M & R CS 10757-8-2

DOE/CS/10757--T1

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SAI-444-80-472-LJ

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VARIABLE INTERVAL
TIME/TEMPERATURE (VITT)
DEFROST CONTROL-SYSTEM EVALUATION

MASTER

Topical Report Subtask 8.3

Consumer Products Minimum Energy
Efficiency Standards Program

12 August 1980

Prepared for
The Assistant Secretary for Conservation
and Solar Applications
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Under Contract No.
DE-AC03-79-CS10757 (MOD-1)

Prepared by
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MGW

12 August 1980

U. S. Department of Energy
1000 Independence Avenue, S.W.
Mail Stop 068/Room GH095
Washington, D.C. 20585

Attention: Mr. Richard Dudley, Program Manager

Subject: Topical Report Subtask 8.3: Variable Integral
Time/Temperature (VITT) Defrost Control System
Evaluation
Contract No. DE-AC03-79-CS10757 (MOD-1)
SAI 1-444-03-521-00

Dear Mr. Dudley:

In accordance with the requirements of the subject contract, enclosed are four copies of Topical Report Subtask 8.3, entitled "Variable Integral Time/Temperature (VITT) Defrost Control System Evaluation," SAI-444-80-472-LJ.

If you have any questions or comments, please call me at (714) 454-3811, extension 2561.

Sincerely,

M. H. Blatt

Morton H. Blatt
Program Manager

MHB:evm
Enclosures

cc: DOE/SAN, Conservation Division

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EXECUTIVE SUMMARY

This report describes analyses of two variable-interval-time/temperature (VITT) heat pump defrost control systems, one marketed by Honeywell and the other by Ranco. VITT defrost control strategy is different from the more traditional demand defrost and fixed-interval-time/temperature (FITT) defrost control strategies.

A demand defrost system measures variables such as the difference between outdoor air dry-bulb temperature and outdoor coil temperature, or the air pressure drop across the outdoor coil, and initiates a defrost when the measured values exceed preset thresholds. A demand defrost system is thereby directly responsive to the formation of ice on the outdoor coil.

FITT and VITT systems are based on timers. FITT defrosts are typically initiated every 45, 60, 90 or 120 minutes of compressor run time depending on the setting selected by the installer of the system. VITT systems monitor outdoor air dry-bulb temperature and use the measured data to alter the interval between defrosts. However, for any fixed outdoor temperature, the VITT systems defrost at constant intervals of time, which are typically in a range of 60-600 minutes. The installer of a heat pump with VITT defrost control sets a "minimum defrost interval" such as 90 minutes, and the VITT controller uses an algorithm of the form:

$$\text{Actual Interval} = M \times \text{Minimum Defrost Interval},$$

where

$$M = \text{A multiplier, the value of which is a function of the outdoor air dry-bulb temperature, and which is always greater than one,}$$

to determine when the next defrost should be initiated.

Neither an FITT nor a VITT defrost control system measures ice formation directly or indirectly, as evidenced by the fact that defrosts are initiated even under low humidity conditions for which no ice forms on the outdoor coil. Both types of control employ a best estimate of what interval or minimum interval will provide the best performance within the constraints of the design for the site at which the heat pump is located. An installer would tend to set the interval for an FITT system at a low value (e.g., 45 minutes) in a location with high humidity or frequent and heavy snowfall, and at a higher value (e.g., 60 or 90 minutes) in a more temperate location. The VITT systems recognize that typically the interval between defrosts can be longer at some temperatures, and therefore are programmed to increase the interval at those temperatures. Both the initial setting of the minimum interval and the expansion of that interval are best estimates, the former made by the installer and the latter made by the designer of the control system.

The DOE test procedures for heat pumps allow a credit for heat pumps that utilize a demand defrost control system. A 7% increase in capacity in the DOE specified defrost test is allowed for demand defrost systems; the 7% credit has the effect of increasing the Heating Seasonal Performance Factor (HSPF) 3-4% in Region IV as defined in the DOE procedures. Neither FITT nor VITT defrost control systems qualify for the credit, because neither is a demand defrost control system.

The 7% demand defrost credit is based on the superiority of a demand defrost control strategy over a 90 minute FITT control strategy. VITT control systems were not considered at the time credit was established, because to both SAI's and DOE's knowledge, there were no VITT control systems on the market at that time.

Manufacturers are requesting credit for VITT control systems based on the proposition that VITT defrost control systems reduce heat pump seasonal energy consumption relative to 90-minute FITT (90 FITT) defrost control systems. The rationale is that demand defrost control systems qualify for a credit because they cause a reduction in energy consumption relative to FITT defrost control systems, so VITT defrost control systems should also qualify for a credit.

The analyses of the Honeywell and Ranco VITT systems indicate that both reduce heat pump seasonal energy consumption, but neither does so as effectively as an actual demand defrost control system that has been tested by SAI/DOE.

The Heat Pump Seasonal Performance Model (HPSPM), developed by SAI, is used for the calculations. Eight different control strategies are applied to a Trane heat pump, the defrost performance of which has been modeled based on the results of defrost testing conducted by SAI. Each of the defrost control strategies causes the underlying Trane heat pump to operate at different levels of average efficiency in and below the "defrost region" of 15-45°F outdoor air dry-bulb temperatures. The seasonal implications of the differences in the performance characteristics, particularly the total seasonal system energy consumption differences, are estimated by the HPSPM.

Figures S-1 and S-2 illustrate the key HPSPM results. Each of the figures graphs the following ratio in percent:

Seasonal System Energy Consumption with
the Applied Defrost Control System

Seasonal System Energy Consumption for
an "Ideal" Defrost Control System

Figure S-1. Graphic Illustration of the Relative Performance of Different Defrost Control Strategies Relative to a 90 FITT System

Figure S-2. Graphic Illustration of the Relative Performance of Different Defrost Control Strategies Relative to a 60 FITT System

where the ideal system is identical to the system being evaluated except that the heat pump in the ideal system operates at peak instantaneous capacity at all times and never defrosts. The ideal system cannot exist, but provides a convenient reference.

In practice the optimum demand defrost strategy is the best that can be hoped for; it defrosts at "exactly the right time" under all conditions. Given the characteristics of the underlying heat pump, the optimum demand defrost control strategy removes the ice that accumulates at time intervals that result in the maximum possible efficiency from defrost to defrost. Figure S-1 indicates that, depending on location, seasonal system energy consumption for the optimum demand strategy is 2-4% greater than for an ideal system.

Figure S-1 uses a 90 FITT system as a basis for the "percent-of-delta" listed in parentheses in the figure. The delta is defined as:

(Seasonal System Energy Consumption for the Basis
Defrost Control System)
- (Seasonal System Energy Consumption for Optimum
Demand Defrost Control System).

The delta is the potential reduction in energy consumption that could be realized by using an optimum demand defrost control strategy rather than the "basis" control strategy. The basis control strategy is 90 FITT for Figure S-1 and 60 FITT for Figure S-2.

From Figure S-1, the actual demand defrost control system marketed with the Trane heat pump tested achieves 90-95% of the delta. The VITT systems do not do nearly as well. The Honeywell system with a 90-minute minimum interval setting (Honeywell @ 90) achieves 29 to 64% and the Ranco @ 90 achieves 0 to 24% of the potential improvement.

The Honeywell system uses a demand defrost control as backup to the primary VITT control; the demand defrost control overrides the VITT control if the accumulation of ice is so great as to cause a severe degradation in performance between VITT-initiated defrosts. One version of the Ranco system also uses demand defrost as a backup control. It has been suggested that in actual application the installer of the heat pump system will use different philosophies for systems with and without demand defrost backup as follows:

- o Without demand defrost backup:

VITT minimum interval = FITT interval for the same application;

- o But with demand defrost backup:

VITT minimum interval is greater than FITT interval for the same application.

The philosophies differ because installers of the heat pumps will tend to be more conservative in systems without demand defrost backup and set the intervals to a short enough period to remove ice under all weather conditions. For systems with a backup demand defrost control, the installer will be more inclined to set the minimum interval to a period short enough to remove ice under most, but not all, weather conditions and rely on the demand defrost system to override the VITT system under severe conditions.

Thus, it may be a fair reflection of actual practice to compare a 90 VITT system with a backup demand defrost control to a 60 FITT system as illustrated in Figure S-2. Although the performance of the VITT systems do not change from Figure S-1 to S-2, the "basis" system is different, which causes the percentages-of-delta to change.

The following comparisons are a summary of the percent-of-delta results of Figures S-1 and S-2.

	<u>90 FITT Basis</u>		<u>60 FITT Basis</u>	
	<u>Range</u>	<u>Weighted Average</u>	<u>Range</u>	<u>Weighted Average</u>
Actual Demand	90-95%	92.1%	94-96%	95.1%
Honeywell @ 90	29-64%	36.5%	51-76%	57.8%
Ranco @ 90	0-24%	13.9%	34-50%	42.8%
90 FITT	---	---	30-37%	33.6%

It is apparent that a very large fraction of the energy savings achieved by the VITT systems for 60 FITT basis occurs because the minimum interval is set to 90 minutes; the remainder of the savings are achieved by increasing the interval above the minimum value at some outdoor temperatures rather than keeping the interval fixed at 90 minutes. The first effect appears to be more significant than the second, particularly for the Ranco system.

SAI has considered the implications of the results and the regulatory problems that might be created by allowing a credit for VITT systems. Admittedly with less thorough comprehension of the regulatory implications than might be desired, it is recommended that VITT systems receive a credit, and that the credit be based on a very simplistic standard as follows:

- o Use HPSPM calculations or the equivalent to establish seasonal energy consumption for four sites: Chicago, Boston, Philadelphia and Kansas City.
- o For VITT systems with demand defrost backup:
 - Allow the full 7% credit if the percent-of-delta for 60 FITT basis is greater than or equal to 50%.
 - No credit otherwise.

o For VITT systems without demand defrost backup:

- Allow full 7% credit if the percent-of-delta for 90 FITT basis is greater than or equal to 50%.
- No credit otherwise.

Since no VITT strategy is envisioned that will satisfy the second credit policy above, it is not expected that any VITT system without demand backup will be able to qualify for the credit.

The above recommendation is not logically consistent with the current DOE heat pump test procedures, which specify that the interval between defrosts for FITT systems be set at 90 minutes during the defrost region tests. The 90 minute setting formerly was presumed to be typical, which would imply that the appropriate comparisons would be between VITT systems with a 120 minute minimum interval (120 VITT) and 90 FITT defrost control, rather than between 90 VITT and 60 FITT as suggested above. However, the manufacturers of VITT controls have indicated that in their field surveys, the typical setting on FITT controls is 60 minutes or shorter. The inconsistency can be resolved by establishing what setting is indeed typical for FITT defrost control systems and adjusting the test procedures and/or VITT defrost control system comparisons as appropriate. Since the most current data available to the DOE indicates that 60 minute settings or shorter are typical, it is recommended that the test procedures be modified to accommodate a 60 minute defrost interval for FITT systems.

Other recommendations are made for improving the HPSPM in light of its possible use as a standardized computer program for establishing whether different VITT control systems qualify for the credit. It is also recommended that the heat pump model data base be expanded to include products other than the Trane heat pump on which all the analyses discussed here have been based.

Several modifications have been made to the HPSPM in the course of conducting the VITT defrost control system evaluations. The modifications are also discussed in the report.

The current DOE test procedures for heat pumps (Reference 1) provide a credit for heat pumps with demand defrost controls. A "demand defrost control system" is defined in the procedures as:

"A system which is designed to perform the defrost function on the outdoor coil of the heat pump only when a predetermined degradation of performance is measured."

Demand defrost control systems typically measure variables such as the difference between outdoor air temperature and outdoor coil temperature, or the air pressure drop across the outdoor coil, and initiate a defrost when the measured values exceed preset thresholds. The more common method of defrost control uses a fixed interval (typically 90 minutes) time/temperature strategy. In the 90 minute fixed interval time/temperature (90 FITT) systems, a defrost is initiated every 90 minutes of compressor run time, if the outdoor dry-bulb temperature is below a set point value (typically 45°F) at which ice formation is expected to occur.

The credit for heat pumps with demand defrost control systems increases the capacity measured in the defrost test at 35°F outdoor dry-bulb temperature by 7%. Other calculations performed by SAI (Reference 2) indicate that the 7% credit results in a 3-4% increase in the heating seasonal performance factor (HSPF) as calculated by DOE prescriptions for Region IV as defined in the DOE procedures.

The selection of the magnitude of the demand defrost credit was based on the then current best available estimates of the energy savings that would be realized by using demand defrost control rather than 90 FITT defrost control. It should be noted

in this regard that the 3-4% effect on HSPF dictated the 7% credit at 35°F. Heat pump capacity at 35°F was not presumed to be 7% greater for demand defrost control than for 90 FITT control; rather a demand system was presumed to reduce annual energy consumption 3-4% from that experienced for a 90 FITT system, and a 7% capacity enhancement at 35°F produces the desired 3-4% increase in HSPF.

Several presently available defrost control systems are neither demand defrost systems as defined by the DOE nor FITT systems. As a class, these systems are referred to here as variable interval time/temperature (VITT) defrost control systems. The distinguishing feature of VITT control is that instead of being constant, the interval between defrosts is a variable that is dependent on outdoor dry-bulb temperature. For many outdoor temperatures, the interval between defrosts is greater for VITT systems than for a FITT system in the same application.

VITT systems should reduce heat pump seasonal energy consumption below the levels experienced with FITT controls, which has caused some manufacturers of VITT systems to request a credit for their systems. The rationale for the request is that demand defrost systems are given a credit because they reduce energy consumption, and since VITT systems also reduce energy consumption, VITT systems should also receive a credit.

Two VITT systems are analyzed here: a Honeywell system and a Ranco system. The Ranco controller doubles the basic time interval if the outdoor temperature is between 0 and 20°F and quadruples the basic time interval if the outdoor temperature is below 0°F. The Honeywell system is a more complicated variation of the same concept.

The issues that are raised by VITT control are whether heat pumps using such controls should receive any credit and, if so, how much. Also, should the Honeywell and Ranco systems, both of which are VITT systems, receive identical credit and, if not, how should the relative credits be determined. Under the present DOE procedures, VITT systems receive no credit because they are not demand control systems as defined by the DOE.

The following sections describe evaluations of the Honeywell and Ranco VITT systems that are intended to provide information of value to the DOE in making its determinations regarding credits for VITT defrost control systems.

2.0 VITT EVALUATION METHODOLOGY

2.1 GENERAL

The evaluations of VITT systems utilize a modified version of the Heat Pump Seasonal Performance Model (HPSPM) developed by SAI for the DOE and documented in References 3 and 4. The more important modifications made for the VITT analysis are discussed in Appendix A. Appendix B contains a detailed listing and discussion of the HPSPM output.

The basic methodology used in the HPSPM is referred to here as "double binning" in outdoor temperature and relative humidity. It is presumed that a heat pump does not form ice on the outdoor coil for outdoor temperatures above 45°F or below 15°F. Thus double binning is employed only in the intervening defrost region of 15-45°F. Each dry-bulb temperature bin in the defrost region is subdivided into six relative humidity bins of 20, 40, 60, 75, 85, and 95 percent relative humidity.

Product performance and load requirements are modeled separately for each bin. Seasonal performance is determined by summing the results obtained in each bin for which a heating load exists.

2.2 PRODUCT PERFORMANCE MODELS

The modeling of product performance is critical to the VITT defrost control system evaluations. SAI has tested a Trane heat pump and, based on this data, has developed models of its performance for any specified interval between defrost cycles (Reference 5). The various defrost control strategies affect product performance by lengthening or shortening the intervals between defrosts which affects the degree of ice buildup (if any) on the outdoor coil.

Tables 2-1 and 2-2 are "performance maps" of the Trane heat pump with Honeywell and Ranco defrost control systems set at minimum intervals between defrosts of 90 minutes; the models are labeled Honeywell @ 90 and Ranco @ 90, respectively. The input variables to the model of the Trane heat pump are:

- o Outdoor dry-bulb temperature,
- o Outdoor relative humidity, and
- o Time between defrosts.

The outputs of the Trane heat pump model are:

- o Duration of each defrost period,
- o Average capacity over a defrost cycle from one defrost initiation to the next defrost initiation, and
- o Average power draw over a defrost cycle.

The latter two variables are more commonly referred to as "integrated" capacity and power. The interval between defrosts and the duration of each defrost in minutes are listed in the last two columns of Tables 2-1 and 2-2. An "N/A" entry under defrost times stands for Not Applicable meaning that the heat pump does not defrost under the conditions of the bin. The intervals between defrost listed in the tables are frequently slightly different from the nominal values because of the numerical procedures used in the calculations.

The Honeywell control uses a "two-sided ramp", as evidenced in Table 2-1 by the initial decrease in the interval between defrosts from 97 to 90 minutes and the subsequent increase in the interval between defrosts from 90 minutes to 600 minutes. The Ranco control of Table 2-2 uses a "one-sided ramp"; the interval between defrosts is initially constant at 90 minutes and subsequently increases to 360 minutes.

Table 2-1. Performance Map for Honeywell @ 90 Defrost Control
Applied to the Trane Heat Pump

I	TODS	RBO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *				PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR	
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A	
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A	
7	42.0	20.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
8	42.0	40.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
9	42.0	60.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
10	42.0	75.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
11	42.0	85.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
12	42.0	95.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A	
13	37.0	20.0	37150.	4436.	2.45	0.910	0.978	0.931	40817.	4538.	2.64	97.20	3.00	
14	37.0	40.0	37150.	4436.	2.45	0.910	0.978	0.931	40817.	4538.	2.64	97.20	3.00	
15	37.0	60.0	37150.	4436.	2.45	0.910	0.978	0.931	40817.	4538.	2.64	97.20	3.00	
16	37.0	75.0	36730.	4415.	2.44	0.900	0.973	0.925	40817.	4538.	2.64	97.46	3.26	
17	37.0	85.0	36437.	4403.	2.42	0.893	0.970	0.920	40817.	4538.	2.64	96.88	3.58	
18	37.0	95.0	34527.	4324.	2.34	0.846	0.953	0.888	40817.	4538.	2.64	96.67	6.07	
19	32.0	20.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
20	32.0	40.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
21	32.0	60.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
22	32.0	75.0	33271.	4217.	2.31	0.896	0.974	0.920	37137.	4329.	2.51	90.25	3.25	
23	32.0	85.0	33175.	4213.	2.31	0.893	0.973	0.918	37137.	4329.	2.51	90.35	3.35	
24	32.0	95.0	32524.	4187.	2.28	0.876	0.967	0.906	37137.	4329.	2.51	90.36	4.26	
25	27.0	20.0	31148.	4068.	2.24	0.913	0.981	0.932	34099.	4149.	2.41	104.40	3.00	
26	27.0	40.0	31148.	4068.	2.24	0.913	0.981	0.932	34099.	4149.	2.41	104.40	3.00	
27	27.0	60.0	31148.	4068.	2.24	0.913	0.981	0.932	34099.	4149.	2.41	104.40	3.00	
28	27.0	75.0	30856.	4054.	2.23	0.905	0.977	0.926	34099.	4149.	2.41	104.68	3.28	
29	27.0	85.0	30769.	4049.	2.23	0.902	0.976	0.925	34099.	4149.	2.41	104.78	3.38	
30	27.0	95.0	30245.	4029.	2.20	0.887	0.971	0.913	34099.	4149.	2.41	104.78	4.28	
31	22.0	20.0	29114.	3923.	2.17	0.923	0.983	0.939	31545.	3991.	2.32	126.00	3.00	
32	22.0	40.0	29114.	3923.	2.17	0.923	0.983	0.939	31545.	3991.	2.32	126.00	3.00	
33	22.0	60.0	29114.	3923.	2.17	0.923	0.983	0.939	31545.	3991.	2.32	126.00	3.00	
34	22.0	75.0	28855.	3910.	2.16	0.915	0.980	0.934	31545.	3991.	2.32	126.31	3.31	
35	22.0	85.0	28747.	3905.	2.16	0.911	0.978	0.931	31545.	3991.	2.32	125.55	3.45	
36	22.0	95.0	28260.	3886.	2.13	0.896	0.974	0.920	31545.	3991.	2.32	125.69	4.49	
37	17.0	20.0	27370.	3794.	2.11	0.932	0.985	0.946	29367.	3851.	2.23	156.60	3.00	
38	17.0	40.0	27370.	3794.	2.11	0.932	0.985	0.946	29367.	3851.	2.23	156.60	3.00	
39	17.0	60.0	27370.	3794.	2.11	0.932	0.985	0.946	29367.	3851.	2.23	156.60	3.00	
40	17.0	75.0	27209.	3785.	2.11	0.927	0.983	0.943	29367.	3851.	2.23	156.84	3.24	
41	17.0	85.0	27012.	3776.	2.10	0.920	0.980	0.938	29367.	3851.	2.23	156.27	3.57	
42	17.0	95.0	26487.	3755.	2.07	0.902	0.975	0.925	29367.	3851.	2.23	156.81	5.01	
43	12.0	ALL	25871.	3677.	2.06	0.941	0.987	0.954	27486.	3726.	2.16	207.00	3.00	
44	7.0	ALL	23289.	3626.	1.88	0.951	0.988	0.962	24500.	3670.	1.96	306.00	3.00	
45	2.0	ALL	21128.	3590.	1.72	0.960	0.989	0.971	22000.	3630.	1.78	598.50	3.00	
46	-3.0	ALL	19205.	3571.	1.58	0.960	0.989	0.971	20000.	3610.	1.62	600.30	3.00	
47	-8.0	ALL	16800.	3561.	1.38	0.960	0.989	0.971	17500.	3600.	1.42	600.30	3.00	

K.C. CPERS WEIGHTED AVERAGE VALUES: 0.925 0.981 0.942

ALL DATA ARE FOR TIDE = 70. DEG-F.

Table 2-2. Performance Map for Ranco @ 90 Defrost Control
Applied to the Trane Heat Pump

I	TODB	RHO *	INTEGRATED VALUES				* DEFROST PERFORMANCE FACTORS *				PEAK VALUES			DEFROST TIMES:	
			TOTCAP	TOTPWR	COP	GAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR		
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A		
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A		
7	42.0	20.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
8	42.0	40.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
9	42.0	60.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
10	42.0	75.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
11	42.0	85.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
12	42.0	95.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00		
13	37.0	20.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00		
14	37.0	40.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00		
15	37.0	60.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00		
16	37.0	75.0	36560.	4412.	2.43	0.896	0.972	0.921	40817.	4538.	2.64	90.24	3.24		
17	37.0	85.0	36377.	4404.	2.42	0.891	0.970	0.918	40817.	4538.	2.64	90.44	3.44		
18	37.0	95.0	35073.	4350.	2.36	0.859	0.959	0.896	40817.	4538.	2.64	90.23	5.03		
19	32.0	20.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00		
20	32.0	40.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00		
21	32.0	60.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00		
22	32.0	75.0	33271.	4217.	2.31	0.896	0.974	0.920	37137.	4329.	2.51	90.25	3.25		
23	32.0	85.0	33175.	4213.	2.31	0.893	0.973	0.918	37137.	4329.	2.51	90.35	3.35		
24	32.0	95.0	32524.	4187.	2.28	0.876	0.967	0.906	37137.	4329.	2.51	90.36	4.26		
25	27.0	20.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00		
26	27.0	40.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00		
27	27.0	60.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00		
28	27.0	75.0	30576.	4049.	2.21	0.897	0.976	0.919	34099.	4149.	2.41	90.23	3.23		
29	27.0	85.0	30515.	4046.	2.21	0.895	0.975	0.918	34099.	4149.	2.41	90.29	3.29		
30	27.0	95.0	30304.	4039.	2.20	0.889	0.973	0.913	34099.	4149.	2.41	89.70	3.60		
31	22.0	20.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00		
32	22.0	40.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00		
33	22.0	60.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00		
34	22.0	75.0	28310.	3902.	2.13	0.897	0.978	0.918	31545.	3991.	2.32	90.21	3.21		
35	22.0	85.0	28246.	3899.	2.12	0.895	0.977	0.916	31545.	3991.	2.32	90.28	3.28		
36	22.0	95.0	28195.	3897.	2.12	0.894	0.977	0.915	31545.	3991.	2.32	90.36	3.36		
37	17.0	20.0	27519.	3796.	2.12	0.937	0.986	0.951	29367.	3851.	2.23	180.00	3.00		
38	17.0	40.0	27519.	3796.	2.12	0.937	0.986	0.951	29367.	3851.	2.23	180.00	3.00		
39	17.0	60.0	27519.	3796.	2.12	0.937	0.986	0.951	29367.	3851.	2.23	180.00	3.00		
40	17.0	75.0	27339.	3787.	2.12	0.931	0.983	0.947	29367.	3851.	2.23	180.28	3.28		
41	17.0	85.0	27062.	3773.	2.10	0.922	0.980	0.941	29367.	3851.	2.23	179.97	3.87		
42	17.0	95.0	26023.	3732.	2.04	0.886	0.969	0.915	29367.	3851.	2.23	180.43	7.03		
43	12.0	ALL	25749.	3675.	2.05	0.937	0.986	0.950	27486.	3726.	2.16	180.00	3.00		
44	7.0	ALL	22941.	3620.	1.86	0.936	0.986	0.949	24500.	3670.	1.96	180.00	3.00		
45	2.0	ALL	20589.	3582.	1.60	0.936	0.987	0.949	22000.	3630.	1.78	180.00	3.00		
46	-3.0	ALL	19063.	3560.	1.57	0.953	0.988	0.964	20000.	3610.	1.62	360.00	3.00		
47	-8.0	ALL	16673.	3550.	1.37	0.953	0.988	0.964	17500.	3600.	1.42	360.00	3.00		

K.C. CPHRS WEIGHTED AVERAGE VALUES: 0.912 0.979 0.931

ALL DATA ARE FOR TIDB = 70. DEG-F.

The performance maps list the integrated values of capacity, power and coefficient of performance (COP) in Columns 4-6, and the peak values of capacity, power and COP in Columns 10-12. Defrost performance factors, which are defined as the ratio of integrated to peak values and listed in Columns 7-9, are a measure of the degradation that occurs because ice accumulates on the outdoor coil. Table 2-3 is a performance map for a 90 FITT control, and Table 2-4 is a performance map for an optimum demand defrost control. A comparison of the defrost performance factors of Tables 2-1 through 2-4 shows that the 90 VITT control systems are as effective as or superior to the 90 FITT control in all the defrost region bins and inferior to the optimum demand control in every defrost region bin for which defrost occurs.

The optimum demand defrost control is a hypothetical control system that maximizes integrated COP for each temperature/humidity condition based on the empirical models developed for the Trane heat pump. No actual defrost control system should outperform the optimum defrost control system, and clearly the Honeywell, Ranco and FITT control systems of Tables 2-1 through 2-3 do not perform as well as the optimum control system of Table 2-4. The data base also includes an empirical model of the Trane heat pump with its actual demand defrost control system, which is of course inferior to an optimum demand defrost control system.

Finally, an "ideal" heat pump model has been defined for purposes of comparison. The ideal heat pump performs at the peak levels of Columns 10-12 and never defrosts. Obviously, no real heat pump can achieve such performance because ice does form, and real heat pumps must defrost periodically and suffer performance degradation between defrosts. The ideal heat pump model provides a convenient basis for comparison and has been created for that purpose.

Table 2-3. Performance Map for 90 FITT Defrost Control Applied to the Trane Heat Pump

I	TODR	RHO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *				PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPR	COP	CAP	POWER	COP	TOTCAP	TOTPR	COP	D-D	DUR	
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A	
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A	
7	42.0	20.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
8	42.0	40.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
9	42.0	60.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
10	42.0	75.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
11	42.0	85.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
12	42.0	95.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00	
13	37.0	20.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00	
14	37.0	40.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00	
15	37.0	60.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00	
16	37.0	75.0	36560.	4412.	2.43	0.896	0.972	0.921	40817.	4538.	2.64	90.24	3.24	
17	37.0	85.0	36377.	4404.	2.42	0.891	0.970	0.918	40817.	4538.	2.64	90.44	3.44	
18	37.0	95.0	35073.	4350.	2.36	0.859	0.959	0.896	40817.	4538.	2.64	90.23	5.03	
19	32.0	20.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
20	32.0	40.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
21	32.0	60.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00	
22	32.0	75.0	33271.	4217.	2.31	0.896	0.974	0.920	37137.	4329.	2.51	90.25	3.25	
23	32.0	85.0	33176.	4213.	2.31	0.893	0.973	0.918	37137.	4329.	2.51	90.35	3.35	
24	32.0	95.0	32524.	4187.	2.28	0.876	0.967	0.906	37137.	4329.	2.51	90.36	4.26	
25	27.0	20.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00	
26	27.0	40.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00	
27	27.0	60.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00	
28	27.0	75.0	30576.	4049.	2.21	0.897	0.976	0.919	34099.	4149.	2.41	90.23	3.23	
29	27.0	85.0	30515.	4046.	2.21	0.895	0.975	0.918	34099.	4149.	2.41	90.29	3.29	
30	27.0	95.0	30304.	4039.	2.20	0.889	0.973	0.913	34099.	4149.	2.41	89.70	3.60	
31	22.0	20.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00	
32	22.0	40.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00	
33	22.0	60.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00	
34	22.0	75.0	28310.	3902.	2.13	0.897	0.978	0.918	31545.	3991.	2.32	90.21	3.21	
35	22.0	85.0	28246.	3899.	2.12	0.895	0.977	0.916	31545.	3991.	2.32	90.28	3.28	
36	22.0	95.0	28190.	3897.	2.12	0.894	0.977	0.915	31545.	3991.	2.32	90.36	3.36	
37	17.0	20.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00	
38	17.0	40.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00	
39	17.0	60.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00	
40	17.0	75.0	26419.	3774.	2.05	0.900	0.980	0.918	29367.	3851.	2.23	90.13	3.13	
41	17.0	85.0	26306.	3769.	2.04	0.896	0.979	0.915	29367.	3851.	2.23	90.27	3.27	
42	17.0	95.0	26286.	3768.	2.04	0.895	0.978	0.915	29367.	3851.	2.23	90.29	3.29	
43	12.0	ALL	24814.	3661.	1.99	0.903	0.982	0.919	27486.	3726.	2.16	90.00	3.00	
44	7.0	ALL	22095.	3607.	1.79	0.902	0.983	0.918	24500.	3670.	1.96	90.00	3.00	
45	2.0	ALL	19819.	3569.	1.63	0.901	0.983	0.916	22000.	3630.	1.78	90.00	3.00	
46	-3.0	ALL	17998.	3550.	1.49	0.900	0.983	0.915	20000.	3610.	1.62	90.00	3.00	
47	-8.0	ALL	15722.	3540.	1.30	0.898	0.983	0.914	17500.	3600.	1.42	90.00	3.00	

K.C. CPHS WEIGHTED AVERAGE VALUES: 0.905 0.978 0.925

ALL DATA ARE FOR TIDB = 70. DEG-F.

Table 2-4. Performance Map for Optimum Demand Defrost Control
Applied to the Trane Heat Pump

I	TODS	RBO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A
7	42.0	20.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
8	42.0	40.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
9	42.0	60.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
10	42.0	75.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
11	42.0	85.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
12	42.0	95.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
13	37.0	20.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
14	37.0	40.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
15	37.0	60.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
16	37.0	75.0	37615.	4420.	2.49	0.922	0.974	0.946	40817.	4538.	2.64	215.00	3.70
17	37.0	85.0	36447.	4401.	2.43	0.893	0.970	0.921	40817.	4538.	2.64	100.59	3.69
18	37.0	95.0	35582.	4383.	2.38	0.872	0.966	0.903	40817.	4538.	2.64	74.47	3.67
19	32.0	20.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
20	32.0	40.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
21	32.0	60.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
22	32.0	75.0	34260.	4224.	2.38	0.923	0.976	0.945	37137.	4329.	2.51	208.66	3.76
23	32.0	85.0	33331.	4210.	2.32	0.898	0.972	0.923	37137.	4329.	2.51	108.75	3.75
24	32.0	95.0	32629.	4196.	2.28	0.879	0.969	0.906	37137.	4329.	2.51	81.73	3.73
25	27.0	20.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
26	27.0	40.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
27	27.0	60.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
28	27.0	75.0	31668.	4055.	2.29	0.929	0.977	0.950	34099.	4149.	2.41	269.03	3.83
29	27.0	85.0	30910.	4047.	2.24	0.906	0.975	0.929	34099.	4149.	2.41	128.60	3.80
30	27.0	95.0	30321.	4037.	2.20	0.889	0.973	0.914	34099.	4149.	2.41	94.36	3.76
31	22.0	20.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
32	22.0	40.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
33	22.0	60.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
34	22.0	75.0	29448.	3906.	2.21	0.934	0.979	0.954	31545.	3991.	2.32	332.13	3.94
35	22.0	85.0	28847.	3902.	2.17	0.914	0.978	0.935	31545.	3991.	2.32	182.96	3.86
36	22.0	95.0	28353.	3895.	2.13	0.899	0.976	0.921	31545.	3991.	2.32	110.62	3.82
37	17.0	20.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
38	17.0	40.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
39	17.0	60.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
40	17.0	75.0	27714.	3702.	2.15	0.944	0.982	0.961	29367.	3851.	2.23	459.81	3.81
41	17.0	85.0	27063.	3773.	2.10	0.922	0.980	0.941	29367.	3851.	2.23	183.62	3.92
42	17.0	95.0	26650.	3768.	2.07	0.907	0.978	0.928	29367.	3851.	2.23	130.50	3.90
43	12.0	ALL	27486.	3726.	2.16	1.000	1.000	1.000	27486.	3726.	2.16	N/A	N/A
44	7.0	ALL	24500.	3670.	1.96	1.000	1.000	1.000	24500.	3670.	1.96	N/A	N/A
45	2.0	ALL	22000.	3630.	1.78	1.000	1.000	1.000	22000.	3630.	1.78	N/A	N/A
46	-3.0	ALL	20000.	3610.	1.62	1.000	1.000	1.000	20000.	3610.	1.62	N/A	N/A
47	-8.0	ALL	17500.	3600.	1.42	1.000	1.000	1.000	17500.	3600.	1.42	N/A	N/A

K.C. CPERS WEIGHTED AVERAGE VALUES: 0.962 0.989 0.972

ALL DATA ARE FOR TIDS = 70. DEC-F.

All the heat pump models used in the VITT analysis are documented in Appendix C and all heat pump models in the HPSPM data base are documented in Reference 6. The ratings for the Trane heat pump are also listed in Appendix C.

2.3 WEATHER DATA AND SITES

Twelve sites are presently included in the HPSPM data base. These sites have been divided into one group of seven typical sites and one group of five nontypical sites as follows:

<u>Typical</u>	<u>Nontypical</u>
Minneapolis	Seattle
Chicago	Sacramento
Boston	Las Vegas
Philadelphia	Los Angeles
Kansas City	Miami
Dallas	
New Orleans	

The nontypical sites were selected for previous analyses (Reference 3) in which extremes in conditions were of interest. The VITT analysis is concerned more with typical conditions than extreme conditions, and therefore most of the results of Section 3 are based on the seven typical sites listed above.

The weather data for each site are binned by dry-bulb temperature and relative humidity using the same binning structure indicated in Tables 2-1 through 2-4. NOAA five and ten year summaries (Reference 7) have been used for creating the weather data bases. In the NOAA summaries, the hours in each 5°F bin are disaggregated into six relative humidity bins, which is the motive for the binning structure used in the HPSPM. The HPSPM data base actually contains three weather data bases for each site as follows:

Annual: The annual table from the NOAA summaries used without reference to when the conditions occurred during the year.

Six Months: The hours for the months of November through April, representing a "normal" heating season, summed from the NOAA monthly tables.

Estimated Heating Season: The hours for the months that SAI judges to be "heating months" summed from the NOAA monthly tables. The heating season is never less than six months, but is frequently longer than six months.

The Estimated Heating Season data are used for all the VITT evaluations discussed here. For most load model assumptions, the difference in seasonal energy consumption for the "Annual" and "Estimated" heating seasons is less than 2%.

The weather data for all sites are documented in Reference 6.

2.4 HEATING LOAD MODELS

The heating load is assumed to be the sum of three components: infiltration, conduction-only, and internal heat gain. The formulation (Appendix A) is such that for prescribed values of design air changeover rate and internal heat gain, the heating load per square foot of living area at each outdoor dry-bulb temperature is the same for all sites for heat pumps with identically rated cooling capacity. The heat pumps are sized for cooling, and the area of the residence varies between sites based on the cooling design conditions. Since the living area varies, the absolute value of the loads varies, but the Btu/h/ft^2 at each outdoor dry-bulb temperature is identical for all sites using the same heat pump.

One result of the load modeling methodology is that for the same set of assumptions, the outdoor temperature at which the theoretical residence is in heat balance is the same for all sites using the same heat pump. In addition, the total seasonal heat demand for any site is the same for all heat pumps with the same rated cooling capacity.

Although all the results presented in Section 3 are based on the same assumptions regarding infiltration and the conduction-only component of the load, the internal heat gain component is varied to determine the sensitivity of the results to variations in the total heat load. Figure 2-1 illustrates the variations in heat pump balance point temperature, building heat balance temperature, and total heating season heating requirements over a range of internal heat gains from 1 to 6 Btu/h/ft². The range of conditions selected for the sensitivity analysis is at least as great as would be expected to occur in actual application.

The results presented in Appendix A indicate that an internal heat gain of 3-4 Btu/h/ft² is typical; therefore, the "baseline" comparisons are made for a value of 3.5 Btu/h/ft². From Figure 2-1, the seven-site-average baseline heat pump balance point temperature is approximately 25°F and the baseline structure heat balance temperature is approximately 55°F.

Table 2-5 presents a comparison of the HPSPM annual heating requirements for an internal gain of 3.5 Btu/h/ft² with results published by Nall (Reference 3). Nall's analysis used much more sophisticated load calculation procedures. The HPSPM results of Table 2-5 are based on a 1200 ft² living area, which is the value for Nall's typical residence. The behavior from site to site is very similar, however the HPSPM seems to overstates the annual heating requirements at southern sites relative to northern sites. Two possible explanations are that Nall's

a) Seven-Site-Average Heat Pump Balance Point Temperature for 90 FITT Defrost Control

b) Zero Load Temperature for All Sites

c) Seven-Site-Average Annual System Heat Output

Figure 2-1. Load and Heating Demand Variations With Change in Internal Heat Gain Levels in the HPSPM

Table 2-5. Comparison of HPSPM Annual Heating Requirements to Estimates by Nall

SITE	ANNUAL HEATING REQUIREMENT (10^6 Btu)			ANNUAL REQUIREMENT RELATIVE TO MINNEAPOLIS (%)	
	HPSPM	NALL ^a . (Ref. 8)	RATIO	HPSPM	NALL
Typical Sites					
Minneapolis	60.8	50.0	1.22	100%	100%
Chicago	48.9	39.7	1.23	80.4	79.4
Boston	37.4	29.6	1.26	61.5	59.2
Kansas City	33.9	27.1	1.25	55.8	54.2
Philadelphia	31.2	24.5	1.27	51.3	49.0
Dallas	13.3	9.69	1.37	21.9	19.4
New Orleans	5.82	3.60	1.62	9.6	7.2
Other Sites					
Seattle	29.9	22.0	1.36	49.2%	44.0%
Sacramento	13.7	9.16	1.50	22.5	18.3
Las Vegas	13.2	9.30	1.42	21.7	18.6
Los Angeles	3.86	1.66	2.33	6.3	3.3
Miami	0.663	0.0	--	1.1	0.0

a. Best fit algorithm: $0.01 * DD53 - 0.4$

where DD53 is degree days for a 53°F
base temperature

analysis accommodates the greater solar gains that exist at the southern sites, and the "Estimated" heating season used in the HPSPM is six months for the southern sites when it probably should be shorter.

The absolute difference between the HPSPM and Nall annual heating requirements for the first five typical sites of Table 2-5 means that the HPSPM implicitly assumes a less energy efficient building (less insulation, greater infiltration, etc.) than Nall's typical residence.

2.5 MODES OF OPERATION

The HPSPM allows selection of operating modes as follows:

- o Autofan or Continuous Fan, and
- o Cyclic Degradation or Ideal Pulse.

All calculations discussed here assume that the Autofan mode of operation is used, i.e., the indoor fan cycles ON and OFF with the compressor.

The effects of cyclic degradation are not included in the results presented here. The cyclic degradation analytical techniques used in the HPSPM are being reviewed and probably will be revised. Also, since cyclic degradation effects depend on the thermostat models, another variable would be introduced into the analysis if these effects were included in the calculations.

2.6 TEMPERING HEAT

Unless stated otherwise, the calculations assume a level of tempering heat as determined by the algorithms discussed in Appendix A.

3.0 VITT RESULTS

3.1 NOMINAL HEATING LOAD RESULTS

Table 3-1 presents HPSPM seasonal energy consumption results for an assumed internal heat gain of 3.5 Btu/h/ft^2 for eight defrost control systems applied to the Trane heat pump. Both the Honeywell and Ranco controls permit selection of a minimum interval between defrosts. The results of Table 3-1 include two settings for each control system: 60 and 90 minutes. The 90-minute setting is of primary interest, but the 60-minute setting was evaluated for comparison to a 60-minute FITT system.

The bottom row of Table 3-1 lists the percent increase in system energy consumption relative to an ideal heat pump system for the various control strategies. The optimum demand result implies that the unavoidable phenomenon of ice formation requires a minimum expenditure of 3.4% greater energy consumption on average for the Trane heat pump. Actual control systems cause an expenditure of 3.9 to 13.3% on average or 0.5 to 9.9% greater energy consumption than mandated by the climatological conditions and the basic design of the heat pump. The actual demand defrost control system almost achieves the defrost performance effectiveness of an optimum demand defrost control system.

Table 3-2 presents the annual number of defrosts computed by the HPSPM for the different control strategies. The actual demand system defrosts less frequently than the optimum demand system, whereas all other control strategies presented cause a greater number of annual defrosts. Of the non-demand systems, the Honeywell control system produces the fewest number of defrosts, but even the Honeywell control system defrosts 2.5 times as frequently as would an optimum demand system.

Table 3-1. Heating Season Energy Consumption for the Trane Heat Pump With Different Defrost Control Systems

SITE	ANNUAL ENERGY CONSUMPTION (kwh/y)								
	IDEAL	OPTIMUM DEMAND	ACTUAL DEMAND	HONEYWELL @ 90	RANCO @ 90	90 FITT	HONEYWELL @ 60	RANCO @ 60	60 FITT
Minneapolis	24202	25040	25152	25770	26017	26332	26089	26516	27011
Chicago	17001	17718	17827	18380	18595	18758	18676	19048	19298
Boston	11413	11710	11759	12389	12606	12671	12623	12981	13088
Philadelphia	9044	9311	9356	9844	10024	10061	10051	10348	10404
Kansas City	8584	8905	8963	9310	9462	9500	9559	9798	9935
Dallas	2482	2555	2567	2631	2685	2691	2677	2760	2769
New Orleans	1509	1532	1536	1554	1593	1593	1568	1625	1625
Averages	10605	10967	11019	11411	11569	11666	11606	11868	12019
Percent Greater Than Ideal	0%	3.4%	3.9%	7.6%	9.1%	10.0%	9.4%	11.9%	13.3%

Table 3-2. Annual Number of Defrosts for the Trane Heat Pump
With Different Defrost Control Systems

SITE	IDEAL #	OPTIMUM DEMAND #	90 FITT		60 FITT		ACTUAL DEMAND		HONEYWELL @ 90		RANCO @ 90	
			#	% OPT. #	#	% OPT. #	#	% OPT. #	#	% OPT. #	#	% OPT. #
Minneapolis	0	678	2245	331%	3414	504%	498	73%	1407	208%	1779	262%
Chicago	0	640	1928	301	2947	460	469	73	1379	215	1699	265
Boston	0	306	1463	478	2247	734	231	75	1058	346	1372	448
Philadelphia	0	280	1228	439	1891	675	209	75	915	327	1181	422
Kansas City	0	326	1178	361	1811	556	238	73	834	256	1061	325
Dallas	0	95	329	346	510	537	71	75	221	233	321	338
New Orleans	0	32	142	444	221	691	24	75	72	225	142	444
Averages	0	337	1216	--	1863	--	249	--	841	--	1079	--
Percent Based on Averages	0%	100%	--	361%	--	553%	--	74%	--	250%	--	320%

The fewer defrosts of the actual demand control system as compared to the optimum demand system causes an increase in seasonal energy consumption (Table 3-1), because the actual demand control allows the heat pump to operate when there is a large quantity of ice on the coil, a condition for which the instantaneous efficiency (COP) is very low. The optimum strategy indicates that the coil should be cleared of ice earlier in the cycle because the energy expended to clear the ice will be more than returned by more efficient operation after the ice has been removed. It should be noted also that the same factors cause the actual demand defrost control to produce less efficient system operation than either the Honeywell @ 90, Ranco @ 90 or 90 FITT controls for some outdoor temperature/humidity conditions (see the performance maps of Section 2 and Appendix C). However, the conditions for which the actual demand defrost control produces lower efficiencies occur infrequently, so over the course of a season the actual demand defrost control system results in less seasonal energy consumption than all other real systems analyzed.

Figure 3-1 illustrates the energy consumption results of Table 3-1 in a manner that is of particular interest here. Figure 3-1 graphs the percent increase in energy consumption relative to an ideal heat pump system for the seven typical sites and five of the eight defrost control strategies of Table 3-1. The sites are presented in the order of total system seasonal energy consumption. The optimum demand system increases system energy consumption 2-4% depending on the site. The actual demand control system "tracks" the optimum demand system, but is less effective for all sites.

Figure 3-1 lists the values of

$\overline{RH}$ (15-45) = weighted average relative humidity in the defrost region bins from 15 to 45°F

Figure 3-1. Graphic Illustration of the Relative Performance of Different Defrost Control Strategies Relative to a 90 FITT System

for each site. Boston and Philadelphia have lower values of average defrost region relative humidity, which is why the optimum and actual demand defrost control system curves deviate from the parabolic shape characteristic of the results for the timer based strategies. The timer based controls are insensitive to differences in relative humidity because the strategy relies on dry-bulb temperature only. In a sense, the timer based systems are "fooled" by the lower humidity conditions in Boston and Philadelphia.

The increase in relative system energy consumption from New Orleans to Kansas City in Figure 3-1 is caused by the increase in the number of seasonal hours in the defrost region. The decrease in relative system energy consumption from Boston to Minneapolis occurs because the seasonal hours in the defrost region increase less than the seasonal hours at temperatures below the defrost region. A lesser percentage of total system energy consumption is expended in the defrost region in Minneapolis than in Boston, although the absolute value of total system energy consumption expended in the defrost region is greater in Minneapolis than in Boston. Supplementary heaters satisfy most of the load below the defrost region temperatures, which significantly reduces the system COP at those temperatures and therefore increases the relative value of energy consumption required to deliver a fixed amount of heat.

The "HLH" of Figure 3-1 are Heating Load Hours as determined from the HLH map of the DOE test procedures (Reference 1). Heating Load Hours are defined as:

$$HLH = \frac{24 \times DD65}{(65 - TODH)}$$

where

DD65 = annual number of degree days for a 65°F base,

and

TODH = Heating design load temperature.

HLH is an ideal approximation of the annual number of hours that a fossil fired furnace would be ON. As indicated in Figure 3-1, annual compressor ON hours (CPHRS) may be greater than or less than HLH depending on the site, but the behavior of the two are similar, i.e., sites for which HLH is greater are also sites for which CPHRS are greater.

DOE "Regions" are defined by HLH. The regions for each of the seven typical sites are listed under the site names. Region IV is defined by HLH between 2000 and 2500 and Region V by HLH between 2500 and 3000. Chicago has 2500 HLH and is therefore on the boundary between Regions IV and V. Similarly, Kansas City is on or near the boundary between Regions III and IV.

The difference between the results for optimum demand defrost control and 90 FITT defrost control in Figure 3-1 represents the magnitude of the potential energy savings available by improving the defrost control strategy from the 90 FITT method. Optimum demand is the upper limit for improvements, because given the operating characteristics of the underlying heat pump, there is no theoretical or real method for reducing the effects of ice formation below the levels achieved by the optimum demand control strategy.

The percentages in parenthesis in Figure 3-1 are the fractions of the potential improvement that are achieved by the different control strategies. The actual demand system achieves 90-95% of the potential improvement. The Honeywell @ 90 control achieves 29-64% and the Ranco @ 90 achieves 0-24% of the potential improvement.

Figure 3-2 illustrates the percentages achieved by the different control strategies for a baseline system of 60 FITT rather than the 90 FITT of Figure 3-1. Using a 60 FITT system as a baseline, a 90 FITT system becomes an "improvement". The ranges of percentage improvement in Figure 3-2 are 94-96% for the actual demand, 51-76% for the Honeywell @ 90, 34-50% for the Ranco @ 90, and 30-37% for the 90 FITT. Note that the curves for Figures 3-1 and 3-2 are identical for systems that appear on both figures; only the percentages change.

The weighted average percentage of potential improvement can be determined from Table 3-1. For the Honeywell @ 90 and a 90 FITT basis, the calculation is as follows:

$$\begin{array}{lcl} \text{Weighted Average} & & \\ \text{Percent of} & = & 100 \times \frac{11666-11411}{11666-10967} \\ \text{Potential Improvement} & & \end{array}$$

or 36.5%, where the numbers in the equation are taken directly from the "Averages" row of Table 3-1. The following weighted average percentages are based on similar calculations:

	<u>90 FITT Basis</u>	<u>60 FITT Basis</u>
Honeywell @ 90	36.5%	57.8%
Ranco @ 90	13.9%	42.8%
90 FITT	-----	33.6%

3.2 LOAD SENSITIVITY

A sensitivity study of the HPSPM results to changes in internal heat gain produced the curves of Figure 3-3. The corresponding range of annual heat demand and other load variables is illustrated in Figure 2-1.

Figure 3-2. Graphic Illustration of the Relative Performance of Different Defrost Control Strategies Relative to a 60 FITT System

a) Seven-Site-Average Percent of Ideal Heat Pump System Energy Consumption

b) Seven-Site-Average Percent of Optimum Demand Heat Pump System Energy Consumption

c) Seven-Site-Weighted-Average Percent of Optimum-Demand/90-FITT "Delta"

d) Seven-Site-Weighted-Average Percent of Optimum-Demand/60-FITT "Delta"

Figure 3-3. Sensitivity of HPSPM Results for Variations in Internal Heat Gain

It is evident in Figure 3-3 that the HPSPM results presented above for a typical internal heat gain of 3.5 Btu/h/ft² are not significantly different from the results obtained for other values of internal heat gain. The quantizing inherent in binning calculations causes the irregular behavior of some of the curves of Figure 3-3. Reducing the bin size from 5°F to 1°F or smaller would smooth out the curves.

The difference of approximately 6% between the actual demand and 90 FITT curves of Figure 3-3b indicates that the demand defrost credit in the current DOE procedures that produces a 3-4% difference in Region IV HSPF is conservative. The HPSPM results indicate that the credit could be increased. Also a 60 minute timer setting on a FITT system causes approximately 10% greater seasonal energy consumption than a demand system, which corresponds to 1,000 kWh/y for the Trane heat pump. This is clearly significant consumption based on NECPA criteria and criteria published in Reference 9.

Figures 3-3c and 3-3d may be the most meaningful for purposes of DOE regulation. The Ranco @ 90 control improves at larger values of internal gain, because larger internal gains shift a greater fraction of the total heat output to lower temperatures where the Ranco interval between defrosts is greater. The Honeywell @ 90 control is less sensitive because it uses a "two sided ramp" as opposed to the Ranco @ 90 "one sided ramp" as noted in Section 2.2.

3.3 TEMPERING HEAT

The baseline calculations assume that tempering heat is used during the defrost period to prevent cooling of the heated space. The tempering heaters are turned ON at the instant that the heat pump switches into defrost and turned OFF when the heat

pump terminates defrost. The tempering heater output heat compensates for the heat withdrawn from the building during the defrost period.

The assigned capacity of the tempering heaters is determined by algorithms described in Appendix A. The effect of different levels of tempering heat has been examined by setting the capacity of the heaters to zero. The seasonal effects on system energy consumption are presented in Table 3-3.

Tempering heat increases seasonal energy consumption from 0.2 to 2.8% depending on the site and defrost control system as indicated in Table 3-3. The weighted average effect for the seven sites ranges from 0.7 - 1.8% for the different defrost controls. Generally the energy consumption effect is in direct correspondence with the number of defrosts. However, the effect for the actual demand system is greater than for the optimum demand system even though the number of defrosts is less (Table 3-2) because the actual demand system must stay in defrost longer since it allows a greater accumulation of ice between defrosts than does the optimum demand system.

The tempering heater capacities listed in Table 3-3 are larger for the colder sites with the exception of Minneapolis. The sizing algorithm (See Appendix A) does not treat Minneapolis in the same manner as the other sites because the heating design temperature of -10°F is below the lowest temperature bin of -8°F included in the HPSPM. The undersizing is not considered significant.

Tempering heater capacity can not be less than 2.5 kW. The sizing algorithm would assign a 1.1 kW tempering heater to New Orleans if it were not for the lower limit override in the HPSPM.

Table 3-3. Tempering Heat Effects on Heating Season Energy Consumption

DEFROST CONTROL SYSTEM	PERCENT INCREASE IN SEASONAL ENERGY CONSUMPTION CAUSED BY TEMPERING HEAT FOR THE SEVEN TYPICAL SITES		
	MAXIMUM	MINIMUM	WEIGHTED AVERAGE
Optimum Demand	1.0%	0.2%	0.7%
90 FITT	2.5%	0.7%	1.7%
60 FITT	2.8%	0.9%	1.8%
Actual Demand	1.1%	0.2%	0.8%
Honeywell @ 90	2.1%	0.4%	1.5%
Ranco @ 90	2.5%	0.7%	1.8%

Tempering Heater Capacity:

Minneapolis:	8.6 kW
Chicago:	9.0 kW
Boston:	8.6 kW
Philadelphia:	7.9 kW
Kansas City	7.5 kW
Dallas:	3.3 kW
New Orleans:	2.5 kW

It should be noted that the tempering heater capacity is that of the first stage of supplementary heat. Total supplementary heat is larger than the tempering heater capacity if there is more than one stage of heat available. In practice and in the HPSPM, only the first stage of supplementary heat is used during defrost.

The tempering heater capacities are based on the heating capacity of the Trane heat pump, which is rated at 40,000 Btu/h at 47°F and actually produces 44,500 Btu/h at 47°F. For a nominal three ton heat pump, the tempering heater capacities would be:

Chicago:	7.3 - 7.9 kW
Boston:	6.9 - 7.5 kW
Philadelphia:	6.5 - 7.0 kW
Kansas City:	6.1 - 6.6 kW
Dallas:	- 2.7 - 2.9 kW
New Orleans:	2.5 kW

Eliminating tempering heat tends to reduce the "delta" between the seasonal energy consumption for optimum demand defrost control and FITT defrost control. Table 3-4 lists the percentage of potential improvement results of the HPSPM calculations for the assigned levels of tempering heat and for no tempering heat. Eliminating tempering heat improves the theoretical percentage effectiveness of the Honeywell and Ranco controls by approximately 1 to 5%.

Table 3-4. Percent of "Delta" Comparisons with and without Tempering Heat

SITE	PERCENT OF "DELTA" WITH AND WITHOUT TEMPERING HEAT					
	ACTUAL DEMAND		HONEYWELL @ 90		RANCO @ 90	
	TH	No TH	TH	No TH	TH	No TH
<u>Optimum-Demand/90-FITT:</u>						
Minneapolis	91.3%	90.5	43.5%	45.1%	24.4%	27.2%
Chicago	89.5	89.9	36.3	38.3	15.7	18.9
Boston	94.9	95.3	29.8	29.9	7.3	9.4
Philadephia	94.0	94.4	28.9	29.0	4.9	6.4
Kansas City	91.0	91.8	37.2	38.5	13.6	16.6
Dallas	91.1	91.3	44.1	44.3	4.4	5.2
New Orleans	93.4	92.5	63.9	64.2	0.0	0.0
Weighted Average	92.1%	92.1%	36.5%	37.8%	13.9%	16.8%
<u>Optimum-Demand/60-FITT:</u>						
Minneapolis	94.3%	94.1%	63.0%	66.0%	50.4%	55.0%
Chicago	93.1	93.9	58.4	62.5	44.8	50.7
Boston	96.4	96.9	50.7	53.6	35.0	39.9
Philadelphia	95.9	96.4	51.2	53.7	34.8	39.0
Kansas City	94.4	94.8	60.7	60.9	45.9	46.9
Dallas	94.4	94.4	64.5	64.2	39.3	39.1
New Orleans	95.7	95.1	76.3	76.5	34.4	34.6
Weighted Average	94.8%	95.0%	57.8%	60.7%	42.8%	47.4%

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL

VITT defrost controls result in seasonal performance that is more energy efficient than achieved with FITT controls, and less energy efficient than that achievable with demand defrost controls. Defining a "delta" as

$$\text{delta} = (\text{seasonal energy consumption with FITT control}) - (\text{seasonal energy consumption with optimum demand defrost control}),$$

the VITT controls save less than 50% of the "delta". VITT controls do not achieve better results because they are insensitive to relative humidity and therefore cause the heat pump to defrost at low humidity conditions for which no ice forms on the outdoor coil. A demand defrost control system realizes that no ice is accumulating on the coil (even though the dry-bulb temperature might be such as to permit ice formation), and therefore does not initiate defrost cycles.

The Trane heat pump to which the defrost controls have been "applied" in the analysis has an above average efficiency. A lower efficiency heat pump would form ice under conditions for which the Trane heat pump runs "dry", and would form ice more rapidly than the Trane heat pump for conditions under which both accumulate ice on the outdoor coil. Consequently, it is expected that a VITT control system would compare more favorably to an optimum demand system if both were applied to a heat pump with a lower efficiency than that of the Trane heat pump used in the analysis described here.

The Honeywell system and at least one version of the Ranco system are provided with a demand defrost control as a

backup to the primary VITT control. It has been indicated elsewhere that an installer would be inclined to set a FITT system at a lower defrost interval (e.g., 60 minutes) than a VITT system with demand defrost backup, because the installer would know that the demand defrost control would override the VITT control under conditions for which the basic interval selected for the VITT system (e.g., 90 minutes) was inadequate.

The above rationale suggests that comparing a 90 VITT system with demand backup to a 60 FITT system is a fair reflection of field practices. Such a comparison increases the "percent-of-delta" to 57.8% for a seven-site-weighted-average for the Honeywell system and 42.8% for the less complex Ranco system.

Since VITT systems are an energy efficiency improvement compared to FITT systems, it appears appropriate to permit a credit in the DOE procedures for VITT systems. Several methods for establishing the magnitude of the credit have been considered in light of: the regulatory problems that might be created; the accuracy with which calculations reflect actual field performance; the quantity of energy that could be saved; and the inherent limitations of test procedures based on laboratory testing. The simplest approach that has been identified that is consistent with most DOE objectives is as follows:

- o Use HPSPM calculations or the equivalent to establish seasonal energy consumption for four sites: Chicago, Boston, Philadelphia and Kansas City.
- o For VITT systems with demand defrost backup:
 - Allow the full 7% credit if the percent-of-delta for 60 FITT basis is greater than or equal to 50%.
 - No credit otherwise.

- o For VITT systems without demand defrost backup:
 - Allow full 7% credit if the percent-of-delta for 90 FITT basis is greater than or equal to 50%.
 - No credit otherwise.

Since no VITT strategy is envisioned that will satisfy the second credit policy above, it is not expected that any VITT system without demand backup will be able to qualify for the credit.

The seven sites have been reduced to four in the suggested approach, because four sites should be adequate and the required calculations are reduced 43%. The HPSPM results for a four site weighted average are as follows:

	<u>Percent-of-Delta</u>	
	<u>60 FITT Basis</u>	<u>90 FITT Basis</u>
Honeywell @ 90	55.1%	32.9%
Ranco @ 90	40.1%	10.5%

The Honeywell @ 90 system would still qualify for the credit and the Ranco @ 90 would still not qualify.

In theory, a "proportional credit" would be preferable to the "all or none" method suggested above. A proportional credit would be determined by multiplying the 7% credit allowed for demand defrost control systems by the "percent-of-delta". Thus, the Honeywell @ 90 system would receive a credit of 55.1% of 7%. The difficulties that would be created by proportional credits are regulatory. Each and every VITT system in each of its possible configurations would have a different credit. Maintaining control over such a system could be more burdensome to the government and industry than justifiable in terms of energy saved.

Furthermore, a true proportional credit approach should recognize the differences between different implementations of demand defrost control. For example, the actual demand defrost control used in the analysis should receive only 90-95% of the 7% credit, not the full 7%. Incorporating demand defrost control systems in a proportional credit system could create such a burden on the industry as to cause the manufacturers to stop using demand defrost controls at all. The problem is the very extensive testing that would be required to model the performance of a particular demand defrost control system as a function of dry-bulb temperature and relative humidity. Simple analytical models do not exist to SAI's knowledge.

Under the all-or-none allocation method, there is an implicit presumption that any actual demand defrost control will achieve 50% of the delta or more. The presumption appears to be justifiable based on the analytical results of Figures 3-1 and 3-2, and the fact that all demand defrost systems benefit most from not defrosting at all in the low humidity bins in the defrost region in the HPSPM. Thus, the potential criticism that "demand defrost systems receive the credit no matter how poorly they may be designed" would appear to be without merit, because even a poorly designed demand defrost control should achieve 50% of the delta.

The results of the analysis could be used to argue that no credit should be permitted for VITT systems because they perform poorly compared to demand defrost control systems. The response to such a proposition is that the DOE does not intend to prescribe the type of defrost control system, but rather reflect the energy consumption differences of existing controls in the test procedures. If new defrost control system designs save energy as compared to FITT defrost controls, the DOE expects to allow a credit for the improved level of performance. Some manufacturers apparently believe that no existing demand defrost

control system nor any that they could develop at reasonable cost is sufficiently reliable. However, the same manufacturers may well believe that they can use or develop VITT controls that save energy and meet their reliability criteria. The fact that the DOE test procedures do not presently recognize the energy savings of VITT systems as compared to FITT systems could therefore serve as an institutional impediment to the development and use of VITT defrost control systems.

The recommendation that VITT systems with demand defrost backup be compared to 60 FITT systems suffers from the logical fact that the present test procedures assume that FITT systems in the field are set for 90 minute defrost intervals, not 60 minute intervals. It would be more self consistent to:

- o Either compare 120 VITT systems to 90 FITT systems,
- o Or make the interval between defrosts 60 minutes for FITT systems in the DOE procedures.

Presently, manufacturers apparently have taken the position that a typical field setting is 90 minutes when DOE test procedures are discussed and 60 minutes when the energy savings of VITT systems are discussed. It is recommended that the DOE change the interval between defrosts in the test procedure for FITT systems to 60 minutes, and revert back to a 90 minute setting only if the data can be produced that show that 90 minutes is indeed typical.

4.2 HPSPM MODIFICATIONS

Several modifications to the HPSPM are recommended if the HPSPM is to be used to establish whether a particular VITT strategy qualifies for the 7% credit. The two highest priority modifications are:

1. Restructuring of the binning method to reduce the bin size to 1°F or smaller in dry-bulb temperature, and 5% or smaller in relative humidity; and
2. Merging of the Trane heat pump model into the HPSPM.

At present two analyses are required: a heat pump performance characteristics analysis that determines performance characteristics as a function of the interval between defrosts; and an HPSPM analysis that uses the performance characteristics to calculate seasonal heat pump system energy consumption. A merged computer program would eliminate the manual interface that presently exists. The user would simply input the interval between defrost for each dry-bulb temperature and the computer program would create the performance model internally and make the seasonal performance calculations.

The binning approach used in the HPSPM creates "quantizing errors", e.g., doubling the number of bins but maintaining the same total number of seasonal hours would produce slightly different results. Under most circumstances, the differences are not significant; however, if the HPSPM is to be used as a standardized program for determining whether particular defrost control systems qualify for credit, the quantization errors could be significant. The accuracy requirement for defrost credit decisions is approximately 1% of the "delta", which in turn is less than 10% of the seasonal energy consumption. The present binning structure probably does not satisfy such an accuracy requirement. Thus, a system that achieves 49% of the delta by an HPSPM analysis might in fact achieve 51% if the quantizing errors were reduced. The potential problem can be eliminated by reducing the bin size.

Another enhancement that would be desirable is to model several more heat pumps for their defrost region performance as a

function of the interval between defrosts. The present approach relies on test data and analysis of just one heat pump that may not be typical. More models are not included in the data base because the test data necessary for creating the models are not available.

It might also be desirable to define and use generic weather data for Regions I-VI rather than weather data for specific sites. The present DOE test procedures define generic data binned in dry-bulb temperature, but not relative humidity. The hours in each DOE bin could be disaggregated into relative humidity bins according to a "typical" distribution in each region, and the HPSPM analyses could be conducted by regions rather than by specific sites.

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3. Rettberg, R.J., and Smith, C., "Energy Efficiency Program for Room Air Conditioners, Central Air Conditioners, Dehumidifiers, and Heat Pumps," Science Applications, Inc., SAI-77-858-LJ, March 1978.
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APPENDIX A

Modifications to the HPSPM
for the VITT Defrost Control System
Evaluation

APPENDIX A

Modifications to the HPSPM for the VITT Defrost Control System Evaluations

A.1 GENERAL

Several modifications have been made to the HPSPM in the course of conducting the VITT defrost control system evaluations. The modifications are of general applicability and therefore are expected to be retained in future versions of the HPSPM. The specific changes that have been made are as follows:

- o The tempering heater capacity selection procedure has been revised;
- o Each site has been assigned three weather data bases; the one that is used is selected by the user.
- o Internal heat gain per square foot of living area has been added as an input variable.
- o The load models have been revised.
- o The thermostat operation has been modified.

Each of the modifications is discussed separately below.

A.2 TEMPERING HEAT

The original HPSPM did not include tempering heat. An intermediate version incorporated tempering heat with the capacity of the heater specified by the user. The only difficulty with the intermediate approach was that if a series of sites and heat pump models were being analyzed, either all the cases would use the same level of tempering heater capacity, or

each case would have to be run separately. Also the capacity used would be somewhat arbitrary, depending on what the user felt was appropriate.

The latest version calculates the capacity of the tempering heater automatically. The calculations are based on the peak capacity of the heat pump as defined by the "performance maps" (cf. Appendices B and C) and the heating/cooling design conditions for the site.

A design heating load line is defined by assuming linear behavior of the load between zero load at 70°F and design heating load at the heating design temperature. The heat pump performance versus the design load defines a design balance point temperature. The tempering heater capacity is then selected as described in Appendix B using the design heating temperature, design heating load, heat pump capacity at the design heating load, and design balance point temperature in the calculations.

It would be more conventional to use integrated capacity as specified in the performance maps in the tempering heater capacity selection process, since the HVAC installer would presumably be provided with tables or graphs of integrated capacity versus outdoor dry-bulb temperature and use the integrated values in his analyses. However, in the VITT analyses, the integrated capacity is different for each different defrost control strategy, which would cause the tempering heater capacity to be different for each strategy, even though the underlying heat pump is identical. The potential interpretation-of-results problems that could occur are avoided by using peak capacity as the sizing variable.

The heat pump capacity characteristic for tempering heater sizing is defined as the peak capacity for those bins outside the defrost region, and as

90% x Peak Capacity @ 75% RH

for those bins in the defrost region. The 10% loss in capacity in the defrost region is typical for a 90 FITT defrost control in the defrost region.

The net result is that all heat pumps with the same peak capacities produce identical values of tempering heater capacity in the HPSPM.

A tempering heater capacity scale factor has been added as a user specified variable. The user can increase or decrease the tempering heater capacity by setting the variable, SHSF, at a value greater than or less than one respectively, i.e., for SHSF equal to zero, all tempering heater capacities become zero.

Appendix B presents a sample case that provides additional details of the treatment of tempering heat in the HPSPM.

A.3 WEATHER DATA BASES

The original HPSPM used the weather data presented in the annual tables of the NOAA five and ten year summaries for the site. The original weather data bases have been retained, and two more have been added for each site. The three weather data bases for each site are now as follows:

Annual: The annual table from the NOAA summaries is used without reference to when the conditions occurred during the year.

Six Months: The hours for the months of November through April, representing a "normal" heating season, are summed from the NOAA monthly tables.

Estimated Heating Season: The hours for the months that SAI judges to be "heating months" are summed from the NOAA monthly tables. The heating season is never less than six months, but is frequently longer than six months.

A user specified input variable has been added for selection of the type of weather data base:

"ANN" for Annual,

"SIX" for the Six Month Seasonal Heating Season, and

"EST" for the Estimated Heating Season.

Reference A1 contains more detailed information on the three types of weather data bases for the sites.

A.4 LOAD MODELS

The original HPSPM used linear load models based on the heating design load at the heating design temperature and zero load at 65°F. An intermediate version disaggregated the load into three components.

QII: Internal heat gain,

QTRAN: Transmission-only heat loss, and

QINF: Infiltration heat loss.

The algorithms used in the intermediate versions were based on the results of a Seasonal Performance Model Load (SPMLD) computerized analysis for Kansas City. Subsequently the SPMLD analysis was expanded to include other sites, and the algorithms were modified (Reference A2).

The revised treatment of QII is as follows:

$$QII = QIIPSF \times RESAREA$$

where

QIIPSF: User specified value of internal heat gain in Btu/h/ft², and

RESAREA: Area of the residence in ft².

Section A.7 discusses the ranges of QIIPSF obtained from utility records and SAI calculations for 29 residences. The data analyzed indicate that a nominal range of QIIPSF is 2-6 Btu/h/ft², with 3-4 Btu/h/ft² being typical. The present structure of the HPSPM accepts any value for QIIPSF because the range of actual values is significant. In addition, making QIIPSF a user specified variable enables the user to perform load sensitivity analyses.

The algorithm in the HPSPM for QTRAN has been revised to

$$QTRAN = 0.68 \times \frac{QHDL}{70-TODH} \times (65-TODB)$$

where

QHDL: The estimated Manual J design heating load,

TODB: Outdoor dry-bulb temperature, and

TODH: Heating design temperature.

The term

$$\frac{QHDL}{70-TODH}$$

is the design level of total heating load in Btu/h/°F, and is invariant in the HPSPM approach for residences of the same living area. Thus if TODH differs between sites so does QHDL, but if the area of the residence stays constant, so does the above ratio.

The SPMLD analyses of Reference A2 indicate that approximately 65% of the Manual J design heating load is the

result of transmission losses. The above algorithm assumes approximately 68% of the Manufal J design heating load is the result of transmission losses, because the SPMLD residence was heavily insulated, and other analyses (Reference A3) indicate that 60-75% is a typical range of values.

The final multiplier in the algorithm above causes QTRAN to be zero at 65°F.

The algorithm for QINF is

$$\begin{aligned} \text{QINF} &= \text{NACH} \times (\text{Residence Volume}) \\ &\quad \times 0.075 \times 0.24 \times (70 - \text{TODB}) \end{aligned}$$

where

$$\begin{aligned} \text{NACH} &= \text{NACH}(\text{DESIGN}) \times (0.38475 \\ &\quad + 0.00577125 \times (70 - \text{TODB})). \end{aligned}$$

For a "design" air changeover rate, NACH(DESIGN), of 1 per hour and an indoor to outdoor temperature difference of 20°F, the above algorithm produces an actual air changeover rate at 0.5 per hour. The 0.5 per hour for a 20°F temperature difference was selected as a basis, because, for cooling, a value of 0.5 per hour is generally accepted as typical for a temperature difference of 20°F. Similar guidance for heating has not been identified except that it is generally stated that the air changeover rate for heating is greater than that for cooling. The above algorithm makes the air changeover rate greater than that for cooling for all outdoor temperatures below 50°F. The change in NACH with outdoor temperature is based on the revised SPMLD results of Reference A2.

Appendix B presents an example case that provides additional details of the treatment of heating loads in the HPSPM.

A.5

THERMOSTAT OPERATION

The thermostat models have not been revised, but the method of employing the Percent-On-Time thermostat model has been modified. For purposes of determining the cycle rate, FCY, the peak capacities of the heat pumps are used to determine an ideal percent-on-time. The ideal percent-on-time so calculated is increased by the effects of one turn-on time constant and the final value of FCY is determined based on the revised ideal percent-on-time.

Basing FCY on calculations involving peak capacity rather than integrated capacity causes FCY to be equal for all heat pumps with the same peak capacity values. Thus for the VITT defrost control system evaluations, all the heat pump models cycle as frequently in all the bins because all of the models are based on the same Trane heat pump. This feature is of little if any significance for calculations in which cyclic degradation is not considered, but avoids a problem of confusing different effects when both cyclic degradation and different defrost control strategies are being evaluated simultaneously.

A.6

TYPICAL RANGES OF INTERNAL HEAT GAIN

The SPMLD analyses of Reference A2 assumed internal heat gains equal to the values used in the original HPSPM which were as follows:

People: 250 Btu/h/500 ft²

Appliances: 250 Btu/h/500 ft²

for a total of

$$Q_{II} = 1 \text{ Btu/h/ft}^2.$$

Reference A4 data indicate that the above value is, in general, too small and the actual value varies significantly among households. The HPSPM therefore has been modified to permit the internal heat gain value per unit floor area to be an input variable, QIIPSF.

An appliance energy utilization computer program was developed for the Reference A4 evaluations. The computer program accounted for the energy consumption of all appliances and lighting in residences used in a companion field study. Actual utility records were made available for the field study residences.

The electricity consumption as determined from utility records was accounted for with less than 2% error on average by the audit of the individual appliances and lighting. The electric appliances located at the 29 residences included: a refrigerator, a dishwasher, a clothes washer, televisions and an assortment of miscellaneous loads such as clocks. The internal heat from these sources excluding the clothes washer and the electricity consumption of the clothes dryer motor, was approximately

11 to 13 kWh/day,

or

1550 to 1850 Btu/h.

The residences examined had a natural gas range, clothes dryer, water heater and furnace. The accounting for natural gas energy consumption was accurate within 7% on average for an early summer billing period when space heating was not required. The natural gas appliances were assumed to provide internal heat gain as follows:

- o Range at 100%;
- o Clothes dryer: no contribution because the clothes dryers were located outside the heated space; and
- o Water heater: half the energy content of the water. No standby loss or other contributions because the water heaters were located outside the heated space.

The internal heat as a percentage of total natural gas consumption averaged approximately 25% for the above conditions and assumptions. Total natural gas consumption averaged

120,000 to 150,000 Btu/day,

which for a 25% conversion factor produces

30,000 to 40,000 Btu/day

or

1250 to 1650 Btu/h

internal heat gain. Much of the internal heat gain is accounted for by the water heat. If 550 gallons of hot water is consumed per week and half the energy put into the water to raise it 85°F is eventually delivered to the heated space, the internal heat gain is approximately 1150 Btu/h.

The final component of internal heat gain is the sensible heat generated by the people present in the residence. Assuming that each person is present 50% of the time results in an average heat gain of

125 Btu/h/person,

which for the average number of occupants of Reference A4 of 3.885 people per residence is:

485 Btu/h.

The three results are thus:

Electric appliance and lighting component:	1550 to 1350 Btu/h
Natural gas appliance component:	<u>1250 to 1650 Btu/h</u>
Total appliance and lighting:	2800 to 3500 Btu/h
Residents	485
Grand Total	<u>3300 to 4000 Btu/h</u>

The residences in the Reference A4 study averaged 1035 ft^2 in living area. Converting the above internal gains to a per square foot basis results in

$$3.1 \text{ to } 3.8 \text{ Btu/h/ft}^2$$

of internal heat gain.

Further examination of the data for individual residences indicates that the range of values is approximately 2 to 6 Btu/h/ft² with 3 to 4 Btu/h/ft² being characteristic of medium density and average use.

A.7 APPENDIX A REFERENCES

- A1 _____, "Heat Pump Seasonal Performance Model (HPSPM) Data Bases," Science Applications, Inc., SAI-444-80-473-LJ. To be published.
- A2 _____, "Additional Cooling and Heating Load Improvements in Seasonal Performance Modeling of Room and Central Air Conditioners and Heat Pumps," Science Applications, Inc., SAI-444-80-311-LJ, 9 April 1980.

- A3 ASHRAE Handbook and Product Directory: 1977
Fundamentals, Chapter 24, American Society of Heating,
Refrigerating and Air Conditioning Engineers, 1977.
- A4 Huston, K.J., and Erickson, R. "The Utility Norm Analysis
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APPENDIX B

An Example HPSPM Output

APPENDIX B
An Example HPSPM Output

B.1 DISCUSSION

The set of HPSPM output listings included below is a composition of the following subsets of output:

Heat Pump Performance Map:	Page 1
Heating Load Data:	Pages 2 & 3
Seasonal Performance Results:	Page 4
Tempering Heat Details:	Page 5

The output listings for each subset of information are discussed separately below.

B.2 HEAT PUMP PERFORMANCE MAP

The data listed on the heat pump performance map are as follows:

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

TODB: Outdoor dry-bulb temperature for the bin in $^{\circ}\text{F}$.

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 45°F .

TOTCAP: Total capacity in Btu/h.

TOTPWR: Total power in W.

COP: Coefficient of performance.

D-D: Time between defrosts in minutes.

DUR: Duration of defrost in minutes.

"N/A" in the "Defrost Times" columns stands for Not Applicable. The heat pump does not defrost in the bins which contain N/A under Defrost Times.

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". Perhaps the COP Defrost Performance Factor is the most illuminating. At 42°F (Bins 7-12) the Trane heat pump does not form ice on the outdoor coil because the outdoor coil temperature is above 32°F (approximately at 34°F); however, it is assumed that the set-point for the timer is above 42°F so the heat pump defrosts even though defrosts are not necessary. There is a 7.2% reduction in COP created by the defrost cycles in the 42°F bins.

At 37°F (Bins 13-18) the heat pump does not form ice at 20, 40 or 60% relative humidity because the coil temperature is above the dewpoint temperature for these relative humidities. The heat pump does not require defrosting but defrosts anyhow because of the control strategy, and COP is reduced 7.3%. In the 75, 85 and 95% relative humidity bins, ice does form and defrosting is necessary. The loss in COP increases from 7.9% in the 75% relative humidity bin to 10.4% in the 95% relative humidity bin. The duration of defrost is longer in the higher humidity bins because there is a greater accumulation of ice between defrosts.

It is notable that the integrated power is less than the peak power. The reasons are that: power draw during defrost is less than during heating; and power draw with a large quantity of ice on the coil is less than the clear coil power draw. However, while integrated power is reduced 2-4%, integrated capacity is reduced 9-15% resulting in a net reduction in COP.

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 7.5% lesser efficiency in Kansas City than would be the case if defrosting was not necessary and the heat pump could operate at peak, clear coil capacity at all times.

B.3 HEATING LOAD DATA

The column headings on Page 2 have the following meanings:

I:	Bin number. There are 47 bins from -8°F to 72°F. 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 62°F.
TODB:	Outdoor dry-bulb temperature for the bin in °F.
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 45°F.
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 #/h.

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.

KBTUTOT: Heat requirement for the bin in kBtu.

The footnote variables are as follows:

QIIPSF: Input value of internal heat gain in Btu/h/ft².

ZLTEMP: The dry-bulb temperature in °F for which QTOTAL is zero.

The second page of load data includes "Cooling Design Load Components" which are used to size the heating load to the heat pump. The heat pump is sized according to its cooling capacity and the cooling design conditions. The cooling variables are:

TODC: Cooling design temperature in °F.

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

QCSDL: Total cooling design sensible load in Btu/h.

RESVOL (W/O SF): Volume of the residence in which the heat pump is located based on cooling conditions and cooling capacity only, and not considering the load scale factor (SFLOAD).

RESAREA (W/O SF): Area of the residence in which the heat pump is located based on cooling conditions and cooling capacity only, and not considering the load scale factor (SFLOAD).

For the example presented, the cooling design load analysis, which is based on Manual J methods, determines that the heat pump will be installed in a 2108 ft² residence for the Kansas City cooling design temperature of 95°F with a "medium" daily range in temperature.

The heating reference design load of 55814 is calculated according to:

$$55814 = 2.0 \times \text{QCSDL} \times \text{SFLOAD}$$

Under normal circumstances, SFLOAD would equal 1, in which case the load analysis simply indicates that for a site with a 95°F cooling design temperature, and a heating design temperature of 10°F, which produces a heating design delta temperature of 70-10 or 60°F, the design heating load is typically twice the cooling design sensible load.

SFLOAD is introduced to adjust for heat pump heating performance that is different from rated performance. For the example heat pump, the performance model value of heating capacity at 47°F, which is based on test data, is 44,500 Btu/h, whereas the product rating is 40,000 Btu/h. Rather than reduce the test data to agree with the rating data, the computer program increases the design heating load values to agree with the performance data. An 11.25% increase is required for the example heat pump.

For the example site:

TODH: Heating design temperature in °F,

is 5°F, and the design delta temperature is 70-5 or 65°F, not the 60°F assumed in calculating the reference heating design load. The final adjustment in determining

QHDL: Heating design load in Btu/h,

is as follows:

$$\begin{aligned} \text{QHDL} &= \frac{\text{Actual Design Delta Temperature}}{60} \times 55814 \\ &= \frac{65}{60} \times 55814 \end{aligned}$$

or 60465 Btu/h.

SFLOAD is used to adjust the residence area and volume as well as the design heating load, because RESVOL and RESAREA are used in the calculations of the operating load components QINF and QII respectively.

Returning to the first page of load results,

$$\begin{aligned} \text{QII} &= -\text{QIIPSF} \times \text{RESAREA (W/ SF)} \\ &= -3.5 \times 2345 \\ &= -8207 \text{ Btu/h.} \end{aligned}$$

The transmitted load component, QTRAN, is calculated as follows for an outdoor dry-bulb temperature of 42°F:

$$\begin{aligned} \text{QTRAN} &= 0.68 \times \frac{60,465}{(70-5)} \times (65-42) \\ &= 14,549 \text{ Btu/h.} \end{aligned}$$

QTRAN is the only load component actually based on the design heating load.

The final load component is determined as follows:

$$\begin{aligned}
 QINF &= NACH \times RESVOL (W/ SF) \\
 &\quad \times 0.075 (lb/ft^3) \\
 &\quad \times 0.24 (Btu/lb/^{\circ}F) \\
 &\quad \times (70 - TODB).
 \end{aligned}$$

For

$$\begin{aligned}
 TODB &= 42^{\circ}F, \\
 QINF &= 0.546 \times 18,760 \times 0.075 \\
 &\quad \times 0.24 \times (70-42) \\
 &= 5166 \text{ Btu/h.}
 \end{aligned}$$

The air changeover rate is determined from the following algorithm:

$$\begin{aligned}
 NACH &= NACH (DESIGN) \\
 &\quad \times (0.385 + 0.00577 (70-TODB))
 \end{aligned}$$

which for

$$NACH (DESIGN) = 1,$$

and

$$TODB = 42$$

becomes

$$\begin{aligned}
 NACH &= 1 \times (0.385 + 0.00577 (70-42)) \\
 &= 0.546,
 \end{aligned}$$

which is the value listed.

The total heat requirement is determined by

$$KBTUTOT = \text{HEATING-HRS} \times QTOTAL/1000,$$

which at 47°F for the example becomes:

$$\begin{aligned} \text{KBTUTOT} &= 554 \times 7198/1000 \\ &= 3986 \text{ kBtu.} \end{aligned}$$

The total seasonal heat requirement for the example is 66.3 million Btu.

The second page of load data presents results based on the calculations in the DOE test procedures. The DOE average heating load assigned to a heat pump that produces 44,500 Btu/h capacity under the DOE test at 47°F would be 51,398 Btu/h at 5°F and zero load at 65°F. The values cited are operating load values used in the DOE bin calculations. In contrast, QTOTAL at 5°F is 46,435 Btu/h based on interpolation in the table.

The DOE average heating requirement for the example heat pump and site is 101.4 million Btu compared to the 66.3 million Btu of the table summation.

The DOE results are calculated as follows:

$$\text{DOE Load @ TODH} = \frac{0.77 \times k \times (\text{Capacity @ 47°F}) \times (65 - \text{TODH})}{60}$$

where

$$\begin{aligned} k &= 1.5 \text{ for Regions I-IV and VI} \\ &= 1.6 \text{ for Region VI.} \end{aligned}$$

The values of k are averages of the values for "min" and "max" in the DOE procedures. Thus for the example product and the Region I-IV value of k,

$$\begin{aligned}\text{DOE Load @ TODH} &= \frac{0.77 \times 1.5 \times 44,500 \times (65-5)}{60} \\ &= 51,398 \text{ Btu/h.}\end{aligned}$$

The DOE output is calculated from:

$$\text{DOE Heating Output} = \frac{(\text{DOE Load @ TODH}) \times 24 \times \text{DEGDYS}}{1,000 \times (65 - \text{TODH})}$$

where

$$\text{DEGDYS} = \frac{\sum \text{HEATING-HRS} \times (65 - \text{TODH})}{24.}$$

As indicated in Section B.4, the DEGDYS for the weather data used in the example equals 4932 for which

$$\begin{aligned}\text{DOE Heating Output} &= \frac{51,398 \times 24 \times 4932}{1000 \times (65-5)} \\ &= 101,405 \text{ kBtu}\end{aligned}$$

for Regions I-IV and VI.

B.4 SEASONAL PERFORMANCE DATA

The variables listed above the table of seasonal performance data are defined as follows:

ICYCLE:	Cyclic degradation flag. If zero, cyclic degradation is not included in the calculations. If 1, cyclic degradation is included in the calculations.
IAF:	Autofan flag. If zero, continuous fan operation is assumed. If 1, autofan mode is assumed (indoor fan cycles ON and OFF with the compressor).

TIDB: Indoor dry-bulb temperature in °F.

NACH (DESIGN): Design air changeover rate in #/h.

QIIPSF: Internal heat gain in Btu/h/ft².

TSTAT: Thermostat model to be used. NEW is a parabolic model based on percent ON-time. OLD is a parabolic model based on outdoor dry-bulb temperature.

SHSF: Supplementary heat scale factor.

All of the above are input variables to the computer program. The only other inputs are the identification flags for the heat pump and site weather data bases.

The table headings have the following definitions:

I: Bin number. There are 47 bins from -8°F to 72°F. 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 for the bin in °F.

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 45°F.

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 ON 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.

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.

FYC: The ON/OFF cycle rate in $\#/h$.

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.

Since cyclic degradation is not included in the example calculations, the APCT-ON and PW-ACT columns duplicate the IPCT-ON and PW-I columns with the minor exception that when the heat pump

"ideally" would be ON over 100% of the time, it "actually" is limited to being ON 100% of the time. 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 are not particularly menaingful, 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 tabular data indicate the the heat pump would produce the average value of HP-CAP at an outdoor temperature between 27 and 32°F (29.6°F by linear interpretation of dry-coil capacities) and the average COP would occur for an outdoor temperature between 27 and 32°F (29.7°F by linear interpolation of dry-coil COPs).

The footnoted 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 in °F. Part load operation does not occur in any bin with a dry-bulb temperature less than TBPNOM.

TBPDY: Dry coil balance point temperature in °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 that results from design heating load calculations in °F. Since design loads are invariably greater than operating loads, TBPDES is invariably greater than TBPDY.

SlKW: The capacity of the first stage of supplementary heat in kW. The tempering heater capacity is SlKW.

ZLTEMP: The zero load temperature or structure heat balance temperature in °F. ZLTEMP is calculated by linear interpolation. TODB for the first bin listed is always the highest bin temperature that is also less than ZLTEMP.

DEGDYS(ABOVE): Heating degree days for the hourly weather data presented for a base temperature of 65°F, 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 65°F.

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.

DOE Heating Load Hours and "Equivalent Full Load Hours" are different labels for the same weather data characteristic.

B.5 TEMPERING HEAT DETAILS

The column headings for the Tempering Heat Details listing have the following meanings:

I: Bin number. There are 47 bins from -8°F to 72°F. This table starts with bin 7 because defrosts do not occur for outdoor dry-bulb temperatures of 47°F 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 approximately (cf. below) equals $60 \times \text{CPHRS} / \text{TIM}(\text{D-D})$.

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 $\# \text{DEF} \times \text{TIM}(\text{DUR}) / 60$.

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. Using the terminology "Original" and "Adjusted", the procedure is as follows:

1. Calculate

$$\# \text{ DEF} = \frac{\text{CPHRS (Original)} \times 60}{\text{TIM}(\text{D-D})}$$

2. Calculate TH-ON, TH-OUT and TH-IN as noted above.

3. Revise the heat pump seasonal results to reflect the effects of the tempering heat as follows:

- a. Heat Pump Output (Revised)
= Heat Pump Output (Original) - (TH-OUT).
- b. CPHRS (Revised) = CPHRS (Original)
- (TH-OUT)/(Heat Pump Capacity)
- c. Heat pump input = CPHRS (Revised)
x Heat pump power.
- d. DELTIM = 60 x (CPHRS (Revised))
- CPHRS (Original))/(FCY x HRS)
where FCY and HRS are defined in Section B.3.
- e. Heat pump ON time per cycle (Revised)
= Original value - DELTIM.
- f. Percent ON time of the heat pump (Revised)
= 100 x (ON time per cycle (revised))
x FCY/60.

The bottom portion of the listing describes the analytical results from the tempering heater sizing calculations. The design load is that obtained from the analysis described in Section B.2. The heat pump capacity at the heating design temperature is determined by linear interpolation of the performance map data. The difference between the heating design load and the heat pump capacity is the total supplementary heater capacity required. The input variable SHSF can be used to oversize or undersize the total supplementary heater capacity.

Tempering heat is provided by the first stage of supplementary heat. The following algorithm is used to establish what fraction of the total supplementary heat will be assigned to the first stage:

$$\text{State 1 Percent} = 10^A,$$

where

$$A = 1.465 + 0.01025 \times (60 - (\text{TBPDES} - \text{TODH}))$$

and where TBPDES is the balance point temperature based on the heating design load analysis, and TODH is the heating design temperature.

The theory on which the algorithm is based is as follows:

- o For TBPDES-TODH less than 20°F , one stage of supplementary heat will be used;
- o For TBPDES-TODH from 20 - 40°F , two stages of supplementary heat will be used;
- o For each succeeding 20°F increment in TBPDES-TODH, an additional stage of supplementary heat will be added;
- o At the one/two stage switch point of 20°F for TBPDES-TODH, the first stage supplementary heat will switch from 100% to 50% of the total or have an average value at the discontinuity of 75% of the total;
- o At the three/four stage switch point of 60°F for TBPDES-TODH, the first stage supplementary heat will switch from 33% to 25% of the total or have an average value at the discontinuity of 29%.
- o A linear fit to a semilogarithmic graph of the two percentages cited above versus TBPDES-TODH produces the algorithm used in the calculations.

The equation for Stage 1 Percent listed above does in fact equal 29% and 75% for TBPDES-TODH equal to 60 and 20°F respectively.

For the example presented, TBPDES-TODH equals 28.21°F , and the corresponding percentage is 62%. In reality, two stages of supplementary heat would probably be used for the example conditions, in which case the real percentage would likely be 50%. However, if the temperature difference were 40°F instead of the 28.21°F of the example, the algorithm produces a percentage of 46% whereas the real percentage-would likely be 50%. Thus,

the desire to smooth out a phenomenon that in reality is discontinuous causes oversizing of the tempering heater capacity under some conditions and undersizing under other conditions. Since field practices vary, the type of compromise used in the HPSPM is virtually unavoidable.

The algorithms used for sizing the tempering heat capacity assume that no less than

$$\text{SHSF} \times 2.5 \text{ kW}$$

will ever be installed in a heat pump system of any capacity for any design conditions.

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

4 --- TRANE W/ 90 MIN TIME/TEMP DEFROST (5/5/80 DATA).

I	TODS	RHO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPNR	COP	CAP	POWER	COP	TOTCAP	TOTPNR	COP	D-D	DUR
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A
7	42.0	20.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
8	42.0	40.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
9	42.0	60.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
10	42.0	75.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
11	42.0	85.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
12	42.0	95.0	38757.	4576.	2.48	0.906	0.976	0.928	42800.	4690.	2.67	90.00	3.00
13	37.0	20.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00
14	37.0	40.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00
15	37.0	60.0	36951.	4431.	2.44	0.905	0.976	0.927	40817.	4538.	2.64	90.00	3.00
16	37.0	75.0	36560.	4412.	2.43	0.896	0.972	0.921	40817.	4538.	2.64	90.24	3.24
17	37.0	85.0	36377.	4404.	2.42	0.891	0.970	0.918	40817.	4538.	2.64	90.44	3.44
18	37.0	95.0	35073.	4350.	2.36	0.859	0.959	0.896	40817.	4538.	2.64	90.23	5.03
19	32.0	20.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00
20	32.0	40.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00
21	32.0	60.0	33601.	4233.	2.33	0.905	0.978	0.925	37137.	4329.	2.51	90.00	3.00
22	32.0	75.0	33271.	4217.	2.31	0.896	0.974	0.920	37137.	4329.	2.51	90.25	3.25
23	32.0	85.0	33175.	4213.	2.31	0.893	0.973	0.918	37137.	4329.	2.51	90.35	3.35
24	32.0	95.0	32524.	4187.	2.28	0.876	0.967	0.906	37137.	4329.	2.51	90.36	4.26
25	27.0	20.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00
26	27.0	40.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00
27	27.0	60.0	30834.	4062.	2.22	0.904	0.979	0.924	34099.	4149.	2.41	90.00	3.00
28	27.0	75.0	30576.	4049.	2.21	0.897	0.976	0.919	34099.	4149.	2.41	90.23	3.23
29	27.0	85.0	30515.	4046.	2.21	0.895	0.975	0.918	34099.	4149.	2.41	90.29	3.29
30	27.0	95.0	30304.	4039.	2.20	0.889	0.973	0.913	34099.	4149.	2.41	89.70	3.60
31	22.0	20.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00
32	22.0	40.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00
33	22.0	60.0	28509.	3912.	2.14	0.904	0.980	0.922	31545.	3991.	2.32	90.00	3.00
34	22.0	75.0	28310.	3902.	2.13	0.897	0.978	0.918	31545.	3991.	2.32	90.21	3.21
35	22.0	85.0	28246.	3899.	2.12	0.895	0.977	0.916	31545.	3991.	2.32	90.28	3.28
36	22.0	95.0	28195.	3897.	2.12	0.894	0.977	0.915	31545.	3991.	2.32	90.36	3.36
37	17.0	20.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00
38	17.0	40.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00
39	17.0	60.0	26526.	3779.	2.06	0.903	0.981	0.921	29367.	3851.	2.23	90.00	3.00
40	17.0	75.0	26419.	3774.	2.05	0.900	0.980	0.918	29367.	3851.	2.23	90.13	3.13
41	17.0	85.0	26306.	3769.	2.04	0.896	0.979	0.915	29367.	3851.	2.23	90.27	3.27
42	17.0	95.0	26206.	3768.	2.04	0.895	0.978	0.915	29367.	3851.	2.23	90.29	3.29
43	12.0	ALL	24814.	3661.	1.99	0.903	0.982	0.919	27486.	3726.	2.16	90.00	3.00
44	7.0	ALL	22095.	3607.	1.79	0.902	0.983	0.918	24500.	3670.	1.96	90.00	3.00
45	2.0	ALL	19819.	3569.	1.63	0.901	0.983	0.916	22000.	3630.	1.78	90.00	3.00
46	-3.0	ALL	17998.	3550.	1.49	0.900	0.983	0.915	20000.	3610.	1.62	90.00	3.00
47	-8.0	ALL	15722.	3540.	1.30	0.898	0.983	0.914	17500.	3600.	1.42	90.00	3.00

K.C. CPERS WEIGHTED AVERAGE VALUES: 0.905 0.978 0.925

ALL DATA ARE FOR TIDB = 70. DEG-F.

***** HEAT PUMP LOAD DATA AS MODELED *****

4 --- TRANE W/ 90 MIN TIME/TEMP DEFROST (5/5/80 DATA).
5 --- KANSAS CITY MUNICIPAL AIRPORT (ANNUAL MINUS JUN-SEP)

I	TODB	RBO	HEATING-HRS BIN	ACC	NACH	QINF	QTRAN	QII	QTOTAL	KBTUTOT
3	62.0	ALL	444.	444.	0.431	1164.	1898.	-8207.	-5146.	0.
4	57.0	ALL	479.	479.	0.460	2018.	5060.	-8207.	-1129.	0.
5	52.0	ALL	520.	520.	0.489	2970.	8223.	-8207.	2986.	1552.
6	47.0	ALL	554.	554.	0.517	4019.	11386.	-8207.	7198.	3986.
7	42.0	20.0	7.		0.546	5166.	14549.	-8207.	11507.	78.
8	42.0	40.0	120.		0.546	5166.	14549.	-8207.	11507.	1381.
9	42.0	60.0	240.		0.546	5166.	14549.	-8207.	11507.	2756.
10	42.0	75.0	183.		0.546	5166.	14549.	-8207.	11507.	1184.
11	42.0	85.0	81.		0.546	5166.	14549.	-8207.	11507.	932.
12	42.0	95.0	72.		0.546	5166.	14549.	-8207.	11507.	829.
				622.						
13	37.0	20.0	0.		0.575	6410.	17712.	-8207.	15914.	0.
14	37.0	40.0	61.		0.575	6410.	17712.	-8207.	15914.	971.
15	37.0	60.0	253.		0.575	6410.	17712.	-8207.	15914.	4026.
16	37.0	75.0	120.		0.575	6410.	17712.	-8207.	15914.	1908.
17	37.0	85.0	93.		0.575	6410.	17712.	-8207.	15914.	1480.
18	37.0	95.0	98.		0.575	6410.	17712.	-8207.	15914.	1560.
				625.						
19	32.0	20.0	0.		0.604	7751.	20874.	-8207.	20418.	4.
20	32.0	40.0	26.		0.604	7751.	20874.	-8207.	20418.	535.
21	32.0	60.0	188.		0.604	7751.	20874.	-8207.	20418.	3843.
22	32.0	75.0	147.		0.604	7751.	20874.	-8207.	20418.	3006.
23	32.0	85.0	123.		0.604	7751.	20874.	-8207.	20418.	2511.
24	32.0	95.0	106.		0.604	7751.	20874.	-8207.	20418.	2168.
				591.						
25	27.0	20.0	0.		0.633	9190.	24037.	-8207.	25020.	0.
26	27.0	40.0	22.		0.633	9190.	24037.	-8207.	25020.	550.
27	27.0	60.0	132.		0.633	9190.	24037.	-8207.	25020.	3303.
28	27.0	75.0	113.		0.633	9190.	24037.	-8207.	25020.	2827.
29	27.0	85.0	98.		0.633	9190.	24037.	-8207.	25020.	2452.
30	27.0	95.0	42.		0.633	9190.	24037.	-8207.	25020.	1051.
				407.						
31	22.0	20.0	0.		0.662	10726.	27200.	-8207.	29719.	0.
32	22.0	40.0	17.		0.662	10726.	27200.	-8207.	29719.	499.
33	22.0	60.0	111.		0.662	10726.	27200.	-8207.	29719.	3305.
34	22.0	75.0	64.		0.662	10726.	27200.	-8207.	29719.	1902.
35	22.0	85.0	60.		0.662	10726.	27200.	-8207.	29719.	1777.
36	22.0	95.0	13.		0.662	10726.	27200.	-8207.	29719.	392.
				265.						
37	17.0	20.0	0.		0.691	12360.	30363.	-8207.	34515.	0.
38	17.0	40.0	17.		0.691	12360.	30363.	-8207.	34515.	587.
39	17.0	60.0	84.		0.691	12360.	30363.	-8207.	34515.	2899.
40	17.0	75.0	46.		0.691	12360.	30363.	-8207.	34515.	1588.
41	17.0	85.0	25.		0.691	12360.	30363.	-8207.	34515.	863.
42	17.0	95.0	3.		0.691	12360.	30363.	-8207.	34515.	104.
				175.						
43	12.0	ALL	99.	99.	0.719	14091.	33525.	-8207.	39409.	3901.
44	7.0	ALL	53.	53.	0.748	15920.	36688.	-8207.	44400.	2353.
45	2.0	ALL	21.	21.	0.777	17846.	39851.	-8207.	49489.	1039.
46	-3.0	ALL	4.	4.	0.806	19869.	43014.	-8207.	54676.	219.
47	-8.0	ALL	0.	0.	0.835	21990.	46176.	-8207.	59959.	0.
TOTALS:			3936.	3936.						66320.

QII PSF: 3.50

ZLTEMP: 55.63

COOLING DESIGN LOAD COMPONENTS:

SUN: 6898. WINDOW CONDUCTION: 1957. WALL CONDUCTION: 7149. CEILING CONDUCTION: 3111.
 SENSIBLE INFILTRATION: 3035. TOTAL SENSIBLE: 25085.

HEATING DESIGN LOAD COMPONENTS (SFLOAD = 1.11250):

COOLING REFERENCE FOR 95 DEG-F COOLING DESIGN TEMP: 25085.
 HEATING REFERENCE FOR 95 DEG-F COOLING DESIGN TEMP
 & 60 DEG-F HEATING DESIGN DELTA TEMP: 55814.

HEATING TOTAL FOR ACTUAL CONDITIONS:

60465.

NOTE: SFLOAD = (ACTUAL INTEGRATED CAPACITY @ 47 DEG-F) / (RATING POINT CAPACITY @ 47 DEG-F).

FOR THIS SITE:

TODH:

5.0 DEG-F;

TODC:
RANGE:95.0 DEG-F.
MED

FOR THIS HEAT PUMP:

RATED CAPACITIES:

@ 47 DEG-F: 40000.0 BTU/H;
 @ 17 DEG-F: 23500.0 BTU/H.

@ 95 DEG-F: 37000.0 BTU/H.

DESIGN LOAD RESULTS:

QHDL: 60464.7 BTU/H;
 RESVOL
 (W/ SF): 18759.6 FT**3.
 RESAREA
 (W/ SF): 2344.9 FT**2.

QCSDL: 25084.7 BTU/H.
 RESVOL
 (W/O SF): 16862.5 FT**3.
 RESAREA
 (W/O SF): 2107.8 FT**2.

DOE AVERAGE HEATING LOADS @ TODH:

I-IV & VI: 51397.5 BTU/H;
 V: 54824.0 BTU/H.

DOE AVG HEATING OUTPUT:

I-IV & VI: 101404.9 KBTU/Y;
 V: 108165.2 KBTU/Y.

HBODDE

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

4 --- TRANE W/ 90 MIN TIME/TEMP DEFROST (5/5/80 DATA).

5 --- KANSAS CITY MUNICIPAL AIRPORT

(ANNUAL MINUS JUN-SEP)

ICYCLE = 0 IAF = 1 TIDB = 70.0 NACH (DESIGN) = 1.00 QIIPSF = 3.50 TSTAT: NEW SHSF = 1.00

I	TODD	RHO	HRS	CPHRS	HT-LOAD	HP-CAP	SH-CAP	HP-KBTU	SH-KBTU	HP-KWH	COP	IPCT-ON	APCT-ON	FCY	PW-I	PW-ACT
5	52.0	ALL	519.7	33.6	2986.	46200.	0.	1552.	0.	164.	2.77	6.5	6.5	1.169	3.32	3.32
6	47.0	ALL	553.8	89.6	7198.	44500.	0.	3986.	0.	431.	2.71	16.2	16.2	2.321	4.18	4.18
7	42.0	20.0	6.8	2.0	11507.	38757.	25570.	77.	2.	9.	2.48	29.0	29.0	2.912	5.98	5.98
8	42.0	40.0	120.0	34.8	11507.	38757.	25570.	1350.	30.	159.	2.48	29.0	29.0	2.912	5.98	5.98
9	42.0	60.0	239.5	69.5	11507.	38757.	25570.	2695.	61.	318.	2.48	29.0	29.0	2.912	5.98	5.98
10	42.0	75.0	102.9	29.9	11507.	38757.	25570.	1158.	26.	137.	2.48	29.0	29.0	2.912	5.98	5.98
11	42.0	85.0	81.0	23.5	11507.	38757.	25570.	912.	20.	108.	2.48	29.0	29.0	2.912	5.98	5.98
12	42.0	95.0	72.0	20.9	11507.	38757.	25570.	810.	18.	96.	2.48	29.0	29.0	2.912	5.98	5.98
14	37.0	40.0	61.0	25.7	15914.	36951.	25570.	948.	22.	114.	2.44	42.1	42.1	2.948	8.56	8.56
15	37.0	60.0	253.0	106.4	15914.	36951.	25570.	3933.	93.	472.	2.44	42.1	42.1	2.948	8.56	8.56
16	37.0	75.0	119.9	50.9	15914.	36560.	25570.	1860.	48.	224.	2.43	42.4	42.4	2.948	8.64	8.64
17	37.0	85.0	93.0	39.6	15914.	36377.	25570.	1440.	40.	174.	2.42	42.6	42.6	2.948	8.67	8.67
18	37.0	95.0	98.0	42.7	15914.	35073.	25570.	1496.	63.	186.	2.36	43.5	43.5	2.948	8.86	8.86
19	32.0	20.0	0.2	0.1	20418.	33601.	25570.	4.	0.	1.	2.33	59.2	59.2	2.349	15.13	15.13
20	32.0	40.0	26.2	15.5	20418.	33601.	25570.	521.	14.	66.	2.33	59.2	59.2	2.349	15.13	15.13
21	32.0	60.0	188.2	111.5	20418.	33601.	25570.	3745.	97.	472.	2.33	59.2	59.2	2.349	15.13	15.13
22	32.0	75.0	147.2	87.8	20418.	33271.	25570.	2922.	83.	370.	2.31	59.7	59.7	2.349	15.24	15.24
23	32.0	85.0	123.0	73.5	20418.	33175.	25570.	2440.	72.	310.	2.31	59.8	59.8	2.349	15.27	15.27
24	32.0	95.0	106.2	64.2	20418.	32524.	25570.	2088.	80.	269.	2.28	60.5	60.5	2.349	15.44	15.44
26	27.0	40.0	22.0	17.4	25020.	30834.	25570.	535.	15.	71.	2.22	78.9	78.9	1.283	36.91	36.91
27	27.0	60.0	132.0	104.1	25020.	30834.	25570.	3211.	91.	423.	2.22	78.9	78.9	1.283	36.91	36.91
28	27.0	75.0	113.0	89.7	25020.	30576.	25570.	2743.	85.	363.	2.21	79.4	79.4	1.283	37.13	37.13
29	27.0	85.0	98.0	77.9	25020.	30515.	25570.	2377.	75.	315.	2.21	79.5	79.5	1.283	37.19	37.19
30	27.0	95.0	42.0	33.5	25020.	30304.	25570.	1015.	36.	135.	2.20	79.8	79.8	1.283	37.32	37.32
32	22.0	40.0	16.8	16.8	29719.	28509.	1209.	479.	20.	66.	2.14	104.2	100.0	0.000	600.00	600.00
33	22.0	60.0	111.2	111.2	29719.	28509.	1209.	3170.	134.	435.	2.14	104.2	100.0	0.000	600.00	600.00
34	22.0	75.0	64.0	64.0	29719.	28310.	1408.	1812.	90.	250.	2.13	105.0	100.0	0.000	600.00	600.00
35	22.0	85.0	59.8	59.8	29719.	28246.	1473.	1689.	88.	233.	2.12	105.2	100.0	0.000	600.00	600.00
36	22.0	95.0	13.2	13.2	29719.	28195.	1523.	372.	20.	51.	2.12	105.4	100.0	0.000	600.00	600.00
38	17.0	40.0	17.0	17.0	34515.	26526.	7989.	451.	136.	64.	2.06	130.1	100.0	0.000	600.00	600.00
39	17.0	60.0	84.0	84.0	34515.	26526.	7989.	2228.	671.	317.	2.06	130.1	100.0	0.000	600.00	600.00
40	17.0	75.0	46.0	46.0	34515.	26419.	8096.	1215.	372.	174.	2.05	130.6	100.0	0.000	600.00	600.00
41	17.0	85.0	25.0	25.0	34515.	26306.	8210.	658.	205.	94.	2.04	131.2	100.0	0.000	600.00	600.00
42	17.0	95.0	3.0	3.0	34515.	26286.	8229.	79.	25.	11.	2.04	131.3	100.0	0.000	600.00	600.00
43	12.0	ALL	99.0	99.0	39409.	24814.	14595.	2457.	1445.	362.	1.99	158.8	100.0	0.000	600.00	600.00
44	7.0	ALL	53.0	53.0	44400.	22095.	22305.	1171.	1182.	191.	1.79	200.9	100.0	0.000	600.00	600.00
45	2.0	ALL	21.0	21.0	49489.	19819.	29670.	416.	623.	75.	1.63	249.7	100.0	0.000	600.00	600.00
46	-3.0	ALL	4.0	4.0	54676.	17998.	36677.	72.	147.	14.	1.49	303.8	100.0	0.000	600.00	600.00

TOTALS 5935.6 1861.4 60090. 6231. 7725.

AVERAGES 16851. 32283. 2.28 47.3 1.895 14.98

TOT OUT (KBTU): 66320. TOT IN (KWH): 9550. SYSTEM COP: 2.03 * COMP CYCLES: 7456

TBPNOM = 25.00 TBPDRY = 22.86 TBPDES = 33.21 * DEFROST CYCLES: 1178(767)

SIKW = 7.4918 DEGDYS(ABOVE): 4932. EQFLH(ABOVE): 1973. DOERCN: 111/IV

ZLTEMP: 55.63 DEGDYS(NOAA): 5161. EQFLH(NOAA): 2064. DOEHLH: 2000.

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

4 --- TRANE W/ 90 MIN TIME/TEMP DEPROST (5/5/80 DATA).
5 --- KANSAS CITY MUNICIPAL AIRPORT (ANNUAL MINUS JUN-SEP):

I	TODB	RBO	CPHRS	TIN(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	1.97	90.00	1.35	3.00	0.07	25570.	2.	1.	0.135
8	42.0	40.0	34.84	90.00	23.75	3.00	1.19	25570.	30.	9.	0.135
9	42.0	60.0	69.54	90.00	47.41	3.00	2.37	25570.	61.	18.	0.135
10	42.0	75.0	29.88	90.00	20.37	3.00	1.02	25570.	26.	8.	0.135
11	42.0	85.0	23.52	90.00	16.03	3.00	0.80	25570.	20.	6.	0.135
12	42.0	95.0	20.91	90.00	14.25	3.00	0.71	25570.	18.	5.	0.135
13	37.0	20.0	0.00	90.00	0.00	3.00	0.00	0.	0.	0.	0.000
14	37.0	40.0	25.66	90.00	17.51	3.00	0.88	25570.	22.	7.	0.202
15	37.0	60.0	106.45	90.00	72.64	3.00	3.63	25570.	93.	27.	0.202
16	37.0	75.0	50.88	90.24	34.70	3.24	1.87	25570.	48.	14.	0.223
17	37.0	85.0	39.60	90.44	26.99	3.44	1.55	25570.	40.	12.	0.238
18	37.0	95.0	42.66	90.23	29.57	5.03	2.48	25570.	63.	19.	0.378
19	32.0	20.0	0.12	90.00	0.00	3.00	0.00	25570.	0.	0.	0.394
20	32.0	40.0	15.52	90.00	10.61	3.00	0.53	25570.	14.	4.	0.394
21	32.0	60.0	111.46	90.00	76.24	3.00	3.81	25570.	97.	29.	0.394
22	32.0	75.0	87.84	90.25	60.06	3.25	3.25	25570.	83.	24.	0.434
23	32.0	85.0	73.53	90.35	50.27	3.35	2.81	25570.	72.	21.	0.450
24	32.0	95.0	64.20	90.36	44.27	4.26	3.14	25570.	80.	24.	0.594
25	27.0	20.0	0.00	90.00	0.00	3.00	0.00	0.	0.	0.	0.000
26	27.0	40.0	17.36	90.00	11.90	3.00	0.60	25570.	15.	4.	1.049
27	27.0	60.0	104.15	90.00	71.40	3.00	3.57	25570.	91.	27.	1.049
28	27.0	75.0	89.70	90.23	61.49	3.23	3.31	25570.	85.	25.	1.147
29	27.0	85.0	77.90	90.29	53.40	3.29	2.93	25570.	75.	22.	1.170
30	27.0	95.0	33.50	89.70	23.20	3.60	1.39	25570.	36.	10.	1.306

TOTALS:

767.41

1071.

814.

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: 7.4918 KW, OR 25570. BTU/H.

THE TEMPERING HEAT CAPACITY IS BASED ON THE FOLLOWING RESULTS:

DESIGN LOAD @ TODB = 5.0 DEC-F IS: 60465.
HP CAPACITY @ TODB = 5.0 DEC-F IS: 19080.

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

41385. BTU/H, OR 12.1256 KW.

THE TEMPERING HEATER (I.E. 1ST STAGE) PERCENT OF TOTAL
FOR THE CALCULATED DESIGN BALANCE POINT
TEMPERATURE OF 33.21 DEC-F IS:

62. % 61.7853 %

WHICH RESULTS IN THE FOLLOWING HEATER CAPACITY:

25570. BTU/H, OR 7.4918 KW.

APPENDIX C

The Heat Pump Models
in the HPSPM Data Base
for the VITT Evaluation

APPENDIX C
The Heat Pump Models in the
HPSPM Data Base for the VITT Evaluation

C.1 DISCUSSION

The computer listings in this Appendix are "performance maps" for the heat pump models used in the VITT evaluations. The maps for four models are presented in Tables 2-1 through 2-4 and are not repeated here.

The rated capacities and efficiencies for all models are set equal to the published values for the actual Trane heat pump with demand defrost. Most of the models are hypothetical configurations and therefore can not be rated. However, if such products actually existed, all the ratings except those for low temperature heating would in fact be identical, because only the low temperature (17°F) rating point reflects the differences in integrated capacity and power caused by different control systems. The only relationship that the ratings have to the HPSPM calculations is that for any particular site, identical cooling and high temperature heating capacities produce identical loads in the HPSPM. The rating point values for the actual Trane heat pump are as follows:

Cooling @ 95°F

Capacity:	37,000 Btu/h
Power:	4,870 W
EER:	7.6

High Temperature Heating @ 47°F

Capacity:	40,000 Btu/h
Power:	4,300 W
COP:	2.7

Low Temperature Heating @ 17°F

Capacity:	23,500 Btu/h
Power:	3,400 W
COP:	2.0

The performance maps are presented in the order of assigned model numbers as follows:

1. Ideal Performance
2. Optimum Demand (Table 2-4)
3. Actual Demand
4. 90 minute time/temperature (Table 2-3)
5. 60 minute time/temperature
6. Honeywell @ 90 (Table 2-1)
7. Honeywell @ 60
8. Ranco @ 90 (Table 2-2)
9. Ranco @ 60

All the entries in the following performance maps are explained in the descriptions of an example HPSPM output listing in Section B.2 of Appendix B.

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

HB0DDE (10)

1 --- TRANE: IDEAL PERFORMANCE (5/5/80 DATA).

I	TODB	RBO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A
7	42.0	20.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
8	42.0	40.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
9	42.0	60.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
10	42.0	75.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
11	42.0	85.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
12	42.0	95.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
13	37.0	20.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
14	37.0	40.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
15	37.0	60.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
16	37.0	75.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
17	37.0	85.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
18	37.0	95.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A
19	32.0	20.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
20	32.0	40.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
21	32.0	60.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
22	32.0	75.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
23	32.0	85.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
24	32.0	95.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A
25	27.0	20.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
26	27.0	40.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
27	27.0	60.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
28	27.0	75.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
29	27.0	85.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
30	27.0	95.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A
31	22.0	20.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
32	22.0	40.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
33	22.0	60.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
34	22.0	75.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
35	22.0	85.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
36	22.0	95.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A
37	17.0	20.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
38	17.0	40.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
39	17.0	60.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
40	17.0	75.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
41	17.0	85.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
42	17.0	95.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A
43	12.0	ALL	27486.	3726.	2.16	1.000	1.000	1.000	27486.	3726.	2.16	N/A	N/A
44	7.0	ALL	24500.	3670.	1.96	1.000	1.000	1.000	24500.	3670.	1.96	N/A	N/A
45	2.0	ALL	22000.	3630.	1.78	1.000	1.000	1.000	22000.	3630.	1.78	N/A	N/A
46	-3.0	ALL	20000.	3610.	1.62	1.000	1.000	1.000	20000.	3610.	1.62	N/A	N/A
47	-8.0	ALL	17500.	3600.	1.42	1.000	1.000	1.000	17500.	3600.	1.42	N/A	N/A

K.C. CPHRS WEIGHTED AVERAGE VALUES: 1.000 1.000 1.000

ALL DATA ARE FOR TIDB = 70. DEG-F.

HB0DDE

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

3 --- TRANE W/ DEMAND DEFROST (5/5/80 DATA).

I	TODB	RHO *	INTEGRATED VALUES				* DEFROST PERFORMANCE FACTORS *				PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR		
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A		
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A		
7	42.0	20.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
8	42.0	40.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
9	42.0	60.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
10	42.0	75.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
11	42.0	85.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
12	42.0	95.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A		
13	37.0	20.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A		
14	37.0	40.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A		
15	37.0	60.0	40817.	4538.	2.64	1.000	1.000	1.000	40817.	4538.	2.64	N/A	N/A		
16	37.0	75.0	36676.	4356.	2.47	0.899	0.960	0.936	40817.	4538.	2.64	360.42	6.12		
17	37.0	85.0	35536.	4346.	2.40	0.871	0.958	0.909	40817.	4538.	2.64	135.35	6.05		
18	37.0	95.0	34527.	4324.	2.34	0.846	0.953	0.888	40817.	4538.	2.64	96.67	6.07		
19	32.0	20.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A		
20	32.0	40.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A		
21	32.0	60.0	37137.	4329.	2.51	1.000	1.000	1.000	37137.	4329.	2.51	N/A	N/A		
22	32.0	75.0	33554.	4174.	2.36	0.904	0.964	0.937	37137.	4329.	2.51	327.12	6.12		
23	32.0	85.0	32593.	4165.	2.29	0.878	0.962	0.912	37137.	4329.	2.51	145.27	6.07		
24	32.0	95.0	31763.	4148.	2.24	0.855	0.958	0.893	37137.	4329.	2.51	105.71	6.11		
25	27.0	20.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A		
26	27.0	40.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A		
27	27.0	60.0	34099.	4149.	2.41	1.000	1.000	1.000	34099.	4149.	2.41	N/A	N/A		
28	27.0	75.0	31094.	4011.	2.27	0.912	0.967	0.943	34099.	4149.	2.41	453.11	6.11		
29	27.0	85.0	30341.	4010.	2.22	0.890	0.967	0.921	34099.	4149.	2.41	173.16	6.06		
30	27.0	95.0	29679.	3999.	2.17	0.870	0.964	0.903	34099.	4149.	2.41	122.71	6.01		
31	22.0	20.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A		
32	22.0	40.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A		
33	22.0	60.0	31545.	3991.	2.32	1.000	1.000	1.000	31545.	3991.	2.32	N/A	N/A		
34	22.0	75.0	28929.	3860.	2.20	0.917	0.967	0.948	31545.	3991.	2.32	697.92	6.12		
35	22.0	85.0	28393.	3871.	2.15	0.900	0.970	0.928	31545.	3991.	2.32	209.21	6.11		
36	22.0	95.0	27848.	3864.	2.11	0.883	0.968	0.912	31545.	3991.	2.32	144.33	6.03		
37	17.0	20.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A		
38	17.0	40.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A		
39	17.0	60.0	29367.	3851.	2.23	1.000	1.000	1.000	29367.	3851.	2.23	N/A	N/A		
40	17.0	75.0	27625.	3769.	2.15	0.941	0.979	0.961	29367.	3851.	2.23	720.48	4.38		
41	17.0	85.0	26713.	3747.	2.09	0.910	0.973	0.935	29367.	3851.	2.23	254.20	6.10		
42	17.0	95.0	26241.	3742.	2.05	0.894	0.972	0.920	29367.	3851.	2.23	171.41	6.11		
43	12.0	ALL	27486.	3726.	2.16	1.000	1.000	1.000	27486.	3726.	2.16	N/A	N/A		
44	7.0	ALL	24500.	3670.	1.96	1.000	1.000	1.000	24500.	3670.	1.96	N/A	N/A		
45	2.0	ALL	22000.	3630.	1.78	1.000	1.000	1.000	22000.	3630.	1.78	N/A	N/A		
46	-3.0	ALL	20000.	3610.	1.62	1.000	1.000	1.000	20000.	3610.	1.62	N/A	N/A		
47	-8.0	ALL	17500.	3600.	1.42	1.000	1.000	1.000	17500.	3600.	1.42	N/A	N/A		

K.C. CPHRS WEIGHTED AVERAGE VALUES: 0.954 0.985 0.960

ALL DATA ARE FOR TIDB = 70. DEG-F.

HB0DDZ

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

5 --- TRANE W/ 60 MIN TIME/TEMP DEFROST (5/5/80 DATA).

I	TODD	RHO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A
7	42.0	20.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
8	42.0	40.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
9	42.0	60.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
10	42.0	75.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
11	42.0	85.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
12	42.0	95.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00
13	37.0	20.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00
14	37.0	40.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00
15	37.0	60.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00
16	37.0	75.0	35360.	4380.	2.36	0.866	0.967	0.896	40817.	4538.	2.64	60.45	3.15
17	37.0	85.0	35240.	4384.	2.36	0.863	0.966	0.894	40817.	4538.	2.64	59.58	3.18
18	37.0	95.0	35195.	4382.	2.35	0.862	0.966	0.893	40817.	4538.	2.64	59.62	3.22
19	32.0	20.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
20	32.0	40.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
21	32.0	60.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
22	32.0	75.0	32105.	4195.	2.24	0.864	0.969	0.892	37137.	4329.	2.51	59.55	3.15
23	32.0	85.0	32061.	4193.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.58	3.18
24	32.0	95.0	32041.	4192.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.59	3.19
25	27.0	20.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00
26	27.0	40.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00
27	27.0	60.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00
28	27.0	75.0	29529.	4031.	2.15	0.866	0.971	0.891	34099.	4149.	2.41	60.44	3.14
29	27.0	85.0	29436.	4028.	2.14	0.863	0.971	0.889	34099.	4149.	2.41	59.58	3.18
30	27.0	95.0	29419.	4027.	2.14	0.863	0.971	0.889	34099.	4149.	2.41	59.59	3.19
31	22.0	20.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00
32	22.0	40.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00
33	22.0	60.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00
34	22.0	75.0	27320.	3886.	2.06	0.866	0.974	0.890	31545.	3991.	2.32	60.43	3.13
35	22.0	85.0	27227.	3883.	2.05	0.863	0.973	0.887	31545.	3991.	2.32	59.57	3.17
36	22.0	95.0	27211.	3882.	2.05	0.863	0.973	0.887	31545.	3991.	2.32	59.58	3.18
37	17.0	20.0	25534.	3762.	1.99	0.869	0.977	0.890	29367.	3851.	2.23	60.00	3.00
38	17.0	40.0	25534.	3762.	1.99	0.869	0.977	0.890	29367.	3851.	2.23	60.00	3.00
39	17.0	60.0	25534.	3762.	1.99	0.869	0.977	0.890	29367.	3851.	2.23	60.00	3.00
40	17.0	75.0	25467.	3759.	1.99	0.867	0.976	0.889	29367.	3851.	2.23	60.38	3.08
41	17.0	85.0	25340.	3755.	1.98	0.863	0.975	0.885	29367.	3851.	2.23	59.56	3.16
42	17.0	95.0	25325.	3754.	1.98	0.862	0.975	0.885	29367.	3851.	2.23	59.58	3.18
43	12.0	ALL	23878.	3646.	1.92	0.869	0.978	0.888	27486.	3726.	2.16	60.00	3.00
44	7.0	ALL	21250.	3594.	1.73	0.867	0.979	0.886	24500.	3670.	1.96	60.00	3.00
45	2.0	ALL	19049.	3536.	1.57	0.866	0.980	0.884	22000.	3630.	1.78	60.00	3.00
46	-3.0	ALL	17289.	3538.	1.43	0.864	0.980	0.882	20000.	3610.	1.62	60.00	3.00
47	-8.0	ALL	15088.	3529.	1.25	0.862	0.900	0.880	17500.	3600.	1.42	60.00	3.00

K.C. CPHRS WEIGHTED AVERAGE VALUES: 0.877 0.974 0.900

ALL DATA ARE FOR TIDB = 70. DEC-F.

HB0DDE

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

7 --- TRANE: HONEYWELL T/T W/ 60 MIN BASE (5/24/80 DATA).

I	TODD	RHO *	INTEGRATED VALUES			* DEFROST PERFORMANCE FACTORS *			PEAK VALUES			* DEFROST TIMES	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A
7	42.0	20.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
8	42.0	40.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
9	42.0	60.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
10	42.0	75.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
11	42.0	85.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
12	42.0	95.0	42800.	4690.	2.67	1.000	1.000	1.000	42800.	4690.	2.67	N/A	N/A
13	37.0	20.0	35910.	4407.	2.39	0.880	0.971	0.906	40817.	4538.	2.64	64.80	3.00
14	37.0	40.0	35910.	4407.	2.39	0.880	0.971	0.906	40817.	4538.	2.64	64.80	3.00
15	37.0	60.0	35910.	4407.	2.39	0.880	0.971	0.906	40817.	4538.	2.64	64.80	3.00
16	37.0	75.0	35619.	4393.	2.38	0.873	0.968	0.901	40817.	4538.	2.64	64.96	3.16
17	37.0	85.0	35531.	4390.	2.37	0.871	0.967	0.900	40817.	4538.	2.64	65.00	3.20
18	37.0	95.0	35426.	4385.	2.37	0.868	0.966	0.898	40817.	4538.	2.64	65.13	3.33
19	32.0	20.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
20	32.0	40.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
21	32.0	60.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00
22	32.0	75.0	32105.	4195.	2.24	0.864	0.969	0.892	37137.	4329.	2.51	59.55	3.15
23	32.0	85.0	32061.	4193.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.58	3.18
24	32.0	95.0	32041.	4192.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.59	3.19
25	27.0	20.0	30169.	4048.	2.18	0.885	0.976	0.907	34099.	4149.	2.41	69.60	3.00
26	27.0	40.0	30169.	4048.	2.18	0.885	0.976	0.907	34099.	4149.	2.41	69.60	3.00
27	27.0	60.0	30169.	4048.	2.18	0.885	0.976	0.907	34099.	4149.	2.41	69.60	3.00
28	27.0	75.0	29947.	4038.	2.17	0.878	0.973	0.902	34099.	4149.	2.41	69.47	3.17
29	27.0	85.0	29898.	4036.	2.17	0.877	0.973	0.901	34099.	4149.	2.41	69.51	3.21
30	27.0	95.0	29878.	4035.	2.17	0.876	0.973	0.901	34099.	4149.	2.41	69.53	3.23
31	22.0	20.0	28358.	3909.	2.13	0.899	0.979	0.918	31545.	3991.	2.32	84.00	3.00
32	22.0	40.0	28358.	3909.	2.13	0.899	0.979	0.918	31545.	3991.	2.32	84.00	3.00
33	22.0	60.0	28358.	3909.	2.13	0.899	0.979	0.918	31545.	3991.	2.32	84.00	3.00
34	22.0	75.0	28162.	3900.	2.12	0.893	0.977	0.914	31545.	3991.	2.32	83.89	3.19
35	22.0	85.0	28101.	3897.	2.11	0.891	0.976	0.912	31545.	3991.	2.32	83.96	3.26
36	22.0	95.0	28079.	3896.	2.11	0.890	0.976	0.912	31545.	3991.	2.32	83.98	3.28
37	17.0	20.0	26800.	3784.	2.08	0.913	0.982	0.929	29367.	3851.	2.23	104.40	3.00
38	17.0	40.0	26800.	3784.	2.08	0.913	0.982	0.929	29367.	3851.	2.23	104.40	3.00
39	17.0	60.0	26800.	3784.	2.08	0.913	0.982	0.929	29367.	3851.	2.23	104.40	3.00
40	17.0	75.0	26681.	3778.	2.07	0.909	0.981	0.926	29367.	3851.	2.23	104.55	3.15
41	17.0	85.0	26554.	3772.	2.06	0.904	0.979	0.923	29367.	3851.	2.23	104.72	3.32
42	17.0	95.0	26513.	3771.	2.06	0.903	0.979	0.922	29367.	3851.	2.23	104.80	3.40
43	12.0	ALL	25465.	3671.	2.03	0.926	0.985	0.941	27486.	3726.	2.16	138.00	3.00
44	7.0	ALL	23040.	3622.	1.86	0.940	0.987	0.953	24500.	3670.	1.96	204.00	3.00
45	2.0	ALL	21012.	3588.	1.72	0.955	0.989	0.966	22000.	3630.	1.78	399.00	3.00
46	-3.0	ALL	19090.	3569.	1.57	0.955	0.989	0.966	20000.	3610.	1.62	400.20	3.00
47	-8.0	ALL	16705.	3559.	1.30	0.955	0.989	0.966	17500.	3600.	1.42	400.20	3.00

K.C. CPHRS WEIGHTED AVERAGE VALUES: 0.906 0.979 0.925

ALL DATA ARE FOR TIDB = 70. DEG-F.

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

9 --- TRANE: RANCO VITT W/ 60 MIN BASE (5/24/80 DATA).

I	TODB	RHO *	INTEGRATED VALUES				* DEFROST PERFORMANCE FACTORS *				PEAK VALUES		* DEFROST TIMES:	
			TOTCAP	TOTPWR	COP	CAP	POWER	COP	TOTCAP	TOTPWR	COP	D-D	DUR	
5	52.0	ALL	46200.	4890.	2.77	1.000	1.000	1.000	46200.	4890.	2.77	N/A	N/A	
6	47.0	ALL	44500.	4810.	2.71	1.000	1.000	1.000	44500.	4810.	2.71	N/A	N/A	
7	42.0	20.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
8	42.0	40.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
9	42.0	60.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
10	42.0	75.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
11	42.0	85.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
12	42.0	95.0	37358.	4542.	2.41	0.873	0.968	0.901	42800.	4690.	2.67	60.00	3.00	
13	37.0	20.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00	
14	37.0	40.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00	
15	37.0	60.0	35613.	4400.	2.37	0.873	0.970	0.900	40817.	4538.	2.64	60.00	3.00	
16	37.0	75.0	35360.	4388.	2.36	0.866	0.967	0.896	40817.	4538.	2.64	60.45	3.15	
17	37.0	85.0	35240.	4384.	2.36	0.863	0.966	0.894	40817.	4538.	2.64	59.58	3.18	
18	37.0	95.0	35195.	4382.	2.35	0.862	0.966	0.893	40817.	4538.	2.64	59.62	3.22	
19	32.0	20.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00	
20	32.0	40.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00	
21	32.0	60.0	32374.	4206.	2.25	0.872	0.972	0.897	37137.	4329.	2.51	60.00	3.00	
22	32.0	75.0	32105.	4195.	2.24	0.864	0.969	0.892	37137.	4329.	2.51	59.55	3.15	
23	32.0	85.0	32061.	4193.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.58	3.18	
24	32.0	95.0	32041.	4192.	2.24	0.863	0.968	0.891	37137.	4329.	2.51	59.59	3.19	
25	27.0	20.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00	
26	27.0	40.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00	
27	27.0	60.0	29699.	4039.	2.15	0.871	0.973	0.895	34099.	4149.	2.41	60.00	3.00	
28	27.0	75.0	29529.	4031.	2.15	0.866	0.971	0.891	34099.	4149.	2.41	60.44	3.14	
29	27.0	85.0	29436.	4028.	2.14	0.863	0.971	0.889	34099.	4149.	2.41	59.58	3.18	
30	27.0	95.0	29419.	4027.	2.14	0.863	0.971	0.889	34099.	4149.	2.41	59.59	3.19	
31	22.0	20.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00	
32	22.0	40.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00	
33	22.0	60.0	27451.	3892.	2.07	0.870	0.975	0.892	31545.	3991.	2.32	60.00	3.00	
34	22.0	75.0	27320.	3886.	2.06	0.866	0.974	0.890	31545.	3991.	2.32	60.43	3.13	
35	22.0	85.0	27227.	3883.	2.05	0.863	0.973	0.887	31545.	3991.	2.32	59.57	3.17	
36	22.0	95.0	27211.	3882.	2.05	0.863	0.973	0.887	31545.	3991.	2.32	59.58	3.18	
37	17.0	20.0	27023.	3788.	2.09	0.920	0.983	0.936	29367.	3851.	2.23	120.00	3.00	
38	17.0	40.0	27023.	3788.	2.09	0.920	0.983	0.936	29367.	3851.	2.23	120.00	3.00	
39	17.0	60.0	27023.	3788.	2.09	0.920	0.983	0.936	29367.	3851.	2.23	120.00	3.00	
40	17.0	75.0	26807.	3781.	2.08	0.916	0.982	0.933	29367.	3851.	2.23	119.88	3.18	
41	17.0	85.0	26746.	3774.	2.08	0.911	0.980	0.929	29367.	3851.	2.23	120.07	3.38	
42	17.0	95.0	26629.	3770.	2.07	0.907	0.979	0.926	29367.	3851.	2.23	120.35	3.65	
43	12.0	ALL	25282.	3668.	2.02	0.920	0.904	0.935	27486.	3726.	2.16	120.00	3.00	
44	7.0	ALL	22518.	3614.	1.83	0.919	0.985	0.933	24500.	3670.	1.96	120.00	3.00	
45	2.0	ALL	20204.	3575.	1.66	0.918	0.985	0.932	22000.	3630.	1.78	120.00	3.00	
46	-3.0	ALL	10005.	3565.	1.55	0.944	0.988	0.956	20000.	3610.	1.62	240.00	3.00	
47	-8.0	ALL	16515.	3555.	1.36	0.944	0.980	0.956	17500.	3600.	1.42	240.00	3.00	

K.C. CPHS WEIGHTED AVERAGE VALUES: 0.886 0.975 0.989

ALL DATA ARE FOR TIDB = 70. DEG-F.