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Comparison of ice-bank actual results against simulated predicted results in Carroll refurbishment project DKIT

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Abstract

This paper reviews the selection methods used in the design of an ice-bank thermal energy storage (TES) application in the Carroll's building in Dundalk IT.

The complexities of the interaction between the on- site wind turbine, existing campus load and the refurbished building meant that traditional calculation methods and programmes could not be used and specialist software had to be developed during the design process. The research reviews this tool against the actual results obtained from the operation in the building for one college term of full time use.

The paper also examines the operation of the system in order to produce recommendations for its potential modification to improve its efficiency and utilisation.

Simulation software is evaluated and maximum import capacity is minimised.

Significant budget constraints limited the level of control and metering that could be provided for the project, and this paper demonstrates some investigative processes that were used to overcome the limitations on data availability.

Key Words:

Ice-bank, smart metering, wind turbine optimisation, electric load levelling.

1. Introduction

1.1 Research paper overview

This paper reviews the selection methods used in the design of an ice-bank thermal energy storage (TES) application in the Carroll's building in Dundalk IT. Specialist software was developed to simulate the interaction of the cooling loads in the building and assess the feasibility of using the on site campus wind turbine in combination with a chiller and a thermal energy storage system to satisfy the building's cooling needs.

1.2 Project background

The Carroll's building was built as a cigarette factory in the 1960s and is said to be one of the finest examples of Miesien architecture in Europe. As such it is a protected structure. The building was purchased by the Dundalk Institute of Technology to facilitate expansion within the college. This necessitated the complete refurbishment of the building. The deep plan of the building and large internal area (17,000m^2) meant that the majority of rooms would require mechanical ventilation and cooling. This would necessitate energy intensive systems, including chillers.

The mechanical design concept for the project was driven by two important considerations,

1. Demonstrating the potential improvements that can be made to the energy efficiency of existing buildings, and
2. Utilising excess electricity generated from the on-site campus wind turbine wiht thermal energy storage.

Ireland has one of the best natural resources available in Europe in terms of wind generation potential (Troen & Peterson 1989), and is currently producing about 10% of its electrical energy needs nationally from wind (EWEA Annual Statistics 2010, Pg 11). According to Irish Government Energy White paper (2007), wind generation as a percentage of total generation is due to increase to 37% by 2020.

However, the addition of wind resources to the national grid can result in some grid instability due to the unreliability of a wind load being available to match the peak grid loads. Ireland will soon be connected to the European grid by the electricity interconnector which is due for completion in 2012 (Eirgrid-Website). The use of the interconnector as a first line of defence is not necessarily the most economical solution.

1.3 Design concept and research

The refurbishment of the Carroll's factory, presented an excellent opportunity to produce a case study of an existing building that could be vastly improved in terms of energy efficiency, while also demonstrating that the excess electricity generated by the wind turbine could be stored via a Thermal Energy Storage (TES) system, thereby demonstrating how buildings can be used to smooth the electricity peaks and troughs created on the national grid by the addition of wind resources.

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It was decided to include ice-banks – a type of energy storage system – in the Carroll's building which could store energy generated by the chiller, using excess wind electricity or night time grid electricity, as ice.

The ice is used to provide chilled water to the building's AHUs, chilled beams and fan coils, whenever cooling is required.

This paper reviews the selection methods used in the design of the ice-bank thermal energy storage (TES) application in the Carroll's building. Specialist software was developed during the design process to simulate the optimum ice-bank size in comparison with the building cooling loads. The software also took into consideration site specifics including maximising the use of the on-site wind turbine and reducing the risk of the college exceeding its maximum import capacity (MIC). This paper examines the ice-bank load profile results obtained in the building over the college term 2011/2012 and compares these to the predicted results from the simulation software.

2. Thermal energy storage

2.4 Project background

TES systems store energy for use at a later stage. TES has advantages both on the demand side where it can assist with reducing facilities costs and also on the supply side where it reduces consumption and reduces peak electricity demands by shifting the timing of the electricity use, Hasnain (1997). Shifting the peak load to off peak times reduces the need for utility companies to use peak load generating plant which tends to be more expensive to run and uses less efficient generators.

With the advent of smart metering and an increase in the number of rate structures used by utility companies, reducing peak electrical demand will become more incentivised, especially for larger customers.

In conventional cooling systems the electrical power load is proportional to the cooling load – with a peak generally in the evening – corresponding with peak utility company demand periods. By providing TES in the building the refrigeration system could be used at night time – or in the case of Carroll's whenever there is available excess electricity from the turbine. Then during the day time, cooling is provided by pumping the chilled water through the TES, avoiding the need to run a chiller during peak electrical load times. This also means that the refrigeration capacity of the chiller can be substantially reduced as it no longer has to deal with the peak cooling load. When the chiller plant is sized to meet only the base load it can operate at close to 100% of its rated capacity for much longer durations as opposed to operating at part loads for significant periods of time. This significantly increases its efficiency, Hasnain (1997).

2.5 Types of TES

Chilled Water Storage

In CWS systems the chilled water tank is charged with water from 4-6°C.

Figure 1 Internal heat exchange tubes in the Ice-bank tank.

The water is stored in the tank in stratified layers. During the day time cycle chilled water from the tank is circulated through the buildings chilled water system, Hasnain (1997).

Ice-banks

The system chosen for the Carroll's building is an ice-bank system which consists of eight tanks connected together in a series of two banks (i.e. 4 groups of 2).

Charge temperatures are -6°C to -2°C. Chilled water with glycol (30% mixture to prevent freezing of the primary circuit) flows from the chiller to charge the bank. The chiller will typically be run at night time to avail of cheap night time electric rates or, in the case of Carrolls, the chiller can run whenever there is excess electricity available from the wind turbine. During the cooling demand period in the building the chilled water circulates through the ice-banks to the various system heat exchangers. The main advantage of ice-banks over chilled water storage is that they have a higher cooling capacity per volume due to the latent effect of the phase change that occurs as the water turns to ice.

The tanks are modular, insulated polyethylene tanks which contain a spiral wound plastic tube heat exchanger which is surrounded by water contained within the ice tank, Fig 1. A total of eight ice tanks were installed in the basement area of the Carrolls building, each with a capacity of 6.25m^3 ice per tank. During the charge cycle chilled water with added ethylene glycol is cooled by a chiller and is circulated through the heat exchanger, extracting heat from the water in the tank until 95% of the water in the tank is frozen solid.

3. Wind turbine in DKIT

Figure 2 shows the profile of national electrical energy usage in Ireland over three typical days (Eirgird).

As more wind energy is added to the grid, the grid becomes more unstable and less able to match the load profile required.

Ice-banks can assist with smoothing out of the grid profile by storing electrical energy as thermal energy for use when the demand requires it.

DKIT commissioned a Vestas V52-850kW wind turbine on its campus in October 2005.

When it was commissioned it was the first auto-production application for a wind turbine in Ireland, the first large commercial

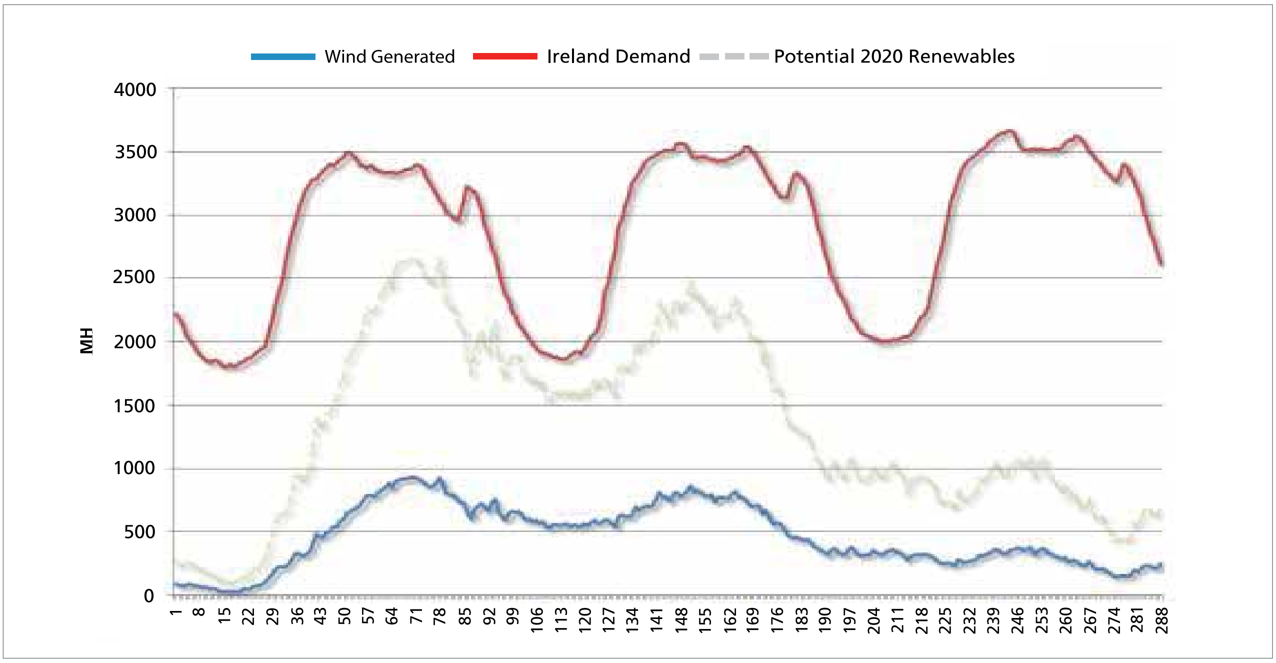

Figure 2: Ireland 3 day-15min electrical usage.

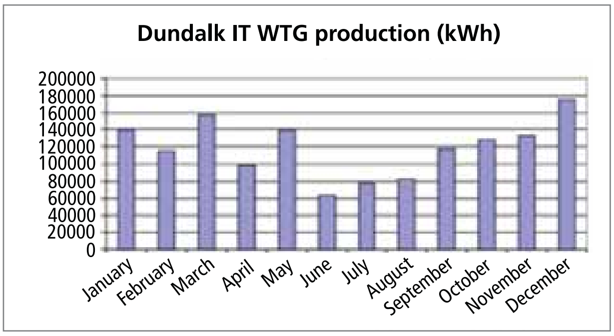

Figure 3: 2006 monthly energy production DKIT.

"urban turbine" in Ireland, and the first large commercial wind turbine on a college campus in the world.

Figure 3 shows energy output in kWh of wind produced by the turbine in 2006, a low wind year in Dundalk, Staudt (2006).

Figure 4 was generated using data obtained from utility companies on the campus load profile and the wind turbine output in 2006, Staudt (2006).

It shows three typical days for the campus load profile and the corresponding wind profile. The data is taken prior to the addition of the Carroll's building to the campus loads.

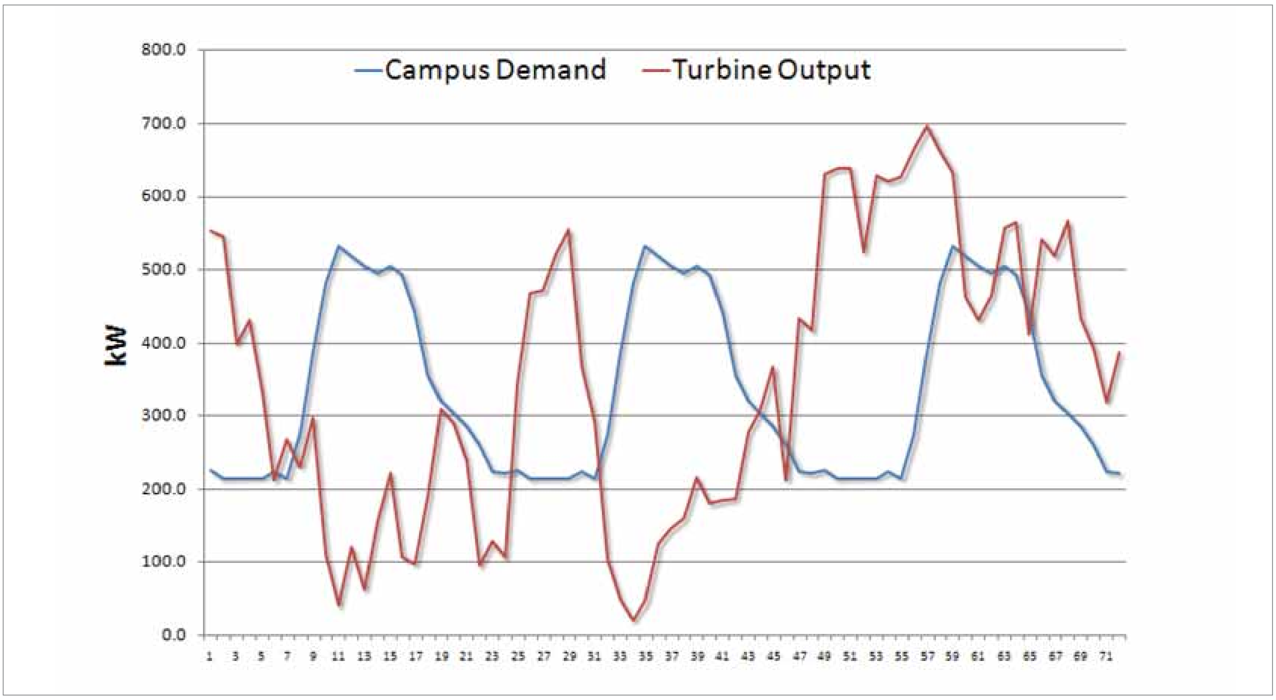

Figure 4: Campus demand curve vs turbine output.

It is clear that the availability of wind power does not always match the campus demand when required. This was the driving factor in recommending to DKIT that a thermal storage system be included to assist with smoothing the campus loading curve.

4. BMS operational strategies

The TES system chosen for the Carroll's building is a full storage system. However it differs in two respects. Firstly, it is connected to a wind turbine and secondly, the chiller can run in the day time and recharge the ice-banks as necessary if there is excess electricity available from the wind turbine. Due to the tight budget requirements it was not possible to directly measure the energy exported from the campus or the overall campus demand as part of the Carroll's BMS system. Therefore an anemometer linked to the buildings BMS system simulates the wind turbine energy availability. For the purpose of this research, the campus electrical demand is inferred to follow the electrical energy demand in the Carroll's building i.e. when the electrical demand in Carroll's building is high it is presumed that the overall campus demand is also high. These routines are included within the Carroll's BMS to control the ice-bank, chiller and cooling controls. If the BMS detects that there is sufficient available electricity from the wind turbine *and* the ice-banks require charging, the chiller shall run during the day and charge the banks. On the other hand, if the inferred campus electrical demand increases to the point where the campus MIC might be exceeded, the Carroll's building BMS enables controls routines that allow the heating and cooling temperature set points in rooms to decrease/increase and therefore consume less energy and avoid a utility fine for the college.

5. Simulation design

5.1 Software simulation

During the design process it was felt that the software tools available were not fully sufficient to assist with the modelling of the Ice-bank system. The standard method of sizing ice-banks uses the maximum peak cooling load required for the building for the ice-banks capacity. Although this was the starting point for the software design, other site-specific conditions were taken into consideration:

1. Minimise the campus MIC, as the college was close to its MIC limit, while maximising the use of the wind turbine to ensure that all excess wind energy is used.
2. Effects of smart metering.
3. Lowering carbon emissions.

The raw data used in the software development consisted of the campus 15-minute electrical meter readings from the national grid and the electrical generation from the wind turbine. Using this information and predicted energy demands for the Carroll's building and chiller, the average hourly campus electrical usage profile was developed for one year.

Dynamic thermal load simulations of the building cooling load using a model of the building built in IES software were also fed into the calculations in order to determine the typical hourly ice-bank charge and therefore the associated amount of export wind energy capacity that could theoretically be utilised on campus to charge the ice-banks. Table 1 summarises the analysis of the predicted data obtained from the software simulations.

The results from Table 1 show:

- The Campus energy requirements are 3.88GWh. The Carroll's building was estimated to be 15% of this load – excluding the Carroll's building chiller and 20% of this load – including the chiller. The chiller was calculated to represent 45% of the anticipated electrical loading in the Carroll's building.
- Annual wind energy generated (based on turbine figures) is 1.5GWh.
- Energy exported back to the grid – i.e. not used in the college – was 96MWh per year.
- The chiller electrical load is 254MW. It was therefore calculated that the wind turbine could potentially provide 30% of this

Table 1: Summary of ice bank simulator predictions

	Energy Requirements (kWhrs)	Wind Energy Generated (kWhrs)	Wind Energy Utilised (kWhrs)	Export Capacity (kWhrs)	Chiller Requirements (kWhrs)	Chiller Energy from Grid	Chiller Energy from Wind Generator	Percentage of Chiller Electricity Provided by Turbine
Jan	392474	180432	177686	2746	15345	12599	2746	18%
Feb	338727	114958	111870	3088	13913	10825	3088	22%
Mar	387298	167978	150722	17256	16305	0	16305	100%
Apr	298546	96181	94261	1920	17726	15806	1920	11%
May	329608	138975	133466	5509	21823	16314	5509	25%
June	223793	43882	41086	2796	29351	26554	2796	10%
July	230484	88212	86311	1902	33733	31831	1902	6%
Aug	263973	116991	116549	442	30902	30460	442	1%
Sep	309762	120900	112391	8509	24307	15799	8509	35%
Oct	381196	137488	132287	5201	20179	14978	5201	26%
Nov	395958	161571	148026	13545	15655	2110	13545	87%
Dec	337235	180432	145604	34828	15639	0	15639	100%
Total	**3889055**	**1548002**	**1450259**	**97743**	**254879**	**177276**	**77603**	**30.45%**

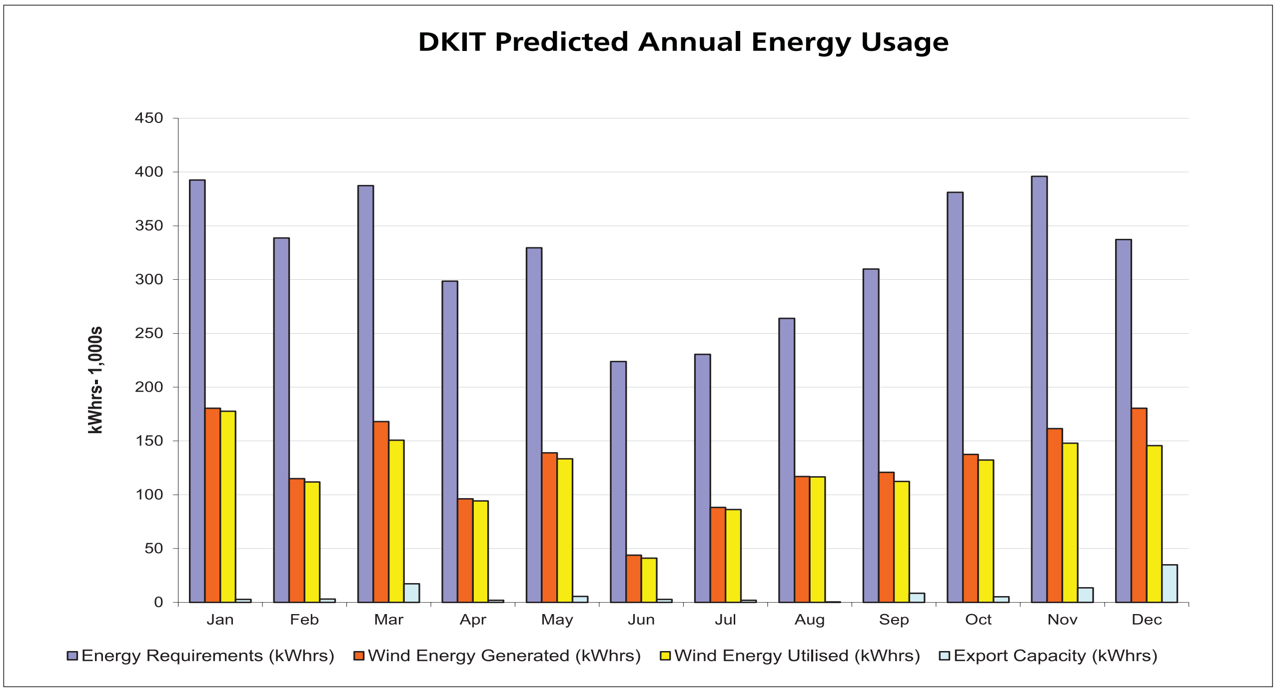

Figure 5: DKIT energy usage.

power. This was determined by considering the cooling required against the campus load profile and wind power available at any particular hour for the course of the typical year. The annual cooling load in the Carroll's building was determined to be 764,636 kWh cooling.

Figure 5 shows a graph of the typical campus energy requirements vs wind energy generated by the turbine. It also shows the proportion of wind that can be utilised to serve the campus electrical load and conversely how much gets exported to the national grid.

What the predicted results show is that while the energy that was predicted to be exported from the turbine was relatively low, potential savings existed in the campus, particularly for the night load, and if this was addressed there would be a notable increase in wind turbine power utilised on the campus. This was an important consideration for installing the ice banks. Another consideration was the very high percentage of electrical power that the chiller would use in the Carrolls building.

Figure 6 shows the graphed turbine export capacity vs the chiller electrical load.

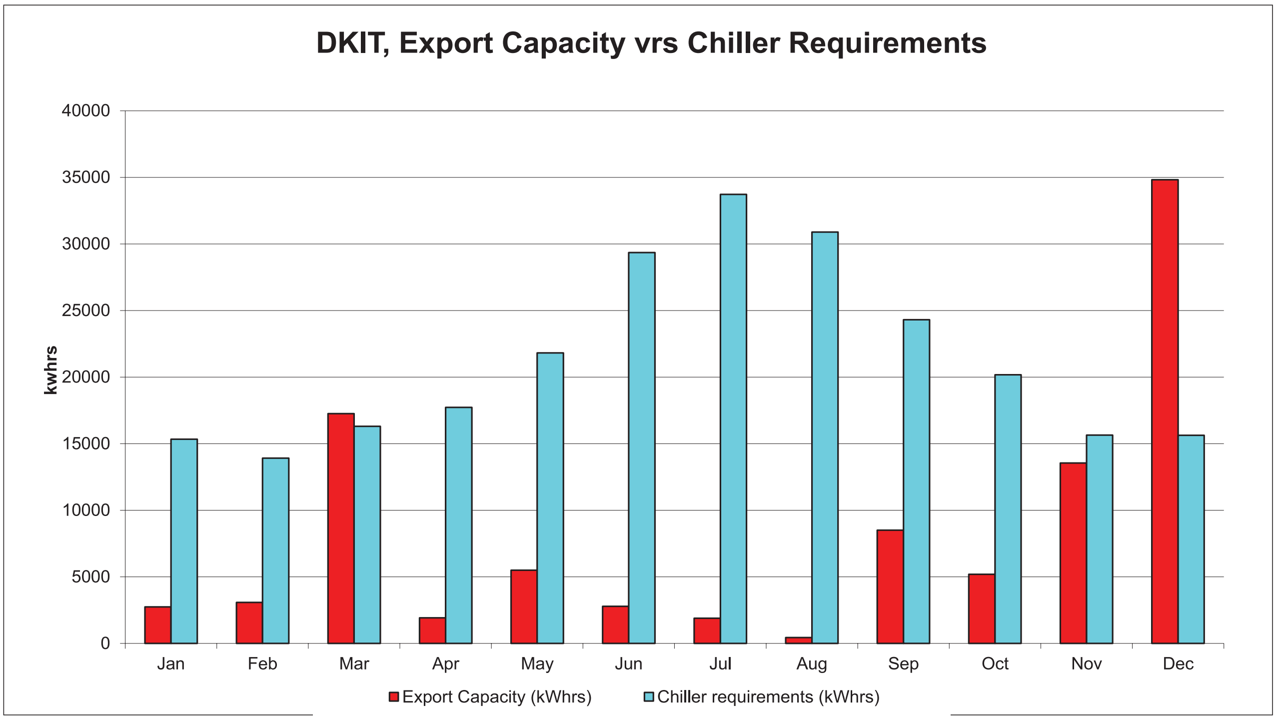

Figure 6: Predicted export capacity vs chiller load.

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5.2 Ice-bank sizing

IES simulations determined the peak cooling day as 5th July, requiring a 5617kWh cooling load. The estimated cooling load required in the server rooms was 60kWh.

The energy density of ice is 92.16kW/m^3. Therefore to meet the max peak cooling load a total ice-bank capacity of 60m^3 was required. A total of eight ice-banks were installed to achieve a total volume of 50m^3 of ice – or a total kWh of 4,560 kWh. Based on this figure the payback period for the ice-banks was calculated to be *10.5 years*. The sizing criteria generated showed that the smaller the ice-bank system installed, the better the payback period but the less the absolute savings achieved. It would be standard practice to install a much smaller ice-bank size if the system was to be used solely to optimise the costs, but in this particular case the aim was to minimise the campus maximum electrical demand as it was approaching its maximum potential capacity (MIC).

Figure 7 shows the ice-bank expected charge over a year. The graph shows a sharp reduction in spare cooling capacity during the peak summer months. The predicted state of charge was calculated by considering the previous state of charge and whether the banks were charging or discharging according to the predicted cooling load in the building and the predicted availability of the wind or night-time electricity.

6. Results achieved on site

6.1 BMS data

The system has been operational in DKIT since March 2010. The results focussed on below show the figures obtained for the second full college year of operation – August 2011 to May 2012. This is partially as the college systems were not fully functional during the first year but also because the BMS data storage system for the first year of operation has been accidently lost due to a campus-wide change-over of the BMS systems.

Data collected from the flow and return temperature sensors on the chilled water to and from the ice-banks, the state of charge of the ice-banks from the ice-bank meter and the electrical building load for the period 26th August to 14th May 2012 have been collated and analysed. Figures for the wind turbine generation have also been collected for the same period. As information from DKIT's main electrical campus meter was not available to compare against the 2011/12 results it is assumed that the Campus electrical load profile – excluding Carroll's building – has not changed significantly since the initial meter readings were obtained in 2006.

6.2 Icebank behaviour

From the data provided, a typical profile of the ice-bank behaviour was developed. The ice-banks and chiller are performing as expected under the various controls routines set up in the BMS.

Figure 8 shows a typical college week in October 2011. On Friday the temperature of the flow water increases from -6C to +2C during the daytime. The icebank meter level shows a corresponding drop off in the amount of stored ice in the tank from 100% to a low of 78% indicating that the system is discharging to meet the cooling load in the building. At 11pm the chiller turns on and starts the recharge cycle. It takes four hours for the ice-bank to recharge to 100%. This is recorded by the flow temperature dramatically reducing from +2C to -5C as the chilled water is now flowing through the chiller to the ice bank. During the weekend period the chiller and pumped schedule is timed off – therefore the chilled water in the pipe gradually gains heat from its surroundings resulting in the steady curve rise in the chilled water temperature – whereas the ice-bank charge remains unchanged.

The chiller turns on again at 5am on Monday morning. However, it only stays on for approximately two hours as the ice-banks have

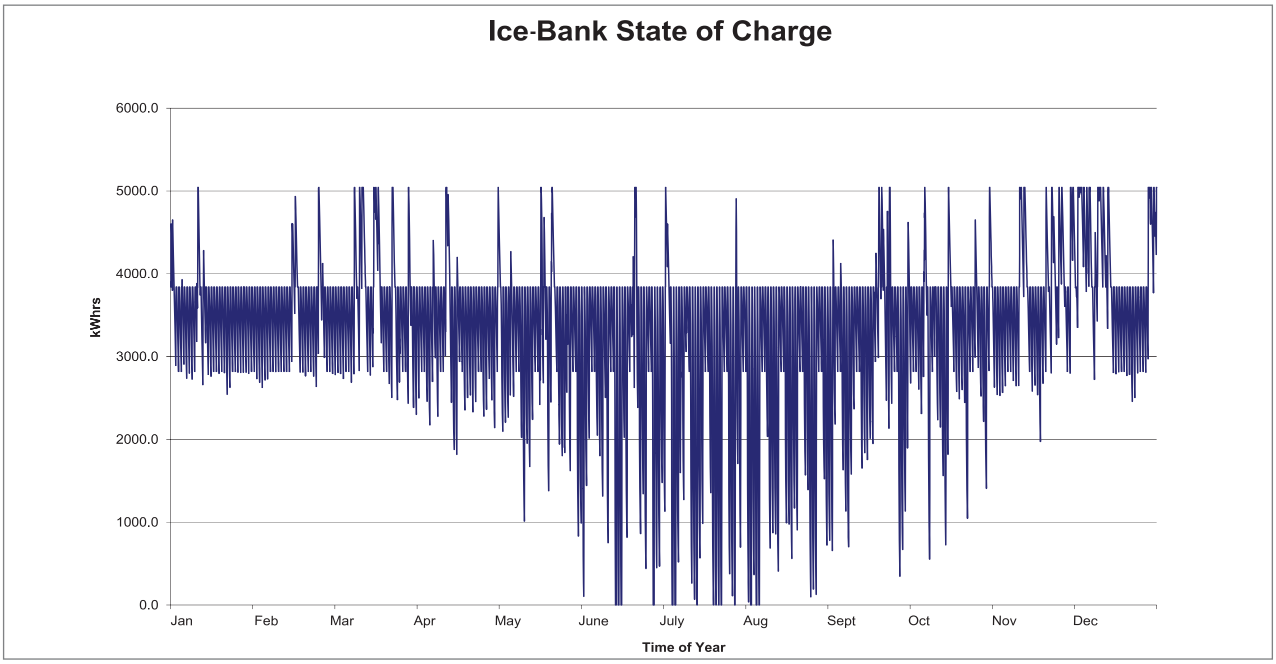

Figure 7: Ice-bank state of charge.

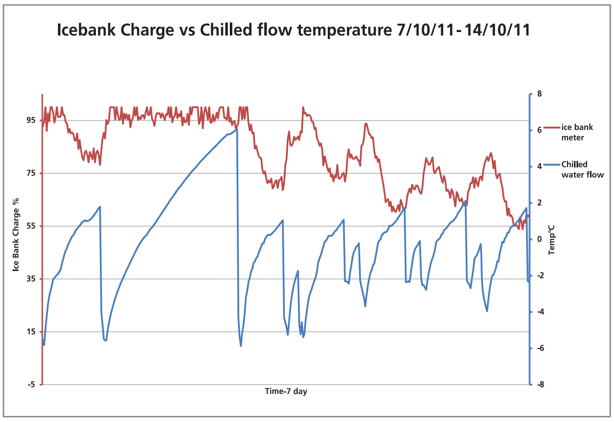

Figure 8: Ice-bank Charge vs Chilled Flow

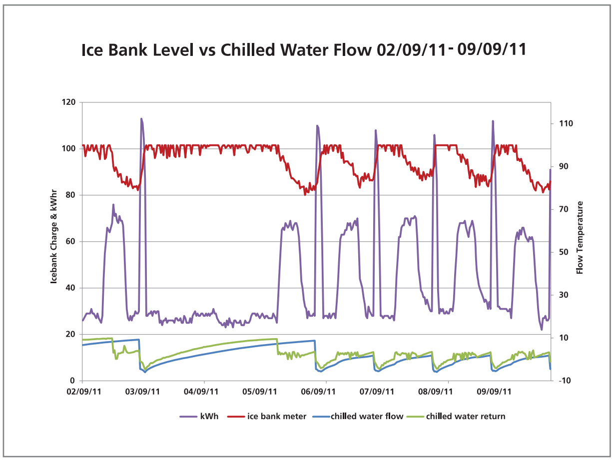

Figure 9: Ice bank Level vs Chilled Water Flow.

held their charge over the weekend. The ice-bank then starts to deplete during the day cooling period until the chiller once again turns on on Monday night.

The cycle of charging and discharging then continues for the remainder of the week. This graph shows the chiller oscillating quite frequently during the charge cycle. This was identified by the college as a period when the chiller was undergoing maintenance.

Figure 9 shows another typical week but with the kWh electric usage and return chilled water temperature from the building also graphed. As expected, the chilled water return temperature closely lags the chilled water flow temperature. The graph also shows the electrical usage peaks during the day. The smaller peaks are the building base electrical load for this period. The higher peak, which are of shorter duration show the peak electrical energy used by the chiller at night to recharge the ice-banks. It corresponds neatly to the return of the ice-banks to full capacity.

Figure 10 is the corresponding graph for December showing the electrical usage graphed against the ice bank charge. This highlights the typical daily base electrical load in the building in December – higher than that in September as the buildings heating systems are in winter mode.

The spike in electrical loading caused by the chiller is not as pronounced as the building general base load now exceeds this during peak heating season.

Figures 9 and 10 clearly demonstrate the load levelling applied by the use of the ice-bank – transferring the peak cooling loads to night-time.

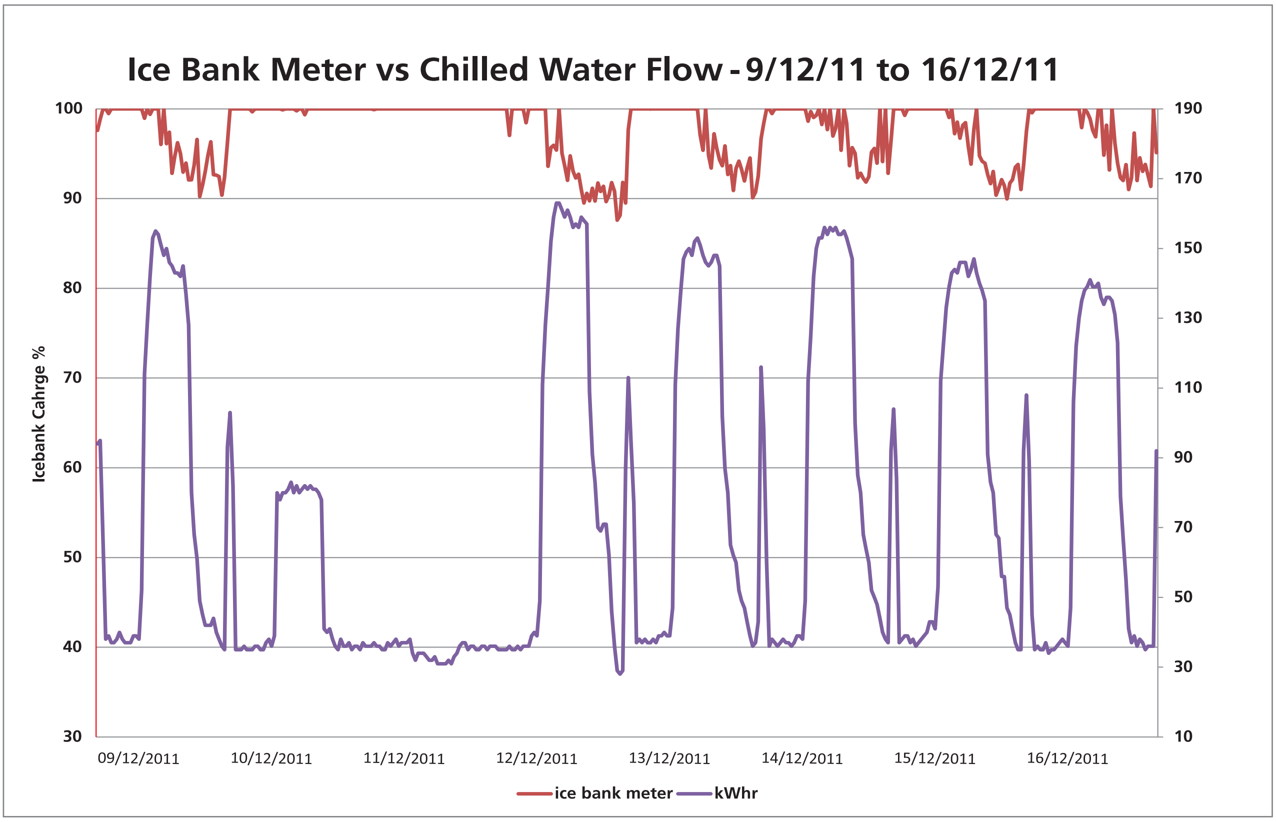

Figure 10: Ice-bank meter vs chilled water flow.

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Table 2: Ice bank simulation actual results 26th Aug 2011 - 14th May 2012

	Energy Requirements (kWhrs)	Wind Energy Generated (kWhrs)	Wind Energy Utilised (kWhrs)	Export Capacity (kWhrs)	Chiller Requirements (kWhrs)	Potential Chiller Energy from Grid	Potential Chiller Energy from Wind Generator	Percentage of Chiller Electricity Provided by Turbine
Aug 11	41285.4	10488	10436	52	2231	2178	52	2%
Sep 11	298458	164122	137651	26472	10193	0	10193	100%
Oct 11	384391	165500	135795	29705	10720	0	10720	100%
Nov 11	402010	209216	170625	38591	7575	0	7575	100%
Dec 11	318120	222114	165433	56681	6807	0	6807	100%
Jan 12	389795	118082	6731	16256	6091	0	6091	100%
Feb 12	356588	126446	112011	14435	6408	0	6408	100%
Mar 12	387826	116645	108087	8558	5082	0	5082	100%
Apr 12	295065	128896	108028	20868	6364	0	6364	100%
May 12	145044	46084	34613	11471	2164	0	2164	100%
Total	**3018583**	**1307594**	**989410**	**223089**	**63635**	**2178**	**61457**	**96.58%**

Note: The potential energy from the chiller noted above is calculated on a monthly basis from the data available to show how much energy could be potentially utilised. The recorded energy figures for the times the chiller is currently running show about 13% of the chiller energy coming from the turbine.

6.3 Design results vs actual results

The raw data obtained from the building was modelled using the software developed at design stage. Below is a table showing the results obtained.

The comments below are for the period 26th August 2011 to 14th May, unless otherwise noted. Also note that the readings reflect the college term time and therefore August and May are not full months.

- The energy requirements on the campus were 3GWh. The Carroll's building was calculated to be 13% of this load, excluding the chiller, and 16% of this load including the chiller.
- Generation from the turbine was 1.3 GWh. The amount of electrical energy exported from the campus was 223MWh. The utilisation factor of wind generated vs wind exported was 24% (compared to a predicted utilisation factor of 10%).

This increase is largely due to the increased levels of wind during the monitored year relative to the relatively low wind year used within the simulations.

- The chiller electrical load was determined to be 63MWh (electrical) and the wind turbine provided 13% of this power during the period noted above.

  The corresponding cooling load for the period is 190MWh (thermal) cooling – which was determined from the ice-bank state of charge. The design simulations had predicted this to be 84MW for the same period.
- The only month where the energy generated from the wind turbine was not sufficient to cover 100% of the chiller load was August (data for August is only one week and for that week it covered only 5%) showing that the summer time load profiles – although the building is primarily used by staff during summer – will have an impact on the results shown in Table 2.

While the calculations show that up to 96% of the chiller load could have been provided by wind energy, a relatively small amount actually was. The reason for this appears to be due to limitations in the control system that resulted in part from the loss of the wind anemometer that was damaged and not replaced to date.

Table 3: Predicted design simulation results ice-bank simulator

	Simulated Energy Requirements (kWhrs)	Simulated Wind Energy Generated (kWhrs)	Simulated Wind Energy Utilised (kWhrs)	Simulated Export Capacity (kWhrs)	Simulated Chiller Requirements (kWhrs)	Simulated Chiller Energy from Grid	Simulated Chiller Energy from Wind Generator	Simulated Percentage of Chiller Electricity Provided by Turbine
Sep	309762	120900	112391	8509	24307	15799	8509	35%
Oct	381196	137488	132287	5201	20179	14978	5201	26%
Nov	395958	161571	148026	13545	15655	2110	13545	87%
Dec	337235	180432	145604	34828	15639	0	15639	100%
Jan	392474	180432	177686	2746	15345	12599	2746	18%
Feb	338727	114958	118070	3088	13913	10825	3088	22%
Mar	387298	167978	150722	17256	16305	0	16305	100%
Apr	298546	96181	94261	1920	17726	15806	1920	11%
May	329608	138975	133466	5509	21823	16314	5509	25%
Total	**3170805**	**1298916**	**1206313**	**92602**	**160893**	**88431**	**72462**	**45%**

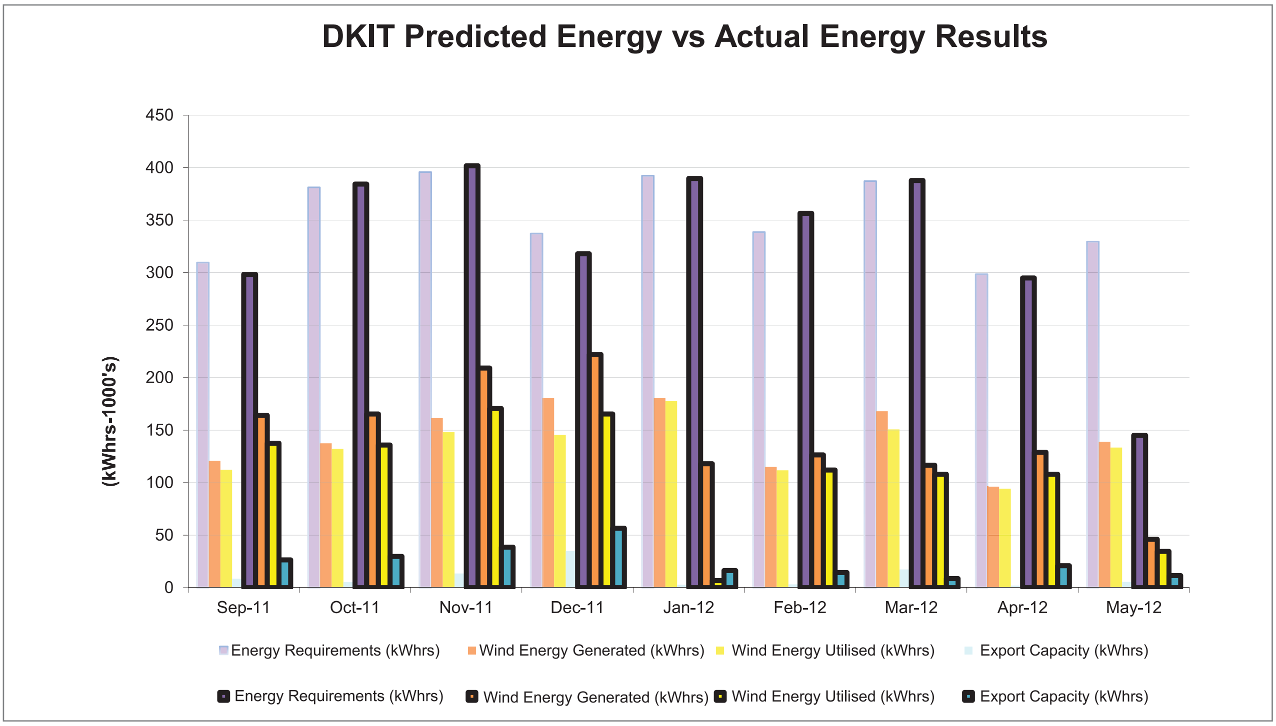

Figure 11: Predicted simulated results vs actual energy results. Darker purple bar represents actual, while the lighter bar represents simulated.

- Savings resulting from the chiller electricity coming from the wind turbine are approximately €5,903.30 over using a conventional chiller system run during the day.
- The savings noted result in an actual 16 year pay-back period, as the system is operating presently.

Table 3 shows the predicted results from the software developed during design for the same period as the actual results above. Comparing the actual BMS results achieved on site and the simulated results from the design software produces the following:

- Actual Carroll's energy requirements were 152MWh lower than that predicted.
- Wind energy generated was 8MW higher than it was for the initial monitoring that was fed into the simulation.
- There was 130MW more export capacity available resulting in higher export figures but also more energy was utilised by the campus than predicted: 4% vs 1.2%, for the period August 2011- May 2012.
- The amount of chiller energy that was derived from the grid was 80MWe less than predicted and correspondingly the amount of wind turbine electricity used by the chiller is 64MWe more than predicted.

Figure 11 shows the data from Table 1 and Table 2 plotted in bar graph format. The bars bordered in black represent the BMS/Measured results on site. The fainter bars represent the data from the simulated design results.

Figure 12 shows the ice bank state of charge in kWh. When compared to Figure 7 it corroborates the results shown in the tables with the amount of cooling required in the building less than that predicted.

7. Data analysis

The cooling loads in the building are significantly less than those expected. The IES loads predicted during initial simulations seemed quite low and, as a result, boundary conditions were increased to achieve a larger safety margin. The initial IES loads simulated appear to have been more accurate. The predicted cooling load of 24kWhr/m^2 is actually more like 19kWhr/m^2. The following factors will also have an effect on building load:

- One third of the building is not yet refurbished or occupied, including the front office spaces – which, due to their architectural sensitivity, will remain as fully glazed offices and will have a large cooling load.
- Full yearly cooling load is not yet known
- Teaching spaces with higher cooling loads such as recording and film studios are not yet fully fitted out.
- The AC systems in the server rooms were not included on the ice-bank chilled water system during site works – but they had been included in the original cooling load simulations. As a result of the analysis in this paper we have recommended to the client that the server room cooling is added to the system as it offers a large and consistent cooling load.
- The amount of free cooling from the air systems may not have been fully appreciated within the simulations.

  As the building is not fully utilised, the fresh air available provides a larger proportion of free cooling than predicted. There is some logic to the tuning of the air systems to reduce fresh air volumes and this will result in an increase of the use of the ice bank. A careful balance must be achieved between lowering fan energy and increasing chiller energy.

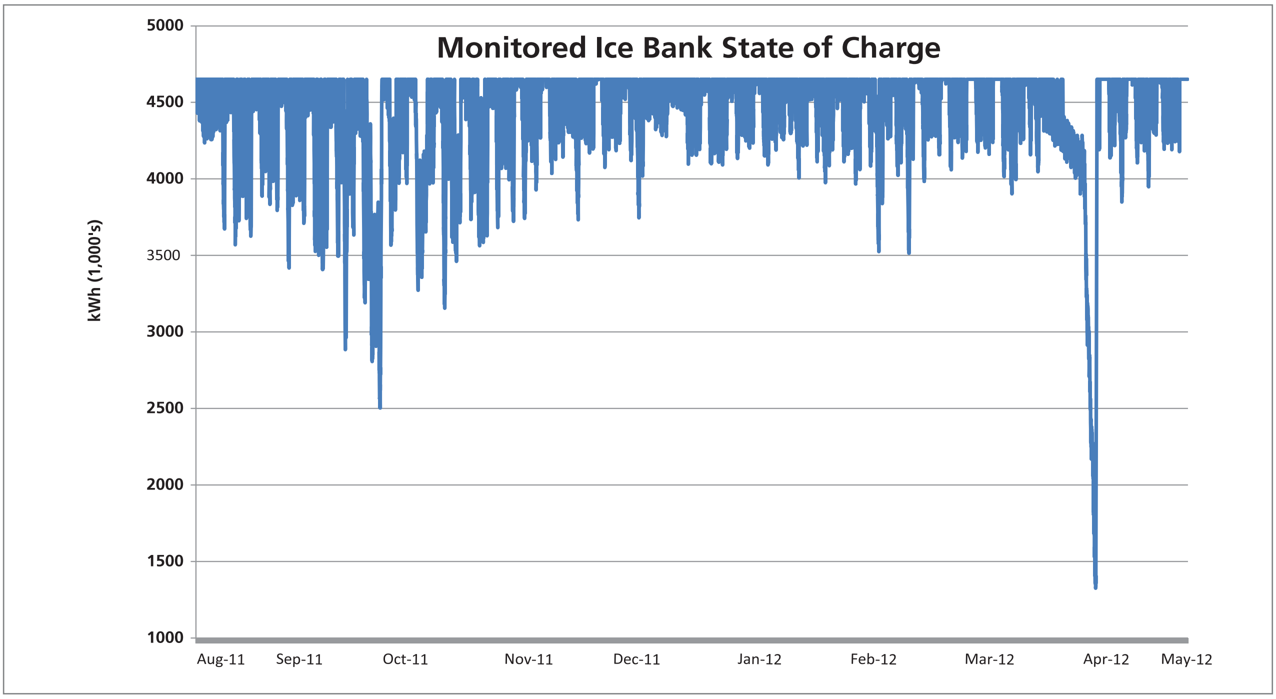

Figure 12: Monitored ice bank state of charge.

Although some evidence of the daytime wind turbine ice charging routine was found, this is minimal. Quite possibly this is due to the ice-banks not reaching sufficient depletion during operational periods.

It is still quite surprising that the cooling loads are as low as they are given that the building is fully air-conditioned. The predicted design cooling requirement was 15kWhr/m^2 for the predicted period (for the full year the predicted cooling was 24kWhr/m^2).

The actual cooling load recorded for the period end of August 2011 to middle May 2012 is 20kWhr/m^2. Figure 13 below shows a graph of the measured export capacity vs the chiller requirements from September 2011 - May 2012.

Figure 13 demonstrates that the current electrical requirements can be fully covered by the wind turbine export capacity.

While this has not happened, partly due to the loss (due to damage) of the anemometer that was used to predict wind levels,

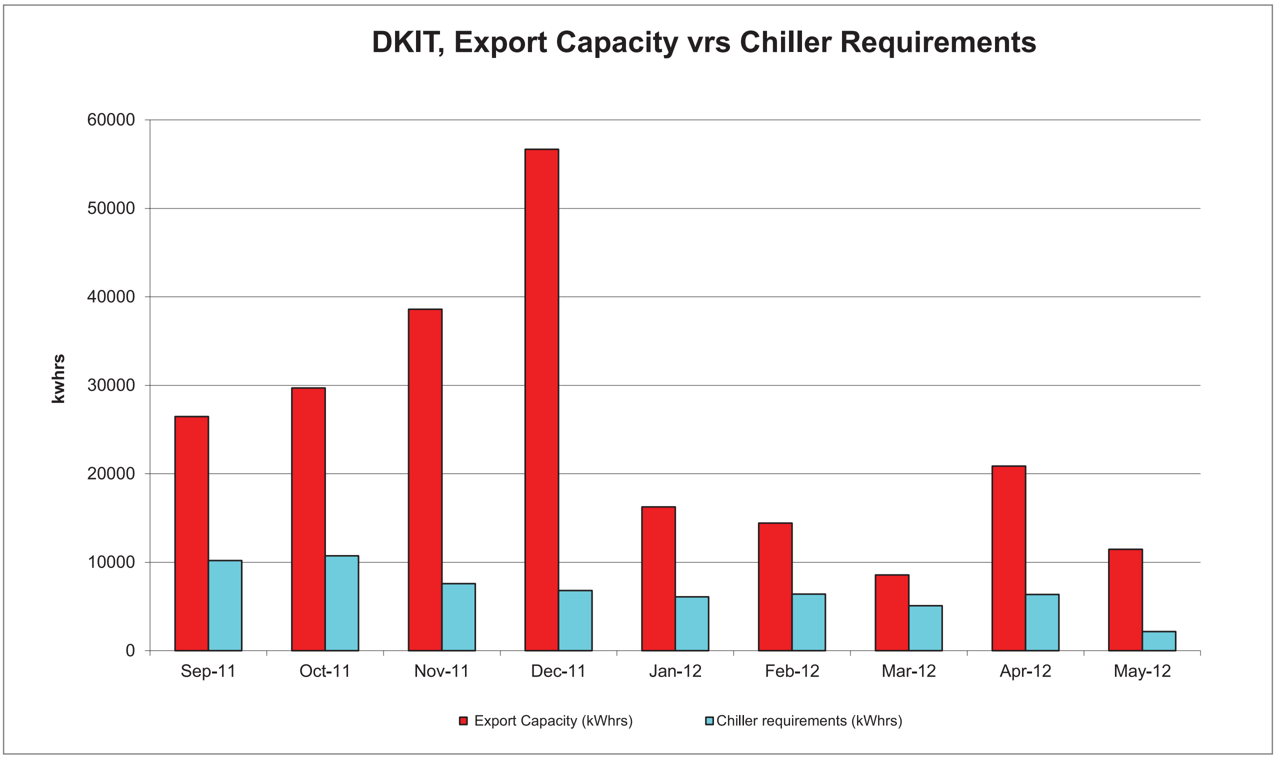

Figure 13: Export capacity vs chiller requirements.

further system tuning is recommended to improve the utilisation of the system. Recommendations that do not rely on the use of the anemometer have been tabled, in addition to the recommendation that the anemometer be fixed.

8. Conclusions

Ice-banks are excellent sources of cooling in buildings and can result in significant cost savings to users when used in off peak electricity times.

The effect of the savings is magnified by using a wind turbine, therefore the ice banks are an excellent example of how thermal storage in buildings can help to smooth out the electricity grid demand profile and therefore allow more wind resources to be added to the grid

The system monitoring identified that the ice store is currently oversized, and is not taking full advantage of the wind energy available.

The utilisation of the store is likely to increase notably over the next few years as the building fit out continues and we have tabled several potential modifications to the control routines that would increase the utilisation of available wind energy.

9. Future research, questions/ recommendations

1. It is recommended to install an electric meter on power supply to the chiller, in order to determine exactly how much energy the chiller is using.

   Should the opportunity arise a campus meter connection should be added to allow direct control of the ice bank system in response to turbine capacity. This is the optimum method of system control but was not initially possible due to budget constraints.

2. A heat recovery chiller could be utilised to provide some building heating "free of charge" during the winter while charging the ice-bank. Sufficient funding was not available to incorporate this into this project.

3. Although the building comms rooms were included in the cooling load calculations for the chiller and ice-banks, the comms room are stand-alone AC systems. This would have provided a constant load for one ice bank.

4. Part of the reason for the low cooling load appears to be due to the large free cooling achieved by the air systems. If the airflow rates were pulled back by optimising the pressure set points this would reduce the fresh air heating load, increase the cooling load and reduce the fan energy during the day.

5. The slowing down of the main chilled water pump during the ice charge cycle would notably improve the utilisation of wind energy by generating a lower chiller load over a larger period. This can easily be achieved by a modification to the BMS programming. This restriction on the chiller will also improve the chillers generation efficiency by forcing it to operate in part load where its efficiency is greater.

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