VCR model - AN INTERACTIVE REFRIGERATION SYSTEM SIMULATOR SOFTWARE

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Introduction ….

AIM:

- To describe a new software tool known as the VCR model for simulating the energy performance of whole refrigeration systems and to indicate how the software might be used to aid design and reduce energy consumption in food refrigeration

BACKGROUND:

- The writing of the VCR model formed part of a larger DEFRA funded project entitled 'Fostering the development of technologies and practices to reduce energy inputs into the refrigeration of food'. Details of the project can be found at:http://www.grimsby.ac.uk/what-we-offer/DEFRA-Energy

The VCR model front-screen

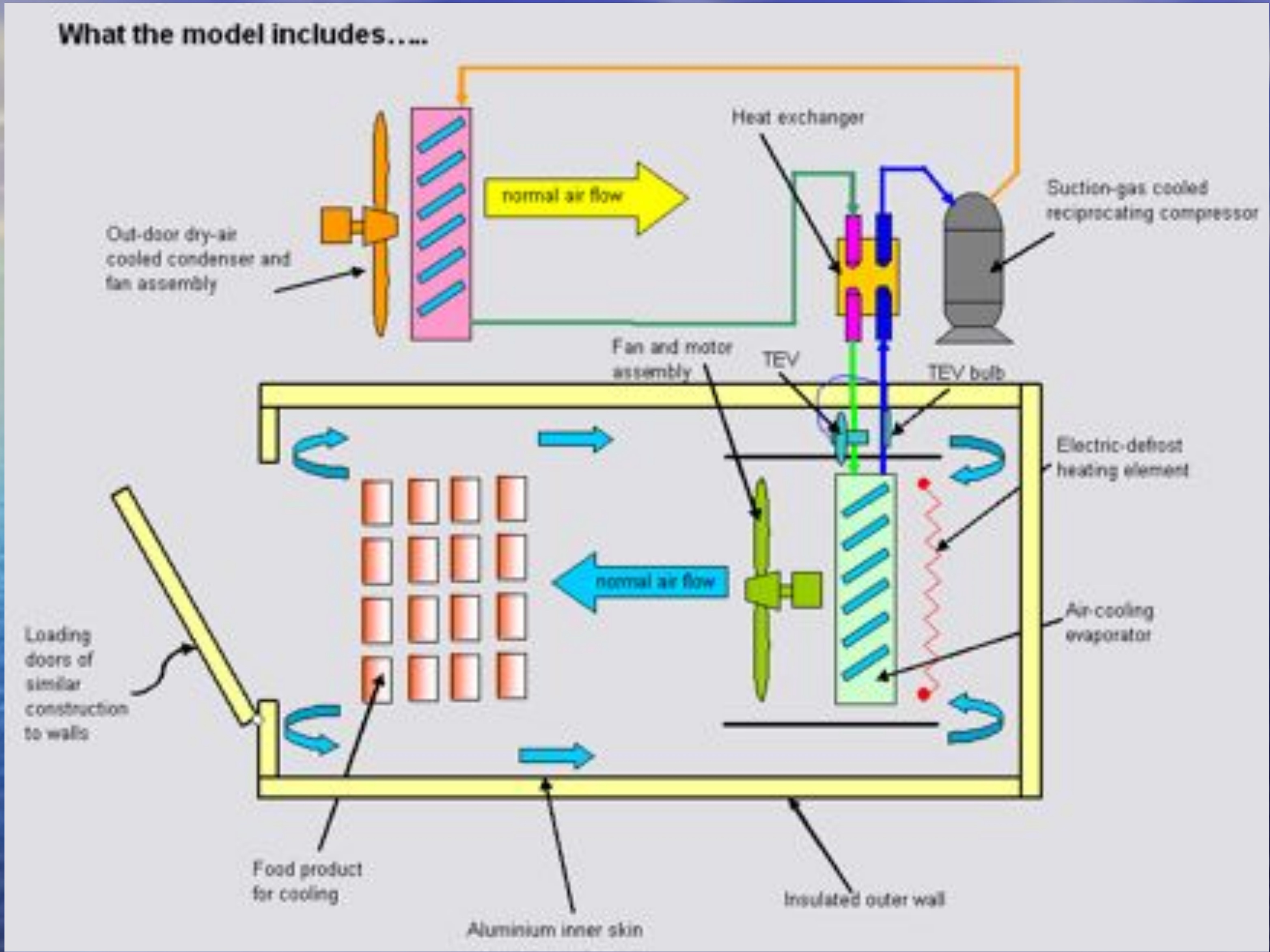
What the VCR model is and does…

- The VCR (vapour compression refrigeration) model is interactive software which simulates the transient and steady state operation of refrigeration systems powered by air-air vapour compression refrigerators.

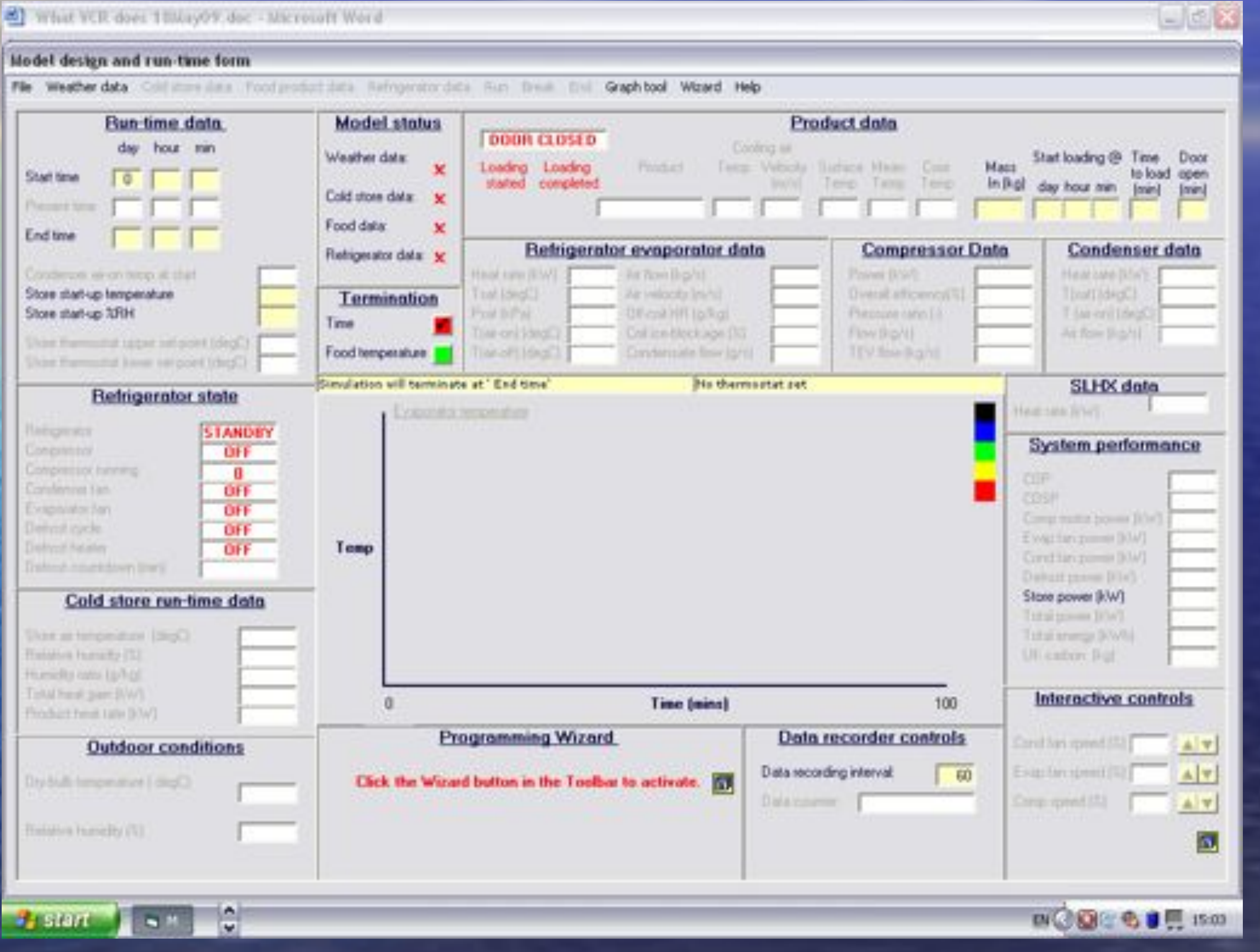
- The software provides a flexible, interactive, dynamic refrigeration system simulator which combines theoretical, semi-empiric and empiric component models for a whole refrigeration system, including the cooled space and its environment, the refrigerator and the food product.

- The software is able to model the transient response of whole refrigeration systems to time dependent variations in inputs, such as outdoor ambient temperature, and provide information on energy consumption and CO2 emissions over a selected period of operation.

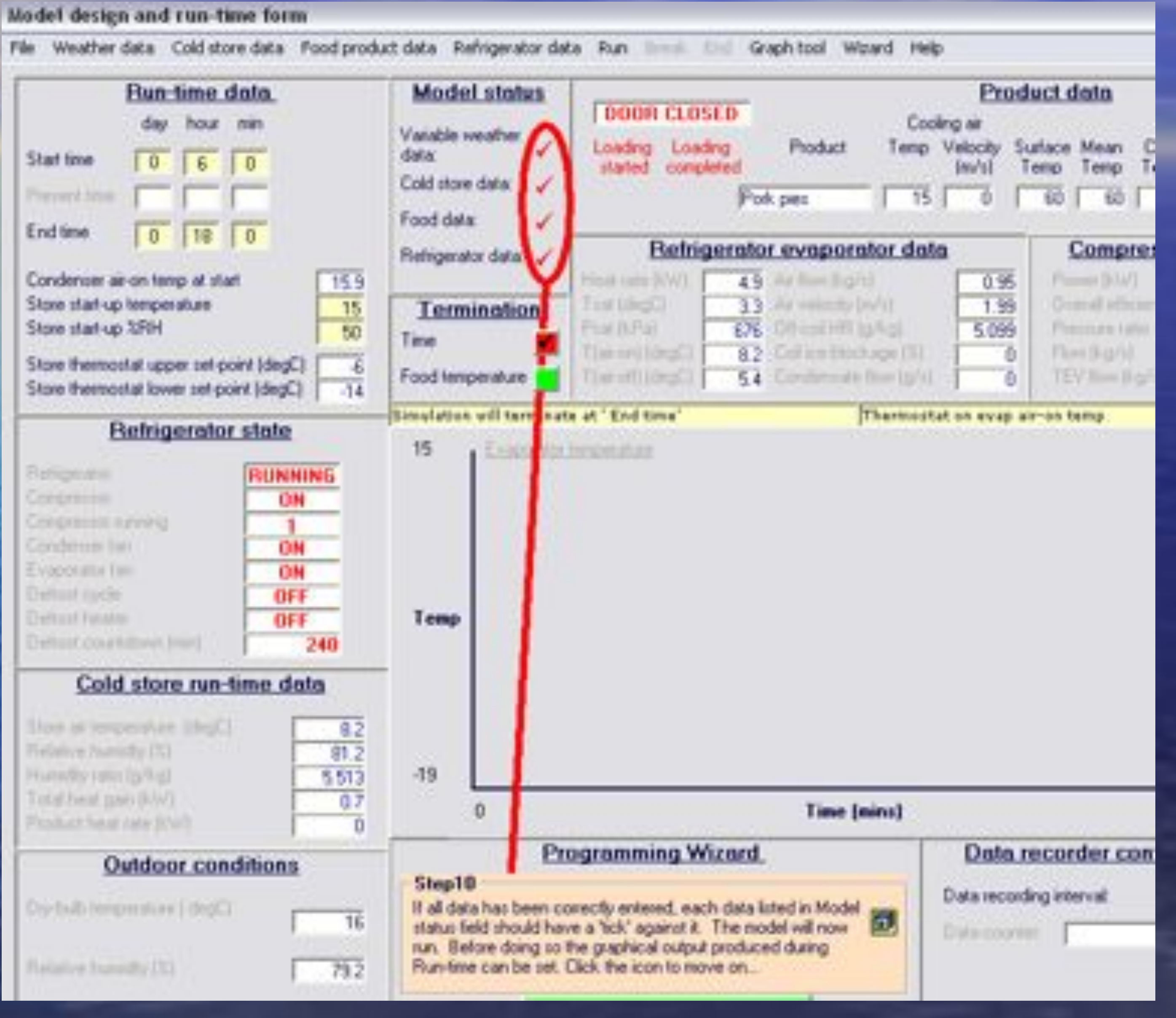
- The software model takes account of: Ambient weather, cold space design, food-product, refrigerator design and so on…


What the model includes…..
Heat exchanger
normal air flow
Suction-gas cooled reciprocating compressor
Out-door dry-air cooled condenser and fan assembly
Fan and motor assembly
TEV
TEV bulb
Electric-defrost heating element
normal air flow
Air-cooling evaporator
Loading doors of similar construction to walls
Food product for cooling
Insulated outer wall
Aluminium inner skin

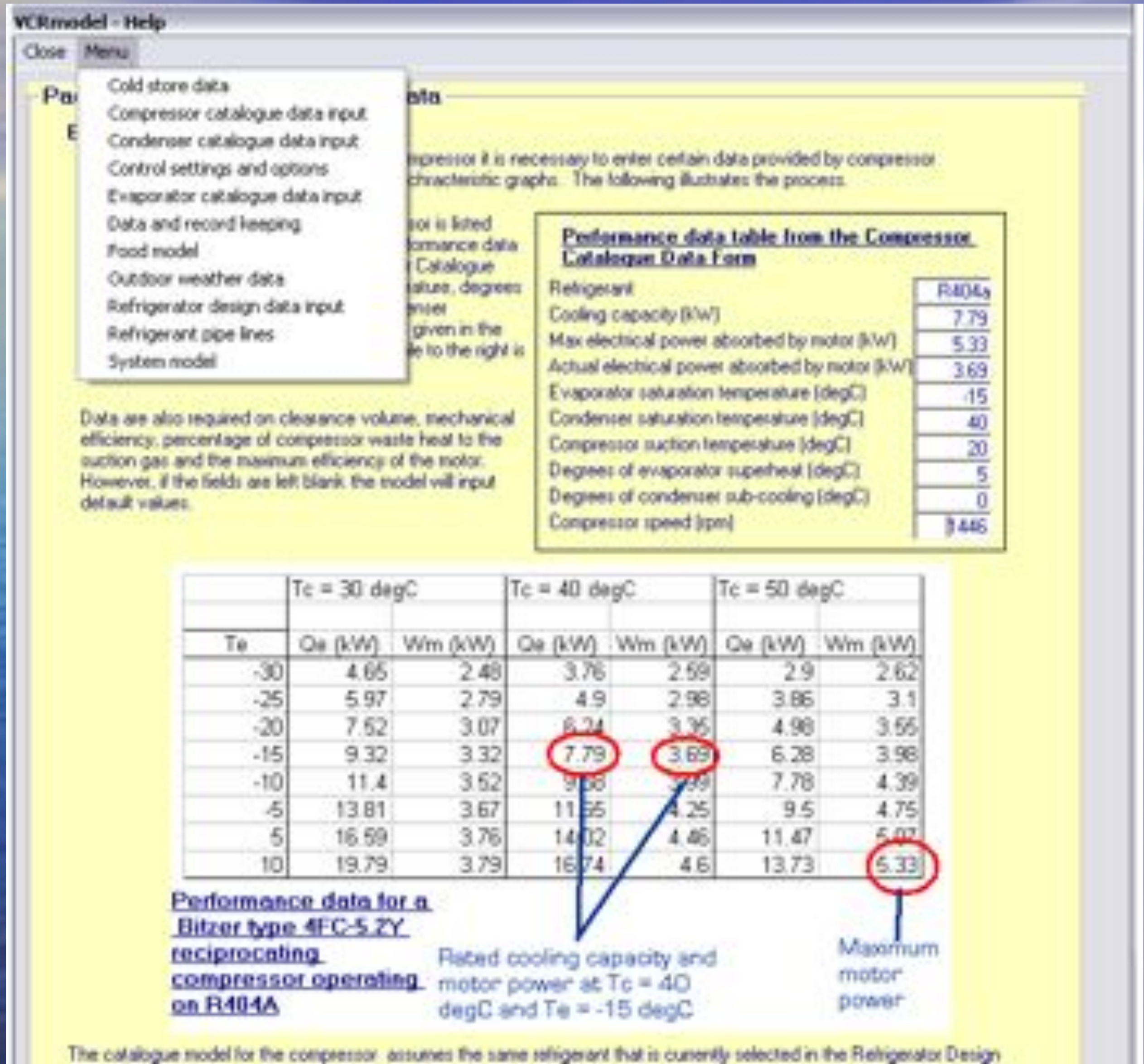
Run-time screen



Design wizard



Help pages



VCRmodel - Help

Close Menu

Cold store data
Compressor catalogue data input
Condenser catalogue data input
Control settings and options
Evaporator catalogue data input
Data and record keeping
Food model
Outdoor weather data
Refrigerator design data input
Refrigerant pipe lines
System model

...pressor it is necessary to enter certain data provided by compressor ...characteristic graphs. The following illustrates the process.

...sor is listed ...formance data ...Catalogue ...ature, degrees ...enser ...given in the ...e to the right is

Data are also required on clearance volume, mechanical efficiency, percentage of compressor waste heat to the suction gas and the maximum efficiency of the motor. However, if the fields are left blank the model will input default values.

Performance data table from the Compressor Catalogue Data Form

Refrigerant	R404a
Cooling capacity (kW)	7.79
Max electrical power absorbed by motor (kW)	5.33
Actual electrical power absorbed by motor (kW)	3.69
Evaporator saturation temperature (degC)	-15
Condenser saturation temperature (degC)	40
Compressor suction temperature (degC)	20
Degrees of evaporator superheat (degC)	5
Degrees of condenser sub-cooling (degC)	0
Compressor speed (rpm)	1446

	Tc = 30 degC		Tc = 40 degC		Tc = 50 degC	
Te	Qe (kW)	Wm (kW)	Qe (kW)	Wm (kW)	Qe (kW)	Wm (kW)
-30	4.65	2.48	3.76	2.59	2.9	2.62
-25	5.97	2.79	4.9	2.98	3.86	3.1
-20	7.52	3.07	6.24	3.36	4.98	3.55
-15	9.32	3.32	7.79	3.69	6.28	3.98
-10	11.4	3.52	[illegible]	[illegible]	7.78	4.39
-5	13.81	3.67	[illegible]	4.25	9.5	4.75
5	16.59	3.76	14.02	4.46	11.47	5.07
10	19.79	3.79	16.74	4.6	13.73	5.33

Performance data for a Bitzer type 4FC-5.2Y reciprocating compressor operating on R404A

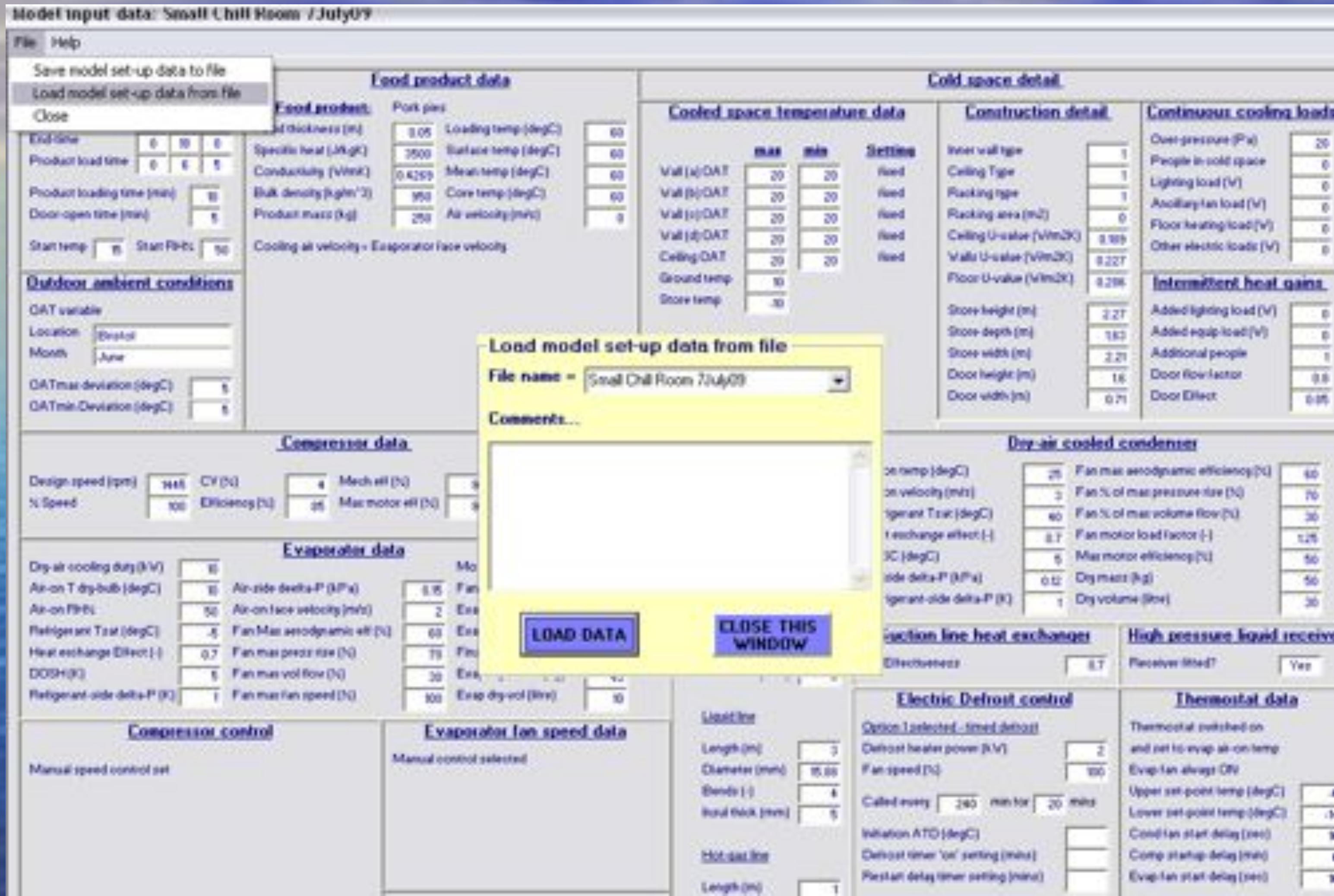
Rated cooling capacity and motor power at Tc = 40 degC and Te = -15 degC

Maximum motor power

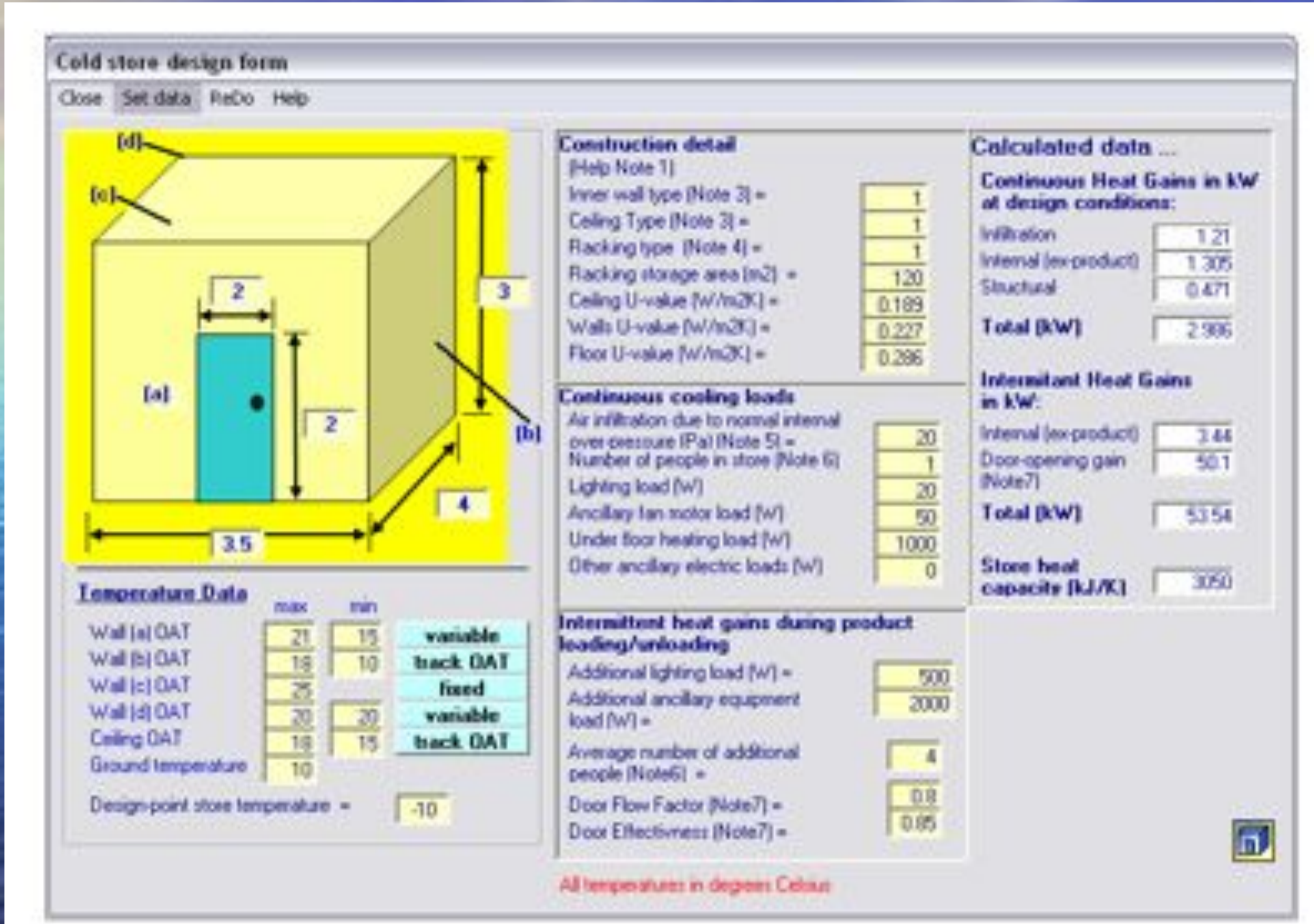
The catalogue model for the compressor assumes the same refrigerant that is currently selected in the Refrigerator Design

Getting started - using default data…

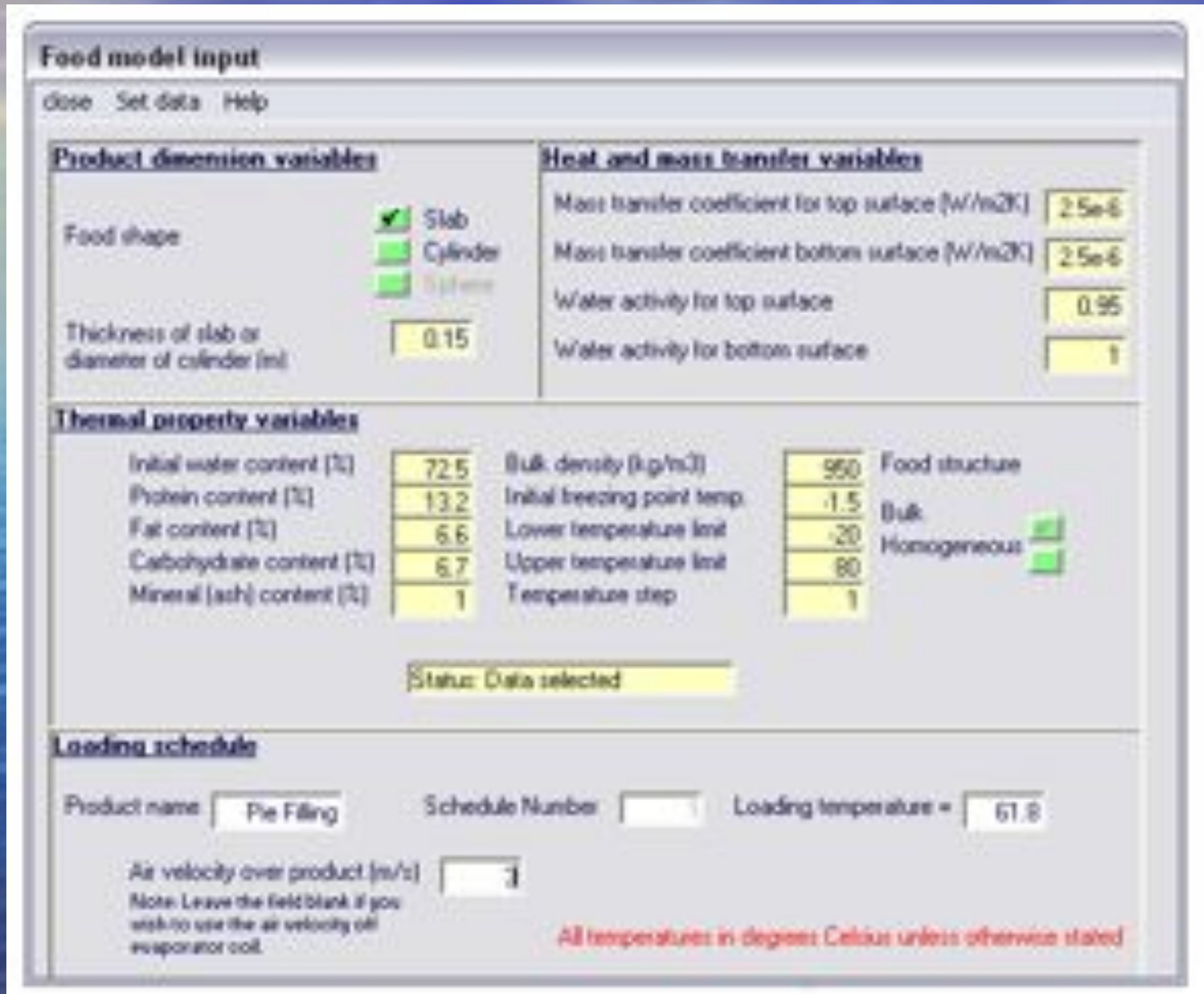
Default data



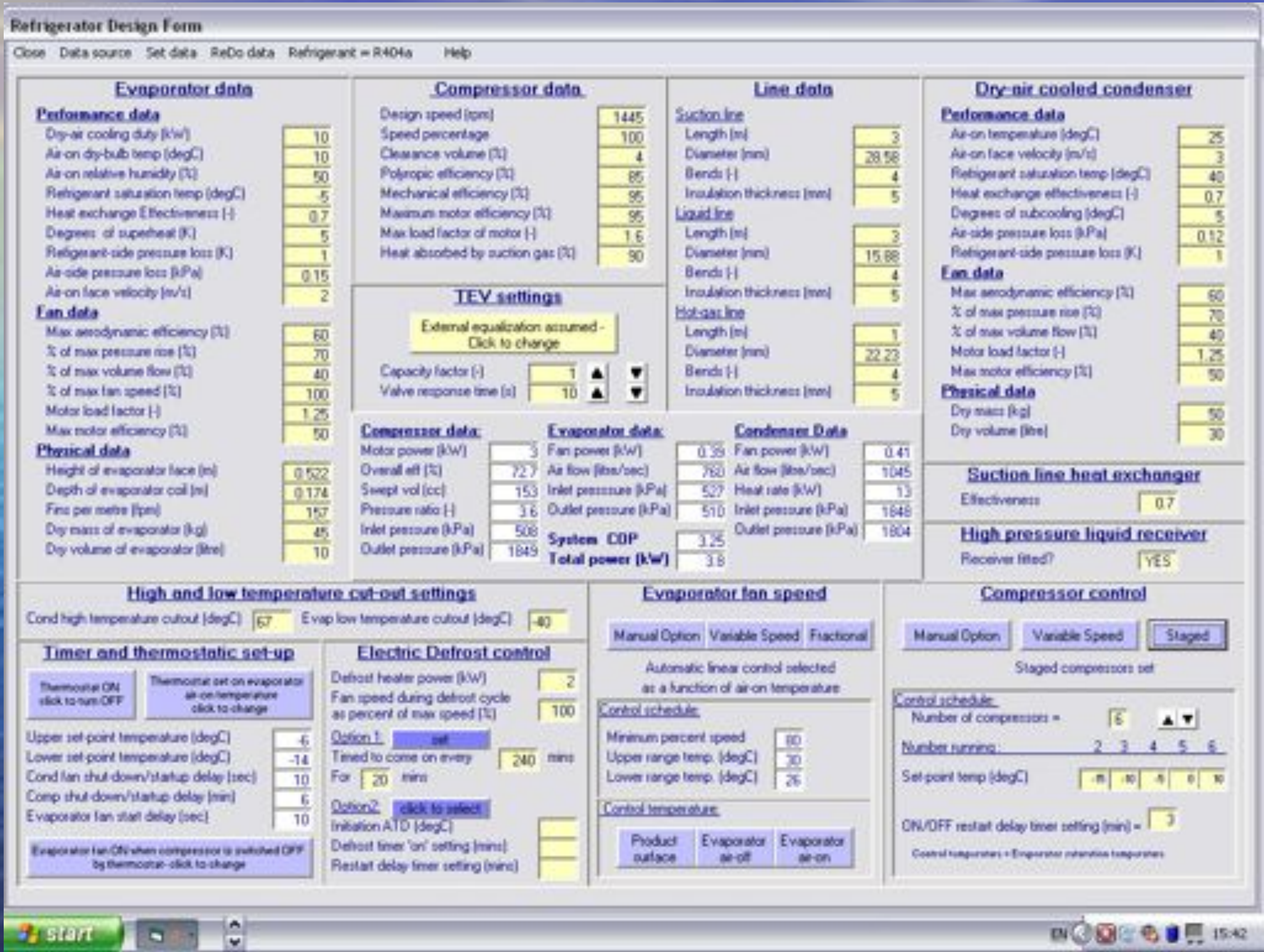
Cold store design…



Food design


Food model input
close Set data Help
Product dimension variables
Food shape
Slab
Cylinder
Thickness of slab or diameter of cylinder (m)
0.15
Heat and mass transfer variables
Mass transfer coefficient for top surface (W/m2K)
2.5e-6
Mass transfer coefficient bottom surface (W/m2K)
2.5e-6
Water activity for top surface
0.95
Water activity for bottom surface
1
Thermal property variables
Initial water content (%)
72.5
Protein content (%)
13.2
Fat content (%)
6.6
Carbohydrate content (%)
6.7
Mineral (ash) content (%)
1
Bulk density (kg/m3)
950
Initial freezing point temp
-1.5
Lower temperature limit
-20
Upper temperature limit
80
Temperature step
1
Food structure
Bulk
Homogeneous
Status: Data selected
Loading schedule
Product name
Pie Filling
Schedule Number
Loading temperature =
61.8
Air velocity over product (m/s)
1
Note: Leave the field blank if you wish to use the air velocity off evaporator coil.
All temperatures in degrees Celsius unless otherwise stated

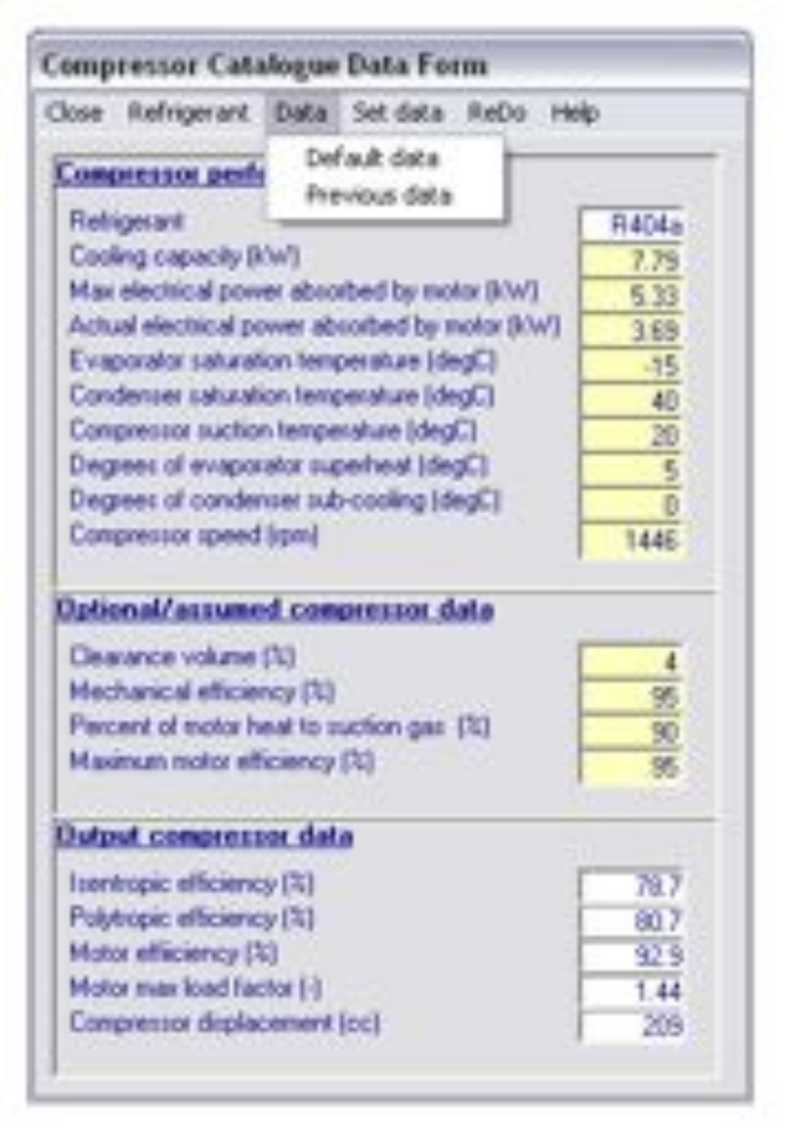
Refrigerator design



Select a refrigerant

Select to use default, user-defined or catalogue data

Example catalogue data input forms



Compressor Catalogue Data Form

Close | Refrigerant | Data | Set data | ReDo | Help

Default data
Previous data

Compressor perf

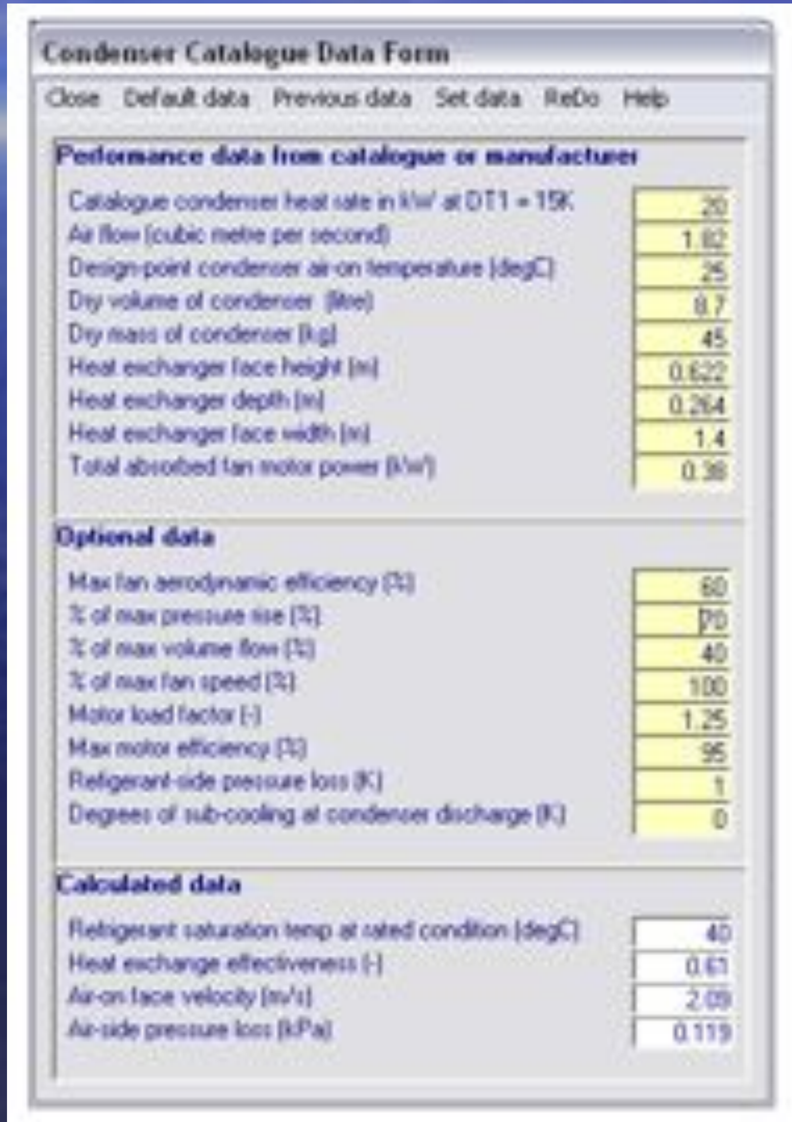
Refrigerant	R404a
Cooling capacity (kW)	7.79
Max electrical power absorbed by motor (kW)	5.33
Actual electrical power absorbed by motor (kW)	3.69
Evaporator saturation temperature (degC)	-15
Condenser saturation temperature (degC)	40
Compressor suction temperature (degC)	20
Degrees of evaporator superheat (degC)	5
Degrees of condenser sub-cooling (degC)	0
Compressor speed (rpm)	1446

Optional/assumed compressor data

Clearance volume (%)	4
Mechanical efficiency (%)	95
Percent of motor heat to suction gas (%)	90
Maximum motor efficiency (%)	95

Output compressor data

Isentropic efficiency (%)	78.7
Polytropic efficiency (%)	80.7
Motor efficiency (%)	92.9
Motor max load factor (-)	1.44
Compressor displacement (cc)	209



Condenser Catalogue Data Form

Close | Default data | Previous data | Set data | ReDo | Help

Performance data from catalogue or manufacturer

Catalogue condenser heat rate in kW at DT1 = 15K	20
Air flow (cubic metre per second)	1.82
Design-point condenser air-on temperature (degC)	25
Dry volume of condenser (litre)	8.7
Dry mass of condenser (kg)	45
Heat exchanger face height (m)	0.622
Heat exchanger depth (m)	0.264
Heat exchanger face width (m)	1.4
Total absorbed fan motor power (kW)	0.38

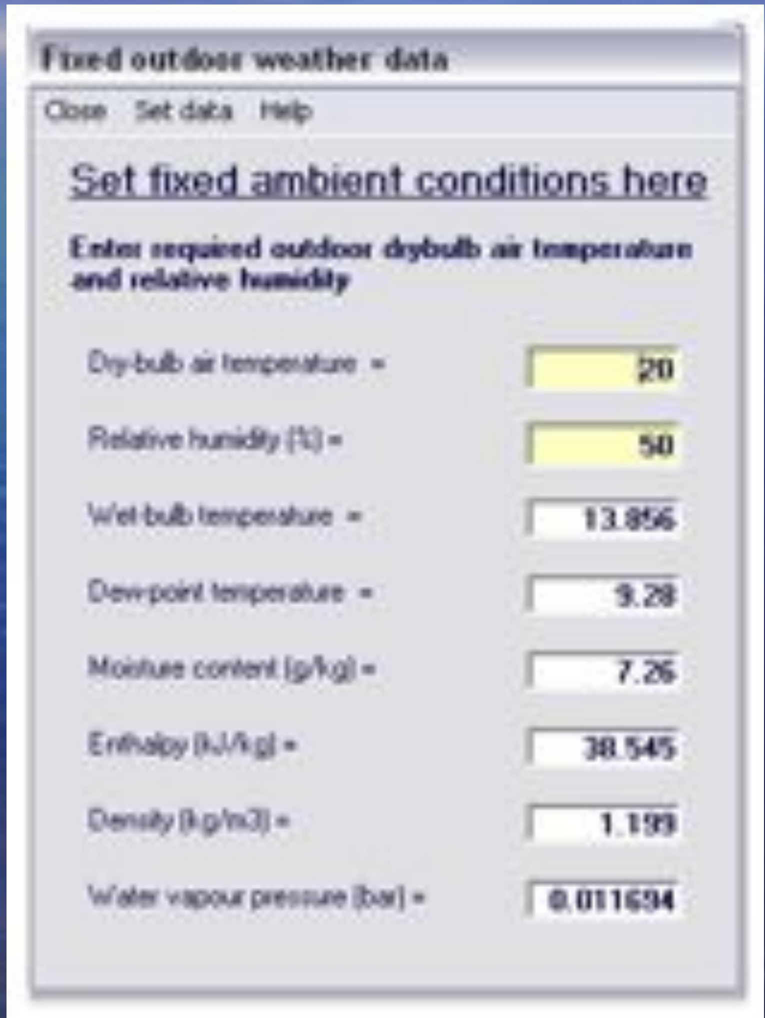
Optional data

Max fan aerodynamic efficiency (%)	60
% of max pressure rise (%)	70
% of max volume flow (%)	40
% of max fan speed (%)	100
Motor load factor (-)	1.25
Max motor efficiency (%)	95
Refrigerant-side pressure loss (K)	1
Degrees of sub-cooling at condenser discharge (K)	0

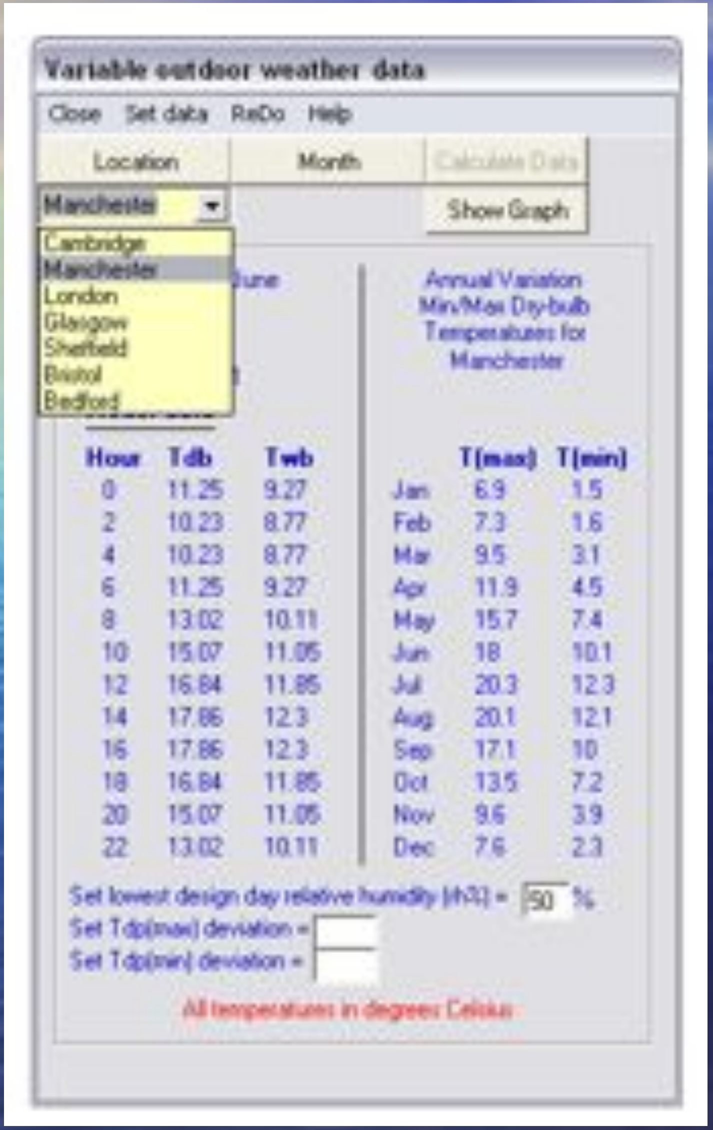
Calculated data

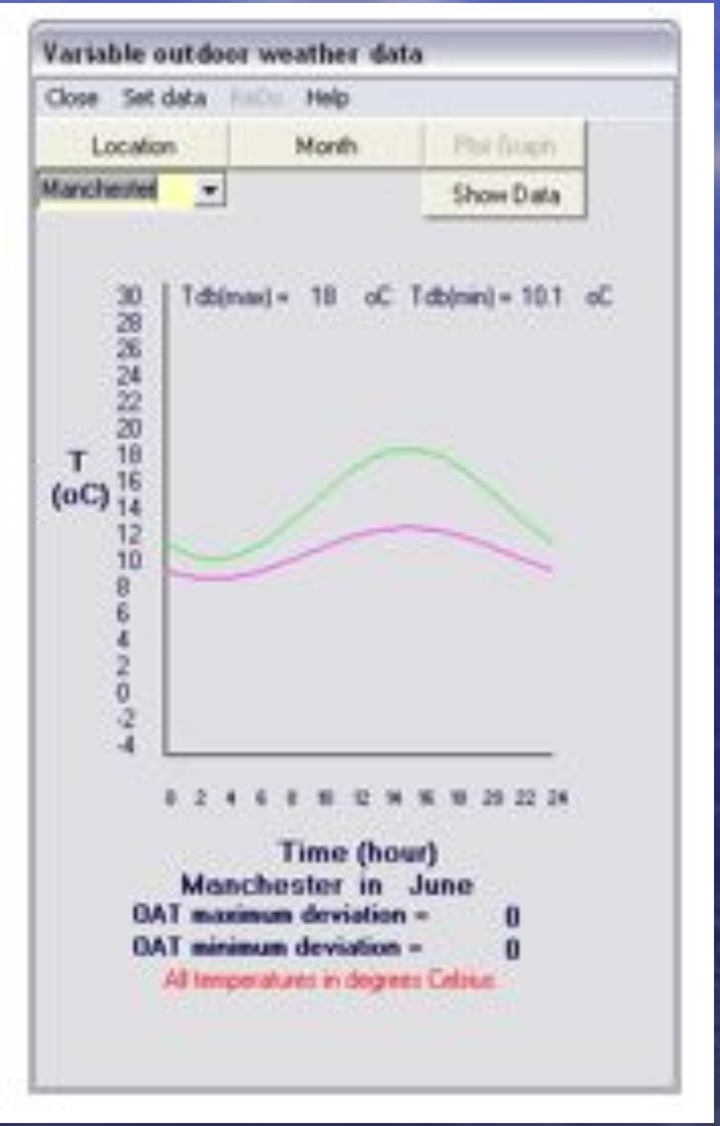
Refrigerant saturation temp at rated condition (degC)	40
Heat exchange effectiveness (-)	0.61
Air-on face velocity (m/s)	2.09
Air-side pressure loss (kPa)	0.119

Weather data, fixed or variable

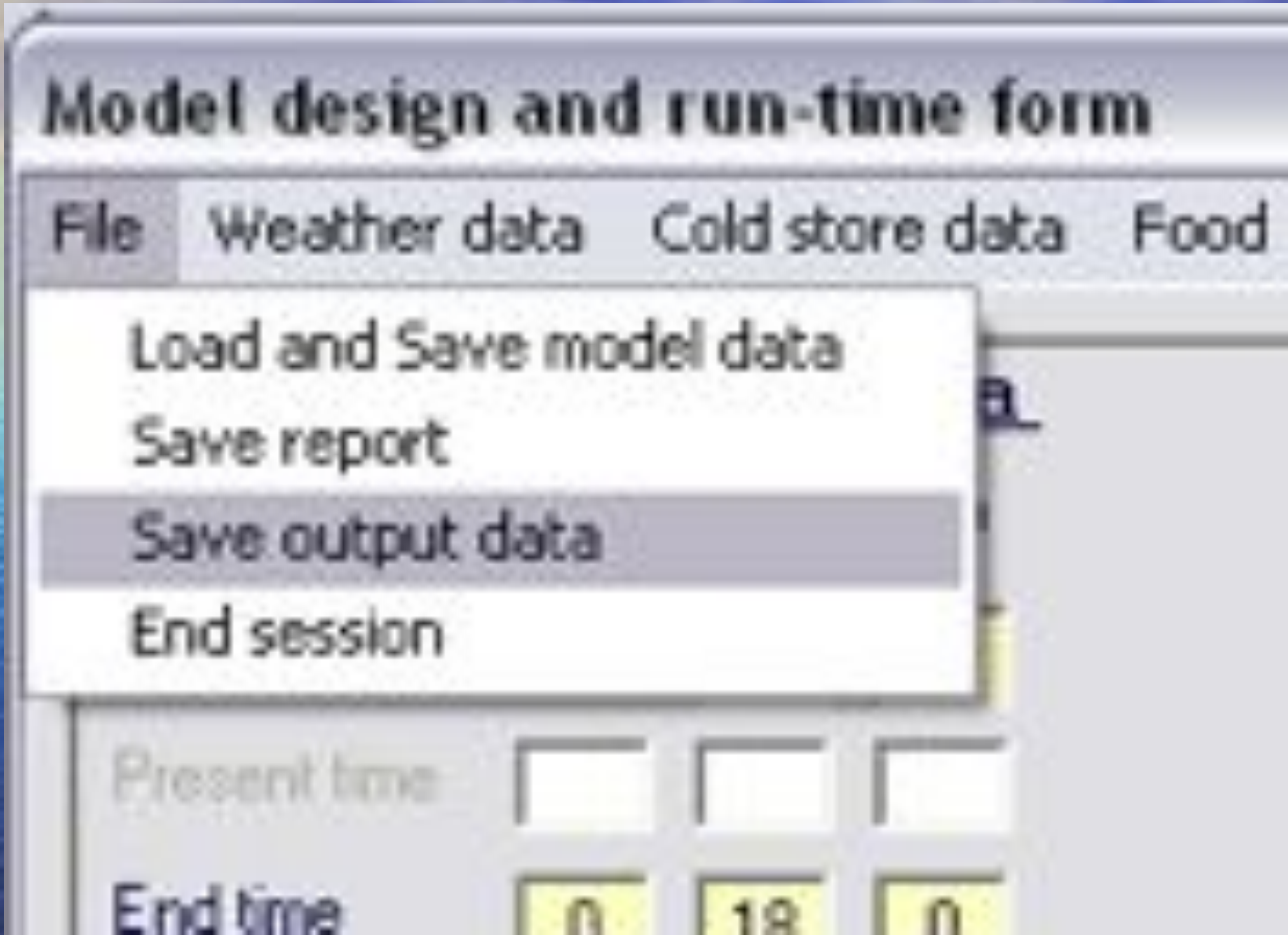


Variable weather data forms





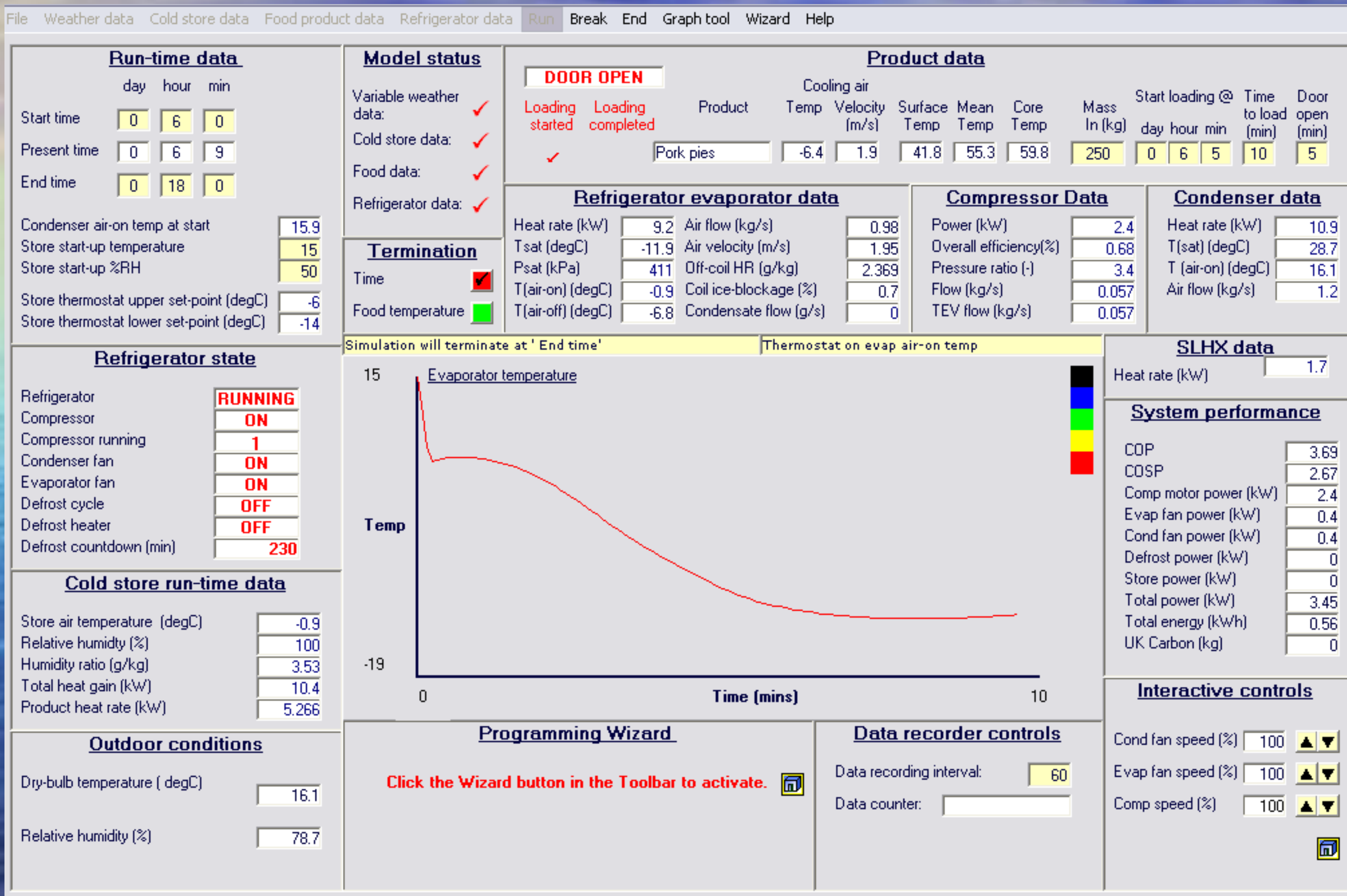
Saving-loading data



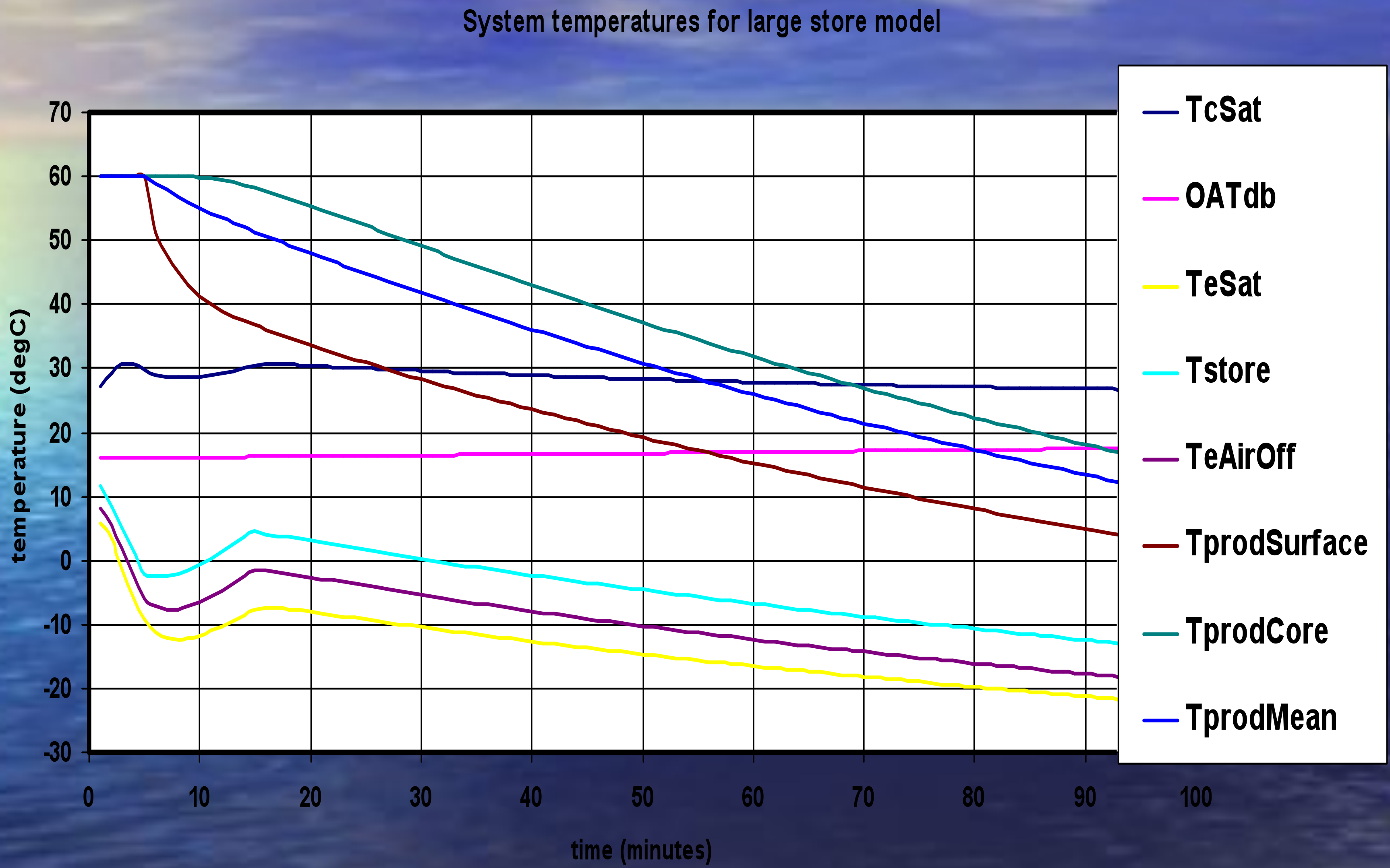
Saving output data to excel

Save data for a report to a word.doc file

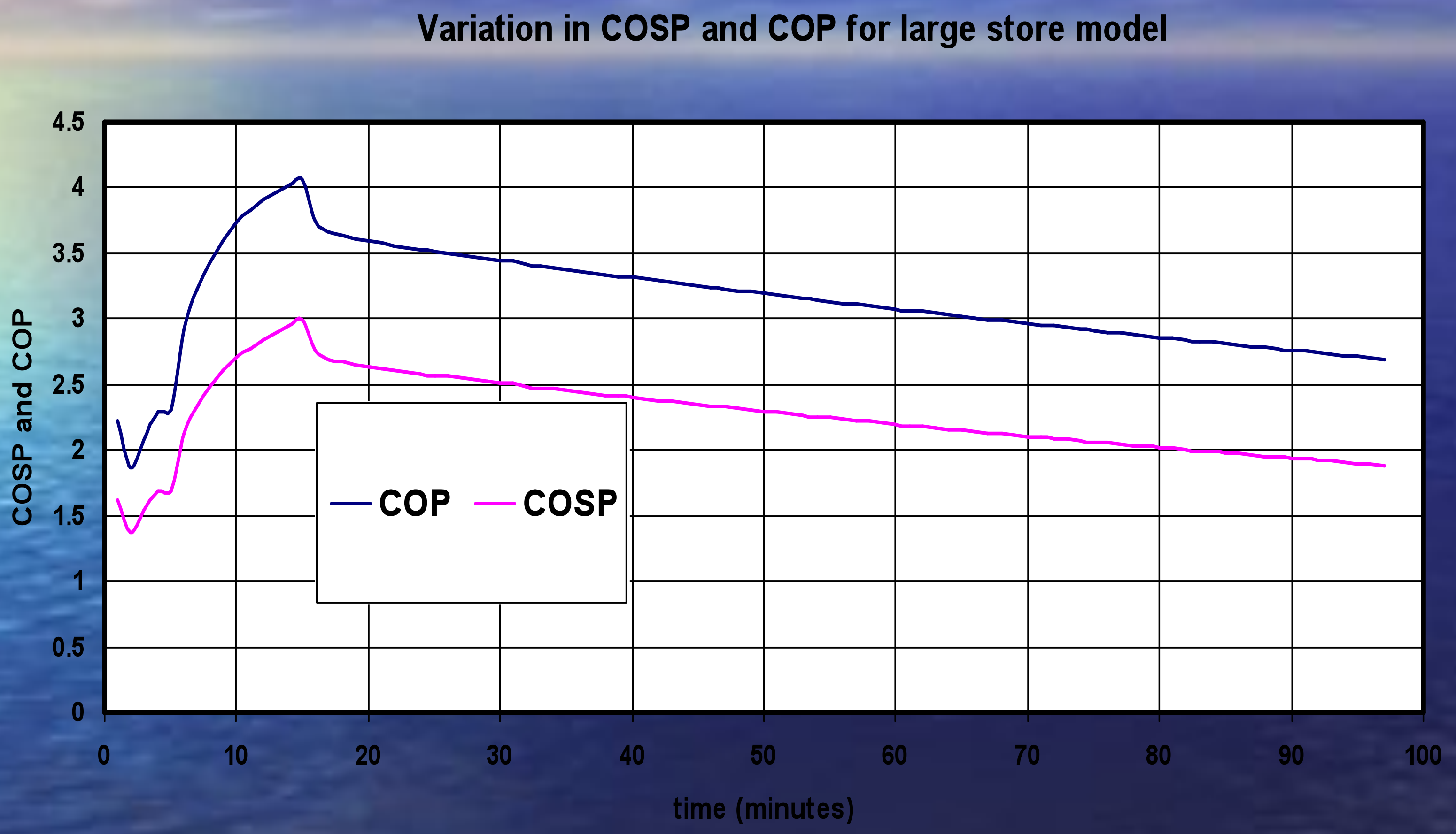
Running the model



Typical output



Typical output



Validation study at a pie manufacturing company

Pie-filling cooling room

Condenser unit

Compressor unit

Some system input data

Compressor data:

Compressor model:	PR1500/0138
Copeland compressor model input data:	
Motor speed:	50Hz , 4-pole
Compressor speed	1450 rpm, (24.167 hz)
Required refrigeration capacity:	12kW
Refrigerant:	R22
Suction return temperature:	20.0°C
Liquid sub-cooling:	0.0K
Condenser temperature:	30.0°Csat
Evaporator temperature:	-25°Csat
Performance at the above conditions:	
Refrigeration capacity:	13.19 kW
Electrical power consumption: 5.83 kW	
Current at 400VAC:	13.32A
Mechanical data:	
Displacement at 50Hz:	49.9162 m^3/h
Optional capacity steps:	33.3%
Number of cylinders:	3
Bore:	61.925mm
Stroke:	63.5mm
Gross weight:	176kg
Max high pressure:	25bar
Suction inlet diameter:	1 5/8 inch
Discharge diameter:	1 1/8 inch

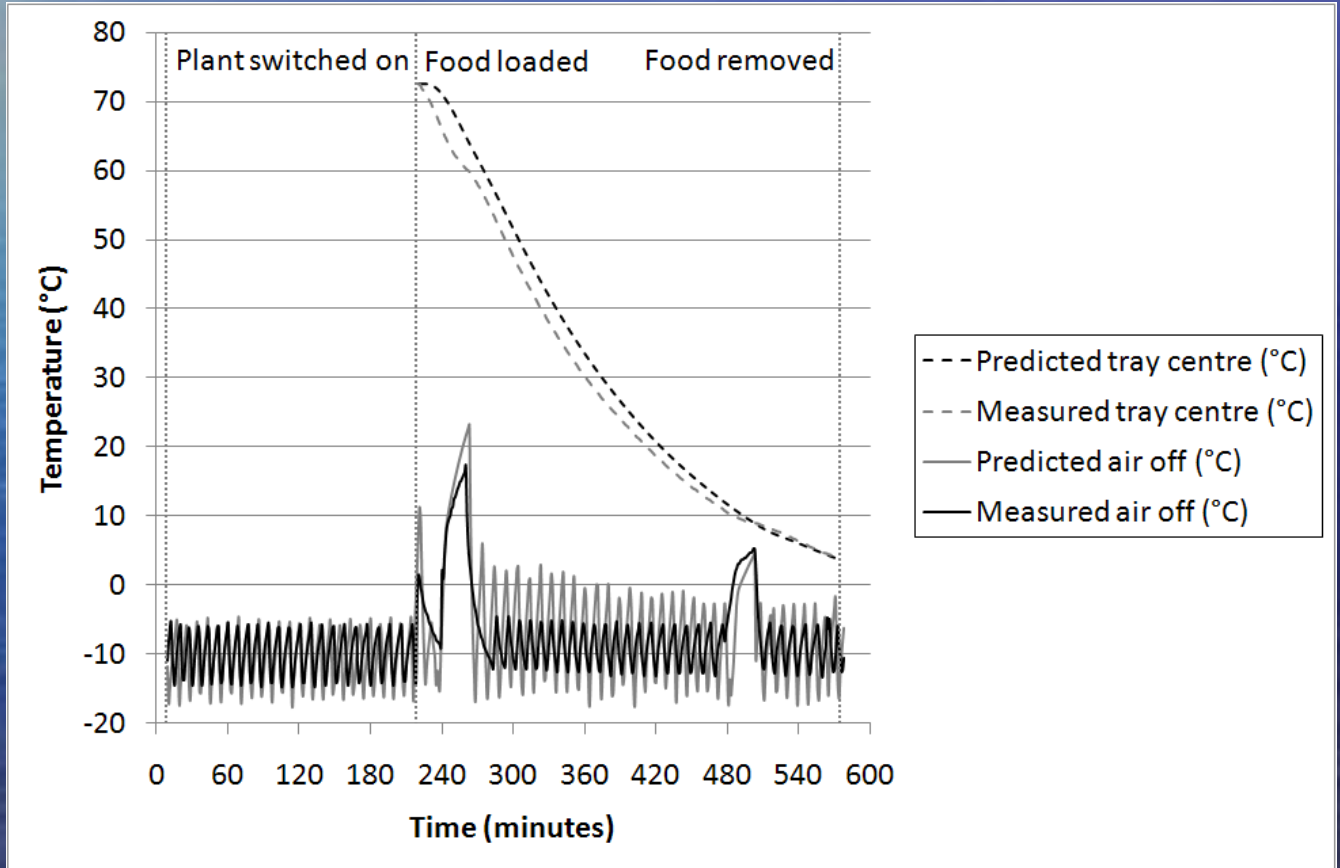
Pipe-line data

Evaporator to compressor = 38.5 m x 28.6 mm O/D
Compressor to condenser = 3 m x 28.6
Condenser to receiver = 3 m x 19.1 mm O/D
Receiver to evaporator = 38.5 m x 19.1 mm O/D
Insulation = Armaflex type, 15 mm thickness

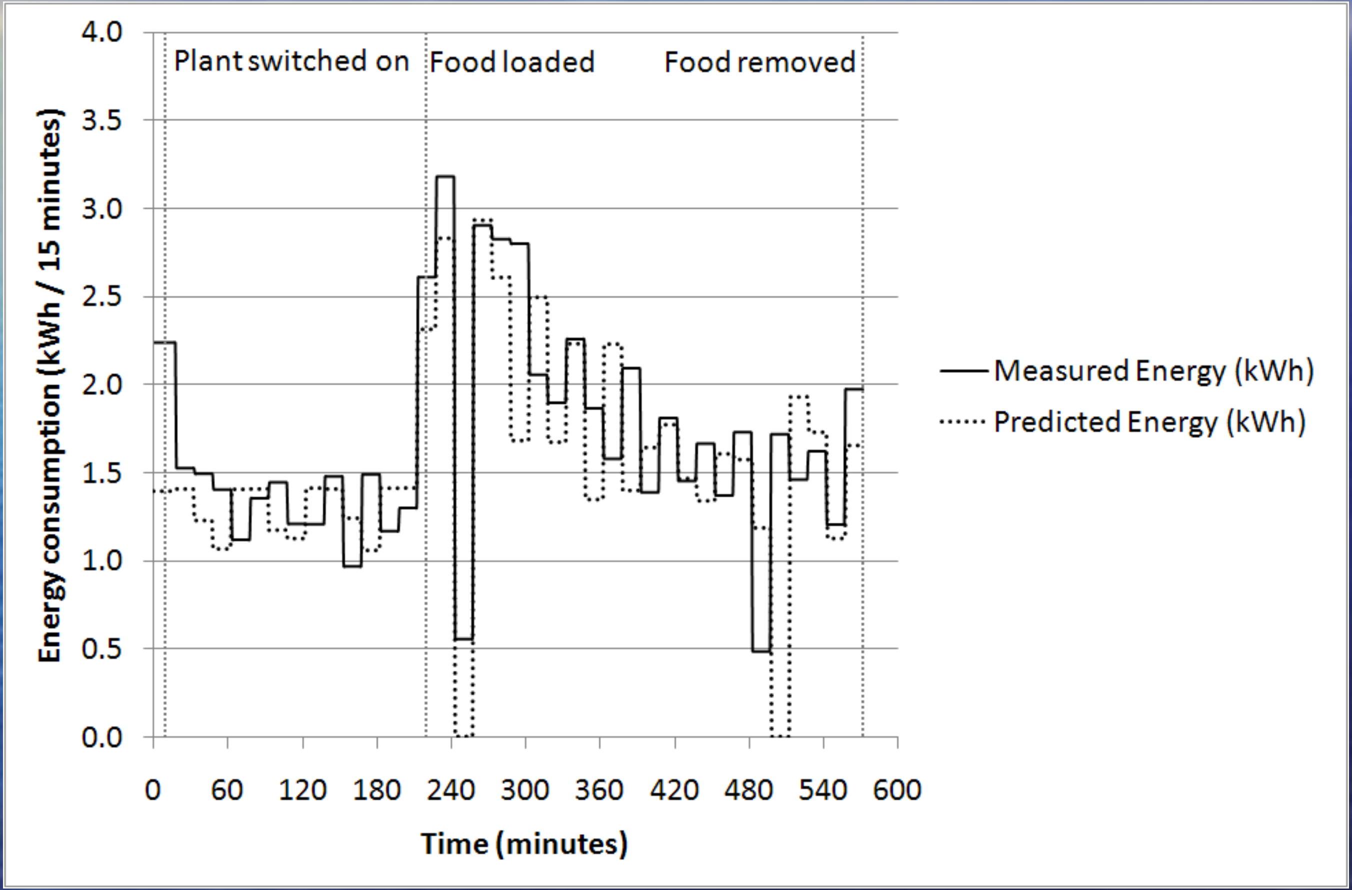
Coold space data:

Internal length = 195.0 cm
Internal width (between inner wall and evaporator face) = 86.5cm
Internal height = 195.5 cm
External length (excluding doors) = 221.0 cm
External width = 163.0 cm
External height = 226.5 cm

Validation: Comparing predicted and actual temperatures



Validation: Comparing predicted and actual energy consumption



Conclusions

- The VCR software offers a means of simulating the transient and steady state energy performance of existing and proposed refrigeration systems, particularly those used for refrigerated food storage.

- Real component data for compressor, evaporators and condensers can be taken form manufacturer's catalogues to run a simulation. Where such data is not available then scientifically based models are provided.

- The VCR software allows users to simulate the effects on energy consumption due to variations in outdoor and store temperatures, food properties and cooling air velocity, amongst other things.

- The software also allows users to simulate the effects of control system choices, particularly defrost power and timer settings, evaporator and condenser fan speed control, TEV settings, compressor stages and speed control.

- The validation case study described in the paper showed that the model predictions compared favourably with measured data both in terms of absolute values of results and general trends in terms of the test system's temperatures and energy consumption over the test day.

- It is hoped the results of this work will provide a useful addition to the tools available to the designer.

Look forward

Dissemination workshop events at LSBU. Its free to all delegates as is the software. The first is on 21 April – book early to avoid disappointment by contacting Jessica at baldocj3@lsbu.ac.uk

Software now available as a download through the project website at http:/www.grimsby.ac.uk/what-we-offer/DEFRA-Energy

A few CD copies available – please collect from me at the next break

Write to me at ianweames@aol.com and I will send you a copy by return

Acknowledgements

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