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

About... Contact details... Read me first... Start session...

Technologies and practices to reduce energy inputs in the refrigeration of food

An interactive refrigeration system simulator

Software created by London South Bank and Bristol Universities on behalf of DEFRA





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

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Run-time screen

What YCR does 1884y09 doc - Microsoft Word

Model design and run-time form

File Weather data Coll stars data Footgroduct data Refrigerator data Fun Dreal Divi Graph tool Woard Help



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- 02

Design wizard

Model design and run-time form



Help pages

E	Cold store Compress Condense Control s Evaporation	e data sor catalogue o er catalogue d ettings and op or catalogue d	Sata nput ata input tions lata input	ata npressor it is chracteristic	necessary to graphs. The	enter certain following illust	data provided	(by compresso	(
	Data and record keeping Pood model Outdoor weather data Refrigerator design data input Refrigerant pipe lines System model			tor is listed comance dat i Catalogue sature, degre sature, degre sature given in the le to the right	te Pesta Cola Rehige Cooling Max ele Actual	Performance data table from the Collaborar Data Form Refrigerant Cooling capacity (KW) Max electrical power absorbed by moto Actual electrical power absorbed by moto			R404a 7.79 5.33 3.69
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The catalogue model for the compressor assumes the same religerant that is currently selected in the Religerator Design

Getting started - using default data...

Model design and run-time form	
File Weather data Cold store data Food prod	et data
Load and save project model data Save project report Save project output data End session	Mor Variabil data
End time 0 18 0	Cold st Food d Relige
Store start-up temperature 15 Store start-up 1/SH 50 Store thermostal upper set point (degC) 6 Store thermostal lower set point (degC) -14	Time Food to

Default data

Model input data: Small Chi	Il Room / July09					-		
File Help								
Save model set-up data to Ne	E	ood product data		,	Cold space detail			
Close	Eand product.	Park pies	Cooled space temperature data Construct			fetal Continuous coolin		na load
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Outdoor ambient conditions			Ground temp 10 Store temp 10		Floor U-value (Wim2k)	0.296	Intermittent heat	L Gains
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Cold store design...



Food design

Product dimension variable		Heat and mass transfer variables	
Food shape	Slab Cylinder	Mass transfer coefficient for top surface (W/m2K) Mass transfer coefficient bottom surface (W/m2K)	256-6
Thickness of slab or diameter of colinder (m)	0.15	Water activity for bottom surface	0.95
Thermal property variables			
Initial water content (1) Protein content (1) Fat content (1) Catbohydrate content (1 Mineral (ach) content (1)	725 In 132 In 6.6 Lo 6.7 Un 1 1 To Status Data	Ale density (k.g/h.0) 950 Food structure Ale freezing point temp:	
Loading schedule			
Product name Pie Filling Air velocity over product Note Leave the field blank i wish to use the air velocity	Schedule1	Number 61.8	states

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Refrigerator design

Refrigerator Design Form

Close Data source Set data ReDo data Refrigerant = R404a Help





Select a refrigerant

esign Form								
ce Set data ReDo data	Refrigerant	= R404a	Help					
Evaporator data e data	R404a R407c R717	Design	Compress speed (rpm)					
ig duty (kW)	R134a	Speed	percentage					
e humidity (%)	R22	Polyrop	nce volume (%) nic efficiency (%)					
aturation temp [degC]	.5	Mecha	nical efficiency [2					

Select to use default, user-defined **15** or catalogue data



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Example catalogue data input forms

lose Refrigerant	Data Set data ReDo He	ilp .
Compressor perfe	Default data Previous data	
Cooling capacity (k Max electrical pow Actual electrical po Evaporator saturati Condenser saturati Condenser saturati Congressor suction Degrees of evapor Degrees of conden Congressor speed	W) er absorbed by motor (kW) wer absorbed by motor (kW) on temperature (degC) on temperature (degC) stor superheat (degC) stor superheat (degC) stor superheat (degC) stor superheat (degC) (gm)	H404a 7.79 5.33 3.69 -15 40 20 5 0 1446
ptional/assume	d compressor data	
Dearance volume t	00	4
Mechanical efficier	vcy (t)	95
Percent of motor hy Maximum motor eff	eal to suction gas (%) iciency (%)	90 95
Dutput compress	or data	0 ±
Isentropic efficiency	9(3)	79.7
	121	80.7
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Polytopic efficiency Motor efficiency (3	1	92.9
Polytropic efficiency (% Motor efficiency (% Motor max load fac	a Nor (-)	92.9

Cose Default data Previous data Set data ReDo	Help
Performance data from catalogue or manufactu	
Catalogue condenser heat rate in k/w/ at DT1 = 15K	20
Air flow (cubic metre per second)	1.82
Design-point condenser air on temperature [degC]	25
Dry volume of condenser (Mre)	87
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 wotor power (k/w/)	0.38
Optional data	
Max fan aerodynamic efficiency (%)	60
32 of max pressure rise (32)	20
32 of max volume flow (32)	40
3 of max fan speed (3)	100
Motor load factor (-)	1.25
Max motor efficiency (2)	95
Refigerant-side pressure loss (K)	1
Degrees of sub-cooling at condenses discharge (K)	0
Calculated data	
Religerant saturation temp at rated condition (degC)	40
Heat exchange effectiveness [-]	0.61
Auron face velocity (m/s)	2.09
All side many in here fifted	0.100

Weather data, fixed or variable

Set fixed ambient cor	nditions he
Enter required outdoor drybull and relative humidity	b air temperatur
Dry-bulb air temperature +	20
Relative hunidity (%) =	50
Wet-bulb temperature =	13.856
Dev-point temperature -	9.28
Moisture content (gr/kg) =	7.26
Enthalpy (kJ/kg) =	38.545
Density (kg/m3) =	1.199
Water vapour pressure (bar) =	0.011694



Variable weather data forms

	CORCE IN	tero seb			
Local	ion	Month	1 5	Calculate Data	
lancheste		10.000	Show Graph Annual Variation MinuMas Daybub Temperatures for Manchester		
ambridge landheste ondon lasigow hefheld nistol edfoed		une			
Hour	Tdb	Twb	100	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	95	3.1
6	11.25	9.27	Act	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	34	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
	15.07	11.05	Nov	9.6	3.9
20	and the second second	10.00	Deen	70	29



Saving-loading data

Model design and run-time form File Weather data Cold store data Food 19

Load and Save model data

Save report Save output data

End session

Present time

Endtime

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Saving output data to excel

D	o you want to:-
	Append data to an existing Excel file?
	Overwrite data in an existing Excel Ne?
	Create a new Excel file? Click here
E	nter file name here:-
	BigPieMan
	SAVE

Save data for a report to a word.doc file

ent and p	neiect.		Project data and sim	ulation outputs to far
lent name ddecs Line 1 Line 2 Line 3 Line 4 out code ontact nam ontact pho ontact ema	Ann D Big Pie Lefite Bistol UK	Per Factory Avenue [82:00 [Avenue [0123:456789 [AnnOther [0123:456789 [AnnOther@BigPie	City location of plant Food product Simulated month Start lime End time Kitowatt hours UK Carbon(kg)	Bristol Pook pers Durne 16:0 18:0 19:0 10
ect name	and not	AnnOther@BigPle Onling Ples es on project nts and notes here		
	1	Type the name of the MS WOP BigPieFactory 23Marc	10 file in which you wish to store your ch10 5	report data

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Running the model

File Weather data Cold store data Food product data Refrigerator data Run Break End Graph tool Wizard Help Run-time data Model status Product data DOOR OPEN Cooling air day hour min Variable weather Start loading @ Time Door Loading Loading Temp Velocity Surface Mean Core Mass Product data: to load open Start time 0 6 0 Temp Temp Temp In (kg) day hour min (min) started completed (m/s) (min) Cold store data: Present time 6 9 41.8 55.3 59.8 Pork pies -6.4 1.9 250 0 6 5 10 5 Food data: End time 0 18 0 Refrigerator evaporator data **Compressor Data** Condenser data Refrigerator data: 🧹 9.2 Air flow (kg/s) Condenser air-on temp at start 15.9 Heat rate (kW) 0.98 Power (kW) 2.4 Heat rate (kW) 10.9 Store start-up temperature -11.9 Air velocity (m/s) Overall efficiency(%) T(sat) (degC) Tsat (degC) 0.68 15 1.95 28.7 Termination Store start-up %RH Psat (kPa) 411 Off-coil HR (g/kg) Pressure ratio (-) T (air-on) (degC) 2.369 3.4 16.1 50 Time \checkmark T(air-on) (degC) -0.9 Coil ice-blockage (%) 0.7 Flow (ka/s) 0.057 Air flow (kg/s) 1.2 Store thermostat upper set-point (degC) -6 T(air-off) (degC) -6.8 Condensate flow (g/s) TEV flow (kg/s) Food temperature n 0.057 Store thermostat lower set-point (degC) -14 Thermostat on evap air-on temp Simulation will terminate at ' End time' SLHX data Refrigerator state 1.7 Heat rate (kW) 15 Evaporator temperature Refrigerator BUNNING System performance Compressor ON Compressor running 1 COP 3.69 Condenser fan ON COSP 2.67 Evaporator fan ON Comp motor power (kW) 2.4 Defrost cycle **OFF** Evap fan power (kW) 0.4 Defrost heater OFF Temp Cond fan power (kW) 0.4 Defrost countdown (min) 230 Defrost power (kW) 0 Store power (kW) 0 Cold store run-time data Total power (kW) 3.45 Store air temperature (degC) Total energy (kWh) -0.9 0.56 Relative humidty (%) UK Carbon (kg) 100 0 Humidity ratio (g/kg) 3.53 -19 Total heat gain (kW) 10.4 Interactive controls 0 Time (mins) 10 Product heat rate (kW) 5.266 Programming Wizard Data recorder controls Cond fan speed (%) 100 A Y Outdoor conditions Evap fan speed (%) 100 🔺 🔻 Data recording interval: 60 Dry-bulb temperature (degC) Click the Wizard button in the Toolbar to activate. 16.1 Data counter: Comp speed (%) 100 🔺 🔻 Relative humidity (%) 78.7 ٦

Typical output

System temperatures for large store model

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Typical output

Variation in COSP and COP for large store model

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Validation study at a pie manufacturing company



Pie-filling cooling room



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Condenser unit



Compressor unit

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Some system input data

Compressor data:

Compressor model:	PR15
Copeland compressor model input data:	
Motor speed:	50Hz
Compressor speed	1450
hz)	
Required refrigeration capacity:	12kV
Refrigerant:	R22
Suction return temperature:	20.04
Liquid sub-cooling:	0.0K
Condenser temperature:	30.00
Evaporator temperature:	-25°C
Performance at the above conditions:	
Refrigeration capacity:	13.19
Electrical power consumption: 5.83 kW	
Current at 400VAC:	13.32
Mechanical data:	
Displacement at 50Hz:	49.9
Optional capacity steps:	33.39
Number of cylinders:	3
Bore:	61.92
Stroke:	63.51
Gross weight:	176k
Max high pressure:	25ba
Suction inlet diameter:	1 5/8
Discharge diameter:	1 1/8

R1500/0138

50Hz , 4-pole 1450 rpm, (24.167

2kW 22 0.0°C .0K 0.0°Csat 25°Csat 3.19 kW 3.32A 9.9162 m³/h 3.3% 1.925mm 3.5mm 76kg 5bar 5/8 inch 1/8 inch

Pipe-line data

Evaporator to compressor = 38.5 m x 28.6 mm O/DCompressor to condenser = 3 m x 28.6Condenser to receiver = 3 m x 19.1 mm O/DReceiver to evaporator = 38.5 m x 19.1 mm O/DInsulation = 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



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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 <u>baldocj3@lsbu.ac.uk</u>

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

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

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

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