ERA 1.2E
EPA Refrigerator Analysis Program

User's Manual
Peer Review Draft

Prepared for
Environmental Protection Agency
Atmospheric Pollution Prevention Division

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NOTICE

Installation Instructions for the User in a Hurry

Section 2 of the ERA User's Manual contains full instructions for installation of the original version of ERA. The new user is advised to scan this material since it contains information about the overall file structure of the program and provides useful data concerning the actual running of the model.

Program Installation. Two procedures are available: 1) ERA may be installed from Windows (3.1 or 95) using the setup.exe program provided with the Windows installation disk; or 2) ERA may be installed directly in the DOS mode using the DOS installation diskette.

To install from Windows, place the installation diskette in the a: drive and run a:\setup.exe from windows. To install from DOS, create a directory C:\ERA and copy the contents of the diskette into this directory using the XCOPY command: xcopy /s a: c:. Then unzip the era.zip file copied into \ERA. The unzip process creates a file README.TXT which describes all the files that are installed by this process.

Virus Checking. The installation diskettes have been checked using a commercial product. An additional check by the user prior to installation is recommended.

COMMAND.COM. The root directory of the disk containing the \ERA directory must have a copy of COMMAND.COM, or ERA will not function.

SETUP.TXT. Type out or print SETUP.TXT for information relating to computer hardware requirements and methods of configuring ERA to work with your computer.

SETUP.DAT. This file contains information relating to the default hardware expected by ERA. After reading SETUP.TXT, make any necessary changes to SETUP.DAT with an ASCII text editor. Otherwise, the program might not run properly on your computer.

Math Co-Processor. ERA uses some very intensive calculation methods. Your computer must have a math co-processor to run ERA.

Help Menus. Extensive Help menus are built into ERA at all levels. Press the F1 function key to request the menu. The program manual assumes that the user accesses the Help menu as the primary means of resolving program data requests.

Starting the Program. Type ERA and press the <Enter> key.

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1. INTRODUCTION

1.1. Background

Substantial advances have been made in the energy efficiency of refrigerators and freezers in the past four decades since the introduction of CFCs. Prior to concerns over the environmental impacts of ozone depletion, these fluids were felt to have ideal properties for this application. The ban on the use of these chemicals requires rapid product redesign which must not only eliminate the use of CFCs but also meet tightened energy efficiency standards.

Development of improved refrigerators and freezers has been primarily achieved by evolutionary improvement of the product, largely by component design. Because of the simultaneous needs for refrigerant replacement, new foam blowing methods (or alternate insulation concepts) and significant reductions from current energy consumption levels, the industry must now look at a wide range of refrigerant possibilities and alternative cycle concepts. Refrigerant options include pure HFCs, HCFCs, and mixtures of fluids.

The EPA Refrigerator Analysis Program (ERA) was designed to enable a comparison of the performance potential of alternate cabinet and cycle designs of current and near-term interest. A goal of the program is to allow evaluations of the various design options on a common analytical basis and to enable a consistent means of determining the performance and economic tradeoffs between these options. It is recognized that the use of such a model is only one step towards improving the appliance design.

ERA combines an analysis of the refrigeration load requirements of the cabinet with a simulation of the capacity and efficiency of the refrigeration cycle. The cabinet loads programs is an enhancement of a program developed for the U.S. Department of Energy during the late 1970s [1]. Model enhancements include addition of door opening effects, additional flexibility in describing the cabinet geometry, and an ability to deal with complex insulation systems.

The cycle model is a derivative of the NIST CYCLE 7 program [2] which uses the CSD equation of state to represent the thermodynamic properties of pure and mixed refrigerants [3]. Routines for calculating properties, and refrigerant property coefficients, are similar to those in the REFPROP3 program, available from NIST [4].

Changes in the cycle model include 1) incorporation of an ability to deal with refrigerator/freezer cycle design, 2) addition of interchangers, 3) specification of the heat exchanger parameters in terms of its design details, and 4) determination of mass flow and motor power consumption from a compressor model. The refrigerant cycle options added to the model are 1) standard single evaporator refrigerator/freezer, 2) Lorenz cycle with refrigerant mixture, 3) dual-loop system employing two independent refrigeration cycles, one for each compartment, and 4) dual evaporator cycle, with two evaporators connected in series, normally employing a pure refrigerant.

1.2. Capabilities and Limitations

ERA determines the daily energy projection assuming quasi-steady cabinet heat flow and cycle-averaged operating efficiencies. The underlying assumption is that the effects of cabinet load dynamics and the uncertainties associated with corrections to describe refrigeration system cycling behavior, are small in relation to the difference between alternative cabinet and cycle designs.

Most, but not all, of the common refrigerator classes are represented within ERA. Version 1.0 of the program is not capable of directly modeling a single door refrigerator/freezer, such as found in compact units.

The program is best thought as a design tool, intended to provide a means of sorting through the consequences of alternative design concepts and/or component characteristics on potential energy savings. As such, the model calculates what is theoretically possible, not what may be achieved in actual practice. For example, various design approaches may or may not be acceptable from a customer standpoint (e.g., impact on moisture level control). The refrigerator designer must consider the practicality, potential reliability , and costs of all design options. ERA is a tool that can be used as part of the design process to determine the energy potential performance benefits of a candidate option.

Table 1 summarizes the refrigerator/freezer (R/F) design and performance factors considered by the program. In most instances, the individual heat flow and cycle parameters can be treated on the basis of physical principles. In certain instances basic assumptions must be provided by the user (for example, the temperature of the air under the refrigerator cabinet must be specified). In all instances, certain idealizations must be accepted as a starting point for describing the physical or model parameter.

For this reason, proper use of the model requires an adequate understanding of its capabilities and inherent limitations. Descriptions of each of the input and output parameters is provided throughout this manual and in the Help menus found in the program.

1.3. Microcomputer Requirements

ERA runs in the MS-DOS environment. A minimum computer configuration will include:

- 640 K on-board memory
- 4 Meg hard disk storage available
- math compressor (80X87 chip)

Because of the extensive computational requirements for the thermodynamic property determination, it is highly recommended that a 386 or 486 class machine be utilized. Although not required, a color monitor of high resolution is also recommended to take advantage of the use of various color attributes by the program as a means of conveying information.

1.4. How to Use this Manual

The structure of this manual attempts to follow the ERA input data processor program to the greatest degree possible. For the user in a hurry, the most important sections to read are: Section 2 (Program Installation), Section 4 (Data Input Processor) and Section 7 (Sample Problem). Various Help Menus within the program are available to provide on-line information as needed. Section 3 (Model Overview) provides a description of the overall structure of ERA and the relationships between the three executable files comprising ERA. Summary discussions of the engineering algorithms used in these sub-programs appear in Appendices A (Cabinet Loads) and B (Cycle Analysis). These sections can be read as required to answer specific questions or to gain a deeper understanding of what ERA can and cannot do.

Sections 5 and 6 are reference chapters which define the input data requirements for each data menu in ERA. They supplement material found in the on-line Help Menu. If additional information is desired about an input data, the program user should turn to these sections.

Several important addenda appear in Section 9. These were prepared after release of ERA 1.0 and the first edition of the User's Manual. The reader should find this material to be a valuable resource, particularly the sample problem description.

1. Table 1-1 Refrigerator/Freezer Design/Performance Parameters

Category	***Parameter***	***How Treated***
Cabinet Loads	Configurations	Top-Mount R/F, Bottom-Mount R/F, Side-by-Side R/F, Chest Freezer, Upright Freezer, Single-Door R/F
	External Dimensions	Specified
	Internal Dimensions	Calculated
	Control Temperatures	Specified for each cabinet section Assumed constant
	Ambient Conditions	Specify temperature and relative humidity of the environment
	Insulation System	
	- Edge Losses	Calculated analytically within program
	- Construction	Foam, advanced insulation, or composite panels treated
	- Penetrations	User-specified heat leaks
	Heat Conduction from Environment	Wedge, wall panel, door, top, bottom, back panel, mullion edges
	Internal Heat Conduction	Across mullion between compartments
	Gasket Heat Leaks	Conduction loss related to door perimeter
	Heaters	Anti-sweat heater
	Ancillary Heat Input	Fan heat determined by compressor run-time; controls heat input considered constant and/or run-time dependent
	Mullion and Cabinet Flange Heat	Electric Hot gas from compressor Condenser liquid line
	Door Openings Effects	Latent and sensible loads Time dependent openings
	Number of doors	1 or 2
	Moisture	
	- Open Door	Calculated moisture input
	- Condensation	Mass balance, with all moisture condensing
	Defrost	Determined from moisture balance and temperature of evaporator. Defrost energy equal to heat of freezing

1. Table 1-1 Refrigerator/Freezer Design/Performance Parameters (continued)

Category	*Parameter*	*How Treated*
Refrigeration Cycle	Cycle Types	Standard (1 evap/1 cond) Dual Loop (2 units) Lorenz Cycle Dual evaporator
	Refrigerants	34 Pure refrigerants Binary or ternary blends
	Heat Exchanger Types	Static or fan-forced Cross-flow or counter-flow In-cabinet space or hot-wall/cold-wall
	Heat Exchange Parameters	Specify or calculate overall U by regime Specify or calculate total area Specify fan air flow Specify fan powers
	Heat Transfer Rates	Specify or calculate. Effect of degradation due to mixtures not considered
	Heat Exchanger Model	Effectiveness - NTU Model
	Pressure Drops	Specify or calculate
	Refrigerant Flow Control	Specify subcooling and superheat Independent of refrigerant charge or type of expansion device
	Compressor Model	Built-in model determines power and mass flow. Control options include single speed and variable speed. Compressor map option available
	Compressor Design	Single stage reciprocating design or rotary
Details of Compressor Model	Mass Flow	Speed, displacement specified. Suction gas density calculated
	Volumetric Efficiency	Determined by clearance volume, pressure ratio, temperature.
Energy Consumption	Cabinet	Heaters Defrost Ancillary (lights, controls)
	Cycle	Fan Power Compressor power Electronics

2. PROGRAM INSTALLATION

2.1. Initial Steps

ERA uses a simple file structure. All files should be loaded in a single hard-drive directory (e.g., C:\ERA) The root directory of the drive should contain COMMAND.COM. If a virtual drive is set up or if an auxiliary hard-card type drive is used, the root directory might not contain COMMAND.COM. The absence of this file in the root directory *even if a path is defined to another drive or directory*, will result in incomplete operation of ERA, since the program must have access to a secondary command processor for some of its functions.

ERA and its files are supplied on a single high-density diskette. The diskette has been virus-checked; however, the user should perform a secondary virus check before loading the disk contents onto the hard disk.

ERA 1.2E can be installed directly from DOS or by using the supplied Windows installation program. Both methods result in the same file structure and program executables. ERA is a DOS application that can be run directly in the DOS operation system or from Windows as a DOS application.

2.1.1 *DOS Installation*

Program installation consists of the following steps, where it is assumed that the program is to be installed on hard drive C: from the program diskette in drive A:

Step 1: Create a directory named ERA on the hard drive and then change to this directory.

```
>C:
>MD/ERA
>CD/ERA
```

Step 2: Copy the contents of the diskette, including the subdirectories, using the XCOPY command:

```
>XCOPY /s A:C:
```

If this is followed, **exactly,** a self-extracting zip file will be copied to C\ERA and various subdirectories will be created with the necessary files.

Step 3: Execute the self-extracting “unzipera.exe” file to complete the installation. This will load all the required data files and executables in the directory.

```
>UNZIPERA.EXE
```

2.1.2 *Windows Installation*

Installation is performed using the supplied program SETUP.EXE, which must be run from Windows. It can be run from Program Manager, File Manager, or using the Start-Run buttons in Windows 95. Follow the setup wizard as in any Windows installation procedure. A program icon will be created from which the program may then be executed (remember, ERA is a DOS program which can be run directly from DOS or as a DOS application from Windows).

Following completion of the installation, the supplied diskette(s) should be stored in a safe place with the write protection tab set.

2.2. Program Data and Execution Files

ERA consists of 6 executable files (programs), a batch file (ERA.BAT), and approximately 80 data files. Most of the data files are either static (not changed by the user) or are modified under the control of an interactive menu - driven input data processor. Several, optional, files are used to control the assumptions used by ERA relating to the computer configuration, to control the solution tolerances, or to define compressor performance by a map. Default files are supplied with ERA. They may be modified by using an ASCII editor.

Although not required, it is recommended that a full screen scientific (ASCII) editor be utilized with the program. All output is in ASCII form, which can be read with an ASCII editor. In addition, several intermediate files are prepared by the interactive menu-driven processor, as inputs to the executable programs. ERA has been designed to pass data between the various programs using formatted ASCII files to facilitate an understanding of the workings of the program.

These intermediate files may be printed out and stored with each run as part of the run documentation. In rare circumstances the user may choose to edit these intermediate data files directly and execute the cabinet loads (CAB) or cycle performance (ERACYC) program directly. This option is discussed further in Section 3.

Table 2.1 lists the files supplied with ERA. A brief discussion of each follows.

ERA.BAT. The overall program and data flow is controlled by this batch file. This file should not be modified.

BLOCK01.DAT to *BLOCK72.DAT*. ERA uses 72 data and help menus. They must not be changed.

CABINET.DAT. ERA creates this intermediate file as input to the cabinet loads program. Under most circumstances this file is not modified by the user, but is available as an ASCII file describing the input data to the cabinet loads model.

CABINET.FRM. This is a static file used to create the intermediate file CABINET.DAT. This file must not be changed.

**.TAB.* If the compressor map option is selected, the performance data of the compressor must be defined using a file with this extension. The file is prepared using an external editor. A sample file, COMPMAP.TAB is supplied. The structure of this file should be evident, and should not be modified. Compressor map files can be prepared for as many compressors as desired, and may be given any legal DOS file name (e.g., ROTARY1.TAB). Ordinarily the name should indicate the compressor type. It is assumed that the compressor map files are stored in the directory containing ERA.

CYCLE.DAT. ERA creates this intermediate file as input to the cycle program. Under most circumstances this file is not modified by the user, but is available as an ASCII file describing the input data to the cycle model.

CYCLE.FRM. This is a static file used to create the intermediate file CYCLE.DAT. This file must not be changed.

ERACOND.BAK and *ERACOND.DAT.* ERA provides the facility to determine heat transfer rates and pressure drops from various condenser designs. ERACOND.DAT is an intermediate file prepared by ERA as part of this process. A readable copy of this intermediate file is given by file ERACOND.BAK. Neither of these files should be modified.

ERAEVAP.BAK and *ERAEVAP.DAT.* These files are prepared for the evaporator heat transfer and pressure drop analysis. They should not be modified.

SETUP.DAT. ERA assumes the presence of a color monitor, and printer port LPT1. These assumptions, and other program options, may be changed by editing SETUP.DAT using an external editor. A full discussion of this option is given below (see "Customizing ERA to your Computer Environment").

README.DOC. This file is intended to catch the attention of users who do not take the time to read this Manual. It contains important summary information about ERA.

**.ERA.* Each of the input data files describing the cabinet and cycle design have the extension .ERA. The name of the file may have up to 8 characters (e.g., MODEL_D.ERA). Creation and modification of these files is done within the ERA menu system. All files are in binary format. The user must not attempt to edit these files directly since the file structure may be inadvertently changed.

CAB.EXE. Cabinet loads analyses are performed, using CABINET.DAT as input, under control of the ERA batch command.

ERACOND.EXE. Calculation of condenser heat transfer coefficients and pressure drops is carried out for specified design data. Operation of the program is under control of the ERA Menu-driven data processor.

ERACYC.EXE. Refrigeration cycle performance and energy use is calculated by this program, which is called by the ERA batch command.

ERAEVAP.EXE. Calculation of evaporator heat transfer coefficients and pressure drops is carried out for specified design data. Operation of the program is under control of the ERA menu-driven data processor.

Table 2.1 ERA Data and Execution Files

File	*Description*	*Form*
ERA.BAT	Batch file that controls processing of input data and program execution	ASCII
BLOCK01.DAT to BLOCK 72.DAT	Data menus and Help menus (72)	Binary and ASCII
CABINET.DAT	Intermediate file, input to cabinet loads program	ASCII
CABINET.FRM	Template for input data to cabinet loads program	ASCII
*.TAB	Compressor map files	ASCII
CYCLE.DAT	Intermediate file, input to cycle program	ASCII
CYCLE.FRM	Template for input data to cycle program	ASCII
ERACOND.DAT ERACOND.BAK	Intermediate file, input to condenser heat exchanger analysis program	ASCII
ERAEVAP.DAT ERAEVAP.BAK	Intermediate file, input to evaporator heat exchanger analysis program	ASCII
SETUP.DAT	Configuration data. Used to select options for ERA	ASCII
README.DOC	Notes on ERA. Documentation file	ASCII
*.ERA	Input data files (see Appendix C)	Binary
CAB.EXE	Cabinet loads analysis program	Binary
ERACOND.EXE	Condenser heat exchanger analysis program	Binary
ERACYC.EXE	Cycle analysis program and energy use calculation	Binary
ERAEVAP.EXE	Evaporator heat exchanger analysis program	Binary
MENU.EXE	Input data processor	Binary
SHOWERA.EXE	Automated program output display	Binary
*.FIG	Drawings of cycles (4)	Binary
*.PRP	Thermophysical proprietary data files (7)	ASCII
CYCLE.TOL	Optional file for specifying solution tolerances	ASCII
SUMMARY	Blank form for summarizing results of analysis.	ASCII

Notes: Files, SETUP.DAT, CYCLE.TOL, and *.TAB may be changed using an external ASCII editor. They are read by the executable files (program). The intermediate files CABINET.DAT and CYCLE.DAT are prepared by ERA. Normally they should not be changed by the user. However, if desired they may be edited by an external editor and the corresponding files (CAB.EXE and ERACYC.EXE) run separately.

MENU.EXE. ERA processes all input data through a menu-driven, interaction program. MENU prepares the input files for subsequent cabinet loads and cycle analyses.

SHOWERA.EXE. Display summary results for cabinet loads and daily energy consumption. ERA.BAT calls SHOWERA at the completion of the cycle analysis.

**.FIG.* Sketches of the refrigeration cycles are contained within these four files, which are used by the cycle analysis program. They must not be modified.

**.PRP.* Tables of thermophysical properties are available for CFC-12, HCFC-22, HFC-152a, HC-270 (cyclopropane), HC-290 (propane) and HFC-134a in these files. They are used in the analysis of evaporator and condenser heat transfer and pressure drops. ERA will estimate the properties of other refrigerants, or refrigerant mixtures, and store them in file REFRIG.PRP. These files must not be modified.

CYCLE.TOL. Solution tolerances are contained in this file, which may be modified using an external ASCII editor. The structure of the file is self-explanatory. Additional information in given below ("Solution tolerances").

SUMMARY. A blank form is provided to summarize the results of the analysis. If desired, this form may be modified with an external editor. Copies of the form are obtained by multiple printouts of the file.

2.3. Customizing ERA to Your Computer Environment

ERA assumes the following: 1) presence of a color monitor, 2) print output sent to parallel print port LPT1:, 3) data limits within the program must be obeyed, 4) a page eject will not be sent at the beginning of an output file (only at the end), 5) ASCII character 12 serves as the form feed character, and 6) the ERA data files (*.ERA) are contained in directory \ERA. To change these assumptions, a file SETUP.DAT must be present. A sample of this file is shown below:

mono_screen=no
print_port=lptl
form_feed=no
page_feed=no
ignore_limits=no
path=\ERA\DATA

If your computer setup does not include a color graphics monitor, then change the command in SETUP.DAT to read "mono_screen=yes".

The program assumes that the printer is connected to LPT1 (or to a COM port using the MODE LPT1:=COM? command in the autoexec file). If the printer is connected to LPT2, insert a line reading "print_port=lpt2" into the SETUP.DAT file (the program is supplied with a default setting of "print_port=lpt1").

Depending upon the printer setup, page ejects are controlled by issuing a "1" or a form feed character (ASCII character 12) in column one. ERA assumes that all files written to a disk use ASCII character 12 for print control, and that those written directly to a printer also use this character. To Utilize "1" in column 1 as the print form feed character insert a line reading "form_feed=yes" into the SETUP.DAT file. To issue a page eject prior to the printout of the first data file enter the command "page_feed=yes" in SETUP.DAT.

Every data value entered into ERA is checked against upper and lower limits to prevent running a problem with obvious errors. However, in some instances the user may wish to over-ride this capability to force the program to look at some unusual conditions. To allow the program to attempt to run for all data values supplied, enter the command "ignore_limits=yes" in the SETUP.DAT file. The user should note that the program may not work for all data values entered.

It is assumed that the data files (which have extension .ERA) are on the same directory as the program. However, the user may define a path towards another directory or drive where the data files are kept. This is accomplished by inserting the "path=" directive followed by the drive and directory. The example shown above assumes that the files are on the C: drive in subdirectory \ERA\DATA. In order for the command to work, it must be left justified in the SETUP.DAT file. If it is not present, ERA will assume all files are found in the directory containing ERA.

Two additional statements appear at the end of the SETUP.DAT file supplied with the program: "expand" and "shadow." These commands control the display of the program title screen. With both present, the title ERA is shown using an exploding windowing method and appears to cast a shadow on the screen. These effects can be removed, if desired, by eliminating these last two commands in SETUP.DAT.

2.4. Solution Tolerances

Because of the many, highly non-linear equations utilized to describe the refrigerator cycle, an iterative solution technique is employed. That is, sets of equations are solved sequentially until the differences between two succeeding solutions fall within some tolerance.

The first five data lines in CYCLE.TOL relate to solution for refrigerant temperatures and mass flow. Of these, the most sensitive are the condenser temperature tolerances (set to 0.01F) and the mass flow rate tolerance (set to 0.001). The user may wish to experiment with different values for these tolerances to determine an acceptable trade-off between computer execution time and refrigerator cycle performance prediction.

The program is capable of dividing the two-phase heat transfer region in the evaporator or condenser into an arbitrary number of nodes. In most instances the choice of only one node will yield nearly the same predicted cycle performance as the choice of 5 or 10 nodes. To speed computation it is recommended that the specified number of subdivisions remain at one. In unusual cases, where a refrigerant blend is used which has a highly non-linear relationship between temperature and quality over the evaporation or condensation process, a larger number of subdivisions can be used (3 is recommended).

2.5. Running ERA

To run the program type ERA and press the <Enter> key.

2.6. Display of Results

Following completion of an analysis under control of the ERA batch command, an automatic display of the results will occur. If a complete analysis is done, including the cycle and energy calculations, the summary results for cabinet loads and daily energy consumption are displayed; if a only a cabinet loads analysis has been requested the cabinet loads output will be displayed.

Ordinarily, three output files are available for display: 1) the summary output (ERA.OUT); 2) the cabinet loads output (CABINET.OUT); and 3) the cycle analysis results (CYCLE.OUT). Any of these may be requested during the output display by pressing the <F1> key (summary output), <F2> key (cabinet loads), or the <F3> key (cycle output). If only a cabinet loads analysis has been requested, the only available output will be the calculated cabinet loads. Request of another output from within execution of the display program, will cause a return to DOS with an error message.

A print of any of the files displayed may be requested by simultaneously pressing the <Alt> and <P> keys. It is assumed that the print port is LPT1:.

To return to the menu program and perform another analysis press the <F10> key.

To make a normal return to DOS from the display of the output results press the <Esc> key.

3. MODEL OVERVIEW

3.1. Basic Structure of the ERA Program

ERA consists of a batch command file (ERA.BAT), and three major modules:

- MENU - a menu driven interaction input processor and analysis flow control program. The program interacts with the user during the program input specification phase and prepares the data files needed for the subsequent program modules;

- CAB - analyses of the cabinet loads. The steady-state heat inputs to the cabinet section are determined for various configuration refrigerator/freezers, alternative insulation system designs, and specified environment and usage conditions;

- ERACYC - determination of the steady-state, instantaneous, refrigeration cycle capacity and power draws. The hourly average cabinet loads and instantaneous refrigeration capacities determine the compressor duty cycle and the corresponding fan powers. Corrections are made to the compressor energy to account for cycling effects. ERACYC establishes the net duty energy consumption and prepares a summary of the results.

Data input to both the cabinet loads and cycle models are in the form of ASCII files that can be edited off-line from the main calculation stream if desired.

The overall data and program flow is illustrated in Figure 3-1. The program is under the control of the batch file ERA.BAT. Operations specified by ERA.BAT will depend upon choices selected by the user from the Main Menu of the overall control program, MENU. However, because of the modularity of the program structure, and the design of the intermediate files, the program user can elect to run only a portion of the analysis, either from the menu driven program, or external to it using a data editor. Figure 3-1 attempts to differentiate these different types of files: program (executable files), data (output from one or more programs which serve as input to another program), and output (given the extension .OUT). The cycle data intermediate file, CYCLE.DAT, receives cycle parameters from the menu program, and has a summary of the cabinet loads results concatenated to it. The cabinet loads are used by ERACYC to determine the compressor and fan run times.

Operation of the heat exchanger analysis programs, ERACOND and ERAEVAP, is completely under the control of the menu program. MENU prepares the required input data, calls the executable files using a secondary command processor, reads the output files, and updates the heat exchanger data values (UA, area, pressure drop).

Following completion of an analysis, the ERA batch command calls a file display program (SHOWERA.EXE). Any of the three output files (ERA.OUT, CABINET.OUT, CYCLE.OUT) may be selected within the display program by pressing the <F1>, <F2>, and <F3> function keys, respectively. In addition, a return to the menu program for another analysis can be requested by pressing the <F10> function key.

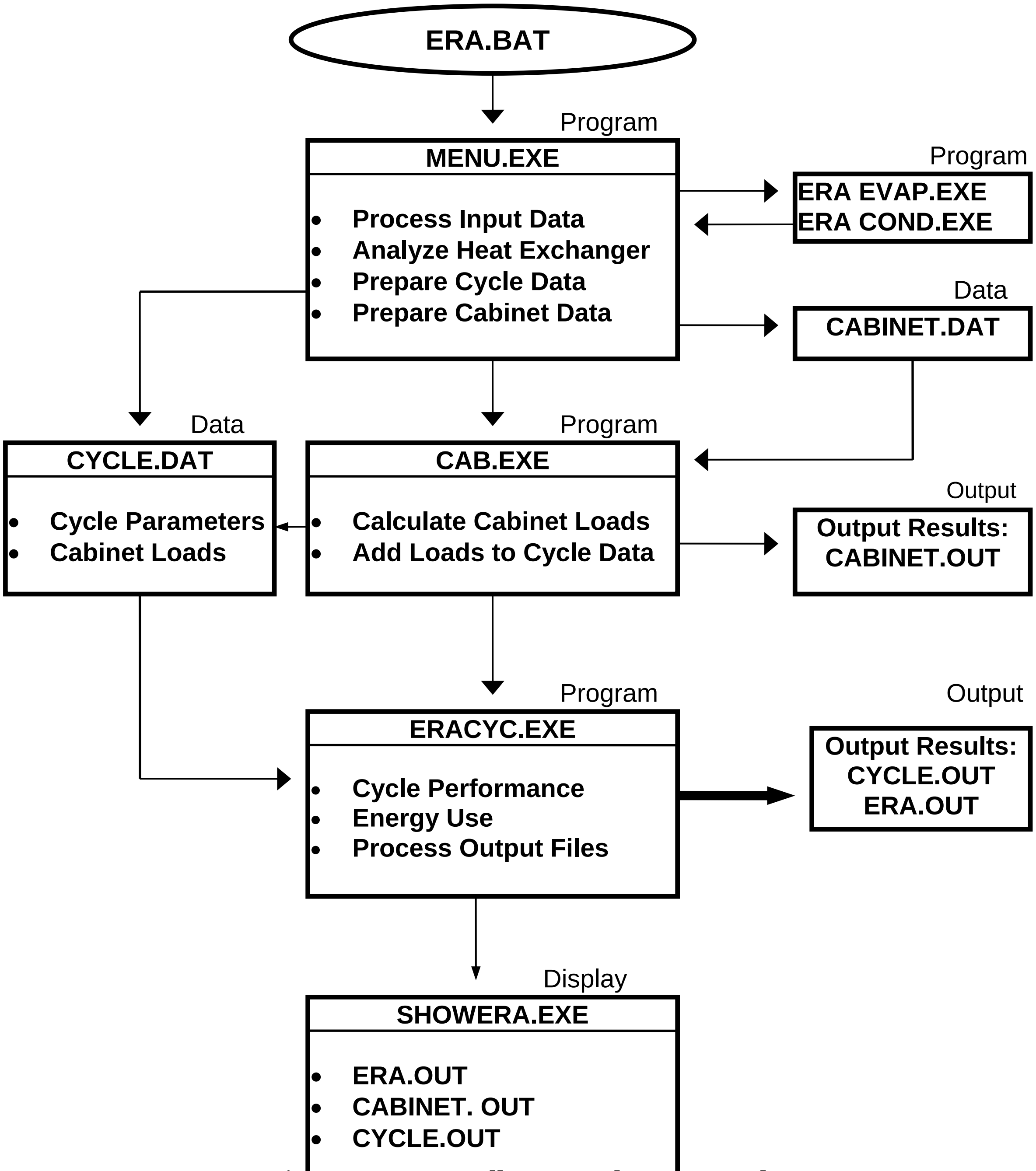


Figure 3-1: Overall Data and Program Flow

3.2. ERA.BAT

As illustrated in Figure 3-1, the overall data and program execution flow is controlled by the ERA batch file. The file is reproduced below:

```
@ echo off
:START
  if exist cabinet.dat erase cabinet.dat
  if exist cycle.dat erase cycle.dat
  if exist era.dat erase era.dat
  MENU
  if not exist cabinet.dat goto DONE
  CAB
  if not exist cycle.dat goto SHOW_CAB
  ERACYC
  if not exist era.out goto done
  goto SHOW_ERA
:DISPLAY
  if errorlevel 5 goto NO_FILE
  if errorlevel 4 goto START
  if errorlevel 3 goto SHOW_CYCLE
  if errorlevel 2 goto SHOW_CAB
  if errorlevel 1 goto SHOW_ERA
  goto DONE
:NO_FILE
  cls
  echo Requested File is not Present
  goto STOP
:SHOW_CYCLE
  showera cycle.out
  goto DISPLAY:
:SHOW_CAB
  showera cabinet.out
  goto DISPLAY
:SHOW_ERA
  showera era.out
  goto DISPLAY
:DONE
  cls
:STOP
  echo on
```

The analysis programs (CAB and ERACYC) will be executed only if the intermediate data files have been prepared by MENU.

3.3. Input Data Processor (MENU.EXE)

MENU allows the following basic options: 1) retrieve and edit the cabinet loads input data, 2) retrieve and edit the refrigeration cycle data, 3) write out the data input file in readable form to a file or directly to the printer, 4) run the cabinet loads program only, and 5) run both the cabinet loads and cycle models and determine the total daily energy consumption and load components.

Every menu has an associated Help menu. A logical tree structure is utilized to group the data and to provide a means of specifying the data in a fashion similar to the evolution of the overall design. Every data value is screened for the allowable range and for logical consistency with other data.

Data specification help routines are available for: 1) determination of the net resistivity of an insulation panel, 2) calculation of evaporator and condenser heat exchanger parameters and pressure drops, and 3) calculation of variable speed fan air flow and fan energy.

Input data to the MENU program is a user selected .ERA data file. The output files are CABINET.DAT and CYCLE.DAT.

3.4. Cabinet Loads Model (CAB.EXE)

Five basic R/F configurations are represented 1) top-mount refrigerator/freezer, 2) side-by-side refrigerator/freezer, 3) bottom-mount refrigerator/freezer, 4) chest freezer, and 5) upright freezer. Design parameters considered are: external dimensions, internal volumes, insulation system geometry and resistivities, mullion dimensions and resistivity, compressor cabinet dimensions and insulation design, gasket heat leaks, cabinet section control temperatures, environmental conditions, door opening schedules, and ancillary electrical energies.

The cabinet loads program breaks down the steady-state heat loads by component as well as by compartment. Note that the fan heat inputs are not yet considered in the thermal loads budget. They are treated as a correction to the refrigeration capacity, by the cycle program, and are related to the compressor run time.

The major heat flows present in the cabinet are considered, including the effects of edge losses associated with vacuum insulation panels. The major uncertainties in the modeled loads will be associated with the gaskets (conduction and an unknown infiltration), penetrations of the insulation system, and moisture input.

A door opening model has been included. Based on some limited research data [7] and a simple description of time-dependent air exchanges, both the sensible and latent heat loads are estimated for assumed door opening schedules. The moisture exchange may result in additional defrost loads, depending on the temperature of the evaporator.

3.5. Refrigeration Cycle Analysis and Energy Use (ERACYC.EXE)

Four cycle configurations are represented: 1) standard single evaporator refrigerator/freezer, 2) Lorenz cycle with refrigerant mixtures, 3) dual-loop system employing two independent refrigeration cycles, one for each compartment, and 4) dual evaporator cycle, with two evaporators connected in series, normally employing a pure refrigerant.

Figure 3-2 illustrates one of the cycles (Lorenz) represented by ERA. ERACYC will establish the refrigerant pressures and enthalpies around the cycle and the mass flow that satisfies the heat and mass balances of each location in the cycle. Note that the single evaporation cycle and dual evaporator cycle are derivatives of the Lorenz cycle.

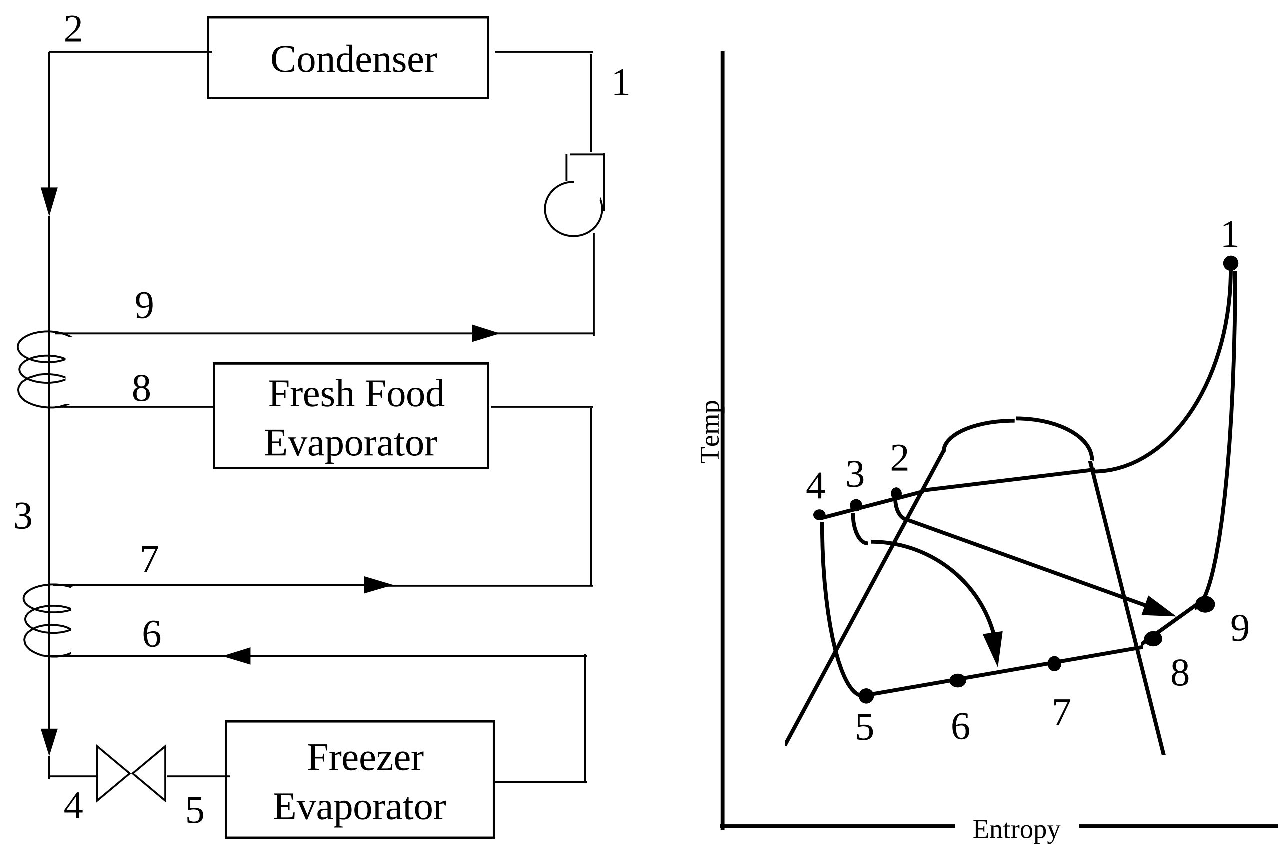


Figure 3-2. Lorenz-Meutzner Refrigerator/Freezer Cycle

The following control methods are adopted by the program:

- Standard Single Evaporator Cycle - The fresh food section and freezer section temperatures are specified. Air damper control is assumed to achieve these temperatures. The analysis involves calculation of the temperature of the air mixing from the two compartments as it approaches the evaporator. For example, if cabinet temperatures of 38F and 5F are specified for the two compartments, the mixed air temperature inlet to the evaporator will be about 12F, depending on the ratio of the cabinet loads and the evaporator refrigerant temperature.

- Dual Loop Cycle - Each refrigeration loop, which contains its own evaporator, compressor, and condenser, acts independently to achieve the average temperatures specified for the individual compartments. The model simulates each loop separately.

- Lorenz Cycle - The air temperatures approaching the two evaporators are assumed to be at the specified control points. Normally the evaporator loads will be unbalanced, requiring additional refrigeration delivered to one of the compartments during an off-cycle period for the other compartment. The control options are: 1) adjust the fresh food section temperature; 2) adjust the freezer temperature; 3) adjust the evaporator areas; 4) use a means to bypass the refrigerant cooling of one evaporators during a portion of the cycle to enable the other evaporator to meet its cabinet load; or 5) allow an imbalance to occur. Control option 4 is intended to represent the use of a solenoid valve for refrigerant bypass, or the effects of turning off the fan in a fan-forced evaporator. The energy consumption from a solenoid valve can be specified.

- Dual Evaporator Cycle - The control logic is similar to the Lorenz cycle, with the exception that an interchanger is present between the evaporators, and that pure refrigerants are normally used with this cycle. An additional control option provided is alternately circuiting the refrigerant to one evaporator and then to another. This would be accomplished by a switching valve. The energy consumption from such a valve can be specified.

<u>Energy Consumption Model</u>

The relationship between the hourly total cabinet heat loads (the refrigeration requirement at the evaporators), and the instantaneous capacity of the refrigeration cycle establishes the compressor run time (duty cycle = fraction of the hour that the compressor operates to meet the load):

Duty = Cabinet_Load/(Evaporator_Capacity - Fan_Power)

Cabinet_Load = Duty*Fan_On_Cabinet_Load + (1.0 - Duty)*Fan_Off_Cabinet_Load

where,

Duty = Calculated duty cycle (0 to 1)

Fan_On_Cabinet_Load = Cabinet load during compressor operation

Fan_Off_Cabinet_Load = Cabinet load during compressor off-cycle

The underlying assumption is that both the thermal transients in the cabinet and in the refrigeration cycle are small. That is, it is assumed that the cabinet temperature is either relatively constant over the complete cycle, or that the sensible heat corresponding to temperature swings between compressor operation and off-cycle conditions is small. The equations above link the time averaged cabinet loads to the *instantaneous* capacity of the refrigeration system.

Once the duty cycle is determined, the energy consumption terms are easily calculated:

Compressor energy use =	Compressor power times the duty cycle
Fan energy use =	Fan power times the duty cycle
Electronics (variable speed motor) =	Electronics losses times the duty cycle
Heaters and controls =	Specified hourly total values
Defrost energy =	Net electrical input corresponding to heat of fusion of the moisture condensing on the cold evaporator. (Note that it is assumed that moisture will not freeze on a fresh food evaporator in the dual loop cycle, the Lorenz cycle, or the dual evaporator cycle.)
Total Electrical Energy Use =	Sum of above components

CYCLE.DAT is the input data file to ERACYC. Output files are ERA.OUT and CYCLE.OUT.

Full documentation of a single run would consist of the following files:

ERA.OUT -- summary of energy use and cabinet loads
CABINET.DAT -- input to CAB
CABINET.OUT -- output from CAB
CYCLE.DAT -- input to ERACYC
CYCLE.OUT -- results of cycle analysis

Sample data input and output files are given in Section 7.

4. INPUT PROCESSOR

4.1. Menu Structure

ERA uses an iterative, menu driven input processor. Menus, or instructions, are used at all levels of the input processing. For the most part, the appropriate response is a cursor movement, or a data entry, followed by use of the <Enter> key or <Pg Dn> key.

The menu structure has been developed to be as intuitive as possible. Standard key stroke interpretations apply throughout the program:

- <Esc> : escape back to previous process or terminate current process
- <Pg Up> : go back to previous menu
- <Pg Dn> : go to next menu
- <Enter> : enter value or select option
- <Home> : move cursor to start of list
- <End> : move cursor to end of list

In addition, a common menu structure has been designed for most of the functions of the input data processor.

The program begins at the Main Menu, illustrated in Figure 4-1. Eleven specific actions are grouped into 4 sets. The first set deals with data file editing and manipulation (read data, edit cabinet data, edit cycle data, save data, delete data). A second set provides two means to return to DOS (temporary exit to DOS, quit program). A third set relates to the type of analysis to be performed (calculate cabinet loads, calculate energy). The last set provides a permanent, off-line copy of the input data (print data menus, write data menus to a file). An action is selected by moving the cursor to the desired option and pressing the <Enter> key.

As illustrated in Figure 4-1, available help keys are shown at the top of each menu. Function key <F1> always leads to a Help menu which explains the intent of the menu; function key <F9> always provides an explanation of the use of special keys.

As also illustrated in Figure 4-1, the bottom line of each menu normally lists important keys. For example, at the Main Menu level, touching the <Esc> key will move the cursor to the "Quit Program" option; pressing the <Pg Dn> key, or the <Enter> key will select the highlighted option.

The Main Menu contains a two line description for the highlighted function. A new message will appear each time the cursor is moved.

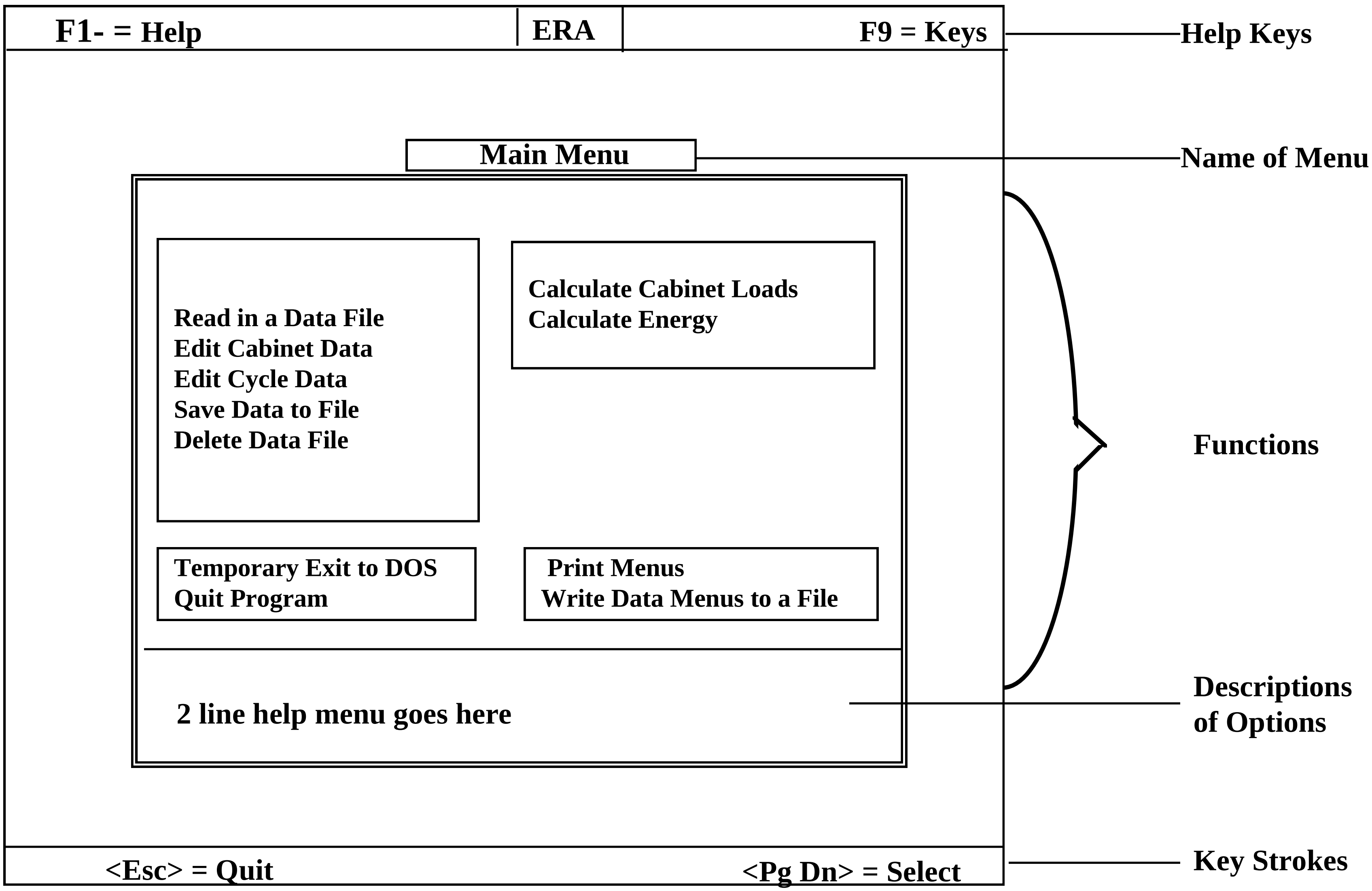


Figure 4-1: Main Menu

4.2. Retrieving and Saving Input Data Files

The first step in preparing an analysis is to create the input required for the analysis programs (CAB and ERACYC). This is accomplished by selecting a data file and then using the menu-driven editor.

All data files have the extension .ERA. When a request is made to retrieve data, ERA performs a search for all files (up to 200 in a sub-directory) with this extension and lists them in alphabetical order in the File Selection Menu, illustrated by Figure 4-2. To select an existing file move the cursor to highlight the name and press the <Enter> key. An automatic return to the next menu will then occur.

If more than 40 data files are available for selection, pressing the <Pg Dn> key will scroll the screen forward to display the next 40 (or fewer) files. The <Pg Up> key will scroll backwards to the previous display of files.

The File Selection Menu shows the name of the current data sub-directory (called the "Current Path"). To change to a different sub-directory, press the <F10> key and enter the data path (e.g., "\ERA\CHEST"). If the data path is valid, a list of the available *.ERA data files will be displayed.

Once a file is selected, it is read into the data "buffer" where it is available for editing or for analysis. The file name will appear in a window on the File Selection Menu (see Figure 4-2). If a new file is read in, this new name will be shown the next time the File Selection Menu is called.

Two methods of creating a data file with a new name are provided. One method involves selecting a file, as described above, editing the data values, and then saving it under a new name. The process of saving the data creates a file with the desired name, but does not change the name of the file in the buffer. A second, more direct method, involves pressing the <F5> key first (see Figure 4-2) and then entering the (new) name of the file to be created as requested. The new name will automatically be entered into the buffer when the data is saved. The data in the new file will be same as those in the highlighted file. Hence, using the cursor, the highlight should be moved to the file most similar to the new file to be created. Once the data is edited it will be assigned the new file name.

The procedure for saving a file is similar to the process of selecting a file. If a file name is the same as that shown in the buffer area (see Figure 4-2), the changed file can be saved simply by pressing the <F5> key. Otherwise, the name of the file must be typed where requested. The extension .ERA is always assumed. Up to 8 characters may be entered.

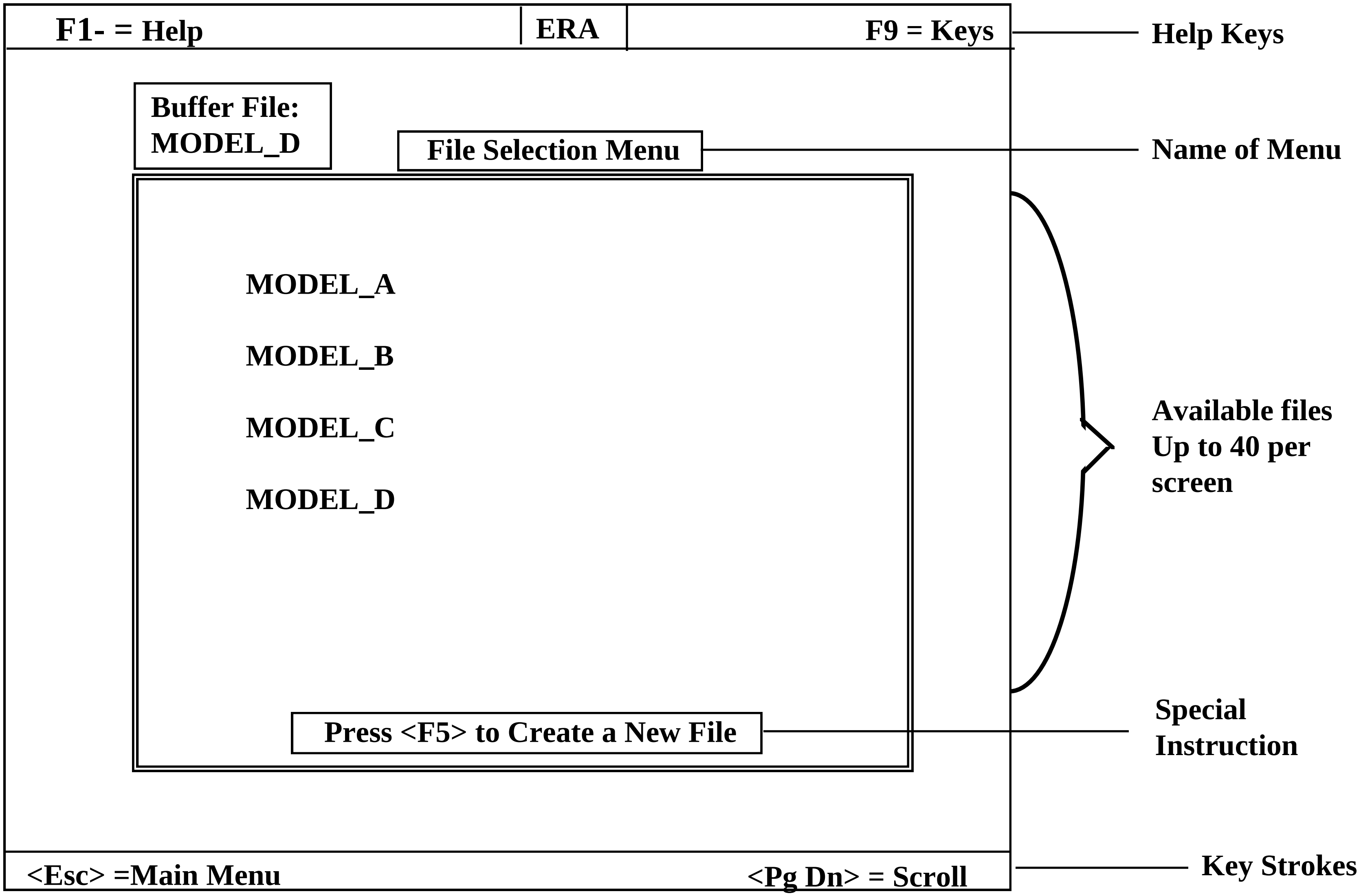


Figure 4-2: File Selection Menu Example

4.3. Data File Management

In some instances the user may wish to create and store more than 200 data files. ERA allows the definition of any valid DOS path for designating the location of the data files. This can be accomplished using the "path=" command in the SETUP.DAT file as discussed in Section 2 where a sample data file sub-directory \ERA\DATA was defined.

The "path=" command might also be used to define sub-directories that are specific to the type of refrigerating unit. For example, top-mount units might be stored in sub-directory \ERA\TOP, chest freezers in sub-directory \ERA\CHEST, and so on. The limit of 200 data files will apply to each sub-directory defined. An external editor must be used to change the path command in SETUP.DAT.

An alternate means of creating additional file space in a sub-directory is to request the "Delete Data File" command from the Main Menu (see Figure 4-1). This function changes the file extension to .BAK rather than actually erasing it. Hence if the file has been accidentally "deleted" it can be retrieved. The function allows additional file name space, but does not result in a reduction in the hard disk memory usage.

4.4. Editing Data

Once a file has been read into the buffer, editing proceeds by selecting the type of data (cabinet loads or cycle data). As an example, Figure 4-3 illustrates the Cycle Data Edit Menu. The data set to be edited is selected by moving the cursor to highlight the item (e.g., Evaporator Design) and pressing the <Enter> or <Pg Dn> key.

Figure 4-4 illustrates an example of a data edit menu for freezer insulation resistivities. Each data set is comprised of 1 to 14 values, which are displayed in the menu. They are edited by moving the cursor key to highlight the parameter, and then typing the new value, followed by pressing the <Enter> key.

A moving "data entry box", with an arrow pointing to the current value, identifies the parameter to be changed. As the new data is entered it appears in this box until it is entered (by pressing the <Enter> key, or any other key that will move the cursor). The simplest way to enter a new value is to type the data into the box and then press a cursor key to move the box to a new location.

4.5. Getting Help

As shown in Figure 4-4, an explanation of the data menu and the parameters to be edited can be obtained by pressing the <F1> key. Figure 4-5 illustrates the structure of the Help menu. Each Help menu shows the name of the data menu, and provides text and simple line drawings, as needed, to explain the data requirements. If the information requires more than 17 lines, the text may be scrolled within the window by using the cursor or the <Pg Up> and <Pg Dn> keys. A bar indicator to either side of the text window symbolizes what portion of the Help menu appears on the screen.

As noted in the top line of the Help menu (Figure 4-5), a return to the edit menu is made using the <Esc> key.

A print out of the Help menu may be obtained by simultaneously pressing the <Alt> and <P> keys. The print port called is that defined in the SETUP.DAT file (see Section 2). If the program does not provide a print out or it hangs up at this point, the information in SETUP.DAT is probably incorrect for the particular computer hardware configuration. Options relating to printing from within ERA are explained in Section 2 and in the README.DOC file supplied with the program.

The Keys Menu, accessed by pressing the <F9> key, defines the actions specific to individual keys.

A considerable amount of information has been collected in the Help and Keys menus. It is highly recommended that these menus be read at each level of the program until the user is very familiar with ERA

4.6. Default Data

Preparation of an input data file involves editing, or selecting, current data. That is, the data preparation process always begins with the data file last read into the data buffer. By definition, therefore, the current data values in the selected file are default data.

Suggestions for values, or ranges of values, for data parameters are found in the Help menus.

4.7. Calculation Assists

In certain instances the requested data value may be difficult to assign without additional analysis. Examples include: the effective resistivity of a cabinet wall containing foam and vacuum insulation in a sandwich arrangement, evaporator UA value, and fan power in a variable-speed fan configuration.

ERA provides a calculation assist to determine these values by calling secondary menus. Data values that can be estimated in this manner are indicated by an asterisk (*) next to the name of the parameter and a message at the bottom of the data window (see Figure 4-4).

To call the calculation assist menu, position the highlight to the variable of interest using a cursor key and press the <F5> key.

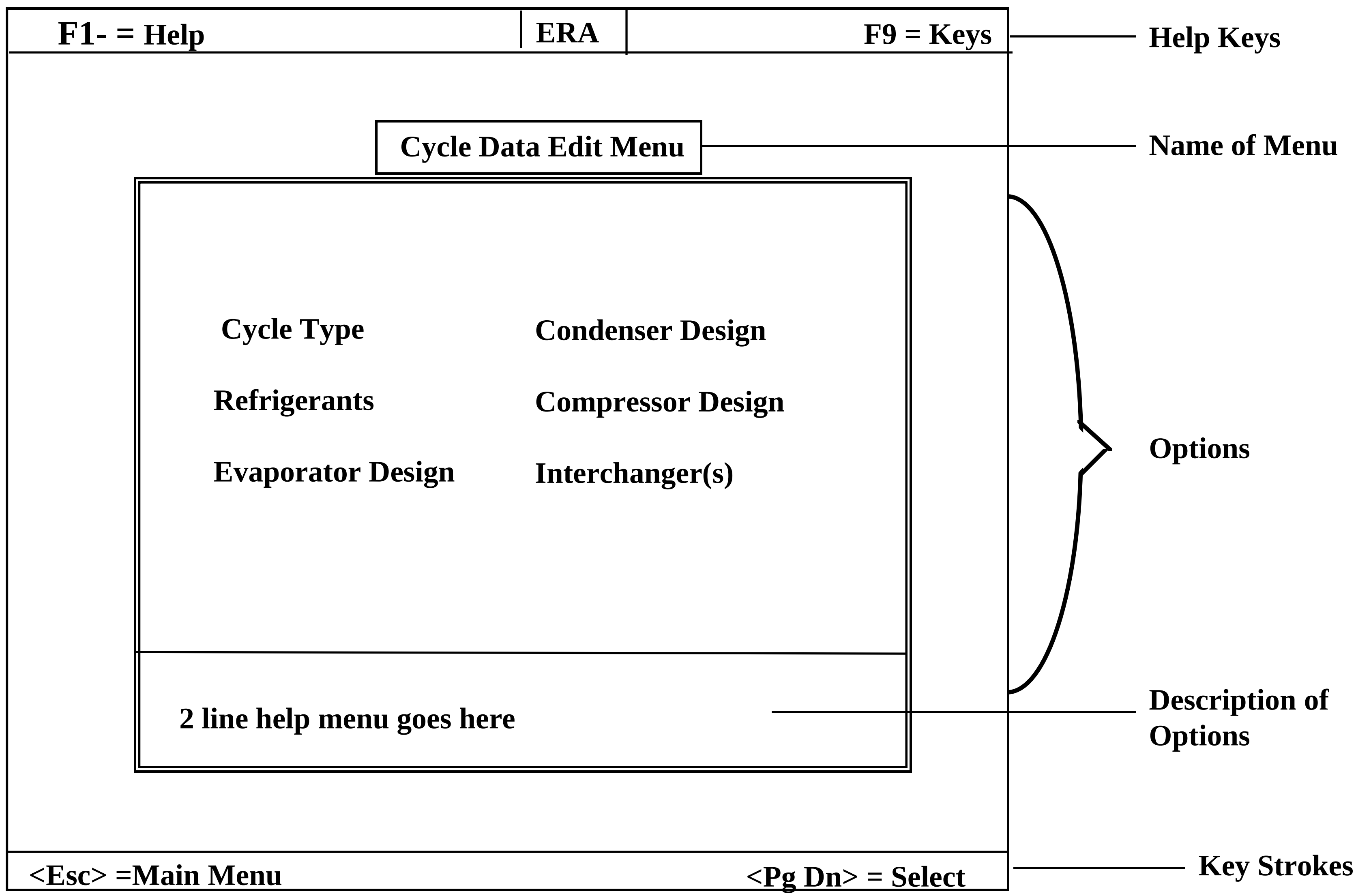


Figure 4-3: Cycle Data Edit Menu

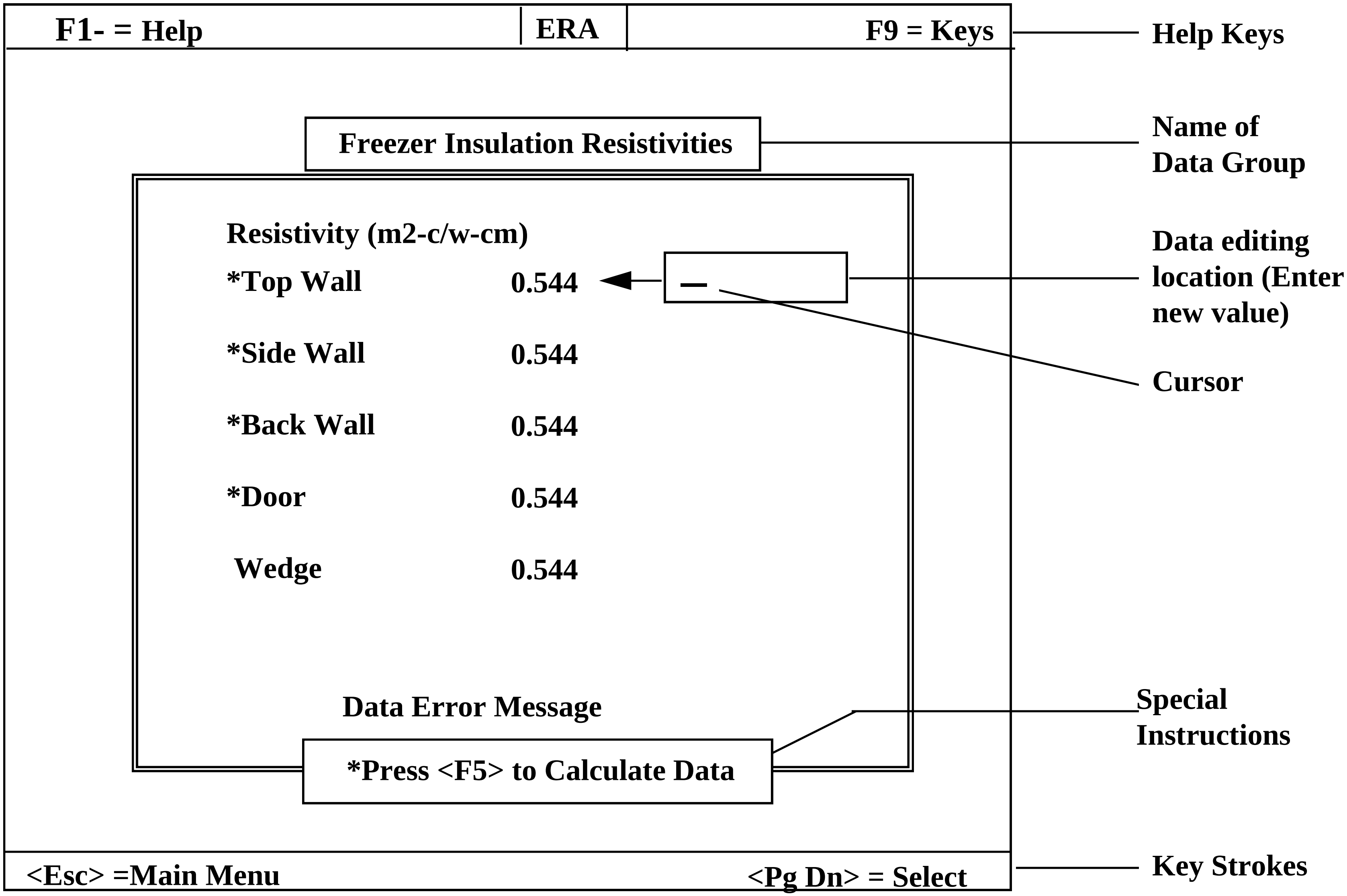


Figure 4-4: Data Edit Menu Example

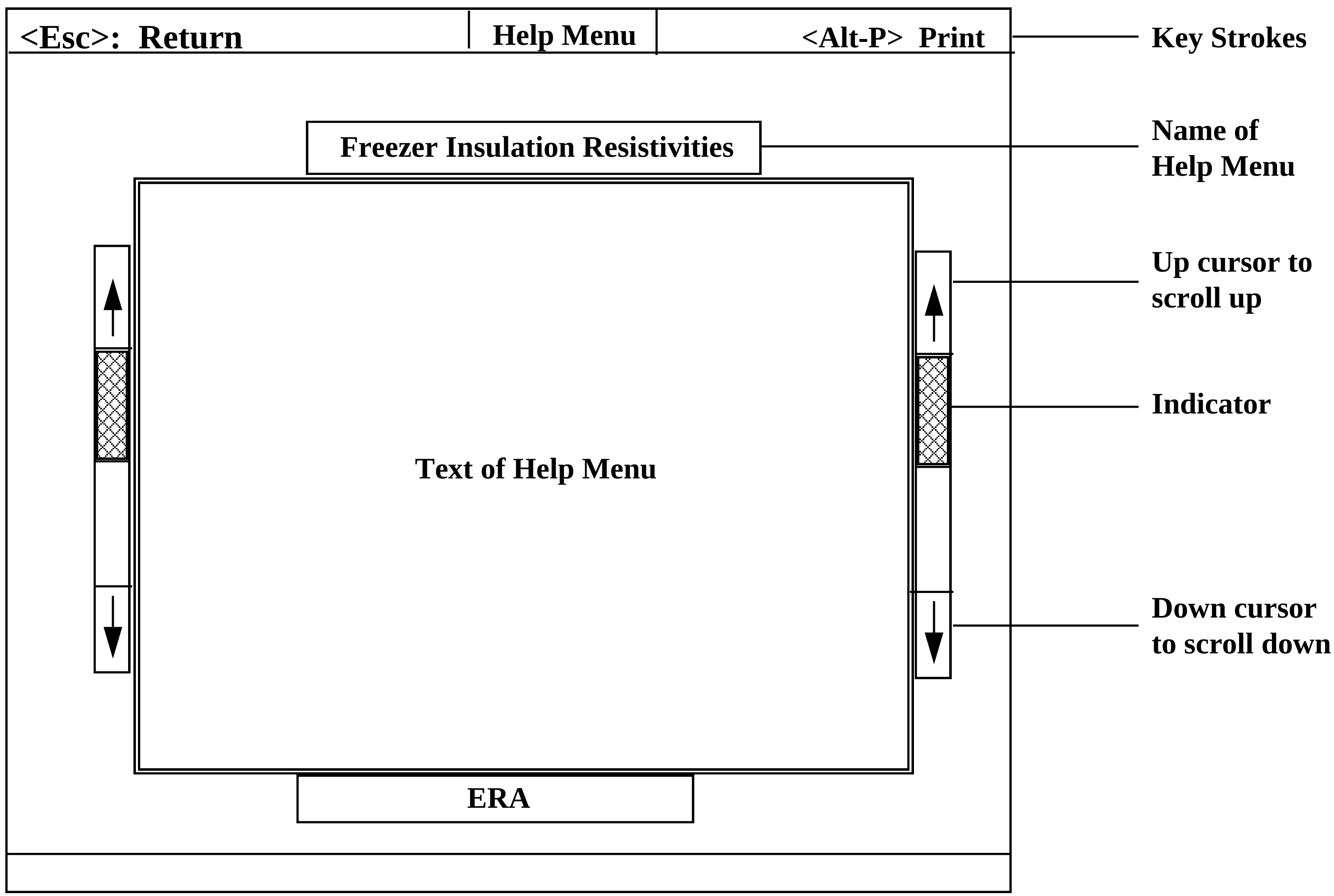


Figure 4-5: Help Menu Example

The structure of the calculation assist menu is shown in Figure 4-6 for the example of a variable speed fan. As with data edit menus, a Help menu is available by using the <F1> key. A return to the calling menu is made by pressing the <Pg Dn> key or the <Esc> key. If the <Pg Dn> key is pressed, the calculation is performed and the results are automatically entered into the calling menu. To avoid making the calculation and to return directly to the calling menu, press the <Esc> key.

In some instances, the data appearing in the calculation assist menu may appear not to be retained when the file is saved. This is because the assist facilities are considered to be only a means of calculating some data value that is saved in the menu from which the calculation assist function is called. This approach reduces the size of the data files, thereby speeding the file read and write functions and freeing up disk space.

4.8. Input Data Error Trapping and Correction

All input data are checked against high and low limits whenever they are entered in a data edit menu. If the data value lies outside the expected range, an error message is written at the bottom of the data window (Figure 4-4). Depending on the nature of the parameters, one of three actions is taken:

- The data will not be accepted since it must lie within the limits. An example would be the code for the type of compressor (only 1 and 2 are allowed).

- The data must be above a minimum value but may exceed the upper limit. If the data is above the expected upper limit it may be accepted by pressing the <Esc> key (the menu will display this message).

- Data below the expected range may be accepted by pressing the <Esc> key.

In certain instances the user may wish to exceed the upper and lower limits, no matter what type of parameter is being edited. This can be allowed by entering the statement "ignore_limits = yes" in the SETUP.DAT file. The user should be cautioned that violation of expected limits may lead to erroneous answers or even a computer crash if an illogical request is made.

Prior to executing the cabinet loads analysis, a check of the consistency of the data is made. Obvious errors, such as a door flange wider than the wall insulation, are caught and an error message is displayed. The user <u>must</u> resolve the error before execution of the analysis is allowed.

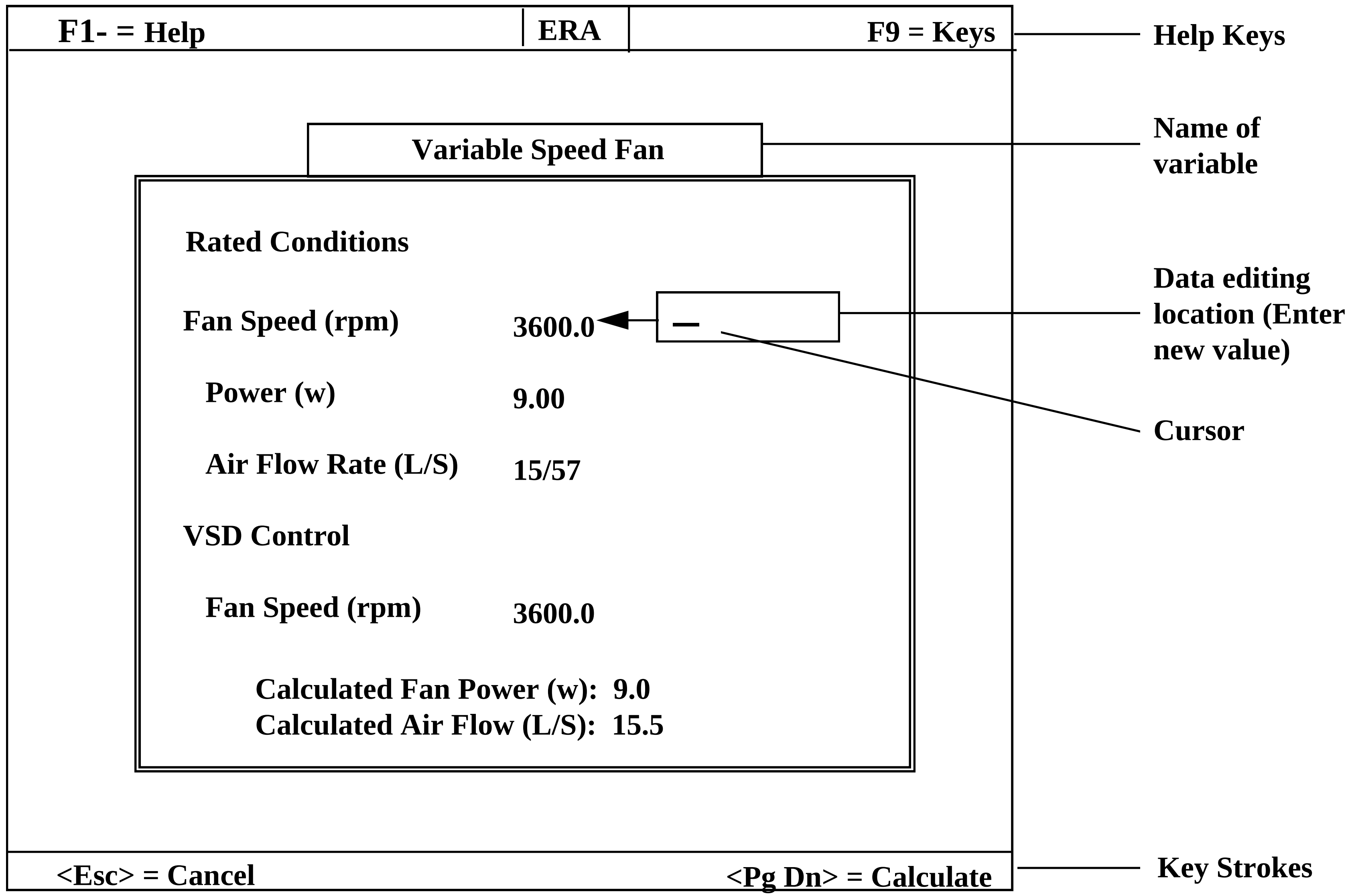


Figure 4-6: Calculation Assist Menu Example

4.9. Using DOS Within ERA

In some instances the user may wish to call a DOS function or some other program (such as a data editor) without leaving ERA. An example situation might be the need to look at an ASCII file using an external editor to determine a data value to be entered into one of the ERA menus.

This is accomplished by returning to the Main Menu and then choosing the "Temporary Exit to DOS" function (see Figure 4-1). A second version of COMMAND.COM will be executed, while leaving the ERA MENU program resident in memory. After all DOS requests have been completed a return to ERA will be made if the command "EXIT" is entered. The return will be made to the drive and directory containing the ERA program.

Because ERA remains as a memory resident program during this temporary return to DOS, the available memory will be smaller (ERA requires about 390 K of memory). As a consequence, programs or DOS functions that require a large amount of memory may not work.

In all instances the user should avoid loading another memory resident program during a temporary exit to DOS since this second memory resident program may prevent the release of the memory used by ERA upon exiting the program. In such a case the only recourse would be to reboot the computer.

4.10. Printing Input Data Files

A permanent copy of the data appearing in the data menus may be obtained by selecting the "Print Data Menus" or "Write Data Menus to a File" options from the Main Menu (see Figure 4-1). If the data are printed directly, the user must ensure that a printer is connected and that the correct print port is defined in the SETUP.DAT file. Otherwise the printout may not occur or the computer may hang-up.

A safer procedure is to write the data to a file and print it after leaving the ERA program. Data written to a file are stored with extension .INP. The name of the file, which contains the data as ASCII text, will be the same as the file in the buffer.

4.11. Program Execution

As shown in Figure 3-1 (Section 3.2), a cabinet loads analysis and cycle analysis may be requested. This request occurs at the Main Menu where the user selects "Calculate Cabinet Loads" or "Calculate energy". The first request results in a calculation of the cabinet loads only. The second request results in both the loads and cycle analysis.

The selected program will run to completion unless aborted by pressing the <Esc> key. Time requirements for the cabinet loads program are very small. The cycle model may require a small or large computational time, depending on the refrigeration cycle defined and the refrigerant characteristics. The most time consuming calculations will occur for a ternary refrigerant mixture in a two-evaporator cycle (such as the Lorenz or dual evaporator cycles which use a single compressor) where some adjustments to the cabinet set points or to the evaporator areas may be required to balance the loads and the evaporator capacities.

As discussed earlier, ERACYC uses an iterative solution technique to solve the many coupled, non-linear equation. A screen display of the estimated temperatures and the refrigerant mass flow is made throughout the iteration process. Although not indicated on the screen, a solution may be "forced" by hitting the <F10> key. This will result in an assumed satisfaction of the solution tolerances following a condenser analysis and lead to termination of the analysis. A note will appear in the output that the solution was forced.

As long as execution is not terminated by pressing the <Esc> key, a display of the output files will automatically occur. However, a direct return to DOS, without display of any files, will occur if the <Esc> key is pressed.

5. CABINET LOADS INPUT DATA REFERENCE

The material within the present and following chapters are meant to supplement information provided within the ERA menu program.

During the first run of the program and when questions arises concerning some data requirement the Help menu should be used (press the <F1> key). A printed copy of each Help menu may be obtained by pressing the <Alt-P> key from within the Help menu. Over 60 pages of Help menus can be printed out and assembled in a separate note book if desired.

5.1. Title of Analysis

Five lines of information may be entered as a description of the design analysis. The entered title will appear on the summary output.

A full screen editor is built into the menu program. The Help or Keys screen describes the editing keys.

5.2. Cabinet Type and Dimension

Five basic designs are described: 1) top-mount refrigerator/freezer, 2) bottom-mount refrigerator/freezer, 3) side-by-side refrigerator/freezer, 4) chest freezer, and 5) upright freezer. Specific design variables (such as the presence or absence of automatic defrost) are requested later in the menu structure. For the purposes of the analysis select the configuration that most closely represents the design under study.

Not all refrigeration cycles are consistent with each cabinet configuration. To enable the user to edit portions of the input data in an arbitrary order, a consistency check between the specified cabinet data and cycle data is made only prior to the program execution step.

The Help menu illustrates the definition of height, width and depth. The following conventions are adopted:

- Cabinet height is measured from the bottom to top of the cabinet, not from the floor. Hence, space below the cabinet that may contain a fan-forced condenser and compressor is not included in this parameter.

- Depth includes the cabinet doors. This dimension measures the distance from the outside (front) surface of the doors to the back of the cabinet. Protrusions such as a handle on the front of the cabinet or a cover over a wire harness on the back of the unit are NOT included in this value.

- To facilitate an understanding of the data request, the width of the gasket and the door edge thickness are requested. ERA interprets the depth of the refrigerated box, not containing the door, as the total depth minus the sum of the door edge thickness and the gasket width. Later data requests for the door thickness refer to the center thickness, thereby allowing the specification of doors that are thicker in the middle than at the edges. The effects of door thickness on the internal volume are taken into account.

Wedge dimensions are requested in a separate menu. The cabinet wedge is the section of the cabinet near the door. In all cabinet types, except the chest freezer, the thickness of the insulation is reduced near the door to accommodate the door geometry. Dimensions are assumed to be the same within each cabinet section (i.e., the side and top wedges of the freezer compartment in a top-mount unit are taken to be the same) although they may be different in one compartment from another.

It is assumed that a freezer compartment in a refrigerator/freezer will always have a wedge with a taper; a wedge is often present in the fresh food section, but may be set to zero (typical of Chinese designs). An upright freezer will also have a wedge. The chest freezer is assumed not to have a wedge.

An illustration of the wedge geometry is given in the Help screen. The wedge depth is the length of the taper from the front towards the back. Wedge width is the thickness of the cabinet at the front.

5.3. Refrigerated Volumes

ERA will calculate internal volumes of the cabinet compartments based on the input data for the cabinet dimensions. The calculated volume is used in the simulation of the contribution to the cabinet loads from door openings. If the calculated volumes are significantly different from the manufacturer's specifications then the input data is probably faulty. For example, the location of the mullion at the wrong position within the cabinet will result in an incorrect calculation of the individual compartment volumes.

See Help screen for additional information.

Normally, the compressor will be located in a space at the rear, bottom of the cabinet, where it is cooled by air blown over the condenser or by natural convection. This space requirement will reduce the food storage volume of the cabinet located above, and will also affect the net external surface area available for heat exchange with the room. A separate menu is provided to describe the compressor compartment.

Three cases are described: 1) the compressor is located outside the dimensions of the cabinet, requiring no reduction in food storage volume; 2) the bottom portion of the back wall is slanted; and 3) the bottom portion of the cabinet contains a compressor space with a horizontal wall. If the compressor is located outside the envelope of a rectangular cabinet box enter 0 for the three data values requested. Otherwise enter data values as directed by the Help menu.

5.4. Freezer and Fresh Food Cabinets

Two menus request the data input for each cabinet section: 1) the wall and door thicknesses, and 2) insulation resistivity for each wall element and door. The net resistance of each cabinet element is determined by the resistivity and the thickness. Drawings of the cabinets showing the requested data are given in the Help screens.

In most instances, interpretation of the wall thickness requests should be straight forward. If the thickness varies over the element, such as the floor of a fresh food cabinet that may have thicker insulation over the compressor, use an averaged thickness value.

The specified thickness of a wall containing a sandwich of foam and a vacuum insulation panel should be the total thickness (neglecting the thickness of the liner).

The thermal resistivities are properties of the materials of construction and the construction methods. For example, typical CFC-11 blown polyurethane foams have a resistivity of 0.55 m^2-C/W-cm. Some vacuum insulation panels may have resistivities of greater than 1.5. Default values for many of the insulation strategies under consideration are available to the user by using the <F5> function key.

Some example insulation values are:

HCFC Blown Foam	0.48 m^2-C/W-cm	7 hr-ft^2-F/Btu-in
CFC-11 Blown Foam	0.55 m^2-C/W-cm	8 hr-ft^2-F/Btu-in
Water Blown Foam	0.42 m^2-C/W-cm	6 hr-ft^2-F/Btu-in
Evacuated Powder	1.73 m^2-C/W-cm	25 hr-ft^2-F/Btu-in
Evacuated Aerogel	1.39 m^2-C/W-cm	20 hr-ft^2-F/Btu-in

The corresponding thermal conductivity of the HCFC blown foam is (typically):

Metric units:	0.0206 W/m-C
Calory units:	0.0177 kCal/m-hr-C
English units:	0.0119 Bth/hr-ft-F

When a composite insulation system is used, an average resistivity for the wall should be specified. ERA provides a method of estimating the average resistivity of a composite consisting of a foam sandwich containing a vacuum insulation panel (see Appendix A). The general case assumes a vacuum insulation panel located between inner and outer foam panels and surrounded by foam along all four edges.

This calculational assist is reached by pressing the <F5> key within the Insulation Resistivity menu. This will cause an additional menu to be displayed which requests information on the design of the insulation system. A Help menu is available which shows the geometry and describes each of the required input parameters. Typical material property values are also given in the Help menu.

Once within the calculational assist menu, two additional editing assists are provided: 1) the fraction of the refrigerator wall consisting of foam may be determined by pressing the <F4> key and entering the vacuum panel thickness; and 2) the amount of foam along the four edges of the panel may be determined by pressing the <F5> key and entering the fractional coverage of the wall by the panel. These functions are explained in further depth in the Help menu.

The user should note that the data displayed in this calculational assist menu will be the last entered and will be carried forth to the next set of calculations. Hence, the user should always be sure that the entire set of data shown in the menu applies to the specific configuration being analyzed.

After leaving the calculation assist menu (press <Pg Dn> key), the calculated net resistivity for the insulation system is directly entered into the Insulation Resistivity menu. Note that different constructions can be used at various locations of the cabinet.

5.5. Mullion

The mullion is the wall between the fresh food and freezer sections of the refrigerator. One is found in the (R/F) configuration type 1 (top-mount: horizontal mullion), type 2 (bottom-mount: horizontal mullion) and in type 3 (side-by-side: vertical mullion). By definition, there is no mullion in a chest freezer or upright freezer.

Typically the resistivity of the mullion insulation is less than that of the foam walls since a removable insulation is often installed in this area. The resistivity is normally about half that of the walls.

5.6. Air and Cabinet Temperatures

The room air and cabinet temperatures establish the heat loads of each compartment on the refrigeration system. For a DOE closed door test simulation a room air temperature of 32.2 C (90 F) is ordinarily specified, along with a freezer temperature of -15 C (5 F) and a fresh food cabinet temperature of 3.3 C (38 F). Temperatures must also be specified for under the cabinet (where the compressor is normally located) and for "air entering the condenser". There will be some uncertainty in these temperatures, since a heat balance is not modeled for the space under the cabinet. Both the compressor and condenser release considerable heat to this compartment. As a rule of thumb, the air temperature in this region should be 10 to 15 F (5 to 10 C) higher than the room temperature.

ERA also contains algorithms for estimating the effects of open door loads on energy consumption. For these analyses (which require door opening schedules) a typical room temperature will be 18 to 24 C (64 to 75 F).

5.7. Door Opening Schedules

The schedule of door openings is defined here to establish the net sensible and latent load heat inputs to the cabinet during the hour. The model assumes an initial complete spilling of the cold air and replacement with warm, relatively more humid, room air, followed by a longer term free convective driven air exchange. The controlling parameters are: the room relative humidity, the number of times each door is opened during the hour, and the average duration of each opening.

Parameters controlling the sensible and latent loads are: room temperature, cabinet temperature, room relative humidity, number of openings/hour, average duration of each door opening, and type of defrost (manual or automatic). A typical schedule for door openings might be:

Fresh Food Door	- Opening/hr.	2.5
	- Duration (sec)	20
Freezer Door	- Opening/hr.	1
	- Duration (sec)	15

Moisture exchange with the room will result in condensation in both cabinets and frost build-up in the freezer section. It is assumed that all moisture entering the fresh food section will end up as frost on the evaporator of a single evaporator system. Frost buildup is not assumed to occur in the fresh food cabinet of a two evaporator system. Defrost energy may result from use of a resistance heating element in the evaporator. This energy is added to the defrost energy specified for the closed door condition, and is reported as "Defrost" in the summary output.

5.8. Gasket Heat Leaks

The gasket areas around the cabinet doors are sources of heat due to conduction loads from the room air along the cabinet and door flanges, and through the gasket itself. Correct estimates of the heat leaks must take into consideration the geometry and materials used in the wall panels and doors. Reference values for the gasket heat leaks may be obtained from the Help menu by pressing the <F1> function key.

All gasket heat leaks are expressed in units of conductance per length of the gasket. The net leak is determined by the program from the total door perimeter and from the outside-inside air temperature difference.

Because of the low values of the conductance, enter the data in units of W/m-100C. A typical value is 10 W/m-100 C temperature difference.

5.9. Defrost and Controls Energy Use

Electrical energy consumption consists of compressor energy, fan energy, anti-sweat energy, and other (ancillary) sources. Such ancillary energy includes automatic defrost and controls. It is assumed that any electrical energy consumed within the cabinet is converted to an equivalent heat load that must be removed by the refrigeration system.

The data menu defines constant and cycle-dependent electrical energy uses, not including fan energy or anti-sweat energy.

Automatic defrost energy usage is a cycle-dependent load, which is normally triggered by a controller that keeps track of compressor operation. Under closed-door test conditions, a typical defrost system might use a 450 watt heater, activated for 10 minutes once every 10 hours of compressor run-time. Additional defrost energy will be required under normal usage conditions. ERA assumes that the additional defrost loads resulting from door openings are additive to the defined closed-door automatic defrost energy.

Energy use from timers and other sources may be defined as being cycle-dependent (related to the compressor run-time) or constant. The locations of these loads determine their effects on the cabinet heat loads. For example, a defrost timer located in the space below the fresh food section will not add to the cabinet heat load, whereas electric defrost heat will add to the load.

5.10. Electric Anti-Sweat Heat

Moisture control on the outside of the cabinet may be accomplished by the use of electric heaters in the area of the cabinet flanges and the mullion. Ordinarily an "energy-saver" switch is supplied with the refrigerator to allow these heaters to be disabled.

Under a DOE closed-door test, the refrigerator is operated under both conditions -- with the heaters on and with the heaters off. ERA can be run for both cases, and the results then averaged to simulate the test conditions. A simple approximation that can be employed is to run ERA once using one half of the heater power to represent an average condition.

Since the heaters are normally installed immediately under the cabinet flanges and/or the mullion, a portion of the heat will leak into the cabinet. A typical fractional heat leak is 20% - 40% in the cabinet flange region, and 40% - 80% in the mullion region.

Electrical heat applied in the mullion region will contribute to heat loads in both compartments. Because of the lower freezer temperature, more of the heat will likely flow to this compartment.

5.11. Refrigerant Line Anti-Sweat Heat

Moisture control on the outside of the cabinet may be accomplished by the use of refrigerant lines in the area of the cabinet door flanges and the mullion. To simplify construction, a combination of refrigerant lines around the cabinet flanges and electrical heaters in the mullion region might also be used.

Either a refrigerant vapor line (containing superheated vapor leaving the compressor) or a refrigerant liquid line (containing refrigerant leaving the condenser) may be used for this function. An advantage resulting from using a liquid line is that additional subcooling occurs prior to entering the capillary tube.

In actual practice, the refrigerant entering a liquid line around the door flange or across the mullion may be in two-phase, with condensation completed within the liquid line. This may be desirable to limit the total refrigerant charge. ERA cannot model this situation, since it assumes completion of condensation in the condenser. The condenser subcooling should be set to zero when a liquid line is represented.

The refrigerant enthalpy decrease from the use of a vapor or liquid line is dependent on the compressor run time. File CYCLE.OUT (the cycle analysis output file) should be reviewed to ensure that the specified cycle-average refrigerant line heating has not resulted in an excessive enthalpy drop (e.g., liquid subcooling to below ambient conditions). A warning message indicating excessive heat withdrawal from the liquid line will appear in the summary output file (ERA.OUT) whenever the refrigerant is cooled below room temperature. In this instance, the degree of refrigerant line heat should be reduced and replaced with an equivalent amount of electric anti-sweat heat. Since the electric anti-sweat heat is switchable, only one-half of the heat deficit should be entered as electric anti-sweat heat to represent average conditions for the DOE closed door test.

(For example, assume that a 6 watt switchable anti-sweat heater is to replaced by a liquid line. Under the closed door test condition, the average condition is represented by 3 watts electrical anti-sweat heat. Since the liquid line heat is not switchable, the 3 watts electrical heat should be replaced by 6 watts liquid line heat. If only 4 watts of liquid line heat can be withdrawn without cooling the refrigerant below room temperature, enter 4 watts liquid line heat and supplement it with 1 watt average electrical anti-sweat heat.)

For the dual loop cycle, ERA assumes that the refrigerant line used for anti-sweat and/or mullion heating is associated with the freezer loop.

5.12. Penetration Heat Input

Heat inputs to the cabinet not associated with electrical sources can be specified as "penetration heat inputs." One such heat source would be associated with through-the-door ice service. In this instance, an estimate of the additional heat leak due to the presence of the mechanism in the door can be made and included as a direct heat leak. This menu can be used for all heat inputs that cannot be directly associated with electrical energy usage.

6. REFRIGERATION CYCLE INPUT DATA REFERENCE

6.1. Cycle Type

Four generic cycle types are described: 1) standard single evaporator and single compressor configuration; 2) Lorenz cycle; 3) dual loop cycle, and 4) dual evaporator cycle.

The standard cycle (type 1) uses a baffle arrangement to mix the airs from the freezer and fresh food cabinets before entering the evaporator. Two evaporators are employed in the Lorenz cycle (type 2), with two interchangers used to promote additional subcooling of the refrigerant leaving the condenser. Two independent refrigeration loops are used in the dual loop cycle (type 3) to cool the fresh food and freezer sections; each loop has its own components.

The dual evaporator cycle (type 4) is similar to the Lorenz cycle, except that pure refrigerants are normally used. The evaporators are in series, with little interchange between the lines connecting the two evaporators and the liquid line leaving the condenser.

Pure refrigerants or refrigerant mixtures can be used with any of the cycles. Normally a binary or ternary non-azeotropic mixture (NARM) is used with the Lorenz cycle, and a pure refrigerant or a near-azeotropic mixture will be used with the standard single evaporator cycle and with the dual loop cycle.

Not all of the cycle types apply to each of the cabinet designs. The table below illustrates the allowable cycles for the five cabinet designs:

	Top Mount	***Bottom Mount***	***Side-by-Side***	***Chest Freezer***	***Upright Freezer***
1: Single Evap	*	*	*	*	*
2: Lorenz	*	*	*		
3: Dual Loop	*	*	*		
4: Dual Evap	*	*	*		

A check of the consistency between the cabinet design and refrigeration cycle is made prior to execution of an energy analysis.

Control of the evaporator loads in the Lorenz cycle or the dual evaporator cycle is difficult if fans are not used. Without some active control method, the cabinet temperatures will change until the loads and evaporator capacities are in balance.

ERA provides six analysis options for the Lorenz and dual evaporator cycles: 0) no control (allow an imbalance in the loads); 1) "mathematically" adjust the relative sizes of the evaporators in the two compartments to obtain balanced loads; 2) adjust the fresh food cabinet temperature to balance the loads; 3) adjust the freezer cabinet temperature to balance the loads; 4) use a flow control valve to alternately direct the refrigerant to one evaporator at a time; and 5) activate a solenoid valve to isolate one of the evaporators during part of the cycle, while allowing refrigerant to flow to the other evaporator whenever the compressor operates.

Option 0 allows an imbalance to occur; it provides the user maximum control over the analysis. Option 1 assumes that the total heat exchanger area is held constant; it is provided as a "design analysis" tool, to determine the necessary distribution of evaporator areas to achieve balanced loads.

Options 2 and 3 result in a change in the cabinet temperatures until the loads in each cabinet are met by the individual evaporators.

Option 4 assumes that the flow control valve will sequentially divert the refrigerant to one and then to the other of the two evaporators over a portion of the cycle. At any given time in the cycle, only one evaporator receives refrigerant.

Option 5 assumes that the refrigerant flows through both evaporators during the major portion of the cycle, and then diverts it past one of the evaporators during the remainder of the cycle. This can be accomplished by a solenoid valve (requiring some energy use). In concept, the use of active fan control accomplishes the same objective; deactivation of an evaporator fan during a portion of the cycle effectively removes the fan-forced heat exchanger from the circuit by substantially reducing its heat transfer capacity.

6.2. Refrigerants

Thirty-four refrigerants, whose data values are stored in a built-in data base, can be utilized as either pure refrigerants or as components of a mixture:

01 = R11,	02 = R12,	03 = R13,	04 = R13B1,
05 = R14,	06 = R22,	07 = R23,	08 = R113,
09 = R114,	10 = R142b,	11 = R152a,	12 = R216a,
13 = R125,	14 = R143a,	15 = R134a,	16 = R123,
17 = RC318,	18 = R134,	19 = RC270,	20 = R141b
21 = S02,	22 = R290,	23 = R600,	24 = R600a,
25 = R32,	26 = R1270,	27 = R124,	28 = R115,
29 = CE216,	30 = E125,	31 = R21,	32 = R143,
33 = R218,	34 = E134.		

The refrigerant data menu references two function keys:

- <F4>: pressing this key results in display of the refrigerant properties and chemical formulas. This may be valuable when selecting one refrigerant in favor of another or when putting together candidate refrigerant mixtures.

- <F5>: pressing this key results in selection of default interaction parameters for mixture pairs.

6.3. Evaporator Design

The options for evaporator design are:

- type: fan forced or natural convection

- air flow pattern: cross-flow or counter-flow

- location of natural convection evaporator: in cabinet space, cold-plate (mounted on the cabinet wall with one side facing the cabinet space), or directly behind the plastic liner.

The state of the refrigerant leaving the evaporator is determined by specification of: 1) the superheat (C) at the exit of the evaporator, 2) the superheat (C) at the exit of the interchanger between the evaporator and the compressor, or 3) the refrigerant quality (less than 1.0) at the exit of the evaporator.

Specification of the evaporator exit condition (quality or superheat) avoids the necessity to model the flow control device (cap-tube). The superheat condition at the evaporator exit actually corresponds to a design goal. Normally, the selection of cap-tube diameter and length will depend on the amount of superheat desired.

The heat transfer from a fan-forced evaporator will depend on the overall U-values in the two-phase (evaporating) and single-phase (superheating) regimes. These values, along with the refrigerant pressure drop, may be estimated by pressing the <F5> key where noted in the evaporator menu and by inputting the requested heat exchanger design information. For computational purposes, the heat exchanger is assumed to be composed of circular tubes containing refrigerant in cross-flow with air. The face area is determined from the number and spacing of the tubes in the transverse direction (perpendicular to the air flow) and the tube length. The depth of the heat exchanger is determined from the number and spacing of the tubes in the direction of the air flow. A "deep" heat exchanger (more than 3 - 5 tubes deep) will behave like a counter-flow design.

The user may also elect to enter an overall UA value for the evaporator. This may be useful if a measured value is available. In this instance, ERA will assume a constant U-value along the length of the heat exchanger.
If fan-forced, the evaporator may be considered as being in cross-flow or in counter-flow. For a pure refrigerant, in the absence of a significant pressure drop, there is essentially no difference between the two. However, with a refrigerant mixture that results in a large temperature glide from the entrance to the exit of the evaporator, a counter-flow design may be more efficient.

Solution of counter-flow heat transfer in the evaporator is more difficult and time consuming than cross-flow. Because of this, the following recommendations are made:

- select the cross-flow model unless a large temperature glide is expected. Set the number of two-phase nodes equal to 1 in file CYCLE.TOL;

- explore the effects of counter-flow heat transfer if the temperature glide is larger than 10 C. Set the number of nodes in the two-phase regime equal to 3 in file CYCLE.TOL.

ERA uses a built-in natural convection model to establish the rate of natural convection heat exchange between the evaporator plate and the cabinet air. Both radiative and free convective heat transfer contribute to the net cooling accomplished by the evaporator.

A data menu requests information relating to the geometry of the evaporator to calculate the refrigerant pressure drop. Evaporation and sensible heat exchange will determine the two-phase and vapor velocities, which will in turn establish the refrigerant pressure loss across the evaporator.

Three generic types of natural convection evaporators are modeled: 1) a flat plate located within the cabinet space, 2) a cold-plate configuration, and 3) a behind-the-liner configuration. If the evaporator is mounted behind the plastic liner, an additional heat transfer resistance will be encountered, with a typical reduction in the cooling capacity of 10 to 15%. ERA assumes an added resistance equal to 2.5 mm polystyrene (0.9 cal/hr-cm-C thermal conductivity).

A higher cooling capacity will be achieved from a plate of a given size that is located within the cooled space since both sides of the plate will be available for heat convection and since the wall temperature will not be significantly affected by the plate. A cold-plate evaporator or a behind-the-liner (mounted directly under the liner) type of evaporator provides more internal volume, but will result in an increased refrigeration load due to the cooling of the wall by the evaporator and a reduced foam thickness.

An ERA data menu requests information on the evaporator heat transfer area. This is the total effective area available for heat transfer. For a free convective evaporator located within the cabinet space, the total area of both sides of the evaporator should be entered; for a cold-plate evaporator, only the area of the plate facing the cabinet space should be entered.

ERA was not intended to substitute for a detailed heat exchanger design program. For instance, if a roll-bond type free convective evaporator design is employed, some estimate of the effects of thermal bond resistance on the effective heat transfer area must be made by the user. Normally, the level of uncertainty in the net effective area will not have a large impact on the cycle performance calculations.

For the refrigerator/freezer configurations, a portion of a natural convection freezer evaporator may be located in the mullion area between the two cabinet sections. The evaporator thickness determines the volume occupied in the cabinet wall and/or mullion that would otherwise be occupied by insulation.

Specification of this geometry, which satisfies the definition of a cold-plate evaporator, will be requested only for a natural convection design. A fan-forced freezer evaporator of a refrigerator/freezer is always assumed to be located in the back of the freezer section (vertical orientation).

6.4. Condenser Design

As with the evaporator, the condenser may employ a fan-forced or natural convection design; if fan-forced it may be cross-flow or counter flow. Liquid subcooling is specified as a design goal (this replaces the need for a mass inventory balance about the refrigerator loop to calculate the subcooling).

Hot-wall condensers (tubes attached to the underside of the outer skin of the cabinet) may be specified for any of the refrigerator/freezer or freezer designs other than the side-by-side unit. Free convection (static) condensers may be used for all designs. Fan-forced condensers are assumed to be located under the cabinet. The increase in air temperature under the cabinet from condenser (and compressor shell) heat losses must be estimated and specified by the program user.

It is assumed that most of a static or fan-forced heat exchanger has flat or wire fins to increase the effective heat transfer area. The condenser fins provide extended heat transfer area to increase the overall effectiveness of the heat exchanger. Wire fins will act to break up the air flow (promote turbulence) as well as to provide additional heat transfer area.

The issues relating to cross-flow versus counter-flow heat transfer are essentially the same as discussed above for the evaporator.

Heat losses will occur along the line from the compressor discharge port to the condenser inlet. These may be uncontrolled, as in a bare or partially insulated line, or may result from cabinet flange heating. A hot gas loop used for cabinet flange heating will normally lose a fraction of its heat to both of the cabinet sections as well as to the environment.

6.5. Calculation Assist Menus for Evaporator and Condenser UA Values

If the analysis involves alternate refrigerants or various compressor designs, use of the calculation assist menus to calculate the heat exchanger UAs is recommended. The UA analysis algorithms take into consideration the influence of refrigerant thermophysical properties and the refrigerant mass flow rate on the refrigerant-side heat transfer (see Appendix B).

It is noted that the calculation of UA values is done within the data input program, rather than during the cycle simulation. The required inputs for the refrigerant mass flow rate and evaporator inlet quality may not be known until the cycle analysis has been completed. Once the cycle analysis has been run, the output file (CYCLE.OUT) should be reviewed to ensure that the calculated mass flow rate and inlet quality agree with those used to determine the heat exchanger UAs. If the values differ significantly, the analysis should be rerun using updated values for these parameters in the heat exchanger calculation assist menus.

6.6. Compressor Design

Separate models are provided for a reciprocating compressor and a rotary compressor. The models differ in the treatment of suction gas heating within the shell and in the volumetric efficiency algorithm (see Appendix B).

A compressor map based model, an EER and capacity model, or an efficiency model may be selected to describe compressor performance.

The compressor map approach utilizes a table of performance data (supplied by the user) for the specific refrigerant. A sample performance map table (a file, which may have any valid 8 character name with the extension .TAB) is shown below:

Sample Compressor Map Data Table (*.TAB)

Name of Compressor

12.3	Mass flow at standard rating point (lb/hr or kg/hr)
3	Number of data points along evaporating temperature axis
3	Number of data points along condensing temperature axis
1	Compressor type (1 - reciprocating; 2 - rotary)
1	Units for capacity, temperature data, and mass flow (1 - btu/hr, deg F, lb/hr; 2 - kcal/hr, deg C, kg/hr)

Capacity Data

Cond Temp	Evaporating Temperature		
	-30.00	-10.00	10.00
110	441	837	1428
120	419	794	1384
130	397	762	1340

Compressor Power, Watts

Cond Temp	Evaporating Temperature		
	-30.00	-10.00	10.00
110	107	160	210
120	108	160	214
130	108	162	218

The EER and capacity model requests a single calorimeter data point at the standard test condition with CFC-12 refrigerant. Correlations for the suction gas superheat and shell heat loss (discussed in APPENDIX B) are use to determine values for the clearance volume and the compression efficiency. A correction for the thermodynamic characteristics of the circulating refrigerant is made.

To extend the performance data to other conditions and other refrigerants, it is necessary to know the conditions under which the data were obtained. These parameters are the displacement and the method of compressor can cooling during the calorimeter test.

The efficiency model requests information concerning the compressor components and the piston displacement. Approximate values for the shell losses and internal tubing losses must be supplied as well. Specific instructions for defining these data are provided in the Help menu for the physically based model.

The efficiency model may only be used for a reciprocating compressor. However, the analysis approach allows the evaluation of variable speed drive options, an investigation of the effects of motor efficiency on performance, and the direct specification of size as measured by the displacement.

The cycle model (ERACYC) calculates the mass flow of the refrigerant pumped by the compressor, based on the estimated conditions at the suction port of the pump and the volumetric efficiency. Suction gas superheat at the suction port is determined from the heat exchange internal to the compressor can. The can loss parameter, which defines the rate of shell cooling, directly affects the internal heating.

Additional details about the input data requirements for the compressor models are provided by the Help menu (press <F1> key). Appendix B summarizes the algorithms employed for the various models.

6.7. Cycling Losses

Cycling losses are caused by thermal transient effects in the evaporator and condenser as well as by migration of refrigerant from the condenser to the evaporator during the off-cycle.

Some system designs with a rotary compressor employ a shut-off valve between the condenser and evaporator to reduce the off-cycle refrigerant flow. In those designs, it may be advantageous to maintain tight temperature control in the cabinets to force more frequent cycling, thereby maintaining a higher average temperature evaporator and a lower average temperature condenser. For the standard design, without a shut-off valve, it will be advantageous to minimize the compressor stop/starts, thereby minimizing the losses associated with refrigerant migration (a typical cycle time might be 20 minutes on and 30 minutes off).

ERA provides two options relative to cycling losses: 1) ignore losses on compressor energy use; or 2) adjust the calculated steady-state compressor power for losses using an algorithm based on the cycling rate. At a cycling rate of 2 cycles per hour, the estimated cycling loss would be 2.2%. The cycling model is described in Appendix B.

There are indications that a shut-off valve can actually increase the cycle-average compressor performance above the steady-state level [6]. At a cycling rate of 2 cpm, the "cycle loss model" predicts an efficiency gain of about 3%. Hence the overall efficiency increase from using a shut-off valve (with a rotary compressor) may be about 5%. This is discussed in further detail in Appendix B.

6.8. Interchangers

The line leaving the condenser is normally in thermal contact with the line leaving the evaporator on its way to the compressor. This line contact provides liquid subcooling at the expense of additional superheat in the suction line. ERA requests information relating to the effectiveness of the interchanger (and of the interchanger between the fresh food and freezer evaporators in the Lorenz cycle). Additional heat transfer may also take place in the refrigeration line between the interchanger and compressor shell inlet (normally heating of the refrigerant by the room air).

7. SAMPLE PROBLEM

7.1. Multiple Pathway "Model D" Prototype Design

Use of the ERA model for loads and energy use analysis is illustrated for the Multiple Pathway Model D refrigerator [5]. This design is intended to be a composite of design features for a prototype 18 cu-ft top-mount refrigerator/freezer that would meet the 1993 energy standard by a comfortable margin using off-the-shelf technology. The specific design approach adopted provides an outer shell 76 cm (30 inches) wide, amenable to thicker wall insulation without exceeding normal width constraints. Figures 7-1 through 7-3 illustrate design features (where the dimensions are in units of inches to facilitate comparison with typical designs of current model refrigerators). The overall characteristics of the prototype model are summarized in Table 7-1, where data are shown in both English and metric units.

Most of the parameters in Table 7-1 are well defined (e.g., dimensions, temperatures, compressor characteristics). Others are either estimates (e.g., temperature under fresh food cabinet) or "typical" (e.g., gasket heat loss). The model user can easily adopt alternate assumptions and investigate the effects of uncertainties in these parameters on the predicted cabinet loads and energy use.

7.2. Input Data Menus (MODEL_D.INP)

The data file for the sample problem is MODEL_D.ERA.

Figure 7-4 shows the input data menus for the sample problem. Individual data menus and values are shown for each data block defining the sample problem, exactly as displayed during the input data processing phase of the analysis. The specific menus are consistent with the type of cabinet (top-mount, refrigerator/freezer) and the type of refrigerator cycle (single evaporator, fan-forced). Only data relevant to the particular problem are shown.

This data is not normally output for each analysis. However, the user may choose to create and save the menu data as part of the documentation for an analysis. The output (MODEL_D.INP) is obtained from the Main Menu of ERA using the "Print Data Menus" or "Write Data Menus to a File" function.

7.3. Intermediate Cabinet Loads Data File (CABINET.DAT)

The first executable module of ERA (MENU.EXE) creates an intermediate data file which serves as the input to the cabinet loads program (see Figure 3-1 for the relationship between the executable program modules and the data transfers). As illustrated in Figure 7-5, the structure of the intermediate file is designed to facilitate interpretation by the program user.

Because of the overall structure of ERA, the intermediate data file is not meant to be modified. Program module CAB.EXE will read the file, whose structure will be different for each cabinet type, and perform the cabinet loads analysis. The user may choose to print out this file for documentation purposes.

Table 7-1. Characteristics of Model D Prototype Refrigerator

Dimensions		
Height	61.50 in	156.21 cm
Width	30.01 in	76.20 cm
Depth	28.25 in	71.76 cm
Freezer Volume (approx.)	4.60 cu-ft	130.30 liter
Fresh Food Volume (approx.)	13.40 cu-ft	379.50 liter
Door Thickness	1.75 in	4.45 cm
Freezer Wall Thickness	2.38 in	6.03 cm
Fresh Food Thickness	1.88 in	4.76 cm
Gasket Heat Loss	0.004 Btu/hr-in-F	0.0900 w/m-C
Air Temperatures		
Room	90.0 F	32.2 C
Freezer	5.0 F	-15.0 C
Fresh Food	38.0 F	3.3 C
Under Cabinet/Condenser	100.0 F	37.8 C
Auxiliary Energy (Cycle Average)		
Door Flange Heater	Liquid Line	Liquid Line
Mullion Heater	2.75 w	2.75 w
Defrost Heat	2.81 w	2.81 w
Defrost Timer	1.50 w	1.50 w
Refrigeration Cycle	Single Evaporator	
Compressor		
Type	Reciprocating	
EER	5.28	
Capacity	865 Btuh	218 kcal/hr
Evaporator		
Area (Air side)	25.2 ft^2	2.34 m^2
Air Flow	50.0 cfm	23.6 liter/sec.
Fan Energy	9.4 w	9.4 w
Condenser		
Area (Air side)	9.15 ft^2	0.85 m^2
Air Flow	90.0 cfm	42.48 liter/sec.
Fan Energy	12.0 w	12.0 w

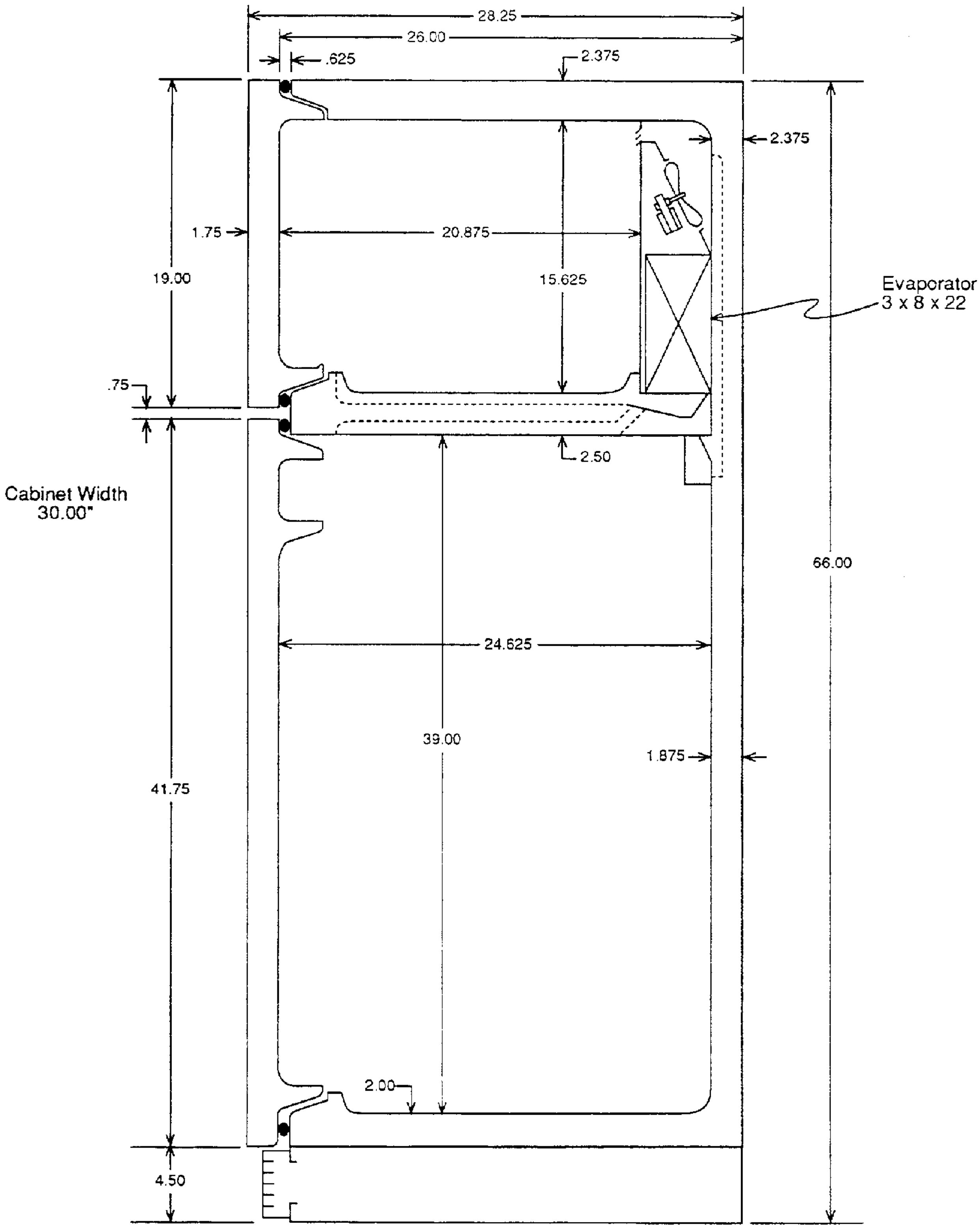


FIGURE 7–1
VERTICAL SECTION — 18 FT^3 PROTOTYPE MODEL
(APPROX. 1/8 SCALE)

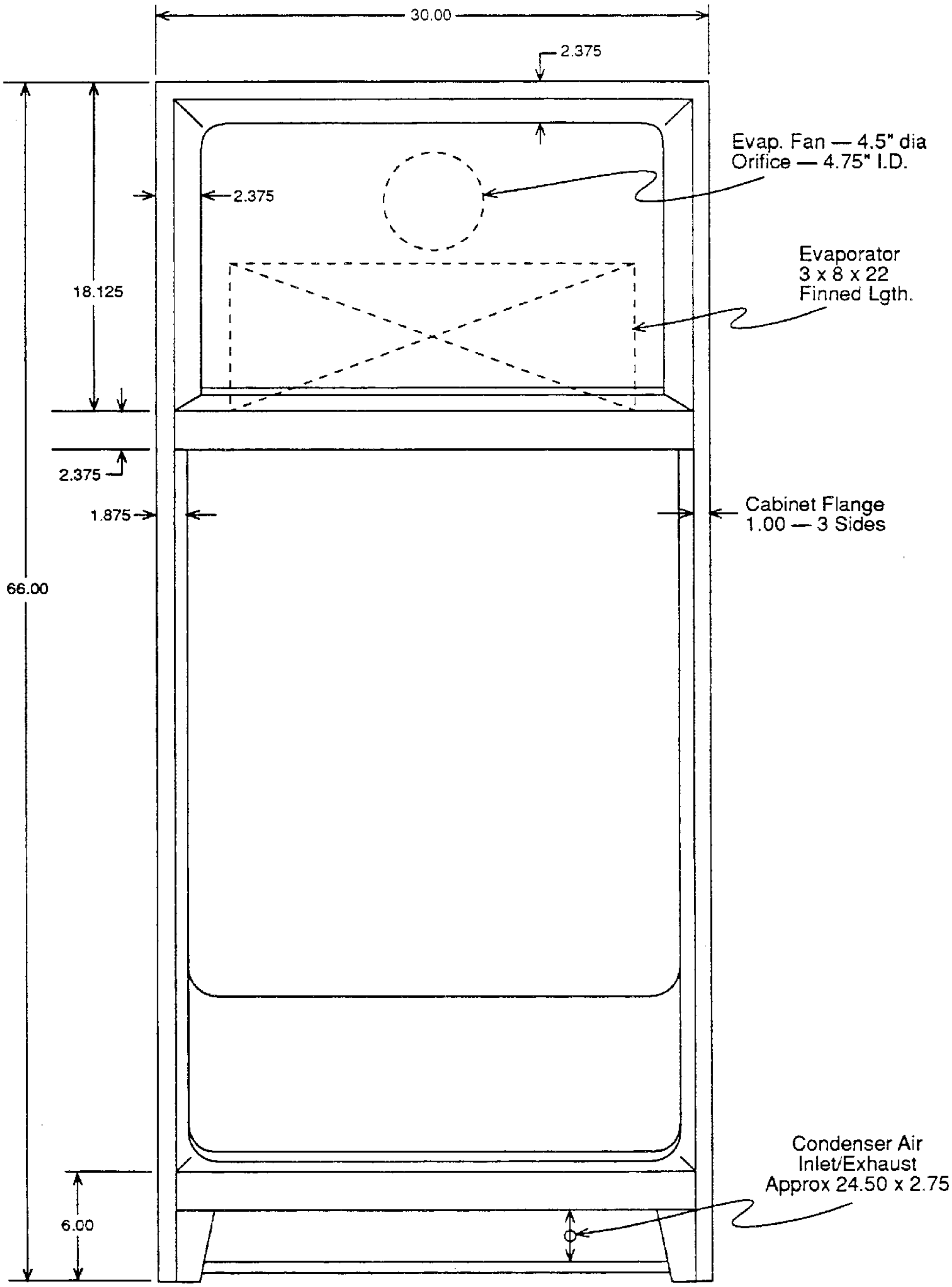
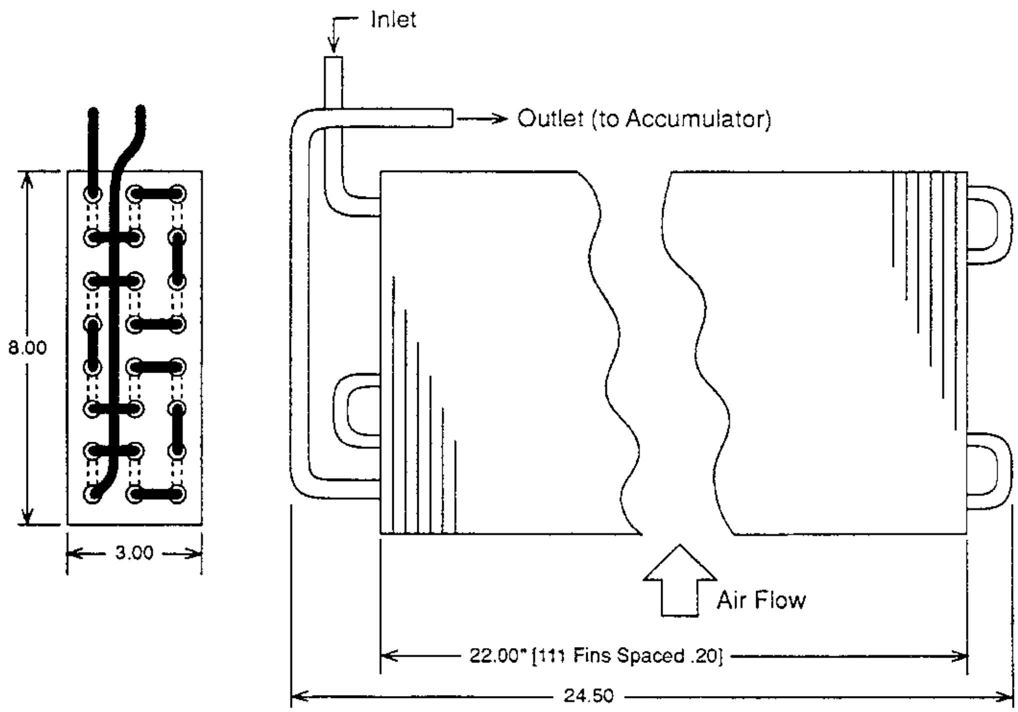


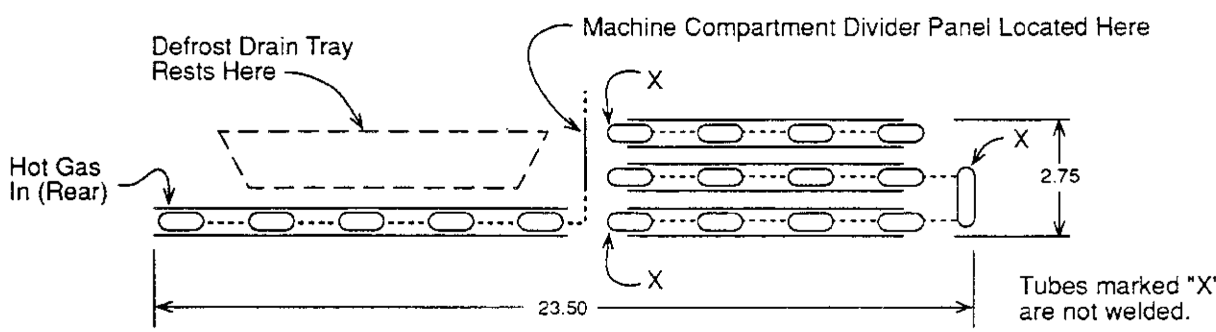
FIGURE 7-2
FRONT VIEW, CABINET ONLY — 18 FT^3 PROTOTYPE MODEL
(APPROX. 1/8 SCALE)



EVAPORATOR DETAIL

Fin & Tube: 24 Tubes — 5/16 OD x .028 Wall Al.
111 Fins — 3 x 8 x Mfrs. Recommended Thickness

Note: Circuitry shown is compatible with Peerless mfg. techniques. Other circuitry possible.



CONDENSER DETAIL (WIRE & TUBE — FAN COOLED)

Specs: Tubing — 1/4 OD x .028 Wall Steel
Serpentine — 36 Tubes — 16" Overall Width
Wires — .046 Dia. — 60 per Side (120 total) — Spaced .200"

FIGURE 7–3
HEAT EXCHANGER DESIGNS

MULTIPLE PATHWAYS BASELINE PROTOTYPE: MODEL D (TOP-MOUNT)	
CABINET TYPE AND OVERALL DIMENSIONS	
Configuration Type (1-5)	1
Cabinet Height (cm)	156.21
Cabinet Width (cm)	76.20
Cabinet Depth* (cm)	71.75
Gasket Width (cm)	1.59
Door Edge Thickness (cm)	4.45
* including door and gasket	
CABINET WEDGE DIMENSIONS	
Freezer Section	
Wedge Depth (cm)	7.62
Flange Width (cm)	3.87
Fresh Food Section	
Wedge Depth (cm)	7.62
Flange Width (cm)	3.87
REFRIGERATED VOLUME	
Freezer Section	
Volume Used by Evap (L)	21.01
Volume Used by Food (L)	.00
Volume Used by Shelf (L)	.00
Net Storage Volume (l)	135.07
Fresh Food Section	
Volume Used by Evap (L)	.00
Volume Used by Food (L)	.00
Volume Used by Shelf (L)	18.34
Net Storage Volume (L)	394.74
COMPRESSOR COMPARTMENT DIMENSIONS	
Top Depth (cm)	.00
Bottom Depth (cm)	.00
Height (cm)	.00
FREEZER INSULATION THICKNESS	
Top Wall Thickness (cm)	6.03
Side Wall Thickness (cm)	6.03
Back Wall Thickness (cm)	6.03
Door Thickness (cm)	4.45

Figure 7-4. Input Data Menus

FREEZER INSULATION RESISTIVITIES	
Resistivity (m2-C/W-cm)	
Top Wall	.555
Side Wall	.555
Back Wall	.555
Door .555	
Wedge .555	
FRESH FOOD INSULATION THICKNESS	
Side Wall Thickness (cm)	4.76
Back Wall Thickness (cm)	4.76
Bottom Wall Thickness (cm)	5.08
Door Thickness (cm)	4.45
FRESH FOOD INSULATION RESISTIVITIES	
Resistivity (m2-C/W-cm)	.555
Side Wall	.555
Back Wall	.555
Bottom	.555
Door .555	
Wedge .555	
MULLION	
Distance to Top (cm)	45.72
Thickness (cm)	6.35
Resistivity (m2-C/W-cm)	.31
AIR AND CABINET TEMPERATURES	
Room Air (C)	32.22
Freezer Section (C)	-15.00
Fresh Food Section (C)	3.33
Air Under Cabinet (C)	37.80
Air Entering Condenser (C)	35.00
DOOR OPENING SCHEDULE	
Room Relative Humidity (%)	50.00
Fresh Food Door - #Hr	.00
Fresh Food Door - Sec Open	15.00
Freezer Door - #/Hr	.00
Freezer Door - Sec Open	20.00
Manual Defrost (0=N, 1=Y)	0
GASKET HEAT LEAKS (W/M-100C)	
Fresh Food Section	9.00
Freezer Section	9.00

Figure 7-4. Input Data Menus (continued)

DEFROST AND CONTROLS ENERGY USE	
Automatic Defrost Load	
Timer Interval (Hr)	10.00
Heater on-Time (Hr)	10.00
Defrost Heater Energy (W)	450.00
Other Cycle-Dependent Loads	
Freezer Section (W)	.00
Fresh Food Section (W)	.00
Outside Cabinet (W)	1.50
Constant Electrical Loads*	
Freezer Section (W)	.00
Fresh Food Section (W)	.00
Outside Cabinet (W)	.00
* See Help Menu <F1>	
ELECTRIC ANTI-SWEAT HEAT	
Freezer Door Flange	
Cycle Average Energy (W)	.00
Fraction Heat Leak (0-1)	.00
Fresh Food Door Flange	
Cycle Average Energy (W)	.00
Fraction Heat Leak (0-1)	.00
Mullion	
Cycle Average Energy (W)	2.75
Heat Leak to FZ (0-1)	.50
Heat Leak to FF (0-1)	.25
REFRIGERANT LINE ANTI-SWEAT HEAT	
Type (1=Vapor, 2=Liquid)	2
Freezer Door Flange	
Cycle Average Energy (W)	4.00
Fraction Heat Leak (0-1)	.30
Fresh Food Door Flange	
Cycle Average Energy (W)	.00
Fraction Heat Leak (0-1)	.00
Mullion	
Cycle Average Energy (W)	.00
Heat Leak to FZ (0-1)	.00
Heat Leak to FF (0-1)	.00

Figure 7-4. Input Data Menus (continued)

PENETRATION HEAT INPUT	
Penetration Heat to FZ (W)	.00
Penetration Heat to FF (W)	.00
CYCLE DEFINITION	
Cycle Type (1-4)	1
1 = Single Evap	
2 = Lorenz Cycle	
3 = Dual Loop Cycle	
4 = Dual Evap Cycle	
Number Refrigerants (1-3)	1
1 = Pure Refrigerant	
2 = Binary Mixture	
3 = Ternary Mixture	
REFRIGERANT CODES	
Refrigerant Code (1-34)	2
EVAPORATOR DATA	
Ref Control Option (1-3)	1
1: Evaporator Superheat	
2 : Interchanger Superheat	
3: Evap Exit Quality	
Refrigerant Superheat (C)	3.00
Heat Exchanger Type (1-2)	1
1: Cross-flow	
2: Counter-flow	
Heat Transfer Type (1-2)	1
1: Forced Convection	
2: Free Convection	
Fan Motor Power (W)	9.40
Heat Transfer Area (m2)	2.338
Air Flow Rate (L/s)	23.600
Two-Phase U (W/m2-C)	13.787
Superheat U (W/m2-C)	5.633
Refr Pressure Drop (kPa)	7.200
CONDENSER DATA	
Refrigerant Subcooling (C)	.00
Heat Exchanger Type (1,2)	1
1 = Cross-Flow	
2 = Counter-Flow	

Figure 7-4. Input Data Menus (continued)

CONDENSER DATA (continued)	
Heat Transfer Type (1,2)	1
1 = Forced Convection	
2 = Free Convention	
Fan Motor Power (w)	12.00
Heat Transfer Area (m2)	.85
Air Flow Rate (L/s)	42.48
Sub-Cool U (W/m2-C)	15.43
Two-Phase U (W/m2-C)	19.23
Superheat U (W/m2-C)	15.17
Refr Pressure Drop (kPa)	4.72
COMPRESSOR MODEL OPTIONS	
Compressor Type (1,2)	1
1: Reciprocating	
2: Rotary	
Compressor Model (0.1,2)	1
0: Compressor Map	
1: EER and Capacity	
2: Efficiency Model	
Cycling Loss Analysis (0,1)	1
0: No, 1: Yes	
Cycles per Hour	2.00
Typical: 1.5 to 4.0	
Shut-off Valve (0, 1)	0
0: No, 1: Yes	
COMPRESSOR DATA	
Displacement (cc)	6.57
Rated Capacity (kcal/hr)	218.00
Nominal Speed (rpm)	3450.00
Rated EER	5.28
Type of Can Cooling (0, 1)	
0: Static, 1: FAn-Forced	
Fractional Speed (0.2-1.0)	1.00
Mass Flow Guess (kg/hr)	5.80
INTERCHANGER DATA	
Compr Shell Inlet Temp (C)	-1.00
(-1 Means Unspecified)	
Interchanger Effect (0 - 1)	.80
Condenser Subcooler	

Figure 7-4. Input Data Menus (continued)

MULTIPLE PATHWAYS BASELINE PROTOTYPE: MODEL D (Top-Mount)

CABINET TYPE	
1	TOP-MOUNT REFRIGERATOR/FREEZER
CABINET DIMENSIONS	
156.2100	CABINET HEIGHT (CM)
76.2000	CABINET WIDTH (CM)
71.7500	CABINET DEPTH (CM)
7.6200	FREEZER WEDGE (CM)
3.8700	FREEZER FLANGE (CM)
7.6200	FRESH FOOD WEDGE (CM)
3.8700	FRESH FOOD FLANGE (CM)
4.4450	DOOR EDGE THICKNESS (CM)
1.5900	GASKET THICKNESS (CM)
.0000	COMPRESSOR COMPARTMENT TOP DEPTH (CM)
.0000	COMPRESSOR COMPARTMENT BOTTOM DEPTH (CM)
.0000	COMPRESSOR COMPARTMENT HEIGHT (CM)
MULLION DATA	
45.7200	DISTANCE TO TOP (CM)
6.3500	THICKNESS OF MULLION (CM)
FREEZER INSULATION THICKNESS	
6.0300	THICKNESS OF INSULATION ON TOP OF FREEZER (CM)
6.0300	THICKNESS OF INSULATION ON LEFT SIDE OF FREEZER (CM)
6.0300	THICKNESS OF INSULATION ON RIGHT SIDE OF FREEZER (CM)
4.4450	THICKNESS OF INSULATION ON FRONT OF FREEZER (CM)
6.0300	THICKNESS OF INSULATION ON BACK OF FREEZER (CM)
FRESH FOOD INSULATION THICKNESS	
4.7600	THICKNESS OF INSULATION ON LEFT SIDE OF FRESH FOOD (CM)
4.7600	THICKNESS OF INSULATION ON RIGHT SIDE OF FRESH FOOD (CM)
4.4450	THICKNESS OF INSULATION ON FRONT OF FRESH FOOD (CM)
4.7600	THICKNESS OF INSULATION ON BACK OF FRESH FOOD (CM)
COMPRESSOR CABINET INSULATION THICKNESS	
5.0800	MAXIMUM THICKNESS OF BOTTOM INSULATION FRESH FOOD (CM)
5.0800	THICKNESS OF INSULATION OVER COMPRESSOR (CM)
REFRIGERATED VOLUMES	
21.0100	FREEZER VOLUME USED FOR HEAT EXCHANGERS (L)
135.0700	ADJUSTED FREEZER VOLUME (L)
18.3400	FRESH FOOD VOLUME USED FOR HEAT EXCHANGERS (L)
394.7400	ADJUSTED GENERAL REFRIGERATED VOLUME (L)

Figure 7-5. Intermediate Data: Cabinet Loads Analysis

AIR AND CABINET TEMPERATURES

```
   32.2200      ROOM TEMPERATURE (C)
   -15.000      FREEZER TEMPERATURE (C)
    3.3300      FRESH FOOD COMPARTMENT TEMPERATURE (C)
   37.8000      UNDERSIDE AIR TEMPERATURE (C)

INSULATION RESISTIVITIES
     .5550      RESISTIVITY OF REFRIGERATOR INSULATION
     .5550      RESISTIVITY OF FREEZER INSULATION
     .5550      RESISTIVITY OF REFRIGERATOR WEDGE INSULATION
     .5550      RESISTIVITY OF FREEZER WEDGE INSULATION
     .5550      RESISTIVITY OF REFRIGERATOR DOOR
     .5550      RESISTIVITY OF FREEZER DOOR
     .3150      RESITIVITY OF THE MULLION INSULATION

GASKET HEAT LEAKS
     .0900      GASKET HEAT LEAK FOR FREEZER COMPARTMENT
     .0900      GASKET HEAT LEAK FOR FRESH FOOD COMPARTMENT

DOOR OPENING SCHEDULES
   32.2200      ROOM TEMPERATURE (C)
   50.0000      ROOM RELATIVE HUMIDITY (%)
     .0000      FRESH FOOD DOOR - OPEN #/hr
    15.000      FRESH FOOD DOOR - SEC OPN
     .0000      FREEZER DOOR - OPEN #/HR
   20.0000      FREEZER DOOR - SEC OPEN

AUXILIARY ENERGY USE (CONSTANT)
     .9167      FRESH FOOD ANTI-SWEAT HEATER (W)
    1.8333      FREEZER ANTI-SWEAT HEATER (W)
     .0000      FRESH FOOD OTHER ENERGY (W)
     .0000      FREEZER OTHER ENERGY (W)
     .0000      OUTSIDE CABINET (W)

PENETRATIONS
     .0000      FRESH FOOD (W)
     .0000      FREEZER (W)

AUXILIARY THERMAL HEAT INPUTS
     .6875      FRESH FOOD ELECTRIC ANTI-SWEAT (W)
    1.3750      FREEZER ELECTRIC ANTI-SWEAT (W)
     .0000      FRESH FOOD REFRIGERANT LINE ANTI-SWEAT (W)
    1.2000      FREEZER REFRIGERANT LINE ANTI-SWEAT (W)
     .0000      FRESH FOOD OTHER HEAT SOURCES (W)
     .0000      FREEZER OTHER HEAT SOURCES (W)
END
```

Figure 7-5. Intermediate Data: Cabinet Loads Analysis (continued)

7.4. Cabinet Loads Results (CABINET.OUT)

The cabinet loads program creates an output file (CABINET.OUT) which summarizes the input data and the calculated loads. Figure 7-6 illustrates the output for the sample problem.

Interpretation of most of the input data is straight forward. The freezer and general refrigerated (fresh food section) volumes are shown to provide a check on the accuracy of the specified input. (A large difference between the calculated and specified net volumes may indicate an input error.)

Most of the file CABINET.OUT summarizes the individual cabinet design parameters. Results of the steady state analysis are listed under the heading "HEAT LEAK BREAKDOWN", where components of the net heat load are shown. As discussed earlier, the listed quantities do not yet include the effects of fan heat and of a cold-plate evaporator or hot-wall condenser.

The gasket heat loss is a product of the heat leak per unit perimeter, the calculated door perimeter and the room to cabinet temperature difference. The fresh food section always has a negative heat leak across the mullion, since heat flows from the fresh food section to the freezer section.

7.5. Intermediate Cycle Data File (CYCLE.DAT)

An ASCII file containing inputs to the cycle model is also created by the menu-driven input processor. An example of the file (CYCLE.DAT) for the sample problem is shown in Figure 7-7. As with the cabinet loads intermediate data file, CYCLE.DAT is not meant to be edited directly, but is written in a formatted style for ease of interpretation. The actual format will differ with the cycle type and according to the types of evaporator and condenser. Hence, the user should not attempt to run the cycle model directly without using the ERA overall program facilities.

Most of the data listed in Figure 7-7 are self explanatory. The section of data entitled "In-wall Evaporator Data" contains correction factors to the cabinet loads that are made in the cycle model to account for the presence of a cold-plate evaporator, or a hot-wall condenser, or both. A code (0, 1) indicates if the evaporator is behind the inner plastic liner.

Summary cabinet loads output data are appended to the CYCLE.DAT file for use by the cycle model. These parameters enable calculation of the compressor run time, fan energy, and the daily energy consumption. Each of the cabinet loads data found in Figure 7-7, for the sample problem, can be found in the cabinet loads output report, Figure 7-6.

File CYCLE.DAT is essential to run the final executable program, ERACYC.EXE. The ERA program user may wish to print the file out as part of the run documentation.

MULTIPLE PATHWAYS BASELINE PROTOTYPE: MODEL D (TOP-MOUNT)

THERMAL ANALYSIS OF A TOP-MOUNT REFRIGERATOR/FREEZER

CONFIGURATION TYPE: 1

DIMENSIONAL SPECIFICATIONS

OVERALL: 156.21 CM HIGH X 76.20 CM WIDE X 71.75 CM DEEP
FREEZER:
THE WEDGE IS 7.62 CM DEEP
THE FLANGES ARE 3.87 CM WIDE
FRESH FOOD COMPARTMENT:
THE WEDGE IS 7.62 CM DEEP
THE FLANGES ARE 3.87 CM WIDE
THE TOP OF THE MULLION IS 45.72 CM FROM THE TOP OF THE CABINET
THE MULLION IS 6.35 CM THICK
COMPRESSOR COMPARTMENT DIMENSIONS:
TOP DEPTH: .00 CM BOTTOM DEPTH: .00 CM HEIGHT: .00 CM

INSULATION THICKNESS
FREEZER

TOP	6.03 CM
LEFT SIDE	6.03 CM
RIGHT SIDE	6.03 CM
FRONT (DOOR)	4.45 CM
BACK	6.03 CM

INSULATION THICKNESS
FRESH FOOD

LEFT SIDE	4.76 CM
RIGHT SIDE	4.76 CM
FRONT (DOOR)	4.45 CM
BACK	4.76 CM
BOTTOM	5.08 CM

VOLUMES

FREEZER REFRIGERATED VOLUME

CALCULATED	134.98 LITER
SPECIFIED	
SHELF/EVAP	21.01 LITER
NET VOLUME	135.07 LITER

Figure 7-6. Cabinet Loads Output

GENERAL REFRIGERATED VOLUME	
CALCULATED	394.79 LITER
SPECIFIED	
SHELF/EVAP	18.34 LITER
NET VOLUME	394.74 LITER
TEMPERATURES	
ROOM	32.22 DEG C
FREEZER CABINET	-15.00 DEG C
FRESH FOOD CABINET	3.33 DEG C
AIR UNDER REFRIGERATOR	37.80 DEG C
THERMAL CHARACTERISTICS	
THERMAL RESISITIVITY	
FRESH FOOD CABINET	.5550 m2-C/W-cm
FREEZER CABINET	.5550 m2-C/W-cm
FRESH FOOD WEDGE	.5550 m2-C/W-cm
FREEZER WEDGE	.5550 m2-C/W-cm
FRESH FOOD DOOR	.5550 m2-C/W-cm
MULLION	.3150 m2-C/W-cm
GASKET HEAT LEAK	
FREEZER	.0900 W/m-C
REFRIGERATOR	.0900 W/m-C
DOOR OPENINGS	
AIR TEMPERATURE	32.2 Deg C
RELATIVE HUMIDITY	50.0 (%)
FRESH FOOD COMPARTMENT	
OPENINGS/HR	.0 #/HR
DURATION OF 1 OPENING	15.0 SECONDS
FREEZER COMPARTMENT	
OPENINGS/HR	.0 #/HR
DURATION OF 1 OPENING	20.0 SECONDS
ANTI-SWEAT HEATERS	
FRESH FOOD CABINET	.92 W
FREEZER CABINET	1.83 W
AUXILIARY ENERGY	
FRESH FOOD CABINET	.00 W
FREEZER CABINET	.00 W
OUTSIDE CABINET	.00 W

Figure 7-6. Cabinet Loads Output (continued)

HEAT LEAK BREAKDOWN		
	FRESH FOOD (W)	FREEZER (W)
RIGHT WALL	5.53	2.97
LEFT WALL	5.53	2.97
BACK WALL	6.86	3.62
FRONT (DOOR)	7.27	`4.69
TOP WALL	.00	4.84
BOTTOM	4.31	.00
MULLION	-2.60	2.60
WEDGE	2.45	1.94
GASKET	9.12	10.37
OPEN DOOR SENSIBLE LOAD	.00	.00
MOISTURE LOAD - CONDENSE	.00	.00
MOISTURE LOAD - FROST	.00	.00
ANTI-SWEAT HEATER	.69	1.38
REFRIGERANT LINE HEAT	.00	1.20
PENETRATIONS	.00	.00
OTHER THERMAL INPUT	.00	.00
TOTAL	39.16	36.57

Figure 7-6. Cabinet Loads Output (continued)

MULTIPLE PATHWAYS BASELINE PROTOTYPE: MODEL D (TOP MOUNT)

FILE NAME: MODEL_D.ERA

REFRIGERATOR/FREEZER CONFIGURATION

1	REFRIGERATION TYPE (1-5)
1	CYCLE TYPE (1=STANDARD, 2=LORENZ, 3=DUAL LOOP, 4=DUAL EVAP)

MOISTURE CONTROL

0	MANUAL DEFROST: 0=NO, 1=YES
1000	HOURS SHUTDOWN FOR CYCLE DEFROST

COMPRESSOR OPTIONS

1	COMPRESSOR TYPE (1=RECIPROCATING, 2=ROTARY)
1	COMPRESSOR ANALYSIS (0-MAP, 1=EER, 2=EFFICIENCY MODEL)
1	CYCLING LOSS ANALYSIS (0=NO, 1=YES)
2.000	CYCLES PER HOUR
0	SHUT-OFF VALVE (O=NO, 1=YES)

REFRIGERANT CODES (1 - 34):

1 = R11
2 = R12
3 =R13
4 = n-C5
5 = R14
6 = R22
7 = R23
8 = R113
9 = R114
10 = R142b
11 = R152a
12 = R216a
13 = R125
14 = R143a
15 =R134a
16 = R123
17 = Rc318
18 = R134
19 = RC270
20 = R141b
21 = i-C5
22 = R290
23 = R600
24 = R600a
25 = R32

Figure 7-7. Intermediate Data: Cycle Analysis

26 = R1270
27 = R124
28 = R115
29 = CE-216
30 = E-125
31 = R123a
32 = R143
33 = R218
34 = E-134

INPUT DATA FOR THE REFRIGERATION SYSTEM

REFRIGERANT DATA

2	CODE (IR(1)) FOR 1ST REFRIGERANT
0	CODE (IR(2)) FOR 2ND REFRIGERANT
0	CODE (IR(3)) FOR 3RD REFRIGERANT
1	NUMBER OF COMPONENTS (MAXIMUM OF THREE)
0.0	MIXTURE INTERACTION PARAMETERS- COMPONENT 1-2
0.0	MIXTURE INTERACTION PARAMETER- COMPONENT 1-3
0.0	MIXTURE INTERACTION PARAMETER- COMPONENT 2-3
1.000	MASS FRACTION OF 1ST REFRIGERANT
0.0	MASS FRACTION OF 2ND REFRIGERANT
0.0	MASS FRACTION OF 3RD REFRIGERANT

CONDENSER PARAMETERS

1	HEAT EXCHANGER CONFIGURATION (0=NATURAL CONVECTION, 1=CROSS-FLOW, 2 = COUNTER-FLOW)
35.000	TEMP OF AIR ENTERING CONDENSER (C)
42.476	AIR FLOW RATE ACROSS COIL (L/s)
12.000	FAN POWER (W)
4.720	PRESSURE DROP THROUGH CONDENSER (KpA)
15.167	DESUPERHEATING HEAT TRANSFER CONDUCTANCE, W/m2-c
19.227	TWO-PHASE HEAT TRANSFER CONDUCTANCE, W/m2-C
15.434	SUBCOOLING HEAT TRANSFER CONDUCTANCE, W/m2-C
.849	TOTAL HEAT TRANSFER SURFACE AREA, m2
.000	REFRIGERANT EXIT SUBCOOLING, DEG C
4.000	LIQUID-LINE ANTI-SWEAT HEAT (W)
.000	VAPOR-LINE ANTI-SWEAT HEAT (W)

EVAPORATOR PARAMETERS

1	EVAPORATOR SPECIFICATION (1=EVAP EXIT SUPERHEAT, 2=INTERCHANGER EXIT SUPERHEAT, 3=EVAP EXIT QUALITY)
1	HEAT EXCHANGER CONFIGURATION (0=NATURAL CONVECTION, 1=CROSS-FLOW, 2 =COUNTER-FLOW)

Figure 7-7. Intermediate Data: Cycle Analysis (continued)

-11.334	TEMP OF AIR ENTERING FRESH FOOD SECTION EVAPORATOR (C)
23.600	AIR FLOW RATE ACROSS COIL (L/S)
9.400	FAN POWER (W)
7.200	PRESSURE DROP THROUGH FRESH FOOD EVAPORATOR (kPa)
13.787	TWO-PHASE HEAT TRANSFER CONDUCTANCE, W/m2-C
5.633	SUPERHEAT REGION CONDUCTANCE, W/m2-C
2.338	TOTAL HEAT TRANSFER SURFACE AREA, m2
3.000	REFRIGERANT EXIT SUPERHEAT (C) OR QUALITY (0-1)
COMPRESSOR PARAMETERS	
5.800	INITIAL GUESS FOR REFRIGERANT MAS FLOW RATE (kg/hr)
6.570	COMPRESSOR DISPLACEMENT, (cc)
218.000	RATED CAPACITY (kcal/hr)
3450.000	NOMINAL SPEED (rpm)
5.280	RATED EER
1	TYPE OF CAN COOLING (0: STATIC, 1: FAN-FORCED)
1.000	FRACTIONAL SPEED (-)
-1.000	TEMP. AT COMP., INLET (C) [-1 IF UNSPECIFIED]
INTERCHANGERS	
.000	INTERCHANGER EXIT SUPERHEAT (C)
.800	EFFECTIVENESS OF HIGH TEMP INTERCHANGER
IN-WALL EVAPORATOR DATA	
.000	EVAP: A/R IN FRESH FOOD SECTION (OR CABINET WALLS)
.000	EVAP: A/R IN FREEZER SECTION WALLS (IF SEPARATE SECTION)
.000	EVAP: A/R IN MULLION SECTION (IF PRESENT)
.000	COND: A/R IN FRESH FOOD SECTION (OR CABINET WALLS)
.000	COND: A/R IN FREEZER SECTION WALLS (IF SEPARATE SECTION)
.000	BOTH: A/R IN FRESH FOOD SECTION (OR CABINET WALLS)
.000	BOTH: A/R IN FREEZER SECTION WALLS (IF SEPARATE SECTION)
.000	FRACTION OF FRESH FOOD SECTION (OR CABINET WALLS)
.000	FRACTION OF FREEZER SECTION WALLS (INCLUDING MULLION)
0	FF (OR CABINET) EVAPORATOR BEHIND LINER (O: NO, 1: YES)
0	FZ EVAPORATOR BEHIND LINER (0: NO, 1: YES)
CYCLE-DEPENDENT ELECTRICAL ENERGY DATA	
7.500	CLOSED-DOOR AUTOMATIC DEFROST (W)
.000	FRESH FOOD SECTION
.000	FREEZER SECTION
1.500	OUTSIDE CABINET

Figure 7.7. Intermediate Data: Cycle Analysis (continued)

CABINET LOADS DATA	
.92	FRESH FOOD ANTISWEAT HEATER (W)
.00	FRESH FOOD AUXILIARY POWER (W)
1.83	FREEZER ANTISWEAT HEATER (W)
.00	FREEZER AUXILIARY POWER (W)
32.22	ROOM TEMPERATURE (C)
3.33	FRESH FOOD TEMPERATURE (C)
-15.00	FREEZER TEMPERATURE (C)
39.16	FRESH FOOD NET LOAD (W)
36.57	FREEZER LOAD (W)
.00	FRESH FOOD DOOR SENSIBLE LOAD (W)
.00	FRESH FOOD DOOR CONDENSATION (W)
.00	FRESH FOOD DOOR FROST LOAD (W)
.00	FREEZER DOOR SENSIBLE LOAD (W)
.00	FREEZER DOOR CONDENSATION LOAD (W)
.00	FREEZER DOOR FROST LOAD (W)
.00	FRESH FOOD PENETRATIONS (W)
.00	FREEZER PENETRATIONS (W)
.69	FRESH FOOD HEATERS AND CONTROLS (W)
1.38	FREEZER HEATERS AND CONTROLS (W)
.00	FRESH FOOD REFRIGERANT LINE (W)
1.20	FREEZER REFRIGERANT LINE (W)
2.60	MULLION HEAT LOAD (W)

Figure 7-7. Intermediate Data: Cycle Analysis (continued)

7.6. Cycle Analysis Results (CYCLE.OUT)

Program ERACYC.EXE reads the cycle data, CYCLE.DAT, and then simulates the steady state thermodynamic cycle. The calculations assume constant operation of the compressor. Transient effects are, by definition, missing. From the evaporator capacity, the fan power, and the cabinet loads, the compressor run time is estimated. A correction to the net compressor power to account for cycle transients is estimated and utilized when determining the daily energy consumption (see Appendix A).

Figure 7-8 lists the output from the cycle program (CYCLE.OUT). Thermodynamic state points are shown for 12 locations about the circuit. In the instance of the single evaporator cycle only one subcooling heat exchanger and one evaporator are present.

Temperatures and thermodynamic data are shown for the refrigerant at each state point. Temperature data are also shown for the air in the instance of a fan forced heat exchanger. The air temperatures are shown as if counter-flow heat exchangers were used, even if the flow is cross-flow. The important parameter is the product of the air flow rate, specific heat, and air temperature change across the heat exchanger. This product must agree with the mass flow - enthalpy difference product of the refrigerant across the heat exchanger.

The listed evaporator capacity ignores the effects of fan heat, which are taken into account in another manner. Capacities and power are shown in units of kJ/hr and watts.

The data listed in the cycle output will be dependent on the type of compressor model selected. For the sample case, the compressor was described in terms of the capacity, EER, and the displacement in a standard calorimeter test configuration. ERA estimates the values for the adiabatic compression efficiency, combined motor-pump efficiency and shell loss from built-in algorithms (see Appendix B). The estimated clearance volume is determined from the calorimeter data for capacity (and, hence, refrigerant mass flow). These are printed, followed by "(Compressor EER Model)," to indicate the source of the compressor model data. The data values may be used for a subsequent analysis using the compressor efficiency model option, if desired.

The output also lists the calculated air flow distribution between the fresh food and freezer sections. A change in the cabinet or cycle design may result in significant changes in the required distribution of refrigerated air. For example, use of a variable capacity compressor may require a means of active baffle control to ensure that both cabinet temperatures are maintained.

The second page of CYCLE.OUT gives a simple diagram of the cycle, with calculated refrigerant temperatures.

STANDARD ONE EVAPORATOR CYCLE

THE REFRIGERANT MIXTURE CONSISTS OF 100.% R12

OUTPUT RESULTS

STATE	T(C) AIR	T(C) REF	P (KPA)	H (KJ/KG)	V (M3/KG)	S (KG/KG-C)	XL (MASS FRAC)	XV (MASS FRAC)	XQ (MASS FRAC)
1 COMP IN	N/A	32.4	125.2	202.0	.1639	.799	.000	1.000	1.000
2. COMP DIS	N/A	77.9	1259.2	218.3	.0160	.702	.000	1.000	1.000
3. COND IN	39.8	77.9	1259.4	218.3	.0186	.715	.000	1.000	1.000
4. COND DEW	N/A	51.5	1258.6	198.1	.0137	.643	.000	1.000	1.000
5. COND BUB	N/A	51.3	1254.7	77.8	.0008	.272	1.000	.000	.000
6. COND OUT	35.0	51.3	1254.4	77.8	.0008	.272	1.000	.000	.000
7. LIQ LINE	N/A	45.2	1254.4	71.4	.0008	.252`	1.000	.000	.000
8. SUBCOOL	N/A	12.9	1254.4	39.5	.0007	.146	1.000	.000	.000
9. EVAP IN	-19.1	-23.2	132.4	39.5	.0262	.190	1.000	1.000	.206
10. EVAP DEW	N/A	-24.6	125.3	168.5	.1302	.678	.000	1.000	1.000
11. EVAP OUT	-12.3	-21.6	125.2	170.1	.1321	.685	.000	1.000	1.000
12. HX OUT	N/A	32.4	125.2	202.0	.1639	.799	.000	1.000	1.000

CYCLE PERFORMANCE SUMMARY

EVAPORATOR CAPACITY	789.6 KJ/HR (219.3 W)
CONDENSER HEAT REJECTION RATE	849.7 KJ/HR (236.0W)
COMPRESSOR POWER REQUIREMENT	564.0 KJ/HR (156.5 W)
COEFFICIENT OF PERFORMANCE	1.402
FRACTION AIR TO FRESH FOOD	.150 (SINGLE EVAPORATOR CYCLE)
ESTIMATED COMPRESSION EFFICIENCY	1.348 (COMPRESSOR EER MODEL)
ESTIMATED MOTOR-PUMP EFFICIENCY	.450 (COMPRESSOR EER MODEL)
ESTIMATED CLEARANCE VOLUME	.022 (COMPRESSOR EER MODEL)
ESTIMATED SHELL LOSS	.825 (COMPRESSOR EER MODEL)
ESTIMATED DISC TUBE HEAT LOSS	.387 (COMPRESSOR EER MODEL)

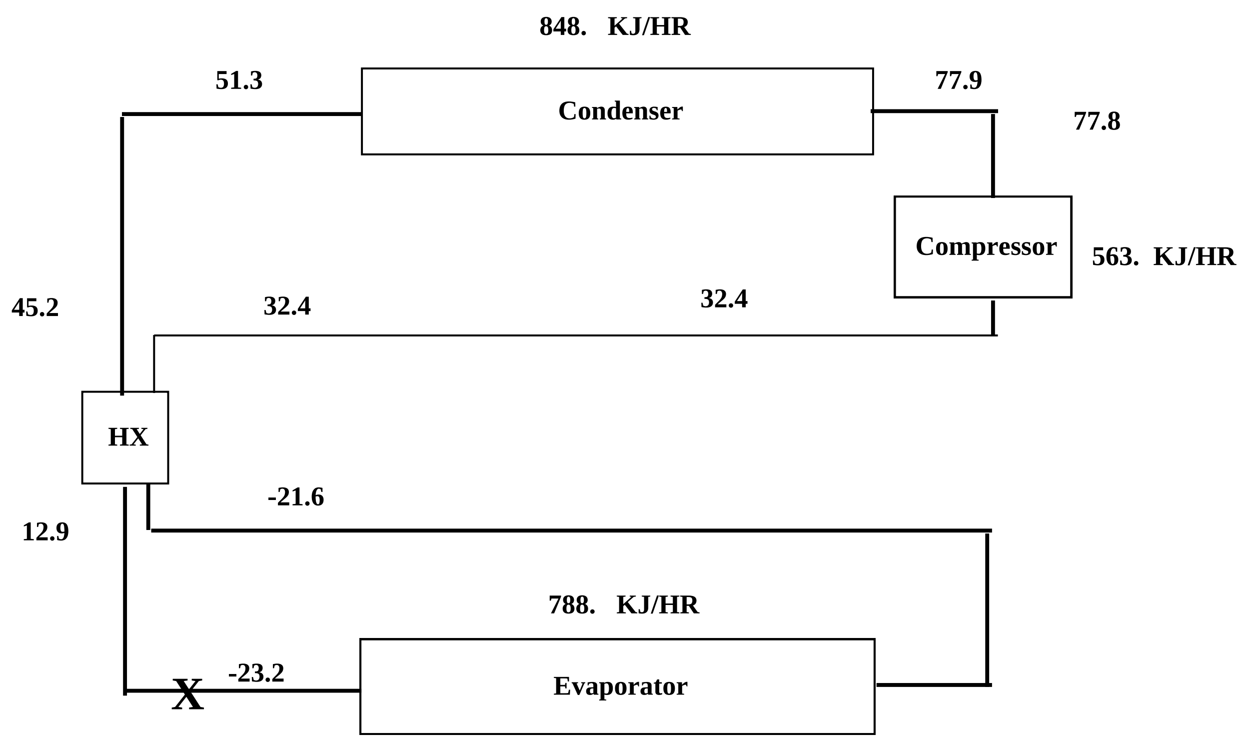
HEAT EXCHANGER PERFORMANCE SUMMARY

EXCHANGER	EFFECTIVENESS, %	SUBCOOLED FRACTION, %	SUPERHEATED FRACTION, %
EVAPORATOR	96.2	N/A	2.5
CONDENSER	89.4	.0	11.0

COMPRESSOR PERFORMANCE SUMMARY

REFRIGERANT MASS FLOW RATE	6.043 KG/HR
VOLUMETRIC EFFICIENCY	.773
PRESSURE RATIO	10.06
SUCTION PORT TEMPERATURE	49.9 C
DISCHARGE PORT TEMPERATURE	126.3 C
DISCHARGE SUPERHEAT	26.4 C

Figure 7-8. Cycle Analysis Output


848. KJ/HR
51.3
Condenser
77.9
77.8
Compressor
563. KJ/HR
45.2
32.4
32.4
HX
-21.6
12.9
788. KJ/HR
X
-23.2
Evaporator

7.7. Energy Consumption Results (ERA.OUT)

Output file ERA.OUT provides a summary of the calculated loads and daily energy consumption (Figure 7-9). It also gives information on the type of refrigerator cabinet, thermodynamic cycle, and refrigerant. For a single evaporator, the cabinet set points are fixed and the air baffle is adjusted (mathematically) by the model to achieve the cabinet temperatures. For some cases, this temperature may not be fixed, but may be dependent on the cabinet design and the design of the refrigeration cycle (for example, with a Lorenz cycle using natural convection evaporators). In this instance the output will show both the desired and actual cabinet temperatures.

A number of heat load parameters appear in the summary cabinet loads table in addition to the wall conduction loads. These include: electric defrost, penetrations, heaters and controls, fan heat, refrigerant line heat, in-wall evaporator, in-mullion evaporator, and in-wall condenser:

- Electric Defrost -- total heat associated with defrost, including scheduled defrost energy from closed door test and from frosting effects associated with door openings

- Penetrations -- defined heat leaks not directly associated with controls or heaters

- Heaters and Controls -- sum of "constant" and "cycle-dependent" controls and heaters

- Fan Heat --calculated on the basis of compressor run time and fan power

- Refrigerant Line Heat -- heat from a vapor line or a liquid line used for anti-sweat purposes that enters the cabinet around door flanges and the mullion

- In-Wall Evaporator -- additional heat flow into the cabinet from the presence of a cold-plate evaporator, not accounted for in the cabinet loads analysis CABINET.OUT file

- In-Mullion Evaporator -- added cooling of the fresh food section due to the presence of an evaporator in the mullion section of the freezer. The load will be negative (cooling)

- In-Wall Condenser -- added cabinet heat load due to the presence of a hot-wall condenser.

The total values shown for the cabinet section are the hourly average loads which must be removed by the refrigeration system.

Two cooling capacities are shown: 1) evaporator load, and 2) net capacity. Normally these two quantities are the same. If a cold-plate evaporator is used, however, the total evaporator load will be higher than the net capacity due to the heat going directly to the back of the evaporator through the insulation.

SUMMARY RESULTS

MULTIPLE PATHWAYS BASELINE PROTOTYPE: MODEL_D (TOP-MOUNT)

TOP-MOUNT REFRIGERATOR/FREEZER

STANDARD SINGLE EVAPORATOR CYCLE

REFRIGERANT DATA	FRESH FOOD	FREEZER	
	R12	R12	
SET POINTS (C)	3.330	-15.000	
CABINET LOADS (W)			
	FRESH FOOD	FREEZER	TOTAL
CONDUCTION	38.470	33.990	72.460
DOOR OPENINGS	.000	.000	.000
FROSTING	.000	.000	.000
ELEC DEFROST	..000	2.804	2.804
PENETRATIONS	.000	.000	.000
HEATERS & CONTROLS	.690	1.380	2.070
FAN HEAT	.526	2.989	3.515
REFRIGERANT LINE	.000	1.200	1.200
IN_WALL EVAP	.000	.000	.000
IN_MULLION EVAP	.000	.000	.000
IN_WALL COND	.000	.000	.000
TOTAL LOADS	39.686	42.363	82.049

REFRIGERATION CYCLE

EVAP LOAD (W)	219.343
NET CAPACITY (W)	219.343
MASS FLOW (KG/HR)	6.043
COP - STEADY STATE	1.402
COP - CYCLING	1.374
DUTY CYCLE	.374
COMPRESSOR (KWH/DAY)	1.433
FANS (KWH/DAY)	.192
ELECTRONICS (KWH/DAY)	.000
HEATERS & CONTROLS (KWH/DAY)	.079
DEFROST (KWH/DAY)	.067
TOTAL ENERGY USE (KWH/DAY)	1.772

Figure 7-9. Energy Consumption Results

The refrigerant mass flow rate and steady state COP are taken directly from the cycle output (Figure 7-8). Duty cycle (compressor run time fraction) is calculated by the ratio of the hourly average cabinet load and the instantaneous evaporator capacity. Cycling losses are established from the duty cycle (see Appendix B).

The total daily energy consumption is the sum of the following:

- Compressor energy -- compressor power times duty cycle
- Fan energy -- fan power times duty cycle
- Electronics -- variable speed drive electronics loss
- Heaters and controls -- auxiliary electrical energy
- Defrost -- total defrost energy, including frosting effects associated with open doors

For the sample problem, a 1993 prototype 18 cu-ft top-mount refrigerator/freezer, the daily energy consumption is 1.77 kWh, yielding an annual consumption of 647 kWh.

Figure 7-9 shows the summary output for a single evaporator cycle using a pure refrigerant. Alterations to this file will appear for the other refrigeration cycles.

8. REFERENCES

1. "Engineering Computer Models for Refrigerators, Freezers, Furnaces, Water Heaters, Room and Central Air Conditioners," Report to U.S. DOE, by Arthur D. Little, Inc., November 1982.

2. McLinden, M., "Theoretical Vapor Compression Cycle, CYCLE7," unpublished.

3. Morrison, G., and McLinden, M., "Application of a Hard Sphere Equation of State to Refrigerants and Refrigerant Mixtures," National Bureau of Standards Technical Note 1218, 1986.

4. "NIST Standard Reference Database 23: NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database, Version 3.0," NIST, December 1991.

5. "Multiple Pathways to Super Efficient Refrigerators," U.S. EPA, Global Change Division, Office of Atmospheric Programs, 1993.

6. Janssen, M.J.P., de Wit, J.A., and Kuijpers, L.J.M., "Cycling Losses in Domestic Appliances: An Experimental and Theoretical Analysis," Proceedings of the 1990 USNC/IIR-Purdue Refrigeration Conference, July 17-20, 1990, Purdue University, West Lafayette, Indiana

7. Alissi, H.S., Ramadhyani, S., and Schoenhals, R.J., "Effects of Ambient Temperature, Ambient Humidity, and Door Openings on Energy Consumption of a Household Refrigerator-Freezer," ASHRAE Transactions, 1988, 94 (Part 2), pp. 1713-1736.

APPENDIX A

OVERVIEW OF CABINET LOADS ANALYSIS TECHNICAL APPROACH

A.1 Wall Heat Loads

The major heat load on the cabinet results from heat conduction across the walls comprising the cabinet, with convection boundary conditions. Calculation of the conduction heat flow is based on the following assumptions:

- steady heat flow, with fixed thermal properties characterizing each wall;
- constant heat transfer coefficients;
- fixed inside and outside temperatures;
- one dimensional heat transfer (longitudinal heat flow is neglected).

Corrections to the simple 1-D heat flow analyses are made for:

- corner and edge effects (to account for different outside and inside surface areas);
- composite structures, such as foam and vacuum panel sandwich constructions.

The overall heat flow across a wall of the cabinet can be written:

$$Q_w (UA)_w (T_r - T_c) \qquad (A\text{-}1)$$

where

U = overall heat transfer conductance
A = wall area (inside surface)
T_r = room temperature
T_c = cabinet temperature

The expression *UA* is composed of inside and outside film coefficients and areas, cabinet insulation properties, and correction factors for corners and edges:

$$UA = \frac{1}{1/h_o A_0 + 1/U_w A_i + 1/h_i A_i} \qquad (A\text{-}2)$$

where

h_i, h_o = film coefficients, inside and outside surfaces
A_i, A_o = surface areas, inside and outside cabinet
U_w = wall conductance

The wall conductance is the sum of the conductance across a plane, with corrections for the additional heat flow along the edges and at the corners [1]:

$$U_w A_i = kA_i/x + 0.54k \sum l_i + 0.14nkt \qquad (A\text{-}3)$$

where

x = thickness of wall (ft)
k = thermal conductivity (Btu/hr-ft-F)
l = inside edge length (ft)
t = average insulation thickness (ft)
n = number of corners

Equation (A-3) gives the wall conduction in English units (Btu/hr-ft^2-^{o}F); the edge and corner correction factors assume the same units since this is the form in which they were first published [2].

Equations (A-1) through (A-3) are applied to all surfaces, including the mullion between the freezer and fresh food section, and the doors. Note that some average thermal conductivity, k , is assumed for the wall. Determination of the appropriate average value for an advanced insulation panel is discussed later.

The values assumed for the inside and outside free convective surface heat transfer coefficients (including radiative heat transfer effects) are [1]:

h_i = 1.00 Btu/hr-ft^2-$^\circ$F (5.68 W/m^2-C)
h_o = 1.47 Btu/hr- ft^2-$^\circ$F (8.35 W/m^2-C)

A.2 Advanced Insulation Panels

The use of advanced insulation panels may require installation of some sort of a sandwich of foam, and vacuum insulation panel. Depending on the thickness and material properties of the enclosing material, some "edge" effects for multidimensional heat transfer in the wall must be taken into account.

The approach adopted by ERA is to determine approximate correction factors to the one dimensional heat flow. These factors are intended to account for: 1) heat flow along a conducting enclosure material, and 2) incomplete coverage of the wall by the high-R panel. Calculation of these factors is carried out in one of the Help menus in the input processor program.

Figure A-1 illustrates the general geometrical situation treated by the model. Parameters describing the configuration are: the overall dimensions of the wall slab, the distances from the edges of the high resistance center panel to each of the four edges of the slab (they may be different), the distances from the two faces of the panel to the inside and outside surfaces of the wall (one or both may be zero), the panel resistivity in the absence of edge losses, the panel enclosure thickness, and the enclosure thermal conductivity. Note that wall slabs may have one or more beveled edges, depending on the cabinet element under consideration.

As noted in Figure A-1, the refrigerator wall is treated as a composite system of foam and an interior high-resistance panel. Foam along the side of the panel contributes to the net "heat transfer coefficient" on the side by combining with the air-side film coefficient; the inverse of the net resistance is the effective heat transfer coefficient along the panel side. Heat transfer through the foam along the edges is considered parallel heat transfer; that is, the wall is broken into two sections, one containing the panel, and the other containing pure foam. Although the method ignores the possibilities of "short circuiting" of heat through the foam around the panel, detailed finite difference calculations for practical geometries and panel properties showed this to be a very small effect. However, as discussed in the next paragraph, short circuiting of heat along the high conductivity panel enclosure *was* taken into account.

As a first step in the calculation of the overall thermal resistance, the perimeter heat loss from a semi-infinite slab containing the thermally conducting panel enclosure is established. A standard fin analysis is utilized to represent the longitudinal heat flows along the enclosure surfaces towards the edges (perimeter). The calculated perimeter heat flow is considered as a parallel heat flow term to the normal heat flow across the semi-infinite slab.

Calculations for perimeter heat flow are carried out independently for both directions: a semi-infinite slab in the width direction and a semi-infinite slab in the length direction. Because of corner effects, the two perimeter heat flows are not additive. They are combined using a correction factor, based on the relative dimensions of the panel edges in the width and length directions. Once the total perimeter heat flow is established the net resistance of the wall slab is determined.

Although the approach is only approximate, it is intended to capture most of the effects associated with multidimensional heat transfer with composites of foam and vacuum insulation panels. This has been confirmed by comparing ERA model predictions with the results of a high resolution finite element analysis, performed on a main frame computer, of several test conditions.

Two generic cases were considered: 1) a composite flat square slab of 36 inch by 36 inch, 1.5 inch thick, with 0.5 inch thick vacuum panel in the center, and with 0.5 inch foam on either side; 2) a corner of a two foot cube with 1.5 inch thick walls and with a vacuum panel located in the center of the wall. Case 1 is typical of the geometry of a door element. Case 2 is typical of the back wall of a cabinet (where the outside surface is larger than the inside surface). The inner panel consists of an evacuated r-20 powder enclosed in an 8-mil stainless steel structure. The results of these two test cases are summarized below:

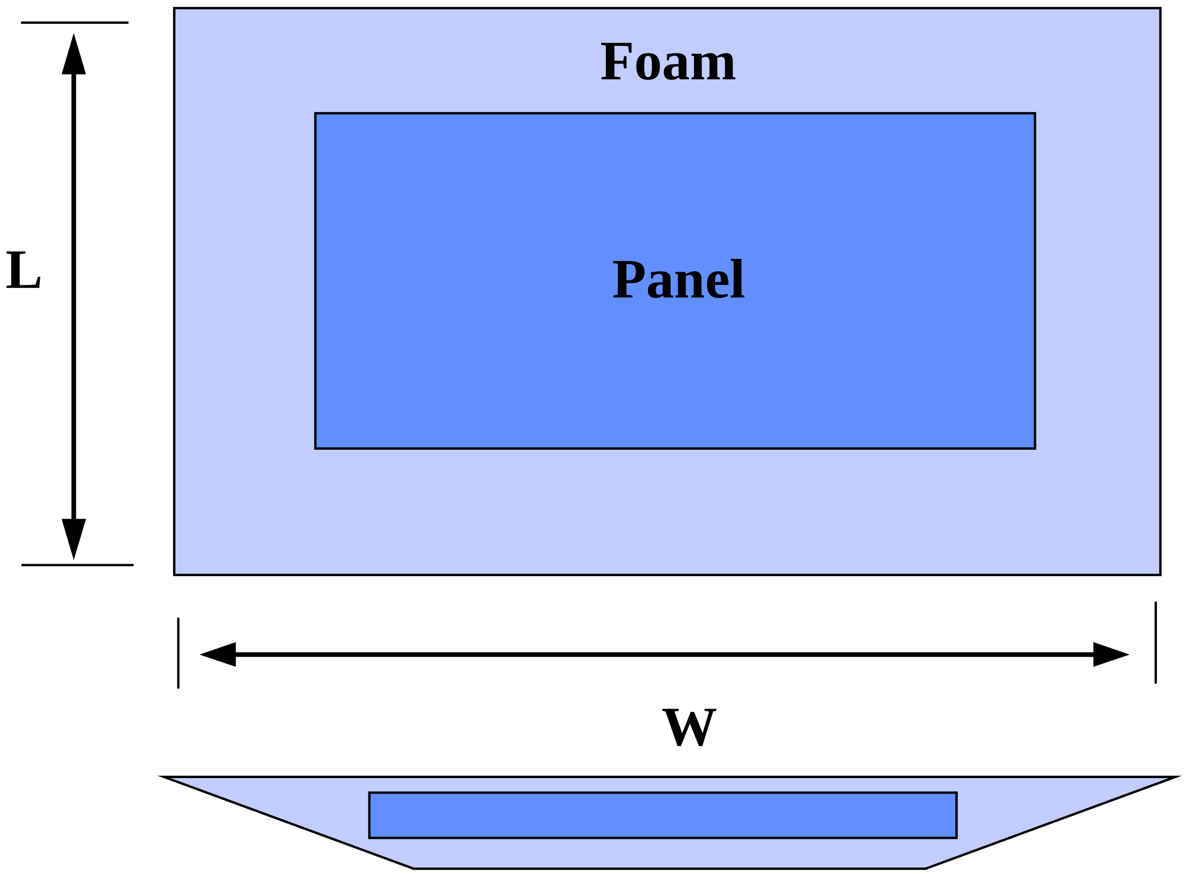


Figure A-1. Foam and Advanced Insulation Composite System

Exhibit A

	Distance of Panel from an Edge (in)	*Overall Resistance (Finite Element)*	*Overall Resistance (ERA Model)*
Case 1	0.00	14.34	14.58
	1.00	13.69	13.90
	6.00	11.61	11.68
	12.00	10.54	10.57
Case 2	1.00	15.66	16.05
	0.50	15.51	15.22
	0.00	15.16	14.50
	-1.00	14.23	13.31
	-2.00	12.96	12.39
	all foam	9.32	9.31

The maximum difference between the very detailed (and time consuming) finite element solution and the ERA simplified algorithm solutions for these two test cases is about 6%, with an average difference of about 2%. Hence, for the purposes of the types of design tradeoffs to be carried out with ERA, the model appears adequate.

A.3 Door Openings

A simplified model for the effects of open doors on the cabinet loads has been developed. A basis for the model is provided by the published work of Alissi, et. al. [3].

Door openings introduce dynamic phenomena into the net heat exchange between the cabinet and the room air. At least four flow patterns are set up during the period the door is open: 1) cool air will drain from the bottom of the cabinet due to density gradient driving forces, 2) warm air is sucked into the cabinet as the door is opened due to the pressure gradient caused by the opening, 3) natural convection will occur between the warm and cool air due to the buoyancy force differences, and 4) the cabinet air will be disturbed due to human factors.

Modeled heat and mass transfer between the cabinet and the room air assumes two distinct phenomena: 1) an initial tumbling of the air (essentially immediate replacement of the air occurs), 2) long term continuous convective flow and mass exchange. Modeled convective sensible heat flow rates are dependent on the room air to cabinet wall temperature difference. The air densities and partial pressures of water vapor in the compartment and room determine the rate of mass (water vapor) exchange.

All moisture that enters the cabinet is assumed to condense, releasing a heat of condensation. In addition, moisture that enters the freezer compartment, either directly or through air exchange with the fresh food compartment, is assumed to form frost. This releases an additional amount of heat in the freezer compartment. If the appliance uses automatic defrost, the heat required to melt the frost will be a further heat load on the freezer; if manual defrost is assumed, the heat of defrost is not part of the overall heat load.

As discussed, the net heat load due to each door opening is comprised of four terms:

- Initial Sensible Load: $Q_s = \rho C_p (T_r - T_c)(V_c n)$ (A-4)
- Initial Latent Load $Q_l = (\omega_a - \omega_c) h_{fg} (V_c n)$ (A-5)
- Convective Sensible Load $Q_{c,s} = h_i A_i (T_r - T_c) t_d$ (A-6)
- Convective Latent Load $Q_{c,l} = h_m (h_{ig})(\phi \rho_r - \rho_c) A_i t_d$ (A-7)

where
A_i = inside surface area of cabinet
h = convective heat transfer coefficient
h_{ig} = heat of sublimation
h_{fg} = heat of condensation
h_m = mass transfer coefficient (related to convective heat transfer coefficient
T_c = cabinet air temperature
T_r = room temperature
t_d = length of time the door is open each hour
$V_c n$ = volume of cabinet times number of times door opened during the hour
ϕ = relative humidity
ρ_c = density of air at cabinet temperature
ρ_r = density of air at room temperature
ω = humidity ratio of room air ® or cabinet air (c)

The above equations hold for all cabinet types except the chest freezer. Here, it is assumed that there is not an initial emptying of the cabinet, and that the heat and mass transfer coefficients are one half of those for an upright unit.

A.4 Gasket Model

The gasket model assumes that the rate of heat input is a linear function of the gasket path length (door perimeter) and the room-cabinet temperature difference. In actuality, the rate of heat leak may be influenced by fan operation, and may vary according to the tightness of fit.

A detailed finite element analysis carried out the by University of Kentucky [4] has shown that the major paths for heat flow are along the cabinet flange and the door flange, with a lesser amount through the gasket itself. Because of the complexity of the heat flows in this region, ERA relies on the user to specify realistic values for the heat loss coefficient, rather than attempting to model the gasket region itself. Typical values for heat loss are provided in the Help menu.

A.5 Anti-sweat Heat

Anti-sweat heat may be applied along the front surface of the cabinet and across the front face of the mullion. It may be supplied from electrical resistance heater wires, hot gas leaving the compressor prior to entering the condenser or heat from the refrigerant leaving the condenser.

If electric heater wires are used, standard closed door rating tests normally require that the refrigerator performance be measured with the heaters on and then with the heaters off. The rating is based on the average of these tests. As a short cut analytical approach, the user may assume that the DOE test conditions are equivalent to measuring performance with half the anti-sweat heat input. Operation of the heaters is continuous, not dependent on the behavior of the refrigeration system. If hot gas from the compressor output line, or heat from the condenser liquid line, is used for door flange and/or mullion heating, the net heat input will be dependent upon the compressor run time. This is modelled by specifying the value for refrigerant line anti-sweat heat input equal to that used for switchable electric heat in the on-position. For example, if a 6 watt electric heater (average of 3 watts in simulation of the DOE test condition) is replaced by liquid line heat, the user should specify 6 watts of refrigerant line heat. Since refrigerant line heat is not "switchable" the total heat input will be larger than the average heat input corresponding to the DOE test conditions.

ERA will calculate the on-cycle heat removal required from the refrigerant line heater to supply the cycle-averaged specified heat input. For example, if a cycle-average heat input of 6 watts is specified and the duty cycle is 45%, the on-cycle heat removal must be 6/0.45 = 13.3 watts. If this would result in an overcooling of the refrigerant line, ERA will issue a warning message in the summary output (ERA.OUT). Then the user must reduce the specified refrigerant line heat and replace the amount reduced with switchable electric heat. Hence, is some situations the mullion may receive anti-sweat from a liquid line and from a (smaller) electric heater at the same time.

A.6 References

1. "Engineering Computer Models for Refrigerators, Freezers, Furnaces, water Heaters, Room and Central Air Conditioners," Report to U.S. DOE by Arthur D. Little, Inc, November, 1982.

2. Langmuir, I., Adams, E., And Meikle, G., "Flow of Heat Through Furnace Walls: The Shape Factor," Trans. Amer. Electrochem. Soc., 24, pp. 53-84 (1913).

3. Alissi, M.S., Ramadhyani, S., and Schoenhals, R.J., "Effects of Ambient Temperature, Ambient Humidity, and Door Openings on Energy Consumption of a Household Refrigerator-Freezer," ASHRAE Transactions, 1988, 94 (Part 2), pp. 1713 - 1736.

4. "Finite Element Analysis of Heat Transfer Through the Gasket Region of Refrigerator/Freezers," EPA/430/R-92/009.

APPENDIX B

OVERVIEW OF CYCLE ANALYSIS TECHNICAL APPROACH

B.1 Cycle Model Solution Procedure

ERACYC.EXE is an iterative solver that starts with initial guesses for the refrigerant mass flow rate and the refrigerant temperatures at the exits of the condenser and evaporator. A converged solution is reached when a global energy balance for the entire refrigeration system is satisfied while satisfying local energy balances and heat transfer relationships for each system component. Schematic diagrams of a two evaporator system and single evaporator system, along with refrigerant state points are shown in Figures B-1 and B-2. The refrigerant state points are defined in Table B-1.

Table B-1. Summary of Refrigerant State Point Locations

Refrigerant State Point Number	***Corresponding State Point Location***
1	compressor inlet
2	compressor outlet
3	condenser inlet
4	refrigerant dew point within condenser
5	refrigerant bubble point within condenser
6	condenser exit
7	inlet to high temperature interchanger
8	outlet from high temperature interchanger (also the inlet to the low temperature interchanger)
9*	outlet from the low temperature interchanger
10	freezer evaporator inlet
11**	freezer evaporator outlet (also the inlet to the low temperature interchanger)
12**	fresh food evaporator inlet (also the outlet from the low temperature interchanger)
13	refrigerant dew point within fresh food evaporator
14	fresh food evaporator outlet (also the inlet to the high temperature evaporator)
15	outlet from the high temperature evaporator

* This state point is set equal to state (8) when a single evaporator cycle is specified.
** These state points are set equal to state (10) when a single evaporator cycle is specified.

For calculation purposes, the program divides the refrigeration cycle into the following two major subsystems:

- a high-pressure subsystem that includes the compressor, condenser, and refrigerant lines, including state (1) up through and including state (7) on Figure B-1, and

- a low-pressure subsystem that includes the high and low temperature interchangers, expansion device, freezer and fresh food evaporators, and refrigerant lines starting after state (7) up through and including state (15).

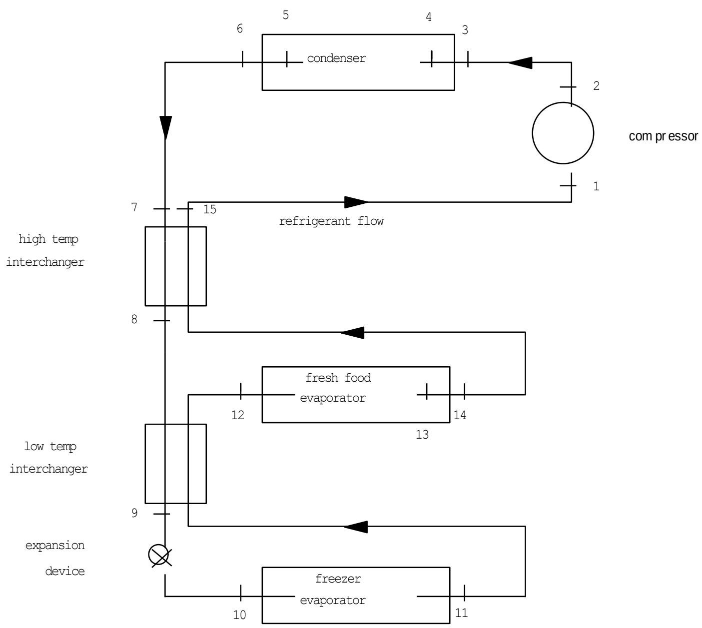


Figure B-1. Schematic Diagram of a Two Evaporator Cycle and Corresponding Refrigerant State Points

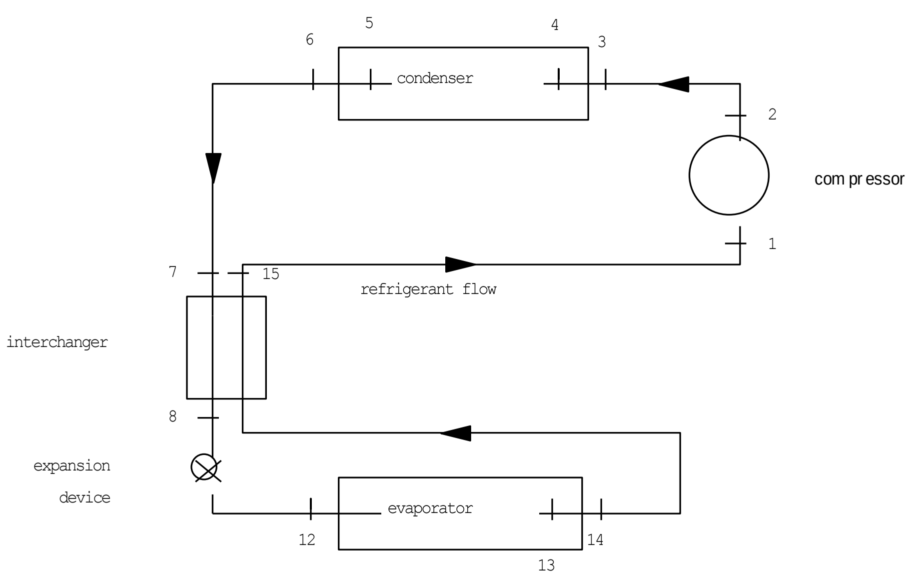


Figure B-2. Schematic Diagram of a Single Evaporator Cycle and Corresponding Refrigerant State Points

The low-pressure subsystem is broken further into the following two components:

a. a fresh food component that includes the high temperature interchanger and fresh food evaporator, from (but not including) state (7) and including states (8), (12), (13), (14), and (15).

b. a freezer evaporator component that includes the low temperature interchanger, expansion device, freezer evaporator, from (but not including) state (8) and including states (9), (10), and (11), and up to, but not including state (12).

An outline of the general solution algorithm is as follows:

1. The program guesses initial values for the refrigerant mass flow rate, condenser exit temperature, fresh food evaporator exit temperature, and freezer evaporator temperature, which correspond to states (6), (14), and (11) on Figure B-1.

2. Based on the user specified values for liquid subcooling at the condenser exit and vapor superheating at the evaporator exit, the program calculates the liquid bubble point at state (5) and the vapor dew point at state (13). Based on these temperatures, the remainder of the refrigerant properties, (i.e., saturation pressures, enthalpies, specific volumes, etc.) are calculated. The program then calculates the remainder of the refrigerant properties at states (6) and (14).

3. Holding the refrigerant mass flow rate and properties at state (7) constant, the program iterates to solve an energy balance and the heat transfer relationships for the low pressure side of the system, as described in the following:

   a. Based on the refrigerant properties at states (7) and (14), state (8) at the high temperature is determined.

   b. Using state (8) as the inlet to the low temperature interchanger, the program iterates to solve for states (9), (10), (11), and (12) and the freezer evaporator performance. The freezer evaporator performance is determined using the heat exchanger relationships for the evaporator along with refrigerant-side and air-side energy balances. Convergence is achieved when the difference between the values of the refrigerant temperature at the freezer evaporator exit for two successive iterations is less than a user defined value (see file CYCLE.TOL).

      If a single evaporator system is specified, the program internally sets refrigerant state (9) equal to state (8), and (11) and (12) equal to state (10). A single evaporator system is shown schematically in Figure B-2.

   c. Using state (12) as the inlet state to the fresh food evaporator, the program solves for the heat transfer in the fresh food evaporator based on heat exchanger relationships for the evaporator along with refrigerant-side and air-side energy balances.

d. The refrigerant enthalpy difference between states (14) and (12) are compared to the heat transfer calculated in Step 3c. Depending on the difference between these two quantities, the refrigerant exit temperature (state (14)) is adjusted to reduce this difference.

e. Steps 3a through 3d are repeated until a converged solution is reached for the low pressure side of the system. A converged solution on the low-pressure side of the system is achieved when the difference in the refrigerant evaporator exit temperatures for two successive iteration steps is less than a user defined value (see file CYCLE.TOL).

4. Based on states (7) and (14), the high temperature interchanger performance is determined, along with state (15).

5. State (1) at the inlet to the compressor is determined.

6. Compressor performance is determined using a theoretically based model, an efficiency/capacity based model , or a tabulated performance based model. Outputs from the compressor calculation include the compressor power requirement, compressor heat loss, the refrigerant properties at state (2), and a new value for the refrigerant mass flow rate.

7. The refrigerant properties at the condenser inlet, state (3), are calculated.

8. Next, the program solves for the heat transfer in the condenser, based on heat exchanger relationships for the condenser along with refrigerant-side and air-side energy balances.

9. The refrigerant enthalpy difference between states (6) and (3) are compared to the heat transfer calculated in Step 8. Depending on the difference between these two quantities, the refrigerant exit temperature at state (6) is adjusted to reduce this difference.

10. Based on the new values for the refrigerant mass flow rate and refrigerant properties at state (6), the program repeats Steps 2 through 9 until a converged solution for condenser exit temperature and refrigerant mass flow rate has been obtained. A converged solution on the high-pressure side of the system is achieved when the differences between the refrigerant condenser exit temperatures and the refrigerant mass flow rates for two successive iteration steps are less than user defined values (see file CYCLE.TOL).

B.2 Compressor Performance Models

B.2.1. Physically Based Compressor Model (Efficiency Model)

This section summarizes the basic structure of the physically based compressor model employed in the program module ERACYC. The analysis is a hybrid between a purely theoretical model and an empirical model in that it uses empirical coefficients as inputs to theoretically derived equations. A description is provided of the basic physical processes that are represented, the analysis assumptions, and the equation set developed to characterize the performance parameters.

Physical Processes Modeled

The model is based on representing the following physical processes depicted in Figure B-3:

- The compressor is a low side hermetic reciprocating design.
- Suction gas (state point 1 in Figure B-3) enters the shell and is in thermal communication with the discharge line and with the motor, providing its main cooling.
- The motor is entirely within the shell and is physically separated from it.
- The suction gas transfers heat to the shell which is in thermal communication with its environment.
- The suction gas enters the pump inlet valve in a heated condition (state point 2) and is compressed to a higher pressure.
- At the outlet of the pump (state point 3) the refrigerant gas enters a discharge line which is in thermal communication with the refrigerant vapor contained within the compressor shell volume.
- After losing heat to the gas within the shell, the high pressure discharge gas leaves the compressor (state point 4).
- No pressure changes are taken into account within the shell other than across the pump (point 2 to 3). The net pressure change includes pressure losses through the pump suction and discharge valves.

Figure B-4 illustrates the thermodynamic state points of the gas throughout the modeled process.

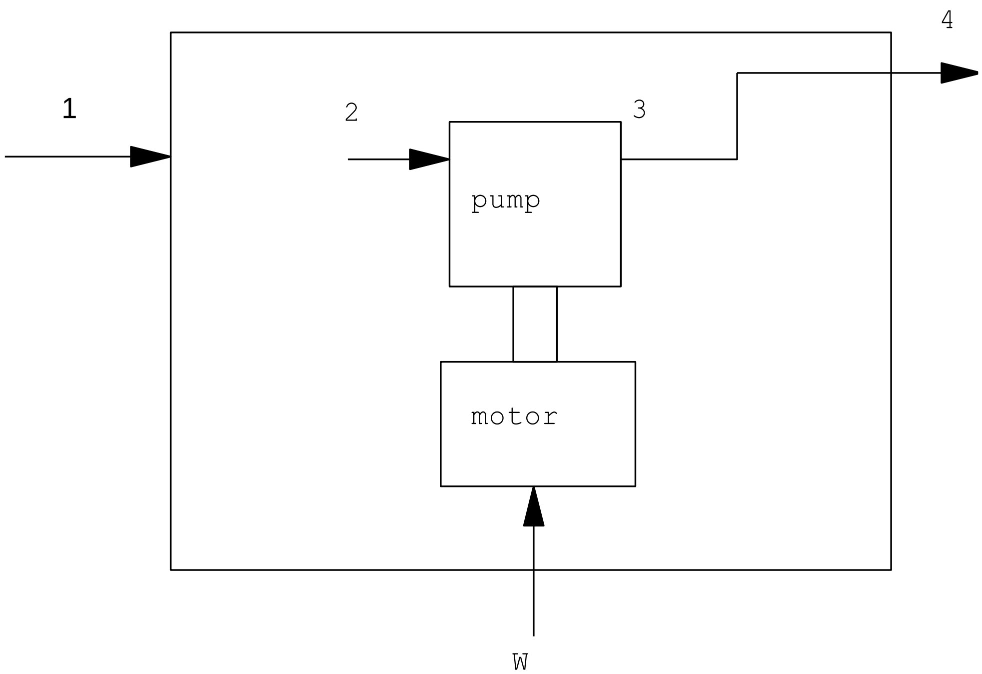


Figure B-3. Physical Processes in Compressor

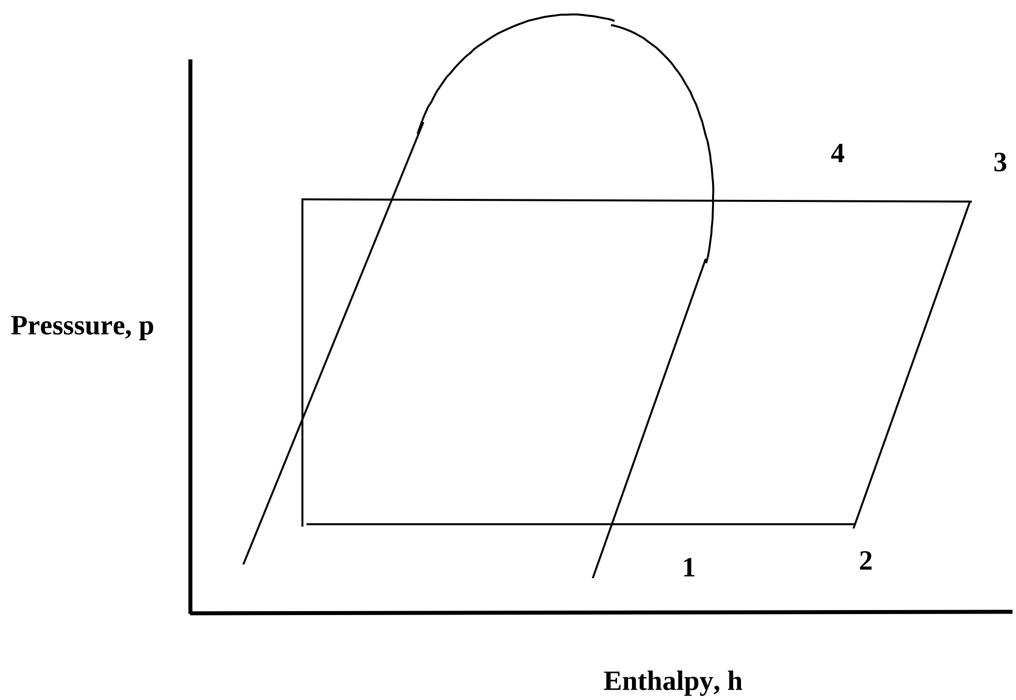


Figure B-4. Thermodynamic State Points In Compressor

The thermal processes represented are:

- The shell heat transfer is correlated to motor inlet power. For the purposes of simplification, it is assumed that the constant of proportionality is independent of the actual operating conditions. Input values for the shell heat loss are based on actual compressor performance data and are typically 70 - 80 percent of the compressor inlet power.

- The internal heat exchange between the high pressure gas within the discharge line and the low pressure gas within the shell can be also represented as a fraction of the compressor input power.

- Work of compression is determined using an isentropic efficiency.

Governing Equations

Six equations represent the physical processes within the shell:

Overall Energy Balance

$$\mathrm{W} = \dot{m}(h_4 - h_1) + Q_s \tag{B-1}$$

where

W = compressor motor input power
Q_s = rate of heat loss from shell

Shell Heat Loss to the Environment

$$Q_s = fw \tag{B-2}$$

where

f = correlating parameter

Suction Gas Heat Balance

$$\dot{m}(h_2 - h_1) = (1 - \eta_m)W + Q_{3-4} - Q_s \tag{B-3}$$

where

η_m = motor efficiency

$Q_{3\text{-}4}$ = discharge line heat loss

Discharge Line Hat Loss

$$Q_{3-4} = \alpha W = \dot{m}(h_4 - h_3) \qquad \text{(B-4)}$$

where

α = correlating parameter

Compressor Work Input

$$\eta_m W = \dot{m}(h_3 - h_2) \qquad \text{(B-5)}$$

Compressor Efficiency

$$h_3 = h_2 + \frac{(h_{3s} - h_2)}{\eta_s} \qquad \text{(B-6)}$$

where

η_s = isentropic efficiency

and the subscript *s* refers to the enthalpy that would exist if the compression process were reversible and adiabatic and therefore, isentropic.

Eqns (B-1) through (B-6) are solved iteratively to determine the enthalpies at the pump inlet, h_2, and outlet, h_3. The shell discharge condition, h_4, is found from:

$$h_4 = h_1 + \frac{(h_3 - h_1)}{1 + \frac{\alpha}{(1 - f)}} \qquad \text{(B-7)}$$

The refrigerant mass flow rate is then calculated from

$$\dot{m} = \frac{(60 rpm)\,\eta_v\, disp}{v_{suc}} \qquad \text{(B-8)}$$

where

rpm = compressor speed in rpm
disp = cylinder displacement volume
v_{suc} = specific volume of refrigerant vapor at the pump inlet vale
η_v = volumetric efficiency

The volumetric efficiency is determined from:

$$\eta_v = 0.92\left\{1 - C_v\left(\left(\frac{p_3}{p_2}\right)^{\frac{1}{n}} - 1\right)\right\} \tag{B-9}$$

where

C_v = clearance volume, expressed as a fraction of the displacement volume

and

n = polytropic exponent, defined as $n = 0.97\gamma$, where γ is the specific heat capacity ratio of the suction vapor.

Model Input Parameters

The following data are required input to the model:

Parameter	***Typical Value***	***Data Source***
Displacement (cc or cu-in)	8 (0.5)	Manufacturer
Speed (rpm)	3450	Manufacturer
Clearance volume (%)	2	Manufacturer
Compression (isentropic) efficiency	1.3	Model Fit
Motor-pump efficiency (-)	0.41	Estimate
Shell loss (% of power input)	75	Data
Discharge tube heat loss (% of power input)	35	Model Fit

Data values for most of the parameters are either known from the manufacturer's literature or can be estimated. Model fits have to be carried out to arrive at values from the isentropic efficiency, which has a value greater than one as a result of its definition. Strictly speaking, the so-called isentropic efficiency uses as a reference value for the minimum work input the amount of work required to compress the refrigerant during a reversible and adiabatic (hence isentropic) process. In the actual compression process, significant heat loss from the refrigerant occurs to the cylinder walls, resulting in a lower refrigerant enthalpy at the end of the compression process compared to the ideal process, thereby corresponding to an efficiency greater than one. This does not imply, however, that the work input is less than the ideal process.

B.2.2. Rating Point Compressor Model

Generally, the only information that can be obtained for a particular compressor are the rating point capacity, motor power input (or EER), displacement volume, and the type of shell cooling was employed (i.e., static of fan-forced). The model discussed in the following is an empirical model that allows realistic simulation of compressor performance with a minimum of required input parameters.

The foundation of this model is comprehensive compressor performance data from AHAM [??] that includes compressor capacity, input power, refrigerant mass flow rate, and refrigerant temperatures at various locations within the compressor, all as a function of evaporating and condensing temperatures and type of compressor shell cooling. Analysis of this data yielded the following important conclusions:

1. The compression process behaves like a polytropic process with a polytropic exponent defined as $n = 0.97\gamma$, where γ is the refrigerant suction vapor specific heat capacity ratio.

2. The refrigerant vapor temperature at the suction port can be correlated with EER at the rating point.

3. The ratio of compressor discharge temperature and suction port temperature (both in absolute units) is nearly constant at 1.2.

4. The compressor discharge temperature can be correlated with the cylinder discharge temperature, ambient temperature, and the type of compressor cooling.

Model Description

The model requires as inputs the following information:

- compressor type (reciprocating or rotary),
- compressor capacity at the rating point,
- EER at the rating point,
- compressor displacement volume,
- compressor speed (usually about 3450 rpm); and
- type of compressor cooling.

Calculation of Parameters

At the beginning of the program, the model estimates values for the volumetric and isentropic efficiencies from the compressor rating point capacity and EER using the procedures described below.

Compressor Clearance Volume

The compressor clearance volume is calculated using the following algorithm.

1. The model calculates the enthalpy of refrigerant vapor and liquid at 32°C (90°F) and at pressures corresponding to the saturation pressures at -23°C (-10°F) and 54°C (130°F).

2. The refrigerant mass flow rate is calculated using the rating point capacity divided by the quantity (vapor enthalpy - liquid enthalpy).

3. The refrigerant vapor temperature at the compressor suction point is calculated using the following correlations:

T_{suc} = 479.59-64.815*EER*, reciprocating - static cooling,
T_{suc} = 427.84-57.895*EER*, reciprocating - fan cooling, or
T_{suc} = 120, rotary.

where the temperatures are expressed in Fahrenheit.

4. The refrigerant density at the suction port is calculated at the suction pressure calculated in Step 1 and the suction temperature calculated in Step 3.

5. The volumetric efficiency is calculated using the following relationship:

$$\eta_v = \frac{\dot{m}}{60 \cdot \rho_{suc} \cdot rpm \cdot disp}$$

where

$\dot{m}$ = refrigerant mass flow rate
ρ_{suc}=-= density of the refrigerant suction vapor
rpm = compressor speed in rpm
disp = compressor displacement volume

6. The clearance volume is determined from the following relationship:

$$\eta_v = const\left\{1 - C_v\left(\left(\frac{P_{dis}}{P_{suc}}\right)^{\frac{1}{n}} - 1\right)\right\}$$

where *const*=0.92 and *const*=1.0 for reciprocating and rotary compressors, respectively, and p_{dis} and p_{suc} are the discharge and suction pressures, respectively. The exponent that best fits the data has been determined to be $n = 0.97\gamma$.

Isentropic Efficiency

The isentropic efficiency is determined using the following procedure:

1. Calculate the enthalpy and entropy of the refrigerant vapor at the suction port.

2. Calculate refrigerant enthalpy $h_{dis,s}$ at the discharge pressure assuming an isentropic process.

3. Calculate the isentropic efficiency as

$$\eta_s = (h_{dis,s} - h_{suc})\dot{m} / W_r$$

where W_r is the compressor work at the rating point.

It is assumed that the isentropic efficiency determined in the above equation applies for all operating conditions.

<u>Performance Analysis</u>

The above parameters are used in the calculation of compressor performance at conditions off the rating point using the following algorithm.

1. Input the values of the suction and discharge pressures from the main program.

2. Estimate the refrigerant temperature at the suction port using

   $T_{suc} = T_i + 389.59\text{-}64.815EER$, reciprocating - static cooling,
   $T_{suc} = T_i + 337.84\text{-}57.895EER$, reciprocating - fan cooling, or
   $T_{suc} = T_i + 30$, rotary.

   where T_i is the temperature of the refrigerant entering the compressor shell, expressed in Fahrenheit.

3. Calculate the refrigerant density, enthalpy and entropy at suction port conditions.

4. Calculate refrigerant enthalpy $h_{dis,s}$ at the discharge pressure assuming an isentropic process.

5. Calculate the required work input using

$$W = \frac{h_{dis,s} - h_{suc}}{\eta_s}$$

6. Using the value of the clearance volume determined previously, calculate the volumetric efficiency using the following equation.

$$\eta_v = const\left\{1 - C_v\left(\left(\frac{P_{dis}}{P_{suc}}\right)^{\frac{1}{n}} - 1\right)\right\}$$

where *const*=0.92 and *const*=1.0 for reciprocating and rotary compressors, respectively.

7. Finally, the mass flow rate and the heat losses from the compressor shell and discharge tube are calculated.

B.2.3. Map-Based Compressor Model

The third method of calculating compressor performance is a map-based model that uses actual compressor map data applicable to a particular compressor. The user inputs data points for compressor capacity and motor power input as a function of evaporating and condensing temperatures. This data must be at the standard rating condition in which the temperature of the vapor exiting the evaporator (and entering the compressor), the liquid exiting the condenser, and the ambient are all at 32°C (90°F). The data for compressor capacity and motor power input is stored in a user-supplied file with extension .TAB in the following form.

	$T_e(1)$	$T_e(2)$	•	•	$T_e(N_e)$
$T_c(1)$	$cap(1,1)$	$cap(1,2)$	•	•	$cap(1,N_e)$
$T_c(2)$	$cap(2,1)$	$cap(2,2)$	•	•	$cap(2,N_e)$
•	•	•	•	•	•
•	•	•	•	•	•
$T_c(N_c)$	$cap(N_c,1)$	•	•	•	$cap(N_e,N_e)$

and

	$T_e(1)$	$T_e(2)$	•	•	$T_e(N_e)$
$T_c(1)$	$pow(1,1)$	$pow(1,2)$	•	•	$pow(1,N_e)$
$T_c(2)$	$pow(2,1)$	$pow(2,2)$	•	•	$pow(2,N_e)$
•	•	•	•	•	•
•	•	•	•	•	•
$T_c(N_c)$	$pow(N_c,1)$	•	•	•	$pow(N_e,N_e)$

where T_e and T_c are the evaporating and condensing temperatures, respectively. The terms *cap* and *pow* refer to the compressor capacity and motor power input, respectively. Units for the data can be input in either °F, Btu/hr, and watts, or °C, kcal/hr, and watts. Up to 20 data points in each of the T_e and T_c directions can be input, resulting in a maximum of 400 data points for the capacity and compressor power. The user must specify whether the compressor is a reciprocating or rotary type.

The user does not specify the type of refrigerant in the compressor map file. Hence, it is necessary that the user insures that the refrigerant with which the compressor was tested to generate the performance data corresponds to the refrigerant specified in the ERACYC model input data.

Upon the initial call of the compressor subroutine the program reads the data file and stores the data internally in arrays.

The input variables transferred from the main program include the suction and discharge pressures, and suction and ambient temperatures. Subroutine output variables output to the main program include the refrigerant mass flow rate, compressor power input and shell heat loss.

Note that the compressor capacity is not included in the list of output variables. This is because the capacity as listed in the performance data is determined at fixed values of temperature of vapor exiting the evaporator and liquid exiting the condenser. These conditions do not, in general, exist in an actual refrigerator during normal operation. Thus, use of the capacity as listed in the performance data is incorrect, even for identical evaporating and condensing temperatures. This subroutine answers the following question: "Given specified compressor suction and discharge pressures and a vapor temperature at the inlet to compressor shell, what refrigerant mass flow rate can the compressor produce?" Once the mass flow rate is determined, the value of refrigerant mass flow rate is output to the main program, where the evaporator capacity is determined.

The algorithm which is used to determine the refrigerant mass flow rate proceeds as follows:

1. Values for the suction and discharge pressure, refrigerant vapor temperature at the shell, and ambient temperature are input from the main subroutine.

2. The enthalpies of the refrigerant vapor and liquid at the standard rating temperatures and at the values of suction and discharge pressures are passed from the main program.

3. Based of the values of suction and discharge pressures input from the main program, corresponding values for evaporating and condensing temperatures are determined.

4. Using the values for evaporating and condensing temperatures determined in Step 3, determine values for the compressor capacity and motor power input by interpolation from the stored performance map.

5. The refrigerant mass flow rate is calculated based on the following relationship:

    refrigerant mass flow rate = (capacity from map) / (vapor enthalpy - liquid enthalpy) where the refrigerant enthalpies are those determined in Step 3.

6. The heat loss from the compressor shell to the ambient is calculated assuming it is a fixed fraction of the compressor power input. This fraction is assumed to be 75 percent of the compressor motor power input.

7. Now that the values for the refrigerant mass flow rate, motor power input, and shell heat loss corresponding to the standard rating condition have been determined, the subroutine corrects for conditions which do not correspond to the standard conditions. The means for determining the amount of correction are based on the data of Reference [2]. The corrections to the refrigerant mass flow rate, motor power input, and shell heat loss are normally small, generally only a few percent of the values at the standard rating condition.

B.3 Cycling Losses

Cycling of the compressor will normally lead to a reduction in the cycle average efficiency (COP) compared to the steady state value. This will occur due to at least three major effects:

- during the on-time the thermal load of the heat exchangers is higher than the cycle average load, leading to increased heat exchanger irreversibilities,

- when the compressor stops, the pressure ratio rapidly decreases towards one, leading to flashing of the liquid in the condenser and condensation of liquid in the evaporator,

- vapor flows from the condenser to the evaporator where it condenses during the off-cycle.

To minimize the effects of such losses, the cabinet controls are usually set to ensure a small number of cycles per hour (typically 2 - 3). An alternate approach, suitable for a rotary compressor, is to place a shut-off valve between the condenser and the capillary tube which is shut during the off-cycle.

Detailed analysis of cycling losses is extremely complicated (and of inherently limited accuracy due to fundamental inabilities to accurately represent all the major mass flow and two-phase heat transfer effects throughout the cycle). As a consequence, a simple correlative procedure, partially based on experimental data, has been adopted. Two general situations are represented: 1) normal operation without a shut-off valve, and 2) use of a shut-off valve.

B.3.1. Cycling Rates

The degree of cycling loss is dependent on the cycling rate since the controlling phenomena are time dependent. In general, the rate is dependent on the thermal characteristics of the refrigerator cabinet and the control system. The cycling rate is a user input, generally ranging from 1 to 3 cycles per hour.

B.3.2. Cycling Losses Without a Valve

Janssen, de Wit, and Kuijpers have found that the cycle average COP varies roughly linearly with cycle frequency [3]. From an analysis of the experimental data given in Reference [3], the cycle loss can be estimated as:

$$\text{Loss} = 1.0\%/t_{cycle}$$

For example, at a cycling rate of 2.5 cycles per hour, (t_{cycle} = 0.4), the cycle efficiency loss would be about 2.5%.

B.3.3. Cycling Effects with a Shut-off Valve

Short cycling with a valve present will actually *increase* the cycle average COP due to the thermal mass effects of the heat exchangers. In principle, with very massive heat exchangers and short cycling, the theoretical performance should approach that of a variable speed drive system due to the elimination of over- or under-shoot of the heat exchanger temperatures. This effect is illustrated in the experimental data of Philips Research [3].

From the experimental data given in [3], the efficiency gain over steady state from the presence the valve can estimated as:

$$\text{Gain} = 1.5\%/t_{cycle}$$

Hence, for a system with 2 cycle/hr, the overall efficiency gain from introducing a microvalve (rotary compressor, only) is approximately (1.0 + 1.5)/0.5 = 5%.

B.4 Summary of Help Menu Heat Exchanger Analyses

ERA contains subroutines in the help menu to assist the user in determining the heat exchanger input data required for the refrigeration cycle performance calculations. This feature should be used when actual heat transfer performance data for a particular heat exchanger is unavailable, but should not be used in lieu of actual data. A summary of the methods used for estimating the heat exchanger performance is presented in the following paragraphs. This summary is very brief, thus the reader is referred to the references at the end of the section and to heat transfer textbooks for further information.

The help menu assists the user to estimate both the air-side and refrigerant-side heat transfer coefficients, the refrigerant-side pressure drop, and the heat exchanger surface areas for the following heat exchanger configurations:

Summary of Help Menu Heat Exchanger Configurations

Heat Exchanger Type	***Heat Exchanger Geometry***
condenser	forced convection - straight fin-tube, wavy fin-tube, wire-tube natural convection - vertical plate, hot-wall, wire-tube
evaporator	forced convection - straight fin-tube, wavy fin-tube natural convection - vertical plate, cold-wall, horizontal plate

The algorithms for calculating the average heat transfer coefficients follow the general outline presented below:

1. Air-side heat transfer coefficients are calculated first. Generally, air-side heat transfer coefficients are reasonably independent of the refrigerant-side conditions.

2. Heat transfer coefficients for single phase refrigerant flow (i.e., refrigerant vapor or liquid) are calculated next. Heat transfer coefficients in this flow regime are essentially independent of the air-side conditions.

3. Heat transfer coefficients and pressure losses for the condensation and evaporating flow regimes are calculated. In general these depend strongly on the air-side heat transfer coefficient.

4. Finally, the average overall heat transfer coefficient based on air-side surface area corresponding to the single phase vapor, single phase liquid, condensing, and evaporating regimes are calculated. The pressure drops for the condensing and evaporating heat transfer regimes are also calculated.

A brief description of the analyses is presented below.

B.4.1. Air-Side Heat Transfer Coefficients

Forced Convection - Fin-Tube

Air-side performance for fin-tube heat exchangers is calculated using methods similar to those found in Reference [4]. Depending on user defined values for heat exchanger geometry (i.e. tube diameter, tube spacing, fin spacing, etc.) and air flow rate, the program calculates the air-side heat exchanger area (which is required for the ERACYC model input) and the geometric and fluid dynamic parameters required for the heat transfer calculation. The program uses empirical heat transfer correlations to calculate the Nusselt number of the form

$$Nu = C Re^{a} Pr^{b} \tag{B-10}$$

The heat transfer coefficient is calculated from a relation of the form

$$h = \frac{Nu k_{air}}{d_h} \tag{B-11}$$

Separate correlations are used for the straight and wavy fin types and are based on several sets of data for each fin type presented in Reference [4]. The Reynolds number Re is defined in terms of the hydraulic diameter d_h of the heat exchanger (calculated internally by the program) and Pr is the Prandtl number of the fluid. The fin efficiency is calculated based on the heat transfer coefficient calculated in Eqn. (B-11), and is used in the calculation for the average air-side U-value.

Forced Convection - Wire-Tube

It is assumed that the heat exchanger orientation is such that the wires are aligned parallel with the air flow direction and the condenser tubes are perpendicular to the air flow direction. The user provides information regarding diameter and spacing of the condenser tubing and wires, and the air flow rate. Heat transfer coefficients for the wires and the condenser tubes are calculated using correlations of the same form as (B-10) and (B-11).

Radiative Component

A radiative component of heat transfer is added to the convective components discussed above. The radiative component is calculated by linearizing the equations for radiation heat transfer, from which a radiative heat transfer coefficient can be defined and calculated using the following equation:

$$h_{rad} = 4\sigma\varepsilon T^{3}_{r,ave} \tag{B-12}$$

where $T_{r,ave}$ in Eqn. (B-12) is the refrigerant saturation temperature in absolute temperature units and σ is the Stefan-Boltzman constant which has a value of 5.67 x 10^{-8} W/m^2-K. The surface emittance, , is assumed equal to 0.8 for the condenser surfaces and equal to 0.2 for the evaporator surfaces.

Natural Convection

The heat transfer coefficients for natural convection heat exchangers are composed of two components; convective and radiative. The total heat transfer coefficient is the sum of these two components, or

$$h = h_{nc} + h_{rad} \tag{B-13}$$

Correlations for air which are appropriate for the specified geometry are used to calculate the convective component, and have the form

$$h_{nc} = C\left|T_{r,ave} - T_{air}\right|^{0.33} \tag{B-14}$$

More detailed descriptions of the correlations can be found in References [5, 6]. The term $|T_{r.ave}-T_{air}|$ is the absolute value of the difference between the average refrigerant saturation temperature and the bulk air temperature. The air temperature corresponds to the ambient (i.e., room) air temperature for analyzing a condenser and the cabinet temperature for analyzing an evaporator. The constant C in Eqn. (B-14) depends on the heat exchanger geometry. Geometries included in these analyses are a vertical plate condenser, hot-wall condenser, vertical wire-tube condenser, vertical plate evaporator, cold-wall evaporator, and a horizontal plate evaporator. The user provides data for each heat exchanger type as requested by the help menu.

B.4.2. Refrigerant-Side Heat Transfer Coefficients and Pressure Drops

Single Phase Refrigerant Flow

The single phase refrigerant heat transfer coefficients are calculated assuming fully-developed laminar or turbulent flow. The Nusselt number correlations used in this analysis are

$$Nu = 3.66 \tag{B-15}$$

for laminar flow, and

$$Nu = 0.023Re^{0.8}Pr^{0.4} \tag{B-16}$$

for turbulent flow.

In most instances, the pressure drops are small compared to the pressure drop in the condensation and evaporating flow regimes and are therefore ignored.

Condensation Heat Transfer Regime

Heat transfer coefficients and pressure drops are calculated simultaneously in the condensing flow regime. The analysis begins at saturated vapor and marches stepwise downstream, calculating the local heat transfer coefficient and pressure gradient until the point at which complete condensation has occurred, from which the average heat transfer coefficient and total pressure drop can be determined. The equations and algorithms for calculating the condensation heat transfer coefficients and two-phase pressure drop are too complex to be presented here, but can be found in References [7 - 10].

Evaporation Heat Transfer Regime

The analysis for the evaporating heat transfer regime is very similar to that of for the condensation regime. The major difference is that much simpler equations are used to calculate the average evaporating heat transfer coefficient, eliminating the need for a stepwise calculation. However, the pressure drop in the evaporating heat transfer regime is calculated by marching stepwise downstream, calculating the local pressure gradient, and summing the local pressure drops to calculated the total pressure drop. The equations for calculating the average evaporating heat transfer coefficient are taken from Reference [11] while the pressure drop is calculated using the method from Reference [10].

B.4.3. Fluid Properties

The help menu contains refrigerant thermodynamic and transport properties for six pure refrigerants; CFC-12, HFC-134a, HFC-152a, HC-290 (propane), HC-270 (cyclopropane), and HCFC-22. For both pure fluids and mixtures in which the properties are not tabulated, the thermophysical properties are calculated based on the critical properties (which are stored in ERA) using various molecular models. The methods of thermophysical property calculation used in ERA are outlined in Reference [12]. Use of the Help menu to calculate the heat transfer coefficients for NARMs should be done with caution, as NARMs generally behave very differently than pure fluids. The heat transfer coefficient correlations used in the Help menu models are derived for pure fluids, and thus generally do not apply to NARMs.

The properties of dry air are calculated in the program based on the user defined value of air temperature, assuming atmospheric pressure.

B.5 Corrections for Hot-Wall Condenser or Cold-Wall Evaporator

Corrections are required to the cabinet loads output from CAB.EXE to account for the presence of a cold-wall evaporator and/or hot-wall condenser. Two factors must be considered:

- The presence of the heat exchanger over a portion of the wall reduces the thickness of the insulation over the same area. The menu program calculates the UAs of the cabinet walls containing the heat exchangers and inputs these values to the cycle model in file CYCLE.DAT.

- During the on-cycle period (when the compressor is operating) the environment communicates with the heat exchanger through the insulation. This results in an incremental refrigeration load and a change in the cabinet load during the on-cycle period.

As an example, assume that a cold-wall evaporator is used in the fresh food section of a dual evaporator cycle. If the thermal conductance of the area of the wall containing the evaporator is written:

UA_FF_EVP = UA of fresh food section wall evaporator

then the additional refrigeration load on the evaporator is

$$\Delta Q_e = \text{UA\_FF\_EVP}\ (T_a - T_e)$$

where T_a = room temperature and T_e = evaporator temperature.

During the time the compressor is operating, the evaporator effectively isolates this portion of the cabinet wall from the environment. This will result in a correction to the duty cycle (compressor on-time):

$$\text{Duty Cycle} = \text{Cabinet\_Load} / \text{CAP}^*$$

where

$$\text{CAP}^* = \text{CAP} + \Delta Q_e - \text{UA\_FF\_EVP}\ (T_a - T_{FF})$$

where T_{FF} = fresh food cabinet temperature and CAP is the evaporator capacity in the absence of the additional heat input to the evaporator through the insulation.

Similar equations hold for the freezer evaporator.

The presence of a hot-wall condenser will have similar effects on the cabinet loads and refrigeration cycle behavior. During the time the compressor is running the outside wall will be warmer than the ambient, which will result in additional heat flow into the cabinet. As a consequence, the duty cycle will be lengthened by the additional cabinet heat load.

For example, if the condenser is in the walls of a fresh food section, the duty cycle becomes:

$$\text{Duty} = \text{Cabinet\_Load}/(\text{CAP}^* + \Delta Q_c)$$

where

ΔQ_c=UA_FF_CND(T_c-T_a)

UA_FF_CND=UA value of portion of wall containing condenser

T_c = condenser temperature

B.6 Matching Evaporator Capacities and Cabinet Loads

The overall analysis of daily energy use takes place in four steps:

- Step 1: Calculate cabinet loads assuming fixed cabinet temperatures
- Step 2: Calculate cycle parameters for given cabinet air temperature
- Step 3: Perform adjustments to match cabinet loads and evaporator capacity
- Step 4: Calculate compressor run time and the net energy consumption

Steps 2 and 3 are normally done iteratively since there will often be an imbalance between the loads of the two cabinets and the corresponding cooling rates.

The method for matching the capacities and loads depends on the refrigeration cycle and the control option. This is discussed below for the three basic cycles: 1) single evaporator - single compressor cycle; 2) dual-loop cycle; 3) dual evaporator cycle (with one compressor). Note that the Lorenz cycle is a subset of the dual evaporator cycle.

B.6.1. Single Evaporator Cycle

The single evaporator cycle uses an air baffle arrangement to deliver cool air to both compartments from the single evaporator, located in the back of the freezer compartment. It is assumed that the user has properly set the baffle, or that an electronically controlled baffle is used, to deliver the necessary air to each compartment to simultaneously meet the two cabinet loads at the assumed setpoints.

The cooling rate of each compartment is given by:

$$Q_{FF} = \dot{m} C_p f (T_{FF} - T_{out})$$

$$Q_{FZ} = \dot{m} C_p (1 - f)(T_{FZ} - T_{out})$$

where

$\dot{m} C_p$ = mass flow - specific heat of air across the evaporator

f = fraction of air going to fresh food compartment

T_{out} = temperature of air leaving the evaporator coil

The inlet air temperature of the coil, and the net evaporator capacity, must satisfy:

$$T_{in} = f\,T_{FF} + (1 - f)\,T_{FZ}$$
$$\text{Capacity} = \dot{m} C_p (T_{in} - T_{out})$$

The equations are solved simultaneously to determine the fraction of air going to the fresh food section (typically 10 - 15%) and the inlet air temperature to the evaporator.

B.6.2. Dual Loop

The dual loop cycle employes two separate refrigeration loops and controls, one for each compartment. They are solved separately, and the energy consumption values combined to establish the overall consumption level.

B.6.3. Dual Evaporator Cycle

This is the most complex cycle from a controls standpoint. Although fans could be used in both compartments and cycled on and off to effectively couple or de-couple the evaporator from the cabinet air, it is assumed that at least one of these evaporators will be a natural convection type. Hence, there will almost always be an imbalance between the delivered cooling rates and the needs of the individual compartments.

ERA provides 5 options for dealing with this:

- Allow imbalance -- the summary output will note an imbalance when one occurs. A second run can then be made with an adjustment in parameters in an attempt to reduce the imbalance below some level. For example, most current Chinese refrigerator/freezer designs use a resistance heater in the fresh food section to artificially add a heat load when necessary to keep the compressor running to ensure that the freezer compartment is adequately refrigerated.

- Allow the fresh food section cabinet temperature to float when the compressor is controlled by the freezer set point. Corrections to the fresh food section cabinet heat load and temperature are made until the cabinet loads are in balance with the relative evaporator capacities.

- Allow the freezer temperature to float when the compressor is controlled by the fresh food section set point. The freezer cabinet load is adjusted, along with the freezer temperature, to achieve a balance between the cabinet loads and evaporator capacities.

- Mathematically adjust the areas of the two evaporators to achieve the balance. The algorithm adopted maintains total evaporator area, while adjusting the fraction in each compartment. This is, of course, not possible in a hardware configuration. However, it yields information useful to a researcher or designer about the proportion of evaporator areas required to achieve a correct balance.

- Bypass one of the evaporators during a portion of the cycle.

B.7 Variable Speed Operation

Variable speed control is one means of achieving efficiency improvements. Motor speed is modulated to maintain essentially constant operation of the compressor at a reduced capacity that nearly matches the cabinet load. Both the physically based (loss-efficiency) model and rating point (EER-capacity) model for the compressor allow specification of reduced speed. Because of the complex phenomena involved throughout the refrigeration cycle, capacity is not linear with respect to speed, but varies with some fractional power of the speed. These variations are taken into account by the compressor models. Hence, the program user merely need specify a change in the speed and ERA will determine a corresponding capacity. Because of lubrication issues as well as motor efficiency concerns, the minimum desirable speed would be 25 - 40% of normal operating speed.

Electric motors show efficiency changes with speed [13]. ERA does not automatically adjust for motor efficiency, but assumes the program user will account for this by inputting a lower EER level or lower pump-motor efficiency parameters, depending on the compressor model selected.

Electronics losses will partially affect gains realized by variable speed operation. These losses occur in the speed control device which will be located outside the refrigerator cabinet. Two means for accounting for the electronics losses are provided: 1) specify the losses directly when using the loss-efficiency compressor model, 2) incorporate these losses into a reduced effective EER when using the EER-capacity compressor model. Reference [13] discusses the nature and magnitude of such losses.

In order to realize the efficiency potential of variable speed control, reduced wattage fans must be utilized since the fans will also be operated nearly continuously. In addition, it may be advantageous to vary the fan speed to reduce the air flow over the heat exchanger since the dominant heat transfer resistance may be on the refrigerant side at reduced mass flow.

A simple model is employed to estimate the variation in air flow rate and fan power as a function of speed [14]:

$$\text{Air flow} \propto \text{speed}$$

$$\text{Fan power} \propto (\text{speed})^3$$

A calculation assist menu is available to automatically scale the air flow and fan power.

If a variable speed analysis is carried out, the calculation assist menu for evaporator and condenser heat transfer should be utilized. The effects of both reduced refrigerant mass flow and variable speed fan induced air flow will be taken into account.

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EPA Refrigerator Analysis (ERA) Program, Version 1.2E
Addendum to User's Manual

This file describes changes that have been made to ERA Version 1.0 and an installation procedure for running in the Windows platform.

Enhancements to ERA Version 1.0

1) An additional cabinet design has been added to Version 1.0 of the EPA Refrigerator Analysis Program (ERA) since its release in June 1993 (Report EPA-430-R-93-007):

- a single-door refrigerator model (cabinet type 6), which assumes the use of a free convection evaporator and manual defrost. A small freezer section may be present, with an interior door, but without active temperature control. According to the DOE definition, an all-refrigerator has a freezer compartment less than 14 liters (0.5 cu-ft) in volume. Typically a cabinet type 6 design will apply to compact refrigerators.

With this cabinet type, and the associated refrigeration cycles, all product classes covered under the DOE standards can now be analyzed with ERA.

2) Explicit inputs are now requested for the thickness of the cabinet shell, inner liner, foam, and high thermal resistance panels when included in the analysis. ERA will calculate the thermal resistances of all of these elements in the cabinet loads analysis.

3) Several use-related features have also been incorporated into Version 1.2E:

- Function keys <F6> and <F7> , highlighted in the main menu, provide two new functions. Using <F6>, the user may request that all data range checks be bypassed, allowing the specification of any data value to the program. Using <F7>, the user can select either device LPT1 or LPT2 as the print port. Both of these selections can be made without leaving the program to edit the SETUP.DAT file.

- The Cabinet Data edit menu displays the current cabinet type being edited. This should help the user to interpret the menu choices offered by ERA while editing the various blocks of cabinet design parameters.

- The Cycle Data Edit menu displays both the current cabinet type and the current cycle type. This is intended to help the user to interpret the menu choices offered by ERA while editing the various blocks of cycle design parameters.

- A check of available memory is made prior to attempted execution of the "calculation assist" programs for evaporator and condenser U-values and refrigerant pressure drops.

- A description of the relationship between the DOE product classifications for refrigerators, freezers, and refrigerator/freezers and the ERA cabinet types and cycle designs is given in a Help menu. The menu is called with the <F5> key from the Cabinet Type and Dimensions menu.

- In Version 1.0, a shut-off valve was not allowed with a reciprocating compressor. This restriction has been replaced by a warning message in the current version.

- Multiple data inputs are requested for the estimated value of the refrigerant mass flow in those instances where more than one cycle analysis is required (e.g., the dual-evaporator cycle using a bypass valve for cabinet temperature control). A value for the second mass flow estimate is assigned by a data file conversion program supplied with the diskette (see Data File Updates). If the converted file does not execute properly with ERA 1.2E, the second mass flow estimate may be too high.

- An input menu for the estimated mass flow is now presented when a compressor map is used. The value entered on the first line of the compressor map is ignored. The advantages of this change are that a consistent method of specifying the mass flow estimate is utilized and that the user is no longer required to edit the compressor map file externally to ERA.

- A warning message is output if one of the evaporators is bypassed during a portion of the compressor run time in a dual-evaporator or Lorenz cycle. The message identifies which evaporator has been bypassed.

- A warning message is displayed if a compressor run time duty cycle greater than 1.0 is required to meet the cabinet loads. This faulty condition can occur in an improperly specified dual-evaporator cycle, or Lorenz cycle, using refrigerant bypass control or evaporator cycling control.

- The CSD equation of state coefficients have been updated to be consistent with REFPROP 4.0. Refrigerants pentane, iso-pentane, and R123a have been added to the ERA data base.

Installation

A completely new installation procedure is provided. From Windows (3.1, 95. or NT) execute the setup.exe file to extract the program and associated files. The installation will create a program group (ERA) with icons for the program and for un-install instructions.

In Windows 95 (or NT 4.0) a short cut may be put on the desktop by selecting this option from the setup wizard.

DOE Product Classes

For rating purposes, DOE defines ten product classes for refrigerators, freezers, and refrigerator/freezers. The definitions encompass the attributes of defrost, and through-the-door ice features. ERA defines cabinet types in terms of the design of the cabinet only, rather than in terms of the overall cabinet/cycle functionalities utilized by DOE in its product classifications.

Specification of the cabinet design, defrost method, cycle design, and the presence or absence of cabinet penetrations enables ERA to represent a larger combination of designs than implied by the DOE product classifications. ERA does not, however, explicitly represent a cabinet with through-the-door ice features. The user must estimate the added heat leak through the door associated with this feature. This additional load is defined as a "penetration."

The table below lists each of the ERA cabinet types and the corresponding DOE product classes.

	DOE Product Classes	
ERA Cabinet Type	**Auto Defrost**	**Manual Defrost**
1 Two-Door Top-Mount R/F	2, 3, 6	1
2 Two-Door Bottom-Mount R/F	5	1
3 Side-by-Side R/F	4, 7	N/A
4 Chest Freezer	10	10
5 Upright Freezer	9	8
6 Refrigerator	N/A	1

Descriptions of the DOE product classification are listed next:

DOE Product Class	1	Refrigerator and Refrigerator/Freezer - Manual Defrost
	2	Refrigerator/Freezer - Partial Auto Defrost
	3	Refrigerator/Freezer - Auto Defrost Top Mount Freezer w/o Through-the-Door Ice
	4	Refrigerator/Freezer - Auto Defrost Side

	Mount Freezer w/o Through-the-Door Ice
5	Refrigerator/Freezer - Auto Defrost Bottom Mount Freezer w/o Through-the Door Ice
6	Refrigerator/Freezer - Auto Defrost Top Mount Freezer with Through-the Door Ice
7	Refrigerator/Freezer - Auto Defrost Side Mount Freezer with Through-the-Door Ice
8	Upright Freezer - Manual Defrost
9	Upright Freezer - Automatic Defrost
10	Chest Freezer and All Other Freezers

Cabinet Type 6: Single-Door Refrigerator

ERA cabinet Type 6, "Refrigerator," is a single-door cabinet that provides fresh food temperature control, but may also contain a small freezer section. If a separate freezer section is present, the temperature will normally be above 8 ^{o}F. Typically, the freezer section volume is only a small fraction of the total food storage volume.

DOE also defines an "all-refrigerator" class that may contain a freezer section, limited to 14.2 liters (0.5 cu-ft) in volume; normally the "freezer," if present, is used only for ice storage. ERA accounts for the presence of a "refrigerator" freezer section on the cabinet load and the refrigeration cycle behavior.

If a small freezer section is used in the ERA type 6 refrigerator, the dimensions of the freezer must be specified (height, width, and depth). The width can be smaller than the inside dimensions of the refrigerator.

In some instances, one side of the evaporator may be against one of the inside walls of the cabinet. In this situation the heat load to the evaporator will be higher since that portion of the cabinet wall will be colder. To account for this, separate values for the exposed evaporator area on the refrigerator side and the freezer side are requested. These will be the same if the top and side portions of the evaporator are exposed.

In a true all-refrigerator, with no freezer compartment, the evaporator will normally be attached to, or stood off slightly from, a cabinet wall. Only the exposed area should be entered as the evaporator area.

Installation Considerations

Because ERA requires a large amount of memory (434K), and remains memory resident during calls to the heat exchanger calculation programs (which use another 70K), approximately 520 K bytes of memory must be available when in the DOS shell. Type "mem" to determine the available memory. If DOS 5.0, or higher is used (recommended), it will be advantageous to place DOS in high memory. (Placing DOS in high memory is done by adding the command DOS=HIGH to the CONFIG.SYS file.) If less than 520 K bytes are available in the DOS shell, ERA will still probably execute, but may not be able to call the heat exchanger programs to calculate the evaporator and condenser UA values. A warning message will be issued if an insufficient memory condition is encountered.

ERA Subdirectory Structure

The program and its basic supporting files are placed in the user-specified base directory (default C:\ERA). Four subdirectories are created as well:

- \FILES is the default directory for the refrigerator data files (*.ERA)[1];
- \DOCUMENT contains supporting documentation for the program;
- \SAMPLE contains the results of an ERA run for the SAMPLE data file; and
- \REMAP contains a compressor performance map smoothing program.

See file README.DOC (WORD file) or README.TXT (text file) for additional details.

Getting Started

Although the program installation takes place in the Windows environment, ERA is a DOS-based program. It may be run from DOS, or launched from Windows by clicking on the ERA icon.

Prior to the first run, the program setup assumptions, defined in file SETUP.DAT, should be reviewed. A description of these parameters is given in file SETUP.TXT.

Six sample ERA files (*.ERA) are included[2]: MODEL_A, MODEL_B, MODEL_C, and MODEL_D correspond to the refrigerator designs discussed in the ERA 1.0 User's Manual. TYPE6 corresponds to a TYPE6 refrigerator design. SAMPLE is an example input file discussed in detail in the SAMPLE.DOC Microsoft WORD 6.0 file installed in the \DOCUMENT subdirectory.

[1] the program allows the arbitrary use of other subdirectories as well as a means of grouping a series of data files.
[2] installed in \FILES subdirectory

ERA Input Data Parameter Glossary

Although considerable effort has been put into providing a user-friendly calculation tool, the many design approaches used in refrigerator/freezers necessitates a somewhat complex model. Three primary sources of information have been developed to assist in the proper use of the ERA program: the ERA User's Manual, the built-in Help menus, and the data glossary in this document.

The program should not be expected to provide "reasonable" results if the specification of input data is not consisted with the assumptions made as part of the program design. The data glossary, presented according to the various ERA input data menus, is intended to ensure that the program assumptions concerning the various input data are available to the ERA user.

Glossary of Input Data Parameters: Cabinet Data

Data Menu	Term	Description
Cabinet Type and Overall Dimensions	Configuration Type	Define the basic cabinet configuration by selecting a cabinet type code (1-6). This only determines the general nature of the cabinet design, not the refrigeration cycle. For example, cabinet type 1 (2-door, top mount) is compatible with all of the refrigeration systems modeled by ERA.
	Cabinet Height	The vertical distance from the bottom of the cabinet section to the top surface of the cabinet. These are ***outside*** dimensions. The *bottom surface* of the cabinet is normally above the compressor, and/or above a forced convection condenser area. It is the outside surface, just below the bottom insulation wall in the cabinet. *This distance is* ***not*** *the distance from the floor to the cabinet top.*
	Cabinet Width	The ***outer***, side-to-side dimensions of the cabinet, seen when looking at the cabinet door (other than a chest freezer, where the door is on the top).

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Cabinet Type and Overall Dimensions, Continued	Cabinet Depth	The ***outer*** depth of the cabinet, from the outer surface of the door to the back of the cabinet. Do not include the door handle or any protrusions on the back (for a static condenser, for example). Note: this dimension includes the door edge and gasket dimensions.
	Gasket Width	The door gasket separates the flange of the cabinet from the inner surface of the closing door. By adding the gasket width and the door edge thickness, the distance form the cabinet flange to the outer door surface is determined.
	Door Edge Thickness	This is the distance from the door gasket to the outer door surface, not including any protrusions such as a door handle.
Cabinet Liners	Thickness	A typical cabinet will have a steel liner of approximately 20 mils (0.5 mm).
	Conductivity	Cold-rolled steel has a typical conductivity of 24 Btu/hr-ft-F (41 W/m-C).
Cabinet Wedge Dimensions	Wedge Depth	The wedge is a section of the cabinet near the door flange. Typically, it defines a tapir extending from a short distance inside the cabinet flange to the flange surface. The depth is defined as the distance from the flange surface to the beginning of the tapir. If a wedge is not present (as in some fresh food designs where the wall thickness does not vary), enter a zero value for the wedge depth. Note: ERA requires that a non-zero wedge depth be defined for the freezer cabinet section.

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Cabinet Wedge Dimensions, Continued	Flange Width	This is the thickness of the cabinet flange. It must be a positive number, but must be less than or equal to the cabinet wall thickness. If a wedge is not present, enter the wall thickness value (or set the flange depth equal to 0 for the fresh food section).
Refrigerated Volume	Compressor Box Width	Defined only for a chest freezer. This is the width of the compressor box under a portion of the cabinet (see Help menu diagram).
	Compressor Box Height	Height of chest freezer compressor cabinet (see Help menu diagram).
	Freezer Section Height	Defined only for a Type 6 single-door refrigerator. This is the height of a small freezer section inside the refrigerator cabinet.
	Freezer Section Width	Defined only for a Type 6 single-door refrigerator. Width of small internal freezer section.
	Freezer Section Depth	Defined only for a Type 6 single-door refrigerator. This is the depth of the freezer evaporator, not including an interior door over the freezer section.
	Volume Used by Evap	Freezer section volume lost for food storage due to the freezer evaporator.
	Volume Used by Food	Estimated volume used by food.
	Volume Used by Shelf	Estimated cabinet storage volume lost due to shelving
	Net Storage Volume	Net, unused, food storage volume. Used as part of analysis of effects of door openings.

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Compressor Compartment Dimensions	Top Depth	Depth of top-most wall of compressor compartment at back of the cabinet (see Help menu diagram).
	Bottom Depth	Depth of bottom of compressor compartment at back of cabinet (see Help menu diagram).
	Height	Height of compressor cabinet (see Help menu diagram).
Insulation Thickness	Top Wall	Thickness of insulation system, from *inside* of outer shell to *inside* of inner liner. Includes thickness of foam and/or any high resistance panels. The insulation thickness ***does not*** include the shell or liner thickness.
	Side Wall	See above
	Bottom Wall	See above
	Back Wall	See above
	Cabinet Panels	See above
	Door	See above
	Side of Compressor Box	See above
	Top of Compressor Box	See above
Fresh Food Insulation Thickness	See Insulation Thickness	
Freezer Insulation thickness	See Insulation thickness	

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Insulation Resistivities	Top Wall	Net resistivity of insulation system in top wall of cabinet section, based on foam and/or high resistance panel ***inside*** the outer shell and the inner liner. Aid in calculating the net resistivity of a composite foam-panel insulation system can be obtained by pressing the <F5> key and following the instruction in the Help menu.
	Side Wall	See above
	Back Wall	See above
	Bottom Wall	See above
	Cabinet Panels	See above
	Door	See above
	Wedge	See above
Fresh Food Insulation Resistivities	See Insulation Resistivities	
Freezer Insulation Resistivities	See Insulation Resistivities	
Calculate Wall Resistivity	Section Full Width	Full width of the cabinet section wall whose net resistivity is to be determined, based on the ***outside dimensions*** of the cabinet. ERA will account for the wall thickness in determining the net resistivity. Definition of width depends on wall section (see Help menu). .
	Section Full Length	Full height of the wall section, ***based on outside*** dimensions. Definition of length depends on wall section (see Help menu).

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Calculate Wall Resistivity, Continued	"Top" Edge	Distance of high-resistance panel from top of the wall section, based on the ***outside dimensions*** of the wall element (see Help menu). ERA will correct for wall thickness and the effects of an edge.
	"Right" Edge	Distance of high-resistance panel from right-hand edge of wall section, based on the ***outside dimensions*** of the wall element (see Help menu).
	"Bottom" Edge	Distance of high-resistance panel from bottom of wall section, based on the ***outside dimensions*** of the wall element (see Help menu).
	"Left" Edge	Distance of high-resistance panel from left-hand edge of wall section, based on the ***outside dimensions*** of the wall element (see Help menu).
	Total Insulation Thickness	Distance from inside of outer shell to inside of inner shell (shell and liner thickness are not included).
	Outer Foam Fraction	Fraction of insulation thickness made up of foam on outside of inner panel.
	Inner Foam Fraction	Fraction of insulation thickness made up of foam on inside of inner panel.
	Foam Resistivity	Resistivity of foam in wall composite
	Panel Resistivity	Resistivity of panel, not including edge effects (ERA will estimate edge effects).
	Enclosure Thickness	Thickness of material (barrier material) forming outer sheath of high-resistance panel.
	Enclosure Conductivity	Thermal conductivity of material forming outer sheath of high-resistance inner panel (see Help menu).

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Mullion	Distance to Top	Distance from top of mullion to outer surface of top of the cabinet.
	Distance to Wall	For side-by-side cabinet (Type 3), the distance from the mullion surface to the outside wall (see Help menu).
	Thickness	Mullion thickness.
	Resistivity	Mullion resistivity. Normally, this is lower than the resistivity of foam used in the walls.
Air and Cabinet Temperatures	Room Air	Temperature of environment around the cabinet. If the cabinet is in an enclosed area, with little opportunity for air flow, increase the specified air temperature a few degrees.
	Freezer Section	Control setting for the freezer. This is the average freezer temperature throughout a compressor cycle.
	Fresh Food Section	Control setting for the fresh food section. This is the average fresh food section temperature throughout a compressor cycle.
	Cabinet Setpoint	Setpoint for cabinet.
	Air Under Cabinet	Approximate temperature of the air under the cabinet, accounting for compressor thermal losses and the presence of a condenser, if any. Typically equal to the room air + 5 to 10 F.
	Air Entering Condenser	Approximate temperature of the air entering the condenser. Equal the room air for a exposed cabinet with the condenser on the back. If in an enclosed area, add 2 to 5 F to the room temperature.

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Door Opening Schedule	Room Relative Humidity	Used for calculation of door opening effects on the cabinet load.
	Fresh Food Door - #/hr	Number of times the fresh food door is opened each hour, on average, throughout the day. Used for calculation of door opening effects.
	Fresh Food Door - sec open	Average time the fresh food door is open during each opening event.
	Freezer Door - #/hr	See above
	Freezer Door - sec open	See above
	Cabinet Door - #/hr	See above
	Cabinet Door - sec open	See above
	Manual Defrost	Indicate if manual defrost method used (1=yes, 0=no)
Gasket Heat Leaks	Fresh Food Section	Average heat leak associated with the fresh food section, in units of watts per meter of door edge perimeter per 100 degrees C. Typical value is 6 to 12 W/m-100 C (see Help menu).
	Freezer Section	See above
	Cabinet Heat Leak	See above
Defrost and Controls Energy Use	Auto Defrost: Timer Interval	Time between initiation of defrost cycles, in units of compressor run-time.
	Auto Defrost: Heater On-Time	Duration of defrost heat during defrost cycle.
	Auto Defrost: Defrost Power	Heater power used for defrost.
	Other Cycle-Dependent Loads	Electrical loads that cycle on and off with the compressor (not including fan powers, which are specified elsewhere).

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Defrost and Controls Energy Use, Continued	Constant Electrical Loads	Constant electrical power not accounted for elsewhere. Example could be a timer or other control.
	Hours/Day Shutoff	For Type 6 only (single-door refrigerator), number of hours each day the compressor is disabled to provide cycle defrost.
Electric Anti-Sweat Heat	Freezer Door: Cycle Average Energy	The cycle average electrical heat input to the cabinet flange around the freezer door (W). For example, if the heater power were 5 watts, and the heater were activated 60% of the time, the cycle average energy would be 3 watts.
	Freezer Door: Fraction Heat Leak	Because the heater raises the temperature of the cabinet flange, a fraction of the heat input around the flange will re-enter the cabinet as an additional heat load; the rest will radiate or be convected away to the room. Enter an estimate of the fraction of the heat that re-enters the cabinet. A typical value is 30%.
	Fresh Food Door: Cycle Average Energy	See Freezer Door: Cycle Average Energy
	Fresh Food Door: Fraction Heat Leak	See Freezer Door: Cycle Fraction Heat Leak
	Mullion: Cycle Average Energy	Electrical heat in the mullion area (between the freezer door and fresh food doors) will contribute to heat leaks in both cabinets.
	Mullion: Heat Leak to FZ	The fraction of electrical heat in the mullion area that leaks into the freezer compartment.

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Electric Anti-Sweat Heat, Continued	Mullion: Heat Leak to FF	The fraction of electrical heat in the mullion area that leaks into the fresh food section. The sum of the heat leak to the freezer section and to the fresh food section must be less than unity (a typical value for the sum is 0.5)
	Cycle Average Energy	The cycle average anti-sweat heat in a single compartment cabinet
	Fraction Heat Leak	Fraction of the cabinet anti-sweat heat that re-appears as a cabinet load.
Refrigerant Line Anti-Sweat Heat	Type (Vapor or Liquid)	Anti-sweat heat can be provided by a line from the condenser leading to the capillary tube (containing liquid or two-phase refrigerant still condensing) or from the compressor leading to the condenser (containing superheated vapor). The type of anti-sweat heat is indicated by the type code (1=vapor, 2=liquid).
	Freezer Door: Cycle Average Energy	The cycle average heat input is specified in watts. For example, if the refrigerant line supplies 10 watts while the compressor is operating, and the compressor run time is 35%, the cycle average heat input is 3.5 watts
	Freezer Door: Fraction Heat Leak	See Electric Anti-Sweat Heat
	Fresh Food Door: Cycle Average Energy	See Electric Anti-Sweat Heat
	Fresh Food Door: Fraction Heat Leak	See Electric Anti-Sweat Heat
	Mullion: Cycle Average Energy	See Electric Anti-Sweat Heat
	Mullion: Heat Leak to FZ	See Electric Anti-Sweat Heat
	Mullion: Heat Leak to FF	See Electric Anti-Sweat Heat

Glossary of Input Data Parameters: Cabinet Data (Continued)

Data Menu	Term	Description
Refrigerant Line Anti-Sweat Heat, continued	Cycle Average Energy	See Electric Anti-Sweat Heat
	Fraction Heat Leak	See Electric Anti-Sweat Heat
Penetration Heat Input	Penetration Heat to FZ	Additional known heat inputs to the freezer cabinet that are not modeled elsewhere can be specified here. Enter the values in watts.
	Penetration Heat to FF	Same as above. An example would be a through-the-door convenience item.
	Penetration Heat Input	See above

Glossary of Input Data Parameters: Cycle Data

Data Menu	Term	Description
Cycle Definition	Cycle Type	Four different types of refrigeration cycles are modeled. The type code defines the cycle used to refrigerate the cabinet: 1=single evaporator cycle, 2=Lorenz cycle, 3=dual loop cycle, 4=dual-evaporator cycle.
	Number of Refrigerants	Up to three refrigerants can be used in a blend. Define the number of refrigerants used in the cycle (1 - 3).
Lorenz or Dual-Evaporator Cycle Control	Evaporator Control	If a Lorenz cycle or dual-evaporator cycle is defined, some means of simulating the cabinet temperature control must be specified. Specify a control code (0 - 5) to designate the type of control to be modeled. Details of the control options are given in the Help menu.
Refrigerant Codes	Refrigerant Code	The refrigerant (blend) used in the cycle is defined by specifying refrigerant code(s) and by specifying the mass fraction of each refrigerant in a blend. Currently, properties for 34 different refrigerants are built into the program. Only one refrigerant code need be specified for a pure refrigerant.
	Refrigerant A Code	This is the code for one of the refrigerants in a blend.
	Mass Fraction	This is the mass fraction of blend component A.
	Refrigerant B Code	See above

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Refrigerant Codes, Continued	Mass Fraction	See above
	Refrigerant C Code	See above
	Interaction Coefficient(s)	The refrigerant binary interaction coefficients are specified. Default values are available by pressing the <F4>: key.
Evaporator Data	Refrigerant Control Option	ERA does not model an expansion device. Rather, it asks the user to specify the behavior of the expansion device by defining the vapor condition leaving the evaporator or interchanger. The refrigerant control option defines the type of information about the state of the vapor to be provided by the user. Details are given in the Help menu.
	Refrigerant Superheat	The refrigerant superheat at the exit of the evaporator or leaving the interchanger, depending on the refrigerant control option (see above).
	Evaporator Exit Quality	Quality of the two-phase refrigerant at the exit of the evaporator. This is specified only if the refrigerant control is based on the exit quality (see above).
	Heat Exchanger Type	A code that defines the type of forced-convection heat exchanger (1=cross flow, 2=counter flow). This parameter applies only to a fan forced evaporator.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Evaporator Data, Continued	Heat Transfer Type	A code that defines the type of heat transfer (1=fan forced, 2=natural convection).
	Fan Motor Power	Power of fan motor used in fan-forced evaporator.
	Heat Transfer Area	This is the net heat transfer area available for direct heat exchange with the air. Include fins and other extended surfaces
	Air Flow Rate	Data for the air flow rate applies to a fan-forced evaporator. ERA assumes it is uniformly distributed across the face of the evaporator.
	Two-Phase U	Estimate the net heat transfer coefficient between the air and the boiling refrigerant. An estimate of this value can be obtained by pressing the <F5> calculation assist key and entering data that describes details of the evaporator.
	Superheat U	This is the net heat transfer coefficient between the superheated refrigerant and the air. Use the <F5> calculation assist if the data value is not known.
	Heat Exchanger UA	If the overall UA value is known from heat exchanger tests, press the <F4> key to define the overall UA.
	Refr Pressure Drop	The refrigerant pressure drop across the evaporator (from entrance to exit) depends on the evaporator design, the refrigerant properties, and the mass flow rate.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Evaporator Data, Continued	Evaporator Area Exposed to the Freezer	This applies only to a Type 6 single door refrigerator with a small freezer box. If the box is not against a cabinet wall the total evaporator areas exposed to the inside (freezer) and outside (cabinet) will be nearly the same. Enter the total area exposed to the freezer, even if partially obscured by food.
	Evaporator Area Exposed to the Cabinet	This applies only to a single door refrigerator. Enter the area not against a wall. This is the total area exposed to the cabinet space and available for heat transfer with the interior of the cabinet.
Natural Convection Evaporator Location	Location	If the air gap between an evaporator surface and the cabinet wall is > 2 cm, consider the surface as being in the cabinet space (option 0). If the surface is part of the cabinet wall, it may be exposed to the air (option 1), or under the cabinet liner (option 2)
	Evaporator Thickness	This data value is requested only if the evaporator is part of the cabinet wall. Enter 0 if none of the evaporator actually lies behind the cabinet inner liner.
	Fraction in Side Wall	This applies only to an evaporator that is attached to, or underneath, a portion of the cabinet inner liner. The data value defines the fractional area of the evaporator associated with a cabinet wall. The total fractional values for the cabinet walls must sum to unity.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Natural Convection Evaporator Location, Continued	Fraction in Back Wall	See above
	Fraction in Mullion	See above
Freezer Evaporator Data	See Evaporator Data	
Fresh Food Evaporator Data	See Evaporator Data	
Variable Speed Fan	Fan Speed (Rated Conditions)	This menu is reached only by pressing the <F5> calculation assist key from the fan-forced evaporator or fan-forced condenser menus. This is the nominal fan speed under rated conditions.
	Power (Rated Conditions)	The fan power at nominal fan speed.
	Air Flow Rate (Rated Conditions)	Air flow rate induced by the fan at nominal conditions.
	Fan Speed (VSD Control)	Actual fan speed of a variable speed fan. From this speed, the conditions entered above, and a simple power-law relationship, the fan power and air flow rate are estimated.
Condenser Data	Refrigerant Subcooling	ERA does not include a refrigerant mass balance in its analysis. Hence, the condition at the exit of the condenser must be stated.
	Heat Exchanger Type	See Evaporator Data
	Heat Transfer Type	See Evaporator Data
	Fan Motor	See Evaporator Data
	Heat Transfer Area	See Evaporator Data

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Condenser Data, Continued	Air Flow Rate	See Evaporator Data
	Sub-Cool U	This is the net heat transfer coefficient between the subcooled refrigerant and the air. Use the <F5> calculation assist if the data value is not known
	Two-Phase U	See Evaporator Data
	Superheat U	See Evaporator Data
	Heat Exchanger UA	See Evaporator Data
	Refr Pressure Drop	See Evaporator Data
Natural Convection Condenser Location	Location	This applies only to a static condenser or hot-wall condenser. The entered code tells ERA if the condenser is a static type or a hot wall type.
	Condenser Thickness	This applies to a hot-wall condenser. The condenser (tube) thickness determines the loss of insulation in the wall covered by the condenser.
	Fraction in Side Walls	This applies only to a hot-wall condenser. Estimate the fraction in the side walls. The fractions assigned to all walls must add to unity.
	Fraction in Back Wall	See above
	Fraction in Top Wall	See above
Freezer Condenser Data	See Condenser Data	
Fresh Food Condenser Data	See Condenser Data	
Compressor Model Options	Compressor Type	Specify the type or compressor (1=reciprocating, 2=rotary)

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Compressor Model Options, Continued	Compressor Model	ERA provides three approaches to compressor performance simulation. Enter the code.
	Cycling Loss Analysis	A simple model for estimating the effects of compressor cycling is provided by ERA. A typical cycle loss of efficiency is around 2%.
	Cycles Per Hour	This is used only if a cycle loss analysis has been requested.
	Shut-Off Valve	A shut-off valve is sometimes used between the condenser and evaporator as a means of reducing refrigerant migration during off-cycle. Loss of pressure in the condenser, and gain of pressure in the evaporator, due to such migration represents a loss of efficiency. Normally, a shut-off valve is not used with a reciprocating type of compressor due to high starting torque.
Compressor Data: EER and Capacity Model	Displacement	The EER and Capacity model is the most common choice when only the capacity and power at the rating point are known. In order to estimate refrigerant mass flow, the compressor displacement must be known.
	Rated Capacity	This is the capacity, *with CFC-12 refrigerant*, at the ASHRAE rating point.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Compressor Data: EER and Capacity Model, Continued	Nominal Speed	The nominal speed is lower than synchronous speed due to motor slippage. Typical speeds for 60 Hz and 50 Hz are 3500 and 2900 rpm, respectively.
	Rated EER	The EER, *with CFC-12 refrigerant*, at the standard rating condition.
	Type of Can Cooling	Specify type of compressor can cooling in the compressor calorimeter test (static or fan-forced).
	Fractional Speed	This applies to variable speed control. If the compressor is running at nominal speed (see above), enter the ratio 1.0
	Mass Flow Guess	ERA solves for the refrigerant mass flow as well as for the thermodynamic states around the cycle. An initial guess is required to start the solution process. If the solution appears unstable (a convergent solution is not reached), the initial guess for the mass flow may have been to high. In this instance, try a lower value (say, lower by half) as the initial mass flow guess.
Compressor Data: Efficiency Model *Note: this model applies only to a reciprocating compressor*.	Displacement	The Efficiency Model attempts to model the thermodynamic processes occurring at the pump suction port. The displacement defines the swept volume, from which the mass flow rate can be determined.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Compressor Data: Efficiency Model, Continued	Speed (rpm)	The piston speed is lower than synchronous speed due to motor slippage. Typical speeds for 60 Hz and 50 Hz are 3500 and 2900 rpm, respectively.
	Clearance Volume	The clearance volume is expressed as a percent of the swept volume. A typical; value is in the range 2 - 4%.
	Compressor Efficiency	This is the isentropic efficiency *expressed at the pump suction port*. Because of cylinder heat exchange, the isentropic efficiency is actually higher than 100%. A typical value is 130%.
	Motor-Pump Efficiency	The is the product of the compressor mechanical efficiency and the electric motor efficiency. A typical value is 40%.
	Can Loss	Most of the electrical heat input to the compressor appears as heat loss out of the shell from the internal heating of the gas. A typical shell loss is 75% of the electrical energy input.
	Discharge Line Loss	Internal heat transfer occurs from the hot gas in the discharge line to the gas within the shell. This will contribute to the heating of the suction gas prior to entering the pump inlet manifold. A typical discharge line loss is 40%.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Compressor Data: Efficiency Model, Continued	Electronics Losses	This applies only to variable speed control. Enter the loss terms in watts.
Fresh Food Compressor Data	See Compressor Data	
Freezer Compressor Data	See Compressor Data	
Interchanger Data	Compressor Shell Inlet Temperature	The capillary tube is normally attached to the vapor line from the evaporator to the compressor can inlet port, forming an interchanger. The inlet temperature to the compressor can may be specified (fixed), or may be calculated based on the effectiveness of the interchanger.
	Interchanger Effectiveness	A typical interchanger effectiveness is 80 - 85%. The value specified determines the amount of liquid subcooling prior the entering the expansion device.
	Interchanger Effect: Condenser Subcooler	A Lorenz cycle uses two interchangers. The condenser subcooler is equivalent to the interchanger normally found in a single evaporator cycle.
	Interchanger Effect: Freezer Evaporator	This is the interchanger used between the freezer and fresh food evaporators in a Lorenz cycle.
Fresh Food Interchanger Data	See Interchanger Data	
Freezer Interchanger Data	See Interchanger Data	

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Forced Flow Evaporator Design Data	Outer (Tube) Diameter	This "calculation assist" menu is used to calculate the UA values for a fan-forced, finned tube, evaporator. The data value applies to the tube.
	(Tube) Wall thickness	The tube wall thickness and outer diameter determine the tube inner diameter.
	Number of Parallel Rows	When looking at the evaporator in the direction the air flow (normally up) the face area is normally made up of two or more parallel tube rows.
	Tube-Tube Spacing	Spacing between the tubes making up the face of the heat exchanger.
	Number of Rows Deep	Number of tube rows deep, counting from the first row making up the face of the heat exchanger.
	Tube-Tube Spacing	Spacing between rows in the depth direction.
	Width of Tube Row	Width of the face tubing (see Help menu).
	Fraction Finned	Fraction of the face width that is finned (see Help menu)
	Inlet Air Temp	Air from the fresh food section is mixed with the freezer air in a two-door, single evaporator system. The mixed air temperature is listed in file CYCLE.OUT as the air temperature at state point 11. For a single cabinet design the inlet air temperature is the cabinet temperature.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Forced Flow Evaporator Design Data, Continued	Air Flow Rate	The air is assumed to flow uniformly across the face of the heat exchanger.
	Refr Mass Flow	Enter a guess for the mass flow or, if solving the problem iteratively, the mass flow listed in ERA.OUT or CYCLE.OUT from the previous run.
	Superheated Fraction	If solving the problem iteratively, the superheated fraction is listed in CYCLE.OUT under the heading Heat Exchanger Performance Summary. Express the superheat as a fraction (0 - 1) rather than as a percentage value.
	Refr Inlet Quality	If solving the problem iteratively, enter the value listed at state point 9 under the heading XQ.
	Refr Outlet Quality	Normally, the outlet quality is 1.0, except for the freezer evaporator in a Lorenz cycle or dual-evaporator cycle refrigerator (see Help menu).
Evaporator Plate-Fin Design Data	# Fin/cm	Express the fin density as number of fins per cm across the finned area (do not average across the entire face area).
	Fin Thickness	The fin thickness helps determine the fin efficiency.
	Fin Conductivity	The fin conductivity helps determine the fin efficiency.
	Fin Type	Designate if the fins are straight or wavy.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Evaporator Plate-Fin Design Data, Continued	Configuration	Specify if the fins are in a line across the depth of the heat exchanger (enter 0) of if they are staggered (enter 1).
Natural Convection Design Data	Configuration	One of three types of natural convection evaporators can be specified: 1) vertical, in the cabinet space; 2) vertical wall (cold plate); or 3) horizontal, in the cabinet space.
	Area on One Side	Enter the area on only one side of the heat exchanger, even if it is entirely with the cabinet space. ERA will take the configuration into account.
	Refrigerant Tube Length	This is the total tube length traversed by the refrigerant. It is used for pressure drop calculations.
	Tube Outer Diam	See Forced Flow Evaporator Design Data
	Wall Thickness	See Forced Flow Evaporator Design Data
	Inlet Air Temp	See Forced Flow Evaporator Design Data
	Refr Mass Flow	See Forced Flow Evaporator Design Data
	Superheated Fraction	See Forced Flow Evaporator Design Data
	Refr Inlet Quality	See Forced Flow Evaporator Design Data
	Refr Outlet Quality	See Forced Flow Evaporator Design Data

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Forced Flow Condenser Design Data	Type	See Forced Flow Evaporator Design Data
	Outer (Tube) Diameter	See Forced Flow Evaporator Design Data
	(Tube) Wall Thickness	See Forced Flow Evaporator Design Data
	Number of Parallel Rows	See Forced Flow Evaporator Design Data
	Tube-Tube Spacing	See Forced Flow Evaporator Design Data
	Number Rows Deep	See Forced Flow Evaporator Design Data
	Tube-Tube Spacing	See Forced Flow Evaporator Design Data
	Width of Tube Row	See Forced Flow Evaporator Design Data
	Fraction Finned	See Forced Flow Evaporator Design Data
	Fraction Face Area	A condenser located under the cabinet only partially fills the air passage. Hence the air flow velocity across the face is dependent on the total air flow rate and the fraction of the passage filled by the evaporator frontal area (face). Enter the fraction (typically 0.4 to 0.8).
	Inlet Air Temp	See Forced Flow Evaporator Design Data
	Air Flow Rate	See Forced Flow Evaporator Design Data
	Refr Mass Flow	See Forced Flow Evaporator Design Data

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Condenser Wire-Fin Design Data	# Wire/cm	This menu is reached only for a wire-fin design condenser. The number of wires/cm applies only over that portion of the condenser that has fins, and is not averaged over the whole condenser area.
	Wire Diameter	Wire diameter helps determine the fin efficiency.
	Wire Conductivity	Wire conductivity helps determine fin efficiency.
	Wire Mounting	The wires may be mounted on only one side of the condenser face (enter 1) or on both sides (enter 2).
	Configuration (for Two Sided)	This applies only if wires are mounted on both sides.
Condenser Plate-Fin Design Data	# Fin/cm	See Evaporator Plate-Fin Design Data.
	Fin Thickness	See Evaporator Plate-Fin Design Data.
	Fin Conductivity	See Evaporator Plate-Fin Design Data.
	Fin Type	See Evaporator Plate-Fin Design Data.
	Configuration	See Evaporator Plate-Fin Design Data.
Natural Convection Condenser Design	Configuration	Define the configuration (see Help menu).
	Area on One Side	Enter area of only one side, even if the condenser is suspended off the back of the cabinet.

Glossary of Input Data Parameters: Cycle Data (Continued)

Data Menu	Term	Description
Natural Convection Condenser Design, Continued	Refrigerant Tube Length	The is the total length of tubing traversed by the refrigerant. It is used in pressure drop calculations.
	Width of Tube Row	This the width of a single row of tubes. If the internal tubing of a hot-wall condenser extends around the cabinet, enter the length of the cabinet perimeter.
	Tube Outer Diam	The tube diameter is used in pressure drop calculations.
	Wall Thickness	The wall thickness of a single (average sized) refrigerant tube making up the condenser.
	Number of Wires	This applies only to vertical tube-with-wires configuration. Enter the total number, on both sides of the condenser.
	Wire Diameter	This applies only to vertical tube-with-wires configuration
	Wire Length	This applies only to vertical tube-with-wires configuration. Normally, this is the equal to the height of the condenser.
	Inlet Air Temp	This is usually the room temperature.
	Refr Mass Flow	See Forced Flow Evaporator Design Data

Discussion of ERA 1.2E Sample Analysis

General Problem Description

The test problem defines a manual defrost, bottom-mount refrigerator-freezer cabinet design, using a dual evaporator cycle refrigeration system with the compressor located in a cut-out area below the freezer section. The cabinet is assumed located in a 25 ^{o}C room. Freezer flange and mullion anti-sweat energy is provided by a liquid-line routed from the condenser towards the capillary tube. Parasitic electrical energy is used only for controls.

The evaporators (two) and condenser (one) are natural convection type, requiring no fan power. A cold-wall design is employed in the fresh food section, with the evaporator plate located behind the inner liner; a free standing evaporator is located in the freezer section (possibly comprised of the compartment shelving). The condenser is also free standing, located on the back of the unit. Because the unit is assumed to be located near a wall, and because natural convection cooling of the compressor is assumed to occur, the temperature of the air cooling the condenser is assumed to be 5 ^{o}C higher than the room temperature. A reciprocating type compressor is used, operating at 2900 rpm (50 Hz).

Cabinet loads, duty cycle, and energy consumption are to be calculated for closed-door conditions. Since both evaporators are natural convection type, there will normally be an imbalance between the evaporator capacities and loads required to maintain the cabinets at design set points. For example, the freezer evaporator capacity could be 35% of the total refrigeration capacity while the freezer cabinet load would be 40% of the total cabinet load at the specified set points. The sample problem assumes that the compressor operation is controlled on the fresh food cabinet temperature, and that the freezer temperature will adjust itself in relation to the actual freezer evaporator capacity (that is, the freezer temperature is a result rather than in program input).

Output Files

ERA normally outputs three report files: ERA.OUT (summary of loads and energy use), CABINET.OUT (details of the cabinet loads analysis), and CYCLE.OUT (details of the cycle analysis). These files are intended to summarize how the cabinet and refrigeration cycle performed. Care has been taken to describe the data fields in a reasonably unambiguous manner, consistent with space requirements on each page.

Several intermediate data files are prepared by ERA to convey data between program modules (CABINET.DAT, and CYCLE.DAT). Although these are written in text format, and can be read by the program user, the terminology used in these data files is not as precise as in the report files. Further, some of the data reported in the intermediate files may not be exactly the same as those input to the program since some intermediate processing may have already taken place by the time these files are output.

If desired, the user may also obtain a file of the input data menus, with the exact input data specified for the run. The name of this file is X.INP, where “X” is replaced by the name of the data file (for example, SAMPLE.INP, where the data file name is SAMPLE).

Calculation Procedure

For a full interpretation of the program output, it is important that the program calculation sequence be understood. Program simulation involves four steps: 1) input data processing and error correction, 2) cabinet loads analysis, 3) cycle analysis, and 4) energy consumption analysis. The input data processor works with the complete set of data menus and Help menus to prepare the intermediate data files. Actual data passed to the executable program modules are somewhat consolidated and are in a form expected by these modules.

Both the cabinet loads calculation and cycle calculation are essentially static in nature. That is, the cabinet load analysis assumes that the refrigeration cycle is capable of maintaining the user-specified cabinet set point temperatures, while the refrigeration cycle analysis uses the calculated cabinet loads to determine the compressor run time.

Corrections to the cabinet loads are made within the cycle analysis program, where required to account for cabinet load imbalances, and the indirect effects of the refrigeration system on the cabinet. Because of a need to adjust cabinet temperatures under certain control assumptions, a subset of the cabinet loads output is appended to the intermediate data file used by the cycle analysis module. To emphasize what was stated earlier, the meaning of all of the intermediate data files entries may not be obvious without a thorough understanding of what the program is doing.

Indirect effects of the cycle on the cabinet include possible cooling of the inner walls by a cold-wall evaporator, and heating of the outer walls by a hot-plate condenser. Effects of vapor-line, or liquid-line, anti-sweat flange and mullion heating are included in the cabinet loads calculation module (before the cycle program is executed). Fan heats appearing from forced-convection evaporators are also added to the cabinet loads. Finally, certain control energies may be compressor run-time dependent. Adjustments to the cabinet loads account for the heat energies if the controls are located within a cabinet space.

Exhibits

Exhibits A through F are used to explain these concepts:

Exhibit	***File Name***	***Contents***
A	SAMPLE.INP	Input data menus for the sample problem
B	CABINET.DAT	Intermediate data file used for cabinet loads analysis
C	CABINET.OUT	Output report for cabinet loads
D	CYCLE.DAT	Intermediate data file used for cycle analysis
E	CYCLE.OUT	Output report for cycle performance
F	ERA.OUT	Summary performance report

Exhibit A: Input Data Menus

The user must request a copy of the input menus from the main menu of the ERA program (select the Write or Print commands appearing in lower right hand section of main menu). The data written out are identical to the menus presented to the user. Help menus are available within the program for each of these menus. The meanings of most of these inputs should be apparent from the menu titles and the Help menus. A limited discussion will be given here to amplify on those inputs that may not be immediately obvious.

<u>Cabinet Type and Overall Dimensions</u>

The "configuration" is a code that identifies the basic cabinet design (full definitions are given in the program documentation). It is not required that the designated design code be the same as normally associated with a particular type of refrigerator-freezer product. For example, a "freezer" cabinet (type 5) can be used to represent a single-door refrigerator without a separate freezer compartment. The cabinet design codes designate the basic configuration of the containing unit (the cabinet) rather than the refrigeration cycle used to cool the unit.

Outside dimensions for the cabinet are requested, including the door thickness and gasket. The program will calculate inside dimensions from the overall dimensions and wall thicknesses. According to the sample data in Exhibit A, the overall front-to-back depth is 56.5 cm (not counting any protrusions such as door handles or a back-mounted condenser). The corresponding distance from the cabinet door flange to the back surface is 50.6 cm.

<u>Cabinet Liners</u>

Calculation of the insulation thickness and the overall thermal resistance of each cabinet wall takes into account the outer skin thickness (normally steel), and the inner liner thickness (normally plastic). Later data menus, referring to the insulation, request values for the thickness of the insulation alone; inner and outer liner thicknesses are added by the program to determine the overall wall thicknesses.

<u>Cabinet Wedge Dimensions</u>

The model assumes that the refrigerator and freezer cabinets may each have a wedge around all door surfaces, not including the mullion. For example, in a top mount refrigerator/freezer, the freezer section wedge is assumed to be the same around the sides and top of the freezer; similarly a wedge of a single size may appear around the sides and bottom of the fresh food section.

The two dimensions that characterize a wedge are the door flange "width" and the wedge "depth." If a cabinet does not have a wedge (the flange thickness is the same as the wall thickness, specify a wedge depth of 0. Note that a specified flange width must be less than the minimum wall thickness for the cabinet (side, top, or bottom) since the same wedge dimensions are assumed to apply to all these surfaces. This rule applies even if there is no wedge (wedge depth is 0). In the example problem, the freezer flange width is 5.0 cm, which is slightly less than the freezer bottom wall thickness of 5.3 cm; the fresh food flange width is 3.5 cm, less than the side wall thickness of 4.45 cm.

Refrigerated Volume

The net storage volume is used only in open door heat and mass transfer calculations. However, the values for the internal volume estimated by the program (printed in file CABINET.OUT, shown in Exhibit C) can be compared with the user-specified net storage volumes. Large differences between the calculated and specified net storage volumes probably indicate incorrect specification of the cabinet dimensions.

Compressor Compartment Dimensions

If the bottom cabinet section has a “cut-out” to accommodate the compressor, the dimensions are entered here. An illustration of these dimensions is provided by the Help menu.

Freezer Insulation Thickness

This is the thickness of the insulation, not including the cabinet inner liner or shell thickness. For example, if the outside wall liner (shell) thickness is 0.5 mm, the inner liner thickness is 2.0 mm, and the insulation thickness is 4.9 cm, the total wall thickness is 5.15 cm. High resistance panels, if any, lie within the insulation space.

Insulation Resistivity

The net resistivity of the insulation foam, or of a composite of high resistance panels and foam insulation, is entered here. The total resistance of the insulation is then equal to the product of the insulation thickness and the net resistivity.

ERA provides some help in estimating the resistivity of an insulation composite. This functionality is available using the <F5> key from an insulation resistivity menu.

Mullion

The Help menu describes the requested dimensions for the mullion. Note that the insulation material used in the mullion area may be different from that used elsewhere.

Air and Cabinet Temperatures

The “room air” temperature represents the thermal environment around the cabinet. Temperatures specified for the freezer and fresh food sections represent the desired control setpoints. ERA assumes that, on average, these cabinet temperatures are satisfied by the refrigeration system and its controls. However, if necessary, they will be adjusted later during the cycle analysis, and the cabinet loads will be correspondingly adjusted.

In most instances, the temperature under the cabinet will be somewhat higher than in the room, due to heat given off the compressor shell and heat dumped from the condenser. The value of the temperature of the “air under the cabinet” is used during the calculation of cabinet loads. ERA requires that the user estimate this value; it has no ability to determine a value itself.

The value specified for the "air entering the condenser" is used in the condenser heat exchanger calculations. Normally, this value is somewhat higher than the room temperature, particularly if the condenser is located below the cabinet. If a static condenser is hung from the back of the cabinet, and the cabinet is located in a tight space, the specified value for the "air entering the condenser" should also be higher than the room temperature. A typical value might be 3 - 5 ^{o}C higher than the room temperature.

Door Opening Schedule

A full description of this input is given by the Help menu. To represent a closed door test condition, set the door "#/hr" values to 0.

To represent a manual defrost system, enter 1 on the last line of the menu. *Any data specified later for automatic defrost are ignored if the cabinet is declared here to be manual defrost type.*

Gasket Heat Leaks

"Gasket" heat leaks include the effects of thermal shorting across the cabinet flanges. The data entered in this menu are intended to represent the overall effect of cabinet flange, door flange, and gasket heat transfers. Actual rates of heat transfer are highly specific to the design details, and are not easily determined. Representative values are suggested by the Help menu.

Defrost and Controls Energy Use

Data entered in the category "automatic defrost load" represent the defrost heat only, not including control energy use. Defrost energy shows up as an electrical energy and a thermal load in the freezer section which must be removed by the refrigeration system.

Two other types of electrical power use may be specified: 1) powers that cycle on and off with the compressor, and 2) constant powers. Each of these may be located in one of the two cabinet sections or may be outside the cabinet. The example data (Exhibit A) specify a constant energy use of 0.5 watts in the freezer section, 1 watt in the fresh food section, and 2 watts outside the cabinet. The heat dissipated inside the cabinet (1.5 watts) must be removed by the refrigeration system.

Some Chinese refrigerators, using a dual evaporator cycle system with natural convection evaporators, employ resistance heat in the fresh food section at low room temperatures as a means of extending compressor operation to maintain a low freezer temperature. This additional heat input, used for control purposes, should be specified in this menu. Normally, it is a constant electrical load, located in the fresh food section. At a higher room temperature, the heating element is off; the heat input specified in the menu is zero in this case.

Electric Line Anti-Sweat Heat and Refrigerant Line Anti-Sweat Heat

Anti-sweat heat, for cabinet flange and/or mullion moisture control, may be provided by electrical elements, and/or by refrigeration lines. The user must specify the cycle-average heat input (watts-hr/hr). An estimate of the fraction of the total anti-sweat heat that enters the cabinet as a heat load must also be specified. The example problem defined in Exhibit A (pg. A-3) specifies that liquid line anti-sweat heat (from the condensed refrigerant) is used around the freezer door flange and across the mullion. A total cycle-average heat of 1 watt (0.7 around the door and 0.3 to the mullion) is used. Of this amount, 0.36 watts enters the freezer section as an additional heat load (0.7 x 0.3 + 0.3 x 0.5), and 0.075 watts enters the fresh food section (0.3 x 0.25). Note that only a fraction of the cycle-average anti-sweat heats enter the cabinet (roughly 40%); the remainder is dissipated directly to the room.

Refrigerant line anti-sweat heat is assumed to be either from the high temperature vapor leaving the compressor shell or from lower temperature liquid leaving the condenser. If liquid line heat is specified, the program checks to make sure that the specified cycle-average anti-sweat heat would not require cooling the liquid line to below room temperature.

Penetration Heat Input

Data entered here are intended to represent heat leaks not modeled elsewhere. As an example, “penetration” heat leak could be associated with a through-the-door ice dispenser or cold water dispenser. Calculations for the level of additional heat leak must be carried out manually and then specified as a program data input.

Cycle Definition

The basic type of refrigeration cycle is specified here. Most Chinese and European designs employ the dual evaporator cycle (two evaporators linked in series using a single compressor). Any of the basic cycle concepts may use natural or forced convection evaporators.

Lorenz or Dual Evaporator Cycle Control

Since the Lorenz cycle and dual evaporator cycle both use two evaporators, some additional information is required to describe how the unit is controlled. In an actual device, control is either provided by some active means (such as fan operation, or refrigerant flow diversion during a part of the cycle), or the cabinet temperatures will adjust to the cooling capacity of the individual evaporators.

ERA initially calculates the cabinet loads separately from the operation of the refrigeration system, under the assumption that the user-specified cabinet temperatures can be maintained by the refrigeration cycle. In the case of a Lorenz cycle or dual evaporator cycle using natural convection evaporators, this assumption may not be valid. The five “control” strategies listed in the menu are designed to deal with this situation. A complete discussion of these is given in the Help menu. For most European and Chinese designs, the pertinent control option is 2 or 3 (the cabinet temperature is adjusted to account for the mismatch between the cabinet loads and evaporator capacities). If either of these control strategies is selected, ERA will recalculate the cabinet loads during the cycle analysis part of the simulation and output the adjusted cabinet temperatures.

Refrigerant Codes

Currently, 34 pure refrigerants are represented. A list of these is obtained by pressing the <F4> key from the data menu. These refrigerants may be combined into binary or ternary mixtures if desired. The azeotropic behavior will be determined by the properties of the refrigerants and the mixing coefficients.

Fresh Food Evaporator Data

ERA does not directly model the behavior of a flow control device such as a cap-tube. The user must specify the degree of superheat of the vapor leaving the evaporator (or the interchanger, if desired). If the evaporator is flooded, the outlet quality may be specified as an alternative.

In most instances a reasonable estimate of the superheat at the outlet of the evaporator can be made (typically 2 to 10 ^{o}C). Although ERA does not simulate a flow control device, it can be used to examine the *effects* of changes in the refrigerant outlet state at various conditions. For example, different degrees of superheat may be specified at a given operating condition and the effects on the cycle performance can be studied.

Either free convection or forced convection may be specified for the evaporator. If forced convection occurs (a fan is used), the type of heat exchange that is most applicable is specified (cross-flow or counter-flow). If uncertain about which is most applicable (most evaporators use fairly complicated refrigerant flow paths), select the “cross-flow” option. This will provide the more conservative estimate of performance. In most instances, the calculated performance will not be a strong function of the heat exchanger type.

If a free convection evaporator is used, the information provided concerning heat exchanger type (cross- or counter-flow) is ignored by the program.

Since the fresh food evaporator in the sample problem was defined to be a free convection heat transfer type, only the total heat transfer area and the refrigerant pressure drop are requested in this menu. The heat exchanger area requested is the total effective area for heat transfer with the cabinet air. If a cold-wall evaporator is used, only the area facing the cabinet should be specified; on the other hand, if the evaporator is suspended within the cabinet, offset from a wall, the area of both sides of the evaporator should be specified since both sides will be in heat exchange with the cabinet interior and walls.

“Free convection” evaporators are assumed to be in natural convection and radiative heat exchange with the cabinet. Details are given in the ERA User’s Manual. The “convection” coefficient for a fan-forced heat exchanger includes the radiative component.

Natural Convection Evaporator Location

This menu appears only if the evaporator is assumed to be a natural convection type.

Three options are available to locate the heat exchanger with respect to the cabinet: 1) the heat exchanger is within the cabinet, so that both sides are available for heat transfer, 2) the heat exchanger is on one or more walls of the cabinet, or 3) the heat exchanger appears immediately under the inner plastic liner of the cabinet. In cases 2 and 3, only one side of the heat exchanger "sees" the cabinet; the other side faces the cabinet insulation. If the heat exchanger is located behind the inner liner, the additional thermal resistance of the liner is taken into account.

Specification of option 3 (behind the liner) means that a smaller portion of the insulation is now occupied by the evaporator. In this instance, *the insulation resistivity for this wall will be reported as a smaller value than the resistivities of the walls not containing the heat exchanger* (see Exhibits B and C for examples). This adjustment (which includes both the effects of reduce insulation thickness and the loss of the additional air film resistance over the portion of the wall containing the evaporator) is necessary since the cabinet loads calculation module doesn't know anything about the refrigeration system.

To assist the program in determining the effects of reduced cabinet resistance, the menu requests information about the thickness of the evaporator and its location. The specified values for the fractions of the evaporator located in each cabinet wall must sum to 1.

Freezer Data

Similar information is requested about the design of the freezer evaporator if a dual loop, dual evaporator cycle, or Lorenz cycle is specified. Note that either evaporator may be free convection or forced convection; the two evaporators need not be the same type. For example, a fan-forced heat exchanger could be used in the freezer compartment while a cold-plate natural convection evaporator could be found in the fresh food section.

Condenser Data

The structure and content of the condenser menus are similar to the evaporator menus. As was the case with the evaporator, ERA does not attempt to determine the amount of subcooling achieved by the condenser. To accomplish this, ERA would have to take into account the refrigerant mass inventory around the cycle and account for the refrigerant vapor slip conditions in the condenser. This would result in a far more complex analysis, requiring considerably longer calculation. Hence, the user must provide ERA with an estimate of the subcooling that applies to the particular operating condition. The consequences of uncertainties in the degree of subcooling can be investigated by performing analyses for a range of values.

Comments made earlier for the evaporator, relating to the type of heat transfer and the location of the heat exchanger, apply to the condenser as well.

Note that the condenser may be located under the cabinet (normally in fan-forced heat transfer) or on (or off) the back of the cabinet. If located on the cabinet, as a hot-wall condenser, it is assumed to lie directly under the metal outer shell of the cabinet. An estimate of the effects of shell heat transfer (fin effect) must be made when specifying the effective heat transfer area. If located off the back of the cabinet, both sides of the condenser are normally available for heat exchange. The program requests data for the total effective heat transfer area.

The “air entering condenser” temperature was specified earlier. This may be the same as, or different from, the room air temperature. In most instances, the specified temperature of a natural convection condenser will be the same as the room temperature.

The specified “air entering condenser” temperature is used as the far-stream temperature in the natural convection and radiative exchange calculations (see ERA User’s Manual).

Compressor Model Options

This menu requests information about the compressor type (reciprocating or rotary), the structure of the model to be used to represent the compressor (Compressor Map model, EER and Capacity model, or Efficiency model), and whether a correction for cycling losses should be attempted.

The “Compressor Map” and “EER and Capacity” models may be used for either a reciprocating or rotary compressor; the “Efficiency Model” applies only to a reciprocating type compressor.

In principle, the compressor map model should be the most accurate. However, it requires data for the refrigerant being used, and should cover the full set of operating conditions expected. Most compressor maps developed *do not* meet these conditions. In particular, natural convection evaporators will normally operate at temperatures below the range covered by most maps. In such an instance, ERA must extrapolate the map data to this lower range. Similarly, the condenser often operates at a temperature below that covered by a map. Extrapolation must be used in this case as well. In many cases, the operating conditions are *totally* outside the available map data.

Map data are developed from calorimeter tests with typical error tolerances of 5 - 10%. If the experimental data are not statistically smoothed and only limited operating conditions are covered, the results determined by the extrapolation procedure can be *seriously in error.*

Hence, proper use of map data requires careful characterization of the compressor over a wide range of conditions. Future versions of ERA will provide an optional means for smoothing map data.

The EER and Capacity model allows estimation of the compressor behavior over the range of operating conditions encountered from specification of performance at a single point. It utilizes a simple model developed from detailed measurements obtained with two compressors. Since the data were only for CFC-12 refrigerant, and for a reciprocating compressor, its applicability to other refrigerants or compressor designs is uncertain.

The “Efficiency Model” calculation approach is normally used in conjunction with the EER and Capacity model to estimate the effects of variable speed operation.

A description of each of these approaches is given in the ERA User’s Manual.

Where possible, it is recommended that a compressor map, developed for the particular type of compressor and refrigerant, be utilized, subject to the cautions given above. The EER and Capacity model approach is very convenient where limited performance data are available. However, data listed in manufacturer’s literature for the performance at the rating point are *often* *optimistic* (the listed capacities may be 10 - 15% higher than what is actually achieved, while the EERs may be 5 - 10% too high). Where possible, the refrigerator manufacturer should confirm by test the behavior of the purchased compressor and then use this data during ERA analyses.

<u>Compressor Data</u>

Exhibit A shows the data menu for the EER and Capacity model. The data values entered here apply to the standard ASHRAE conditions (-23.3 evaporator, 54.4 condenser, and 32.2 room environment temperature). To account for differences in the electrical current typically found in the US and other part of the world, the nominal speed of the compressor at the rating point is also specified. A typical speed of 2900 rpm applies with 50 Hz current. The "fractional speed" menu item refers to the ratio of the nominal speed and the actual speed. Without variable- or multi-speed control, this ratio is 1. Variable speed operation can be simulated by specifying a fractional speed that represents the operation.

<u>Interchanger Data</u>

The "interchanger" refers to the thermal coupling between the cap-tube and the vapor line from the evaporator to the compressor. With good bonding, an overall heat transfer effectiveness of 0.8 or higher is normally achieved. The inlet temperature of the vapor to the compressor shell is determined by this heat exchange. However, if the option "-1, unspecified" is used for the first menu item, the inlet vapor temperature is assumed equal to the room temperature.

Exhibit B: CABINET.DAT

Prior to a discussion of this exhibit, certain things must be understood:

- the CABINET.DAT file is an *intermediate* data file, intended as a means of passing user-specified cabinet design data to the cabinet loads calculation module.

- adjustments to the user-specified cabinet data are made by ERA, where required, to account for the indirect effects of the refrigeration cycle design on the cabinet loads.

- the terminology used in the file is not always precise to the specific design situation, since the cabinet loads calculation module does not actually read the descriptive information -- it only pays attention to the numbers contained within the file.

- all the information required by the program are requested in the ERA data menus. No additional data are requested by the intermediate data files, Exhibits B and D. Hence, it is not necessary to understand these intermediate data files to correctly use the program. However, a basic understanding of these files can help identify errors made during the input data phase of the program.

- Because the ERA input module prepares the intermediate data files, the information in these files should never be modified. All specification of cabinet and cycle data should be done through the facilities provided by the ERA input menus.

In most instances, the information contained in the data file mirrors the data specified in the ERA data input menus. Where questions arise, it is recommended that the Help menus provided by ERA be reviewed. However, certain terminology used in this intermediate file is discussed in Table 1 below in order to facilitate understanding of what the data mean and how they are being used:

The cabinet loads calculation module determines the refrigeration loads in each cabinet section based on the data appearing in this intermediate data file. Cycle-dependent loads, such as fan powers, and cycle-dependent electrical energy use, are determined as part of the refrigeration cycle and are used to adjust the calculations completed by the cabinet loads module.

Table 1. Terminology Used in CABINET.DAT

Cabinet Type	Listed as Configuration Type in ERA menu. Values 1 - 6 (see ERA Help menu)
Cabinet Dimensions Liner Properties Mullion Data Freezer Insulation Thickness Fresh Food Insulation thickness Penetrations	Identical to data values requested by ERA input menus. Compare Exhibits A and B.
Refrigerated Volumes	"... Volume used for Heat Exchangers" listed in CABINET.DAT are the sum of the volumes listed in ERA data menus for the evaporator, shelf and food. "Adjusted ... Volume" are the "Net Storage Volume" data values in the ERA menus.
Compressor Cabinet Insulation Thickness	Describes the insulation over the compressor compartment. For the example in Exhibits A and B, this is the insulation thickness in the bottom of the freezer compartment (bottom-mount unit).
Insulation Resistivities	The resistivities of the cabinet walls (top, side, and back) are combined to determine an "average" resistivity that gives the same overall cabinet load as the individual resistivities. The impacts of a hot-wall condenser and a cold-wall evaporator, are taken into account when determining this value. For example, the listed resistivity of 0.5296 for the refrigerator cabinet in Exhibit B is slightly lower than the 0.532 value used in the other parts of the cabinet due to the effect of the cold-wall natural convection evaporator specified for the fresh food section.
Gasket Heat Leaks	The same values specified in the ERA data input, divided by 100.
Door Opening Schedules	Same information as in the ERA data menus, except that the room air temperature is repeated and the information relating to manual or automatic defrost is missing (specified in the CYCLE.DAT data file).

Table 1. Terminology Used in CABINET.DAT

Auxiliary Energy Use	The information listed here is a composite of the user-specified data in the ERA menus for "Defrost and Controls Energy Use" and "Electrical Anti-Sweat Heat." Only the electrical energy that is "constant" is entered here. The data listed in Exhibit B correspond to the constant electrical energy specified in Exhibit A under the "Defrost and Controls Energy Use" since no electrical anti-sweat heat was specified.
Auxiliary Thermal Heat Inputs	Electrical energies in the cabinet will appear as partial or complete heat inputs to the cabinet. This includes electrical anti-sweat heat input, and other heat inputs. In addition, a fraction of refrigerant line anti-sweat heat input to the cabinet outer surfaces will appear as heat inputs to the cabinet which must be removed by the refrigeration system. As noted earlier, the cycle-average fresh food refrigerant line anti-sweat heat input to the fresh food compartment is 0.36 watts, while the refrigerant line heat input to the freezer compartment is 0.075 watts. Other cycle-dependent heat inputs are specified in the CYCLE.DAT intermediate data file.

Exhibit C: CABINET.OUT

This file reports the calculated cabinet loads under the assumptions described earlier: 1) steady-state loads, assuming the refrigeration cycle satisfies the individual cabinet section setpoints loads, 2) cycle-dependent loads are added later, and 3) corrections are made for the influence of a cold-wall evaporator and/or a hot-wall condenser on the resistance of the cabinet walls.

The data specifications, appearing as the first part of the output report, are the same as those passed through the intermediate file. Results of the cabinet loads analysis appear at the end of the data file, beginning with the line "Heat Leak Breakdown." Calculated contributions of the individual cabinet elements to the total cabinet load are given for each cabinet section. Since only an average resistivity data value is input for the cabinet sides and top, the contribution of the individual walls reflects only the dimensions of the walls, rather than differences in individual wall resistivities. Normally there are no differences in individual wall resistivities so this is not a problem. If one wall, however, has a significantly different resistivity than the others (due to the use of a high-resistance panel, for example) this difference will not show up in the table of contributions to the total heat load of the individual walls. However, the total cabinet load will still be correct since the "average" resistivity determined by the ERA data input part of the program, and passed to the cabinet loads module through the CABINET.DAT intermediate data file, takes the design details of the individual walls into account.

The listed cabinet loads will appear later in the final summary output, ERA.OUT, subdivided into 6 categories: "conduction," "door openings," "frosting," "elec defrost," "penetrations," and "heaters & controls." Adjustments to the calculated cabinet loads dur-ing the cycle analysis are also reported in the final summary output file (discussed later).

Note that the mullion load is positive in one section (freezer section) and negative in the other (fresh food section). Since this is entirely an internal load, the sum for the two cabinet sections must be zero. A positive load is heat that must be removed by the refrigeration cycle. Accordingly, the mullion heat transfer removes heat from the fresh food section and adds it to the freezer section.

Exhibit D: CYCLE.DAT

CYCLE.DAT is an intermediate data file, used as input to the cycle analysis module. All of the qualifications stated earlier for the CABINET.DAT intermediate data file hold here as well.

The structure of the file consists of general information about the overall characteristics of the cycle, specific information about the heat exchangers and the compressor, data relating to the effects of a cold-wall evaporator and/or hot-wall condenser on the cabinet loads, and a summary of cabinet loads output. As stated earlier for the CABINET.DAT file, the intermediate data file is primarily intended for interpretation by an ERA analysis module (CYCLE.EXE in this instance), rather than by the program user. The information contained in this file should not be changed by the program user.

Although it is not necessary for the user to understand this file to properly use the program, a brief summary of parts of the file is given in Table 2 below:

Table 2. Terminology Used in CYCLE.DAT

File Name	The file name is listed for later printing on the summary output file (ERA.OUT) as a means of associating a data file with the result.
Refrigerator/Freezer Configuration Moisture Control Lorenz/Dual Evaporator Control Compressor Options Refrigerant Data Interchangers	These data values are taken directly from the input menus and should be unambiguous. The data value entitled "hours shut down for cycle defrost," under the moisture control heading, is not used (it will always be 0).
Condenser Parameters	Data headings used here apply mostly to a fan-forced condenser. The temperature of the air entering the condenser is the same as specified in the ERA menu entitled "Air and Cabinet Temperatures" (see Exhibit A). If a natural convection condenser is specified, the air flow rate value is meaningless (it will be set to 5 liters/sec), since it is not used in the calculation. Individual conductances in the three heat transfer regimes (desuperheating, condensing, and subcooling) are repeated from the ERA input menu; they are listed as 0 when a free convection condenser is specified). The "total heat transfer surface area" is the effective heat transfer area specified in the ERA data menu (see Exhibit A). This is the net area assumed available for heat exchange with the surroundings.
Fresh Food Section	Data are given here for the evaporator used in the fresh food section. The "temperature of the air entering the fresh food evaporator" is the same as the cabinet control point. If the cabinet temperature needs to be adjusted during the cycle calculation of a dual evaporator or Lorenz cycle, ERA will also adjust this value. Data for the air flow rate across

Table 2. Terminology Used in CYCLE.DAT

	the evaporator are ignored if the evaporator is in free convection with the cabinet. The total heat transfer area is the net effective area specified by the user in the ERA data menus (see Exhibit A).
Freezer Section	Interpretation of the data here is similar to that given above. The air flow rate is automatically set to 5 liters/sec if the evaporator is free convection (the data value is not actually used in the cycle analysis in this instance). The freezer area is the same as input in the ERA data menu for the net effective heat transfer area. If the evaporator is fan-forced the overall UA value for the evaporator appears as the next data item; otherwise it is the total effective heat transfer area (the cycle analysis module will calculate the U-value).
In-Wall Evaporator Data	This section of the data file collects the information needed by the cycle analysis program to correct for the effects of a cold-wall evaporator, and/or hot-wall condenser on the cabinet loads. The user need not try to understand these data, since they are strictly for internal purposes. However, a non-zero value means that some adjustment to the cabinet load and the refrigeration load will be made in the section of the cabinet referenced by the data line. For example, the data in Exhibit D designates that the fresh food evaporator is located behind the inner liner, covers 6% of the total wall surface of the fresh food section, and makes a small impact on the net conduction through the wall. Details of how this data are used are tied up in the cycle analysis module.
Cycle Dependent Electrical Energy	The data entered here are taken from the Defrost and Controls Energy Use menu (see Exhibit A). All values are scaled by the duty cycle. They appear directly as electrical energy expenditures not associated with the compressor, and indirectly as additional cabinet loads that must be removed by the refrigeration cycle. For the example problem, all data values are 0.
Cabinet Loads Data	A summary of the output from the cabinet loads analysis is appended to the CYCLE.DAT data file prepared by the ERA input module. A comparison of the data listed here and the output from the cabinet loads analysis (Exhibit C) should clarify the meaning of the individual data lines.

Exhibit E: CYCLE.OUT

CYCLE.OUT presents a detailed report of the behavior of the refrigeration cycle. The output report is designed to be understood by the program user.

The beginning of the report summarizes the type of refrigeration cycle (dual evaporator cycle in the sample problem), the refrigerant mixture (pure CFC-12 in the sample problem), and whether the solution converged. If a convergent solution to the iterative analysis procedure is not found in 40 iterations of the condenser temperature, an output message will appear at the top of the report stating the difference in the estimated condenser temperatures between the last (40th) and previous iteration. A large difference (greater than 0.05 ^{o}C) means that the solution is probably not reliable. Normally this means that an unrealistic data value was specified for some variable representing the refrigeration cycle.

Next, a table of thermodynamic states around the refrigeration cycle is presented. Interpretation of this table is facilitated by referring to the simple line drawing of the cycle given on the second page of output.

Two temperature columns appear: one for the air entering or leaving a heat exchanger, and the other for the refrigerant temperature at the various locations about the cycle. The listing of air temperatures is given assuming counter-flow heat exchange between the air and refrigerant. Locations noted as "... IN" (for example, "COND IN") are given from the refrigerant point of view. Hence, "FREZ IN" means the refrigerant inlet to the freezer (at the outlet of the cap-tube), whereas "FREZ OUT" refers to the temperature of refrigerant leaving the freezer. Because the reporting convention assumes counter-flow heat exchange, the air temperature listed as "FREZ OUT" is actually the temperature of the air *entering* the heat exchanger (the cabinet air temperature). If the heat exchanger is the free convection type, the outlet air temperature listed as "... IN" is meaningless.

The remaining columns in the table are P (pressure), H (enthalpy), V (specific volume), S (entropy), XL (liquid mass fraction), XV (vapor mass fraction), and XQ (vapor quality).

The cycle performance summary for the capacities and compressor power can be determined from the tabular data provided and the refrigerant mass flow given later. For example, the fresh food evaporator capacity is (163.2 - 116.0) x 2.085 = 98.5 kJ/hr (27.4 watts).

If the EER-Capacity compressor model is used, the cycle output file lists some internal parameters used to determine the compressor power and refrigerant temperature at the outlet of the shell. The efficiencies are broken into an "isentropic compression efficiency" and the "motor-pump efficiency." The isentropic compression efficiency is always greater than one because of the definition of this term (see ERA User's Manual) and the internal cooling of the refrigerant leaving the pump. However, the overall efficiency from the standpoint of the electrical energy input to the motor is the product of these two values (1.39 x 0.362 = 0.50, which is a more typical overall compressor efficiency). The five data values listed as being determined by the EER model ("COMPRESSOR EER MODEL") could be used as input to the compressor efficiency model, for example to study the effects of changes in clearance volume or the effects of improved the motor efficiency.

The next set of data refer to the calculated performance of the evaporator(s) and condenser. Effectiveness values are not defined for free convection heat exchangers. If fan-forced heat exchangers are modeled, the reported effectiveness values are determined using the standard definition of heat exchanger effectiveness. Data listed for the subcooled and superheated fractions refer to the fractional areas of the heat exchangers in these heat transfer regimes (for example, 1.4 % of the condenser area is in the subcooling regime, and 3.7% of the condenser area is in the superheat regime).

Finally, calculated compressor performance data are output. These represent conditions estimated by ERA for the particular compressor in the refrigerator. They are listed to enable a reasonableness check on the model.

Note that detailed compressor performance data are not output when a compressor map is used. In this instance, the program determines the compressor behavior directly from the map data, with a correction made for the temperature of the suction gas entering the compressor shell (the map data apply only to an entering gas temperature of 32.2 ^{o}C).

As noted earlier, a simple line drawing of the cycle completes the cycle output report. Data shown in the diagram include the evaporator capacities (in units of kJ/hr) and the overall UA values for each heat exchanger (in units of W/^{o}C).

Exhibit F: ERA.OUT

This is the final summary output file. It summarizes the cabinet loads (adjusted where necessary to account for the behavior of the cycle) and the cycle energy use. The file lists the type of refrigerator/freezer cabinet design, and the refrigerant cycle used.

Both the specified (desired) cabinet set points, and the actual cabinet temperatures, are listed. In the particular example, an adjustment to the freezer temperature was required because natural convection evaporators were used in both cabinet sections. Cabinet loads listed as “conduction” are the sum of the following data items appearing in the cabinet loads output file (Exhibit C): right wall, left wall, back wall, front (door), top wall, bottom, mullion, wedge, and gasket. Note that the data listed for these items in the fresh food section sum exactly to the value listed in the summary output for the fresh food conduction load. The same data listed for the freezer section sum to 23.96, a value slightly lower than the conduction load listed in ERA.OUT. This difference arises from the adjustment made to the cabinet load during the cycle analysis because of the need to match the cabinet loads to the evaporator capacities (the freezer cabinet temperature was adjusted to -22.2 ^{o}C to achieve this balance).

Reported cabinet load inputs from the heater controls and refrigerant line anti-sweat heat are unambiguous and need no additional explanation (see Exhibits A, B and C). The data value listed as “IN_WALL EVAP” is the additional cabinet load resulting from placing the cold evaporator surface against the inner wall. Since the inside surface of the cabinet insulation will be at the refrigerant temperature while the compressor is running, rather than near the cabinet air temperature, the heat transfer through this portion of the insulation is increased. It represents an additional refrigeration load, which is listed under this category. Similar data would have appeared if a hot-wall condenser were used. Data appearing under the category “IN_MULLION EVAP” refer to the effect of a cold plate evaporator used over a portion (of all) of the mullion. Because this refers to an internal heat exchange, the sum of the two values in the freezer and fresh food sections will always equal 0.

The next block of data summarizes the relationship between the refrigeration capacity and the cabinet loads. “Evaporator Load” is the sum of the two evaporator capacities (in watts). Net capacity is the portion of the capacity available for refrigeration of the cabinet. In most instances this will be the same as the “evaporator load.” However, if both a cold-wall evaporator and hot-wall condenser are used, and they face one another across the same wall(s), a portion of the refrigeration evaporator capacity will be lost by the heat exchange between the evaporator and condenser across the insulation. The value listed as “net capacity” is the remaining evaporator capacity available to cool the cabinet.

The mass flow is repeated from the CYCLE.OUT file. COP values are listed both for steady state operation (assuming no cycle losses) and cyclic operation (cycling losses were not considered in the sample problem -- see Exhibit A, page A-6). The duty cycle is the ratio of the cabinet loads and the refrigerant cycle capacities (37.378 / 81.946 = 0.456). Note that the duty cycles for the individual cabinet sections are the same, since the freezer temperature was adjusted to achieve a balance between the loads and the individual evaporator capacities.

The final block of data summarizes the daily energy consumption. These are taken directly from the CYCLE.OUT compressor power and the specified heater and control energies. Fan and defrost energy do not appear for the specific problem in Exhibit A.

Evaluation of ERA with University of Maryland Refrigerator/Freezer Test Data

Background

Under funding from the EPA (RTP), the University of Maryland carried out experiments to determine the effects of room ambient temperature and entering suction gas temperature on the performance of compressors. Calorimeter tests were performed for a Panasonic DA51L88RA reciprocating compressor (0.311 cu-in displacement) at environment temperatures ranging from 60 F to 110 F. Energy consumption measurements were also carried out for a 1990 design GE, two-door refrigerator/freezer (R/F) using the same compressor.

All measurements were performed by Michael Feng, under the direction of Dr. Reinhard Radermacher. Access to the experimental data was provided to A .D. Little, under authorization received by Dr. Radermacher from the EPA.

On the basis of these data, three type of studies have been carried out:

- Refinement of a procedure for “smoothing” calorimeter data to reduce potential problems associated with extrapolation outside of a compressor map temperature range;

- Evaluation of the effects of the canister suction port vapor temperature on compressor performance; and

- Evaluation of the ability of the ERA program to simulate the effects of room temperature on the R/F energy consumption.

Compressor Map Smoothing and Estimation of Behavior with Alternate Refrigerant

Development of a compressor map smoothing procedure began during a previous work assignment. The results of this effort showed that most compressor map data could be correlated against pressure-ratio-dependent isentropic and volumetric efficiencies, based on the compressor canister input conditions (see report for WA2-49, September, 1994).

Tables 1-3, on the following page, summarize the results of the calorimeter tests. Measurements were made at 60 F, 90 F and 110 F ambient conditions. The suction gas temperature at the entrance to the canister was equal to the ambient temperature.

Table 1. Compressor Calorimeter Data: 90 F Environment

Evap Temp (F)	Cond Temp (F)	Power (W)	Capacity (Btu/hr)	EER	Isentropic Efficiency	Volumetric Efficiency
-20	130	118.3	564.6	4.77	0.574	0.744
-20	120	115.8	582.6	5.03	0.572	0.767
-20	110	113.6	603.2	5.31	0.568	0.794
-10	130	135.9	741.2	5.45	0.587	0.774
-10	120	132.4	778.3	5.88	0.595	0.812
-10	110	127.7	795.6	6.23	0.590	0.830
0	130	154.4	963.0	6.24	0.598	0.806
0	120	148.9	997.9	6.70	0.600	0.834
0	110	142.6	1034.8	7.26	0.604	0.865

Table 2. Compressor Calorimeter Data: 110 F Environment

Evap Temp (F)	Cond Temp (F)	Power (W)	Capacity (Btu/hr)	EER	Isentropic Efficiency	Volumetric Efficiency
-20	130	116.6	521.4	4.47	0.576	0.734
-20	120	114.3	547.0	4.78	0.583	0.771
-10	130	134.5	710.3	5.28	0.609	0.793
-10	120	130.4	716.6	5.50	0.596	0.801

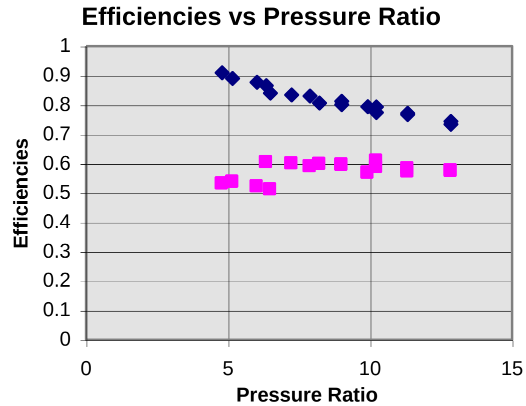
Table 3. Compressor Calorimeter Data: 60 F Environment

Evap Temp (F)	Cond Temp (F)	Power (W)	Capacity (Btu/hr)	EER	Isentropic Efficiency	Volumetric Efficiency
-20	80	106.9	705.5	6.60	0.511	0.840
-20	75	104.6	736.7	7.04	0.521	0.877
-10	80	117.3	943.9	8.05	0.537	0.890
-10	75	115.1	963.9	8.37	0.531	0.909

Measurements of the compressor power and compressor capacity followed standard compressor calorimeter procedures. Capacity was defined as the enthalpy difference between the vapor and liquid states at the environment temperature (60, 90, or 110 F). EER (efficiency) data were derived from the capacity and power measurements.

Using the refrigerant property routines embodied in the ERA program (based on the NIST REFPROP program), isentropic and volumetric efficiency values were derived. These are shown in Tables 1-3 as well. A rotational speed of 3550 rpm was assumed when calculating the volumetric efficiency.

The efficiencies were correlated against the pressure ratios, determined from the evaporator and condenser temperatures. Results for the tests at the three ambient conditions are shown in the plot at the right. The four lowest data values for isentropic efficiency were obtained at the 60 F ambient conditions, where the condenser temperatures were also much lower.



As anticipated, very strong correlations with pressure ratio appear. These can be fitted to linear relations and used to create "smoothed" maps.

The compressor map algorithm employed in the ERA program utilizes interpolation methods to determine the mass flow and compressor power, at each step of the solution procedure, from the condenser and evaporator temperatures. The procedure works reasonably well for compressor maps that span the full range of conditions under simulation. However, in many instances (e.g., when simulating a European or Asian refrigerator using natural convection evaporators and condensers), the evaporator and/or condenser temperature(s) may lie outside of the measured data. In such an instance, estimation of the compressor mass flow and power requires data extrapolation, a process which can result in large errors.

A compressor map smoothing program, REMAP, was developed to smooth the compressor calorimeter data and to derive maps that cover a wide range of operating conditions. The basic process involves determination of linear relationships between isentropic efficiency and pressure ratio and between volumetric efficiency and pressure ratio. Two sets of data inputs are required: 1) the refrigerant codes, and 2) the compressor map to be smoothed. For consistency, the refrigerant code definitions are the same as required by the ERA program. The first code refers to the refrigerant used during the calorimeter tests; the second code refers to the refrigerant for which the new map is to be derived. Normally these are the same. However, REMAP provides a basis for estimating the first-order behavior of a compressor with a substitute refrigerant.

A sample compressor calorimeter-based map and its "smoothed" and extended counterpart are shown below. Limited measurements taken with CFC-12 were extended over a wider temperature range (70 to 130 F condenser, -40 to 10 F evaporator). The smoothed compressor map (named NEWMAP.TAB) is in a form that can be directly used by ERA. A more complete description of REMAP is provided in Appendix A.

SAMPLE CALORIMETER-BASED MAP

Default Data:

4.5 MASS FLOW AT STANDARD RATING POINT (LB/HR OR KG/HR)
3 NUMBER OF DATA POINTS ALONG EVAPORATING TEMPERATURE AXIS
3 NUMBER OF DATA POINTS ALONG CONDENSING TEMPERATURE AXIS
1 COMPRESSOR TYPE (1 - RECIPROCATING; 2 - ROTARY)
1 UNITS FOR CAPACITY, TEMPERATURE DATA, AND MASS FLOW (1 - BTU/HR, DEG F, LB/HR; 2 - KCAL/HR, DEG C, KG/HR) POWER DATA MUST BE IN WATTS

CAPACITY DATA, BTU/HR

COND TEMP, F	EVAPORATING TEMPERATURE, F		
	-20	-10	0
110	603.2	795.6	1034.8
120	582.6	778.3	997.9
130	564.6	741.2	963.0

COMPRESSOR POWER, WATTS

COND TEMP, F	EVAPORATING TEMPERATURE, F		
	-20	-10	0
110	113.6	127.7	142.6
120	115.8	132.4	148.9
130	118.3	135.9	154.4

SMOOTHED MAP CREATED BY REMAP

Default Data

12.2 MASS FLOW AT STANDARD RATING POINT (LB/HR OR KG/HR)
6 NUMBER OF DATA POINTS ALONG EVAPORATING TEMPERATURE AXIS
7 NUMBER OF DATA POINTS ALONG CONDENSING TEMPERATURE AXIS
1 COMPRESSOR TYPE (1 - RECIPROCATING; 2 - ROTARY)
1 UNITS FOR CAPACITY, TEMPERATURE DATA, AND MASS FLOW (1 - BTU/HR, DEG F, LB/HR; 2 - KCAL/HR, DEG C, KG/HR) POWER DATA MUST BE IN WATTS

CAPACITY DATA, BTU/HR

COND TEMP, F	EVAPORATING TEMPERATURE, F					
	-40	-30	-20	-10	0	10
70	370.4	500.5	659.3	851.1	1080.8	1353.5
80	358.1	488.2	647.0	838.8	1068.5	1341.2
90	344.3	474.4	633.1	824.9	1054.6	1327.2
100	328.9	458.9	617.7	809.4	1039.0	1311.6
110	311.8	441.8	600.4	792.1	1021.6	1294.1
120	292.9	422.8	581.4	772.9	1002.3	1274.6
130	272.1	401.9	560.3	751.8	980.9	1253.0

COMPRESSOR POWER, WATTS

COND TEMP, F	EVAPORATING TEMPERATURE, F					
	-40	-30	-20	-10	0	10
70	65.5	75.6	84.8	92.3	97.7	100.1
80	69.1	80.9	91.9	101.7	109.5	114.7
90	72.2	85.7	98.5	110.4	120.6	128.6
100	74.6	89.8	104.6	118.5	131.1	141.8
110	76.4	93.3	110.0	126.0	141.0	154.2
120	77.3	96.1	114.7	132.9	150.2	166.0
130	77.3	98.1	118.7	139.0	158.6	177.0

Effect of Vapor Temperature at the Canister Inlet Port on Compressor Behavior

The strong correlation of isentropic and volumetric efficiencies with pressure ratio provides a basis of estimating the effects of suction temperature on compressor behavior. Correction of the capacity and compressor power determined from the compressor map can be made by applying the corresponding isentropic and volumetric efficiencies to the actual inlet condition. The calculation proceeds according to the following steps:

- Step 1: read the compressor map for the 90 F ambient condition and determine the refrigerant mass flow and compressor power at the evaporator and condenser temperatures;

- Step 2: adjust the mass flow rate, accounting for the vapor density at the entering temperature;

- Step 3: determine the isentropic efficiency corresponding to the mass flow at 90 F entering vapor temperature; and

- Step 4: assuming that the isentropic efficiency is a function of pressure ratio only, apply it at the actual vapor entering temperature to determine the compressor power.

Subroutine COMPCALL, of the ERACYC.EXE cycle analysis module in ERA, was modified to implement the steps outlined above. The revised ERA program is designated Version 1.2D.

Comparison with University of Maryland Test Data

Careful measurements of refrigerator/freezer behavior were carried out by the University of Maryland at four ambient conditions: 60 F, 77 F, 92 F, and 110 F. Measured data values included: local (ambient) temperature around the refrigerator, cabinet section temperatures, total power, compressor on-time, evaporator and condenser temperatures at the entrances, mid-points, and exits of the heat exchangers, compressor can inlet temperature, and compressor can outlet temperature. Data, logged at 30 second intervals, were analyzed to determine cycle average power and end-of-cycle heat exchanger temperatures.

Table 1 summarizes the test data at the four ambient conditions.

ERA analyses were undertaken, using two compressor models: the revised map model (Table 2) and the capacity and EER model (Table 3). The "smoothed" map was used for the four map model studies. Adjustments to the map data, to account for the compressor can entering conditions, were made by ERA as outlined in the four steps above. Because the adjustments were made internally, based on the map-derived isentropic and volumetric efficiencies, a single map can be used for all conditions.

CFC-11 blown foam was used in the 1990 model refrigerator tested. The changes in foam resistivity with temperature were taken into account in the ERA model studies. Table 4 summarizes the variation in foam conductivity with temperature. An average of the ambient and cabinet section temperatures was used to estimate the variation in foam conductivity for each test condition. For reference, the foam resistivity in the 1990 model GE R/F was assumed to be 9.2 Btu-in/ft2-hr-F at 64 F average temperature.

Comparison between Tables 2 and 3 reveals that the compressor map model and the capacity-EER compressor model yield nearly the same performance predictions. Hence, in most situations, the capacity-EER model will be adequate for initial studies.

Table 1. Refrigerator Test Data

Ambient Temperature (F)	60	77	92	110
Fresh Food Section Temperature (F)	38.4	38.5	41.9	39.4
Freezer Section Temperature (F)	-3.9	-1.5	-1.5	-1.9
Energy Consumption (kWh/day)	0.80	1.31	1.77	3.09
Compressor Duty cycle (%)	26	40	53	90
End of Cycle Evaporator Temperature (F)	-27	-20	-18	-15
End of Cycle Condenser Temperature (F)	76	95	108	124
Compressor Can Inlet Temperature (F)	57	72	85	99
Compressor Can Outlet Temperature (F)	113	136	155	177

Table 2. ERA Outputs: Compressor Map Model

Ambient Temperature (F)	60	77	92	110
Fresh Food Section Temperature (F)	38.4	38.5	41.9	39.4
Freezer Section Temperature (F)	-3.9	-1.5	-1.5	-1.9
Energy Consumption (kWh/day)	0.71	1.21	1.72	2.70
Compressor Duty cycle (%)	26	39	53	78
End of Cycle Evaporator Temperature (F)	-27	-23	-22	-20
End of Cycle Condenser Temperature (F)	89	108	119	135
Compressor Can Inlet Temperature (F)	38	65	79	97
Compressor Can Outlet Temperature (F)	118	153	175	206

Table 3. ERA Outputs: Capacity and EER Compressor Model

Ambient Temperature (F)	60	77	92	110
Fresh Food Section Temperature (F)	38.4	38.5	41.9	39.4
Freezer Section Temperature (F)	-3.9	-1.5	-1.5	-1.9
Energy Consumption (kWh/day)	0.76	1.26	1.76	2.67
Compressor Duty cycle (%)	26	39	53	76
End of Cycle Evaporator Temperature (F)	-27	-23	-22	-21
End of Cycle Condenser Temperature (F)	89	108	119	135
Compressor Can Inlet Temperature (F)	38	65	79	97
Compressor Can Outlet Temperature (F)	120	149	166	192

Table 4. Effects of Temperature on R-11 Foam Resistivity

Temperature	Conductivity (Btu-in/ft2-hr-F)
15	0.122
30	0.107
45	0.113
60	0.118
75	0.126

Source: Conversation with Jeff Haworth, Admiral company, Sept. 14, 1995.

The predicted and measured total energies and compressor duty cycles are within a few percent over the ambient temperature range of 60 F to 90 F. The difference between measured and predicted energy consumption is nearly 13% at 110 F ambient. However, the measured energy value appears higher than expected at this temperature. These trends are illustrated in Figure 1.

Surprisingly, the capacity-EER compressor model yields closer agreement with the measured data than the compressor map model. The agreements between predicted and measured duty cycles are nearly exact at each condition, other than the 110 ambient temperature. Very close agreements between the measured and predicted evaporator temperatures were also obtained at the lower three ambient conditions.

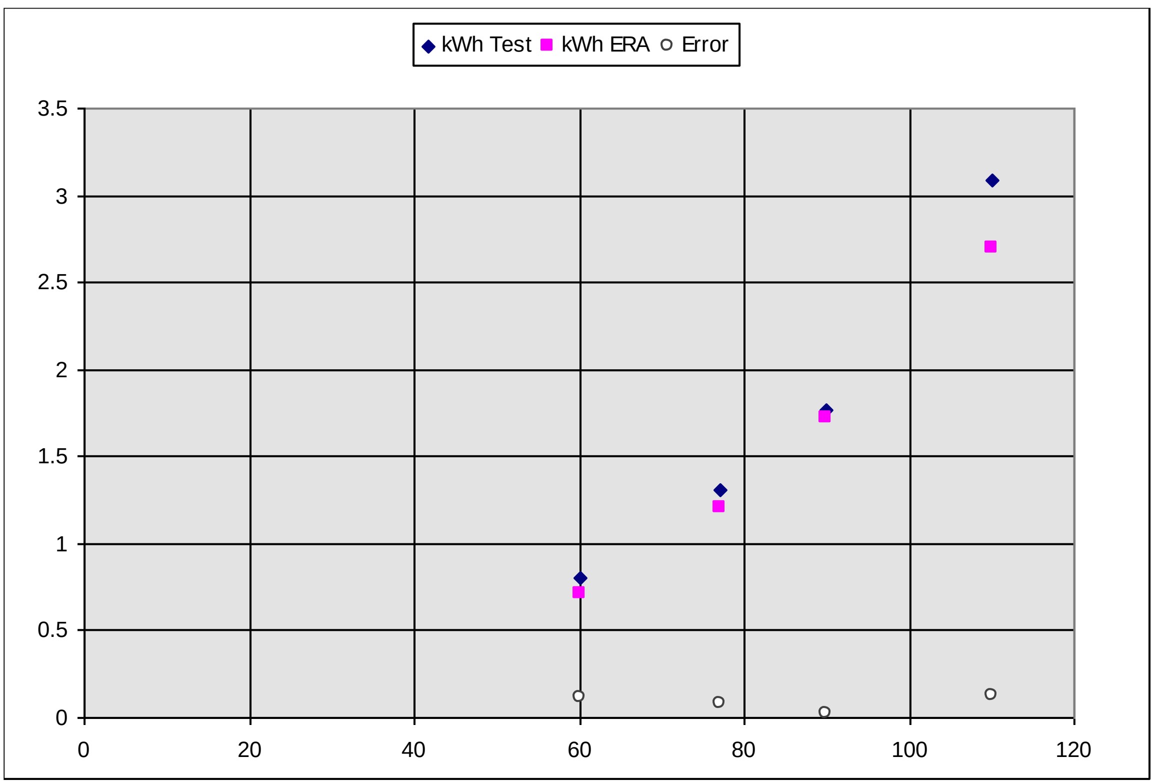


Figure 1. Test Results and ERA Outputs for Daily Energy Consumption vs. Ambient Temperature

Significant differences occur between predicted and measured condenser and compressor discharge temperatures. These differences point to a model deficiency relating to the determination of compressor shell heat loss. Currently, a simple correlation is used to predict can loss as a fraction of the compressor electrical power. Typical can loss values are in the range of 65% to 85%.

A large difference in modeled and measured performance occurs at the 110 F ambient condition. As illustrated in Figure 1, the jump in energy consumption from the 90 F ambient to the 110 F ambient is larger than what would be expected. This difference is not currently understood.

Conclusions

Compressor behavior appears to be adequately represented by linear relationships between pressure ratio and isentropic efficiency and between pressure ratio and volumetric efficiency. These relationships provide a basis for smoothing compressor maps measured over a small temperature range. A smoothing program, called REMAP.EXE, has been developed for this purpose. A description of REMAP is given in the attached Appendix.

Compressor behavior depends on the suction gas temperature as well as the evaporator and condenser temperatures. The isentropic efficiency and volumetric efficiency correlations with pressure ratio provide a basis for representing the effects of suction gas temperature. This can be done internally by the program without the requirement for compressor maps at different suction gas temperatures.

With properly adjusted foam resistivities, ERA provides an adequate means to predict the effects of ambient temperature on refrigerator performance.

The compressor map model and the capacity and EER model give nearly the same performance predictions. An advantage of the compressor map model, combined with REMAP, is the ability to adequately account for the effects of alternate refrigerants on refrigerator performance.

REMAP Model Documentation

REMAP is designed to serve three purposes:

- smooth compressor calorimeter test data to more confidently permit data extrapolation;

- extend a compressor map to cover a broader range of evaporator and condenser pressures; and

- provide a first-order estimation of the compressor behavior with an alternate refrigerant.

Extension, and smoothing, of a compressor map is particularly important when attempting to apply a map outside of the conditions covered by the calorimeter tests. Such a situation frequently occurs in the simulation of a refrigerator/freezer using a natural convection evaporator.

Algorithm

The basis for the algorithms used by REMAP is a representation of each point in the calorimeter-based map by isentropic and volumetric efficiencies based on the inlet temperature and pressure at the compressor canister inlet. REMAP calculates values for the two efficiencies at each data point of the original map and then correlates them against the condenser-evaporator pressure ratio. Following calculation of a least-squares fit to a linear relationship in terms of the pressure ratio, a new map is constructed over an evaporator temperature range of -40 to +10 F and a condenser temperature range of 70 to 130 F.

The same approach is adopted when constructing a new map for an alternate refrigerant. Construction of the new map is based on the thermodynamic properties of the alternate refrigerant.

Data Files

REMAP expects two data files:

- REMAP.DAT, which lists the refrigerant codes for the existing and new maps. The refrigerant codes will be the same for both maps if REMAP is being used only to smooth and extend an existing map; and

- OLDMAP.TAB, which contains the map to be processed. OLDMAP.TAB is assumed to be in the format required by ERA.

The output from REMAP is a reconstructed compressor map file, NEWMAP.TAB, which is also in the format required by ERA. DOS COPY or RENAME commands can be used to copy the compressor map files to different file names.

Distribution Code

REMAP is distributed as a companion program to ERA. It is accompanied by sample input files, REMAP.DAT and OLDMAP.TAB, and a sample output file, NEWMAP.TAB.

Although not required by ERA, it is highly recommended that any maps used with ERA be processed by REMAP first. This need be done only once, since the output file (NEWMAP.TAB) should be copied into a file name (with extension .TAB) for use with ERA