Ground Source Case Study

The Castle Course Golf Course 6

St Andrews Links Trust

Contents Page

Introduction

St Andrews Links Trust, the management organisation for the Old Course and associated golf courses, decided to build a new golf course (called the Castle Course) to cater for the increasing demand for top quality golf facilities in the area.

St Andrews Links Trust wanted to heat and cool their new build club house in a highly efficient manner and therefore chose a Mitsubishi Electric Watercooled Ground Source Heat Recovery system.

The location of the club house and surrounding acres of land made it ideal for a ground source heat pump solution. The requirement for providing simultaneous heating and cooling to the building in a highly efficient manner also further enhanced the suitability of installing a watercooled ground source VRF heat recovery system.

The club house is a circular design with glazing around most of the façade to make the most of the panoramic views of the golf course and the coast. The extensive glazing had created problems with overheating which prompted the client to install an air conditioning system to provide a comfortable internal environment for visitors. The fact that the building is located on an exposed high cliff head and open to the North Sea elements prompted the client to install an underfloor heating system as well.

The features of the club house are:

~ total floor space of approximately 1100m^2
~ large constant cooling load for the kitchens
~ regular heating load required for the changing rooms
~ a large domed glass ceiling in the shop area which acts as a 'Greenhouse' even at cooler temperatures

The table below shows the approximate club house opening hours.

Month	Opening hour
April	6am-7pm
May	6am-8pm
June	6am-10pm
July	6am-10pm
August	6am-9pm
September	6am-7pm

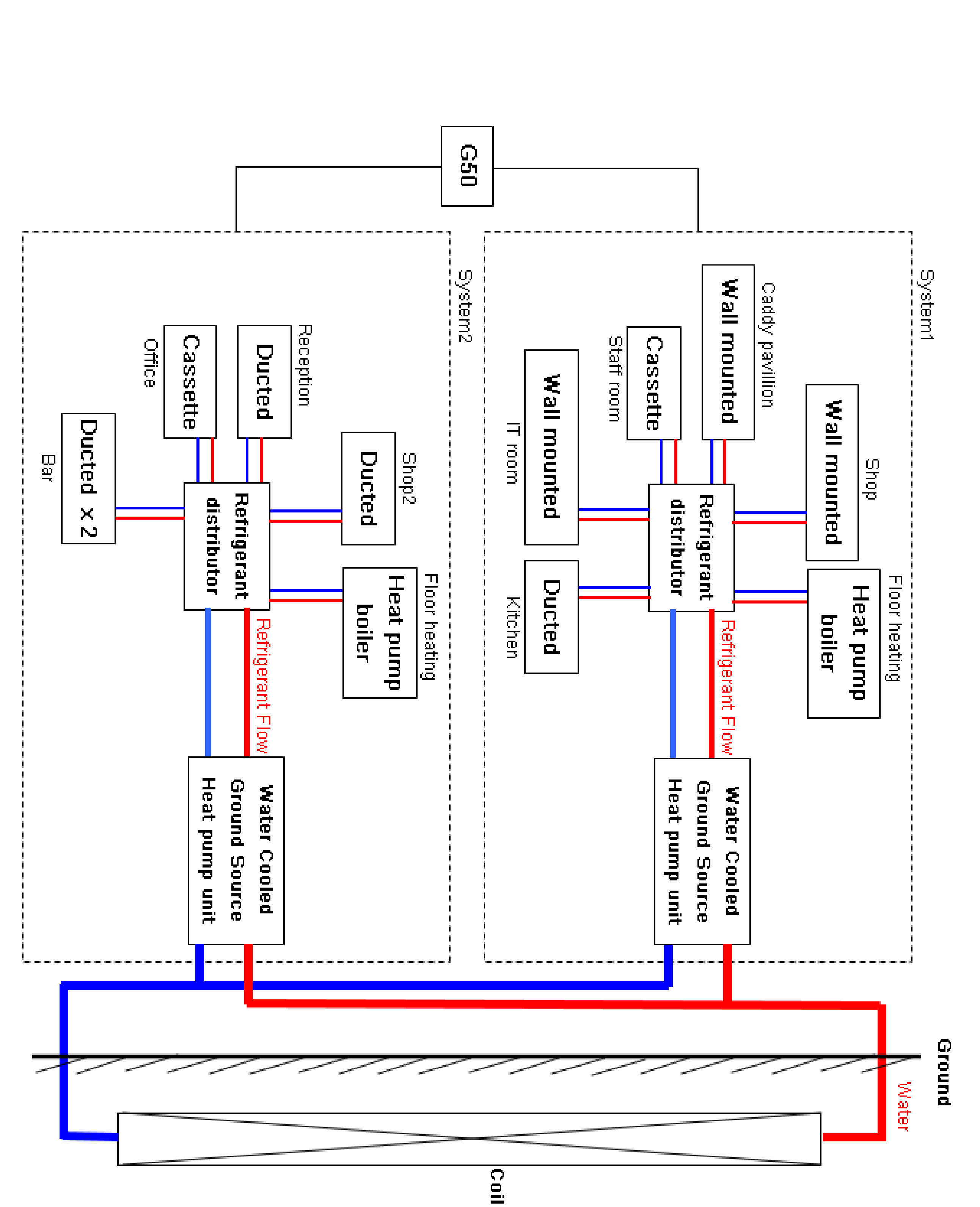
Data was monitored 24 hours a day, seven days a week however this case study focuses on the opening hours during open season only.

Overview

This report details the installation, monitoring and analysis of the two Mitsubishi Electric WR2 Water Cooled Variable Refrigerant Flow (VRF) condensing units used in conjunction with a closed loop ground array buried under the driving range.

The diagram on the following page shows a brief system configuration. In both system 1 and system 2 a watercooled ground source heat pump unit is connected to 6 indoor units one of which is a PQFY heat pump boiler which serves the underfloor heating system. Power consumption is measured for each system. With information from measured inlet air temperatures of all indoor units are measured and with the running mode data logged for each indoor unit we are able to determine whether each unit is running or not and whether it is cooling or heating at any given time.

The system running data was monitored and logged using 2 Maxi M2M (Machine to Machine) GPRS remote management interfaces.



The above diagram demonstrates when the system is in heating main.

Capacity	System1						System2				
	Underfloor heating	Kitchen	IT Room	Staff Room	Caddy Pavillion	Shop	Underfloor heating	Bar	Office	Reception	Shop 2
Heating	25kW	12.5kW	4.0kW	3.2kW	4.0kW	10.0kW	25kW	20kW	2.5kW	10.0kW	6.3kW
Cooling	-	11.2kW	3.6kW	2.8kW	3.6kW	9.0kW	-	18kW	2.2kW	9.0kW	5.6kW

The table above shows nominal heating and cooling capacity of each indoor unit. The total nominal heating capacity of all the indoor units is 122.5kW, and total nominal cooling capacity is 65kW.

<u>Note:</u> The indoor unit in the staff room was not working throughout the period of analysis.

This report details monthly ambient temperatures and operational data for the ground source watercooled heat pump units as well as the indoor units. The report concludes by looking at monthly system efficiencies, total running costs and CO_2 emissions.

<u>Kit List</u>

• 2 x PQRY-P400YGM-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

• 2 x PQFY-P250 (provides hot water to underfloor heating system)
- 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

• 1 x PLFY-P20VCM-E (indoor Unit)
- 4 Way Cassette Unit
- Capacity (Cooling nominal) 2.2 kW
- Power input (Cooling nominal) 0.05 kW
- Noise Level 28 to 35dBA

• 1 x PLFY-P25VCM-E (indoor Unit)
- 4 Way Cassette Unit
- Capacity (Cooling nominal) 2.8 kW
- Power input (Cooling nominal) 0.05 kW
- Noise Level 28 to 37dBA

• 4 x PEFY-P80-VMM-E (Indoor units)
- Ceiling Concealed Ducted Unit
- Capacity (Cooling nominal) 9.0 kW
- Power input (Cooling nominal) 0.25 kW
- Noise Level 32 to 39dBA

• 2 x PKFY-P32-VGM-E (Indoor units)
- Wall Mounted Unit
- Capacity (Cooling nominal) 3.6 kW
- Power input (Cooling nominal) 0.07 kW
- Noise Level 33 to 41dBA

• 2 x PEFY-P100-VMM-E (Indoor units)
- Ceiling Concealed Ducted Unit
- Capacity (Cooling nominal) 11.2 kW
- Power input (Cooling nominal) 0.29 kW
- Noise Level 40 to 44dBA

• 1 x PEFY-P50-VMM-E (Indoor unit)
- Ceiling Concealed Ducted Unit
- Capacity (Cooling nominal) 5.6 kW
- Power input (Cooling nominal) 0.20 kW
- Noise Level 31 to 38dBA

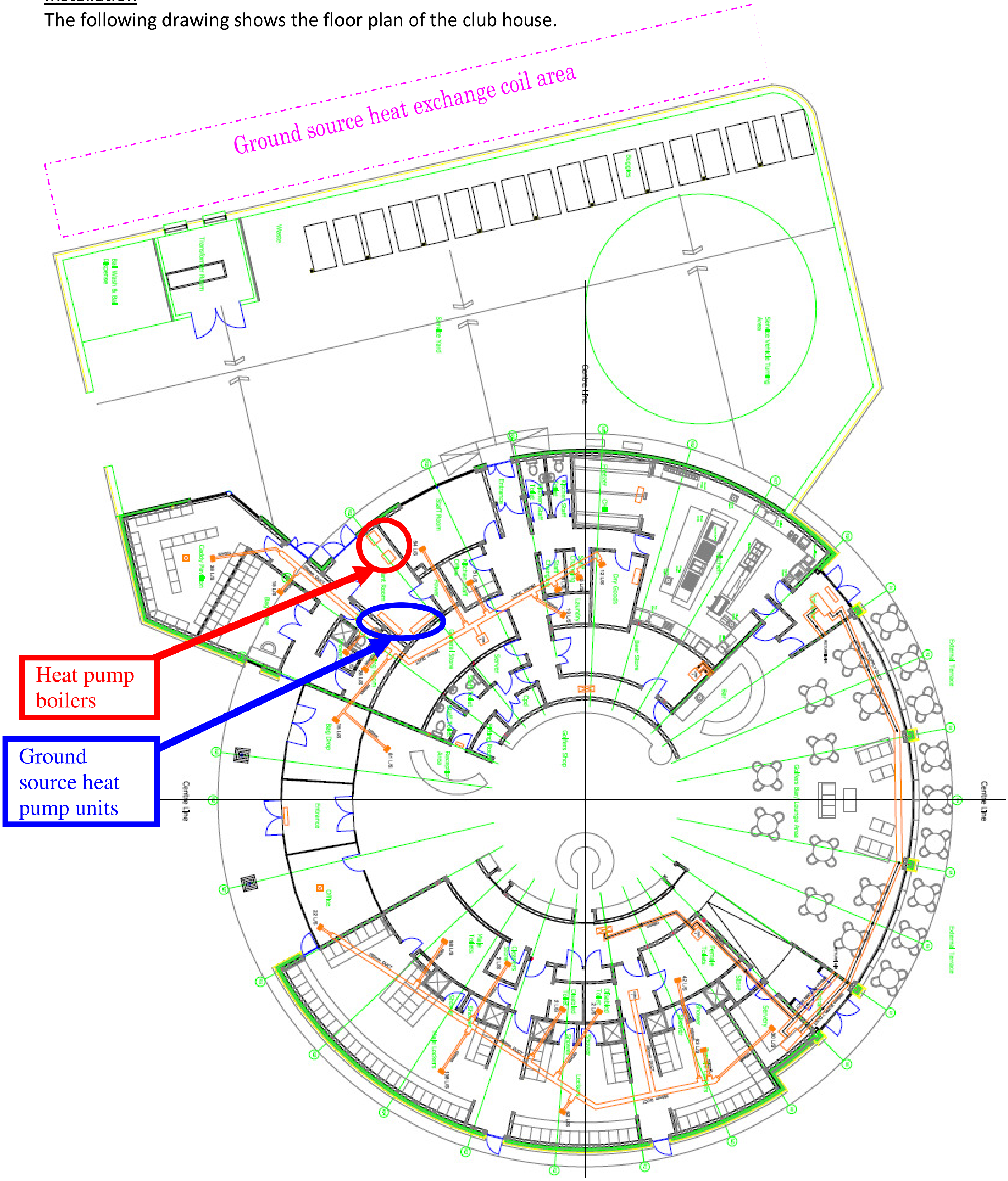
4 x LGH-100RX4 (Lossnay)
- Heat Recovery Ventilator
- Air Flow Rate 1000m3/h
- Power Input 0.49 kW
- Noise Level 37dBA

• 1 x G-50 (System Controller)
- Centralised Controller with Webserver Capabilities
- Dimensions (WxDxH) 300x79x120

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

Installation

The following drawing shows the floor plan of the club house.

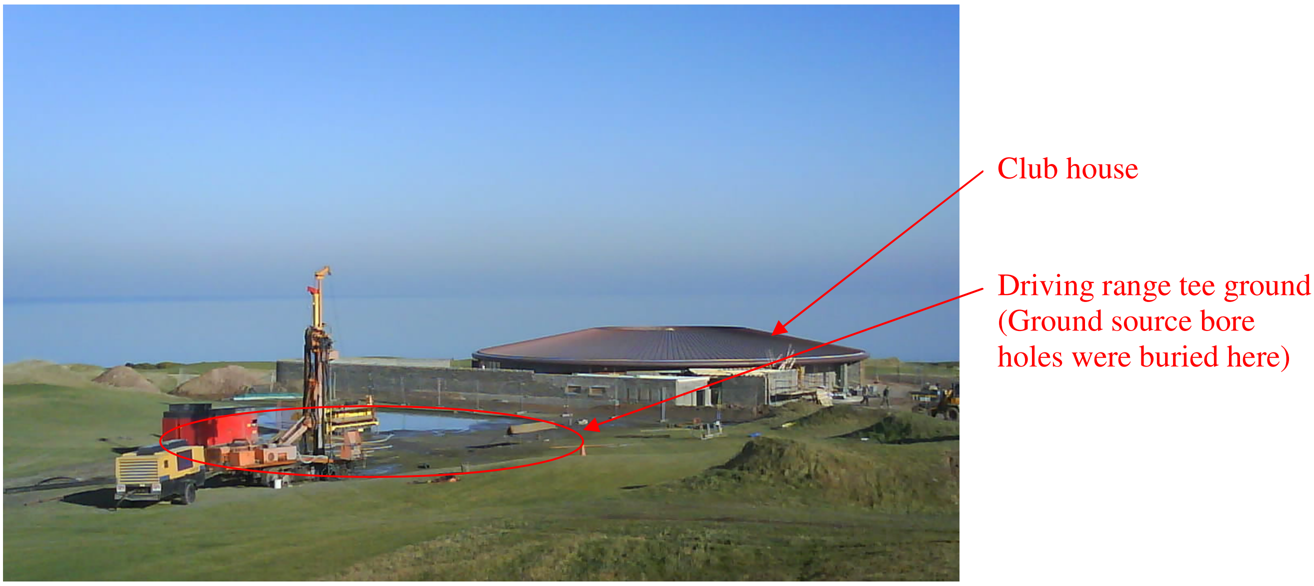


As St Andrews Links Trust had specified that high energy efficient technologies were to be used a ground source heat recovery system was installed in conjunction with a number of other technologies including heat pump boilers.

Ground source watercooled heat pump units and the PQFY VRF heat pump boiler units were installed in the plant room which faces the service yard. Background heating to the building is supplied via an underfloor heating system fed by the PQFY units with main heating and cooling via various ducted, wall mounted and cassette indoor units installed. Initially for the ground works slinky coils were considered however this was difficult to install as 1m below the ground was solid rock. It was decided therefore that a bore hole array was to be installed with 10 bores each 150m deep providing the heating and cooling to the building. The water in the ground source loops was mixed with glycol to prevent freezing during cooler ambient temperature conditions with high internal heating demands.

The equipment was designed and installed to provide 100% of the heating and cooling demand for the building.

The system was, installed and commissioned by Specialist Mechanical Services before being handed over to St Andrews Links Trust in July 2008 when the new golf course was opened to the public.



Ground source water cooled heat pump unit (PQRY)

VRF heat pump boiler units (PQFY)

VRF watercooled unit (PQRY)

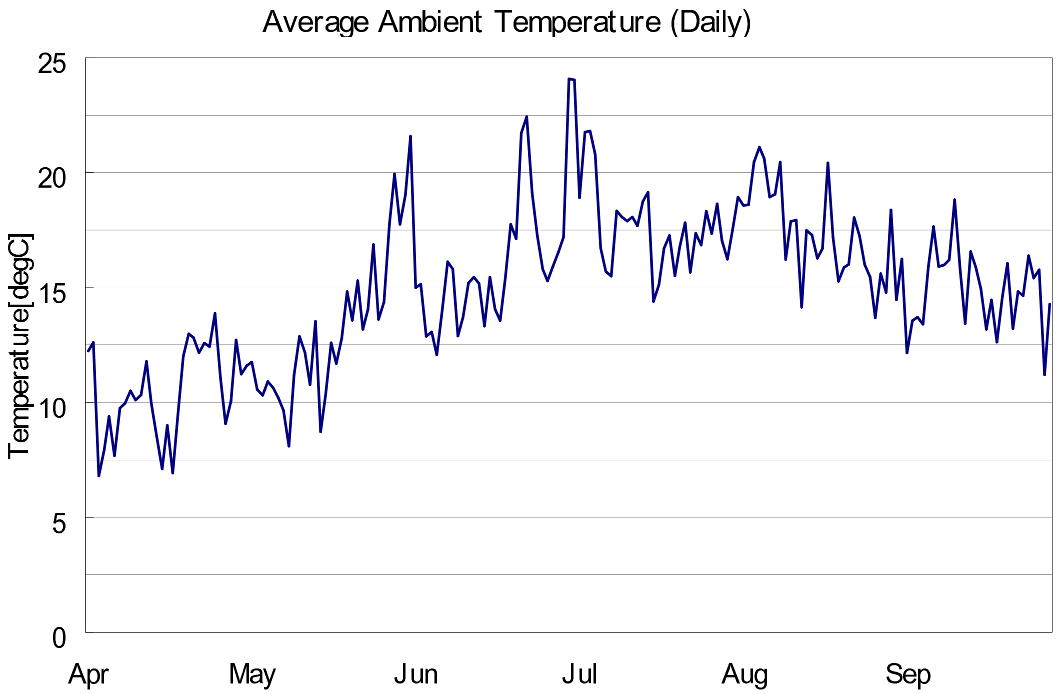
Underfloor heating manifold

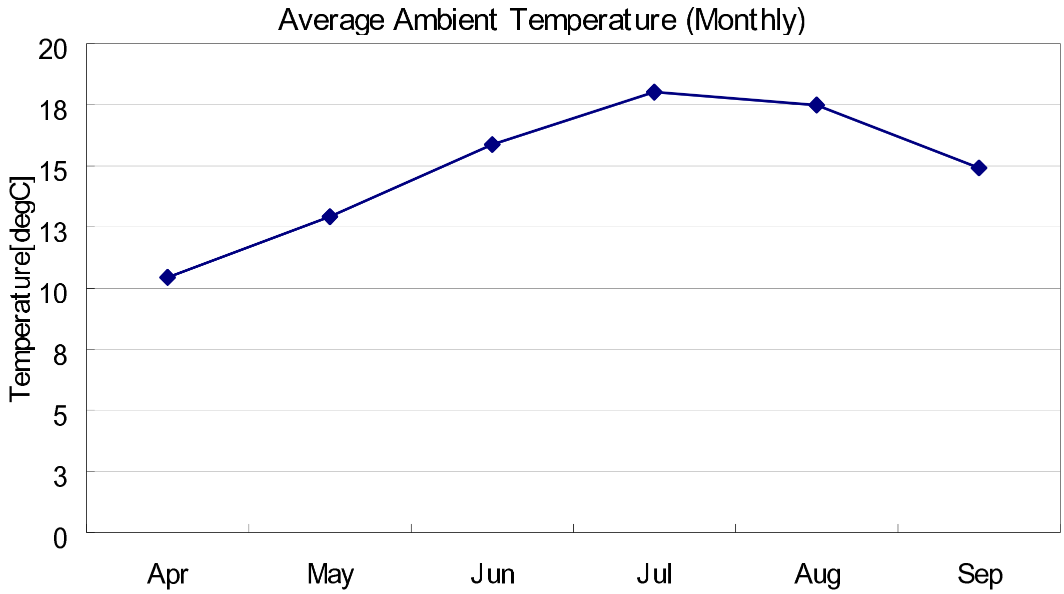
Logging & Data

Data was logged 24 hours a day, seven days a week from March 2009 until February 2010 using M2M remote monitoring interfaces. Only open season data during open hours was analysed for this case study report. The month of October falls into the open season (April-October) however there was large amounts of data missing for this month due to data logging issues and so information has not been included for October.

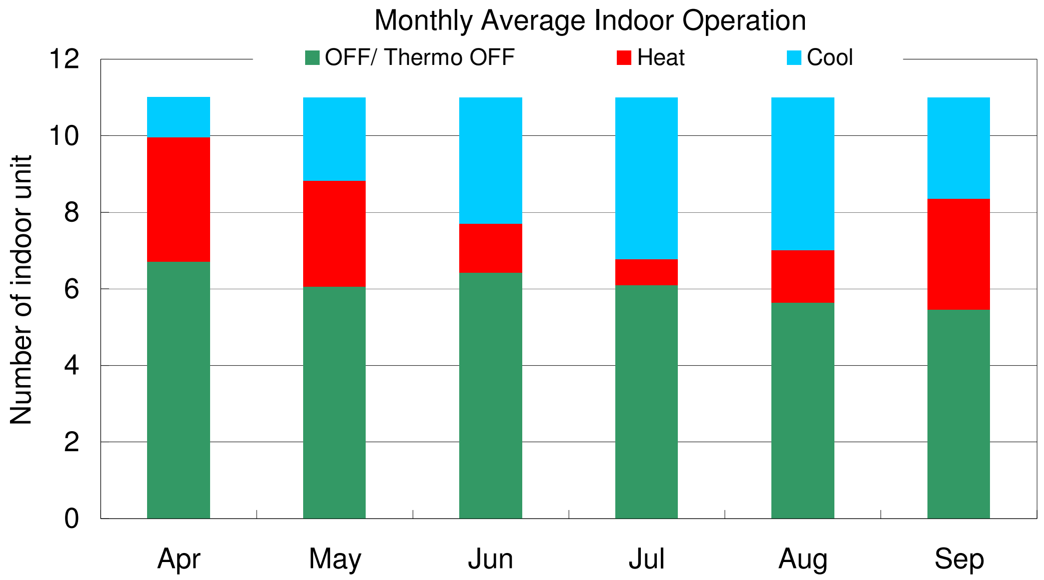
Results & Analysis

Taking a look at the ambient conditions over the 6 months we find the following:



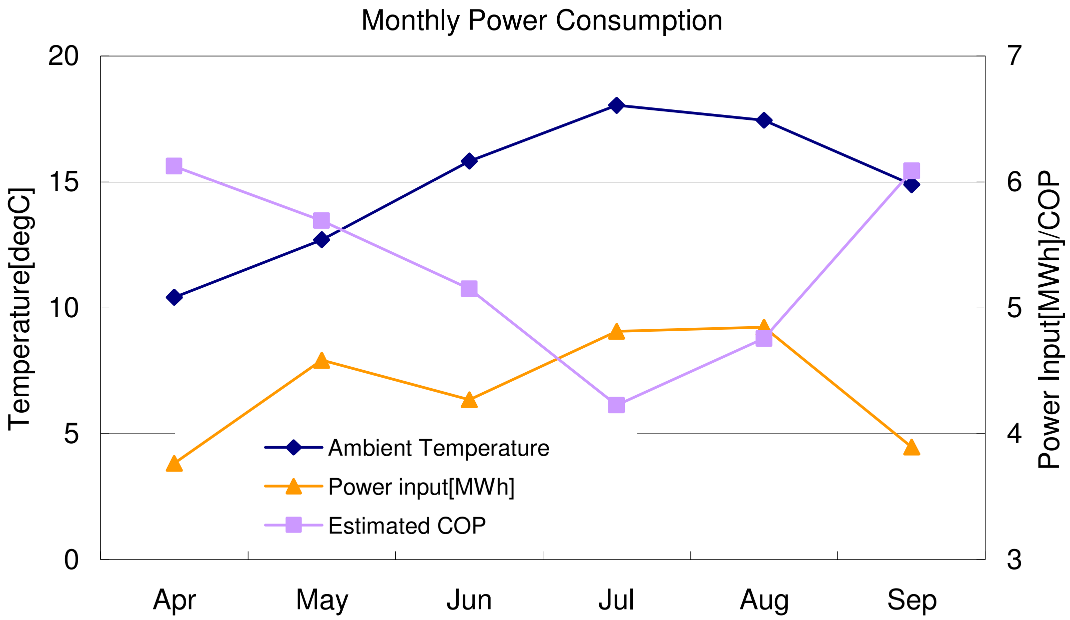


The graphs on the previous page show average daily and average monthly ambient temperatures during the opening hours of open season.
Both graphs show a typical trend in outside air temperature and as expected spring months show moderate temperatures between approximately 10degC and 15degC. Moving into the summer months the average ambient temperatures increase and peak in July and August at around 18degC. At the end of the summer as we move into autumn in September there is a typical decrease in ambient temperatures back down to approximately 15degC. Temperatures may seem a bit high for Scotland however this could be due to the ambient temperature sensor being too sheltered or being affected by solar gains.



The above graph is a guide of the heating and cooling demand that the club house required over the 6 months that were monitored and analysed. There are a large number of units that seem to be off however off here actually refers to thermo off and off.

<u>Monthly Power Consumption and Estimated COP</u>



Using the data analysed over the 6 months covered in this case study we were able to calculate monthly COP's for the entire system as shown in the graph above.

Looking at both of the graphs above April showed an average ambient temperature of around 10.4degC. Few indoor units were running and the majority of those that were running were providing heating to the building. There was also a small demand for cooling suggesting that there was a potential for heat recovery to take place. This, combined with the fact that few indoor units were running, allowed the systems to work at partial load, explaining the lowest power consumption for this month and the highest estimated system COP of 6.12.

As the average ambient temperature increased in May to around 12.7degC and the occupancy increased, the number of indoor units running increased as well explaining the increase in power consumption seen during this month compared to April. The club house showed a good balance of heating and cooling suggesting high rates of heat recovery were taking place as is reflected in the estimated system COP of approximately 5.69.

Overall power consumption in June was 4.3MWh. It was lower than that of May even though average ambient temperatures increased up to 15.8degC. This can potentially be explained in the higher demand for cooling rather than heating. With less heating required one or both of the PQFY heat pump boiler units were probably running at partial load to provide a pre-heated domestic hot water supply only therefore decreasing the amount of power needed to run the system and meet the buildings demand. The estimated efficiency of the system dropped to approximately 5.15 as less heat recovery would have occurred during this month given the main demand for cooling.

The average ambient temperature in July was 18degC, and was the highest of the 6 months analysed. On the other hand, the estimated system COP was the lowest at 4.23 as very little heat recovery took place during this month due to the high cooling demand, high ambient temperatures and high occupancy levels with very little heating required. The overall power consumption of the system was 4.8MWh.

The average ambient temperature for August was slightly lower than in July at 17.4degC. The overall power consumption was almost the same as July however the estimated system COP was higher than in July at approximately 4.76. This can be explained by the fact that of the indoor units that were running, more were in heating mode than in July suggesting that the potential for heat recovery taking place was higher therefore increasing system efficiency.

The overall power consumption in September was 3.9MWh, and the average ambient temperature was around 15degC. The estimated system COP was high over the 6 months at 6.09. During this month there was an almost perfect 50/50 balance in heating and cooling demand suggesting a high rate of heat recovery taking place increasing system efficiency. A large number of indoor units were also not running suggesting that the system was running at partial load further increasing the efficiency.

Conclusion

From six months of analysis it is clear that the ground source systems installed at this site were highly efficient and more than 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 i.e. during May and September. However, even when heat recovery was not occurring the ground source system was still able to produce a very high system COP.

	Average Ambient Temperature(°C)	Heat	Cool	OFF	System COP	Power input (kWh)
April	10.4	33%	10%	57%	6.12	3765
May	12.7	28%	22%	51%	5.69	4584
June	15.8	13%	33%	54%	5.15	4271
July	18.0	7%	42%	51%	4.23	4814
August	17.4	14%	40%	46%	4.76	4847
September	14.9	29%	26%	44%	6.09	3895
					Total	26177

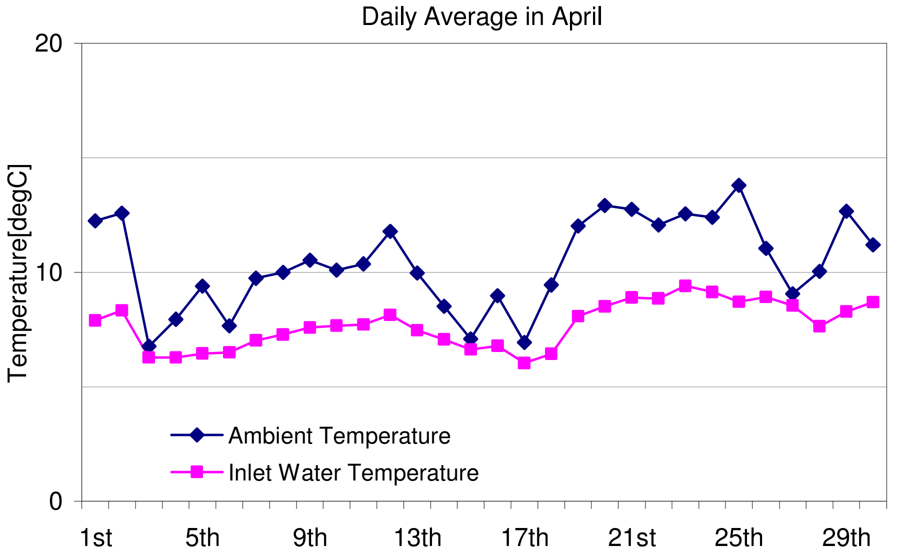
Based on the system COP data for each month we can calculate an average system COP over the 6 months of 5.34 which demonstrates a highly efficient system being used to its full potential in this difficult application of large window area and a harsh outdoor environment.

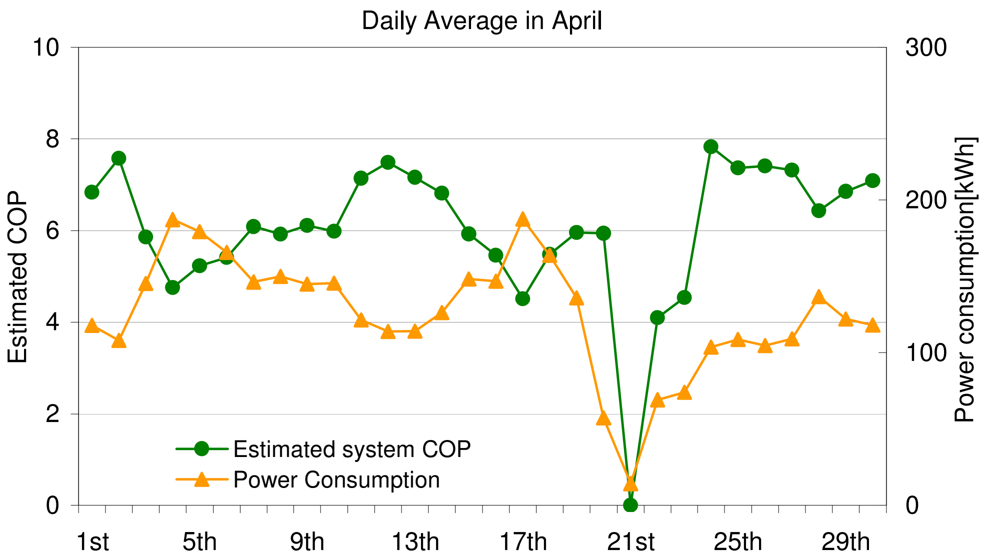
The ground source system installed currently showed running costs over the 6 months of **£2,618** and CO_2 emissions over the same period of 11,256kg. In comparison a chiller/ boiler combination that would be required to satisfy the heating and cooling demands of the building over the 6 months would produce running costs of £5,356 and CO_2 emissions of 24,110kg. This equates to a 51% reduction in running costs of the ground source system compared to the chiller/boiler combination as well as a 53% decrease in CO_2 emissions. Taking this a step further the cost per m^2 to heat and cool the building over the 6 month period using the installed ground source system was £2.38/m^2.

The case study demonstrates that the installed Mitsubishi Electric ground source system achieved the following during opening hours in open season:

~ **Monthly COP's of between 4.23 and 6.12.**
~ **Running costs of £2,618 over the 6 month period**
~ **CO_2 emissions of 11,256kg for the 6 month period.**
~ **Cost of £2.38 per m^2 to heat and cool the building over 6 months**
~ **A 51% reduction in running costs when compared to a typical chiller/ boiler combination**
~ **A 53% reduction in CO_2 emissions when compared to a typical chiller/ boiler combination**

<u>Appendices 1.0 April Overview – Whole Building</u>

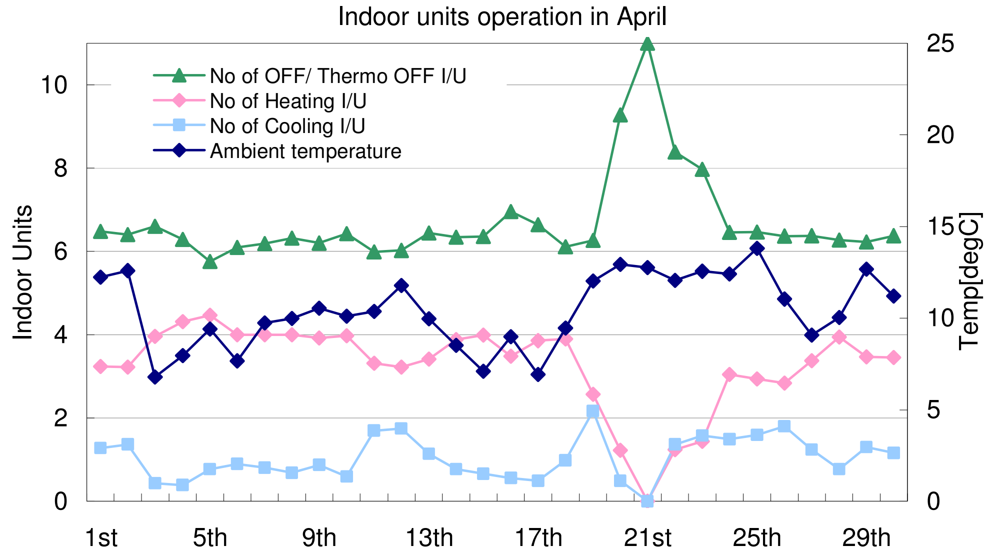




The graph on the top shows daily averages for ambient temperature and inlet water temperature for the ground source units in April. The graph on the bottom shows the daily power consumption and total system COP during opening hours.

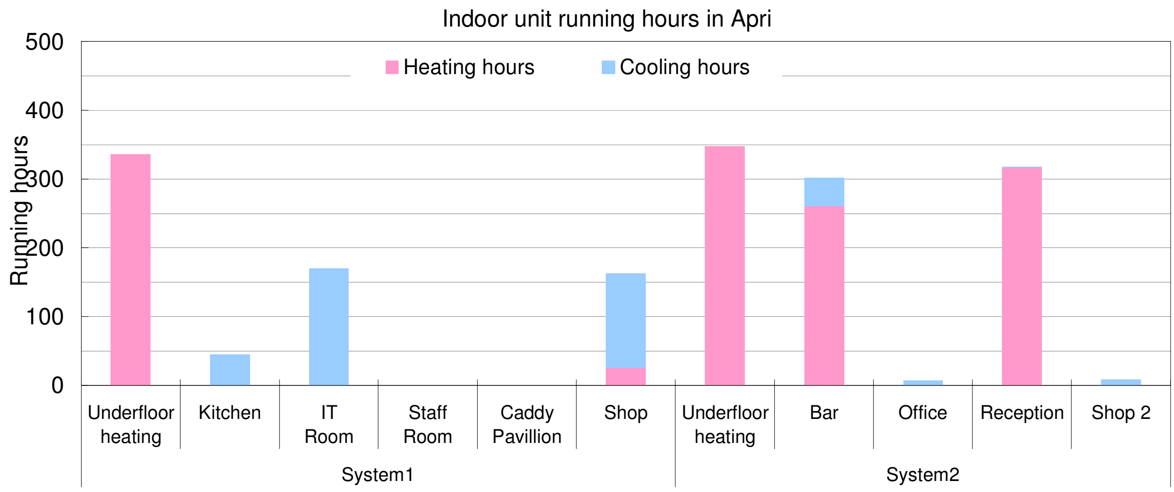
Average ambient temperatures ranged between 6degC and 13degC. The inlet water temperature of the watercooled units ranged between around 6degC and 9degC and showed a general increase in temperature as the ambient temperature increased however the system was mainly heating therefore the inlet water temperature was not as expected. Potential large amounts of rainfall may have allowed the ground to recoup its heat energy therefore explaining the increase in ground temperature. The daily power consumption was approximately 100kWh to 200kWh suggesting that the system was working at partial load therefore increasing the efficiency. The daily average total system COP ranged between 4 and 8 portraying a highly efficient system. The system does not seem to be running on the 21^{st} possibly due to system servicing, with all of the indoor units turned off and system power consumption at 0. The cost of running the system to heat and cool the building during this month was calculated to be approximately £377 and the CO_2 emissions were estimated at 1,619kg.

.Indoor Units



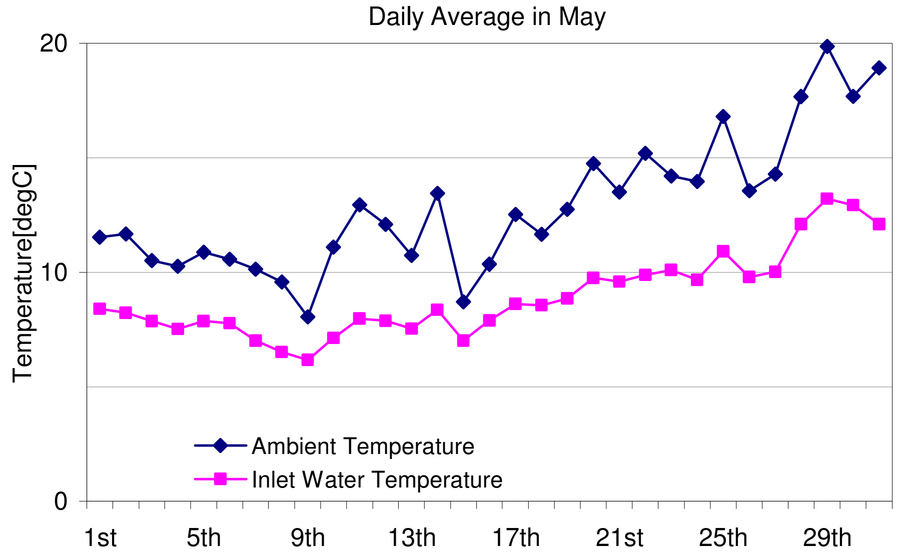
The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in April.

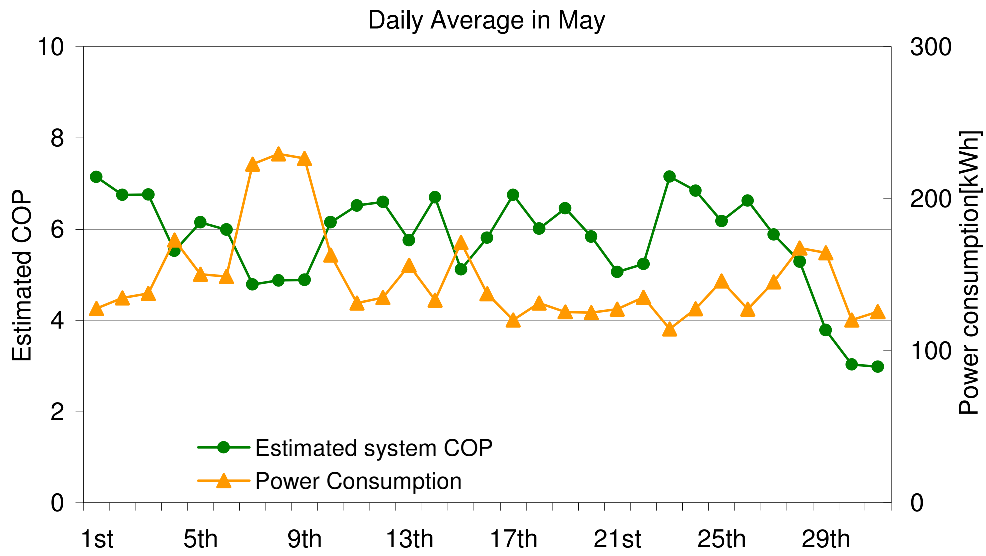
The number of indoor units that were off on any one day during this month was 6. Of the units that were running the majority were in heating over the month between 1 and 2 indoor units providing cooling as is expected with ambient temperatures between approximately 7degC and 11degC. Some heat recovery could potentially have occurred with this balance of heating and cooling demand.



The graph above shows heating and cooling running hours of each indoor unit during opening hours. The main demand for cooling was in the IT room and the shop area where there is a high window area. There is a main cooling demand in the kitchen as well however we would normally expect the demand to be higher but the Lossnay unit takes some of the load therefore decreasing the cooling required from the air conditioning system. The indoor unit in the caddy pavilion was always off/ thermo off. There was a high heating demand in the bar area and in the reception where the doors are constantly open therefore requires high heating loads. The balance of heating and cooling load in system 1 seemed to be more balanced than in system 2, which showed a high heating demand, suggesting that heat recovery was more likely to take place within units in system 1.

Appendices 2.0 May Overview – Whole Building

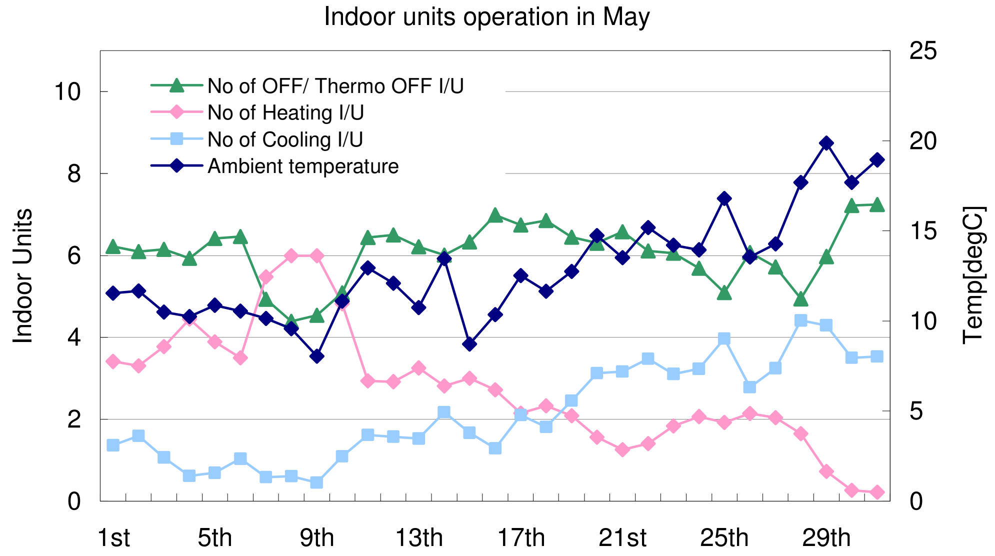




The top graph shows daily averages for ambient temperature and inlet water temperature for the ground source units in May. The graph on the bottom shows the daily power consumption and total system COP during opening hours.

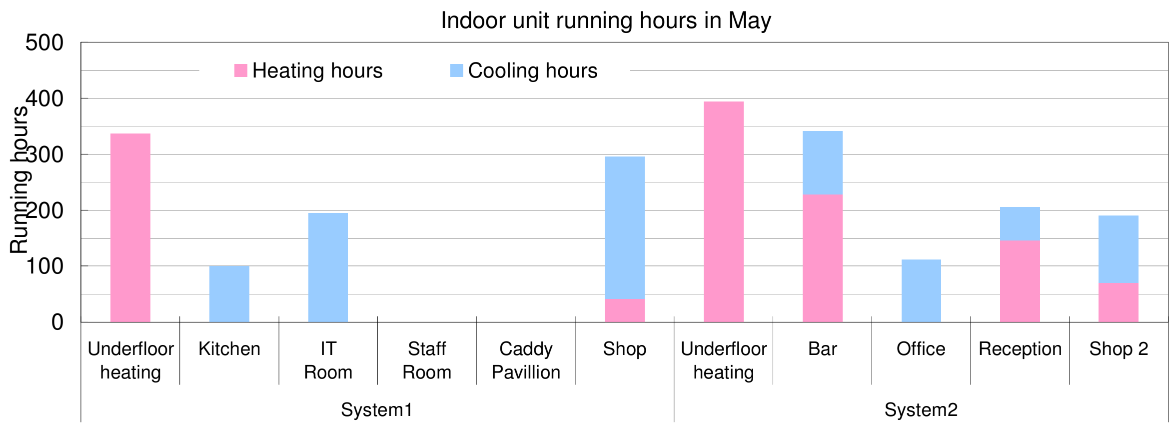
Taking a look at May the average ambient showed a general increasing trend over the month from approximately 10degC up to around 17degC at the end of the month. The average inlet water temperature seemed to follow the increasing trend of the ambient temperature as well suggesting that more cooling was required therefore more heat energy was rejected to the ground. The total power consumption ranged between approximately 120kWh to 220kWh per day and the average total system COP was estimated to be between approximately 3.50 and 7.50 on any given day in May, The efficiency of the system seems to drop at the end of the month and this could be due to the bank holiday weekend. With ambient temperatures relatively high over this weekend the occupancy levels would have increased therefore increasing the demand for cooling. Little heat recovery occurred over this period of time. The cost of running the system to heat and cool the building during opening hours this month was calculated to be approximately £458 and the CO_2 emissions were estimated at 1,971kg.

Indoor Units



The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in May.

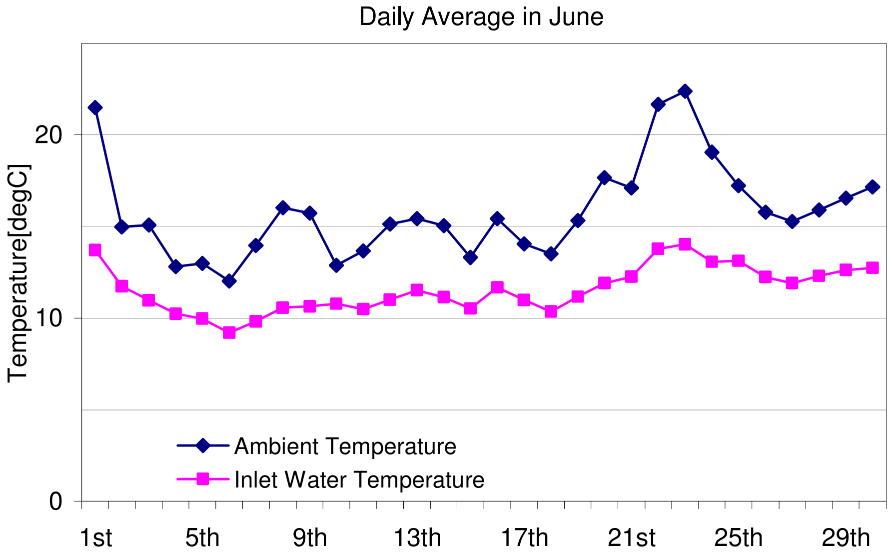
As the average ambient temperature was around 10degC during the first half of May, the number of heating indoor units was higher than that of cooling indoor units. As, the ambient temperature gradually increased during the second half of this month the cooling demand increased and the number of indoor units in heating decreased suggesting the internal environment was affected by the increase in ambient temperature as is expected with large areas on the club house structure being made of glass.

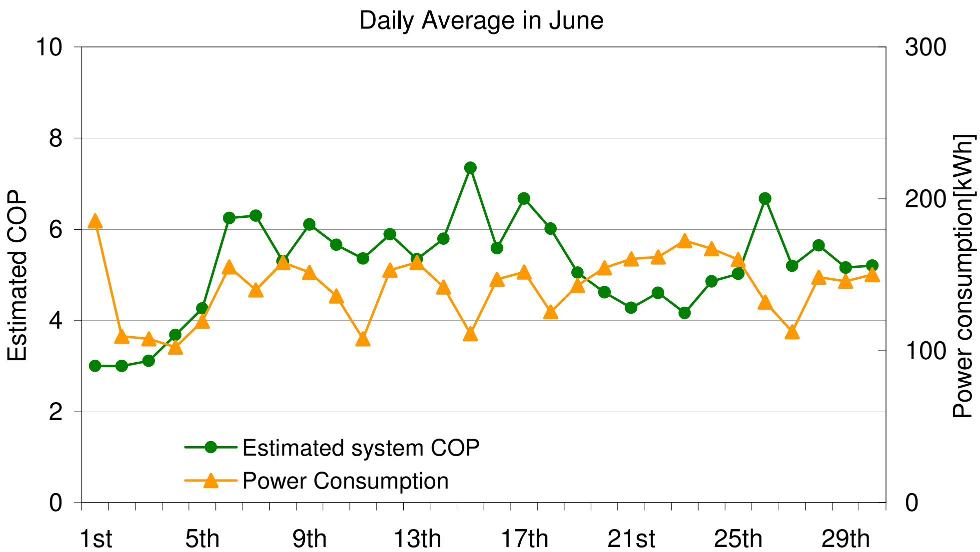


The graph above shows heating and cooling running hours of each indoor unit during opening hours.

The indoor unit in the shop ran the longest in cooling mode at about 250 hours. The indoor unit in the caddy pavilion was always off/ thermo off. Both system 1 and system 2 had indoor units running in heating and cooling mode in fairly equal proportions suggesting that a high rate of heat recovery was taking place therefore increasing system efficiency.

Appendices 3.0 June Overview – Whole Building



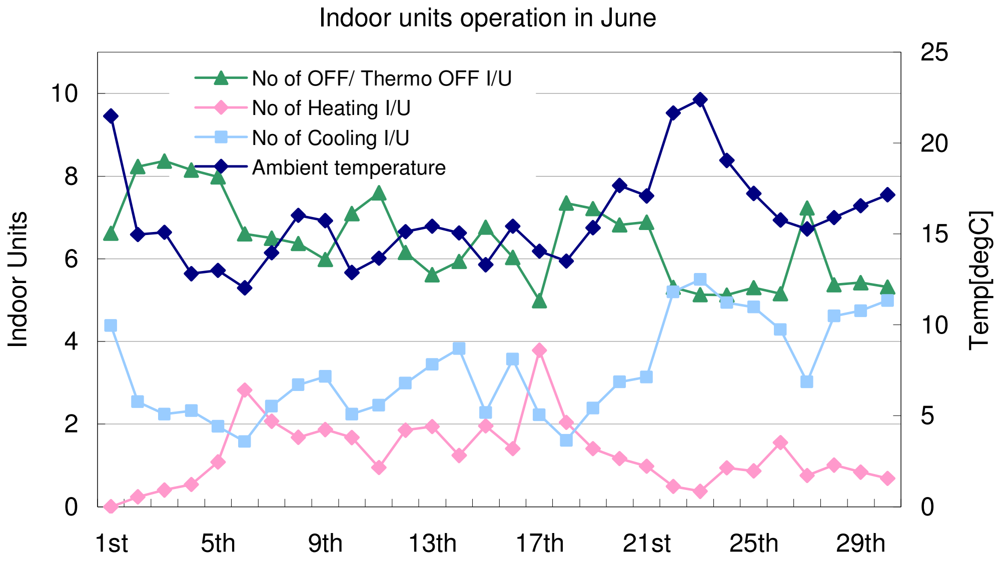


The graph on the top shows daily averages for ambient temperature and inlet water temperature for the ground source units in June. The graph on the bottom shows the daily power consumption and total system COP during opening hours.

Daily average ambient temperatures in June ranged approximately between 10degC and 20degC. Again the average inlet water temperature of the ground source units seemed to increase as the ambient temperature increased and decreased as the ambient temperature decreased suggesting the internal environment was affected significantly by ambient conditions.

The total power consumption ranged from 100kWh to 190kWh per day during opening hours suggesting that the system was working at partial load to heat and cool the building therefore increasing the system efficiency. The average total system COP ranged between 3.0 and 7 with daily system COP's of above 4 on most days. The cost of running the system to heat and cool the building during opening hours this month was calculated to be approximately £427 and the CO_2 emissions were estimated at 1,837kg.

Indoor Units



The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in June.

The number of indoor units that were off/ thermo off ranged between 4 and 7. During the month the number of cooling indoor units was higher than that of the number of units in heating as is expected given the increased ambient temperatures.

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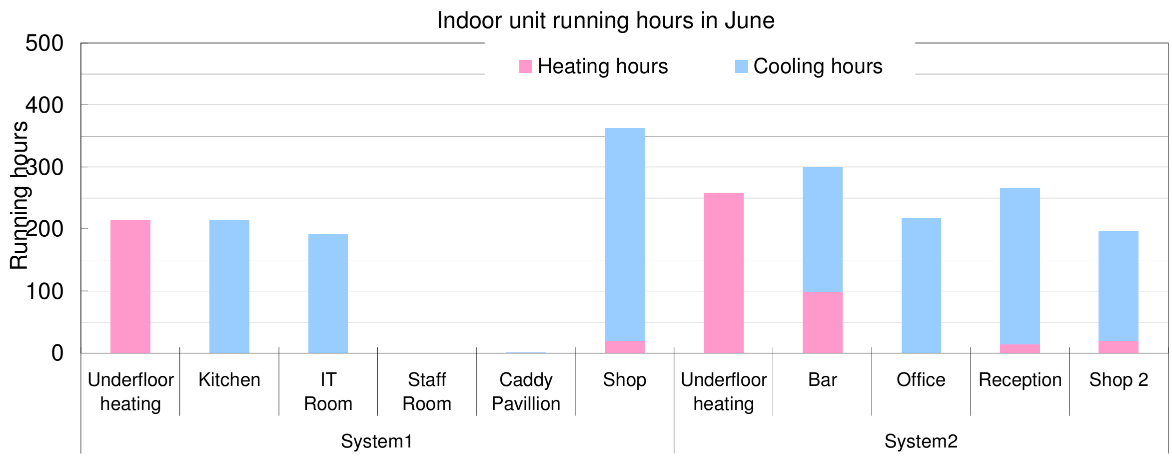
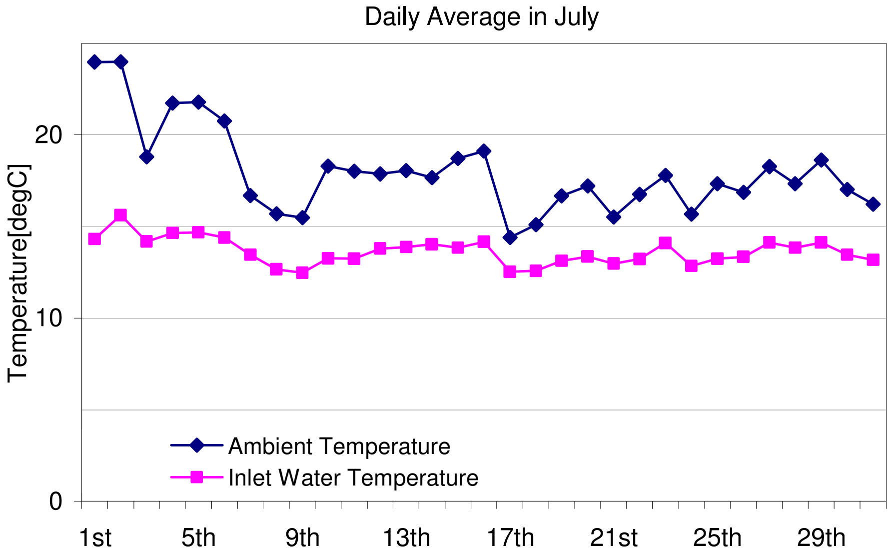
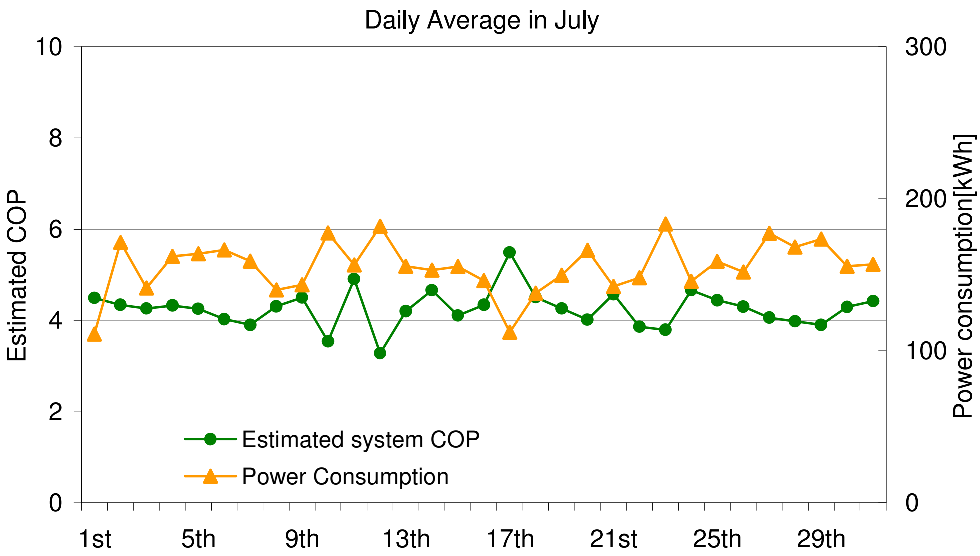


The graph above shows heating and cooling running hours of each indoor unit during opening hours.

The indoor unit in the caddy pavilion was always off/ thermo off. The number of hours that the underfloor heating was running was around 200 - 250 hours during opening hours equating to a 35% decrease compared to the previous month. It is clear that even though there was a demand for heating the main demand across both the systems was for cooling. Small amounts of heat recovery would have occurred during this month.

Appendices 4.0 July Overview – Whole Building



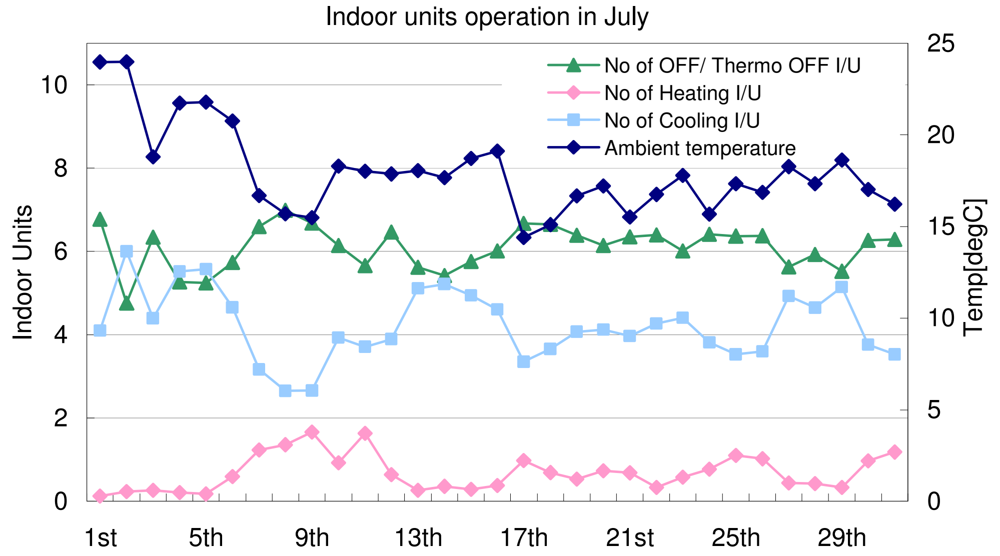


The graph on top shows daily averages for ambient temperature and inlet water temperature for the ground source units in July. The graph on the bottom shows the daily power consumption and total system COP during opening hours.

During the first half of this month, the average ambient temperature decreased from over 20degC to 15degC. Over the second half of July the average ambient temperature was stable at around 15degC. The average inlet water temperature was relatively constant at around 13-15degC all through the month. This indicates that the ground temperature was able to recover overnight as the PQFY units were not running/ running less.

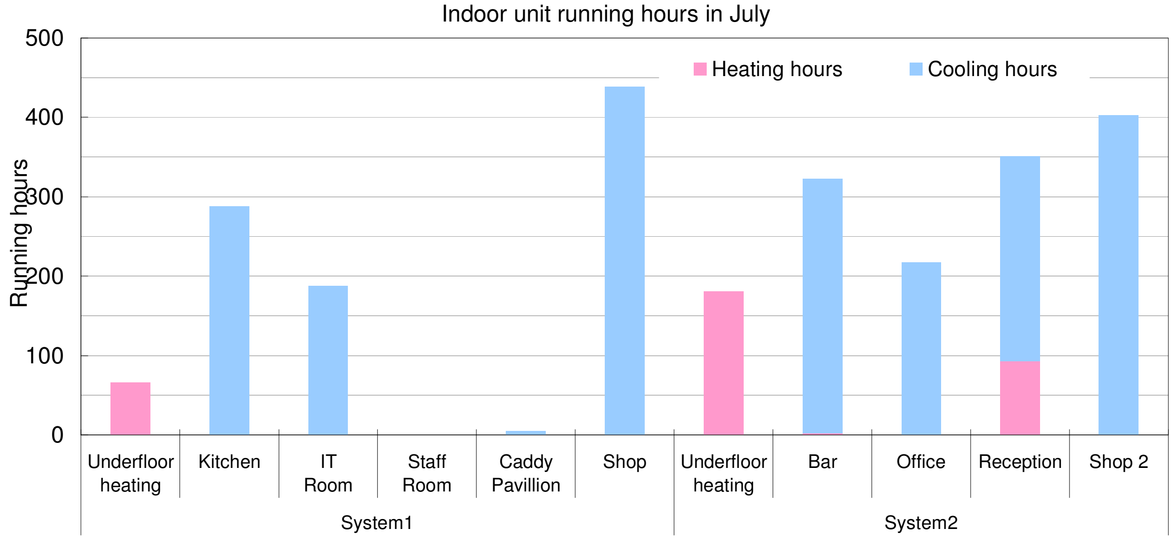
Over the month the total power consumed during opening hours on any one day ranged from approximately 100kWh to 200kWh per day. The average total estimated system COP ranged between approximately 3.5 and 5.5 showing that the system efficiency was more stable over this month. The cost of running the system to heat and cool the building during this month was calculated to be approximately £481 and the CO_2 emissions were estimated at 2,070kg.

Indoor Units



The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in July.

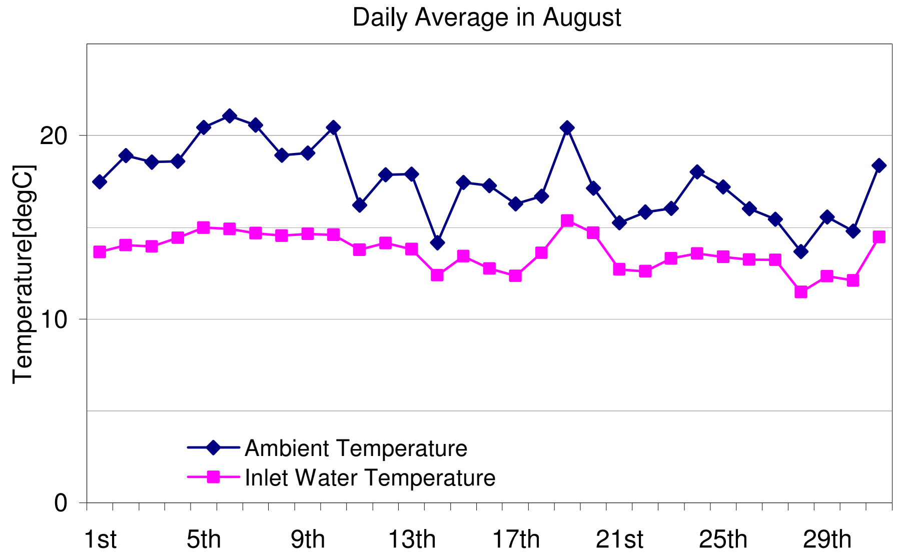
It is clear from the graph that the building required mainly cooling throughout the month. During the first part of the month ambient temperatures were higher at around 20degC. During this time there was no demand for heating with up to 7 units providing cooling. As the ambient temperature decreased and then stabilised at around 15degC for the rest of the month the number of units in cooling averaged at around 5 with 1 unit in heating indicating that the building retained heat energy from the earlier part of the month when ambient temperatures were higher and solar gains were high. Very little or no heat recovery would have occurred during July.

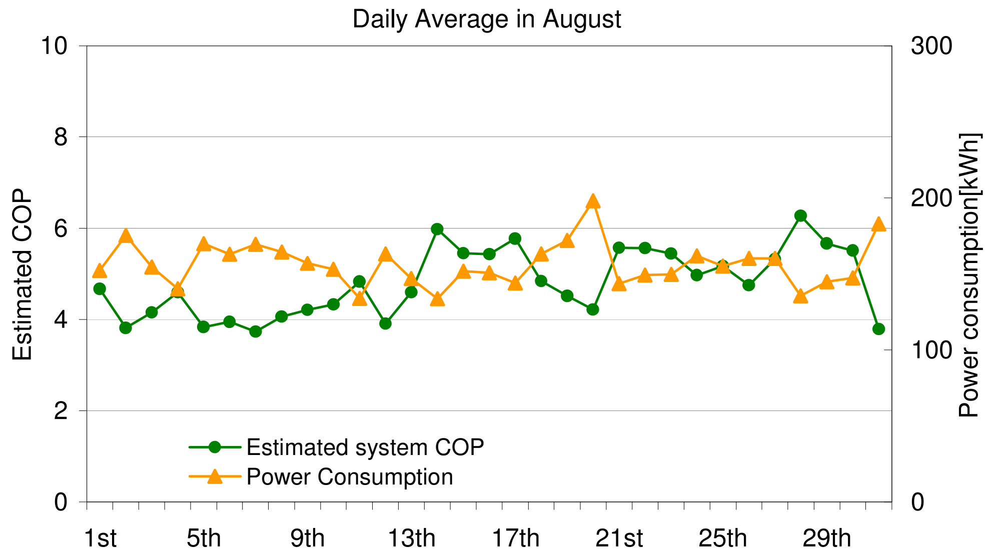


The graph above shows heating and cooling running hours of each indoor unit during opening hours.

The indoor unit in the staff room ran the longest amount of time in cooling for 468 hours. It is clear that the main demand was for cooling during July with approximately 300 hours of heating demand and that the system was more than likely to be running at peak system capacity. As a result very little heat recovery took place between indoor units explaining the lower system COP of 4.23 estimated for this month.

Appendices 5.0 August Overview – Whole Building



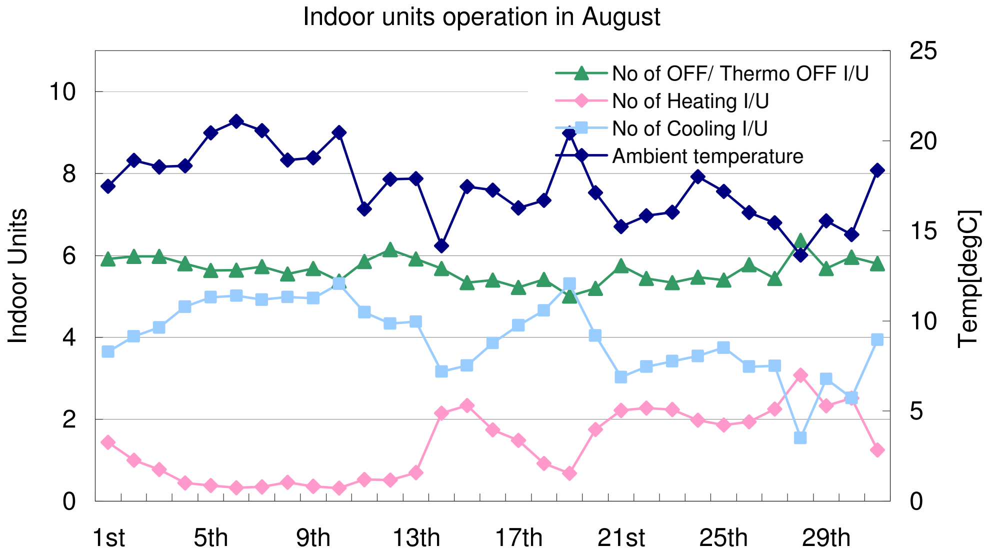


The graph on the top shows daily averages for ambient temperature and inlet water temperature for the ground source units in August. The graph on the bottom shows the daily power consumption and total system COP during opening hours.

Average ambient temperatures ranged between 13degC and 20degC and peaked at nearly 20degC on the 19^{th}. Average inlet water temperatures of the watercooled units ranged approximately between 12degC and 15degC and showed a trend similar to that of the average ambient temperature.

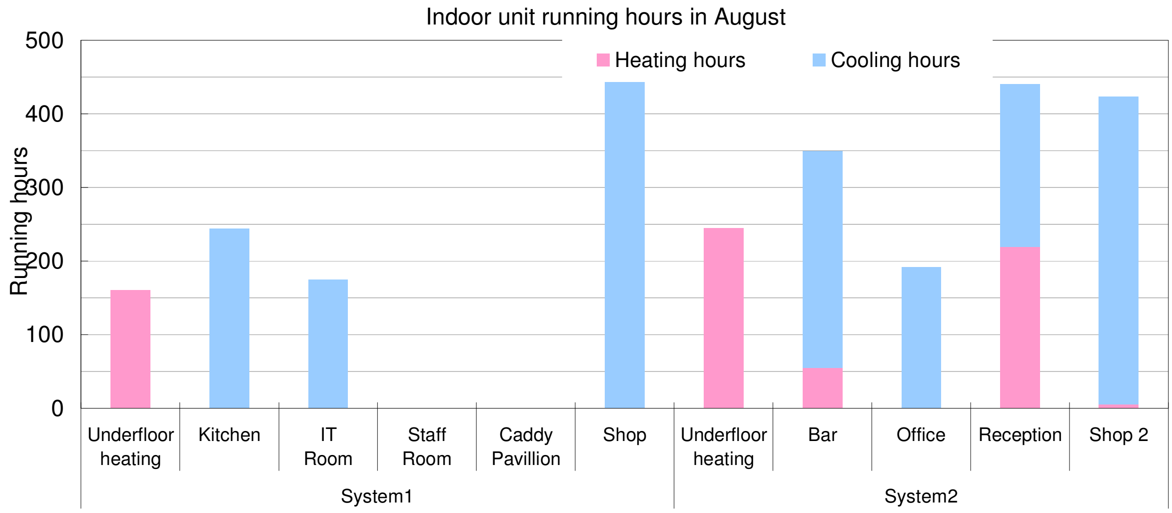
The daily power consumption of the system ranged between approximately 131kWh and 196kWh showing that the system was working at quite a steady rate and at partial load to satisfy the building's heating and cooling demand in an efficient manner. The estimates system COP ranged between approximately 4 and 6 portraying a highly efficient system. The cost of running the system to heat and cool the building during this month was calculated to be approximately £484 and the CO_2 emissions were estimated at 2,084kg.

Indoor Units



The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in August.

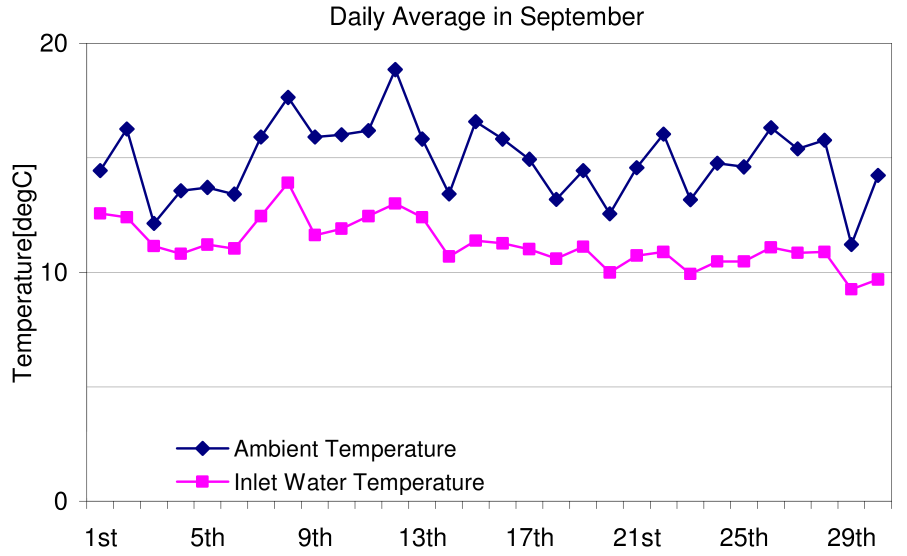
The month showed an overall main demand for cooling. A large proportion of the indoor units on the system were also off throughout the month suggesting that they system was running at partial load. There was very little demand for heating during the first part of the month however the heating demand to the building increased after the 13th of the month as there was a slight drop in ambient temperatures to around 15degC. The building would have started to lose some of its retained thermal energy and ambient temperatures would have dropped overnight therefore there would be a demand for heating first thing in the mornings. Some heat recovery between indoor units would have occurred towards the end of the month therefore increasing system efficiency.

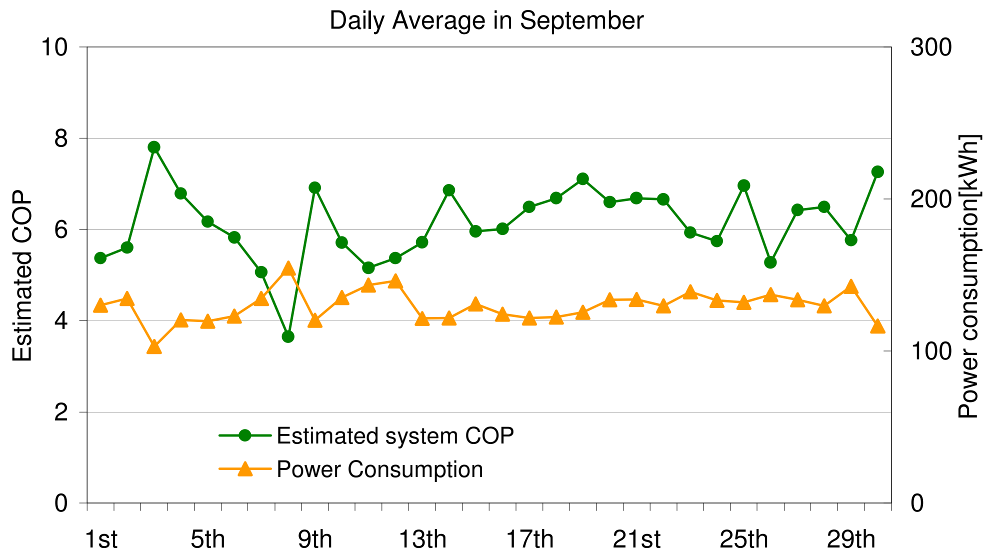


The graph above shows heating and cooling running hours of each indoor unit during opening hours.

It is clear that the main demand over the month was for cooling however the floor heating running hours for August increased by 65% compared to July and the heating hours of the unit in the reception ran for twice as long compared to July. The main cooling demand during this month was in the shops, kitchen and bar areas.

Appendices 6.0 September Overview – Whole Building



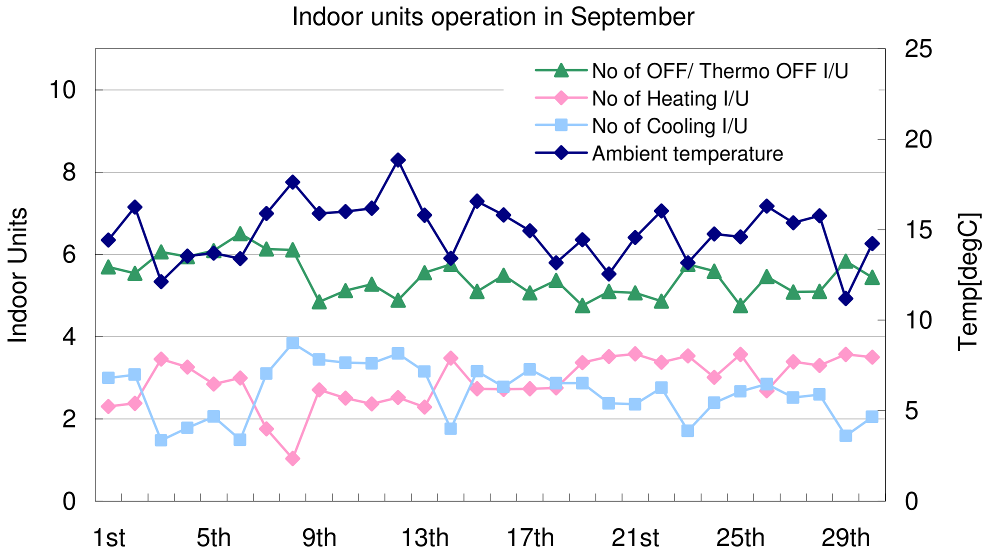


The graph on the top shows daily averages for ambient temperature and inlet water temperature for the ground source units in September. The graph on the bottom shows the daily power consumption and total estimated system COP during opening hours.

Average ambient temperatures ranged between 11degC and 18degC. The average inlet water temperature was gradually decreased throughout this month suggesting that heat energy was being utilised from the ground heat the internal environment as ambient temperatures were lower during this month.

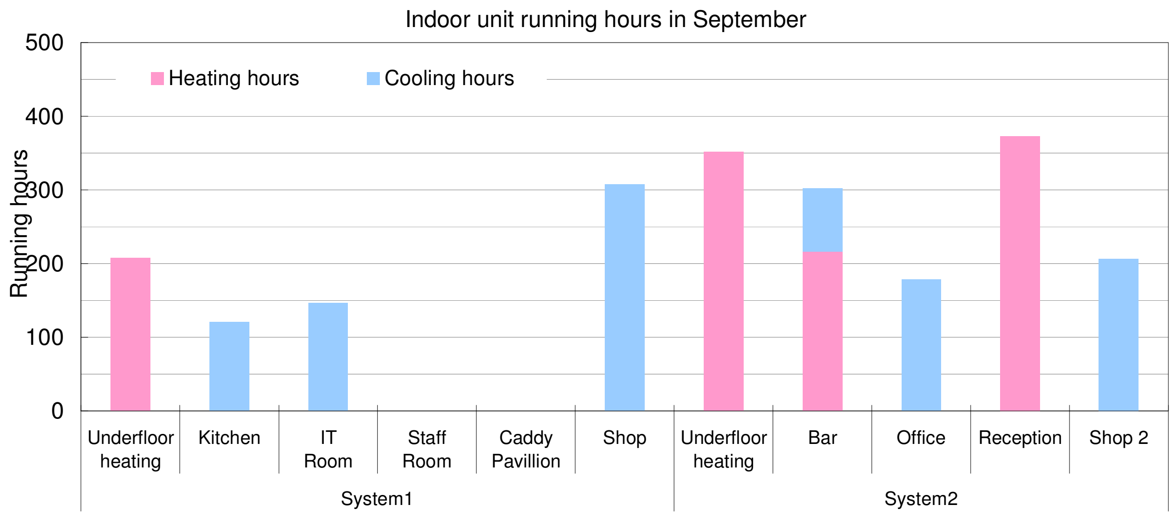
The total power consumption per day was very stable between approximately 100kWh and 150kWh per day showing that they system was working at partial load therefore increasing the efficiency. The average total system COP ranged between 3.8 and 8 with all but one day having average COP's over 5. The cost of running the system to heat and cool the building during this month was calculated to be approximately £390 and the CO_2 emissions were estimated at 1,675kg.

Indoor Units



The graph shows daily average numbers of cooling indoor units, heating indoor units and off/thermo off indoor units during opening hours in September.

The average number of indoor units that were off was around 5 to 6. The number of heating indoor units and cooling indoor units were very similar suggesting that there was an almost equal demand for heating and cooling allowing the system efficiency to be increased due to large amounts of heat recovery occurring.



The graph above shows heating and cooling running hours of each indoor unit during opening hours.

The indoor units in the shop areas were still running in cooling mode for the longest periods of time throughout this month. Other areas that required a cooling only demand during this month were the kitchen, IT room and office areas with a small demand in the bar. The rest of the areas demanded heating. The number of heating indoor units and cooling indoor units were quite similar with an almost 50/50 balance for demand strongly indicating that high rates of heat recovery took place this month therefore maximising system efficiency and explaining the estimated system COP of 6.09 for this month.