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Saving Electrical Energy & Cost Phase Changing Materials

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Abstract

Electricity costs the red meat industry $1 to $2 million per year for each of the top 25 processors. This cost will rise by 14 to 28%, depending on the State the abattoir is in, due to the carbon tax. Refrigeration uses 40-70% of this electricity. Generally, abattoirs use most refrigeration during the day when the peak tariff is more than twice the overnight off peak tariff.

The idea of this project was to do a desk study on electrically generating cheap "cold" overnight to replace refrigeration used during the day. This would also lower the fixed peak demand charge. When the "cold" is used for refrigerant cooling during the day, it further lowers the amount of electricity needed by making refrigeration more efficient. Two different temperatures of storing "cold" were examined (+12^{0}C and -10^{0}C) offering different ways of using the "cold". While the amount of electricity use for refrigeration was substantially lowered and GHG emissions were reduced, the payback periods for expenditures of $392,000 and $570,000 were 18 and 38 years respectively. An increase in electricity cost of 28% would only reduced the 18 year payback to 14 years. It is recommended that this idea is not proceeded with in practice.

Executive Summary

One of the major cost inputs for abattoirs is electricity, estimated to be $1 to $2 million per year for each of the top 25 processors equivalent to over $8 per head for beef and $0.80 per head for sheep/lamb. At the recent AMPC "Changing the Climate" conference (2012), it was predicted that electricity costs would rise by 14 to 28%, depending on the State, due to the recently introduced carbon tax. Refrigeration generally accounts for 40-70% of electricity used by abattoirs. The dairy industry historically have used off peak electricity to make "cold" which is then used during the following day replacing the use of peak tariff electricity which is more than twice the price. An extra benefit of generating some "cold" overnight to replace that generated during the day is that it would lower the peak kW demand which is a component in the overall electrical bill. Electricity use at abattoirs is not constant over a 24 hour period but generally rises to a shallow peak during the day and then falls off to a low steady demand overnight. This pattern varies depending on whether it is a one shift, two shift, or continuous operation with a shut down just for cleaning, and whether the abattoir has only chillers or also has freezers and/or a rendering plant.

An undergraduate vacation project funded by MLA/AMPC focussing on an electricity audit at an abattoir in 2008/09, mentioned that reducing the refrigeration compressor cooling water temperature would improve the COP of the refrigeration cycle. The COP is kWh heat removed per kWh of work done by the refrigeration compressor ie the amount of "cold" made per kWh of electricity used.

Thus, there were two potential benefits of making "cold" overnight and using it during the day. It would lower the overall cost of electricity and it would lower the amount used, which has the added bonus of reducing the emission of GHG caused by the red meat industry. If proved of value, this concept would be beneficial to all abattoirs with refrigeration as even those that operate continuously, still shut down processing during the overnight cleaning period.

These potential benefits needed to be quantified and the cost/benefits calculated. It was decided to do a desk study on just one abattoir and have one site visit by the team. MLA/AMPC chose CRF, a sheep/lamb abattoir with chillers and no rendering plant which operated a two shift, 5 day per week system for the year that was to be examined ie FY 2010/11.

The objectives were to calculate the improvement in COP by cooling refrigerant during the day with "cold" generated overnight, calculate the optimum size of the phase change material tank used to store the "cold" generated overnight, and calculate the resultant change in electrical use and GHG emissions.

The following conclusions were drawn:

Using a phase change material (PCM) tank to store "cold" made with low cost off peak electricity to save using high cost peak electricity is uneconomic.
CRF uses 273 kWh of electrical energy/tonne HSCW for their kill/chill/bone/pack operation which is higher than some abattoirs that also have freezing and rendering processes on site.
CRF only use 200 to 230 kW for their refrigeration needs out of the 1,260 (year minimum) to 1,560 KW (year maximum) peak daily demand.
Using a PCM tank at 120C to sub cool the liquid receiver and lower the ammonia compressor discharge temperature (OPTION 1) resulted in improving the COP by 25% and reducing the energy consumption by 20%. For an expenditure of $392,000, payback period was 18 years reducing to 14 years if electricity increased in price by 29%. GHG emissions reduced by 32 to 124 t CO2-equiv annually depending on the State.

Using a PCM tank at -100C to cool the Boning Room (OPTION 2), reduced the energy cost but increased the electrical energy cost and attendant GHG emissions by 5%. For an expenditure of $570,000, payback period was 38 years.
The team could not think of an abattoir situation which would yield better results than produced by this study at CRF.

It was recommended that the concept of using a PCM tank to reduce electrical costs is not proceeded with and that the conclusions of this study are circulated.

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1. Background

1.1 Abattoir electricity use

One of the major cost inputs for abattoirs is electricity. It is estimated to be $1 to $2 million per year for each of the top 25 processors which amounts to over $8 per head for beef and $0.80 per head for sheep/lamb. Electricity costs are rising and will substantially jump in the 2012/13 financial year when the controversial carbon tax is implemented.

Refrigeration generally accounts for 40-70% of electricity used by abattoirs that have chillers and/or freezers. Electricity use is not constant over a 24 hour period but generally rises to a shallow peak during the day and then falls off to a low steady demand overnight. This pattern varies depending on whether it is a one shift, two shift, or continuous operation with a shut down just for cleaning.

1.2 Cost of electricity

The cost of electricity is usually made up of a fixed component, a per kWh tariff component, and a peak demand component. The per kWh component is usually made up of a peak demand cost and an off peak demand cost, and sometimes there is a shoulder demand cost. Generally, the peak period is during the day and the off peak is overnight and at weekends. Electricity cost increases have risen by more than the CPI in recent years and will continue to do so even more in the future as the carbon tax takes effect. At the recent AMPC 2012 Conference “Changing the Climate”, Selwyn Heilbron said that because the red meat industry is a price taker, the government is wrong in saying we can pass through costs, and he also said that electricity cost increases will not follow what the government says. His economic modelling suggested Victorian price increases of 21-28% and NSW of 14-17%.

1.3 Reducing electricity cost

The dairy industry has widely used ice tanks for many years to generate ice overnight from cheaper off peak electricity and then recovering the “cold” during the day by melting the ice. They have always had an obvious use for this low grade “cold” by circulating water through the ice tanks and using the chilled water to cool the millions of litres of milk processed daily. The system has not been used in the red meat industry because there was no obvious use for the “cold”.

An undergraduate vacation project funded by MLA/AMPC focussing on an electricity audit at an abattoir in 2008/09, mentioned that reducing cooling water temperature would improve the COP of the refrigeration cycle. The student’s mentor who had dairy experience realised that this was a potential way of using “cold” generated overnight. This could reduce the use of peak cost electricity by using off peak cost electricity. There could be the added saving of reducing the “fixed” peak demand charge. This peak demand charge is administered in different ways. Some States and supply companies fix this peak at the maximum a company has ever used and it is only reduced by written request after a long period of demonstration that the peak demand is always lower. Sometimes it is automatically reduced on a rolling 1 year or more historical period.

1.4 Reducing electricity use

The increase in COP will reduce the actual electricity used and this will reduce the carbon footprint and so further reduce cost. The reduction in Scope 2 emissions is also good for the public image. There is an electricity usage/cost in pumping the fluid through the phase change storage tank and loss of energy through the insulation to account for. The improvement in COP as cooling water temperature is lowered is illustrated in the chart APPENDIX J with the results summarised in the table below.

TEMPERATURE	^0C	35	30	25	20
COP		3.85	4.49	5.32	6.25

COP is kWh heat removed per kWh of work done by the compressor.

2. Project Objectives

Beef and lamb abattoirs are operated differently depending on whether there is just single stage refrigeration for chilling or two stage for chilling and freezing. Abattoirs that are single shift have a noticeable peak in the day's electricity consumption. A two shift operation has the peak spread out over a longer period in the day. A continuous operation shows little change in electrical consumption during the week. It is generally noticeable that when the first chiller starts to load in the morning, electrical consumption starts to rise. This continues until all chillers are loaded and closed up after the last animal is processed for the day. By then, depending on the size and number of chillers, the demand from the first chillers loaded is reducing. If there are freezers, then the chilled product that is unloaded into the boning room starts to get put into tunnel or plate freezers. This is a separate rise and fall in electrical demand overlaying the chiller operation. Thus, there are many different scenarios. However, there is a similar overall pattern of electrical use from the refrigeration compressors with a steady background use of motors and pumps operating the abattoir processes.

2.1 The Plan

Despite the variety of possible electrical use patterns, the plan was to do a simple desk study at only one abattoir chosen by MLA/AMPC to produce a description, a plan of how to investigate any abattoir situation. One site visit was scheduled in the contract. The plan was to do calculations based on the FY 2010/11 using more up to date actual site electrical costs.

2.2 The Outputs

2.2.1 Calculate the improvement in COP by cooling a refrigerant using a phase change material.
2.2.2 Calculate the optimum size of the phase change material tank to minimise capital/operating cost while paying regard to minimising net energy and net emissions
2.2.3 Graph and compare the electrical use of the "old" and "new" system
2.2.4 Calculate the reduction in GHG emissions.

3. Methodology

3.1 Site

CRF, Colac was chosen as the site to investigate. This was a sheep/lamb abattoir in Victoria. It operated on a two shift system for the FY10/11 but unfortunately due to a major alteration in its supply contracts and ownership, it changed to only operating on one shift by the time we received permission to visit site.

3.2 Electrical usage

The electrical data was supplied for the financial year 2010/11 in 30 min intervals. An extract of this data is given in table 1 below and shown in Appendix A.

NMI	Kwh	Meters	Day	Interval	Period	EndTime	KVA	KW	Peak	OffPeak	Shoulder
VCCCTC0062	542.056	1	9/05/2011 0:00	30	42	9/05/2011 21:00	1309.27	1084.112	542.056	0	0
VCCCTC0062	555.77	1	9/05/2011 0:00	30	43	9/05/2011 21:30	1322.428	1111.54	555.77	0	0
VCCCTC0062	458.841	1	9/05/2011 0:00	30	44	9/05/2011 22:00	1098.387	917.682	458.841	0	0
VCCCTC0062	414.414	1	9/05/2011 0:00	30	45	9/05/2011 22:30	1001.862	828.828	414.414	0	0
VCCCTC0062	408.274	1	9/05/2011 0:00	30	46	9/05/2011 23:00	985.447	816.548	408.274	0	0
VCCCTC0062	380.335	1	9/05/2011 0:00	30	47	9/05/2011 23:30	914.673	760.67	0	380.335	0
VCCCTC0062	367.459	1	9/05/2011 0:00	30	48	10/05/2011 0:00	881.619	734.918	0	367.459	0
VCCCTC0062	367.679	1	10/05/2011 0:00	30	1	10/05/2011 0:30	885.115	735.358	0	367.679	0
VCCCTC0062	366.922	1	10/05/2011 0:00	30	2	10/05/2011 1:00	886.087	733.844	0	366.922	0

Table 1. Extract of 30min electrical use at CRF FY 2010/11

The year's data was examined to find the maximum usage and minimum usage of electricity in a week during the year with normal running ie not including extended downtime for maintenance or public holidays. The plan was then to look at the costs of a system that would handle the maximum with due regard to not over capitalising. Figure 1 and 2 show the full variation in electrical use between the maximum and the minimum normal 5 day two shift working week. There is the same pattern of use after midnight on Friday night with the demand dropping to 400kW over Saturday and plateauing at 300kW on Sunday. The single day pattern is shown in figure 3. There is no obvious sharp peak. The highest daily usage in the highest week and the lowest daily usage in the lowest week for the year show a similar pattern in figure 4. So, it was thought that it was acceptable to use these figures as "normal". Note that the peak and off peak tariff periods are one hour apart between the maximum and minimum usage days as one is in the summer and one in the winter when tariff periods are different.

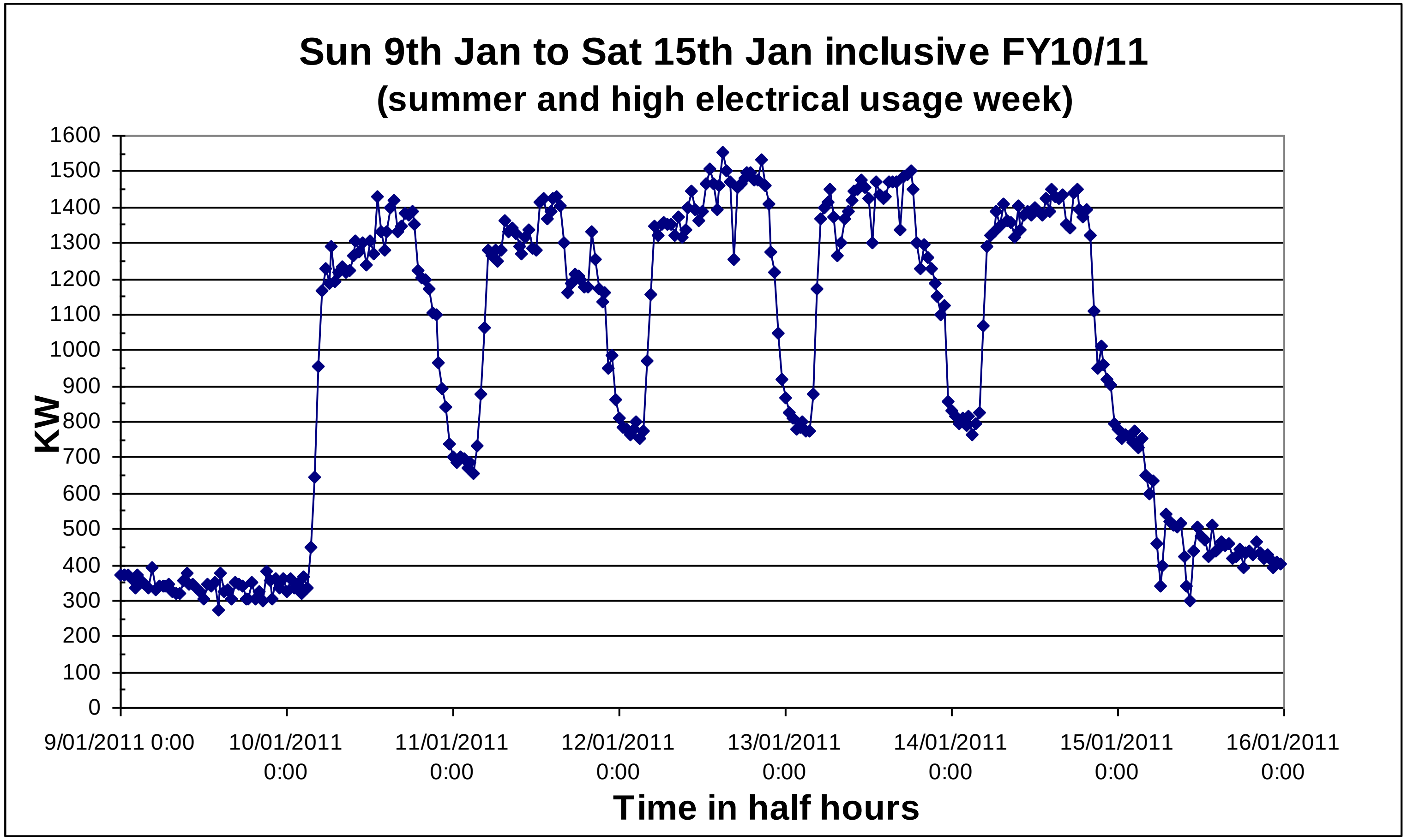


Figure 1. Highest overall electrical use for a 5 day week

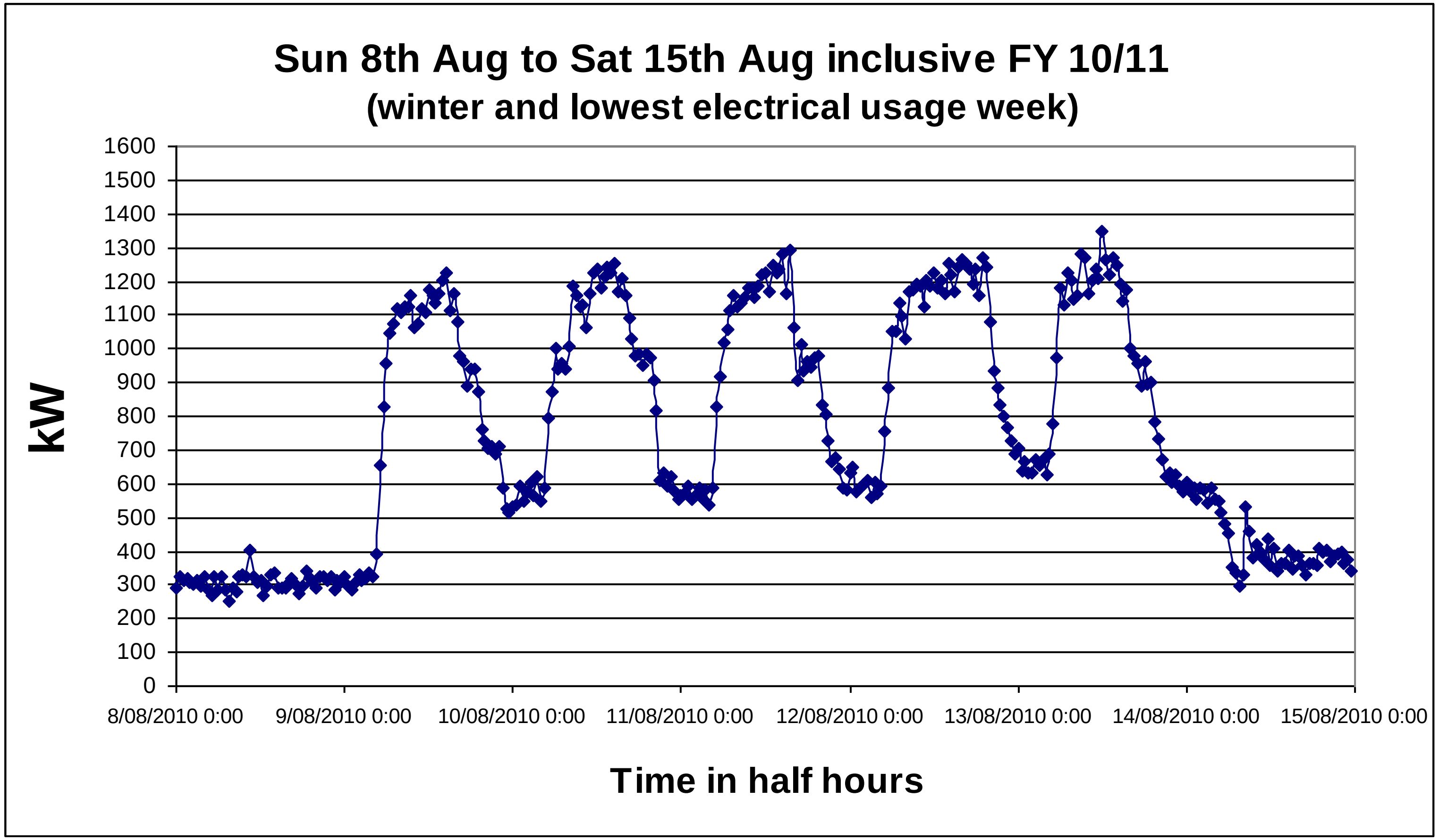


Figure 2 Lowest overall electrical use for a 5 day week

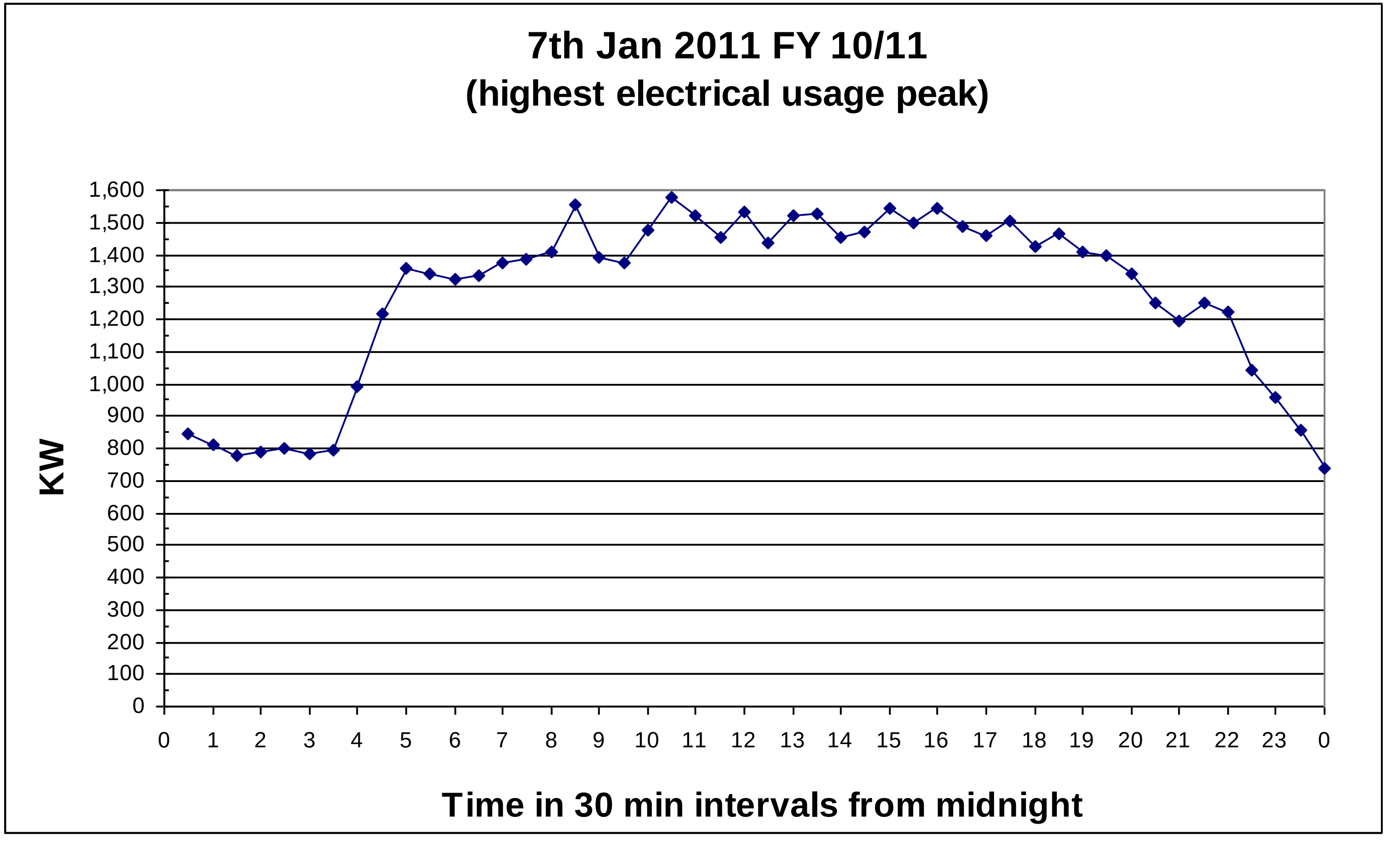


Figure 3. Pattern of electrical use on highest day in week of highest use.

Some abattoirs show a more distinct peak than CRF but there is still an opportunity to use off peak electricity in place of peak cost electricity even if there is less saving in the peak demand tariff part of the charges.

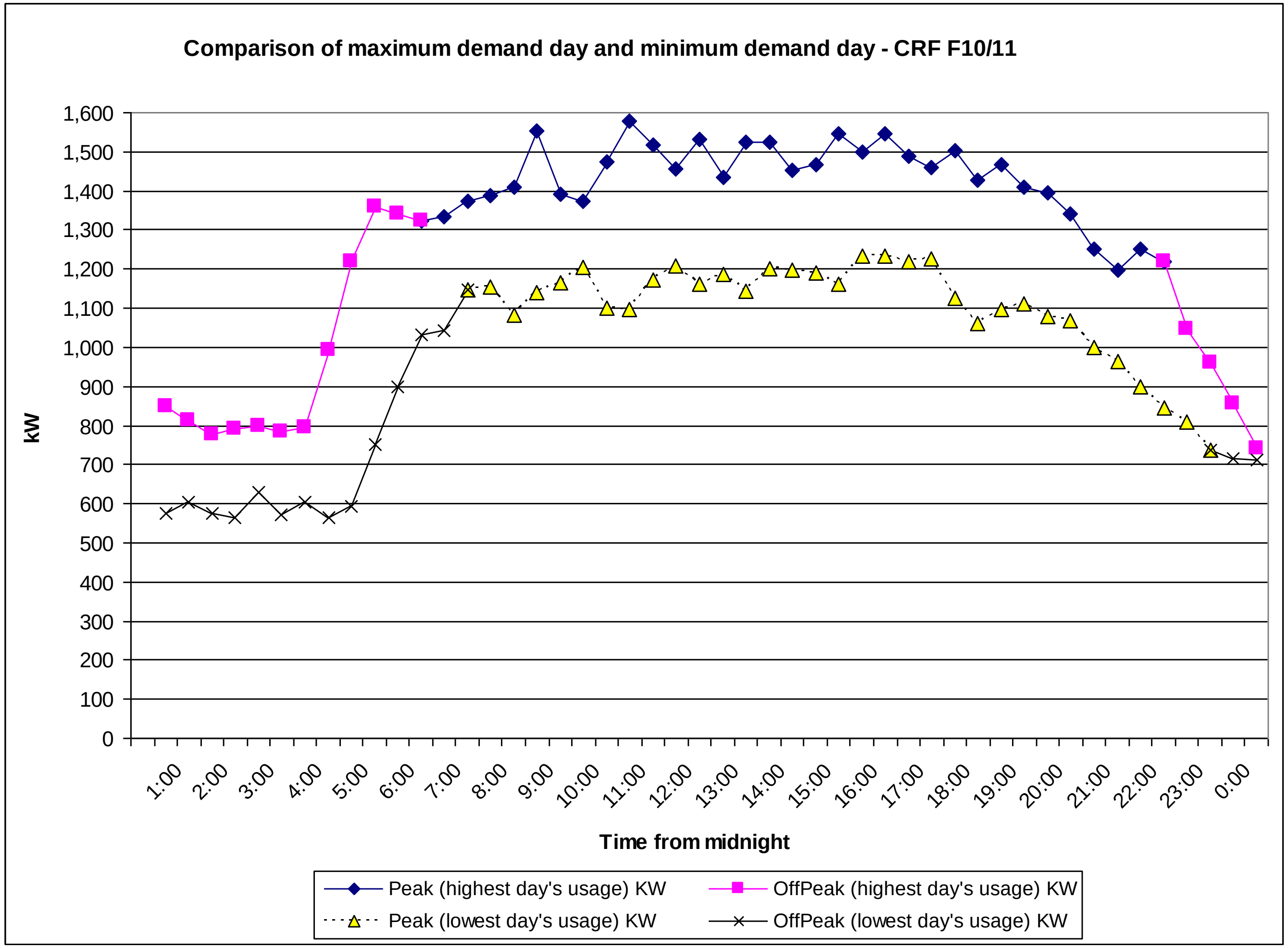


Figure 4. Comparison of the highest electricity use day and lowest electricity use day

Examination of other weeks in the year showed an even variation between these two graphs.

3.3 Electrical costs

The electrical charges taken from the supplier bill for Oct 2011 are shown below.

Electrical charges	$	
Energy charges inc GST		
Peak tariff	$0.0957110	$/KWh
Off peak tariff	$0.0446787	$/KWh
Network charges inc GST		
Peak tariff	$0.0237501	$/KWh
Off peak tariff	$0.0076945	$/KWh
Demand	$0.0706668	$/KW based on 1,706 KW
Other inc GST		
NEMMCO charge	$0.0004730	$/total KWh
NEMMCO ancillary	$0.0008943	$/total KWh
REC charge (SREC rate)	$0.0071500	$/total KWh
REC charge (LREC rate)	$0.0035266	$/total KWh
Meter provider	$73.33	$/month
Service charge	$33.00	$/month
Value added service charge	$15.58	$/month

Table 2. Billed electricity charges at CRF Oct 2011

The above charges can be reconciled into a more compact form as shown below.

Peak tariff	$0.1194611	$/KWh
Off peak tariff	$0.0523732	$/KWh
Extra tariff charges	$0.0120439	$/KWh
Peak demand	$7.0666750	$/KW based on 1,706 KW monthly charge
Annual fixed charges	$1,463.00	$/yr fixed
CRF peak demand	1,706	KW

Table 3. Reconciled electricity charges at CRF Oct 2011

The extra tariff charges are partly peak and partly off peak so costs can be again further simplified to the following table.

Peak tariff	$0.1315050	$/KWh
Off peak tariff	$0.0644171	$/KWh
Extra tariff charges	inc in above	$/KWh
Peak demand	$7.0666750	$/KW based on 1,706 KW monthly charge
Annual fixed charges	$1,463.00	$/yr fixed
CRF peak demand	1,706	KW

Table 4. Simplified electricity charges at CRF Oct 2011

For October 2011, the overall costs are:

peak elec	393,676.90	kWh
off peak elec	255,907.83	kWh
total elec	649,584.73	kWh
peak tariff	$47,029.08	
offpeak tariff	$13,402.71	
extra tariff peak	$4,741.41	
extra tariff offpeak	$3,082.13	

Table 5. Overall costs of electricity at CRF Oct 2011

total tariff peak	$51,770.48	64.4%
total tariff offpeak	$16,484.84	20.5%
demand charge	$12,055.75	15.0%
fixed charge	$121.92	0.2%
total charge	$80,432.99	100%

Table 6. Simplified breakdown of electricity charges at CRF Oct 2011

The peak charges are from 7am to 11pm in winter and 6am to 10pm in summer. Saturday and Sunday are also off peak. Summer time was from Mon 4th Oct to Mon 4th April. This gives abattoirs the opportunity of moving electrical usage to the 8 hours of off peak time.

The demand charge which is levied each month on the maximum peak demand the abattoir ever used just for one half hour period some time in the last few years is 15% of the bill. It is charged on 1,706 kW whereas the maximum peak in the year examined was only 1,600 kW. If the abattoir specified 1,600 kW as their maximum demand it would lower the bill by about $9,000 per year. This may not be considered a large enough saving to worth bothering about.

There is a major difference between the consolidated $0.1315 peak tariff and $0.0644 off peak tariff for it to be worth proceeding to look at shifting usage from the peak to off peak period in the day.

3.4 Potential for electrical cost saving

Without regard to how “cold” could be usefully used, a number of scenarios were costed to see the potential savings of moving electrical usage from peak period to off peak. Clearly, the “cold” generated would need to be usefully reusable during the peak period to reduce the electrical load on the compressors. These calculations are useful in showing whether the demand charge is really important ie should emphasis be placed on trying to reduce peak demand during the day or is it sufficient to just transfer electrical use at any part of the peak charge period into the off peak charge period and whether the amount of potential saving is worth pursuing.

Six scenarios were costed based on moving electricity consumption from the peak tariff charge period to the off peak tariff charge period. These were the original base case at CRF of 1,276kW, using this amount of electricity in the off peak tariff period, then ramping up until 80% of all the 24hr electrical usage was consumed in the off peak period. Clearly, no more than 80% of electricity use is ever used for refrigeration so this takes the calculation beyond what is feasible but it sets upper limits.

The following table gives these results. The “variable” cost in table 7 below is the summation of peak and off peak tariff charges as electrical usage is moved into the off peak period while maintaining the overall 24 hr usage for the day.

Demand peak KW	Variable $ cost	Demand peak $ cost	Total $ cost	KWh "cold" put in storage	$ Saving
1,276	$801,883	$108,166	$911,512	2,484	$76,505
1,360	$790,968	$115,352	$907,783	3,162	$80,234
1,706	$746,436	$144,669	$892,568	5,928	$95,449
2,679	$621,152	$227,149	$849,764	13,709	$138,253
3,061	$571,861	$259,599	$832,923	16,770	$155,094
2,679	$415,040	$227,149	$643,652	15,638	$169,313

Table 7. Cost saving in six theoretical scenarios of shifting demand

These are graphed below.

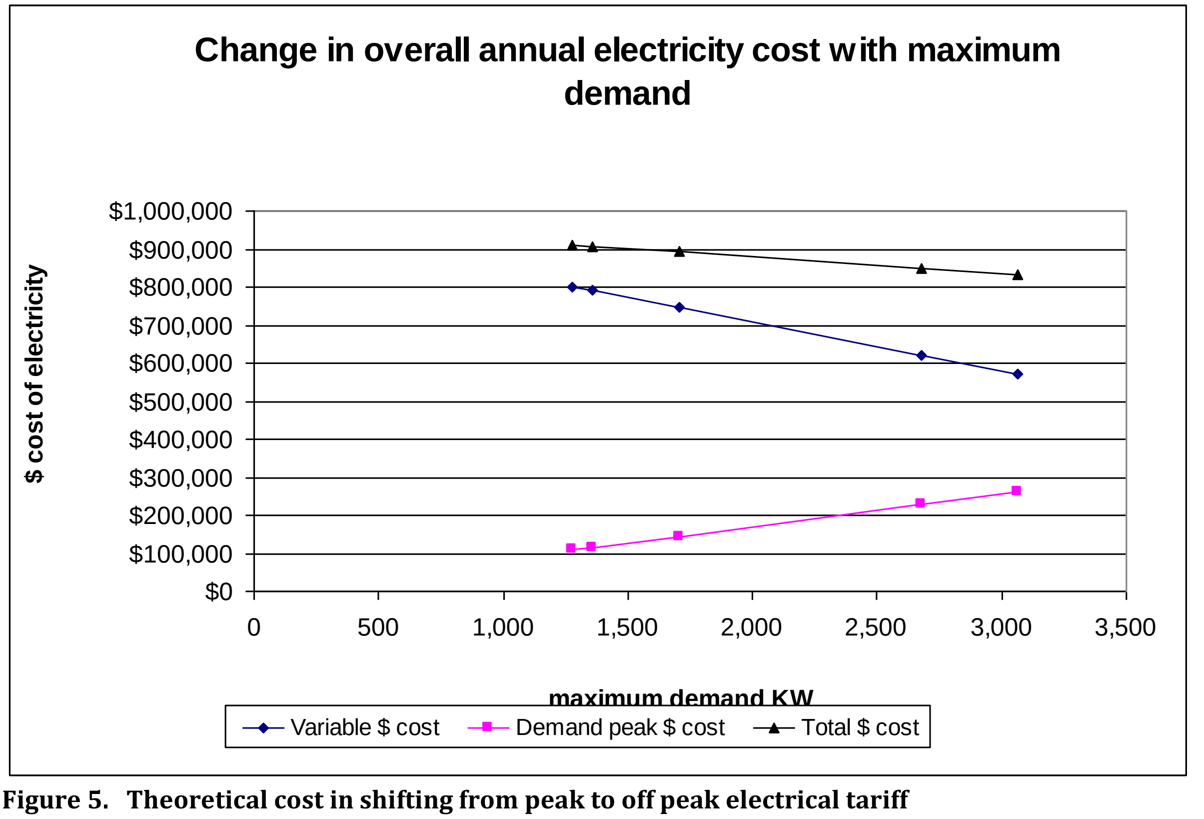


Figure 5. Theoretical cost in shifting from peak to off peak electrical tariff

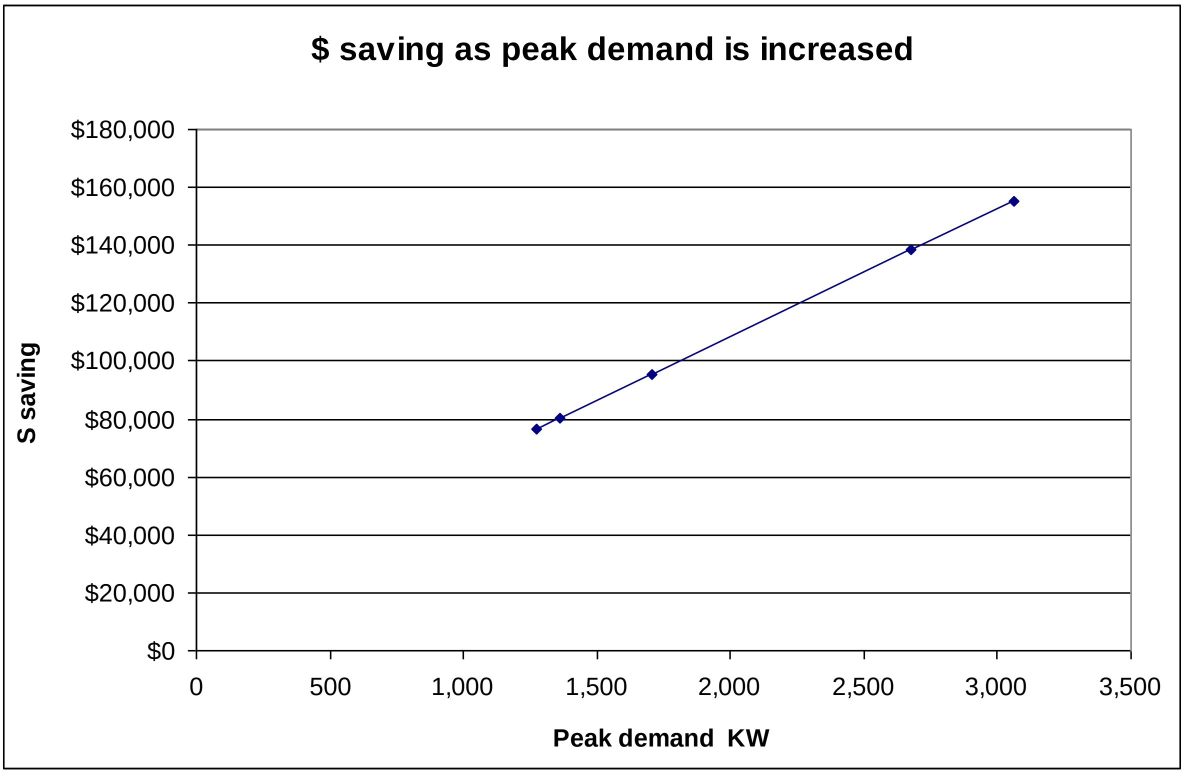


Figure 6. Theoretical annual saving in shifting to off peak tariff at CRF

Overall, this potential for saving electrical costs by switching to the use of off peak electricity was encouraging to continue with the desk study by seeing how this may be done. While the "cold" can be stored overnight by using a phase change material, there needs to be a way of usefully using that "cold" during the day in order to reduce the use of refrigeration compressors. In its simple form, water can be changed to ice and then that ice can be melted during the day but any material that changes phase can be use and there are materials commonly change phase at a wide range of temperatures from below 0^0C to above 100^0C.

4. Results

In the following sections the reductions in energy consumption plus attendant reductions in costs have been calculated with the use of phase change material (PCM) thermal storage systems. Two options were examined, storing energy at 12^{0}C and at -10^{0}C.

4.1 Option 1. Storing energy at 12^{0}C

There are two uses for using energy stored at a melting/freezing point of 12^{o}C.

4.1.1 Sub cool the receiver liquid from +25^{0}C to +15^{0}C

4.1.2 Reduce the ammonia compressor discharge temperature (by removing some of the superheat, which will reduce the evaporative condenser (EC) load and, most importantly, enhance heat transfer in the condensing coils as none of the condensing surface is used for desuperheating dry ammonia vapour and more condensing coil surface is used for liquefying the wet ammonia vapour.

The calculations covering this option are listed in Appendix B. They show that the consequences of the above measures are as follows

.1 The discharge vapour enters the condenser with a quality of 97%, i.e. 3% is condensed. This improves the condenser heat transfer rate by about 35%, which is why the SCT will reduce by 5^{0}K from an average of 30°C to an average of 25°C.

.2 The COP will improve from 4.47 to 5.25, i.e. an increase of 17.5%. Therefore, the energy consumption will reduce by 15%.

.3 The COPs are based on Saturated Suction vapour. The liquid sub cooling reduces the mass flow by 0.04 kg/sec or 6%.

.4 The heat rejection to the condenser reduces from 954 kW to 929 kW ie a reduction of 25 kW or 2.5% which will add a further 1.5% improvement to the COP.

.5 Therefore, the total COP improvement is 0.27 + 0.28 + 0.29 = 25% and the energy consumption will reduce by 20%.

4.2 Option 2. Storing energy at -10^{0}C

4.2.1 By storing cold thermal energy with an FMP of about −10°C, this could then be used to operate the Boning Room (BR) and remove its load from the peak electrical tariff period. Boning Room Cooling is effected by circulating chilled polypropylene brine at a temperature of −2°C to the cooling coils in the AH units with a combined capacity of about 200 kW. The BR operates for two shifts plus pre-cooling and repack time, say 18 hrs/day. The polypropylene glycol brine used in the BR cooling system could be cooled by cold brine generated by melting the PCM material at a temperature of about -5^{0}C. The calculations covering this option are listed in Appendix C.

5. Discussion

Although operating cost reductions are achieved in both options, the simple payback periods calculated in Appendix B (for OPTION 1) and Appendix C (for OPTION 2) with budget estimates in Appendix D are far too long for the schemes to be considered worthy of implementation.
The high temperature phase change material proposal (OPTION 1) will reduce both the electrical energy costs and consumption and attendant emissions. The estimated budget cost is $392,000 (Appendix D) with a saving of $21,753 (Appendix E). This gives a simple pay back period of 18 years. This only reduces to 14 years if electricity prices rise by 29%. Appendix F graphs how the COP changes with the use of a PCM tank.
There would be no change to chargeable GHG ie carbon permits, because the emission from electricity use is a Scope 2 emission. However, there would be a “marketing” bonus for the industry if changes were made which resulted in a reduction in global carbon dioxide emissions. The emissions vary depending on the State in which the electricity is used/saved as the electricity is generated in different States by processes that generate different amounts of GHG from high emitters eg brown coal, to low emitters eg hydro generation. The following table gives the 2010 factors, which the federal government may change annually.

State	kg CO_2/kWh
Vic	1.23
NSW/ACT	0.90
Qld	0.89
SA	0.72
NT	0.68
Tasmania	0.32

For OPTION 1, this only amounts to a saving of 32 to 124 tonnes/year of CO_2-e emissions. This would impact on an NGERS Outcomes report and affect the abattoir if it was reporting on OSCAR.

The low temperature PCM proposal (OPTION 2) will reduce the energy cost but increase the electrical energy cost and attendant GHG emissions by 5%. The calculations are shown in Appendix C which demonstrates for an investment cost of $570,000, there is a saving of $15,000 per year giving a payback period of 38 years.
It is difficult to think of an abattoir situation which would yield better results. This is disappointing, as it was thought initially that the prospect for improved results would be better. However, until these calculations were done it could not be seen that this would be the result.
In proposing to shift heat load from one part of the day where refrigeration energy is expensive to where it is cheaper, it is necessary to store 5% more condenser or boning room cooling capacity than is being replaced because the additional heat transfer process involves losses. Furthermore, there is additional electrical energy consumed by the fluid circulating pumps, which also generate heat load as they are in the cooling fluid stream.
Any energy savings are due to the fact that the compressor COP is much higher when freezing the high melt point material to enhance condenser performance, but in the case of storing cooling capacity the energy consumption increases by 5% due to system losses.
At the plant on which this study is based, the specific energy consumption is 273 kWh/tonne HSCW. This seems to be very high for a kill/chill/boning and packing plant where there is no

on site freezing or rendering.   In fact, it is higher than some plants that also have freezing and rendering.
At CRF, the refrigeration plant's total energy consumption is a relatively small proportion of the total energy consumption. This is further confirmed by the fact that in the FY2010/11, the refrigeration compressors draw a demand of about 200 to 230 kW out of a total maximum demand (MD) ranging from a minimum daily 1,260 kW on Tuesday August 10 2010 to a maximum daily 1,560 kW on Wednesday the 12th of January 2011. Therefore, most of the demand is production related, including parasitic refrigeration energy consumers like fans, condensers, liquid pumps, brine pump etc., none of which can be switched off.
There is only scope to manipulate the actual heat coming out of the product and this calculation is shown in the table, Appendix E. It is based on CRF plant data with the assumption that the heat coming out of the product constitutes only 20% of the total refrigeration load.   Therefore, the scope of reducing both energy consumption and cost, and attendant emissions is limited by the product heat to be removed by the compressors as all other electrical energy consumers need to operate, because they are process requirements.

6. Conclusions

In the desk study on CRF data for FY 2010/2011, the following conclusions were drawn

6.1 Using a phase change material (PCM) tank to store "cold" made with low cost off peak electricity to save using high cost peak electricity is uneconomic.

6.2 CRF uses 273 kWh of electrical energy/tonne HSCW for their kill/chill/bone/pack operation which is higher than some abattoirs that also have freezing and rendering processes on site.

6.3 CRF only use 200 to 230 kW for their refrigeration needs out of the 1,260 (year minimum) to 1,560 KW (year maximum) peak daily demand.

6.4 Using a PCM tank at 12^0C to sub cool the liquid receiver and lower the ammonia compressor discharge temperature (OPTION 1) results in improving the COP by 25% and reducing the energy consumption by 20%. For an expenditure of $392,000, payback period is 18 years reducing to 14 years if electricity increases in price by 29%. GHG emissions reduce by 32 to 124 t CO_2-equiv annually depending on the State.

6.5 Using a PCM tank at -10^0C to cool the Boning Room (OPTION 2), will reduce the energy cost but increase the electrical energy cost and attendant GHG emissions by 5%. For an expenditure of $570,000, payback period is 38 years.

6.6 It is difficult to think of an abattoir situation which would yield better results than produced at CRF.

7. Recommendations

7.1 That the concept of using a PCM tank to reduce electrical costs is not proceeded with but that the conclusions of this study are circulated.

APPENDIX A. Example of Electrical data FYT 10/11

NMI	Kwh	Meters	Day	Interval	Period	EndTime	KVA	KW	Peak	OffPeak	Shoulder
VCCCTC0062	542.056	1	9/05/2011 0:00	30	42	9/05/2011 21:00	1309.27	1084.112	542.056	0	0
VCCCTC0062	555.77	1	9/05/2011 0:00	30	43	9/05/2011 21:30	1322.428	1111.54	555.77	0	0
VCCCTC0062	458.841	1	9/05/2011 0:00	30	44	9/05/2011 22:00	1098.387	917.682	458.841	0	0
VCCCTC0062	414.414	1	9/05/2011 0:00	30	45	9/05/2011 22:30	1001.862	828.828	414.414	0	0
VCCCTC0062	408.274	1	9/05/2011 0:00	30	46	9/05/2011 23:00	985.447	816.548	408.274	0	0
VCCCTC0062	380.335	1	9/05/2011 0:00	30	47	9/05/2011 23:30	914.673	760.67	0	380.335	0
VCCCTC0062	367.459	1	9/05/2011 0:00	30	48	10/05/2011 0:00	881.619	734.918	0	367.459	0
VCCCTC0062	367.679	1	10/05/2011 0:00	30	1	10/05/2011 0:30	885.115	735.358	0	367.679	0
VCCCTC0062	366.922	1	10/05/2011 0:00	30	2	10/05/2011 1:00	886.087	733.844	0	366.922	0

APPENDIX B. CALCULATIONS OPTION 1

Reducing condensing pressure and ammonia sub cooling by 10^{0}K

Present performance
.1 Saturated Suction Temperature (SST), °C −10
.2 SCT, °C +30
.3 Liquid sub cooling, k Nil
.4 Useful suction superheat, k Nil
.5 Vapour enthalpy @ −10°C, kJ/kg 1,673.46
.6 Liquid enthalpy @ +30°C, kJ/kg 562.75
.7 Enthalpy rise in evaporator, kJ/kg 1,110.71
.8 COP from attached Figure 1 4.47
.9 Enthalpy rise in compressor, kJ/kg 248.48
.10 Enthalpy at compressor discharge 1,921.94
.11 Compressor discharge temperature, °C ≈ 108
.12 System design capacity, kWR 780
.13 NH_3 mass flow rate, .12 ÷ .7, kg/sec 0.70
.14 Heat rejection to condenser, .13 x (.10 - .6), kW 954
Desirable performance
.1 SST, °C −10
.2 SCT, °C +25
.3 Liquid sub cooling at condenser Nil
.4 Useful suction superheat, K Nil
.5 Liquid enthalpy condenser exit, kJ/kg 539.26
.6 Liquid sub cooling after receiver, K 10
.7 Vapour enthalpy at evaporator exit @ −10°C SST, kJ/kg 1,673.46
.8 Liquid enthalpy at +15°C after liquid sub cooler 492.71
.9 Enthalpy rise in evaporator 1,180.75
.10 COP from Figure 1 @ −10/+25 5.25
.11 Enthalpy rise in the compressor, .9 ÷ .10, kJ/kg 224.9
.12 Enthalpy @ compressor discharge, .7 + .11, kJ/kg 1,898.36
.13 Compressor discharge temperature, °C 96
.14 System design capacity, kW 780
.15 NH_3 mass flow, .14 ÷ .9, kg/sec 0.66
.16 Heat rejected, .15 x (.12 - .8), kW 929
.17 Liquid sub cooling enthalpy reduction, .15 x (.5 - .7), kJ/kg 46.55
.18 Liquid sub cooling capacity, .15 x .17, kW 31.0
.19 Available capacity, kW 175
.20 Available capacity for compressor discharge desuperheating
= .19 - .18, kW144
.21 Enthalpy reduction compressor discharge, .20 ÷ .15, kJ/kg 218
.22 Enthalpy at condenser entry, .12 - .21, kJ/kg1,670.36
.23 Saturated vapour enthalpy @ 25°C SCT, kJ/kg 1,706.35
.24 Heat to be removed from +25°C Sat. Vapour to Sat. Liquid,
.23 - .5, kJ/kg 1,167.01
.25 Enthalpy reduction from Sat. Vapour to Wet Vapour,
.23 - .22, kJ/kg 36
Summary of above
.1 Therefore, the discharge vapour enters the condenser with a quality of 97%, i.e. 3% is condensed. This improves the condenser heat transfer rate by about 35%, which is why the SCT will reduce by 5K from an average of 30°C to an average of 25°C.
.2 The COP will improve from 4.47 to 5.25, i.e. an increase of 17.5%. Therefore, the energy consumption will reduce by 15%.

.3 The COPs in the previous items are based on Saturated Suction vapour. The liquid sub cooling reduces the mass flow by 0.04 kg/sec or 6%.

.4 The heat rejection to the condenser reduces from 954 kW (Item 2.1.1.14) to 929 kW (Item 2.1.2.16). A reduction of 25 kW or 2.5%. This will add a further 1.5% improvement to the COP.

.5 Therefore the total COP improvement is 0.27 + .28 + .29 = 25% and energy consumption will reduce by 20%.

APPENDIX C. CALCULATIONS OPTION 2

Storing thermal energy for operating the Boning Room.

.1	Cooling capacity, kW	200
.2	Operating time, hrs	18
.3	Total cooling capacity storage, kWh	3,600
.4	Losses, %	5
.5	Design cooling capacity storage, kWh	3,780
.6	Brine temp. to BR, °C	−2
.7	Freezing/Melting Point PCM, °C	−4
.8	Compressor SST, °C	−10
.9	Compressor COP @ −10°C/+30°C	4
.10	Energy consumption to freeze PCM, .5 ÷ .9, kWh	945
.11	Energy consumption normal operation, .3 ÷ .9, kWh	900
.12	Energy cost on peak, 900 x 0.13	$117
.13	Energy cost off peak 945 x 0.06	$ 57
.14	Daily saving	$ 60
.15	Say number of days/annum	250
.16	Annual saving	$15,000
.17	Estimated investment required	$570,000
.18	Simple payback, years	38

APPENDIX D. BUDGET ESTIMATES

OPTION 1.
.1 Budget from UK – see attached email. GBP 130,000 + 10%
(import duty and local delivery) @1 GBP= 1.65 AU$ 236,000
.2 Condensing Plate Heat Exchanger (PHX) 144 kW 10,000
.3 Sub cooling PHX, 31 kW 5,000
.4 Chilled water circulating pump (CHWP) 2,000
.5 Install PHXs in ammonia side 15,000
.6 Install CHWP 2,000
.7 Install chilled water piping, valves and controls 25,000
.8 Insulate tank 16,000
.9 Electrical works 30,000
.10 Test and commission 15,000
.11 Total budget estimate 356,000
.12 Add 10% contingency 36,000
.13 Grand total budget cost 392,000
.14 Estimated annual saving – See calculations based on production. 22,000
.15 Simple payback, years 18

OPTION 2. Boning room cooling
.1 Estimated budget cost for 3,780 kWh capacity storage 350,000
.2 Glycol to ammonia PHX, 470 kW 18,000
.3 Glycol to glycol PHX, 200 kW 12,000
.4 Primary brine pump 3,500
.5 Install PHXs on ammonia side 15,000
.6 Install primary brine pump 2,500
.7 Install primary and secondary brine piping 30,000
.8 Insulate the brine tank 25,000
.9 Electrical works 35,000
.10 Test and commission including primary brine change
of propylene glycol 25,000
.11 Total budget estimate 516,000
.12 Add 10% contingency 54,000
.13 Grand total budget estimate 570,000
.14 Estimated annual saving 15,000
.15 Simple payback, years 38

APPENDIX E. PRODUCT HEAT LOAD

	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Number (head processed)	88,699	78,370	100,667	118,484	122,990	119,101
Weight (kg) HSCW	2,001,124.6	1,662,618.2	2,131,042.4	2,550,348.2	2,713,616.1	2,571,831.9
Weight (tonne) HSCW	2,001.1	1,662.6	2,131.0	2,550.3	2,713.6	2,571.8
Water Consumption (L)	17,882,000	16,728,000	16,621,000	19,044,000	19,520,000	19,164,000
Water Consumption (kL)	17,882	16,728	16,621	19,044	19,520	19,164
Gas Consumption (Gj)	3,472.0	3,106.0	3,242.0	3,084.0	3,174.0	2,935.0
Electricity Consumption (kWh)	607,435.96	581,764.90	617,247.95	664,733.03	662,915.10	666,838.40
kWh/t HSCW	303.6	349.9	284.6	260.6	244.3	259.3
Lamb Temperature after stimulation ◦C	40	40	40	40	40	40
Final product temp., ◦C	0	0	0	0	0	0
Temp. reduction, k	40	40	40	40	40	40
Sbl fat lamb, kJ/kg	2.9	2.9	2.9	2.9	2.9	2.9
Heat removed, kJ/kg	116	116	116	116	116	116
Total product heat removed, GJ	232.1	192.9	247.2	295.8	314.8	298.3
Product heat removed, kWh @ 277.77 kWh/GJ	64,481	53,573	68,666	82,176	87,438	82,869
Say product heat is 20% of total refrigeration load then total refrigeration capacity, kWh	322,405	267,865	343,330	410,882	437,191	414,346
Nett COP 4.47 x 0.9	4	4	4	4	4	4
Then compressor energy consumption, kWh	80,601	66,966	85,832	102,720	109,298	103,586
Energy saving 20%, kWh	16,120	13,393	17,166	20,544	21,859	20,717

APPENDIX E. PRODUCT HEAT LOAD (CONT)

	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11
Number (head processed)	102,679	96,341	110,125	94,307	109,779	104,166
Weight (kg) HSCW	2,309,227.7	2,202,889.4	2,539,780.9	2,192,021.0	2,545,370.6	2,419,485.7
Weight (tonne) HSCW	2,309.2	2,202.9	2,539.8	2,192.0	2,545.4	2,419.5
Water Consumption (L)	17,134,000	17,084,000	19,539,000	18,126,000	19,573,000	2,094,900
Water Consumption (kL)	17,134	17,084	19,539	18,126	19,573	2,095
Gas Consumption (Gj)	2,616.0	2,535.5	2,997.2	2,723.7	3,668.0	3,744.3
Electricity Consumption (kWh)	634,042.66	606,090.33	656,032.69	589,040.45	663,888.23	653,854.23
kWh/t HSCW	274.6	275.1	258.3	268.7	260.8	270.2
Lamb Temperature after stimulation ◦C	40	40	40	40	40	40
Final product temp., ◦C	0	0	0	0	0	0
Temp. reduction, k	40	40	40	40	40	40
Sbl fat lamb, kJ/kg	2.9	2.9	2.9	2.9	2.9	2.9
Heat removed, kJ/kg	116	116	116	116	116	116
Total product heat removed, GJ	267.9	255.5	294.6	254.3	295.3	280.7
Product heat removed, kWh @ 277.77 kWh/GJ	74,408	70,982	81,838	70,631	82,018	77,962
Say product heat is 20% of total refrigeration load then total refrigeration capacity, kWh	372,038	354,912	409,190	353,155	410,092	389,808
Nett COP 4.47 x 0.9	4	4	4	4	4	4
Then compressor energy consumption, kWh	93,009	88,728	102,298	82,289	102,523	97,452
Energy saving 20%, kWh	18,602	17,746	20,460	17,658	20,505	19,490

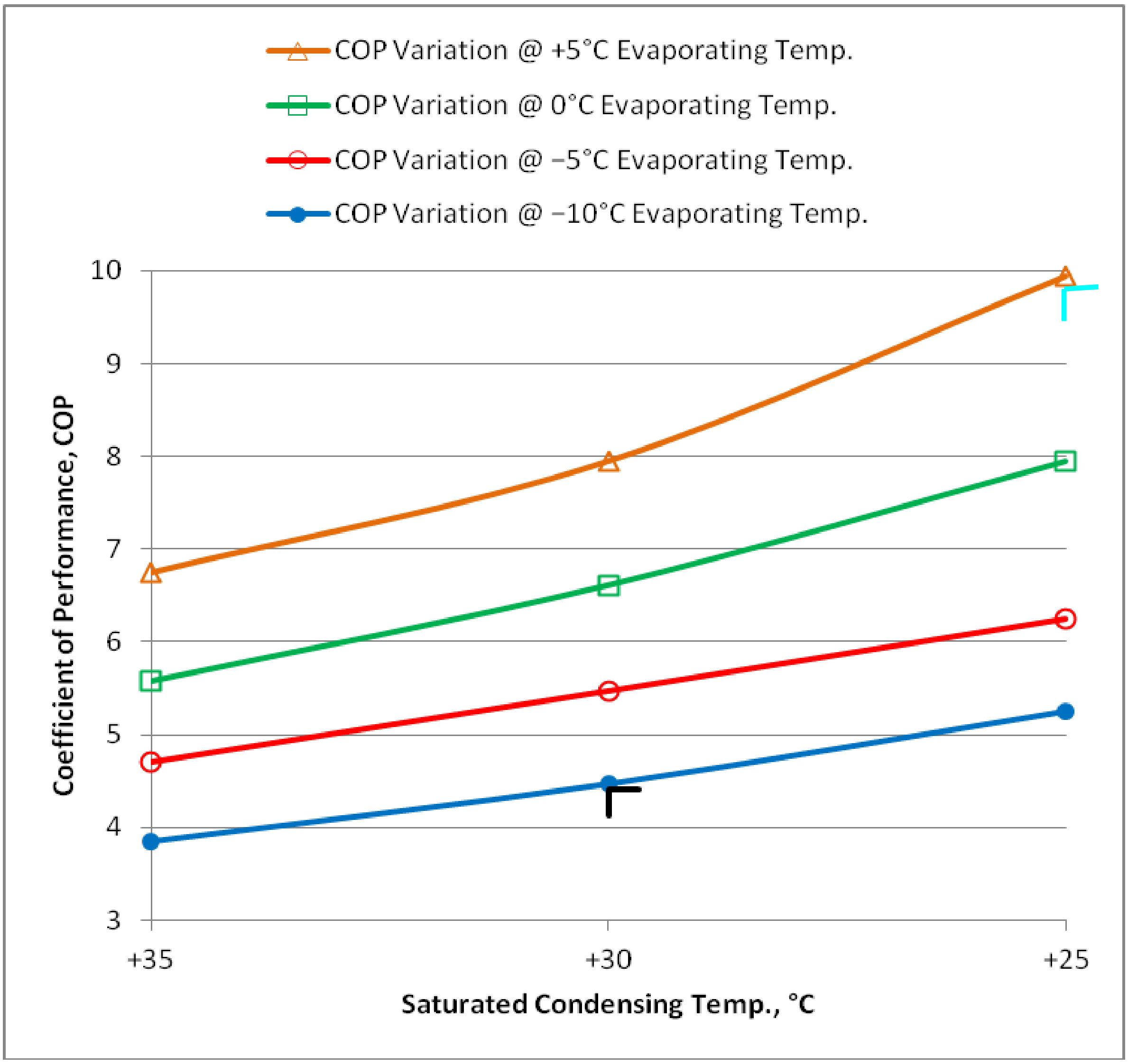
APPENDIX E. PRODUCT HEAT LOAD (CONT)

	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11
Number (head processed)	96,954	97,324	95,221	99,224	95,792	66,083
Weight (kg) HSCW	2,227,714.8	2,196,615.0	2,107,359.3	2,202,296.3	2,214,366.4	1,534,476.6
Weight (tonne) HSCW	2,227.7	2,196.6	2,107.4	2,202.3	2,214.4	1,534.5
Water Consumption (L)	19,431,000	19,173,000	18,733,000	18,941,000	16,264,000	11,728,000
Water Consumption (kL)	19,431	19,173	18,733	18,941	16,264	11,728
Gas Consumption (Gj)	3,569.3	3,598.5	3,452.2	3,570.5	2,983.3	2,055.9
Electricity Consumption (kWh)	633,241.64	652,188.79	609,407.15	649,584.00	649,583.73	658,751.25
kWh/t HSCW	284.3	296.9	289.2	295.0	293.3	429.3
Lamb Temperature after stimulation ◦C	40	40	40	40	40	40
Final product temp., ◦C	0	0	0	0	0	0
Temp. reduction, k	40	40	40	40	40	40
Sbl fat lamb, kJ/kg	2.9	2.9	2.9	2.9	2.9	2.9
Heat removed, kJ/kg	116	116	116	116	116	116
Total product heat removed, GJ						
Product heat removed, kWh @ 277.77 kWh/GJ						
Say product heat is 20% of total refrigeration load then total refrigeration capacity, kWh						
Nett COP 4.47 x 0.9	4	4	4	4	4	4
Then compressor energy consumption, kWh						
Energy saving 20%, kWh						

CONCLUSION

Total energy saving, kWh Financial Year 10/11	224,260 @ $0.13 =	$29,154	
Energy to freeze 55% of energy saved	123,343 kWh @ $0.06 =	$ 7401	
Nett Saving		$21,753	/annum

APPENDIX F. COP VARIATION



Point 1. COP = 4.47 @ normal refrigeration duty @ −10°C Evap. Temp. & +30°C SCT.

Point 2. COP = 9.94 when freezing PCM @ +5°C Evap. Temp. & +25°C SCT.

APPENDIX G. EMAILS and QUOTES

From: Zafer (EPS) [mailto:info@pcmproducts.net]
Sent: Monday, 14 May 2012 7:08 PM
To: Kav Consult
Subject: Re: PCM/12/05/046/ZU, Re: Website Form Submission

Kav
Thank you for the feed back. 1/10 of the capacity (~1,670 kWh) details are as follows;
No Description Unit Cost(£) (GBP) Qty TOTAL (£)(GBP)
1 FlatICE filled with S17 8.95 7,450 66,677.50
2 Export packaging, handling 25.00 34 850.00
& documentation
3 Delivery to port 2,465.00 2 4,930.00
4 Tank Model C-225-120 50,695.00 1 50,695.00
5 FOB Charges 1,495.00 1 1,495.00
6 Shipping to Australian port 4,950.00 1 4,950.00
+__________
TOTAL DELIVERED COST (£)(GBP) 129,597.50
Delivery : 10~12 weeks
Validity : 60 Days
Payment : 50% With the order and the remaining before shipment.
Regards
Zafer URE
Phase Change Material Products Limited
Unit 32, Mere View Industrial Estate,
Yaxley, Cambridgeshire, PE7 3HS,
UNITED KINGDOM
Tel.: +44 -(0)-1733-245511
Fax: +44 -(0)-1733-243344
www.pcmproducts.net
z.ure@pcmproducts.net

From: Kav Consult
Sent: Sunday, May 13, 2012 3:23 PM
To: 'Zafer (EPS)'
Cc: 'Joy'
Subject: RE: PCM/12/05/046/ZU, Re: Website Form Submission

Thank you very much for your prompt reply. We need a total of 6 million kJ in 10 hours, i.e a rate of 600,000 kJ
per hour, i.e. 167 kWh/hr or 1,667 kWh total. Please give me a budget for a project one tenth the size you
provided below. Thank you very much. With best wishes and kind regards
Yours sincerely
Klaas Visser.

From: Zafer (EPS) [mailto:info@pcmproducts.net]
Sent: Sunday, 13 May 2012 7:16 PM
To: Klaas Visser
Cc: Joy
Subject: PCM/12/05/046/ZU, Re: Website Form Submission

Visser
3

Thank you for the enquiry. I guess the attached FlatICE would be the best option. Your
6,000,000 kJ x 10h = 16,666
kWh energy storage and if we use the attached rule of thumb numbers i.e. 50 kWh/m3 you may need a TES tanks
size of closer to 333m3 lets say 350 m3 filled with ~66,000 FlatICE containers filled with S17 solution.
I am assuming this water comes from the cooling towers and you may be able to use an atmospheric site built
rectangular tank (a big swimming pool with lid like the attached Gosnell City Job) but if you have to pressurise the
tank they must be steel cylindrical tanks like the attached CH2, Melbourne City Council building job. The largest
cylindrical tank would be ~100 m3
As a BUDGET costing if you allow £ 550K for the FlatICE and if the tanks are steel £250~300K but if you can build a
site built tank the tank cost would half of this.
I hope this gives you a good starting point. L:et us know if the initial budget and design fits into your scheme we can
look in details and come up with some firm numbers and design.
Regards
Zafer URE
Phase Change Material Products Limited
Unit 32, Mere View Industrial Estate,
Yaxley, Cambridgeshire, PE7 3HS,
UNITED KINGDOM
Tel.: +44 -(0)-1733-245511
Fax: +44 -(0)-1733-243344
www.pcmproducts.net
z.ure@pcmproducts.net

From: Klaas Visser
Sent: Sunday, May 13, 2012 4:13 AM
To: info@pcmproducts.net
Subject: Website Form Submission

Someone has emailed from your SiteWizard website.
They submitted from the following page of your web site:
http://www.pcmproducts.net/contact_us.htm
Submitted on: Sun May 13 04:13:45 2012 by IP: 121.220.67.48
----
realname: Klaas Visser
email: kavconsult@bigpond.com
telephone: +61354479436
enquiry: We have been commissioned by Meat and Livestock Australia (MLA) to investigate the feasibility
and viability of reducing eletrical energy costs by reducing the ammonia plant head pressure during the
day by removing about 20% of the Total Heat Rejection (THR) during the peak refrigeration and maximum
electrical energy cost periods during the day. The total amount of heat to be removed is 6000MJ during a
10 hour period. We would have 2 to 4 hours to freeze the PCM between midnight and 5 am. We are
thinking of freezing the S17 PCM at +17 deg. C with a compressor Sat. Suction of +10 deg. C. The return

water temp. during the PCM melting period would be +24 deg. C. Please quote us a budget price for a system with 38 tonnes (25 m^3) S17. We can look after all the pumps and piping systems this end. If you have a better solution to offer please offer it. Please contact me if you need further information. Thank you very much. With best wishes and kind regards Yours sincerely Klaas Visser.

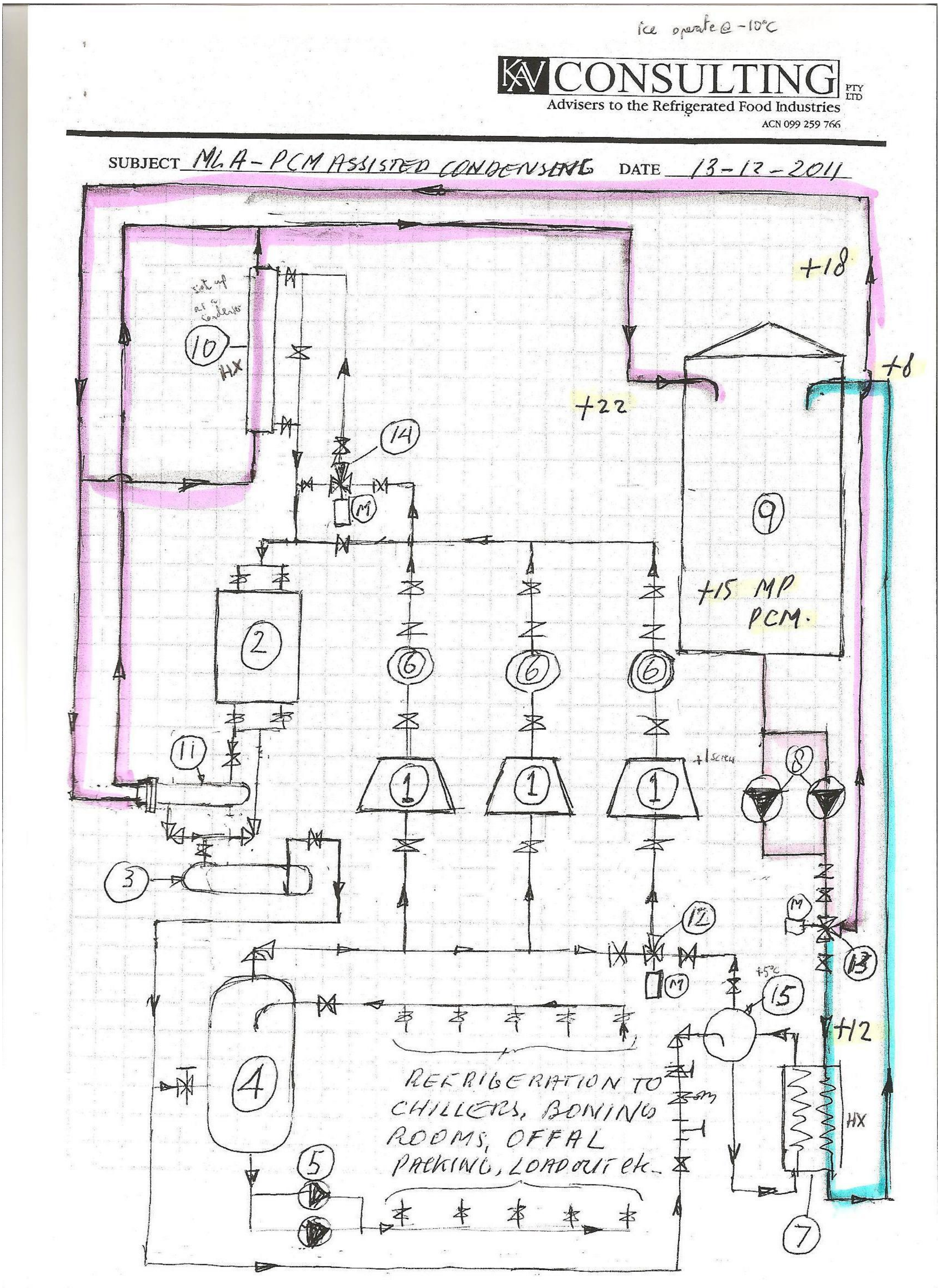
PCM
Phase Change Materials
Thermal Energy Storage
+44 (0) 1733-245511

FlatICE STORAGE TANK SPECIFICATIONS

Model : C-225-1200 Cylindrical Tank
Nominal Capacity : 35 m3
TES Capacity : 1,750 kWh (Nominal max.)
Diameter (mm) : 2,250
Length (mm) : 12,000 (depending on the site pipe orientation)
ShippingWeight : 13 Tons
WorkingWeight : 90 Tons
Fittings : 1 x 600 mm Manway Access
2 x Inlet & Outlet Diffusers
2 No Lifting Lugs
Connections : 1 x 150 mm NP16 Stub Flange for System Outlet.
1 x 150 mm NP16 Stub Flange for System Return.
1 x 50 mm NP16 Stub Flange for Vent / Relief Valve.
1 x 50 mm NP16 Stub Flange for Drain
Design Pressure : 3.5 Barg
Test Pressure : 5.05 Barg
Delivery : 12 ~ 14Weeks
Supplied &
Installed Price : £ 50,695.00 excluding VAT

Notes : 1) Tank require a flat bed, level solid base. A power floated concrete base would provide the quality finish and support required.
2) The design is such that the tank can be fully insulated (supplied by others) flange to flange.
3) Inspection and Service ladders are excluded from our design.
4) EPS standard colour finish.

APPENDIX H. SKETCH LAYOUT of PCM ASSISTED CONDENSING

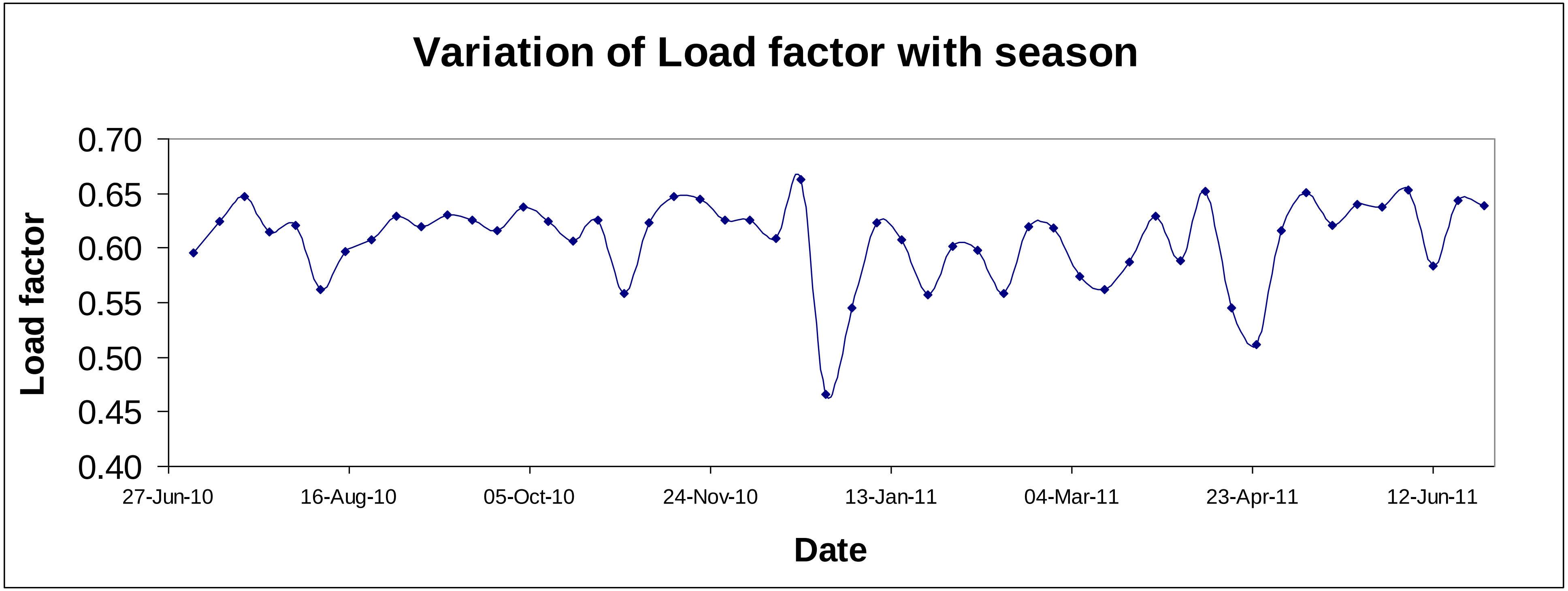


Item	Description	No.
1	Ammonia compressors	4
2	Ammonia evaporative condenser	1
3	Ammonia liquid receiver	1
4	Ammonia accumulator	1
5	Ammonia liquid	2
6	Oil separators in compressor discharge	3
7	Plate heat exchanger tochill water	1
8	Chilled water circulating pumps	2
9	Phase change material silo	1
10	Ammonia condenser cooled by chilled water	1
11	Ammonia liquid subcooler cooled by chilled water	1
12	Three way valve to change ammonia suction from 4 to 15	1
13	Three way valve to change from chilled water flow from freezing PCM in 9 by chilled water from 7 to melting PCM to assist condensing in 10	1
14	Three way valve to divert hot ammonia gas from condenser 2 directly to condenser 2 via auxiliary condenser 10	1
15	Ammonia surge drum for flooded 7	1

Operational description:

1. Liquid pumps 5 supply -10^{0}C liquid ammonia to evaporators in chillers etc
2. ammonia vapour is separated from ammonia liquid in vessel 4, the accumulator
3. -10^{0}C ammonia vapour is compressed in compressor 1 and flows to condenser 2 via oil separators 6
4. The condensed ammonia drains from the condenser 2 to the liquid receiver 3 at a pressure up to 1,250kPag corresponding to a condensing temperature of +35^{0}C, the normal design pressure
5. the 1,250 kPag ammonia pressure is reduced to the compressor suction pressure of approximately 190 kPag which corresponds to -10^{0}C. This trottling process involves a loss
6. It can be seen from following the figure above that the coefficient of performance (COP) reduces with increasing condensing temperature and reducing evaporating ie suction temperature
7. This phenomena may be advantageously used by
    a. Lowering the condensing pressure by adding extra condensing capacity
    b. Reducing the temperature of the liquid ammonia before it enters the accumulator.
    c.

APPENDIX I. LOAD FACTOR VARIATION WITH SEASON



APPENDIX J. IMPROVEMENT IN COP WITH FALLING COOLING WATER TEMPERATURE