IGEN

OCHSNER GMLW 19 - Air Source Heat Pump Performance in Irish Climate

One Year Monitoring Study

Report

27-09-2010

Centre for Renewable Energy

DUNDALK INSTITUTE of TECHNOLOGY
Institiúid Teicneolaíochta Dhún Dealgan

Contents   Page

1.0 Introduction

A heat pump is a device that extracts heat from a low temperature energy source and raises the temperature of the heat energy to a suitable level so that can be used effectively to provide space heat and hot water to a domestic or commercial building. To date many heat pump installations in Ireland are *Ground Source* heat pumps that extract heat energy from the ground via horizontal loop collectors or vertical borehole collectors. The excavation for the horizontal collectors and drilling for vertical boreholes add to the overall capital cost of ground source heat pump systems. An *Air Source* heat pump can extract heat energy from the outdoor ambient air and raise it to a level suitable for domestic and commercial uses. Air source heat pumps use air exchanger instead of a ground loop to extract energy from the air. Air source heat pumps can also be used to extract energy from waste/exhaust heat in certain applications. The efficiency of heat pumps depends on a number of factors but one of the primary factors is the difference between the temperature of the energy source at the input and the required temperature at the output i.e. the temperature lift from input to output. In the case of a ground source heat pump the temperature of the ground (source) remains relatively constant at ~ 8C to 10C. In the case of air source heat pumps performance is influenced by ambient outdoor air temperatures and the relative humidity. However Ireland has a maritime climate and ambient air temperatures in winter do not fall as low as temperatures in continental regions such e.g. central European countries. This study monitors the performance an Ochsner GMLW 19 air source heat pump on the east coast of Ireland. The study was carried by the Centre for Renewable Energy at Dundalk Institute of Technology (CREDIT) and was funded by Enterprise Ireland under the Innovation Voucher scheme.

2.0 Installation Details

A 16kW Ochsner GMLW 19 air source heat pump was installed by IGEN in a crèche on the east coast of Ireland. It supplies the building's total space heat and hot water requirements. The building is well insulated and has under floor heating. The floor area of the building is ~ 400m^2. The building is shown in Figure 1.

Figure 1 – Building where heat pump is installed

The principal parts of the heat pump system is shown in Figure 2

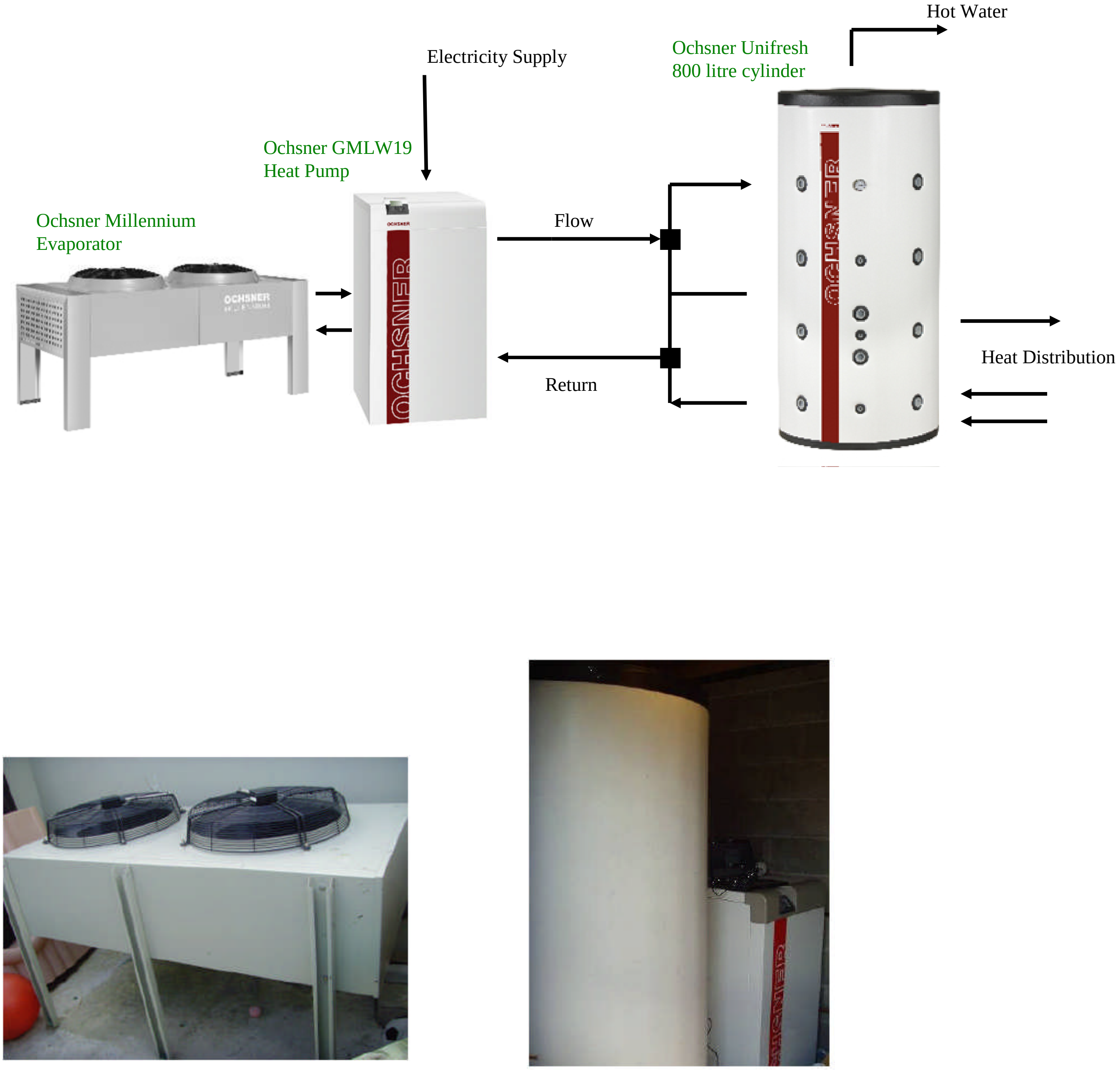

Figure 2 Ochsner Air Source heat pump system- principal parts schematic and pictures at the site

3.0 Monitoring System

The following parameters are being monitored

- Heat output from heat pump
- Electricity consumption of heat pump
- Flow and return temperatures (Tf &Tr) at output of heat pump
- Outdoor temperature
- Outdoor humidity

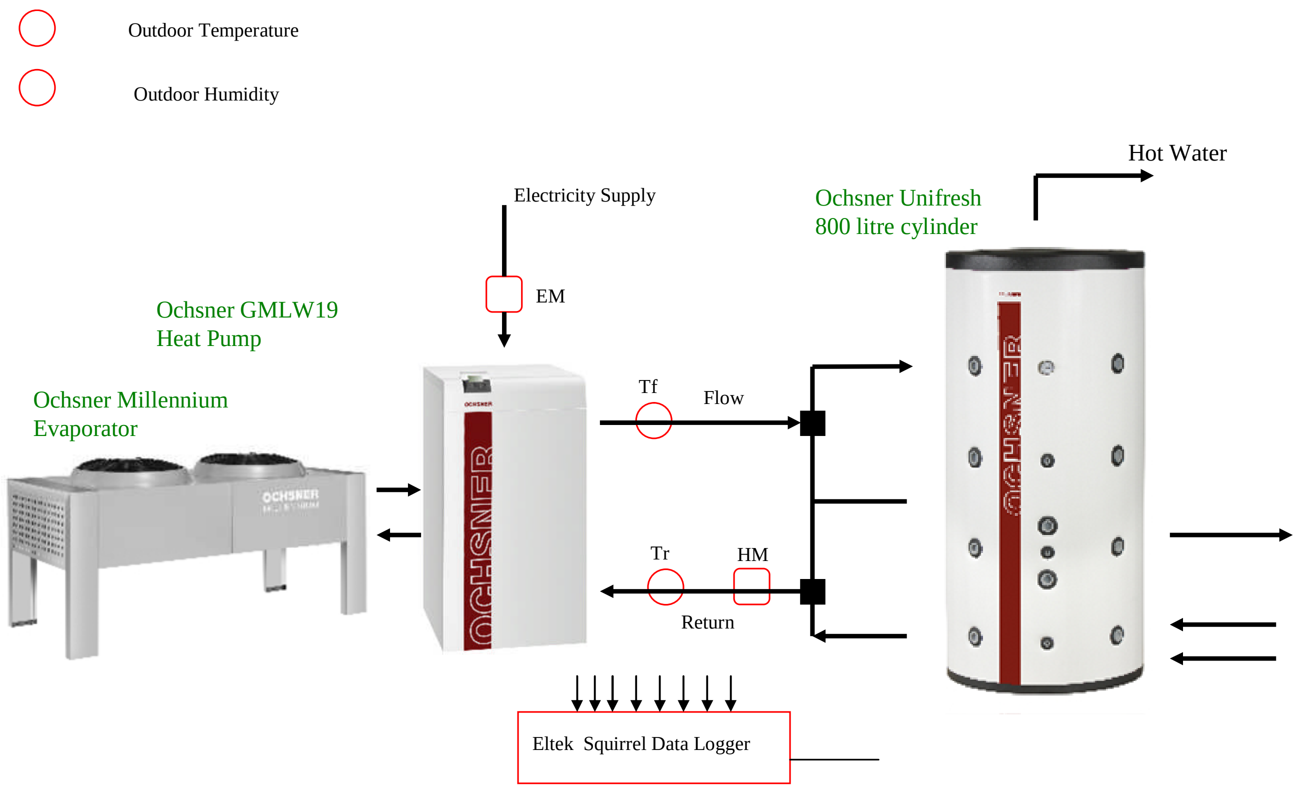

Figure 3: Heat Pump monitoring system. Components in red show the meters and sensors

HM = heat meter
EM = Electricity meter
Tf = Flow Temperature
Tr = Return Temperature
Outdoor temperature sensor
Outdoor humidity sensor

4.0 Monitoring Results

The following results are based on measurement taken over 1 year from 16th February 2009 to 16th February 2010

4.1 Total Energy Production and Consumption February 16th 2009 – February 16th 2010

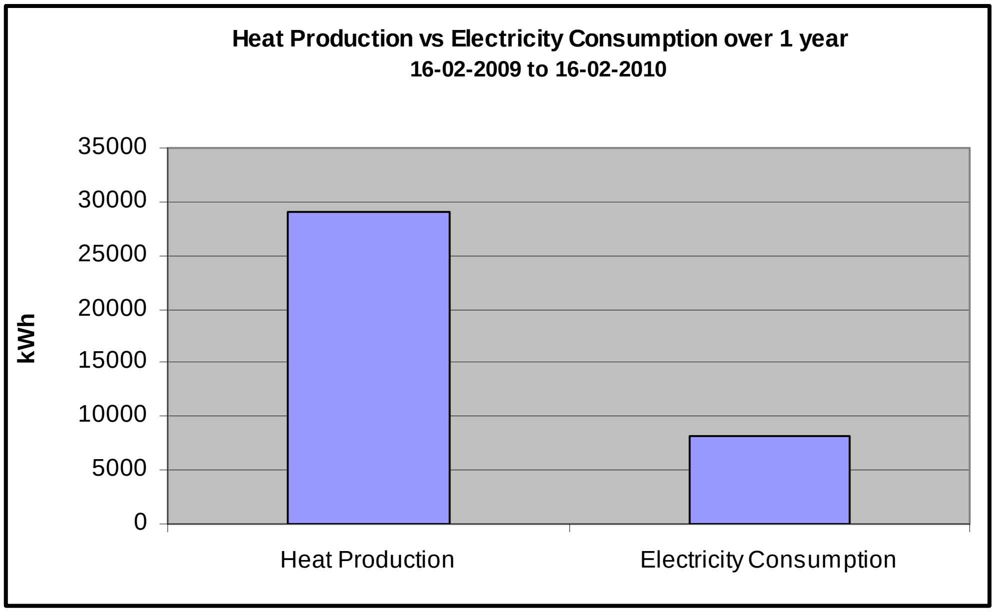

Figure 4: Heat production vs electricity consumption for 1 year

The graph shows the total heat produced by the heat pump for space heating and hot water and the corresponding total electricity consumed by the heat pump over the period from February 16th 2009 to February 16th 2010.

Heat production (kWh)	***Total electricity consumption (kWh)***	***Seasonal performance factor (SPF)***
28,973	*8,169*	*3.55*

Table 1: Heat production vs electricity consumption and SPF from 16th February 2009 to 16th February 2010

The seasonal performance factor (SPF) is the ratio of useful heat produced to the electricity consumed. Over this period the SPF was 3.55 as shown in Table1. The values take into account energy used for defrosting.

4.2 Hot water and defrosting

The heating flow and return temperatures to and from the heat pump were monitored and used to indicate when hot water was being produced and also when the heat pump was carrying out a defrosting cycle. When the flow temperature rises above 40C in winter and 35C in summer the heat pump is producing hot water. When the return temperature is higher than the flow temperature the heat pump carries out defrosting of the air collector. Table 2 shows the proportion of the total electricity consumed by the heat pump used for delivering hot water and defrosting during the period.

Total electricity consumption (kWh)	***Electricity consumption for hot water (kWh)***	***Electricity consumed defrosting (kWh)***
8,169	*3,433*	*54*

Table 2: Proportion of total electricity consumed for hot water and defrosting

4.3 Breakdown of heat production and electricity consumption February 16th 2009– February 16th 2010

The proportion of the heat produced by the heat pump for space heat and hot water and the corresponding electrical consumption by the heat pump is shown in Figure 5 and Table 3.

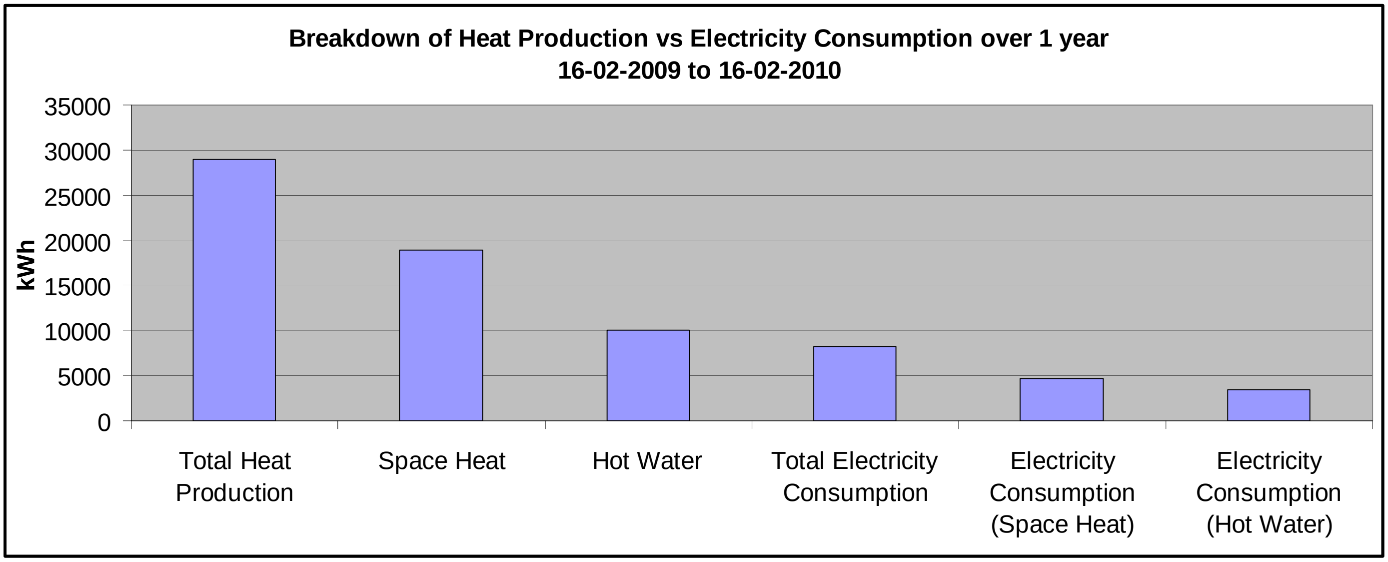

Figure 5: Proportion of heat production for hot water and space heat vs electricity consumption

Total Heat Production (kWh)	***Space Heat Production (kWh)***	***Hot Water Production (kWh)***	***Total Electricity Consumption (kWh)***	***Electricity Consumption (Space Heat) (kWh)***	***Electricity Consumption (Hot Water) (kWh)***
28,973	*18,973*	*10,000*	*8,169*	*4,682*	*3,433*

Table 3: Proportion of heat production for hot water and space heat vs electricity consumption

On the basis that hot water is produced when the flow temperature is above 40C in winter and 35C in summer then over the 1 year period approximately 35% of the total heat produced was for hot water. The average SPF for hot water was ~ 2.91 while the average SPF for space heating was ~ 4.01

4.4 Breakdown of electricity night rate and day rate consumption February 16th 2009 – February 16th 2010

In Ireland the night rate period is defined as 23:00 to 08:00 in winter (November to February inclusive) and 00:00 to 09:00 in summer (March to October inclusive). The breakdown of night and day rate electricity units consumed over the period is shown in Figure 6 and Table 4. Approximately 48.8 % of the total electricity consumed over the period was at night rate. The associated running costs and environmental benefits are shown in a later section of this report

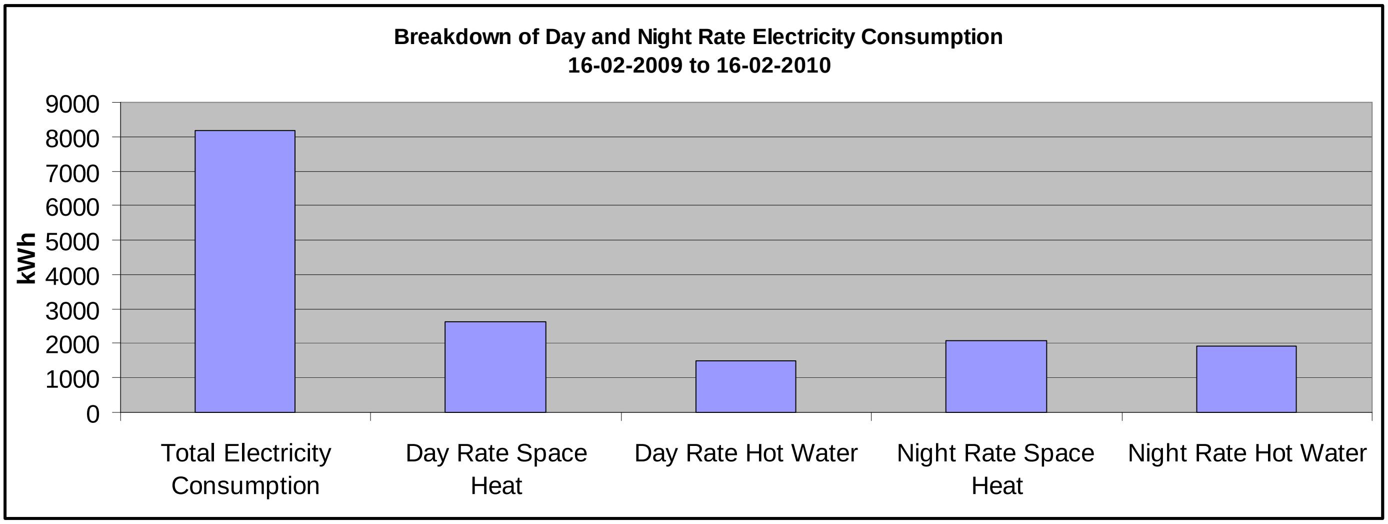

Figure 6: Breakdown of day and night rate electricity consumption

Total Electricity Consumption (kWh)	***Total Day Rate Electricity (kWh)***	***Day Rate Electricity (Space Heat) (kWh)***	***Day Rate Electricity (Hot Water) (kWh)***	***Total Night Rate Electricity (kWh)***	***Night Rate Electricity (Space Heat) (kWh)***	***Night Rate Electricity (Hot Water) (kWh)***
8,169	*4,148*	*2,617*	*1,506*	*4,021*	*2,065*	*1,927*

Table 4: Day and night rate electricity consumption

As mentioned earlier, the total electricity consumed by the heat pump includes 54kWh of electricity consumed for defrosting. The electricity consumed for perforating at day rate was ~25kWh and ~29kWh at night rate.

4.5 Performance during a cold period December 1st 2009 – January 31st 2010

Ireland experienced an unusual and exceptionally cold winter in 2009/2010. The table below show the minimum, maximum and average outdoor temperatures measured at the heat pump installation for the coldest two month period of December and January. The recorded minimum, maximum and average during this two month period are also shown. It should be noted that the minima and that maxima of temperature and relative humidity do not occur at the same time

Outdoor Conditions	***Min Day time***	***Max Day time***	***Average Day time***	***Min Night time***	***Max Night time***	***Average Night time***
Temperature (°C)	*-6.5*	*12*	*2.1*	*-8.2*	*12*	*1.5*
Relative Humidity (%)	*48.2*	*98.1*	*84.9*	*50.8*	*98.0*	*87.4*

Table 5: Recorded outdoor environmental conditions December and January 2010

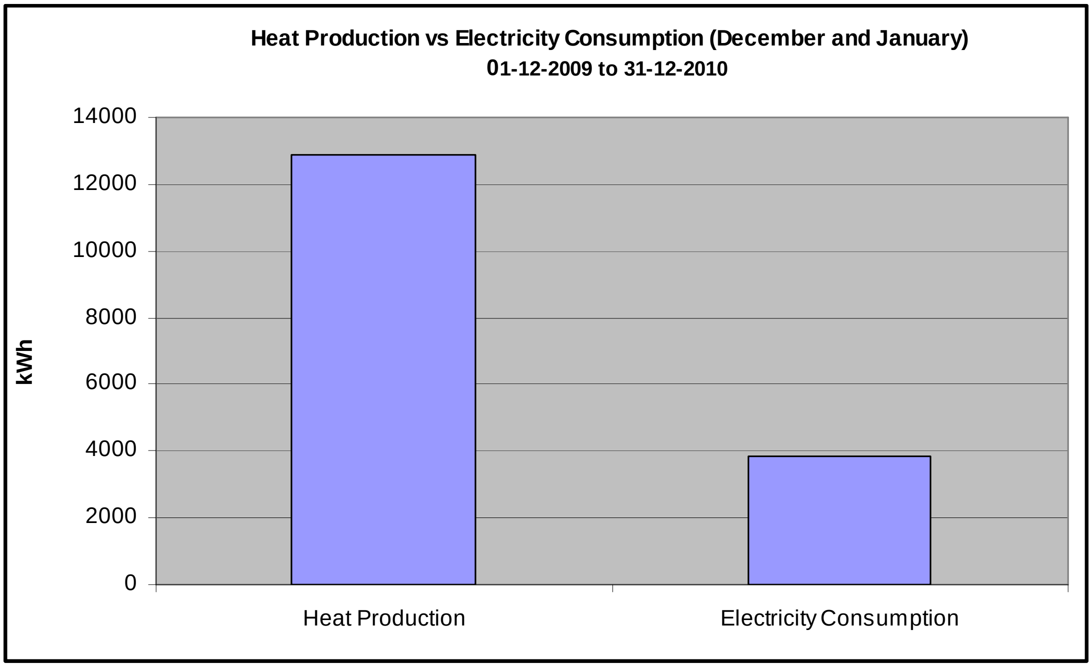

Figure 7: Heat production vs electricity consumption during December 2010 and January 2010

Heat production (kWh)	***Electricity consumption (kWh)***	***Seasonal performance factor (SPF)***
12,895	*3,831*	*3.37*

Table 6: Heat production vs electricity consumption and SPF during December 2010 and January 2010

As expected the SPF due to the environmental conditions is less than the average for the whole period

Total electricity consumption (kWh)	***Electricity consumption for hot water (kWh)***	***Electricity consumed defrosting (kWh)***
3,831	*1,581*	*41*

Table 7: Proportion of total electricity consumed for hot water and defrosting during December 2010 and January 2010

Approximately 76% of the total annual electricity consumed for defrosting occurred during December and January
4.6 Breakdown of heat production and electricity consumption December 1st 2009 – January 31st 2010

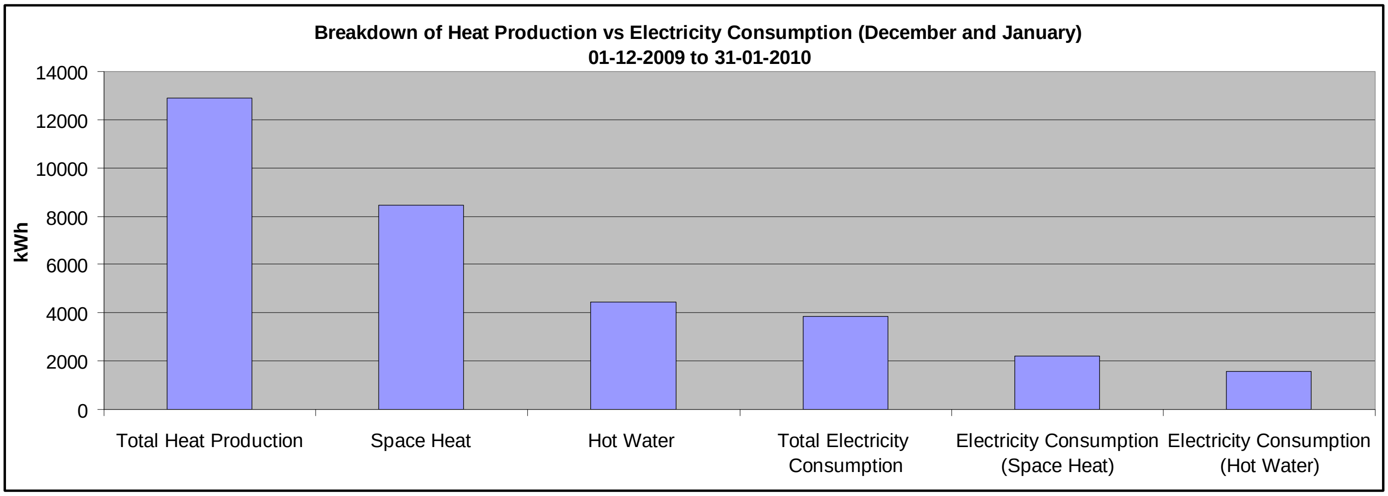

Figure 8: Heat production vs electricity consumption

Total Heat Production (kWh)	***Space Heat Production (kWh)***	***Hot Water Production (kWh)***	***Total Electricity Consumption (kWh)***	***Electricity Consumption (Space Heat) (kWh)***	***Electricity Consumption (Hot Water) (kWh)***
12,895	8,445	4,450	3,831	2,208	1,581

Table 8: Heat production vs electricity consumption and SPF for December 2010 and January 2010

On the basis that hot water is produced when the flow temperature is above 40C then over this period approximately 34.7% of the total heat produced was for hot water. The average SPF for hot water was ~ 2.81 while the average SPF for space heating was ~ 3.82

4.7 Breakdown of electricity night rate and day rate consumption December 1st 2009 – January 31st 2010

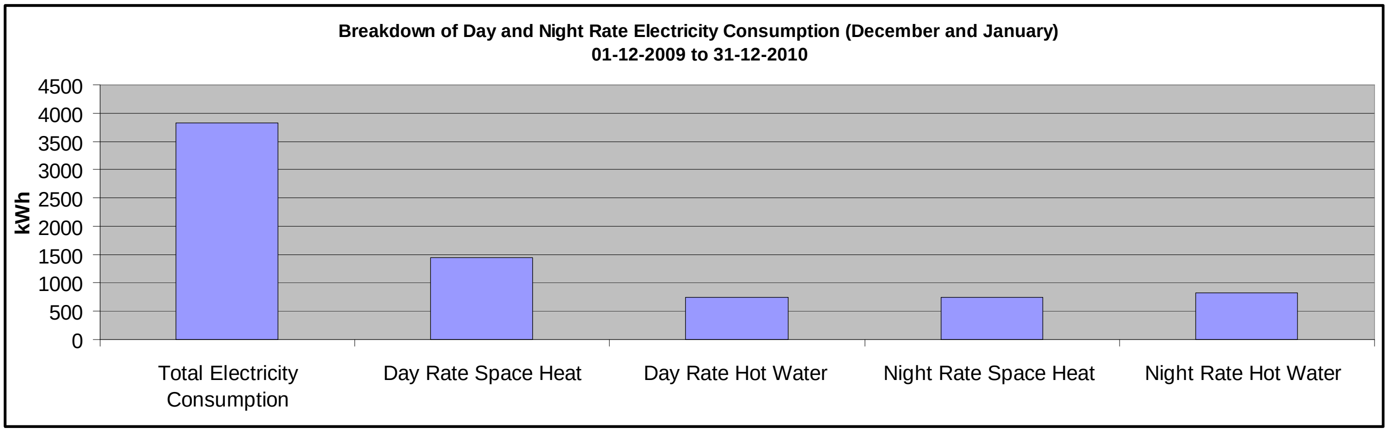

Figure 9: Breakdown of electricity consumption in day and night rate for space heat and hot water for December 2010 and January 2010

Total Electricity Consumption (kWh)	***Total Day Rate Electricity (kWh)***	***Day Rate Electricity (Space Heat) (kWh)***	***Day Rate Electricity (Hot Water) (kWh)***	***Total Night Rate Electricity (kWh)***	***Night Rate Electricity (Space Heat) (kWh)***	***Night Rate Electricity (Hot Water) (kWh)***
3,831	*2,230*	*1,455*	*754*	*1,601*	*754*	*827*

Table 9: Breakdown of electricity consumption in day and night rate units for space heat and hot water February 16-March 16 2009

The breakdown of night and day rate electricity unit consumption over the period is shown in Figure 9 and Table 9. Approximately 41.8% of the total electricity consumed over the period is night rate. Due the outdoor environmental conditions the space heat and hot water demand during the day time results in a total day rate electricity consumption that is 58.2% of the total.

4.8 Performance during a summer period

The heat pump performance in June and July 2009 is shown below. Most of the heat provided was for hot water during this month with no energy required for defrosting

Outdoor Conditions	***Min Day time***	***Max Day time***	***Average Day time***	***Min Night time***	***Max Night time***	***Average Night time***
Temperature (^oC)	*8.0*	*25.8*	*17.0*	*6.6*	*22.0*	*13.2*
Relative Humidity (%)	*34.7*	*97.5*	*70.0*	*52.5*	*97.1*	*84.4*

Table 10: Average outdoor environmental conditions during June and July 2009

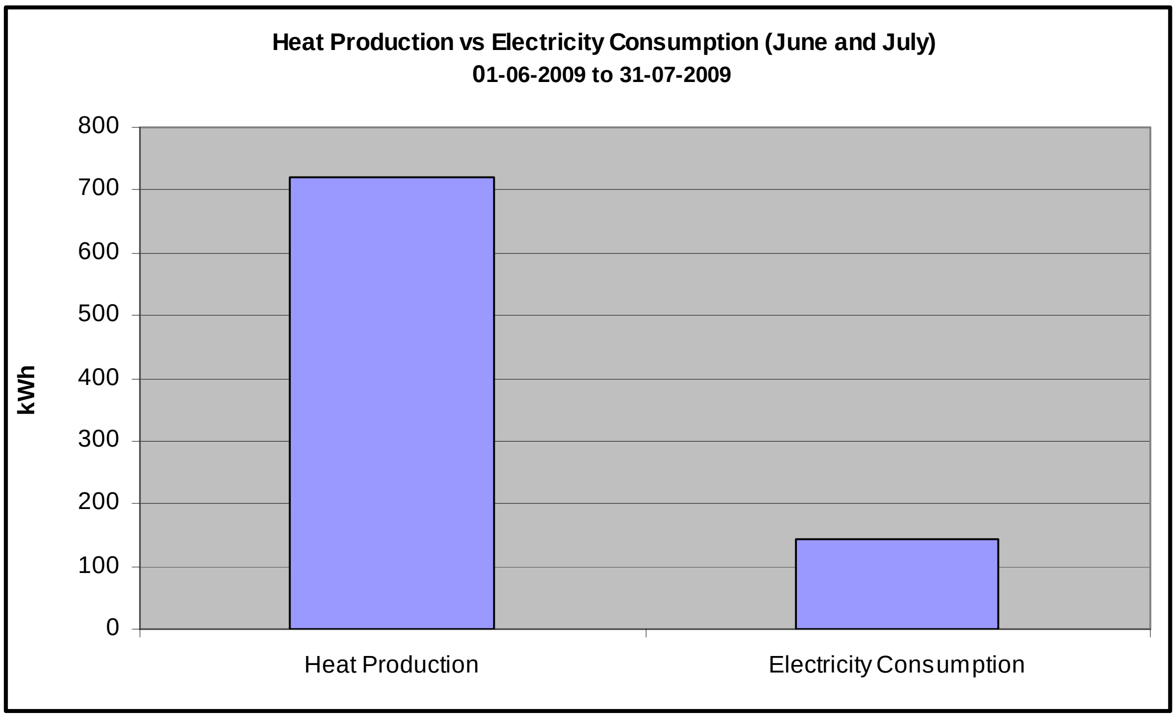

Figure 10: Heat production vs electricity consumption during June and July 2009

Total Heat production (kWh)	***Total electricity consumption (kWh)***	***Seasonal performance factor (SPF)***
760	*142.5*	*4.9*

Table 11: Heat production vs electricity consumption and SPF during June and July 2009

Total electricity consumption (kWh)	***Electricity consumption for hot water (kWh)***	***Electricity consumed defrosting (kWh)***
142.5	*130*	*0*

Table 12: Proportion of total electricity consumed for hot water and defrosting during June and July 2009

As can be seen a large proportion of energy consumed by heat pump was for hot water during this month with a much smaller proportion being consumed for a flow temperature less than 35C suitable for space heating or heating water from cold temperatures.

4.9 Breakdown of heat production and electricity consumption during June and July 2009

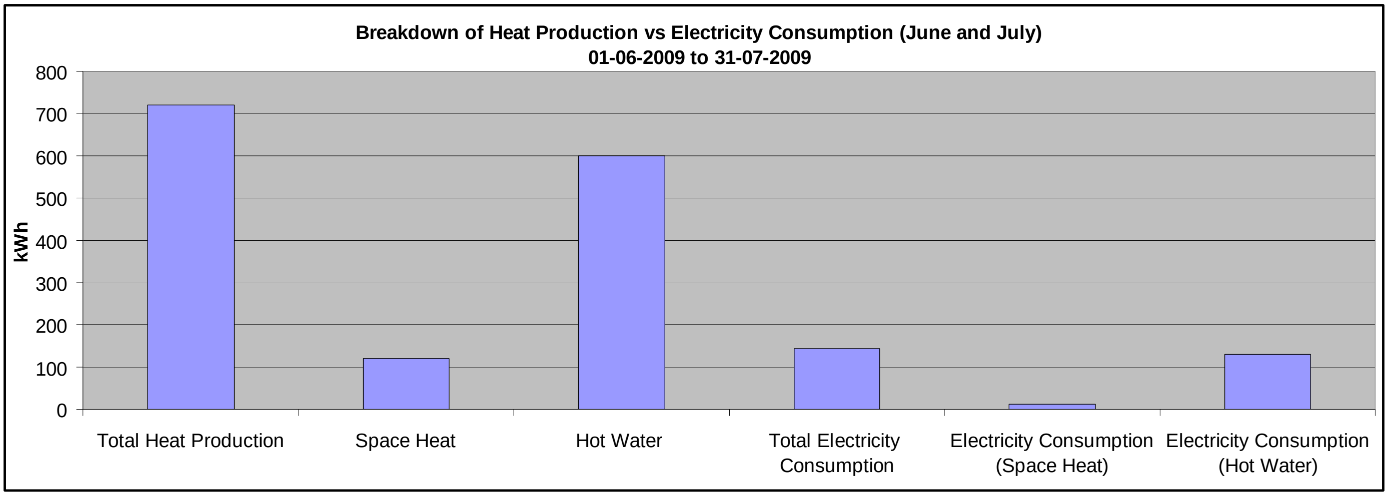

Figure 11: Heat production vs electricity consumption June 2009

Total Heat Production (kWh)	***Space Heat Production (kWh)***	***Hot Water Production (kWh)***	***Total Electricity Consumption (kWh)***	***Electricity Consumption (Space Heat) (kWh)***	***Electricity Consumption (Hot Water) (kWh)***
720	*120*	*600*	*142.5*	*12.5*	*130*

Table 13: Heat production vs electricity consumption during June and July 2009

On the basis that hot water is produced when the flow temperature is above 35C during the summer period then over 91% of the total heat produced was for hot water. The average SPF for hot water was ~ 4.6 while the average SPF for space heating was ~ 9.6

4.10 Breakdown of electricity night rate and day rate consumption June and July 2009

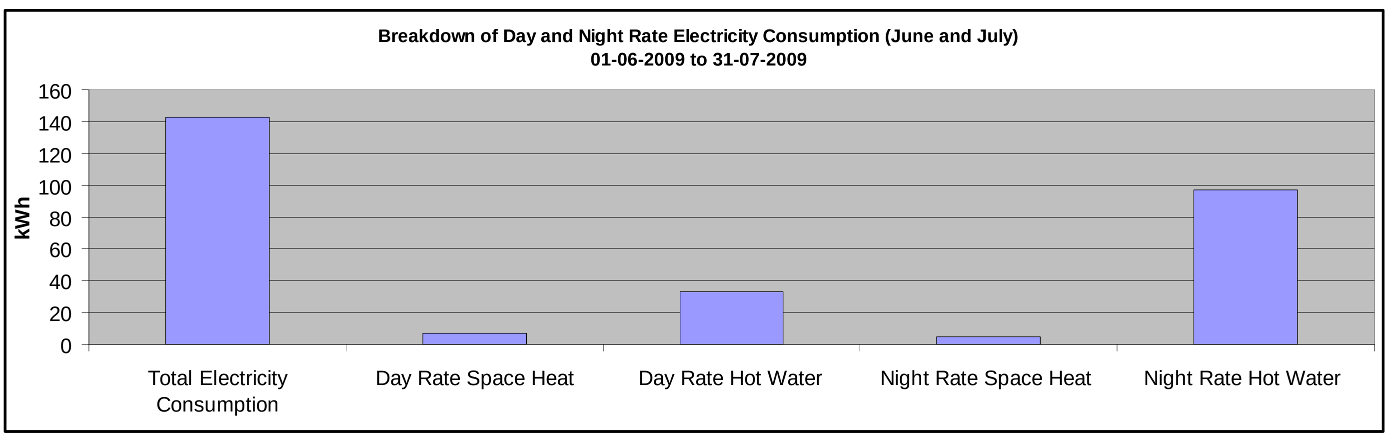

Figure 12: Breakdown of electricity consumption in day and night rate for space heat and hot water during June and July 2009

Total Electricity Consumption (kWh)	***Total Day Rate Electricity***	***Day Rate Electricity (Space Heat)***	***Day Rate Electricity (Hot Water)***	***Total Night Rate Electricity***	***Night Rate Electricity (Space Heat)***	***Night Rate Electricity (Hot Water)***

	(kWh)	*(kWh)*	*(kWh)*	*(kWh)*	*(kWh)*	*(kWh)*
142.5	*40*	*7*	*33*	*102.5*	*5*	*97.5*

Table 14: Breakdown of electricity consumption in day and night rate units for space heat and hot water during June and July 2009

The breakdown of night and day rate electricity unit consumption over the period is shown in Figure 12 and Table 14. Approximately 72% of the total electricity consumed over the period is night rate. As can be seen from the graphs the space heat demand during June and July is very low.

4.11 Worst Case Performance of Heat Pump

The worst case performance of the heat occurred pump over a 55 minute period on the 08th January 2010 between 22.15pm and 23.10pm. The SPF was 2.0 over the 55 minute period. It occurred when the heat pumps was producing hot water and the outdoor temperature was between -7C and -8C and the relative humidity was ~ 88.5%.The following graphs show the environmental conditions along with the heat pump output flow and return temperatures and their variation during the whole day of 08th January.

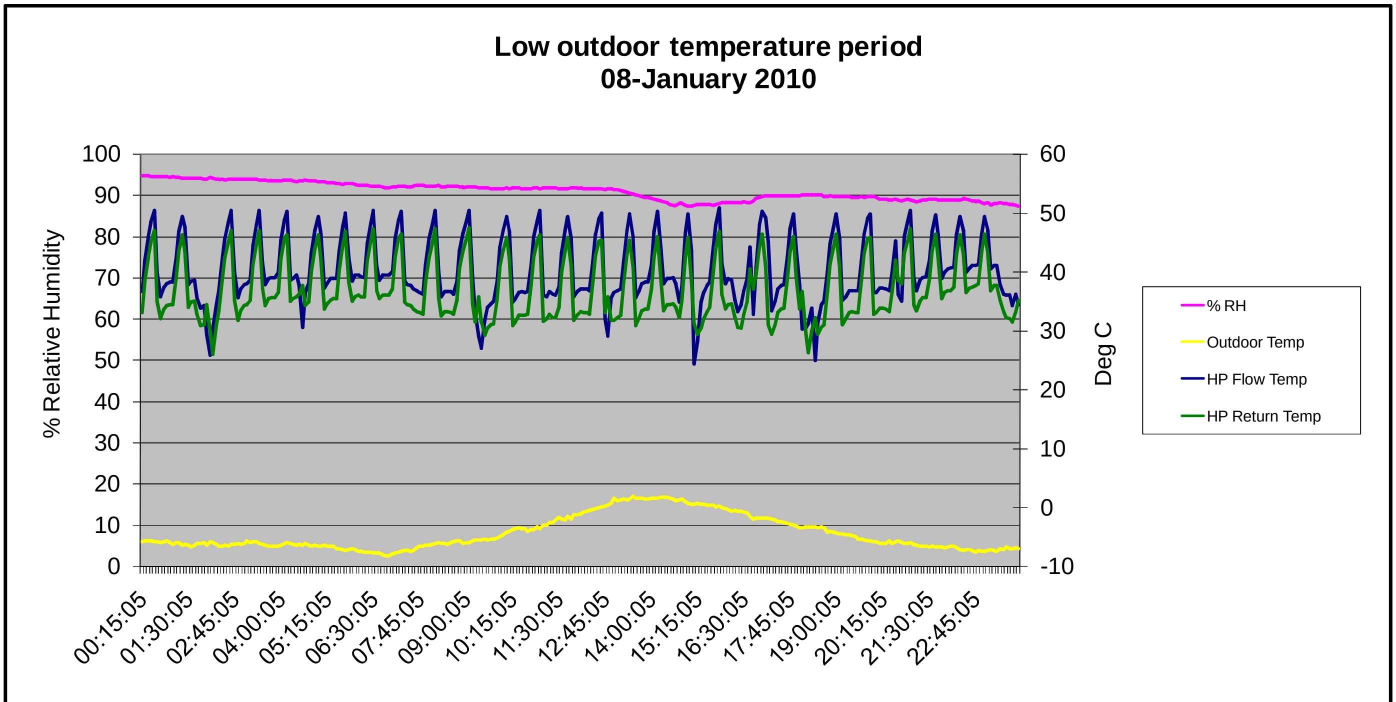

Figure 13: Outdoor environmental conditions and output flow and return temperatures on 08th January 2010

Some defrosting occurred where the difference between the flow and return temperatures (delta T) was negative as can be seen Figure 14.

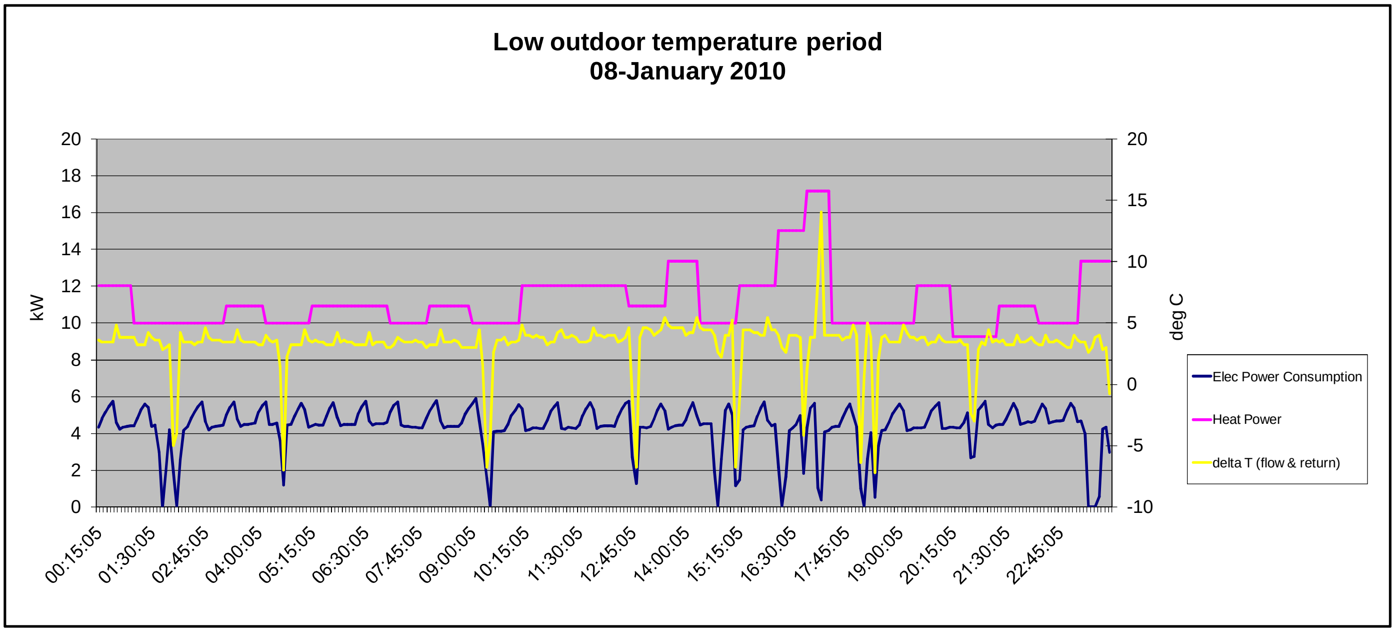

Figure 14: Heat power production vs electric power consumption and difference between output in flow and return temperatures on 08th January 2010

4.12 Operating Conditions on January 08th 2010 22.15 – 23.10

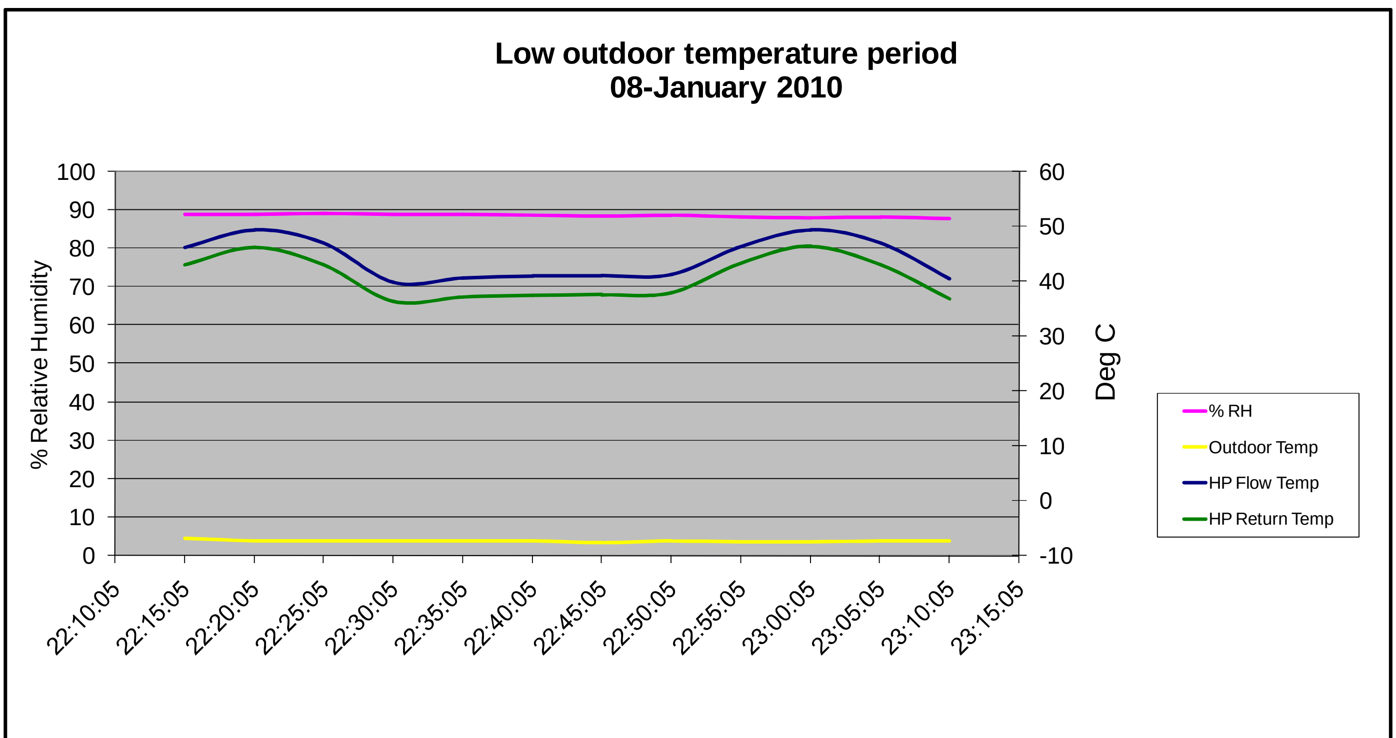

Figure 15: Outdoor environmental conditions and output flow and return temperatures on 08th January 2010 22:15-23:10

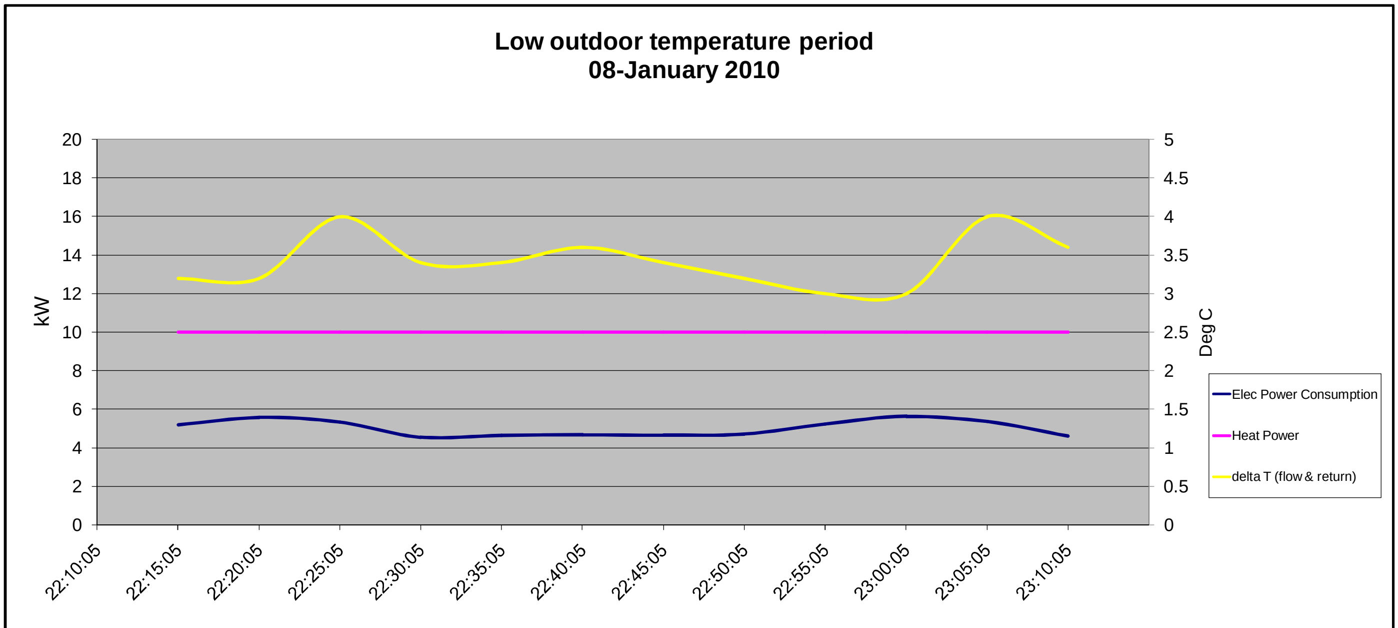

Figure 16: Heat power production vs electric power consumption on 08th January 2010 22:15 - 23:10

Total Heat production (kWh)	***Total electricity consumption (kWh)***	***Seasonal performance factor (SPF)***
10	*3.82*	*2.62*

Table 15: Heat production vs electricity consumption and SPF on January 08th 2010 22:15 to 23:10

4.13 Backup Electrical Heating over the 1 year period

The 800 litre cylinder is fitted with a 2kW electrical element to assist the heat pump during only if required, very. The heat pump records the number of hours the electrical element was operational since the heat pump was installed. From December 2009 to August 2010 370 hours were recorded. This implies that 740hWh of electricity was consumed over a 20 month period. As the coldest period in the year is from November to February inclusive then there were 7 cold months over the period. As the logging period for this study was from February 16th 2009 to February 16th 2010 then the number of cold months was 4. As a result approximately 4/7 of the backup electricity consumed since the heat pump was installed occurred during the monitoring period i.e. 4/7 x 740kWh ~ 423kWh. However as December and January 2010 was colder than the previous year a value of 500kWh will be considered for the purposes of this study.

5.0 Economic and Environmental Benefits

5.1 Cost of using Ochsner Air Source Heat Pump

A cost comparison between using the heat pump and oil, LPG and natural gas is given in this section for the period full period from 16th February to 16th February 2010.

Night rate electricity is availed of by the system. The current rates (October 1st 2009) for ESB, Airtricity and Bord Gáis in the case of residential urban night saves tariffs for are show below in Table 16.

Electricity Tariffs (including 13.5% VAT)	***ESB Rates (c/kWh)***	***Airtricity (c/kWh)***	***Bord Gáis (c/kWh)***
Day Rate	*17.09*	*14.87*	*14.87*
Night Rate *23:00-08:00 Winter (Nov - Feb)* *00:00-09:00 Summer (March – Oct)*	*8.46*	*7.36*	*7.36*
Standing Charge	*39.27c/day*	*39.27c/day*	*39.27c/day*

Table 16: Electricity tariffs – Domestic urban night rate

From Table 1 previously the total heat supplied was 28,973kWh and the total electricity consumed was 8,169kWh. From Table 4 it was seen that 49% of the electricity consumed by the heat pump was at the night rate in this particular case. In addition 500kWh for backup immersion as was discussed in section 4.13. The calculated heat pump (and backup immersion) electricity cost for the one year period (16th February to 16th February 2010) is shown in Table 17.

Cost Breakdown (including 13.5% VAT)	***ESB***		***Airtricity***		***Bord Gáis***	
	Day Rate	***Night Rate***	***Day Rate***	***Night Rate***	***Day Rate***	***Night Rate***
Heat Pump Consumption (kWh)	*4,148*	*4,021*	*4,148*	*4,021*	*4,148*	*4,021*
Back up Immersion (kWh)	*333*	*167*	*333*	*167*	*333*	*167*
Heat Pump Consumption Cost (€)	*€708.89*	*€340.18*	*€616.81*	*€295.95*	*€616.81*	*€295.95*
Backup Immersion Cost (€)	*€56.91*	*€14.13*	*€49.52*	*€12.29*	*€49.52*	*€12.29*
Standing Charge (€)	*€38.95*		*€38.95*		*€38.95*	
Total Cost of Electricity (€)	***€1159.06***		***€1013.38***		***€1013.38***	

Table 17: Electricity consumption cost breakdown February 16th to February 16th February 2010 ESB

A note in electricity standing charges-

Domestic night rate urban standing charge is €0.3927/day. Normal domestic Urban 24 hour standard tariff standing charge €0.2860/day (as may be the case when an oil or gas system is used). By having night rate the daily addition to the standing charge €0.1067/day. Over the period 16th February 2009 to 16th February 2010 the standing charge for night rate is €38.95 more expensive than the standard 24 hour tariff standing charge.

5.2 Comparison with home heating oil

The price of home heating is relatively volatile at present. Current prices (July 2010) vary from 60c/litre to 70c/litre delivered to the home. In these calculations an average price of 65c/litre (including VAT) is used.

Oil Systems	
Energy in 1 litre of kerosene	*10.55kWh/litre*
Oil fired boiler efficiency	*70%*

Table 19: Energy in oil and efficiency of oil boiler- Source SEI

Cost Breakdown for Oil	
Heating Demand (kWh)	*28,973*
Raw fuel demand for efficiency of 70% (kWh)	*41,390*
Litres of oil required (10.55kWh/litre)	*3,923*
Total Cost @ 65c/litre	***€2,550***

Table 20: Heating oil cost to provide the same amount of energy as heat pump

5.3 Comparison with home LPG

The price of LPG is relatively volatile at present as it tracks the price of oil. Current prices from Flowgas for bulk LPG delivered (July 2009) 72.07c/litre (including VAT) delivered to the home.

LPG Systems	
Energy in 1 litre of Bulk LPG	*7.09 kWh/litre*
Condensing gas fired boiler efficiency	*90%*

Table 21: Energy in LPG and efficiency of condensing gas boiler- Source SEI

Cost Breakdown for LPG	
Heating Demand (kWh)	*28,973*
Raw fuel demand for efficiency of 90% (kWh)	*32,192*
Litres of LPG required (7.09kWh/litre)	*4,540*
Total Cost @ 72.07c/litre	***€3272.34***

Table 22: LPG cost to provide the same amount of energy as heat pump

5.4 Comparison with natural gas using Bord Gáis standard tariff (2010)

Bord Gáis (July 2010), "The Standard Tariff consists of two elements. There is a standing charge of 18.7 c/day and a consumption charge of 4.463c/kWh (including 13.5% VAT)

From most manufacturers data, condensing gas boilers are ~ 90% efficient

Cost Breakdown for Natural Gas	
Heating Demand (kWh)	*28,973*
Raw fuel demand for efficiency of 90% (kWh)	*32,192*
Cost @ 4.463c/kWh (Standard Tariff)	*€1436.73*
Standing Charge @ 18.7c/day	*€68.10*
Total Cost	***€1504.83***

Table 23: Heating oil cost to provide the same amount of energy as heat pump

5.5 Summary of Fuel Cost Comparisons

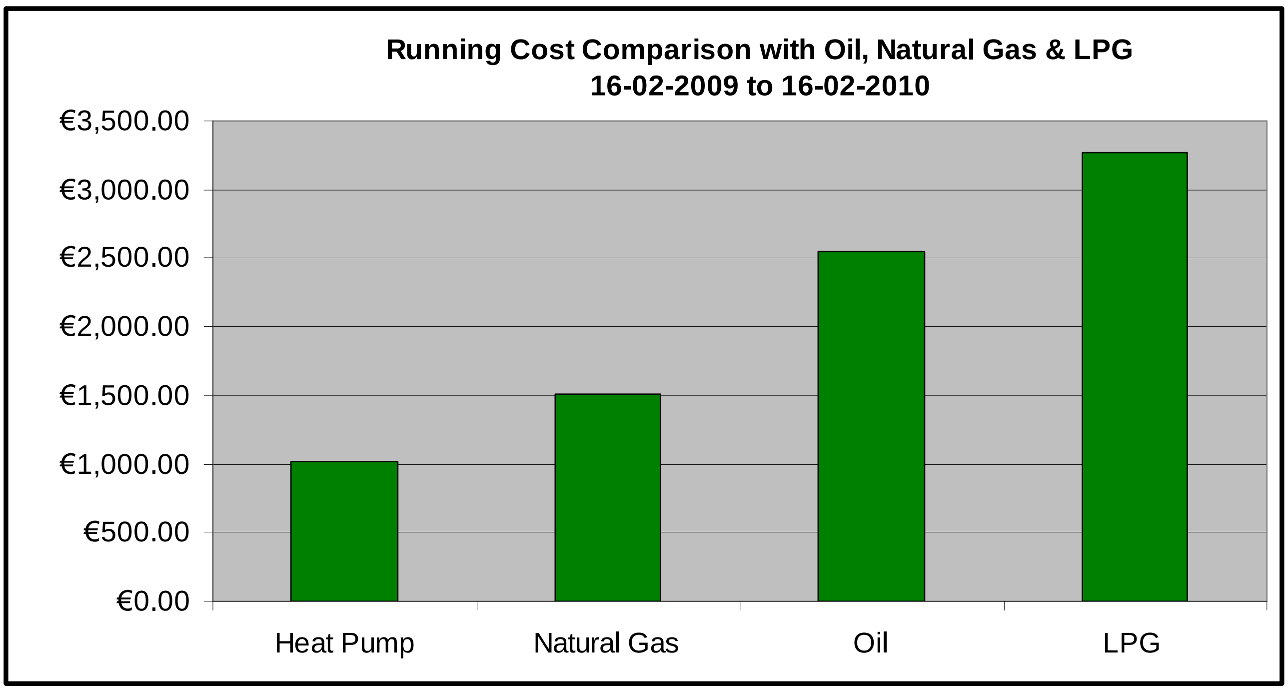

Figure 17: Cost comparison

Based on current (2010) cheapest electricity rates, natural gas and oil prices the cost of running the heat pump from February 16th to February 16th 2010 is

~ 33% less than the cost of using natural gas
~ 60% less than the cost of using home heating oil
~ 69% less than the cost of using LPG

5.6 CO_2 Emission Comparisons

A comparison of the CO_2 emissions is show below

Emission Factors	***gCO2/kWh***
Kerosene	*257.0*
LPG	*229.3*
Natural Gas	*205.6*
Conventional Electricity (depends on generation plant mix which can vary from year to year)	*542.8*

Table 24:CO_2 emission factors for heating oil and natural gas- Source SEI

	Heat Pump	***Oil Boiler***	***LPG Boiler***	***Natural Gas Boiler***
Energy consumption (kWh)	*8,669*	*41,390*	*32,192*	*32,192*
CO2 Emissions (kg)	*4,705*	*10,637*	*7,382*	*6,619*

Table 25: CO_2 emission comparison

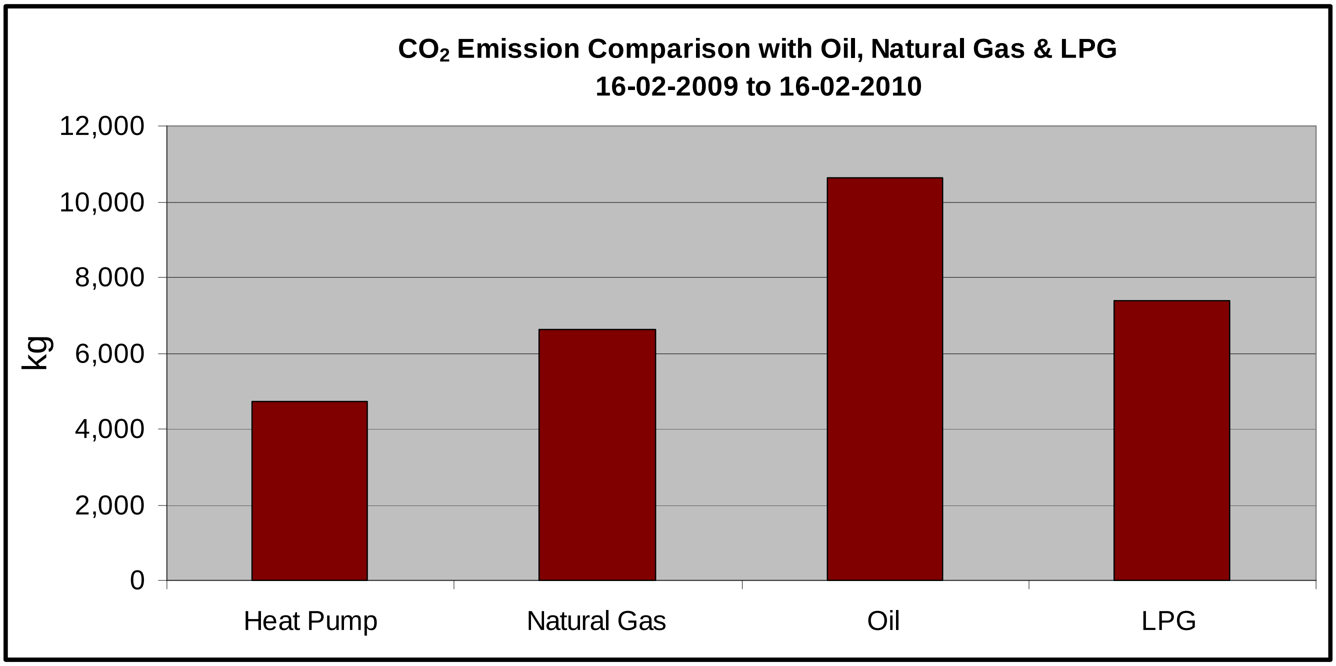

Figure 18: Heat production vs electricity consumption

The emissions as a result of using a heat pump depend on what the source of electricity is i.e. the generation plant mix. In recent Irish electricity generation stations have been moving from peat and oil to natural gas. The amount of wind generation is increasing which is also reducing emissions from the national grid. This has resulted in decreasing CO_2 emissions form electricity use. In this case the CO_2 emissions as result of using this heat pump is 60% that of using a natural gas heating system and 44% that of using a oil heating system.

6.0 Relevance to Irish Building Regulations

According to the Building Regulations 2007 Technical Guidance Document L Conservation of Fuel and Energy – Dwellings- (http://www.environ.ie)

"A building shall be designed and constructed so as to ensure that the energy performance of the building is such as to limit the amount of energy required for the operation of the building and the amount of CO2 emissions associated with this energy use insofar as is reasonably practicable"

For new dwellings (from 2008 onwards), the requirements can be met by a number of measures including a reasonable proportion of the energy consumption to meet the energy performance of a dwelling is provided by renewable energy sources.

The regulations state that the following represents a reasonable minimum level of energy provision from renewable energy technologies in order to satisfy Regulation L2(b):

- *"10 kWh/m2/annum contributing to energy use for domestic hot water heating, space heating or cooling."*

or

- *"4 kWh/m2 annum of electrical energy, or a combination of these which would have equivalent effect."*

The regulation also states that- "*In the case of electrically powered heat pumps, only energy in excess of 2.5 times the electrical energy directly consumed by the heat pump can be counted towards meeting the minimum level of energy provision from renewable technology*."

As was discussed in section 4.1 in the case of this installation the average annual SPF was 3.55 and the heat pump provided space heating and hot water for the building. The building primary heat demand (including hot water) was

28,973kWh heat from heat pump
500kWh heat from backup immersion
Total primary heat demand (including hot water) was 29,473kWh

For the 400m2 building this is ~ 75kWh/m2/year

The heat pump supplied 98.3% of the heating demand which is well in excess of the requirements of the building regulation requirements outlined above.

7.0 Conclusions

- This measured data for this Ochsner air source heat pump shows that it is performing well in the provision of space heating and water heating under various outdoor environmental conditions over one year. It had an overall average SPF of 3.55 over the monitoring period which comprised of an average SPF of 2.9 for hot water and an average SPF of 4.0 for space heat. This period included one of the coldest Irish winters on record in 2009/10.

- The heat demand of the building was relatively low and can be attributed to the building insulation, under floor heating and Ochsner heat pump heating controls.

- During the two coldest winter months of the year (December 2009 – January 2010) approximately 35% of the total demand was for hot water and 65% for space heat. The average SPF was ~ 3.37 and this comprised of an average hot water SPF of 2.8 and a space heating SPF of 3.8.

- During two summer months of the one year monitoring (June and July 2009) approximately 91% of the total demand was for hot water and 9% for space heat. The average SPF was ~ 4.9 and this comprised of an average hot water SPF of 4.5 and a space heating SPF of 9.6.

- It has been shown that the cost of running a heat pump is significantly less than using natural gas, LPG or heating oil at 2010 fuel and electricity prices.

- CO_2 emissions are less using the heat pump and will reduce in the future as more wind energy is connected to national grid. Also they can be reduced further by using a green electricity supplier.

- The study has shown that over the monitoring period an Ochsner GMLW19 air source heat pump is well suited to an Irish maritime climate in the provision of hot water and space heat to domestic and commercial buildings.

- The installation met the building regulation requirements well in excess of the requirements 2007 Technical Guidance Document L Conservation of Fuel and Energy – Dwellings