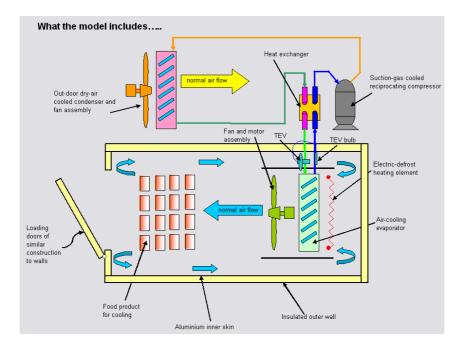
VCR: An interactive refrigeration system simulator

What VCR is

VCR stands for vapour compression refrigerator. The software calculates the behaviour of a refrigerated cold space, for example a cold-store, when it is subjected to variations in outdoor ambient conditions and the loading of (usually hot) food stuff and so on. The calculations VVCR does are based on scientifically based models of a system's components, including the cold space itself and right down to refrigerator pipe work. You design your system model using various input data screens and then run a simulation to see how much energy it uses and carbon it produces, amongst other things. The calculations are non-steady state and so time-dependent effects, such as the variation in outdoor dry bulb temperature, are accounted for. If you imagine a flight simulator software that allows you to design your own aircraft, well! VCR is a bit like that.



A schematic view of the basic system model is shown in Figure 1.

Figure 1: Schematic of refrigerated model cold space, from VCR-HELP

At the moment VCR is restricted to an air-air refrigerator powered by up to six staged hermetic or semi-hermetic reciprocating compressors and a thermostatic expansion valve. The model also assumes electrically heated evaporator defrost system and the compressor(s) is(are) controlled by thermostat.

Run-time screen functions

A Run-time screen, shown below in Figure 2, is provided through which all design screens and other functions are accessed. If necessary you can navigate through the system design using the *WIZARD* function or the *HELP* facility, both accessed by the click of a button in the toolbar in the Run-time screen. A typical *HELP* screen is shown in Figure 3.

Because VCR is a time-dependent simulator it is necessary for you to tell it between what times of the day you want to simulate your system's operation. These are known as 'model' start and end-times. These are set by you in the Run-time screen, which when the simulation is running, displays the current 'model-time'.

In addition and to setting both model start and end-times you will need to fix the model-time when the food stuff is loaded into the cold-space. This product loading time is just another of a number of selections you must make to run the simulation. The screens are easy to follow, but if you get stuck the *WIZARD* will help you through.

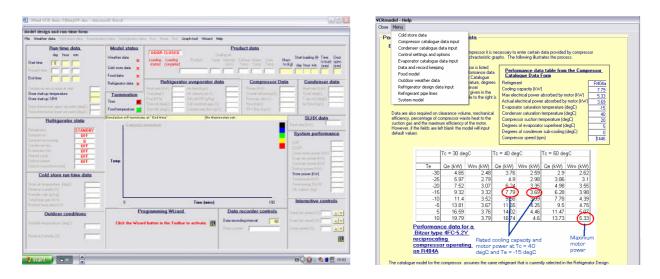


Figure 3: A typical HELP screen showing how to use the compressor catalogue data form

Figure 2: The run-time screen

Design screen functions

Cold-store design: Easy to navigate design data input screens, exampled by those shown for the cold-store in Figure 4a and the Food-product in Figure 4b, are accessed through the Runtime screen for both the cold-store unit and refrigerator system. Both are provided with default data settings and guidance on the setting of design values through the *HELP* function. Data text boxes are also provided with 'hover' functions. When the cursor is placed over a data text box the range in which entry data should lie is automatically displayed for the users information. Also, in many cases, if inappropriate or out of range data are entered in text boxes then default values are automatically inserted by the software before the simulation can be run.

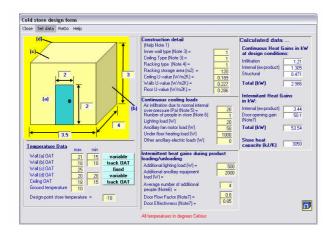


Figure 4(a): Cold store design screen

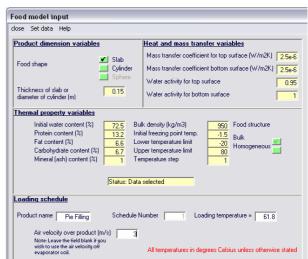


Figure 4(b): Food design screen

Refrigerator design: The

refrigerator design screen, shown in Figure 5, allows users to specify design-point data either by default or individually or in any combinations, for the evaporator, condenser, compressor, fans and motors, thermostatic expansion valve, refrigerant pipelines and refrigerant fluid, as shown in Figure 6. If catalogue data are available for the compressor or evaporator or condenser (or for any combination of these) then special easy to follow data input screens are provided for each. These are accessed also by navigating through the toolbar, as shown in Figure 7. Figure 8 and 9

	tefrigerant = R404a Help		
Evaporator data	<u>Compressor data</u>	<u>1 Line data</u>	Dry-air cooled condenser
Performance data	Design speed (rpm)	1445 Suction line	Performance data
Dry-air cooling duty (kW)	10 Speed percentage	100 Length (m)	3 Air-on temperature (degC)
Air-on diy-bulb temp (degC)	10 Clearance volume (%)	4 Diameter (mm)	28.58 Air-on face velocity (m/s)
Air-on relative humidity (%)	50 Polyropic efficiency (%)	85 Bends (-)	4 Refrigerant saturation temp (degC)
Refrigerant saturation temp (degC)	5 Mechanical efficiency [%]	95 Insulation thickness (mm)	5 Heat exchange effectiveness (·)
Heat exchange Effectiveness (-)	0.7 Maximum motor efficiency (%)	95 Liquid line	Degrees of subcooling (degC)
Degrees of superheat (K) Refigerant-side pressure loss (K)	5 Max load factor of motor (-) Heat absorbed by suction gas [%]	1.6 Length (m) 90 Diameter (mm)	3 Air-side pressure loss (kPa) 0 15 00 Refrigerant-side pressure loss (K)
Ainside pressure loss (KPa)		90 Diameter (mm) Bends (-)	
Air-on face velocity (m/s)	0.15	Insulation thickness (mm)	
an data	2 <u>TEV settings</u>	Hot-gas line	5 Max aerodynamic efficiency (%) % of max pressure rise (%)
an Gata Max aerodynamic efficiency (%)	External equalization assur	ned - Length (m)	
% of max pressure rise [%]	60 Click to change	Diameter (mm)	
% of max volume flow (%)	70 40 Capacity factor (-) 1		22 23 Motor load factor (-) 1 4 Max motor efficiency (%)
% of max fan speed (%)	100 Valve response time (s) 10		5 Physical data
Motor load factor (-)	125		Dry mass (kg)
Max motor efficiency (%)		porator data: Condenser Data	Dry volume (litre)
hvsical data		power (kW) 0.39 Fan power (kW)	0.41
		ow [litre/sec] 760 Air flow [litre/sec]	
		presssure (kPa) 527 Heat rate (kW)	to dector me neur excitanget
Fins per metre (fpm)		t pressure (kPa) 510 Inlet pressure (kPa)	1848 Effectiveness 0.7
Dry mass of evaporator (kg)	un Indet executes (Ir.P.s.) 500	0.444	
Dry volume of evaporator (litre)	10 Outlat marging (kPa) 1040 Syst	tem COP 3.25 al power (kW) 3.8	Receiver fitted?
High and low tempe	rature cut-out settings	Evaporator fan speed	Compressor control
nd high temperature cutout (degC) 67	Evap low temperature cutout (degC) .40		
1.5		Manual Option Variable Speed Fractio	nal Manual Option Variable Speed Stager
Timer and thermostatic set-up	Electric Defrost control		
hermostat ON Thermostat set on evaporate	Defrost heater power (kW)	Automatic linear control selected as a function of air-on temperature	Staged compressors set
lick to tum OFF click to change	Fan speed during defrost cycle	as a function or all on temperature	Control schedule:
CIECK to change	as percent of max speed (%) 100	Control schedule:	Number of compressors = 6 🔺 🔻
per set-point temperature (degC)	-6 Option 1: set	Minimum percent speed 80	Number running: 2 3 4 5
	14 Timed to come on every 240 mins	Upper range temp. (degC) 30	
	10 For 20 mins	Lower range temp. (degC) 26	Set-point temp (degC) -15 -10 -5 0
	6 Option2 click to select	Control temperature:	
aporator fan start delay (sec)	10 Initiation ATD (deoC)		ON/OFF restart delay timer setting (min) = 3
aporator fan ON when compressor is switched OF		Product Evaporator Evaporator	
by thermostat- click to change	Restart delay timer setting (mins)	surface air-off air-on	Control temperature = Evaporator saturation temperature

Figure 5: Refrigerator design input screen

show the catalogue data entry screen for the compressor and evaporator.

esign Form			
ce Set data ReDo data	Refrigerant =	Help	
Evaporator data <u>s data</u> Ig duty (kW) Ib temp (degC) s humidity (%) aturation temp (degC)	R404a R407c R717 R134a R22	Speed Cleara Polyroj	Compress n speed (rpm) percentage nce volume (%) pic efficiency (%) anical efficiency (%)

Figure 6: Refrigerant fluid selector accessed through the toolbar

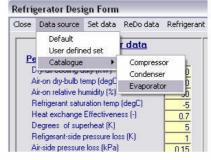


Figure 7: Showing how the catalogue input data functions are accessed through the tool bar

Ilose Refrigerant	Data Set data ReD	o Help
Compressor perf	Default data Previous data	
Refrigerant	4.0	R404a
Cooling capacity (I May electrical pow	<w) ier absorbed by motor (k'</w) 	7.79
	ower absorbed by motor	
	ion temperature (degC)	-15
I S S S S S S S S S S S S S S S S S S S	ion temperature (degC)	40
Compressor suctio	n temperature (degC)	20
	rator superheat (degC)	5
	nser sub-cooling (degC)	0
Compressor speed	(rpm)	1446
Optional/assume	ed compressor data	
Clearance volume	(%)	4
Mechanical efficie	ncy (%)	95
Percent of motor h	eat to suction gas (%)	90
Maximum motor eff	ficiency (%)	95
Output compress	or data	
Isentropic efficience	w (%)	78.7
Polytropic efficience		80.7
Motor efficiency (2	%)	92.9
		and the second design of the s
Motor max load fai	otor (-)	1.44

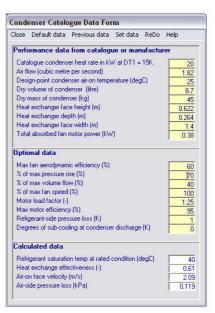


Figure 8: Showing the Compressor catalogue data form

Figure 9: Showing the condenser catalogue data form

The refrigerator design screen also allows users to choose between from a range of system control options, including:

- Six system thermostat control options
- Three evaporator fan speed control options (manual, automatic variable and automatic fractional)
- Three compressor control selections, (manual speed control, automatic speed control based on temperature and staged, with up to six compressor stages available)
- Two automatic electric defrost control options,(set either on by time and on by ATD)
- High and Low Temperature cut-out controls
- Compressor and fan motor start-up delay controls.

In addition user can alter the time-constant and cooling capacity of the thermostatic expansion value to simulate the effects of both a badly positioned sensing bulb and an over or undersized valve, resulting in valve hunting and evaporator flooding.

Outdoor ambient conditions: VCR software allows users to select between fixed or simulated variable outdoor temperature and relative humidity. The fixed outdoor weather data function requires you to enter only the desired ambient temperature and relative humidity. The screen for this function is shown in Figure 10. Although the inputs and outputs of the fixed weather data function are intended for use by the VCR simulator, the calculated output shown in Figure 10 provides useful psychrometric data for moist air.

For the variable weather data option you need select both the location of the plant (from a list of seven major UK mainland cities) and the month of the year for which you wish to simulate its operation. The variable weather screen is shown in Figure 11. With the variable outdoor weather option set, the model simulates the diurnal variation in ambient temperature and humidity ratio. This simulation is based on published whether data for average monthly peak temperatures in seven UK cities taken over 30 years.

Ilose Set data Help	
Set fixed ambient co	nditions here
Enter required outdoor drybul and relative humidity	b air temperature
Dry-bulb air temperature =	20
Relative humidity (%) =	50
Wet-bulb temperature =	13.856
Dew-point temperature =	9.28
Moisture content (g/kg) =	7.26
Enthalpy (kJ/kg) =	38.545
Density (kg/m3) =	1.199
Water vapour pressure (bar) =	0.011694

	data F	teDo Help				
Location		Month		Calculate Data		
Manchester 👻)	Show Graph			
Cambridge Manchester London Glasgow Sheffield Bristol Bedford		une	Annual Variation Min/Max Dry-bulb Temperatures for Manchester			
Hour	Tdb	Twb		T(max)	T(min)	
0	11.25	9.27	Jan	6.9	1.5	
2	10.23	8.77	Feb	7.3	1.6	
4	10.23	8.77	Mar	9.5	3.1	
6	11.25	9.27	Apr	11.9	4.5	
8	13.02	10.11	May	15.7	7.4	
10	15.07	11.05	Jun	18	10.1	
12	16.84	11.85	Jul	20.3	12.3	
14	17.86	12.3	Aug	20.1	12.1	
16	17.86	12.3	Sep	17.1	10	
18	16.84	11.85	Oct	13.5	7.2	
20	15.07	11.05	Nov	9.6	3.9	
22	13.02	10.11	Dec	7,6	2.3	
14 16 18 20 22	17.86 17.86 16.84 15.07 13.02 at design nax) dev	12.3 12.3 11.85 11.05 10.11 day relative (Aug Sep Oct Nov Dec	20.1 17.1 13.5 9.6 7.6	12 10 7.2 3.9 2.3	

Figure 10: Fixed ambient weather data screen

Figure 11: Variable ambient weather data screen

A graph of wet and dry-bulb temperature for the selected day is provided through the variable ambient weather data screen. An example is shown in Figure 12

In the Run-time screen there is a facility which allows all the necessary system design data, which has been entered during a session, to be saved for future use in a user named file. There is a library function provided for saved input data files so that, conversely, if project data has been previously saved it can easily found and reload into the VCR model and RUN without further inputs being required.

The Run-time screen allows model output data to be saved to a user named Excel file for later analysis and assistance in preparing project reports using a 'report generation function' which saves necessary information to a WORD.DOC. Figure 13 shows the data and report saving options available through the Run-time screen toolbar

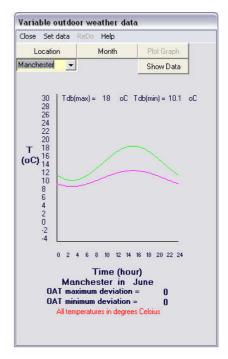


Figure 12: Showing the variation in wet and dry bulb temperature for a June day in Manchester

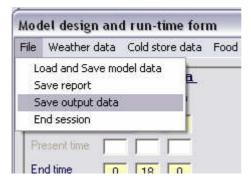


Figure 13: Showing data and report saving options

Run-time

Once all the input data needed to run the simulator have been set and the RUN button has been clicked, the Run-time screen acts as both a control and instrument panels. It displays in 'model' time the instantaneous values of output data, such as evaporator cooling effect, ambient temperature, energy consumption and power values as well as performance data such as instantaneous COP and COSP values. Continuously updated graphical output of selected operating parameters is also provided through the Run-time screen. Depending upon the configuration of the compressor and evaporator fan controls (discussed below), the Run-time screen provides a facility to manually vary compressor and fan speeds in order to allow a user to investigate the effects of varying these important part-load parameters.

Bun-time data day from nim Stat line 0 0 7 Pasent line 0 0 7 Stat line 0	Model status Volable weather data Cold stare data: V Food data	Loading Loading Product Ten started completed	Product Cooling al In Velocity Surfac In Velocity Surfac In Velocity Surfac In Velocity Surfac	ce Mean Eare M a Tanap Tanap M	1955 Start loading (3) Time Door to load open n Rig) day hour nin (nin) (nin) (50 0 8 0 5 3
Enditive 0 18 0 Condense airon temp al stat 15.5 Store clark up temperature 10 Store clark up ter point (degC) 6 Store themositik upper cert point (degC) 6 Store themositik upper cert point (degC) 6	Religeator data: Teamination Time Food temperature	Befrigerator evaporator d Heatrate (MV) 45 Ak few (kg/k) Tast (de)C1 19 5 Ak relocity (n/k) Post (NPa) 21 Of coll FR (kg/k) Planol (de)C1 10 4 Coll FR (kg/k) Takroth (de)C1 12 4 Coll FR (kg/k) Takroth (de)C1 12 4 Coll FR (kg/k) Takroth (de)C1 13 5 Condensate flow(p)	1.15 0.95 1.25 1.8	Compressor De Power (KW) Overall efficiency(V) Pessure ratio H Row (kg/s) TEV flow (kg/s)	Condenser deta 34 Hestrate (kW) 82 0.7 T(set)(degC) 40 6 T (set)(degC) 10 0.052 Aa flow (lig/h) 1
Refinitionator state Perspector RUNNING Concessor uning Condensor uning Condensor for DN DN Decoder for Decoder for DM Decoder for DM DM Decoder for Decoder for DFF Decoder for DFF Decoder for Decoder for DFF Decoder for DFF Decoder for	Tenp	e at ' fod tive' (Theme Inner dare	antat en ovap air-en	a Goraș	SLHX date Heat rate (Kr) 24 Switzen performanize CDF 13 COSP 13 Evop fran power (Kr) 3 Evop fran power (Kr) Confan power (Kr) 0 Defroit power (Kr) 0
Cold store run-time data Store ar temperature (depC) 40.4 Relative hundry (N) 100 Hundry (sto) (pNg) 1.553 Total teat gain (WV) 0.9 Poduct teat rate (kW) 0.9	-29	Tine (nins)		104	Stare power (kW) Total power (kW) Total cover (kWh) UK Cabon (kg) Interactive controls
Outdoor conditions Dry bub terrorsawe I degCi 17.5 Reserve investor (C) 71.6	Introduction This Wized provideo reference for program	an introductory guide and guick ming the model. It is supported by a Help sed through the tool bar. When teady, the	Data reco Data recording Data counter	order controls resvat 60	Condran speed (%) TOO
		Open: Show me where			

Figure 14: Run-time screen during run-time

Further information

Further information and copies of VCR software are available from ianweames@aol.com