VolkerFitzpatrick

MITSUBISHI ELECTRIC
LIVING ENVIRONMENTAL SYSTEMS

Ground Source Case Study

VolkerFitzpatrick Hoddesdon

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Introduction

VolkerFitzpatrick's new Head Office in Hoddesdon, Hertfordshire was commissioned in 2006 and completed in December 2007 with the aim of replacing outdated facilities, enhancing the company's corporate identity and showcasing its sustainable credentials.

VolkerFitzpatrick's Building Division carried out the design and build of the new office space.

The pioneering three storey office design included:

- ~ the regeneration of a brownfield plant compound
- ~ realistic and practical low energy design
- ~ utilising current best practice and sensible sustainable solutions
- ~ an aspiration to achieve a BREEAM Excellent rating
- ~ reducing carbon emissions, both in construction and in use

The location on the outskirts of Hoddesdon and the amount of surrounding land made it ideal for a ground source heat pump solution.

Both trench and vertical closed loop boreholes were considered at feasibility stage for the ground source heat pump. Boreholes were preferred because they could be confined to particular areas of the site and in comparison to their trench counterparts impinged less on the construction works as a whole.

Overview

This report details the installation, monitoring and analysis of the six Mitsubishi Electric WR2 Water Cooled Variable Refrigerant Flow (VRF) condensing units used in conjunction with closed loop ground array of 32 bore holes arranged at a spacing of 5.5 metres and at a depth of 100 metres. Each would provide heating and cooling to the new VolkerFitzpatrick office building.

At design stage, thermal modelling calculated the dynamic loads for the new office as follows:

Peak Total Loads		Annual Loads	
Heating	163 kW	Heating	138 MWh
Cooling	220 kW	Cooling	49.5 MWh

Data was logged 24 hours a day, seven days a week from 1st March 2009 until 30th September 2009 using two Procon Maxi M2M remote monitoring interfaces. The data used for analysis however is the data logged from Mon to Fri between 8am and 6pm over the seven months during normal occupation of the building.

This report details monthly ambient temperatures and operational data for the water cooled units as well as the indoor units before looking at a typical temperature day within each month and then breaking it down further to look at one specific water cooled unit's operation on that one particular day.

The report concludes by looking at monthly system efficiencies and comparing running costs and CO_2 emission data of the ground source system installed alongside an alternative chiller and boiler system.

Monthly Coefficients Of Performance (COP's) of 5.54 to 7.14 were calculated using monitored data and shown over the 7 months and in a comparison with a chiller and gas boiler combination system it was found that running the ground source system showed a 46% reduction in running costs over the 7 month period compared to if the chiller/ boiler combination had been used, and a 53% reduction in CO_2 emissions. The cost per square metre to heat and cool the building over the seven months using the ground source system installed was calculated at £1.29/m^2.

Alternative Technologies

The building encompasses an array of sustainable solutions ranging from solar thermal technology to intelligent power supplies. In terms of heating and cooling VolkerFitzpatrick chose to install a ground source heat pump system, coupled with WR2 water/refrigerant heat pumps along with PQFY heat pump boilers and VRF internal chassis units.

Their choice was governed by the requirement for environmentally friendly technologies and the fact that the fixed height of the building determined by the planners meant that smaller bore refrigerant pipework had to be installed rather than its larger water based equivalent.

The fact that limited gas was available in the rural location made the choice of ground source more attractive. Other alternative options such as chillers, boilers and/or electric panel heaters were ruled out during the feasibility stage as it was understood that there was insufficient power in the area to supply the new building without costly upgrade works. Air source heat pumps were used to provide standby alternative means of conditioning the buildings critical IT suite and server area.

Although the installation costs of air source units are generally lower than installing a ground source system the benefits such as higher COP, lower CO_2 emissions and lower running costs were particularly attractive to VolkerFitzpatrick in terms of its aspiration for achieving excellence in sustainable development and showcasing the company's construction expertise.

Kit List

• 5 x PQRY-P400YSGM-A

- Heat Recovery Water Cooled Condensing Unit
- Capacity (Cooling nominal) 45.0kW
- Power Input (Cooling nominal) 11.35kW
- Noise Level 50dBA
- Weight 440kg
- Dimensions (WxDxH) 1980x550x1800

• 1 x PQRY-P500YSGM-A

- Heat Recovery Water Cooled Condensing Unit
- Capacity (Cooling nominal) 56.0kW
- Power Input (Cooling nominal) 15.06kW
- Noise Level 53dBA
- Weight 444kg
- Dimensions (WxDxH) 1980x550x1800

• 3 x PQFY-P250 (provides hot water to Air Handling Unit)

- VRF Heat Pump Boiler
- Capacity (Heating nominal) 25.0kW
- Hot water supply up to 45degC
- Flow rate 0.61 to 1.52 l/s
- Weight 50kg
- Dimensions (WxDxH) 610x510x560

• Air Handling Unit (AHU) (fan supply 9.2kW, extract 5.5kW)
- Fan supply 9.2kW
- Extract 5.5kW

• PQFY Water Pump
- Grundfos UPS D32-120F
- Model C
- Speed 3

• 82 x PEFY-P20-63VMS-E Ducted Indoor units
- Ultra Thin Ceiling Concealed Ducted Unit
- Capacity (Cooling nominal) 2.2 to 7.1kW
- Power input (Cooling nominal) 0.05 to 0.09kW
- Noise Level 23 to 36dBA

• 2 x Maxi M2M-IP/50
- Machine to Machine GPRS Remote Management Interface
- 22 inputs
- 8 outputs
- Dimensions (WxDxH) 300x70x350

• GSHP Water Pump
- SMEDEGARD Motor Head Omega

Installation

The equipment was designed and installed to provide 100% of the heating and cooling demand for the building. As VolkerFitzpatrick had specified that only the most energy efficient technologies were to be used a ground source heat recovery system was installed in conjunction with a number of other technologies including PQFY heat pump boilers, solar thermal hot water preheating, an “Ecodan” hot water generator, ground air technology, low energy light fittings, daylight saving lighting controls and photo-voltaic brise soleil.

Cool Planet was contracted by VolkerFitzpatrick to design and install a closed loop geothermal system to provide 100% of the heating and cooling load for its new Corporate Headquarters building. The first stage was to carry out a feasibility study to determine the scale of the ground works installation required based on indicative peak heating and cooling loads.

Initially a client questionnaire was completed by VolkerFitzpatrick in order to capture all the key information and requirements, after which a design review and initial quotation for the project were produced.

Cool Planet carried out an initial software study of the ground conditions using indicative heating and cooling peak loads provided by VolkerFitzpatrick. Initial feasibility indicated that 44 bore holes would be needed however Cool Planet worked with VolkerFitzpatrick's in house Building Services Department to reduce capital expenditure and the number of borehole to 32. This was achieved by using actual on site test bore data to carry out a detailed dynamic assessment of loads including a computerised thermal model to calculate the performance of the array.

Using thermal modelling and specialist design software Cool Planet was able to size the borehole array and determine the number and depth of bores required. In addition Cool Planet was able to provide VolkerFitzpatrick with COP data, thermal conductivity and analysis of the peak ground temperatures enabling them to provide VolkerFitzpatrick with the most cost effective solution for the project.

The revised loads and other design variables equated to a reduction of 12 bore holes to 32 bore holes reducing the array size by 27% allowing VolkerFitzpatrick to minimise its project costs.

The system was then detailed, installed and commissioned by Cool Planet before being handed over to VolkerFitzpatrick.

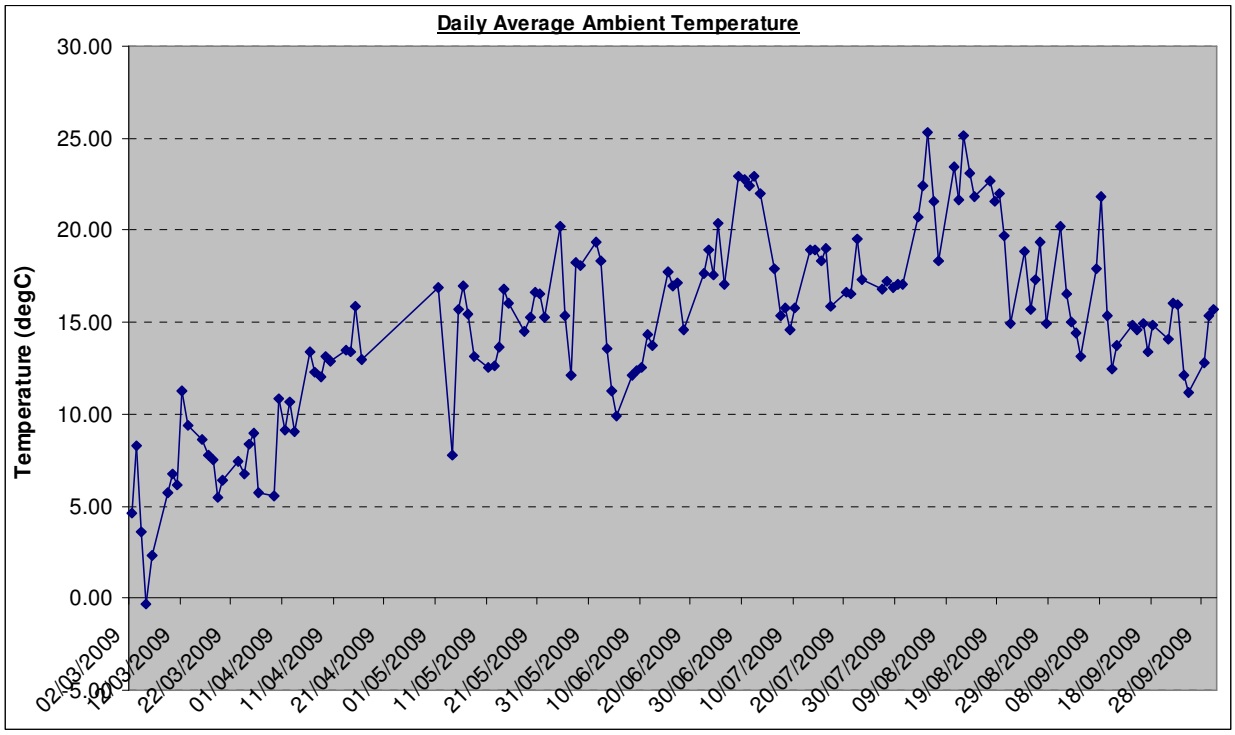
[Above Left: Maxi M2M Remote Monitoring Interface]
[Above Right: PQFY VRF Heat Pump Boilers]

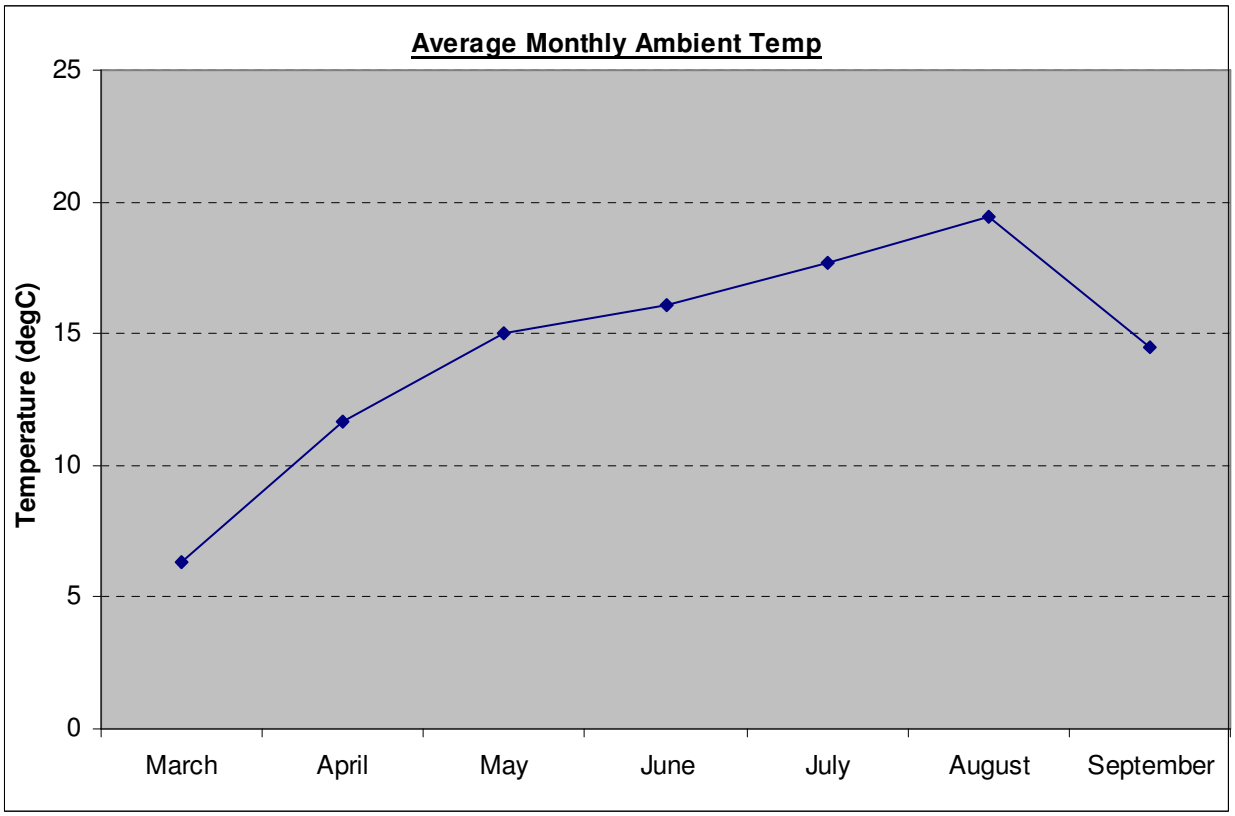
Logging & Data

Data was logged 24 hours a day, seven days a week from 1st March 2009 until 30th September 2009 using two Procon Maxi M2M remote monitoring interfaces. The data used for analysis however is the data logged from Mon to Fri between 8am and 6pm over the seven months during normal occupation of the building.

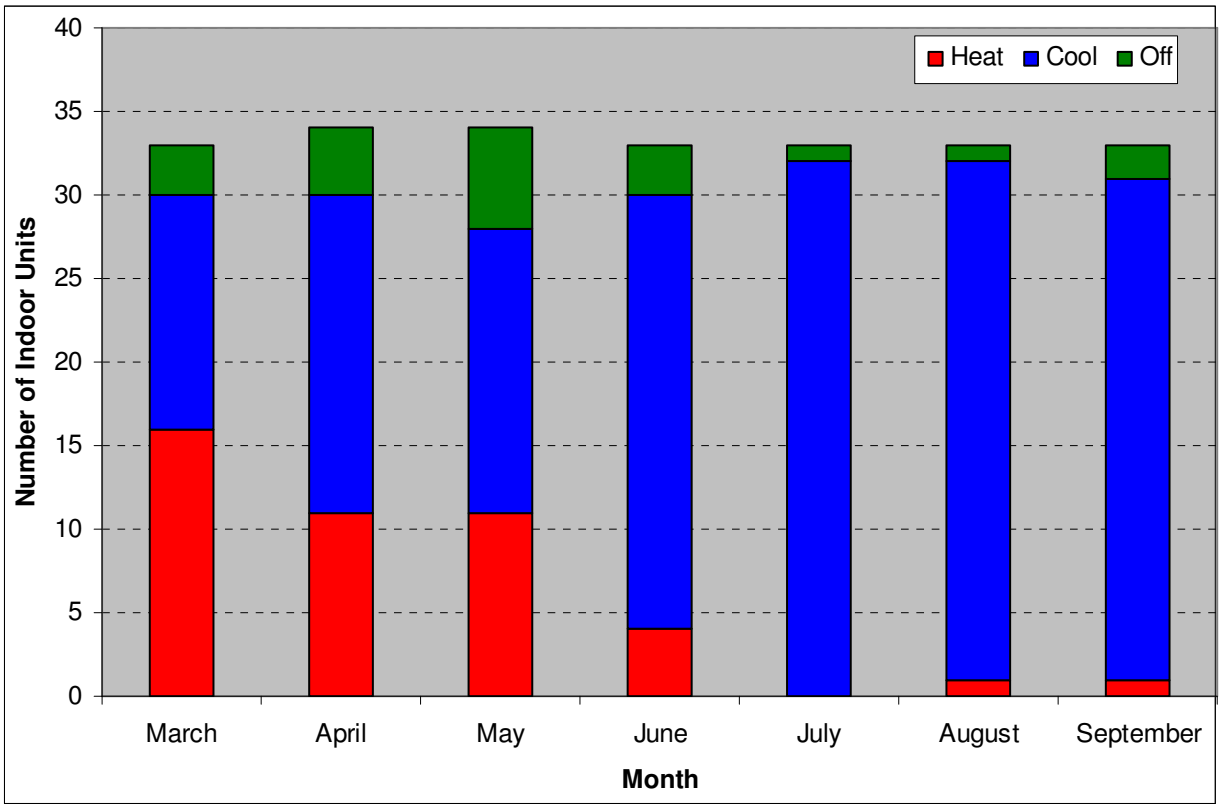
Results & Analysis

Taking a look at the ambient conditions over the seven months we find the following:





Both graphs show the same trend in outside air temperature. As expected when we move from the spring months into the summer months the ambient temperatures increase and peak in August. At the end of the summer as we move into autumn in September there is a decrease in ambient temperatures.



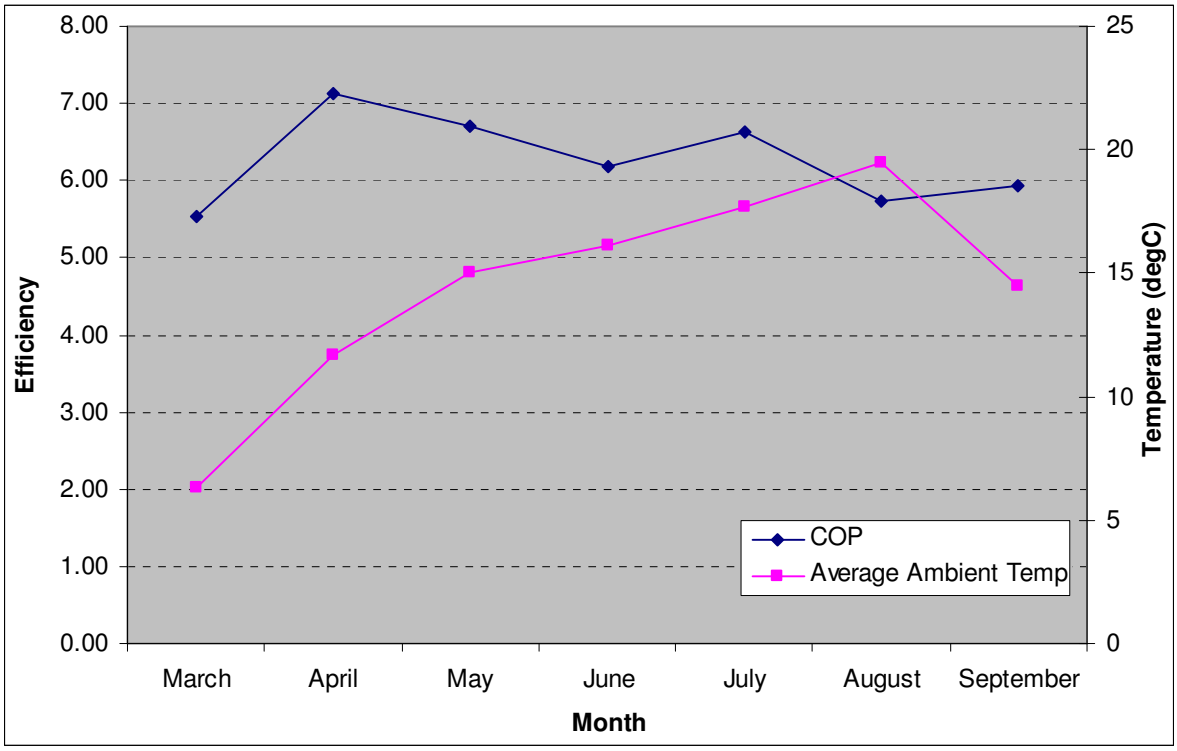
The above graph is a guide of the heating and cooling demand that the building required over the 7 months analysed. It is clear that initially during the spring months when average ambient temperatures were low that the building required both heating and cooling in reasonable quantities. March in particular shows average ambient temperatures as low as 6degC and the heating/ cooling demand is still balanced at almost 50/50 thus indicating that the building is very well insulated. From June onwards as outside air temperatures started to increase the amount of cooling increased dramatically and in July there was no heating demand at all. August and September saw a small amount of heating required however the building mainly needed to be cooled as ambient temperatures were still relatively high.

The following analysis looks at how the watercooled systems are working throughout these months. For each month we take a look at how the systems perform over the whole month, how the whole buildings systems work on a particular day and how one particular system works on that same particular day.

The number of indoor units analysed when looking at the entire building is 33 of the 82 (40%). This is because only data from one centralised controller installed is being monitored and logged. The behaviour of these 33 indoor units over the 7 months is used as an indication to how all the indoor units installed in the building are working.

The specific system that is analysed is system 4. System 4 provides heating and cooling to small office areas in one part of the building via 9 fan coils. Floor plans of the areas covered by system 4 are included (Reference Appendix 1.1).

Estimated Monthly Efficiency



Using the data analysed over the 7 months covered in this case study we were able to calculate monthly COP's for the entire system as shown in the graph above.

March showed an overall average ambient temperature of around 6.3degC and at these conditions the system was mainly heating the building. The derived efficiency of the system was still high at 5.54 however with little heat recovery taking place it was not working at its maximum efficiency. The ground conditions were also cooler as during the depths of winter heat energy was extracted from the ground to provide heating to the building making it difficult to extract even more heat energy from the ground in March.

As the average ambient temperature increased in April to around 11.7degC there was also an increase in efficiency to a COP of 7.14. As ambient temperatures rose there was a mixed demand for heating and cooling within the building compared to a cooler month like March and so there was a higher potential for heat recovery to take place therefore increasing system efficiency significantly as shown. This month showed the perfect balance in demand for heat recovery.

As temperatures increased further in May and June to 15.1degC and 16.1degC respectively there was a decrease in efficiency. May and June saw COP's of 6.70 and 6.19 and although these efficiency levels are very high they are lower than the COP for April as, in May and June the building demanded mainly cooling with very little or no heating requirements during the working day therefore little or no heat recovery took place.

In July the average ambient temperature increased again to 17.7 degC and the calculated efficiency of the systems also increased to give a COP of 6.62.

The average ambient temperature for August was 19.47degC and the building demanded mostly cooling at this temperature. Following on from this the derived COP in August dropped to 5.73 as there was again little or no heat recovery taking place during this month. The COP of the system was still very high though enabling the building to be cooled in an efficient manner even without heat recovery between indoor units. This also showed a high efficiency as the ground temperature was a lot lower than 20degC thus making it easier for the ground source heat pump to reject heat energy to the ground.

Compared to August there was a significant drop in average ambient temperature in September to 14.5degC. At this temperature the building had a mixed demand for cooling and heating therefore more heat recovery took place therefore the system efficiency increased slightly to give a COP of 5.94 portraying a highly efficient system.

Conclusion

From seven months of analysis it is clear that the ground source system installed at this site was highly efficient and capable of dealing with the buildings heating and cooling requirements in an environmentally friendly way. From efficiencies derived from the data monitored, logged and analysed it is clear that system efficiency is maximised when heat recovery takes place during months when there was a mixed demand for heating and cooling. However, even when heat recovery was not occurring the ground source system was still able to produce very high COP's.

	Average Ambient Temperature	Heat	Cool	Off	COP
March	6.3	48%	42%	10%	5.54
April	11.7	33%	58%	9%	7.14
May	15.1	33%	52%	15%	6.70
June	16.1	12%	79%	9%	6.19
July	17.7	0%	97%	3%	6.62
August	19.5	3%	94%	3%	5.73
September	14.5	3%	91%	6%	5.94

Based on the COP data for each month we can calculate an average COP over the 7 months of 6.27 which demonstrates that the ground source system installed is highly efficient.

Taking a look at the alternative technologies previously mentioned we are able to compare estimated efficiencies.

The ground source system installed currently showed running costs over the 7 months of **£3,869** and CO_2 emissions over the same period of 1,663kg. In comparison taking a chiller system with a COP of 2.80 (minimum criteria required for chiller to be listed on ECA) to provide the cooling and using a gas boiler with efficiency of 0.95 to provide the heating we estimated running costs over the 7 months of £8,332 and CO_2 emissions of 3,163kg. This calculates to a 46% reduction in running costs if using the

ground source system against the gas boiler and chiller system as well as a 53% reduction in CO_2 emissions over the 7 months. Taking this a step further the cost per m^2 to heat and cool the building using the ground source system over the 7 months was £1.29/m^2.

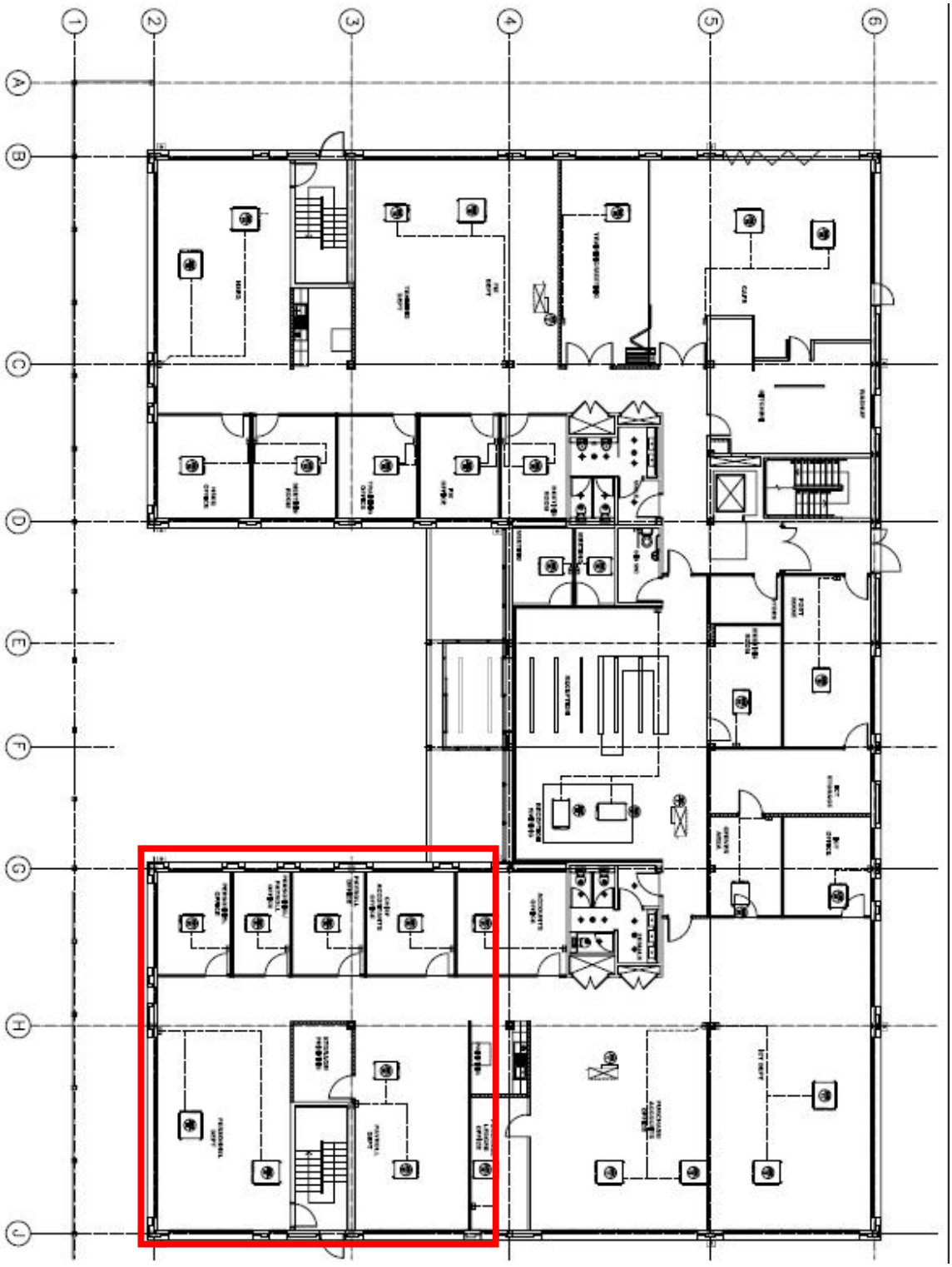
The case study demonstrates that Mitsubishi Electric and VolkerFitzpatrick achieved the following:

- **Monthly COP's of between 5.54 and 7.14 which is an improvement on the 4.00 to 6.00 considered at design stage.**
- **CO_2 emissions of just 1,663kg for the seven month period.**
- **A 46% reduction in running costs when compared to a chiller boiler combination.**
- **A 53% reduction in CO_2 emissions when compared to a chiller boiler combination**

From the results it is clear that the building is actually performing better than envisaged at design stage highlighting the efficiency of the Mitsubishi Electric ground source units and therefore enabling VolkerFitzpatrick to heat and cool there building in a highly environmentally friendly manner.

Appendices 1.0

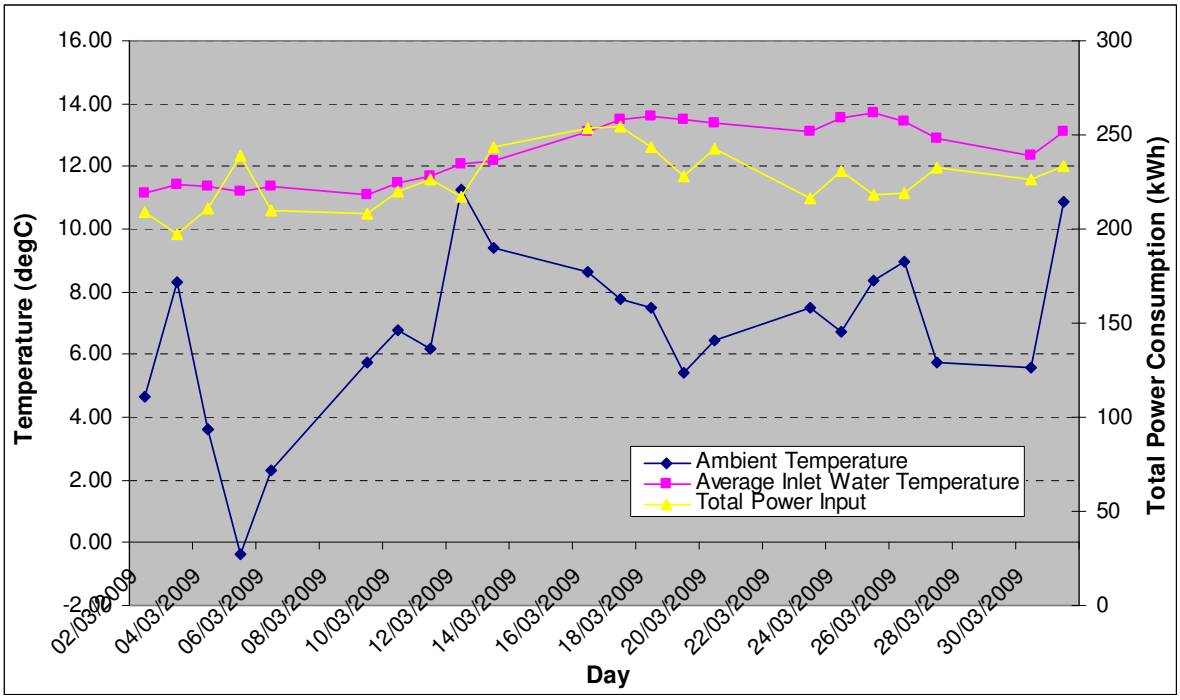
1.1 System 4 Floor Plans



Appendices 2.0

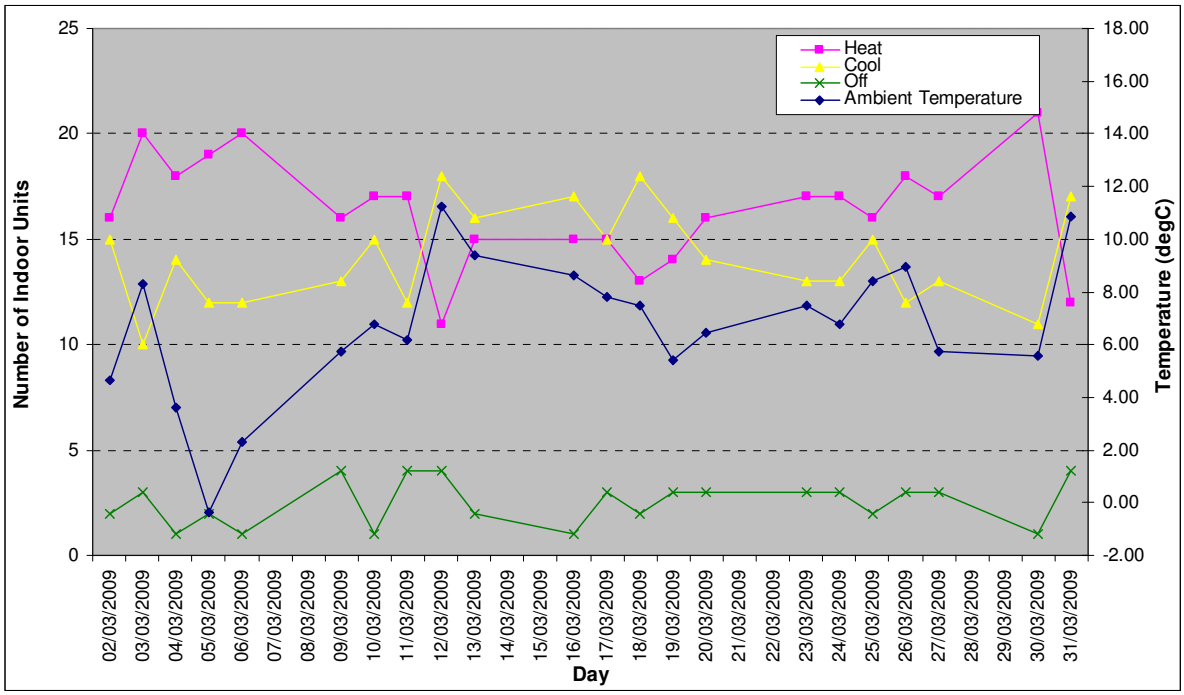
March Overview – Whole Building

Watercooled Units



The graph above shows the activity of the watercooled units during the month of March. The month shows a big variation in ambient temperature which ranged from as low as -0.4degC to a high of approximately 11degC. The inlet water temperature of the units ranged between around 11degC and 14degC as heat was rejected to the ground. The total average power consumption was quite stable at approximately 200kWh to 250kWh per day which is lower than expected from a newly built, well insulated building. The cost of running the system to heat and cool the building during this month was calculated to be approximately £498.

Indoor Units

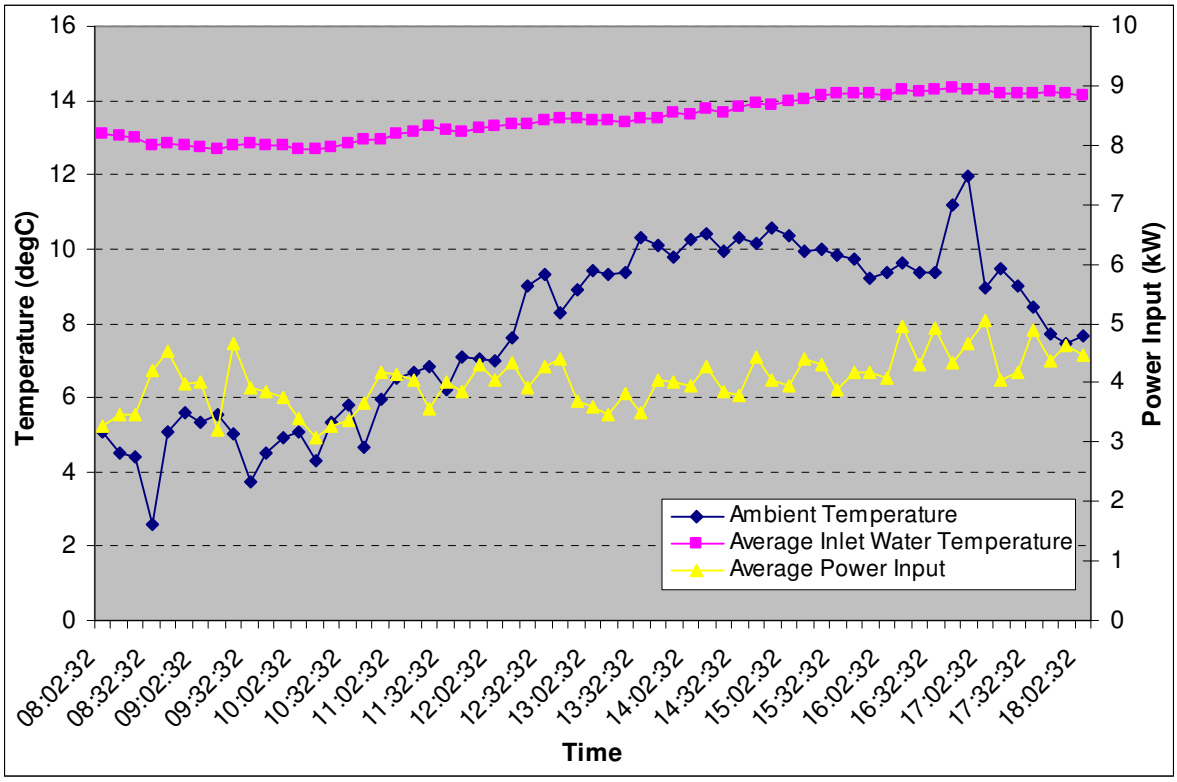


Less than 5 indoor units were off on any one day during this month. The first part of the month where the ambient temperatures were lower than 15degC most of the indoor units were heating the building reacting to increased heat loss from the building. As the ambient increased mid month between the 11th and 25th of March there was an almost equal amount of units in heating and cooling suggesting that a high rate of heat recovery was occurring between the units therefore maximising the system efficiency.

20th March 2009 – Whole Building

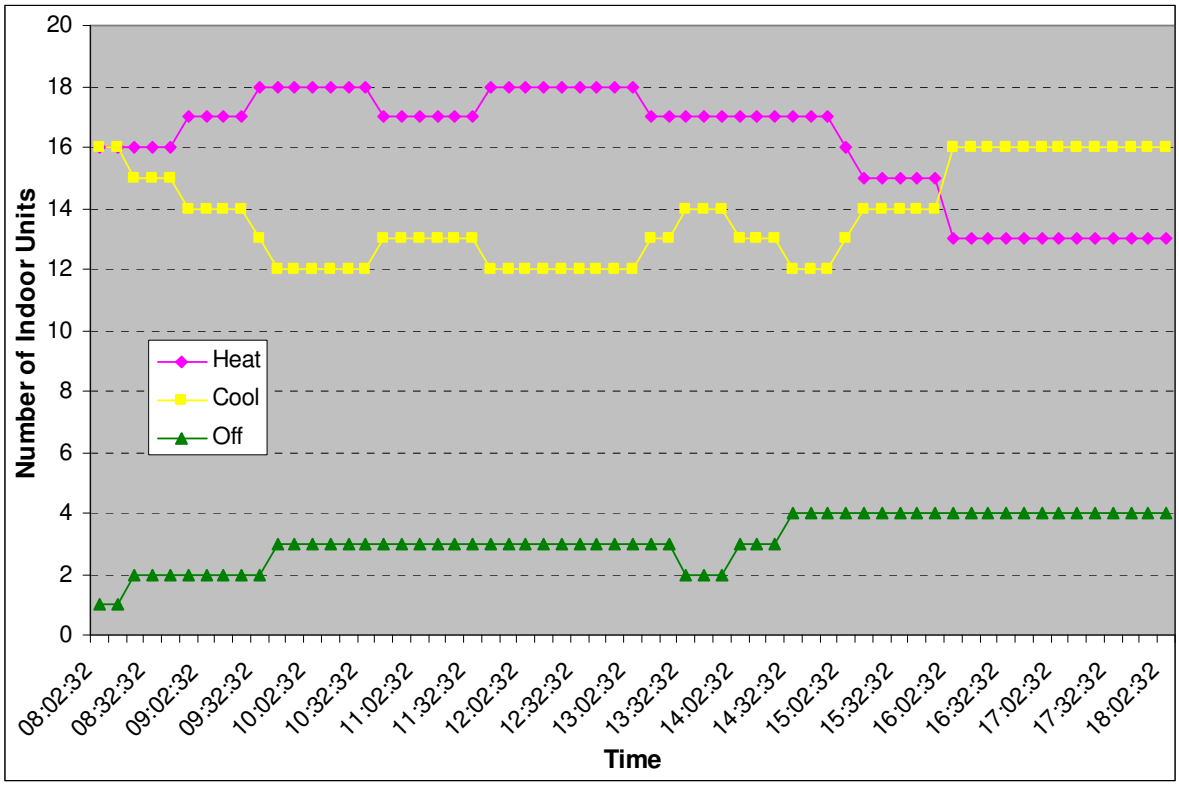
Taking a look at the building on a specific day in March we find the following results:

Watercooled Units



Ambient temperatures at the start of the working day were generally between 4 to 6degC. As the day progressed the outside air temperatures increased steadily peaking at approximately 10.5degC during the mid-afternoon. This is reflected in the slight increase in inlet water temperature over the day from approximately 13 to 14degC. As the building required more cooling, and the heating demand decreased, excess heat energy was dissipated into the ground therefore explaining the rise in inlet water temperature. The average power input for the water cooled units was low between 3 to 5kW at any given time during the day suggesting that they were fully using the inverter and working at part load which increases the efficiency.

Indoor Units

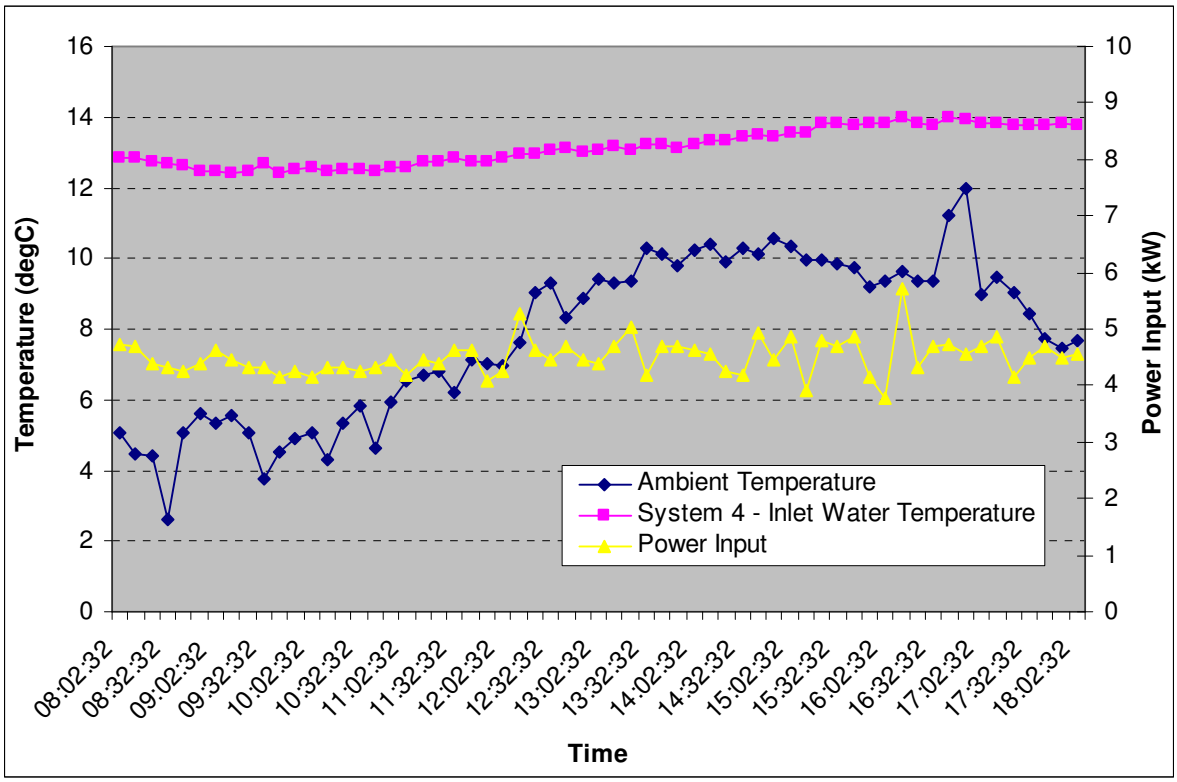


On this day most of the indoor units were on and were either heating or cooling the building. During the first part of the day when the ambient temperatures were lower most of the indoor units were heating. As the outdoor temperature increased the building started to heat up therefore we saw an increase in cooling. Again with most of the units running in either heating or cooling heat recovery was taking place between them meaning that the system was running in an efficient manner. Due to March being mid-season the opportunity for heat recovery was high as the system was running in part heat/cool mode for significant periods.

20th March 2009 – System 4

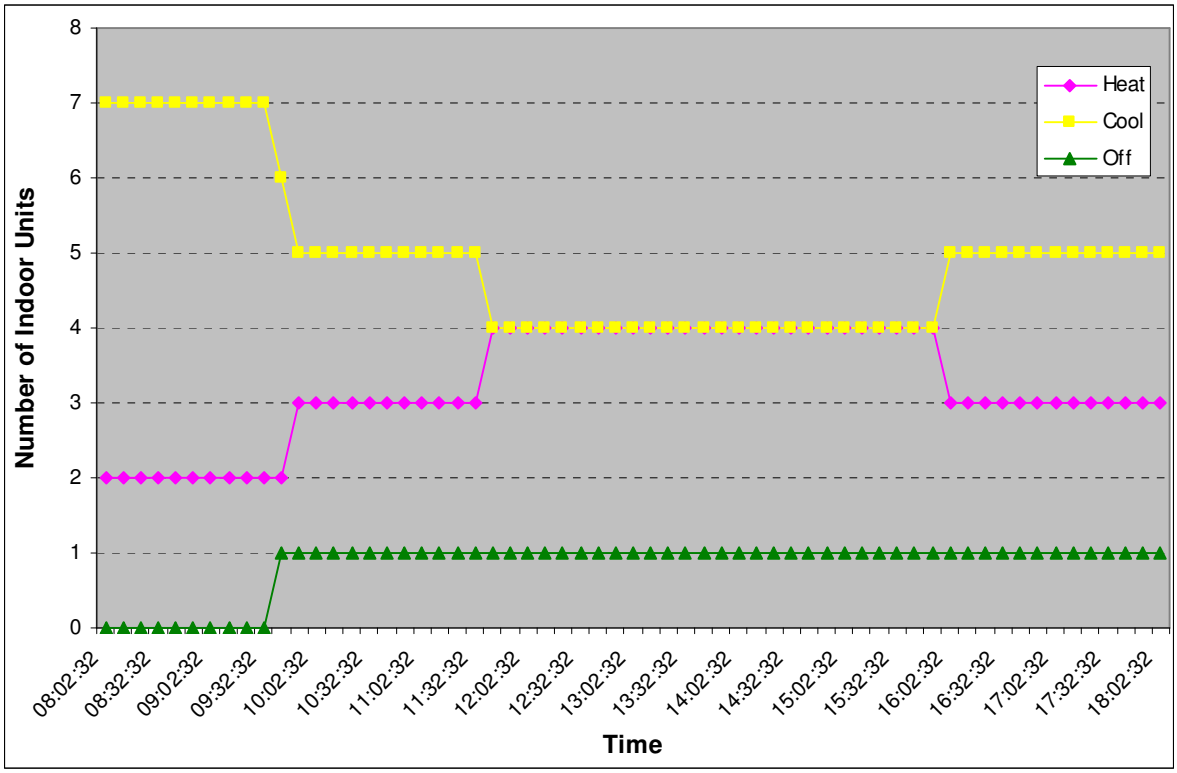
Taking this a step further we look at a specific system on a specific day in March. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



System 4 worked in a similar manner to all the other 5 systems. The inlet water temperature generally increased across the day from approximately 13 to 14degC as did the ambient temperature suggesting that the offices required more cooling. The power input was low mostly between 4 to 5kW at any one time during the day suggesting that the system was working at a higher efficiency at part load.

Indoor Units



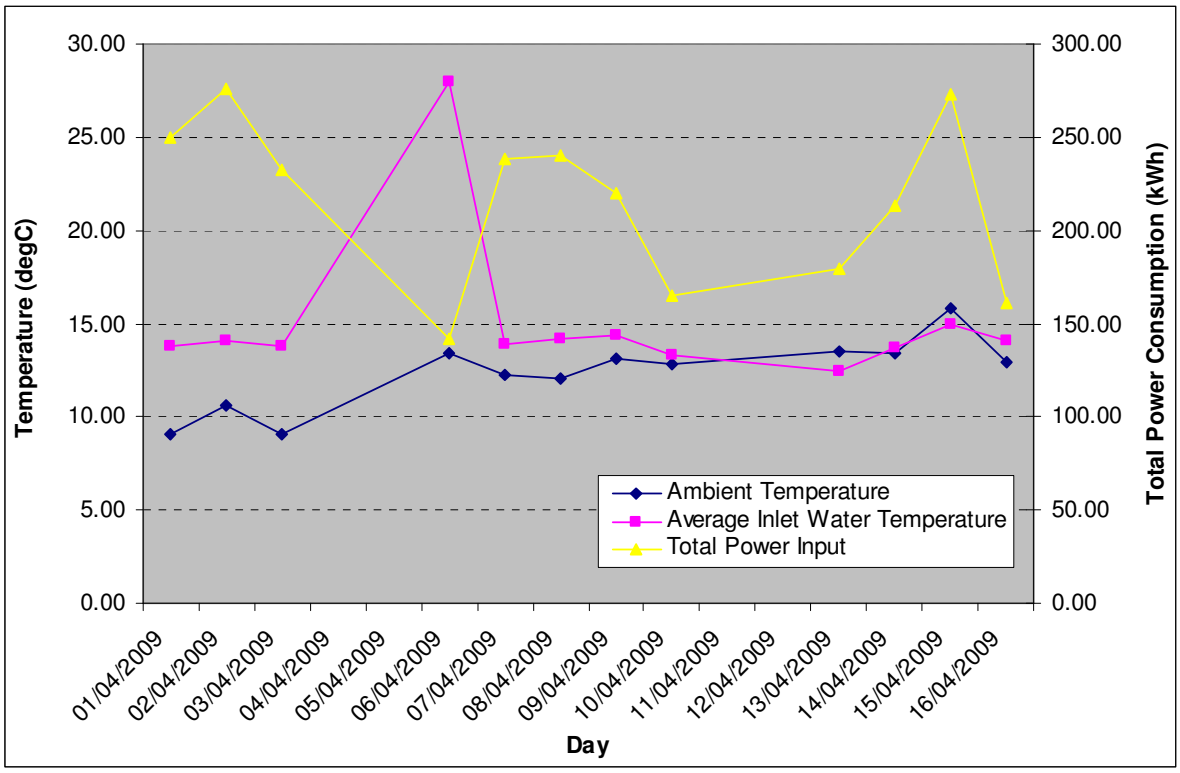
At least 7 of the 8 indoor units on system 4 were running all day in either heating or cooling. There was a large cooling demand at the beginning of the working day with 7 units running in cooling mode and 2 units in heating mode. As the day progressed some indoors changed from cooling to heating. It can be seen from the graph that from 10am to 6pm there were very high rates of heat recovery making the system extremely efficient.

Appendices 3.0

April Overview – Whole Building

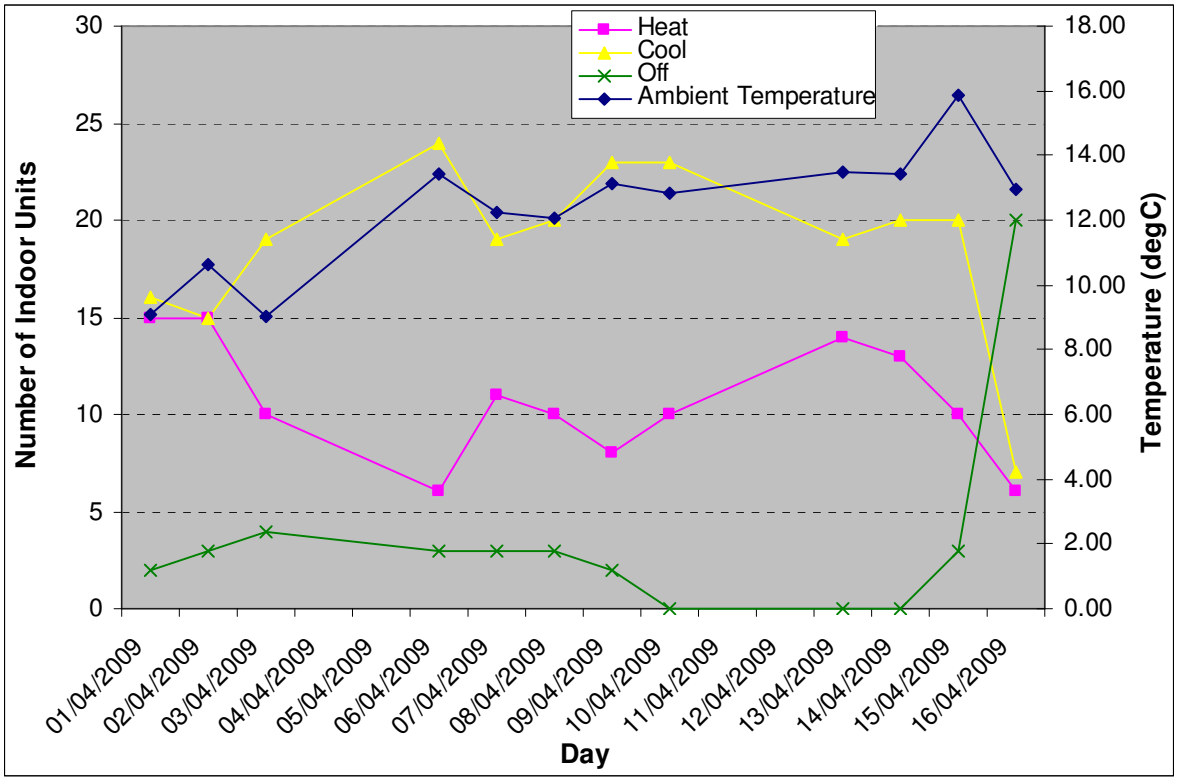
The month of April only has data for the first 16 days as data could not be logged for the rest of the month due to server availability.

Watercooled Units



Taking a look at April the average ambient temperature ranged between approximately 9 to 15degC which was higher than March when the highest temperature was just over 11degC. The average inlet water temperature ranged from approximately 13 to 15degC with the exception of the 6th April which shows an extremely high temperature which is likely to be a false reading. The power input of the water-cooled condensing units ranges between approximately 150kWh to 275kWh per day. This still indicates that the systems are working at part load to cope with the buildings heating and cooling requirements which means efficiency is increased. The cost of running the system to heat and cool the building during this month was calculated to be approximately £259.

Indoor Units

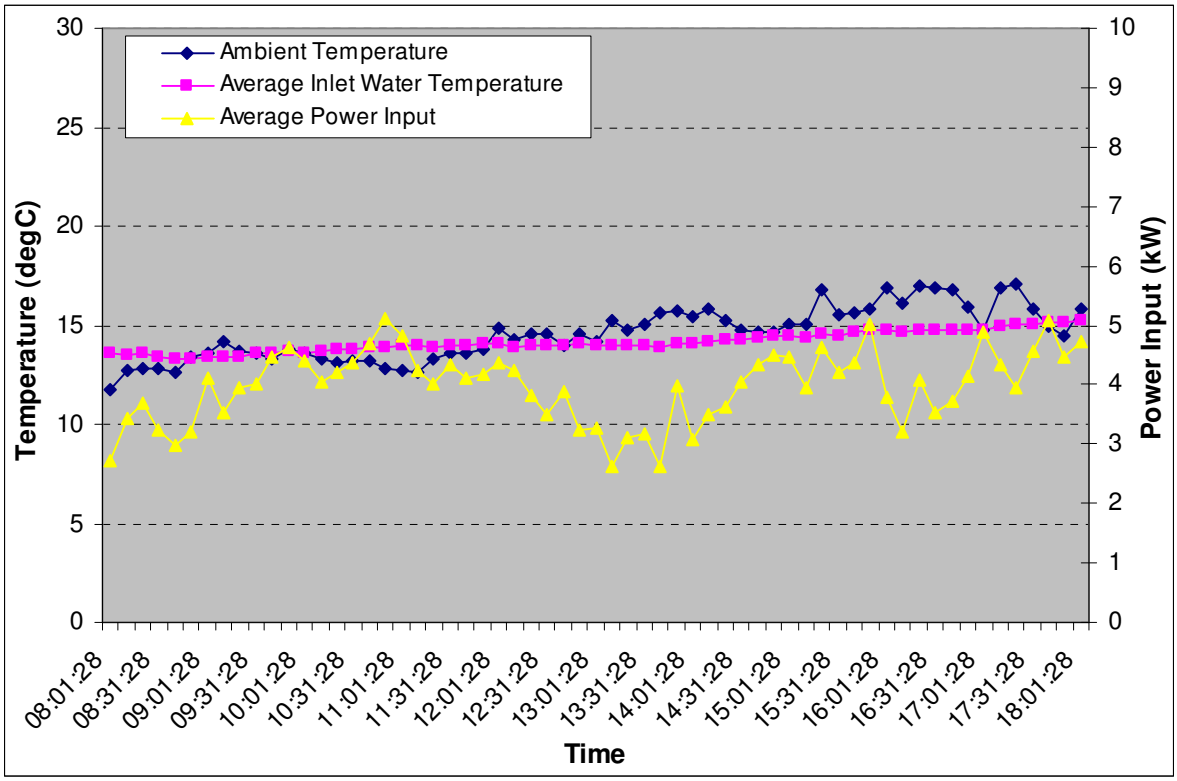


During the month of April it is clear that most of the units are in heating or cooling mode with less than 5 units switched off for all but one day of the month. The number of units in cooling tracks the ambient temperature trend. With 5 to 15 units running in heating mode over the month and 5 to 24 units in cooling mode on any day during the month it is clear that the month of April was a good month for heat recovery. The efficiency of the entire system would have been high due to this.

8th April 2009 – Whole Building

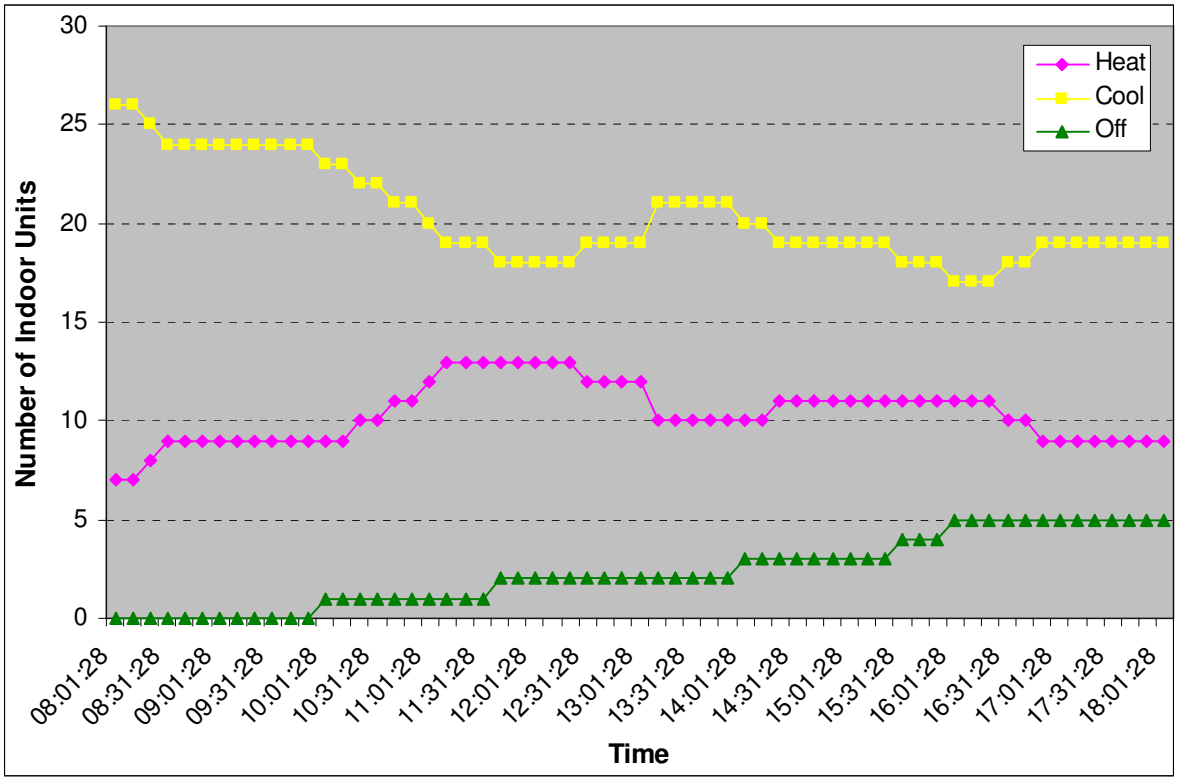
Taking a look at a specific day in April we find the following results:

Watercooled Units



The average ambient temperature on this day was typical of that of a day in April at around 14degC. The day starts off cooler at approximately 12degC and ambient temperatures rise steadily as the day goes on to approximately 16degC at 4pm. The average inlet water temperature of the 6 systems range from around 13.5degC to just above 15degC indicating the building is being cooled. The average power consumption was approximately between 2.5kW and 5kW per condenser at any given time during the day which is still quite low. This suggests a high system efficiency as the units are running at part load.

Indoor Units

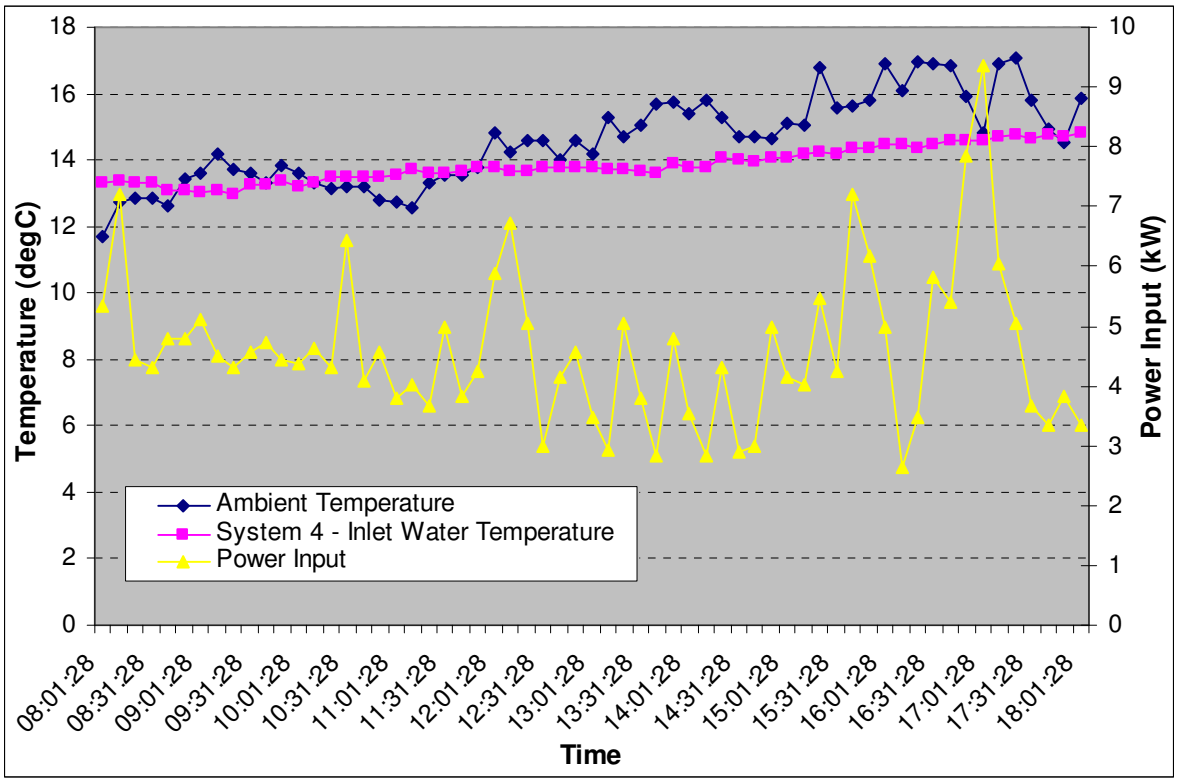


On this particular day it is clear that there was a high demand for cooling with between 17 and 26 indoors in cooling mode. This is as expected as the building is well insulated therefore retains heat energy well and ambient temperatures were moderate at approximately 14degC. Throughout the day between 7 and 13 indoors were in heating mode and so heat recovery took place between the indoor units increasing the system efficiency significantly. Towards the end of the day the number of units that were off increased as did the number of units cooling.

8th April 2009 – System 4

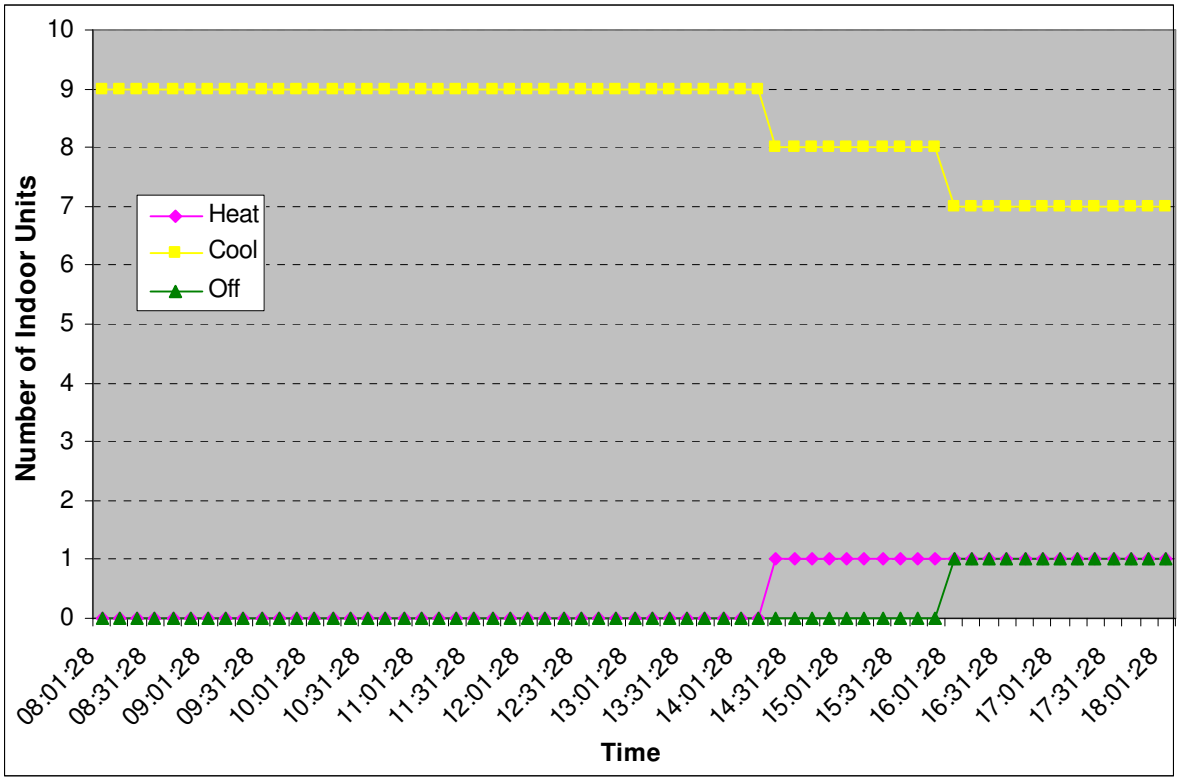
Taking this a step further we look at a specific system on a specific day in April. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



It is clear that system 4 works in a similar way to the rest of the systems. As the ambient temperature increased from approximately 11.5degC to around 17degC throughout the day the inlet water temperature increased slightly from 13.5 to 15degC as well indicating that the offices demanded more cooling. The power input of system 4 ranged from approximately 2.5 to 9kW at any one time during the day.

Indoor Units

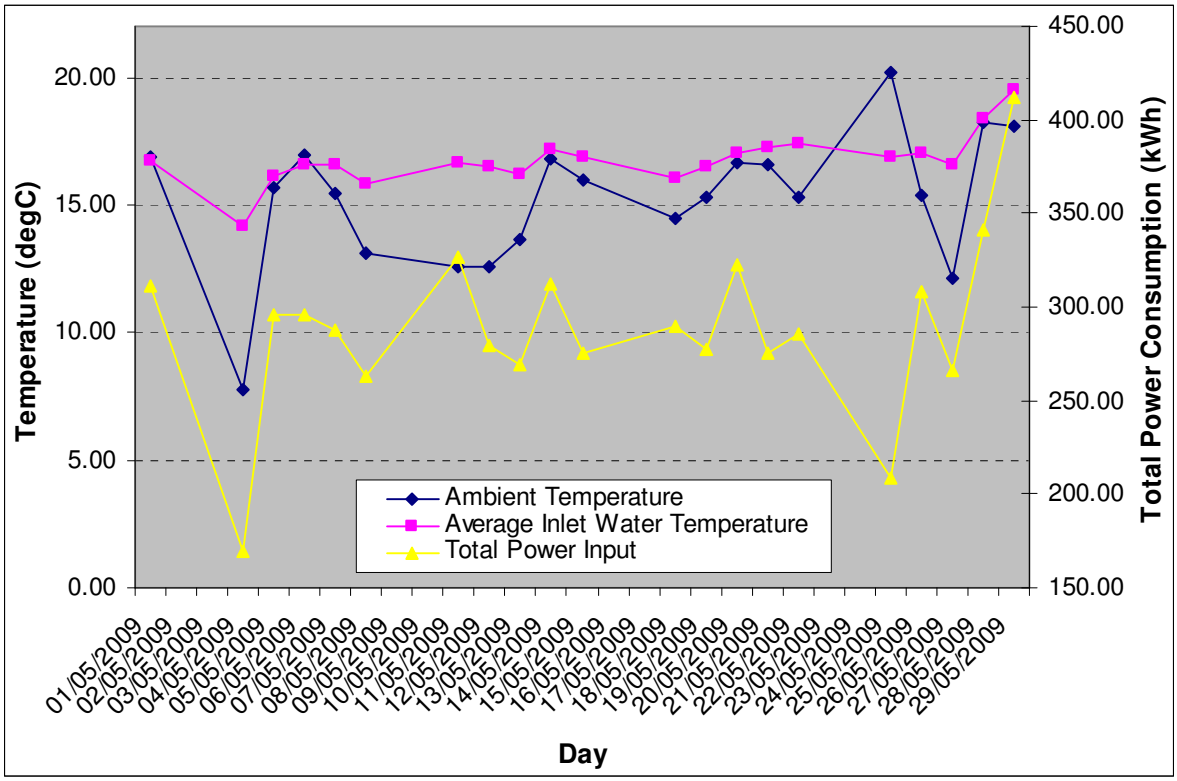


As expected most if not all of the units on system 4 were in cooling mode throughout the day. Towards the end of the working day as a comfortable indoor environment had been achieved and as the offices started to close a few units switched into heating or switched off. On this day very little heat recovery took place as only one indoor unit was heating towards the end of the day. Efficiency of this system on this day is lower as minimal heat recovery was occurring.

Appendices 4.0

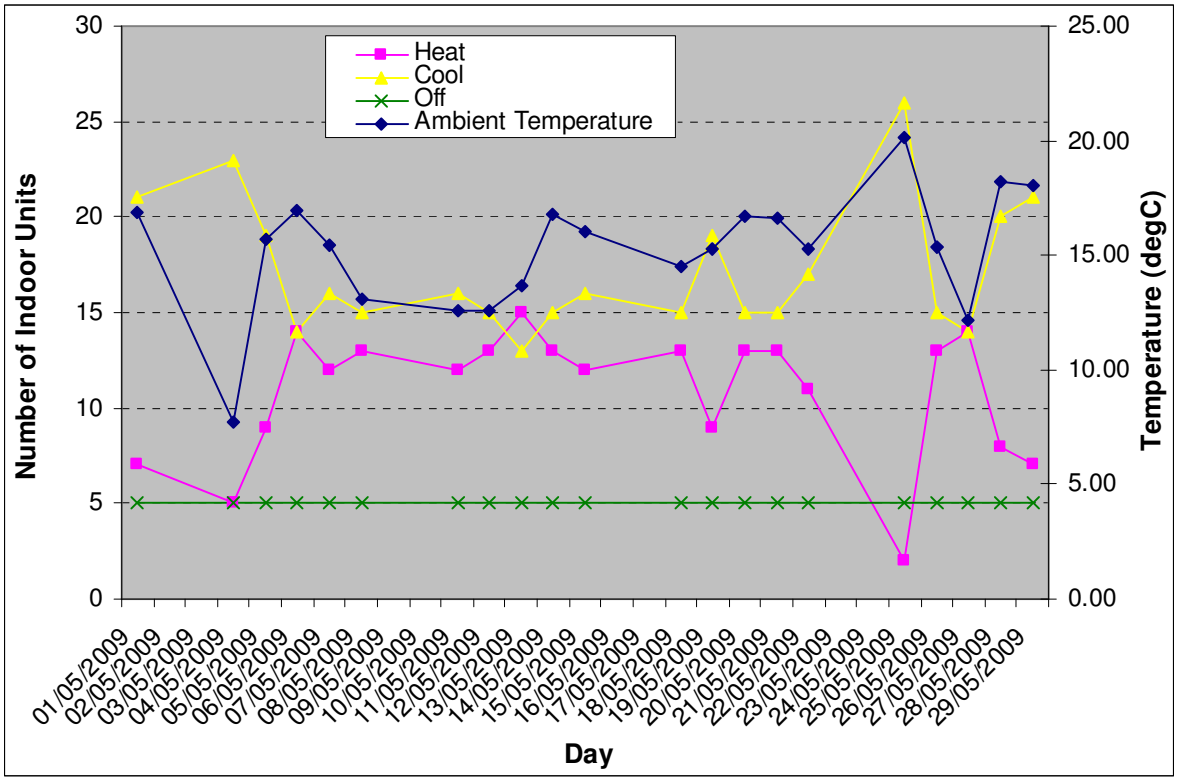
May Overview – Whole Building

Watercooled Units



Average ambient temperatures in May ranged between approximately 8degC and 20degC which was higher than in April when the highest average temperature was around 15degC. Along with this increase in ambient temperatures average inlet water temperatures ranged from approximately 14degC to 19.5degC indicating that the ground temperatures were warmer during this month and the system is overall providing more cooling than heating. The total power consumption across all 6 systems ranged from 170kWh to 410kWh per day over the month indicating that the systems were working harder to cool/ heat the building. The cost of running the system to heat and cool the building during this month was calculated to be approximately £607.

Indoor Units

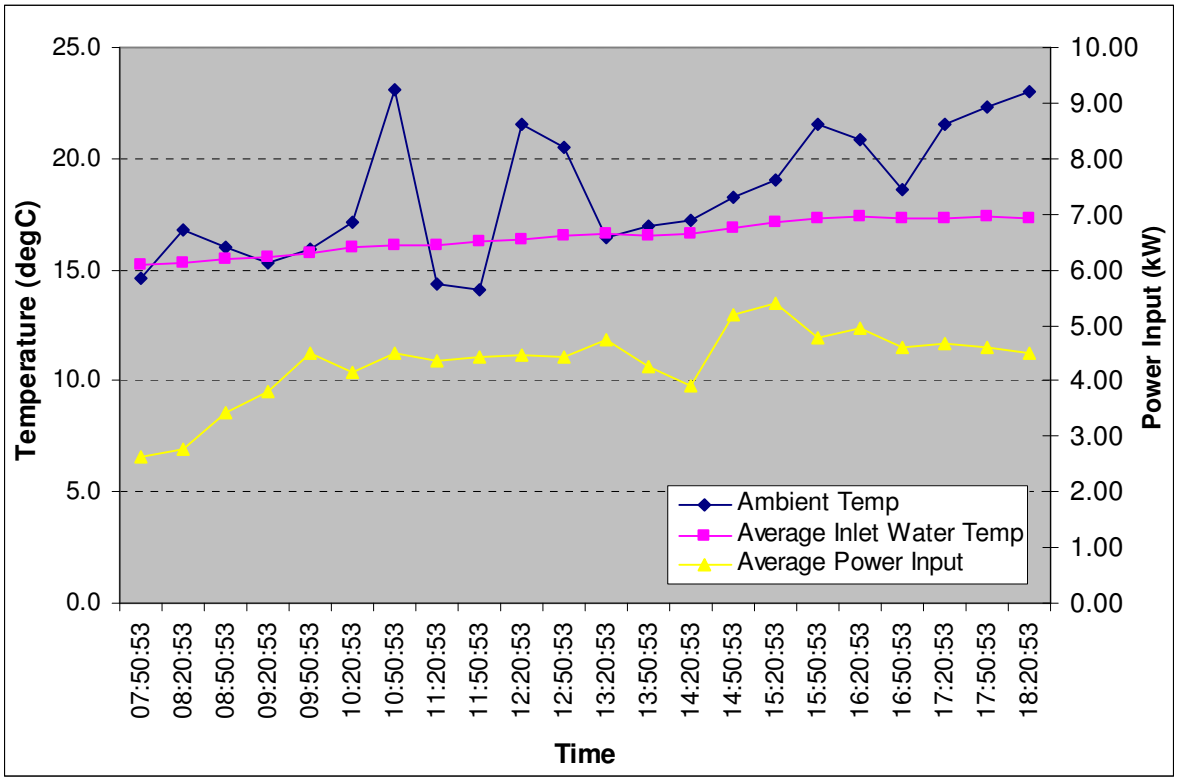


During this month we can see that the ambient starts to affect the indoor environment more. Previous months that had average ambient temperatures below 15degC seemed to affect the indoor unit demand less as the building is a new build and is well insulated and has solar shading. The higher ambient temperatures, as high as 24degC mean that between 13 and 26 indoor units were in cooling for most of the month. There were still quite a few units in heating mode in May allowing some heat recovery to take place and therefore increasing system efficiency.

19th May 2009 – Whole Building

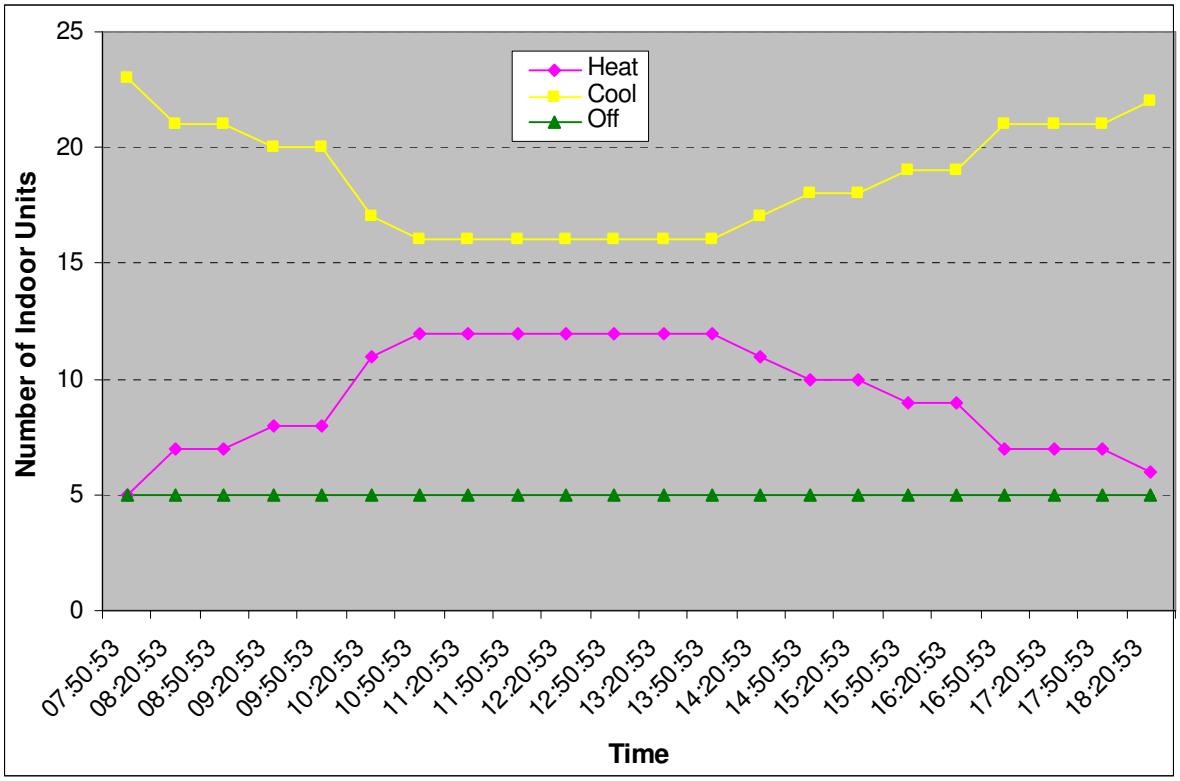
Taking a look at the whole building on a specific day in May we find the following results:

Watercooled Units



As the day progressed, on average the ambient temperature increased from approximately 15degC to 23degC. These higher ambient temperatures, especially towards the end of the day, suggested that the building demanded more cooling which is reflected in the increase in inlet water temperatures which averaged around 16.5degC compared to 14degC for the previous month. As excess heat energy was removed from the building it was disposed of into the ground therefore causing an increase in ground temperatures. The average power consumption ranged from around 2.5kW to 5.5kW per condenser at any given time during the day indicating that the systems were still working at part load in a highly efficient manner.

Indoor Units

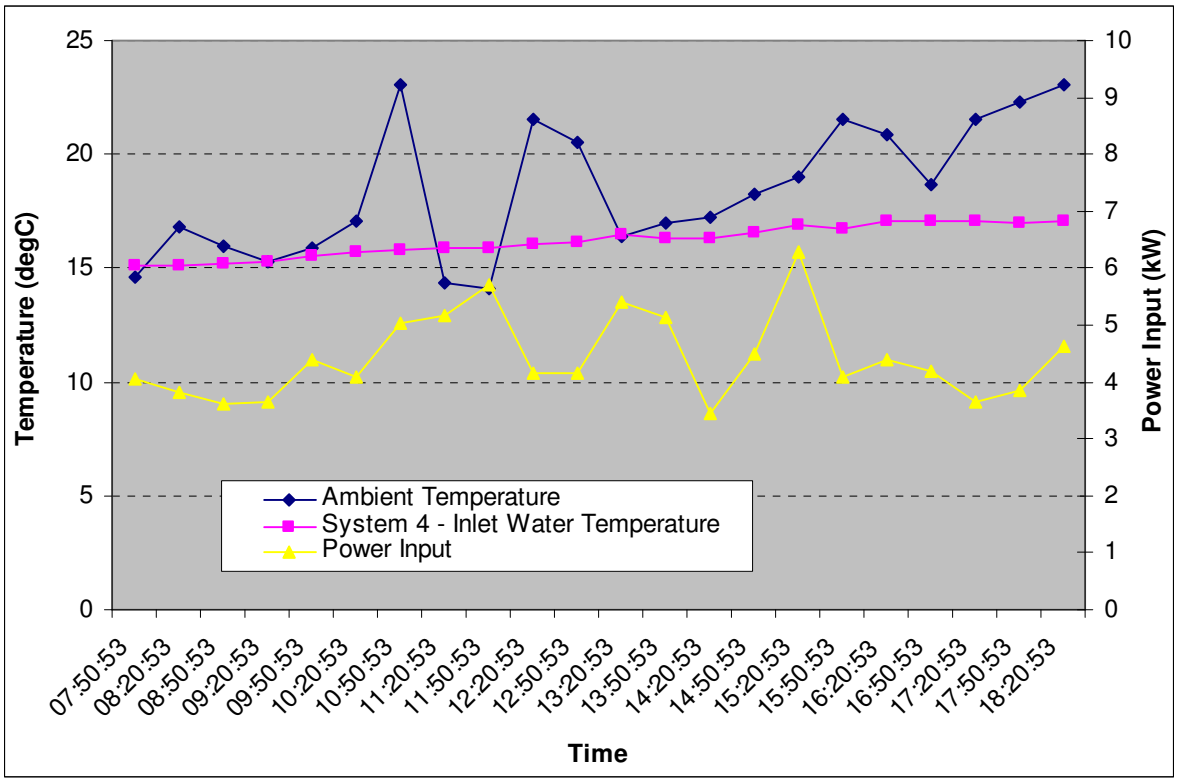


As expected with the ambient conditions on this day the biggest demand was for cooling with 16 or more units in cooling mode at any time during the day. More cooling was required in the morning and this decreased and levelled out during the middle of the day. As the ambient temperature increased in the afternoon the number of units in cooling also increased. Some parts of the building also required heating throughout the day which suggests that heat recovery took place here enabling higher efficiency. Heat recovery was greatest between approximately 11am and 2pm when a maximum of 12 indoor units were in heating mode. Over the whole working day only 5 units were switched off.

19th May 2009 – System 4

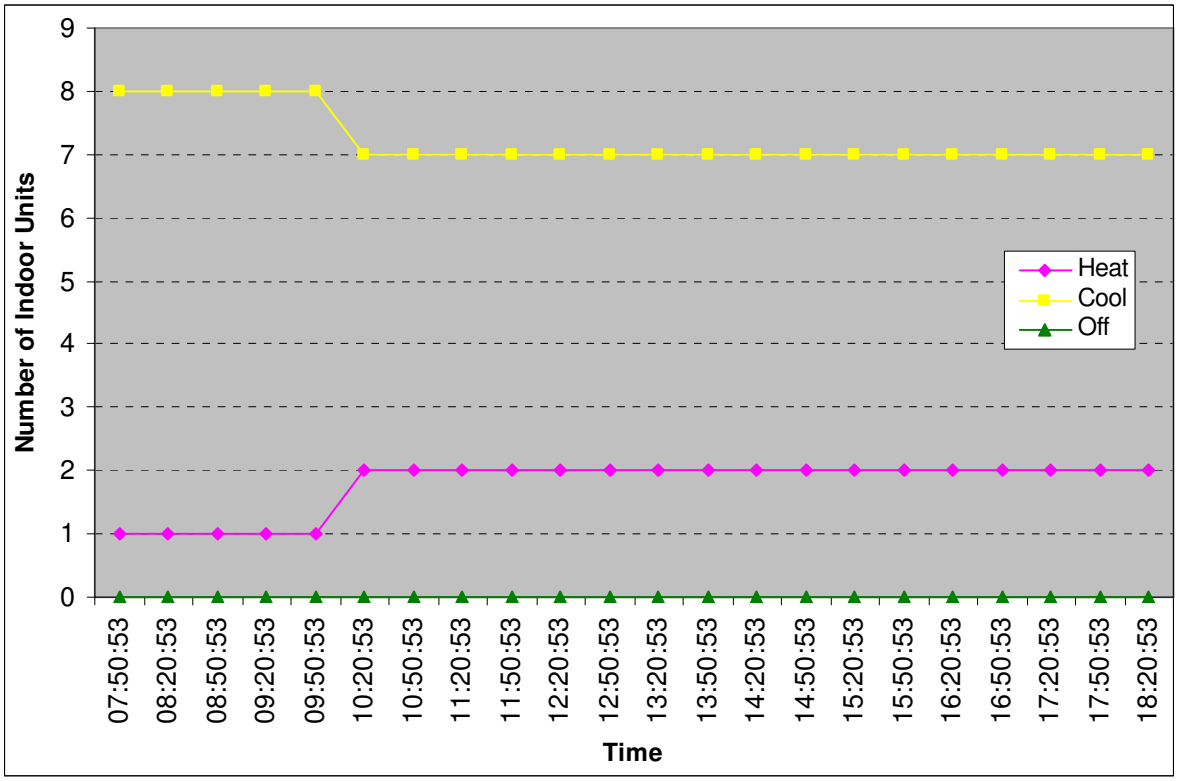
Taking this a step further we look at a specific system on a specific day in May. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



On average the ambient temperature increased as the working day progressed. There was also an approximate 2degC increase in the inlet water temperature from 15 to 17degC of the ground source unit over the day suggesting that the offices were mainly being cooled and heat was being rejected to the ground. The power consumption of the unit was between 3.5 and 6.5kW at any given point during the day which is low suggesting that the system was working in an efficient way at part load.

Indoor Units

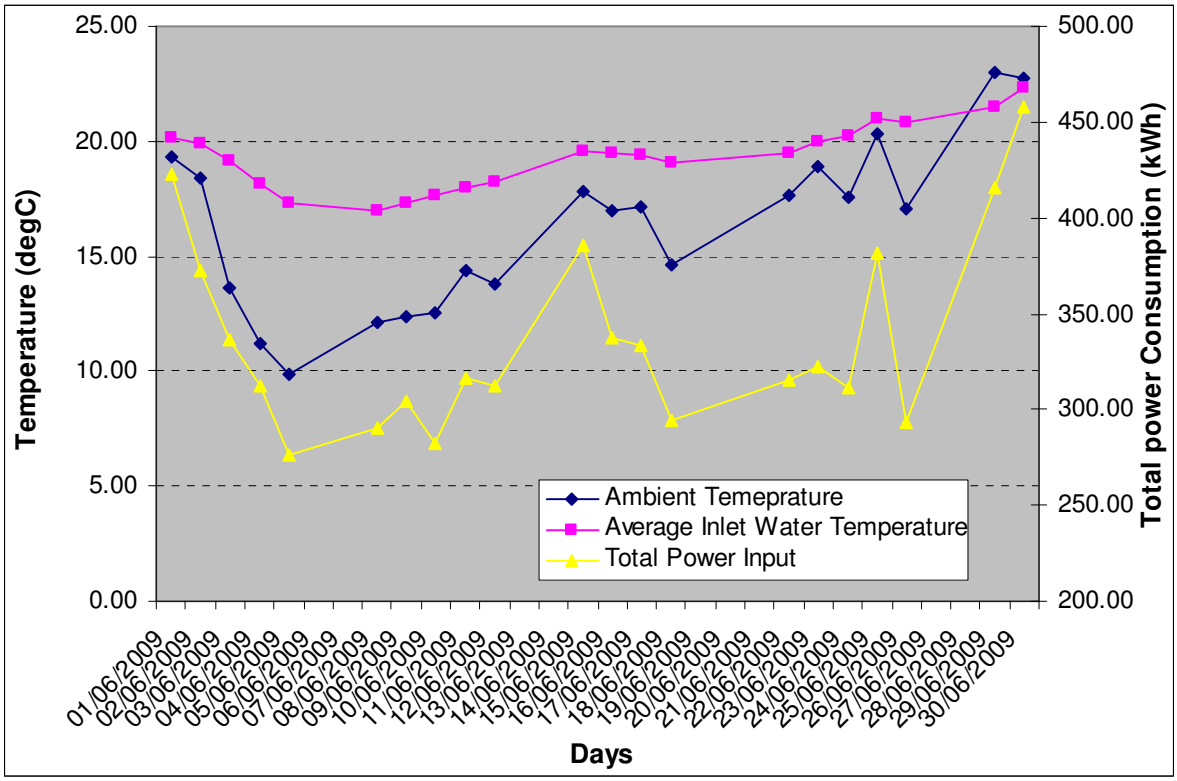


As expected, with the higher ambient conditions the majority of units on system 4 were cooling the office areas. There were a couple indoor units in heating suggesting that there was some heat recovery that took place but not as much as previous months when more units on this system were in heating.

Appendices 5.0

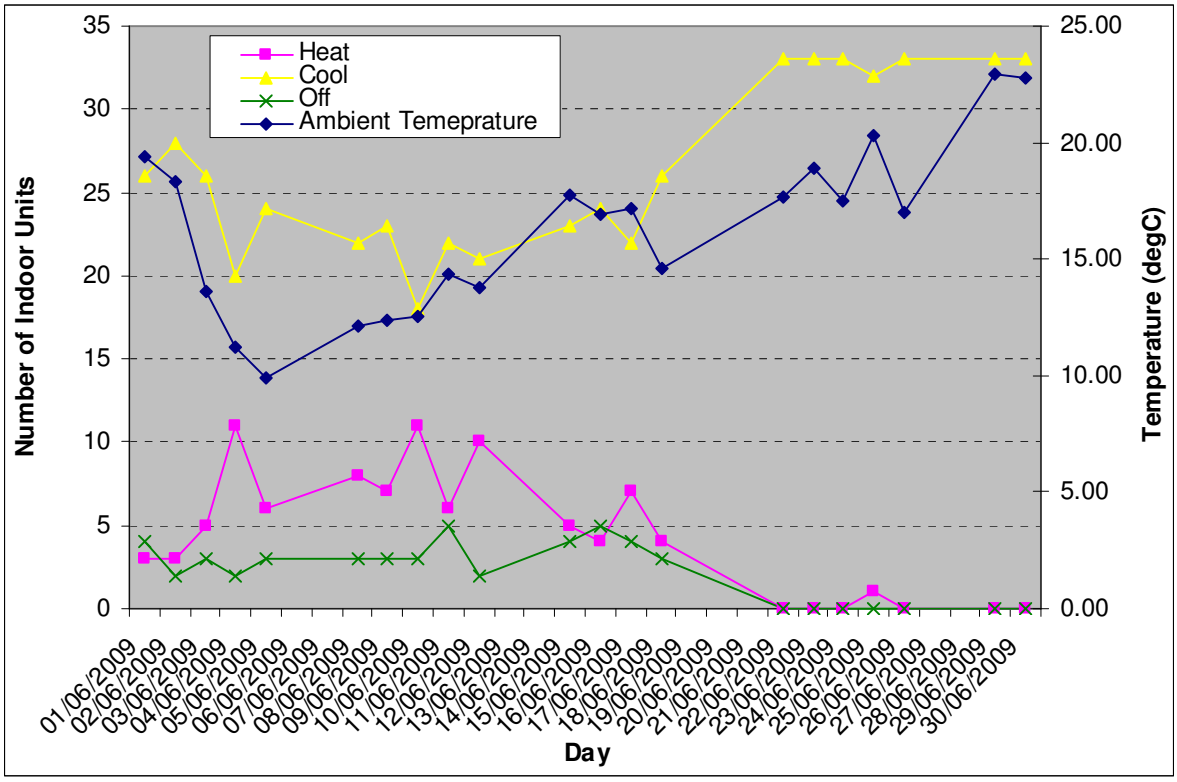
June Overview – Whole Building

Watercooled Units



Average ambient temperatures in June were quite varied and ranged from approximately 10degC to 23degC. The average inlet water temperature was high at 20degC at the beginning of the month. As the ambient decreased the inlet water temperature decreased as well for the first week in June to a low of around 17degC. This indicates that less heat energy was being rejected to the ground allowing the ground temperatures to recover slightly. After this first week as the ambient increased as did the inlet water temperature to a maximum of 22degC at the end of the month. The power consumption followed a similar trend and tracked the ambient trend. Over the month the total power consumed on any one day ranged from approximately 275kWh to 460kWh per day indicating that the systems were working harder to provide the cooling demanded by the building. The cost of running the system to heat and cool the building during this month was calculated to be approximately £708.

Indoor Units

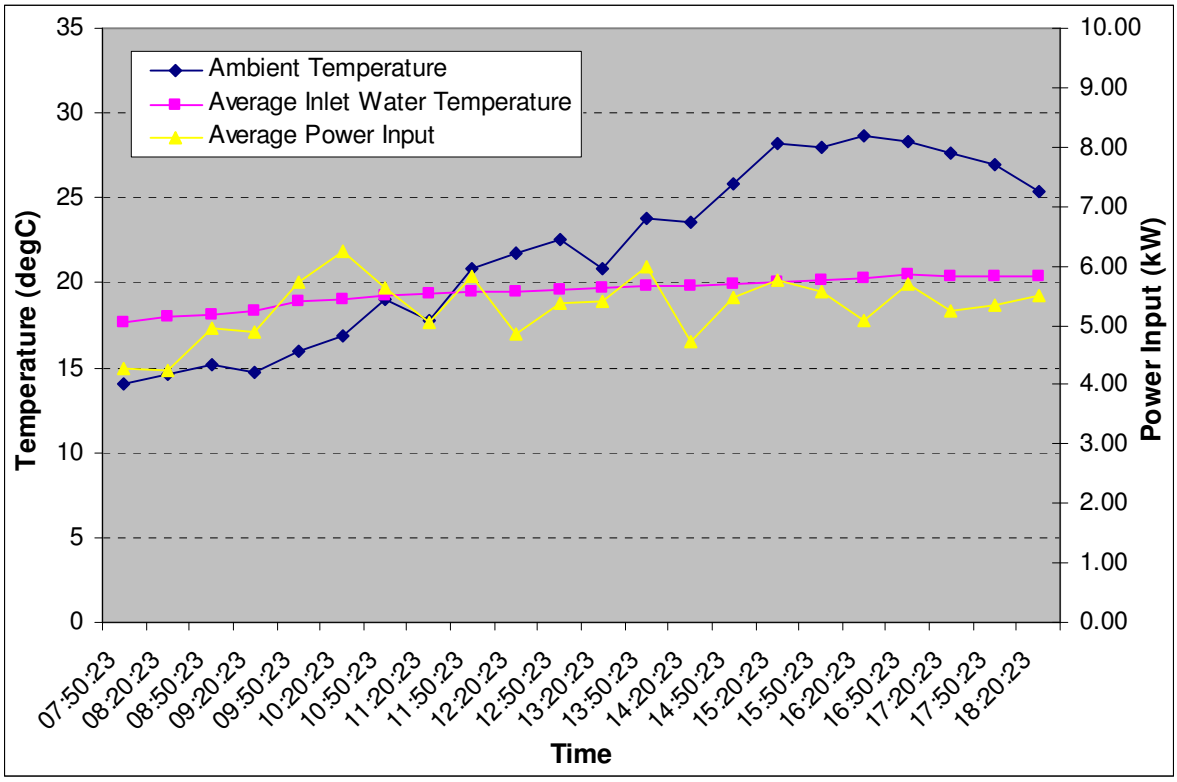


The indoor unit modes trend reflected what is expected given the ambient conditions. The building required cooling mainly throughout the month with all 33 of the fancoils in cooling by the end of the month as ambient conditions increased. During the first part of the month there were some units in heating as well allowing the system to benefit from heat recovery however it was on a smaller scale than previous, cooler months when more units were heating the building. As this is a high season month for cooling there is a potential for heat recovery to take place between the indoor units and the PQFY heat pump boiler units.

16th June 2009 – Whole Building

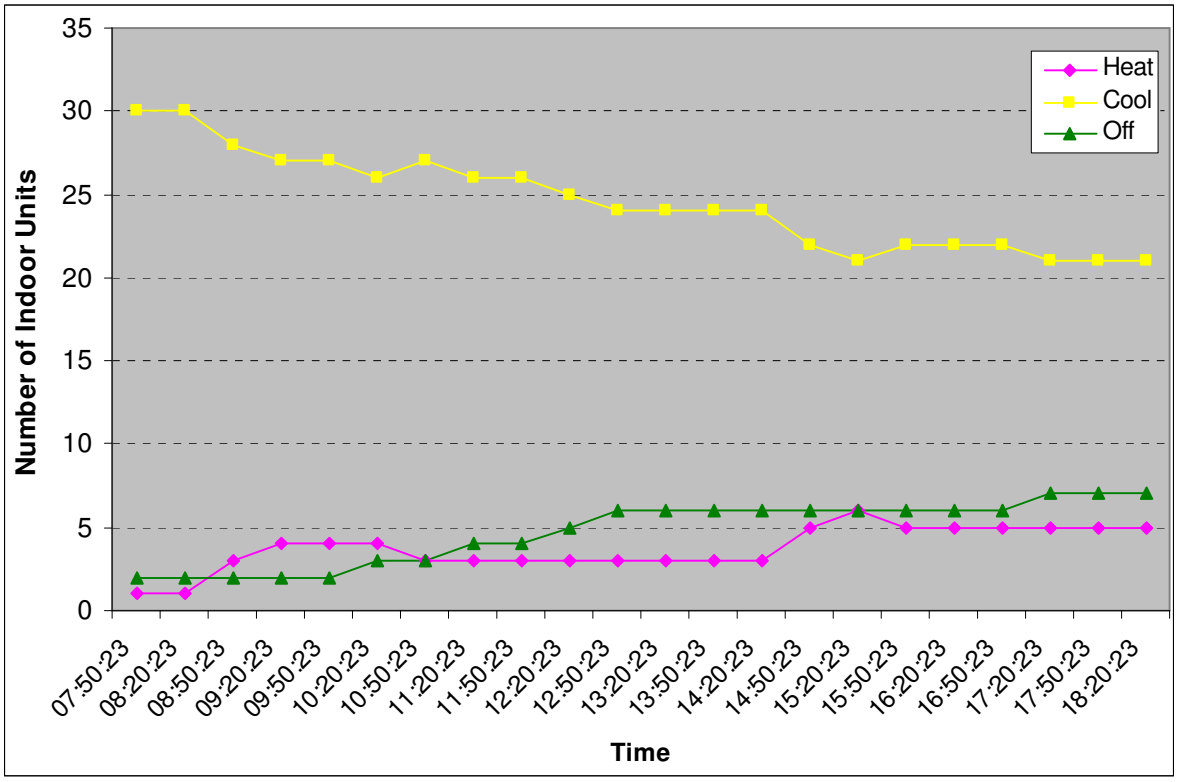
Taking a look at a specific day in June we find the following results:

Watercooled Units



The ambient temperature increased as the day progressed from a low of 14degC to a high of 29degC suggesting that the building required cooling. This was further supported by the fact that there was an increase in average inlet water temperature over the day by approximately 3degC. The average power consumption of each ground source unit varied between approximately 4kW and 6kW per condenser over the day indicating that the units were working at part load over the day therefore maximising the efficiency of the system.

Indoor Units

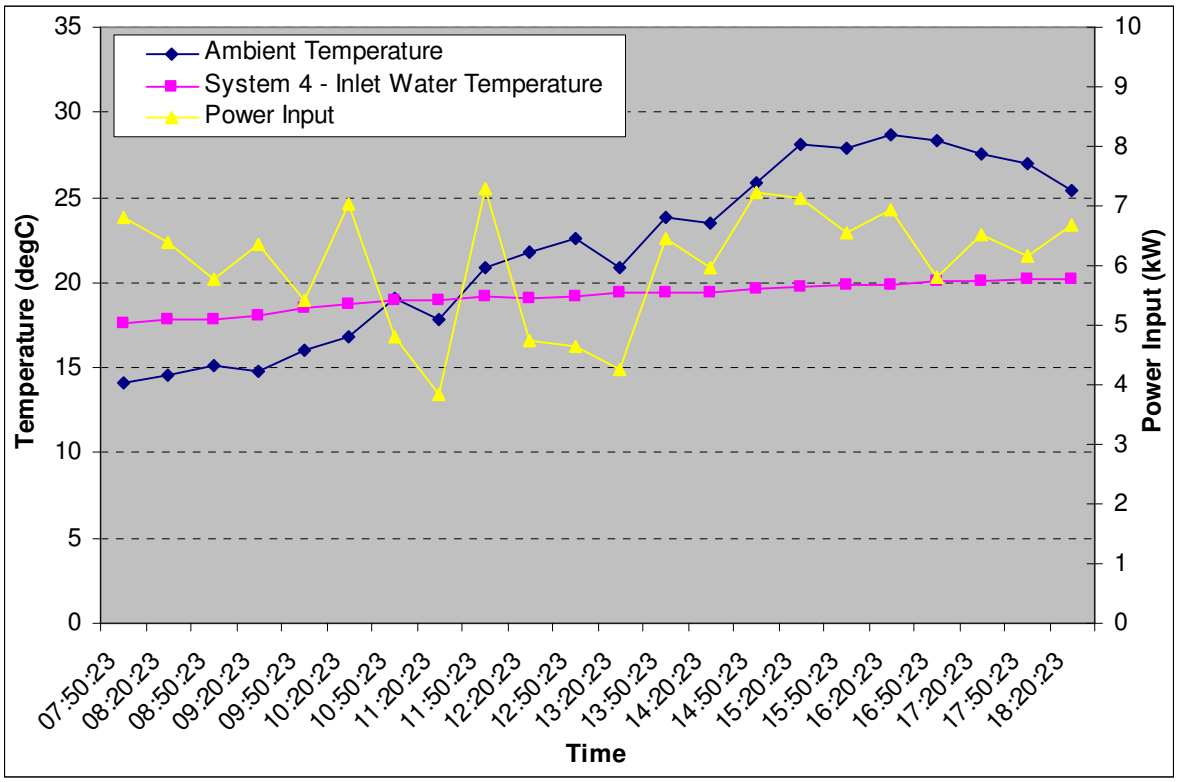


The majority of the 33 indoor units were in cooling mode over the whole day. As the indoor temperature became more comfortable towards late afternoon the units started to turn off however there were still 22 units in cooling at the end of the day. There were still at least 1 to 6 indoor units in heating mode throughout the day suggesting that some heat recovery was taking place to increase the efficiency of the systems.

16th June 2009 – System 4

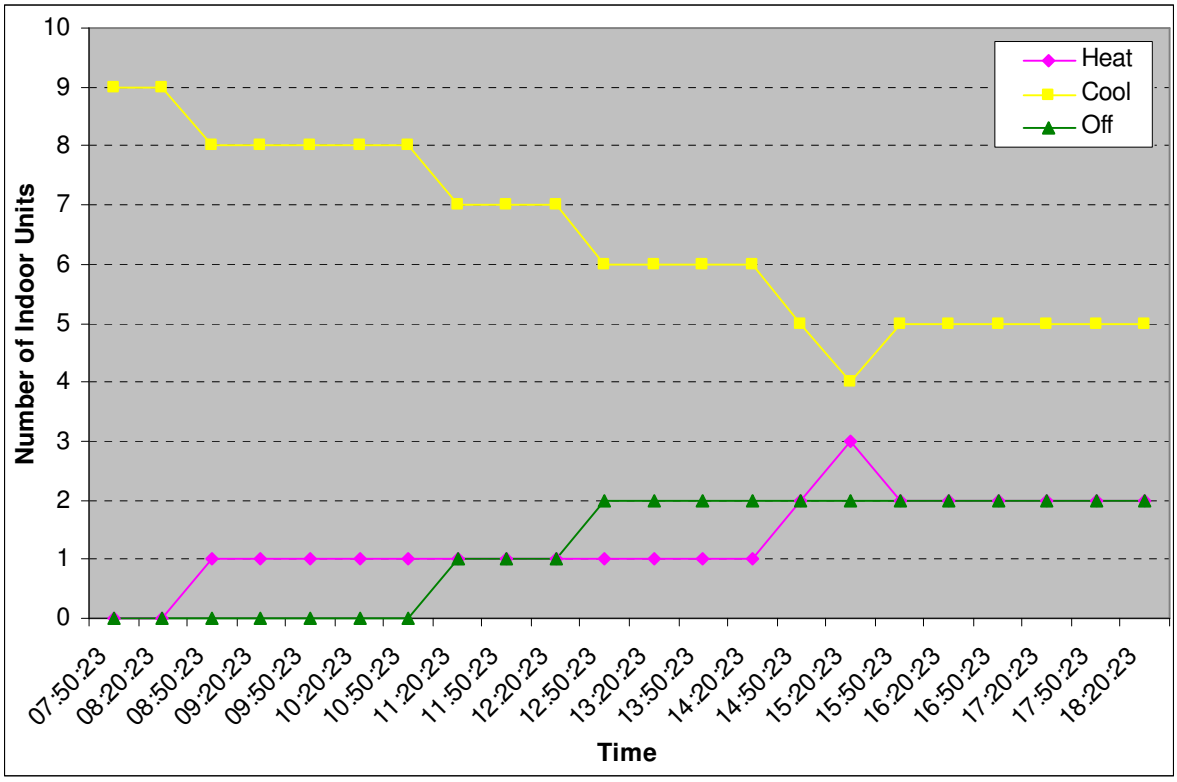
Taking this a step further we look at a specific system on a specific day in June. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



Ambient temperatures reflected the average for the month on this day. As the day progressed the outdoor temperature increased from approximately 14degC to a maximum of 28degC. Along with this we see that the power consumption of the watercooled unit increased from previous months to an average of around 6kW compared to averages of 4-5kW. This was as expected as the system was working harder to provide more cooling to the offices as outside temperatures exceeded 20degC from midday onwards. The average inlet water temperature increased over the day from around 18degC to just above 20degC indicating that the ground warmed up during the working day due to excess heat energy being removed from the building.

Indoor Units

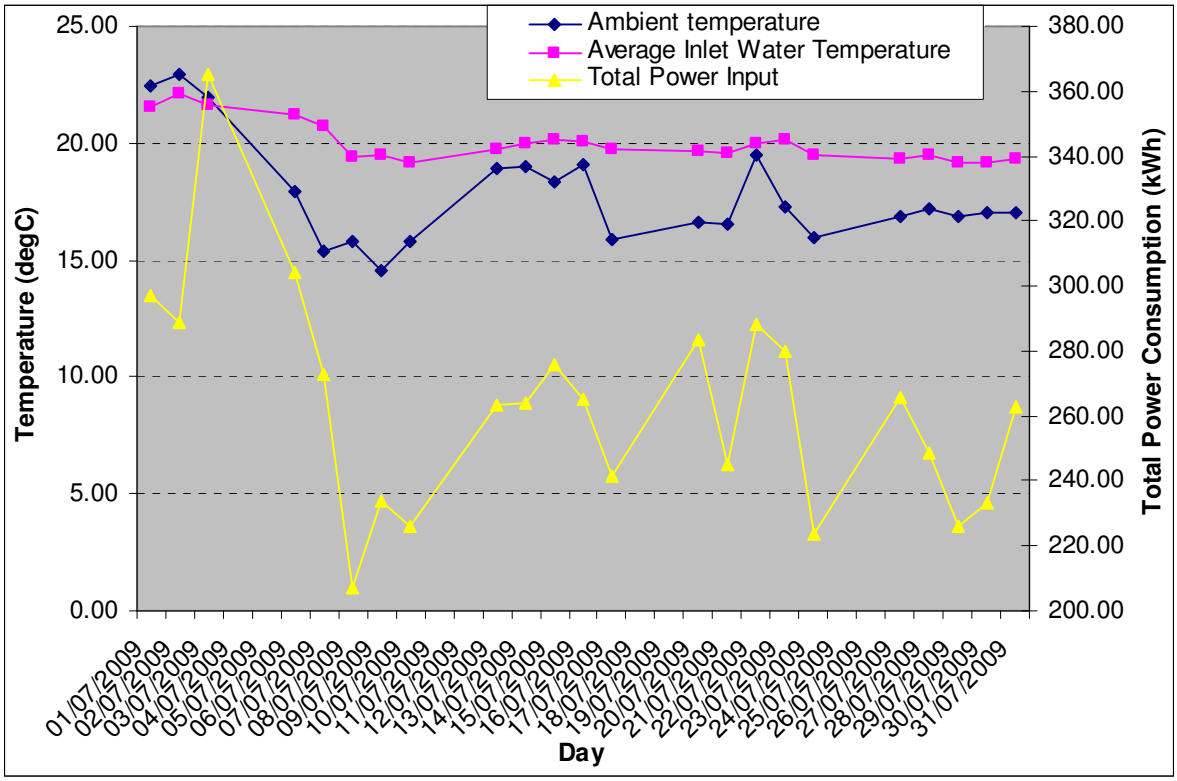


Most of the 9 indoor units on system 4 were in cooling mode which is expected at this time of year and at these ambient conditions. As the day progressed more units switched off suggesting that the building temperature was sufficient enough for occupants to work comfortably. There were up to 3 units heating. The decrease of units in cooling indicated that less heat energy was being rejected into the ground allowing the ground temperature to recover overnight while the building was unoccupied.

Appendices 6.0

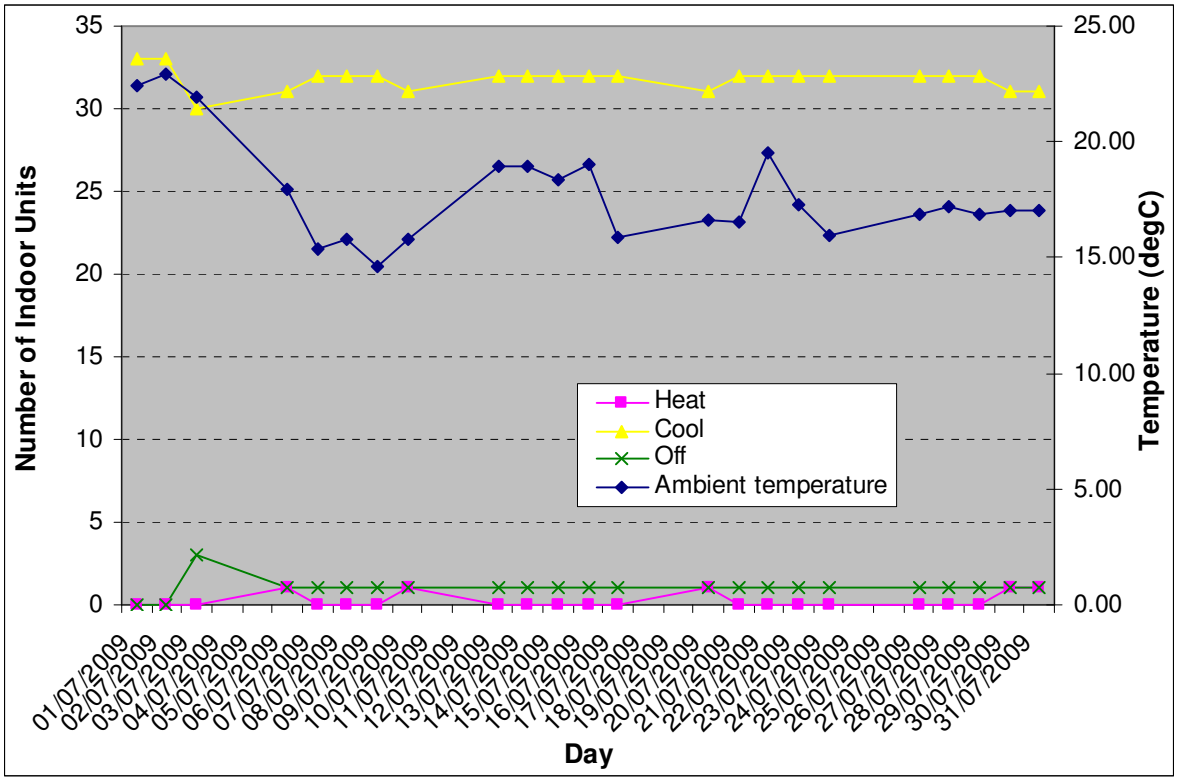
July Overview – Whole Building

Watercooled Units



Average ambient temperatures were lower in July than expected at this time of year with temperatures ranging from approximately 15degC to 23degC. At the beginning of the month when ambient temperatures were at their highest the total power consumption was at a maximum at 365kWh per day as well as the inlet water temperature at approximately 22degC. When the ambient temperature was at its lowest the total power consumption of the watercooled units were as well at 207kWh per day and the inlet water temperature was at its lowest at around 19degC. It is clear that the ambient temperature was affecting the internal environment of the building as the systems were working as expected. The inlet water temperature was relatively flat partly due to not as much heat being rejected to the ground , but also this is probably near the limit in temperature that the ground will get to for this specific ground loop system. The cost of running the system to heat and cool the building during this month was calculated to be approximately £606.

Indoor Units

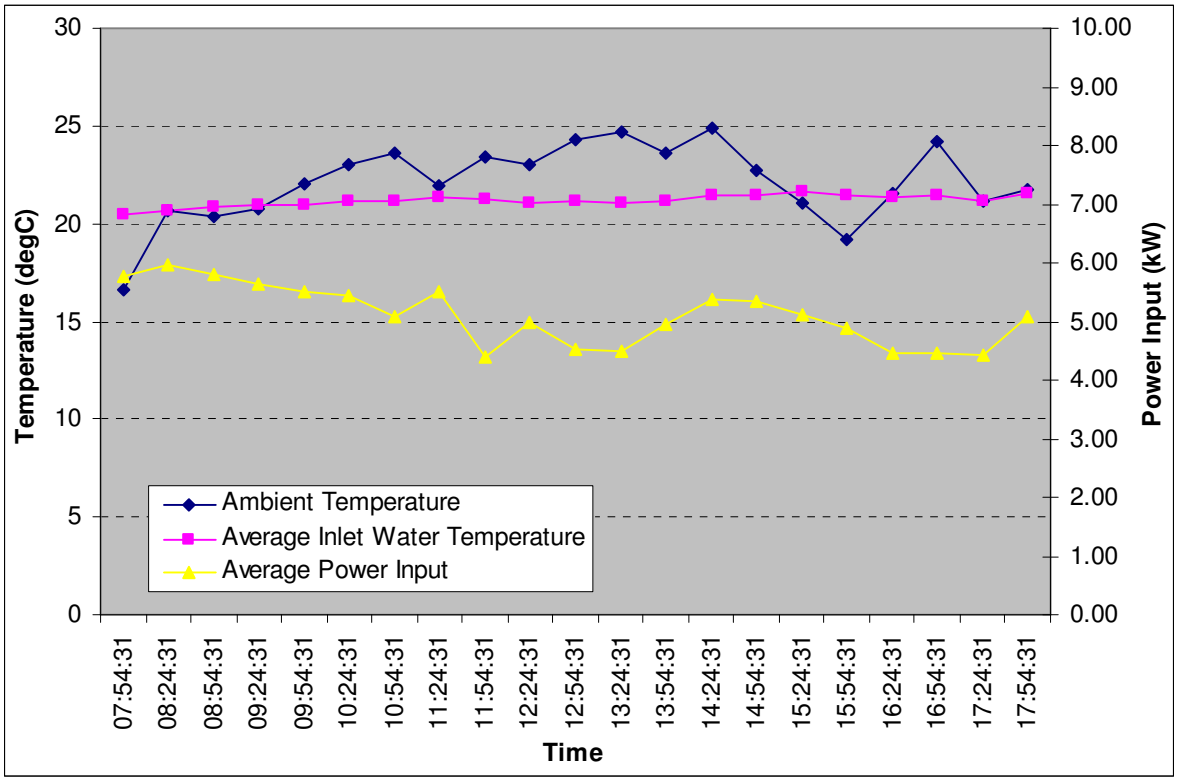


The month showed a high demand for cooling in the entire building as is expected with the ambient conditions over this period. At least 30 of the 33 units were in cooling mode and only 1 unit was in heating mode at various times during the day. As a result very little heat recovery took place between indoor units however this did not compromise the efficiency of the system on a large scale.

6th July 2009 – Whole Building

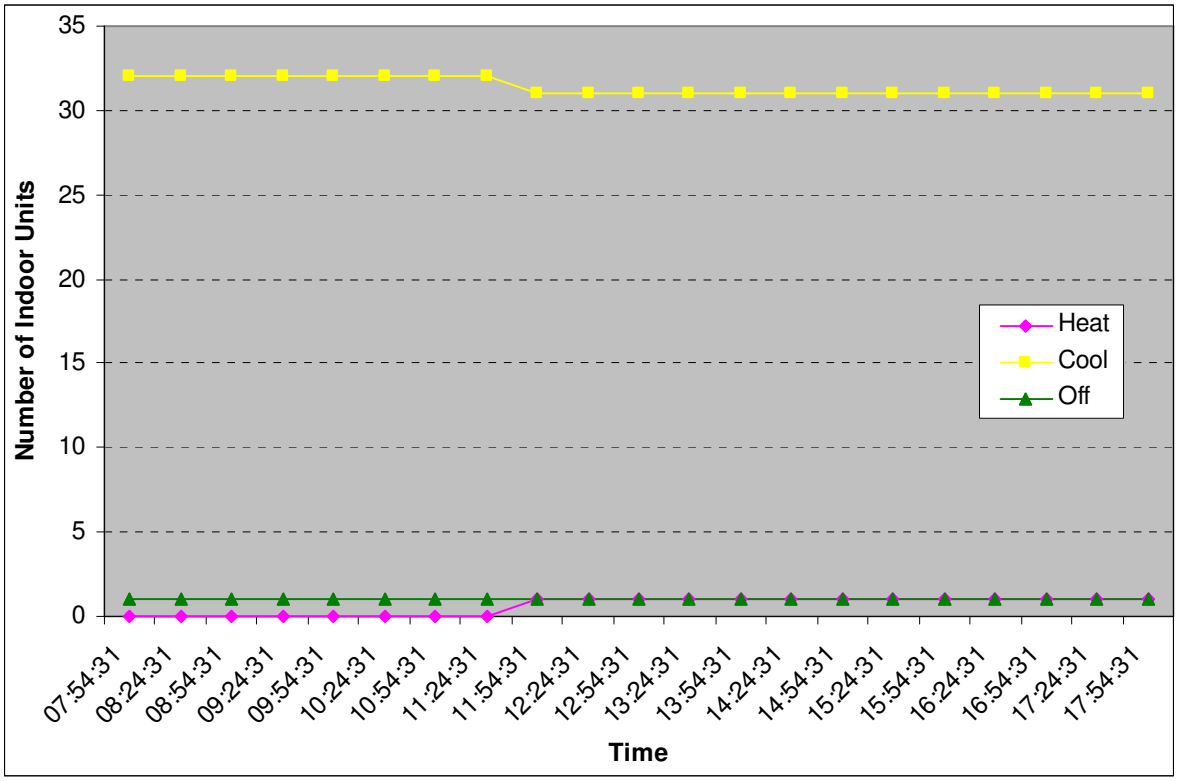
Taking a look at a typical day in July we find the following results:

Watercooled Units



Varying ambient conditions on this particular day did not seem to affect the building much. The outside temperature ranged from 16degC to 25degC however very little change can be was seen in the inlet water temperatures for the ground source units which ranged from 20.5degC to 21.5degC. The average power input varied between around 4.5kW to 6kW per condenser which indicates that the systems were not working at full capacity yet meaning that the efficiency was higher.

Indoor Units

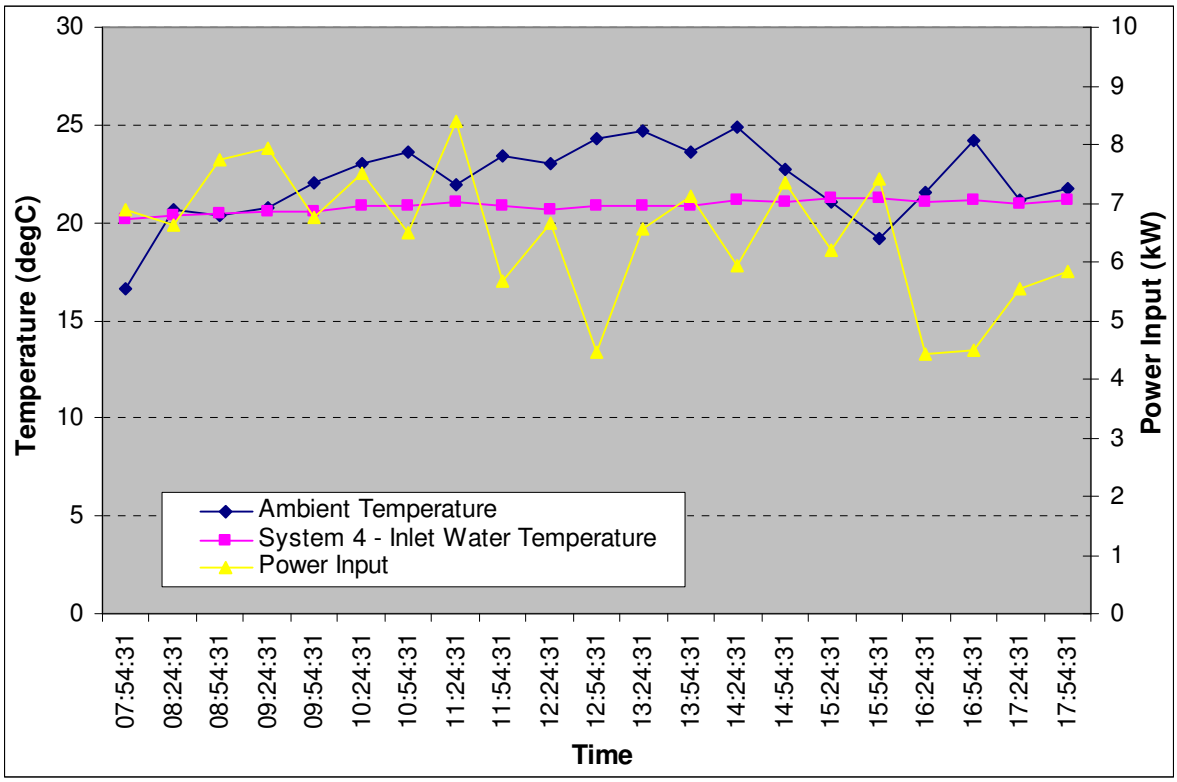


The entire building required mostly cooling on this relatively warm day in July with at least 31 of the 33 indoor units in cooling mode during the day. With the rest of the 2 units either off or in heating mode there was very little heat recovery taking place here. Although we would expect a high system efficiency as the ground source units are highly efficient the COP was not as high as it could be if more heat recovery was taking place between indoor units.

6th July 2009 – System 4

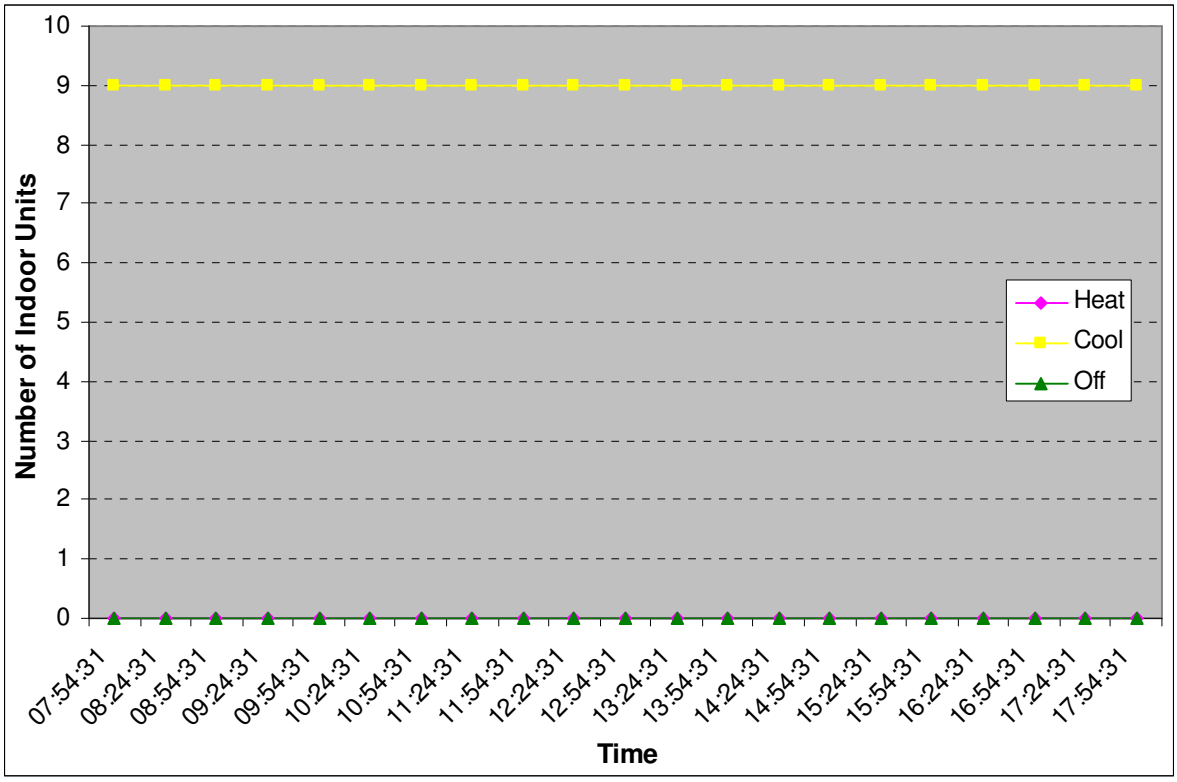
Taking this a step further we look at a specific system on a specific day in July. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



On this day it is clear that system 4 is worked harder than during the spring months to cool the offices as the power consumption had increased. Previous months such as March and April showed average power consumption data between 3 to 6kW however on this day the power input of the system ranged from approximately 5 to 8.5kW. The average inlet water temperature of the unit changed by approximately 1degC from 20degC to 21degC.

Indoor Units

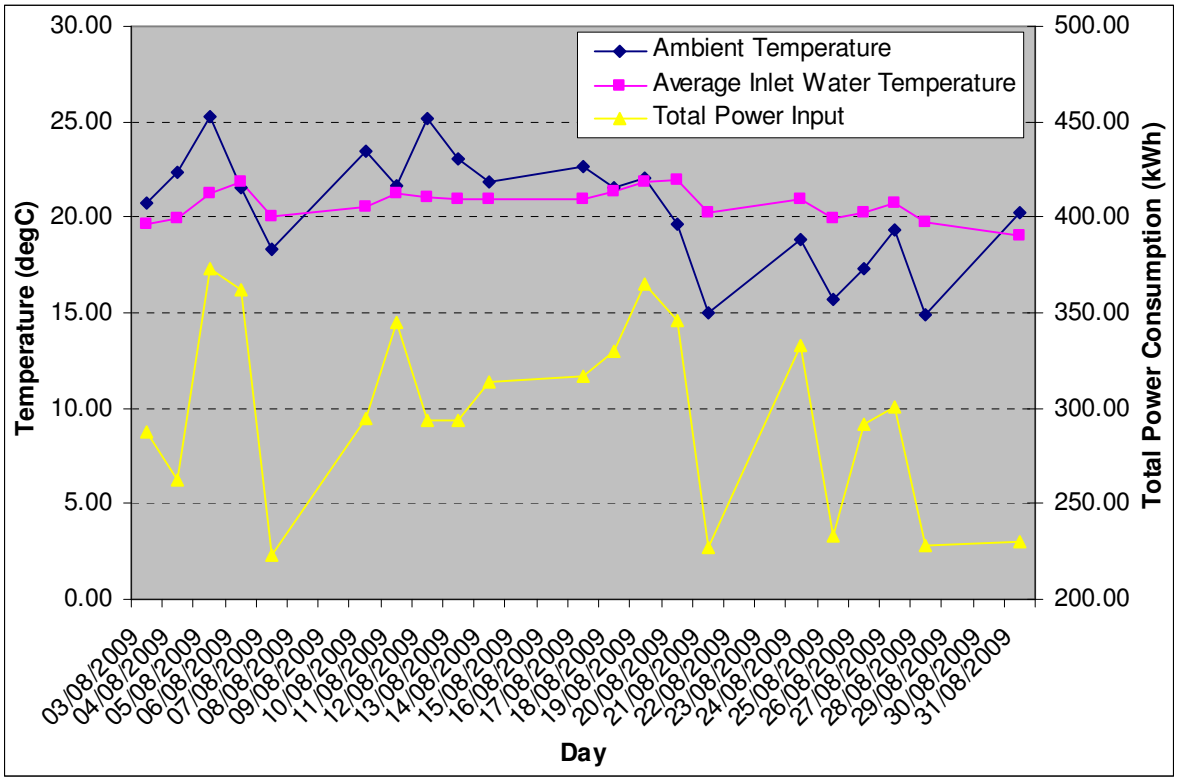


All 9 of the indoor units on system 4 were cooling the office areas throughout the whole working day. Based on the data for this system on this day we were able to derive a COP of over 6.00 showing that it was working in a highly efficient manner even though no heat recovery to took place between the indoor units on this system on this particular day.

Appendices 7.0

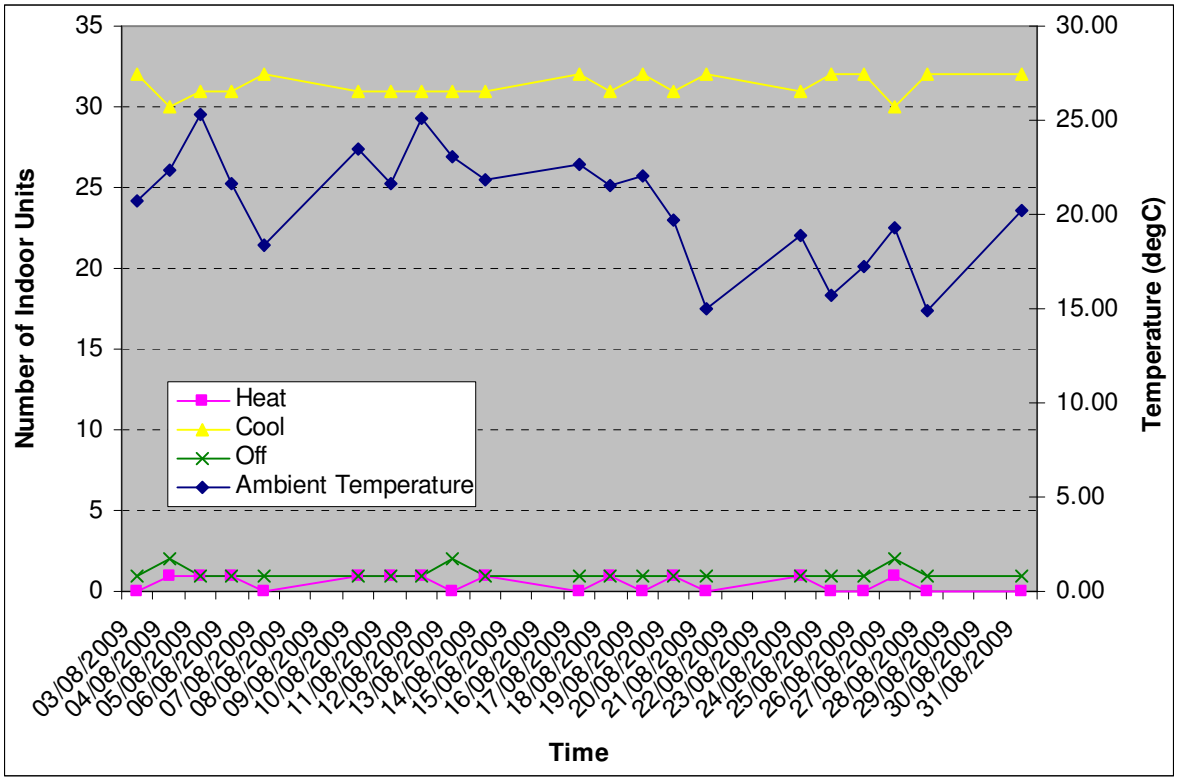
August Overview – Whole Building

Watercooled Units



Average ambient temperatures were still relatively high for the first half of the month between 20 and 25degC. After the 20th August the average daily ambient temperatures decreased for the rest of the month and ranged from 15 to 20degC. The inlet water temperature had a similar pattern and was higher at the beginning of the month at around 20 to 23degC. As ambient temperatures dropped later in the month the average inlet water temperatures dropped down to approximately 18 to 21degC indicating that the ground temperatures were able to recover slightly as less heat energy was dissipated into it. The total power consumption across the 6 system per day varied between approximately 220kWh and 370kWh per day. This suggests that the units were working at part load to meet the building's heating and cooling demands therefore were working in a highly efficient manner. The cost of running the system to heat and cool the building during this month was calculated to be approximately £625.

Indoor Units

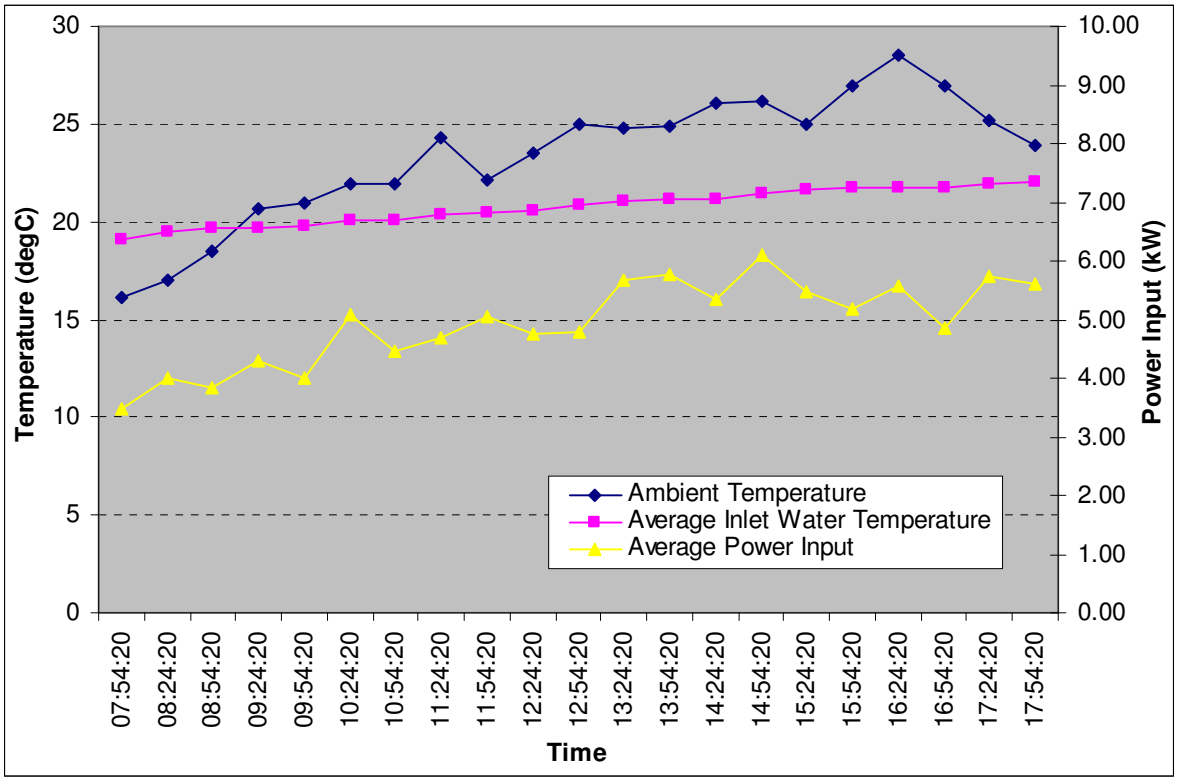


At least 30 of the 33 indoor units were in cooling mode at any one time on this day as is expected with ambient temperatures nearly as high as 30degC at the beginning of the month. The rest of the indoors were switched off with one unit occasionally in heating mode. The system as a whole worked in an efficient manner however the COP was not as high as it could be as little or no heat recovery was taking place on this day between indoor units.

27th August 2009 – Whole Building

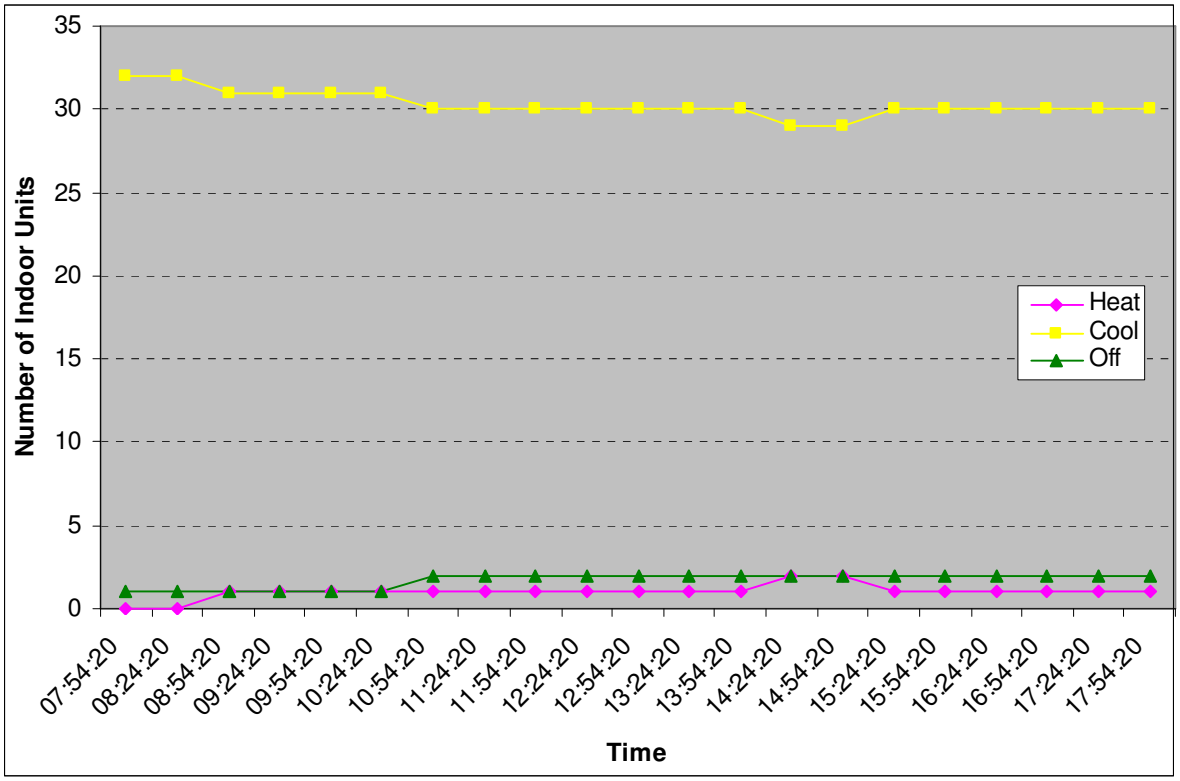
Taking a look at a typical day in August we find the following results:

Watercooled Units



This day in August saw an increase in ambient temperatures as the day progressed from around 16degC at the start of the day to a high of 28degC at just after 4pm. As the day went on the inlet water temperature increased from approximately 19degC to 22degC indicating the ground temperature heated up as the building was cooled. The average power consumption also saw a general increase across the day ranging from around 3.5kW to 6kW per condenser.

Indoor Units

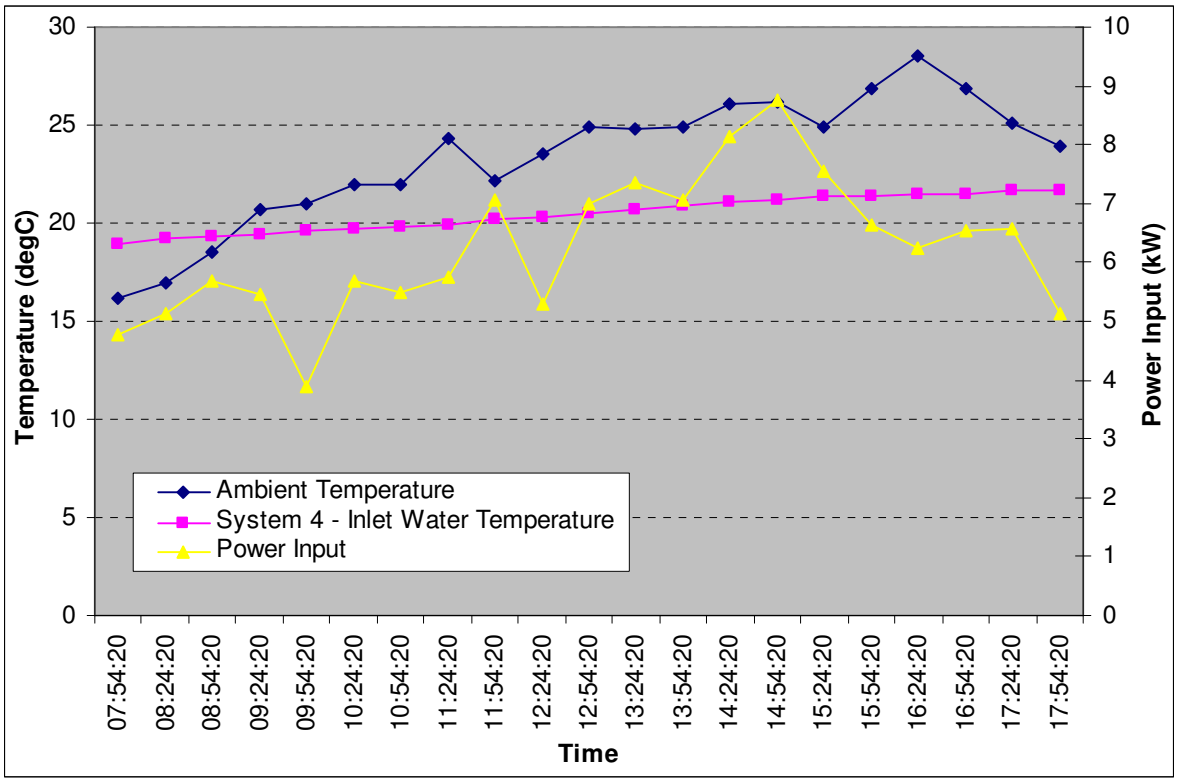


The indoor units reflect the behaviour of the watercooled units and at least 29 out of the 33 units were in cooling mode at any one time during the day. The rest of the units were in heating mode or switched off. Very little or no heat recovery took place between indoors on this day.

27th August 2009 – System 4

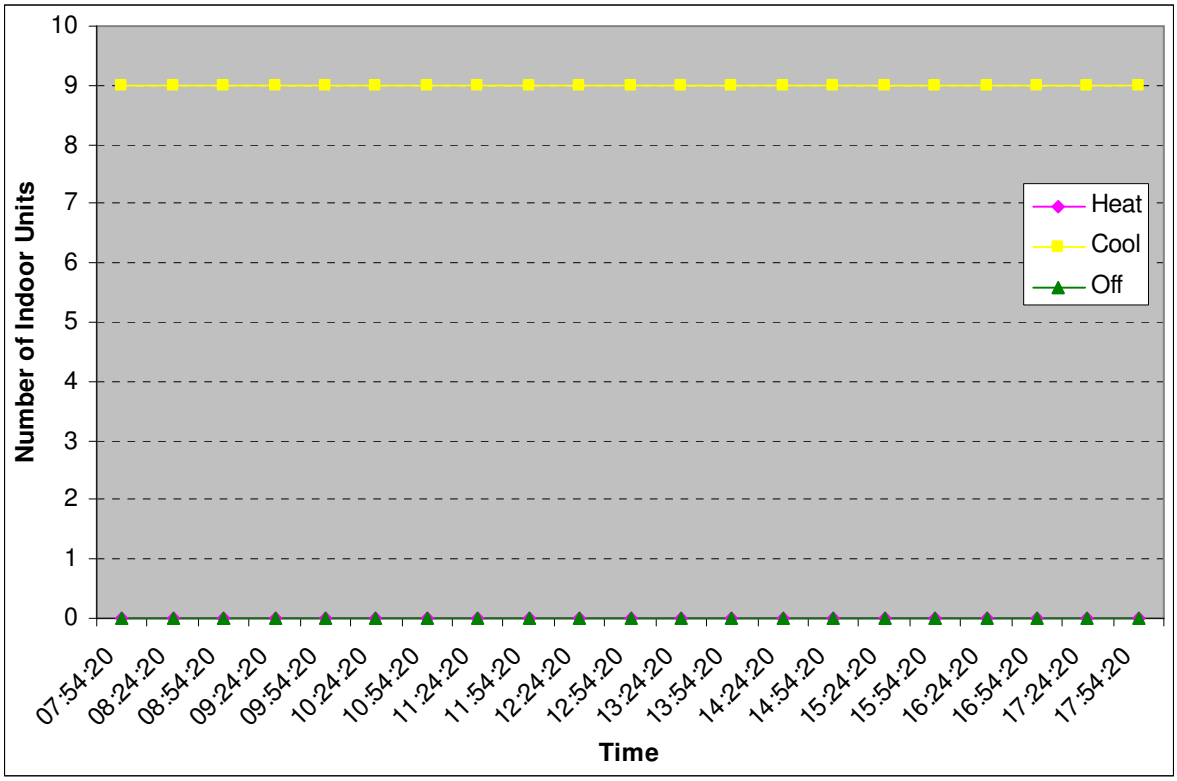
Taking this a step further we look at a specific system on a specific day in August. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



As the ambient temperature increased from around 16degC at the start of the day to above 25degC by the afternoon there was an increase in average inlet water temperatures from approximately 19degC to 22degC indicating that the ground was warmed up by rejected heat energy from the water loop. The average power input ranged from 3.9kW to 8.8kW but showed a general increasing trend for most of the day that indicates the condensing unit was working harder to provide a suitable internal environment.

Indoor Units

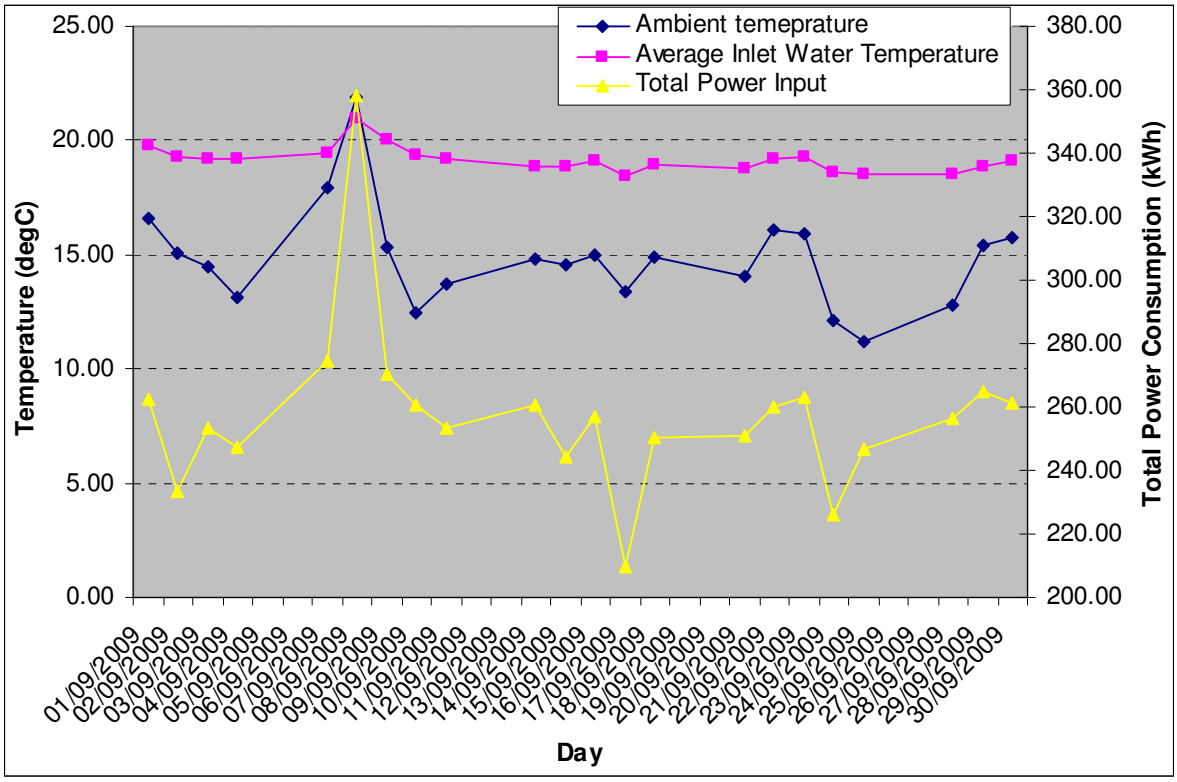


All 9 indoor units within the office space were in cooling mode throughout the day. Using this information we were able to derive a COP for this system of over 6.50 highlighting that the office areas were being cooled in a very efficient way even when no heat recovery was occurring between indoor units.

Appendices 8.0

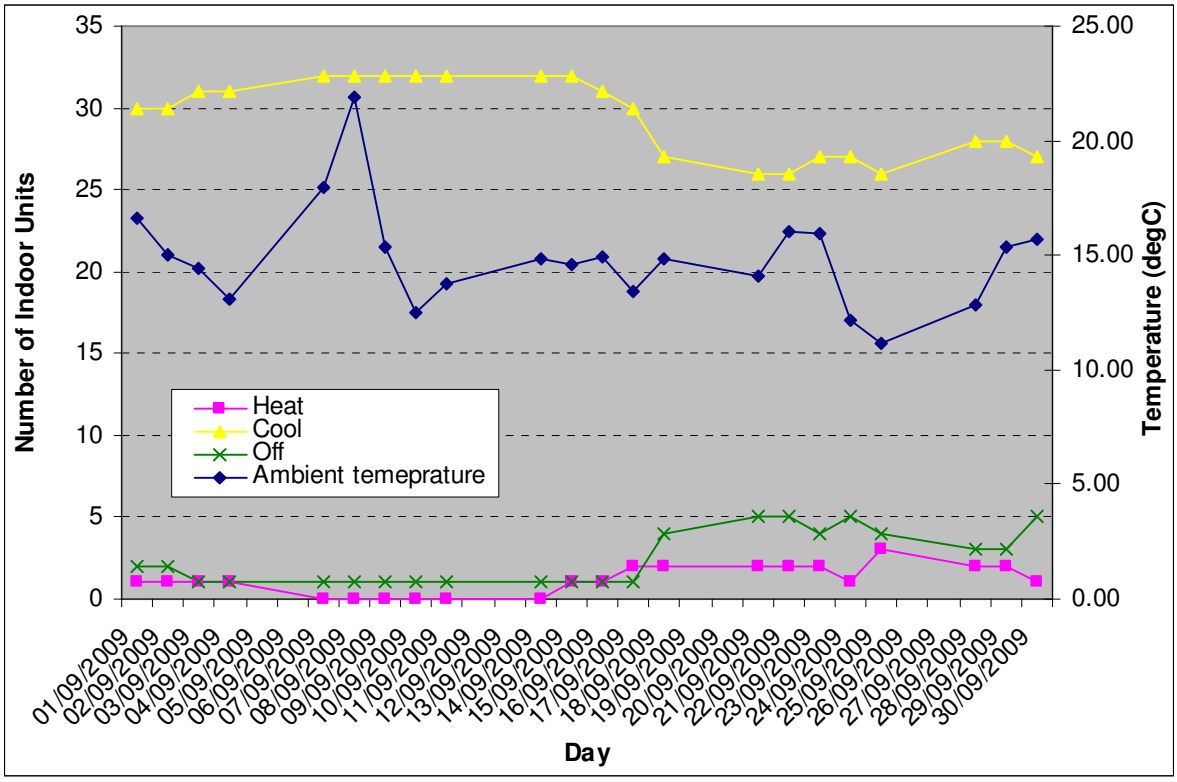
September Overview – Whole Building

Watercooled Units



Average ambient temperatures varied from 11degC to 22degC which was lower than August when temperatures were reaching an average of 25degC on some days. September 8th was the warmest day of the month averaging 22degC and the average inlet water temperature of the watercooled units peaked on this day at around 21degC. This is as expected as the ambient temperature was high the building demanded cooling and therefore the ground temperature increased therefore increasing the inlet water temperature. The total power consumption across all 6 units also peaked on this day at approximately 358kWh per day demonstrating that the units were working harder to meet the cooling demand. For the rest of the month the average inlet water temperatures and the total power consumption tracked the ambient changes as expected suggesting that changes in the ambient were affecting the indoor environment. The cost of running the system to heat and cool the building during this month was calculated to be approximately £566.

Indoor Units

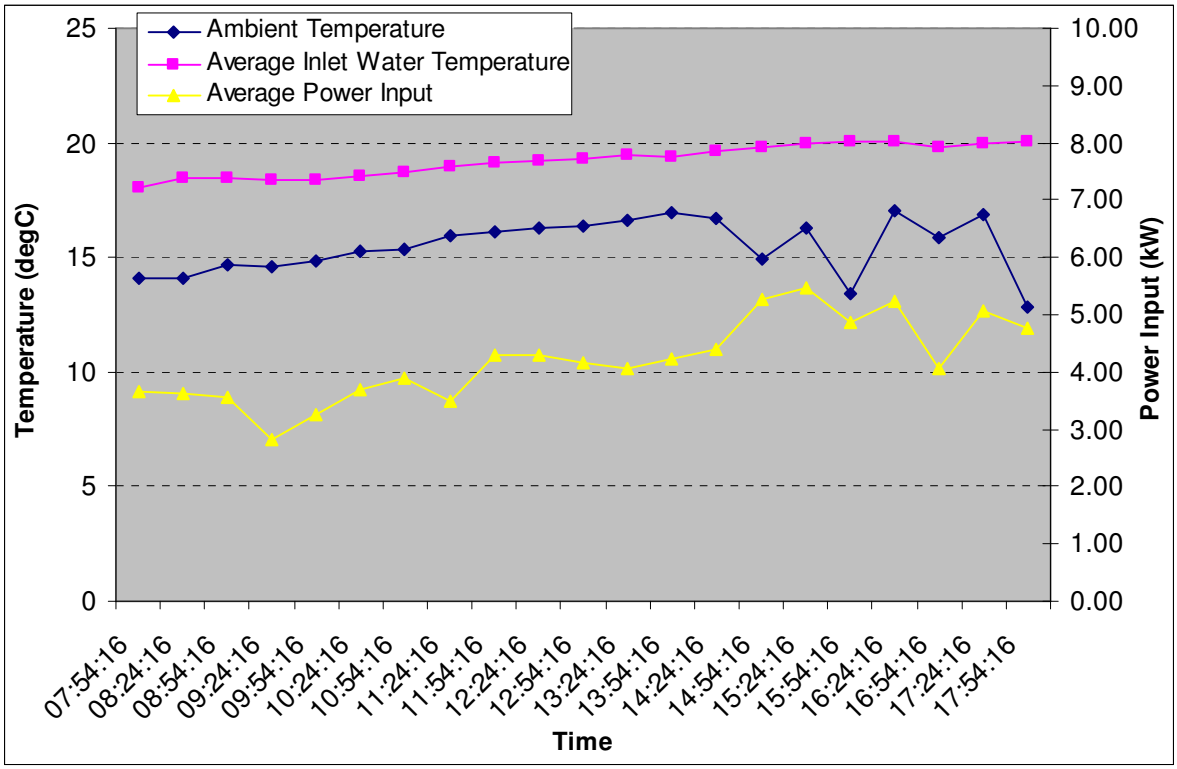


With ambient conditions still relatively moderate between 11degC and 22degC the building required cooling mostly however there was an increase in indoor units that were switched off or in heating at the end of the month as outside air temperatures dropped. The building material also retained heat energy throughout June, July and August when ambient temperatures were higher therefore insulating the building for September as well explaining the high demand of cooling. Towards the end of the month there was a little bit of heat recovery between indoor units therefore system efficiency was increased.

3rd September 2009 – Whole Building

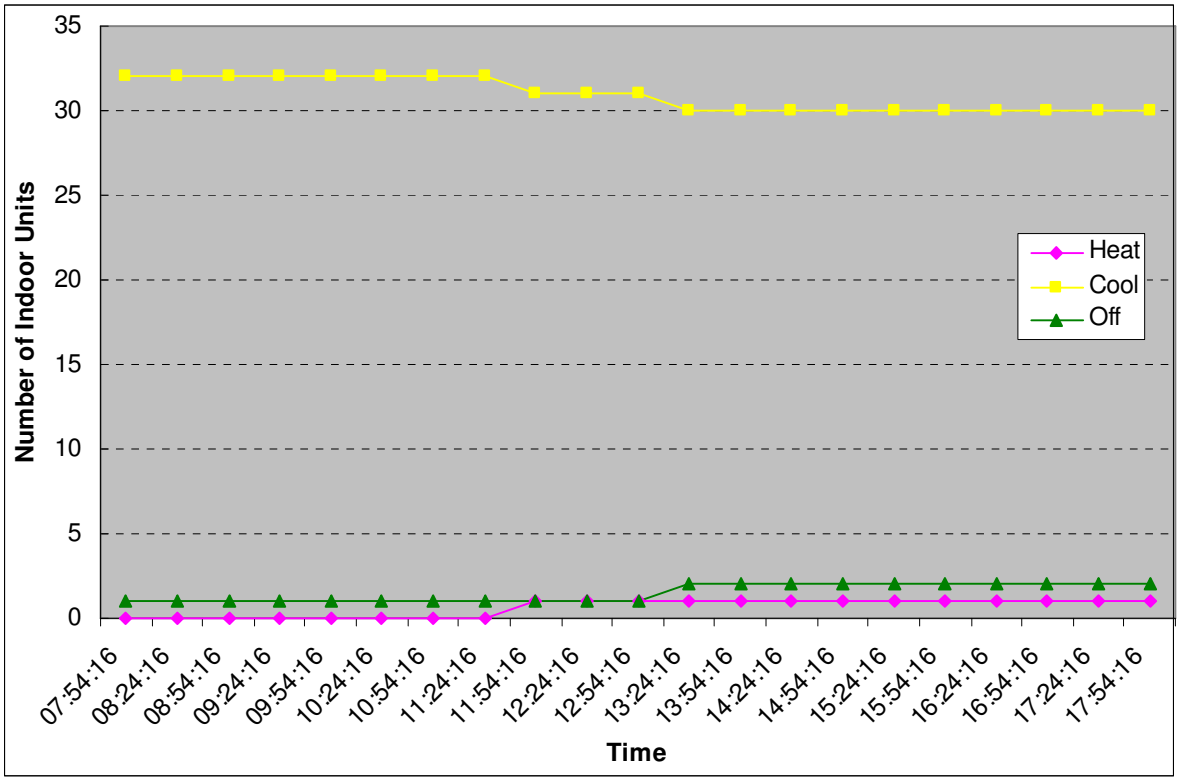
Taking a look at a typical day in September we find the following results:

Watercooled Units



The ambient temperature generally increased throughout the working day to a maximum of 17degC. The steady increase in inlet water temperature from around 18degC to 20degC indicates that the ground warmed throughout the course of the day suggesting that the building was being cooled. This is further reflected in the increase in power consumption of the watercooled units demonstrating that the systems were working slightly harder as the day went on. Average power input data on the day ranged from 2.8kW to 5.5kW per condenser which on the whole was lower than seen in August (3.5kW to 6kW per condenser) indicating the units were working less and at partial load therefore increasing efficiency more.

Indoor Units

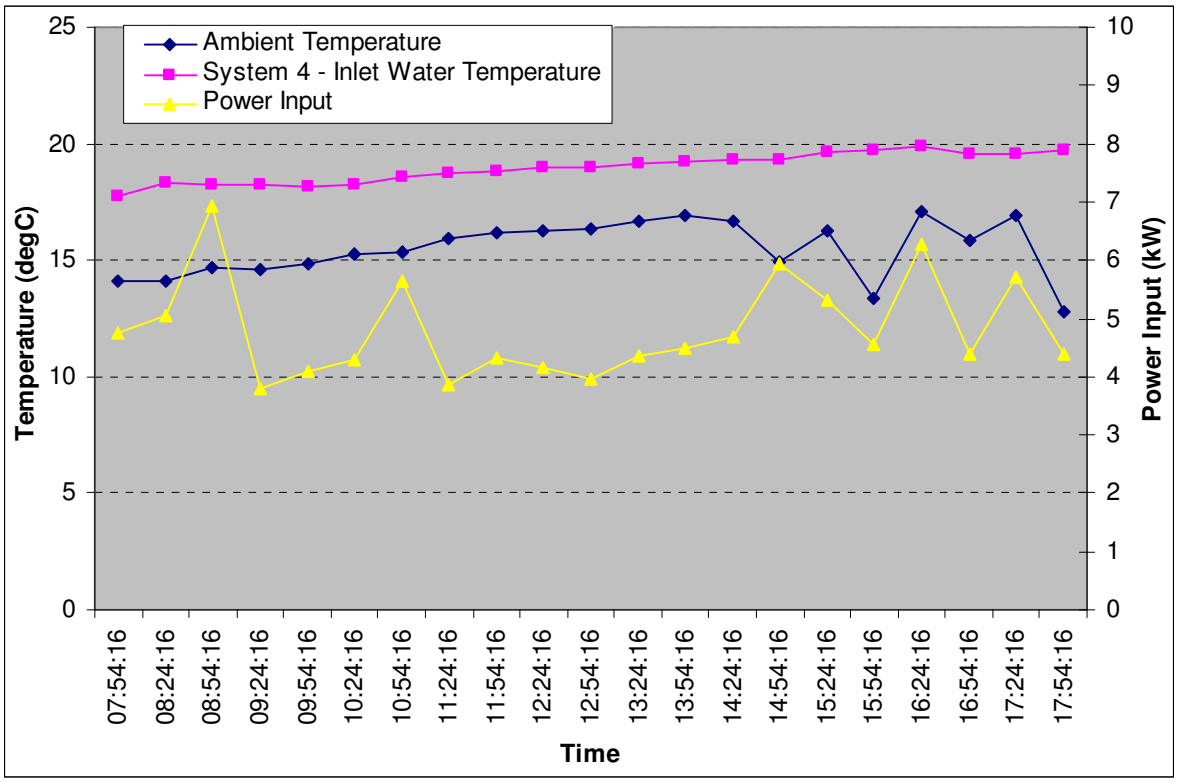


At least 30 of the 33 indoor units were in cooling mode at any one time on this day therefore very little or no heat recovery occurred as only 1 indoor unit was in heating mode from midday onwards however this did not compromise the efficiency of the system.

3rd September 2009 – System 4

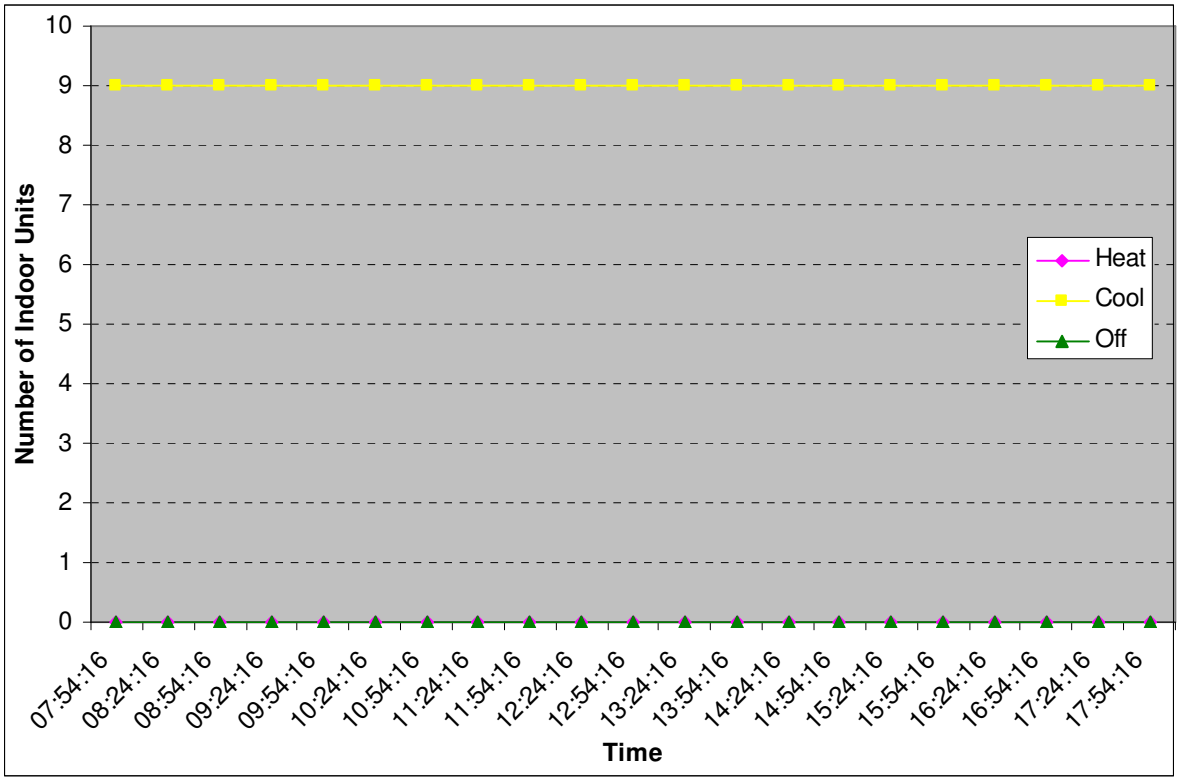
Taking this a step further we look at a specific system on a specific day in September. System 4 has 9 indoor units running all of which are located in office areas. The results obtained were as below:

Watercooled Unit



System 4 on this particular day worked to cool the office areas as the ambient temperatures were averaging around 15degC. The inlet water temperatures increased from around 17.7degC to 19.7degC suggesting that the ground had heated up slightly due to excess heat energy being rejected into it from the water loop. The power input of the system ranged from 3.8kW to around 7kW across the day.

Indoor Units



All of the indoor units on system 4 were in cooling mode providing cooling to the office areas. Based on this we are able to derive a COP of over 5.00 for this system on this particular day showing that the efficiency still remained high even when no heat recovery was taking place.