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THE ORNL MODULATING HEAT PUMP DESIGN TOOL — MARK IV USER'S GUIDE

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THE ORNL MODULATING HEAT PUMP DESIGN TOOL —

MARK IV USER'S GUIDE

EXECUTIVE SUMMARY

The ORNL Modulating Heat Pump Design Tool consists of a Modulating HPDM (Heat Pump Design Model) and a parametric-analysis (contour-data generating) front-end. Collectively the program is also referred to as MODCON which is in reference to the modulating and the contour data generating capabilities. The program was developed by Oak Ridge National Laboratory for the Department of Energy to provide a publicly-available *system* design tool for variable- and single-speed heat pumps.

Overview Of New Features

MODCON predicts the *steady-state* heating and cooling performance of *variable-speed* electric-driven vapor compression air-to-air heat pumps for a wide range of system configuration and operational variables. Engine-driven vapor-compression heat pump systems can also be modeled with appropriate engine models supplied by the user. The present model is an extension of the (single-speed) ORNL Mark III HPDM (Fischer and Rice 1988) with the following key additional capabilities and improvements:

- variable-speed electric-driven compressors and/or fans with four levels of drive technology,
- substantially improved and extended air-side heat exchanger correlations for modulating applications,
- a refrigerant charge inventory option allowing the user to either specify or determine the required charge,
- provision for variable-opening flow controls used in modulating heat pumps, e.g., pulse-width-modulated (PWM) valves, stepper motors, thermal electric valves (TEV's) and thermal expansion valves (TXV's),
- provision for input selection of refrigerant and the addition of R134a to the refrigerant choices, and
- automated means to conduct parametric performance mappings of selected pairs of independent design variables.

The user can generate steady-state performance data sets at fixed ambients or as a function of ambient temperature. The range of selection options includes:

- 52 design and control variables for parametric analysis,
- 8 user-defined operational control relationships as functions of compressor speed or ambient temperature, and
- over 100 possible heat pump model output parameters.

Basic modulating compressor performance is represented by the use of performance maps at discrete speeds with interpolations and extrapolations as necessary to represent a continuous range of speed control. Continuously-variable-speed operation of both induction-motor and electronically-commutated-motor (ECM) types are modeled. Compressor motor performance of both types can be simulated based on a specified motor size or, alternatively, each motor can be sized automatically by the model to operate at a required percentage of rated load.

For modulating blowers and fans, required modulated power can be computed from first principles or referenced to a specified nominal power at design speed. For ECM blowers and fans, a full range of motor sizing options is also available.

The combination of the above capabilities provides a general tool for system configuration design and operational control of variable-speed heat pumps. The tool can be used to automate the generation of extensive simulation datasets for design studies. These datasets, once generated, can be accessed independently by other engineers to plot and analyze selected dependent performance variables of interest in two- or three-dimensional space. The program execution time is sufficiently fast so that a parametric evaluation in two variables can be performed in less than 30 seconds on a Pentium III, 300 MHZ PC. An example of the use of the model for a complete design analysis of a ECM-driven variable-speed system is given by Rice (1992).

Validations and Applications

Modulating model validations were conducted on an initial version of the ORNL Modulating HPDM using measurements on a modified commercially-available variable-speed heat pump tested at ORNL. The model was compared to experimental *trends* with respect to compressor and indoor blower speeds and also the basis of *absolute* COPs and capacities. The trends in COP and capacity were generally well predicted as reported by Miller (1988a).

The results of the *absolute* comparisons over a range of speeds and ambients indicated that best model agreement was obtained at the lower speeds in both heating and cooling mode, with increasing performance overpredictions (to maximums of about 10% in both COP and capacity) occurring at higher speeds. This increase in model overprediction with speed occurs because of limitations of the simplified models of refrigerant circuitry with the higher subcooled (and/or superheated), more heavily loaded heat exchanger conditions.

Different versions of the single-speed model have been validated by various researchers for both single-speed and dual-stroke heat pumps. The single-speed model has also been used by others in the simulation of variable-speed engine-driven heat pumps (Fischer 1986b, Monahan 1986, and Rusk 1990). With one exception, the validations of the original single-speed version in both nonmodulating and modulating applications of sizes from 2 to 10 tons capacity have been reported as satisfactory to excellent.

The electric-driven version has been used as 1) an aid in the experimental evaluation of optimal hardware control, 2) as a tool to determine potential performance levels for residential unitary equipment, and 3) as a tool to assess the potential of variable-speed drives for commercial unitary equipment.

The program has also been modified to be used with newer HFC refrigerant alternatives such as R134a. With this capability, the ORNL Modulating Heat Pump Design Tool is ready to be utilized for the equipment redesign issues facing heat pump manufacturers in the coming decade.

VARIABLE-SPEED COMPRESSORS

Basic Compressor Representation

Manufacturers' compressor performance maps based on calorimeter tests are the starting point for the modulating compressor model. These maps *at a given drive frequency* are functions of compressor inlet and exit conditions — typically defined by evaporating and condensing saturation temperatures and suction superheat. The map-based option for compressor representation is the only choice developed for the modulating model (the other possible choice being the loss-and-efficiency model discussed previously in the ORNL report by Fischer and Rice 1983). Positive displacement compressors of reciprocating, rotary, and scroll type for which manufacturers' map data are available can be modeled. Single-speed, multiple-speed, and continuously-variable-speed compressors can be accommodated if the appropriate performance maps are available.

With some adjustments, both low and high-side-cooled compressors with varying amounts of suction superheat can be handled. As in earlier versions of the ORNL HPDM, the default suction gas superheat corrections are somewhat specific to reciprocating compressors but can be generalized by suitable adjustment of superheat correction factors set in BLOCK DATA. These corrections as well as newer adjustments for motor efficiency effects on suction gas superheat assume low-side motor cooling as the default. However, this assumption can also be changed by suitable adjustment of BLOCK DATA parameters.

Modulating Compressor Performance

Compressor performance as a function of speed is represented by the use of maps at discrete frequencies with interpolations and extrapolations as necessary to represent a continuous range of speed control. The modulating HPDM requires the user to input compressor map-based coefficients for power and mass flow rate (or alternatively, for derived isentropic and volumetric efficiency based on compressor shell conditions) as functions of operating conditions at each speed for which sufficient data are available.

In cases where minimal data are available, curve fits to the derived efficiency values have been found to often give more reliable interpolations and extrapolations over speed than similar representations based on basic power and mass flow data. All the curve fit representations are biquadratic functions of condenser and evaporator saturation temperatures except for volumetric efficiency. Because of this, all extrapolations of polynomial curve fits are inherently suspect and should be tested for acceptable behavior outside of the fitting data range. The latter is a linear function of pressure ratio and a quadratic function of discharge pressure. The specific forms of the curve-fitting equations are given in Table B.1 describing the required heat pump specification file. Further description of the power and mass flow rate equations can be found in the ORNL report by Fischer and Rice (1983).

The interpolations in power and refrigerant mass flow rate (or in isentropic and volumetric efficiency) are presently done linearly with frequency. This can be rather easily changed to quadratic if desired by changing the value of NPT from 2 to 3 in the CMPMAP subroutine. Extrapolations, if necessary, are always done linearly.

Compressor Map-Fitting Program

A compressor-map-fitting program is provided with the HPDM to fit compressor manufacturers' available map data into either of the above representations. Appendix G describes the input data and format requirements for the curve-fit program. Sample plots of curve fits by the two methods to compressor data of a specified frequency of 30 Hz are shown in Figures 1 – 4. In Figures 5 – 9, curve fits to isentropic efficiency at other frequencies (20, 45, 60, 75, and 90 Hz) are shown. All plots are for a reference sine-wave-driven, induction motor (SWDIM) compressor calorimeter-tested at ORNL by Miller (1989) and supplemented by data provided by the manufacturer. The curve-fit coefficients for this compressor are included in the sample data sets of Appendix B.

The map-fitting program also prints tabular results comparing the individual data points to their corresponding curve fit values. Additional tables are generated for the direct power and mass flow rate curve-fits showing the differences between the resultant isentropic and volumetric efficiencies versus the values derived directly from the map data. With this information, the user can judge which curve-fitting approach is more suitable for their data.

The map-fitting program can be run for any number of speeds and will create a data file of curve-fit coefficients of the format required by the heat pump specification file. This file can be imported into an existing heat pump data file with only minor editing required. The program can also convert the maps to superheat or return gas temperature conditions other than those for which compressor map data are available.

RECIP VS–A/2.75 COMPRESSOR PERFORMANCE, DATA AND FIT, 30 HZ
ISENTROPIC EFFICIENCY

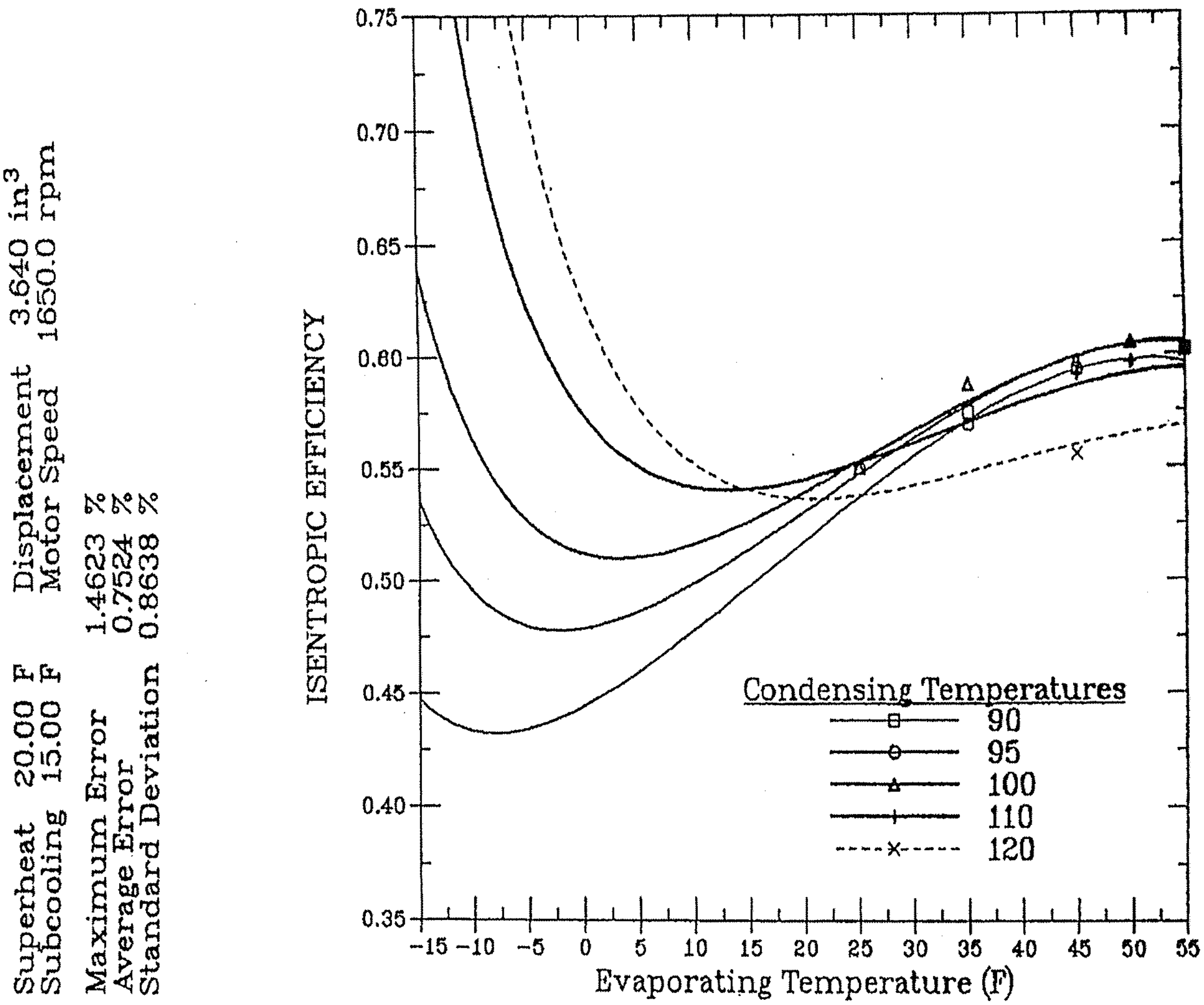

Figure 1. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 30 Hz Frequency — From Curve-Fits To Basic Power and Refrigerant Mass Flow Rate Data.

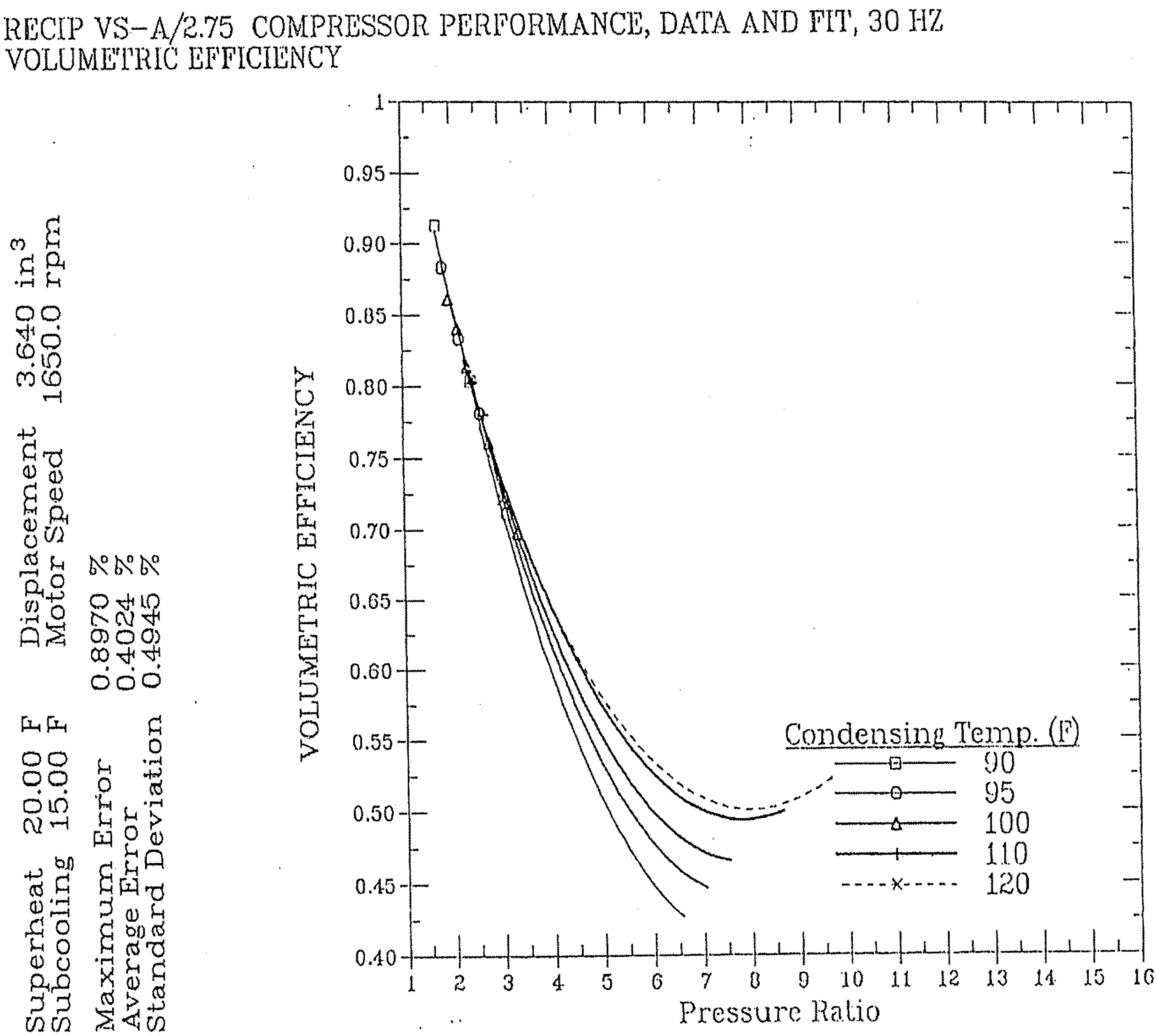

Figure 2. Compressor Volumetric Efficiency As a Function of Pressure Ratio and Condensing Pressure At 30 Hz Frequency — From Curve-Fits To Basic Power and Refrigerant Mass Flow Rate Data.

RECIP VS-A/2.75 COMPRESSOR PERFORMANCE, RAW DATA AND FIT, 30 HZ
ISENTROPIC EFFICIENCY

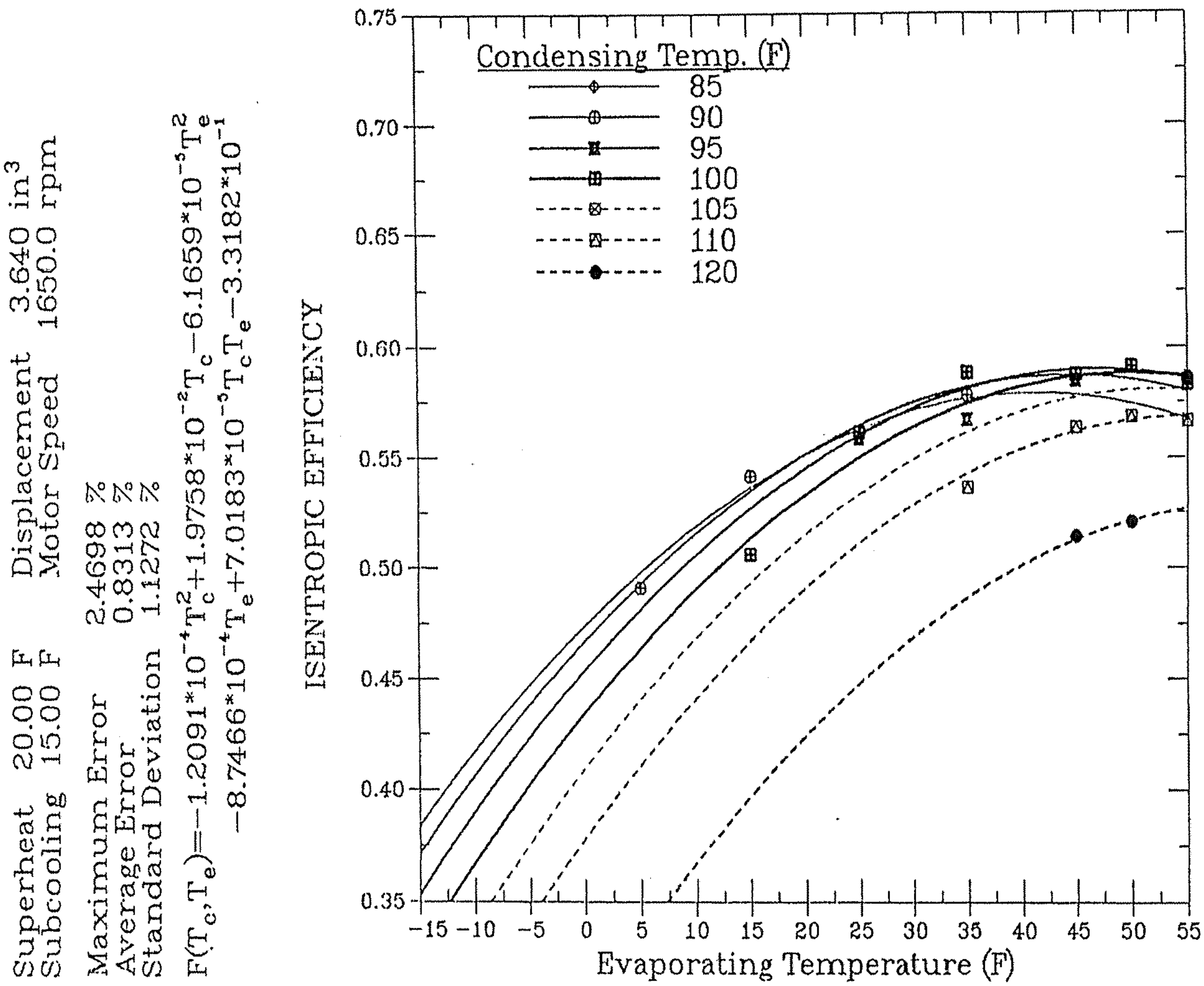

Figure 3. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 30 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

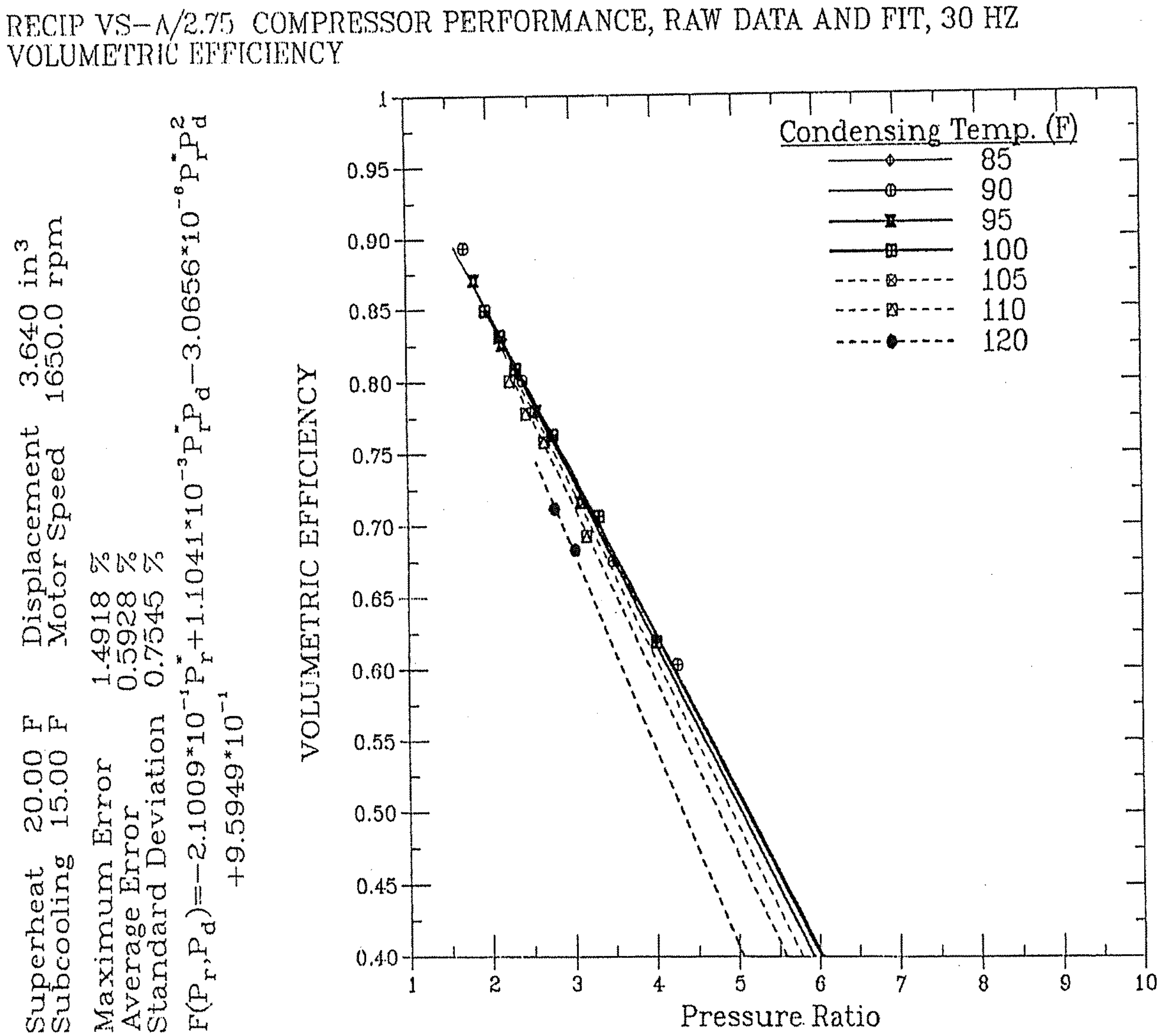

Figure 4. Compressor Volumetric Efficiency As a Function of Pressure Ratio and Condensing Pressure At 30 Hz Frequency — From Curve-Fits To Derived Volumetric Efficiency Values.

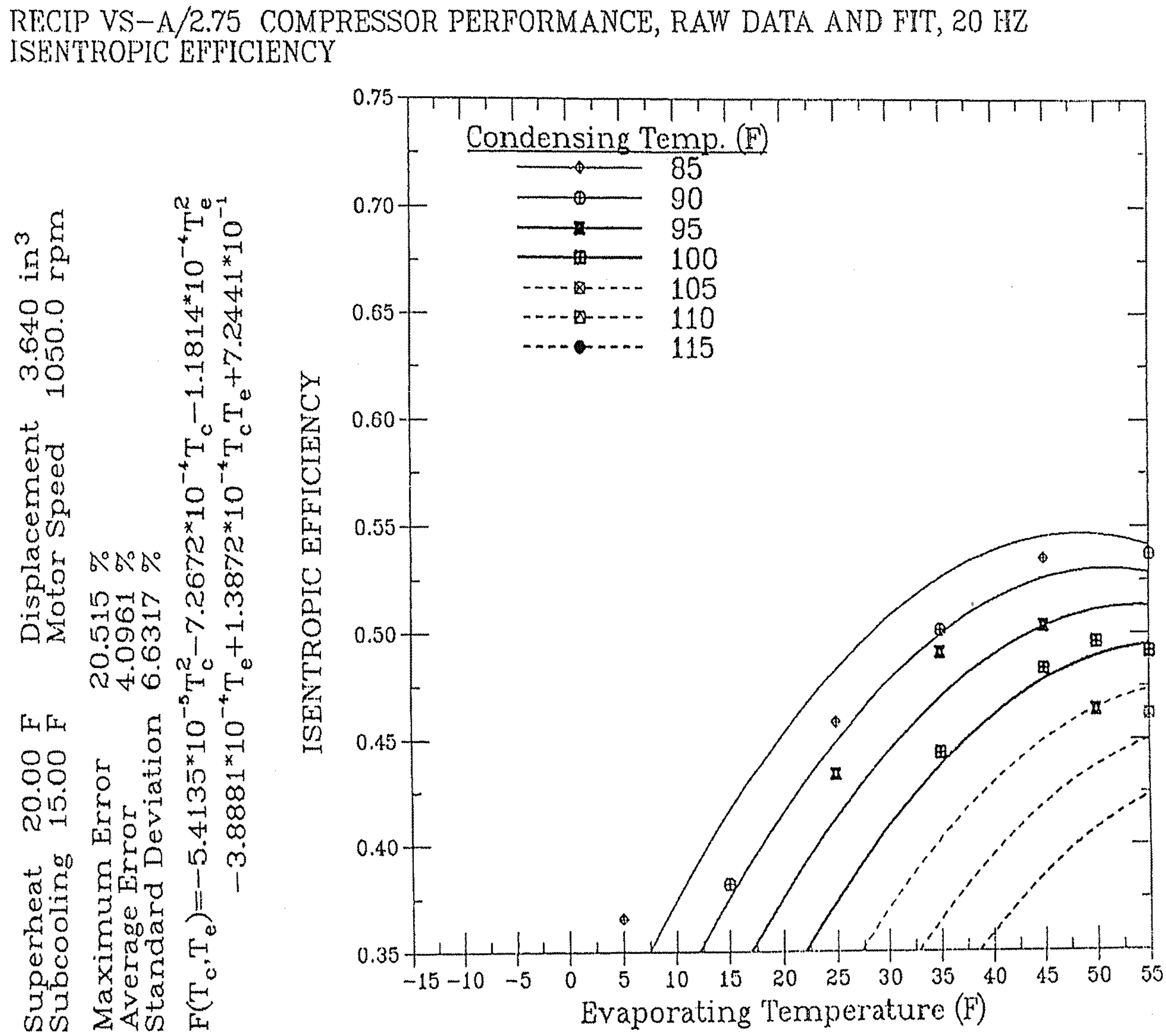

Figure 5. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 20 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

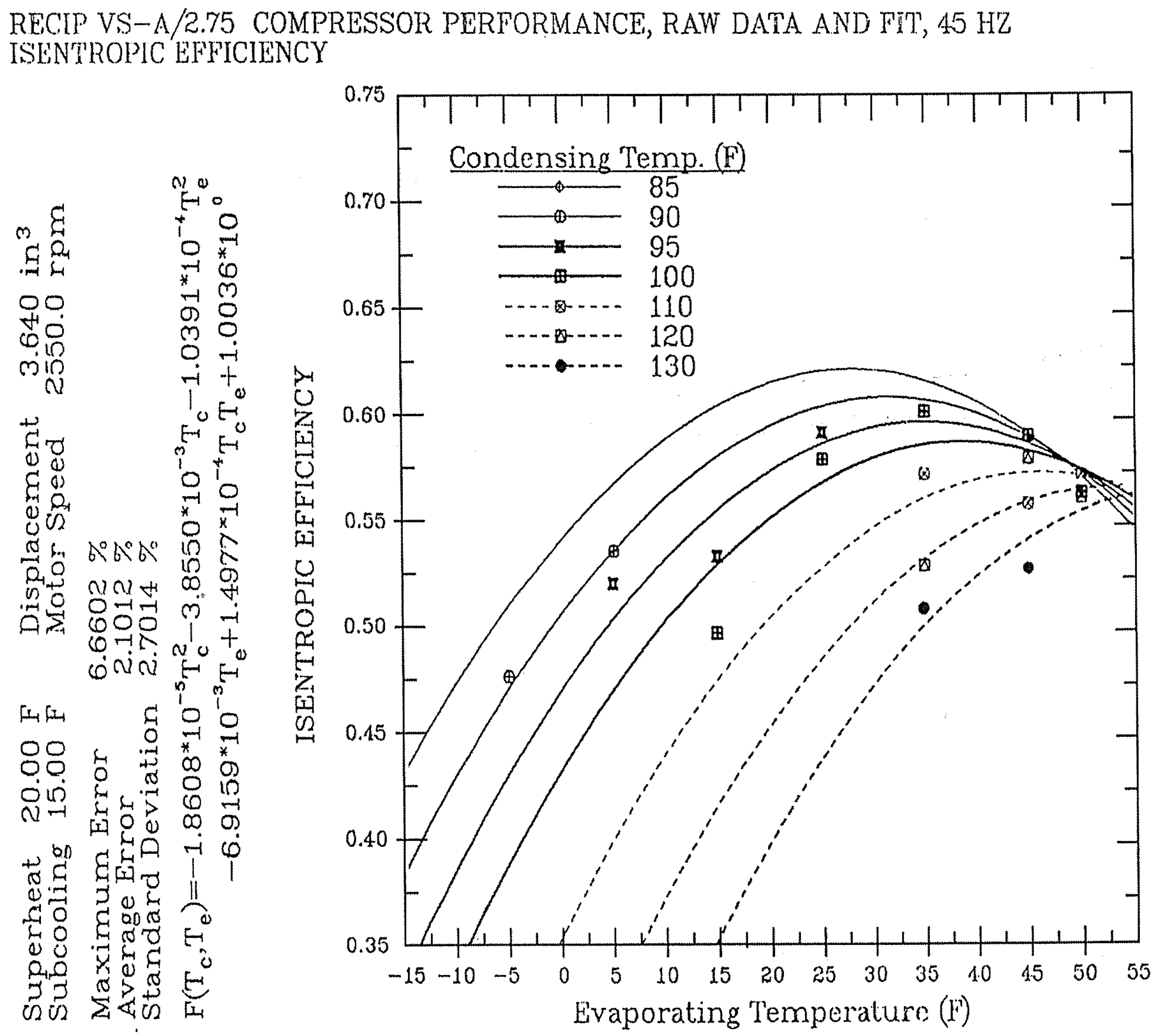

Figure 6. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 45 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

RECIP VS–A/2.75 COMPRESSOR PERFORMANCE, RAW DATA AND FIT, 60 HZ
ISENTROPIC EFFICIENCY

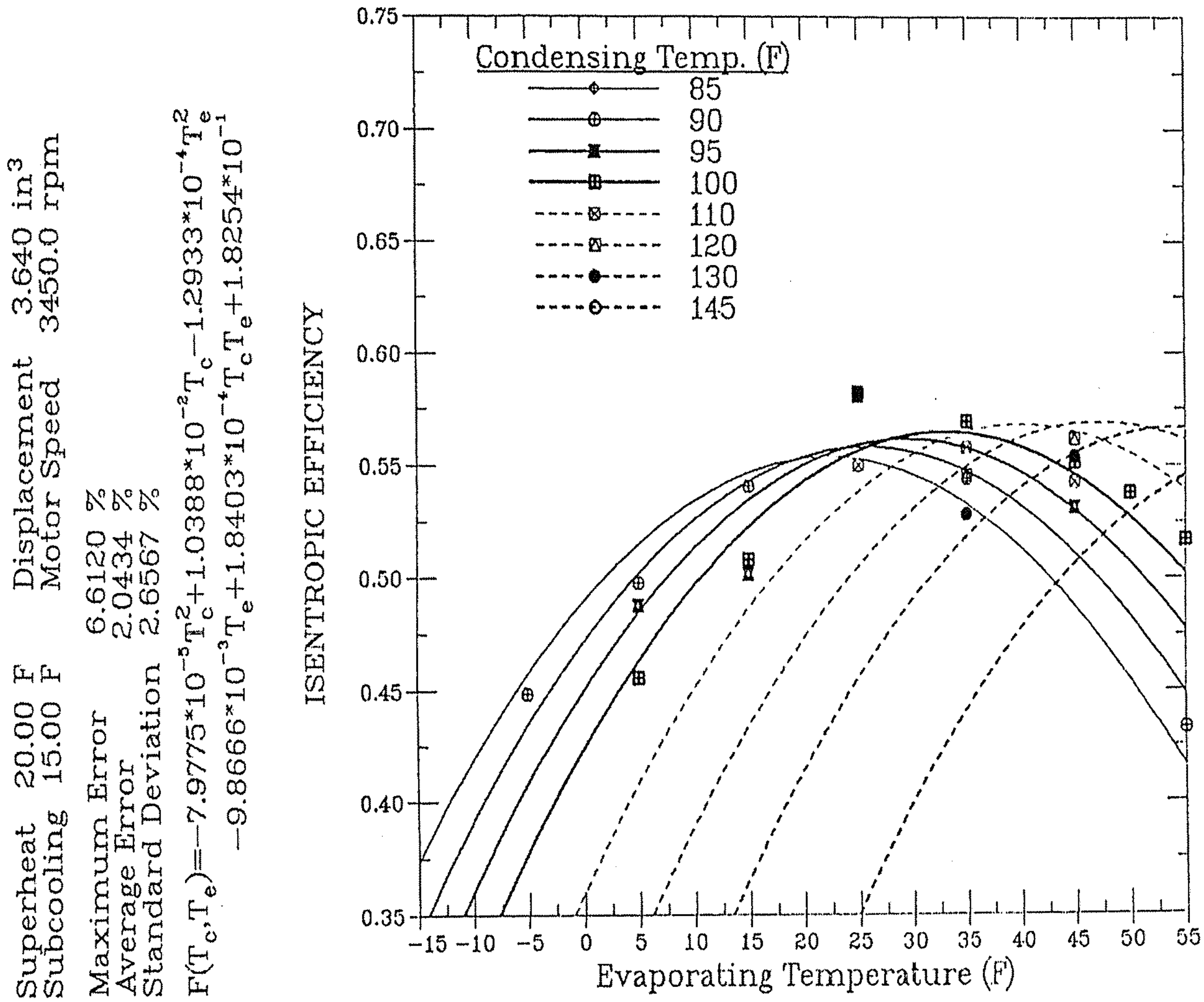

Figure 7. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 60 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

RECIP VS−A/2.75 COMPRESSOR PERFORMANCE, RAW DATA AND FIT, 75 HZ
ISENTROPIC EFFICIENCY

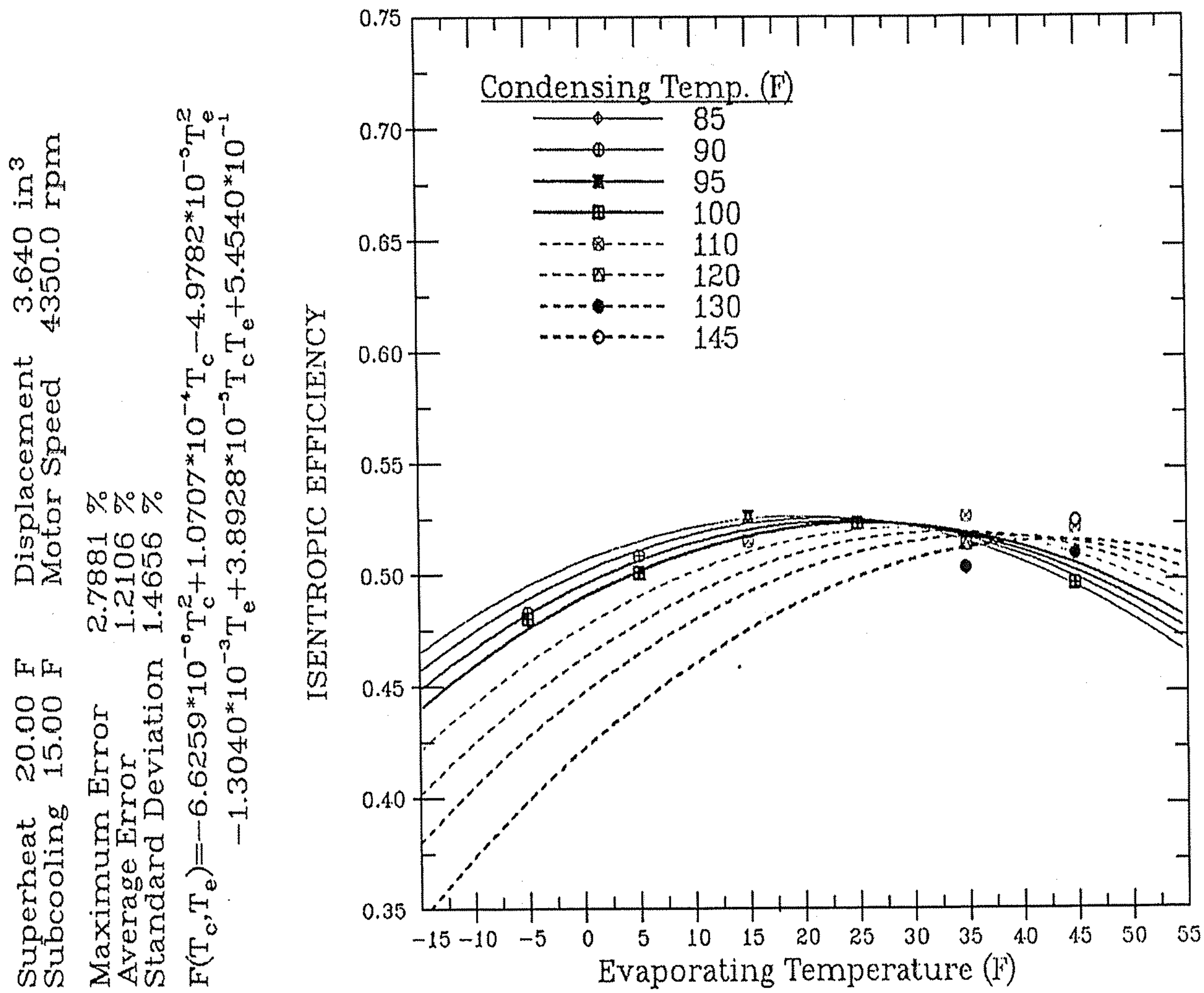

Figure 8. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 75 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

RECIP VS−A/2.75 COMPRESSOR PERFORMANCE, RAW DATA AND FIT, 90 HZ
ISENTROPIC EFFICIENCY

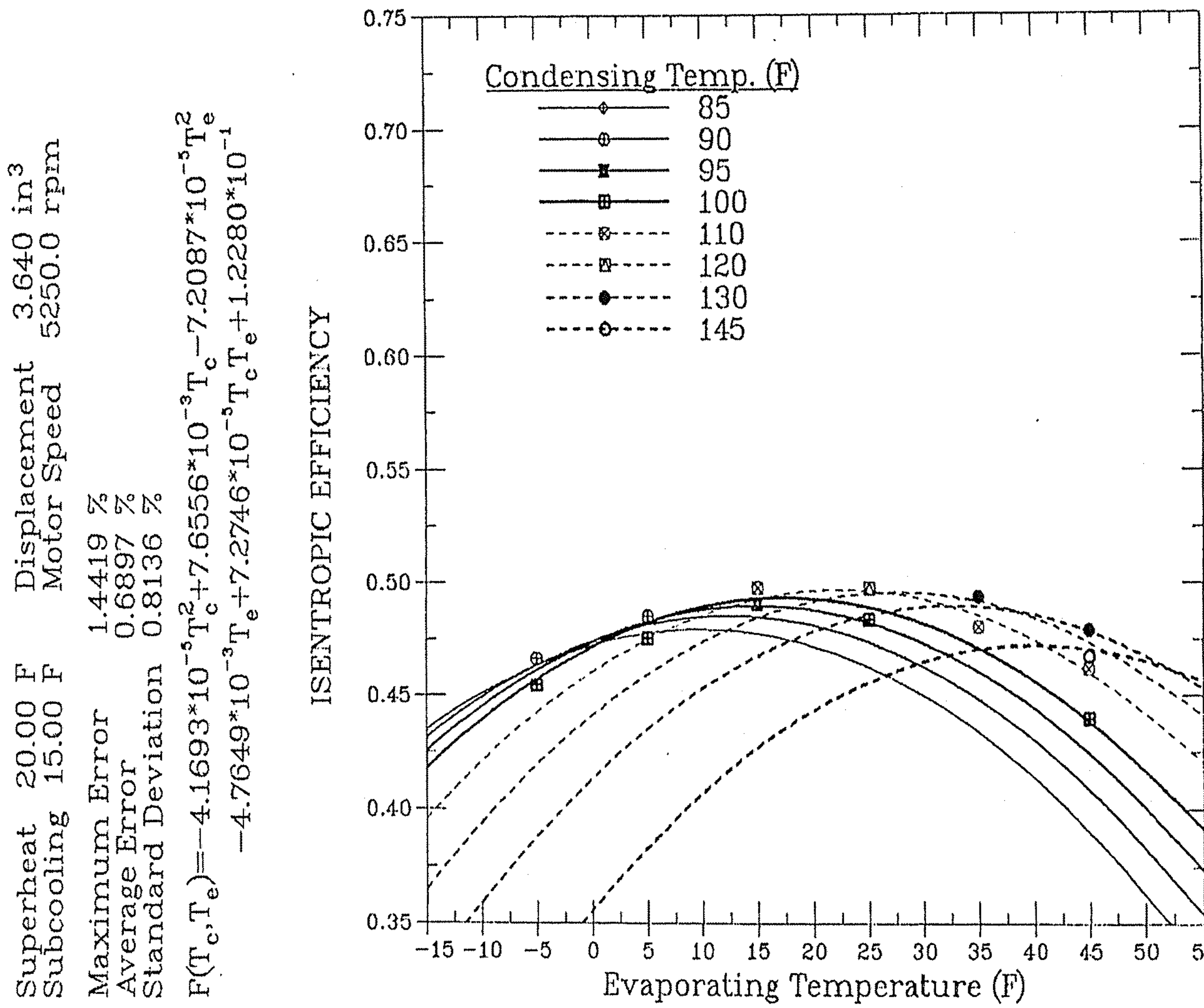

Figure 9. Compressor Isentropic Efficiency As a Function of Evaporating and Condensing Temperatures At 90 Hz Frequency — From Curve-Fits To Derived Isentropic Efficiency Values.

Modulating Drive Options

Drive Efficiency Options. Four drive efficiency conversion options are available in the program. They are:

1) a moderate-efficiency inverter drive (first-generation IDIM),

2) a high-efficiency inverter drive (state-of-the-art IDIM),

3) an ideal sine-wave-driven induction motor (SWDIM) [limiting case for modulating induction motor],

4) an electronically commutated motor (ECM)

The user-supplied compressor data can be for an inverter-driven system (either IDIM or ECM) or for a reference SWDIM compressor. The user selects whether this base compressor map is to remain unmodified or be converted to one of the above drive types.

If a conversion is to be made, the user must be especially careful to properly identify the supplied map with one of the four types so that the most accurate conversion is made. The potential error involved in such conversions is reduced if the base map data is for a SWDIM drive. This is typically obtained by testing the compressor with a variable-frequency motor-generator set. The SWDIM option is also useful in evaluating the total system loss resulting from the direct (inverter) and indirect (increased motor inefficiency and suction gas superheat) losses of inverter-driven induction motors.

IDIM Correction Factors. Efficiency reduction factors for first-generation IDIMs were based on comparative 2.75-ton hermetic reciprocating compressor tests using alternately a voltage-source-inverter (VSI) and a motor-generator (m-g) set (the SWDIM reference) as described by Miller (1988b). From these tests conducted at representative modulating conditions, the following efficiency multipliers of Table 1 were determined for the combined motor and inverter efficiency of first-generation IDIMs relative to SWDIM efficiency:

Table 1. Efficiency Degradation Multipliers For Compressor First-Generation IDIMs

Drive Frequency	Heating Mode	Cooling Mode
15	0.621	0.625
30	0.784	0.809
45	0.840	0.860
60	0.868	0.841
75	0.878	0.83 (est.)
90	0.879	0.82 (est.)

By the nature of the tests, these factors include any suction gas heating differences between the two drive types.

Similar multipliers were developed for the state-of-the-art IDIM option using bench efficiency data on high-efficiency VSI inverter drives and model simulations of the corresponding reference SWDIM efficiency — both obtained from Lloyd (1987). The efficiency degradation multipliers obtained from this information in shown in Table 2.

Table 2. Efficiency Degradation Multipliers For Compressor SOA IDIMs

Drive Frequency	Heating Mode	Cooling Mode
15	0.82 (est.)	0.78 (est.)
30	0.87	0.872
45	0.908	0.915
60	0.921	0.919
75	0.929	0.920 (est.)
90	0.946	0.920 (est.)

By the nature of this data, these factors do not include any suction gas heating differences between the two drive types — although as these degradation factors are closer to unity, this secondary effect would be expected to be small. In all the above cases, the motors were 2-pole with nominal speeds of 3450 – 3500 rpm.

Induction-Motor (IM) to ECM Conversion. The user can have the program simulate the replacement of the drive used in an IDIM or SWDIM compressor drive with a PM-ECM drive. This replacement option will allow the same basic modulating compressor characteristics to be applied with a different drive characteristic. In this way, calorimeter data with existing compressors and drives can be used with more advanced drive combinations.

Most compressor maps are available only for induction-motor (IM) drives. Many of these are for single-speed motors (equivalent to the SWDIM option but only for one or at most two frequencies, i.e., 50 and 60 Hz). The variable-speed compressor data are usually for IDIMs of either the PWM or VSI type. Variable-speed SWDIM data are rather scarce. However, as this latter type of data has fewer uncertainties with regard to the level of inverter-waveform-related losses, it is preferred for cases where a conversion of motor type is required.

To make such a conversion, it was necessary to provide to the model representative SWDIM and ECM performance at least as a function of drive frequency. However, to avoid having to preselect an appropriate torque vs speed profile for the drives and to further provide for motor sizing generality, complete mappings of representative SWDIM and ECM performance as a function of normalized drive frequency and torque were incorporated.

SWDIM Performance. Performance information on a representative sine-wave-driven induction motor were obtained from Zigler (1987). He generated simulated sine-wave performance maps on an existing variable-speed motor for which the basic motor characteristics were well known and for which standard motor efficiency test data were available at the standard motor rating temperature of 77°F (25°C).

From these empirical simulations, motor efficiency and slip were provided for a 2.75 hp (2.05 kW), 2-pole, 3-phase motor over a range of frequencies from 15 to 90 Hz, a range of torques from 20 to 200% of nominal, and a range of voltages from 90% to 110% of nominal. Nominal torque was at 60 Hz frequency (3450 rpm). All simulated values were for estimated typical rotor and stator temperatures in a hermetic compressor environment. Motor windage and friction losses were not included in the motor efficiency values. Contour plots of the SWDIM performance mappings for motor efficiency and slip are shown in Figures 10 and 11.

To provide further analysis flexibility, the motor data were generalized in the model to apply to a normalized speed range of 25 to 150% of nominal and for motor sizes other than the original 2.75 hp (2.05 kW). However, the original basis for the data are provided here so that users can make their own judgements as to whether or not such generalizations are sufficiently accurate for their specific analysis purposes.

The SWDIM motor for which data were provided was, in fact, the same model motor used in the reference SWDIM compressor tested by Miller (1989). Therefore, when used together, these two data sets provide a most consistent basis for extraction of the SWDIM performance and replacement with ECM efficiency characteristics.

ECM Performance. Dynamometer performance data were obtained from Young (1990) on a production 4-pole, 3 hp (2.24 kW) ECM for a range of compressor speed and torque. As there is no motor slip in an ECM motor, speed is directly proportional to drive frequency. Therefore, for ECMs, only motor efficiency as a function of speed and torque is needed to characterize motor performance.

The range of motor speed was from 1000 to 6250 rpm with a nominal speed of 5400 for a normalized speed range of 0.2 to 1.15 of nominal. The torque range was from about 20 to 190% of the nominal value. No windage and friction losses were included as for the SWDIM case; however, estimated magnetization losses due to the permanent magnet rotor were included.

Similarly as for the SWDIM motor data, the ECM performance data were generalized to apply for nominal speeds and motor sizes other than that for which the data were available. Contours of compressor ECM drive efficiency as a function of speed and fractional load are shown in Figure 12.

ECM Operating Temperature Corrections. The ECM data were taken at the standard motor rating temperature of 77°F (25°C). Therefore, to properly apply the data to a hermetic application, correction factors for motor temperature effects were developed. These were based on information provided by Zigler (1987) and supplemented by Young (1990) and are functions of stator and rotor temperature, winding resistances, the motor current vs torque relationship, and magnet flux temperature coefficients. Appropriate values for these parameters are specified in BLOCK DATA

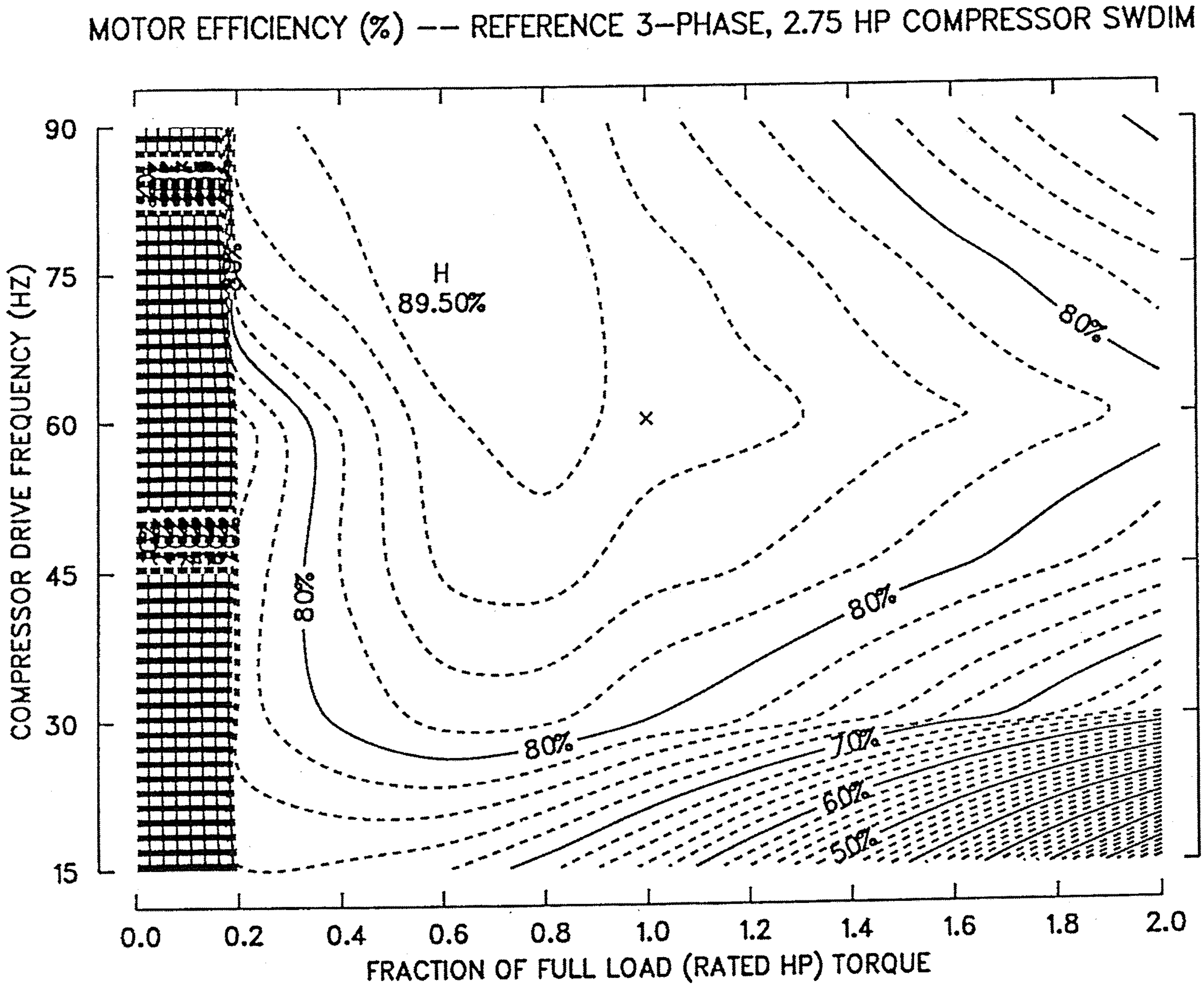

Figure 10. Modulating, Sine-Wave-Driven, Induction Motor (SWDIM) Efficiency — Reference 3-Phase, 2-Pole, 2.75 Hp Compressor Motor.

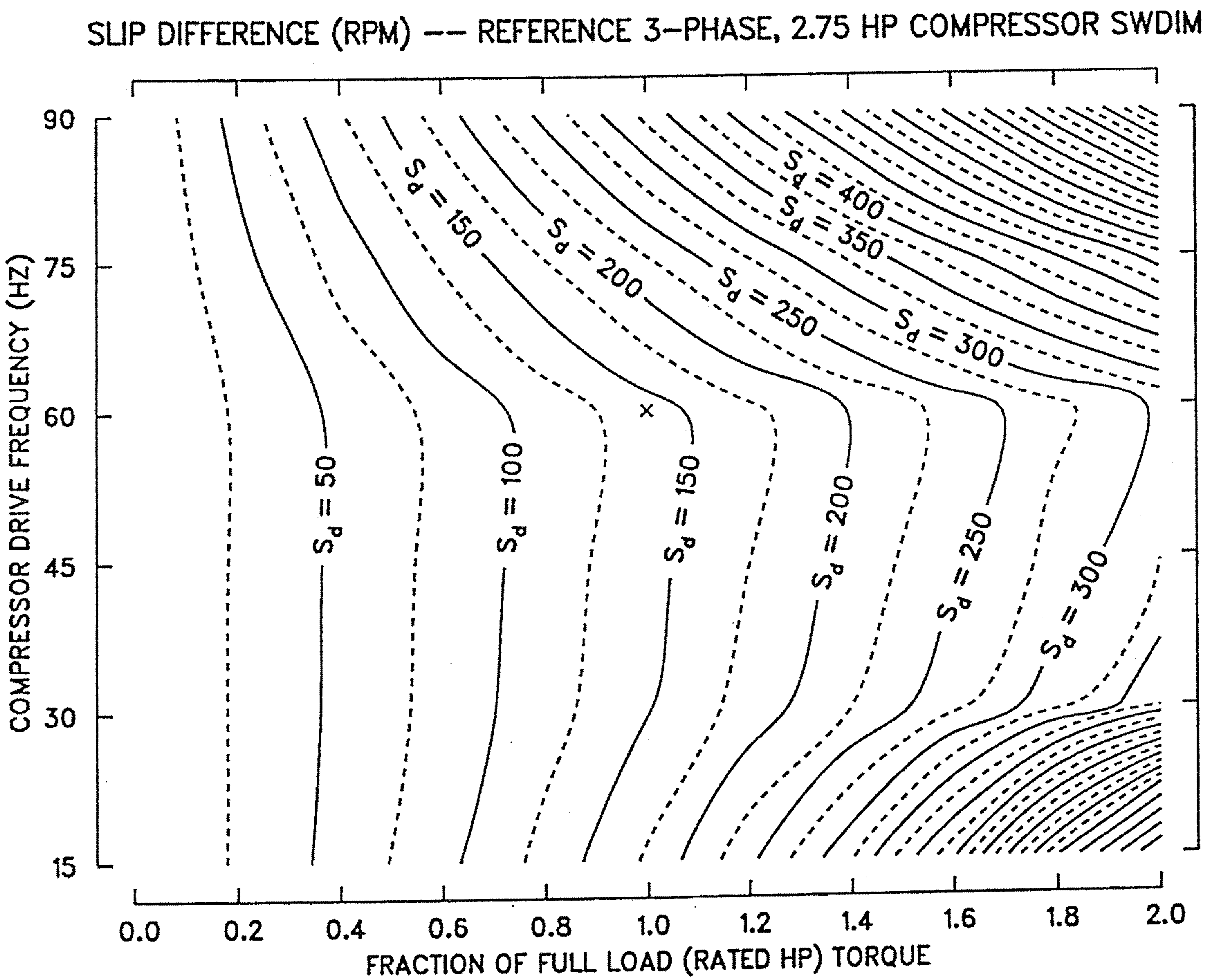

Figure 11. Modulating, Sine-Wave-Driven, Induction Motor (SWDIM) Slip Difference — Reference 3-Phase, 2-Pole, 2.75 Hp Compressor Motor.

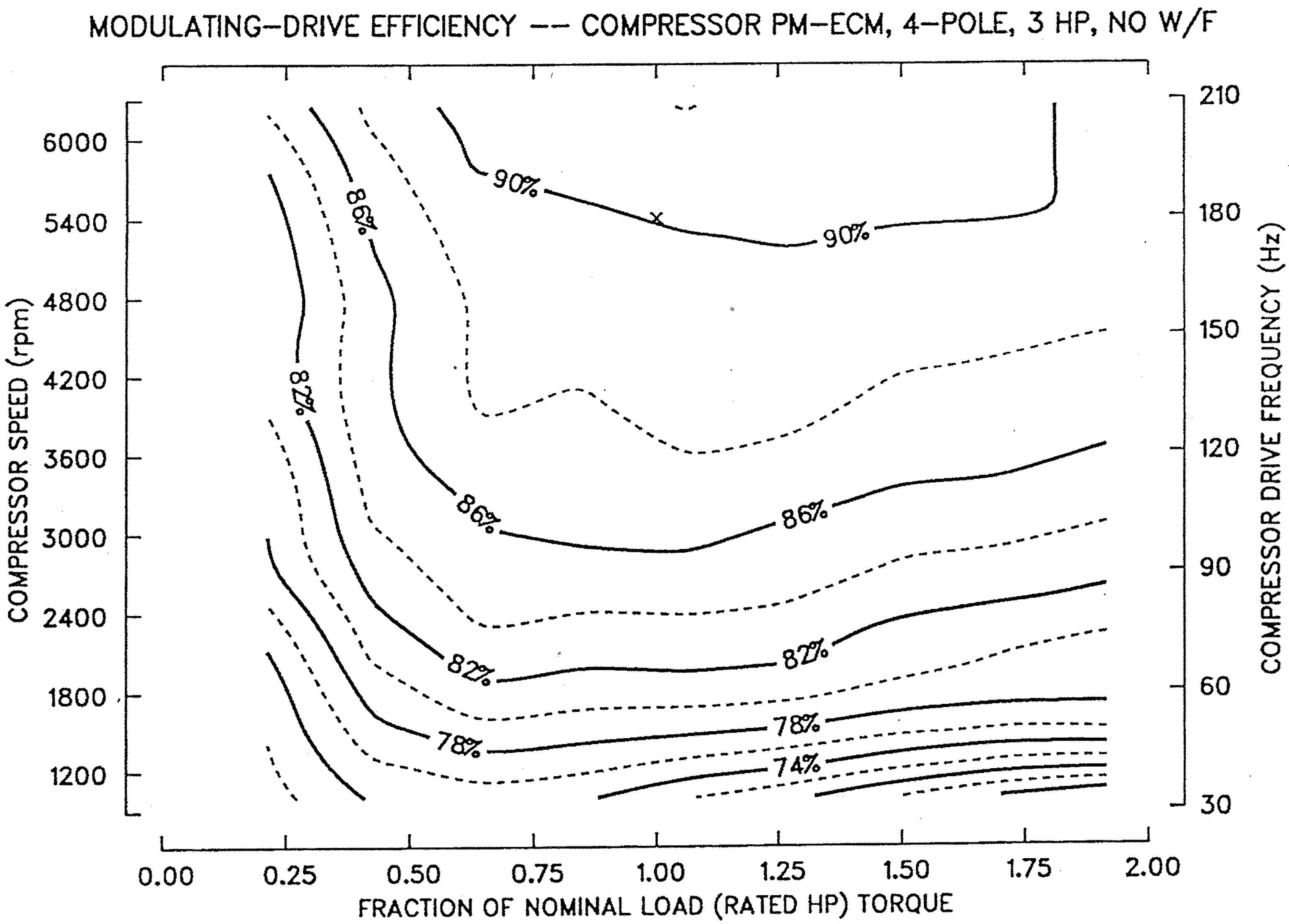

Figure 12. Modulating Drive (Motor and Inverter) Efficiency of a Permanent-Magnet, Electronically-Commutated Motor (PM-ECM) — Reference 3-Phase, 4-Pole, 3 Hp Compressor Motor.

for two nominal-speed designs; the corrections for other nominal speeds are determined by interpolation.

IM-To-ECM Conversion Procedure. For given compressor operating conditions and operating frequency, the model first calculates the compressor input power for the base compressor map. Given frequency and drive input power, the motor operating speed, torque and efficiency can be found by iteration using the reference SWDIM performance maps (and the efficiency corrections for direct and indirect inverter losses, depending on the type of compressor drive). The computed torque and the specified frequency are next used with the ECM performance map to calculate the efficiency of the replacement motor. This difference in efficiency is then applied to the power requirements predicted from the baseline compressor map. Corrections for the differences in speed between the SWDIM and the ECM operating at the same frequency are also applied to the power and refrigerant mass flow rate values.

Secondary Effects of Reduced Suction Gas Superheating. An approximate method was also developed to adjust for the performance effects of reduced suction gas superheating with the more efficient ECM motor. The reduction in motor losses resulting from the use of a more efficient motor is calculated and an estimated portion of this is used to reduce suction gas heating from a computed baseline level. The effect of this estimated superheat reduction on ideal compression work is applied as a secondary correction ratio to the overall isentropic efficiency. The result is an approximate measure of the compounded benefit of conversion to the more efficient ECM drive.

Motor Sizing/Loading Options

Compressor motor performance of either IDIM, SWDIM, and ECM types can be simulated based on a specified motor size or, alternatively, each motor can be sized automatically by the model to operate at a required percentage of rated load.

Automatic Motor Sizing. In this option, users can investigate alternative motor sizing choices by directly selecting the degree of loading (percent of rated torque) at which they would like the motor to operate on the appropriate motor efficiency curve . This percentage is then specified in place of motor size and the model will determine the required size to maintain motor operation at this loading.

This approach is advantageous when users know where they would like the motor to operate on its performance curve (i.e., the specific motor sizing strategies they would like to evaluate) and would like to maintain that point (and efficiency) while various system configurations and/or operating variables (such as air flow rates) are being evaluated. Then once the system configuration is decided upon, the program determines the required motor size.

Specified Motor Size. *This option is most useful once the motor size has been fixed by a previous design analysis or when only certain sizes are available for consideration.* The user directly specifies the desired motor size (in hp) for the selected drive type. The model uses the chosen size along with the selected nominal speed to compute a nominal torque. This rated torque is then compared to the required operating torque to determine the resultant fractional loading on the motor. The motor performance curves are then used to determine the motor efficiency and speed (for IMs) at the operating torque and drive frequency ratios.

In this approach, the motor efficiency at a given speed will change as the system configuration and operating conditions change. Specified motor sizes are the preferred approach at off-design conditions during the design process and at all operating conditions once the system design has been finalized. It should be noted that if a compressor base displacement is scaled manually by the user, the specified motor size should be scaled similarly.

A recommended procedure for sizing compressor motors and simulating off-design performance for a modulating application using these options has been presented by Rice (1992).

VARIABLE-SPEED BLOWERS

Modulating Blower Performance

Modeling Perspective Relative To That For The Compressor. The modeling of variable-speed drives for blowers and fans is somewhat more straightforward than for compressors. This is because a combined blower(or fan)/motor/drive performance map is not required to be provided by the user as in the case of the compressor. Blower/fan performance is instead handled separately from that of the motor/drive combination.

Whereas compressor efficiency (both isentropic and volumetric) varies with speed, to a close approximation, blower and fan efficiencies remain constant with speed (from the fan laws). Therefore the modeling assumptions and options provided for modeling blower and fan efficiencies discussed by Fischer and Rice (1983) hold equally well for modulating air flows.

The primary added capability in the new model which relates to blower- and fan-only efficiencies is the new option of being able to specify a nominal power from an existing system and have the program internally compute and apply the implicit impeller efficiency (based on the calculated air-side pressure drop) to a new drive type.

General Capabilities. For modulating blowers and fans, the required fan power can be computed from first principles or referenced to a specified nominal power at design speed. The conversion-option categories available for modulating blowers and fans is similar in type to that provided for the compressor drives — first generation and SOA IDIM, SWDIM, and ECM. For all drive types, the program will compute the required motor size (when the model is run at nominal speed). However, only for ECM blowers and fans is the full range of motor sizing options available — comparable to that provided for all drive types in the case of compressors.

The blower/fan drive models are based on:

- first-generation IDIM and SWDIM blower drive efficiency data derived from ORNL tests of a modulating heat pump conducted by Miller (1988b), and

- SOA IDIM versus SWDIM comparative efficiency data obtained from a motor manufacturer (Lloyd 1987),

Reference SWDIM. The reference SWDIM data built into the model was taken from combined blower and motor tests of Miller (1988b) on a three-phase, six-pole, 1/3 hp (0.25 kW) air handler. A variable-frequency motor-generator was used for the baseline test and the volts/Hz ratio of the motor was adjusted at each tested frequency to maintain best efficiency.

A nominal efficiency of 75% was obtained from the motor manufacturer and used to determine a blower-only efficiency of 28% at nominal speed. By assuming the blower efficiency was constant with speed, motor efficiencies were derived from measured blower power for the range of tested frequencies from 25 Hz to 60 Hz. As the tests were performed in an actual air handler unit, the appropriate fan load for a modulating application was automatically provided.

The resultant reference SWDIM efficiencies taken from a curve-fit and extrapolation (where shown as estimated) of the derived efficiency points are tabulated in Table 3 as a function of drive frequency. The function FANSWV contains a curve-fit representation of these data points.

Table 3. Reference SWDIM Efficiency For Blower Applications

Drive Frequency	SWDIM Efficiency
15	0.40 (est.)
20	0.52 (est.)
25	0.584
30	0.637
35	0.680
40	0.712
45	0.732
50	0.745
55	0.750
60	0.750

First-Generation IDIM. The same procedure was used to derive drive efficiencies from similar air-handler tests over a slightly wider speed range conducted by Miller (1988b) on the same motor with a first-generation VSI inverter drive. The derived IDIM efficiencies were divided by their corresponding SWDIM values to obtain efficiency degradation factors due to the direct and indirect inverter losses (Miller 1988b). These multipliers are given in Table 4 — a curve fit of which is built into the model in function FANFGN.

Table 4. Efficiency Degradation Multipliers For Blower First-Generation IDIMs

Drive Frequency	Multiplier
15	0.13 (est.)
20	0.23 (est.)
25	0.36
30	0.47
35	0.56
40	0.62
45	0.69
50	0.75
55	0.80
60	0.82

SOA IDIM. For state-of-the-art (SOA) IDIMs, bench test efficiency data taken under representative fan loading conditions were obtained from a motor manufacturer (Lloyd 1987). The corresponding SWDIM performance at the same conditions was also estimated by the manufacturer. From these data, consistent degradation factors for the SOA IDIMs were obtained. The resultant degradation factors for SOA IDIMs are shown in Table 5 — a curve-fit representation of which is contained in function FANSOA.

Table 5. Efficiency Degradation Multipliers For Blower State-Of-The-Art IDIMs

Drive Frequency	Multiplier
15	0.32 (est.)
20	0.45 (est.)
25	0.58
30	0.66
35	0.73
40	0.78
45	0.83
50	0.86
55	0.89
60	0.92

ECM Indoor Blower and Outdoor Fan Performance. For both the indoor blower and outdoor fan modulating drives, an efficiency map obtained from Young (1990) for a 12-pole, 1/5 hp (0.15 kW) production ECM as a function of speed and torque was used. The range of motor speed was from 300 to 1300 rpm with a nominal speed of 1200 for a normalized speed range of 0.2 to 1.15 of nominal. The torque range was from about 20 to 160% of the nominal value. Windage and friction losses were included as were magnetization losses due to the permanent magnet rotor. A plot of the blower ECM performance mapping is shown in Figure 13.

The torque range for the 1/5 hp ECM was generalized in the model to be applicable for other nominal motor sizes as specified by the user. The ECM speed range was not normalized, however, as it was felt that it would be less likely to have a range of fan motors designed for different nominal speeds available (in contrast to the compressor where a redesigned motor would have more potential for energy savings). By not normalizing the blower ECM speed range, it was also possible to more easily simulate the more common use of different speed taps on a single ECM drive to meet different application requirements with the same nominal speed design. In this way, the same basic drive design can be applied to indoor blowers and outdoor fans with different nominal speeds (e.g. 1080 rpm for the blower and 825 rpm for the outdoor fan).

Further Discussion of Blower and Fan Modeling Capabilities

Model Calibration Options. As noted earlier, there are two options for computing modulating blower or fan power — by first principles or based on a baseline nominal power input. For a specified operating frequency and drive type, the *first principles* approach uses model-calculated air flow, pressure drops, and blower and blower drive efficiencies to directly calculate required fan power based on the given indoor or outdoor unit air-side configuration. If the computed values do not agree closely enough with available test data, the input values of blower efficiency and/or the coil/system pressure drop multipliers can be adjusted at one test condition in each mode (to account for wet-to-dry coil effects) to calibrate the model.

An alternative approach which can be more convenient when comparing to existing hardware is to specify known nominal power values for the indoor and/or outdoor units and the associated drive types. The model will compute the proper modulating fan power based on the fan laws and the ratio of drive efficiencies between the baseline and the selected drive types at the specified operating frequency. In this alternative approach, the calculated system pressure drop is not used directly in the fan power calculations but is used to compute the implied blower efficiency and the required motor size.

Indoor Duct System Options. The options for specifying the indoor duct system have been enhanced to provide more convenient ways to control the external pressure drop seen by the indoor blower for nominal design conditions. In place of a specified duct size, a fixed external pressure drop can now be specified to meet ARI minimum requirements (ARI 1989) or to agree with a measured value for a given test setup. The required duct size is also computed in this case so that this value can, in turn, be specified for an off-design-point calculation (Rice 1992).

Coil and indoor system (which includes the built-in heater and filter correlations) pressure drop multipliers have been added to the input to provide further model calibration capability.

ECM Motor Sizing Options. For the blower and fan motors, speed versus torque maps are supplied only for the ECM drives. As a result, motor size or loading selections are possible only for the ECMs. Otherwise, these options work the same as for the compressor case. A recommended

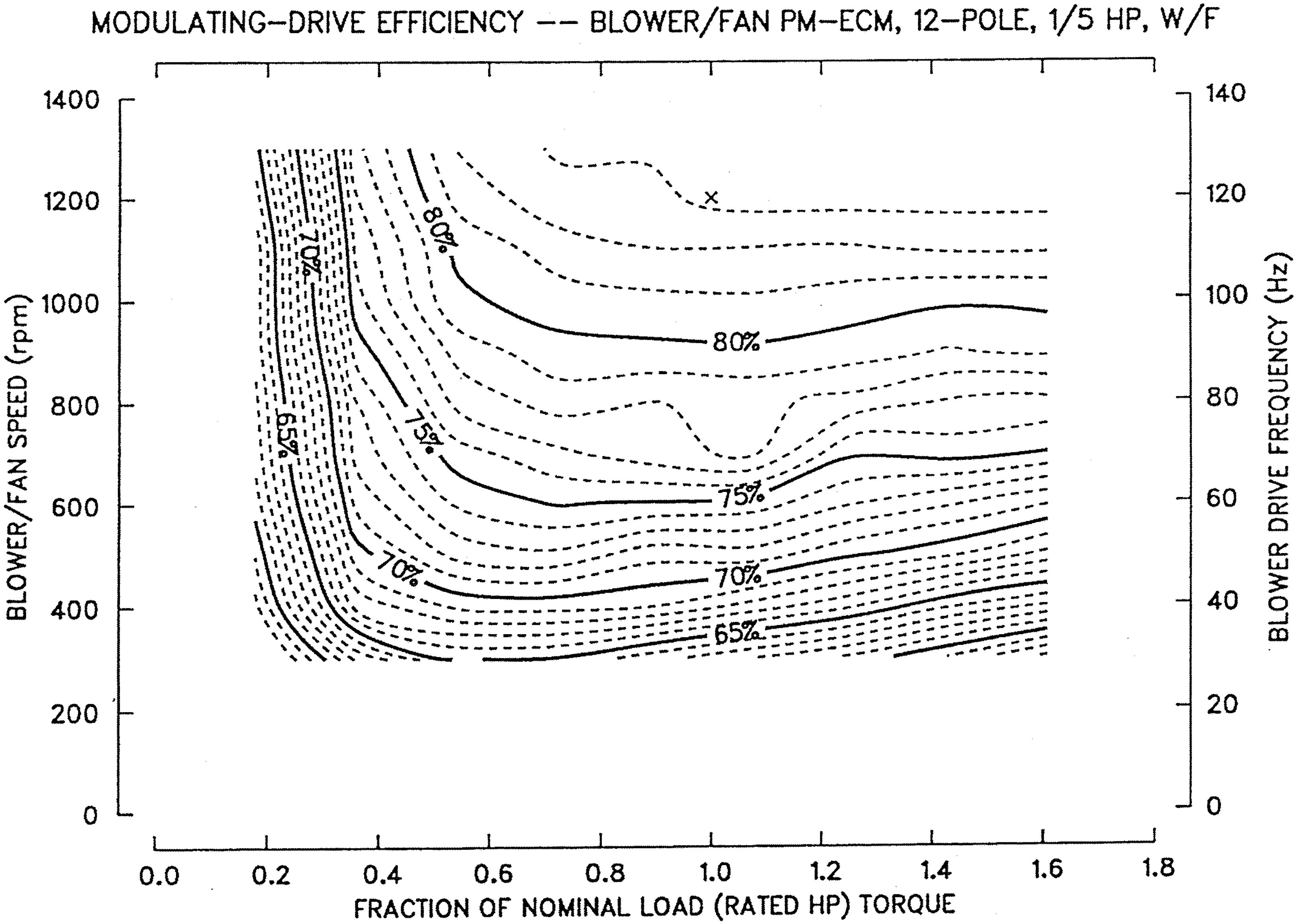

Figure 13. Modulating Drive (Motor and Inverter) Efficiency of a Permanent-Magnet, Electronically-Commutated Motor (PM-ECM) — Reference 3-Phase, 12-Pole, 1/5 Hp Blower Motor.

approach to sizing ECM blower and fan motors and simulating off-design performance for a modulating application using these options has been presented by Rice (1992).

AIR-SIDE CORRELATIONS FOR MODULATION AND ENHANCED SURFACES

Advantages and Features

A major update of air-side heat transfer and pressure drop calculations was completed for improved prediction for modulating air flows based on work by Gray and Webb (1986). Other heat exchanger modeling improvements included the addition of augmentation treatments of wavy and louvered surfaces dependent on Reynolds number and fin pattern specifics. The calculation of coil entrance and exit losses is now done explicitly rather than as just a percentage of the calculated loss.

The benefits of these changes are:

- improved low flow correlations over those used in the ORNL Mark III Model,
- added flow and geometry -dependent augmented surface analysis, and
- more consistent treatment of ancillary air-side pressure losses

<u>New Baseline Air-Side Correlations.</u> The baseline air-side heat transfer and pressure drop correlations (McQuiston 1981) used in the ORNL Mark III HPDM (Fischer and Rice 1983) were replaced by more accurate representations by Gray and Webb (1986). These newer correlations developed for plain fin-and-tube heat exchangers are especially improved at low Reynolds numbers and for prediction of the row effect. This is primarily because Gray and Webb made corrections for experimental error in the original data taken by earlier researchers which had been used by McQuiston. Furthermore, the correlations are much better behaved at low flow rates, as are extrapolations beyond the available test range — which are sometimes needed with modulating applications when exploring the design envelope.

<u>Correction Factor Format.</u> The Gray and Webb smooth-fin correlations were used as the new reference base for plain, wavy, and louvered fin options in the ORNL Modulating HPDM. All augmented surface correlations were represented as correction factors (multipliers), of varying degrees of complexity, to the reference smooth fin equations. This is an especially useful format as most reported data on improved surfaces are for a limited number of tube size, spacing, and row configurations. The referencing of all the correlations to the general model for plain fins adds both generality and consistency to the correlation predictions.

<u>New Geometry and Flow-Dependent Correction Factors.</u> The wavy- and louvered-fin enhancement choices are now offered at two levels of complexity. The first level is as was done in the Mark III Model where constant multipliers are applied to the (new) baseline plain-fin equations. The second level choices are to use multiplier correlations which are now dependent on Reynolds number and fin pattern specifics. For wavy (zig-zag) fins, correlations developed for ORNL by Beecher and Fagan of Westinghouse R & D Center (1987) were used. For simple louvered fin patterns, the

multiplier correlations obtained from Makayama and Xu (1983) were used. These second-level options require additional user input to specify the details of the fin patternations.

Further Improvements In Pressure Drop Calculations. The air-side pressure-drop correlations were further revised, beyond the change to newer reference plain-fin correlations, to improve the consistency of the calculations for the various options. Explicit calculations were added of entrance and exit pressure losses and velocity head loss using expansion and contraction coefficients and methodology from Kays and London (1974). User-supplied pressure-drop adjustment factors were also added for optional application to the overall coil pressure drops and the indoor system pressure drop.

CHARGE INVENTORY AND RELATED WIDE-RANGE FLOW CONTROL OPTIONS

Advantages and Features

Overview. A summary of the advantages of the charge inventory capability are as follows:

- Allows the user to either specify or determine refrigerant charge,
- Enables more realistic off-design predictions for a range of flow control types, and
- Accommodates variable-opening flow control devices needed for modulating heat pumps
  — e.g., PWM valve, stepper motor, TEV's and TXV's.

A major new feature of the ORNL Modulating HPDM is refrigerant charge (mass) inventory capability. This capability can be used in the HPDM in two ways. The user can either specify or determine the refrigerant charge requirements. In the first option, the user specifies the refrigerant charge and requires the model to adjust the operating conditions so that the system requires exactly that amount of active charge (charge balancing). The latter approach is to specify desired operating conditions and have the model calculate the required charge to obtain those conditions (charge determining).

The charge-balancing procedure is more useful in simulating system performance with predetermined flow control hardware over a range of off-design operating conditions. The charge-determining alternative is useful in evaluating system charge and storage requirements in the design phase when the equipment is being evaluated for (or being controlled to obtain) optimum condenser subcooling or flow control sizing and evaporator superheat levels over a range of operating conditions.

The charge inventory feature can also be turned off completely. In this case, the model calculations are essentially the same as for the Mark III version.

Charge-Balancing Option. With a charge inventory balance, one can predict the effects of a given charge level on systems with little or no charge storage capacity or predict the levels at which over- or under-charging effects begin to occur. The additional information about system charge-balancing requirements enables more realistic off-design predictions for a range of flow control approaches. Existing and advanced (or idealized) *variable-opening* flow control devices, which are more necessary in modulating systems, can be modeled more directly with the addition of a charge balance (which determines required condenser subcooling or evaporator superheat levels).

From a computational perspective, use of a charge balance requires an additional outermost iterative loop in the heat pump solution scheme. As such, the model run-time is increased approximately by the number of times the outermost loop must be repeated to obtain agreement between the specified and the calculated refrigerant charge. On each successive iteration, the evaporator exit superheat or the condenser exit subcooling is adjusted (depending on the flow control type specified) so as to bring the calculated and specified charges into agreement.

Charge-Determining Option. In contrast, the charge-determining alternative has much less computational overhead — at most a factor of about two. This option provides the designer with feedback on how various heat exchanger size and control options affect the charge requirements but without prematurely limiting the range of possible system operating conditions with an additional charge constraint. Both the added flexibility and computational speed of the charge-determining approach make it a more suitable choice for initial scoping and more general system design optimization studies.

Recommended Design Procedure. Once the optimum control conditions of the system are established, over a range of operating conditions without the constraints of charge inventory-balancing, the charge and flow control requirements of the idealized design can be evaluated and approaches prescribed to approximate this in hardware. (Valve sizing information for various types is provided in the model output.) At this stage, the charge-balancing model can be brought into effective use to evaluate the refrigerant charge levels needed for various flow-control types and sizings to most closely approach the thermodynamically-optimum design over the range of required operating conditions. In this way, the available charge inventory options can be used in combination to find a design which is not only workable but which also obtains the best performance out of the available hardware.

Flow diagrams of the HPDM solution logic for the charge-determining and the charge-balancing options are shown in Figures 14 and 15. The various options of specified flow control or heat exchanger exit conditions with and without a specified charge are discussed at some length in the sections to follow.

Inventory Calculation Features. The charge inventory calculational model includes the following features :

- user choice of inventory method ranging from simplified to SOA (Rice 1987). The simplified analytical formulation is provided for first-level analysis as it is much faster than the other more accurate methods that are included but which require numerical integration (Rice 1987),

- tabulations of the steady-state on- and off-cycle charge distributions in a heat pump, and

- a j-tube accumulator model adapted from the NIST mixed — refrigerant heat pump simulation (Domanski, 1985, 1986).

More specifics of the inventory choices and the accumulator model requirements can be found in the description of the HPDATA input file in Appendix B. Details of the available inventory methods, covering the different possible void fraction models and heat flux assumptions can be found in the paper by Rice (1987). Recent heat pump validation tests with the different methods have been reported by Damasceno et al (1991).

Modeling Interrelationships Between Refrigerant Charge and System Flow Control

As discussed in the preceding section, the inclusion of charge inventory capability in the ORNL Modulating HPDM allows the user to either determine or specify the refrigerant charge inventory. The various options for specifying flow control devices or heat exchanger exit conditions with and without a specified charge are discussed in this section with reference to the flow diagrams shown in Figures 14 and 15. The charge-determining path is taken when refrigerant charge is not specified while the charge-balancing route is taken if a refrigerant charge level is provided.

<u>If the refrigerant charge is not specified</u>, the user must define, as input, values for

1) compressor inlet superheat

and

2) either condenser exit subcooling directly
or specific flow control devices
(indirectly determining condenser subcooling).

<u>If the refrigerant charge is specified</u>, the user may only specify one of the above categories with the remaining category to be determined by a system charge balance. Otherwise, the system would be overspecified. From a thermodynamic cycle perspective, either *compressor inlet superheat* or *condenser exit subcooling* must be left as a free parameter to be determined by charge balancing when the refrigerant charge is an additional given quantity. If the compressor inlet superheat is specified, the cycle is considered *low-side-determined* while if condenser exit subcooling (or a flow control device) is specified the cycle is *high-side-determined.*

These choices are made in the HPDATA input data file (Appendix B) on Lines #4 and #5 where the *Charge Inventory / Superheat Data* and the *Charge Inventory Calculational Data* are specified. Related specification of condenser subcooling or specific flow control devices is made by the user under *Flow Control Device Data* on Line #6.

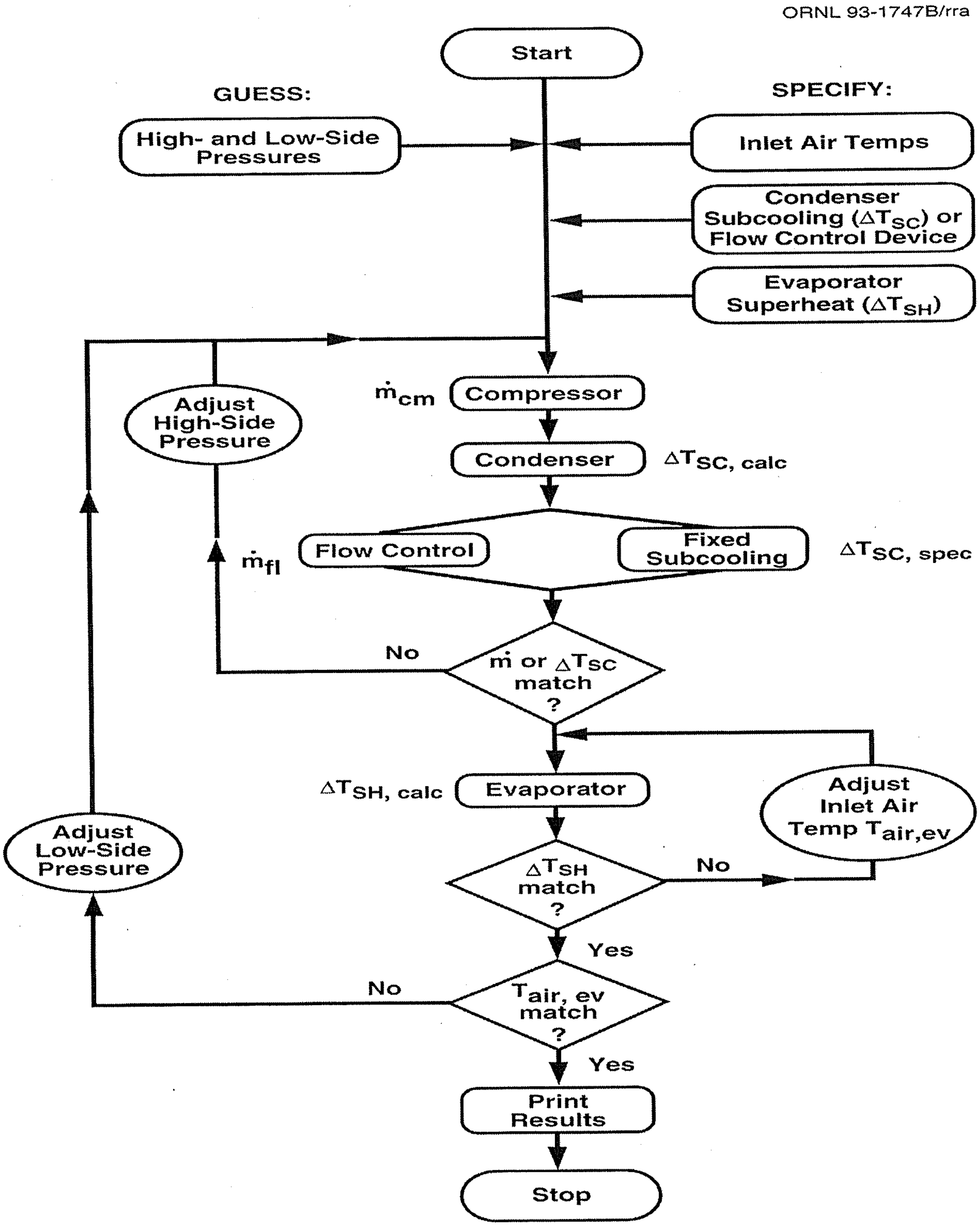

Figure 14. Solution Logic of ORNL Modulating HPDM With Charge-Determining Option Selected.

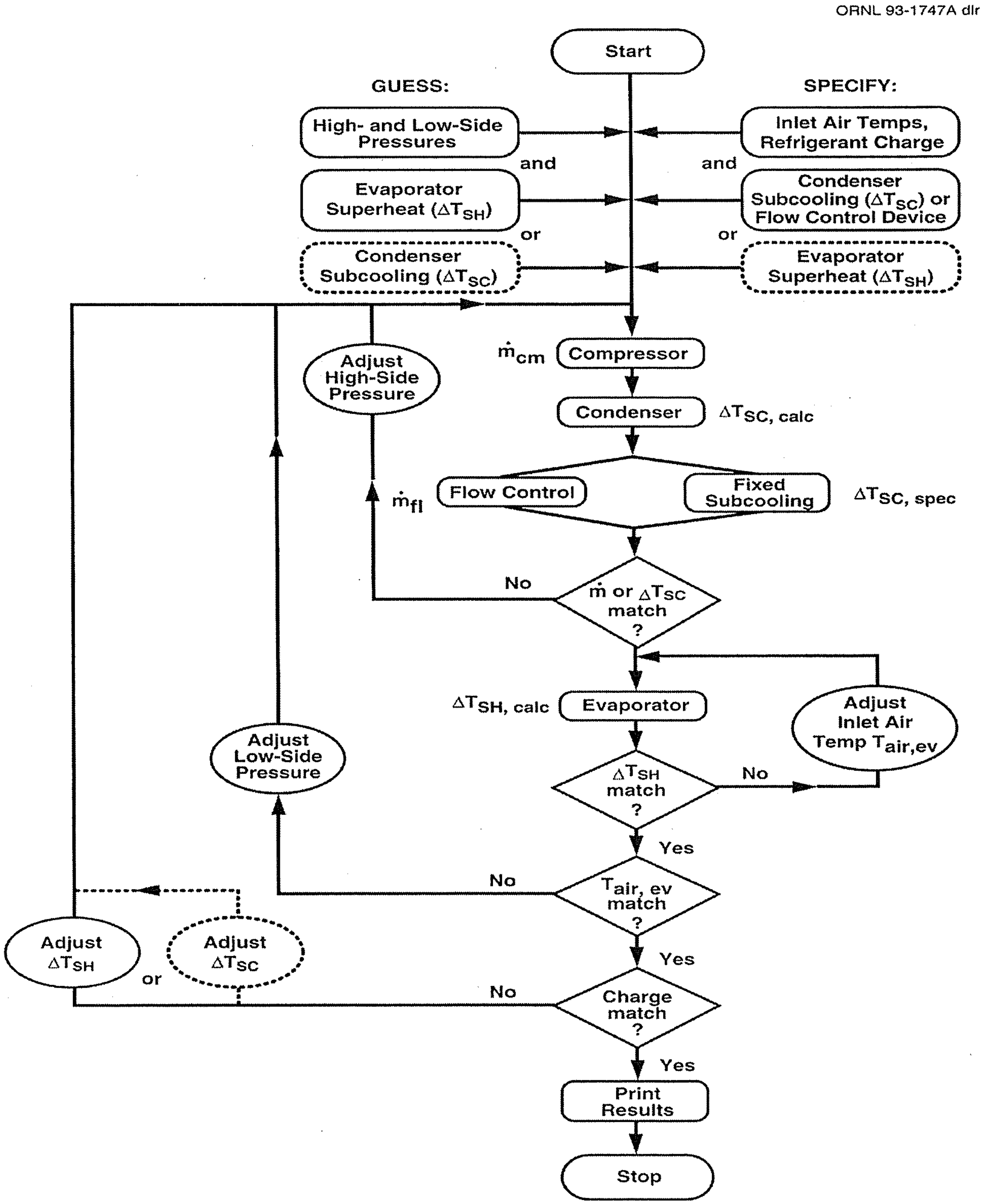

Figure 15. Solution Logic of ORNL Modulating HPDM With Charge-Balancing Option Selected.

If the refrigerant charge is to be determined,

then	ICHRGE	is set to 0 on Line #4
and	IMASS	is set to 1 on Line #5.

If the refrigerant charge is specified on Line #4 as REFCHG),

then	ICHRGE	is set to 1 or 2 on Line #4
and	either compressor inlet superheat or condenser exit subcooling	
		is determined, respectively.

The refrigerant charge inventory values which are calculated for each system component and tabulated in the program output are given in Table 6. Listings C.1 and C.2 contain examples of computed charge inventory values as listed in Table 6. Figures 16 and 17 provide some sample results using the charge inventory model for a heat pump system with capillary tubes and a suction line accumulator.

If no refrigerant charge calculations are desired,

then	ICHRGE	must be set to 0 on Line #4
and	IMASS	is also set to 0 on Line #5.

In this latter case, the program runs as fast as the ORNL Mark III single-speed model and no charge-related output is provided.

Discussion of TXV Modeling With And Without A Charge Inventory Balance

Potential Area Of Confusion. *A potential point of confusion in both the single- and variable-speed ORNL heat pump models is the modeling of systems with thermal expansion valves (TXV's).* Such valves are often described as maintaining the compressor inlet superheat at a constant value. Because of this generalization, users of the single-speed model (without a charge inventory balance) often specify a TXV valve and a constant compressor inlet superheat value and expect the model to properly represent behavior of such a system over a range of operating conditions.

In reality, a TXV does not hold superheat at a constant value but requires that the superheat vary above a prescribed minimum value as the operating conditions change. While the superheat value required for proper control of the TXV does not vary a great deal (maybe 7 to 10 F°), the important point from a system modeling perspective is that the change in TXV opening is tied to the change in superheat value from one ambient condition to the next.

Charge-Dependent Nature Of TXV Operation. As ambient conditions change and the TXV tries to maintain a design value of superheat, the condenser subcooling must change to adjust for the new saturation temperatures and new amounts of refrigerant in the two-phase regions of the heat exchangers. This is accomplished as the TXV adjusts its opening trying to bring the superheat back as close as possible to its previous value until a new balance is obtained. This change in opening and thereby superheat with ambient is dependent on the system charge balance. Thus the change in TXV opening with ambient is charge-determined.

Table 6. Definitions Of Charge Inventory Output Variables

LINE #1	**Descriptive Title Identifying Void Fraction Model Used** (as selected with MVOID on card 4 of the HPDATA specification file)
LINE #2	**Refrigerant Mass Totals (Steady-State)**
TREFMS	Total calculated steady-state refrigerant mass in the heat pump (lbm)
SSMSHI	Steady-state refrigerant mass in the high side of the unit (lbm)
SSMSLO	Steady-state refrigerant mass in the low side of the unit (lbm)
LINE #3	**Refrigerant Mass By Component (Steady-State)**
TMASSC	Steady-state refrigerant mass in the condenser (lbm)
TMASSE	Steady-state refrigerant mass in the evaporator (lbm)
CMPMAS	Steady-state refrigerant mass in the compressor can (lbm)
XMASLL	Steady-state refrigerant mass in the liquid lines (lbm)
ACCMAS	Steady-state refrigerant mass in the accumulator (lbm)
SSVPLO	Steady-state refrigerant mass in the low-side vapor lines (lbm)
SSVPHI	Steady-state refrigerant mass in the high-side vapor lines (lbm)
LINE #4	**Refrigerant Mass Totals (Off-Cycle Equilibrium)**
EQMSHI	High-side refrigerant mass in the heap pump at off-cycle equilibrium (lbm)
EQMSLO	Low-side refrigerant mass in the heap pump at off-cycle equilibrium (lbm)
XMSLQ	Low-side refrigerant liquid in the heap pump at off-cycle equilibrium (lbm)
XEQUIL	Low-side refrigerant quality in the heap pump at off-cycle equilibrium
LINE #5	**Refrigerant Internal Volumes**
VOLHI	High-side internal volume (cu ft)
VOLLOW	Low-side internal volume (cu ft)
VOLCND	Condenser internal volume (cu ft)
VOLEVP	Evaporator internal volume (cu ft)
VOLCMP	Compressor internal volume (cu ft)
VOLACC	Accumulator internal volume (cu ft)
XLEVEL	Liquid level in accumulator (in.)

<u>TXV Modeling Without A Charge Balance.</u> In the single-speed model, which lacks a charge inventory balance, specification of a TXV valve and constant superheat for a range of ambient conditions results in modeling a TXV operating <u>*at a fixed opening*</u>. Such a specification is suitable only for making a single design point calculation and should be avoided if the intent is to model a TXV system over a range of ambients.

An alternative approach to modeling such a system (without use of the charge inventory model) is to specify an approximate average compressor inlet superheat and a range of condenser subcooling values appropriate for different ambients. These would be obtained from experimental data on an operating TXV system. Runs of the model set up in this way could serve as a basis for model validation of overall system performance predictions. Predicted TXV sizes for such a system would

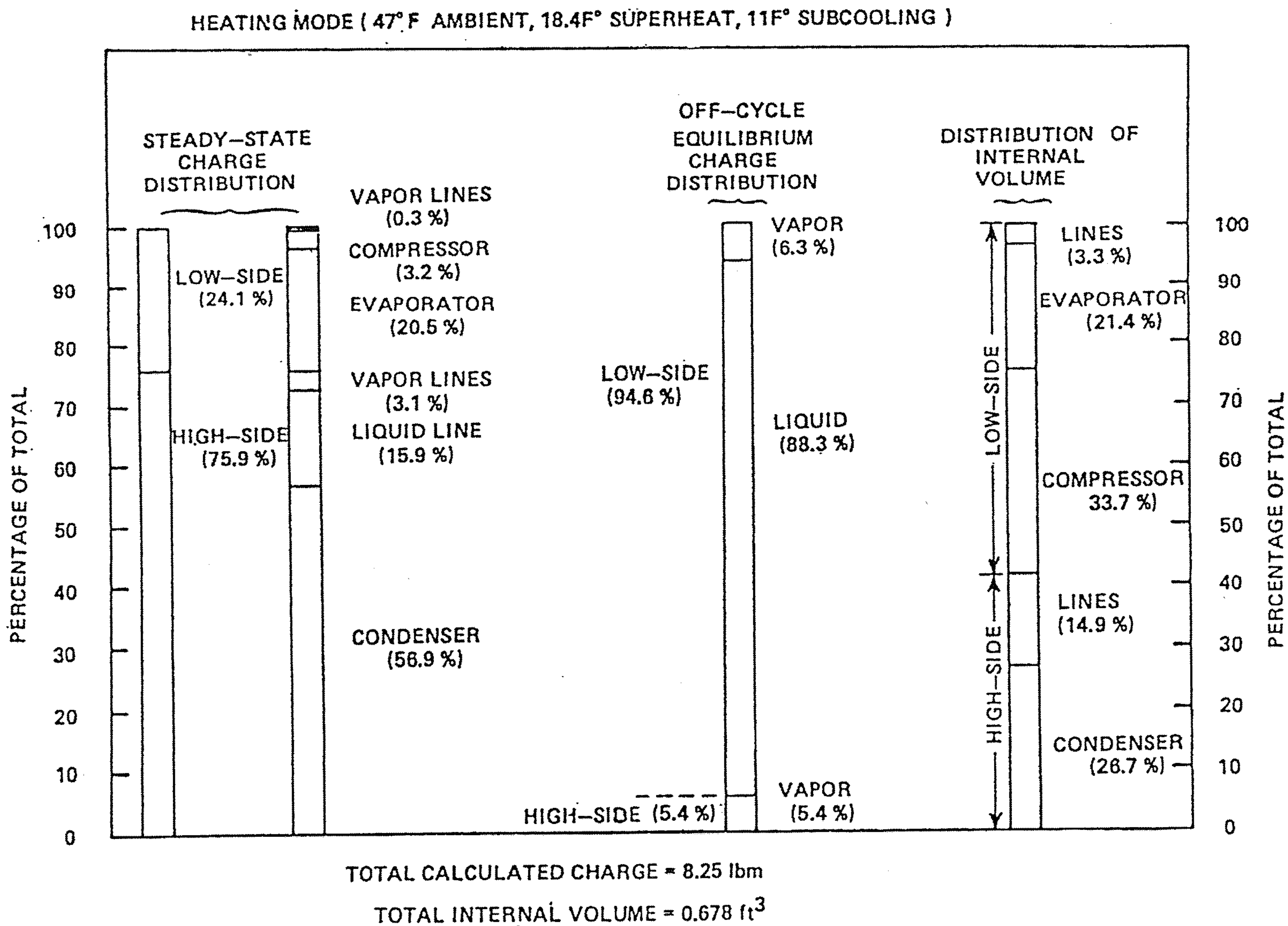

Figure 16. Sample Refrigerant Charge Distribution Within a Heat Pump as Predicted by the ORNL Charge Inventory Model.

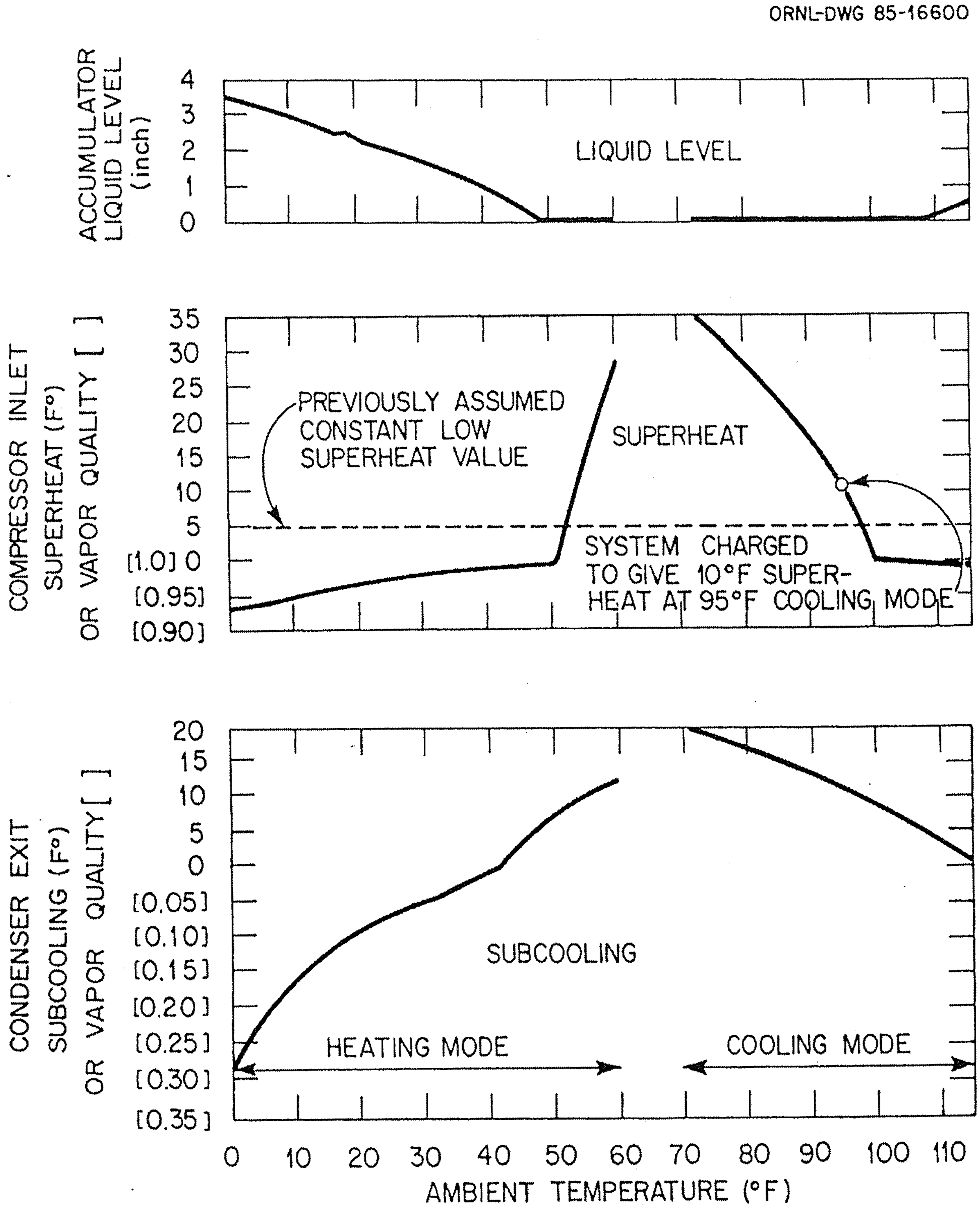

Figure 17. Sample Heat Exchanger Exit Conditions and Accumulator Level Predicted As a Function Of Ambient With Capillary Tube Flow Control Using the ORNL Charge Inventory Model.

then be compared to the actual valve used in the operating system. The obvious disadvantage of the above approach is that experimental data over a range of ambient conditions are needed to accurately simulate such a system.

Explicit–Versus–Implicit TXV Modeling With A Charge Balance. With the inclusion of the charge inventory model, an additional known, the total refrigerant charge, is available for use in place of knowledge of low-side superheat (when modeling non-adjustable, subcool-controlling or superheat-controlled valves explicitly) or high-side subcooling (superheat-controlling valves) to completely determine the system operating conditions. With reasonable values specified for TXV size and total refrigerant charge, a TXV system can be *explicitly* modeled (as superheat-controlled) over a range of ambient conditions. Alternatively, a TXV-controlled-system can be *implicitly* modeled (as superheat-controlling) by using an approximate fixed design value for superheat and specifying the total system charge. This latter approach would be preferred for a system where not much information is available about the TXV and/or distributor lines that may be used with it. In either case, the refrigerant charge model should be calibrated to a known design point (as was done by Domanski 1983 and by Damasceno et al 1991) to insure the best possible predictions.

Explicit TXV Model. With a TXV size and a total refrigerant charge specified, the model will try to adjust the superheat level until the overall refrigerant mass calculation agrees with the specified charge. However, care should be taken when specifying refrigerant charge and TXV sizes so that the values given will result in superheat values within the specified TXV operating range. A safe way to approach such a simulation is by using as a starting point refrigerant charge values and TXV sizes predicted from a previous model run where reasonable values of low-side superheat and high-side subcooling were specified at a design point condition.

Also, by nature, the explicit TXV model tends to be rather unstable, since small changes in superheat result in large changes in valve opening. To prevent the model from trying to close the TXV valve completely during the course of the refrigerant mass iteration, we presently recommend that an initial guess for superheat be used which is only about 1 °F above the static superheat setting given on Line #6 of the input data. This should give an initial iteration point with a large degree of condenser subcooling and thereby a higher refrigerant charge requirement than specified for normal operation. Solution bracketing and subsequent iterations should then head in the safe direction away from total valve closure.

Implicit (Or Approximate) TXV Model. Using the ORNL charge inventory model, a fixed-charge system with constant low-side superheat can also be modeled directly. In this case, the condenser subcooling is allowed to float to meet system requirements over a range of ambient conditions. Over a certain range of ambient conditions, a properly-sized TXV system may be approximated by this control option. (Just what range can be determined by tabulating the computed required TXV sizes over the range of ambient conditions and determining if this range of sizes could be handled with one valve about its design point.) This approach is recommended for first-cut and idealized TXV analyses and as a way to obtain good estimates of valve size and range requirements before running with the explicit TXV model. Recent advanced valves such as the pulse-width-modulated (PWM) valve as well as stepper motor and TEV valves controlled by low-side thermistors may be able to more closely approach the performance predicted for this control option over a broader range of ambients.

Subcool-Controlling Valves. Systems which control on condenser subcooling can be simulated by specifying refrigerant charge and subcooling. In this case, the low-side superheat is allowed to float to meet the system fixed-charge requirements.

Adjustable- vs Fixed-Opening Flow Controls

For fixed-opening flow control choices such as capillary tubes and short-tube orifices, an accumulator is needed to act as a storage reservoir for extra refrigerant at extreme ambients in heating and cooling mode. Otherwise, the values of low-side superheat and/or high-side subcooling can become excessive at these conditions.

With adjustable-opening flow control valves, the need for an accumulator is minimized from the perspective of the influence of fixed-charge requirements on the system steady-state operating conditions. Such valves can maintain acceptable values of superheat and subcooling over a wide-range of ambient conditions. However, to provide the final degree of freedom to maintain optimum values of subcooling and superheat over a wide range of speeds and ambients, some type of charge reservoir would still be required.

Adjustable-opening valves as modeled in the ORNL program must be controlled by low-side superheat or high-side subcooling. The system performance with adjustable-opening valves controlling on other system parameters, such as compressor discharge temperature, cannot be handled at present unless their effects can be translated into a relationship for high-side subcooling or low-side superheat as a function of ambient temperature.

MODEL VALIDATIONS, LIMITATIONS, AND RECOMMENDATIONS

Single-Speed Validation History. Different versions of the single-speed model have been validated by various researchers for both single-speed (Dabiri 1982, Fischer and Rice 1983, Fischer and Rice 1985, Damasceno et al. 1990) and dual-stroke (Fagan et al.1987) heat pumps. The single-speed model has also been used in the simulation of variable-speed engine-driven heat pumps (Fischer 1986b, Monahan 1986, and Rusk 1990). With the exception of the results obtained by Damasceno (1990), the validations of the original single-speed version in both nonmodulating and modulating applications of sizes from 2 to 10 tons capacity have been reported as satisfactory to excellent.

ORNL Modulating Model Validations. Limited model validations were conducted on an initial[1] version of the ORNL Modulating HPDM using ORNL-obtained system laboratory data (Miller 1987 and 1988a) on a modified[2] commercially-available variable-speed heat pump. The model was compared to experimental *trends* with respect to compressor and indoor blower speeds and also the basis of *absolute* COPs and capacities. The trends in COP and capacity were generally well predicted as shown and discussed by Miller (1988a).

The results of the *absolute* comparisons over a range of speeds and ambients indicated that best model agreement was obtained at the lower speeds in both heating and cooling mode, with increasing performance overpredictions[3] (to maximums of about 10% in both COP and capacity) occurring at higher speeds. This increase in model overprediction with speed occurs because of limitations of the simplified circuiting models with the higher subcooled (and/or superheated), more heavily loaded heat exchanger conditions.

Known Model Limitations. This moderate overprediction at high subcooling and/or superheat conditions is consistent with the assumptions inherent in the original heat exchanger model formulation developed by Hiller and Glicksman (1976) — who sought a model to represent the most efficient cross-flow circuiting arrangement with respect to the single and two-phase refrigerant regions. Heat exchanger modeling simplifications include the assumption of equivalent parallel refrigerant circuiting and that efficient coil circuiting is maintained in all operation modes relative to the air flow direction.

Occasionally, these assumptions can be violated rather significantly at the more loaded operating conditions in existing heat pump designs, generally due to complex circuiting patterns used by some manufacturers to meet their design requirements within the limitations of refrigerant-flow-reversing heating and cooling mode operation. (This is because in a heat pump, the circuiting arrangements must serve double-duty with a reversal of refrigerant flow direction between heating and cooling. Consequently, the model should have better general applicability to air-conditioning-only units.)

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[1]The main difference (relating to the validation results) between the initial model and the present version was in the compressor map representation formulas. Triquadratic curve fits (with drive frequency as the third variable) to available calorimeter and application data (Miller 1988b) for a motor-generator-driven reciprocating compressor were used in the initial model validations. However, a later evaluation by the author of the triquadratic-curve-fits to the compressor data available at that time (Miller 1988a) indicated that some significant efficiency trends with speed were not being represented adequately. Through experience gained from different curve fitting attempts to later reciprocating and scroll data, improved representations were achieved and implemented in the first distribution version of the modulating HPDM. These representations generally improved the absolute validation comparisons given by Miller (1988a), especially in the heating mode, where initial underpredictions were mainly due to compressor-data curve-fitting errors.

[2]The unit was modified to allow manual control of the expansion valve opening and to be modulated by a motor-generator set rather than the originally-supplied inverters.

[3]Some heating mode underpredictions also occurred but these were later traced to problems in an originally-used triquadratic curve-fit to the compressor map.

These non-optimal air-to-refrigerant flow arrangements usually occur as a result of operating conditions and speeds which require higher levels (and therefore greater occupied coil fractions) of condenser subcooling and evaporator superheat. These non-ideal flow arrangements cannot be fully accounted for in the more-simplified heat exchanger representation.

Further Caveats. Further difficulties can result if the equivalent number of refrigerant circuits is not chosen carefully for each heat exchanger — resulting in poor predictions of refrigerant-side pressure drops. In the tests reported by Damasceno (1990), for a system with capillary tube flow control, the heating COP at 47°F was surprisingly underpredicted by almost 10% while at 95°F in cooling, the COP was more expectedly overpredicted by 8%. Insufficient information on coil circuiting and flow control was provided in the paper to fully determine the cause of the excessive amount of condenser subcooling predicted in their heating test cases. However, it appears that the choice of the number of equivalent circuits in the heat exchangers was not selected appropriately and that the low-side pressure drop of the test unit was excessively large. This may account for why the model underpredicted the heating COP in this instance instead of overpredicting as is more often the case.

The results of Damasceno (1990) do point out that the model should be used with caution if trying to predict the absolute and/or relative performance over a wide-efficiency-range with existing equipment. The ORNL Heat Pump Models were developed primarily for economical, generalized, system design analysis of high-efficiency electric air-to-air heat pumps. As such, the models are not always well suited for detailed simulation purposes of all possible configurations and operating conditions of existing unitary equipment. In these cases, more detailed (and consequently longer running) models such as those developed by Domanski (1983, 1986) may be more appropriate.

Validation Procedure Recommendations. The circuiting simplifications in the ORNL models can be overcome to a large degree for many heat pumps (at least with regard to coil pressure-drop calculations) by judicious selection of an appropriate number of equivalent circuits. This can initially be calculated algebraically by the user (similarly to equivalent resistance in parallel electrical circuits) based on the relative lengths (resistance) of the various subcircuits to determine an equivalent-network-based number of circuits (which can be a non-integer value). As a further refinement, we presently recommend to program users that, if coil pressure drop data are available, the number of equivalent circuits for each coil should be adjusted for best agreement with these data — using separate sets of adjusted circuit numbers for heating and cooling modes because of the flow reversal effects on circuit equivalence.

Validations should also be done, at least initially, using as much experimental data as is available on the unit. For example, if measured values are available for compressor inlet superheat and condenser exit subcooling, these should be used for the initial or first-level heat exchanger validations. The agreement of the compressor map with the measured compressor data over the range of expected, operating conditions should be tabulated and any observed trends of over- or underpredictions in power or mass flow rate identified. Specific flow control devices and the refrigerant charge used in the unit can then be added in second- and perhaps third-level validations. Charge calibration procedures (for both heating and cooling modes) such as those discussed by Damasceno et al (1991) are recommended as well to correct for various uncertainties in the charge calculation process.

With this sequential approach, the accuracy of the various heat exchanger, compressor, flow-control, and charge inventory models can be individually evaluated and possibly corrected for on a component basis rather than on a system basis. Adjustments made at the component level are more likely to be more broadly applicable over one manufacturer's line of equipment than externally applied system correction factors. Some user-specified adjustment factors to the refrigerant- and air-side heat transfer and pressure drop predictions for the individual coils have been provided in the latest version.

PARAMETRIC PERFORMANCE MAPPING

Overview. A key to the effective use of single-speed or modulating design models is a convenient yet flexible means to parametrically evaluate the effect of design, control, and operating variables. Such a "front-end" program is now included with the modulating HPDM for use in steady-state nominal- and off-design analysis. A flow diagram of the structure of the parametric front-end, the possible input and output data sets, and the connections to basic heat pump model routines are shown in Figures 18, 19, and 20. Parametric evaluation of seasonal and annual performance using the ORNL APF/Loads Model was planned to follow (as can be seen as dotted lines in the provided flow chart) but this portion has been deferred indefinitely.

The front-end program allows use of the modulating HPDM to parametrically generate sets of steady-state performance data suitable either for tabulation, for plotting y vs x_1 for families of x_2, or for plotting y-contours for ranges of x_1 vs x_2. Such data, once generated on a reasonably-fast PC, workstation, or minicomputer, can be later analyzed with generally available PC 2-dimensional x-y or contouring packages or with 3-D visualization programs.

The parametric, or contour-data generating, front-end provides an automated means to conduct parametric performance mappings of selected pairs of independent design variables. The user can generate steady-state performance data sets at fixed ambients or as a function of ambient temperature. The range of selection options includes:

- 52 design, control , and operating (independent) variables for parametric analysis,
- 9 user-defined operational control relationships as functions of compressor speed or ambient temperature, and
- over 100 possible heat pump model output (dependent) parameters.

Design, Control, and Operating Variable Choices. The 52 independent variable choices can be classified under two main headings:

- flow rate or ambient variables and
- heat exchanger area variables

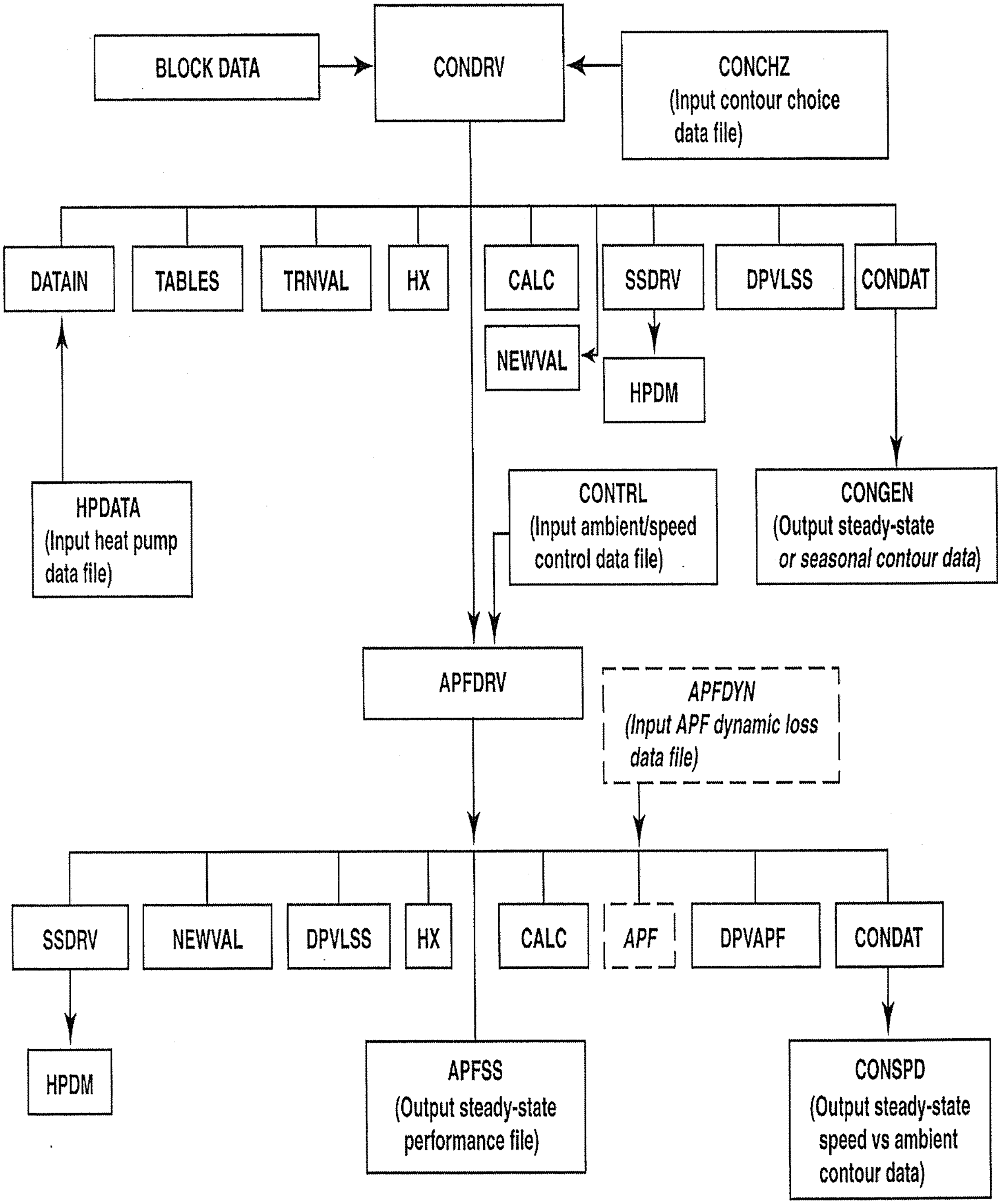

Figure 18. Overall Structure of ORNL Modulating Contour Data Generating Program — MODCON.

ORNL 2001-02148/vwp

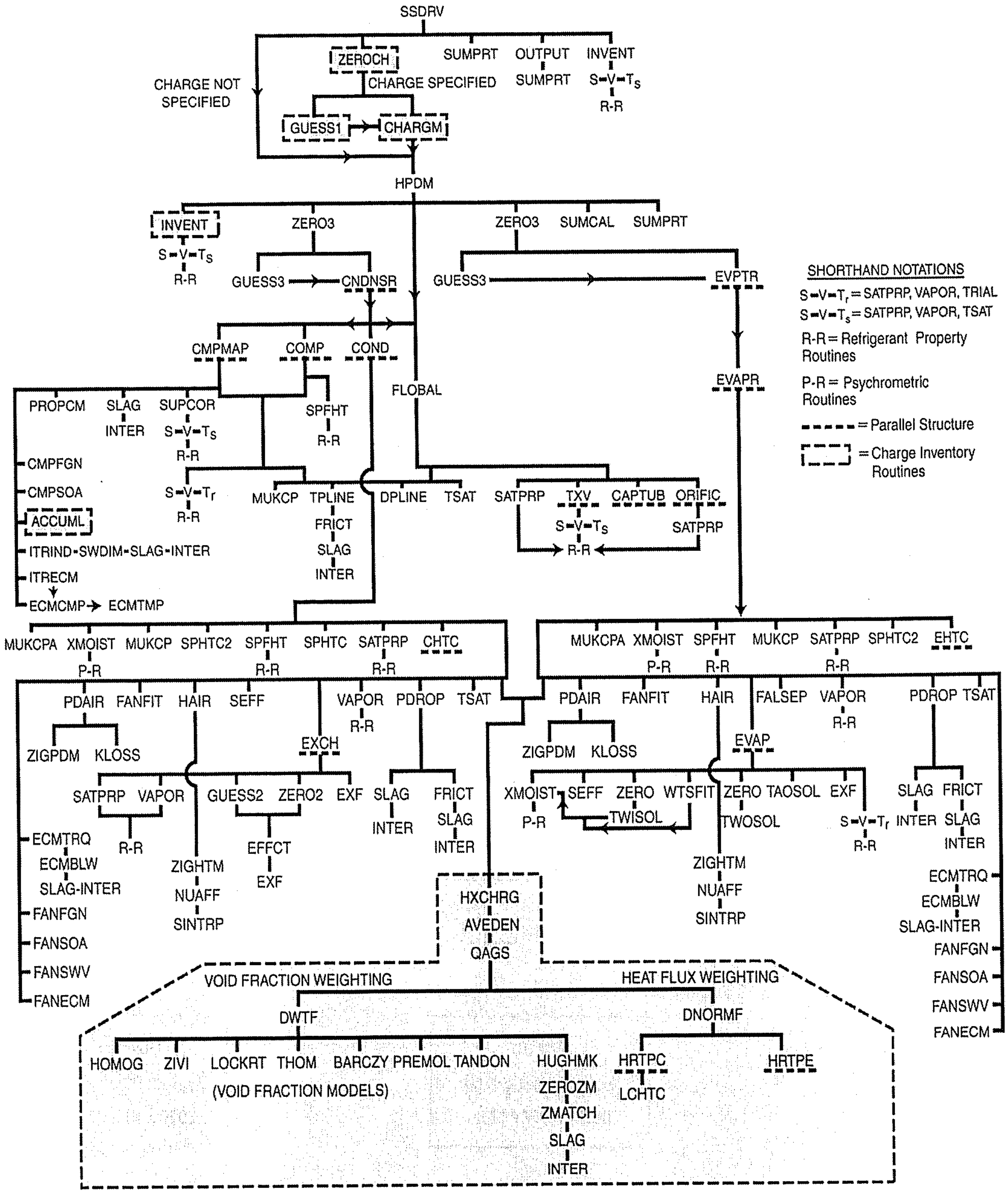

Figure 19. Detailed Structure of ORNL Modulating Heat Pump Design Model.

ORNL-DWG 88-8014

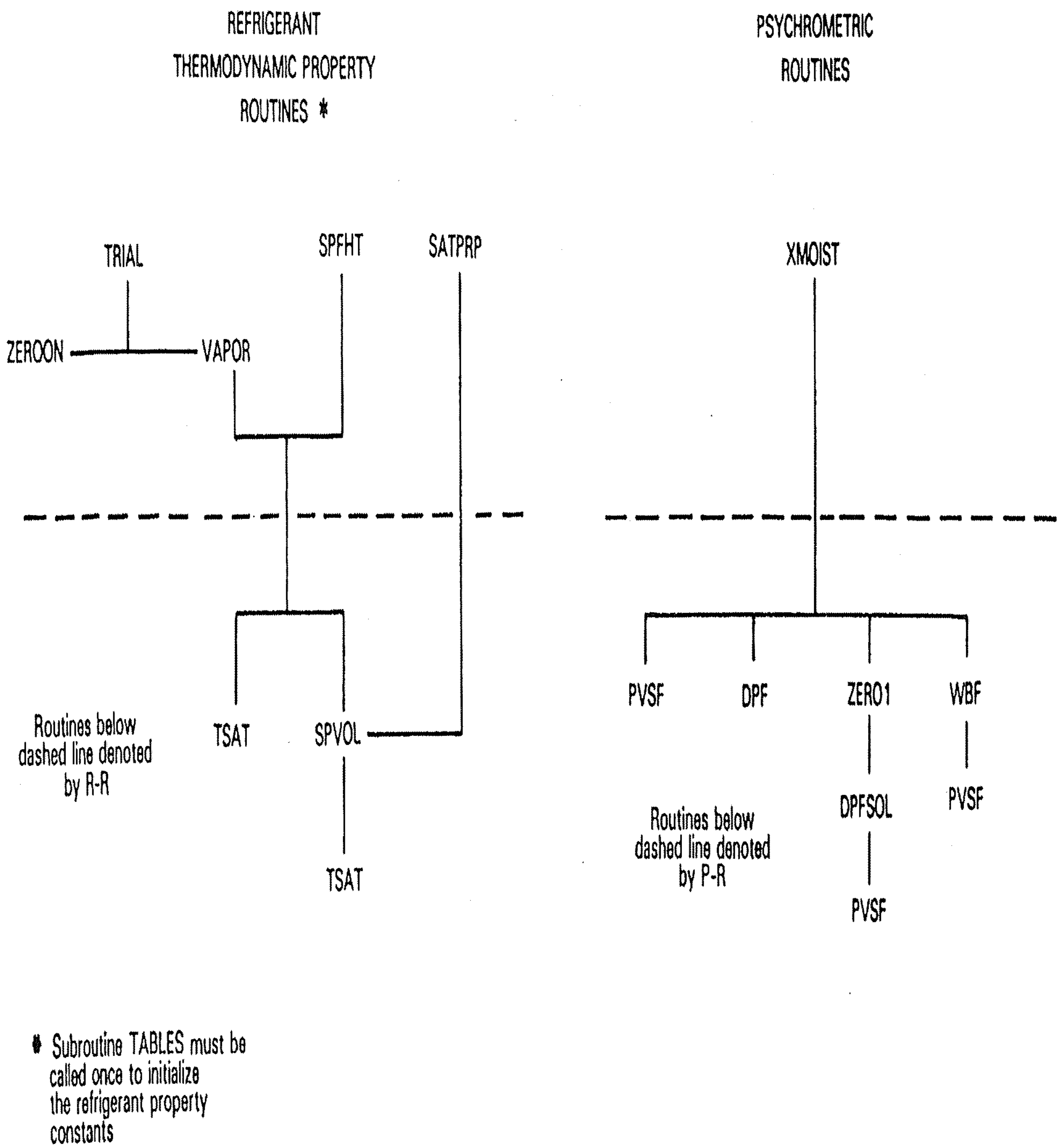

Figure 20. Structure of Thermodynamic Supporting Routines for Refrigerant and Air Properties.

MODULATING APPLICATIONS-TO-DATE

The ORNL steady-state heat pump models have been applied to a number of modulating applications to date. Somewhat curiously, more outside uses of the models for modulating applications (that we have been made aware of) have been for engine-driven heat pumps rather than for electric-driven. This can perhaps be attributed in part to the wider availability of variable-speed data for open compressors than for hermetics.[4] This lack of publicly available data for variable-speed hermetic compressor was a significant factor in the ORNL laboratory testing of various IDIM and SWDIM compressor drives as reported by Miller (1987, 1988a, 1988b).

Engine-Driven Applications

Stirling-Engine-Driven. Through a DOE Work-For-Others contract with Borg-Warner, ORNL adapted the Mark III HPDM to a variable-speed (1000 to 3000 rpm) Stirling-engine-driven heat pump application. This adaptation was accomplished using proprietary Borg-Warner / Stirling Power Systems (SPS) engine, compressor, and radiator representations for a 10-ton commercial system. The modified model was transferred to Borg Warner for their use in system design and control analysis for the Gas Research Institute (GRI) as reported by Monahan (1986).

Internal-Combustion-Engine-Driven. We also provided the Mark III HPDM to Battelle Columbus Laboratory for another variable-speed engine-driven heat pump application (again 1000 to 3000 rpm) under development for GRI. The ORNL program was selected by Fischer (1986a) as best suited to Battelle's needs after review of available heat pump models and modified by their staff to model residential internal-combustion, engine-driven gas-fired heat pumps for use in another GRI development project (Fischer 1986b).

A third variable-speed engine-driven project using the ORNL Mark III model was conducted by Rusk et al (1990) of Iowa State University. These researchers combined an extensive internal combustion model with the ORNL program and reported performance values and trends with ambient temperature which agreed well with earlier work reported by others using proprietary models.

Electric-Driven Applications

At ORNL, different versions of the modulating model have been used in analytical studies and as an aid in developing and guiding an experimental test plan on a variable-speed breadboard system.

As An Aid To Experimental Testing. Before the breadboard tests described by Miller (1987) were actually conducted, the modulating model was used to conduct a parametric evaluation of the optimal control scheme for the selected control variables of indoor and outdoor fan speed, condenser

[4]No doubt there is also an element of greater openness in the reporting of research on the engine-driven variable-speed units which are not yet commercially marketed — in contrast to the electric-driven field where discussion of variable-speed research is more guarded.

subcooling and flow control openings at appropriate ambient and compressor speed combinations. The charge requirements over the range of conditions planned for the tests were also evaluated.

The predicted control-variable optimums were used to narrow the required test ranges for the control variables to those which would most likely bracket the final experimentally determined values. The range of charge requirements similarly predicted were used to guide the experimental test procedure by indicating under which speed and operating conditions the unit should be charged.[5] Using the model in this manner, the experimental testing required to find the system optimums was minimized. As noted earlier in the section on validation, the model did a credible job of predicting the trends in COP and capacity — as well as the relative charge requirements of the system.

As A Tool To Determine Potential Performance Levels For Residential Unitary Equipment. The present version of the modulating design tool was used by Rice (1992) in a benchmark analysis to predict the maximum performance potential of a near-term modulating residential-size heat pump. Continuously-variable-speed ECMs were assumed to modulate the compressor and the indoor and outdoor fans with ambient temperature in conjunction with existing modulating reciprocating compressor technology. The modulating heat pump design tool was used to optimize such an ECM Benchmark heat pump using speed ranges and total heat exchanger sizes per-unit-capacity equivalent to that used by the highest-SEER-rated variable-speed unit presently on the market. Parametric steady-state performance optimization was conducted at a nominal design cooling ambient of 95°F (35°C) and three off-design ambients of 82°F (27.8°C) cooling and 47 and 17°F (8.3 and –8.3°C) heating.

The purpose of this near-term benchmark analysis was two-fold. One purpose was to evaluate the potential performance improvement predicted by a modulating heat pump model *with high-efficiency heat exchangers and drives and current reciprocating compressor technology*. The second was to demonstrate a methodology for using a modulating heat pump design tool for such a system design analysis.

With regard to the first purpose, a potential increase in steady-state cooling performance ranging from 12 to 24% was found depending on the sensible-to-total capacity ratio constraints imposed. Steady-state heating performance improvements of 32 to 39% were also predicted compared to the reference commercially available residential unit.

Relating to the demonstration purpose, the experience with the benchmark analysis suggests that a reasonably-optimized modulating system can be obtained using the-four-point design approach presented there. Comparing this most recent design approach with a black-box optimization approach conducted in an earlier assessment of variable-speed potential (Rice and Fischer 1985), it was found that the present approach was intuitively superior with regard to maintaining engineering control of the design process and by providing a visual (and tabular) mapping of the design objectives and constraints about the vicinity of the optimums.

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[5]As the test unit had a suction-line accumulator, the predicted point of maximum required active charge was used as the charging condition. At the other conditions of lesser required charge, the accumulator was sufficient to store the excess.

As A Tool To Assess Potential Of Variable-Speed-Drives For Commercial Unitary Equipment. The present version of the modulating design tool is also currently being used by an EPRI contractor to assess the potential of existing and advanced variable-speed-drives and control strategies for commercial air-conditioners and heat pumps. In this analysis, special attention is being given to the motor sizing strategies by making use of the sizing options and the torque mapping capabilities unique to the ORNL modulating design tool. Some of these capabilities were demonstrated previously by Rice (1988a) where an earlier version of the modulating model was used to determine torque requirements and potential efficiency levels for modulating drives in both heating and cooling modes of operation.

USE WITH ALTERNATIVE REFRIGERANTS

The program has been modified to be capable of using the HFC R134a as a refrigerant. The equations and coding necessary to add R134a using a modified form of the Martin-Hou (Martin 1959) equation of state (EOS) were provided by an industry user of the program (Spatz 1990). Correlations for the thermophysical properties needed by the model were also included. (With these additions, the model can use EOS coefficients for two variations of the Martin-Hou EOS format.) The available thermodynamic property routines have been described by Kartsounes and Erth (1971) and are shown in Figure 20.

The user input has also been modified in the latest version of the modulating model to specify the refrigerant type directly. This is in anticipation of the increased need to evaluate refrigerant alternatives to R22. Presently, only five refrigerants (R12, R22, R114, R502, and R134a) are available to be called directly in the program although thermophysical properties for R11, R13, R21, R23, R113, and C318 are also included in subroutine MUKCP. Use of any of these other refrigerants in the model requires only that the appropriate thermodynamic EOS constants given by Downing (1974) be added to the TABLES subroutine and that compressor maps for these refrigerants be available. The user should be aware that the flow control device models are also somewhat specific to R22, R12, and R502 (in the case of cap tubes and TXVs) and to R22 for short-tube orifices and therefore condenser subcooling should be specified in lieu of specific devices until the flow control models can be further generalized by the user.

Newer *pure* or azeotropic refrigerant alternatives to R22 can be added with minimal effort as their thermodynamic and thermophysical properties become available. Provided that compressor performance maps are also available for these candidate alternative refrigerants, the program could be used to determine their comparative performance in optimally configured-and-controlled single- or variable-speed air-to-air heat pump systems.

MODEL AVAILABILITY

The modulating design tool described in this report is available for use by the HVAC research and development community. An executable version for MS-DOS personal computers is provided.

The source program in FORTRAN can be made available under certain conditions and is modularized so that manufacturers with proprietary compressor, motor, and/or drive information can customize the program to their needs.

The author can be contacted directly (e-mail: riceck@ornl.gov) regarding specifics on how copies of the model can be obtained for research and development purposes. It is hoped that the description of the model capabilities in this report and the demonstration in a companion document (Rice 1992) of the use of the modulating design tool for the design of high-efficiency modulating heat pumps will encourage U.S. manufacturers to obtain the program and investigate further its use for this purpose.

REFERENCES

Air-Conditioning and Refrigeration Institute. 1989. *Standard for Unitary Air-Conditioning and Air-Source Heat Pump Equipment*, Standard 210/240-89. Arlington, Virginia

D. T. Beecher and T. J. Fagan, "The Effects of Fin Pattern on the Air-Side Heat Transfer Coefficient in Plate Finned-Tube Heat Exchangers," *ASHRAE Transactions, 93,* Pt. 2, 1987.

Dabiri, A. E., 1982. "A Steady-State Computer Simulation Model for Air-To-Air Heat Pumps", *ASHRAE Transactions*, *88*, Pt. 2, pp. 973–987.

Damasceno, G. S., Goldschmidt, V. W., and Rooke, S. P., 1990. "Comparison of Three Steady-State Heat Pump Computer Models", *ASHRAE Transactions*, *96*, Pt. 2.

Damasceno, G. S., Domanski, P.A., Rooke, S. P., Goldschmidt, V. W., 1991. "Refrigerant Charge Effects On Heat Pump Performance", *ASHRAE Transactions*, *97*, Pt. 1.

Domanski, P.A., 1985. Personal communication, National Institute of Standards and Technology, Building Equipment Division, Gaithersburg, Maryland, August.

Domanski, P.A., 1986. *Modeling Of a Heat Pump Charged With a Non-Azeotropic Refrigerant Mixture,* NBS Technical Note 1218, National Bureau of Standards / U. S. Department of Commerce, January.

Domanski, P.A., 1988. *Recommended Procedure for Rating and Testing of Variable Speed Air Source Unitary Air Conditioners and Heat Pumps*, NBSIR 88-3781, National Bureau of Standards, May.

Downing, R. C., 1974. "Refrigerant Equations", *ASHRAE Transactions, 80*, Pt.2.

Fagan, T. J., Lucheta, R. A., and Beecher, D.T., 1987. *Oak Ridge National Laboratory Heat Pump Performance Prediction Computer Code: Additions and Verification,* Westinghouse Research Report 87-9J8-MATHP-R1, November.

Fischer, R. D., 1986a. *State-of-the-Art Review of Vapor-Compression Heat Pump System Models, Task 2.1-Technical Report*, GRI, February 1986.

Fischer, R. D., 1986b. *Gas Engine Heat Pump Cycle Analysis, Volume I. Model Description and Generic Analysis*, GRI-86/0235, October.

Fischer, S. K. and Rice, C. K. 1983. *The Oak Ridge Heat Pump Models: I. A Steady-State Computer Design Model for Air-to-Air Heat Pumps,* ORNL/CON-80/R1, August.

Fischer, S. K. and Rice, C. K. 1985. "System Design Optimization and Validation for Single-Speed Heat Pumps", *ASHRAE Transactions*, *91*, Pt. 2B, pp. 509–523.

Fischer, S. K., Rice, C. K., and Jackson, W. L., 1988. *The Oak Ridge Heat Pump Model: Mark III Version Program Documentation,* ORNL/TM-10192, Oak Ridge National Laboratory, March.

Gray, D. L. and Webb, R. L., 1986. "Heat Transfer and Friction Correlations for Plate Finned-Tube Heat Exchangers Having Plain Fins," *Proc. Eighth International Heat Transfer Conference*, San Francisco, Heat Transfer 1986, Vol. 6, pp. 2745–2750, Hemisphere: New York

Hiller, C. C. and Glicksman, L. R., 1976. *Improving Heat Pump Performance via Compressor Capacity Control – Analysis and Test, Vols. I and II,* MIT Energy Laboratory Report No. MIT-EL 76–001.

Lloyd, J. D., 1987, Personal communication, Emerson Electric Company, Electronic Speed Control Division, Hazelwood, Missouri, April.

Kartsounes, G. T. and Erth, R. A., 1971. "Computer Calculation of the Thermodynamic Properties of Refrigerants 12, 22, and 502", *ASHRAE Transactions, 77*, Pt. 2.

Kays, W. M. and London, A. L., 1974. *Compact Heat Exchangers*, McGraw-Hill, New York.

Martin, J. J., 1959. "Correlations and Equations Used in Calculating Thermodynamic Properties of 'Freon' Refrigerants", *Thermodynamic and Transport Properties of Gases, Liquids, and Solids*, ASME, New York City, p.110.

Makayama, W. and Xu, L. P. , 1983. "Enhanced Fins for Air-Cooled Heat Exchangers -Heat Transfer and Friction Factor Correlations," *Proc. ASME-JSME Thermal Engineering Joint Conference*, Hawaii, March 1983, eds. Yasuo Mori and Wen-Jei Yang, New York.

Miller, W. A. 1987. "Steady-State Refrigerant Flow and Airflow Control Experiments Conducted on a Continuously Variable Speed Air-to-Air Heat Pumps", *ASHRAE Transactions*, 93, Pt. 2, pp. 1191–1204.

Miller, W. A. 1988a. "Laboratory Capacity Modulation Experiments, Analyses, and Validation", *Proceedings of the 2nd DOE/ORNL Heat Pump Conference: Research and Development on Heat Pumps for Space Conditioning Applications*, CONF-8804100, Washington, D.C., April, pp. 7–21.

Miller, W.A. 1988b. "Modulating Heat Pump Component and Adjustable Speed Drive Efficiencies Measured In The Laboratory", *ASHRAE Transactions*, *94*, Pt. 1, pp. 874–891.

Miller, W.A. 1988c. "Laboratory Examination and Seasonal Analyses of the Dynamic Losses for a Continuously Variable Speed Heat Pump", *ASHRAE Transactions*, *94*, Pt. 2, pp. 1246–1268.

Miller, W.A. 1989. Personal communication, Oak Ridge National Laboratory, Energy Division, Oak Ridge, Tennessee, January.

Monahan, R. E., 1986. *Phase 1-B Development of Kinematic Stirling/Rankine Commercial Gas-Fired Heat Pump System , Final Report,* GRI-86/0192, July.

Rice, C. K. and Fischer, S. K., 1985. "A Comparative Analysis of Single- and Continuously-Variable-Capacity Heat Pump Concepts", *Proceedings of the DOE/ORNL Heat Pump Conference: Research and Development on Heat Pumps for Space Conditioning Applications*, CONF-841231, Washington, D. C., pp. 57–65.

Rice, C. K., Fischer, S. K., and Emerson, C. J., 1985. *The Oak Ridge Heat Pump Models: II. An Annual Performance Factor / Loads Model for Residential Air-Source Heat Pumps*, ORNL-CON-160.

Rice, C. K. 1987. "The Effect Of Void Fraction Correlation and Heat Flux Assumption On Refrigerant Charge Inventory Predictions", *ASHRAE Transactions*, *93*, Pt. 1, pp. 341–367.

Rice, C. K. 1988a. "Efficiency Characteristics of Speed-Modulated Drives at Predicted Torque Conditions for Air-To Air Heat Pumps", *ASHRAE Transactions*, *93*, Pt. 1, pp. 341–367.

Rice, C.K. 1988b. "Capacity Modulation Component Characterization and Design Tool Development", *Proceedings of the 2nd DOE/ORNL Heat Pump Conference: Research and Development on Heat Pumps for Space Conditioning Applications*, CONF-8804100, Washington, D.C., April, pp. 23–33.

Rice, C.K., 1992. "Benchmark Performance Analysis Of An ECM-Modulated Air-To-Air-Heat Pump With Reciprocating Compressor", *ASHRAE Transactions, 97,* Pt.1.

Rusk, R. P., Van Gerpen, J. H., Nelson, R. M., Pate, M. B., 1990. "Development And Use Of a Mathematical Model Of An Engine-Driven Heat Pump", *ASHRAE Transactions*, *96*, Pt. 2

Spatz, M., 1990. Personal communication, Allied-Signal Corporation, Buffalo, New York, April.

Young, G. 1990. Personal communication, General Electric, Motor Technology Department, Fort Wayne, Indiana, October.

Zigler, R. V. 1987. Personal communication, General Electric, Motor Technology Department, Fort Wayne, Indiana, May

APPENDIX A

CONTOUR SELECTION DATA FILE 'CONCHZ'

Input Data Definitions and Format

Tables A.1 to A.4 describe the input data options for the parametric front-end to the ORNL Modulating Heat Pump Model. The input format for the choice of independent and dependent variables for parametric analysis is first given. This is supplemented by Tables A.2 through A.4 which describe the choices of independent and dependent variables which are built into the program. Table A.5 describes the format of the output contour-data-generation file generated by the model for the parameters selected by the user.

The 'CONCHZ' data file must always be the first input file to be read by Unit 5 — the default input unit number. CONCHZ is followed by the heat pump specification file 'HPDATA' — also read by Unit 5 as default. The remaining (optional) input data file 'CONTRL' , which is described in Appendix H, has a default unit number of 24. The printed output is sent to unit 6 and the contour-data -generation file as described by Table A.5 is sent to unit 8 by default. All of the default input and output unit number settings are specified in the BLOCK DATA routine and are described further at the beginning of Appendix D and at the end of Appendix E.

Sample Input File (Regular and Annotated)

This section contains regular and annotated listings, Listings A.1 and A.2, respectively, of a sample 'CONCHZ' data file. The selected example is for a heat pump operating in the heating mode with a compressor frequency range from 180 Hz down to 50 Hz and for an ambient range from 17°F to 47°F. All the available dependent variables were selected for this example.

The regular listing represents the data set as directly used by the model while the annotated version of the same data set is labeled with the variable names as described in Table A.1. The annotated listing is provided as a visual reference to users modifying existing data sets.

Table A.1. Description of CONCHZ Input Data to MODCON Program

Variable Name	Variable Description	Sample Value
Selection of Operating Mode(s)		
LINE 1	FORMAT(I3)	
MODEGN	operating mode selector = 0, bypass contour data generation front-end (omit remainder of data set) = 1, steady-state heating mode = 2, steady-state cooling mode = 3, annual, with seasonal breakdowns (not yet operational) = 4, steady-state heating and cooling modes (for use with CONTRL.DAT) = 5, steady-state heating, cooling, and annual modes, with seasonal breakdowns (not yet operational)	1
Heading Identifiers For Selected Operating Mode(s)		
LINE 2	FORMAT(10A8)	
MTITLE(J)	title heading(s) identifying contour data sets generated for heating, cooling, and/or annual modes as appropriate J=1 if MODEGN = 1 or 2, J=1, 2 if MODEGN = 4, or J=1, 2, 3 if MODEGN = 3 or 5	HEATING MODE
Selection of X and Y Independent Variables		
LINE 3	FORMAT(2I3, 5F10.0)	
IDVARX	ID number of X independent variable (refer to Table A.2)	18
NX	number of X values to be evaluated	6
XLO	minimum value of X variable	7.0
XHI	maximum value of X variable	57.0
XREF(J)	X reference point to mark on contour plots where J=1 if MODEGN = 1 or 2, J=1, 2 if MODEGN = 4, or J=1, 2, 3 if MODEGN = 3 or 5	47.0
LINE 4	FORMAT(2I3, 5F10.0)	
IDVARY	ID number of Y independent variable (refer to Table A.2)	21
NY	number of Y values to be evaluated (set to 0 for 1-D parameters)	6

YLO	minimum value of Y variable	60.0
YHI	maximum value of Y variable	240.0
YREF(J)	Y reference point to mark on contour plots where J=1 if MODEGN = 1 or 2, J=1, 2 if MODEGN = 4, or J=1, 2, 3 if MODEGN = 3 or 5	120.0

Operational Data (Included Only If MODEGN <3)

LINE 5	FORMAT(I3)	
NVALS	number of control variables to be user-specified	1
LINES J=1,NVALS	FORMAT(2I3,6F10.0)	
NFUN(J)	integer value selecting *controlled* parameter "y" where y = f(x) = 1, for compressor inlet superheat (F°) = 2, for condenser exit subcooling (F°) = 3, for indoor blower frequency (Hz) = 4, for outdoor fan frequency (Hz) = 5, for building load (kBtuh/h) — not fully operational, only used to determine supplemental heating needs	1
NIND(J)	integer value selecting *controlling* parameter "x" = 1, for ambient temperature (°F) = 2, for compressor frequency (Hz)	1

Coefficients of linear control algorithm of the form $y = (y_2 - y_1)/(x_2 - x_1) \bullet (x - x_1) + y_1$

VINDEP(J,1)	selected value of x_1	17.0
VINDEP(J,2)	selected value of x_2	47.0
VDEPEN(J,1)	prescribed value of y_1	5.0
VDEPEN(J,2)	prescribed value of y_2	20.0
VDEPLO(J)	minimum-allowable value of y_1	0.0
VDEPHI(J)	maximum-allowable value of y_2	30.0

Dependent Variable Selections

LINE 6	FORMAT(I3)
NDVSS	number of steady-state dependent variables
LINES J=1,NDVSS	FORMAT(I3,2X,8A8)
IDVSS(J)	ID number of dependent steady-state performance variable (see Table A.3)
NAMSS(J)	user-selected descriptive label for variable IDVSS(J)

(The following lines are omitted if MODEGN is equal to 1, 2, or 4.)

LINE 7	FORMAT(I3)
NDVAPF	number of seasonal performance variables
LINES J=1,NDVAPF	FORMAT(I3,2X,8A8)
IDVAPF(J)	ID number of dependent seasonal performance variable (see Table A.4)
NAMAPF(J)	user-selected descriptive label for variable IDVAPF(J)

Table A.2. Key to Independent Contour Variables Available for Selection in Input Data File CONCHZ

ID #	NAME	INDEPENDENT CONTOUR VARIABLE*
Primary Refrigerant/Air Throughput Variables		
1	DISPL	compressor displacement (in^3)
2	QANMI	nominal indoor air flow rate (cfm)
3	QANMO	nominal outdoor air flow rate (cfm)
Primary Hx Area Variables (Where Total Hx Area Is Allowed To Vary)		
4	AAFI	frontal area of indoor coil (ft^2)
5	AAFO	frontal area of outdoor coil (ft^2)
6	NTI	number of indoor refrigerant tube rows
7	NTO	number of outdoor refrigerant tube rows
8	FPI	air-side fin spacing in indoor coil (fins/inch)
9	FPO	air-side fin spacing in outdoor coil (fins/inch)
10**	HXMULT	total Hx area multiplier relative to baseline values in the heat pump data file 'HPDATA', Hx configurations adjusted to maintain approximately constant fan power requirements
Flow Control Variables		
11	DTROC	refrigerant subcooling at condenser exit (F°)
12	TXVRAT	capacity of the TXV (tons)
13	CAPFLO	capillary tube flow factor
14	ORIFD	diameter of short-tube orifice (in.)
Charge Control Variables		
15	SUPER	compressor inlet superheat (F°)
16	REFCHG	system refrigerant charge (lbm)
Air-Side-Condition Variables		
17	TAIII	temperature of air entering indoor unit (°F)
18	TAIIO	temperature of air entering outdoor unit (°F)
19	RHII	indoor relative humidity
20	RHIO	outdoor relative humidity
Modulation Variables		
21	CMPFRQ	operating compressor drive frequency (Hz)
22	FRQIDF	operating indoor blower frequency (Hz)
23	FRQODF	operating outdoor blower frequency (Hz)
24	CFRQRT	operating compressor drive frequency ratio (relative to nominal)
25	FRQRTI	operating indoor fan drive frequency ratio (relative to nominal)
26	FRQRTO	operating outdoor fan drive frequency ratio (relative to nominal)
Motor Sizing Variables		
27	CSIZMT	nominal motor size for selected compressor (hp)
28	SIZMTI	nominal indoor blower motor size (hp)
29	SIZMTO	nominal outdoor fan motor size (hp)

*See the HPDATA input description and the text description accompanying Table 1 for further definitions of the independent variables.

**Refrigerant circuiting adjusted to hold refrigerant-side pressure drop constant.

Table A.2. Key to Independent Contour Variables Available for Selection in Input Data File CONCHZ (continued)

ID #	NAME	INDEPENDENT CONTOUR VARIABLE
Hx Design Variables (Where Total Hx Area For Both Coils Is Held Constant)		
Independent of Total Hx Area		
30	NSECTI	number of equivalent indoor circuits
31	NSECTO	number of equivalent outdoor circuits
32	DDUCT	indoor duct size (+in.) or external pressure drop (–in. H_2O)
Fixed Area Ratio, Tradeoff Variables For Single Hx's Holding Individual Hx Area Constant		
33	NTI (vs AAFI)	# of indoor refrigerant tube rows vs frontal area — *FPI held constant*
34	NTO (vs AAFO)	# of outdoor refrigerant tube rows vs frontal area — *FPO held constant*
35**	FPI (vs AAFI)	indoor fin pitch (fins/in) vs frontal area — *NTI held constant*
36**	FPO (vs AAFO)	outdoor fin pitch (fins/in) vs frontal area — *NTO held constant*
37**	FPI (vs NTI)	indoor fin pitch (fins/in) vs # of tube rows — *AAFI held constant*
38**	FPO (vs NTO)	outdoor fin pitch (fins/in) vs # of tube rows — *AAFO held constant*
Adjustable Area Ratio, Tradeoff Variables Across Hx's Holding Total Hx Area Constant		
One-Variable-Adjustment		
39**	FRACI with AAFI	fraction of total area in indoor coil, frontal area AAFI adjusted and offset by AAFO to maintain fixed total hx area —*fixed NT and FP*
40**	FRACO with AAFO	fraction of total area in outdoor coil, frontal area AAFO adjusted and offset by AAFI to maintain fixed total hx area —*fixed NT and FP*
41**	FRACI with NTI	fraction of total area in indoor coil, # of tube rows NTI adjusted and offset by NTO to maintain fixed total hx area —*fixed AAF and FP*
42**	FRACO with NTO	fraction of total area in outdoor coil, # of tube rows NTO adjusted and offset by NTI to maintain fixed total hx area —*fixed AAF and FP*
43	FRACI with FPI	fraction of total area in indoor coil, fin spacing FPI adjusted and offset by FPO to maintain fixed total hx area —*fixed AAF and NT*
44	FRACO with FPO	fraction of total area in outdoor coil, fin spacing FPO adjusted and offset by FPI to maintain fixed total hx area —*fixed AAF and NT*
Two-Variable-Adjustment		
45**	FRACI with AAFI and NTI	fraction of total area in indoor coil, AAFI and NTI adjusted and offset by AAFO and NTO to maintain fixed total hx area —*fixed FP*
46**	FRACO with AAFO and NTO	fraction of total area in outdoor coil, AAFO and NTO adjusted and offset by AAFI and NTI to maintain fixed total hx area —*fixed FP*
47**	FRACI with AAFI and FPI	fraction of total area in indoor coil, AAFI and FPI adjusted and offset by AAFO and FPO to maintain fixed total hx area —*fixed NT*
48**	FRACO with AAFO and FPO	fraction of total area in outdoor coil, AAFO and FPO adjusted and offset by AAFI and FPI to maintain fixed total hx area —*fixed NT*
49**	FRACI with NTI and FPI	fraction of total area in indoor coil, NTI and FPI adjusted and offset by AAFO and FPO to maintain fixed total hx area —*fixed AAF*
50**	FRACO with NTO and FPO	fraction of total area in outdoor coil, NTO and FPO adjusted and offset by AAFI and FPI to maintain fixed total hx area —*fixed AAF*
Three-Variable-Adjustment (Maintains Approx. Constant Fan Powers)		
51**	FRACI w/NTI, AAFI and FPI	fraction of total area in indoor coil, NTI, AAFI, and FPI adjusted and offset by NTO, AAFO, and FPO to maintain fixed total hx area
52**	FRACO w/NTO AAFO, and FPO	fraction of total area in outdoor coil, NTO, AAFO, and FPO adjusted and offset by NTI, AAFI, and FPI to maintain fixed total hx area

Table A.3. Key to Steady-State Dependent Contour Variables Available for Selection in Input Data File CONCHZ

ID #	STEADY-STATE DEPENDENT VARIABLE
Heat Pump Performance	
1	heat pump COP
2	heat pump capacity (kBtu/h)
3	heat pump EER (BTU/w-h)
4	evaporator sensible-to-total capacity ratio (sensible heat ratio — SHR)
5	supply air temperature (°F)
6	heat pump system COP including I^2R heat to meet specified heating load
7	heat pump system capacity including I^2R heat (kBtu/h)
8	required I^2R heat (kBtu/h)
Heat Pump Power Requirements	
9	total heat pump / I^2R input power (kw)
10	average resistance heater power draw (kw)
11	compressor input power (kw)
12	total heat pump fan power (watts)
13	indoor blower power (watts)
14	outdoor fan power (watts)
Refrigerant-Side Conditions	
15	evaporator average refrigerant saturation temperature (°F)
16	condenser average refrigerant saturation temperature (°F)
17	evaporator exit refrigerant temperature (°F)
18	condenser exit refrigerant temperature (°F)
19	refrigerant saturation temperature entering compressor (°F)
20	refrigerant saturation temperature leaving compressor (°F)
21	compressor pressure ratio
22	refrigerant mass flow rate (lbm/h)
23	evaporator refrigerant pressure drop (psi)
24	condenser refrigerant pressure drop (psi)
25	evaporator average refrigerant two-phase heat transfer coefficient (Btu/h/ft^2/°F)
26	condenser average refrigerant two-phase heat transfer coefficient (Btu/h/ft^2/°F)
Compressor Values — Selected Compressor	
27	percentage of nominal drive frequency of selected compressor (%)
28	selected compressor operating speed (rpm)
29	selected compressor operating torque (lb-ft)
30	selected compressor required nominal torque (lb-ft)
31	percentage of selected compressor nominal torque (%)
32	required motor size for selected compressor (hp)
33	ECM efficiency degradation multiplier for operating temperature effects
34	selected compressor motor/drive efficiency (%)
35	estimated compressor superheat efficiency of selected compressor (%)
36	selected compressor can isentropic efficiency (%)
37	selected compressor can volumetric efficiency (%)

Table A.3. Key to Steady-State Dependent Contour Variables Available for Selection in Input Data File CONCHZ (continued)

Compressor Values — Base Compressor

38	base compressor operating speed (rpm)
39	base compressor operating torque (lb-ft)
40	base compressor nominal torque (lb-ft)
41	percentage of base compressor nominal torque (%)
42	base compressor motor/drive efficiency (%)
43	base compressor can isentropic efficiency (%)
44	base compressor can volumetric efficiency (%)

Compressor Motor Conversion Multipliers

45	ratio of selected (converted) to base compressor speed
46	ratio of selected (converted) to base motor/drive efficiency w/o suction gas heating effects
47	estimated suction gas superheating from base compressor motor (F°)
48	estimated suction gas superheating from selected compressor motor (F°)
49	efficiency multiplier due to differential suction gas heating effects
50	mass flow rate multiplier due to differential suction gas heating effects
51	ratio of selected (converted) to base motor/drive efficiency with suction gas heating effects
52	ratio of selected (converted) to base refrigerant mass flow rate with suction gas heating effects
53	ratio of selected (converted) to base compressor power with suction gas heating effects

Indoor Coil / Blower Values

54	indoor air flow rate (cfm)
55	indoor blower speed (rpm)
56	percentage of nominal indoor blower frequency (%)
57	indoor air face velocity (ft/min)
58	indoor air surface velocity (ft/min)
59	indoor air-side heat transfer coefficient (Btu/h/ft^2/°F)
60	indoor air-side total pressure drop (in. of H_2O)
61	indoor coil fin augmentation heat transfer multiplier
62	indoor coil fin augmentation pressure drop multiplier
63	indoor blower operating torque (oz-ft)
64	percentage of selected indoor motor nominal torque (%)
65	required nominal size of selected indoor motor (hp)
66	motor/drive efficiency of selected indoor drive (%)
67	motor/drive efficiency of base indoor drive (%)
68	combined blower/motor/drive efficiency of selected indoor blower (%)

Outdoor Coil / Fan Values

69	outdoor air flow rate (cfm)
70	outdoor fan speed (rpm)
71	percentage of nominal outdoor fan frequency (%)
72	outdoor air face velocity (ft/min)
73	outdoor air surface velocity (ft/min)
74	outdoor air-side heat transfer coefficient (Btu/h/ft^2/°F)
75	outdoor air-side total pressure drop (in. of H_2O)

Table A.3. Key to Steady-State Dependent Contour Variables Available for Selection in Input Data File CONCHZ (continued)

<u>Outdoor Coil / Fan Values (continued)</u>	
76	outdoor coil fin augmentation heat transfer multiplier
77	outdoor coil fin augmentation pressure drop multiplier
78	outdoor fan operating torque (oz-ft)
79	percentage of selected outdoor motor nominal torque (%)
80	required nominal size of selected outdoor motor (hp)
81	motor/drive efficiency of selected outdoor drive (%)
82	motor/drive efficiency of base outdoor drive (%)
83	combined fan/motor/drive efficiency of selected outdoor fan (%)
84	outdoor fan-only efficiency (%)
85	outdoor fan specific speed
<u>Charge And Flow Control Requirements</u>	
86	required refrigerant charge (lbm)
87	required capillary flow factor
88	required TXV capacity rating (tons)
89	fraction of rated TXV opening
90	required short tube orifice diameter (in)
91	required simple orifice effective kA product (in^2)
<u>Flow Control Parameters</u>	
92	evaporator exit refrigerant superheat (F°) or quality (negative of)
93	compressor inlet refrigerant superheat (F°) or quality (negative of)
94	compressor exit refrigerant superheat (F°) or quality (negative of)
95	condenser exit refrigerant subcooling (F°) or quality (negative of)
96	flow control inlet refrigerant subcooling (F°) or quality (negative of)
97	refrigerant temperature at flow control inlet (°F)
98	refrigerant suction temperature at compressor inlet (°F)
99	refrigerant discharge temperature at compressor exit (°F)
100	refrigerant suction pressure at compressor inlet (psia)
101	refrigerant discharge pressure at compressor exit (psia)
<u>Indoor Air-Side Pressure-Drop-Related Values</u>	
102	required indoor duct size (in.)
103	indoor duct pressure drop (in. of H_2O)
104	indoor filter pressure drop (in. of H_2O)
105	indoor heater pressure drop (in. of H_2O)
106	indoor coil pressure drop (in. of H_2O)
<u>Additional Derived Compressor Efficiency Values</u>	
107	selected compressor-only isentropic efficiency — excluding motor (%)
108	baseline compressor-only isentropic efficiency — excluding motor (%)
<u>Additional Dehumidification Parameters</u>	
109	wetted fraction of evaporator coil
110	moisture removal rate (lbm/h)

Table A.4. Key to Seasonal Dependent Contour Variables Available for Selection in Input Data File CONCHZ (Not Yet Available)

ID #	SEASONAL DEPENDENT VARIABLE
1	heating seasonal performance factor
2	cooling seasonal performance factor
3	annual performance factor
4	heating seasonal energy load (kBtuh)
5	cooling seasonal energy load (kBtuh)
6	annual energy load (kBtuh)
7	heating seasonal energy use (kWh or kBtuh)
8	cooling seasonal energy use (kWh or kBtuh)
9	annual energy use (kWh or kBtuh)
10	heating seasonal parasitic energy use (kWh)
11	cooling seasonal parasitic energy use (kWh)
12	annual parasitic energy use (kWh)
13	heating operating time (h)
14	cooling operating time (h)
15	annual operating time (h)
16	supplemental heating energy use (kWh or kBtuh)
17	defrost tempering energy use (kWh or kBtuh)
18	defrost heat pump energy use (kWh or kBtuh)
19	total defrost time (h)
20	total number of defrosts

Table A.5. Description of Output Contour Data File From MODCON

Identifying Name for Data Set:
RECORD 1 FORMAT (80A)

MTITLE	data set identifier from line 2 of CONCHZ input data

Independent Variable (Parametric) Data:

Identification of X and Y Independent Variables

X-Data
RECORD 2 FORMAT (2I3, 3F10.2)

IDVARX	identifying ID number of X independent variable (refer to Table A.2)
NX	number of X values to be evaluated
XLO	minimum value of X variable
XHI	maximum value of X variable
XREF	X coordinate of any specified reference point (to mark on contour plot)

Y-Data
RECORD 3 FORMAT (2I3, 3F10.2)

IDVARY	identifying ID number of Y independent variable (refer to Table A.2)
NY	number of Y values to be evaluated
YLO	minimum value of Y variable
YHI	maximum value of Y variable
YREF	Y coordinate of any specified reference point (to mark on contour plot)

Dependent Variable (Performance) Data:

Number of Data Sets
RECORD 4 FORMAT (I3)

NDVAR	number of dependent variables for which data are generated

Records 5 and 6 are generated for each dependent variable (J = 1, NDVAR).

Identification of Dependent Variable
RECORD 5 FORMAT (I3, 2X, 75A)

IDVARD(J)	identifier number for dependent variable
NAMDEP(J)	descriptive label for dependent variable

Values of Dependent Variable
RECORD 6 FORMAT (1P, 6E13.5)

VALDEP —>	(IX, IY, IDVARD(J)) array of function values stored as vectors with the X subscript increasing most rapidly and the Y subscript increasing least rapidly going from left to right and top to bottom, respectively. A new line starts each time the Y subscript changes.

Listing A.1. Sample Contour Selection Data File 'CONCHZ' —

File: H2118V.CHZ

```
 01
HEATING MODE PARAMETRIC EVALUATION — COMPRESSOR FREQUENCY VERSUS AMBIENT
 21 06     180.0      50.0     180.0
 18 03      17.0      47.0      47.0
 05
  1  2      50.0     180.0       1.0       1.0       1.0       1.0
  2  2      50.0     180.0      10.0      24.0      10.0      24.0
  3  2      50.0     180.0      64.8      95.0      64.8      95.0
  4  2      50.0     180.0      37.1      55.3      37.1      55.3
  5  1      17.0      62.0      20.0       0.0       0.0      50.0
110
  1  Heat Pump COP
  2  Heat Pump Capacity (KBtu/H)
  3  Heat Pump EER (BTU/W-H)
  4  Evaporator Sensible-To-Total Capacity Ratio
  5  Supply Air Temperature (F)
  6  Heat Pump System COP With I2R Heat To Meet Specified Heating Load
  7  Heat Pump System Capacity Including I2R Heat (KBtu/H)
  8  Required I2R Heat (KBtu/H)
  9  Total Heat Pump/I2R Input Power (Kw)
 10  Average Resistance Heater Power Draw  (Kw)
 11  Compressor Input Power (Kw)
 12  Total Heat Pump Fan Power (Watts)
 13  Indoor Blower Power (Watts)
 14  Outdoor Fan Power (Watts)
 15  Evaporator Average Refrigerant Saturation Temperature (F)
 16  Condenser Average Refrigerant Saturation Temperature (F)
 17  Evaporator Exit Refrigerant Temperature (F)
 18  Condenser Exit Refrigerant Temperature (F)
 19  Refrigerant Saturation Temperature Entering Compressor (F)
 20  Refrigerant Saturation Temperature Leaving Compressor (F)
 21  Compressor Pressure Ratio
 22  Refrigerant Mass Flow Rate (lbm/h)
 23  Evaporator Refrigerant Pressure Drop (psi)
 24  Condenser Refrigerant Pressure Drop (psi)
 25  Evaporator Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft2/F)
 26  Condenser Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft2/F)
 27  Percentage Of Nominal Drive Frequency Of Selected Compressor (%)
 28  Selected Compressor Operating Speed (rpm)
 29  Selected Compressor Operating Torque (lb-ft)
 30  Selected Compressor Required Nominal Torque (lb-ft)
 31  Percentage Of Selected Compressor Nominal Torque (%)
 32  Required Motor Size For Selected Compressor (Hp)
 33  ECM Efficiency Degradation Multiplier For Operating Temp Effects
```

Listing A.1. Sample Contour Selection Data File 'CONCHZ' — (continued)

34 Selected Compressor Motor/Drive Efficiency (%)
35 Estimated Compressor Superheat Efficiency Of Selected Comp (%)
36 Selected Compressor Can Isentropic Efficiency (%)
37 Selected Compressor Can Volumetric Efficiency (%)
38 Base Compressor Operating Speed (rpm)
39 Base Compressor Operating Torque (lb-ft)
40 Base Compressor Nominal Torque (lb-ft)
41 Percentage Of Base Compressor Nominal Torque (%)
42 Base Compressor Motor/Drive Efficiency (%)
43 Base Compressor Can Isentropic Efficiency (%)
44 Base Compressor Can Volumetric Efficiency (%)
45 Ratio Of Selected To Base Compressor Speed
46 Ratio Of Selected To Base Motor/Drive Efficiency W/O SGH Effects
47 Estimated Suction Gas Superheating From Base Compressor Motor (F)
48 Estimated Suction Gas Superheating From Selected Comp. Motor (F)
49 Efficiency Multiplier Due To Differential SGH Effects
50 Mass Flow Rate Multiplier Due To Differential SGH Effects
51 Ratio Of Selected To Base Motor/Drive Efficiency With SGH Effects
52 Ratio Of Selected To Base Refrig. Mass Flow Rate With SGH Effects
53 Ratio Of Selected To Base Compressor Power With SGH Effects
54 Indoor Air Flow Rate (cfm)
55 Indoor Blower Speed (rpm)
56 Percentage Of Nominal Indoor Blower Frequency (%)
57 Indoor Air Face Velocity (ft/min)
58 Indoor Air Surface Velocity (ft/min)
59 Indoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)
60 Indoor Air-Side Pressure Drop (In Of H2O)
61 Indoor Coil Fin Patternation Heat Transfer Multiplier
62 Indoor Coil Fin Patternation Pressure Drop Multiplier
63 Indoor Blower Operating Torque (oz-ft)
64 Percentage Of Selected Indoor Motor Nominal Torque (%)
65 Required Nominal Size Of Selected Indoor Motor (Hp)
66 Motor/Drive Efficiency Of Selected Indoor Drive (%)
67 Motor/Drive Efficiency Of Base Indoor Drive (%)
68 Combined Blower/Motor/Drive Efficiency Of Selected Indoor Blower (%)
69 Outdoor Air Flow Rate (cfm)
70 Outdoor Fan Speed (rpm)
71 Percentage Of Nominal Outdoor Fan Frequency (%)
72 Outdoor Air Face Velocity (ft/min)
73 Outdoor Air Surface Velocity (ft/min)
74 Outdoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)
75 Outdoor Air-Side Pressure Drop (In Of H_2O)
76 Outdoor Coil Fin Patternation Heat Transfer Multiplier
77 Outdoor Coil Fin Patternation Pressure Drop Multiplier
78 Outdoor Fan Operating Torque (oz-ft)
79 Percentage Of Selected Outdoor Motor Nominal Torque (%)
80 Required Nominal Size Of Selected Outdoor Motor (Hp)

Listing A.1. Sample Contour Selection Data File 'CONCHZ' — (continued)

```
 81  Motor/Drive Efficiency Of Selected Outdoor Drive (%)
 82  Motor/Drive Efficiency Of Base Outdoor Drive (%)
 83  Combined Fan/Motor/Drive Efficiency Of Selected Outdoor Fan (%)
 84  Outdoor Fan-Only Efficiency (%)
 85  Outdoor Fan Specific Speed
 86  Required Refrigerant Charge (lbm)
 87  Required Capillary Flow Factor
 88  Required TXV Capacity Rating (tons)
 89  Fraction Of Rated TXV Opening
 90  Required Short Tube Orifice Diameter (In)
 91  Required Simple Orifice Effective KA Product (In2)
 92  Evaporator Exit Refrigerant Superheat (F) Or Quality (-)
 93  Compressor Inlet Refrigerant Superheat (F) Or Quality (-)
 94  Compressor Exit Refrigerant Superheat (F) Or Quality (-)
 95  Condenser  Exit Refrigerant Subcooling (F) Or Quality (-)
 96  Flow Control Inlet Refrigerant Subcooling (F) Or Quality (-)
 97  Refrigerant Temperature At Flow Control Inlet (F)
 98  Refrigerant Suction Temperature At Compressor Inlet (F)
 99  Refrigerant Discharge Temperature At Compressor Exit (F)
100  Refrigerant Suction Pressure At Compressor Inlet (psia)
101  Refrigerant Discharge Pressure At Compressor Exit (psia)
102  Required Indoor Duct Size (Inches)
103  Indoor Duct Pressure Drop (Inches of Water)
104  Indoor Filter Pressure Drop (Inches of Water)
105  Indoor Heater Pressure Drop (Inches of Water)
106  Indoor Coil Pressure Drop (Inches of Water)
107  Selected Compressor-Only Isentropic Efficiency — Excluding Motor (%)
108  Baseline Compressor-Only Isentropic Efficiency — Excluding Motor (%)
109  Wetted Fraction of Evaporator Coil
110  Moisture Removal Rate (lbm/h)
```

Listing A.2. Annotated Sample Contour Selection Data File 'CONCHZ'

File: H2118V.CHZ

```
Selection of Operating Mode(s):
MODEGN
 01

Heading Identifiers For Selected Operating Mode(s):
MTITLE
HEATING MODE PARAMETRIC EVALUATION — COMPRESSOR FREQUENCY VERSUS AMBIENT

Selection of X and Y Independent Variables:
IDVARX
    NX        XLO        XHI     XREF(J)
 21 06      180.0       50.0      180.0
IDVARY
    NY        YLO        YHI     YREF(J)
 18 03       17.0       47.0       47.0

Operational Data:
NVALS
 05
 >>>J=1,NVALS
NFUN NIND VINDEP1   VINDEP2   VDEPEN1    VDEPEN2    VDEPLO     VDEPHI
  1   2      50.0     180.0       1.0        1.0        1.0        1.0
  2   2      50.0     180.0      10.0       24.0       10.0       24.0
  3   2      50.0     180.0      64.8       95.0       64.8       95.0
  4   2      50.0     180.0      37.1       55.3       37.1       55.3
  5   1      17.0      62.0      20.0        0.0        0.0       50.0

Dependent Variable Selections:
NDVSS
110
>>>J=1,NDVSS
IDVSS   NAMSS
  1  Heat Pump COP
  2  Heat Pump Capacity (KBtu/H)
  3  Heat Pump EER (BTU/W-H)
  4  Evaporator Sensible-To-Total Capacity Ratio
  5  Supply Air Temperature (F)
  6  Heat Pump System COP With I2R Heat To Meet Specified Heating Load
  7  Heat Pump System Capacity Including I2R Heat (KBtu/H)
  8  Required I2R Heat (KBtu/H)
  9  Total Heat Pump/I2R Input Power (Kw)
 10  Average Resistance Heater Power Draw  (Kw)
...
>>>  Continuing Until J = NDVSS
```

APPENDIX B

HEAT PUMP SPECIFICATION DATA FILE 'HPDATA'

Input Data Definitions and Format

In Table B.1, the input parameters and format requirements for the heat pump specification data file are described. Changes from the ORNL Mark III Single-Speed Version are denoted by vertical change bars in the extreme leftmost column.

The new data file format was designed to minimize changes required to update existing Mark III data sets. Most of the new input requirements are additive (either by appending to existing lines or by adding new lines). Extra lines for variable-speed compressors, specific augmented heat exchanger surfaces, charge inventory aspects, and convengence tolerances were the main additions. The options available to some previous entries have also been expanded.

Sample Input Files (Regular and Annotated)

This section contains regular Listings B.1 and B.2 and an annotated Listing B.3 of sample 'HPDATA' files. The regular listings B.1 and B.2 are for the same heat pump but for different ambient conditions and analysis purposes.

Listing B.1 is a data set appropriate for use in initial design calculations where the compressor and fan motors sizes have not yet been selected. This example data set is for the 95°F design cooling condition and the motors are to be sized by the model to meet user-specified percentages of nominal loading. The external pressure drop of the indoor duct system has also been specified by the user to impose a constant value at the design condition.

Listing B.2 is a data set appropriate for use in off-design calculations once the compressor and fan motors sizes and the indoor duct size have been selected. This example data set is for the 47°F off-design heating condition and the motors and indoor duct system were sized previously by the design calculation at the 95°F condition.

The changes required to the data sets to switch from a design to an off-design calculation are highlighted in bold type in Listings B.1 and B.2.

The regular listings represent the data set as directly used by the model while the annotated version of the first data set is sectioned and labeled with the header types and variable names as described in Table B.1. The annotated listing is provided as a visual reference to users modifying existing data sets.

The compressor curve-fit coefficients required for the 'HPDATA' file can be generated as an output file from the compressor map-fitting program described in Appendix G. This output file can be imported into an existing heat pump model data set with minimal editing when a different compressor needs to be modeled.

The example data set is for a fairly-representative modulating heat pump with total heat exchanger surface area approximately equivalent to that of a present-day commercially-available variable speed unit. The heat exchanger geometry details and compressor are that of a first-generation modulating heat pump described by Miller (1987, 1988a, 1988b). However, the compressor curve-fits provided are for sine-wave-driven tests of the first-generation-modulating compressor rather than for the inverter-driven case. The sine-wave-driven modulating induction motor data built into the model is for the same model motor used in the tested compressor. As such, the provided sample-compressor-data is the most consistent baseline for use in assessing the effect of the benefits of advanced drives.

Table B.1. Description of HPDATA Input to the MODCON Program

TITLE and OUTPUT DATA:

LINE #1 FORMAT(A80)

HTITLE	Descriptive title for heat pump system defined by this data set	SAMPLE

LINE #2 FORMAT(8I10)

LPRINT — Output switch to control the type and amount of printed results — 1

- =–2, for minimum output from contour data generation front end, no heat pump model output
- =–1, for diagnostic output from contour data generation front end, no heat pump model output
- =0, for minimum heat pump model output with only an energy input and output summary
- =1, for a summary of the system operating conditions and component performance calculations as well as the energy summary
- =2, for output *after* each intermediate iteration converges
- =3, for continuous output *during* intermediate iterations

MODE and REFRIGERANT DATA:

LINE #3 FORMAT(8I10)

NCORH — Switch to specify cooling or heating mode — 1

- =1, for cooling mode
- =2, for heating mode
- =3, for dual mode (used in conjunction with contour data generation)

NR — Refrigerant number — 12, 22, 114, 502, or 134(a) (If NR is omitted, the default is R22) — 22

CHARGE INVENTORY / SUPERHEAT DATA:

LINE #4 FORMAT(I10, 2F10.4, I10)

ICHRGE — Indicator for specifying charge inventory balance choice — 0

- =0, *no* charge balance — charge to be determined;
  specify compressor inlet superheat,
  specify condenser exit subcooling or flow control requirements.
- =1, charge balance — high-side determined;
  specify refrigerant charge,
  estimate compressor inlet superheat,
  specify condenser exit subcooling or flow control requirements.
- =2, charge balance — low-side determined;
  specify refrigerant charge,
  specify compressor inlet superheat,
  estimate condenser exit subcooling, *determine* flow control requirements.

*Bars in left-hand margins indicate changes in input or definitions from Mark III single-speed version.

SUPER	*Specified* (if ICHRGE=0,2) or *estimated* (if ICHRGE=1) refrigerant superheat (or quality) at the compressor shell inlet (F° or negative of the desired quality fraction)	10.0
REFCHG	*Specified* system refrigerant charge (lbm) (not needed if ICHRGE=0)	(8.8)
MVOID	Switch to specify heat exchanger void fraction (slip) method for charge inventory calculations	0

=0, default method — Zivi void fraction model
with analytical solution
for a *constant* heat flux approximation

>0, various user-selected void fraction models
with *variable* heat flux effects
(which require slower numerical solutions)

— mass-flow independent methods
=1, Homogeneous (no slip)
=2, Zivi
=3, Lockhart-Martinelli
=4, Thom
=5, Baroczy

— mass-flow dependent methods
=6, Hughmark
=7, Premoli*
=8, Tandon

CHARGE INVENTORY CALCULATIONAL DATA:

<u>LINE #5</u> <u>FORMAT(I10, 7F10.4)</u>

IMASS	Switch for option to omit refrigerant charge calculations, only active for ICHRGE=0 case =0, if charge calculations are to be omitted =1, if charge calculations are to be made	1

Compressor and Accumulator Geometry Values for Refrigerant Charge Calculations:
(not required if IMASS = 0 and ICHRGE = 0)
(if an accumulator is not used, set accumulator height ACCHGT to 0.0)

VOLCMP	Internal void space volume of compressor (cu. in.)	395.0
ACCHGT	Height of accumulator (in.)	10.0
ACCDIA	Internal diameter of accumulator (in.)	4.834
OILDIA	Inner diameter of oil return hole J-tube (in.)	0.035

*Presently configured only with R-22 surface tension properties.

UPPDIA	Inner diameter of upper hole in J-tube (in.)	0.040
HOLDIS	Vertical distance between holes (in.)	2.50
ATBDIA	Inner diameter of J-tube (in.)	0.680

FLOW CONTROL DEVICE DATA: (the variables on this line depend on the type of flow control device selected)

LINE #6 FORMAT(I10, 7F10.4)

Specified or Estimated Condenser Subcooling:

IREFC	=0, for specified or estimated refrigerant subcooling at the condenser exit	0
DTROC	*Specified* (if ICHRGE=0,1) or *estimated* (if ICHRGE=2) refrigerant subcooling (or quality) at the condenser exit (F° or negative of the desired quality fraction)	16.0

Thermostatic Expansion Valve:

IREFC	=1, for a thermostatic expansion valve (TXV)	1
TXVRAT	Rated capacity of the TXV (tons)	2.0
STATIC	Static superheat setting for the TXV (F°)	6.0
SUPRAT	TXV superheat at rating conditions (F°)	11.0
SUPMAX	Maximum effective operating superheat (F°)	13.0
BLEEDF	TXV bypass or bleed factor	1.15
NZTBOP	Switch to omit TXV nozzle and tube pressure drop calculations =0.0, to omit tube and nozzle pressure drops =1.0, to include tube and nozzle pressure drop calculations	0.0

Capillary Tube:

IREFC	=2, for a capillary tube(s)	2
CAPFLO	Capillary tube flow factor, see ASHRAE Handbook, Equipment Vol. (1988), Fig. 39, p. 19.27	3.8
NCAP	Number of capillary tubes in parallel	1.0

Short Tube Orifice:

IREFC	=3, for a short tube orifice	3
ORIFD	Diameter of the short-tube orifice (in.)	0.0544

ESTIMATES of the LOW- and HIGH-SIDE REFRIGERANT SATURATION TEMPERATURES:

<u>LINE #7</u>	<u>FORMAT(8F10.4)</u>	
TSICMP	Estimate of the refrigerant saturation temperature at the compressor shell inlet (°F)	48.0
TSOCMP	Estimate of the refrigerant saturation temperature at the compressor shell outlet (°F)	120.0

GENERAL COMPRESSOR DATA:

<u>LINE #8</u>	<u>FORMAT(I10, 7F10.4)</u>	
ICOMP	Switch to specify which compressor submodel is to be used, =1, for the efficiency-and-loss model (*single-speed only*) =2, for the map-based model (*single- or variable-speed*)	2
DISPL	Total piston displacement for *selected* compressor (cu. in.)	1.70
CMPSPD	Speed/frequency-determining-parameter for *selected* compressor —	
	Operating frequency ratio (relative to nominal frequency on Line 9.1), if value ≤ 5 and ICOMP= 2;	1.0
	Operating drive frequency (Hz), if value > 5 and ICOMP= 2,	(180.0)
	Synchronous compressor motor speed (rpm) if ICOMP=1 and FLMOT is specified on LINE #9;	(5400.)
	Rated compressor motor speed (rpm) if ICOMP=1 and FLMOT is to be calculated	(5250.)
QCAN	Compressor shell heat loss rate (Btu/h), used if CANFAC is 0.0	0.0
CANFAC	Switch to control the method of specifying compressor shell heat loss rate, QCAN	1.0

=0.0, to specify QCAN explicitly
<1.0, to calculate QCAN as a fraction of compressor input power, POW, (i.e., QCAN = CANFAC * POW)
=1.0, QCAN is based on map submodel of CANFAC (Map-based model only, Line 9.8)
>1.0, to calculate QCAN from the relationship : QCAN = 0.90 * [1 – {motor η * mechanical η}] * POW, (only if ICOMP = 1)

COMPRESSOR DATA FOR EFFICIENCY-AND-LOSS MODEL:
(Lines 9.0 and 9.1)

LINE #9.0 FORMAT(8F10.4)

VR	Compressor actual clearance volume ratio	0.06
EFFMMX	Maximum efficiency of the compressor motor	0.82
ETAISN	Isentropic efficiency of the compressor	0.70
ETAMEC	Mechanical efficiency of the compressor	0.80

LINE #9.1 FORMAT(I10, 7F10.4)

MTRCLC	Switch to determine whether to calculate the full load motor power (FLMOT) or to use the input value =0, to calculate FLMOT =1, to use the input value of FLMOT	0
FLMOT	Compressor motor output at full load (kW) (not used if MTRCLC = 0)	( )
QHILO	Heat transfer rate from the compressor inlet line to the inlet gas (Btu/h), used if HILOFC=0.0	300.0
HILOFC	Switch to determine internal heat transfer from the high side to the low side, QHILO = 0.0, to specify QHILO explicitly < 1.0, to calculate QHILO = HILOFC * POW ≥ 1.0, to calculate QHILO = 0.03 * POW	0.0

OR

MAP-BASED COMPRESSOR MODEL INPUT DATA:
(Alternative Lines 9.0 through 9.6)

LINE #9.0 FORMAT(A80)

CTITLE	Descriptive title for map-based compressor data	MAP DATA

LINE #9.1 FORMAT(3I10, 5F10.4)

MODEDT	Switch indicating type of compressor data representation =1, curve fits to compressor input power and refrigerant mass flow rate =2, curve fits to compressor shell isentropic and volumetric efficiencies	2

ICMPDT	Switch *identifying* drive efficiency level of *base* compressor data =0, first-generation inverter-driven induction-motor (IDIM) efficiency =1, state-of-the-art IDIM efficiency =2, ideal sine-wave-driven, induction motor (SWDIM) efficiency =3, electronically-commutated motor (ECM) efficiency	2
ICDVCH	Switch *choosing selected* drive efficiency level (to convert *base* compressor data) =0, first-generation IDIM efficiency =1, state-of-the-art IDIM efficiency =2, ideal SWDIM efficiency =3, ECM efficiency	3
CSIZMT	If > 0.0, *nominal* motor size for *selected* compressor (hp), used to determine relative motor loading and resultant motor efficiency	(2.27)
	If < 0.0, (negative of) specified percentage of nominal loading at which the motor efficiency of the *selected* compressor is to be evaluated, also (if CMPFRQ = CFRQNM) the required motor size will be calculated (auto-sizing)	–130.0
CFRQNM	*Nominal* frequency for *selected* motor rating (Hz)	180.0
CVLTNM	*Nominal* voltage for *selected* motor rating (Volts) — induction motors only	210.0
CVLHZM	*Selected* operating volts/Hertz ratio multiplier (range of 0.85 to 1.15) — induction motors only	1.0
<u>LINE #9.2</u>	<u>FORMAT(I10, 7F10.4)</u>	
NHZ	Number of frequencies for which compressor-data curve-fits are available,	7
DISPLB	*Base* compressor displacement for compressor map (cubic inches)	3.64
SUPERB	*Base* 'superheat' value for compressor map, If ≥ 0, base superheat entering compressor (F°), If < 0, negative of return gas temperature into compressor (°F)	 20.0 (–95.0)
CSIZMB	Motor size for *base* compressor (hp)	2.75
CFRQNB	*Nominal* frequency for *base* motor rating (Hz)	60.0
CVLTNB	*Nominal* voltage for *base* motor rating (volts) — induction motors only	210.0

MAP DATA AT SPECIFIED COMPRESSOR FREQUENCY (HZVAL):

LINE #9.3 FORMAT(8F10.4)

HZVAL	Compressor frequency value (Hz) for which map data follow	15.0
RPMVAL	*Nominal* compressor speed *at given frequency* (rpm) (to be used in volumetric efficiency calculations)	750.0
VLTVAL	Compressor motor voltage (volts) *at given frequency* for which map data apply — induction motors only	53.0

(If MODEDT = 1 on LINE 9.1)

POWADJ	Adjustment factor to curve-fit for power *at given frequency* (set to 1.0 if value is omitted)	1.0
XMRADJ	Adjustment factor to curve-fit for mass flow rate *at given frequency* (set to 1.0 if value is omitted)	1.0

(If MODEDT = 2 on LINE 9.1)

ETIADJ	Adjustment factor to curve-fit for isentropic efficiency *at given frequency* (set to 1.0 if value is omitted)	1.0
ETVADJ	Adjustment factor to curve-fit for volumetric efficiency *at given frequency* (set to 1.0 if value is omitted)	1.0

(If MODEDT = 1 on Line 9.1, Read Lines 9.4 and 9.5)

LINE #9.4 FORMAT(6E10.3)

CPOWER Coefficients for bi-quadratic fit to *compressor power* (kW) as a function of compressor suction and discharge saturation temperatures (°F), TSICMP and TSOCMP, of the form —

POWER(IHZ) =

CPOWER (1,IHZ)	*	$TSOCMP^2$	+	( )
CPOWER (2,IHZ)	*	TSOCMP	+	( )
CPOWER (3,IHZ)	*	$TSICMP^2$	+	( )
CPOWER (4,IHZ)	*	TSICMP	+	( )
CPOWER (5,IHZ)	*	TSOCMP * TSICMP	+	( )
CPOWER (6,IHZ)				( )

LINE #9.5 FORMAT(6E10.3)

CMASSF Coefficients for bi-quadratic fit to *compressor mass flow rate* (lbm/h) as a function of compressor suction and discharge saturation temperatures (°F),TSICMP and TSOCMP, of the form —

XMR(IHZ) =

CMASSF (1,IHZ)	*	$TSOCMP^2$	+	( )
CMASSF (2,IHZ)	*	TSOCMP	+	( )
CMASSF (3,IHZ)	*	$TSICMP^2$	+	( )
CMASSF (4,IHZ)	*	TSICMP	+	( )
CMASSF (5,IHZ)	*	TSOCMP * TSICMP	+	( )
CMASSF (6,IHZ)				( )

(If MODEDT = 2 on Line 9.1, Read Lines 9.6 and 9.7)

LINE #9.6 FORMAT(6E10.3)

CETAIS Coefficients for bi-quadratic fit to *compressor shell isentropic efficiency* as a function of compressor suction and discharge saturation temperatures (°F), TSICMP and TSOCMP, of the form —

ETAISN(IHZ) =

CETAIS (1,IHZ) * $TSOCMP^2$		+	–2.324E–04
CETAIS (2,IHZ) * TSOCMP		+	–5.143E–02
CETAIS (3,IHZ) * $TSICMP^2$		+	–2.726E–04
CETAIS (4,IHZ) * TSICMP		+	–9.975E–02
CETAIS (5,IHZ) * TSOCMP * TSICMP		+	1.515E–03
CETAIS (6,IHZ)			5.760E+00

LINE #9.7 FORMAT(6E10.3)

CETAVL Coefficients for curve fit to *compressor shell volumetric efficiency* as a function of pressure ratio P_R and discharge pressure P_D (psia) of the form —

ETAVOL(IHZ) =

CETAVL (1,IHZ)	*	$(P_R - 1.)$	+	–6.560E+00
CETAVL (2,IHZ)	*	$(P_R - 1.) * P_D$	+	7.350E–02
CETAVL (3,IHZ)	*	$(P_R - 1.) * P_D * P_D$	+	–2.192E–04
CETAVL (4,IHZ)				1.176E+00

(Repeat Lines 9.3 — 9.7 For Each Compressor Frequency, IHZ=1, NHZ)

Compressor Shell Heat Loss Correlation :

LINE #9.8 FORMAT(6E10.3)

CQCAN Coefficients of quadratic fit to *compressor shell heat loss* as a function of compressor dischargesaturation temperature (°F) of the form —

CANFAC =

CQCAN (1)	*	TSOCMP	+	–1.704E–02
CQCAN (2)	*	$TSOCMP^2$	+	5.610E–05
CQCAN (3)				1.314E+00

(If CANFAC ≠ 1 on Line #8, Line #9.8 must be omitted)

INDOOR UNIT DATA:

<u>LINE #10</u> <u>FORMAT(8F10.4)</u>

Indoor Operating Conditions:

TAIII	Air temperature entering the indoor unit (°F)	80.0
RHII	Relative humidity of the air entering the indoor unit	0.52

<u>LINE #11</u> <u>FORMAT(5F10.4,2I5,2F10.4)</u>

Indoor Blower:

FRQIDF — *Operating* frequency parameter for indoor blower —

- if ≤ 5, operating frequency *ratio* relative to nominal given by FRQNMI — 1.0
- if > 5, operating frequency (Hz) — (108.0)

FRQNMI — *Nominal* indoor blower frequency (Hz) — 108.0

QANMI — *Nominal* air flow rate (cfm) — 900.

SIZMTI — ECM blower motor sizing parameter —
(SIZMTI is only used if ICHIDF=3)

- > 0.0, *nominal* blower motor size (hp), used to determine relative motor loading and resultant ECM efficiency — (0.22)
- < 0.0, (negative of) *percentage of nominal loading* at which the ECM efficiency is to be evaluated, also — if FRQIDF = FRQNMI — the required motor size will be calculated (auto-sizing) — –75.0

FANEFI — Fan / fan-motor efficiency parameter —

- ≤ 1.0, specified fixed value of separate or combined efficiencies of fan and/or drive:
  (those values not explicitly specified by FANEFI will be calculated based on ICHIDF selection)

  If ICHIDF < 0, specified value of combined fan / fan-motor efficiency — (0.335)

  If ICHIDF ≥ 0, specified fan-only efficiency; — 0.45

FANEFI...	>1.0, directly-specified power (watts) of <u>*reference*</u> drive *at nominal air flow rate (if available measured power is not at selected nominal cfm, then ratio the measured power by cube of cfm ratio),* at reference inlet air temperatures of 70°F heating and 80°F cooling	(148.0)
IRFIDF	Integer switch to identify <u>*reference*</u> drive type if FANEFI is used to specify nominal fan power (only used if FANEFI > 1.0) < 0, No reference drive type to be used, gives a constant implicit drive efficiency with speed ≥ 0, Nominal input power is referenced to choice of following drives — (drive efficiency will vary with speed) =0, specifies a first-generation IDIM drive =1, specifies a state-of-the-art IDIM drive =2, specifies an ideal SWDIM drive =3, specifies an ECM drive	3
ICHIDF	Integer switch for choosing <u>*selected*</u> drive type: For use in combination with given FANEFI values (If FANEFI ≤ 1.0) or For conversion from reference IRFIDF values to selected ICHIDF drive type (If FANEFI > 1.0) < 0, drive efficiency assumed constant as explicitly or implicitly given by FANEFI (If IRFIDF < 0 and FANEFI > 1.0, ICHIDF will be automatically set to –1) ≥ 0, drive efficiency computed using choice of following drives — (drive efficiency will vary with speed) =0, specifies a first-generation IDIM drive =1, specifies a state-of-the-art IDIM drive =2, specifies an ideal SWDIM drive =3, specifies an ECM drive	3
DDUCT	Indoor duct sizing parameter —. If > 0, equivalent diameter of each of 6 identical air ducts (in.) — each with an equivalent length of 100 ft If ≤ 0, (negative of) specified external pressure drop of duct system — independent of specified air flow rate or fan speed (Note: DDUCT is not used in fan power calculations if FANEFI > 1.0)	(6.20) –0.15
FIXCAP	House heating load (Btu/h), optional, used to calculate the necessary backup resistance heat in the heating mode	0.0

LINE #12 FORMAT(8F10.4)

Indoor Heat Exchanger Configuration:

AAFI	Frontal (face) area of the coil (sq. ft.)	3.90
NTI	Number of refrigerant tube rows in the direction of air flow	4.0
NSECTI	Number of equivalent, parallel refrigerant circuits in heat exchanger	3.0
WTI	Spacing of the refrigerant tubes in the direction of air flow (in.)	0.866
STI	Spacing of the refrigerant tube passes perpendicular to the direction of air flow (in.)	1.00
RTBI	Total number of return bends in heat exchanger (all circuits)	128.0

LINE #13.0 FORMAT(8F10.4)

Indoor Heat Exchanger Configuration (continued):

FINTYI	Switch to specify the type of fin surface, =1.0, for smooth fins =2.0, for *general* wavy (sinusoidal) or zig-zag (corrugated) fins — using multipliers to smooth fin equations =3.0, for *general* louvered (simple-strip) fins — using multipliers to smooth fin equations =4.0, for *specific* zig-zag fin designs =5.0, for *specific* louvered (simple-strip) fin designs	2.0
FPI	Fin pitch (fins/in.)	14.0
DELTAI	Fin thickness (in.)	0.0050
DEAI	Outside diameter of the refrigerant tubes (in.)	0.395
DERI	Inside diameter of the refrigerant tubes (in.)	0.371
XKFI	Thermal conductivity of the fins (Btu/h-ft-~F)	128.3
XKTI	Thermal conductivity of the tubes (Btu/h-ft-~F)	225.0
HCONTI	Fraction of the default computed contact conductance between the fins and tubes	999.999

LINE #14 FORMAT(I10, 7F10.4)

Fin Patternation Data for Indoor Coil:

If FINTYI < 4.0, leave a blank line

If FINTYI = 4.0,

NFPZGI	Number of fin patterns per row of tubes in flow direction (integer)	2
FPDZGI	Fin pattern depth (in)	0.045

If FINTYI = 5.0,

NSLVI	Number of strips in an enhanced zone (integer)	(4)
XLSLVI	Length of enhanced louvered zone (mm)	(8.0)
XWSLVI	Width of single strip in flow direction (mm)	(2.0)

<u>LINE #15</u> <u>FORMAT(8F10.4)</u>

Heat Transfer and Pressure Drop Multipliers for Indoor Coil :

HTRMLI	Refrigerant-side heat transfer multiplier	1.0
PDRMLI	Refrigerant-side pressure-drop multiplier	1.0
HTAMLI	Air-side heat transfer multiplier	1.0
PDAMLI	Air-side *coil* pressure-drop multiplier	1.0
CABMLI	Air-side system pressure-drop multiplier	1.0

OUTDOOR UNIT DATA:

<u>LINE #16</u> <u>FORMAT(8F10.4)</u>

Outdoor Operating Conditions:

TAIIO	Air temperature entering the heat exchanger (F)	95.0
RHIO	Relative humidity of the air entering the heat exchanger	0.40

<u>LINE #17</u> <u>FORMAT(5F10.4,2I5,I10)</u>

Outdoor Fan:

FRQODF	*Operating* frequency parameter for outdoor fan —	
	if ≤ 5, operating frequency *ratio* relative to nominal given by FRQNMO	1.0
	if > 5, operating frequency (Hz)	(82.5)
FRQNMO	*Nominal* outdoor fan frequency (Hz)	82.5

QANMO	*Nominal* air flow rate (cfm)	2700.0
SIZMTO	ECM blower motor sizing parameter — (SIZMTO is only used if ICHODF=3)	
	> 0.0, *nominal* blower motor size (hp), used to determine relative motor loading and resultant ECM efficiency	(0.16)
	< 0.0, (negative of) *percentage of nominal loading* at which the ECM efficiency is to be evaluated, also — if FRQODF = FRQNMO — the required motor size will be calculated (auto-sizing)	–75.0
FANEFO	Fan / fan motor efficiency parameter —	
	≤ 1.0, specified fixed value of separate or combined efficiencies of fan and/or drive: (those values not explicitly specified by FANEFO will be calculated based on MFANFT / ICHODF selections)	
	If MFANFT = 0 and ICHODF < 0, specified value of combined fan / fan motor efficiency	(0.245)
	If MFANFT = 0 and ICHODF ≥ 0, specified fan-only efficiency	(0.35)
	If MFANFT = 1 and ICHODF < 0, specified drive efficiency	(0.70)
	If MFANFT = 1 and ICHODF => 0, specified value is ignored, model calculates both fan and drive efficiencies	0.00
	>1.0, directly-specified power (watts) of <u>*reference*</u> drive *at nominal air flow rate (if available measured power is not at selected nominal cfm, then ratio the measured power by cube of cfm ratio)*, at reference inlet air temperatures of 47°F heating or 95°F cooling	112.0
IRFODF	Integer switch to identify <u>*reference*</u> drive type if FANEFO is used to specify nominal fan power (only used if FANEFO > 1.0)	3
	< 0, No reference drive type to be used, gives a constant implicit drive efficiency with speed	

IRFODF...	≥ 0, Nominal input power is referenced to choice of following drives — (drive efficiency will vary with speed) =0, specifies a first-generation IDIM drive =1, specifies a state-of-the-art IDIM drive =2, specifies an ideal SWDIM drive =3, specifies an ECM drive	
ICHODF	Integer switch for choosing *selected* drive type: For use in combination with given FANEFO values (If FANEFO ≤ 1.0) or For conversion from reference IRFODF values to selected ICHODF drive type (If FANEFO > 1.0) < 0, drive efficiency assumed constant as explicitly or implicitly given by FANEFO (If IRFODF < 0 and FANEFO > 1.0, ICHODF will be automatically set to −1) ≥ 0, drive efficiency computed using choice of following drives — (drive efficiency will vary with speed) =0, specifies a first-generation IDIM drive =1, specifies a state-of-the-art IDIM drive =2, specifies an ideal SWDIM drive =3, specifies an ECM drive	3
MFANFT	Switch for using static efficiency vs specific speed for the efficiency of the outdoor fan — =0, specified value of FANEFO is used =1, curve fit for fan static efficiency is used — with fan motor efficiency either specified by FANEFO or calculated internally (should not be chosen if FANEFO > 1.0)	1

<u>LINE #18</u> <u>FORMAT(8F10.4)</u>

Outdoor Heat Exchanger Configuration:

AAFO	Frontal (face) area of the coil (sq. ft.)	9.05
NTO	Number of refrigerant tube rows in the direction of air flow	3.0
NSECTO	Number of equivalent, parallel refrigerant circuits in heat exchanger	3.0
WTO	Spacing of the refrigerant tubes in the direction of air flow (in.)	1.08
STO	Spacing of the refrigerant tube passes perpendicular to the direction of the air flow (in.)	1.25
RTBO	Total number of return bends in heat exchanger (all circuits)	72.0

LINE #19.0 FORMAT(8F10.4)

Outdoor Heat Exchanger Configuration (continued):

FINTYO	Switch to specify the type of fin surface, =1.0, for smooth fins =2.0, for *general* wavy (sinusoidal) or zig-zag (corrugated) fins — using multipliers to smooth fin equations =3.0, for *general* louvered (simple-strip) fins — using multipliers to smooth fin equations =4.0, for *specific* zig-zag fin designs =5.0, for *specific* louvered (simple-strip) fin designs	2.0
FPO	Fin pitch (fins/in.)	13.0
DELTAO	Fin thickness (in.)	0.006
DEAO	Outside diameter of the refrigerant tubes (in.)	0.395
DERO	Inside diameter of the refrigerant tubes (in.)	0.371
XKFO	Thermal conductivity of the fins (Btu/h-ft-°F)	128.3
XKTO	Thermal conductivity of the tubes (Btu/h-ft-°F)	225.0
HCONTO	Fraction of the default computed contact conductance between the fins and tubes	999.999

Fin Patternation Data for Outdoor Coil:

LINE # 20 FORMAT(I10, 7F10.4)

If FINTYO < 4.0, leave a blank line

If FINTYO = 4.0,

NFPZGO	Number of fin patterns per row of tubes in flow direction (integer)	2
FPDZGO	Fin pattern depth (in.)	0.045

If FINTYO = 5.0,

NSLVO	Number of strips in an enhanced zone (integer)	(4)
XLSLVO	Length of enhanced louvered zone (mm)	(8.0)
XWSLVO	Width of single strip in flow direction (mm)	(2.0)

LINE #21 FORMAT(8F10.4)

Heat Transfer and Pressure Drop Multipliers for Outdoor Coil :

HTRMLO	Refrigerant-side heat transfer multiplier	1.0
PDRMLO	Refrigerant-side pressure-drop multiplier	1.0
HTAMLO	Air-side heat transfer multiplier	1.0
PDAMLO	Air — side *coil* pressure-drop multiplier	1.0
CABMLO	Air — side system pressure-drop multiplier	1.0

CONFIGURATION OPTIONS DATA:

LINE #22 FORMAT(8I10)

MCMPOP	Switch for adding *compressor can* heat loss to air in the outdoor coil =0, heat loss not added to outdoor air =1, heat loss added to air *before* crossing the outdoor coil =2, heat loss added to air *after* crossing the outdoor coil	0
MFANIN	Switch for adding heat loss from the *indoor fan* to air stream, settings are similar to those for MCMPOP	2
MFANOU	Switch for adding heat loss from the *outdoor fan* to air stream, settings are similar to those for MCMPOP	2

REFRIGERANT LINES DATA:

LINE #23 FORMAT(8F10.4)

Heat Transfer in Refrigerant Lines :

QSUCLN	If > 0, rate of heat gain in the compressor suction line (Btu/h);	100.
	If < 0, the negative of the desired temperature rise in the suction line (F°)	(–10.)
QDISLN	Rate of heat loss in the compressor discharge line (Btu/h)	700.
QLIQLN	Rate of heat loss in the liquid line (Btu/h)	700.

LINE #24 FORMAT(8F10.4)

Lines Between Coils and from Reversing Valve to Coils:

DLL	Inside diameter of the liquid line (in.)	0.2555
XLEQLL	Equivalent length of the liquid line (ft.)	39.8
DLRVIC	Inside diameter of the vapor line between the reversing valve and the indoor coil (in.)	0.686
XLRVIC	Equivalent length of the vapor line between the reversing valve and the indoor coil (ft.)	31.0
DLRVOC	Inside diameter of the vapor line between the reversing valve and the outdoor coil (in.)	0.686
XLRVOC	Equivalent length of the vapor line between the reversing valve and the outdoor coil (ft.)	2.0

LINE #25 FORMAT(8F10.4)

Lines from the Reversing Valve to the Compressor:

DSLRV	Inside diameter of the suction line from the reversing valve to the compressor inlet (in.)	0.793
XLEQLP	Equivalent length of the low-pressure line from the reversing valve to the compressor inlet (ft.)	5.0
DDLRV	Inside diameter of the discharge line from the compressor outlet to the reversing valve (in.)	0.561
XLEQHP	Equivalent length of the high-pressure line from the compressor outlet to the reversing valve (ft.)	2.0

SOLUTION CONVERGENCE CRITERIA :

<u>LINE #26</u> <u>FORMAT(8F10.4)</u>

Iteration Convergence Parameters :

AMBCON	Convergence parameter for the iteration on evaporator inlet air temperature (°F)	0.20
CNDCON	Convergence parameter for the iteration on condenser exit subcooling (or on exit quality * 200) — used when IREFC = 0 on Line 6 (F°); also the quantity {2 * CNDCON} is used as the convergence parameter for the charge balancing iteration when ICHRGE =2	0.20
FLOCON	Convergence parameter for iteration on refrigerant mass flow rate — used when IREFC › 0 on Line 6 (equivalent F°), value is specified as if it were in degrees F and is scaled internally (by 1/20th) to give a mass flow convergence factor	0.20
EVPCON	Convergence parameter for iteration on evaporator exit superheat (F°), (or on exit quality * 500); Also the quantity {2 * EVPCON} is used as the convergence parameter for the charge balancing iteration when ICHRGE =1	0.50
CONMST	Convergence parameter for iterations on evaporator tube wall temperatures in subroutine EVAP and dew-point temperature in subroutine XMOIST (F°)	0.003
CMPCON	Convergence parameter for iteration on suction gas enthalpy in the efficiency-and-loss compressor model (Btu/lbm) — only used when ICOMP = 1 on Line 8	0.05
TOLH	Tolerance parameter used by refrigerant routines in calculating properties of superheated vapor when converging on a known *enthalpy* value (Btu/lbm)	0.001
TOLS	Tolerance parameter used by refrigerant routines in calculating properties of superheated vapor when converging on a known *entropy* value (Btu/lbm/°R)	0.00005

Listing B.1. Sample Heat Pump Specification File 'HPDATA'
— 95°F Design Cooling Condition —

File: DESIGN.HPS

```
SAMPLE ECM HEAT PUMP, 95 F DESIGN PT: AUTO-MOTOR + DUCT SIZING, FILE:DESIGN.HPS
         1
         1        22
         0      10.0       0.0         0
         1     395.0      10.0     4.834     0.035     0.040       2.5      0.68
         0      16.0       0.0       0.0       0.0       0.0       0.0
      48.0     120.0
         2     1.700       1.0       0.0       1.0
SWDIM RECIPROCATING COMPRESSOR — CURVE FITS FROM ORNL AND MANUF'S DATA
         2         2         3    -130.0     180.0     210.0       1.0
         7      3.64      20.0      2.75      60.0     210.0
   15.0000  750.0000   53.0000       1.0       1.0
-2.324E-04-5.143E-02-2.726E-04-9.975E-02 1.515E-03 5.760E+00
-6.560E+00 7.350E-02-2.192E-04 1.176E+00
   20.0000 1050.0000   70.0000       1.0       1.0
-5.414E-05-7.267E-04-1.181E-04-3.888E-04 1.387E-04 7.244E-01
-5.320E-01 4.385E-03-1.290E-05 9.773E-01
   30.0000 1650.0000  107.0000       1.0       1.0
-1.209E-04 1.976E-02-6.166E-05-8.747E-04 7.018E-05-3.318E-01
-2.101E-01 1.104E-03-3.066E-06 9.595E-01
   45.0000 2550.0000  156.0000       1.0       1.0
-1.861E-05-3.855E-03-1.039E-04-6.916E-03 1.498E-04 1.004E+00
-1.106E-01 3.117E-04-8.162E-07 8.922E-01
   60.0000 3450.0000  208.0000       1.0       1.0
-7.977E-05 1.039E-02-1.293E-04-9.867E-03 1.840E-04 1.825E-01
-1.789E-01 4.585E-04-6.751E-07 9.523E-01
   75.0000 4350.0000  208.0000       1.0       1.0
-6.626E-06 1.071E-04-4.978E-05-1.304E-03 3.893E-05 5.454E-01
-1.445E-01 4.353E-04-7.215E-07 8.580E-01
   90.0000 5250.0000  208.0000       1.0       1.0
-4.169E-05 7.656E-03-7.209E-05-4.765E-03 7.275E-05 1.228E-01
-8.835E-02 1.966E-04-4.783E-07 7.990E-01
-1.704E-02 5.610E-05 1.314E+00
      80.0      0.52
       1.0     108.0      900.     -75.0      0.45    3    3     -0.15       0.0
     3.900       4.0      3.00     0.866      1.00     128.0       1.0
       2.0      14.0    0.0050    0.3950    0.3710     128.3     225.0   999.999
         2     0.045
       1.0       1.0       1.0       1.0       1.0
      95.0      0.40
       1.0      82.5    2700.0     -75.0      0.00    3    3         1
     9.050       3.0      3.00      1.08      1.25      72.0       1.0
       2.0      13.0    0.0060    0.3950    0.3710     128.3     225.0   999.999
         3     0.092
       1.0       1.0       1.0       1.0       1.0
         0         2         2
      100.      700.      700.
    0.2555      39.8    0.6860     31.00    0.6860      2.00
    0.7930      5.00    0.5610      2.00
      0.05      0.05      0.40      0.10    0.0015      0.05    0.0005   0.00003
```

Listing B.3. Annotated Sample Heat Pump Specification File 'HPDATA'
— 95°F Design Cooling Condition —

File: DESIGN.HPS

```
Title and Output Data:
    ITITLE
SAMPLE ECM HEAT PUMP, 95 F AMBIENT   DESIGN POINT CALCULATION, FILE:DESIGN.HPS
    LPRINT
         1

Mode and Refrigerant Data:
     NCORH         NR
         1         22

Charge Inventory / Superheat Data:
    ICHRGE      SUPER     REFCHG      MVOID
         0       10.0        0.0          0
Charge Inventory Calculational Data:
     IMASS     VOLCMP     ACCHGT     ACCDIA     OILDIA     UPPDIA     HOLDIS
ATBDIA
         1      395.0       10.0      4.834      0.035      0.040        2.5
0.68

Flow Control Device Data:
->>>IREFC
         0       16.0        0.0        0.0        0.0        0.0        0.0
  >>>IF =0      DTROC <<<--------------------------------- (Subcooling Control)
  >>>IF =1     TXVRAT     STATIC     SUPRAT     SUPMAX     BLEEDF     NZTBOP <<<
(TXV)
  >>>IF =2     CAPFLO       NCAP <<<---------------------- (Capillary Tube)
  >>>IF =3      ORIFD <<<--------------------------------- (Short Tube Orifice)

Estimates of Low- and High-Side Refrigerant Saturation Temperatures:
    TSICMP     TSOCMP
      48.0      120.0

General Compressor Data:
->>>ICOMP       DISPL     CMPSPD       QCAN     CANFAC
         2      1.700        1.0        0.0        1.0
Compressor-Model(ICOMP)-Dependent Data:
  >>>IF =1,     <<<----------------------- Loss-and-Efficiency-Based Model
  Loss-and-Efficiency-Based Compressor Data:
        VR     EFFMMX     ETAISN     ETAMEC
    MTRCLC      FLMOT      QHILO     HILOFC
  >>>IF =2,     <<<----------------------- Map-Based Model
```

Listing B.3. Annotated Sample Heat Pump Specification File 'HPDATA' — 95°F Design Cooling Condition — (continued)

```
Compressor-Model(ICOMP)-Dependent Data (continued):
  Map-Based Compressor Data:
    CTITLE
SWDIM RECIPROCATING COMPRESSOR — CURVE FITS FROM ORNL AND MANUF'S DATA
    MODEDT     ICMPDT     ICDVCH     CSIZMT     CFRQNM     CVLTNM     CVLHZM
         2          2          3     -130.0      180.0      210.0        1.0
—>>>>>NHZ    DISPLB     SUPERB     CSIZMB     CFRQNB     CVLTNB
         7       3.64       20.0       2.75       60.0      210.0
  >>>IHZ=1,NHZ                    (POWADJ)   (XMRADJ)
   >>HZVAL     RPMVAL     VLTVAL     ETIADJ     ETVADJ
   15.0000   750.0000    53.0000        1.0        1.0
   >>AND IF MODEDT = 1,
 CPOWER(1) CPOWER(2) CPOWER(3) CPOWER(4) CPOWER(5) CPOWER(6)
   CXMR(1)    CXMR(2)    CXMR(3)    CXMR(4)    CXMR(5)    CXMR(6)
   >>OR  IF MODEDT = 2,
 CETAIS(1) CETAIS(2) CETAIS(3) CETAIS(4) CETAIS(5) CETAIS(6)
 CETAVL(1) CETAVL(2) CETAVL(3) CETAVL(4)
-2.324E-04-5.143E-02-2.726E-04-9.975E-02 1.515E-03 5.760E+00
-6.560E+00 7.350E-02-2.192E-04 1.176E+00
  >>>IHZ=2
   20.0000 1050.0000   70.0000        1.0        1.0
-5.414E-05-7.267E-04-1.181E-04-3.888E-04 1.387E-04 7.244E-01
-5.320E-01 4.385E-03-1.290E-05 9.773E-01
  >>>IHZ=3
   30.0000 1650.0000  107.0000        1.0        1.0
-1.209E-04 1.976E-02-6.166E-05-8.747E-04 7.018E-05-3.318E-01
-2.101E-01 1.104E-03-3.066E-06 9.595E-01
  >>>IHZ=4
   45.0000 2550.0000  156.0000        1.0        1.0
-1.861E-05-3.855E-03-1.039E-04-6.916E-03 1.498E-04 1.004E+00
-1.106E-01 3.117E-04-8.162E-07 8.922E-01
  >>>IHZ=5
   60.0000 3450.0000  208.0000        1.0        1.0
-7.977E-05 1.039E-02-1.293E-04-9.867E-03 1.840E-04 1.825E-01
-1.789E-01 4.585E-04-6.751E-07 9.523E-01
  >>>IHZ=6
   75.0000 4350.0000  208.0000        1.0        1.0
-6.626E-06 1.071E-04-4.978E-05-1.304E-03 3.893E-05 5.454E-01
-1.445E-01 4.353E-04-7.215E-07 8.580E-01
  >>>IHZ=7
   90.0000 5250.0000  208.0000        1.0        1.0
-4.169E-05 7.656E-03-7.209E-05-4.765E-03 7.275E-05 1.228E-01
-8.835E-02 1.966E-04-4.783E-07 7.990E-01
  Compressor Shell Heat Loss Correlation:
   CQCAN(1)  CQCAN(2)  CQCAN(3)
-1.704E-02 5.610E-05 1.314E+00
```

Listing B.3. Annotated Sample Heat Pump Specification File 'HPDATA' — 95°F Design Cooling Condition — (continued)

```
Indoor Unit Data:
  Indoor Operating Conditions:
     TAIII      RHII
      80.0      0.52
  Indoor Blower:                                          IRFIDF
    FRQIDF    FRQNMI    QANMI     SIZMTI    FANEFI  ^ ICHIDF      DDUCT
FIXCAP
      1.0     108.0      900.     -75.0      0.45    3     3      -0.15
0.0
  Indoor Heat Exchanger Configuration:
      AAFI       NTI    NSECTI       WTI       STI      RTBI
     3.900       4.0      3.00     0.866      1.00     128.0
->>FINTYI        FPI    DELTAI      DEAI      DERI      XKFI       XKTI
HCONTI
       2.0      14.0    0.0050    0.3950    0.3710     128.3      225.0
999.999
  Fin Patternation Data for Indoor Coil:
  >>IF<4.0, NEXT CARD IS NOT USED
  >>IF=4.0, (specific zig-zag fins)
     NFPZGI   FPDZGI
         2     0.045
  >>IF=5.0, (specific louvered fins)
     NSLVI    XLSLVI    XWSLVI
         4       8.0       2.0
  Heat Transfer and Pressure Drop Adjustment Multipliers for Indoor Unit:
     HTRMLI   PDRMLI    HTAMLI    PDAMLI    CABMLI
       1.0       1.0       1.0       1.0       1.0

Outdoor Unit Data:
  Outdoor Operating Conditions:
     TAIIO      RHIO
      95.0      0.40
  Outdoor Blower:                                         IRFODF
    FRQODF    FRQNMO     QANMO    SIZMTO    FANEFO  ^ ICHODF     MFANFT
       1.0      82.5    2700.0     -75.0      0.00    3     3          1
  Outdoor Heat Exchanger Configuration:
      AAFO       NTO    NSECTO       WTO       STO      RTBO
     9.050       3.0      3.00      1.08      1.25      72.0
->>FINTYO        FPO    DELTAO      DEAO      DERO      XKFO       XKTO
HCONTO
       2.0      13.0    0.0060    0.3950    0.3710     128.3      225.0
999.999
  Fin Patternation Data for Outdoor Coil:
  >>IF<4.0, next card is not used
  >>IF=4.0, (specific zig-zag fins)
     NFPZGO   FPDZGO
         3     0.092
  >>IF=5.0, (specific louvered fins)
     NSLVO    XLSLVO    XWSLVO
         4       8.0       2.0
Heat Transfer and Pressure Drop Adjustment Multipliers for Outdoor Unit:
    HTRMLO    PDRMLO    HTAMLO    PDAMLO    CABMLO
       1.0       1.0       1.0       1.0       1.0
```

Listing B.3. Annotated Sample Heat Pump Specification File 'HPDATA' — 95°F Design Cooling Condition — (continued)

```
Configuration Options Data:
    MCMPOP     MFANIN     MFANOU
         0          2          2

Refrigerant Lines Data:
  Heat Transfer in Refrigerant Lines:
    QSUCLN     QDISLN     QLIQLN
     100.0      700.0      700.0
  Lines Between Coils and from Reversing Valve to Coils:
       DLL     XLEQLL      DRVIC     XLRVIC     DLRVOC     XLRVOC
    0.2555       39.8     0.6860      31.00     0.6860       2.00
  Lines from Reversing Valve to Compressor:
     DSLRV     XLEQLP      DDLRV     XLEQHP
    0.7930       5.00     0.5610       2.00
```

APPENDIX C

SAMPLE PROGRAM RESULTS

Single-Point Cases

Sample program output for single-case runs of the ORNL Modulating Design Tool are shown in Listings C.1 and C.2 for the LPRINT = 3 summary output option. These cases are the results of executing the model with the data files DESIGN.HPS and OFFDES.HPS as given in Listings B.1 and B.2, respectively, with each file preceded by a null 'CONCHZ' data set (a single line with a zero in column 3) indicating that no parametric analysis was desired. In these cases, no contour data generation output file is created.

The two cases show, respectively, results for a maximum-speed, cooling-mode, design point case with auto-motor sizing and a minimum-speed, heating-mode, off-design case with specified motor sizes and indoor duct system. For each run, **the new output added since the Mark III single-speed model is indicated in bold type.** New sections of printed output include a fan/blower performance section and a tabulation of charge inventory computations by component (the latter as described earlier in the report in Table CHG1).

Parametric Case

The outputs from an sample parametric analysis case are shown in Listings C.3 and C.4. For this run, the 'CONCHZ' data set H2118V.CHZ as given in Listing A.1 and the 'HPDATA' file OFFDES.HPS as given in Listing B.2 were used. The selected example is for a heat pump operating in the heating mode with a compressor frequency range from 180 Hz down to 50 Hz and for an ambient range from 17°F to 47°F. All the available dependent variables were selected to be generated for this example.

Listing C.3 gives the sample print output which includes a summary of the operational control parameters specified by the user as a function of compressor frequency and ambient temperature. In this example, compressor inlet superheat, condenser outlet subcooling, and indoor and outdoor air flow rates are controlled as functions of compressor frequency and a building heating load line is given as a function of ambient temperature. The latter allows effects of resistance heat requirements to be included in the system power and COP calculations.

Listing C.4 shows an example of the type of parametric sensitivity data sets that can be generated by the ORNL Modulating Heat Pump Design Tool when the full available parameter list of dependent variables is chosen. These data sets can be readily exported to PC's for graphical analysis of selected parameters of interest. The output format of this data file is described in Table A.5.

```
CURVE FIT COEFFICIENTS AT  20.0 HZ FREQUENCY    NOMINAL SPEED OF  1050.0 RPM    DRIVE VOLTAGE OF     70.0 VOLTS
ISENTROPIC EFF    =     -5.414E-05*CONDENSING  TEMPERATURE**2 + -7.267E-04*CONDENSING  TEMPERATURE
                     + -1.181E-04*EVAPORATING TEMPERATURE**2 + -3.888E-04*EVAPORATING TEMPERATURE
                     +  1.387E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  7.244E-01
VOLUMETRIC EFF    =     -5.320E-01*(PRESSURE RATIO - 1.) +  4.385E-03*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -1.290E-05*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.773E-01

CURVE FIT COEFFICIENTS AT  30.0 HZ FREQUENCY    NOMINAL SPEED OF  1650.0 RPM    DRIVE VOLTAGE OF    107.0 VOLTS
ISENTROPIC EFF    =     -1.209E-04*CONDENSING  TEMPERATURE**2 +  1.976E-02*CONDENSING  TEMPERATURE
                     + -6.166E-05*EVAPORATING TEMPERATURE**2 + -8.747E-04*EVAPORATING TEMPERATURE
                     +  7.018E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE + -3.318E-01
VOLUMETRIC EFF    =     -2.101E-01*(PRESSURE RATIO - 1.) +  1.104E-03*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -3.066E-06*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.595E-01

CURVE FIT COEFFICIENTS AT  45.0 HZ FREQUENCY    NOMINAL SPEED OF  2550.0 RPM    DRIVE VOLTAGE OF    156.0 VOLTS
ISENTROPIC EFF    =     -1.861E-05*CONDENSING  TEMPERATURE**2 + -3.855E-03*CONDENSING  TEMPERATURE
                     + -1.039E-04*EVAPORATING TEMPERATURE**2 + -6.916E-03*EVAPORATING TEMPERATURE
                     +  1.498E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.004E+00
VOLUMETRIC EFF    =     -1.106E-01*(PRESSURE RATIO - 1.) +  3.117E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -8.162E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  8.922E-01

CURVE FIT COEFFICIENTS AT  60.0 HZ FREQUENCY    NOMINAL SPEED OF  3450.0 RPM    DRIVE VOLTAGE OF    208.0 VOLTS
ISENTROPIC EFF    =     -7.977E-05*CONDENSING  TEMPERATURE**2 +  1.039E-02*CONDENSING  TEMPERATURE
                     + -1.293E-04*EVAPORATING TEMPERATURE**2 + -9.867E-03*EVAPORATING TEMPERATURE
                     +  1.840E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.825E-01
VOLUMETRIC EFF    =     -1.789E-01*(PRESSURE RATIO - 1.) +  4.585E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -6.751E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.523E-01

CURVE FIT COEFFICIENTS AT  75.0 HZ FREQUENCY    NOMINAL SPEED OF  4350.0 RPM    DRIVE VOLTAGE OF    208.0 VOLTS
ISENTROPIC EFF    =     -6.626E-06*CONDENSING  TEMPERATURE**2 +  1.071E-04*CONDENSING  TEMPERATURE
                     + -4.978E-05*EVAPORATING TEMPERATURE**2 + -1.304E-03*EVAPORATING TEMPERATURE
                     +  3.893E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  5.454E-01
VOLUMETRIC EFF    =     -1.445E-01*(PRESSURE RATIO - 1.) +  4.353E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -7.215E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  8.580E-01

CURVE FIT COEFFICIENTS AT  90.0 HZ FREQUENCY    NOMINAL SPEED OF  5250.0 RPM    DRIVE VOLTAGE OF    208.0 VOLTS
ISENTROPIC EFF    =     -4.169E-05*CONDENSING  TEMPERATURE**2 +  7.656E-03*CONDENSING  TEMPERATURE
                     + -7.209E-05*EVAPORATING TEMPERATURE**2 + -4.765E-03*EVAPORATING TEMPERATURE
                     +  7.275E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.228E-01
VOLUMETRIC EFF    =     -8.835E-02*(PRESSURE RATIO - 1.) +  1.966E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                     + -4.783E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  7.990E-01

GENERAL SHELL HEAT LOSS CORRELATION IS SELECTED:
  CANFAC =   -1.70400E-02*CONDENSING TEMPERATURE +  5.61000E-05*CONDENSING TEMPERATURE**2 +  1.31400E+00

SUPERHEAT CORRECTION TERMS (SET IN BLOCK DATA):
  SUCTION GAS HEATING FACTOR                0.330
  VOLUMETRIC EFFICIENCY CORRECTION FACTOR   0.750
  SUCTION SUPERHEAT HEAT TRANSFER FACTOR    0.050
  SUCTION GAS HEAT PICKUP FRACTION          0.750
```

**** INPUT DATA *****

```
INDOOR UNIT:
  INLET AIR TEMPERATURE                          80.000 F        RELATIVE HUMIDITY                                  0.52000
  FAN OPERATING FREQUENCY RATIO                   1.00
  FAN NOMINAL    FREQUENCY                      108.00 HZ       NOMINAL AIRFLOW RATE                              900.00 CFM
  FAN NOMINAL    SPEED                         1080.00 RPM      NUMBER OF MOTOR POLES                                 12
  PERCENT OF NOMINAL LOADING                      75.0 %
  CONSTANT  FAN-ONLY EFFICIENCY                   0.45
  SELECTED  FAN DRIVE                      PM-ECM-DRIVEN
  SPECIFIED EXTERNAL (DUCT) PRESSURE DROP         0.15 IN H20
  FRONTAL AREA OF HX                             3.900 SQ FT    GENERAL WAVY OR ZIG-ZAG FINS
  NUMBER OF TUBES IN DIRECTION OF AIR FLOW        4.00          FIN PITCH                                          14.00 FINS/IN
  NUMBER OF PARALLEL CIRCUITS                     3.00          FIN THICKNESS                                    0.00500 IN
  OD OF TUBES IN HX                            0.39500 IN       THERMAL CONDUCTIVITY: FINS                        128.30 BTU/H-FT-F
  ID OF TUBES IN HX                            0.37100 IN       THERMAL CONDUCTIVITY: TUBES                       225.00 BTU/H-FT-F
  HORIZONTAL TUBE.SPACING                        0.866 IN       FRACTION OF COMPUTED CONTACT CONDUCTANCE 999.999
  VERTICAL TUBE SPACING                          1.000 IN       NUMBER OF RETURN BENDS                            128.00
  REF-SIDE HEAT-TRANSFER MULTIPLIER              1.000          AIR-SIDE HEAT-TRANSFER MULTIPLIER                  1.000
  REF-SIDE PRESSURE-DROP MULTIPLIER              1.000          AIR-SIDE PRESSURE-DROP MULTIPLIER — UNIT           1.000
                                                                AIR-SIDE PRESSURE-DROP MULTIPLIER — SYSTEM 1.000


OUTDOOR UNIT:
  INLET AIR TEMPERATURE                          95.000 F        RELATIVE HUMIDITY                                  0.40000
  FAN OPERATING FREQUENCY RATIO                   1.00
  FAN NOMINAL    FREQUENCY                       82.50 HZ       NOMINAL AIRFLOW RATE                             2700.00 CFM
  FAN NOMINAL    SPEED                          825.00 RPM      NUMBER OF MOTOR POLES                                 12
  PERCENT OF NOMINAL LOADING                      75.0 %
  FAN AND DRIVE EFFICIENCY                   CALCULATED
  SELECTED  FAN DRIVE                      PM-ECM-DRIVEN
  FRONTAL AREA OF HX                             9.050 SQ FT    GENERAL WAVY OR ZIG-ZAG FINS
  NUMBER OF TUBES IN DIRECTION OF AIR FLOW        3.00          FIN PITCH                                          13.00 FINS/IN
  NUMBER OF PARALLEL CIRCUITS                     3.00          FIN THICKNESS                                    0.00600 IN
  OD OF TUBES IN HX                            0.39500 IN       THERMAL CONDUCTIVITY: FINS                        128.30 BTU/H-FT-F
  ID OF TUBES IN HX                            0.37100 IN       THERMAL CONDUCTIVITY: TUBES                       225.00 BTU/H-FT-F
  HORIZONTAL TUBE SPACING                        1.080 IN       FRACTION OF COMPUTED CONTACT CONDUCTANCE 999.999
  VERTICAL TUBE SPACING                          1.250 IN       NUMBER OF RETURN BENDS                             72.00
  REF-SIDE HEAT-TRANSFER MULTIPLIER              1.000          AIR-SIDE HEAT-TRANSFER MULTIPLIER                  1.000
  REF-SIDE PRESSURE-DROP MULTIPLIER              1.000          AIR-SIDE PRESSURE-DROP MULTIPLIER — UNIT           1.000
                                                                AIR-SIDE PRESSURE-DROP MULTIPLIER — SYSTEM 1.000

OUTDOOR UNIT: FAN
  FAN STATIC EFFICIENCY =    -3.993E+00 +  4.266E+00 *  LOG10(S/1000.) + -1.024E+00 * (LOG10(S/1000.))**2
  WHERE
    SPECIFIC SPEED  (S) =    FAN RPM * (AIR FLOW CFM**0.5) / (COIL STATIC PRESSURE DROP**0.75)

POWER TO THE INDOOR  FAN ADDED TO AIR AFTER  CROSSING THE INDOOR  COIL.
POWER TO THE OUTDOOR FAN ADDED TO AIR AFTER  CROSSING THE OUTDOOR COIL.
```

***** INPUT DATA *****

LINE HEAT TRANSFER:

HEAT GAIN IN SUCTION LINE	100.0 BTU/H
HEAT LOSS IN DISCHARGE LINE	700.0 BTU/H
HEAT LOSS IN LIQUID LINE	700.0 BTU/H

DESCRIPTION OF CONNECTING TUBING:

LIQUID LINE FROM INDOOR TO OUTDOOR HEAT EXCHANGER

ID	0.25550 IN
EQUIVALENT LENGTH	39.80 FT

FROM INDOOR COIL TO REVERSING VALVE

ID	0.68600 IN
EQUIVALENT LENGTH	31.00 FT

FROM REVERSING VALVE TO COMPRESSOR INLET

ID	0.79300 IN
EQUIVALENT LENGTH	5.00 FT

FROM OUTDOOR COIL TO REVERSING VALVE

ID	0.68600 IN
EQUIVALENT LENGTH	2.00 FT

FROM REVERSING VALVE TO COMPRESSOR OUTLET

ID	0.56100 IN
EQUIVALENT LENGTH	2.00 FT

COMPRESSOR AND ACCUMULATOR GEOMETRY DATA:

VOLCMP =	**395.00 CU IN**				
ACCHGT =	**10.00 IN**	**ACCDIA =**	**4.83 IN**	**ATBDIA =**	**0.6800 IN**
OILDIA =	**0.035 IN**	**UPPDIA =**	**0.040 IN**	**HOLDIS =**	**2.50 IN**

ITERATION TOLERANCES :

AMBCON	**0.050 F**	**CMPCON**	**0.050 BTU/LBM**	**TOLH**	**0.00050 BTU/LBM**
CNDCON	**0.050 F**	**FLOCON**	**0.400 F**	**TOLS**	**0.00003 BTU/LBM-R**
EVPCON	**0.100 F**	**CONMST**	**0.002 F**		

***** CALCULATED HEAT PUMP PERFORMANCE *****

SYSTEM SUMMARY		REFRIGERANT TEMPERATURE	SATURATION TEMPERATURE	REFRIGERANT ENTHALPY	REFRIGERANT QUALITY	REFRIGERANT PRESSURE	AIR TEMPERATURE
COMPRESSOR	SUCTION LINE INLET	58.980 F	50.583 F	110.529 BTU/LBM	1.0000	99.696 PSIA	
	SHELL INLET	59.876	49.876	110.764	1.0000	98.524	
	SHELL OUTLET	187.181	115.410	128.517	1.0000	258.800	
CONDENSER	INLET	179.280 F	115.373 F	126.869 BTU/LBM	1.0000	258.675 PSIA	95.000 F
	OUTLET	98.865	114.871	38.911	0.0000	256.994	107.948
EXPANSION DEVICE		93.553 F	112.896 F	37.263 BTU/LBM	0.0000	250.436 PSIA	
EVAPORATOR	INLET	54.386 F	54.386 F	37.263 BTU/LBM	0.1400	106.176 PSIA	80.000 F
	OUTLET	58.980	50.583	110.529	1.0000	99.696	56.861

***** CALCULATED HEAT PUMP PERFORMANCE *****

DRIVE FREQUENCIES

COMPRESSOR	180.0 HZ
CONDENSER FAN	82.5 HZ
EVAPORATOR FAN	108.0 HZ

COMPRESSOR PERFORMANCE

COMPRESSOR DRIVE POWER	2.441 KW
REFRIGERANT MASS FLOW RATE	424.806 LBM/H
MOTOR OPERATING SPEED	5400.000 RPM
% OF NOMINAL FREQUENCY	100.00 %
MOTOR NOMINAL SIZE REQUIRED	2.265 HP
MOTOR OPERATING TORQUE	45.818 OZ-FT
% OF SELECTED NOMINAL TORQUE	130.000 %
% OF BASE NOMINAL TORQUE	146.459 %
FLOW MULTIPLIER	
MOTOR HEAT	1.043
OVERALL DRIVE CHANGE	1.161
COMPRESSOR SHELL HEAT LOSS	788.339 BTU/H

COMPRESSOR EFFICIENCY

OVERALL ISENTROPIC	0.5406
VOLUMETRIC	0.7658
AT A PRESSURE RATIO OF	2.627

DRIVE EFFICIENCY

SELECTED MOTOR/DRIVE	0.8982
BASE MOTOR/DRIVE	0.7810

EFFICIENCY MULTIPLIER

MOTOR HEAT	1.044
OVERALL DRIVE CHANGE	1.201

SUPERHEAT CORRECTION TERMS

POWER	0.9936
MASS FLOW RATE	1.0183

FAN/BLOWER PERFORMANCE	CONDENSER	EVAPORATOR
AIR FLOW RATE	2700.00 CFM	900.00 CFM
FACE VELOCITY	298.34 FT/MIN	230.77 FT/MIN
SURFACE VELOCITY	479.81 FT/MIN	417.04 FT/MIN
UNIT PRESSURE DROP	0.098 IN H20	0.187 IN H20
DUCT PRESSURE DROP		0.150 IN H20
FILTER PRESSURE DROP		0.072 IN H20
HEATER PRESSURE DROP		0.103 IN H20
TOTAL PRESSURE DROP	0.098 IN H20	0.512 IN H20
MOTOR SPEED	825.00 RPM	1080.00 RPM
% OF NOMINAL FREQUENCY	100.00 %	100.00 %
DRIVE EFFICIENCY AT OPERATING SPEED	0.788	0.814
FAN MOTOR TORQUE	12.01 OZ-FT	12.55 OZ-FT
% OF NOMINAL TORQUE	75.00 %	75.00 %
NOMINAL MOTOR SIZE	0.157 HP	0.215 HP
COMBINED DRIVE & FAN EFFICIENCY	0.280	0.366

OUTDOOR FAN PERFORMANCE:

SPECIFIC SPEED	243.88 E+03
FAN-ONLY EFFICIENCY	0.355

***** CALCULATED HEAT PUMP PERFORMANCE *****

CONDENSER — HEAT TRANSFER PERFORMANCE OF EACH CIRCUIT

INLET AIR TEMPERATURE	95.000 F
AIR TEMPERATURE LEAVING COIL	107.815 F
HEAT GENERATED FROM FAN	380.8 BTU/H
OUTLET AIR TEMPERATURE	107.948 F

TOTAL HEAT EXCHANGER EFFECTIVENESS 0.7199

	SUPERHEATED REGION	TWO-PHASE REGION	SUBCOOLED REGION
NTU	0.0000	1.2551	2.0545
HEAT EXCHANGER EFFECTIVENESS	1.0000	0.7150	0.8057
CR/CA	0.0000		0.2904
FRACTION OF HEAT EXCHANGER	0.0000	0.8367	0.1633
HEAT TRANSFER RATE	8.0 BTU/H	11491.5 BTU/H	724.8 BTU/H
OUTLET AIR TEMPERATURE	102.996 F	109.397 F	99.654 F

AIR SIDE:

MASS FLOW RATE	3863.3 LBM/H
PRESSURE DROP	0.0985 IN H2O
AUGMENTATION FACTOR	**0.918**
HEAT TRANSFER COEFFICIENT	10.981 BTU/H-SQ FT-F
AUGMENTATION FACTOR	**1.450**

REFRIGERANT SIDE:

MASS FLOW RATE	141.6 LBM/H
PRESSURE DROP	1.681 PSI
HEAT TRANSFER COEFFICIENT	
VAPOR REGION	85.873 BTU/H-SQ FT-F
TWO PHASE REGION	356.870 BTU/H-SQ FT-F
SUBCOOLED REGION	94.494 BTU/H-SQ FT-F

CONTACT INTERFACE:

CONTACT CONDUCTANCE ********** BTU/H-SQ FT-F

UA VALUES PER CIRCUIT:

	VAPOR REGION (BTU/H-F)	TWO PHASE REGION (BTU/H-F)	SUBCOOLED REGION (BTU/H-F)
REFRIGERANT SIDE	0.000	2519.781	130.180
AIR SIDE	0.000	1682.943	328.367
CONTACT INTERFACE	0.000	139966.937	27309.605
COMBINED	0.000	1001.802	92.905

FLOW CONTROL DEVICE — CONDENSER EXIT SUBCOOLING IS SPECIFIED AS 16.000 F

CORRESPONDING TXV RATING PARAMETERS:

RATED OPERATING SUPERHEAT	11.000 F
STATIC SUPERHEAT RATING	6.000 F
PERMANENT BLEED FACTOR	1.150
FRACTION OF RATED OPENING	0.476
TXV CAPACITY RATING: WITH NOZZLE AND TUBES	3.537 TONS

CORRESPONDING CAPILLARY TUBE PARAMETERS:

NUMBER OF CAPILLARY TUBES	1
CAPILLARY TUBE FLOW FACTOR	3.458

CORRESPONDING ORIFICE PARAMETER:

ORIFICE DIAMETER 0.0651 IN

***** CALCULATED HEAT PUMP PERFORMANCE *****

EVAPORATOR — HEAT TRANSFER PERFORMANCE OF EACH CIRCUIT

INLET AIR TEMPERATURE	80.000 F
AIR TEMPERATURE LEAVING COIL	56.344 F
HEAT GENERATED FROM FAN	504.4 BTU/H
OUTLET AIR TEMPERATURE	56.861 F

MOISTURE REMOVAL OCCURS

SUMMARY OF DEHUMIDIFICATION PERFORMANCE (TWO-PHASE REGION)

	LEADING EDGE OF COIL	POINT WHERE MOISTURE REMOVAL BEGINS		LEAVING EDGE OF COIL	
	AIR	AIR	WALL	AIR	WALL
DRY BULB TEMPERATURE	80.000 F	80.000 F	60.792 F	55.951 F	54.170 F
HUMIDITY RATIO	0.01136	0.01136	0.01136	0.00936	0.00891
ENTHALPY	31.696 BTU/LBM	31.696 BTU/LBM	26.975 BTU/LBM	23.617 BTU/LBM	22.696 BTU/LBM

RATE OF MOISTURE REMOVAL	2.5355 LBM/H
FRACTION OF EVAPORATOR THAT IS WET	1.0000
LATENT HEAT TRANSFER RATE IN TWO-PHASE REGION	2689. BTU/H
SENSIBLE HEAT TRANSFER RATE IN TWO-PHASE REGION	7471. BTU/H
SENSIBLE TO TOTAL HEAT TRANSFER RATIO FOR TWO-PHASE REGION	0.7353

OVERALL SENSIBLE TO TOTAL HEAT TRANSFER RATIO 0.7408

OVERALL CONDITIONS ACROSS COIL

	ENTERING AIR	EXITING AIR
DRY BULB TEMPERATURE	80.000 F	56.344 F
WET BULB TEMPERATURE	67.074 F	55.975 F
RELATIVE HUMIDITY	0.520	0.979
HUMIDITY RATIO	0.01136	0.00945

TOTAL HEAT EXCHANGER EFFECTIVENESS (SENSIBLE) 0.8819

	SUPERHEATED REGION	TWO-PHASE REGION
NTU	0.9049	2.3051
HEAT EXCHANGER EFFECTIVENESS	0.5164	0.9002
CR/CA	1.8442	
FRACTION OF HEAT EXCHANGER	0.0438	0.9562
HEAT TRANSFER RATE	214.7 BTU/H	10160.3 BTU/H
AIR MASS FLOW RATE	58.02 LBM/H	1265.55 LBM/H
OUTLET AIR TEMPERATURE	64.923 F	55.951 F

EVAPORATOR — HEAT TRANSFER PERFORMANCE OF EACH CIRCUIT

AIR SIDE:

MASS FLOW RATE	1323.6	LBM/H
PRESSURE DROP	0.512	IN H2O
AUGMENTATION FACTOR	**1.112**	
HEAT TRANSFER COEFFICIENT		
DRY COIL	9.196	BTU/H-SQ FT-F
WET COIL	9.973	BTU/H-SQ FT-F
AUGMENTATION FACTOR	**1.450**	

CONTACT INTERFACE:

CONTACT CONDUCTANCE	983204.125	BTU/H-SQ FT-F
DRY FIN EFFICIENCY	0.877	
WET FIN EFFICIENCY (AVERAGE)	0.814	
WET CONTACT FACTOR (AVERAGE)	1.330	

UA VALUES PER CIRCUIT:	VAPOR REGION	TWO PHASE REGION	
REFRIGERANT SIDE	19.051	4071.052	BTU/H-F
AIR SIDE			
DRY COIL	40.119	0.000	BTU/H-F
WET COIL		880.400	BTU/H-F
CONTACT INTERFACE			
DRY COIL	5659.703	0.000	BTU/H-F
WET COIL		124081.250	BTU/H-F
COMBINED			
DRY COIL	12.888	0.000	BTU/H-F
WET COIL		719.661	BTU/H-F

REFRIGERANT SIDE:

MASS FLOW RATE	141.6	LBM/H
PRESSURE DROP	6.480	PSI
HEAT TRANSFER COEFFICIENT		
VAPOR REGION	71.709	BTU/H-SQ FT-F
TWO PHASE REGION	702.501	BTU/H-SQ FT-F

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***** SUMMARY OF ENERGY INPUT AND OUTPUT *****

SAMPLE ECM HEAT PUMP, 95 F DESIGN PT: AUTO-MOTOR + DUCT SIZING, FILE:DESIGN.HPS

        OPERATING CONDITIONS:
          AIR TEMPERATURE INTO EVAPORATOR                80.00 F
          AIR TEMPERATURE INTO CONDENSER                 95.00 F
          SATURATION TEMP INTO   COMPRESSOR              49.88 F
          SATURATION TEMP OUT OF COMPRESSOR             115.41 F

        DRIVE FREQUENCIES:
          COMPRESSOR                                    180.00 HZ
          INDOOR  FAN                                   108.00 HZ
          OUTDOOR FAN                                    82.50 HZ

        DRIVE FREQUENCY RATIOS:
          COMPRESSOR                                      1.00
          INDOOR  FAN                                     1.00
          OUTDOOR FAN                                     1.00

        ENERGY INPUT SUMMARY:
          HEAT PUMPED FROM AIR SOURCE                  31125.1 BTU/H

          POWER TO INDOOR  FAN MOTOR                     147.8 WATTS
          POWER TO OUTDOOR FAN MOTOR                     111.6 WATTS
          TOTAL    PARASITIC   POWER                     259.4 WATTS

          POWER TO COMPRESSOR  MOTOR                    2440.7 WATTS
          TOTAL    INPUT       POWER                    2700.0 WATTS

        REFRIGERANT-SIDE SUMMARY:
          HEAT GAIN    TO  EVAPORATOR FROM AIR         31125.1 BTU/H
          HEAT GAIN    TO  SUCTION LINE                  100.0 BTU/H
          ENERGY INPUT TO  COMPRESSOR                   8330.0 BTU/H
          HEAT LOSS   FROM COMPRESSOR SHELL              788.3 BTU/H
          HEAT LOSS   FROM DISCHARGE LINE                700.0 BTU/H
          HEAT LOSS   FROM CONDENSER  TO   AIR         36672.8 BTU/H
          HEAT LOSS   FROM LIQUID LINE                   700.0 BTU/H

        ENERGY OUTPUT SUMMARY:
          HEAT RATE FROM REFRIGERANT TO INDOOR AIR     31125.1 BTU/H
          HEAT RATE FROM FAN         TO INDOOR AIR       504.4 BTU/H
          TOTAL HEAT RATE       TO/FROM INDOOR AIR     30620.8 BTU/H

        COOLING PERFORMANCE:
          COP                          3.323
          EER                         11.341 BTU/H-W
          CAPACITY                   30620.8 BTU/H
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***** CHARGE INVENTORY RESULTS *****

ANALYTICAL SOLUTION OF ZIVI'S METHOD
FOR A CONSTANT HEAT FLUX APPROXIMATION

STEADY-STATE REFRIGERANT MASS DISTRIBUTION (LBM)

TREFMS = 8.790 SSMSHI = 6.771 SSMSLO = 2.019

TMASSC = 5.720 TMASSE = 1.267 CMPMAS = 0.398 XMASLL = 1.017 ACCMAS = 0.185 SSVPLO = 0.170 SSVPHI = 0.033

EQUILIBRIUM REFRIGERANT MASS DISTRIBUTION (LBM)

EQMSHI = 0.623 EQMSLO = 8.166 XMSLQ = 6.740 XEQUIL = 0.1746

HI/LO AND COMPONENT INTERNAL VOLUMES (CU FT), ACCUMULATOR LIQUID LEVEL (INCHES)

VOLHI = 0.227 VOLLOW = 0.585 VOLCND = 0.205 VOLEVP = 0.153 VOLCMP = 0.229 VOLACC = 0.106 XLEVEL = 0.000 IN

Listing C.2. Sample Single-Point Heat Pump Model Run

— 47°F Off-Design Heating Condition —

Summary Output

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***** CONTOUR DATA GENERATION INFORMATION *****

***   CONTOUR DATA GENERATOR FRONT-END IS BYPASSED   ***

***** INPUT DATA *****

        SAMPLE ECM HEAT PUMP, OFF-DESIGN PT: SPECIFIED MOTORS AND DUCTS, FILE:OFFDES.HPS

        SUMMARY OUTPUT
        HEATING MODE OF OPERATION
        THE REFRIGERANT IS R 22
        REFRIGERANT CHARGE IS NOT SPECIFIED

        COMPRESSOR INLET SUPERHEAT IS SPECIFIED AT    1.00 F

        CONDENSER  EXIT SUBCOOLING IS SPECIFIED AT   10.00 F

        ESTIMATE OF:
          SATURATION TEMPERATURE INTO   COMPRESSOR   40.00 F
          SATURATION TEMPERATURE OUT OF COMPRESSOR  100.00 F

        COMPRESSOR CHARACTERISTICS:
          OPERATING FREQUENCY                       50.000 HZ
          TOTAL DISPLACEMENT                         1.700 CUBIC INCHES

          SWDIM RECIPROCATING COMPRESSOR -- CURVE FITS FROM ORNL AND MANUF'S DATA

          DRIVE TYPE OF INPUT COMPRESSOR DATA IS    SINE-WAVE-DRIVEN
          DRIVE TYPE IS TO BE CONVERTED TO             PM-ECM-DRIVEN

          SELECTED MOTOR SIZE IS                      2.27 HP
          NOMINAL FREQUENCY FOR      MOTOR RATING AT 180.0 HZ

          BASE SUPERHEAT    FOR COMPRESSOR MAP      20.000 F
          BASE DISPLACEMENT FOR COMPRESSOR MAP       3.640 CU IN

          BASE     MOTOR SIZE IS                      2.75 HP
          NOMINAL FREQUENCY FOR BASE MOTOR RATING AT  60.0 HZ
          NOMINAL VOLTAGE   FOR BASE MOTOR RATING AT 210.0 VOLTS

***** INPUT DATA *****

          -- USER PROVIDED COEFFICIENTS FOR COMPRESSOR SHELL ISENTROPIC AND VOLUMETRIC EFFICIENCY --

          CURVE FIT REPRESENTATIONS AT  7 DISCRETE FREQUENCIES

          CURVE FIT COEFFICIENTS AT  15.0 HZ FREQUENCY    NOMINAL SPEED OF    750.0 RPM    DRIVE VOLTAGE OF     53.0 VOLTS
          ISENTROPIC EFF    =     -2.324E-04*CONDENSING  TEMPERATURE**2 + -5.143E-02*CONDENSING  TEMPERATURE
                              + -2.726E-04*EVAPORATING TEMPERATURE**2 + -9.975E-02*EVAPORATING TEMPERATURE
                              +  1.515E-03*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  5.760E+00
          VOLUMETRIC EFF    =     -6.560E+00*(PRESSURE RATIO - 1.) +  7.350E-02*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                              + -2.192E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  1.176E+00
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CURVE FIT COEFFICIENTS AT  20.0 HZ FREQUENCY    NOMINAL SPEED OF  1050.0 RPM    DRIVE VOLTAGE OF    70.0 VOLTS
ISENTROPIC EFF    =     -5.414E-05*CONDENSING  TEMPERATURE**2 + -7.267E-04*CONDENSING  TEMPERATURE
                      + -1.181E-04*EVAPORATING TEMPERATURE**2 + -3.888E-04*EVAPORATING TEMPERATURE
                      +  1.387E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  7.244E-01
VOLUMETRIC EFF    =     -5.320E-01*(PRESSURE RATIO - 1.) +  4.385E-03*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -1.290E-05*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.773E-01

CURVE FIT COEFFICIENTS AT  30.0 HZ FREQUENCY    NOMINAL SPEED OF  1650.0 RPM    DRIVE VOLTAGE OF   107.0 VOLTS
ISENTROPIC EFF    =     -1.209E-04*CONDENSING  TEMPERATURE**2 +  1.976E-02*CONDENSING  TEMPERATURE
                      + -6.166E-05*EVAPORATING TEMPERATURE**2 + -8.747E-04*EVAPORATING TEMPERATURE
                      +  7.018E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE + -3.318E-01
VOLUMETRIC EFF    =     -2.101E-01*(PRESSURE RATIO - 1.) +  1.104E-03*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -3.066E-06*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.595E-01

CURVE FIT COEFFICIENTS AT  45.0 HZ FREQUENCY    NOMINAL SPEED OF  2550.0 RPM    DRIVE VOLTAGE OF   156.0 VOLTS
ISENTROPIC EFF    =     -1.861E-05*CONDENSING  TEMPERATURE**2 + -3.855E-03*CONDENSING  TEMPERATURE
                      + -1.039E-04*EVAPORATING TEMPERATURE**2 + -6.916E-03*EVAPORATING TEMPERATURE
                      +  1.498E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.004E+00
VOLUMETRIC EFF    =     -1.106E-01*(PRESSURE RATIO - 1.) +  3.117E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -8.162E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  8.922E-01

CURVE FIT COEFFICIENTS AT  60.0 HZ FREQUENCY    NOMINAL SPEED OF  3450.0 RPM    DRIVE VOLTAGE OF   208.0 VOLTS
ISENTROPIC EFF    =     -7.977E-05*CONDENSING  TEMPERATURE**2 +  1.039E-02*CONDENSING  TEMPERATURE
                      + -1.293E-04*EVAPORATING TEMPERATURE**2 + -9.867E-03*EVAPORATING TEMPERATURE
                      +  1.840E-04*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.825E-01
VOLUMETRIC EFF    =     -1.789E-01*(PRESSURE RATIO - 1.) +  4.585E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -6.751E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  9.523E-01

CURVE FIT COEFFICIENTS AT  75.0 HZ FREQUENCY    NOMINAL SPEED OF  4350.0 RPM    DRIVE VOLTAGE OF   208.0 VOLTS
ISENTROPIC EFF    =     -6.626E-06*CONDENSING  TEMPERATURE**2 +  1.071E-04*CONDENSING  TEMPERATURE
                      + -4.978E-05*EVAPORATING TEMPERATURE**2 + -1.304E-03*EVAPORATING TEMPERATURE
                      +  3.893E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  5.454E-01
VOLUMETRIC EFF    =     -1.445E-01*(PRESSURE RATIO - 1.) +  4.353E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -7.215E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  8.580E-01

CURVE FIT COEFFICIENTS AT  90.0 HZ FREQUENCY    NOMINAL SPEED OF  5250.0 RPM    DRIVE VOLTAGE OF   208.0 VOLTS
ISENTROPIC EFF    =     -4.169E-05*CONDENSING  TEMPERATURE**2 +  7.656E-03*CONDENSING  TEMPERATURE
                      + -7.209E-05*EVAPORATING TEMPERATURE**2 + -4.765E-03*EVAPORATING TEMPERATURE
                      +  7.275E-05*CONDENSING  TEMPERATURE*EVAPORATING TEMPERATURE +  1.228E-01
VOLUMETRIC EFF    =     -8.835E-02*(PRESSURE RATIO - 1.) +  1.966E-04*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE
                      + -4.783E-07*(PRESSURE RATIO - 1.)*CONDENSING PRESSURE**2 +  7.990E-01

GENERAL SHELL HEAT LOSS CORRELATION IS SELECTED:
  CANFAC =    -1.70400E-02*CONDENSING TEMPERATURE +  5.61000E-05*CONDENSING TEMPERATURE**2 +  1.31400E+00

SUPERHEAT CORRECTION TERMS (SET IN BLOCK DATA):
  SUCTION GAS HEATING FACTOR                0.330
  VOLUMETRIC EFFICIENCY CORRECTION FACTOR   0.750
  SUCTION SUPERHEAT HEAT TRANSFER FACTOR    0.050
  SUCTION GAS HEAT PICKUP FRACTION          0.750
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***** INPUT DATA *****

   INDOOR UNIT:
     INLET AIR TEMPERATURE                        70.000 F        RELATIVE HUMIDITY                                0.58000
     FAN OPERATING FREQUENCY RATIO                 0.60
     FAN NOMINAL    FREQUENCY                    108.00 HZ        NOMINAL AIRFLOW RATE                             900.00 CFM
     FAN NOMINAL    SPEED                       1080.00 RPM       NUMBER OF MOTOR POLES                                12
     NOMINAL MOTOR SIZE                            0.21 HP
     CONSTANT  FAN-ONLY EFFICIENCY                 0.45
     SELECTED  FAN DRIVE                    PM-ECM-DRIVEN
     ID OF EACH OF 6 EQUIVALENT DUCTS              6.22 IN
     FRONTAL AREA OF HX                           3.900 SQ FT     GENERAL WAVY OR ZIG-ZAG FINS
     NUMBER OF TUBES IN DIRECTION OF AIR FLOW      4.00           FIN PITCH                                         14.00 FINS/IN
     NUMBER OF PARALLEL CIRCUITS                   3.00           FIN THICKNESS                                   0.00500 IN
     OD OF TUBES IN HX                          0.39500 IN        THERMAL CONDUCTIVITY: FINS                       128.30 BTU/H-FT-F
     ID OF TUBES IN HX                          0.37100 IN        THERMAL CONDUCTIVITY: TUBES                      225.00 BTU/H-FT-F
     HORIZONTAL TUBE SPACING                      0.866 IN        FRACTION OF COMPUTED CONTACT CONDUCTANCE 999.999
     VERTICAL TUBE SPACING                        1.000 IN        NUMBER OF RETURN BENDS                           128.00
     REF-SIDE HEAT-TRANSFER MULTIPLIER            1.000           AIR-SIDE HEAT-TRANSFER MULTIPLIER                 1.000
     REF-SIDE PRESSURE-DROP MULTIPLIER            1.000           AIR-SIDE PRESSURE-DROP MULTIPLIER — UNIT    1.000
                                                                  AIR-SIDE PRESSURE-DROP MULTIPLIER — SYSTEM 1.000

   OUTDOOR UNIT:
     INLET AIR TEMPERATURE                        47.000 F        RELATIVE HUMIDITY                                0.72000
     FAN OPERATING FREQUENCY RATIO                 0.45
     FAN NOMINAL    FREQUENCY                     82.50 HZ        NOMINAL AIRFLOW RATE                            2700.00 CFM
     FAN NOMINAL    SPEED                        825.00 RPM       NUMBER OF MOTOR POLES                                12
     NOMINAL MOTOR SIZE                            0.16 HP
     FAN AND DRIVE EFFICIENCY                 CALCULATED
     SELECTED  FAN DRIVE                    PM-ECM-DRIVEN
     FRONTAL AREA OF HX                           9.050 SQ FT     GENERAL WAVY OR ZIG-ZAG FINS
     NUMBER OF TUBES IN DIRECTION OF AIR FLOW      3.00           FIN PITCH                                         13.00 FINS/IN
     NUMBER OF PARALLEL CIRCUITS                   3.00           FIN THICKNESS                                   0.00600 IN
     OD OF TUBES IN HX                          0.39500 IN        THERMAL CONDUCTIVITY: FINS                       128.30 BTU/H-FT-F
     ID OF TUBES IN HX                          0.37100 IN        THERMAL CONDUCTIVITY: TUBES                      225.00 BTU/H-FT-F
     HORIZONTAL TUBE SPACING                      1.080 IN        FRACTION OF COMPUTED CONTACT CONDUCTANCE 999.999
     VERTICAL TUBE SPACING                        1.250 IN        NUMBER OF RETURN BENDS                            72.00
     REF-SIDE HEAT-TRANSFER MULTIPLIER            1.000           AIR-SIDE HEAT-TRANSFER MULTIPLIER                 1.000
     REF-SIDE PRESSURE-DROP MULTIPLIER            1.000           AIR-SIDE PRESSURE-DROP MULTIPLIER — UNIT    1.000
                                                                  AIR-SIDE PRESSURE-DROP MULTIPLIER — SYSTEM 1.000

   OUTDOOR UNIT: FAN
     FAN STATIC EFFICIENCY =     -3.993E+00 +  4.266E+00 *  LOG10(S/1000.) + -1.024E+00 * (LOG10(S/1000.))**2
     WHERE
       SPECIFIC SPEED  (S) =     FAN RPM * (AIR FLOW CFM**0.5) / (COIL STATIC PRESSURE DROP**0.75)

   POWER TO THE INDOOR  FAN ADDED TO AIR AFTER  CROSSING THE INDOOR  COIL.
   POWER TO THE OUTDOOR FAN ADDED TO AIR AFTER  CROSSING THE OUTDOOR COIL.
```

***** INPUT DATA *****

LINE HEAT TRANSFER:

HEAT GAIN IN SUCTION LINE	100.0 BTU/H
HEAT LOSS IN DISCHARGE LINE	700.0 BTU/H
HEAT LOSS IN LIQUID LINE	700.0 BTU/H

DESCRIPTION OF CONNECTING TUBING:

LIQUID LINE FROM INDOOR TO OUTDOOR HEAT EXCHANGER

ID	0.25550 IN
EQUIVALENT LENGTH	39.80 FT

FROM INDOOR COIL TO REVERSING VALVE

ID	0.68600 IN
EQUIVALENT LENGTH	31.00 FT

FROM REVERSING VALVE TO COMPRESSOR INLET

ID	0.79300 IN
EQUIVALENT LENGTH	5.00 FT

FROM OUTDOOR COIL TO REVERSING VALVE

ID	0.68600 IN
EQUIVALENT LENGTH	2.00 FT

FROM REVERSING VALVE TO COMPRESSOR OUTLET

ID	0.56100 IN
EQUIVALENT LENGTH	2.00 FT

COMPRESSOR AND ACCUMULATOR GEOMETRY DATA:

VOLCMP = 395.00 CU IN

ACCHGT =	**10.00 IN**	**ACCDIA =**	**4.83 IN**	**ATBDIA =**	**0.6800 IN**
OILDIA =	**0.035 IN**	**UPPDIA =**	**0.040 IN**	**HOLDIS =**	**2.50 IN**

ITERATION TOLERANCES :

AMBCON	**0.050 F**	**CMPCON**	**0.050 BTU/LBM**	**TOLH**	**0.00050 BTU/LBM**
CNDCON	**0.050 F**	**FLOCON**	**0.400 F**	**TOLS**	**0.00003 BTU/LBM-R**
EVPCON	**0.100 F**	**CONMST**	**0.002 F**		

***** CALCULATED HEAT PUMP PERFORMANCE *****

SYSTEM SUMMARY	REFRIGERANT TEMPERATURE	SATURATION TEMPERATURE	REFRIGERANT ENTHALPY	REFRIGERANT QUALITY	REFRIGERANT PRESSURE	AIR TEMPERATURE
COMPRESSOR SUCTION LINE INLET	39.142 F	39.142 F	107.292 BTU/LBM	0.9911	81.966 PSIA	
SHELL INLET	40.132	39.132	108.245	1.0000	81.952	
SHELL OUTLET	125.886	87.735	119.289	1.0000	177.250	
CONDENSER INLET	93.042 F	87.710 F	112.616 BTU/LBM	1.0000	177.188 PSIA	70.000 F
OUTLET	77.639	87.645	32.398	0.0000	177.022	84.374
EXPANSION DEVICE	54.886 F	87.439 F	25.725 BTU/LBM	0.0000	176.497 PSIA	
EVAPORATOR INLET	39.491 F	39.491 F	25:725 BTU/LBM	0.0512	82.469 PSIA	47.002 F
OUTLET	39.142	39.142	107.292	0.9911	81.966	40.864

***** CALCULATED HEAT PUMP PERFORMANCE *****

DRIVE FREQUENCIES

COMPRESSOR	50.0 HZ
CONDENSER FAN	64.8 HZ
EVAPORATOR FAN	37.1 HZ

COMPRESSOR PERFORMANCE

COMPRESSOR DRIVE POWER	0.453 KW
REFRIGERANT MASS FLOW RATE	104.908 LBM/H
MOTOR OPERATING SPEED	1500.000 RPM
% OF NOMINAL FREQUENCY	27.78 %
MOTOR OPERATING TORQUE	26.636 OZ-FT
% OF SELECTED NOMINAL TORQUE	75.569 %
% OF BASE NOMINAL TORQUE	85.145 %
FLOW MULTIPLIER	
MOTOR HEAT	1.008
OVERALL DRIVE CHANGE	1.107
COMPRESSOR SHELL HEAT LOSS	387.865 BTU/H

COMPRESSOR EFFICIENCY

OVERALL ISENTROPIC	0.5543
VOLUMETRIC	0.7931
AT A PRESSURE RATIO OF	2.163

DRIVE EFFICIENCY

SELECTED MOTOR/DRIVE	0.7823
BASE MOTOR/DRIVE	0.7832

EFFICIENCY MULTIPLIER

MOTOR HEAT	1.008
OVERALL DRIVE CHANGE	1.007

SUPERHEAT CORRECTION TERMS

POWER	0.9875
MASS FLOW RATE	1.0371

FAN/BLOWER PERFORMANCE	CONDENSER	EVAPORATOR
AIR FLOW RATE	540.00 CFM	1215.00 CFM
FACE VELOCITY	138.46 FT/MIN	134.25 FT/MIN
SURFACE VELOCITY	250.22 FT/MIN	215.91 FT/MIN
UNIT PRESSURE DROP	0.036 IN H20	0.028 IN H20
DUCT PRESSURE DROP	0.057 IN H20	
FILTER PRESSURE DROP	0.025 IN H20	
HEATER PRESSURE DROP	0.036 IN H20	
TOTAL PRESSURE DROP	0.154 IN H20	0.028 IN H20
MOTOR SPEED	648.00 RPM	371.25 RPM
% OF NOMINAL FREQUENCY	60.00 %	45.00 %
DRIVE EFFICIENCY AT OPERATING SPEED	0.637	0.572
FAN MOTOR TORQUE	3.77 OZ-FT	2.94 OZ-FT
% OF NOMINAL TORQUE	22.53 %	18.36 %
NOMINAL MOTOR SIZE	0.215 HP	0.157 HP
COMBINED DRIVE & FAN EFFICIENCY	0.287	0.235
OUTDOOR FAN PERFORMANCE:		
SPECIFIC SPEED		189.85 E+03
FAN-ONLY EFFICIENCY		0.411

***** CALCULATED HEAT PUMP PERFORMANCE *****

CONDENSER — HEAT TRANSFER PERFORMANCE OF EACH CIRCUIT

INLET AIR TEMPERATURE	70.000 F
AIR TEMPERATURE LEAVING COIL	84.179 F
HEAT GENERATED FROM FAN	116.1 BTU/H
OUTLET AIR TEMPERATURE	84.374 F

TOTAL HEAT EXCHANGER EFFECTIVENESS 0.8262

	SUPERHEATED REGION	TWO-PHASE REGION	SUBCOOLED REGION
NTU	0.0000	1.8411	1.1495
HEAT EXCHANGER EFFECTIVENESS	1.0000	0.8414	0.5671
CR/CA	0.0000		0.6477
FRACTION OF HEAT EXCHANGER	0.0000	0.9172	0.0828
HEAT TRANSFER RATE	0.0 BTU/H	2699.0 BTU/H	106.2 BTU/H
OUTLET AIR TEMPERATURE	70.000 F	84.873 F	76.482 F

AIR SIDE:

MASS FLOW RATE	809.1 LBM/H
PRESSURE DROP	0.1537 IN H2O
AUGMENTATION FACTOR	**0.914**
HEAT TRANSFER COEFFICIENT	6.668 BTU/H-SQ FT-F
AUGMENTATION FACTOR	**1.450**

REFRIGERANT SIDE:

MASS FLOW RATE	35.0 LBM/H
PRESSURE DROP	0.166 PSI
HEAT TRANSFER COEFFICIENT	
VAPOR REGION	23.821 BTU/H-SQ FT-F
TWO PHASE REGION	128.887 BTU/H-SQ FT-F
SUBCOOLED REGION	30.996 BTU/H-SQ FT-F

CONTACT INTERFACE:

CONTACT CONDUCTANCE 983204.125 BTU/H-SQ FT-F

UA VALUES PER CIRCUIT:

	VAPOR REGION (BTU/H-F)	TWO PHASE REGION (BTU/H-F)	SUBCOOLED REGION (BTU/H-F)
REFRIGERANT SIDE	0.000	716.460	15.557
AIR SIDE	0.000	629.362	56.826
CONTACT INTERFACE	0.000	118421.875	10692.523
COMBINED	0.000	334.101	12.200

FLOW CONTROL DEVICE — CONDENSER EXIT SUBCOOLING IS SPECIFIED AS 10.000 F

CORRESPONDING TXV RATING PARAMETERS:

RATED OPERATING SUPERHEAT	11.000 F
STATIC SUPERHEAT RATING	6.000 F
PERMANENT BLEED FACTOR	1.150
FRACTION OF RATED OPENING	1.000
TXV CAPACITY RATING: WITH NOZZLE AND TUBES	0.535 TONS

CALCULATED SUPERHEAT IS BELOW THE OPERATING RANGE:
TXV SIZE BASED ON RATED RATHER THAN ACTUAL
EVAPORATOR EXIT SUPERHEAT

CORRESPONDING CAPILLARY TUBE PARAMETERS:

NUMBER OF CAPILLARY TUBES	1
CAPILLARY TUBE FLOW FACTOR	0.891

CORRESPONDING ORIFICE PARAMETER:

ORIFICE DIAMETER 0.0318 IN

***** CALCULATED HEAT PUMP PERFORMANCE *****

EVAPORATOR — HEAT TRANSFER PERFORMANCE OF EACH CIRCUIT

INLET AIR TEMPERATURE	47.002 F
AIR TEMPERATURE LEAVING COIL	40.823 F
HEAT GENERATED FROM FAN	57.8 BTU/H
OUTLET AIR TEMPERATURE	40.864 F

NO MOISTURE REMOVAL OCCURS

TOTAL HEAT EXCHANGER EFFECTIVENESS (SENSIBLE) 0.8040

	SUPERHEATED REGION	TWO-PHASE REGION
NTU	0.0000	1.6298
HEAT EXCHANGER EFFECTIVENESS	0.0000	0.8040
CR/CA	0.0000	
FRACTION OF HEAT EXCHANGER	0.0000	1.0000
HEAT TRANSFER RATE	0.0 BTU/H	2852.6 BTU/H
AIR MASS FLOW RATE	0.00 LBM/H	1903.18 LBM/H
OUTLET AIR TEMPERATURE	47.002 F	40.823 F

AIR SIDE:

MASS FLOW RATE	1903.2 LBM/H
PRESSURE DROP	0.028 IN H2O
AUGMENTATION FACTOR	**0.900**
HEAT TRANSFER COEFFICIENT	
DRY COIL	6.773 BTU/H-SQ FT-F
WET COIL	6.954 BTU/H-SQ FT-F
AUGMENTATION FACTOR	**1.450**

REFRIGERANT SIDE:

MASS FLOW RATE	35.0 LBM/H
PRESSURE DROP	0.503 PSI
HEAT TRANSFER COEFFICIENT	
VAPOR REGION	22.764 BTU/H-SQ FT-F
TWO PHASE REGION	202.501 BTU/H-SQ FT-F

CONTACT INTERFACE:

CONTACT CONDUCTANCE ********** BTU/H-SQ FT-F

DRY FIN EFFICIENCY	0.840
WET FIN EFFICIENCY (AVERAGE)	0.000
WET CONTACT FACTOR (AVERAGE)	1.000

UA VALUES PER CIRCUIT:	VAPOR REGION	TWO PHASE REGION
REFRIGERANT SIDE	0.000	1708.794 BTU/H-F
AIR SIDE		
DRY COIL	0.000	1355.053 BTU/H-F
WET COIL		0.000 BTU/H-F
CONTACT INTERFACE		
DRY COIL	0.000	167276.562 BTU/H-F
WET COIL		0.000 BTU/H-F
COMBINED		
DRY COIL	0.000	752.352 BTU/H-F
WET COIL		0.000 BTU/H-F

```
***** SUMMARY OF ENERGY INPUT AND OUTPUT *****

SAMPLE ECM HEAT PUMP, OFF-DESIGN PT: SPECIFIED MOTORS AND DUCTS, FILE:OFFDES.HPS

        OPERATING CONDITIONS:
          AIR TEMPERATURE INTO EVAPORATOR              47.00 F
          AIR TEMPERATURE INTO CONDENSER               70.00 F
          SATURATION TEMP INTO   COMPRESSOR            39.13 F
          SATURATION TEMP OUT OF COMPRESSOR            87.73 F

        DRIVE FREQUENCIES:
          COMPRESSOR                                   50.00 HZ
          INDOOR  FAN                                  64.80 HZ
          OUTDOOR FAN                                  37.12 HZ

        DRIVE FREQUENCY RATIOS:
          COMPRESSOR                                    0.28
          INDOOR  FAN                                   0.60
          OUTDOOR FAN                                   0.45

        ENERGY INPUT SUMMARY:
          HEAT PUMPED FROM AIR SOURCE                 8557.9 BTU/H

          POWER TO INDOOR  FAN MOTOR                    34.0 WATTS
          POWER TO OUTDOOR FAN MOTOR                    16.9 WATTS
          TOTAL    PARASITIC   POWER                    51.0 WATTS

          POWER TO COMPRESSOR  MOTOR                   453.1 WATTS
          TOTAL    INPUT       POWER                   504.0 WATTS

        REFRIGERANT-SIDE SUMMARY:
          HEAT GAIN    TO  EVAPORATOR FROM AIR        8557.9 BTU/H
          HEAT GAIN    TO  SUCTION LINE                100.0 BTU/H
          ENERGY INPUT TO  COMPRESSOR                 1546.4 BTU/H
          HEAT LOSS   FROM COMPRESSOR SHELL            387.9 BTU/H
          HEAT LOSS   FROM DISCHARGE LINE              700.0 BTU/H
          HEAT LOSS   FROM CONDENSER  TO   AIR        8415.6 BTU/H
          HEAT LOSS   FROM LIQUID LINE                 700.0 BTU/H

        ENERGY OUTPUT SUMMARY:
          HEAT RATE FROM REFRIGERANT TO INDOOR AIR    8415.6 BTU/H
          HEAT RATE FROM FAN         TO INDOOR AIR     116.1 BTU/H
          TOTAL HEAT RATE       TO/FROM INDOOR AIR    8531.7 BTU/H

        HEATING PERFORMANCE:
          HEAT PUMP COP              4.960
          HEAT PUMP CAPACITY         8531.7 BTU/H
```

***** CHARGE INVENTORY RESULTS *****

ANALYTICAL SOLUTION OF ZIVI'S METHOD
FOR A CONSTANT HEAT FLUX APPROXIMATION

STEADY-STATE REFRIGERANT MASS DISTRIBUTION (LBM)
TREFMS = 7.230 SSMSHI = 4.647 SSMSLO = 2.583
TMASSC = 3.320 TMASSE = 2.049 CMPMAS = 0.342 XMASLL = 1.076 ACCMAS = 0.159 SSVPLO = 0.033 SSVPHI = 0.251

EQUILIBRIUM REFRIGERANT MASS DISTRIBUTION (LBM)
EQMSHI = 0.400 EQMSLO = 6.830 XMSLQ = 5.999 XEQUIL = 0.1215

HI/LO AND COMPONENT INTERNAL VOLUMES (CU FT), ACCUMULATOR LIQUID LEVEL (INCHES)
VOLHI = 0.250 VOLLOW = 0.562 VOLCND = 0.153 VOLEVP = 0.205 VOLCMP = 0.229 VOLACC = 0.106 XLEVEL = 0.000 IN

Listing C.3. Sample Parametric Heat Pump Model Run

— Heating Mode, Compressor Frequency Vs Ambient —

Abbreviated Output Listing

***** CONTOUR DATA GENERATION INFORMATION *****

STEADY-STATE HEATING MODE DATA

CONTOUR DATA FILE TITLES —
HEATING MODE PARAMETRIC EVALUATION — COMPRESSOR FREQUENCY VERSUS AMBIENT

INDEPENDENT VARIABLE SPECIFICATION —

	ID#	# OF PTS.	XLO	XHI	CONTOUR REFERENCE POINTS HEATING	COOLING	SEASONAL
X	21	6	180.000	50.000	180.000		
Y	18	3	17.000	47.000	47.000		

DESIGN PARAMETERS, FUNCTIONS, AND RANGES:

	PARAMETER (Y)	FUNCTION OF (X)	X1	X2	Y1	Y2	Y LO	Y HI
HEATING MODE:								
1.	SUPERHEAT	COMPRESSOR FREQ.	50.00	180.00	1.00	1.00	1.00	1.00
2.	SUBCOOLING	COMPRESSOR FREQ.	50.00	180.00	10.00	24.00	10.00	24.00
3.	INDOOR FAN HZ	COMPRESSOR FREQ.	50.00	180.00	64.80	95.00	64.80	95.00
4.	OUTDOOR FAN HZ	COMPRESSOR FREQ.	50.00	180.00	37.10	55.30	37.10	55.30
5.	BUILDING LOAD	AMBIENT TEMP	17.00	62.00	20.00	0.00	0.00	50.00

DEPENDENT VARIABLE ID#'S AND LABELS —

STEADY-STATE DATA —

1 Heat Pump COP
2 Heat Pump Capacity (KBtu/H)
3 Heat Pump EER (BTU/W-H)
4 Evaporator Sensible-To-Total Capacity Ratio
5 Supply Air Temperature (F)
6 Heat Pump System COP With I2R Heat To Meet Specified Heating Load
7 Heat Pump System Capacity Including I2R Heat (KBtu/H)
8 Required I2R Heat (KBtu/H)
9 Total Heat Pump/I2R Input Power (Kw)
10 Average Resistance Heater Power Draw (Kw)
11 Compressor Input Power (Kw)
12 Total Heat Pump Fan Power (Watts)
13 Indoor Blower Power (Watts)
14 Outdoor Fan Power (Watts)
15 Evaporator Average Refrigerant Saturation Temperature (F)
16 Condenser Average Refrigerant Saturation Temperature (F)
17 Evaporator Exit Refrigerant Temperature (F)
18 Condenser Exit Refrigerant Temperature (F)
19 Refrigerant Saturation Temperature Entering Compressor (F)

20 Refrigerant Saturation Temperature Leaving Compressor (F)
21 Compressor Pressure Ratio
22 Refrigerant Mass Flow Rate (lbm/h)
23 Evaporator Refrigerant Pressure Drop (psi)
24 Condenser Refrigerant Pressure Drop (psi)
25 Evaporator Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft^2/F)
26 Condenser Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft^2/F)
27 Percentage Of Nominal Drive Frequency Of Selected Compressor (%)
28 Selected Compressor Operating Speed (rpm)
29 Selected Compressor Operating Torque (lb-ft)
30 Selected Compressor Required Nominal Torque (lb-ft)
31 Percentage Of Selected Compressor Nominal Torque (%)
32 Required Motor Size For Selected Compressor (Hp)
33 ECM Efficiency Degradation Multiplier For Operating Temp Effects
34 Selected Compressor Motor/Drive Efficiency (%)
35 Estimated Compressor Superheat Efficiency Of Selected Comp (%)
36 Selected Compressor Can Isentropic Efficiency (%)
37 Selected Compressor Can Volumetric Efficiency (%)
38 Base Compressor Operating Speed (rpm)
39 Base Compressor Operating Torque (lb-ft)
40 Base Compressor Nominal Torque (lb-ft)
41 Percentage Of Base Compressor Nominal Torque (%)
42 Base Compressor Motor/Drive Efficiency (%)
43 Base Compressor Can Isentropic Efficiency (%)
44 Base Compressor Can Volumetric Efficiency (%)
45 Ratio Of Selected To Base Compressor Speed
46 Ratio Of Selected To Base Motor/Drive Efficiency W/O SGH Effects
47 Estimated Suction Gas Superheating From Base Compressor Motor (F)
48 Estimated Suction Gas Superheating From Selected Comp. Motor (F)
49 Efficiency Multiplier Due To Differential SGH Effects
50 Mass Flow Rate Multiplier Due To Differential SGH Effects
51 Ratio Of Selected To Base Motor/Drive Efficiency With SGH Effects
52 Ratio Of Selected To Base Refrig. Mass Flow Rate With SGH Effects
53 Ratio Of Selected To Base Compressor Power With SGH Effects
54 Indoor Air Flow Rate (cfm)
55 Indoor Blower Speed (rpm)
56 Percentage Of Nominal Indoor Blower Frequency (%)
57 Indoor Air Face Velocity (ft/min)
58 Indoor Air Surface Velocity (ft/min)
59 Indoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)
60 Indoor Air-Side Pressure Drop (In Of H2O)
61 Indoor Coil Fin Patternation Heat Transfer Multiplier
62 Indoor Coil Fin Patternation Pressure Drop Multiplier
63 Indoor Blower Operating Torque (oz-ft)
64 Percentage Of Selected Indoor Motor Nominal Torque (%)
65 Required Nominal Size Of Selected Indoor Motor (Hp)
66 Motor/Drive Efficiency Of Selected Indoor Drive (%)
67 Motor/Drive Efficiency Of Base Indoor Drive (%)

68 Combined Blower/Motor/Drive Efficiency Of Selected Indoor Blower (%)
69 Outdoor Air Flow Rate (cfm)
70 Outdoor Fan Speed (rpm)
71 Percentage Of Nominal Outdoor Fan Frequency (%)
72 Outdoor Air Face Velocity (ft/min)
73 Outdoor Air Surface Velocity (ft/min)
74 Outdoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)
75 Outdoor Air-Side Pressure Drop (In Of H2O)
76 Outdoor Coil Fin Patternation Heat Transfer Multiplier
77 Outdoor Coil Fin Patternation Pressure Drop Multiplier
78 Outdoor Fan Operating Torque (oz-ft)
79 Percentage Of Selected Outdoor Motor Nominal Torque (%)
80 Required Nominal Size Of Selected Outdoor Motor (Hp)
81 Motor/Drive Efficiency Of Selected Outdoor Drive (%)
82 Motor/Drive Efficiency Of Base Outdoor Drive (%)
83 Combined Fan/Motor/Drive Efficiency Of Selected Outdoor Fan (%)
84 Outdoor Fan-Only Efficiency (%)
85 Outdoor Fan Specific Speed
86 Required Refrigerant Charge (lbm)
87 Required Capillary Flow Factor
88 Required TXV Capacity Rating (Tons)
89 Fraction Of Rated TXV Opening
90 Required Short Tube Orifice Diameter (In)
91 Required Simple Orifice Effective KA Product (In2)
92 Evaporator Exit Refrigerant Superheat (F) Or Quality (–)
93 Compressor Inlet Refrigerant Superheat (F) Or Quality (–)
94 Compressor Exit Refrigerant Superheat (F) Or Quality (–)
95 Condenser Exit Refrigerant Subcooling (F) Or Quality (–)
96 Flow Control Inlet Refrigerant Subcooling (F) Or Quality (–)
97 Refrigerant Temperature At Flow Control Inlet (F)
98 Refrigerant Suction Temperature At Compressor Inlet (F)
99 Refrigerant Discharge Temperature At Compressor Exit (F)
100 Refrigerant Suction Pressure At Compressor Inlet (psia)
101 Refrigerant Discharge Pressure At Compressor Exit (psia)
102 Required Indoor Duct Size (Inches)
103 Indoor Duct Pressure Drop (Inches of Water)
104 Indoor Filter Pressure Drop (Inches of Water)
105 Indoor Heater Pressure Drop (Inches of Water)
106 Indoor Coil Pressure Drop (Inches of Water)
107 Selected Compressor-Only Isentropic Efficiency — Excluding Motor (%)
108 Baseline Compressor-Only Isentropic Efficiency — Excluding Motor (%)
109 Wetted Fraction of Evaporator Coil
110 Moisture Removal Rate (lbm/h)

***** INPUT DATA *****

SAMPLE ECM HEAT PUMP, OFF-DESIGN PT: SPECIFIED MOTORS AND DUCTS, FILE:OFFDES.HPS

NO HEAT PUMP MODEL OUTPUT
HEATING MODE OF OPERATION
THE REFRIGERANT IS R 22
REFRIGERANT CHARGE IS NOT SPECIFIED

COMPRESSOR INLET SUPERHEAT IS SPECIFIED AT 1.00 F

CONDENSER EXIT SUBCOOLING IS SPECIFIED AT 10.00 F

ESTIMATE OF:
SATURATION TEMPERATURE INTO COMPRESSOR 40.00 F
SATURATION TEMPERATURE OUT OF COMPRESSOR 100.00 F

COMPRESSOR CHARACTERISTICS:
OPERATING FREQUENCY 50.000 HZ
TOTAL DISPLACEMENT 1.700 CUBIC INCHES

SWDIM RECIPROCATING COMPRESSOR — CURVE FITS FROM ORNL AND MANUF'S DATA

DRIVE TYPE OF INPUT COMPRESSOR DATA IS SINE-WAVE-DRIVEN
DRIVE TYPE IS TO BE CONVERTED TO PM-ECM-DRIVEN

SELECTED MOTOR SIZE IS 2.27 HP
NOMINAL FREQUENCY FOR MOTOR RATING AT 180.0 HZ

BASE SUPERHEAT FOR COMPRESSOR MAP 20.000 F
BASE DISPLACEMENT FOR COMPRESSOR MAP 3.640 CU IN

BASE MOTOR SIZE IS 2.75 HP
NOMINAL FREQUENCY FOR BASE MOTOR RATING AT 60.0 HZ
NOMINAL VOLTAGE FOR BASE MOTOR RATING AT 210.0 VOLTS

.....

REMAINING INPUT ECHO OMITTED FROM LISTING FOR SAKE OF BREVITY (SAME AS FOR THE OFF-DESIGN RUN SHOWN PREVIOUSLY)

.....

SELECTED OUTPUT FROM PARAMETRIC RUNS — LPRINT = -1 , INTERMEDIATE-FREQUENCY RESULTS OMITTED

IDX = 21   XVAL =   180.000 — *MAXIMUM FREQUENCY CASE*

IDY = 18   YVAL =   17.000

STARTING GUESSES FOR — TSICMP = 40.00   TSOCMP =100.00

COMPRESSOR INLET SUPERHEAT   1.000 F DEG
CONDENSER EXIT SUBCOOLING   24.000 F DEG
INDOOR FAN FREQUENCY   95.000 HZ
OUTDOOR FAN FREQUENCY   55.300 HZ

COMPRESSOR INLET SAT. TEMP.   8.49 F
COMPRESSOR EXIT SAT. TEMP.   96.75 F

COP   2.85
HEAT PUMP CAPACITY   15629.9 BTU/H

SYSTEM COP   2.03
SYSTEM CAPACITY   20000.0 BTU/H

IDY = 18   YVAL =   32.000

STARTING GUESSES FOR — TSICMP = 8.49   TSOCMP = 96.75

COMPRESSOR INLET SUPERHEAT   1.000 F DEG
CONDENSER EXIT SUBCOOLING   24.000 F DEG
INDOOR FAN FREQUENCY   95.000 HZ
OUTDOOR FAN FREQUENCY   55.300 HZ

COMPRESSOR INLET SAT. TEMP.   21.18 F
COMPRESSOR EXIT SAT. TEMP.   102.30 F

COP   3.28
HEAT PUMP CAPACITY   21184.5 BTU/H

SYSTEM COP   3.28
SYSTEM CAPACITY   21184.5 BTU/H

IDY = 18   YVAL =   47.000

STARTING GUESSES FOR — TSICMP = 21.18   TSOCMP =102.30

COMPRESSOR INLET SUPERHEAT   1.000 F DEG
CONDENSER EXIT SUBCOOLING   24.000 F DEG
INDOOR FAN FREQUENCY   95.000 HZ
OUTDOOR FAN FREQUENCY   55.300 HZ

COMPRESSOR INLET SAT. TEMP.   33.58 F
COMPRESSOR EXIT SAT. TEMP.   109.69 F

COP   3.70
HEAT PUMP CAPACITY   27529.0 BTU/H

SYSTEM COP   3.70
SYSTEM CAPACITY   27529.0 BTU/H

..... *OMITTING INTERMEDIATE SPEED RESULTS*

Listing C.4. Sample Parametric Heat Pump Model Run

— Heating Mode, Compressor Frequency Vs Ambient —

Output Contour Data Generation File

```
HEATING MODE PARAMETRIC EVALUATION — COMPRESSOR FREQUENCY VERSUS AMBIENT
 21  6    180.00     50.00    180.00
 18  3     17.00     47.00     47.00
110
  1  Heat Pump COP
 2.85280E+00  2.90026E+00  2.93676E+00  3.09406E+00  3.12847E+00  2.77553E+00
 3.28126E+00  3.35696E+00  3.48342E+00  3.70628E+00  3.91786E+00  3.81673E+00
 3.69837E+00  3.79894E+00  4.02963E+00  4.36367E+00  4.64315E+00  4.96039E+00
  2  Heat Pump Capacity (KBtu/H)
 1.56299E+01  1.32235E+01  1.10660E+01  9.18317E+00  6.93581E+00  4.38348E+00
 2.11845E+01  1.82562E+01  1.54548E+01  1.25808E+01  9.54213E+00  6.33130E+00
 2.75289E+01  2.39991E+01  2.04695E+01  1.65360E+01  1.25191E+01  8.53238E+00
  3  Heat Pump EER (BTU/W-H)
 9.73661E+00  9.89859E+00  1.00232E+01  1.05600E+01  1.06775E+01  9.47289E+00
 1.11989E+01  1.14573E+01  1.18889E+01  1.26495E+01  1.33717E+01  1.30265E+01
 1.26225E+01  1.29658E+01  1.37531E+01  1.48932E+01  1.58471E+01  1.69298E+01
  4  Evaporator Sensible-To-Total Capacity Ratio
 1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00
 9.32079E-01  9.48764E-01  9.67407E-01  9.89548E-01  1.00000E+00  1.00000E+00
 8.82553E-01  8.99782E-01  9.19839E-01  9.54408E-01  9.99949E-01  1.00000E+00
  5  Supply Air Temperature (F)
 9.30711E+01  9.46909E+01  9.65405E+01  9.86737E+01  1.01180E+02  1.04163E+02
 9.43409E+01  9.24014E+01  9.03461E+01  8.89520E+01  9.06520E+01  9.26736E+01
 1.01627E+02  9.94453E+01  9.69454E+01  9.34789E+01  8.92923E+01  8.43753E+01
  6  Heat Pump System COP With I2R Heat To Meet Specified Heating Load
 2.03069E+00  1.76431E+00  1.57455E+00  1.45087E+00  1.30880E+00  1.16307E+00
 3.28126E+00  3.35696E+00  3.48342E+00  3.21517E+00  2.14130E+00  1.53949E+00
 3.69837E+00  3.79894E+00  4.02963E+00  4.36367E+00  4.64315E+00  4.96039E+00
  7  Heat Pump System Capacity Including I2R Heat (KBtu/H)
 2.00000E+01  2.00000E+01  2.00000E+01  2.00000E+01  2.00000E+01  2.00000E+01
 2.11845E+01  1.82562E+01  1.54548E+01  1.33333E+01  1.33333E+01  1.33333E+01
 2.75289E+01  2.39991E+01  2.04695E+01  1.65360E+01  1.25191E+01  8.53238E+00
  8  Required I2R Heat (KBtu/H)
 4.37009E+00  6.77646E+00  8.93396E+00  1.08168E+01  1.30642E+01  1.56165E+01
 0.00000E+00  0.00000E+00  0.00000E+00  7.52551E-01  3.79120E+00  7.00203E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  9  Total Heat Pump/I2R Input Power (Kw)
 2.88570E+00  3.32139E+00  3.72167E+00  4.03892E+00  4.47734E+00  5.03834E+00
 1.89166E+00  1.59341E+00  1.29993E+00  1.21506E+00  1.82442E+00  2.53761E+00
 2.18094E+00  1.85096E+00  1.48836E+00  1.11030E+00  7.89991E-01  5.03985E-01
 10  Average Resistance Heater Power Draw  (Kw)
 1.28043E+00  1.98549E+00  2.61763E+00  3.16930E+00  3.82777E+00  4.57560E+00
 0.00000E+00  0.00000E+00  0.00000E+00  2.20495E-01  1.11081E+00  2.05157E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 11  Compressor Input Power (Kw)
 1.47967E+00  1.22852E+00  1.01265E+00  7.92457E-01  5.85831E-01  4.11033E-01
 1.73378E+00  1.45941E+00  1.18687E+00  9.00207E-01  6.50345E-01  4.34714E-01
 2.02575E+00  1.71914E+00  1.37702E+00  1.01742E+00  7.13560E-01  4.53062E-01
 12  Total Heat Pump Fan Power (Watts)
 1.25604E+02  1.07381E+02  9.13921E+01  7.71595E+01  6.37429E+01  5.17066E+01
 1.57881E+02  1.33996E+02  1.13066E+02  9.43589E+01  6.32632E+01  5.13195E+01
 1.55192E+02  1.31813E+02  1.11336E+02  9.28835E+01  7.64318E+01  5.09238E+01
 13  Indoor Blower Power (Watts)
 8.24440E+01  7.04991E+01  5.99193E+01  5.07496E+01  4.20471E+01  3.42236E+01
 8.20553E+01  7.01818E+01  5.96924E+01  5.05706E+01  4.19164E+01  3.41407E+01
 8.14857E+01  6.97304E+01  5.93816E+01  5.03317E+01  4.17463E+01  3.40253E+01
 14  Outdoor Fan Power (Watts)
 4.31604E+01  3.68816E+01  3.14728E+01  2.64098E+01  2.16958E+01  1.74830E+01
 7.58258E+01  6.38142E+01  5.33737E+01  4.37883E+01  2.13468E+01  1.71789E+01
 7.37063E+01  6.20826E+01  5.19544E+01  4.25518E+01  3.46855E+01  1.68984E+01
 15  Evaporator Average Refrigerant Saturation Temperature (F)
 9.61646E+00  1.01013E+01  1.05586E+01  1.09650E+01  1.16335E+01  1.25725E+01
 2.25566E+01  2.29604E+01  2.33883E+01  2.39264E+01  2.48405E+01  2.61246E+01
 3.51951E+01  3.56101E+01  3.60504E+01  3.67019E+01  3.77039E+01  3.93224E+01
 16  Condenser Average Refrigerant Saturation Temperature (F)
 9.66539E+01  9.37096E+01  9.08684E+01  8.82113E+01  8.49531E+01  8.09836E+01
 1.02134E+02  9.91447E+01  9.61207E+01  9.27286E+01  8.87361E+01  8.39456E+01
 1.09440E+02  1.06268E+02  1.02819E+02  9.84340E+01  9.33960E+01  8.76752E+01
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17 Evaporator Exit Refrigerant Temperature (F)

8.54395E+00	9.30420E+00	9.97437E+00	1.06777E+01	1.14329E+01	1.24617E+01
2.12480E+01	2.19614E+01	2.26416E+01	2.34006E+01	2.45217E+01	2.60149E+01
3.36582E+01	3.44246E+01	3.51587E+01	3.60945E+01	3.73440E+01	3.91467E+01

18 Condenser Exit Refrigerant Temperature (F)

7.25892E+01	7.24459E+01	7.24343E+01	7.25811E+01	7.21320E+01	7.09678E+01
7.80250E+01	7.78655E+01	7.76589E+01	7.70749E+01	7.59065E+01	7.39243E+01
8.53083E+01	8.49496E+01	8.43157E+01	8.27603E+01	8.05282E+01	7.76489E+01

19 Refrigerant Saturation Temperature Entering Compressor (F)

8.48881E+00	9.26110E+00	9.94286E+00	1.06559E+01	1.14196E+01	1.24561E+01
2.11796E+01	2.19095E+01	2.26031E+01	2.33723E+01	2.45040E+01	2.60074E+01
3.35797E+01	3.43631E+01	3.51113E+01	3.60616E+01	3.73258E+01	3.91378E+01

20 Refrigerant Saturation Temperature Leaving Compressor (F)

9.67543E+01	9.37920E+01	9.09345E+01	8.82650E+01	8.49906E+01	8.10005E+01
1.02302E+02	9.92842E+01	9.62369E+01	9.28204E+01	8.88006E+01	8.39718E+01
1.09689E+02	1.06481E+02	1.02994E+02	9.85713E+01	9.34909E+01	8.77343E+01

21 Compressor Pressure Ratio

4.37329E+00	4.13109E+00	3.91360E+00	3.71400E+00	3.48881E+00	3.22371E+00
3.68115E+00	3.48355E+00	3.29594E+00	3.09654E+00	2.86301E+00	2.59622E+00
3.23271E+00	3.05389E+00	2.87469E+00	2.66015E+00	2.42340E+00	2.16257E+00

22 Refrigerant Mass Flow Rate (lbm/h)

1.60387E+02	1.38809E+02	1.18978E+02	1.02608E+02	8.04722E+01	5.28560E+01
2.24178E+02	1.96721E+02	1.70530E+02	1.43351E+02	1.12131E+02	7.70910E+01
2.99332E+02	2.64791E+02	2.31223E+02	1.91991E+02	1.49094E+02	1.04922E+02

23 Evaporator Refrigerant Pressure Drop (psi)

2.02725E+00	1.51884E+00	1.12068E+00	5.56054E-01	3.89868E-01	2.17310E-01
2.99837E+00	2.30301E+00	1.72956E+00	1.22753E+00	7.53081E-01	2.65485E-01
4.19297E+00	3.25357E+00	2.46372E+00	1.69233E+00	1.01569E+00	5.02802E-01

24 Condenser Refrigerant Pressure Drop (psi)

2.73726E-01	2.21252E-01	1.76553E-01	1.43476E-01	9.70379E-02	3.86269E-02
5.24219E-01	4.31084E-01	3.47616E-01	2.65944E-01	1.79377E-01	6.32774E-02
8.73084E-01	7.24401E-01	5.89035E-01	4.40344E-01	2.94312E-01	1.65935E-01

25 Evaporator Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft^2/F)

4.01368E+02	3.51625E+02	3.04917E+02	2.65340E+02	2.08270E+02	1.27868E+02
4.88006E+02	4.34132E+02	3.81412E+02	3.24267E+02	2.54626E+02	1.69554E+02
5.74677E+02	5.14956E+02	4.55064E+02	3.81247E+02	2.96527E+02	2.02525E+02

26 Condenser Refrigerant Two-Phase Heat Transfer Coef (Btu/h/ft^2/F)

1.74848E+02	1.57507E+02	1.40772E+02	1.26381E+02	1.05480E+02	7.69657E+01
2.24290E+02	2.04599E+02	1.84206E+02	1.62341E+02	1.35417E+02	1.02364E+02
2.74392E+02	2.51827E+02	2.29103E+02	2.00726E+02	1.67023E+02	1.28900E+02

27 Percentage Of Nominal Drive Frequency Of Selected Compressor (%)

1.00000E+02	8.55555E+01	7.11111E+01	5.66667E+01	4.22222E+01	2.77778E+01
1.00000E+02	8.55555E+01	7.11111E+01	5.66667E+01	4.22222E+01	2.77778E+01
1.00000E+02	8.55555E+01	7.11111E+01	5.66667E+01	4.22222E+01	2.77778E+01

28 Selected Compressor Operating Speed (rpm)

5.40000E+03	4.62000E+03	3.84000E+03	3.06000E+03	2.28000E+03	1.50000E+03
5.40000E+03	4.62000E+03	3.84000E+03	3.06000E+03	2.28000E+03	1.50000E+03
5.40000E+03	4.62000E+03	3.84000E+03	3.06000E+03	2.28000E+03	1.50000E+03

29 Selected Compressor Operating Torque (lb-ft)

2.76560E+01	2.64968E+01	2.60417E+01	2.50233E+01	2.41361E+01	2.42023E+01
3.23984E+01	3.14337E+01	3.03634E+01	2.84753E+01	2.67702E+01	2.56163E+01
3.79672E+01	3.70762E+01	3.53536E+01	3.21991E+01	2.92285E+01	2.66348E+01

30 Selected Compressor Required Nominal Torque (lb-ft)

3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01
3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01
3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01	3.52475E+01

31 Percentage Of Selected Compressor Nominal Torque (%)

7.84622E+01	7.51735E+01	7.38823E+01	7.09931E+01	6.84759E+01	6.86637E+01
9.19167E+01	8.91799E+01	8.61433E+01	8.07866E+01	7.59491E+01	7.26754E+01
1.07716E+02	1.05188E+02	1.00301E+02	9.13514E+01	8.29234E+01	7.55650E+01

32 Required Motor Size For Selected Compressor (Hp)

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

33 ECM Efficiency Degradation Multiplier For Operating Temp Effects

9.95791E-01	9.95316E-01	9.94497E-01	9.93466E-01	9.91728E-01	9.88151E-01
9.95178E-01	9.94585E-01	9.93757E-01	9.92695E-01	9.90983E-01	9.87580E-01
9.94439E-01	9.93731E-01	9.92844E-01	9.91874E-01	9.90327E-01	9.87178E-01

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34  Selected Compressor Motor/Drive Efficiency (%)
 8.95347E+01  8.84005E+01  8.76109E+01  8.57273E+01  8.33369E+01  7.83589E+01
 8.94826E+01  8.82643E+01  8.71501E+01  8.58840E+01  8.32646E+01  7.83146E+01
 8.97150E+01  8.83654E+01  8.74543E+01  8.59080E+01  8.28573E+01  7.82292E+01
35  Estimated Compressor Superheat Efficiency Of Selected Comp (%)
 9.51716E+01  9.50292E+01  9.49821E+01  9.50380E+01  9.48605E+01  9.32442E+01
 9.58791E+01  9.57345E+01  9.57177E+01  9.58784E+01  9.58407E+01  9.49875E+01
 9.64016E+01  9.62428E+01  9.63593E+01  9.65454E+01  9.64497E+01  9.61843E+01
36  Selected Compressor Can Isentropic Efficiency (%)
 5.09431E+01  5.09158E+01  5.07952E+01  5.36976E+01  5.40884E+01  4.72510E+01
 5.34288E+01  5.32070E+01  5.40603E+01  5.66160E+01  5.68402E+01  5.27842E+01
 5.47364E+01  5.41536E+01  5.56896E+01  5.77860E+01  5.76444E+01  5.54343E+01
37  Selected Compressor Can Volumetric Efficiency (%)
 5.86451E+01  5.84508E+01  5.94960E+01  6.35216E+01  6.58961E+01  6.45083E+01
 6.46291E+01  6.54146E+01  6.73674E+01  7.00827E+01  7.20846E+01  7.33221E+01
 6.91780E+01  7.05587E+01  7.31720E+01  7.50034E+01  7.64872E+01  7.93124E+01
38  Base Compressor Operating Speed (rpm)
 5.10541E+03  4.42087E+03  3.70692E+03  2.94909E+03  2.18307E+03  1.38034E+03
 5.04538E+03  4.37942E+03  3.68341E+03  2.93277E+03  2.17198E+03  1.37203E+03
 4.96805E+03  4.32825E+03  3.65496E+03  2.91477E+03  2.16148E+03  1.36594E+03
39  Base Compressor Operating Torque (lb-ft)
 2.76560E+01  2.64968E+01  2.60417E+01  2.50233E+01  2.41361E+01  2.42023E+01
 3.23984E+01  3.14337E+01  3.03634E+01  2.84753E+01  2.67702E+01  2.56163E+01
 3.79672E+01  3.70762E+01  3.53536E+01  3.21991E+01  2.92285E+01  2.66348E+01
40  Base Compressor Nominal Torque (lb-ft)
 3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01
 3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01
 3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01  3.12835E+01
41  Percentage Of Base Compressor Nominal Torque (%)
 8.84045E+01  8.46990E+01  8.32442E+01  7.99889E+01  7.71527E+01  7.73643E+01
 1.03564E+02  1.00480E+02  9.70589E+01  9.10233E+01  8.55729E+01  8.18844E+01
 1.21365E+02  1.18517E+02  1.13010E+02  1.02927E+02  9.34310E+01  8.51401E+01
42  Base Compressor Motor/Drive Efficiency (%)
 8.66268E+01  8.85265E+01  8.92690E+01  8.81688E+01  8.59727E+01  7.90773E+01
 8.42405E+01  8.64345E+01  8.77669E+01  8.73952E+01  8.56310E+01  7.86714E+01
 8.19207E+01  8.48757E+01  8.68669E+01  8.60083E+01  8.49297E+01  7.83188E+01
43  Base Compressor Can Isentropic Efficiency (%)
 4.87382E+01  5.10943E+01  5.21693E+01  5.57029E+01  5.61939E+01  4.76488E+01
 4.94079E+01  5.18706E+01  5.46596E+01  5.78477E+01  5.87916E+01  5.29165E+01
 4.87645E+01  5.15482E+01  5.53651E+01  5.79361E+01  5.93505E+01  5.53786E+01
44  Base Compressor Can Volumetric Efficiency (%)
 5.69091E+01  5.84668E+01  6.08202E+01  6.55704E+01  6.86914E+01  6.65601E+01
 6.16107E+01  6.44396E+01  6.81999E+01  7.17233E+01  7.46926E+01  7.52438E+01
 6.45573E+01  6.84450E+01  7.32972E+01  7.60474E+01  7.88380E+01  8.10995E+01
45  Ratio Of Selected To Base Compressor Speed
 1.05770E+00  1.04504E+00  1.03590E+00  1.03761E+00  1.04440E+00  1.08669E+00
 1.07028E+00  1.05493E+00  1.04251E+00  1.04338E+00  1.04974E+00  1.09327E+00
 1.08695E+00  1.06740E+00  1.05063E+00  1.04982E+00  1.05483E+00  1.09815E+00
46  Ratio Of Selected To Base Motor/Drive Efficiency W/O SGH Effects
 1.03357E+00  9.98576E-01  9.81426E-01  9.72309E-01  9.69342E-01  9.90916E-01
 1.06223E+00  1.02117E+00  9.92973E-01  9.82709E-01  9.72365E-01  9.95464E-01
 1.69554E+00  1.02117E+00  1.00676E+00  9.98833E-01  9.75599E-01  9.98854E-01
47  Estimated Suction Gas Superheating From Base Compressor Motor (F)
 2.73914E+01  2.24473E+01  2.01112E+01  1.92578E+01  2.04035E+01  3.04001E+01
 2.59180E+01  2.10590E+01  1.76504E+01  1.60270E+01  1.60266E+01  2.16923E+01
 2.52542E+01  1.97235E+01  1.55796E+01  1.43302E+01  1.32426E+01  1.62114E+01
48  Estimated Suction Gas Superheating From Selected Comp. Motor (F)
 1.80946E+01  1.86559E+01  1.88381E+01  1.86052E+01  1.93147E+01  2.59263E+01
 1.48152E+01  1.53599E+01  1.54188E+01  1.45074E+01  1.49230E+01  1.81631E+01
 1.23538E+01  1.29229E+01  1.24968E+01  1.18184E+01  1.21496E+01  1.34000E+01
49  Efficiency Multiplier Due To Differential SGH Effects
 1.02429E+00  1.00994E+00  1.00334E+00  1.00172E+00  1.00286E+00  1.01142E+00
 1.03026E+00  1.01556E+00  1.00611E+00  1.00408E+00  1.00303E+00  1.01084E+00
 1.03666E+00  1.01936E+00  1.00882E+00  1.00722E+00  1.00315E+00  1.00804E+00
50  Mass Flow Rate Multiplier Due To Differential SGH Effects
 1.02412E+00  1.00986E+00  1.00332E+00  1.00170E+00  1.00284E+00  1.01135E+00
 1.02972E+00  1.01530E+00  1.00602E+00  1.00412E+00  1.00300E+00  1.00945E+00
 1.03574E+00  1.01893E+00  1.00865E+00  1.00709E+00  1.00309E+00  1.00793E+00
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51 Ratio Of Selected To Base Motor/Drive Efficiency With SGH Effects

1.05867E+00	1.00850E+00	9.84704E-01	9.73978E-01	9.72111E-01	1.00223E+00
1.09437E+00	1.03706E+00	9.99038E-01	9.86715E-01	9.75312E-01	1.00625E+00
1.13529E+00	1.06127E+00	1.01564E+00	1.00605E+00	9.78673E-01	1.00689E+00

52 Ratio Of Selected To Base Refrig. Mass Flow Rate With SGH Effects

1.08322E+00	1.05534E+00	1.03934E+00	1.03938E+00	1.04737E+00	1.09903E+00
1.10210E+00	1.07108E+00	1.04878E+00	1.04768E+00	1.05288E+00	1.10360E+00
1.12579E+00	1.08761E+00	1.05971E+00	1.05727E+00	1.05809E+00	1.10686E+00

53 Ratio Of Selected To Base Compressor Power With SGH Effects

9.99838E-01	9.99924E-01	9.99976E-01	9.99988E-01	9.99981E-01	9.99937E-01
9.99483E-01	9.99750E-01	9.99908E-01	1.00004E+00	9.99965E-01	9.98629E-01
9.99118E-01	9.99584E-01	9.99825E-01	9.99866E-01	9.99943E-01	9.99888E-01

54 Indoor Air Flow Rate (cfm)

7.91666E+02	7.41333E+02	6.91000E+02	6.40666E+02	5.90333E+02	5.40000E+02
7.91666E+02	7.41333E+02	6.91000E+02	6.40666E+02	5.90333E+02	5.40000E+02
7.91666E+02	7.41333E+02	6.91000E+02	6.40666E+02	5.90333E+02	5.40000E+02

55 Indoor Blower Speed (rpm)

9.50000E+02	8.89600E+02	8.29199E+02	7.68800E+02	7.08400E+02	6.48000E+02
9.50000E+02	8.89600E+02	8.29199E+02	7.68800E+02	7.08400E+02	6.48000E+02
9.50000E+02	8.89600E+02	8.29199E+02	7.68800E+02	7.08400E+02	6.48000E+02

56 Percentage Of Nominal Indoor Blower Frequency (%)

8.79629E+01	8.23703E+01	7.67778E+01	7.11852E+01	6.55926E+01	6.00000E+01
8.79629E+01	8.23703E+01	7.67778E+01	7.11852E+01	6.55926E+01	6.00000E+01
8.79629E+01	8.23703E+01	7.67778E+01	7.11852E+01	6.55926E+01	6.00000E+01

57 Indoor Air Face Velocity (ft/min)

2.02991E+02	1.90085E+02	1.77179E+02	1.64273E+02	1.51367E+02	1.38462E+02
2.02991E+02	1.90085E+02	1.77179E+02	1.64273E+02	1.51367E+02	1.38462E+02
2.02991E+02	1.90085E+02	1.77179E+02	1.64273E+02	1.51367E+02	1.38462E+02

58 Indoor Air Surface Velocity (ft/min)

3.66841E+02	3.43517E+02	3.20194E+02	2.96871E+02	2.73547E+02	2.50224E+02
3.66841E+02	3.43517E+02	3.20194E+02	2.96871E+02	2.73547E+02	2.50224E+02
3.66841E+02	3.43517E+02	3.20194E+02	2.96871E+02	2.73547E+02	2.50224E+02

59 Indoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)

8.64594E+00	8.26366E+00	7.87398E+00	7.48083E+00	7.07170E+00	6.65072E+00
8.66051E+00	8.27794E+00	7.88764E+00	7.48802E+00	7.08169E+00	6.65777E+00
8.68213E+00	8.29844E+00	7.90642E+00	7.50344E+00	7.08953E+00	6.66761E+00

60 Indoor Air-Side Pressure Drop (In Of H2O)

3.12028E-01	2.76706E-01	2.43259E-01	2.11685E-01	1.82203E-01	1.54813E-01
3.10366E-01	2.75196E-01	2.41926E-01	2.10656E-01	1.81454E-01	1.54335E-01
3.07921E-01	2.73044E-01	2.40106E-01	2.09286E-01	1.80481E-01	1.53672E-01

61 Indoor Coil Fin Patternation Heat Transfer Multiplier

1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00
1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00
1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00	1.45000E+00

62 Indoor Coil Fin Patternation Pressure Drop Multiplier

9.54029E-01	9.50904E-01	9.46794E-01	9.41115E-01	9.35715E-01	9.30559E-01
9.41551E-01	9.38170E-01	9.34063E-01	9.29880E-01	9.26271E-01	9.23507E-01
9.23368E-01	9.20193E-01	9.16848E-01	9.15060E-01	9.14087E-01	9.13764E-01

63 Indoor Blower Operating Torque (oz-ft)

7.65280E+00	6.78649E+00	5.96616E+00	5.19180E+00	4.46872E+00	3.79694E+00
7.61203E+00	6.74946E+00	5.93346E+00	5.16654E+00	4.45035E+00	3.78523E+00
7.55206E+00	6.69668E+00	5.88885E+00	5.13296E+00	4.42649E+00	3.76896E+00

64 Percentage Of Selected Indoor Motor Nominal Torque (%)

4.57458E+01	4.05673E+01	3.56637E+01	3.10348E+01	2.67125E+01	2.26968E+01
4.55021E+01	4.03460E+01	3.54682E+01	3.08838E+01	2.66026E+01	2.26268E+01
4.51436E+01	4.00305E+01	3.52015E+01	3.06830E+01	2.64600E+01	2.25295E+01

65 Required Nominal Size Of Selected Indoor Motor (Hp)

2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01
2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01
2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01	2.15000E-01

66 Motor/Drive Efficiency Of Selected Indoor Drive (%)

7.82382E+01	7.59784E+01	7.32523E+01	6.97801E+01	6.67974E+01	6.37849E+01
7.81900E+01	7.59055E+01	7.31278E+01	6.96866E+01	6.67302E+01	6.37425E+01
7.81162E+01	7.57995E+01	7.29577E+01	6.95622E+01	6.66428E+01	6.36837E+01

67 Motor/Drive Efficiency Of Base Indoor Drive (%)

1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02
1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02
1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02	1.00000E+02

68 Combined Blower/Motor/Drive Efficiency Of Selected Indoor Blower (%)
3.52072E+01 3.41903E+01 3.29636E+01 3.14011E+01 3.00588E+01 2.87032E+01
3.51855E+01 3.41575E+01 3.29075E+01 3.13590E+01 3.00286E+01 2.86841E+01
3.51523E+01 3.41098E+01 3.28310E+01 3.13030E+01 2.99893E+01 2.86576E+01
69 Outdoor Air Flow Rate (cfm)
1.80982E+03 1.69069E+03 1.57156E+03 1.45244E+03 1.33331E+03 1.21418E+03
1.80982E+03 1.69069E+03 1.57156E+03 1.45244E+03 1.33331E+03 1.21418E+03
1.80982E+03 1.69069E+03 1.57156E+03 1.45244E+03 1.33331E+03 1.21418E+03
70 Outdoor Fan Speed (rpm)
5.53000E+02 5.16600E+02 4.80200E+02 4.43800E+02 4.07400E+02 3.71000E+02
5.53000E+02 5.16600E+02 4.80200E+02 4.43800E+02 4.07400E+02 3.71000E+02
5.53000E+02 5.16600E+02 4.80200E+02 4.43800E+02 4.07400E+02 3.71000E+02
71 Percentage Of Nominal Outdoor Fan Frequency (%)
6.70303E+01 6.26182E+01 5.82060E+01 5.37939E+01 4.93818E+01 4.49697E+01
6.70303E+01 6.26182E+01 5.82060E+01 5.37939E+01 4.93818E+01 4.49697E+01
6.70303E+01 6.26182E+01 5.82060E+01 5.37939E+01 4.93818E+01 4.49697E+01
72 Outdoor Air Face Velocity (ft/min)
1.99980E+02 1.86816E+02 1.73653E+02 1.60490E+02 1.47327E+02 1.34164E+02
1.99980E+02 1.86816E+02 1.73653E+02 1.60490E+02 1.47327E+02 1.34164E+02
1.99980E+02 1.86816E+02 1.73653E+02 1.60490E+02 1.47327E+02 1.34164E+02
73 Outdoor Air Surface Velocity (ft/min)
3.21616E+02 3.00446E+02 2.79277E+02 2.58107E+02 2.36937E+02 2.15768E+02
3.21616E+02 3.00446E+02 2.79277E+02 2.58107E+02 2.36937E+02 2.15768E+02
3.21616E+02 3.00446E+02 2.79277E+02 2.58107E+02 2.36937E+02 2.15768E+02
74 Outdoor Air-Side Heat Transfer Coefficient (Btu/h/ft^2/F)
8.76709E+00 8.40844E+00 8.03981E+00 7.65958E+00 7.26841E+00 6.86478E+00
8.70135E+00 8.34511E+00 7.97908E+00 7.60258E+00 7.21500E+00 6.81509E+00
8.64127E+00 8.28743E+00 7.92388E+00 7.55044E+00 7.16607E+00 6.76987E+00
75 Outdoor Air-Side Pressure Drop (In Of H2O)
5.87446E-02 5.22247E-02 4.60349E-02 4.01795E-02 3.46544E-02 2.94661E-02
1.18865E-01 1.05761E-01 9.32996E-02 8.14870E-02 3.36568E-02 2.86096E-02
1.15640E-01 1.02893E-01 9.07717E-02 7.92681E-02 6.83920E-02 2.78116E-02
76 Outdoor Coil Fin Patternation Heat Transfer Multiplier
1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00
1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00
1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00 1.45000E+00
77 Outdoor Coil Fin Patternation Pressure Drop Multiplier
1.02962E+00 1.01449E+00 9.98597E-01 9.81952E-01 9.63252E-01 9.42008E-01
1.00735E+00 9.92773E-01 9.77275E-01 9.60453E-01 9.41497E-01 9.20002E-01
9.87129E-01 9.72867E-01 9.57699E-01 9.40830E-01 9.21763E-01 8.99878E-01
78 Outdoor Fan Operating Torque (oz-ft)
6.30075E+00 5.56590E+00 4.87387E+00 4.22481E+00 3.61823E+00 3.05437E+00
1.14560E+01 1.01991E+01 9.00501E+00 7.87388E+00 3.54560E+00 2.99110E+00
1.11390E+01 9.91460E+00 8.75164E+00 7.64894E+00 6.60708E+00 2.93315E+00
79 Percentage Of Selected Outdoor Motor Nominal Torque (%)
3.93996E+01 3.48044E+01 3.04771E+01 2.64184E+01 2.26254E+01 1.90994E+01
7.16361E+01 6.37766E+01 5.63098E+01 4.92366E+01 2.21712E+01 1.87038E+01
6.96542E+01 6.19976E+01 5.47254E+01 4.78300E+01 4.13151E+01 1.83414E+01
80 Required Nominal Size Of Selected Outdoor Motor (Hp)
1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01
1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01
1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01 1.57000E-01
81 Motor/Drive Efficiency Of Selected Outdoor Drive (%)
7.16252E+01 6.91693E+01 6.59773E+01 6.29887E+01 6.02802E+01 5.75060E+01
7.41266E+01 7.32542E+01 7.18807E+01 7.08031E+01 6.00360E+01 5.73119E+01
7.41484E+01 7.31971E+01 7.17668E+01 7.07789E+01 6.88519E+01 5.71341E+01
82 Motor/Drive Efficiency Of Base Outdoor Drive (%)
1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02
1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02
1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02 1.00000E+02
83 Combined Fan/Motor/Drive Efficiency Of Selected Outdoor Fan (%)
2.89449E+01 2.81309E+01 2.70108E+01 2.59651E+01 2.50245E+01 2.40461E+01
3.33371E+01 3.29250E+01 3.22803E+01 3.17601E+01 2.47016E+01 2.37605E+01
3.33650E+01 3.29256E+01 3.22637E+01 3.17930E+01 3.08917E+01 2.34811E+01
84 Outdoor Fan-Only Efficiency (%)
4.04116E+01 4.06696E+01 4.09396E+01 4.12218E+01 4.15137E+01 4.18149E+01
4.49732E+01 4.49462E+01 4.49082E+01 4.48569E+01 4.11447E+01 4.14582E+01
4.49976E+01 4.49821E+01 4.49564E+01 4.49187E+01 4.48669E+01 4.10982E+01

85 Outdoor Fan Specific Speed
1.97159E+05 1.94437E+05 1.91545E+05 1.88466E+05 1.85211E+05 1.81771E+05
1.16212E+05 1.14536E+05 1.12766E+05 1.10897E+05 1.89313E+05 1.85836E+05
1.18635E+05 1.16922E+05 1.15113E+05 1.13217E+05 1.11232E+05 1.89821E+05
86 Required Refrigerant Charge (lbm)
7.50985E+00 7.35836E+00 7.17066E+00 6.96274E+00 6.91199E+00 7.33606E+00
7.30869E+00 7.15395E+00 7.00757E+00 6.89639E+00 6.85434E+00 7.02440E+00
7.47282E+00 7.33289E+00 7.20861E+00 7.12385E+00 7.09869E+00 7.22922E+00
87 Required Capillary Flow Factor
1.21600E+00 1.07633E+00 9.39395E-01 8.21744E-01 6.39803E-01 3.85069E-01
1.70160E+00 1.53953E+00 1.37303E+00 1.18212E+00 9.33278E-01 6.24370E-01
2.22647E+00 2.04173E+00 1.85073E+00 1.59404E+00 1.26948E+00 8.91257E-01
88 Required TXV Capacity Rating (Tons)
6.52690E-01 5.73228E-01 5.02736E-01 4.44119E-01 3.57799E-01 2.42071E-01
9.17941E-01 8.24142E-01 7.32112E-01 6.33391E-01 5.13124E-01 3.68625E-01
1.23416E+00 1.11726E+00 1.00307E+00 8.65020E-01 7.05802E-01 5.30161E-01
89 Fraction Of Rated TXV Opening
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
90 Required Short Tube Orifice Diameter (In)
3.53549E-02 3.31155E-02 3.08688E-02 2.88252E-02 2.59381E-02 2.06967E-02
4.28018E-02 4.06544E-02 3.83227E-02 3.54764E-02 3.14364E-02 2.55628E-02
5.02921E-02 4.80838E-02 4.56756E-02 4.22660E-02 3.76798E-02 3.16748E-02
91 Required Simple Orifice Effective KA Product (In2)
6.19236E-04 5.45346E-04 4.79289E-04 4.24049E-04 3.42261E-04 2.31951E-04
8.63958E-04 7.78723E-04 6.94135E-04 6.02487E-04 4.89690E-04 3.52787E-04
1.14839E-03 1.04565E-03 9.43637E-04 8.18356E-04 6.71279E-04 5.06409E-04
92 Evaporator Exit Refrigerant Superheat (F) Or Quality (-)
-9.94918E-01 -9.93846E-01 -9.92568E-01 -9.91164E-01 -9.88259E-01 -9.81177E-01
-9.96792E-01 -9.96136E-01 -9.95254E-01 -9.94095E-01 -9.91847E-01 -9.87365E-01
-9.98036E-01 -9.97576E-01 -9.97055E-01 -9.95913E-01 -9.94326E-01 -9.90960E-01
93 Compressor Inlet Refrigerant Superheat (F) Or Quality (-)
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00 1.00000E+00
94 Compressor Exit Refrigerant Superheat (F) Or Quality (-)
9.28456E+01 8.66525E+01 8.09977E+01 6.95736E+01 6.26807E+01 6.74081E+01
7.96038E+01 7.47014E+01 6.78053E+01 5.79722E+01 5.10873E+01 4.83998E+01
7.22503E+01 6.82708E+01 6.05123E+01 5.12229E+01 4.41918E+01 3.81429E+01
95 Condenser Exit Refrigerant Subcooling (F) Or Quality (-)
2.40163E+01 2.12248E+01 1.84009E+01 1.56017E+01 1.28011E+01 1.00077E+01
2.40206E+01 2.12044E+01 1.84000E+01 1.56053E+01 1.27939E+01 1.00085E+01
2.39942E+01 2.12010E+01 1.84050E+01 1.55967E+01 1.28134E+01 9.99316E+00
96 Flow Control Inlet Refrigerant Subcooling (F) Or Quality (-)
3.85271E+01 3.81667E+01 3.83289E+01 3.88500E+01 4.27128E+01 5.62174E+01
3.38741E+01 3.26723E+01 3.18529E+01 3.18533E+01 3.38842E+01 4.11991E+01
3.06879E+01 2.91100E+01 2.77840E+01 2.72814E+01 2.83031E+01 3.25375E+01
97 Refrigerant Temperature At Flow Control Inlet (F)
5.76814E+01 5.51873E+01 5.22573E+01 4.91361E+01 4.20865E+01 2.46884E+01
6.74846E+01 6.58362E+01 6.37567E+01 6.04868E+01 5.45868E+01 4.26087E+01
7.75333E+01 7.61461E+01 7.42104E+01 7.05335E+01 6.46754E+01 5.48985E+01
98 Refrigerant Suction Temperature At Compressor Inlet (F)
9.48881E+00 1.02611E+01 1.09429E+01 1.16559E+01 1.24196E+01 1.34561E+01
2.21796E+01 2.29095E+01 2.36031E+01 2.43723E+01 2.55040E+01 2.70074E+01
3.45797E+01 3.53631E+01 3.61113E+01 3.70616E+01 3.83258E+01 4.01378E+01
99 Refrigerant Discharge Temperature At Compressor Exit (F)
1.89600E+02 1.80445E+02 1.71932E+02 1.57839E+02 1.47671E+02 1.48409E+02
1.81906E+02 1.73986E+02 1.64042E+02 1.50793E+02 1.39888E+02 1.32372E+02
1.81940E+02 1.74752E+02 1.63507E+02 1.49794E+02 1.37683E+02 1.25877E+02
100 Refrigerant Suction Pressure At Compressor Inlet (psia)
4.60435E+01 4.67660E+01 4.74104E+01 4.80901E+01 4.88288E+01 4.98450E+01
5.90421E+01 5.98642E+01 6.06562E+01 6.15417E+01 6.28641E+01 6.46526E+01
7.42568E+01 7.53082E+01 7.63236E+01 7.76244E+01 7.93839E+01 8.19598E+01
101 Refrigerant Discharge Pressure At Compressor Exit (psia)
2.01361E+02 1.93195E+02 1.85546E+02 1.78606E+02 1.70355E+02 1.60686E+02
2.17343E+02 2.08540E+02 1.99919E+02 1.90566E+02 1.79980E+02 1.67852E+02
2.40050E+02 2.29983E+02 2.19407E+02 2.06492E+02 1.92379E+02 1.77244E+02

102 Required Indoor Duct Size (Inches)

6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00
6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00
6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00	6.22000E+00

103 Indoor Duct Pressure Drop (Inches of Water)

1.13635E-01	1.01056E-01	8.91031E-02	7.77764E-02	6.71618E-02	5.72620E-02
1.13004E-01	1.00482E-01	8.85949E-02	7.73830E-02	6.68748E-02	5.70785E-02
1.12076E-01	9.96637E-02	8.79012E-02	7.68597E-02	6.65021E-02	5.68237E-02

104 Indoor Filter Pressure Drop (Inches of Water)

5.30885E-02	4.67183E-02	4.07315E-02	3.51262E-02	2.99378E-02	2.51635E-02
5.27938E-02	4.64529E-02	4.04992E-02	3.49485E-02	2.98099E-02	2.50829E-02
5.23602E-02	4.60744E-02	4.01821E-02	3.47121E-02	2.96437E-02	2.49709E-02

105 Indoor Heater Pressure Drop (Inches of Water)

7.62020E-02	6.70585E-02	5.84651E-02	5.04193E-02	4.29720E-02	3.61192E-02
7.57790E-02	6.66775E-02	5.81317E-02	5.01643E-02	4.27884E-02	3.60034E-02
7.51567E-02	6.61343E-02	5.76765E-02	4.98250E-02	4.25499E-02	3.58427E-02

106 Indoor Coil Pressure Drop (Inches of Water)

6.91029E-02	6.18728E-02	5.49590E-02	4.83635E-02	4.21319E-02	3.62685E-02
6.87890E-02	6.15836E-02	5.46998E-02	4.81601E-02	4.19813E-02	3.61706E-02
6.83279E-02	6.11719E-02	5.43464E-02	4.78897E-02	4.17858E-02	3.60348E-02

107 Selected Compressor-Only Isentropic Efficiency — Excluding Motor (%)

5.68977E+01	5.75967E+01	5.79781E+01	6.26377E+01	6.49033E+01	6.03007E+01
5.97086E+01	6.02815E+01	6.20312E+01	6.59214E+01	6.82646E+01	6.74002E+01
6.10114E+01	6.12838E+01	6.36784E+01	6.72649E+01	6.95707E+01	7.08615E+01

108 Baseline Compressor-Only Isentropic Efficiency — Excluding Motor (%)

5.62622E+01	5.77164E+01	5.84405E+01	6.31776E+01	6.53625E+01	6.02560E+01
5.86510E+01	6.00114E+01	6.22781E+01	6.61910E+01	6.86569E+01	6.72627E+01
5.95264E+01	6.07337E+01	6.37356E+01	6.73611E+01	6.98819E+01	7.07092E+01

109 Wetted Fraction of Evaporator Coil

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6.74810E-01	5.79088E-01	4.50076E-01	2.08695E-01	0.00000E+00	0.00000E+00
7.86742E-01	7.24058E-01	6.44594E-01	4.79373E-01	1.54217E-02	0.00000E+00

110 Moisture Removal Rate (lbm/h)

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3.61055E-01	2.40540E-01	1.33662E-01	3.64602E-02	0.00000E+00	0.00000E+00
8.20077E-01	6.22692E-01	4.38385E-01	2.09952E-01	2.02284E-04	0.00000E+00

APPENDIX D

DEFINITIONS OF CONSTANTS ASSIGNED IN BLOCK DATA

A number of variables and constants are used by the Heat Pump Design Model that are unlikely to be changed very often, and consequently they are simply assigned values rather than being specified with each set of input data. They have been brought together in the BLOCK DATA subroutine and given values which are in turn passed to the subroutines where they are used via common blocks. These data are divided into several categories organized by function.

Assignment of Unit Numbers for Input and Output

Input Unit Numbers

IOCHZR for reading 'CONCHZ' and 'HPDATA' data files, 5

IOCNTR for reading 'CONTRL' data files (optional), 24

Output Unit Numbers

IOCONW for printing the input echo and the output listing, 6

IOSSP for punching a steady-state performance data file of the form required for the ORNL Annual Performance Factor Model, 7

IOCONP for punching contour data files 'CONGEN' or 'CONSPD' (from Figure CDG1), 8

Physical Air-Side Parameters

PA atmospheric pressure, 14.7 $lbf/in.^2$

RAU universal gas constant, 53.34 ft-lbf/lbm-°R

AFILTR flow area of filter on indoor unit, 2.78 ft^2

AHEATR cross-sectional area of resistance heater section in indoor unit, (usually equal to indoor blower exit area), 1.28 ft^2

RACKS number of resistance heater racks, 3.0

Data For Loss-and-Efficiency-Based Compressor Model

Compressor Motor Efficiency Correlation

CETAM coefficients for the 0^{th} through $5t^{h}$ order terms of the fit of the compressor motor efficiency as a function of the fractional motor load (Eq. 4.29*), 0.4088, 2.5138, –4.6289, 4.5884, –2.3666, and 0.48324

RPMSLR slope of linear fit for fraction of no-load compressor motor speed as a function of fraction of full load power, –0.042 (see Eq. 4.24*)

Compressor Volumetric Efficiency Parameters

ETAVLA intercept for the fit of theoretical minus actual volumetric efficiencies as a linear function of the correlating parameter given by Davis and Scott, –0.0933

ETAVLB slope of the fit of theoretical minus actual volumetric efficiencies as a linear function of the correlating parameter given by Davis and Scott, 0.733

Data For Map-Based Compressor Model

Shell Inlet Superheat Correction Parameters

SUCFAC suction gas heating factor F_{sh} used in Eq. 4.6*, 0.33

VOLFAC volumetric efficiency correction factor F_v used in Eq. 4.4*, 0.75

Parameters for Converting Between Induction and ECM Compressor Motors

CSLPNM assumed nominal compressor slip speed at rated horsepower for the selected drive, 150 rpm

NPINDC number of poles for compressor induction motor, 2

MPOLCM multiplier to convert number of induction motor poles to number of poles for compressor ECM, 2

*The equation numbers cited throughout the BLOCK DATA variable definitions refer to a previous ORNL Heat Pump Model documentation report (Fischer and Rice 1983).

Factors For Estimating Suction Gas Superheat Effects Of Different Motors

LOCOOL logical variable used to omit suction gas superheat corrections if motor is not low-side cooled, .TRUE.

HTFRAC estimated fraction of the shaft input power (heat from non-motor sources) that contributes to suction gas heating, 0.05

DAMPER damping factor on total suction gas heating from motor cooling and from heat transfer from the compressor body and discharge line, 0.75

PM-ECM Motor Characteristics (Used for Motor Temperature Corrections)

ETSTAT estimate of motor stator temperature, 40.0 °C

ETROTR estimate of motor rotor temperature, 55.0 °C

ETREF reference temperature for motor data, 25.0 °C

ETCOEF magnet flux temperature coefficient (–0.20% / °C)

EFORMF approximate average form factor, 1.01

ESPDNM(J) motor nominal speed (rpm), 5400., 6900.

ETQRAT(J) rating point (design cooling load) torque (oz-ft), 64.0, 50.0

ERTREF(J) motor stator resistance (line-line) at reference temperature (ohms), 0.648, 0.371

EACOEF(J) slope of torque / current relationship, 0.205, 0.263

EBCOEF(J) intercept of torque / current relationship, 0.6, 0.3
where (I = A * T + B) for two motor speeds J = 1,2
which provide 2 points from which to interpolate to other nominal speeds

Fan and Fan Motor Parameters

Data for Outdoor Fan Efficiency Representation

COFAN constant term for the fit of outdoor fan static efficiency to fan specific speed, –3.993

ClFAN coefficient for the linear term of the fit of outdoor fan static efficiency to the fan specific speed, 4.266

C2FAN coefficient for the quadratic term of the fit of outdoor fan static efficiency to fan specific speed, –1.024

Refrigerant Flow Control Parameters

Thermostatic Expansion Valve Constants (Set for R22 as Default)

BLEEDF bypass or bleed factor coefficient used to compute TXV parameters when condenser subcooling is held fixed, 1.15

DPRAT rated pressure drop across the TXV at the design conditions, 100 psi for R-22 and R-502, 60 psi for R-12

NZTBOP switch to bypass nozzle and distributor tube pressure drop calculations when calculating TXV parameters if the condenser subcooling is held fixed, 0

STATIC static superheat setting used to compute the TXV parameters when the condenser subcooling is held fixed, 6.0 F°

SUPRAT rated operating superheat used to compute the TXV parameters when the condenser subcooling is held fixed, 11.0 F°

TERAT rated evaporating temperature for the TXV, 40.0°F

TLQRAT rated liquid refrigerant temperature at the inlet to the TXV, 100.0°F

XLTUBE length of distributor tubes (if used), 30 inches

Capillary Tube Parameter

NCAP number of capillary tubes used to compute capillary tube flow factor, φ, when condenser subcooling is held fixed, 1

APPENDIX E

DESCRIPTION OF NEW SUBROUTINES ADDED SINCE THE MARK III VERSION

New Compressor-Drive-Performance Routines —
Inverter- and Sine-Wave-Driven Induction Motors (IDIM and SWDIMs)
and Permanent-Magnet-Electronically-Commutated-Motors (PM-ECMs)

(in general order of increasing drive efficiency)

CMPFGN computes efficiency reduction factor for first generation inverter drives compared to pure sine wave performance at the same frequency — function of compressor frequency (15 to 90 Hz) and operation mode (heating or cooling) — integral Hp size

CMPSOA computes efficiency reduction factor for state-of-the-art inverter drives compared to pure sine wave performance at the same frequency — function of compressor frequency (15 to 90 Hz) and operation mode (heating or cooling) — integral Hp size

SWDIM interpolates the motor efficiency and speed of a variable-frequency, 2-pole hermetic, sine-wave-driven induction motor (SWDIM) as a function of fractional full load (0.2 to 2.0), frequency ratio (0.25 to 1.5), and Volts/Hz multiplier (0.9 to 1.1) — integral Hp size

ITRIND iterates to find sine-wave-driven induction motor efficiency and speed given electrical input power and drive *frequency*

ITRECM iterates to find PM-ECM motor efficiency given electrical input power and drive *speed*

ECMCMP interpolates the combined drive/motor efficiency of a variable-frequency compressor PM-ECM (4-pole hermetic) as a function of fractional full load (0.2 to 1.9 of full load) and drive frequency ratio (0.2 to 1.15 of nominal) — integral Hp size

ECMTMP corrects ECM motor efficiency for hermetic operating temperature effects as a function of fractional rated torque and operating speed ratio

PROPCM computes refrigerant property values needed to convert compressor-map isentropic and volumetric efficiency values to power and mass flow rate, respectively

New Fan-Drive-Performance Routines —
Inverter- and Sine-Wave-Driven Induction Motors (IDIM and SWDIMs)
and Permanent-Magnet-Electronically-Commutated-Motors (PM-ECMs)

(in general order of increasing drive efficiency)

New Fan-Drive-Performance Routines — (continued)

FANFGN — computes modulating blower combined-motor-and-drive efficiency for a first generation inverter-driven system (fractional Hp size)

FANSOA — computes modulating blower combined-motor-and-drive efficiency for a state-of-the-art inverter-driven system (fractional Hp size)

FANSWV — computes modulating blower combined-motor-and-drive efficiency for a sine-wave-driven system (fractional Hp size)

ECMBLW — interpolates the combined drive/motor efficiency of a variable-frequency blower PM-ECM (12-pole) as a function of fractional full load (0.2 to 1.6 of full load) and drive speed (300 to 1300 rpm)

ECMTRQ — routine to calculate PM-ECM fan drive efficiency as a function of drive speed and air-side pressure drop (similar in function to ITRIND AND ITRECM for the compressor except that iteration is not required because blower torque is calculated directly from first principles rather than derived from required power input in the case of the compressor); also calculates required motor size if user-requested

Refrigerant-Charge-Inventory-Related Routines

(in order of occurrence in structure diagram of heat pump model)

<u>General Charge Inventory Computations</u>

INVENT — calculates total low- and high-side refrigerant mass at steady-state and equilibrium (off-cycle) conditions, prints summary of refrigerant mass in each component

ZEROCH — root-finding routine for the charge balancing outermost iteration loop of the heat pump model

GUESS1 — routine which determines two values of evaporator superheat (or condenser subcooling) which require refrigerant charges that bracket the required charge

CHARGM — function routine called by ZEROCH and GUESS1 which in turn calls the heat pump model subroutine HPDM and calculates and prints, as required, the difference in refrigerant charge between the calculated and the specified values

ACCUML — calculates refrigerant liquid level and mass in a suction line accumulator — accommodates j-tube holes at two user-specified heights

HXCHRG — general purpose routine to calculate refrigerant mass in single and two-phase sections of a tube-and-fin heat exchanger

General Charge Inventory Computations (continued)

AVEDEN general purpose routine to calculate the average liquid and vapor densities in the two-phase refrigerant regions of evaporators and condensers; uses numerical integration of void fraction method specified by MVOID (on line 4 of the HPDATA file) and an exponential heat flux assumption given by function DNORMF — except if MVOID = 0 in which case a much faster (but less accurate) analytical solution for Zivi's method with constant heat flux is used

QAGS standard FORTRAN subroutine for the computation of a definite integral, used to integrate the void fraction weighting function DWTF and the heat flux weighting function DNORMF over a range of refrigerant qualities

DWTF void-fraction weighting function which calls the user-selected void fraction model at a given refrigerant quality and weights the resultant value with the quality-dependent heat flux weighting factor

DNORMF heat flux weighting function which accounts for a variable heat flux (and therefore variable air-to-refrigerant ΔT) as a function of refrigerant quality — this includes the effect of a variable refrigerant-side heat transfer coefficient

HRTPC calculates the local condensation coefficient as a function of refrigerant quality over the range from 0.0 to 1.0

LCHTC calculates the local condensation coefficient as a function of refrigerant quality over the range from 0.05 to 0.95 using the Travis, Baron, and Rosenhow correlation for annular flow

HRTPE calculates the local evaporation coefficient as a function of refrigerant quality over the range from 0.0 to 1.0 as described in ORNL/CON-80/R1 ; also is a routine which, besides subroutine EHTC, uses the refrigerant dryout quality (increased from the 0.65 value reported in CON-80 to a present value of 0.75)

Void-Fraction Function Routines (for further information see Rice 1987, ASHRAE Transactions)

HOMOG homogenous void fraction method — assumes no vapor slip

ZIVI Zivi method (simplest slip formulation) — similar to the default method (if MVOID is set to 0 on line 4 of the HPDATA file) except that there a constant heat flux is also assumed instead of the exponentially-varying value that is applied to this and all of the following void-fraction methods

LOCKRT Lockhart-Martinelli void fraction method

THOM Thom/Ahrens void fraction method (a modified version of the Martinelli-Nelson method)

Void-Fraction Function Routines (for further information see Rice 1987, ASHRAE Transactions) (continued)

BARCZY Baroczy void fraction method

PREMOL Premoli void fraction method (mass-flux dependent), only configured at present for R22 — needs surface tension properties for use with other refrigerants)

TANDON Tandon void fraction method (mass-flux dependent)

HUGHMK Hughmark void fraction method (mass-flux dependent)

ZEROZM zero-finding routine for internal iterations required in Hughmark void fraction method

ZMATCH computes the functional values of the Hughmark void fraction method based on built-in tables

Air-Side Heat-Transfer and Pressure-Drop Correlations

Air-Side Heat Transfer

ZIGHTM calculates augmentation factor for the air-side heat transfer coefficient due to fin patternation with specific zig-zag fin designs

NUAFF used in function ZIGHTM to correct a Nussult number ratio as a function of fin spacing and Graetz number

SINTRP interpolation in a single independent variable using a three point lagrangian method (for use with function ZIGHTM)

Air-Side Pressure Drop

KLOSS calculates contraction and expansion losses entering and leaving a finned heat exchanger (based on Kays and London correlations)

ZIGPDM calculates a multiplying factor for air pressure drop of specific zig-zag fin surfaces relative to an unpatterned fin

Front-End Routines For Contour Data Generation

CONDRV main program and first-level driving routine, reads CONCHZ input data file directly and calls DATAIN to read HPDATA file, also calls CONDAT to punch general contour data files

Front-End Routines For Contour Data Generation (continued)

APFDRV	second-level driver routine, reads ambient / speed / control data file 'CONTRL' and performs selected and dual-mode ambient-vs-speed performance mapping, can punch data file of the form required for the ORNL Annual Performance Factor Model; can generate contour data sets for selected indoor and outdoor ambients and relative humidities whereas with CONCHZ users can only select ambients with a uniform grid and fixed relative humidity
SSDRV	third-level driver routine controlling the individual calls to the ORNL Modulating Heat Pump Design Model
DATAIN	modified version of original DATAIN which is now called from CONDRV and defers assignment of input values for the condenser and the evaporator to subroutine HX
HX	converts indoor and outdoor heat exchanger data from input file HPDATA into condenser and evaporator values
TRNVAL	assigns contour grid values of independent variables (defined in Table XXX) specified in CONCHZ to the appropriate program variables and performs any necessary adjustment of related parameters (such as to maintain a constant total heat exchanger area)
NEWVAL	routine that provides user-specified operational control of design variables as a function of either outdoor ambient temperature or compressor frequency
DPVLSS	saves values of steady-state dependent parameters (defined in Table YYY) computed by the heat pump model — in arrays suitable for use by CONDAT in selecting which are to be punched in output data sets
APF	(presently not included) calculates annual performance factor (APF) for set of speed versus ambient data generated by APFDRV
DPVAPF	(presently not used) saves values of seasonal performance variables computed by the ORNL Annual Performance Factor Model — in arrays suitable for use by CONDAT in selecting which are to be punched in output data sets
CONDAT	generalized routine for punching contour data sets of parameters that have been user-selected in input data set CONCHZ

All Input/Output Data Files and Default Unit Numbers (Set in BLOCK DATA)

(as identified on structure diagram of MODCON program)

Input*	Unit Numbers	Purpose
CONCHZ	5	Contour Selection Data File
HPDATA	5	Heat Pump Specification Data File
CONTRL	24 (optional)	Ambient / Speed / Control Data File For Selected and Dual-Mode Ambient-Vs-Speed Performance Mapping

Output	Unit Numbers	Purpose
PRINT	6	Program Input Echo and Output Listing of Type Selected in Data File HPDATA
APFSS	7 (optional)	Steady-State Performance Data File of the Form Required for the ORNL Annual Performance Factor Model
CONGEN	8	Contour Data Generation File of the Independent and Dependent Variables Selected in Data File CONCHZ
CONSPD	8 (optional)	Contour Data Generation File of the Independent and Dependent Variables Selected in Data File CONTRL
APFDYN	not yet in use	Dynamic Loss Data Needed along with Data File APFSS to run the ORNL Annual Performance Factor Model

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*The order of input data file calls is CONCHZ, HPDATA, then CONTRL. However, design and operating parameters set initially in HPDATA, if selected as parametric variables, are overridden in calls to routine TRNVAL, defined by the selected parametric inputs set in CONCHZ, and optionally by calls to input data file CONTRL from routine APFDRV.

APPENDIX F

DESCRIPTION OF SUBROUTINES USED FOR THE BASIC ORNL HEAT PUMP MODEL

HPDM	original main program which serves as driving program for high- and low-side computations and contains iterative loop converging on evaporator inlet air temperature
BLOCK DATA	assigns default values, values to constants, and infrequently changed parameters
CALC	calculates geometric constants for both heat exchangers
CAPTUB	refrigerant flow control model for capillary tube flow rate or sizing
CHTC	calculates refrigerant-side heat transfer coefficient for the two-phase region of the condenser
CMPMAP	computes refrigerant mass flow and compressor power consumption from compressor map data
CNDNSR	serves as driving routine for COMP, COND and FLOBAL and returns the difference between the calculated and specified condenser subcooling or between the compressor and expansion device refrigerant mass flow rates
COMP	computes refrigerant mass flow rate and compressor power consumption from efficiency and loss parameters
COND	calculates total condenser heat transfer rate, air and refrigerant properties and refrigerant and air-side pressure drops for fixed inlet refrigerant conditions
DPF	determines an approximate dew-point temperature for a given vapor pressure of moist air
DPFSOL	calculates the difference between the known saturation pressure of water vapor at the tube wall and the saturation pressure corresponding to an estimated, or given tube wall temperature
DPLINE	determines the single-phase pressure drop in the refrigerant lines
EFFCT	computes the difference in condenser effectiveness values between the general effectiveness equation and the specific cross-flow effectiveness equation as a function of the fraction of the coil, fv, containing superheated refrigerant vapor

EHTC	calculates refrigerant-side heat transfer coefficient for the two-phase region of the evaporator
EVAP	determines the heat transfer, moisture removal, outlet air temperatures and humidities from one circuit of the evaporator for given heat transfer coefficients and saturation temperatures at the beginning and end of the two-phase region
EVAPR	calculates evaporator heat transfer rate, air and refrigerant properties, and refrigerant and air-side pressure drops for fixed exit refrigerant conditions
EVPTR	serves as a driving routine for EVAPR and returns the difference between the specified evaporator superheat and the calculated value
EXCH	determines the heat transfer and outlet temperatures for one circuit of the condenser for given heat transfer coefficients and saturation temperatures at the beginning and end of the two-phase region
EXF	determines the effectiveness of a cross-flow heat exchanger using the effectiveness — NTU method
FANFIT	calculates combined fan-fan motor efficiency given air-side pressure drop and volumetric air-flow rate
FLOBAL	determines refrigerant conditions at the inlet to the flow control device and drives the expansion device models
FRICT	computes the general Moody friction factor for single phase flow in tubes
GUESS2	brackets a solution prior to using a root finder by shifting end points by factors of 10
GUESS3	brackets a solution prior to using a root finder by shifting end points by constant step
INTER	interpolate in a single dimension using Lagrangian polynomial
HAIR	computes air-side heat transfer coefficient for smooth fin and tube geometry
MUKCP	calculates viscosity, thermal conductivity, and specific heat of 14 refrigerants
MUKCPA	calculates viscosity, thermal conductivity, and specific heat of air
ORIFIC	refrigerant flow control model for computing the refrigerant mass flow rate or sizing of a short-tube orifice
OUTPUT	prints a detailed summary of output data

PDAIR	calculates air-side pressure drop for smooth, wavy, or louvered fin-and-tube heat exchangers
PDROP	determines single- and two-phase pressure drops for flow in heat exchanger tubes
PVSF	calculates partial pressure of water vapor in saturated air
SATPRP	evaluates the saturation thermodynamic properties of a specified refrigerant
SEFF	determines surface efficiency for a hexagonal shaped fin surface
SLAG	computes single-precision Lagrangian interpolation in two dimensions from tabulated data
SPFHT	calculates refrigerant specific heats at constant pressure and volume and specific heat ratio
SPHTC	computes single-phase heat transfer coefficient for laminar, transition, or turbulent gas flow from an abrupt contraction entrance
SPHTC2	computes single-phase heat transfer coefficient for fully developed liquid or gas flow
SPVOL	evaluates specific volume of superheated refrigerant
SUPCOR	calculates power and mass flow correction factors for map-based compressor model to correct for superheat level
TABLES	assigns constants for selected refrigerant for use in the thermodynamic property subroutines
TAOSOL	computes the exit air temperature from the region of the evaporator where moisture removal occurs
TRIAL	determines thermodynamic properties of superheated refrigerant vapor given two known properties
TSAT	calculates saturation temperature of refrigerant given saturation pressure
TWISOL	used to compute the wall temperature at which moisture removal begins on the leading edge of the evaporator
TWOSOL	used to compute the wall temperature at the exit from the evaporator
TXV	refrigerant flow control model for computing the refrigerant mass flow rate or sizing for a thermostatic expansion valve

VAPOR	determines thermodynamic properties of superheated refrigerant vapor given temperature and pressure
WBF	determines wet-bulb temperature of moist air
WTSFIT	computes coefficients for a quadratic fit of wall temperature to enthalpy of moist air
XMOIST	calculates dew point temperature, humidity ratio enthalpy, and wet-bulb temperature or relative humidity of moist air
ZERO's	each of these routines solves for the root, or zero, of a function from two points which bracket the solution using bisection and Newton's method

APPENDIX G

COMPRESSOR-MAP-FITTING PROGRAM 'MAPFIT'

This program is used to generate the compressor map performance coefficients for use with the model. The program requires power and mass flow rate (or capacity) data as a function of saturated condensing and evaporating temperatures (MAPIN.DAT). The resulting sets of coefficients represent biquadratic representations of power and mass flow rate as a function of saturation temperatures. Alternative representations of isentropic efficiency as a function of saturation temperature and volumetric efficiency as a function of discharge pressure and pressure ratio can also be generated by proper setting of the input options.

This version of MAPFIT can process compressor data for single or multiple speeds. The program can also accept map data where either the superheat or return gas temperature is specified and it can convert the data to another user-specified superheat level prior to the curve fitting.

In addition to an output listing (MAPOUT.DAT) showing the results of the curve fitting for a sample case, a file is generated (MAPCOEF.DAT) of the form needed for insertion into the heat pump specification data file 'HPDATA' given in Table B.1 for lines 9.0–9.7.

Input Data Definitions and Format

Listing G.1 describes the specific input data and format requirements for single- or variable-speed data sets. A number of input switches are provided to identify the type of compressor data provided and the type of curve fits and data conversions desired.

Sample Input File (Regular and Annotated)

A sample MAPFIT input file for a single-speed compressor is given in Listing G.2 followed by an annotated version in Listing G.3 which includes the input variable names referenced in Listing G.1.

Sample Output Listing and File (Regular and Annotated)

A sample of the tabular output from the program is given in Listing G.4 where the input map data are echoed followed by tables and summary statistics comparing the calculated values for power, mass flow, isentropic, and volumetric efficiency with those from the biquadratic curve fit representation. Last, the output file generated by the program for use as input to the heat pump model is described in Listing G.5 with actual and annotated versions of the sample file given in Listings G.6 and G.7.

Listing G.1. Input Format Description for MAPFIT Program

```
                         INPUT DESCRIPTION FOR PROGRAM MAPFIT


C      Program To —
C         1) GENERATE and PUNCH COEFFICIENTS of the form
C            needed for the ORNL Modulating Heat Pump Design Model
C         2) TABULATE CURVE FITTING RESULTS For Power and Mass Flow Rates,
C            Isentropic And Volumetric Efficiencies
C         3) COMPARE CURVE FITTING OPTIONS For Most Accurately Representing
C            Isentropic And Volumetric Efficiencies
C
C      ** Free-Format Input (Except For Title Lines)
C
C**
C**  PROGRAM BEGINS WITH INTERACTIVE QUERIES FOR INPUT AND OUTPUT FILE NAMES
C
C   ***** SPECIFY Input and Output Filenames ***********
C
          The default names for input/output files are:
            MAPIN.DAT   - Input file for the curve-fitting program,
            MAPOUT.DAT  - Echo-printed input plus curve fit results, and
            MAPCOEF.DAT - Curve-fit coefs in the format used by the HPDATA file

          Any of these file names can be interactively redefined
          at the start of the program.

C
C               **  FORMAT OF DEFAULT INPUT FILE — MAPIN.DAT **
C
C   READ OPTIONS-SELECTION-DATA
C
C**Line 1 - Free Format
C
          READ(IOREAD,*) NHZ,MPOW,MCAP,MODEDT,MCOMPT,MSUPER
C
C      NHZ     - Number Of Frequencies For Which Pairs Of Power
C                and Capacity Data
C                (or Power and Mass Flow Rate Data) Are To Be Provided
                 (MAXIMUM OF 10 FREQUENCIES)
C      MPOW    - identifier for first input map data set
C                =1, to identify data as power in watts
C                =2, to identify data as power in Kw
C      MCAP    - identifier for second input map data set
C                =1, to identify data as capacity (KBTU/H)
C                =2, to identify data as mass flow rate (LBM/H)
C      MODEDT  - Type Of Curve Fits To Be Performed, Corresponds To MODEDT
C                on Card #9.1 Of Heat Pump Data Specification File —
C                =1, to specify curve fits to compressor power
C                    and refrigerant mass flow rate
C                =2, to specify curve fits to compressor-shell isentropic-
C                    and volumetric-efficiencies
```

```
C     MCOMPT - Switch to select if compressor efficiency test tabulation
C              is to be generated —
C              =1, to generate compressor efficiency test tabulation
C              =2, to omit compressor efficiency test tabulation
C     MSUPER - Switch to identify if map data is to be converted
C              to new superheat level
C              = 0, no conversion
C              > 0, conversion to specified superheat value
C
C              The following value is read interactively if MSUPER >0 :
C
C              SUPERN - Superheat to which map data is to be converted
C              >= 0, degrees of superheat (F deg)
C              <  0, negative of desired return gas temperature (deg F)
C
C
C**Line 2 - FORMAT(A80)
C
        READ (IOREAD,1001) TITLED
1001    FORMAT(A80)
C
C     TITLED - Title to be used for identifying line CTITLE
C              for Map-Coefficients Data Set for transfer
C              into a HPDATA file for the MODCON program
C
->> FOR EACH DRIVE FREQUENCY

C  READ FREQUENCY DEPENDENT AND REFERENCE COMPRESSOR DATA
C
C**Line 3 - FORMAT(A80)
C**Line 4 - FORMAT(A80)
C
        READ(IOREAD,1001) BLANK
        READ(IOREAD,1001) TITLE
C
C     BLANK - Blank Line To Identifying Start Of Compressor Data
              For A New Freq.
C     TITLE - Title To Be Used For Identifying Compressor Data
              For A Given Freq.
C
C
C**Line 5 - Free Format
C**Line 6 - Free Format
C**Line 7 - Free Format
C
        READ(IOREAD,*) HZVAL,RPMVAL,VLTVAL
        READ(IOREAD,*) CFRQNB,CSIZMB,CVLTNB
        READ(IOREAD,*) NR,DISPLB,SUPERB,SUBCLB
C
```

```
C     The Following Input Data Are Defined Consistent With Lines 9.2 And 9.3
C     Of The HPDATA Input
C
C     MAP DATA AT SPECIFIED COMPRESSOR FREQUENCY
C
C     HZVAL - compressor frequency value (Hz) for which map data follow,
C     RPMVAL - nominal compressor speed at given frequency (rpm)
C             (only used for volumetric efficiency calculations)
C     VLTVAL - compressor motor voltage (V) at specified frequency
C             for which map data apply   only used for induction motors
C
C     MAP DATA AT RATED COMPRESSOR FREQUENCY
C
C     CFRQNB - nominal frequency for base motor rating (Hz)
C     CSIZMB - motor size rating  of base compressor (Hp)
C     CVLTNB - nominal voltage   for base motor rating (Volts)
C             - only used for induction motors
C
C     REFRIGERANT-RELATED COMPRESSOR MAP DATA
C
C     NR     - Refrigerant for which compressor map applies
C             -12,134(a),22,114, or 502
C     DISPLB - Compressor displacement (cu in)
C     SUPERB - Compressor inlet superheat for the compressor map data —
C              >= 0, degrees of superheat (F deg)
C              <  0, negative of desired return gas temperature (deg F)
C     SUBCLB - Condenser subcooling (F deg) for the compressor map data —
C             used only if capacity data needs to be converted
C             to refrigerant mass flow rates
C
C
C  READ GRID DESCRIPTION OF AVAILABLE DATA
C
C**Line  8 - Free Format
C**Line  9 - Free Format
C**Line 10 - Free Format

C   XNX    - Number Of Condensing  Temps For Which Map Data Are To Be Provided
C            (MAXIMUM OF 12)
C   XNY    - Number Of Evaporating Temps For Which Map Data Are To Be Provided
C            (MAXIMUM OF 12)
C   TSATC - Values of Condensing  Temps I= 1,XNX (deg F)
C   TSATE - Values of Evaporating Temps I= 1,XNY (deg F)
C
      READ(IOREAD,*) XNX,XNY
      NX=XNX
      NY=XNY
      READ(IOREAD,*) (TSATC(I),I=1,NX)
      READ(IOREAD,*) (TSATE(J),J=1,NY)
C
C
```

```
C  READ DATA FOR COMPRESSOR POWER CONSUMPTION
C
C**Line 11 - FORMAT(A80)
C**Line 12 - Free Format
C**Line 13 - Free Format
C
C   TITLE1- Title To Be Used For Identifying POWER Data At A Given Frequency
C   POWER - Values of Compressor Power (In Watts or kWatts)
C           - Determined By The Value Of The Variable MPOW On Line 2 -
C           To Be Given By Increasing Evaporating Temp TSATE
C           For Each Level Of Condensing Temperature TSATC
C   WGHT1 - Corresponding Curve Fitting Weighting Factors For Each
C           Map Data Point
C
        READ(IOREAD,1001) TITLE1
        DO 10 I=1,NX
        READ(IOREAD,*) (POWER(J,I),J=1,NY)
10      CONTINUE
        DO 20 I=1,NX
20      READ(IOREAD,*) (WGHT1(J,I),J=1,NY)
C
C  READ DATA FOR REFRIGERANT MASS FLOW RATE OR CAPACITY.
C
C**Line 14 - FORMAT(A80)
C**Line 15 - Free Format
C**Line 16 - Free Format
C
C   TITLE2 - Title To Be Used For Identifying Refrigerant Mass Flow Rate
C           Or Capacity Data At A Given Frequency
C   XMR   - Values of Refrigerant Mass Flow Rate Or Capacity (lbm/h or kBtuh)
C           - Determined By The Value Of The Variable MCAP On Line 2 -
C           To Be Given By Increasing Evaporating Temp TSATE
C           For Each Level Of Condensing Temperature TSATC
C   WGHT2 - Corresponding Curve Fitting Weighting Factors For Each
C           Map Data Point
C
        READ(IOREAD,1001) TITLE2
        DO 40 I=1,NX
        READ(IOREAD,*) (XMR(J,I),J=1,NY)
40      CONTINUE
        DO 50 I=1,NX
50      READ(IOREAD,*) (WGHT2(J,I),J=1,NY)

->> REPEAT ABOVE DATA FOR NEXT DRIVE FREQUENCY
```

Listing G.2. Sample Input File for MAPFIT Program

FILE: MAPIN.DAT

```
1 1 2 1 1 0
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, HEATING MODE DATA

SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA
60.     3450.   240.
60.     2.75    240.
R-22    3.64    10.     15.
    4.0000   12.000
    80.000   90.000    100.00    110.00
    -20.00   -15.00    -10.00    -5.000    0.0000    5.0000
    10.000   15.000    20.000    25.000    30.000    35.000
SAMPLE MAP DATA FOR POWER CONSUMPTION (W) FOR HEATING MODE OPERATION
    1467.4   1605.0    1725.2    1860.6    1980.8    2092.3
    2195.1   2293.5    2381.1    2464.4    2538.9    2606.9
    1454.4   1598.5    1731.7    1871.5    2002.5    2124.9
    2236.4   2345.7    2442.0    2536.1    2621.5    2698.2
    1439.2   1587.6    1740.4    1888.9    2028.6    2164.0
    2295.1   2417.4    2531.1    2644.8    2743.2    2841.7
    1419.6   1583.3    1751.3    1910.6    2063.4    2216.2
    2358.1   2500.1    2635.5    2768.7    2886.7    3000.4
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
SAMPLE MAP DATA FOR MASS FLOW RATE (LBM/HR) FOR HEATING MODE OPERATION
    87.926   108.84    131.94    160.48    189.55    224.63
    263.50   306.73    355.40    410.06    467.43    534.06
    80.308   100.13    123.77    152.32    181.94    217.01
    253.71   293.67    339.08    387.75    438.05    495.43
    71.602   91.430    115.07    142.52    171.05    204.49
    241.19   280.06    323.30    371.42    421.18    476.38
    62.349   83.268    106.36    133.82    161.80    194.70
    230.31   266.46    308.61    353.47    399.41    452.44
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000   1.0000    1.0000    1.0000    1.0000    1.0000
```

Listing G.3. Sample Input File for MAPFIT Program — Annotated

```
File: MAPIN.DAT

Options Selection
NHZ MPOW MCAP MODEDT MCOMPT MSUPER
1     1     2     1       1       0
TITLED
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, HEATING MODE DATA

(Data for each speed repeats from here)
Frequency Dependent And Reference Compressor Data

Blank Line

TITLE
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA

Map Data At Specified Compressor Frequency
HZVAL  RPMVAL VLTVAL
60.     3450.   240.
Map Data At Base Compressor Frequency
CFRQNB CSIZMB CVLTNB
60.     2.75    240.
Refrigerant-Related Compressor Map Data
NR   DISPLB SUPERB SUBCLB
R-22    3.64    10.     15.
Grid Definition Of Available Data
   XNX(<13) XNY(<13)
    4.0000    12.000
    TSATC (I=1,XNX)
    80.000    90.000    100.00    110.00
    TSATE (J=1,XNY)
    -20.00    -15.00    -10.00    -5.000    0.0000    5.0000
    10.000    15.000    20.000    25.000    30.000    35.000
```

Listing G.3. Sample Input File for MAPFIT Program — Annotated (continued)

```
Data For Compressor Power Consumption

TITLE1 (for power data)
SAMPLE MAP DATA FOR POWER CONSUMPTION (W) FOR HEATING MODE OPERATION
Power Data (W or kW as selected by MPOW on line 1)
POWER(XNY,1)
    1467.4    1605.0    1725.2    1860.6    1980.8    2092.3
    2195.1    2293.5    2381.1    2464.4    2538.9    2606.9
POWER(XNY,2)
    1454.4    1598.5    1731.7    1871.5    2002.5    2124.9
    2236.4    2345.7    2442.0    2536.1    2621.5    2698.2
POWER(XNY,3)
    1439.2    1587.6    1740.4    1888.9    2028.6    2164.0
    2295.1    2417.4    2531.1    2644.8    2743.2    2841.7
POWER(XNY,XNX)
    1419.6    1583.3    1751.3    1910.6    2063.4    2216.2
    2358.1    2500.1    2635.5    2768.7    2886.7    3000.4
Weighting Data
WGHT1(XNY,1)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT1(XNY,2)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT1(XNY,3)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT1(XNY,XNX)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

Listing G.3. Sample Input File for MAPFIT Program — Annotated (continued)

```
Data For Refrigerant Mass Flow Rate Or Capacity

TITLE2 (for mass flow data)
SAMPLE MAP DATA FOR MASS FLOW RATE (LBM/HR) FOR HEATING MODE OPERATION
Mass Flow(lbm/h) or Capacity(kBtuh) Data
(as selected by MCAP on line 1)
XMR(XNY,1)
    87.926    108.84    131.94    160.48    189.55    224.63
    263.50    306.73    355.40    410.06    467.43    534.06
XMR(XNY,2)
    80.308    100.13    123.77    152.32    181.94    217.01
    253.71    293.67    339.08    387.75    438.05    495.43
XMR(XNY,3)
    71.602    91.430    115.07    142.52    171.05    204.49
    241.19    280.06    323.30    371.42    421.18    476.38
XMR(XNY,XNX)
    62.349    83.268    106.36    133.82    161.80    194.70
    230.31    266.46    308.61    353.47    399.41    452.44
Weighting Data
WGHT2(XNY,1)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT2(XNY,2)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT2(XNY,3)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
WGHT2(XNY,XNX)
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000

Repeat data for additional speeds (N=1,NHZ)
```

Listing G.4. Sample Output Listing for MAPFIT Program

FILE: MAPOUT.DAT

SAMPLE SINGLE-SPEED RECIP COMPRESSOR, HEATING MODE DATA

SAMPLE MAP DATA FOR POWER CONSUMPTION (W) FOR HEATING MODE OPERATION
INPUT DATA FOR MAP COMPRESSOR POWER CONSUMPTION:

```
MOTOR DRIVE FREQUENCY        60.0 HZ
MOTOR NOMINAL SPEED        3450.0 RPM
MOTOR VOLTAGE               240.0 VOLTS
REFRIGERANT                  R-22
COMPRESSOR DISPLACEMENT    3.6400 CU IN
MAP SUBCOOLING VALUE        15.00 F
MAP SUPERHEAT  VALUE        10.00 F
```

COMPRESSOR POWER CONSUMPTION INPUT DATA IS IN WATTS — IT HAS BEEN CONVERTED TO KILOWATTS

EVAPORATING TEMPERATURE (F)		CONDENSING TEMPERATURE (F) 80.00	90.00	100.00	110.00
-20.0	I DATA	1.4674	1.4544	1.4392	1.4196
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
-15.0	I DATA	1.6050	1.5985	1.5876	1.5833
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
-10.0	I DATA	1.7252	1.7317	1.7404	1.7513
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
-5.0	I DATA	1.8606	1.8715	1.8889	1.9106
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
.0	I DATA	1.9808	2.0025	2.0286	2.0634
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
5.0	I DATA	2.0923	2.1249	2.1640	2.2162
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
10.0	I DATA	2.1951	2.2364	2.2951	2.3581
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
15.0	I DATA	2.2935	2.3457	2.4174	2.5001
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
20.0	I DATA	2.3811	2.4420	2.5311	2.6355
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
25.0	I DATA	2.4644	2.5361	2.6448	2.7687
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
30.0	I DATA	2.5389	2.6215	2.7432	2.8867
	I WEIGHT	1.0000	1.0000	1.0000	1.0000
35.0	I DATA	2.6069	2.6982	2.8417	3.0004
	I WEIGHT	1.0000	1.0000	1.0000	1.0000

Listing G.4. Sample Output Listing for MAPFIT Program (continued)

```
SAMPLE MAP DATA FOR MASS FLOW RATE (LBM/HR) FOR HEATING MODE OPERATION
INPUT (OR DERIVED) DATA FOR REFRIGERANT MASS FLOW RATE:

MOTOR DRIVE FREQUENCY         60.0 HZ
MOTOR NOMINAL SPEED         3450.0 RPM
MOTOR VOLTAGE                240.0 VOLTS
REFRIGERANT                    R-22
COMPRESSOR DISPLACEMENT     3.6400 CU IN
MAP SUBCOOLING VALUE         15.00 F
MAP SUPERHEAT  VALUE         10.00 F


EVAPORATING          CONDENSING TEMPERATURE (F)
TEMPERATURE (F)         80.00       90.00      100.00      110.00
_______________      _________   _________   _________   _________
-20.0 I DATA           87.9260     80.3080     71.6020     62.3490
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
-15.0 I DATA          108.8400    100.1300     91.4300     83.2680
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
-10.0 I DATA          131.9400    123.7700    115.0700    106.3600
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 -5.0 I DATA          160.4800    152.3200    142.5200    133.8200
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
   .0 I DATA          189.5500    181.9400    171.0500    161.8000
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
  5.0 I DATA          224.6300    217.0100    204.4900    194.7000
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 10.0 I DATA          263.5000    253.7100    241.1900    230.3100
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 15.0 I DATA          306.7300    293.6700    280.0600    266.4600
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 20.0 I DATA          355.4000    339.0800    323.3000    308.6100
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 25.0 I DATA          410.0600    387.7500    371.4200    353.4700
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 30.0 I DATA          467.4300    438.0500    421.1800    399.4100
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
 35.0 I DATA          534.0600    495.4300    476.3800    452.4400
      I WEIGHT          1.0000      1.0000      1.0000      1.0000
```

Listing G.4. Sample Output Listing for MAPFIT Program (continued)

```
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA
POWER CONSUMPTION (KW)
COEFFICIENTS FOR BI-QUADRATIC FIT:

 F(X,Y)= 6.6604E-05*X*X + -9.4360E-03*X   + -1.2626E-04*Y*Y +  6.1468E-04*Y   +
2.7157E-04*X*Y +  2.3063E+00
```

EVAPORATING TEMPERATURE (F)		CONDENSING TEMPERATURE (F) 80.00	90.00	100.00	110.00
-20.0	I FIT	1.4804	1.4449	1.4228	1.4140
	I MAP	1.4674	1.4544	1.4392	1.4196
	I %	.8856	-.6499	-1.1381	-.3934
-15.0	I FIT	1.6142	1.5923	1.5838	1.5885
	I MAP	1.6050	1.5985	1.5876	1.5833
	I %	.5728	-.3864	-.2409	.3315
-10.0	I FIT	1.7417	1.7334	1.7384	1.7568
	I MAP	1.7252	1.7317	1.7404	1.7513
	I %	.9551	.0974	-.1139	.3123
-5.0	I FIT	1.8628	1.8681	1.8867	1.9187
	I MAP	1.8606	1.8715	1.8889	1.9106
	I %	.1209	-.1796	-.1140	.4228
.0	I FIT	1.9777	1.9966	2.0288	2.0743
	I MAP	1.9808	2.0025	2.0286	2.0634
	I %	-.1561	-.2958	.0081	.5269
5.0	I FIT	2.0863	2.1187	2.1645	2.2236
	I MAP	2.0923	2.1249	2.1640	2.2162
	I %	-.2889	-.2917	.0216	.3319
10.0	I FIT	2.1885	2.2345	2.2939	2.3665
	I MAP	2.1951	2.2364	2.2951	2.3581
	I %	-.3012	-.0844	-.0542	.3572
15.0	I FIT	2.2844	2.3440	2.4169	2.5032
	I MAP	2.2935	2.3457	2.4174	2.5001
	I %	-.3964	-.0720	-.0193	.1232
20.0	I FIT	2.3740	2.4472	2.5337	2.6335
	I MAP	2.3811	2.4420	2.5311	2.6355
	I %	-.2976	.2128	.1027	-.0750
25.0	I FIT	2.4573	2.5441	2.6442	2.7576
	I MAP	2.4644	2.5361	2.6448	2.7687
	I %	-.2877	.3142	-.0246	-.4026
30.0	I FIT	2.5343	2.6346	2.7483	2.8753
	I MAP	2.5389	2.6215	2.7432	2.8867
	I %	-.1816	.5008	.1855	-.3960
35.0	I FIT	2.6050	2.7189	2.8461	2.9867
	I MAP	2.6069	2.6982	2.8417	3.0004
	I %	-.0745	.7663	.1553	-.4575

```
THE MAXIMUM % VARIATION FROM THE MAP VALUE                                1.1381
THE WEIGHTED AVERAGE OF THE ABSOLUTE VALUES OF THE % VARIATIONS            .3058
THE WEIGHTED AVERAGE OF THE % VARIATIONS                                  -.0014
THE STANDARD DEVIATION FROM THE AVERAGE % VARIATION                        .3980
```

Listing G.4. Sample Output Listing for MAPFIT Program (continued)

```
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA
 MASS FLOW RATE (LB/H)
 COEFFICIENTS FOR BI-QUADRATIC FIT:

  F(X,Y)= 4.3090E-03*X*X + -1.9373E+00*X    +  7.1893E-02*Y*Y +  9.2904E+00*Y    + -
3.0419E-02*X*Y +  3.2045E+02
```

EVAPORATING TEMPERATURE (F)		CONDENSING TEMPERATURE (F) 80.00	90.00	100.00	110.00
-20.0	I FIT	84.6637	78.6994	73.5970	69.3563
	I MAP	87.9260	80.3080	71.6020	62.3490
	I %	-3.7103	-2.0030	2.7862	11.2388
-15.0	I FIT	106.3667	98.8815	92.2581	86.4965
	I MAP	108.8400	100.1300	91.4300	83.2680
	I %	-2.2724	-1.2469	.9057	3.8772
-10.0	I FIT	131.6644	122.6583	114.5139	107.2313
	I MAP	131.9400	123.7700	115.0700	106.3600
	I %	-.2089	-.8982	-.4833	.8192
-5.0	I FIT	160.5568	150.0297	140.3643	131.5608
	I MAP	160.4800	152.3200	142.5200	133.8200
	I %	.0478	-1.5036	-1.5125	-1.6882
.0	I FIT	193.0438	180.9957	169.8095	159.4850
	I MAP	189.5500	181.9400	171.0500	161.8000
	I %	1.8432	-.5190	-.7252	-1.4308
5.0	I FIT	229.1255	215.5565	202.8492	191.0038
	I MAP	224.6300	217.0100	204.4900	194.7000
	I %	2.0013	-.6698	-.8024	-1.8984
10.0	I FIT	268.8018	253.7118	239.4837	226.1173
	I MAP	263.5000	253.7100	241.1900	230.3100
	I %	2.0121	.0007	-.7075	-1.8205
15.0	I FIT	312.0728	295.4619	279.7128	264.8254
	I MAP	306.7300	293.6700	280.0600	266.4600
	I %	1.7419	.6102	-.1240	-.6134
20.0	I FIT	358.9385	340.8066	323.5365	307.1283
	I MAP	355.4000	339.0800	323.3000	308.6100
	I %	.9956	.5092	.0732	-.4801
25.0	I FIT	409.3988	389.7460	370.9550	353.0257
	I MAP	410.0600	387.7500	371.4200	353.4700
	I %	-.1612	.5148	-.1252	-.1257
30.0	I FIT	463.4538	442.2800	421.9681	402.5179
	I MAP	467.4300	438.0500	421.1800	399.4100
	I %	-.8507	.9657	.1871	.7781
35.0	I FIT	521.1035	498.4088	476.5758	455.6047
	I MAP	534.0600	495.4300	476.3800	452.4400
	I %	-2.4260	.6012	.0411	.6995

```
 THE MAXIMUM % VARIATION FROM THE MAP VALUE                               11.2388
 THE WEIGHTED AVERAGE OF THE ABSOLUTE VALUES OF THE % VARIATIONS           1.2970
 THE WEIGHTED AVERAGE OF THE % VARIATIONS                                   .0884
 THE STANDARD DEVIATION FROM THE AVERAGE % VARIATION                       2.1667
```

Listing G.4. Sample Output Listing for MAPFIT Program (continued)

```
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA

COMPARISON TABLE OF VALUES DERIVED FROM POWER / MASS FLOW CURVE FITS VERSUS DATA-BASED
(MAP) VALUES

 ISENTROPIC EFFICIENCY

 EVAPORATING         CONDENSING TEMPERATURE (F)
 TEMPERATURE (F)       80.00      90.00      100.00     110.00
 _______________     _________  _________  _________  _________
 -20.0 I CAL           .3467      .3592      .3680      .3739
       I MAP           .3633      .3642      .3540      .3348
       I I %         -4.5555    -1.3619     3.9695    11.6782
 -15.0 I CAL           .3737      .3850      .3911      .3929
       I MAP           .3846      .3883      .3867      .3795
       I I %         -2.8289     -.8638     1.1494     3.5340
 -10.0 I CAL           .4001      .4115      .4166      .4164
       I MAP           .4047      .4156      .4182      .4143
       I I %         -1.1530     -.9947     -.3698      .5053
  -5.0 I CAL           .4244      .4370      .4423      .4415
       I MAP           .4247      .4428      .4486      .4509
       I I %          -.0730    -1.3264    -1.4002    -2.1021
    .0 I CAL           .4457      .4604      .4669      .4664
       I MAP           .4369      .4614      .4703      .4756
       I I %          2.0024     -.2238     -.7333    -1.9475
   5.0 I CAL           .4633      .4808      .4893      .4900
       I MAP           .4529      .4826      .4934      .5011
       I I %          2.2968     -.3792     -.8238    -2.2229
  10.0 I CAL           .4766      .4977      .5088      .5114
       I MAP           .4658      .4972      .5122      .5227
       I I %          2.3203      .0852     -.6537    -2.1699
  15.0 I CAL           .4852      .5105      .5250      .5301
       I MAP           .4750      .5070      .5255      .5340
       I I %          2.1468      .6827     -.1047     -.7357
  20.0 I CAL           .4886      .5189      .5373      .5455
       I MAP           .4824      .5174      .5375      .5478
       I I %          1.2971      .2958     -.0295     -.4054
  25.0 I CAL           .4866      .5225      .5455      .5574
       I MAP           .4860      .5215      .5461      .5559
       I I %           .1269      .1999     -.1006      .2781
  30.0 I CAL           .4788      .5211      .5493      .5655
       I MAP           .4820      .5187      .5493      .5589
       I I %          -.6703      .4625      .0016     1.1788
  35.0 I CAL           .4648      .5143      .5485      .5695
       I MAP           .4760      .5152      .5491      .5630
       I I %         -2.3533     -.1638     -.1140     1.1623


 THE MAXIMUM % VARIATION FROM THE MAP VALUE                             11.6782
 THE WEIGHTED AVERAGE OF THE ABSOLUTE VALUES OF THE % VARIATIONS         1.3799
 THE WEIGHTED AVERAGE OF THE % VARIATIONS                                 .0940
 THE STANDARD DEVIATION FROM THE AVERAGE % VARIATION                     2.3264
```

Listing G.4. Sample Output Listing for MAPFIT Program (continued)

SAMPLE SINGLE-SPEED RECIP COMPRESSOR, 60 HZ CALORIMETER DATA

COMPARISON TABLE OF VALUES DERIVED FROM POWER / MASS FLOW CURVE FITS VERSUS DATA-BASED (MAP) VALUES

VOLUMETRIC EFFICIENCY

EVAPORATING TEMPERATURE (F)		CONDENSING TEMPERATURE (F) 80.00	90.00	100.00	110.00
-20.0	I CAL	.4153	.3861	.3610	.3402
	I MAP	.4313	.3940	.3513	.3059
	I I %	-3.7103	-2.0030	2.7862	11.2389
-15.0	I CAL	.4685	.4355	.4063	.3810
	I MAP	.4794	.4410	.4027	.3667
	I I %	-2.2724	-1.2469	.9057	3.8772
-10.0	I CAL	.5219	.4862	.4539	.4251
	I MAP	.5230	.4906	.4562	.4216
	I I %	-.2089	-.8982	-.4833	.8192
-5.0	I CAL	.5742	.5366	.5020	.4705
	I MAP	.5740	.5448	.5097	.4786
	I I %	.0478	-1.5036	-1.5125	-1.6882
.0	I CAL	.6244	.5854	.5492	.5158
	I MAP	.6131	.5884	.5532	.5233
	I I %	1.8432	-.5190	-.7253	-1.4308
5.0	I CAL	.6716	.6318	.5946	.5599
	I MAP	.6584	.6361	.5994	.5707
	I I %	2.0013	-.6698	-.8024	-1.8984
10.0	I CAL	.7156	.6754	.6375	.6020
	I MAP	.7015	.6754	.6421	.6131
	I I %	2.0121	.0007	-.7075	-1.8205
15.0	I CAL	.7560	.7158	.6776	.6416
	I MAP	.7431	.7115	.6785	.6455
	I I %	1.7419	.6102	-.1240	-.6134
20.0	I CAL	.7929	.7528	.7147	.6784
	I MAP	.7850	.7490	.7141	.6817
	I I %	.9956	.5092	.0732	-.4801
25.0	I CAL	.8260	.7864	.7485	.7123
	I MAP	.8274	.7824	.7494	.7132
	I I %	-.1612	.5148	-.1252	-.1257
30.0	I CAL	.8557	.8166	.7791	.7432
	I MAP	.8630	.8088	.7776	.7374
	I I %	-.8506	.9657	.1871	.7781
35.0	I CAL	.8818	.8434	.8065	.7710
	I MAP	.9038	.8384	.8062	.7656
	I I %	-2.4260	.6012	.0411	.6995

THE MAXIMUM % VARIATION FROM THE MAP VALUE	11.2389
THE WEIGHTED AVERAGE OF THE ABSOLUTE VALUES OF THE % VARIATIONS	1.2970
THE WEIGHTED AVERAGE OF THE % VARIATIONS	.0884
THE STANDARD DEVIATION FROM THE AVERAGE % VARIATION	2.1667

Listing G.5. Output Format Description for MAPFIT Program

```
C     ** DATA FORMAT OF MAP-FIT COEFFICIENTS FOR TRANSFER TO HPDATA FILE **
C
C        SET DEFAULT VALUES FOR PARAMETERS NOT PROVIDED IN MAPIN.DAT
C
C        For Definitions of the Following DEFAULTS,
C        Refer to Line 9.1 Of The HPDATA Input Description, Table B.1
C
         ICMPDT = 2
         ICDVCH = 2
         CSIZMT = CSIZMB
         CFRQNM = CFRQNB
         CVLTNM = CVLTNB
         CVLHZM = 1.0
         ADJ1 = 1.0
         ADJ2 = 1.0

C         Besides the selected value for MODEDT,
C         Line 9.1 also requires values for — ICMPDT, ICDVCH, CSIZMT, CFRQNM,
C         CVLTNM, and CVLHZM. These additional data, defined in Table B.1,
C         identify both the base and selected compressor maps as to drive type
C         and the nominal characteristics of the selected compressor drive.
C
         WRITE(IODATA,1001) TITLED
         WRITE(IODATA,1211) MODEDT,ICMPDT,ICDVCH,
      &                     CSIZMT,CFRQNM,CVLTNM,CVLHZM
         WRITE(IODATA,1210) NHZ, DISPLB, SUPERN,
      &                     CSIZMB,CFRQNB,CVLTNB
C
->> FOR EACH DRIVE FREQUENCY

         WRITE(IODATA,1209) HZVAL, RPMVAL, VLTVAL, ADJ1, ADJ2

    ->IF MODEDT = 1

C        PUNCH CURVE-FIT COEFFICIENTS FOR POWER AND MASS FLOW RATE
C        IN THE FORM READ BY ORNL HEAT PUMP MODEL
C
         WRITE(IODATA,1208) (CPOWER(I,IHZ),I=1,6)
         WRITE(IODATA,1208) (CMASSF(I,IHZ),I=1,6)
C
    ->IF MODEDT = 2
C
C        PUNCH CURVE FIT COEFFICIENTS FOR ISENTROPIC AND VOLUMETRIC
         EFFICIENCIES
C        IN FORM READ BY ORNL HEAT PUMP MODEL
C
         WRITE(IODATA,1208) (CETAIS(I,IHZ),I=1,6)
         WRITE(IODATA,1208) (CETAVL(I,IHZ),I=1,4)
C
C  Note: The data file punched to file MAPCOEF.DAT or the user-named
C  alternative file can be inserted as Lines 9.0 - 9.7 of the HPDATA file as
C  described in Table B.1 of Appendix B of the ORNL MODCON User's Guide.

C  Only Line 9.1 may need adjustment by the user of the default values
C  depending on what type of compressor drive and displacement the user
```

Listing G.6. Sample Output File for MAPFIT Program

```
FILE: MAPCOEF.DAT

*** SAMPLE OUTPUT DATA FILE FROM ORNL MAPFIT PROGRAM
    IN FORMAT NEEDED FOR USE IN ORNL HEAT PUMP DATA INPUT


SAMPLE SINGLE-SPEED RECIP COMPRESSOR, HEATING MODE DATA
        1         2         2    2.7500   60.0000  240.0000    1.0000
        1    3.6400   10.0000    2.7500   60.0000  240.0000
  60.0000 3450.0000  240.0000    1.0000    1.0000
 6.660E-05-9.436E-03-1.263E-04 6.147E-04 2.716E-04 2.306E+00
 4.309E-03-1.937E+00 7.189E-02 9.290E+00-3.042E-02 3.205E+02
```

Listing G.7. Sample Output File for MAPFIT Program — Annotated

```
FILE: MAPCOEF.DAT

*** SAMPLE OUTPUT DATA FILE FROM ORNL MAPFIT PROGRAM
    IN FORMAT NEEDED FOR USE IN ORNL HEAT PUMP DATA INPUT


TITLED
SAMPLE SINGLE-SPEED RECIP COMPRESSOR, HEATING MODE DATA

MODEDT ICMPDT ICDVCH CSIZMT  CFRQNM  CVLTNM   CVLHZM
1         2         2    2.7500   60.0000  240.0000    1.0000

NHZ DISPLB  SUPERB   CSIZMB  CFRQNB  CVLTNB
1    3.6400   10.0000    2.7500   60.0000  240.0000

HZVAL   RPMVAL   VLTVAL     ADJ1     ADJ2
60.0000  3450.0000  240.0000    1.0000    1.0000

(CPOWER(I,IHZ),I=1,6)
 6.660E-05-9.436E-03-1.263E-04 6.147E-04 2.716E-04 2.306E+00
and
(CMASSF(I,IHZ),I=1,6)
 4.309E-03-1.937E+00 7.189E-02 9.290E+00-3.042E-02 3.205E+02

or
if MODEDT=2,
(CETAIS(I,IHZ),I=1,6)
and
(CETAVL(I,IHZ),I=1,4)
```

APPENDIX H

AMBIENT/SPEED/CONTROL DATA FILE 'CONTRL' FOR SELECTED AND DUAL-MODE AMBIENT-vs-SPEED PERFORMANCE MAPPING

Input Data Definitions and Format

The 'CONTRL' data file is an optional additional input file which can be used in special circumstances when more control in needed over the ambient temperatures and relative humidities at which heat pump performance is to be evaluated. It can also be used to generate ambient vs compressor speed data sets for both heating and cooling conditions in one run with full operational variable control. The data file was developed originally to provide a means of generating performance data suitable for the ORNL Annual Performance Factor / Loads Model. As such, it is provided more as a special purpose option than as an integral part of the basic design tool package.

Table H.1 describes the input data requirements for the optional CONTRL data file. The operational variable specification used in CONTRL is identical to that for the CONCHZ data file (although potential users should note that the required data format is different). This input data file is read by the default unit number of 24 although this can be easily changed in the BLOCK DATA routine with reference to Appendix D.

One known inconsistency with the present version is that if temperatures are selected that are not on regular grid intervals, a set of performance data will be punched which contains the starting and ending temperature values and the number of temperatures but no information about what actual temperatures were used within the temperature range. As such, these data sets should not be used to generate contour plots unless the header values are edited to reflect the actual temperatures used for each grid location. Alternatively, a separate version of the CONDAT routine could be written to pass the correct, more detailed, heading information to the version of the CONDAT routine called from the APFDRV routine (to generate the CONSPD dataset as shown in Figure CDG1).

Sample Input File (Regular and Annotated)

This section contains regular and annotated listings, Listings H.1 and H.2, respectively, of a sample 'CONTRL' data file. The regular listing represents the data set as directly used by the model while the annotated version of the same data set is labeled with the variable names as described in Table H.1. The annotated listing is provided as a visual reference to users modifying existing data sets.

The selected example given by file RATING.CTL can be used to generate heating and cooling performance data at the DOE rating conditions for variable speed heat pumps. Operational characteristics which are approximately optimal for the sample heat pump given by the heat pump specification file OFFDES.HPS are included in the CONTRL data set. (These were obtained from the benchmark performance analysis of Rice [1991].) The resultant performance data at low, intermediate, and high speeds, as required for the various ambients, can be used to generate DOE HSPF and SEER ratings for selected DOE regions.

Table H.1. Description of Optional CONTRL Input Data to MODCON Program

(Required Only If MODEGN = 3,4, or 5 in CONCHZ Data File)

Variable Name	Variable Description	Sample Value
OPERATIONAL CONTROL DATA		
>>> Loop Over Heating and Cooling Mode Data — –> M=1, 2		
>>>>> Heating Mode Data (M=1)		
a) Ambient Data		
Operational Line #1	FORMAT(I3)	
NTMPSS(M)	number of ambient temperatures for which heating (M=1) or cooling (M=2) performance is required	2
Operational Lines "I=1,NTPMSS(M)"	FORMAT(6F8.3)	
TOUT(I,M)	ambient temperature (°F)	17.0
RHOUT(I,M)	ambient relative humidity	0.70
TIN(I,M)	indoor thermostat setting (°F)	70.0
RHIN(I,M)	indoor design relative humidity	0.50
TSE(I,M)	estimate of compressor inlet saturation temperature (°F)	10.0
TSC(I,M)	estimate of compressor outlet saturation temperature (°F)	10.0
b) Compressor Frequency Data		
Operational Line # "NTPMSS(M)+2"	FORMAT(I3)	
NFRQSS(M)	number of compressor speeds at which steady-stateheating-mode (M=1) or cooling-mode (M=2) heat pump data are required; – value is set to 1 internally if load/frequency iteration is used	4
Operational Line # "NTPMSS(M)+3"	FORMAT(6F8.3)	
CMFRLO(M)	lowest compressor frequency (Hz)	60.0
CMFRHI(M)	highest compressor frequency (Hz)	240.0
CMFRRF(M)	reference compressor frequency (Hz) for frequency ratio calculation – if load/frequency iteration is not used; initial guess for required compressor frequency (Hz) – if load/frequency iteration is used (not yet operational)	120.0

c) Control Variable Data

Operational Line #
"NTPMSS(M)+4" FORMAT(I3)

NVAL(M)	number of control variables to be user-specified	1

Operational Lines
"J=1,NVAL(M)" FORMAT(2I3,2X,6F8.3)

NFUN(J,M)	integer value selecting *controlled* parameter "y" where y = f(x) = 1, for compressor inlet superheat (F°) = 2, for condenser exit subcooling (F°) = 3, for indoor blower frequency (Hz) = 4, for outdoor fan frequency (Hz) = 5, for building load (kBtuh/h) — not fully operational	1
NIND(J,M)	integer value selecting *controlling* parameter "x" = 1, for ambient temperature (°F) = 2, for compressor frequency (Hz)	1

Coefficients of linear control algorithm of the form $y = (y_2 - y_1)/(x_2 - x_1) \bullet (x - x_1) + y_1$

VINDEP(J,1,M)	selected value of x_1	17.0
VINDEP(J,2,M)	selected value of x_2	47.0
VDEPEN(J,1,M)	prescribed value of y_1	5.0
VDEPEN(J,2,M)	prescribed value of y_2	20.0
VDEPLO(J,M)	minimum-allowable value of y_1	0.0
VDEPHI(J,M)	maximum-allowable value of y_2	30.0

>>>>> Repeat For Cooling Mode Data (M=2)

a) Ambient Data :

NTMPSS(M),
Lines I=1, NTMPSS(M)
TOUT(I,M),RHOUT(I,M),TIN(I,M),RHIN(I,M),TSE(I,M),TSC(I, M)

b) Compressor Frequency Data :

NFRQSS(M)
CMFRLO(M), CMFRHI(M), CMFRRF(M)

c) Control Variable Data :

NVAL(M)
Lines J=1, NVAL(M)
NFUN(J,M),NIND(J,M),VINDEP(J,1,M),VINDEP(J,2,M), . . .
. . .VDEPEN(J,1,M),VDEPEN(J,2,M),VDEPLO(J,M),VDEPHI(J,M)

>>> Loop Complete Over Operational Parameter Data

OUTPUT CONTROL DATA

Steady-State Performance Data Output

Output Line #1 FORMAT(I3)

IPUNCH Integer flag to select if steady-state performance data file is to be created 1

≠ 1, no data file is desired
= 1, steady-state data file will be created in a format suitable for use in the ORNL APF Model

Supplemental Contour Data Sets

>>> Loop Over Heating and Cooling Mode Data — –> M=1, 2

>>>>> Heating Mode Data (M=1)

a) Ambients

Output Line #2 FORMAT(I3,F8.3)

NAMBCN(M) If ≥ 0, number of supplemental ambients 1
If = –1, indicates value of REFX(M) is to be read
If = –99, shortcut way to indicate that no supplemental ambient or frequency data sets are desired

REFX(M) Reference ambient value for secondary ambient-vs-frequency contour data set [only used if NAMBCN(M) = –1]

Output Line #3 FORMAT(20I3)
(if NAMBCN(M) > 0)

IAMBCN(M) Ordinal numbers of selected ambients relative to NTMPSS(M) 2

b) Compressor Frequencies

Output Line #4 FORMAT(I3,F8.3)

NFRQCN(M) If ≥ 0, number of supplemental frequencies 1
If = –1, indicates value of REFY(M) is to be read

REFY(M) Reference frequency value for secondary ambient-vs-frequency contour data set [only used if NFRQCN(M) = –1]

Output Line #5 FORMAT(20I3)
(if NFRQCN(M) > 0)

IFRQCN(M) Ordinal numbers of selected frequencies relative to NFRQSS(M) 2

>>>>> Repeat For Cooling Mode Data (M=2), If NAMBCN(1) > –99

a) Ambients :

NAMBCN(M), REFX(M)
IAMBCN(M)

b) Compressor Frequencies :

NFRQCN(M), REFY(M)
IFRQCN(M)

>>> Loop Complete Over Output Data

Listing H.1. Sample Control Data File 'CONTRL' — Selected Heating And Cooling Ambients With Operational-Variable Control

File: RATING.CTL

```
 04
17.0     0.68     70.0     0.58      8.0      95.0
35.0     0.70     70.0     0.58     28.0      95.0
47.0     0.72     70.0     0.58     40.0      90.0
62.0     0.72     70.0     0.58     55.0      90.0
 06
  50.0    180.0    180.0
 04
  1  2  50.0     180.0     1.0      1.0       1.0     1.0
  2  2  50.0     180.0    10.0     24.0      10.0    24.0
  3  2  50.0     180.0    64.8     95.0      64.8    95.0
  4  2  50.0     180.0    37.1     55.3      37.1    55.3
 04
67.0     0.40     80.0     0.52     55.0      90.0
82.0     0.40     80.0     0.52     55.0      90.0
87.0     0.40     80.0     0.52     48.0     115.0
95.0     0.40     80.0     0.52     48.0     115.0
 06
  50.0    180.0    180.0
 04
  1  2  50.0     180.0    10.0     10.0      10.0    10.0
  2  2  50.0     180.0    5.0      15.0      5.0     15.0
  3  2  50.0     180.0    45.6     108.0     45.6    108.0
  4  2  50.0     180.0    53.0     82.5      53.0    82.5
 01
 -1  17.0
 -1  180.0
 -1  95.0
 -1  180.0
```

Listing H.2. Annotated Sample Control Data File 'CONTRL' — Selected Heating and Cooling Ambients With Operational-Variable Control

File: RATING.CTL

OPERATIONAL CONTROL DATA:

>>> Loop Over Heating and Cooling Mode Data

>>>>> Heating Mode Data

<u>Ambient Data — Heating Mode:</u>

Number Of Ambients

NTMPSS

04

Ambient Conditions and Sat. Temp. Guesses

>>>I=1,NTPMSS

TOUT	RHOUT	TIN	RHIN	TSE	TSC
17.0	0.68	70.0	0.58	8.0	95.0
35.0	0.70	70.0	0.58	28.0	95.0
47.0	0.72	70.0	0.58	40.0	90.0
62.0	0.72	70.0	0.58	55.0	90.0

<u>Compressor Frequency Data — Heating Mode:</u>

Number Of Compressor Frequencies

NFRQSS

06

Minimum, Maximum, and Reference Frequencies

CMFRLO	CMFRHI	CMFRRF
50.0	180.0	180.0

<u>Operational Data — Heating Mode:</u>

NVALS

04

>>>J=1,NVALS

NFUN	NIND	$VINDEP_1$	$VINDEP_2$	$VDEPEN_1$	$VDEPEN_2$	VDEPLO	VDEPHI
1	2	50.0	180.0	1.0	1.0	1.0	1.0
2	2	50.0	180.0	10.0	24.0	10.0	24.0
3	2	50.0	180.0	64.8	95.0	64.8	95.0
4	2	50.0	180.0	37.1	55.3	37.1	55.3

Listing H.2. Annotated Sample Control Data File 'CONTRL' — Selected Heating And Cooling Ambients With Operational-Variable Control (continued)

```
>>>>> Cooling Mode Data

Ambient Data — Cooling Mode:
Number Of Ambients
NTMPSS
 04
Ambient Conditions and Sat. Temp. Guesses
 >>>I=1,NTPMSS
TOUT   RHOUT    TIN    RHIN    TSE     TSC
67.0    0.40    80.0   0.52    55.0     90.0
82.0    0.40    80.0   0.52    55.0     90.0
87.0    0.40    80.0   0.52    48.0    115.0
95.0    0.40    80.0   0.52    48.0    115.0

Compressor Frequency Data — Cooling Mode:
Number Of Compressor Frequencies — Cooling Mode
NFRQSS
 06
Minimum, Maximum, and Reference Frequencies
CMFRLO  CMFRHI  CMFRRF
  50.0   180.0   180.0

Operational Data — Cooling Mode:
NVALS
 04
 >>>J=1,NVALS
NFUN NIND
          VINDEP1 VINDEP2 VDEPEN1  VDEPEN2  VDEPLO VDEPHI
  1   2   50.0     180.0   10.0     10.0     10.0    10.0
  2   2   50.0     180.0   5.0      15.0     5.0     15.0
  3   2   50.0     180.0   45.6     108.0    45.6    108.0
  4   2   50.0     180.0   53.0     82.5     53.0    82.5

>>>  End Of Operational Data Loop Over Heating and Cooling Modes
```

Listing H.2. Annotated Sample Control Data File 'CONTRL' — Selected Heating And Cooling Ambients With Operational-Variable Control (continued)

```
OUTPUT CONTROL DATA:

Steady-State Performance Data Output
IPUNCH
 01

SUPPLEMENTAL CONTOUR DATA SETS:

>>>  Loop Over Heating and Cooling Mode Data

>>>>> Heating Mode Data
Reference Heating Ambient
NAMBCN
     REFX
 -1  17.0
Reference Heating Compressor Frequency
NFRQCN
      REFY
 -1  180.0

>>>>> Cooling Mode Data
Reference Cooling Ambient
NAMBCN
     REFX
-1  95.0
Reference Cooling Compressor Frequency
NFRQCN
      REFY
 -1  180.0

>>>  End Of Supplemental Contour Data Loop
     Over Heating and Cooling Modes
```