Appendix C: Additional Information to SANAE IV Energy Demand

C.1 Heating and Ventilation System Energy Audit

SANAE IV's Heating and Ventilation System (H&V System) is responsible for maintaining comfortable temperatures, humidity levels and good circulation of fresh air in the base. The system does not re-cycle any component of the heated inside air but instead uses only 100 % fresh outside-air. This is an expensive practice, since more heating energy is required, yet one often used in applications where health concerns are significant (such as in operating theatres at hospitals for instance). At SANAE IV the outside air is heated by air-handling units (AHUs), which transfer energy received from the FCU Water System to the fresh air blown in from the outside. Varying the speed of the AHU-fans that blow the outside air past the AHUs can therefore control the station's inside temperature. This is because the amount of energy passing from the FCU Water System into the air is regulated in this manner and the air can be heated to the exact temperature required to offset heat losses from the base.

Cencelli (2002) estimates that the amount of heat lost to the surroundings during summer and winter varies between 39 kW and 72 kW respectively, reaching up to 120 kW during very cold spells (also refer to paragraphs 4 and 5 of section 3.2.2). The processes of conduction through walls, radiative heat transfer and air leakage through poor seals or other openings ultimately cause this heat loss. Fortunately many appliances used in the base (such as computers, lights, kitchen appliances etc.) provide much of the required heat themselves, while the remainder is made up by heating outside air to the required temperature in the AHUs as explained above. With 100 % fresh-air ventilation requirements and the very low ambient temperatures in Antarctica this task of keeping the station warm is nonetheless extremely expensive.

A quick calculation will be performed to determine the energy required by the FCUs. Here Q is the heat load demanded by the H&V System [J] and ΔT is the necessary temperature difference [K] between the supply duct (at temperature T) and room conditions (at temperature T_{inside}).

$$\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T \qquad C.1$$

And,

$$T = \Delta T + T_{inside} \qquad C.2$$

Where T is the temperature of the H&V supply air. Therefore,

$$T = \frac{\dot{Q}}{\dot{m} \times C_p} + T_{inside} \qquad C.3$$

The air leaving the FCU and moving into the supply ducts must be heated from ambient to T, thus the amount of energy required to do this is:

$$\dot{Q}_{FCU} = \dot{m} \times C_p \times (T - T_{ambient}) \qquad C.4$$

However, using equation C.2 for T,

$$\dot{Q}_{FCU} = \dot{m} \times C_p ((\frac{\dot{Q}}{\dot{m} \times C_p} + T_{inside}) - T_{ambient}) \qquad C.5$$

From equation C.5 and values for the variables provided by Cencelli (also given in table C.1) graphs have been created and plotted in figure C.1. It is clear that the most energy-intensive part of the current system is that portion of heating required to bring the cold outside air to room temperature (the y-intercept). Consider the plot of the required FCU thermal summer contribution with 15 % re-circulation (by mass) for instance. A 15 % re-circulation results in a 55 % FCU energy demand reduction.

The present investigation also revealed that a direct link with mass flow-rate and energy requirements exists (i.e. a 10 % reduction or increase in mass flow-rate results in a corresponding 10 % reduction or increase in FCU energy requirements).

Table C.1: A-Block summer and winter conditions suggested by Cencelli (2002)

PARAMETER	SUMMER	WINTER
Estimated heat loss from base due to conduction etc. (kW)	12.6	24.1
Mass flow-rate of air through FCUs (kg/s)	3.23	1.87
Specific heat capacity of air (J/kg.K)	1008	1008
Inside temperature (°C)	22	18
Ambient Temperature (°C)	-10	-55

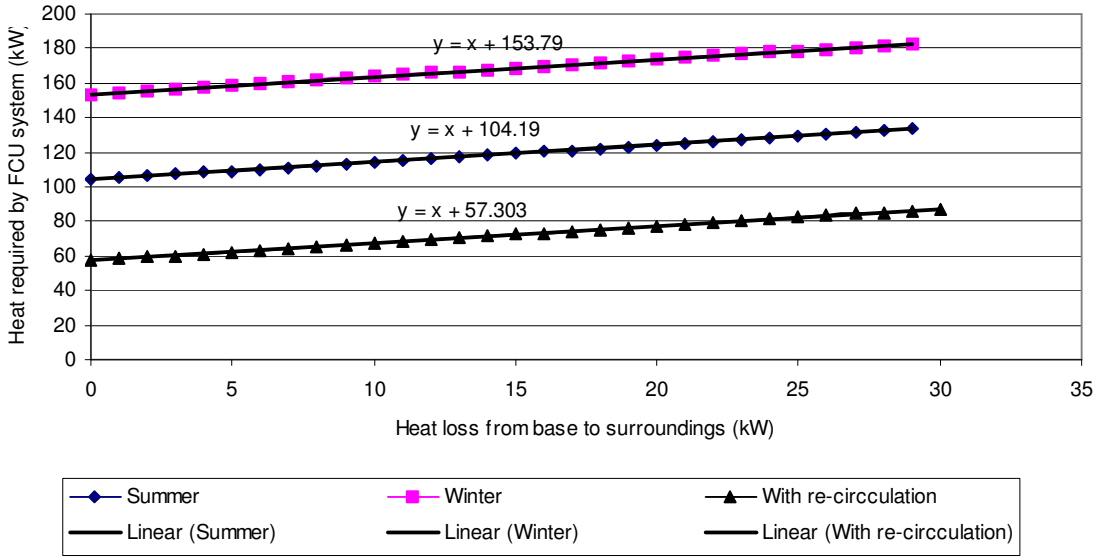


Figure C.1: Contribution required by A-Block FCU to compensate for heat losses from the base

Implementing re-circulation to reduce the FCU energy demand is not practical during the summer, however, even though it is well suited to winter conditions. During the summertime it is necessary to use the H&V System as a means of removing heat from the station (as described in section 3.2.2). A better energy-savings solution would be to control the mass flow-rate instead by running the current FCU-fans at a wider range of speeds in place of, as is currently the case (Cencelli, 2002), just two discreet settings. Furthermore, also note that the FCU-Water System does not presently operate at its set-point temperatures and requires adjustment.

From the discussion above and the information provided in section 3.2.2 it is evident that the H&V System is 180 degrees "out of phase" with the availability of solar energy. During the summer there is ample heat available from the generators to keep the base warm (in fact it is necessary to cool the base) while conversely the winter periods are characterised by cold inside temperatures. With the obvious lack of sunshine during the winter periods it is evident that the Heating and Ventilation System is not an ideal application for the utilisation of solar energy.

The above investigation was not meant as a comprehensive study, but rather as an introduction to the processes of the H&V System. This system is very complex and changes to it should only be considered while simultaneously accounting for the resultant effects on other systems in the station (like for instance the Primary Hot Water System). It is believed that updating the existing computer based simulation programme of SANAE IV (which is entirely separate from the

station's actual control systems and simply models a number of cause and effect relationships at the base) could be very useful in investigating and improving the current performance of SANAE IV.

An energy management and data capture system was once operational at the station, however, difficulties in maintaining the system's hardware have led to its decommissioning. The programme referred to in this instance however is unlike the energy management system and completely based in software. Utilisation of such a programme would mean, firstly, that the entire base operating system will become currently and technically documented. Secondly, this exercise would result in the identification of all the best opportunities for improvements at the base, with a resultant quantification of return on investment. Thirdly, the performance of the base could be monitored constantly and potential problems would therefore be identified soon. It is the opinion of the author that together with the opportunity of ensuring that the base does not lose any heat unnecessarily to the surroundings (through unsealed openings and cracks particularly at the hangar doors, seals around windows and any unplugged cable outlets) such a simulation programme poses a significant opportunity to generate savings.

As an aside, also note that the relative humidity of the base has for a long time been unsatisfactory (Cencelli, 2002). Due to the extremely cold temperatures water vapour in Antarctica tends to freeze and settle out as snow leaving the air dry and uncomfortable. Although humidifiers are installed in all three blocks of the station they exacerbate the problem of water shortages and for this reason are sometimes not used in the summer. However, they only consume a very low 500 W of electrical energy. If one could ensure a greater supply of water to the station then this system could be used more freely and would improve the living conditions at SANAE IV.

C.2 List of Electricity Consuming Devices in SANAE IV (Dec 2004)[¥]

Table C.2: A-Block electricity consumers

A-BLOCK			
SITUATED	**ITEM**	**QUANTITY**	**kW**
Science Lab Top			
	Computers	10	1.56
	Laptops	2	0.13
	Lights (9W)	2	0.02
	Lights (24W)	14	0.34
	Dome Heaters	3	2.50
	Skirting Heaters (0.75 kW)	4	3.00
	UPS	9 amps at 220V	1.56
Science Lab Bottom			
	Computers	10	1.56
	Laptops	4	0.22
	Lights (24W)	32	0.77
	Skirting Heaters (1.5 kW)	1	1.50
	Skirting Heaters (0.75 kW)	6	4.50
	UPS	14 amps at 220V	2.18
Top Passage			
	Lights (9W)	11	0.10
Stairwells			
	Lights (9W)	6	0.05
	Skirting Heaters (0.75 kW)	2	1.50
Top Bedrooms (17 in total)	Lights (9W)	36	0.32
	Lights (24W)	72	1.73
	Computers	0	0.00
	Laptops	6	0.39
	Skirting Heaters (0.75 kW)	18	13.50
Laundry			
	Lights (9W)	0	0.00
	Lights (24W)	8	0.19
	Tumble Dryer (5kW)	2	10.00
	Skirting Heaters (0.75 kW)	1	0.75
	Washing Machine (240V, 5Amps)	2	1.56
Top Men's Bathroom			
	Lights (9W)	14	0.13
Top Ladie's Bathroom			
	Lights (9W)	9	0.08
Bottom Passage			
	Lights (9W)	10	0.09
Bottom Rooms			
	Computers	13	2.02
	Laptops	6	0.39
	Fridge (230V, 0.87Amps)	1	0.14
	Lights (24W)	125	3.00
	Lights (9W)	15	0.14
	Skirting Heaters (0.75 kW)	25	18.75
AB-Link			
	Lights (9W)	27	0.24
	Lights (24W)	12	0.29
	Computers	1	0.16
	Skirting Heaters (1.5 kW)	3	4.50
Heating and Ventilation			
	Fan motor	1	2.20
	Humidifier	1	0.50
	Exhaust fans	1	2.50
	Extraction fan	1	2.50
	Operating theatre	1	0.18
Totals			
	Computers	**34**	**5.29**
	Laptops	**18**	**1.17**
	Lights (9W)	**130**	**1.17**
	Lights (24W)	**263**	**6.31**
	Skirting Heaters (1.5kW)	**4**	**6.00**
	Skirting Heaters (0.75kW)	**56**	**42.00**
	UPS	**14 Amps at 220V**	**2.18**
Graph			
	Heaters		**50.50**
	Lights		**7.48**
	Ventilation and humidification		**7.88**
	Washing machines and driers		**11.56**
	Computers and Laptops		**6.46**

[¥] All data presented in appendix C.2 was collected by the author during the 2004/2005 SANAE IV takeover.

Table C.3: B-Block electricity consumers

B-BLOCK			
SITUATED	**ITEM**	**QUANTITY**	**kW**
Top Passage			
	Lights (9W)	12	0.11
	Fridge (220V, 0.7 Amps)	1	0.11
	Freezer (220V, 0.7 Amps)	1	0.11
Stairwells			
	Lights (9W)	4	0.04
	Skirting Heaters (0.75 kW)	2	1.50
Top TV Lounge			
	Lights (24W)	12	0.29
	Skirting Heaters (0.75 kW)	2	1.50
Top Library			
	Lights (24W)	24	0.58
Top Stores			
	Lights (24W)	8	0.19
	Lights (9W)	4	0.04
	Skirting Heaters (0.75 kW)	2	1.50
Top Bedrooms (11 in total)	Lights (9W)	22	0.20
	Lights (24W)	44	1.06
	Laptops	2	0.13
	Skirting Heaters (0.75 kW)	11	8.25
Laundry			
	Lights (24W)	8	0.19
	Tumble Dryer	3	15.00
	Washing Machine (240V, 5Amps)	3	2.33
Top Men's Bathroom			
	Lights (9W)	20	0.18
Top Ladie's Bathroom			
	Lights (9W)	9	0.08
Bottom Passage			
	Lights (9W)	7	0.06
Bottom Stairwell Stores			
	Lights (9W)	6	0.05
Waste Room			
	Lights (24W)	18	0.43
	Lights (9W)	2	0.02
	Skirting Heaters (0.75 kW)	2	1.50
Bottom TV Lounge			
	Small Spotlights (50W, 2 Amps per 3 lights)	12	3.73
	Lights (24W)	12	0.29
	Skirting Heaters (0.75 kW)	2	1.50
Bottom Bar			
	Small Spotlights (50W, 2 Amps per 3 lights)	19	
	Lights (9W)	1	0.01
	Skirting Heaters (0.75 kW)	1	0.75
	Ice Maker		
	Refrigerator		
Bottom Games Room			
	Small Spotlights (50W, 2 Amps per 3 lights)	2	
	Lights (24W)	31	0.74
	Skirting Heaters (0.75 kW)	2	1.50
Dry Room Store			
	Lights (24W)	15	0.36
	Skirting Heaters (0.75 kW)	2	1.50
Freezer Room			
	Lights (9W)	18	0.16
	Refrigeration Equipment		
	10 HorseP Compressor	*7.46kW*	
	Condensation Fan	*0.37kW*	
	Evaporation Fans	*0.467kW x 3*	
	3/4 HP Compressor	*5.56kW*	
	Evaporation Fans	*0.778kW x 2*	
	Condensation Fan	*0.2kW*	
	Total		11.546
Kitchen			
	Lights (24W)	10	0.24
	Convection Oven (6.5 kW per phase)	1	19.50
	Deep Frier (12kW)	1	12.00
	Snackwich Machine	1	3.00
	Heating Plates (3kW)	1	3.00
	Solid Top Oven (6kW /phase)	1	18.00
	Electric Mixer	2	0.66
	Defy Oven (16 Amps)	1	2.49
Dining Room			
	Lights (9W)	48	0.43
	Skirting Heaters (0.75kW)	6	4.50
	Ice Maker	1	1.00
	Microwave (1.3kW)	1	1.30
	Fridge (0.7 Amp)	1	0.70
	Toaster (3.15 kW)	1	3.15
	Baine Marie	1	2.50
	Drinking Fountain	1	0.20
	Snackwich Machine (2.5kW)	1	2.50
BC-Link			
	Lights (9W)	27	0.24
	Lights (24W)	14	0.34
	Skirting Heaters (1.5 kW)	4	6.00
Heating and Ventilation			
	Fan motor	1	2.20
	Humidifier	1	0.50
	Exhaust fans	2	5.00
	Fresh air supply (kitchen)	1	5.00
	Extraction fan	1	2.50
Totals			
	Lights (9W)	**180**	**1.62**
	Lights (24W)	**196**	**4.70**
	Small Spotlights (50W)	**33**	**10.27**
	Skirting Heaters (0.75kW)	**36**	**27.00**
	Panel Heaters (1.5kW)	**4**	**6.00**
	Freezer Room	**1**	**11.546**
	Kitchen Equipment	**1**	**58.65**
Graph			
	Heaters		**33.00**
	Lights		**16.59**
	Ventilation and Humidification		**15.20**
	Washing machines and driers		**17.33**
	Freezer Room		**11.546**
	Dining Room		**11.35**
	Kitchen		**58.65**

Table C.4: C-Block electricity consumers

C-BLOCK			
SITUATED	**ITEM**	**QUANTITY**	**kW**
Gym			
	Lights (24W)	14	
	Lights (9W)	4	
	Skirting Heaters (0.75W)	4	
Upstairs Passage			
	Lights (9W)	22	
Upstairs Lab			
	Lights (24W)	4	
Upstairs Offices			
	Lights (24W)	22	
	Lights (9W)	0	
	Laptops	2	
	Computers	3	
	Skirting Heaters (0.75W)	3	
Upstairs Stores			
	Lights (24W)	28	
	Lights (65W)	4	
Sauna			
	Lights (24W)	2	
	Lights (9W)	2	
	Sauna (12kW)	1	12.00
Hanger			
	Lights (24W)	32	
Plant Room			
	Lights (24W)	32	
	Lights (58W)	8	
Welding Room			
	Lights (24W)	14	
	Lights (58W)	4	
Daytank Room			
	Lights (20W)	2	
Cat Store			
	Lights (24W)	12	
Sewage Plant			
	Lights (20W)	6	
Downstairs Passage			
	Lights (9W)	3	
Heating and Ventilation			
	Fan motor	1	1.10
	Humidifier	1	0.50
	Exhaust motor (W. purification)	1	2.30
	Hangar Extraction	1	1.10
	Exhaust fan (plantroom)	1	2.20
	Hangar Rejection Unit	1	4.00
Miscellaneous			
	Water purification plant	1	6.75
	Fire System	1	0.08
	Radio Room	1	3.30
Plant Room			
	Primary Hot Water pumps	2	4.00
	Domestic Hot Water pumps	2	1.10
	FCU Water pumps	2	7.50
	Cold Water pumps	2	4.00
Inline heaters			
	Cold water system	1	15.00
	Hot water system	1	15.00
	FCU system	1	90.00
Totals			
	Lights (9W)	**31**	**0.28**
	Lights (20W)	**8**	**0.16**
	Lights (24W)	**160**	**3.84**
	Lights (58W)	**12**	**0.70**
	Lights (65W)	**4**	**0.26**
	Skirting Heaters (0.75kW)	**7**	**5.25**
Graph			
	Heaters		**5.25**
	Lights		**5.24**
	Ventilation and humidification		**11.20**
	Sauna		**12.00**
	Plant room		**16.60**
	Inline heaters		**120.00**
	Snow Smelter		**94.00**

C.3 Graphical Representation of C2 (Electricity Consumption)[¥]

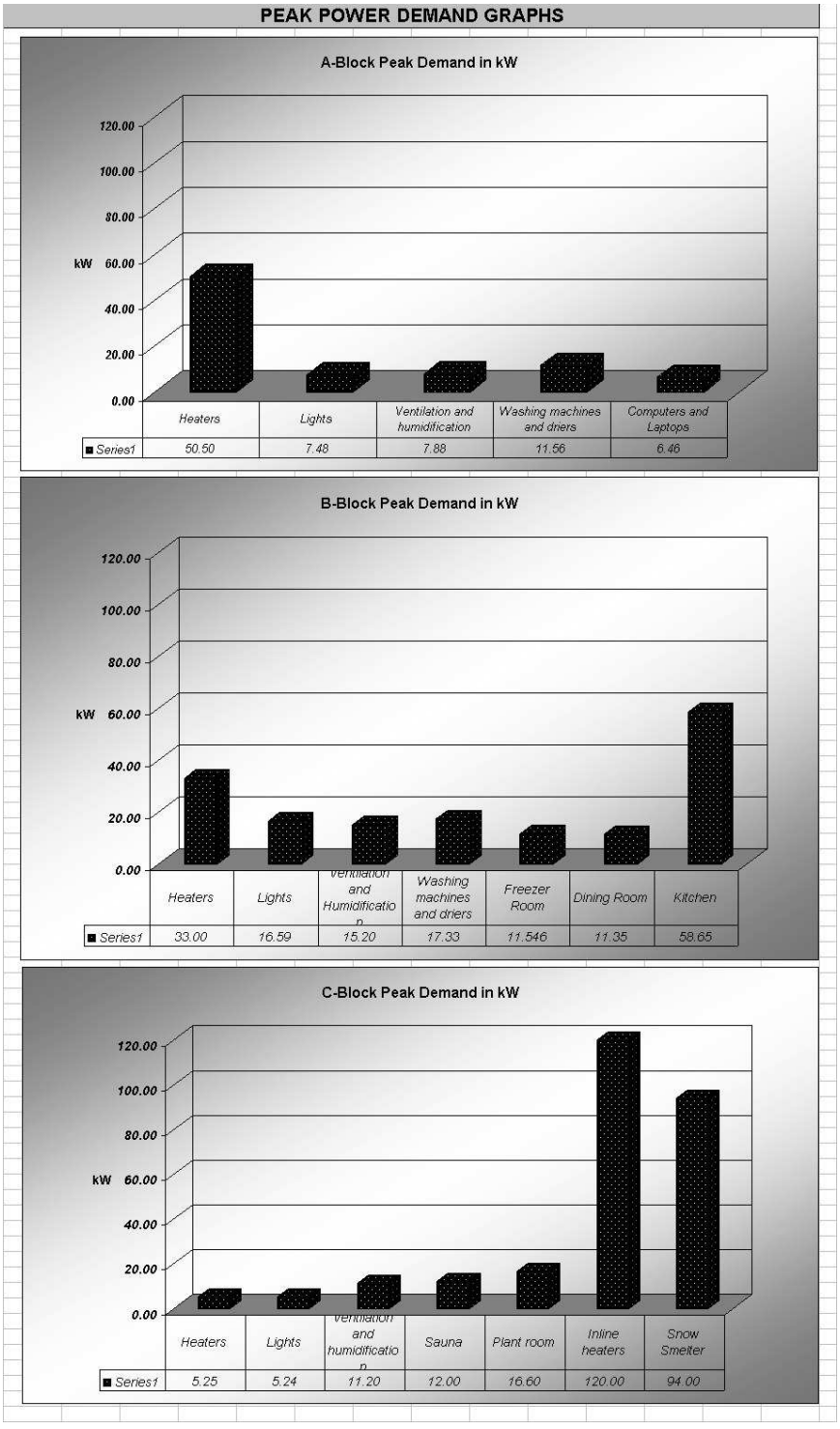


Figure C.2: Graphs of electricity consumers in each block

[¥] All data presented in appendix C.3 was collected by the author during the 2004/2005 SANAE IV takeover.

C.4 Assimilated Data on Generator Output (used for determining load profiles)

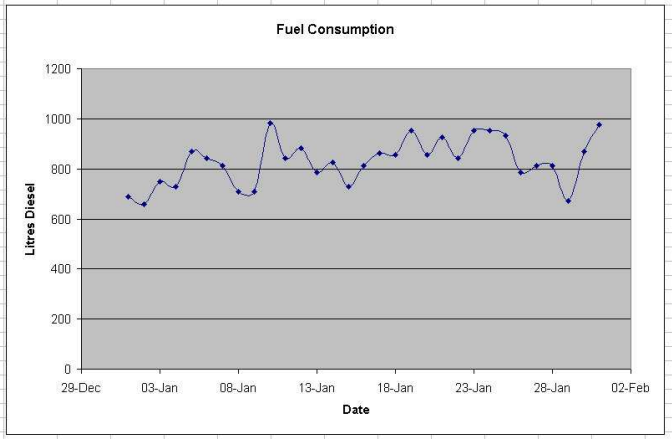
Table C.5: Data collected on generator load profiles

HISTORICAL AND RECORDED SUMMER TAKEOVER GENERATOR DATA													
Previous load profile measurements (Cencelli 2002, Taylor 2002, Teetz 2002, Olivier 2004)											Everyone's Average		
Time	Cencelli				Taylor		Teetz	Olivier			MIN	TIME	AVG
0.00	165.00	131.00	131.00				165.00	123.30	105.00		105.00	0.00	136.72
0.02								112.00	90.00		90.00		
0.04	175.00	125.00	118.00	170.00			150.00	138.00	80.00		80.00	0.04	136.57
0.06								140.00	84.30		84.30		
0.08	176.00	120.00	118.00	180.00			135.00	142.50	87.00		87.00	0.08	136.93
0.10								138.00	84.30		84.30		
0.13	162.00	118.00	118.00	113.00			125.00	128.00	83.00		83.00	0.13	121.00
0.15									85.00		85.00		
0.17	137.00	118.00	118.00	124.00			122.00		77.80		77.80	0.17	116.13
0.19									78.80		78.80		
0.21	113.00	125.00	125.00	131.00			122.00		82.00		82.00	0.21	116.33
0.23									98.50		98.50		
0.25	110.00	113.00	113.00	130.00			122.00		90.00		90.00	0.25	113.00
0.27									92.00		92.00		
0.29	110.00	106.00	106.00	131.00	130.00	130.00	122.00		87.00		87.00	0.29	115.25
0.31									89.00		89.00		
0.33	110.00	106.00	106.00	131.00	112.00	112.00	130.00		100.00	132.00	100.00	0.33	115.44
0.35									100.00	125.00	100.00		
0.38	110.00	113.00	113.00	134.00	160.00	155.00	142.00	103.00	71.50	130.00	71.50	0.38	123.15
0.40								146.50	148.00	101.00	101.00		
0.42	112.50	120.00	120.00	126.00	168.00	175.00	158.00	150.00	160.30	104.00	104.00	0.42	139.38
0.44								142.00	160.00	142.50	142.00		
0.46	113.00	125.00	125.00	119.00	159.00	162.00	162.00	118.00	178.00	142.50	113.00	0.46	140.35
0.48								172.00	175.00	160.00	160.00		
0.50	130.00	125.00	125.00	156.00	150.00	110.00	161.00	118.00	150.00	133.50	110.00	0.50	135.85
0.52								142.50	139.00	166.00	139.00		
0.54	177.00	118.00	118.00	194.00	145.00	162.00	165.00	137.00	115.00	143.33	115.00	0.54	147.43
0.56								133.80	112.00	142.00	112.00		
0.58	174.00	113.00	113.00	194.00	140.00	165.00	150.00	148.00	96.80	151.00	96.80	0.58	144.48
0.60								142.00	96.80	157.67	96.80		
0.63	170.00	112.00	112.00	156.00	158.00	150.00	140.00	154.00	138.00	167.00	112.00	0.63	145.70
0.65								126.50	150.00	156.40	126.50		
0.67	175.00	106.00	106.00	135.00	135.00	148.00	140.00	112.00	170.00	156.50	106.00	0.67	138.35
0.69								106.00	163.30		106.00		
0.71	180.00	104.00	104.00	152.00	150.00	140.00	150.00	132.80	120.00	137.50	104.00	0.71	137.03
0.73								135.50	87.50		87.50		
0.75	187.00	108.00	108.00	156.00	152.00	155.00	155.00	135.30	101.00		101.00	0.75	139.70
0.77								142.00	142.50	145.50	142.00		
0.79	194.00	120.00	120.00	152.00	148.00	155.00	158.00	145.00	150.00	138.00	120.00	0.79	148.00
0.81								149.00	130.00	156.50	130.00		
0.83	187.00	145.00	145.00	152.00	132.00	144.00	158.00	145.00	136.50		132.00	0.83	149.39
0.85								137.00	130.00	150.00	130.00		
0.88	194.00	152.00	152.00				165.00	145.00	121.00		121.00	0.88	154.83
0.90								136.00	116.00		116.00		
0.92	187.00	132.00	132.00				165.00	151.00	117.50		117.50	0.92	147.42
0.94								155.50	120.00	121.00	120.00		
0.96	170.00	112.00	112.00				158.00	138.00	121.00	145.00	112.00	0.96	136.57
0.98								141.00	113.00	147.00	113.00		
AVG	154.94	119.46	119.08	146.80	145.64	147.36	146.67	136.79	115.07	142.04	105.24	0.48	134.79
MAX	194.00	152.00	152.00	194.00	168.00	175.00	165.00	172.00	178.00	167.00	160.00	0.96	154.83
MIN	110.00	104.00	104.00	113.00	112.00	110.00	122.00	103.00	71.50	101.00	71.50	0.00	113.00

C.5 Generator Diesel Consumption at SANAE IV[¥]

DIESEL DEMAND for JANUARY 2005

FUEL CONSUMPTION				
DATE	BEFORE	AFTER	DIFFERENCE	LITERS
01-Jan	450	204	246	689.784
02-Jan	445	210	235	658.94
03-Jan	477	210	267	748.668
04-Jan	460	200	260	729.04
05-Jan	515	205	310	869.24
06-Jan	510	210	300	841.2
07-Jan	505	215	290	813.16
08-Jan	472.5	220	252.5	708.01
09-Jan	472.5	220	252.5	708.01
10-Jan	560	210	350	981.4
11-Jan	515	215	300	841.2
12-Jan	530	215	315	883.26
13-Jan	490	210	280	785.12
14-Jan	510	215	295	827.18
15-Jan	470	210	260	729.04
16-Jan	500	210	290	813.16
17-Jan	522	215	307	860.828
18-Jan	520	215	305	855.22
19-Jan	555	215	340	953.36
20-Jan	520	215	305	855.22
21-Jan	540	210	330	925.32
22-Jan	510	210	300	841.2
23-Jan	550	210	340	953.36
24-Jan	550	210	340	953.36
25-Jan	532	200	332	930.928
26-Jan	490	210	280	785.12
27-Jan	500	210	290	813.16
28-Jan	500	210	290	813.16
29-Jan	450	210	240	672.96
30-Jan	520	210	310	869.24
31-Jan	553	205	348	975.792



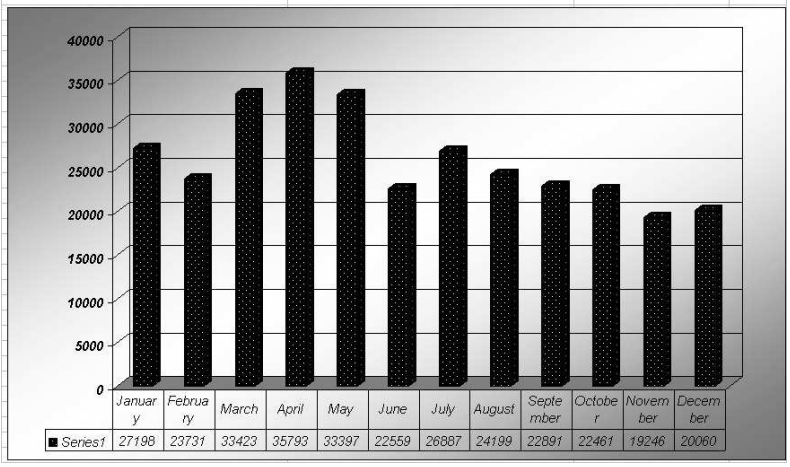
DIESEL DEMAND for 2004

MONTH OF 2004	LITERS DIESEL CONSUMED IN MONTH	MEAN MONTHLY Temp
January	27198	-5.7
February	23731	-9.1
March	33423	-14.3
April	35793	-19.8
May	33397	-22
June	22559	-21.5
July	26887	-25.4
August	24199	-24
September	22891	-22.3
October	22461	-16.6
November	19246	-13.1
December	20060	
Total	**311845**	

Mechanical Engineer's Report		
30-Nov	Bunker diesel remaining on 30 November: 92000 liter	2,3,4 depleted and 5 online
30-Oct		1,2,3,4 depleted and 5 online
30-Sep		1,2,3,4 depleted and 5 online
30-Aug		1,2,3 depleted and 4 online
30-Jul		1,2,3 depleted and 4 online
30-Jun		2 depleted and 3 online
30-May		2 depleted and 3 online
30-Apr		2 depleted and 3 online
30-Mar		1 depleted and 2 online
30-Feb		1 online

380 000 liters received during 2003/2004 takeover
470 000 liters received during 2004/2005 takeover

kWh Readings in 2004	**kWh**	**Difference in kWh**	**Avg**
12-Jun	8076800		
01-Jul	8129060	52260	120.9722
31-Jul	8221740	92680	124.5699



[¥] All data presented in appendix C.5 was collected by the author during the 2004/2005 SANAE IV takeover.

DIESEL DEMAND OF THE BASE

MONTH OF 2000	LITERS DIESEL CONSUMED IN THAT MONTH
Jan	26460
Feb	22960
Mar	28311
Apr	25956
May	26180
Jun	22652
Jul	23352
Aug	21938
Sep	26740
Oct	25550
Nov	23324
Dec	22450
Total	**295873**

MONTH OF 2001	LITERS DIESEL CONSUMED IN THAT MONTH
Jan	25119
Feb	18332
Mar	23680
Apr	23394
May	26250
Jun	25354
Jul	30338
Aug	29019
Sep	28378
Oct	26012
Nov	21350
Dec	21190
Total	**273297**

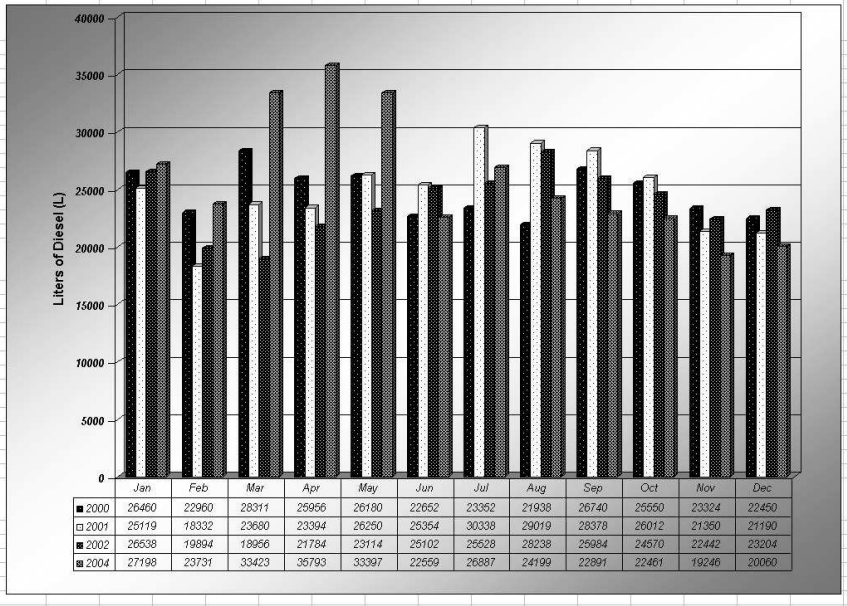
MONTH OF 2002	LITERS DIESEL CONSUMED IN THAT MONTH
Jan	26538
Feb	19894
Mar	18956
Apr	21784
May	23114
Jun	25102
Jul	25528
Aug	28238
Sep	25984
Oct	24570
Nov	22442
Dec	23204
Total	**285354**

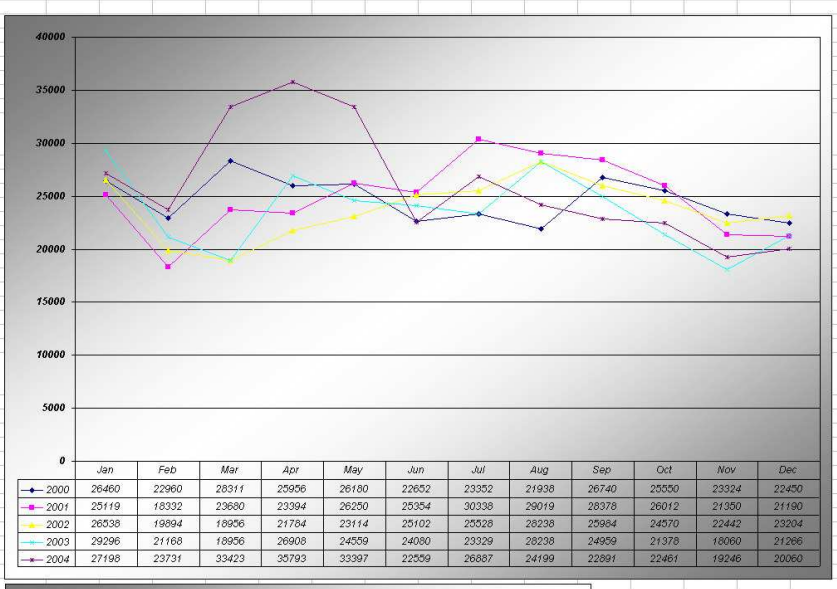
MONTH OF 2003	LITERS DIESEL CONSUMED IN THAT MONTH	Questionable Data (Ommitted)
Jan	29296	
Feb	21168	
Mar	18956	
Apr	26908	
May	24559	
Jun	24080	
Jul	23329	
Aug	28238	
Sep	24959	
Oct	21378	
Nov	18060	
Dec	21266	
Total	**282197**	

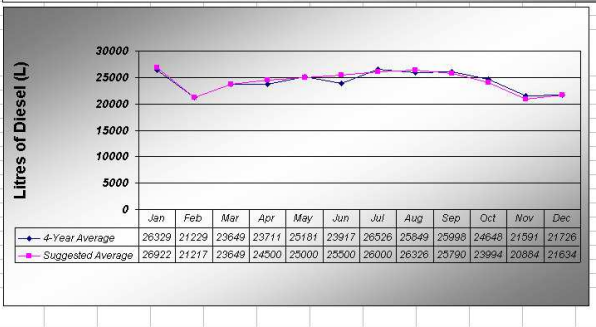
MONTH OF 2004	LITERS DIESEL CONSUMED IN THAT MONTH
Jan	27198
Feb	23731
Mar	33423
Apr	35793
May	33397
Jun	22559
Jul	26887
Aug	24199
Sep	22891
Oct	22461
Nov	19246
Dec	20060
Total	**311845**

AVERAGE (WITHOUT OUTLIERS)	LITRES DIESEL CONSUMED IN THAT MONTH	
Jan	26329	26922
Feb	21229	21217
Mar	23649	23649
Apr	23711	24500
May	25181	25000
Jun	23917	25500
Jul	26526	26000
Aug	25849	26326
Sep	25998	25790
Oct	24648	23994
Nov	21591	20884
Dec	21726	21634
Total	290354	288617

AVERAGE (ALL DATA)	LITRES DIESEL CONSUMED IN THAT MONTH
Jan	26328.75
Feb	21229.25
Mar	26092.5
Apr	26731.75
May	27235.25
Jun	23916.75
Jul	26526.25
Aug	25848.5
Sep	25998.25
Oct	24648.25
Nov	21590.5
Dec	21726
Total	**297872**







C.6 Associated Amounts of Generator Diesel Consumption and Electrical Output[¥]

Table C.6: Generator diesel consumption and electrical power generation

Jan-05					
DATE	TIME	kWh reading	kWh used	Average kW	
06-Jan		43064.90			
16-Jan	23h48	43207.16	28452	118.55	
17-Jan	23h30	43220.85	2738	115.28	
18-Jan	21h45	43235.20	2870	128.99	
19-Jan	22h00	43251.37	3234	133.36	
21-Jan	22h00	43281.59	6044.00	125.92	
22-Jan	22h00	43297.20	3122	130.08	
23-Jan	17h09	43309.80	2520	134.04	
24-Jan	17h15	43325.75	3190	132.92	
25-Jan	19h00	43341.00	3050	118.45	
26-Jan				119.58	
27-Jan				119.58	
28-Jan	19h00	43384.05	8610.00	119.58	
29-Jan	17h15	43395.25	2240.00	100.67	
30-Jan				128.25	
31-Jan	18h30	43425.55	6060.00	128.25	
01-Feb					
02-Feb					
03-Feb					
04-Feb					
05-Feb					
06-Feb					

Coincides with diesel consumption

June to August 2004				
DATE	kWh reading	kWh used	Liters diesel used	Average kW
12-Jun	40384.00			
17-Jun	40449.35	13070.00	3650.90	108.92
18-Jun	40462.30	2590.00	687.00	107.92
19-Jun	40475.10	2560.00	707.00	106.67
20-Jun	40486.70	2320.00	656.00	96.67
24-Jun	40542.20	11100.00	3177.00	115.63
25-Jun	40556.80	2920.00	861.00	121.67
26-Jun	40571.50	2940.00	827.00	122.50
27-Jun	40584.50	2600.00	757.00	108.33
28-Jun	40599.20	2940.00	805.00	122.50
29-Jun	40613.40	2840.00	813.00	118.33
30-Jun	40627.80	2880.00	810.00	120.00
01-Jul	40645.30	3500.00	967.00	145.83
02-Jul	40664.50	3840.00	1138.00	160.00
03-Jul	40680.55	3210.00	920.00	133.75
04-Jul	40695.75	3040.00	827.00	126.67
05-Jul	40710.55	2960.00	827.00	123.33
06-Jul	40725.55	3000.00	850.00	125.00
12-Jul	40819.50	18790.00	5201.00	130.49
13-Jul	40834.60	3020.00	869.00	125.83
14-Jul	40848.75	2830.00	757.00	117.92
15-Jul	40863.60	2970.00	791.00	123.75
16-Jul	40876.80	2640.00	782.00	110.00
17-Jul	40892.10	3060.00	875.00	127.50
18-Jul	40907.30	3040.00	841.00	126.67
20-Jul	40937.35	6010.00	1649.00	125.21
21-Jul	40950.40	2610.00	732.00	108.75
23-Jul	40983.60	6640.00	1825.00	138.33
24-Jul	41002.40	3760.00	1175.00	156.67
25-Jul	41018.20	3160.00	875.00	131.67
26-Jul	41032.40	2840.00	794.00	118.33
27-Jul	41046.70	2860.00	765.00	119.17
28-Jul	41061.20	2900.00	819.00	120.83
29-Jul	41077.10	3180.00	878.00	132.50
30-Jul	41093.70	3320.00	892.00	138.33
31-Jul	41108.70	3000.00	838.00	125.00
02-Aug	41136.20	5500.00	1559.00	114.58
03-Aug	41150.85	2930.00	813.00	122.08
04-Aug	41166.10	3050.00	841.00	127.08
05-Aug	41180.10	2800.00	780.00	116.67
06-Aug	41193.60	2700.00	757.00	112.50
07-Aug	41208.10	2900.00	819.00	120.83
08-Aug	41227.50	3880.00	794.00	161.67
09-Aug	41239.00	2300.00	1090.80	95.83
10-Aug	41254.10	3020.00	679.00	125.83
12-Aug	41283.70	5920.00	1601.00	123.33
13-Aug	41297.65	2790.00	847.00	116.25
14-Aug	41312.00	2870.00	802.00	119.58
16-Aug	41339.80	5560.00	1581.00	115.83
17-Aug	41352.20	2480.00	701.00	103.33
18-Aug	41363.75	2310.00	673.00	96.25
19-Aug	41376.80	2610.00	743.00	108.75
20-Aug	41390.00	2640.00	743.00	110.00
21-Aug	41402.90	2580.00	701.00	107.50
25-Aug	41455.30	10480.00	2974.00	109.17
		214260.00	**60136.70**	**120.64**

Generator Efficiency		
Diesel Properties		
	kWh/liter	9.8
Generator Properties		
	kWh/liter	3.56
Generator Efficiency		
	%	**36.36**

[¥] All data presented in appendix C.6 was collected by the author during the 2004/2005 SANAE IV takeover.

C.7 Graphical Representation of C6

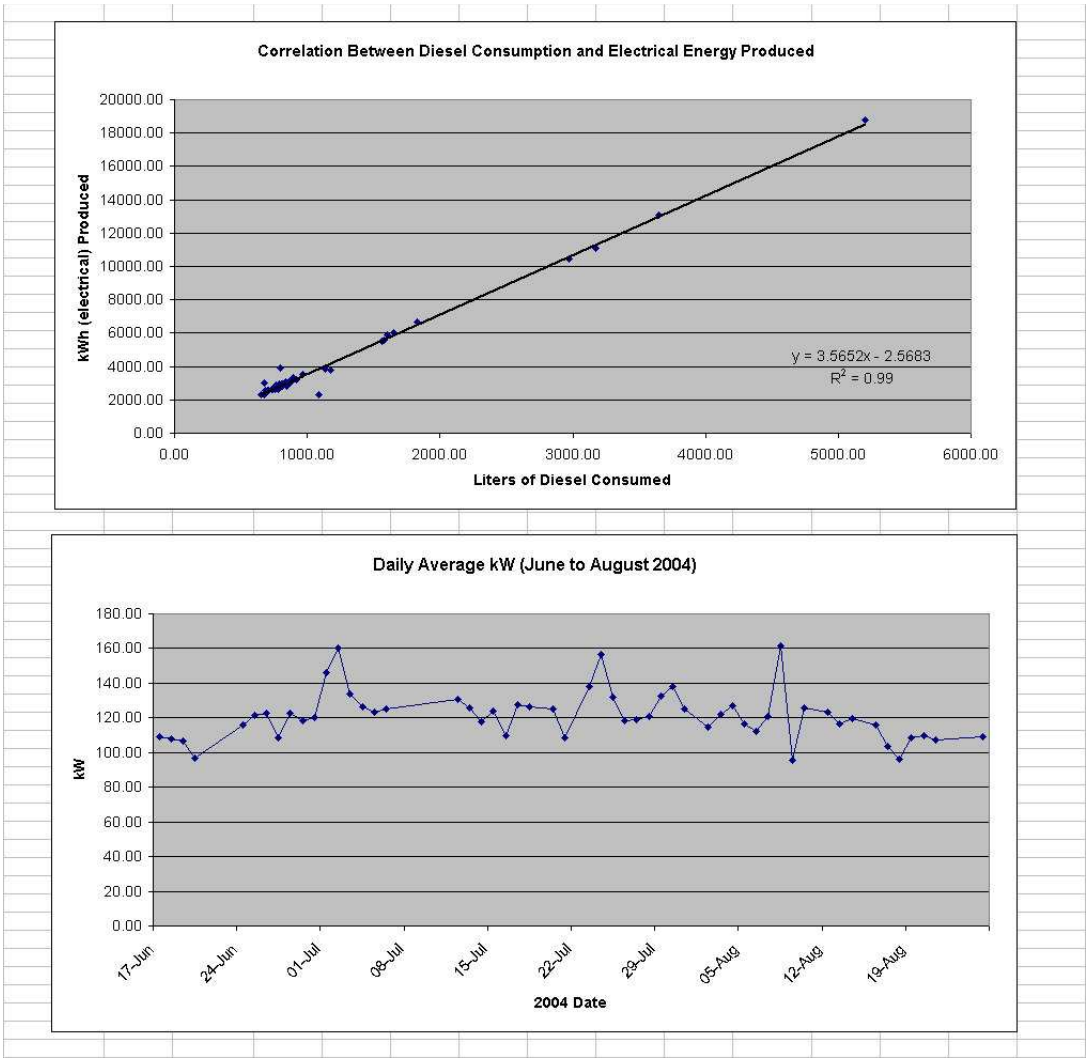


Figure C.3: Graphs of generator diesel consumption and electrical generation

Appendix D: Additional Information to Solar Energy Capturing Solutions

D.1 Energy Capturing Devices

Applications for flat-plate solar thermal collectors were investigated in chapter 3, where it was shown that the energy load of the H&V System at SANAE IV did not match available solar radiation well throughout the year. During the periods of high insolation there was no need to heat the base and in fact the station needed to be cooled, while during winter there was a significant shortage of available solar radiation. It was pointed out, however, that the snow smelter might be a potential point of application. And so, under these assumptions, one would attempt to supplement the current fresh water demand of the station with solar energy captured from a flat-plate solar collector.

Huang et al. (2001) have provided a survey of the three basic commercially available flat-plate solar collectors (viz. Type-A, Type-B and Type-C) as well as their respective average market costs. Type-A is described as a low-cost specially designed single-glazed flat-plate solar collector with selective surface and a 10-centimetre air layer of insulation beneath the glass cover. Type-B is a conventional single-glazed solar collector with selective surface and Type-C is a vacuum-tube collector. A graph of the performance of these collectors is provided below in figure D.1.

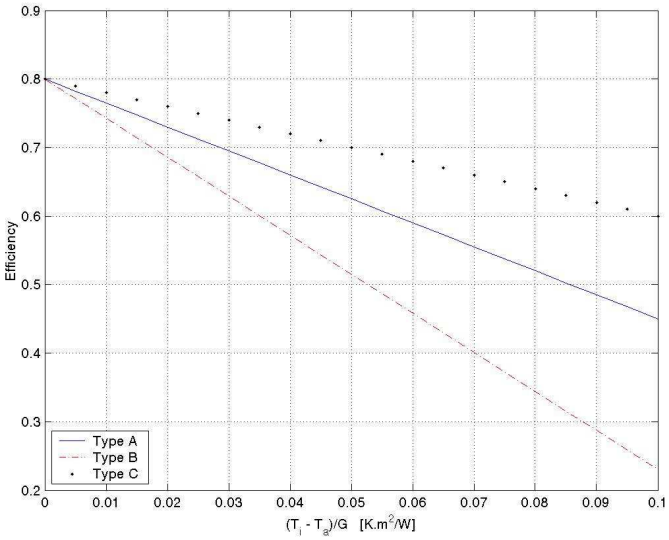


Figure D.1: Characteristics of the standard types of solar collectors (Huang et al., 2001)

The efficiencies of these collectors can therefore be calculated from figure D.1 if the ambient temperature, inlet collector temperature and insolation rate can be estimated. Thus, since the average radiation profile for each month has already been determined, and the average ambient conditions are known, it is only necessary to determine the average collector inlet temperature.

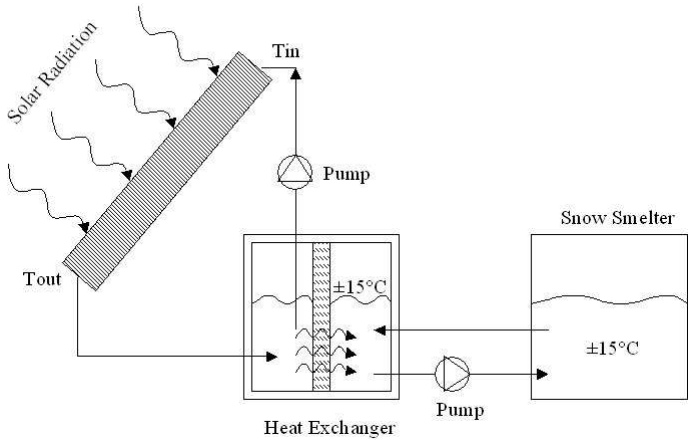


Figure D.2: Potential solar thermal collector set-up

From figure D.2 it is evident that temperature at the collector inlet can be estimated from a simple steady state heat transfer analysis at the heat exchanger, since the snow smelter temperature is fixed and known. Using the equation:

$$Q_{solar} = U_o \cdot A_o \cdot \Delta T \qquad D.1$$

Where Q_{solar} is the heat collected by the flat-plate solar thermal collector [W], U_o is the overall outside heat transfer coefficient of the flat-plate heat exchanger [W/m^{2}K], A_o is the outside area of the flat plate across which heat is exchanged [m^2] and ΔT is the temperature difference across the plate [K]. If we estimate: Q_{solar} as 4752 W (8 panels, each 1.98 m^2, subject to radiation of 500 W/m^2 and a collector efficiency of 50 % which was iterated to convergence), U_o as 1000 W/m^{2}K (Mills, 1999) and the area A_o of the heat exchanger as 1 m^2, the result from equation D.1 is a ΔT of approximately 5 K. Thus (refer to figure D.2) the inlet temperature to the collector would be approximately 20ºC, or 27ºC above the average ambient January temperature. In this manner, using: the performance curves suggested by Huang et al. (2001) shown in figure D.1, the average daily radiation profiles for January described in chapter 1 and the estimated heat exchanger values given above, the average collector efficiencies have been estimated and are presented in table D.1.

Table D.1: Summary of solar thermal collector systems

CRITERIA	TYPE-A	TYPE-B	TYPE-C
Calculated daily January efficiency	0.56	0.45	0.65
Calculated daily December efficiency	0.55	0.44	0.65
Cost (US$/m^2)*	136	121	485
Calculated average January tilted yield (kWh/m^2.day)	4.53	3.63	5.24
Calculated average December tilted yield (kWh/m^2.day)	4.57	3.62	5.36

*These estimates provided by Huang et al. (2001) are low

D.2 Basic Snow Smelter PLC Logic

The following is an extract taken out of the Engineer's training manual (SANAE IV database, 2005) used to explain proper operation and functioning of the snow smelter.

"4.4.2 The basic logic used in the PLC is as follows:

- *The PLC will only switch on elements up to the maximum amount of elements selected by the rotary switches. The reason for this is that you do not want the power consumption to rise to such an extent that a second generator must start unattended.*
- *Once the temperature of the water in each side reaches 30 Degrees Celsius, the PLC will switch off elements to keep the water temperature at 30 Degrees Celsius. This action will happen at 30 minute intervals. (Refer to PLC Manual).*
- *If the temperature drops quickly to below 20 Degrees Celsius as is the case when snow is dumped into the smelly, elements will be switched on at 2 minute intervals. (Refer to PCC Manual).*
- *The level switches are situated in the hot tank. The switches are float level switches which are connected to the indicator lights on the front panel.*
- *When the 100 % level light comes on, the PLC will automatically activate valves 9 and 10 and water will be pumped to the base for a period of 10 minutes. This is just a safety measure to ensure that the tank does not overflow. It would be technically possible to automate the complete pumping action. The reason why it was not done is that at the stage where the level reaches 100 %, the temperature might be 30 Degrees Celsius. The volume of hot water left after 10 minutes of pumping can then be used to melt more snow before it is pumped to the base.*
- *When snow is then added to the cold side of the melter, it must be attempted to stabilise the temperature well above 8 Degrees Celsius after which the pumping action can be started by pressing the pump button for 2 seconds. To stop the pumping action the button must be kept in for 6 seconds."*

D.3 Thermomax Product Prices and Specifications

THERMO TECHNOLOGIES

"Worldwide Leadership in Solar Heating Systems & Services"

Retail Price List 2005

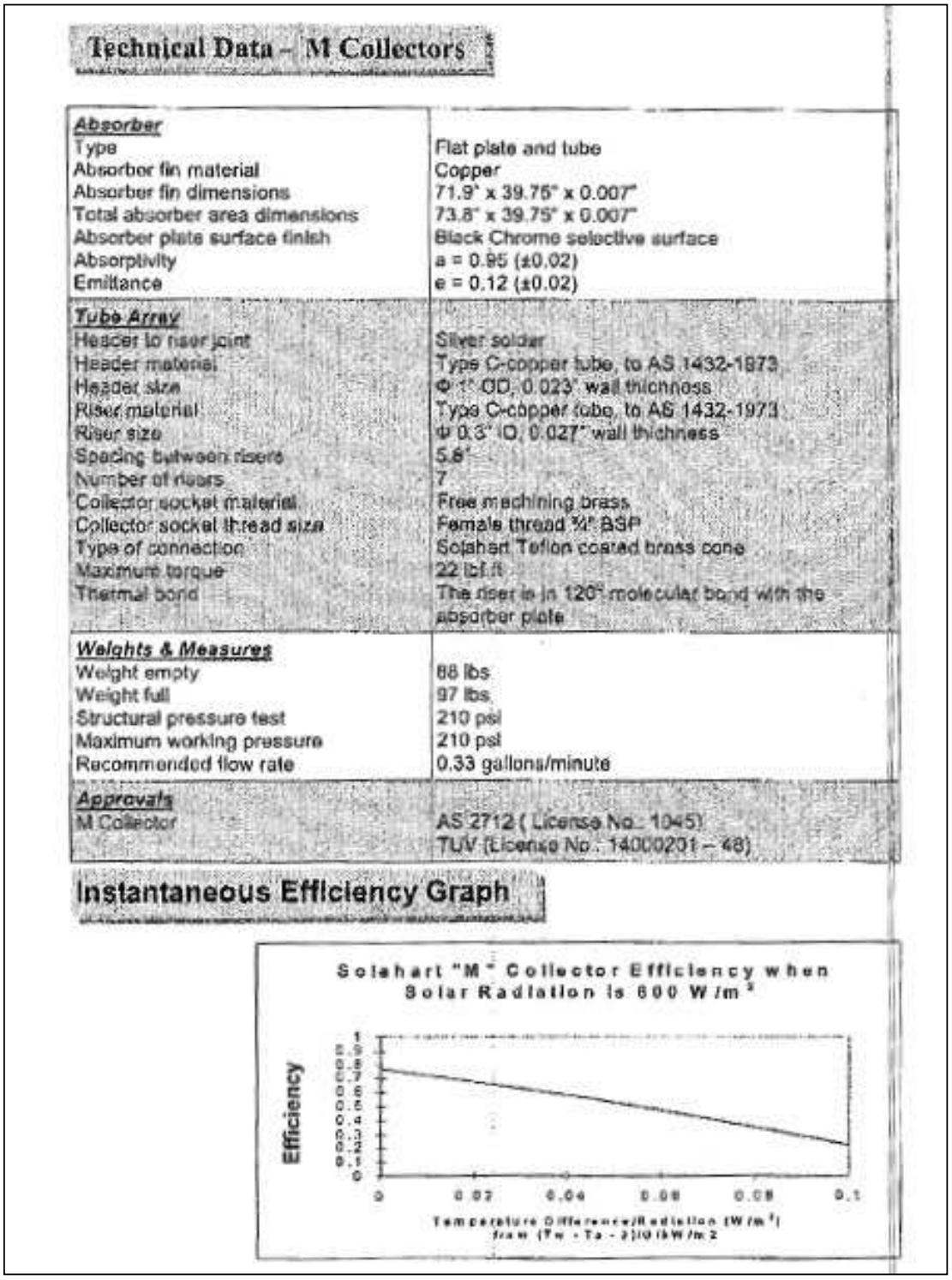
System	Description	Price
MAZ 2-20S	20 Tube Thermomax Collector System (with sloping roof fittings and accessories) 60" x 80", 135 lbs.	$ 1,950.00
MAZ 2-30S	30 Tube Thermomax Collector System (with sloping roof fittings and accessories) 90" x 80", 195 lbs.	$ 2,900.00
MAZ 2-40S	40 Tube Thermomax Collector System (with sloping roof fittings and accessories) 120" x 80", 270 lbs.	$ 3,900.00
MAZ 2-50S	50 Tube Thermomax Collector System (with sloping roof fittings and accessories) 150" x 80", 330 lbs.	$ 4,900.00
MAZ 2-60S	60 Tube Thermomax Collector System (with sloping roof fittings and accessories) 180" x 80", 390 lbs.	$ 5,850.00
Part No.		
MAZ 2-20M	20 Tube Manifold Set	$ 450.00
MAZ 2-30M	30 Tube Manifold Set	$ 650.00
TMA 600	Thermomax Memotron Tube (Box of 10)	$ 750.00
81VR80TC	80 Gallon Rheem Solar Direct Tank without Heat Exchanger	$ 750.00
81V80HE	80 Gallon Rheem Solar Indirect Tank with Heat Exchanger	$ 950.00
81VR120TC	120 Gallon Rheem Solar Direct Tank without Heat Exchanger	$ 950.00
SBB 300 +	80 Gallon Steibel Eltron Solar Tank with two Heat Exchangers	$ 999.00
SBB 400 +	105 Gallon Steibel Eltron Solar Tank with two Heat Exchangers	$ 1,150.00
PCU 20/60	Pump Unit Control for up to 60 Tubes	$ 750.00
USDT 2004	Digital Universal Solar Control Unit (Two Sensors, 3rd optional senor)	$ 149.00
USDT 2005	Analog Universal Solar Control Unit (Two Sensors)	$ 129.00
USDT 3000	Solar Control Unit (Two Tanks, Three Sensors)	$ 239.00
SMT 100T	Solar Control Unit (Two Tanks, Three Sensors)	$ 287.00
SMT 400T	Solar Control Unit (Three Tanks, Three Sensors)	$ 512.00
C0076	Roof Bracket Kit for Flat Roofs	$ 170.00
C0022	Mexican Tile Roof Elevation Kit (set of four)	$ 75.00

Prices Shown Herein are FOB Baltimore, Maryland. Crating: Add $ 150.00 per system for packaging and handling in a wooden crate.

5560 STERRETT PLACE, SUITE 115, COLUMBIA, MD 21044, (410) 997-0778, FAX (410) 997-0779
E-MAIL-> INFO@THERMOTECHS.COM INTERNET -> HTTP://WWW.THERMOTECHS.COM

Figure D.3: Thermomax product price sheet (Thermomax, 2005)

D.4 Solahart Product Specifications for the M-Collector



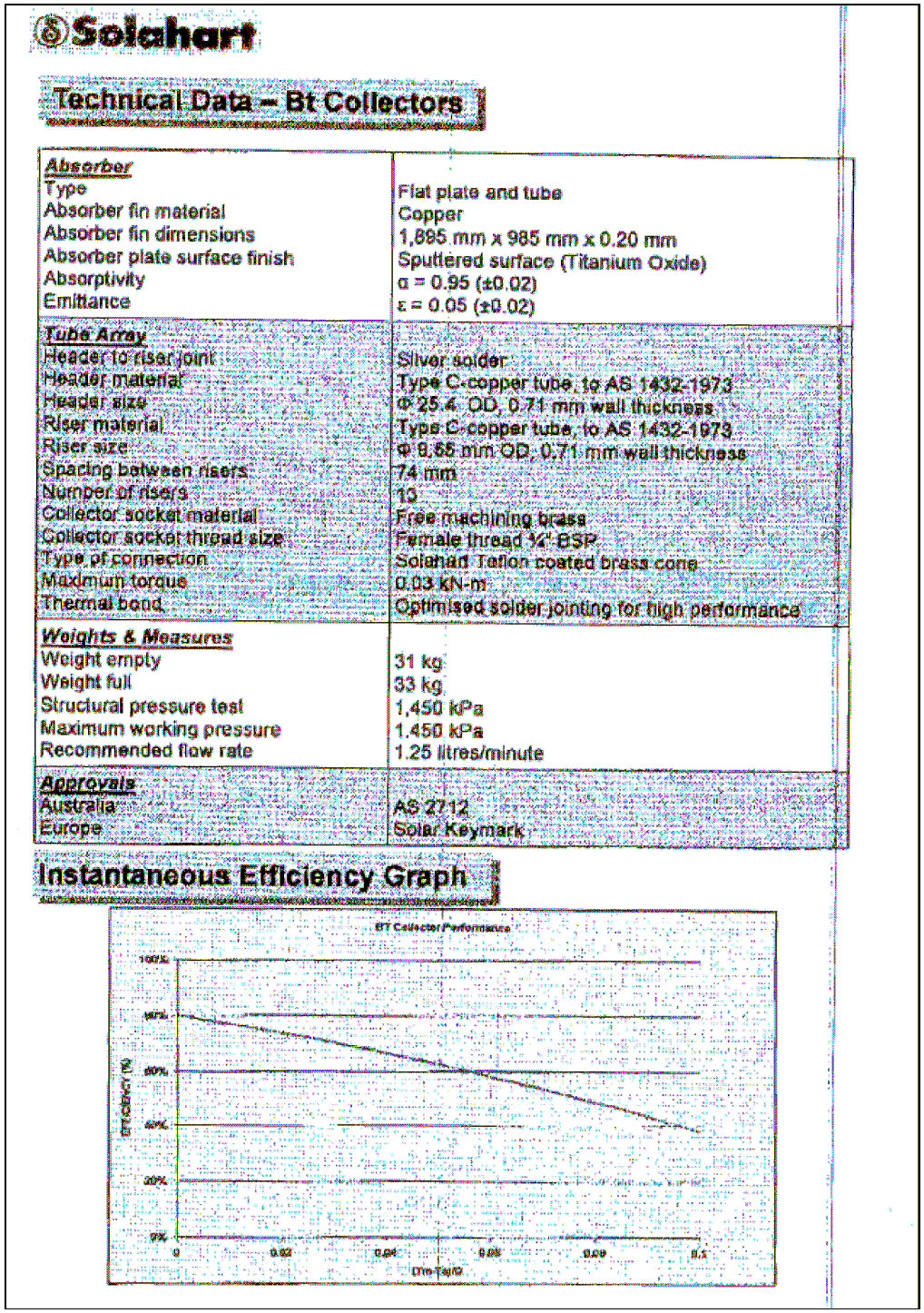
Technical Data – M Collectors

Absorber	
Type	Flat plate and tube
Absorber fin material	Copper
Absorber fin dimensions	71.9" x 39.75" x 0.007"
Total absorber area dimensions	73.8" x 39.75" x 0.007"
Absorber plate surface finish	Black Chrome selective surface
Absorptivity	a = 0.95 (±0.02)
Emittance	e = 0.12 (±0.02)
Tube Array	
Header to riser joint	Silver solder
Header material	Type C-copper tube, to AS 1432-1973
Header size	Φ 1" OD, 0.023" wall thichness
Riser material	Type C-copper tube, to AS 1432-1973
Riser size	Φ 0.3" ID, 0.027" wall thichness
Spacing between risers	5.8"
Number of risers	7
Collector socket material	Free machining brass
Collector socket thread size	Female thread ¾" BSP
Type of connection	Solahart Teflon coated brass cone
Maximum torque	22 lbf.ft
Thermal bond	The riser is in 120° molecular bond with the absorber plate
Weights & Measures	
Weight empty	88 lbs
Weight full	97 lbs
Structural pressure test	210 psi
Maximum working pressure	210 psi
Recommended flow rate	0.33 gallons/minute
Approvals	
M Collector	AS 2712 (License No.: 1045)
	TUV (License No.: 14000201 – 48)

Instantaneous Efficiency Graph

Figure D.4: Solahart M-Collector specifications (Solahart, 2005)

D.5 Solahart Product Specifications for the Bt-Collector



Solahart

Technical Data – Bt Collectors

Absorber	
Type	Flat plate and tube
Absorber fin material	Copper
Absorber fin dimensions	1,895 mm x 985 mm x 0.20 mm
Absorber plate surface finish	Sputtered surface (Titanium Oxide)
Absorptivity	α = 0.95 (±0.02)
Emittance	ε = 0.05 (±0.02)
Tube Array	
Header to riser joint	Silver solder
Header material	Type C-copper tube, to AS 1432-1973
Header size	Φ 25.4 OD, 0.71 mm wall thickness
Riser material	Type C-copper tube, to AS 1432-1973
Riser size	Φ 8.66 mm OD, 0.71 mm wall thickness
Spacing between risers	74 mm
Number of risers	10
Collector socket material	Free machining brass
Collector socket thread size	Female thread ¾" BSP
Type of connection	Solahart Teflon coated brass cone
Maximum torque	0.03 kN-m
Thermal bond	Optimised solder jointing for high performance
Weights & Measures	
Weight empty	31 kg
Weight full	33 kg
Structural pressure test	1,450 kPa
Maximum working pressure	1,450 kPa
Recommended flow rate	1.25 litres/minute
Approvals	
Australia	AS 2712
Europe	Solar Keymark

Instantaneous Efficiency Graph

Figure D.5: Solahart Bt-Collector specifications (Solahart, 2005)

D.6 MATLAB V6.1 Snow Smelter Simulation Programme

```
%%-------------------------------------------------------------------------------------------%%
%%        SNOWSMELTER SIMULATION PROGRAMME SANAE IV -2005   %%
%%-------------------------------------------------------------------------------------------%%
%This programme models the energy transfer characteristics of the snowsmelter at South Africa's
%SANAE IV station in Antarctica. It is used to estimate the reduction in electrical consumption
%of the heating elements when solar thermal collectors are incorperated with the current system.

%%-----------------------------------------------------------%%
%%  Establish some important initial conditions    %%
%%-----------------------------------------------------------%%
close all
clear all
clc
Ta(1)=0;              %The temperature of water in the smelter at which the heating elements are switched off
Ta(2)=50;             %The starting temperature of the solar energy store

while (Ta(1)-Ta(end))<0

   Ta(1)=Ta(1)+3;
   disp(['The starting Temp is: ',num2str(Ta(1))])

for Tmax=20
%The solar collector is currently set as product 1 (see calculation of collector efficiency) with 72 collector panels
NoSolarr=0;                   %Wheather or not the solar contribution must be accounted for in the simulation (1=No contribution)
month=2;                      %The desired month of the year
mm=(0.080*80)*998/3;          %The amount of snow added in one filling of the snowsmleter from: [(L/person.day)*(No. of people at
base)*(kg/L)/(No. of smellies per day)]
NoOfPanels=8*3*3;             %The number of panels contributing to the energy demand of the snowsmelter
response2=10;                 %The number of minutes delay between switching heating elements OFF
response1=2;                  %The number of minutes delay between switching heating elements ON
HEMAX=12;                     %The maximum number of heating elements in the snowsmelter that can be turned on
V=6/24*NoOfPanels;            %The volume of the energy solar thermal store (in m^3)
clearsky=0;                   %If the insolation rate is to based on maximum clear-sky conditions (1=YES)

%%-------------------------------------------------%%
%%  Establish the initial conditions        %%
%%-------------------------------------------------%%
p=1;                    %THE MAIN COUNTER
PanelSize=1.98;         %The collector area of a single panel
tend=24*3600;           %The length of time of a simulation (in seconds)
gamma=180;              %The horizontal orientation of the collector (where 180=SOUTH)
mdot=0.0208;            %The flowrate through the collector (kg/s)
Cp=4181;                %The specific heat of water (in J/kg.K)
Cl=335000;              %The latent heat of snow (in J/kg)
U=1500;                 %Overall heat transfer coefficient of the heat exchanger dividing the solar thermal store and the snowsmelter
Aa=((V^(1/3))^2)*0.7;   %Surface area of heat exchanger mentioned in U above
HESIZE=7500;            %The electrical capacity of a single heating element (in W)
massfraction=1/5;       %The fraction of snow added in one filling that remains in the smelter after pumping water to the base
Uu=20;                  %The overall heat transfer coefficient between the smelter and the surroundings (in J/m^2.K)
Aaa=72;                 %The total area of the snowsmelter exposed to heat loss
Tfill1=8.5;             %The time of day at which the first pumping session and snowsmelter filling takes place
Tfill2=13.5;            %The time of day at which the second pumping session and snowsmelter filling takes place
Tfill3=17.5;            %The time of day at which the third pumping session and snowsmelter filling takes place
Tfill4=32.5;            %The time of day at which the third pumping session and snowsmelter filling takes place
Tfill5=37.5;            %The time of day at which the third pumping session and snowsmelter filling takes place
Tfill6=41.5;            %The time of day at which the third pumping session and snowsmelter filling takes place
Tb(1)=Tmax;             %The starting energy of the snowsmelter
HE(1)=0;                %The number of heating elements on at the start of the day
changer=0;              %A tool used in conjunction with the RESPONSE1 & 2 variables
wait=0;                 %A tool used in conjunction with the RESPONSE1 & 2 variables
PumpSessions=0;         %To keep track of how many times water is pumped up the base during the day
PumpSessionsT(1)=0;     %The temperature of the water at the time it is pumped to the base
NoFlow=0;               %If it is necessary to turn the solar thermal collectors off for a short time
Tamb=[-6.60 -10.30 -14.90 -18.20 -19.50 -20.10 -23.10 -22.90 -22.90 -18.20 -12.80 -7.10];
day=[17 16 16 15 15 11 17 16 15 15 14 10];  %Average meteorological days of every month
Beta=[22 63 74 84 86 86 86 88 78 69 52 48]; %Which are the optimum tilt angles of every month

%Some initial calculations
A=PanelSize*NoOfPanels;                 %Total collector area
dt=min([response1,response2])*60;       %ALL CALCULATIONS BASED ON SECONDS (where 300s=5min)
mass=mm+mm*massfraction;                %Total mass in the smelter at any one time
Qtot(1)=mass*Cl+mass*Cp*Tmax;           %Starting amount of energy in the smelter at beginning of day
Aaaa=((V^(1/3))^2)*6;                   %Surface area from which solar energy store can lose heat
```

```
NoSolar=NoSolarr;

%Start the clock
t=0;

while t < tend
   if t>24*3600
      tt=(t/(24*3600)-floor(t/(24*3600)))*24*3600;
   else
      tt=t;
   end
%Start the iterations
hourr=floor(tt/3600);
minn=floor((tt/3600-floor(t/3600))*60);
secc=floor((tt/3600-hourr-minn/60)*3600);
q=datenum([2005,month,day(month),hourr,minn,secc]);

%%-------------------------------------------------------------------------%%
%%  Incident solar radiation                                               %%
%%-------------------------------------------------------------------------%%
if clearsky==1
   [G,Gcb,Gd]=F_ClearSkyInsolation(q);              %Where G is the global horizontal insolation rate, Gd the diffuse insolation, Gcb the beam
radiation and q the datenum
elseif clearsky==0
   [G,Gd,ttt]=F_MonthlyProfiles(month,tt/3600);  %The time input is a number from 0 to 24
end
%And the insolation rate is calculated on a tilted place from the horizontal measurement
[Gt,Gdt,Gbt]=F_TiltISOSKY(q,Beta(month),G,Gd,0.7,gamma);   %Assumes isotropic-sky conditions

%%-----------------------------------------------%%
%%  Calculate the collector efficiency     %%
%%-----------------------------------------------%%
%This needs to be done with iteration since the specifications are in terms of Tm and not Ti to the collector
if Gt>0
   %See F_SolarThermalEfficiency for a description of each product
   [effm1,effm2,effm3]=F_SolarThermalEfficiency(Gt,Ta(p),month,NoOfPanels,PanelSize);
   eff=effm1;
else
   eff=0;
end
sunshine(p)=Gt*eff;   %The useful energy collected in the solar thermal collector

%%-----------------------------------------------------------------------------------------------------------%%
%%%%%  Couple the collector characteristics with the snow smelter electrical heaters      %%%%%
%%-----------------------------------------------------------------------------------------------------------%%

%%---------------------------------------------------%%
%%  Heating Elements Switched on or off        %%
%%---------------------------------------------------%%
if Tb(p)<Tmax & wait==0;
   HE(p+1) = HE(p)+1;
   wait=1;
   changer=t+response1*60;
elseif Tb(p)>Tmax & wait==0;
   HE(p+1) = HE(p)-1;
   wait=1;
   changer=t+response2*60;
else
   HE(p+1) = HE(p);
end
%Check to ensure that no more than 12 or less than 0 elements are on
if HE(p+1)>HEMAX
   HE(p+1)=HEMAX;
elseif HE(p+1)<0
   HE(p+1)=0;
end

%%---------------------------------------------------%%
%%  Timer to enable the switching of elements   %%
%%---------------------------------------------------%%
if t>=changer
   wait=0;
   changer=tend+60;
end
```

```
%%-------------------------------------------------------------%%
%%  The heat transfer into the tanks is calculated  %%
%%-------------------------------------------------------------%%
Qin=HE(p+1)*HESIZE*dt;          %No. of heating elements x Power per element (in W) x time interval [J]
QinSolar=U*Aa*(Ta(p)-Tb(p))*dt; %The heat exchanged from the solar thermal store to the snowsmelter
if (Ta(p)-Tb(p))<5
   NoSolar=1;
end
if NoSolar==1
   QinSolar=0;
end
NoSolar=0;
contribution(p)=QinSolar;
Qout=-Uu*Aaa*(Tb(p)-0)*dt;      %Heat loss to the surroundings
Qtot(p+1)=Qtot(p)+Qin+Qout+QinSolar;
%Making provision for the latency of snow when calculating the new smelter temperature
if Qtot(p+1)>mass*Cl
   Tb(p+1)=Tb(p)+(QinSolar + Qin + Qout)/(mass*Cp);
elseif Qtot(p+1)<mass*Cl
   Tb(p+1)=0;
end

%%-------------------------------------------------------%%
%%  The water is pumped up to the base        %%
%%-------------------------------------------------------%%
if  (t>(Tfill1*3600-dt)  &  t<(Tfill1*3600+dt))  |  (t>(Tfill2*3600-dt)  &  t<(Tfill2*3600+dt))  |  (t>(Tfill3*3600-dt)  &  t<(Tfill3*3600+dt))  |
(t>(Tfill4*3600-dt) & t<(Tfill4*3600+dt)) | (t>(Tfill5*3600-dt) & t<(Tfill5*3600+dt)) | (t>(Tfill6*3600-dt) & t<(Tfill6*3600+dt))
   if Tb(p+1)>8 %Can only pump water up to the base under these conditions
      PumpSessions=PumpSessions+1;
      PumpSessionsT(PumpSessions)=Tb(p+1);
      Qtot(p+1)=(mm*Cl + mm*Cp*Tb(p+1))*massfraction;     %Remaining energy in the "store" of the snowsmelter
      if Qtot(p+1)>mass*Cl   %If the added snow is immediately melted
         Tb(p+1)=(Qtot(p+1))/(mass*Cp);
      elseif Qtot(p+1)<mass*Cl   %If the added snow still requires heating
         Tb(p+1)=0;
      end
      wait=0;
      changer=tend+60;
   end
end

%%-------------------------------------------------------------------------------------------------%%
%%  The end of the snow smelter code                                                               %%
%%-------------------------------------------------------------------------------------------------%%

%%-----------------------------------------------%%
%%  Calculate collected energy in store       %%
%%-----------------------------------------------%%
Qsolar=Gt*A*eff*dt;       %The solar energy collected in the collector
Qloss=Uu*Aaaa*(Ta(p)-0);    %Heat lost from the solar thermal store to the surroundings
if (Qsolar-mdot*Cp*Ta(p)*dt)<5
   NoFlow=1;
end
if NoFlow==0
   Qoutt=mdot*Cp*Ta(p)*dt; %The amount of energy leaving the solar store and entering the collector
elseif NoFlow==1
   Qoutt=0;
   Qsolar=0;
end
NoFlow=0;
collected(p)=Qsolar;
Qdiff=(Qsolar+Qoutt)-Qoutt-QinSolar-Qloss;              %The energy effecting a change of temperature in the store
Ta(p+1)=Ta(p)+Qdiff/(V*998*Cp);                         %The new temperature of the energy store

t = t + dt;           %0 to 24*3600
p=p+1;
NoSolar=NoSolarr;
end

end

end
```

```
%%-----------------------------------------------%%
%%  Plot the results                             %%
%%-----------------------------------------------%%
r=length(Tb);
time24=0:dt/3600:(r-1)*dt/3600;
subplot(2,1,1)
plot(time24,Tb,'b-',time24,Ta,'r-.',0:1:tend/3600,Tmax,'r.',0:1:tend/3600,8,'b.'), grid on, ylabel('snow smelter Temperature')
legend('Tb','Ta','Limit temperatures')
if NoSolar==0
   axis([0 tend/3600 0 (Tmax+40)])
end
subplot(2,1,2)
plot(time24,HE*HESIZE/1000,'b-',time24(1:end-1),sunshine/1000*A,'r-.'), xlabel('Time in hours from midnight'), ylabel('Load Profiles [kW]'),
grid on,
axis([0 tend/3600 0 140]), legend('Generator load','Harnessed solar energy')

disp('The energy expended by the heating elements is:')
disp([num2str(sum(HE*HESIZE/1000*dt/3600)),' kWh'])
disp(' ')
disp('The energy passed on to the snowsmelter by the solar collectors is:')
disp([num2str(sum(contribution)/3600000), ' kWh'])
disp('The energy collected by the solar collectors is:')
disp([num2str(sum(collected)/3600000), ' kWh'])
disp(' ')
disp(' ')
```

D.7 Snow Smelter Simulation Programme Results for Thermomax and Mt-Collectors

Table D.2: Estimated daily load for snow smelter with and without Thermomax collector system

ESTIMATED DAILY GENERATOR LOAD FROM SNOW SMELTER (kWh/day)																		
Collector Size	**NONE (0 PANELS)**						**MEDIUM (24 PANELS)**						**LARGE (72 PANELS)**					
Tresponse (min)	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*
Tmax (°C)	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*
January	1715	1578	1485	1313	1318	1069	1618	1440	1369	1140	1168	856	1301	1140	1046	746	885	498
February	1715	1578	1485	1313	1318	1069	1644	1460	1404	1187	1222	907	1464	1310	1192	924	925	630
March	1315	1157	1115	865	663	569	1144	1067	761	688	370	379	887	888	515	491	173	130
April	1315	1157	1115	865	663	569	1211	1092	820	730	485	397	988	963	577	573	241	204
May	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
June	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
July	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
August	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
September	1315	1157	1115	865	663	569	1211	1092	820	730	485	397	988	963	577	573	241	204
October	1315	1157	1115	865	663	569	1144	1067	761	688	370	379	887	888	515	491	173	130
November	1315	1157	1115	865	663	569	966	935	595	571	295	262	624	617	301	255	28	15
December	1315	1157	1115	865	663	569	919	897	550	528	278	218	488	460	175	145	26	14

Table D.3: Energy savings generated at snow smelter from Thermomax collector system

DAILY SAVINGS (kWh)												
Collector Size	MEDIUM (24 PANELS)						LARGE (72 PANELS)					
Tresponse (min)	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*
Tmax (°C)	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*
January	97	138	116	173	150	213	414	438	439	567	433	571
February	71	118	81	126	96	162	251	268	293	389	393	439
March	171	90	354	177	293	190	428	269	600	374	490	439
April	104	65	295	135	178	172	327	194	538	292	422	365
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	104	65	295	135	178	172	327	194	538	292	422	365
October	171	90	354	177	293	190	428	269	600	374	490	439
November	349	222	520	294	368	307	691	540	814	610	635	554
December	396	260	565	337	385	351	827	697	940	720	637	555
Average	*122*	*87*	*215*	*130*	*162*	*146*	*308*	*239*	*397*	*302*	*327*	*311*

Table D.4: Estimated daily load for snow smelter with and without Mt collector system

ESTIMATED DAILY GENERATOR LOAD FROM SNOW SMELTER (kWh/day)																		
Collector Size	NONE (0 PANELS)						MEDIUM (24 PANELS)						LARGE (72 PANELS)					
Tresponse (min)	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*
Tmax (°C)	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*
January	1715	1578	1485	1313	1318	1069	1655	1504	1417	1208	1239	950	1542	1380	1294	1036	1048	689
February	1715	1578	1485	1313	1318	1069	1680	1529	1447	1250	1274	989	1601	1401	1350	1086	1170	809
March	1315	1157	1115	865	663	569	1303	1140	939	781	510	458	1195	1097	853	714	384	267
April	1315	1157	1115	865	663	569	1315	1146	1017	821	445	511	1280	1106	856	749	450	435
May	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
June	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
July	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
August	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569	1315	1157	1115	865	663	569
September	1315	1157	1115	865	663	569	1315	1146	1017	821	445	511	1280	1106	856	749	450	435
October	1315	1157	1115	865	663	569	1303	1140	939	781	510	458	1195	1097	853	714	384	267
November	1315	1157	1115	865	663	569	1167	1075	796	713	467	377	943	945	515	509	178	128
December	1315	1157	1115	865	663	569	1045	1026	688	639	356	309	849	823	460	435	134	79

Table D.5: Energy savings generated at snow smelter from Mt collector system

DAILY SAVINGS (kWh)												
Collector Size	MEDIUM (24 PANELS)						LARGE (72 PANELS)					
Tresponse (min)	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*	*30*	*10*
Tmax (°C)	*30*	*30*	*20*	*20*	*10*	*10*	*30*	*30*	*20*	*20*	*10*	*10*
January	60	74	68	105	79	119	173	198	191	277	270	380
February	35	49	38	63	44	80	114	177	135	227	148	260
March	12	17	176	84	153	111	120	60	262	151	279	302
April	0	11	98	44	218	58	35	51	259	116	213	134
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	11	98	44	218	58	35	51	259	116	213	134
October	12	17	176	84	153	111	120	60	262	151	279	302
November	148	82	319	152	196	192	372	212	600	356	485	441
December	270	131	427	226	307	260	466	334	655	430	529	490
Average	60	74	68	105	79	119	173	198	191	277	270	380

Table D.6: System performance comparison

CRITERIA	Bt-COLLECTOR	THERMOMAX	Mt-COLLECTOR
NPV (R)	2 148 811	3 427 161	871 405
IRR (%)	24.47	26.51	15.36
NAW (R)	190 873	304 425	77 404
Breakeven period[∞]	6	5	11

[∞]MARR, 8 % & Fuel escalation rate 5 %

Appendix E: Additional Information to Economic Analysis

E.1 Sample Results for Solar PV System

NET PRESENT VALUE

The NPV of cash flows has been calculated with the help of equations 5.1 and 5.2. For example, the NPV of cash flows for the diesel-only system after the first year equals the total costs at the end of year 1 brought back by the PWF with an interest rate equal to the hurdle rate.

$$NPV = \sum_{n=0}^{N} (C_n + M_n + L_n + F_n) \cdot \left(\frac{1}{(1+i)^n} \right) \qquad E.1$$

$$NPV = -5079770.85 \cdot \left(\frac{1}{(1+0.08)^1} \right)$$

INTERNAL RATE OF RETURN

The IRR can easily be calculated with the help of Microsoft Excel's formulae function, however, by way of example the formula and sample calculation is given here. The IRR is that interest rate which solves the equation given in E.2. Thus for example the IRR in table E.2 at the end of year six is calculated from the column "Yearly Cashflows" in the same table as:

$$\sum_{k=0}^{N} (PWF(IRR,k)) \cdot Income_k = \sum_{k=0}^{N} (PWF(IRR,k)) \cdot Expenses_k \qquad E.2$$

Which is solved by:

$$1653167.13\left[\frac{1}{(1+0.1983)^0}\right] = 92585.66\left[\frac{1}{(1+0.1983)^1}\right] + 100236.95\left[\frac{1}{(1+0.1983)^2}\right] + 108301.02\left[\frac{1}{(1+0.1983)^3}\right] + \ldots$$

$$\ldots 116798.22\left[\frac{1}{(1+0.1983)^4}\right] + 125752.34\left[\frac{1}{(1+0.1983)^5}\right] + 135184.67\left[\frac{1}{(1+0.1983)^6}\right]$$

BENEFIT COST RATIO (BC RATIO)

The BC Ratio is easily calculated as the sum of the total benefits projected to the same point in time (in this instance the NPV) divided by the sum of the total costs. Therefore (excluding externalities):

$$BC = \frac{\sum_{k=0}^{N} (PWF(MARR,k)) \cdot Income_k}{\sum_{k=0}^{N} (PWF(MARR,k)) \cdot Expenses_k} \qquad E.3$$

Which can be calculated from the first 4 columns in table E.1 (viz. Capital, Fuel, Maintenance and Labour) and where "Fuel" is the only column that represents an income as given in equation E.3. Thus the BC-Ratio at the end of year 1 is calculated as:

$$BC = \frac{\left[\frac{1}{(1+0.08)^1}\right] \cdot 168135.79}{\left[\frac{1}{(1+0.08)^0}\right] \cdot 1653167.13 + \left[\frac{1}{(1+0.08)^1}\right] \cdot 74540.13 + \left[\frac{1}{(1+0.08)^1}\right] \cdot 1010}$$

COST OF ENERGY PRODUCED

The cost of energy generation has been calculated by; summing the respective total costs of the system in question (i.e. diesel-only or hybrid) over the 25-year project lifetime, and then dividing by the power generated after that amount of time.

$$Cost = \frac{\sum_{k=0}^{N} (PWF(MARR,k)) \cdot Expenses_k}{\sum_{k=0}^{N} AnnualEnergy\,\mathrm{Pr}oduction_k} \qquad E.4$$

Thus, the normal generation costs of the diesel-only system are calculated as (cost values can be seen at the bottom of table E.1):

$$Cost = \frac{0 + 84903277.43 + 351801.17 + 234534.11}{24 \cdot 1061971}$$

Table E.1: Sample results for the solar PV system (column A is for diesel-only and column B is for the hybrid system)

	A	B	A	B	A	B	A	B	A	B
	CAPITAL INVESTMENT		FUEL COSTS		MAINTENANCE		LABOUR		TOTAL	
0	0.00	-1 653 167.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1 653 167.13
1	0.00	0.00	-5 029 270.85	-4 861 135.06	-30 300.00	-104 840.13	-20 200.00	-21 210.00	-5 079 770.85	-4 987 185.18
2	0.00	0.00	-5 280 734.39	-5 104 191.81	-30 603.00	-105 888.53	-20 402.00	-21 422.10	-5 331 739.39	-5 231 502.44
3	0.00	0.00	-5 544 771.11	-5 359 401.40	-30 909.03	-106 947.41	-20 606.02	-21 636.32	-5 596 286.16	-5 487 985.14
4	0.00	0.00	-5 822 009.67	-5 627 371.47	-31 218.12	-108 016.89	-20 812.08	-21 852.68	-5 874 039.87	-5 757 241.04
5	0.00	0.00	-6 113 110.15	-5 908 740.05	-31 530.30	-109 097.05	-21 020.20	-22 071.21	-6 165 660.65	-6 039 908.31
6	0.00	0.00	-6 418 765.66	-6 204 177.05	-31 845.60	-110 188.03	-21 230.40	-22 291.92	-6 471 841.66	-6 336 657.00
7	0.00	0.00	-6 739 703.94	-6 514 385.90	-32 164.06	-111 289.91	-21 442.71	-22 514.84	-6 793 310.71	-6 648 190.65
8	0.00	0.00	-7 076 689.14	-6 840 105.20	-32 485.70	-112 402.80	-21 657.13	-22 739.99	-7 130 831.97	-6 975 247.99
9	0.00	0.00	-7 430 523.59	-7 182 110.46	-32 810.56	-113 526.83	-21 873.71	-22 967.39	-7 485 207.86	-7 318 604.68
10	0.00	0.00	-7 802 049.77	-7 541 215.98	-33 138.66	-114 662.10	-22 092.44	-23 197.06	-7 857 280.88	-7 679 075.14
11	0.00	0.00	-8 192 152.26	-7 918 276.78	-33 470.05	-115 808.72	-22 313.37	-23 429.04	-8 247 935.68	-8 057 514.54
12	0.00	0.00	-8 601 759.87	-8 314 190.62	-33 804.75	-116 966.81	-22 536.50	-23 663.33	-8 658 101.13	-8 454 820.75
13	0.00	0.00	-9 031 847.87	-8 729 900.15	-34 142.80	-118 136.48	-22 761.87	-23 899.96	-9 088 752.53	-8 871 936.58
14	0.00	0.00	-9 483 440.26	-9 166 395.16	-34 484.23	-119 317.84	-22 989.48	-24 138.96	-9 540 913.97	-9 309 851.96
15	0.00	0.00	-9 957 612.27	-9 624 714.91	-34 829.07	-120 511.02	-23 219.38	-24 380.35	-10 015 660.72	-9 769 606.28
16	0.00	0.00	-10 455 492.89	-10 105 950.66	-35 177.36	-121 716.13	-23 451.57	-24 624.15	-10 514 121.82	-10 252 290.94
17	0.00	0.00	-10 978 267.53	-10 611 248.19	-35 529.13	-122 933.29	-23 686.09	-24 870.39	-11 037 482.75	-10 759 051.88
18	0.00	0.00	-11 527 180.91	-11 141 810.60	-35 884.42	-124 162.62	-23 922.95	-25 119.10	-11 586 988.28	-11 291 092.32
19	0.00	0.00	-12 103 539.95	-11 698 901.13	-36 243.27	-125 404.25	-24 162.18	-25 370.29	-12 163 945.40	-11 849 675.67
20	0.00	0.00	-12 708 716.95	-12 283 846.19	-36 605.70	-126 658.29	-24 403.80	-25 623.99	-12 769 726.45	-12 436 128.47
21	0.00	0.00	-13 344 152.80	-12 898 038.50	-36 971.76	-127 924.88	-24 647.84	-25 880.23	-13 405 772.40	-13 051 843.60
22	0.00	0.00	-14 011 360.44	-13 542 940.42	-37 341.48	-129 204.13	-24 894.32	-26 139.03	-14 073 596.23	-13 698 283.58
23	0.00	0.00	-14 711 928.46	-14 220 087.44	-37 714.89	-130 496.17	-25 143.26	-26 400.42	-14 774 786.61	-14 376 984.03
24	0.00	0.00	-15 447 524.88	-14 931 091.82	-38 092.04	-131 801.13	-25 394.69	-26 664.43	-15 511 011.62	-15 089 557.37
25	0.00	0.00	-16 219 901.13	-15 677 646.41	-38 472.96	-133 119.14	-25 648.64	-26 931.07	-16 284 022.73	-15 837 696.62
PV	R 0.00	R -1 653 167.13	R -84 748 502.27	R -81 915 237.43	R -351 801.17	R -1 217 256.71	R -234 534.11	R -246 260.82	R -85 334 837.55	R -85 031 922.09

Table E.2: Sample results for solar PV system (column A is for diesel-only and column B is for the hybrid system)

		USING A SINGLE CAPITAL INVESTMENT								
A	B	YEARLY CASHFLOWS	DISCOUNTED PAYBACK	SIMPLE PAYBACK	EXTERNALITIES	NPV OF EXTERNALITIES	DSCNTED PAYBACK (WITH EXTERNALITES)	SIMPLE PAYBACK WITH EXTERNALITIES	IRR BASED ON YEARS	BC RATIO BASED ON YEARS
NPV										
0.00	-1 653 167.13	-1 653 167.13	-1 653 167.13	-1 653 167.13	0.00	0.00	-1 653 167.13	-1 653 167.13	#NUM!	0.00
-4 703 491.53	-6 270 931.19	92 585.66	-1 567 439.66	-1 560 581.47	53 554.11	49 587.14	-1 517 852.52	-1 510 994.33	#NUM!	0.09
-9 274 598.69	-10 756 101.32	100 236.95	-1 481 502.63	-1 460 344.51	54 089.65	95 960.30	-1 385 542.33	-1 364 384.21	#NUM!	0.17
-13 717 111.07	-15 112 640.86	108 301.02	-1 395 529.79	-1 352 043.49	54 630.55	139 327.79	-1 256 202.00	-1 212 715.70	#NUM!	0.25
-18 034 705.73	-19 344 384.89	116 798.82	-1 309 679.17	-1 235 244.67	55 176.86	179 884.43	-1 129 794.74	-1 055 360.24	#NUM!	0.31
-22 230 950.76	-23 455 045.00	125 752.34	-1 224 094.24	-1 109 492.33	55 728.62	217 812.39	-1 006 281.85	-891 679.94	#NUM!	0.38
-26 309 308.81	-27 448 213.78	135 184.67	-1 138 904.97	-974 307.66	56 285.91	253 282.06	-885 622.90	-721 025.60	-19.83%	0.43
-30 273 140.36	-31 327 369.17	145 120.06	-1 054 228.81	-829 187.60	56 848.77	286 452.77	-767 776.03	-542 734.83	-14.08%	0.49
-34 125 706.99	-35 095 878.62	155 583.98	-970 171.62	-673 603.63	57 417.26	317 473.53	-652 698.09	-356 130.09	-9.68%	0.54
-37 870 174.49	-38 757 003.05	166 603.18	-886 828.56	-507 000.45	57 991.43	346 483.68	-540 344.87	-160 516.77	-6.23%	0.59
-41 509 615.83	-42 313 900.65	178 205.73	-804 284.82	-328 794.71	58 571.34	373 613.55	-430 671.27	44 818.83	-3.50%	0.63
-45 047 014.07	-45 769 630.53	190 421.14	-722 616.46	-138 373.57	59 157.06	398 985.00	-323 631.46	260 611.42	-1.28%	0.67
-48 485 265.15	-49 127 156.17	203 280.37	-641 891.02	64 906.80	59 748.63	422 712.00	-219 179.03	487 618.80	0.53%	0.71
-51 827 180.59	-52 389 348.84	216 815.95	-562 168.25	281 722.75	60 346.11	444 901.14	-117 267.11	726 623.89	2.03%	0.75
-55 075 490.10	-55 558 990.74	231 062.02	-483 500.64	512 784.77	60 949.57	465 652.09	-17 848.54	978 436.86	3.28%	0.79
-58 232 844.06	-58 638 778.08	246 054.44	-405 934.01	758 839.21	61 559.07	485 058.08	79 124.07	1 243 897.29	4.34%	0.83
-61 301 816.00	-61 631 324.07	261 830.88	-329 508.08	1 020 670.09	62 174.66	503 206.27	173 698.19	1 523 876.36	5.25%	0.86
-64 284 904.89	-64 539 161.74	278 430.88	-254 256.86	1 299 100.96	62 796.41	520 178.19	265 921.34	1 819 279.15	6.02%	0.89
-67 184 537.45	-67 364 746.63	295 895.96	-180 209.18	1 594 996.92	63 424.37	536 050.08	355 840.90	2 131 047.00	6.69%	0.93
-70 003 070.35	-70 110 459.44	314 269.73	-107 389.09	1 909 266.65	64 058.62	550 893.23	443 504.14	2 460 159.89	7.26%	0.96
-72 742 792.27	-72 778 608.51	333 597.98	-35 816.24	2 242 864.63	64 699.20	564 774.33	528 958.09	2 807 638.97	7.77%	0.99
-75 405 926.01	-75 371 432.26	353 928.79	34 493.75	2 596 793.43	65 346.19	577 755.73	612 249.47	3 174 549.15	8.21%	1.01
-77 994 630.43	-77 891 101.49	375 312.65	103 528.95	2 972 106.08	65 999.66	589 895.74	693 424.68	3 562 001.82	8.60%	1.04
-80 511 002.42	-80 339 721.61	397 802.58	171 280.81	3 369 908.66	66 659.65	601 248.90	772 529.70	3 971 157.55	8.94%	1.07
-82 957 078.67	-82 719 334.81	421 454.25	237 743.86	3 791 362.90	67 326.25	611 866.20	849 610.06	4 403 229.10	9.25%	1.09
-85 334 837.55	-85 031 922.09	446 326.11	302 915.46	4 237 689.01	67 999.51	621 795.35	924 710.81	4 859 484.36	9.52%	1.12
R -85 334 837.55	R -85 031 922.09	R 302 915.46	R 302 915.46	R 4 237 689.01	R 621 795.35	R 621 795.35	R 924 710.81	R 4 859 484.36		