



## Calculations of Failure Point of Freezer Doors

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### **Executive Summary**

The result of simulations of a new design of freezer cabinet and refrigerator door are presented in this report. The results demonstrate that the new design of the door frame and with optimally selected glazings result in doors which will not fail (ie not form condensation anywhere on the glazed area of the door) at a relative humidity up to 76% RH (under normal atmospheric pressure) when used in a freezer, or at relative humidities below 92%RH when used in a refrigerator. This compares with a standard triple-glazed freezer door which has an estimated failure point of 35% RH, or 67% RH for the same door used in a refrigerator.

The new freezer and refrigerator doors would not need internal heating on the glazed area (as is currently used) if used in airconditioned environments, and refrigerator doors in unairconditioned environments for in excess of 97% of the year (total hours) in Brisbane.

Reductions in energy use will also result from using these new freezer and refrigerator door designs, both as a result of eliminating the heating wires in the glazed units (which prevents condensation), but also because the new frame and proposed glazing systems significantly reduce heat transfer. Based on figures from Anthony doors ([www.anthonydoors.com/energy.asp](http://www.anthonydoors.com/energy.asp)), the heating of the 0.8mx1.6m glass freezer doors is estimated to be \$175 per annum<sup>1</sup>, which will be eliminated for every door unit, and the reductions in heat transfer into the freezer units is estimated to be up to 56% (680 kWhr per annum of cooling – see Table 3) over an Al-frame triple glazed unit with clear glass panes.

### **Introduction**

At the request of Murray Pickford, I undertook simulations of the heat transfer through a new design of fridge and freezer door. A number of different glazing options were used, and estimation of the failure point of the door were made from the results. Failure in this context is relative humidity at which condensation will form on the glazed area of the door. This, from experience and based on the simulated results, always occurs at the edge of the glass near the frame.

This report outlines the methodology used to calculate the heat transfer characteristics of the door and frame combination, the sources of information used, and the assumptions which have been made in arriving at the results. Detailed results for a range of door options have been obtained, and these are presented in detail in the results section.

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<sup>1</sup> Assuming energy costs of \$0.10 per kWhr, based on the Anthony Doors Model 101 Freezer Door (LT version)

## Methodology

The frame and glazing systems have been modelled using the following software:

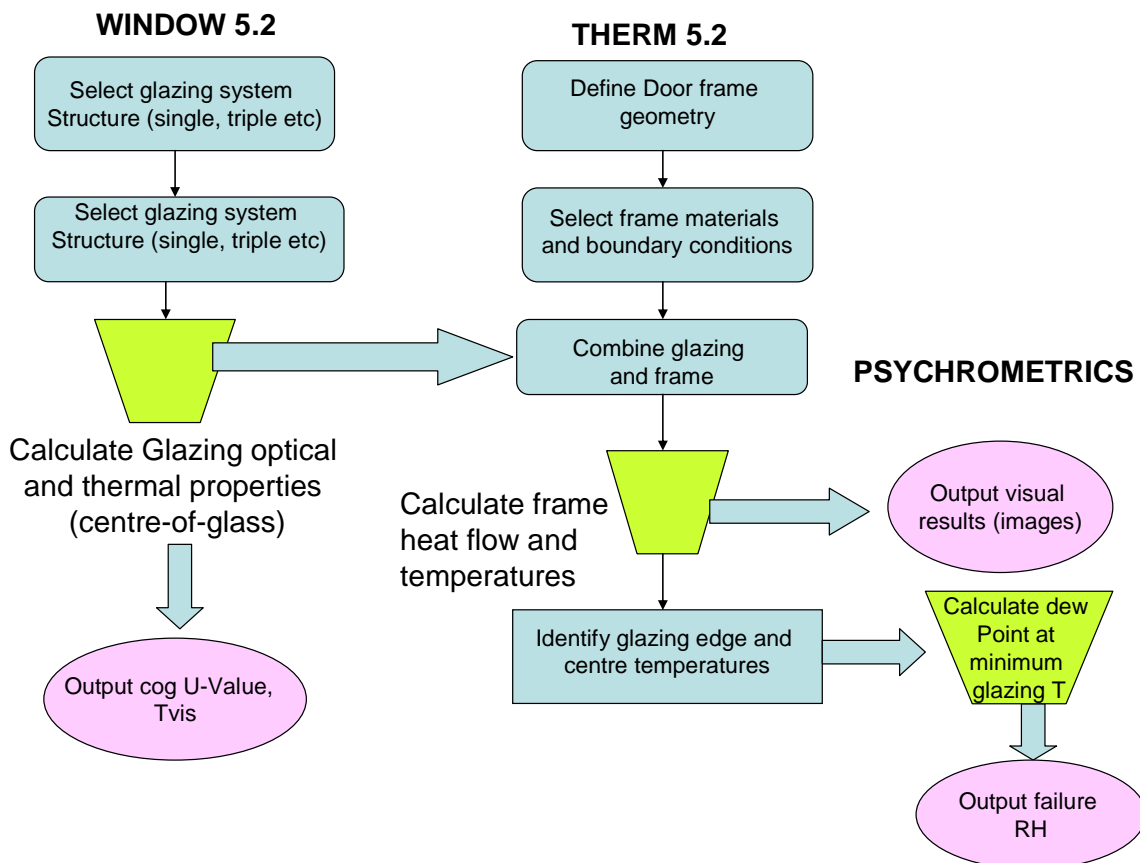
**Glazing Systems:** Window 5.2 (available from Lawrence Berkeley National Laboratory, <http://www.lbnl.doe.gov>)



**Framing Systems:** THERM 5.2 (available from Lawrence Berkeley National Laboratory, <http://www.lbnl.doe.gov>)

**Psychrometrics:** GetPsyched! From kW Engineering, [psych@kw-engineering.com](mailto:psych@kw-engineering.com)

These programs have been developed for the purpose of evaluating thermal performance of windows and glazing systems, and are based on advanced theory of heat transfer in materials and glazing systems. These are the world's leading programs for this purpose, and are used throughout the United States, Australia and Europe.

The basic process for the modelling is shown in Figure 1.



**Figure 1.** Schematic followed for determination of failure point.  represents calculations performed by third party software as described.  represents output data provided in this report.

The basic model for the door is described in Appendix 1

## Material and Boundary Condition Assumptions

The assumptions made in the calculations are detailed in Table 1 & 2 below. The calculations were not performed to optimise the choice of the material for the frame, but were run to consider different glazing options.

**Table 1: Frame Material Parameters**

Material	Thermal Conductivity	Emittance	Notes
Acrylonitrile Styrene Acrylate ASA)	0.17 W/m <sup>2</sup> /K*	0.9	Several other materials could be used: EPDM (K=0.25 W/m <sup>2</sup> /K; expanded polystyrene K=0.038 W/m <sup>2</sup> /K, expanded rubber (rigid), K=0.032 W/m <sup>2</sup> /K)
Frame Cavity – Air	0.0638 W/m <sup>2</sup> /K	0.9	Properties calculated according to NFRC 100-2001
Rubber (gasket)	0.06 W/m <sup>2</sup> /K	0.9	
Al (anodised)	237 W/m <sup>2</sup> /K	0.8	

\* the thermal conductivity is based on polystyrene as data is not available readily, but the variation between modified forms of specific monomers (the styrene monomer is the backbone of ASA) is typically less than 5%. The value used is 5% higher than the quoted value for polystyrene

**Table 2: Boundary condition parameters**

Boundary Condition	Temperature	Convective Heat Transfer	Radiation environment	Notes
Freezer (inside)	-25°C	10W/m <sup>2</sup> (air speed = 1.5m/s)	Radiation to -25°C, emittance 0.84	Convective transfer coefficient calc. assuming ASHRAE/NFRC conditions ( see window 5.2)
Fridge	3°C	8W/m <sup>2</sup> (air speed = 1.0m/s)	Radiation to 3°C, emittance 0.84	
Outside	23°	4.8 W/m <sup>2</sup> (air speed 0.2 m/s)	Radiation to 23°C, emittance 0.84	

The accuracy of the simulations is approximately 7%. However this accuracy refers to a total accuracy of the simulation in THERM, ie the accuracy of the position of isotherms is within 7%, and since the key issue for condensation is the coldest temperature on the glazed area (usually at the edge near the frame), the variation in the failure point (which is assumed to be the relative in the space outside the door at which the dew point on the glazed surface is 100% RH – the dew point) is typically less than 1-2% RH. The results are also very reproducible and not dependent on finite element modelling parameters (mesh parameter, error limits, tolerance on convergence etc), indicating that the results obtained are

## Results

The results obtained are summarised in the Table 3, and a number of simulated thermal images of the door frames are shown in Figures 2-5 to demonstrate the performance of the door frame/glazing combinations. The results in Table 3 are listed in decreasing order of maximum relative humidity at failure when used in a freezer.

The key results are:

- almost ALL combinations of glazing and frame give a failure point above 70%RH (at sea level) when used in a freezer
- almost ALL combinations of glazing and frame give a failure point above 90%RH (at sea level) when used in a refrigerator

- Triple-clear glazing used in the new frame design fails at 62% RH in the freezer. With the new frame design, even this type of glazing system will **not** require internal heating to prevent condensation on the glass (failure) at typical indoor airconditioned conditions (50-55% RH).
- As anticipated, the use of argon in the internal glazed space (nearer the cold side), improves the energy performance (U-Value) and failure point more than when argon is used in the outer glazing space.
- Achieving a failure point near or above 75%RH in freezer use requires the use of a good quality low emittance glass ( $\epsilon < 0.1$ ) or the use of double argon gas fill.
- The results for the refrigerator configuration mirror very closely the freezer configuration but with a failure point approximately 15RH% higher. There are some exceptions, but these are not major deviations.
- The energy flow from the room into the freezer is reduced by between 38% to 54%, depending on the glazing, when compared to a clear glass triple-glazed Al-frame freezer unit. This has been calculated using an area weighted U-value ( $U_{\text{eff}} = (A_{\text{frame}}U_{\text{frame}} + A_{\text{glass}}U_{\text{cog}}) / (A_{\text{frame}} + A_{\text{glass}})$ , where  $U_{\text{frame, cog}}$  are the U value for the frame and centre-of-glass of the glazing system calculated using THERM 5.2 and WINDOW 5.2 respectively). A door unit of dimensions 1.2x0.8m with a 3cm wide frame has been used.

## Conclusions

1. Freezer door frames designed using the proposed frame design and using some of the selected glazing configurations will resist condensation forming on the glazed area of the door in conditions up to 76% RH **with no internal heating of the glass.**
2. All the glazing options with low-e coatings achieved a failure point in excess of 70% RH in the freezer configuration.
3. Refrigerator door frames designed using the proposed frame design and using some of the selected glazing configurations will resist condensation forming on the glazed area of the door in conditions up to 90% RH **with no internal heating of the glass.** (Exceptions among the combinations tested are Sungate 500 (unless argon gas fill is used in both cavities), Comfort E2 or Energy Advantage with air fill in both cavities.)
4. Energy savings realised using these freezer door and refrigerator door configurations include:
  - a. Energy used for heating the glazing to prevent condensation is eliminated (estimated to be 1751kWhr per door, based on Anthony Windows data – see [www.anthonydoors.com/energy.asp](http://www.anthonydoors.com/energy.asp) - note that the data has been scaled to a 0.8mx1.6m model 101 LT (freezer) door)
  - b. The heat load on the freezer unit due to heat transfer through the doors is considerably reduced, by between 38 and 55% compared to a standard triple-glazed freezer door in an Al frame. This equates to 470-680kWhr per annum of cooling.
  - c. The heat load on the freezer will also be reduced by an estimated 600kWhr per annum as up to half the heating of the glazing unit (point a. above) will transmit into the freezer. The figure of 600kWhr per annum is an estimate

and detailed calculations of the fraction of this energy transmitted to the freezer have not been made.

**Table 3. Detailed Simulation Results**

DOOR SYSTEM				FREEZER				FRIDGE		
Glazing	U-Value (frame)	U-Value (cog)	Tvis (%)	T cog	Tmin (edge)	RH at failure	Heat flow (W)*	T cog	Tmin (edge)	RH at failure
Comfort Ti-R Argon-Air.thm	1.058	0.77	57.9	19.1	18.3	76%	63.1	22.2	21.7	92%
Comfort Ti-R Air-Argon.thm	1.060	0.751	57.9	19.6	18.2	74%	61.8	22.2	21.7	92%
TiAC40 Air-Argon.thm	1.069	0.763	56.4	19.5	18.2	74%	62.7	22.2	21.7	92%
TiAC40 Argon-Air.thm	1.067	0.782	56.4	19.1	18.2	74%	64.0	22.1	21.7	92%
Sungate 100 Argon-Argon.thm	1.088	0.765	63.7	19.4	18.1	74%	63.0	22.2	21.7	92%
EnergyAdvantage Argon-Argon.thm	1.081	0.849	64.5	19.0	18.1	74%	68.8	22.0	21.6	92%
Comfort Ti-R Air-Air.thm	1.106	0.861	57.9	18.7	18.1	74%	69.9	21.9	21.5	91%
Sungate 100 Argon-Air.thm	1.128	0.857	63.7	18.7	18.0	73%	69.8	22.0	21.5	91%
TiAC40 Air-Air.thm	1.126	0.872	56.4	18.7	18.0	73%	70.8	21.9	21.5	91%
EnergyAdvantage Argon-Air.thm	1.149	0.935	64.5	18.3	17.9	73%	75.4	21.8	21.4	91%
Sungate 100 Air-Argon.thm	1.100	0.842	63.7	20.0	17.8	73%	68.5	22.0	21.5	91%
Sungate 100 Air-Air.thm	1.174	0.944	63.7	18.3	17.8	73%	76.3	21.7	21.4	91%
Comfort E2 Argon-Argon.thm	1.202	0.913	65	18.6	17.6	72%	74.4	21.8	21.5	91%
Sungate 500 Argon-Argon.thm	1.213	0.927	65.8	18.4	17.5	71%	75.4	21.8	21.4	91%
Comfort E2 Argon-Air.thm	1.239	0.995	65	18.0	17.5	71%	80.4	21.6	21.3	90%
Sungate 500 Air-Argon.thm	1.219	1.000	65.8	18.3	17.5	71%	80.6	21.6	21.2	90%
EnergyAdvantage Air-Air.thm	1.250	1.020	64.5	17.9	17.5	71%	82.3	21.6	21.2	90%
Sungate 500 Argon-Air.thm	1.250	1.009	65.8	17.9	17.4	71%	81.5	21.6	21.3	90%
Comfort E2 Air-1Argon.thm	1.242	0.986	65	18.3	17.4	71%	79.8	21.6	21.3	90%
Comfort E2 Air-Air.thm	1.282	1.078	65	17.6	17.3	70%	86.6	21.4	21.1	89%
Sungate 500 Air-Air.thm	1.292	1.091	65.8	17.6	17.2	70%	87.6	21.4	21.1	89%
Triple Glazed (clear-clear-clear)	1.691	1.762	74.1	15.5	15.3	62%	137.9	20.1	20.2	84%
Triple Glazed Al Frame	2.015	1.762	74.1	14.7	6.2	34%	140.8	20.1	16.6	67%

\* heat flow calculated using an area weighted U-value for a 1.2x0.8m door with a 3cm wide frame

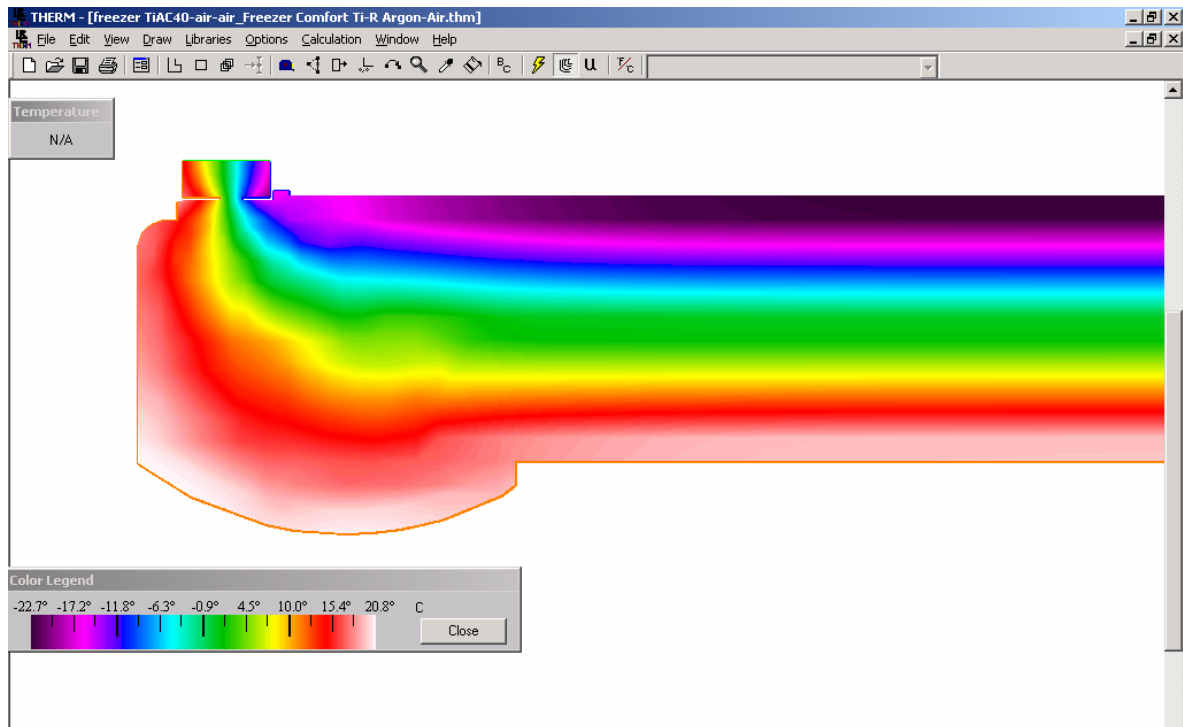


Figure 2. New frame design used with Comfort Ti-R glazing, with argon fill in the internal interpane space.

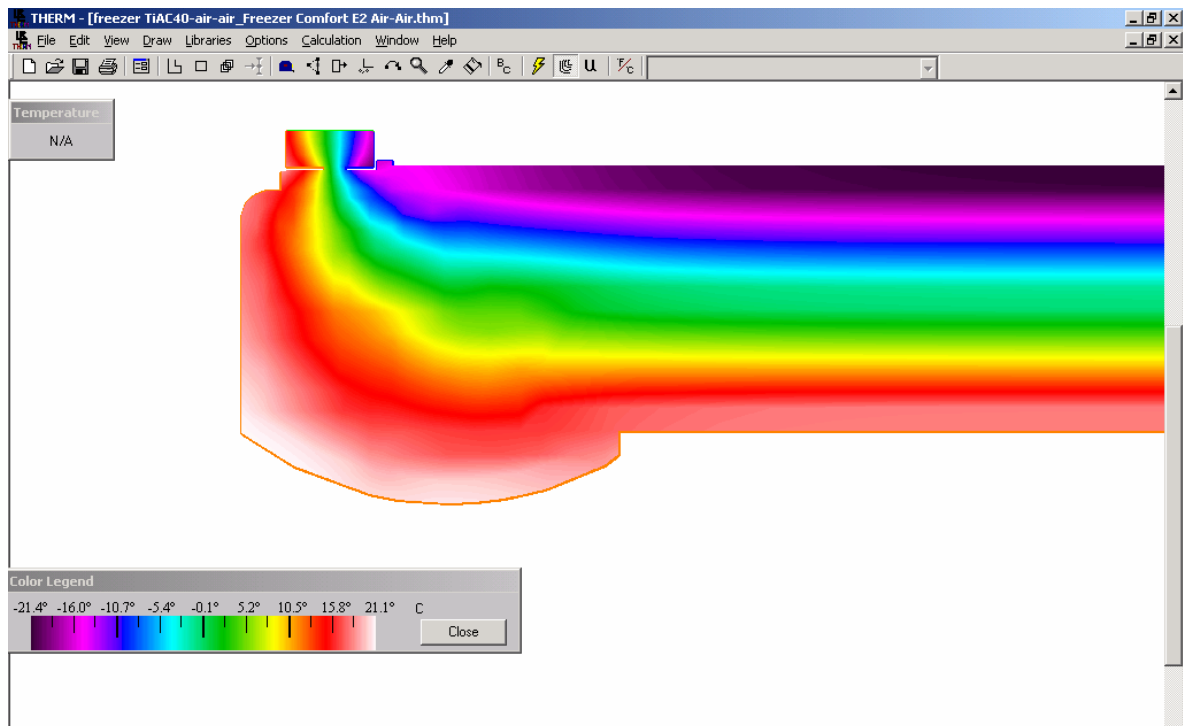


Figure 3. New frame design used with Comfort E2 glazing, with air fill in both internal interpane spaces.

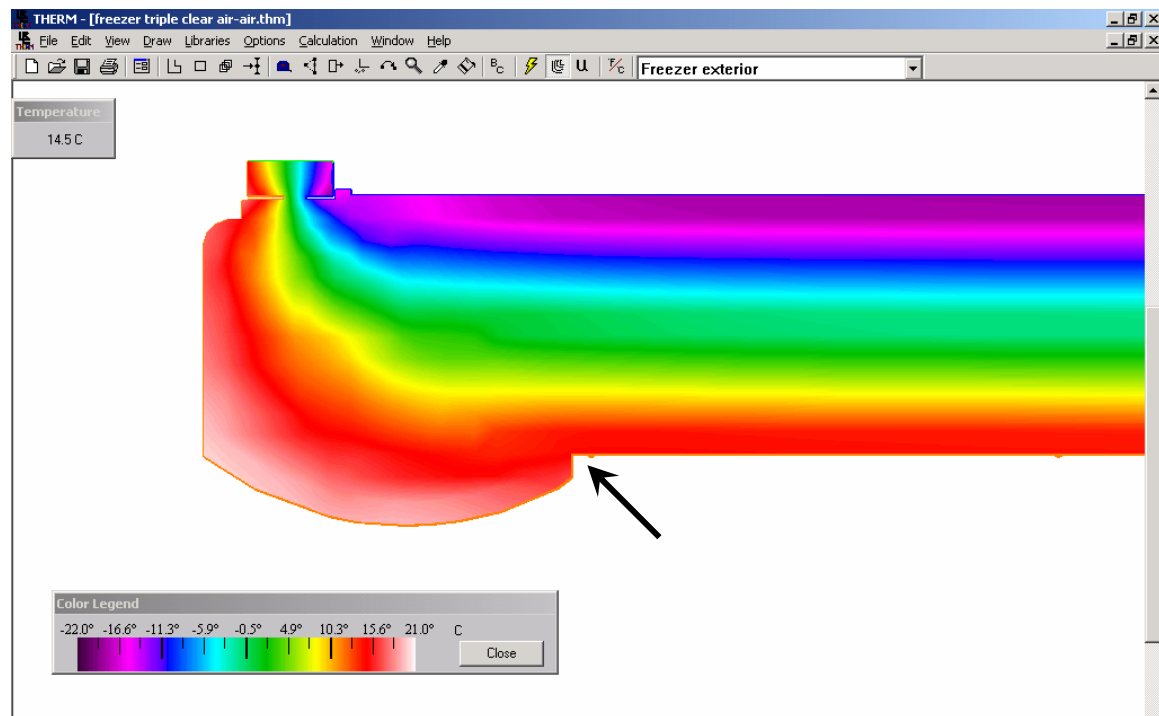


Figure 4. New frame design used with triple clear glass glazing, with air fill in both internal interpane spaces. Note the decreasing temperature at the glazing-frame junction (marked).

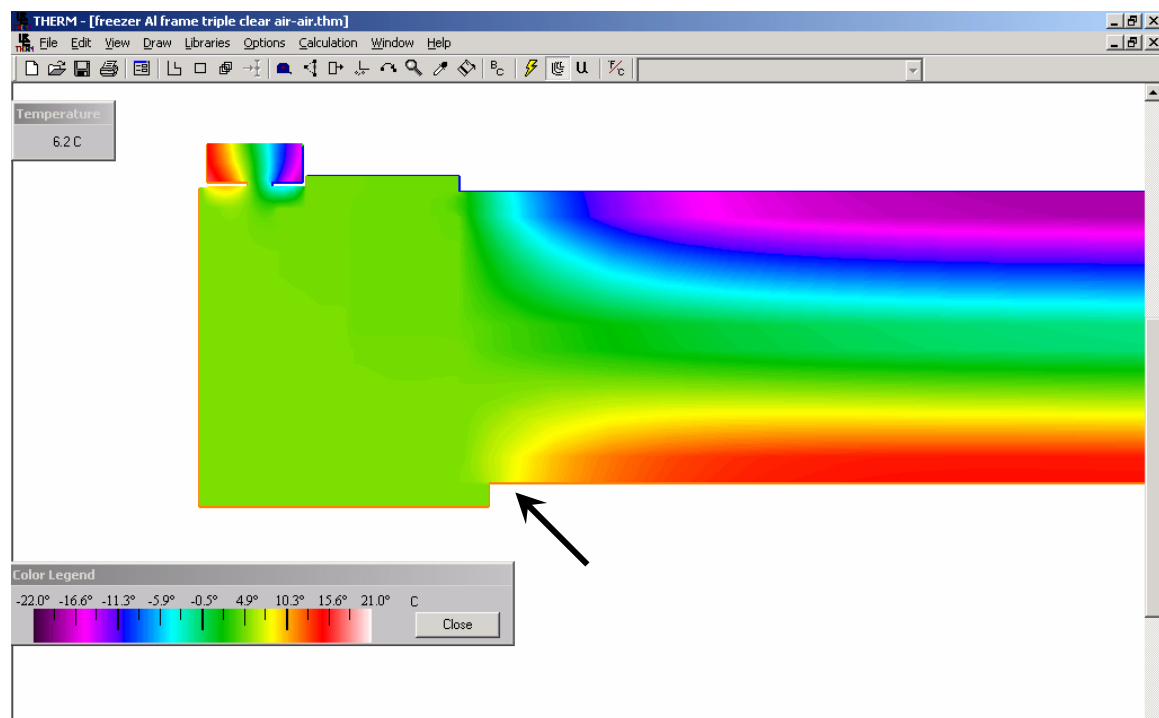
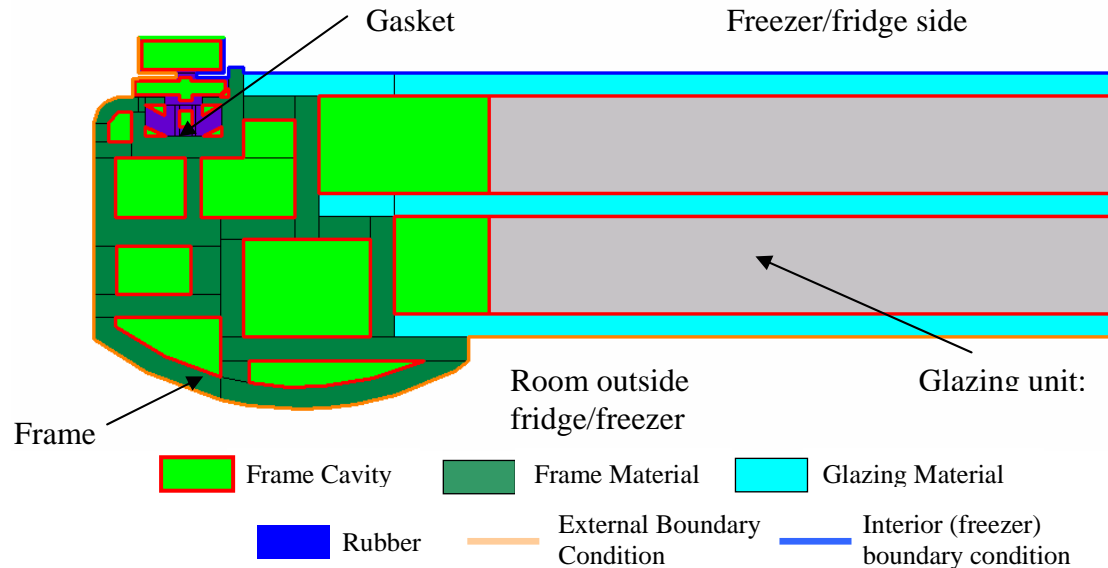


Figure 5. Al frame, with Al-glass spacers, frame design used with triple clear glass glazing, with air fill in both internal interpane spaces. Note the relatively low temperature at the glazing-frame junction (marked) and the very uniform temperature across the frame (owing to the high thermal conductivity of Al).

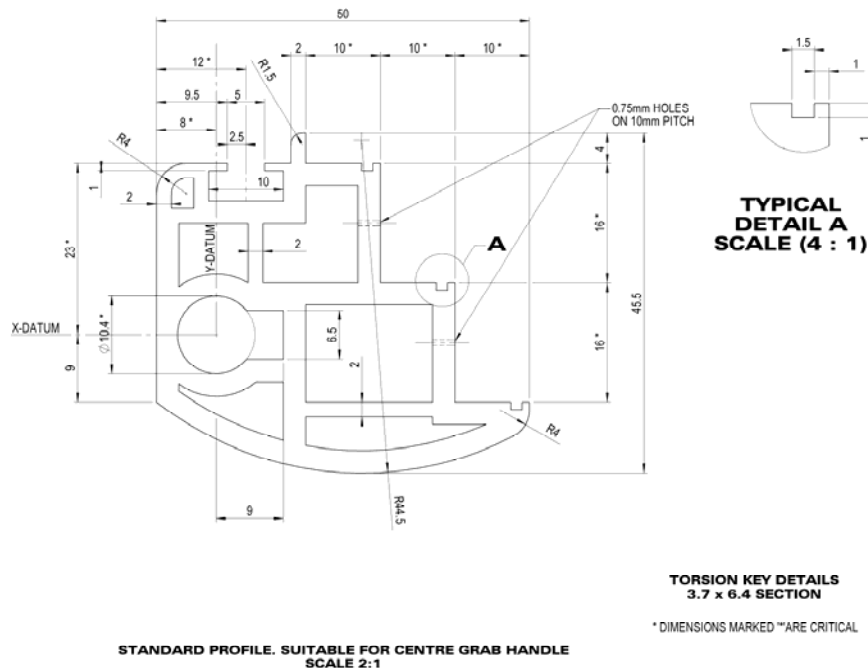
Associate Professor John Bell  
5 July 2004

## Appendix 1. The Door model and detailed structure

The basic frame and glazing model is illustrated in Figure A1-1, and the actual design is illustrated in Figure A1-2.



**Figure A1-1.** The modelled frame with glazing unit



**Figure A1-2** The actual frame design.

Owing to the constraints of the software, some very small deviations from the actual frame have been made in the model. The circular void with a keyway has been assumed to be rectangular, and associated curves in neighbouring voids have been neglected. From the modelling results (temperature isotherms and heat flow), changes in this area of the frame are not significant in terms of the failure criterion.

Note that in Figure 2, there are several components of the glazing system near the frame. This is because when a glazing system is imported into FRAME from WINDOW 5.2, the window is assumed to have equal sized pieces of glass. The additional elements of glass and frame cavity must be included to accurately reflect this design of glazing.

### Glazing Material Options and Parameters:

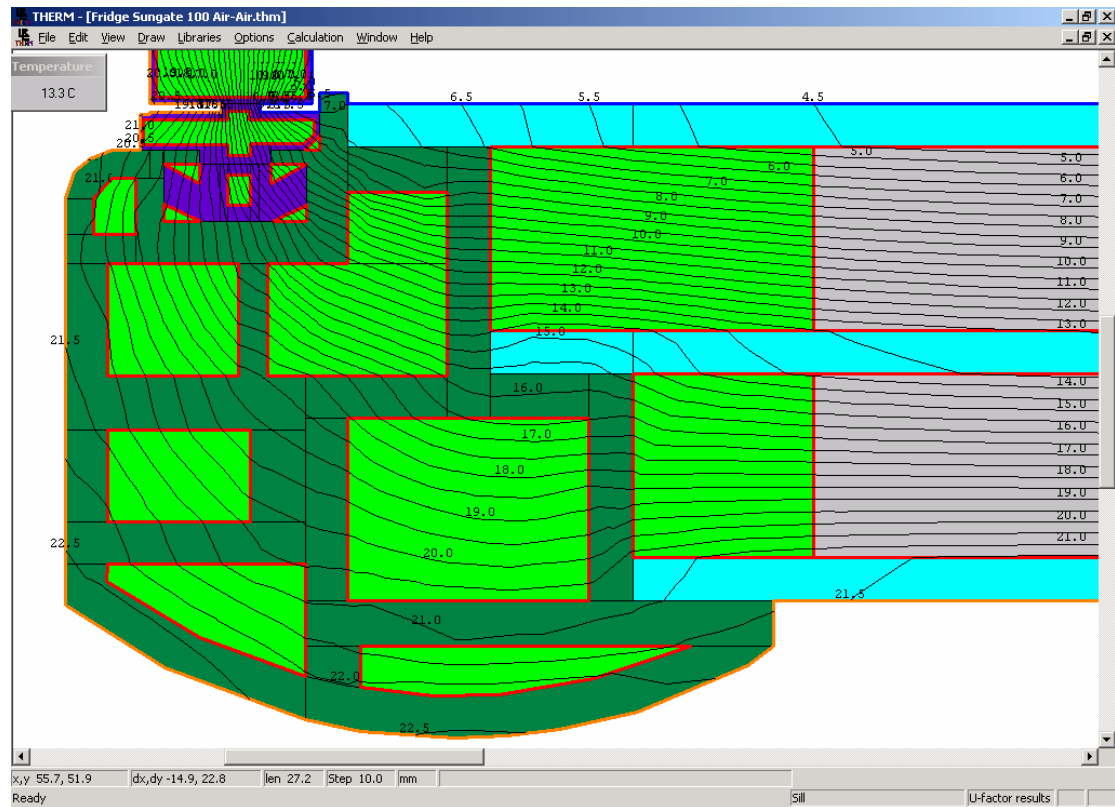
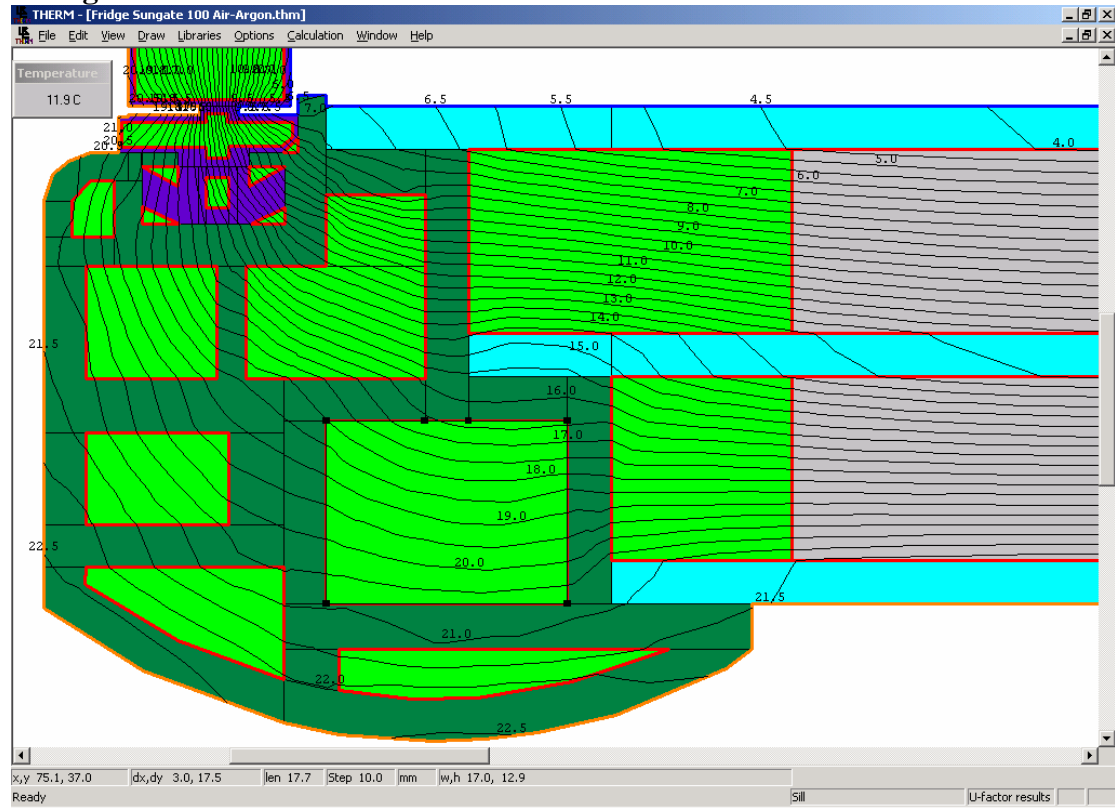
**Table A1-1. Glazing material parameters.**

Glass	Windows ID	K W/m <sup>2</sup> /K	T <sub>vis</sub> (%)	ε <sub>coated</sub>	ε <sub>glass</sub>	thickness (mm)	t* <sup>1</sup> (mm)
Clear Float	102	1.0	88.9	0.84	0.84	3.048	3.023
Energy Advantage	9921	1.0	82.4	0.156	0.84	3.023	3.023
TiAC40	960	1.0	77.9	0.041	0.84	3.023	3.023
Comfort Ti-R	925	1.0	78.0	0.033	0.84	3.175	3.023
Sungate 100	5142	1.0	82.7	0.096	0.84	3.277	3.023
Sungate 500	5242	1.0	83.3	0.113	0.84	3.277	3.023
Comfort E2	908	1.0	83.0	0.204	0.84	3.962	3.023
Plexiglass	2601	0.187	92.2	0.900	0.900	2.997	3.023

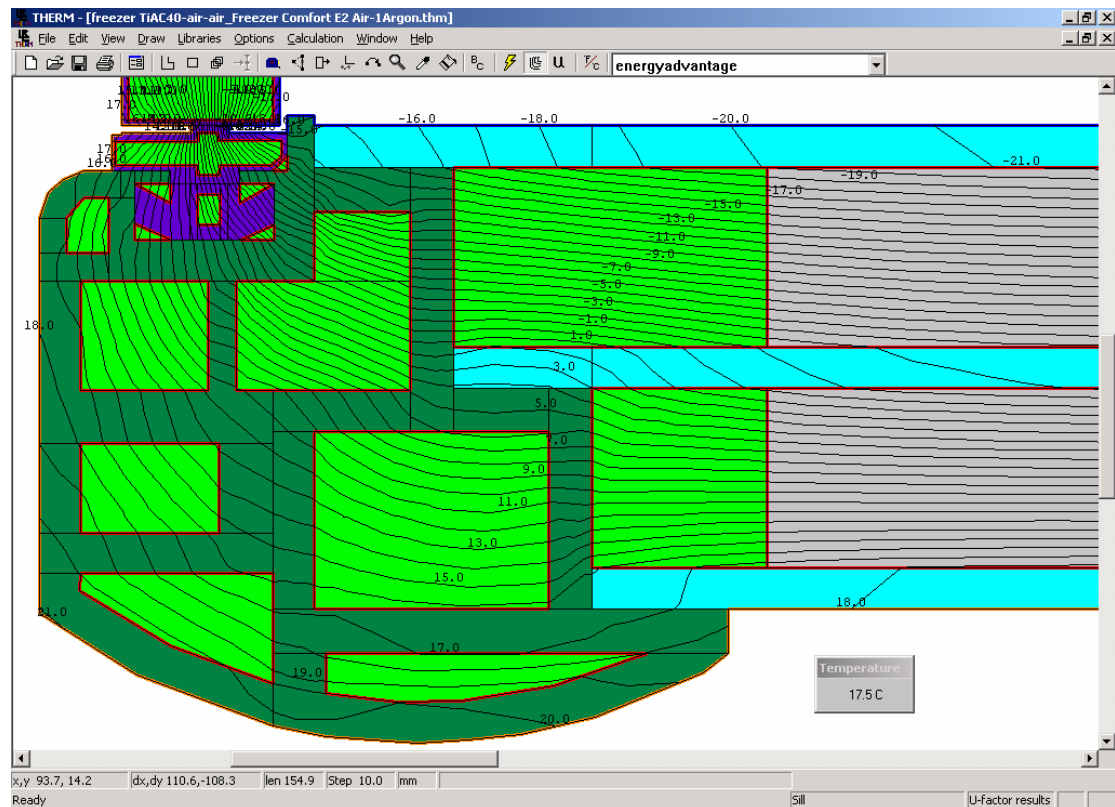
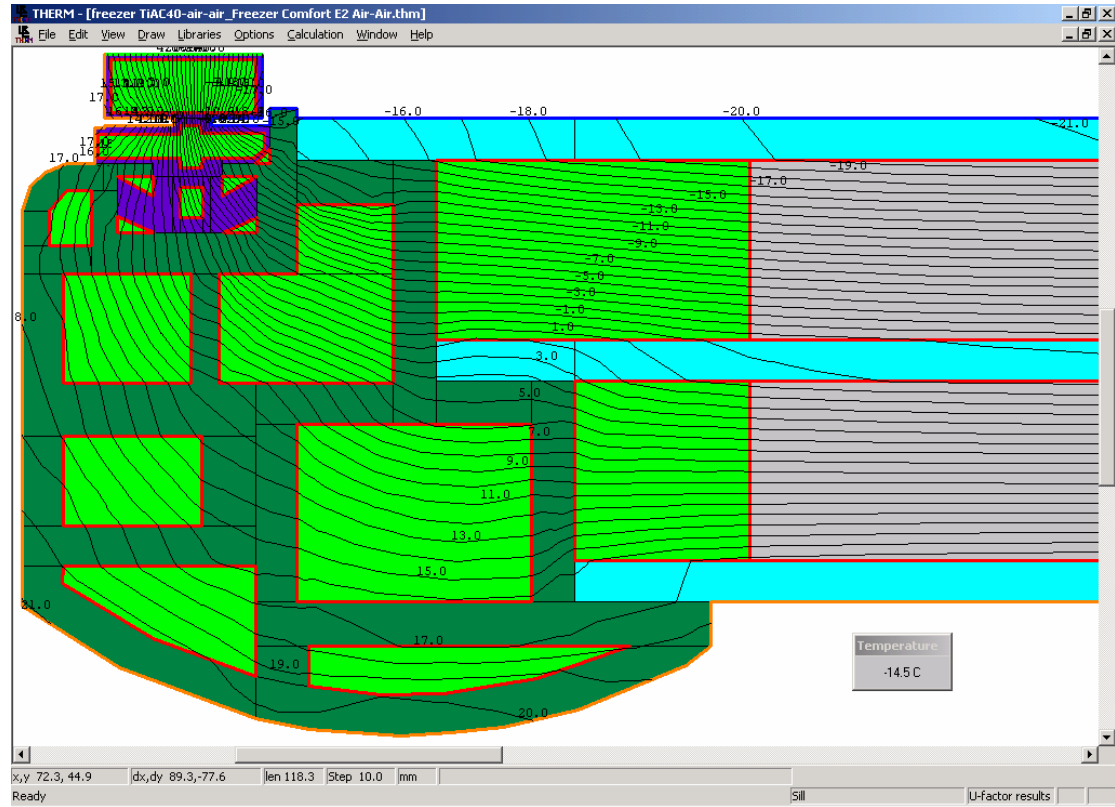
<sup>1</sup> The thickness t\* is the thickness used in Window 5.2 calculations of the glazing system, so that the glazing system could translate directly into the frame without adjusting spacing thickness. The differences are very small.

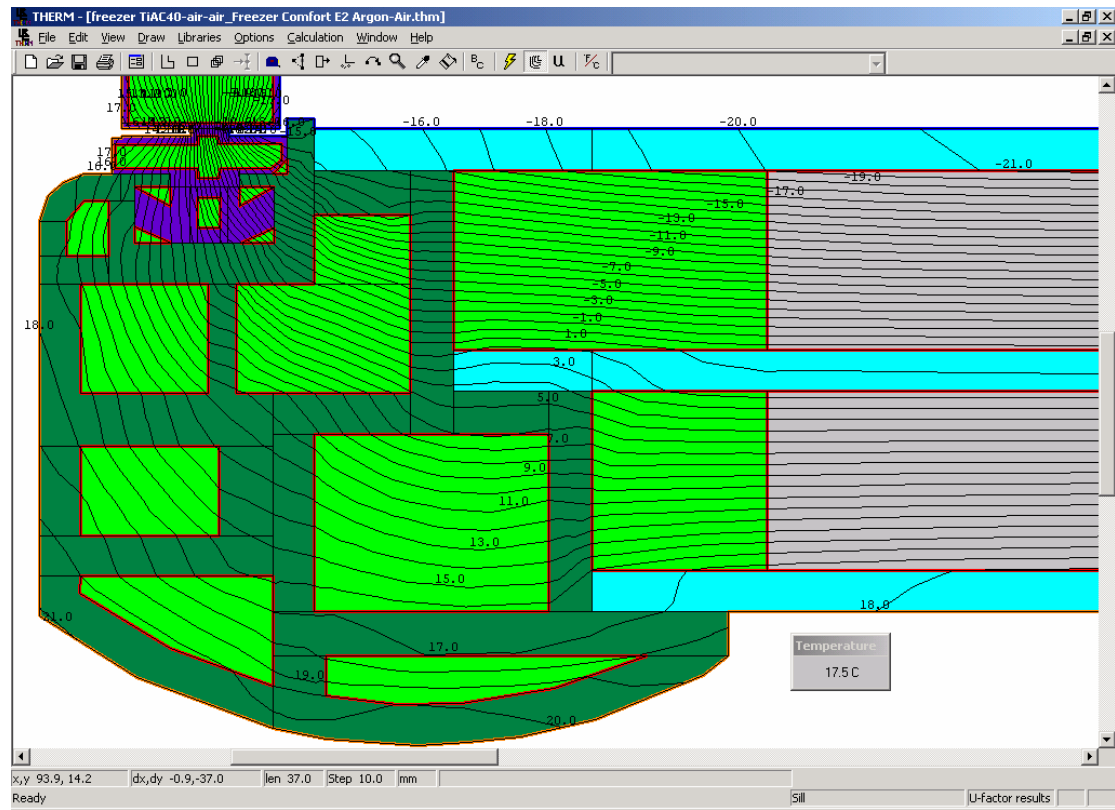
### Appendix 2 Isotherm data for various frame-glazing configurations

#### Refrigerator



### Freezer





## Appendix 2. THERM 5.2 Report on simulation.

Therm Version 5.2 (5.2.14)  
Date: Sat Jun 05 17:08:35 2004

Created by: John Bell  
Created for: Murray Pickford

Therm Filename: E:\John\Research  
Concentration\consulting\freezers\results\freezer TiAC40-air-air\_Freezer Comfort  
E2 Air-Air.thm  
Cross Section Type: Sill  
Underlay Name: E:\John\Research Concentration\consulting\freezers\profile1.bmp

## U-factors

Name	Length mm	Basis	U-factor W/m2-K
Frame	2.78	Unknown	1.2790
Edge	63.50	Unknown	1.1692

## Solid Materials

Name	Conductivity W/m-K	Emissivity
plexiglass	0.10	0.90
energyadvantage	1.00	0.16
Polyvinylchloride (PVC) / Viny l - Rigid*	0.17	0.90
Foam Rubber*	0.06	0.90

**NOTE: PVC thermal conductivity is 0.17W/m-K, while polystyrene thermal conductivity is 0.16W/m-K. PVC has been used to ensure a conservative estimate for ASA, which is not available in THERM.**

## Cavities

Name: Frame Cavity NFRC 100-2001\*  
Gas Fill: Air  
Convection Model: ISO 15099  
Radiation Model: Standard

Poly Keff ID Height W/m-K	Heat Cavity Flow Dir mm	Side 1		Side 2		Dimension		Nu #
		Temp C	Emis	Temp C	Emis	Horz. mm	Vert. mm	
26 0.0683	Horizontal N/A	6.90	0.90	16.42	0.84	12.86	17.00	1.09
44 0.0404	Horizontal N/A	1.53	0.90	16.66	0.20	13.00	12.70	1.14
14 0.0425	Horizontal N/A	-18.37	0.20	1.13	0.90	13.00	22.73	1.37
46 0.0509	Horizontal N/A	-0.99	0.96	8.48	0.90	7.95	12.63	1.00
55 0.0409	Up N/A	-4.15	0.90	-8.27	0.90	5.02	6.96	1.00
50 0.0353	Up N/A	17.03	0.90	13.85	0.90	3.85	2.87	1.00
48 0.0384	Horizontal N/A	17.22	0.90	19.41	0.90	2.99	19.89	1.00
177 0.0543	Up N/A	16.99	0.90	8.88	0.90	7.95	9.26	1.00
99 0.0495	Horizontal N/A	17.55	0.90	20.19	0.90	6.30	11.14	1.00
180 0.0566	Up N/A	18.85	0.90	14.10	0.90	6.48	10.01	1.00
164 0.0249	Horizontal N/A	-12.97	0.84	-9.72	0.90	0.75	0.72	1.00
42 0.0282	Up N/A	2.13	0.90	-3.20	0.90	0.81	1.69	1.00
52 0.0301	Up N/A	12.60	0.90	9.01	0.90	0.84	1.87	1.00

54 Up		13.59	0.90	9.46	0.90	0.98	1.79	1.00
0.0301	N/A							
60 Up		-2.56	0.90	-8.34	0.90	0.97	1.79	1.00
0.0279	N/A							
64 Up		11.47	0.85	-7.16	0.86	2.41	9.49	1.00
0.0455	N/A							
73 Up		15.57	0.85	-16.85	0.84	3.83	10.51	1.00
0.0473	N/A							
211 Up		5.93	0.90	1.57	0.90	2.16	1.62	1.00
0.0294	N/A							

## Glazing Systems

Name	COG	U-factor	Overall Thickness	Cavity Height
	W/m <sup>2</sup> -K		mm	mm
Freezer Comfort E2 Air-Air	1.08		35.04	1000.00

## Standard Boundary Conditions

None

## Advanced Boundary Conditions

Name	Convection		Const	Black Body	
	Temp	Film Coef	Flux Heat	Radiation View Fact	Temp
	C	W/m <sup>2</sup> -K	W/m <sup>2</sup>		C
Freezer exterior	24.00	4.800		1.00	24.00
freezer TiAC40-air-air_Freezer Comfort E2 Air-Air:freezer interior	-26.00	10.000		1.00	-26.00

## Calculation Specifications

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 Mesh Parameter : 6  
 Estimated Error: 7%  
 CR results available  
 Calculations done in Version 5.2 (5.2.14)