267	
10.	D	24000	8.70	21400	2.55	12300	1.75	1.12	.0142	.0267	Large Selection Listed
11.		28200	7.35	29600	2.55	15500	1.75	.95	.0159	.0267	
12.		31600	9.20	27600	2.95	14500	1.95	1.14	.0158	.0333	
13.		31600	8.55	32600	2.70	17200	1.90	.97	.0157	.0267	
14.	E	24000	7.40	23800	2.55	14600	1.90	1.01	.0129	.0217	
15.		30000	8.65	32000	3.00	18800	2.15	.94	.0138	.0283	
16.	F	30600	7.00	30400	2.60	19300	1.95	1.01	.0122	.0217	
17.	G	25000	8.80	25400	2.70	14000	2.30	.98	.0150	.0133	
18.	H	23800	7.90	22800	2.55	12700	1.80	1.04	.0148	.0250	Large Selection Listed, all have similar effi- ciencies
19.		26400	7.50	29800	2.75	17600	2.00	.89	.0136	.0250	
20.	I	22400	6.95	21800	2.30	13600	1.60	1.03	.0125	.0233	
21.		33200	7.55	32400	2.25	18800	1.65	1.02	.0140	.0200	
22.	J	34600	8.35	36400	3.15	20000	2.15	.95	.0150	.0333	

Table 5-4. Case Variables Used for Rating Point Parametric Study (only variations from the base case values are tabulated)

BASE CASE AND VARIATIONS TO BASE CASE	95 F		47 F		17 F		CAPACITY RATIO	NORMALIZED HEATING CAPACITY SLOPE	COP SLOPE
	CAPACITY (Btu/hr)	EER	CAPACITY (Btu/hr)	COP	CAPACITY (Btu/hr)	COP			
Base Case (Default)	24000	7.80	24000	2.70	14400	2.00	1	0.0133	0.0233
Capacity Ratio = 1.12	--*	--	21400	--	12900	--	1.12	--	--
Capacity Ratio = 0.90	--	--	26700	--	16000	--	0.90	--	--
Heating Slope = 0.0158	--	--	--	--	12600	--	--	0.0158	--
Heating Slope = 0.0125	--	--	--	--	15000	--	--	0.0125	--
COP Slope = 0.0333	--	--	--	--	--	1.70	--	--	0.0333
COP Slope = 0.0200	--	--	--	--	--	2.10	--	--	0.0200
High Efficiency Unit	--	8.60	--	3.10	--	2.10	--	0.0133	0.0333
Low Efficiency Unit	--	7.50	--	2.25	13600	1.65	--	0.0144	0.0200

*-- = Base case

LEGEND
□ = RH = 20 %
○ = RH = 75 %
△ = RH = 95 %

COP VS. OUTDOOR TEMPERATURE IN KANSAS CITY

Figure 5-1. Constant Duty COP vs Temperature Including Defrost Losses (Tempering heat not included)

DEMAND DEFROST, KANSAS CITY

LEGEND
□ = W/O CYC LOSSES
○ = τ = 0.5 MIN
△ = τ = 1.2 MIN
+ = τ = 2.0 MIN
x = τ = 3.0 MIN

EQUIPMENT TIME CONSTANT EFFECT ON COP

Figure 5-2. Heat Pump COP vs Temperature for a Range of Time Constants (RH=75%)

LEGEND
□ = RH = 20 %
○ = RH = 75 %
△ = RH = 95 %

DEFROST AND CYCLIC EFFECTS ON COP

Figure 5-3. Heat Pump COP vs Temperature, Defrost and Cyclic Losses Included

LEGEND
□ = RH = 40 %
○ = RH = 75 %
△ = RH = 95 %

DEFROST, CYCLIC AND ELECTRIC RESISTANCE EFFECTS

Figure 5-4. System COP vs Temperature, Including Effects of Cycling, Defrost and Electric Resistance Heat (Backup and Tempering)

OUTDOOR RH - 25 %

LEGEND
□ = W/O CYC LOSSES
○ = TAU = 0.5 MIN
△ = TAU = 1.2 MIN
+ = TAU = 2.0 MIN
x = TAU = 3.0 MIN

EFFECT OF CYCLIC DEGRADATION ON COOLING EER

Figure 5-5. Heat Pump Cooling EER vs Temperature

LEGEND
□ = MINNEAPOLIS
○ = KANSAS CITY
△ = DALLAS

Figure 5-6. Number of Cooling Cycles per Season as a Function of Peak Cycle Rate

LEGEND
□ = MINNEAPOLIS
○ = KANSAS CITY
△ = DALLAS

NUMBER OF HEATING CYCLES VS. PEAK CYCLE RATE

Figure 5-7. Number of Heating Cycles per Season as a Function of Peak Cycle Rate

DEMAND DEFROST

LEGEND
□ = MINNEAPOLIS
○ = KANSAS CITY
△ = DALLAS

COOLING SEER VS. PEAK CYCLE RATE

Figure 5-8. Cooling SEER as a Function of Peak Cycle Rate

DEMAND DEFROST

LEGEND
□ = MINNEAPOLIS
○ = KANSAS CITY
△ = DALLAS

HEATING SPF VS. PEAK CYCLE RATE

Figure 5-9. Heating Seasonal Performance Factor as a Function of Peak Cycle Rate

*Normalized HSPF = $\frac{\text{HSPF for variations to base case}}{\text{HSPF for base case}}$, where base HSPF = $\begin{cases} 1.53, \text{ Minneapolis} \\ 1.85, \text{ Kansas City} \\ 2.11, \text{ Dallas} \end{cases}$

Figure 5-10. Sensitivity of Heating Seasonal Performance Factor to Various Rating Point Parameters

*Base Case Annual Energy Usage = $\begin{cases} 16160 \text{ kWh, Minneapolis} \\ 10030 \text{ kWh, Kansas City} \\ 7720 \text{ kWh, Dallas} \end{cases}$

Figure 5-11. Sensitivity of Annual Electricity Usage to Various Rating Point Parameters

6. SPM PROGRAM LISTING

Due to the size of the listing of the SPM program it is published as a separate volume (Reference 19).

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