PQFY-P140 VRF Heat-Pump Boiler

Cawledge Business Park, Alnwick

Summary

Brief overview of Case study

Cawledge Business Park is a new build development of 12 commercial office properties in Alnwick, Northumberland. Alnwick is the first PQFY VRF Heat pump boiler performance case study. The application was for a space heating and cooling solution. The equipment was installed in May 2008 and was monitored between July 2008 and February 2009.

Brief conclusions of Case study

During the 8 month data logging period the system ran in heating for 91.1% and cooling for 8.9% of the time, which equates to an energy output of 26,315.146 kWh in heating and 2,570.85 kWh in cooling.
The total cost of running the system for 8 months is £800.17. However, the annual cost can be estimated by using our estimated annual COP of 3.61, which equates to estimated annual running cost of £1200.

In comparison to the above figures for running the PQFY heating and cooling system we can compare this to the most feasible alternative option available, which is a gas central heating system. The gas heating system would run at a maximum COP of 0.93. The amount of heating capacity required was 26,315kWh. Therefore, with an assumed cost of gas at 4p/kWh, the cost of heating via a gas heating system would total £1,131.83 for eight months and have a total annual cost of £1,479.78. Therefore PQFY systems total annual running cost at £1,071 is £408.78 cheaper than the alternative. The annual estimated cost for the gas system is calculated from months with similar average ambient temperatures to ensure the estimation is as accurate as possible. However, the estimated annual cost does not factor in the need for cooling which the PQFY provides. The gas central heating system is inadequate for a cooling purpose and therefore the running costs of an air conditioning system would have to be included in this.

The PQFY systems total annual running cost at £1,071 is over £400 cheaper than a gas heating system alternative.

Further to this, the cost of installation is much cheaper for the PQFY system than the gas central heating system as the gas boiler would have been approximately £3,000. In addition to this the building had no gas connection. A gas connection costs about £3,000 to install, and a gas meter about £2,000. Therefore an extra cost of £5,000 for the gas connection would have to be included in this final system cost.
Therefore the total cost of fully installed gas heating system would be approximately £8,000. The overall cost of the PQFY heat pump boiler system including all parts, installation and commissioning totalled £5,800.

The total capital cost of PQFY system including parts, installation and commissioning was £5,800 which is approximately £2,200 cheaper for the end client than total cost for the gas heating system option.

Another comparison that can be drawn between the two options is the amount of C02 emissions expelled. Over the eight months the PQFY system would have given out 3,440.71Kg of C02, and annually it is estimated the unit will eject 5,161.1 kg of C02. Whereas, over the eight months the gas boiler would have given out 5,101.92 kg of C02 which is almost what the PQFY system gives out in a year. Furthermore the annual total of C02 emissions the gas heating system releases would be 7,652.87 kg of C02.

The PQFY system we estimate will save the end client 2,491.77 kg of C02 emissions annually.

Overall the system worked effectively and efficiently at providing heating and cooling with high COPs in a range of ambient temperatures. Moreover there was a prolonged period of snow in February and a colder than average October which proves the unit can work in more extreme conditions and still give COPs of more than 2.4 and higher.

Overall the average COP recorded was 3.28 which is a high COP taking into account that there were only 2 months out of 7 that were monitored that were not in either autumn or winter.

Introduction

Cawledge Business Park is a new build development of 12 commercial office properties in Alnwick, Northumberland. Alnwick is the first PQFY VRF Heat pump boiler performance case study. The application was for a space heating and cooling solution. The equipment was installed in May 2008 and was monitored between July 2008 and February 2009.

The consultant wanted to get a good Buildng Energy Performance BREEAM (Building Research Establishment Environmental Assessment Method) rating. The end client had also stated that they did not want a system which was visible from inside or outside of the building so when looking into potential solutions this had to be taken into account.

Alternative Technologies

For this installation other applications were possible however, these wouldn't have satisfied the client fully as there are factors that would have to compromise.

A gas central heating system in connection with under floor heating could have been installed. The cost of this would have been approximately £3,000. In addition to this the building initially had no gas connection. A gas connection costs about £3,000 to install, and a gas meter about £2,000. Thus an extra cost of £5,000 for the gas connection would have to be included in this final system cost. Therefore the total cost of fully installed gas heating system would be approximately £8,000.

The overall cost of the PQFY heat pump boiler system including all parts, installation and commissioning totalled £5,800. Therefore the overall capital cost of the PQFY system results in savings for the client of approximately £2,200.

Further alternatives include solar thermal collector panels which can be used in conjunction with underfloor heating to provide the space heating for the property. However, this option was ruled out as this equipment wouldn't be able to fulfil the heating capacity needed for this development and at around £5,215 for evacuated tubes it is an expensive option.

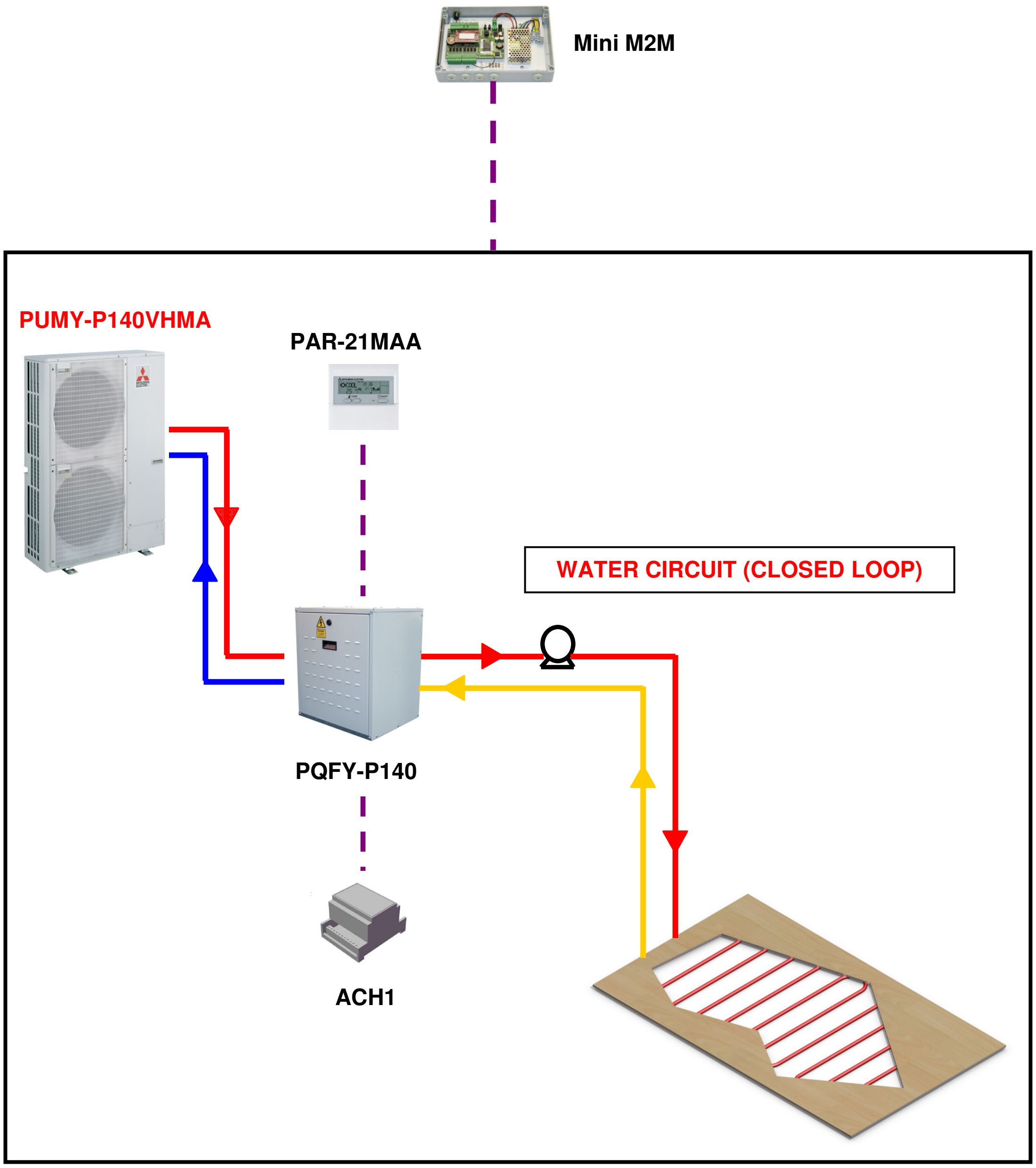
Ground source heat pump option was available and gives high COPs and efficiency. The initial costs can be high and in this application there wasn't enough external space to fit the underground coils, which ruled out this option.

Lastly there was the option of installing an oil fired boiler in the property. The downfall to this installation is that it is a dated approach that has very poor efficiencies and a large detrimental impact on the environment. This option would cost around £3000 for the oil boiler and regular payments for oil barrels.

Overall it was decided that the PQFY heat pump boiler was the most suitable option for this development as it is the lowest cost option from the options reviewed, is one of the most highly efficient systems currently available, does not require specialist installation, such as Solar thermal or Ground source solutions and has a low impact on the environment. Furthermore the system was made non-visible from the outside as the units were able to be housed in a louvered enclosure suitable for the units and the underfloor elements were also hidden internally which was a high priority for the end user.

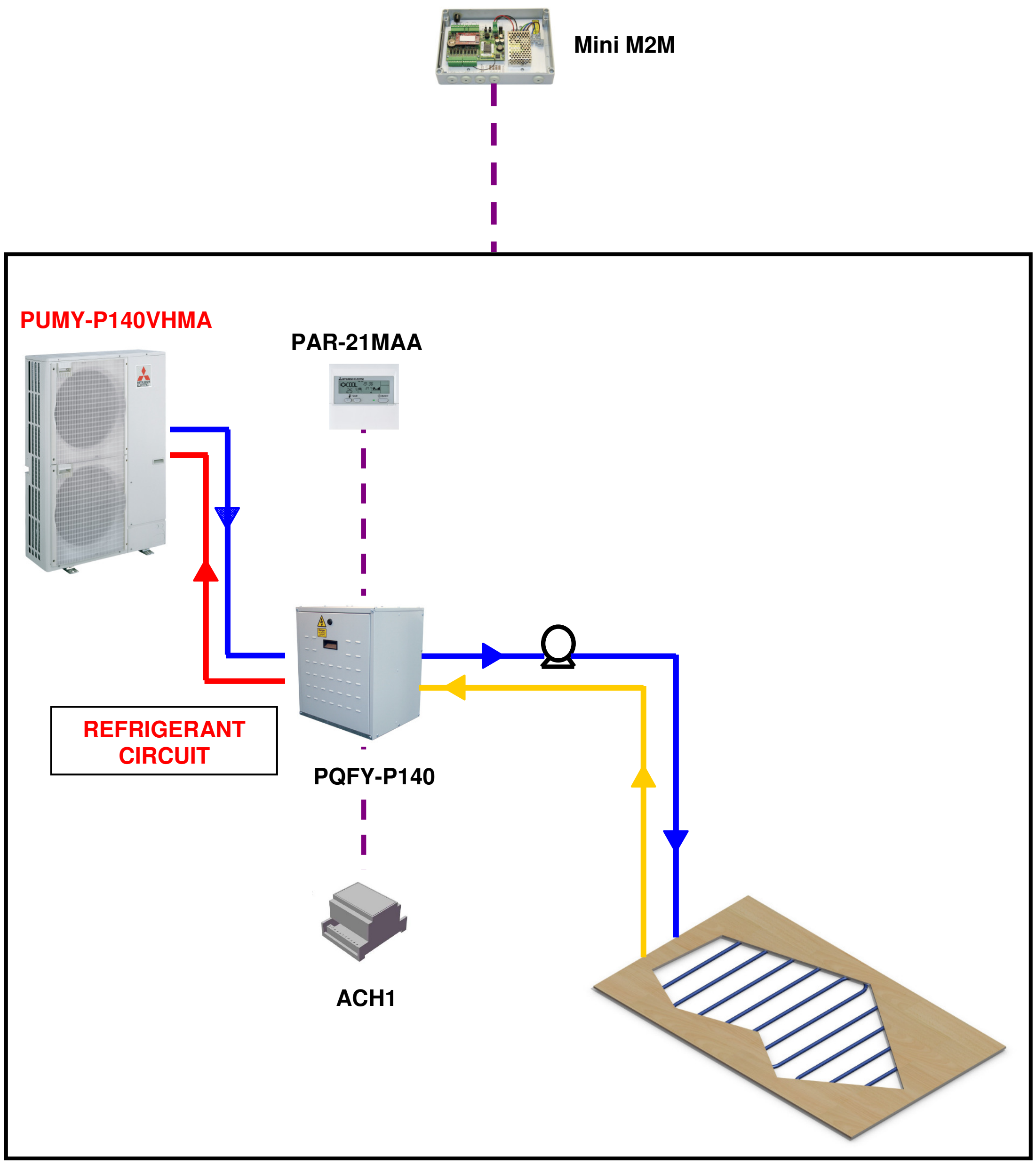
How it Works

*From the PQFY applications guide:
Underfloor heating:



The PUMY-P140VHMA outdoor unit produces hot refrigerant gas which flows to the PQFY heat pump boiler. The energy in this gas, and the energy released when the gas condenses back to liquid is transferred into the water via a coaxial tube in tube heat exchanger in the PQFY. The heated water is then pumped through the under floor heating (UFH) circuit at a steady temperature of around 35 – 45 °C.

Underfloor cooling



The PUMY-P140VHMA outdoor unit produces liquid refrigerant. At the PQFY, the liquid refrigerant absorbs heat from the water loop of the UFH circuit. This heat absorption evaporates the refrigerant into gas, which returns to the outdoor PUMY unit and is then re-compressed in the compressor, and re-condensed to liquid. Which will result in water flow of around 12 – 15 °C. Normally the PQFY will target 17 – 18 °C but since the office is carpeted, the low temperature is required to get any cooling effect.

Kit List

- PQFY-P140VHMA VRF heat-pump boiler
    - High COPs year round
    - Reduction in running cost
    - Reduces CO_2 emissions
- PUMY-P140 YMHA VRF Air Source Heat pump Outdoor unit
    - Anti corrosion blue and flat fin technology
    - Slim line unit allowing for easy application and installation
    - Highly efficiency Inverter driven technology
    - Two core non-polar transmission line which allows for simple installation
- PAR-21MAA (Remote Controller)
    - Mode Selection
    - 7 Day Multi program weekly timer
- ACH1
    - PQFY Auto-changeover controller
- M2M Mini
    - Remote management of you air conditioning units
    - Allows the user to integrate multiple sites into one network
    - Wireless connection

Installation

Alnwick was a new build development which made the installation of the equipment simple as there was no existing system to remove and the contractor could go straight to installing the equipment. Further to this the building was uninhabited until completion which meant there was no inconvenience to the installers from people coming in and out, which enabled the installation to happen at a faster rate. The PQFY heat pump boiler was being installed in order to supply heating and cooling via an under floor system. The client wanted a system which would be efficient and not visible.

The installation of this equipment was very simple. On the refrigerant side, only the PUMY outdoor unit and the PQFY heat-pump boiler need to be piped together. The PQFY then connects to the under-floor system via a circulating pump on the water side. The outdoor unit was placed in a louvered enclosure. The customer was made aware that we do not recommend installing this unit indoors, as there is a possibility of the airflow from the unit short cycling back, which can result in unpredictable operation and reduced efficiencies.

Testing & Data Logging

The units were installed in May 2008. Data was logged 24 hours a day, 7 days a week from July 2008 until February 2009. The data logged included the date and time, outdoor ambient air temperature, water outlet temperature, water inlet temperature, kWh input and output of the PQFY unit. Further to this we calculated the amount of hours the unit was switched on or off and the time spent in either heating or cooling mode.

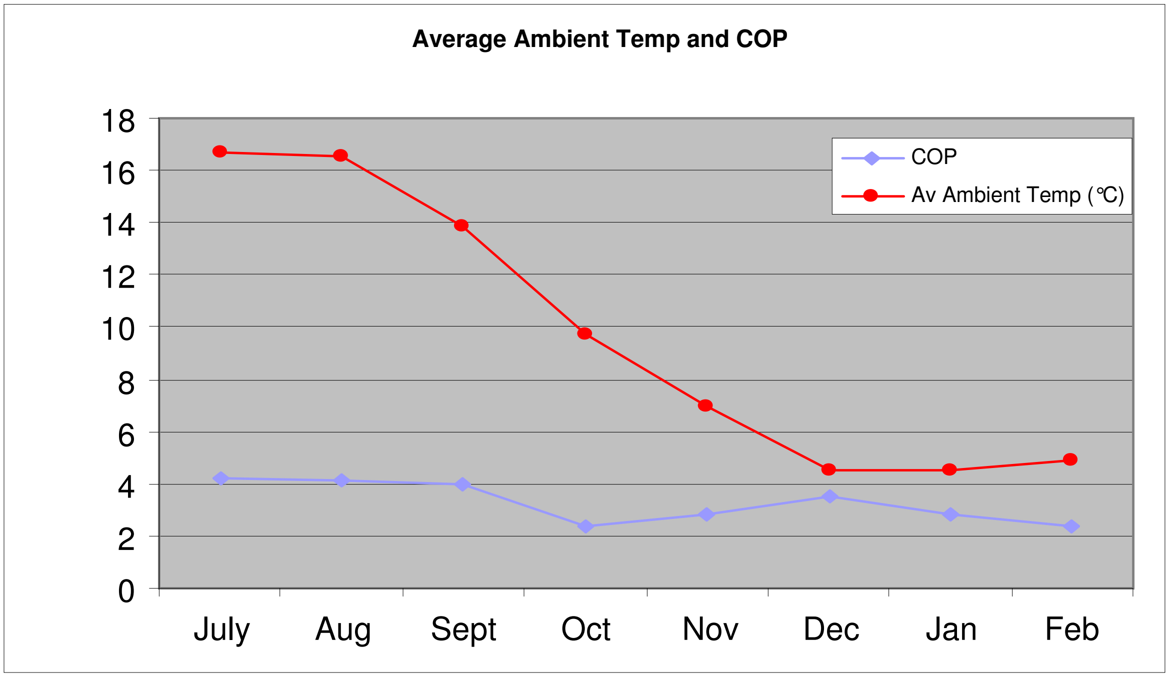
From this information we were able to calculate the average, total and spot COPs the unit was working at, at different points in time. The data was logged using the Machine 2 Machine Mini system (M2M Mini).

[Left Photograph] PUMY Outdoor unit housed inside the louvered enclosure.

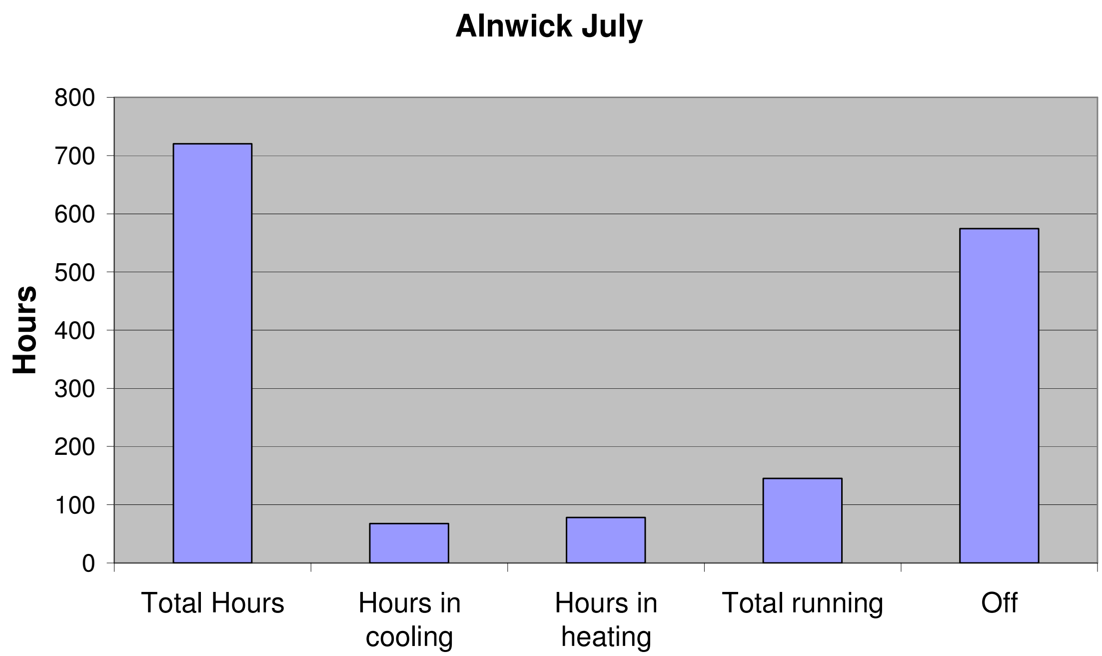
[Right Photograph] Shows the Energy meter mounted above the M2M Mini.

[Left Photograph]
Shows the outside of the Louvered compartment in which the unit is installed behind.

[Right Photograph]
Inside view of the offices.



The above graph shows the Coefficient of Performance (COP) and average ambient temperature for each month in which the system was monitored, from July 2008 to February 2009. Overall the average temperatures were fairly typical of average British seasons, with the exception that the summer months were slightly cooler than normal and October had a low monthly average ambient temperature at just 9.7°C. The average temperature ranged from 5°C to 16.8°C during the monitoring period. The COP range stayed between 2.4 and 4.3 despite some large temperature drops. This shows that the PQFY heat pump boiler was able to maintain a good level of efficiency at a wide range of ambient temperatures.

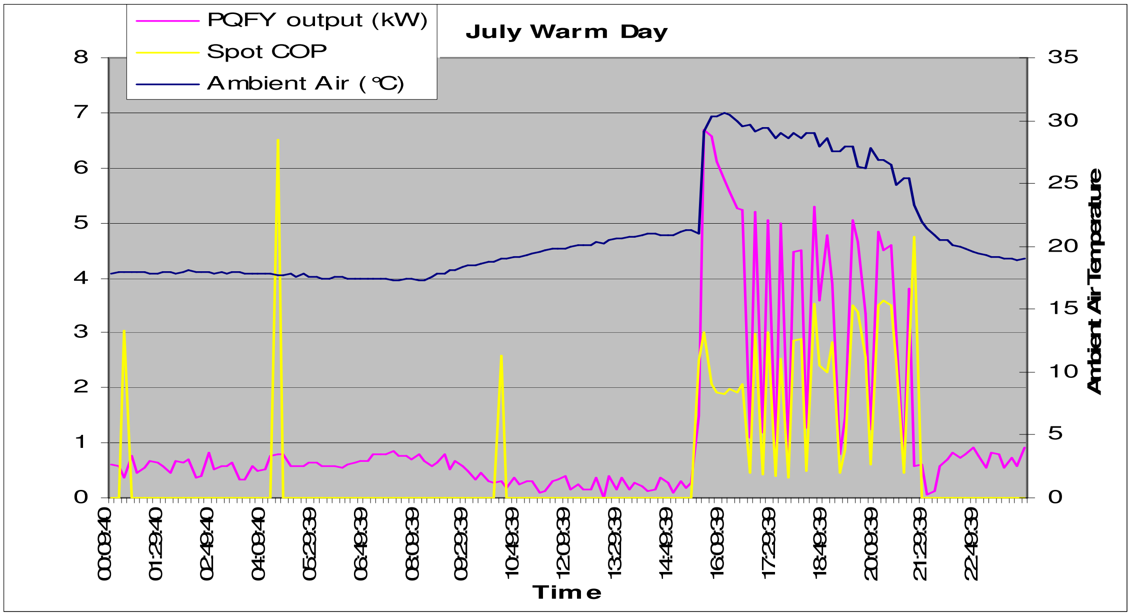


In July the PQFY ran for 157 hours total (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was only on for approximately 20% of the time (587 total hours off in July), but was heating for 82 hours and cooling for 75 hours.

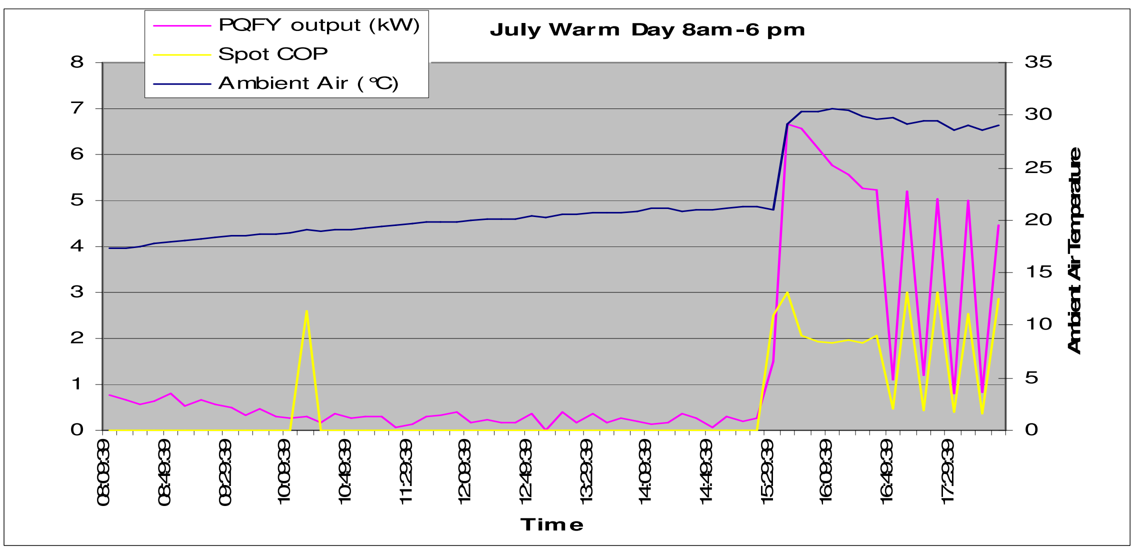
The graph above shows that the unit was only on for a short amount of time, this indicates that the ambient temperature in July was sufficient to provide a comfortable indoor temperature so neither large amounts of cooling or heating was required. We would have expected to have seen more hours in cooling at this time of year. However, as shown above the average ambient of 16.7°C is slightly lower than expected which could explain why less cooling was needed.

July Recorded Data

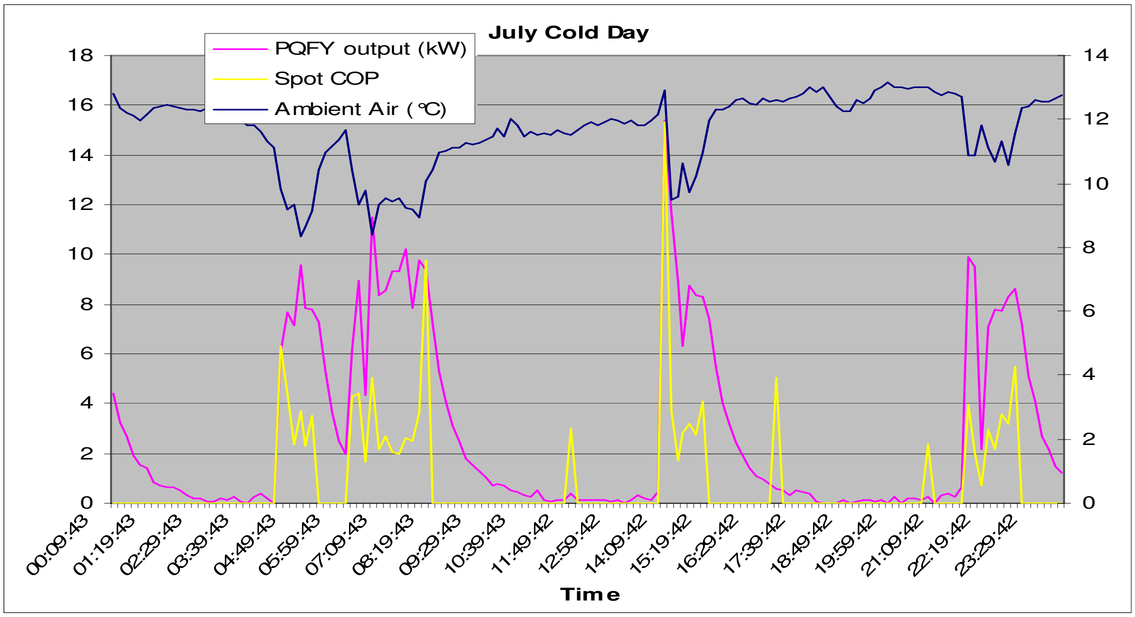
Total kWh output	1382 kWh
Total kWh input	328 kWh
COP	**4.21**



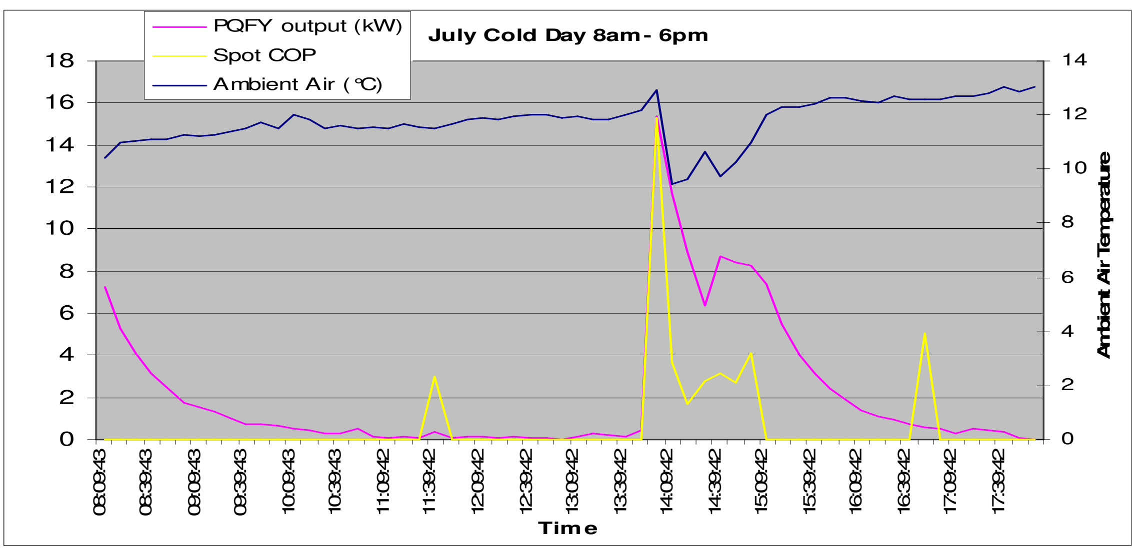
This graph shows the PQFY power output, spot COP and ambient air temperature on a warm day in July. The average ambient temperature on this day was 21.1°C, which is clearly higher than the monthly average of 16.7°C. At this temperature there would be a lot less demand for heating and this would explain why the unit was switched off during the first part of the day. As the ambient temperature rises throughout the day the unit turns on to cool the building, at this point the COP increases and decreases in direct relation to the amount of PQFY output.



This graph shows the PQFY power output, spot COP and ambient air temperature during the office working hours. The office is used mainly between 9am and 5pm however, we must take into account warm up and cool down times, for which we allow an hour either side of the working times. Therefore we are concerned with the hours between 8am and 6pm. From the above graph we can see that in the morning the ambient temperature is high enough so the PQFY unit is barely running to maintain the indoor temperature. Later in the day the ambient temperature rises so the PQFY unit switches over to cooling and cools down the offices. It does this to ensure the indoor temperature does not rise above setpoint and become uncomfortable for those working inside.

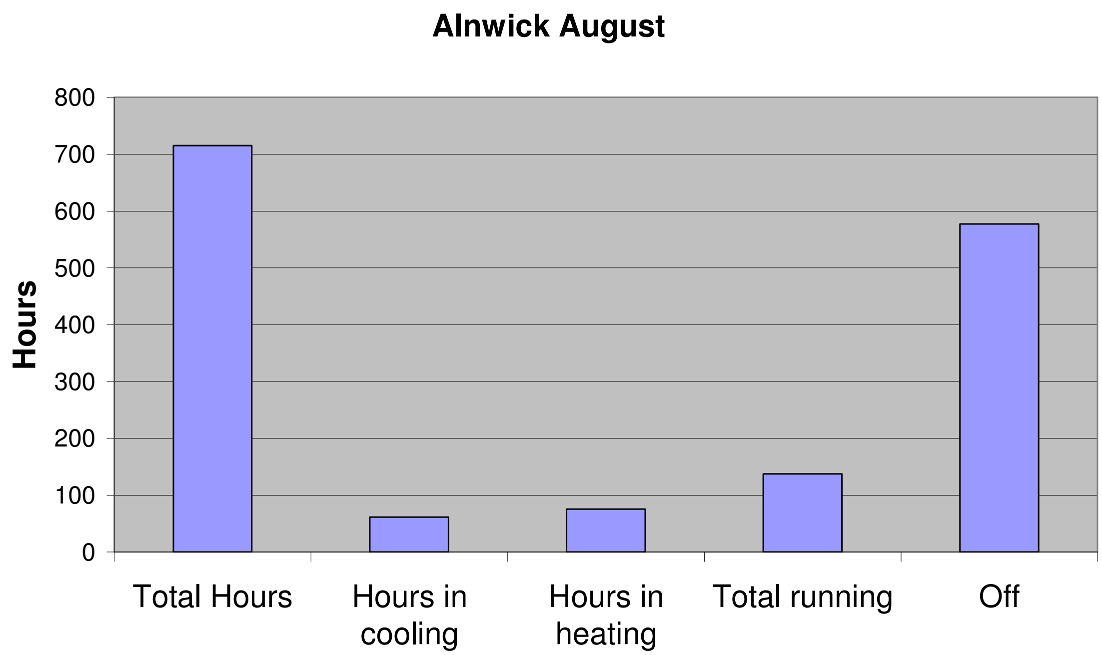


This graph illustrates a cold day in July. It shows that the unit was switched on first thing in the morning to warm up the office, and as it was a lower than average temperature day with an average ambient air temperature of just 11.3°C, the unit turned back on at approximately 13.40 to maintain a comfortable working temperature in the office. After this time it switches back off until approximately 21.00. On this graph you can see heating operation from 21:00 hours onwards, this can be explained by the thermostat, in which the temperatures are set lower to activate the underfloor heating if the room temperature drops below 21°C. This mode is an energy saving feature as it stops the temperature of the building from dropping too low during the evening which would require a higher input to heat the building back up in the morning. By using the thermostat feature it should make the morning heat up time quicker allowing energy to be saved.



The above graph looks in more detail at a cold day in July between 08:00 and 18:00 hours it shows that although it was a relatively cold day for July inside the office did not require a great amount of heating. The main heating activity is from 14:00 until 15:00 hours and from there onwards the PQFY was continually dropping in output indicating it was no longer needed and switching off.

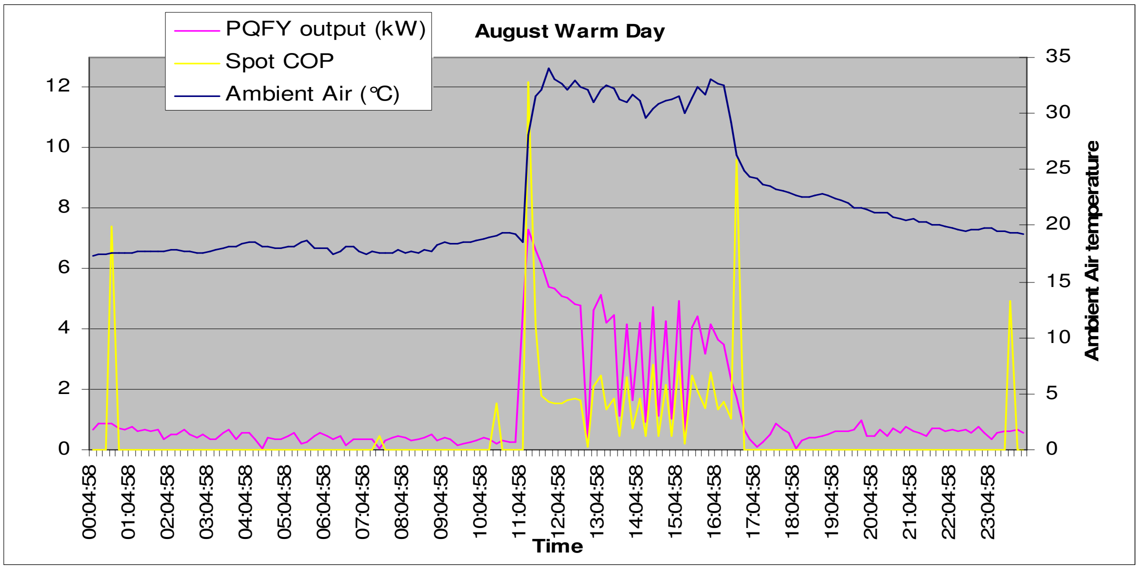
August 2008



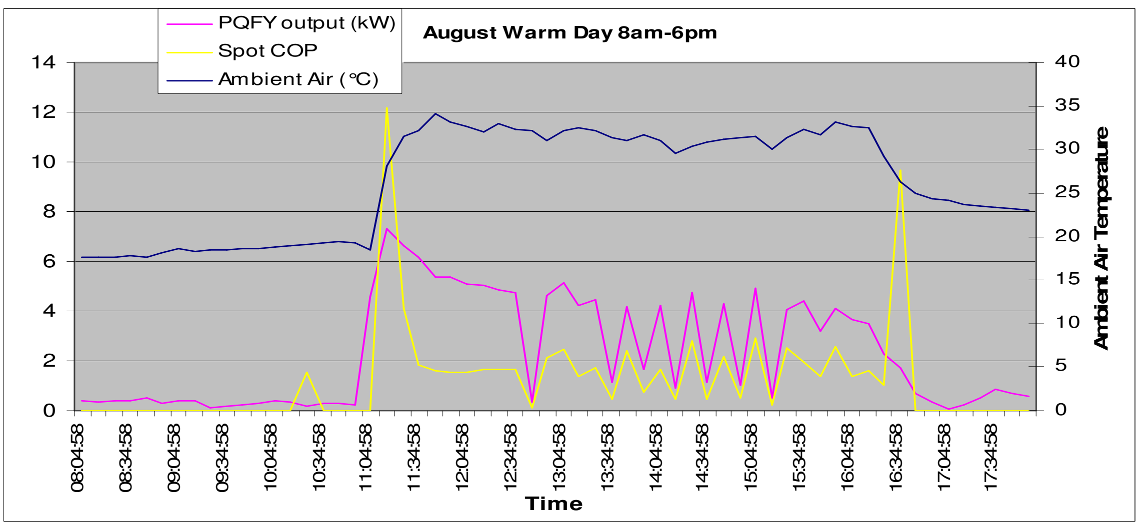
August was very similar to July. The PQFY ran for 139 hours total (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was only on for approximately 20% of the time, but was heating for 76 hours and cooling for 63 hours. The hours of heating are what would be expected for this time of year and again the cooling is slightly less than expected but can be explained by the lower than average ambient temperature for the whole month. This COP is typical of this time of year as the outdoor ambient air temperature is warmer, with an average ambient temperature of 16.5°C, making extracting heat easier. Therefore we can achieve higher levels of COP.

August Recorded Data

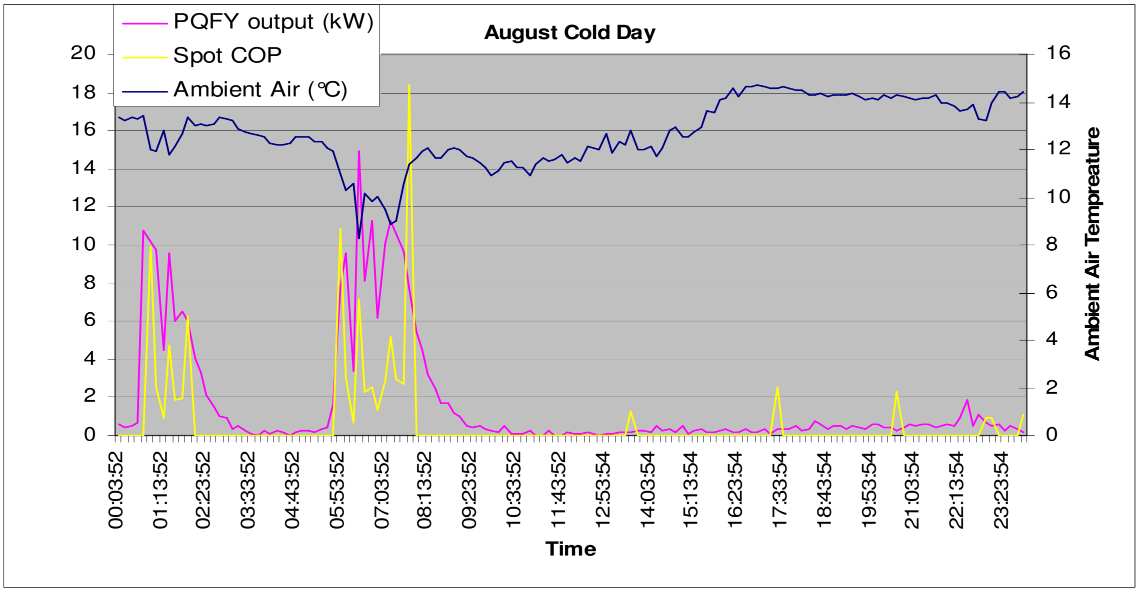
Total kWh output	1175kWh
Total kWh input	282kWh
COP	**4.15**



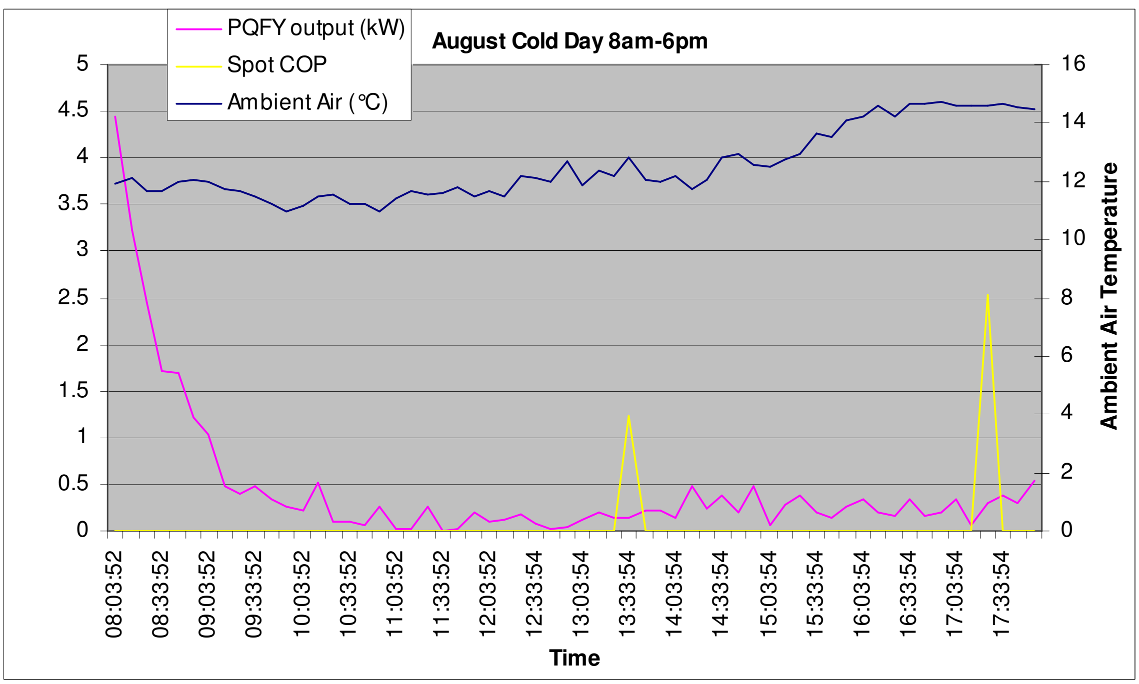
The graph above shows the PQFY power output, spot COP and ambient air temperature for a warm day in August. The average ambient temperature for this day was 23.1°C. The information on the graph shows that the unit was switched on from 11:00 until around 17:00 hours. The time the unit was on coincides with a rise in a temperature during the day which indicates the PQFY is operating in cooling mode during the office hours to ensure the office stays at a comfortable temperature. The PQFY unit may have been short cycling during this period, due to being installed indoors behind louvered panels.



This warm day in August shows the unit mainly being used during the middle of the day and not in the out of office hours where it is still on but at a very low output. Therefore if the unit was used in the hours on the above graph there could be large potential for energy and cost savings. During the out of office hours the unit could be set via a controller on to 'Night Set Back' mode. Night set back is where the indoor set target temperatures drop during the evening so the unit only switches on when it is really needed. This stops the unit working on full capacity during the evening to heat up the building to 21°C and wasting heat energy. Instead of this it may target 17/18°C which will maintain heat energy within the building without any additional wastage. By using these controls we are able to stop the unit from heating up unnecessarily when the building is unoccupied and would therefore able to save energy used to heat the building and reduce the overall cost.

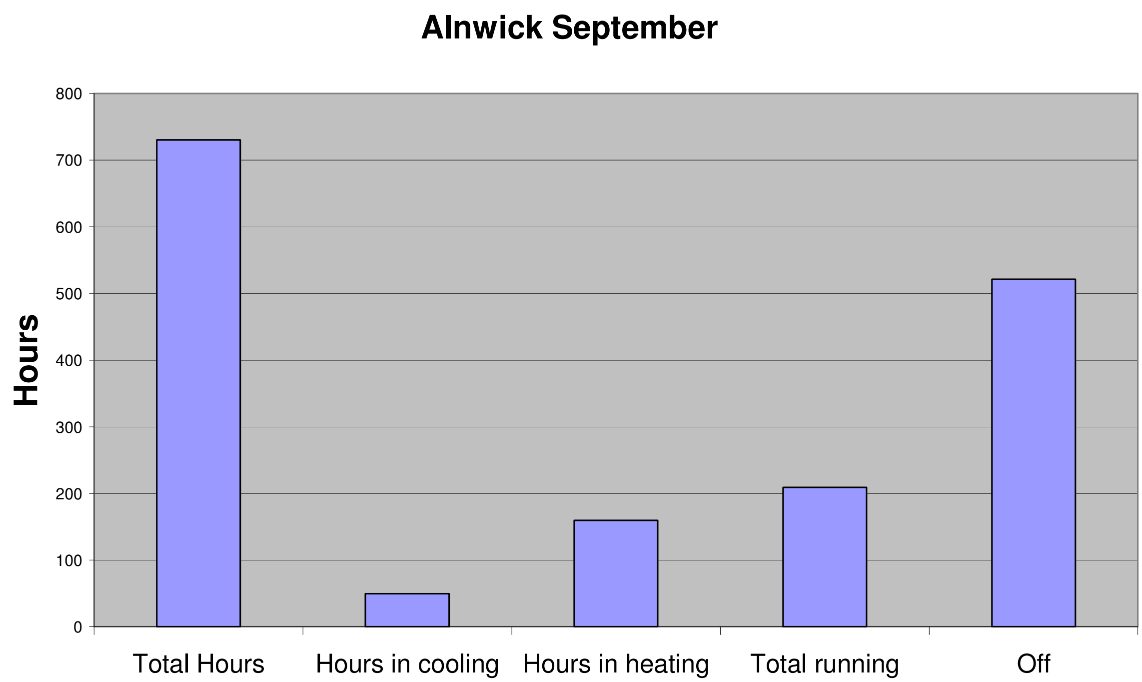


The above graph shows the PQFY power output, Spot COP, and ambient air temperature on a cool day in August when the average temperature for the day is 12.7°C. On this day the PQFY heat pump is running first thing in the morning up until 09:30 hours this could be because the thermostat is telling the unit to heat up the office for the morning when the ambient temperature is at the lowest point of the day. The temperature continually rises for the rest of the day, during this period the unit switches off. It is clear that the unit is operating in heating mode during the evening period (from 12:00- 14:30 hours), this again, can be explained by the thermostat which will have detected a drop in inside temperature and would have turned the system on in heating mode to maintain heat in the building. Although running systems overnight when the space is unused is not that common this does dramatically reduce heat up time in the morning.



The above graph shows the PQFY output, spot COP and ambient air temperature during the office hours. The graph above simply shows the PQFY switching off and running on low output for the rest of the day. Although it is a cold day, the ambient temperature doesn't drop significantly therefore the heat up time in the morning is enough to warm up the building for the day, as the building itself is a new build designed to Part L2 which is able to hold the existing heat well with minimum heat losses.

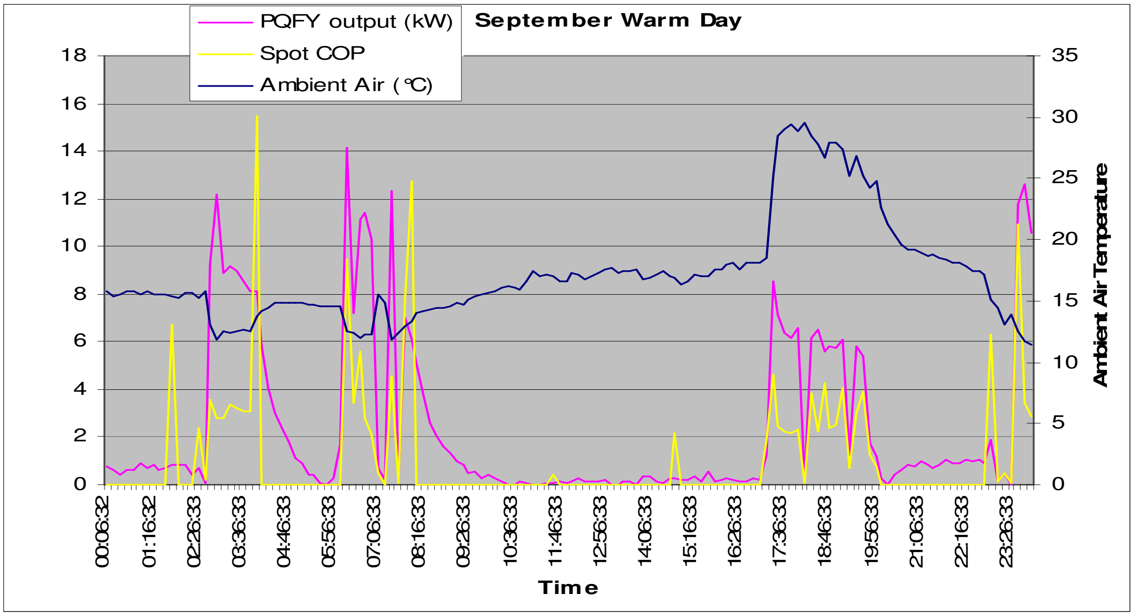
September 2008



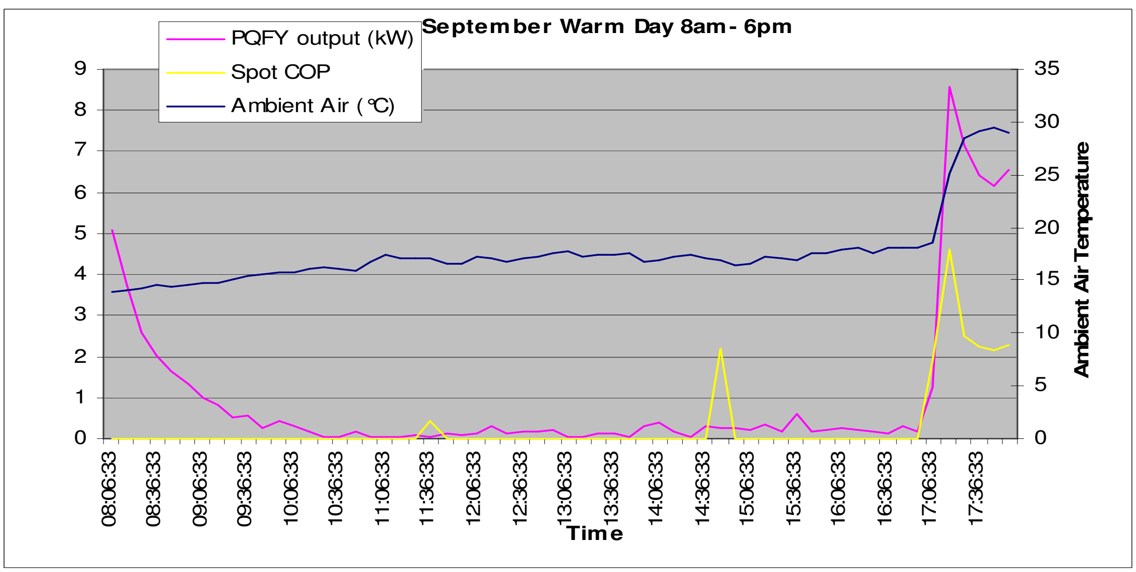
The PQFY ran for 208 hours total (of a total of 731 hours) in September (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was only on for about a 25% of the time, but was heating for 159 hours and cooling for 49 hours. This level of cooling is approximately what we would expect to see at this time of year but typically you might expect to see a higher level of heating. The ambient temperature of 13.8°C is typical for the month of September and the amount of heating / cooling that was required is what we would expect for this time of year. The high COP again reflects the mild temperatures recorded during this month.

September Recorded Data

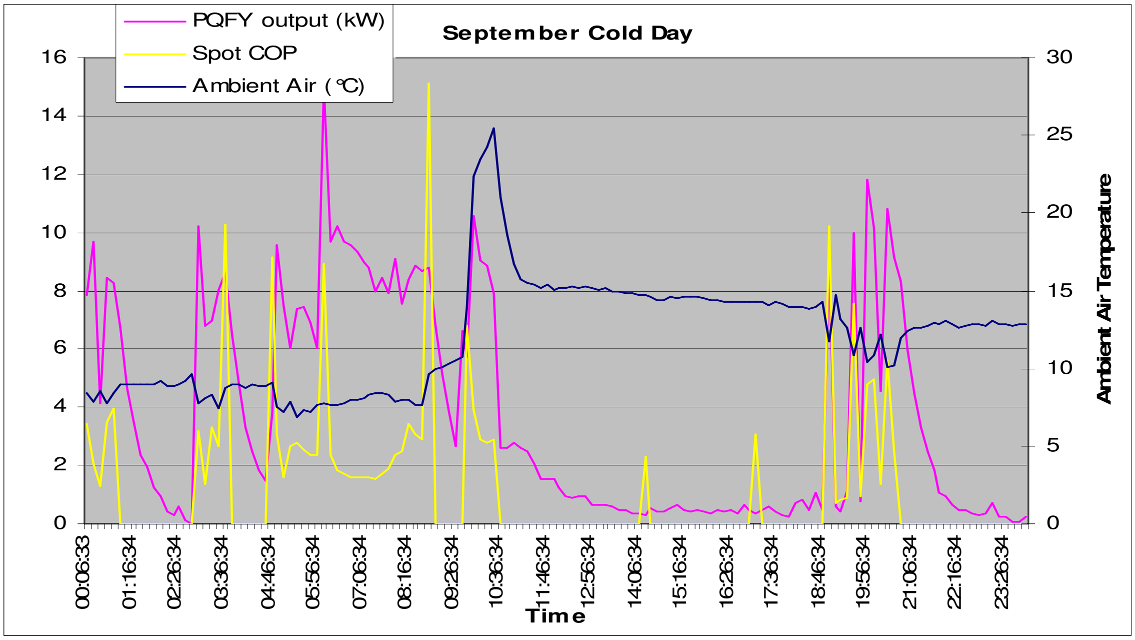
Total kWh output	2047kWh
Total kWh input	515kWh
COP	**3.97**



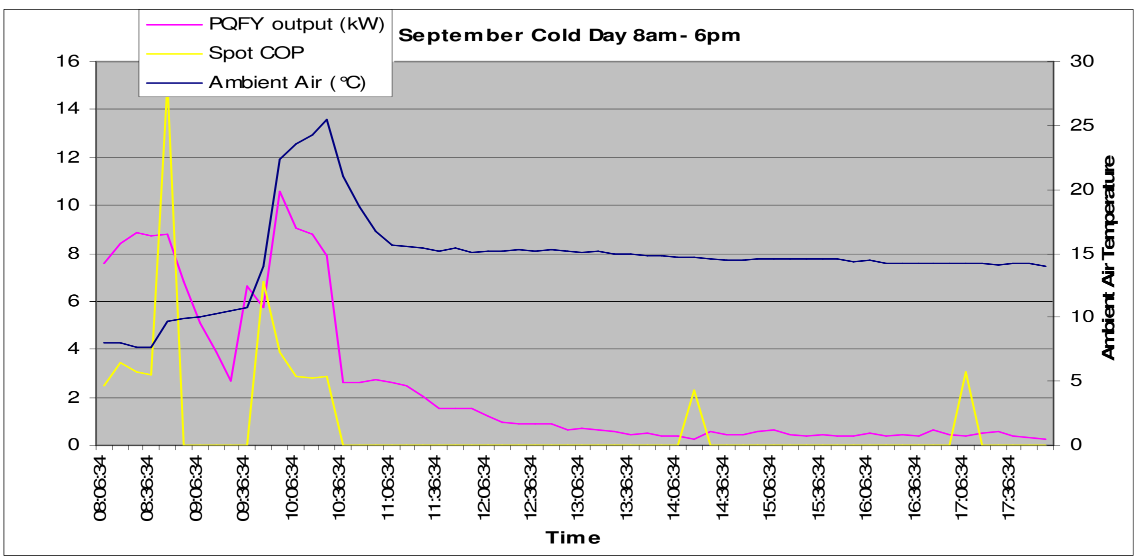
The above graph shows the PQFY power output, spot COP and ambient air temperature for a warm day in September. Again the PQFY starts up early in the morning then switches back off around 10:00. This is to heat up the office in the morning when the ambient temperature is lower, it then switches off during the day whilst the weather outside is fairly warm (the daily average is 16.2°C) it stays switched off until 17:00 hours then turns back on when temperature is at its peak to cool the space down. Again you can see the impact of the thermostat from around 02:30 until 05:00 and 23-:00 hours onwards when the room temperature must have dropped below 21°C.



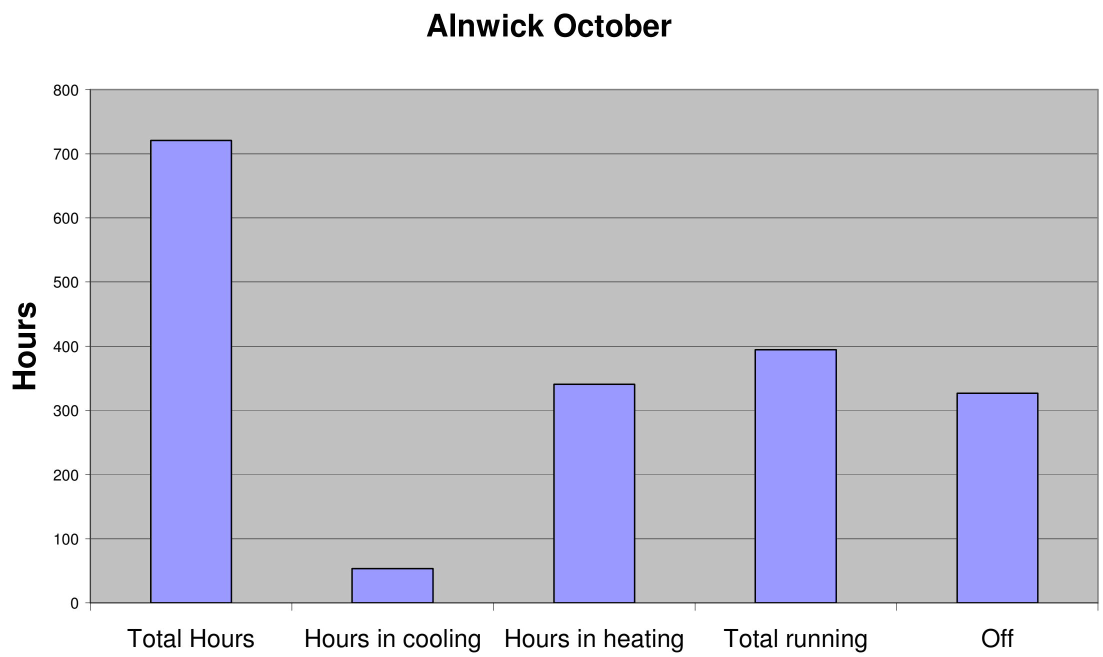
On this September warm day during the main office hours the unit is operating at a low level until approximately 17:00 hours when cooling is activated to counteract the rise in ambient temperature. This is necessary to ensure the office space doesn't become uncomfortably warm for those using the offices. On this day the COP is low as the PQFY has hardly any output. When the PQFY output rises, the COP also moves up to approximately 4.6 which is a reasonably high COP. The ambient temperature rise at 5pm could be due to partial short cycling of the system.



The above graph shows the PQFY power output, spot COP and ambient air temperature for a cold day in September. On this day the average temperature was 11.5°C. Between 12:00 and 13.00 hours the PQFY unit is running this is due to the lower ambient temperatures, then as the ambient temperature rises, the PQFY unit switches off as it is not needed to provide additional heat to the building. Again, when the ambient temperature drops the PQFY switches on to maintain the indoor temperature. It works continuously in this way maintaining the heat inside the building when the outdoor temperature drops. The PQFY system appears to be partially short cycling between 06:00 and 11:00 hours.



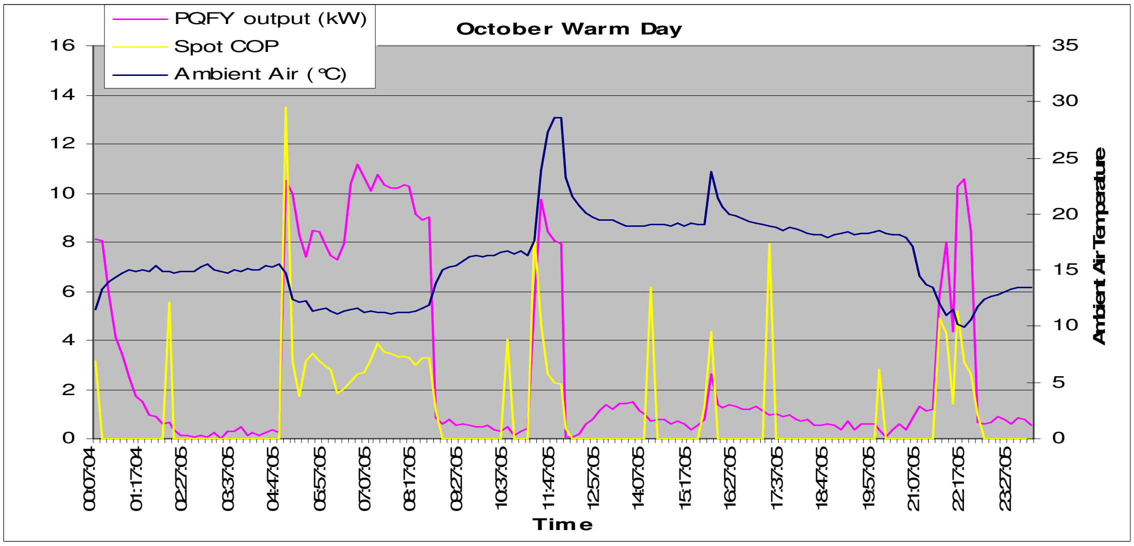
During the office working hours on this cold day in September the unit is simply used to heat up the office in the morning and then maintains that heat for a while until approximately 11:40 hours when the ambient temperature is settled at a higher level and the indoor heat no longer required. The COP goes up as the PQFY output does, then drops as the PQFY is left ticking over.



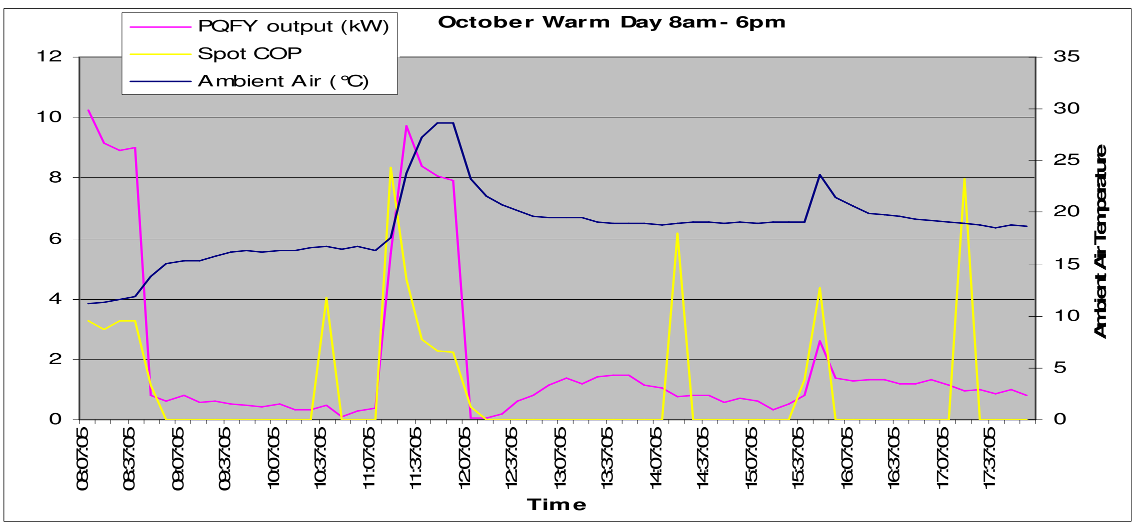
In October the PQFY ran for 394 hours of a total of 721 hours. (Where the average kW power input was < 0.1, the unit was assumed to be off). The unit was on for just over 50% of the time, but was heating for 340 hours and cooling for only 54 hours. This is the first month in which there was a substantial amount of heating and very little demand for cooling. However, this is to be expected as autumn temperatures can be significantly lower. The COP for October is slightly lower than the others months which reflects a large average ambient temperature drop. This month had an average ambient temperature of 9.7°C.

October Recorded Data

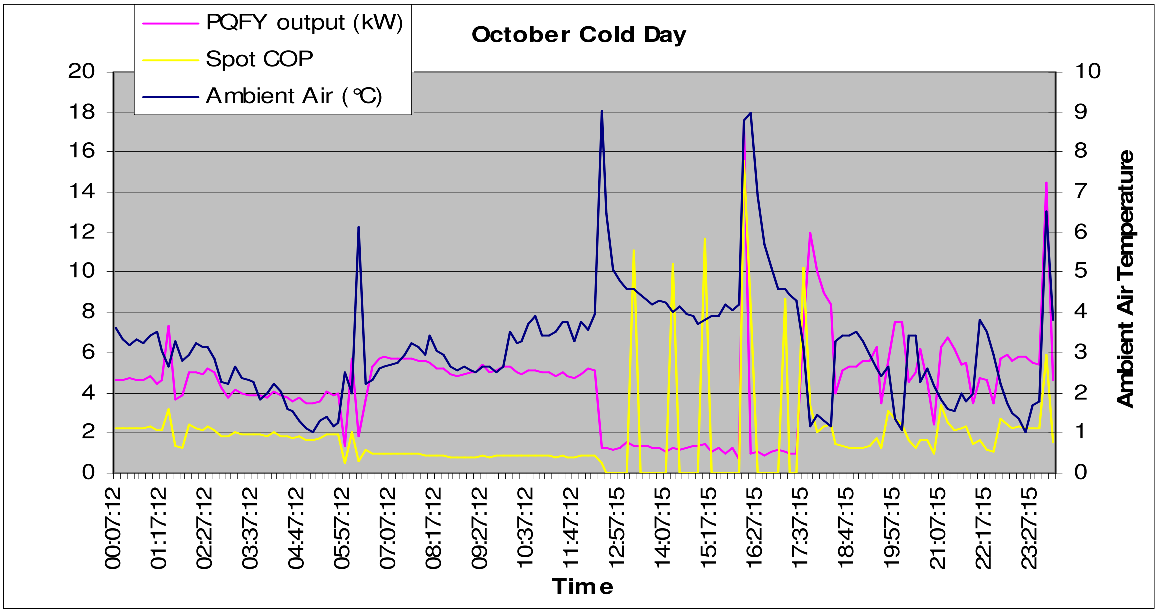
Total kWh output	2876kWh
Total kWh input	1193kWh
COP	**2.40**



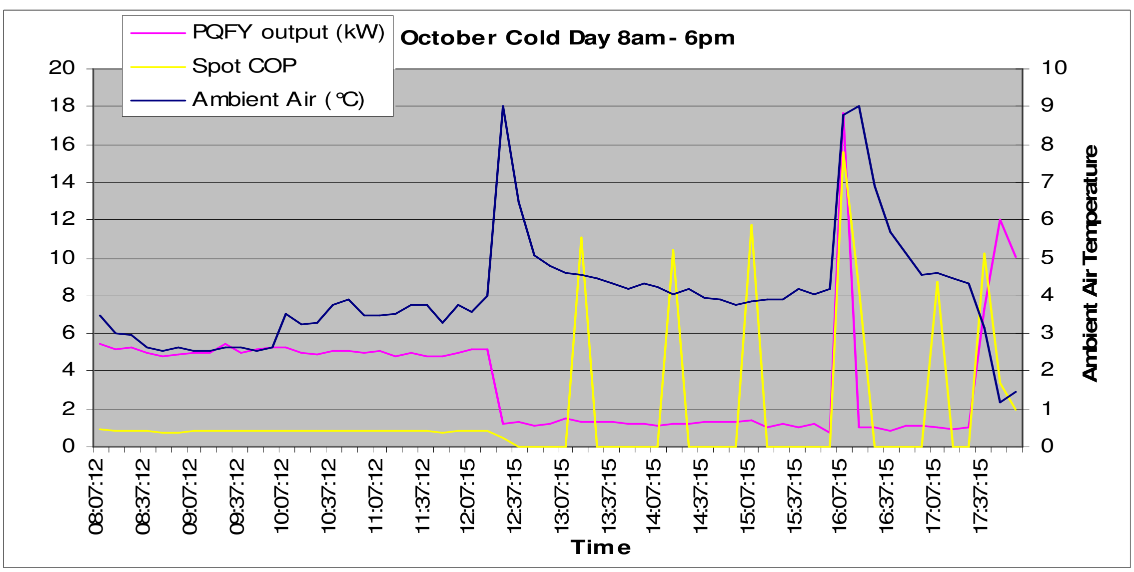
On this warm day in October the average temperature was 15.8°C which is much higher than the monthly average. The graph shows that early in the morning the unit switches on to heat up the office and switches off just before 09.00 hours. At 11:00 the unit switches back on again to cool the building for approximately one hour as the outdoor temperature is unusually high. The unit then stays switched off until around 20:30 hours when the ambient temperature drops back down again and the thermostat switches on the PQFY to maintain the heat within the building. When the PQFY unit is switched on the COP levels have a direct relationship with the output, as the output increases so does the COP.



During the working hours of this warm day in October the PQFY is used for both heating and cooling. It uses both functions to ensure a comfortable indoor temperature is provided for people using the office between 09:00 and 17:00 hours. On this day the COP is around 3 in the morning during the heat up, and a peak of 8 occurs during the cooling later in the day. These are reasonably high levels of COP however the unit is switched off for a sustained period of time which allows for these COPs to level out.

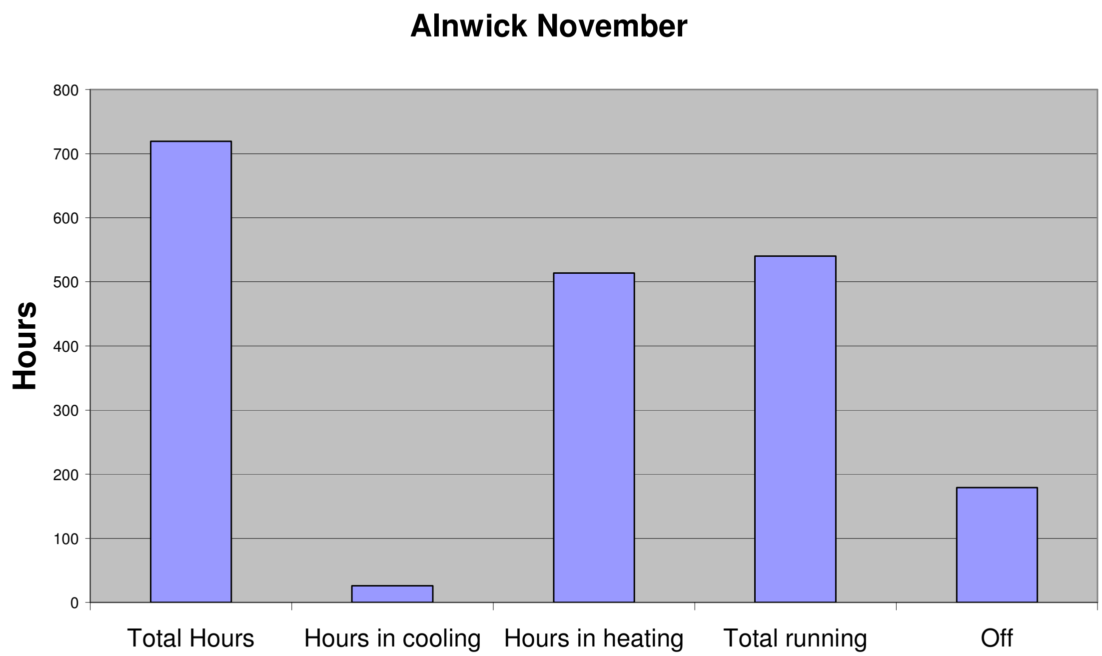


This cold day in October gives totally different results to that of the warm day in October. The average temperature on this day is only 3°C. The constant cool temperature throughout the day means that the system needs to stay switched on at a very low output to maintain a comfortable level of heat within the property to enable people inside the offices to work productively. This means that unit isn't heating but is still switched on to react to any heating needed as quickly as possible. Due to the cold ambient temperature there would be no demand for cooling. The COP on this day jumps up and down due to the unit running at low duty for considerable amount of time. When the PQFY is switched on at a higher output more constantly the COP levels out.



During the office hours on this October cold day the PQFY unit is needed at a higher output as the ambient air temperature is low. The unit simply heats throughout the working hours and peaks whenever the indoor temperature drops to ensure a constant level of heat inside. The COP between these times has a few peaks which indicate the system switching to a slightly higher or lower output.

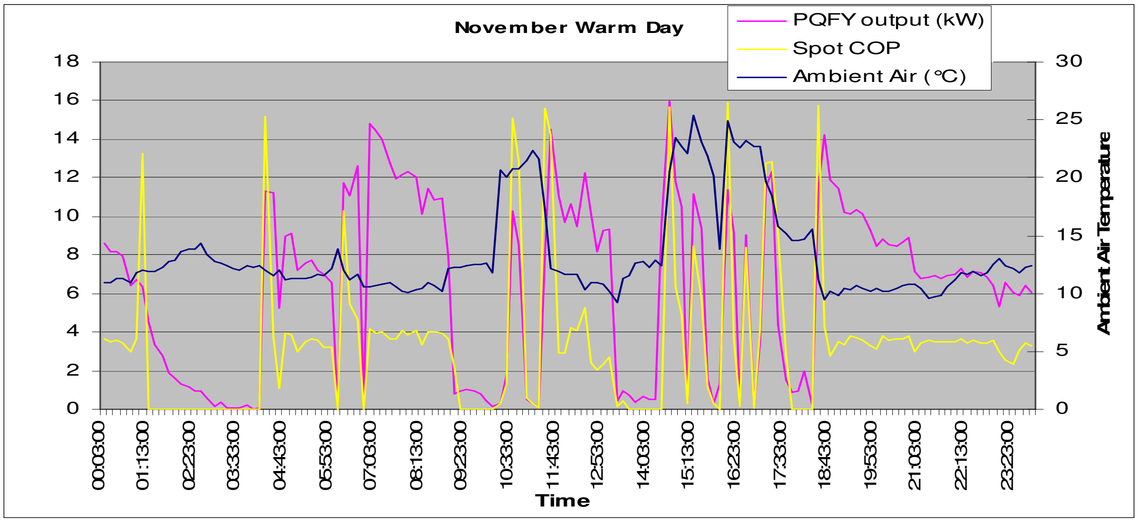
November 2008



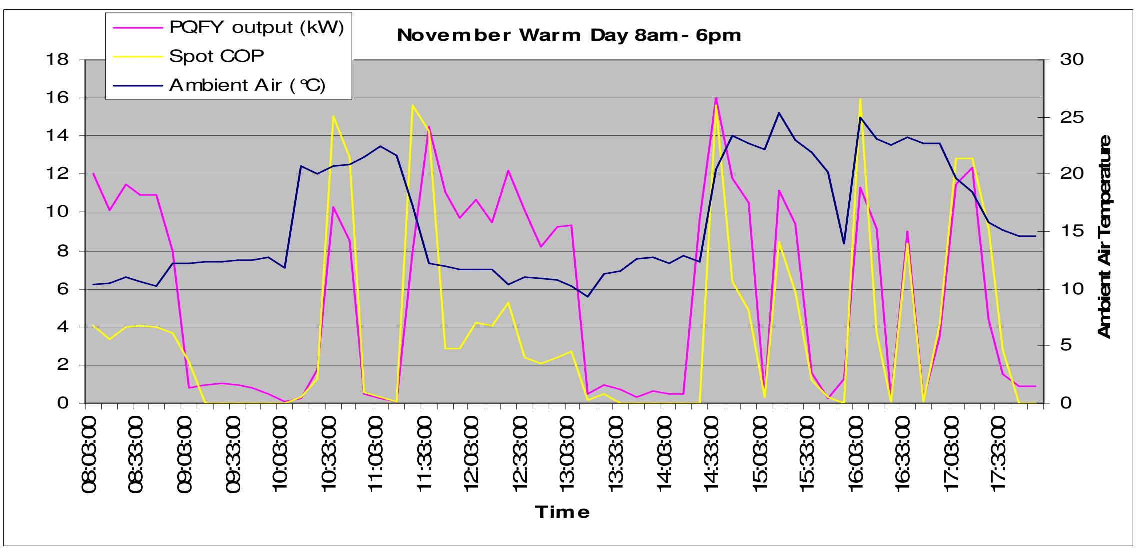
In November the PQFY ran for 540 of a total of 720 hours, (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was only on for 75% of the time, but was heating for 514 hours and cooling for only 26 hours. Some of the cooling load could be attributed to the unit going into defrost mode. However, even in this cold month the PQFY heat pump is still able to operate at an average COP of 2.87 which is a highly efficient level for the temperatures typical of this time of year. The average ambient temperature for this month was 6.9°C which explains the high level of heating.

November Recorded Data

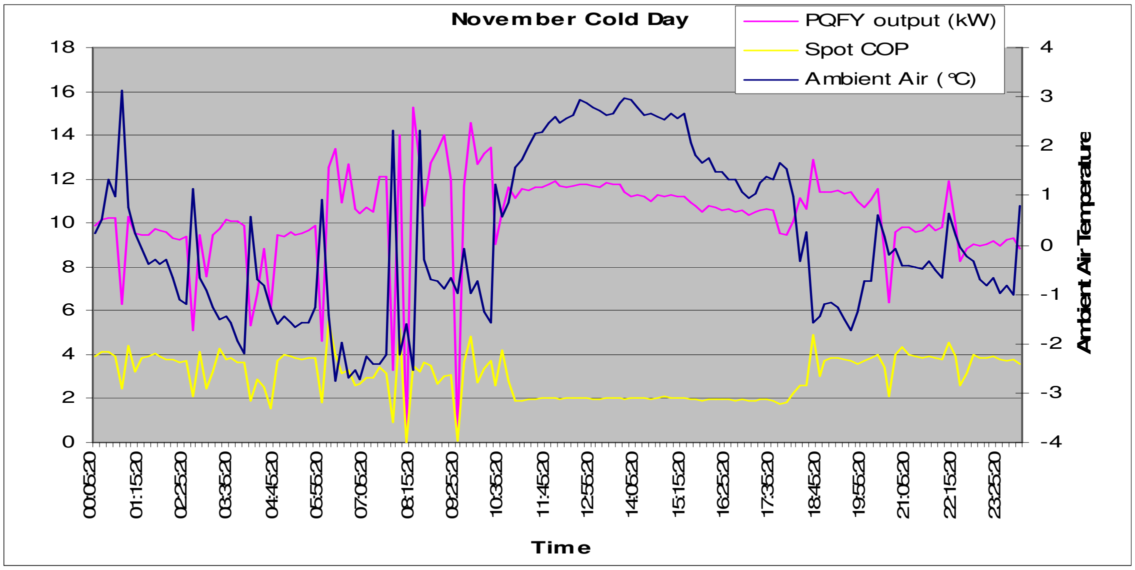
Total kWh output	4293kWh
Total kWh input	1495kWh
COP	**2.87**



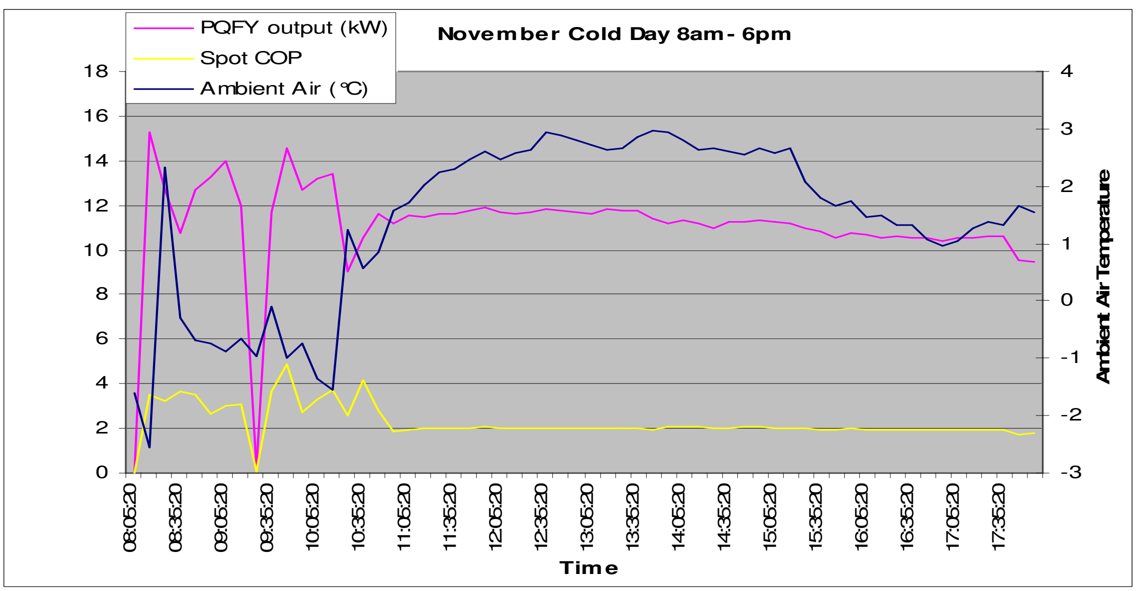
On this warm day in November the PQFY was switched on for most of the day. The average temperature was 12.4°C which doesn't seem very high however there are points during the day when the ambient temperature reaches between 20°C and 25°C which are high temperatures for this time of year. This explains the cooling needed on this day. The system was switched on periodically to keep a moderate temperature in the building. The graph shows that the level of power output from the PQFY varied by cooling when the ambient temperature increased and the indoor temperature started to rise and then stopping as the indoor temperature reaches its target level. You can see on this graph that when the PQFY unit is switched off the COP also drops down to zero, but as soon as the PQFY is switched back on the COP levels rise quite quickly and maintain a high overall level of COP. This shows it is able to reach high efficiency in a fairly short amount of time. This cooling explains a large part of the 25 hours of cooling found in the monthly break down for November.



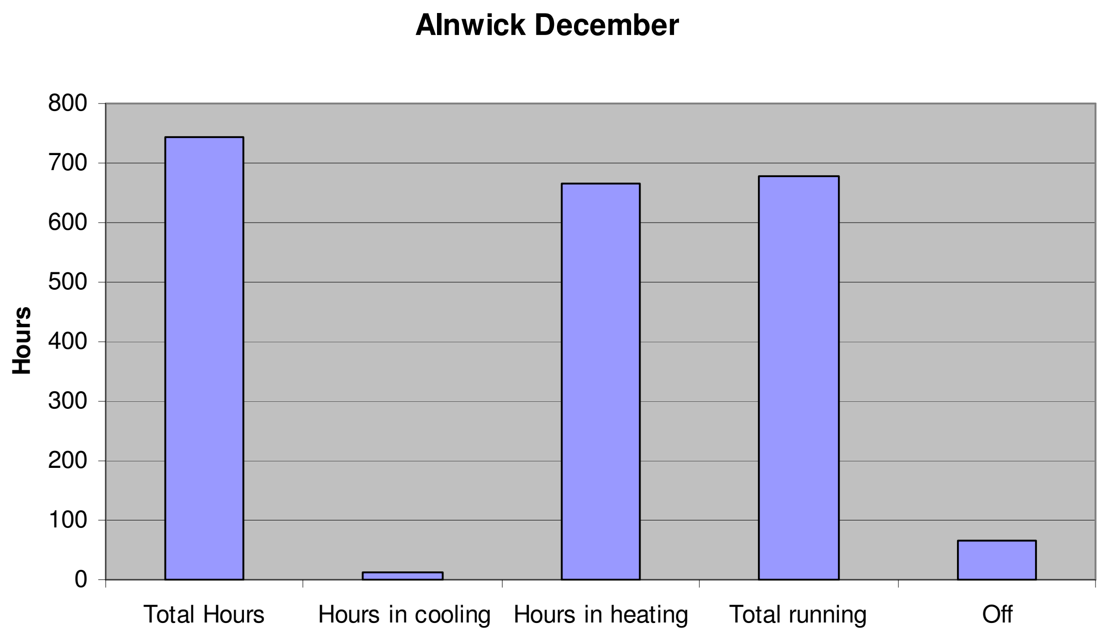
During the office hours on this November warm day the PQFY system is cooling inside the building. The majority of this cooling happens within the office open hours. The system is almost constantly switched on and starts to cool just after the rise in ambient temperature which indicates the systems reacting to the ambient air conditions. The COP on this day is varied along with the PQFY output and increases when the output does. Overall there is a high COP for this day.



On this cold day in November the PQFY heat pump was again working constantly at a high power output. The ambient temperature on this day was very low with an average temperature of 0.1°C. The heat pump was running constantly to ensure the building temperature didn't drop too low and maintained a warm enough environment for people inside the building. Despite the cold weather the unit constantly gave out high COP levels, ranging mainly between 2 and 4.5. The unit entered defrost mode at around 8.00 and 9.00, this is indicated by low PQFY output and low COPs. After this period the system quickly returns to heating mode, maintaining a good level of COP.



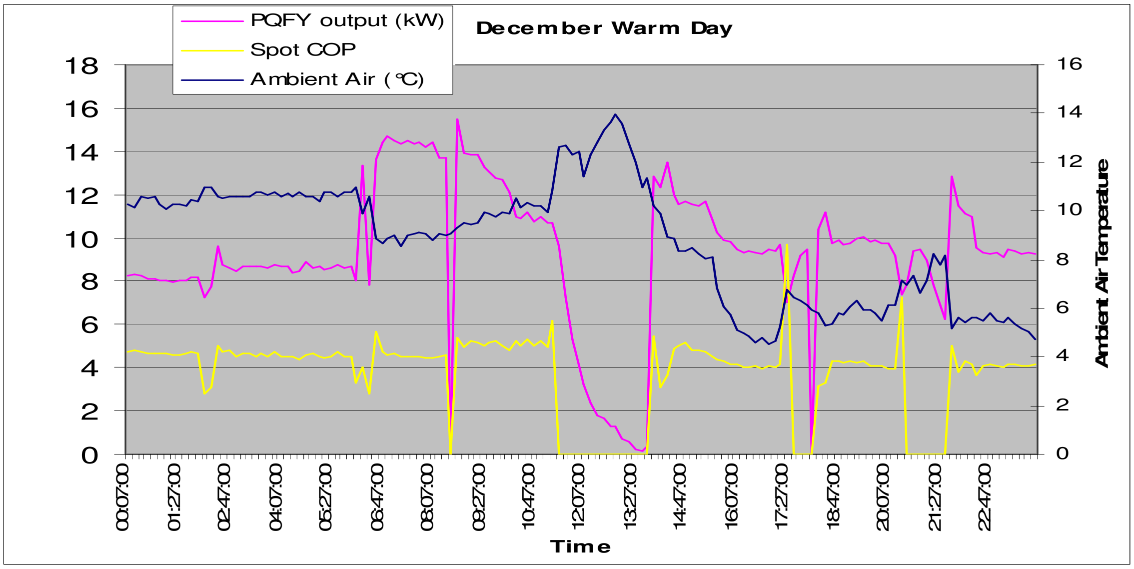
During the office working hours on this cold November day the average temperature was very low and the office needed heating. In the morning at approximately 08:30 the ambient temperature rises then falls and is fairly unstable until 11:00. Until this point the PQFY system is also varying its output to reach its target indoor temperature. The COP levels reflected the same pattern at the beginning of the day and then levelled out to almost constant from 11:00 onwards.



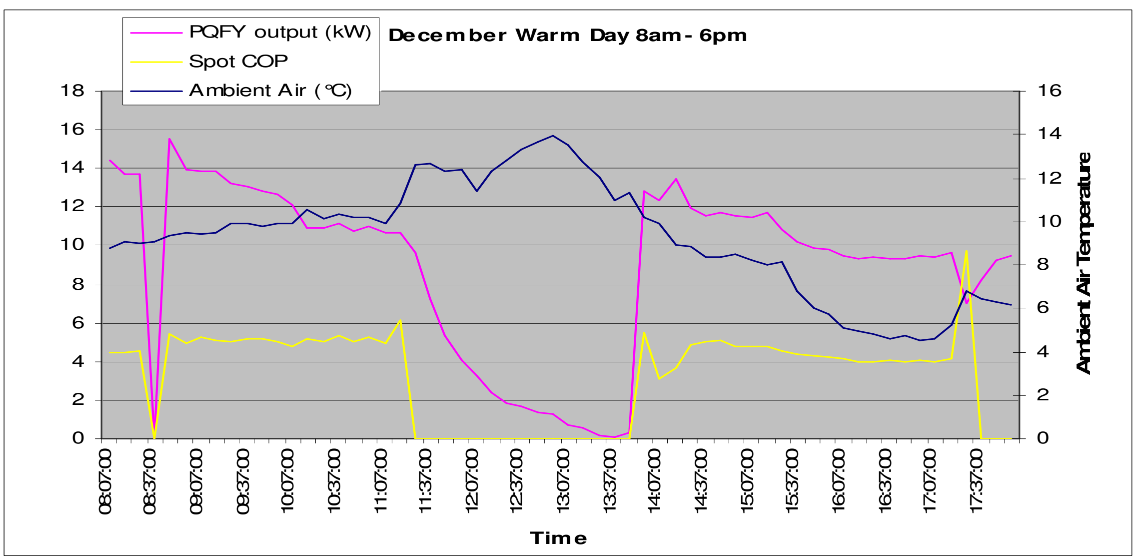
In December the PQFY had 678 running hours of a total of 743 hours, (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was off for (65 hours) approximately 10% of the time. It was heating for 667 hours and cooling for only 11 hours. The large amount of heating reflects what we would expect to see at this time of the year as the temperature is much colder than most other months with an average temperature of 4.4°C. Again the COP of 3.49 is high for the winter months and demonstrates the PQFY units' ability to extract heat energy from the air even at very cold temperatures.

December Recorded Data

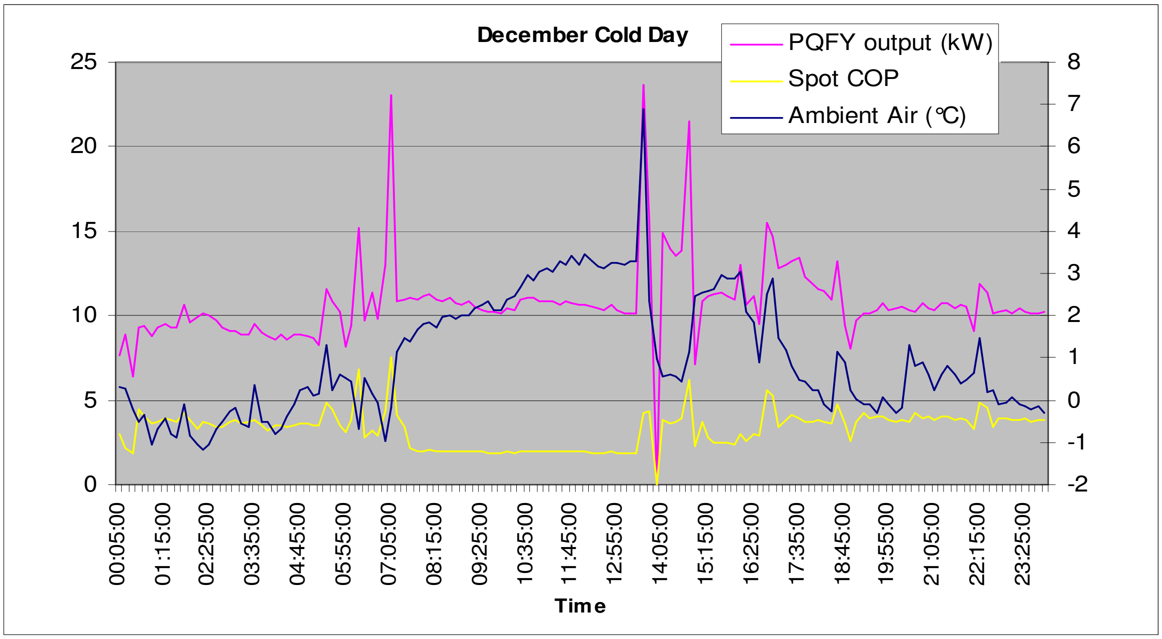
Total kWh output	7102kWh
Total kWh input	2030kWh
COP	**3.49**



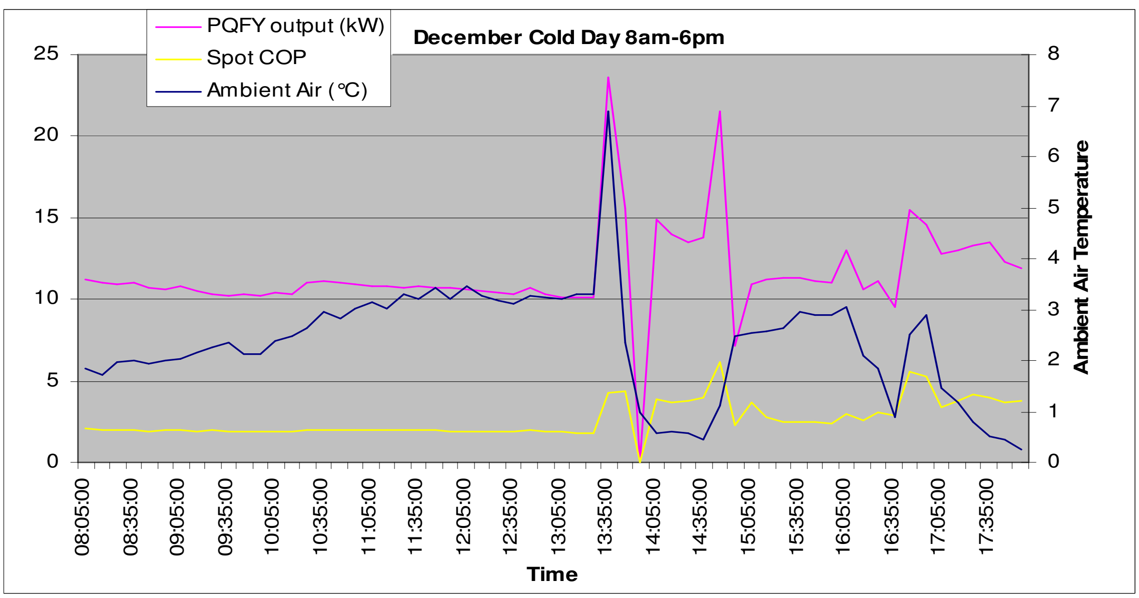
On this warm December day heating is required throughout the day to ensure the internal temperature keeps to the target temperature. The average ambient temperature for this day is 8.7°C. The COP is constantly high which could be due to the milder outdoor temperatures. The PQFY output starts off lower at the beginning of the day and then increases at around 06:30 hours when the ambient temperature decreases. This increase in PQFY output is to compensate for the drop in ambient temperature as the PQFY has to work harder to maintain the same level of heat inside the building. At 12:00 hours the PQFY unit switches off as the building no longer needs any more heat. The system quickly switches back on as the ambient temperature drops again.



During the main office working hours on this day there was an almost constant demand for heating. Although this was the warmest day in December this day is fairly typical of the month because it is still cold. The PQFY output balances with changes in ambient temperature to reach indoor temperature equilibrium. This is illustrated well by a fairly constant level of high COP. This indicates the system is working efficiently even in one of the coldest months of the year.

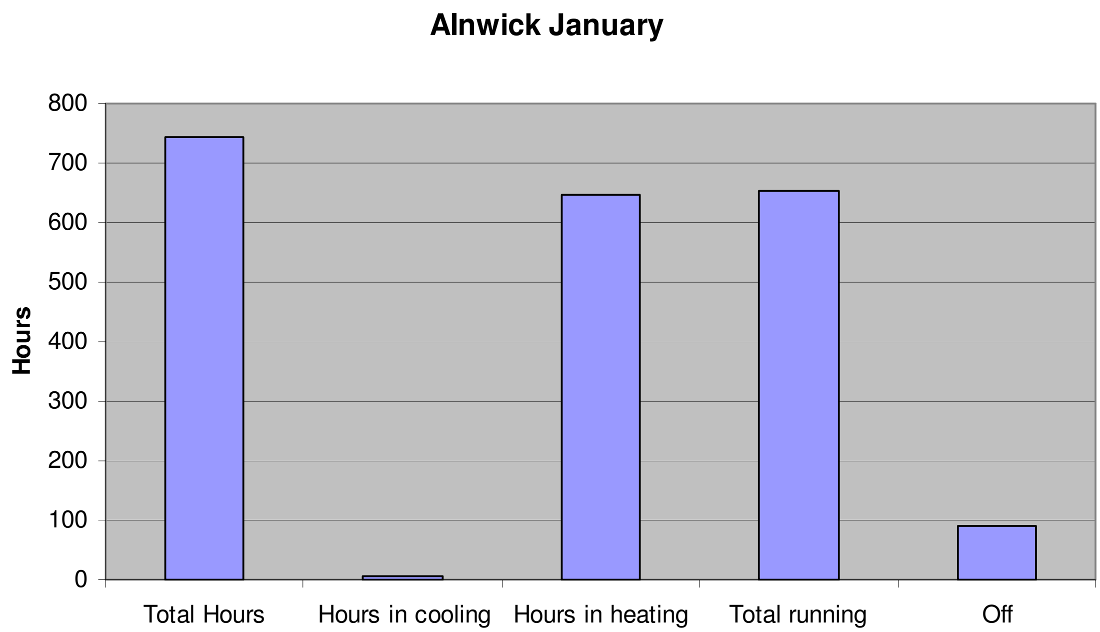


On this December cold day the average temperature was 0.9°C. The graph shows that the PQFY unit was consistently running at 10kW or above. The COP levels were high despite cold ambient temperatures, as low as -1.1°C. This is due to the ability of the PQFY to operate at very low temperatures by extracting existing heat energy. The temperatures recorded on the graph are fairly typical of a cold December day with the highest temperatures in the middle of the day and very low temperatures in early morning and evening. There were no cooling requirements for this day due to the low ambient temperature but the heating requirement was constant.



During the main office working hours on this day there was an almost constant demand for heating. This is typical of the winter months. The PQFY output balances with changes in ambient temperature to reach indoor temperature equilibrium. It appears that the system may have gone into defrost mode around 14:00 hours when the PQFY output seems to drop dramatically, which results in a near zero spot COP. For the rest of the day though we see a fairly constant level of COP. This indicates the system is working efficiently even in one of the coldest days of a winter month.

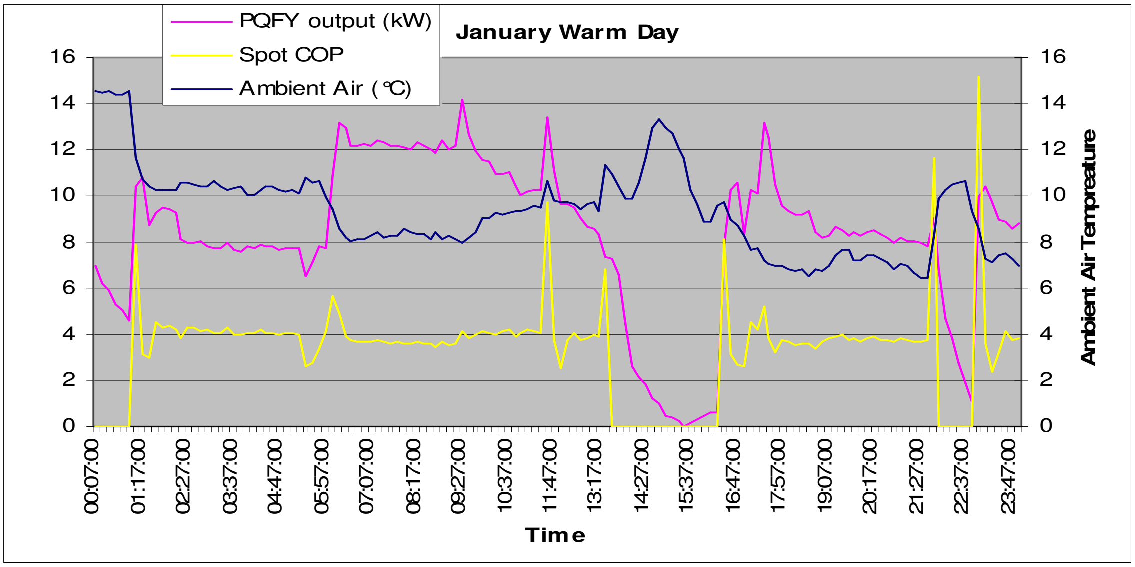
January 2009



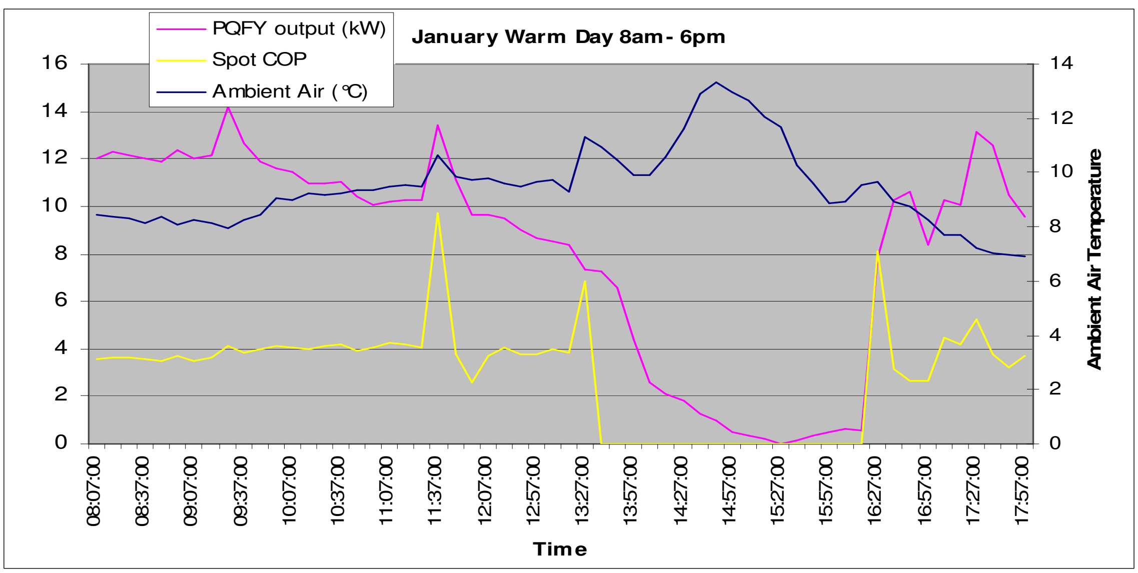
In January the PQFY has 654 running hours of a total of 744 hours. (Where the average kW power input was < 0.1, the unit was assumed to be off). The unit was on for approximately 90% of the time, was off for just over 90 hours, was heating for 647 hours and cooling for only 7 hours. This data is what would be expected of January. January is a cold month which will always require a lot of heating to ensure you can keep the indoor environment at a suitable temperature. The average temperature for this month was 4.5°C. The COP of 2.82 was to be expected, as the ambient temperature is much colder, therefore the PQFY unit has to work harder to maintain the same level of indoor temperature.

January Recorded Data

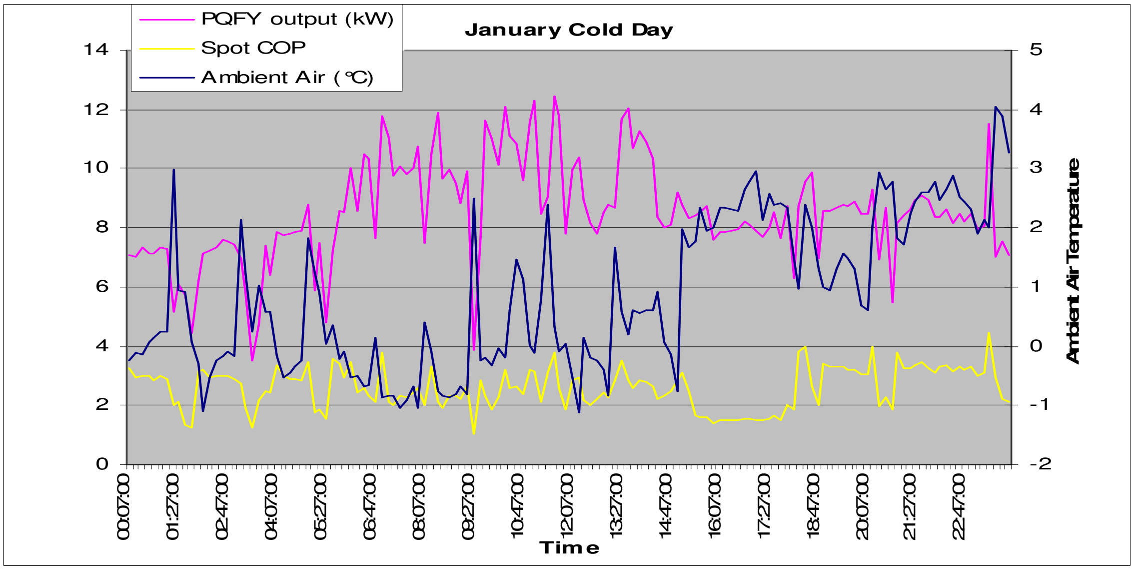
Total kWh output	5711kWh
Total kWh input	2083kWh
COP	**2.74**



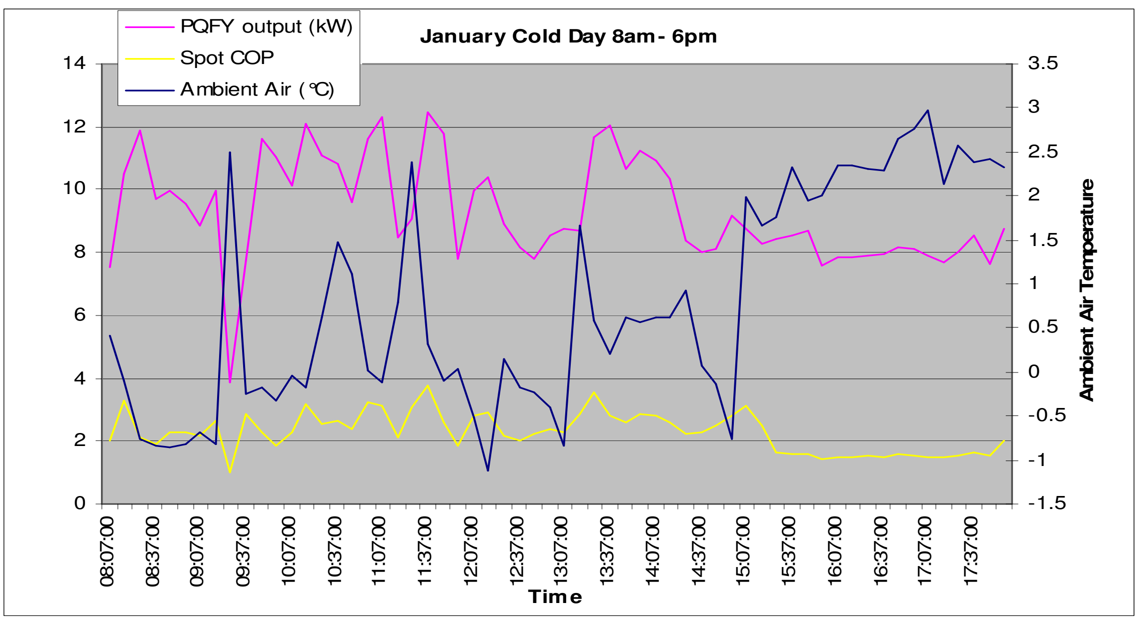
The graph above measures the PQFY power output, spot COP and ambient air temperature. On this warm day in January the average temperature was 9.2°C. The graph illustrates how the PQFY was providing underfloor heating consistently from 00:00 until 15.00 hours. Then again from 16:15 hours onwards the heating starts again after a short gap. This gap is the system achieving a suitable indoor temperature allowing the PQFY to switch off for a short period of time. Looking closely at the ambient air temperature and PQFY output this closely mirrors each other throughout most of the day. The COP on this graph changes slightly as the ambient temperature does, this is because at a higher ambient temperature the system doesn't have to work as hard to maintain the same internal temperature.



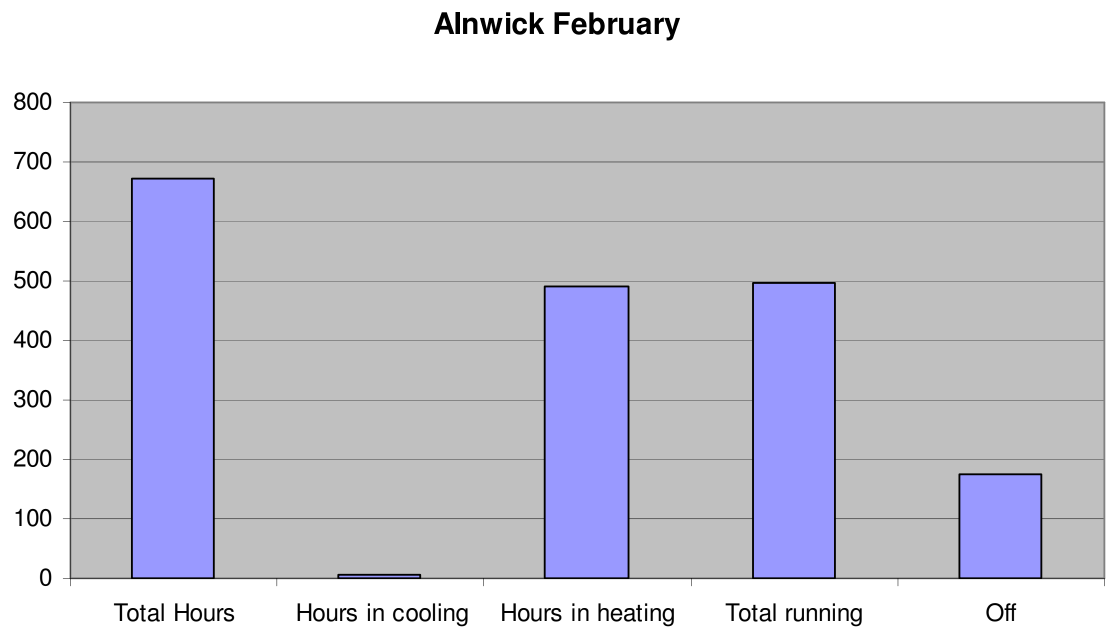
The above graph shows the PQFY output, spot COP and ambient air temperature on a warm day in January during the office working hours 8am- 6pm. During this time there was a large demand for heating from 08.00 until 15:00 hours and then from 16:15 hours onwards. This shows that the system had reached and maintained its target temperature and was no longer needed between these times. By comparing the two above graphs we can see that on the full day graph at 00:00 there was no demand for heat so the system had turned off indicating the indoor temperature was satisfied at 21°C when presumably the office space is unused. This indicates a potential for energy saving if a night set back mode was used it would only target temperatures of perhaps 17/18°C saving energy and money.



On this cold day in January the ambient temperature has a fairly large amount of fluctuation to it, the average ambient temperature is 0.86°C. The fluctuations are somewhat out of the ordinary but could well be naturally occurring heat changes through wind direction etc. However, the PQFY output and spot COP levels are what we would expect them to be in comparison with the fluctuating ambient temperatures enabling the PQFY to heat up the building to a comfortable level inside.



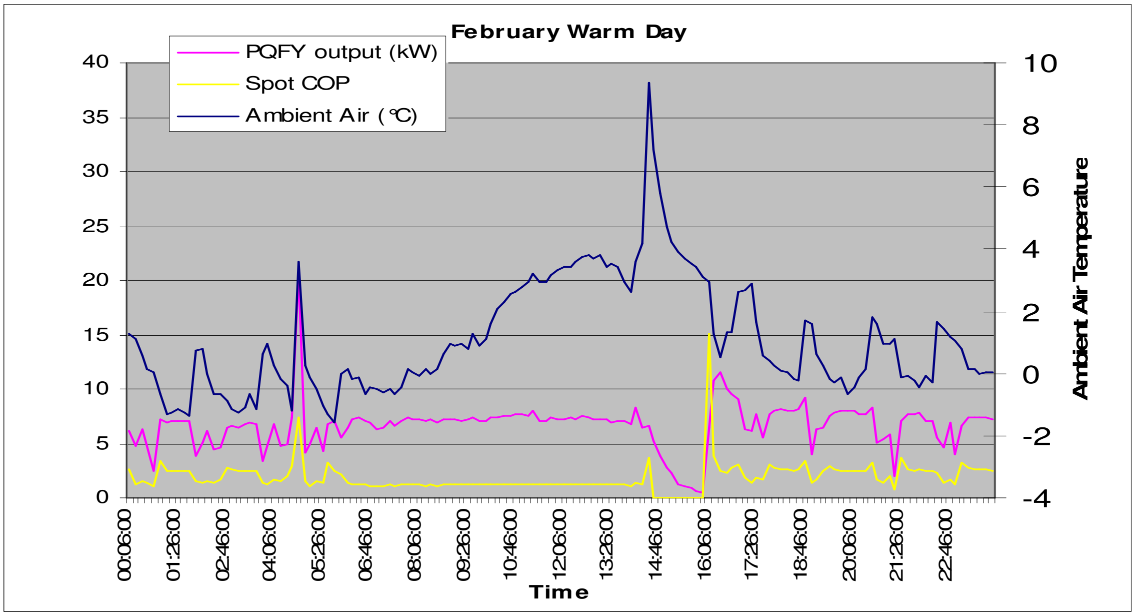
During the office working hours it is clear that the heating on this day is in constant demand due to the cold ambient temperatures. As the ambient temperature rises there are small dips in the PQFY power output to compensate. The COP level is fairly constant and is what may be expected of a day where the ambient temperature is fluctuating. Furthermore this graph shows us the amount of heating happening during the out of office hours i.e. from 00:00 until 08:00 hours and again from 18:00 until 00:00. If we compare the two above graphs we can see there is a large amount of heat being generated late at night and early in the morning which cannot be used as the office is presumed to be unoccupied at these times. There is potential for saving by not heating the office to the same level during the evening and early morning as you do in the day as there will be different temperature demands during these times.



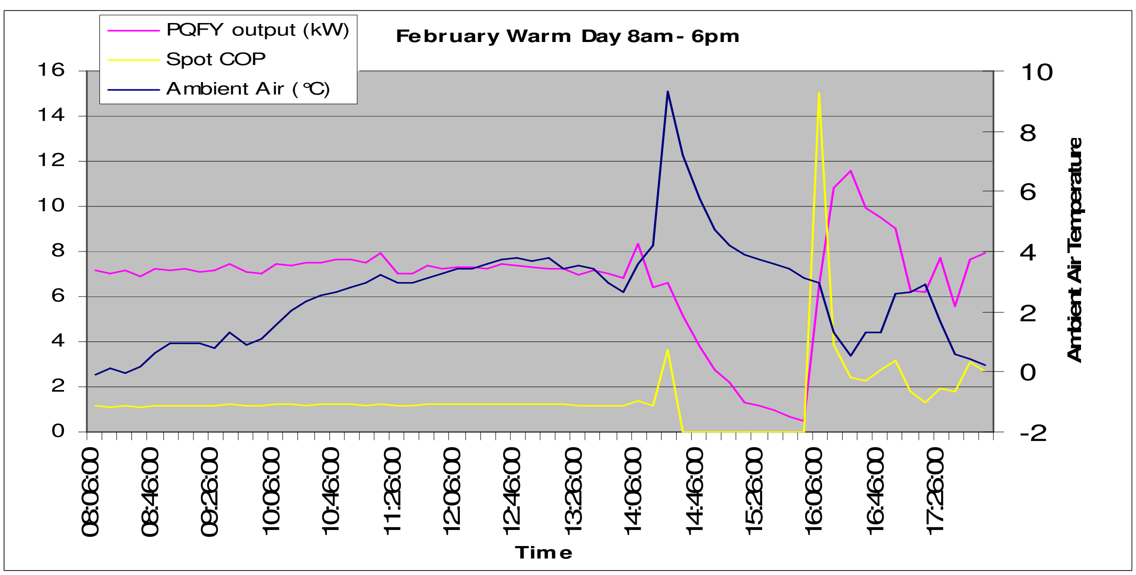
In February The PQFY ran for 497 hours total of a total of 671 hours, (where the average kW power input was < 0.1, the unit was assumed to be off). The unit was only on for 75% of the time, but was heating for 490 hours and cooling for only 7 hours. This is typical of February weather especially for February 2009 which had an unusually high volume of snow for the UK mainland. The average temperature for this month was 4.87°C. The COP we recorded for this cold winter month was as expected. The cold ambient temperatures and heavy snowfall however, does not seem to have affected the performance of the system at all, but it could explain a small amount of cooling encountered as the unit will have entered the defrost mode on a number of occasions.

February Recorded Data

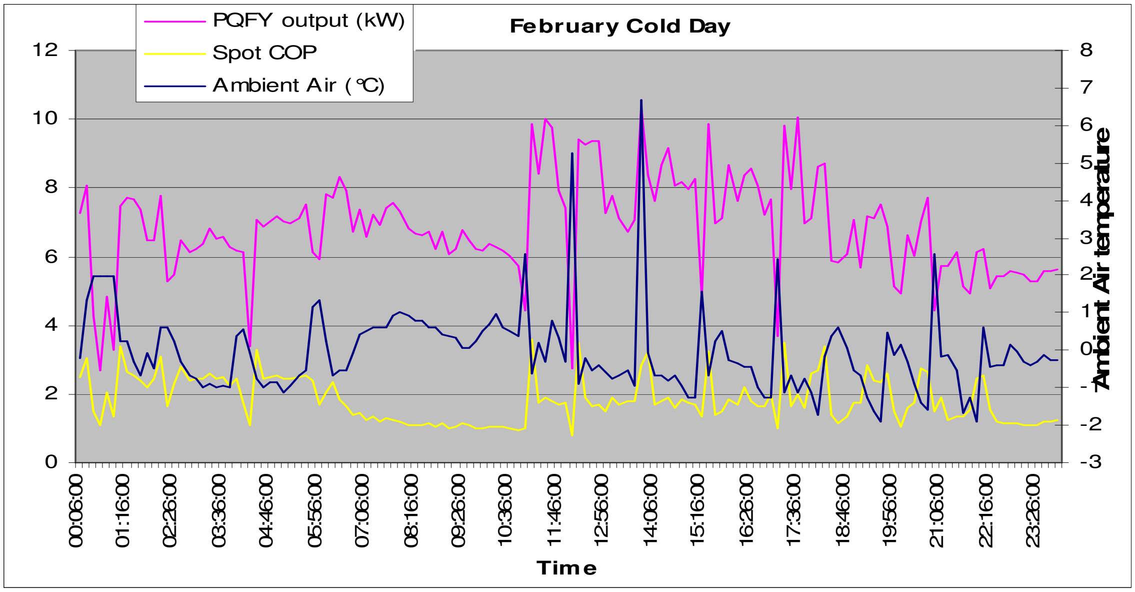
Total kWh output	4300kWh
Total kWh input	1782kWh
COP	**2.41**



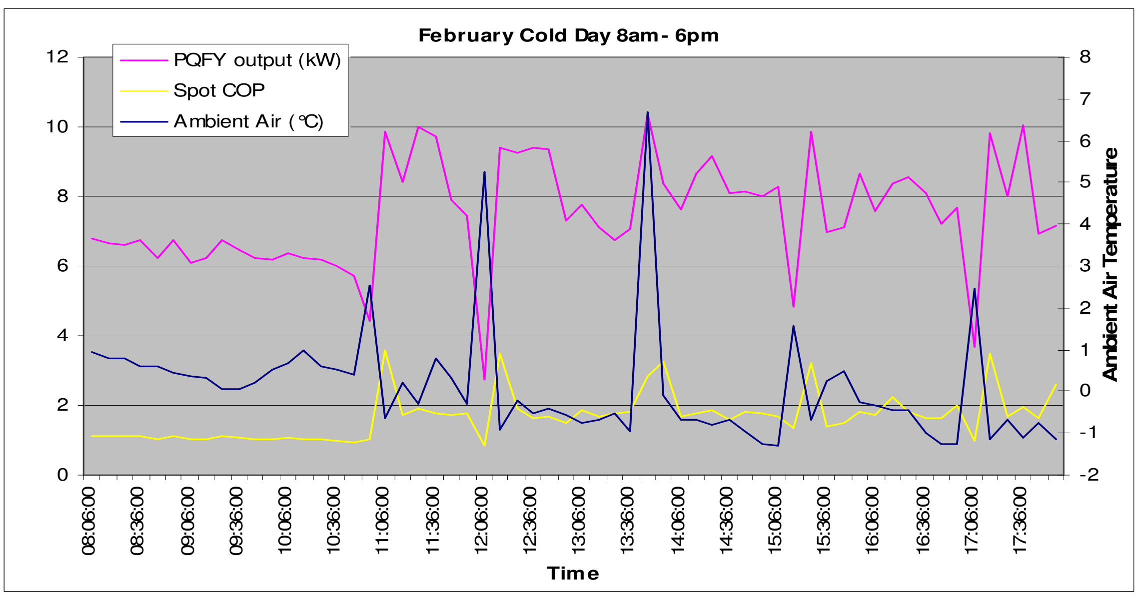
This graph shows a warm day in February measuring the PQFY power output, spot COP and ambient air temperature. The average temperature for this day was 1.08°C. On this day the heating ran continuously until 16;00 hours. The unit was only off for a short period of time and quickly switched back on to carry on heating the office. This drop in PQFY output can be explained by a rise in ambient temperature at around 14:45 hours. After this point the system restarted and carried on heating continuously. The COP on this day was quite steady with only small peaks. Constant heat throughout the night means that the heat up time in the morning will be shorter. However, if the indoor temperature at night is continuously high then the savings from shorter morning heat up time will be outweighed by the cost of heating through the evening. The ambient temperature peak of 9°C recorded at approximately 15:00 hours may have been caused by partial short cycling of the system.



On this warm day in February during the working hours of 8am until 6pm the unit ran almost continually maintaining a comfortable indoor temperature. The switched off for a short period of time at approximately 16:00 hours but quickly switched back on once the ambient temperature dropped back down again.



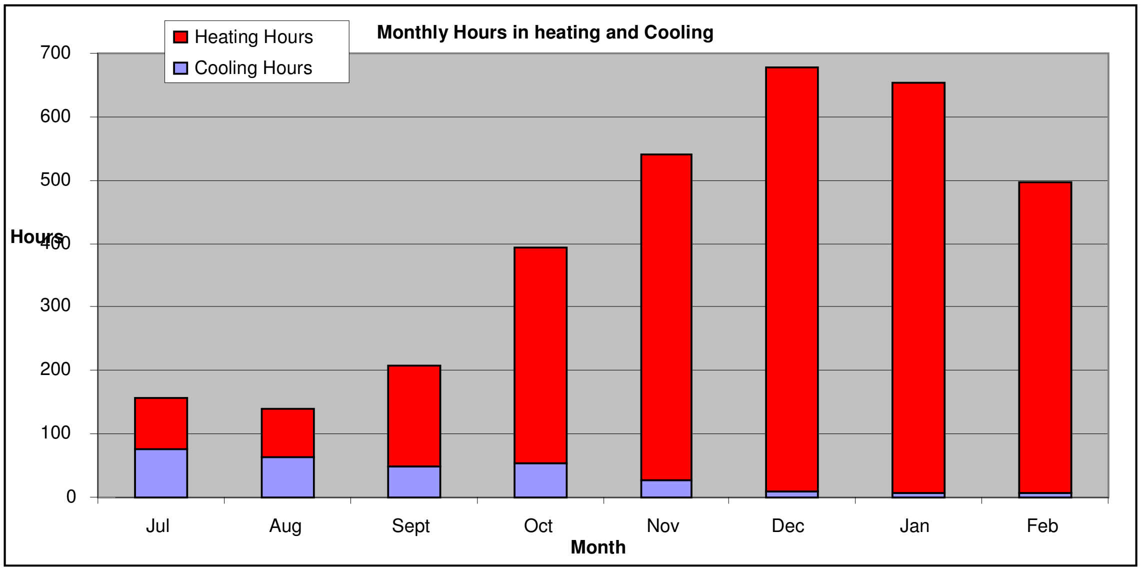
On this cold day in February the ambient temperature was again fluctuating. This could be due to the severe winter conditions and heavy snowfall which occurred around this time. The average ambient temperature for this day was -0.05°C. The unit was continuously heating due to the low ambient temperature. There would have been no demand for cooling at this time. The numerous peaks in ambient temperature recorded between 11:00 and 21:00 hours are likely to be the result of the PUMY unit going into defrost mode, and the heat generated by the unit in this operation.



During the office working hours 8am- 6pm the unit is needed for constant heating. The PQFY output of the system varies as the ambient temperature does as it is trying to maintain a level temperature inside the building. The COP stays at a constant level between 1 and 3.8 and rises as the ambient temperature does, this is because at higher ambient temperatures the heat pumps efficiency increases.

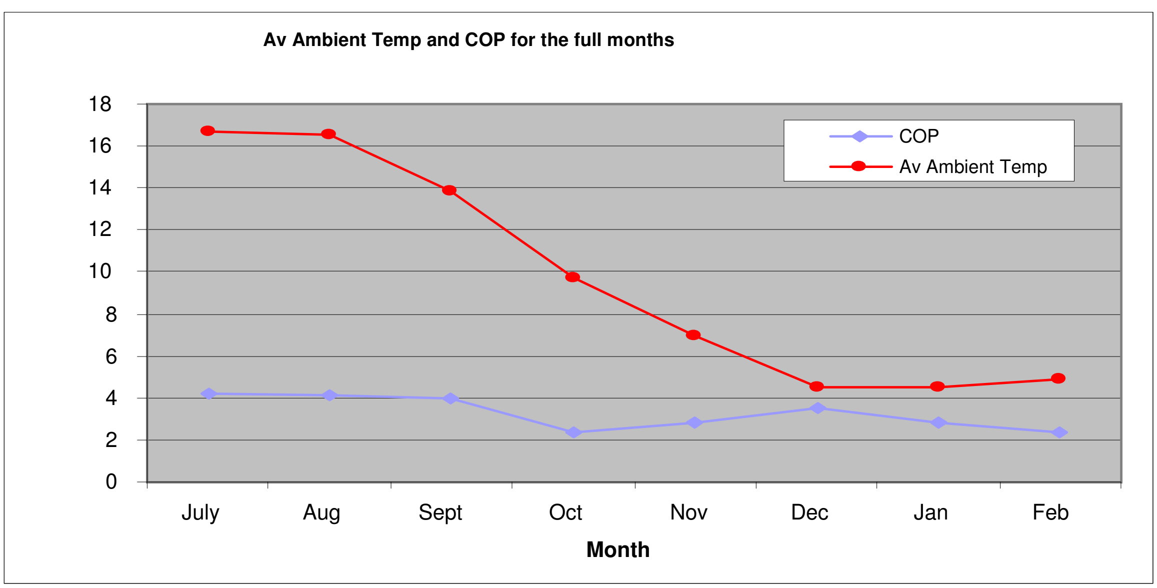
Conclusion

The PQFY system was monitored over 8 months. Throughout this time period the system logged information 24 hours a day 7 days a week. The system was working to heat or cool to the office building via the underfloor system when it was required. The system was linked to a thermostat with a set point of 21°C, which meant if the indoor temperature of the building dropped below 21°C then the heating system was activated. Similarly if the indoor temperature rose too high then the system would be activated in the cooling mode to restore the target room temperature.

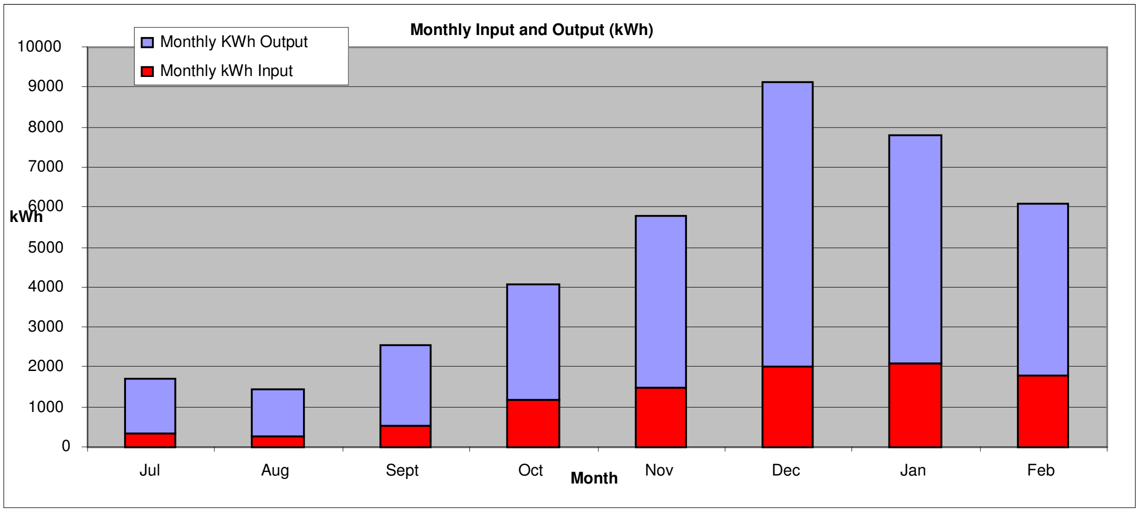


On the above graph we can see the amount of time spent in both heating and cooling mode in each month. From this graph we can see that there isn't a great demand for cooling and the heating has a very high demand over the whole period. As would be expected, the demand for heating rises during the autumn and winter months and demand for cooling falls. Although the total amount of cooling looks small in the summer months a large proportion of the PQFY activity is in cooling mode at this time. This graph also shows that this building requires a large quantity of heating throughout the year. This could indicate the possibility of saving energy by potentially heating to a lower level during the night time period (using night setback mode).

The average monthly temperatures and COPs are as follows in the graph below.



The graph below shows the amount of kWh needed to heat up the building during each month and how much of that is electrical input. The difference between the pink and blue colours is energy which is extracted from the ambient air.



When estimating our annual COP it would be fair to assume that there would be an increase in the overall COP. This is because the majority of months monitored for this case study were during autumn and winter and therefore have colder ambient temperatures. This means the machine has to work at a higher capacity to maintain the same indoor temperature, which in turn can lower the COP. As the remaining months of the year are through the summer we can assume the increase in COP would be approximately 10%. This would make the estimated annual COP 3.61.

During the data logging period we found that the main area for potential saving comes from the night time usage of the PQFY system. Currently the target temperature set via the thermostat is 21°C. This means that the system is constantly working to reach and maintain an indoor temperature of 21°C regardless of the day/time. Therefore at 11.59pm at night the indoor temperature of the office could be 21°C which is wasted energy as the office is unused at this time. The 08:00 -18:00 graphs indicate the main time that the building should need heating and cooling during the day instead of the whole 24 hours. The office hours of 09:00 to 17:00 hours are when the main demand for heating will be, but we also included an hour either side of this time period to allow for heating up and cooling down. Comparing the two graphs for each warm and cold day per month shows the potential for energy saving.

During the 8 month data logging period the system ran in heating for 91.1% and cooling for 8.9% of the time, which equates to an energy output of 26,315 kWh in heating and 2,571 kWh in cooling.
The total cost of running the system for 8 months is £800.17. However, the annual cost can be estimated by using our estimated annual COP of 3.61. This would make the annual cost of running the system £1,071.

In comparison to the above figures for running the PQFY heating and cooling system we can compare this to the most feasible alternative option available, which is a gas central heating system. The gas heating system would run at a maximum COP of 0.93. The amount of heating capacity required was 26,315kWh. Therefore, with an assumed cost of gas at 4p/kWh, the cost of heating via a gas heating system would total £1,131.83 for eight months and have a total annual cost of £1,479.78. Therefore PQFY systems total annual running cost at £1,071 is £408.78 cheaper than the alternative. The annual estimated cost for the gas system is calculated from months with similar average ambient temperatures to ensure the estimation is as accurate as possible. However, the estimated annual cost does not factor in the need for cooling which the PQFY provides. The gas central heating system is inadequate for a cooling purpose and therefore the running costs of an air conditioning system would have to be included in this.

Further to this, the cost of installation is much cheaper for the PQFY system than the gas central heating system. The gas boiler would have been approximately £3,000. In addition to this the building initially had no gas connection. A gas connection costs about £3,000 to install, and a gas meter about £2,000. Therefore an extra cost of £5,000 for the gas connection would have to be included in this final system cost. The total cost of fully installed gas heating system would be approximately £8,000.

Moreover the PQFY system also provides cooling to the property, the cost of this is included in the costs for the PQFY system. However, for the gas central heating option an air conditioning system would have to be installed which adds extra installation, maintenance and run costs.

Another comparison that can be drawn between the two options is the amount of CO2 emissions produced. Over the eight months the PQFY system would have given out 3,440.7 kg of CO2, and annually it is estimated the unit will produce 5,161.1 kg of CO2. Whereas, over the eight months the gas boiler would have given out 5,101.92 kg of CO2 which is almost what the PQFY system gives out in a year. Furthermore the annual total CO2 emissions the gas heating system produces would be 7,652.87 kg. This means by using the PQFY system the client is estimated to be **saving 2,491.77 kg of CO2** per year. This is over a 30% reduction in CO2 emissions.

Overall the system worked effectively and efficiently at providing heating and cooling with high COPs in a range of ambient temperatures. Moreover there was a prolonged period of snow in February and a colder than average October which proves the unit can work in more extreme conditions and still give COPs of more than 2.4 and higher. Overall the average COP for the case study period was 3.28 which is a high COP taking into account that there were only 2 months out of 7 that were not in either autumn or winter.

Further recommendations for additional energy saving

Changing from using just the thermostat to control the system a night set back mode controller could be used in conjunction to control the indoor temperature during the evenings. The night set back mode would work by limiting the indoor target temperature at 'out of office' hours (18:00 until 08:00 hours) to 17°C. This would mean the office is heated in the evenings but would not consume as much energy. Therefore using the night set back more creates potential for reduction of energy used and savings in running costs.

Another option for energy and cost saving would be to address the use of the system over the weekends. As this is a commercial building it will largely be unused at the weekends therefore when the heating system is active over the weekends this is not the most energy efficient solution. To solve this problem the thermostat would need to be replaced with one which has a weekly timer function on it. This is programmable to ensure the system switches off at the beginning of the weekend and back on in time to heat up the system ready for the next working day.