Department of Mechanical and Aerospace Engineering

Domestic Hot Water Efficiency and Losses

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Signed: Jennifer Christine McNulty Date: 17th September 2013

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Abstract

This thesis details an account of an investigation quantifying efficiencies and losses for the underperforming domestic hot water system of a 40-bed care home in Orkney. Domestic Hot Water is provided by a hybrid heat pump and oil boiler system. The geothermal heat pump supplies heat to water contained in a pre-heat cylinder, which subsequently supplies the main domestic hot water cylinder, where an oil boiler is used to inject additional heat to raise water temperatures to 60^0C. However the system appears to be underperforming, requiring an excessive volume of oil to maintain hot water production at the required temperature. Therefore, this project has been commissioned by Orkney Islands Council to examine the current system with the aim of identifying and rectifying any faults found therein, thus raising the system to an acceptable level of performance.

The investigation comprised of a detailed literature review, a period of preliminary analysis, an on-site inspection and a final phase of analysis; examining all of the data obtained throughout the process. The results were then used to identify the faults in the system and to determine the modifications necessary to correct them.

It became apparent during the investigation that both the oil boiler and the heat pump were underperforming. The operational settings on the heat pump were inefficient, resulting in low temperatures in the pre-heat cylinder. The oil boiler was operating with an average efficiency of 4.31%, a daily oil consumption of 47.59 litres and was experiencing losses of approximately 6% due to boiler dry cycling. The boiler was also observed to be firing frequently and unnecessarily, responding to temperatures in the pre-heat cylinder as opposed to the main cylinder. The distribution system was well insulated with the exception of valves in the loft spaces. Annually the domestic hot water system had an oil consumption of 19086 litres, carbon dioxide emissions of approximately 60 tonnes (imperial) and cost £14,539.

Thus, for the system to operate efficiently the sensor error affecting the oil boiler will have to be corrected and the operational settings of the heat pump altered; the return thermostat stop temperature should be raised and the allowed hysteresis lowered, to ensure temperatures in the pre-heat cylinder are as high as possible. Implementing these modifications should significantly improve system performance; resulting in an annual oil consumption of approximately 553 litres, Carbon Dioxide emissions equal to 3.85 tonnes (imperial) and operating costs of £1060.

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Nomenclature

kW	Kilowatt(s)
kWh	Kilowatt-hour(s)
kJ/kg.K	Kilojoules per Kilogram per Degree (Kelvin)
DHW	Domestic Hot Water
TMV	Thermostatic Mixing Valve
CHP	Combined Heat and Power
ASHP	Air-Source Heat Pump
LSHP	Liquid-Source Heat Pump
GSHP	Ground-Source Heat Pump
COP	Coefficient of Performance
BMS	Building Management System
NCV	Net Calorific Value
GCV	Gross Calorific Value
HP 1	Heat Pump 1 (Under Floor Heating System)
HP 2	Heat Pump 2 (Under Floor Heating System)
HP 3	Heat Pump 3 (Domestic Hot Water System)
BRE	Building Research Establishment
MCW	Mains Cold Water
BCW	Boosted Cold Water

1 Introduction

Domestic Hot Water for a residential care home in Orkney is provided via a hybrid geothermal heat pump and oil boiler system. Heat pumps are increasingly being utilised for domestic hot water production due to their low operating costs and high energy efficiency, particularly geothermal heat pumps as they are capable of maintaining the same efficiency year-round, unlike air or water-source variations. However, it is not always possible, or economical, to supply DHW exclusively from a heat pump, particularly in buildings with recirculating hot water systems; where water must be stored above 60^0C and distributed at temperatures in excess of 50^0C (Brown, 2009). In such cases, hybrid systems are often employed; wherein a heat pump supplies the majority of the heating load, with supplementary heat being provided via a more conventional power source, such as an oil boiler, as utilised in the care home.

The hybrid system employed in the care home operates in the following way; the geothermal heat pump supplies heat to water contained in a pre-heat cylinder, which subsequently supplies the main domestic hot water cylinder, where an oil boiler is used to inject additional heat to raise water temperatures to 60^0C (Palmer, 2013). This process should result in DHW production which is energy efficient, with low operating costs and minimal carbon emissions. However the system appears to be underperforming, requiring an excessive volume of oil to maintain hot water production at the required temperature.

Consequently, Orkney Islands Council has commissioned this project to examine the current system with the aim of identifying and rectifying any faults found therein, thus raising the system to an acceptable level of performance. Nevertheless, determining the nature and origin of any faults in the system will prove challenging, due to the increased complexity of hybrid systems. When DHW is produced exclusively by one machine, tracing errors is relatively simple; however, with hybrid systems, both the individual components and the interactions between them must be examined.

To achieve this, the investigation comprised of a detailed literature review on hybrid domestic hot water systems and their typical operation and limitations. This was followed by a period of preliminary analysis to highlight any evidence of potential faults in the system and to aid in the development of an investigation plan for the subsequent site visit. A comprehensive on-site examination of the DHW system was then undertaken, wherein additional data and observations were recorded. A final period of analysis followed, with the purpose of assessing all of the data and results collected during the investigation. The origins of the observed faults were then identified and a modification plan developed to restore the system to an acceptable level of performance.

Table 1-1 illustrates the structure of the project, complete with the main aims of each element in the investigative process. A list of the information contained in the corresponding chapter of the thesis is also included:

Literature Review *Aim: To develop a comprehensive understanding of the fundamental elements of DHW systems.*	**Chapter 2:** Comprises of research on: • DHW Production (focussing on hybrid heat pump and oil boiler systems.) • DHW storage in cylinders and the measures necessary to avoid bacterial contamination. • DHW distribution systems
Current DHW System *Aim: To fully understand the operation of the current system and its component parts.*	**Chapter 3:** Contains Information on: • The current operation of the system. • The role of each key component in the system. • Indications of potential faults in the system.
Initial Analysis *Aim: To evaluate the past performance of the system and to look for any aberrations in the data that could indicate a fault.*	**Chapter 4:** Preliminary analysis encompassed: • Demand analysis. • Care home oil use. • Oil boiler efficiency study. • Care home water requirements.

Investigation Plan *Aim: To maximise the available time and to ensure that all necessary equipment is available for the site visit.*	**Chapter 5:** Chapter contains: • Targeted aims for the site visit. • Identification of key areas. • Investigation plans for each day. • Equipment List
Site Visit *Aim: To observe the system in operation and to collect additional data for analysis.*	**Chapter 6:** Results and observations for: • Heat Pump and pre-heat cylinder. • Oil boiler and main DHW tank. • DHW distribution system.
Further Analysis *Aim: To analyse the data collected during the site visit and to evaluate it, together with the previous results, to arrive at an overall assessment of the DHW system's performance.*	**Chapter 7:** Further analysis encompassed: • Oil boiler efficiency study (using true values collected during site visit). • Secondary Circulation Losses. • Current system performance (analysis of energy requirements, costs and carbon dioxide emissions)
Conclusions and Recommendations *Aim: To determine the nature of the faults within the DHW system and to ascertain the necessary modifications to rectify the issue.*	**Chapter 8:** Discussion on: • Conclusions • Necessary Modifications and the resulting performance improvements.

Table 1-1: Project Structure

2 Literature Review

To develop a comprehensive understanding of the fundamental elements of domestic hot water systems, a detailed literature review was conducted. Research was focussed on the following areas;

- DHW Production (focussing on hybrid heat pump and oil boiler systems).
- DHW storage in cylinders and the measures necessary to avoid bacterial contamination.
- DHW distribution systems.

However, first it was important to establish exactly what functions domestic hot water encompasses, in addition to the various design constraints which shape the system.

2.1 Domestic Hot Water

Domestic hot water comprises of all the water used for sanitation, personal hygiene and food preparation in a building. The type of system required will be dependent on; the size and function of the building, the number, frequency and age of the occupants, in addition to the necessary water requirements. The DHW system requirements of an aged care facility are, in many ways, similar to those required in hospitals; the water network is likely to be extensive and supply a large number of rooms which may not always be occupied. Water discharge temperatures are likely to be maintained at lower temperatures to reduce the risk of scalding and many of the residents will be more susceptible to waterborne diseases, whether through underlying illness or simply advanced age (World health Organisation, 2011).

As such, a typical household DHW system, such as an instantaneous hot water supply provided through a combination boiler, etcetera, is not suitable. Instead a recirculating hot water system, complete with storage, is often utilised. Additionally, it is often cost effective to separate the space heating and domestic hot water systems, as is the case in the residential care home in Orkney (Brown, 2009). A cost effective and energy efficient method of DHW production should then be chosen.

2.2 Domestic Hot Water Production

Domestic hot water can be produced in a variety of different ways from various fuel sources. Hot water can be generated using natural gas or oil in conventional boilers or it can be produced from electricity; as is the case in heat pumps or electric showers. Additionally, water can be heated directly by the sun through the use of solar thermal technology or even by utilising waste heat from power plants through combined heat and power (CHP) (The Chartered Institution of Building Services Engineers, 2012). It is important to note however, that not all of the above mentioned technologies are capable of providing DHW independently, and must instead be utilised as part of a hybrid system.

Ideally, when designing a DHW system, the chosen method of hot water generation should supply the structure's needs whilst still remaining energy efficient, with minimal operating costs and carbon dioxide emissions. Heat pumps can satisfy these conditions when implemented as part of a hybrid system.

2.2.1 Heat Pumps

Heat pumps are devices that transfer heat from a low temperature heat source to a higher temperature heat sink, working against the natural temperature gradient (where heat moves from a hot area to a cold one) (Young, et al, 2007). This is achieved through the operation of a refrigeration cycle.

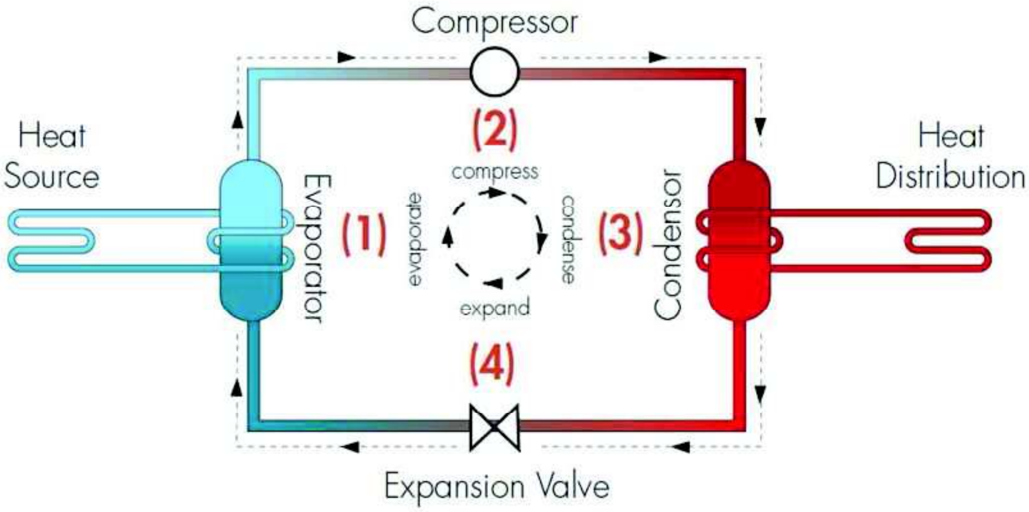


Figure 2-1: Vapour-Compression Refrigeration Cycle

(Image source: http://www.vent-axia.com/heatpump/how)

The most widely used refrigeration cycle is the vapour-compression refrigeration cycle. A refrigerant is defined as "any fluid that has the ability to absorb heat during the process of vapourisation and to release heat during the condensing process" (Silberstein, 2003, p.493). When utilised in a refrigerator or heat pump, it provides the mechanism through which heat can be moved from one area to another. In the vapour-compression refrigeration cycle (shown in **Error! Not a valid**

bookmark self-reference.) the refrigerant, in its vapour state, enters a compressor at a low temperature and pressure and leaves after undergoing compression as a high temperature, high pressure vapour. The vapour then travels to a condensor where heat is rejected to the desired environment when the refrigerant is subcooled (heat removal from a liquid after it has condensed (Tuohy, 2013)). After travelling through the condensor the refrigerant passes through an expansion device; which transforms the high temperature, high pressure subcooled liquid to a low temperature, low pressure saturated liquid in preparation for passing into the evaporator. When passing through the evaporator the refrigeration liquid absorbs heat from the environment (see heat source in **Error! Not a valid bookmark self-reference.**) and vapourises. The vapour then superheats, picking up additional heat from the environment before moving to pass through the compressor, beginning the cycle anew (Silberstein, 2003).

There are several different types of heat pump, determined primarily by the medium of the heat source. These include air-source heat pumps (ASHP) which utilise the outdoor air (or equivalent) as the heat source, liquid-source heat pumps (LSHP) and ground-source (geothermal) heat pumps (GSHP), with air-source heat pumps currently the most common. Heat pumps can also be configured as reverse-acting systems, allowing them to heat an area in winter and cool it in summer (Silberstein, 2003).

The distinguishing feature of a heat pump is that the amount of heat transferred is greater, often significantly so, than the energy required to power the cycle (Brown, 2009). The ratio describing this feature is the coefficient of performance (COP) and is a measure of the efficiency of the heat pump. It is defined as follows (Holland, et al., 1999):

$$COP = \frac{Quantity\ of\ heat\ transferred}{Energy\ used\ to\ drive\ the\ compressor}$$

Therefore a heat pump with a COP of 3 will delivers 3 kWh of heat for every 1kwh of electricity. Typically, coefficients of performance for heat pumps powered by electricity range from 2.5 – 5 (IEA Heat Pump Centre, 2013). However, the COP is also approximately proportional to the temperature difference between the evaporator and condensor (Brown, 2009) which highlights one of the limitations inherent to heat pump technology; that heat pumps become less efficient when demand for heat is at its highest. Air and even liquid-source heat pumps will become less effective as the ambient temperature falls, requiring greater electricity consumption and, in the case of LSHPs, it is often necessary to heat the source body of water at great expense (Silberstein, 2003).

However, the temperature in the earth, beneath a certain distance, remains constant and is unaffected by the temperature above ground. Therefore geothermal heat pumps (which are liquid to liquid heat exchangers) are able to work consistently all year round and in harsh climates. Additionally, heat pumps often have lower operating costs and emissions than other conventional forms of heat generation. For example, a heat pump with a COP equal to 3 will be more cost effective and produce fewer emissions than competing technologies so long as the electricity (typically derived from the national grid) and typical carbon dioxide emissions are no greater than three times that of other fuels (Nottingham Energy Partnership, 2013).

Nevertheless, DHW generation solely through a heat pump is often not cost effective. Only high temperature versions of heat pumps are capable of producing hot water at 60^0C or above and they do so at a reduced COP (Brown, 2009). Therefore it is often beneficial to use a geothermal heat pump to pre-heat the water to temperatures in the region of 50^0C, with the remaining heat being provided by a gas-fired or oil boiler, as is the case in the residential care home.

2.2.2 Oil Boilers

A boiler is defined as “a closed vessel in which water or other liquid is heated, steam or vapour is generated, steam is superheated, or any combination thereof, under pressure or vacuum, for use external to itself, by the direct application of energy from the combustion of fuels, from electricity or nuclear energy.” (North Carolina Department of Labor, 2013) Oil boilers produce hot water through the combustion of various grades of oil. The oil type which is utilised in the boiler is largely determined by the size of the DHW or central/space heating system of the building; Class C2 oil (kerosene) tends to be utilised in domestic boilers, Class D (Gas oil) is used in large heating systems. Classes E to G are categorised as fuel oils and are also used in large installations (The Chartered Institution of Building Services Engineers, 2005).

Oil boilers also require a burner, a machine used to ignite the fuel. The oil is ignited through the process of atomisation; wherein the oil is separated into tiny droplets during the ignition phase (Young, et al., 2007). There are two main types of burner; pressure jet and rotary. In a pressure jet burner a fuel pump feeds oil through a nozzle at high pressure to produce atomised oil droplets. These are then are mixed with air, provided by a fan, to enable the combustion process. They are often restricted to an on/off mode of operation and are most commonly found on small boilers (The Chartered Institution of Building Services Engineers, 2005). Rotary Burners often utilise heavier grades of fuel and are generally required for larger boilers. Atomised oil is produced through centrifugal action wherein a rotating cup propels oil droplets through two combustion air fans. They often require noise-dampening technology (The Chartered Institution of Building Services Engineers, 2005). The care home DHW system features a Riello pressure jet burner utilising Class D (Gas Oil).

Generally, the efficiency of oil boilers are high. Modern high efficiency models, such as the Clyde CK10 boiler installed in the care home, have an expected seasonal efficiency ($Seasonal\, n_{eff} = 0.81n_{30\%} + 0.19n_{100\%}$ (Clyde: Engineering Data Sheet, 2010)) ranging from 84% to 67% over their life cycle. Efficiency varies when a boiler is working at half or full load therefore seasonal efficiency is a measure of the average efficiency of the boiler under varying conditions over the course of the year (The Chartered Institution of Building Services Engineers, 2005).

Boiler efficiency is dependent on many factors; there can be losses due to unburnt fuel, incomplete combustion, radiation losses, dry gas loss and losses due to moisture in the fuel, in which case the latent heat of vapourisation must be subtracted from the calorific (amount of energy) value of the fuel (Evans, et al., 2013). A process known as dry cycling can also have a significant adverse effect on boiler performance. A boiler cycle involves five stages; “a firing interval, a post-purge, an idle period, a pre-purge and a return to firing” (U.S. Department of Energy, 2012). During this process energy is expended to remove the accumulated combustion gases in addition to radiation and convection losses.

Ideally a boiler would only fire when energy was required for DHW or space heating; however the sequence will also be initiated when the integral thermostat calls for heat or a boiler shunt pump is operational to maintain internal temperatures. As a result energy and fuel are wasted when there is “no true heating demand from the building it serves” (Trend Controls, 2013).

A study on biomass boilers concluded that boilers waste energy by cycling unnecessarily up to two hundred times a day, with resulting losses equal to 5% (Faulks, 2013). In an attempt to mitigate these errors the boiler controls are often integrated with Building Management System (BMS) software where sensors are used to monitor internal temperatures and the time between cycles, etcetera. These systems can be used to control various boiler functions with the aim of maximising boiler efficiency (Carbon Trust, 2007).

When integrated as part of a DHW system which contains water storage, boilers will also fire when a calorifier calls for additional heat.

2.2.3 Domestic Hot Water Storage

Domestic hot water systems can be designed around an instantaneous water supply or a stored one. Whilst an instantaneous supply can heat water as required, without the relevant standing losses associated with water storage, this type of supply is not capable of generating all the necessary hot water required in large buildings with high water demand. Additionally, water storage is necessary when higher water temperatures and flow rates are required, as is the case throughout extensive distribution systems.

When utilised in a system with a heat pump and oil boiler the stored water will be kept in calorifier (accumulator) tanks which contain a heat exchanger working between itself and the corresponding machine (Brown, 2009). These are examples of indirect calorifiers. Additionally, there are direct calorifiers which are heated electrically by immersion heaters, and there are also buffer heaters which offer additional water storage for a primary or secondary water heater (McDonald Engineers, 2013). In the residential home in Orkney the heat pump is connected to a pre-heat cylinder, which then feeds into the main DHW cylinder where supplementary heat is provided via the oil boiler (Palmer, 2013). Nevertheless, there are risks associated with storing hot water in calorifiers, as the tanks can provide perfect breeding conditions for microbial growths, such as Legionella (Holland, et al., 1999).

Legionella is a naturally occurring environmental pathogen common to aquatic environments. Inhalation of the bacteria can cause a particularly dangerous strain of pneumonia known as Legionnaire’s disease. It can also cause a non-fatal condition known as Pontiac Fever; which can, in itself, induce pneumonia. Outbreaks are often associated with cooling towers or even hospitals, where, due to the high number of immunocompromised patients, death rates can be particularly high (World Health Organization, 2011). As a result, controlling the propagation of the pathogen is vital.

The bacteria adhere to biofilms on the sides of pipes and tanks and require the presence of the amino-acid L-cysteine and trace metals to multiply and grow. Additionally, the pathogen can also survive and thrive on some species of free-living protozoa (a unicellular organism); in the same way in which a virus invades the host cell, the legionella will attack the protozoan which will then engulf the bacteria in a phagocytic vesicle. The bacteria will then replicate inside the host cell until the amoeba ruptures. It is important to note that under these growth conditions the legionella may be protected, due to its intracellular location, from disinfectant biocides such as chlorine. (McLuckie, et al, 1995). The bacteria replicate faster in slightly acidic water and their growth is heavily temperature dependent (McLuckie, et al., 1995).

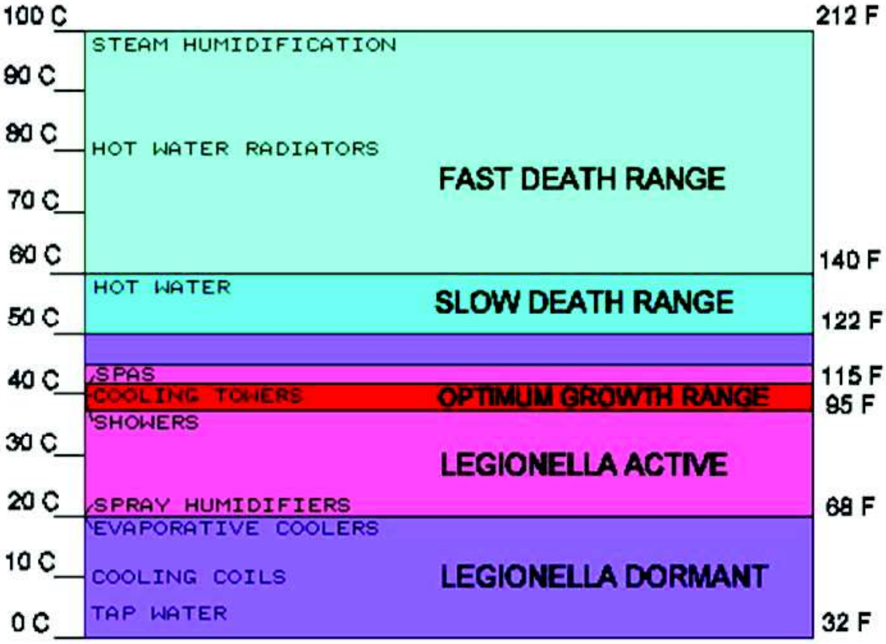


Figure 2-2: Legionella Propagation at Varying Temperatures

(Image source http://www.engr.psu.edu/iec/abe/topics/legionnaires.asp)

Figure 2-2 illustrates the activity of the bacteria with temperature. It also shows the typical temperature range of various water appliances and systems, highlighting those which present a greater risk for a legionella outbreak due to their operating conditions. Therefore, as shown in Figure 2-2, hot water is stored above

60^{o}C due to the fact that legionella bacteria will die at this temperature. In addition to this, hot water tanks should also undergo a disinfectant procedure to reduce the formation of biofilms and other favourable conditions for the growth of the pathogen.

Calorifiers can also be customised to include destratification pumps which circulate the water in the tank to ensure that all of the water is at the same temperature. Copper is also known to inhibit the growth of legionella, therefore many modern accumulator tanks are made from it (McDonald Engineers, 2013). However legionella and bacterial growths can be present throughout the whole of the DHW system, including the distribution system.

2.2.4 DHW Distribution System

Designing a DHW distribution system presents several challenges; the system should deliver water throughout the building at temperatures conducive to the area requirements. At the same time it must be hot enough to prevent the spread of bacteria such as legionella, without presenting a scalding risk. Therefore the world health organisation suggests that hot water should be distributed at temperatures in excess of 50^{o}C, with sufficient flow rates to prevent the growth of biofilms and bacterial cultures. Stagnation (prone to occur in rarely used branches of the system) should be avoided at all costs, as should dead ends in the pipework and areas of low flow. The hot and cold water flows should be insulated, typically using mineral wool, to avoid the hot water heating the cold water to unsafe temperatures and vice versa (World Health Organization, 2011). Additionally, the pipes should be properly sized with the correct valves and insulation to prevent unnecessary heat loss.

Thermostatic mixing valves (TMV) should be utilised to ensure that water being discharged from the system is at a safe temperature. Temperature mixing in the TMVs should also occur as close to the discharge point as possible to reduce the risk of legionella (World Health Organization, 2011). Effective discharge temperature control is particularly important in an environment where a number of the residents are at a risk from scalding. The suggested discharge temperature range is between 35^{o}C to 46^{o}C, with temperatures not exceeding 43^{o}C in bath and sinks used by "older people, people with reduced mental capacity, reduced mobility, a sensory impairment, or people who cannot react appropriately, or quickly enough, to prevent injury." (Health and Safety Executive (UK), 2013)

3 Current Domestic Hot Water System

In this chapter the operation of the current DHW system is described. Additionally, the main components of the system are discussed in greater detail, as are the possible indicators of faults in each machine and the system as a whole.

The current system incorporates an IVT Greenline D40 geothermal heat pump which is connected to a 500 litre pre-heat accumulator tank. The pre-heat tank feeds the main domestic hot water cylinder, a 1400 litre indirect copper calorifier, complete with destratification pump. A Clyde CK10-87/6 oil boiler, complete with Riello 40 G20D burner, provides supplementary heat to the main DHW cylinder. The oil boiler uses Class D oil (gas oil). In domestic settings the heat pump Rego 600 control unit would regulate the boiler operation, only activating it when the heat pump called for additional heat. However, the system at the care home is too complex to be controlled in this manner; therefore a BMS system monitors the temperatures in both accumulator tanks and controls the operation of the oil boiler. Additionally, DHW is provided through calorifiers (capacity of 360 litres) in each wing (with the exception of wing A as the plant room is situated there). The secondary circulating pump is mounted in the pipework and has a flow rate equal to 1.5 litres per second. The main components are illustrated in Figure 3-1.

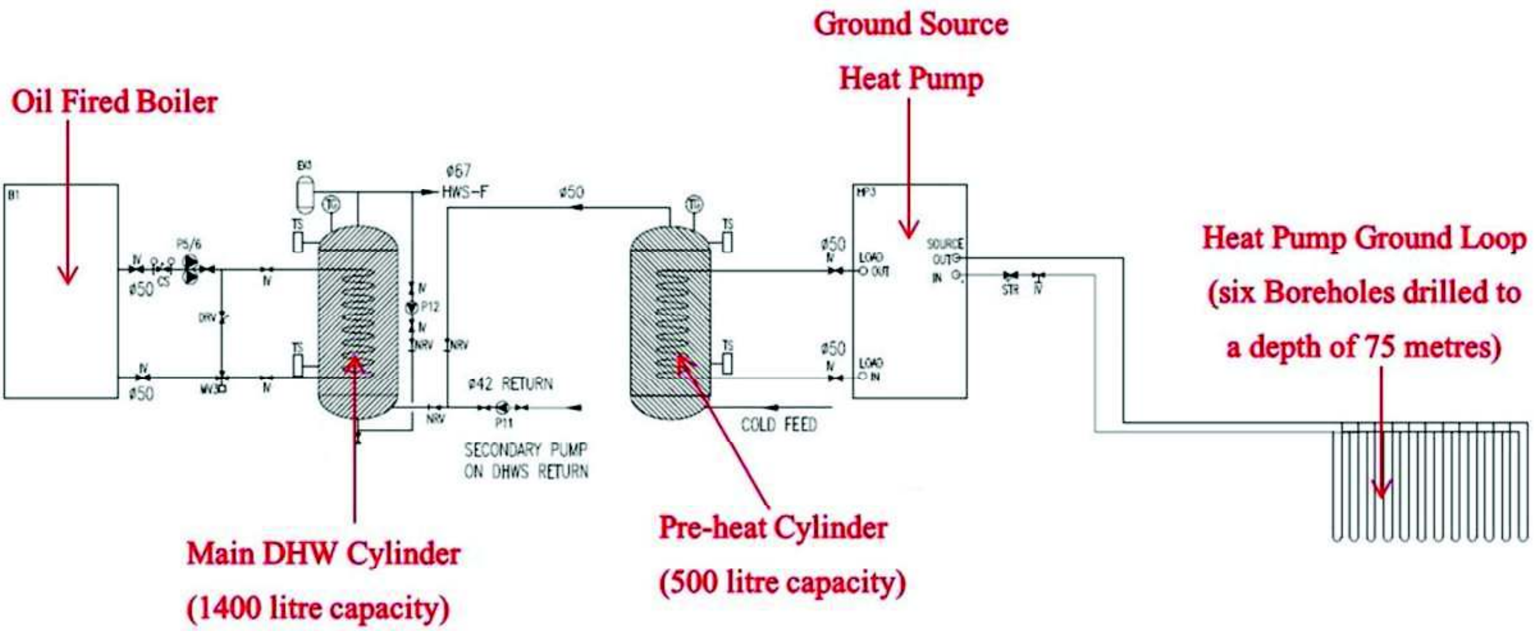


Figure 3-1: DHW System

The boreholes of the geothermal heat pump reach a depth of 75 metres where the temperature remains constant at 13^{0}C (Energy Efficiency Best Practice in Housing, 2004). The heat pump has a COP equal to 3.2 (IVT Heat Pumps, 2003).

3.1 Heat Pump

The internal components of the heat pump are shown in Figure 3-2 below. The image is actually of one of the models in the E series, however the two machines are very similar.

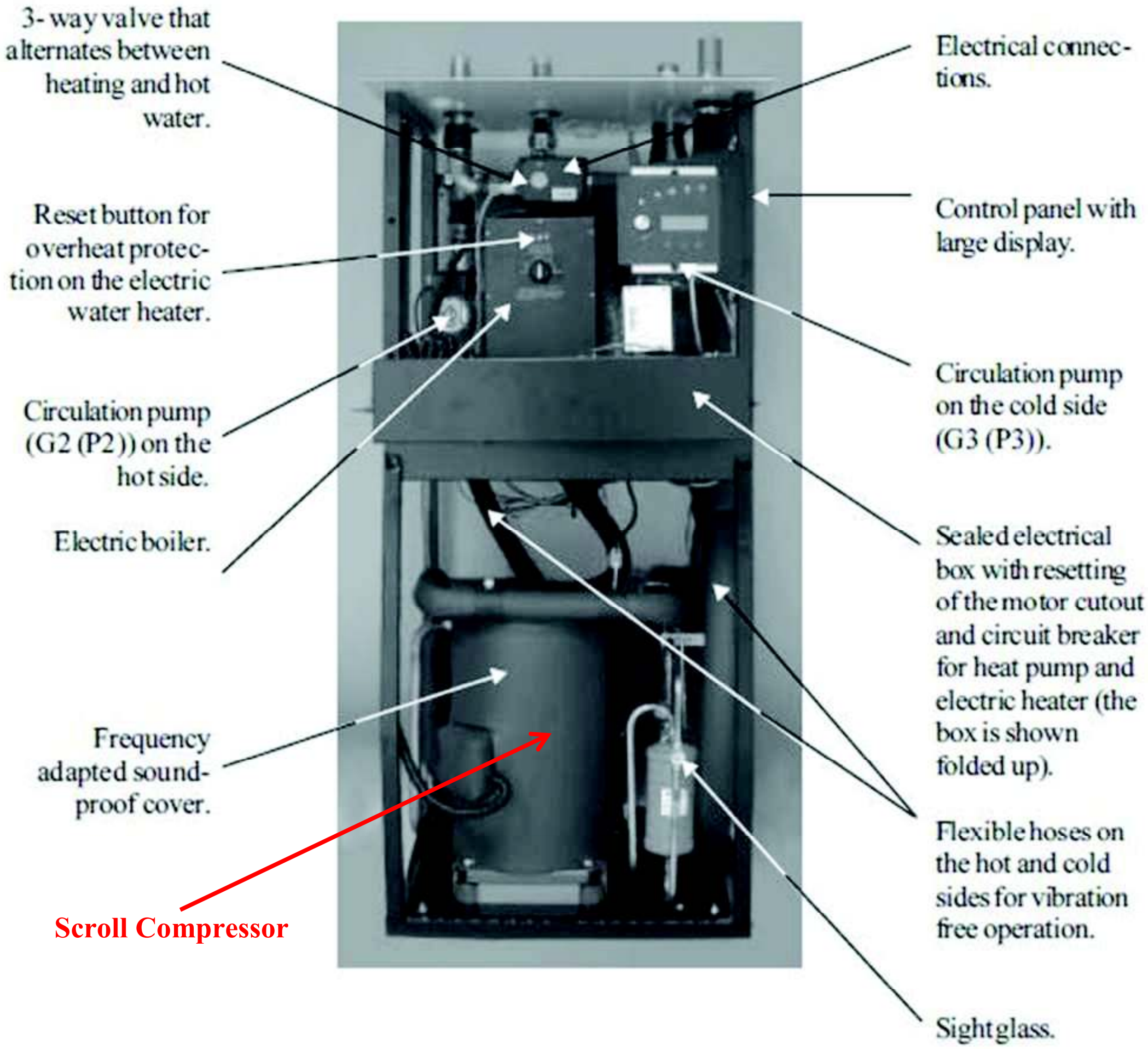


Figure 3-2: Heat Pump (Internal Components)

It will not be possible to examine the interior of the heat pump during the investigation, therefore data on accumulator tank temperatures and electricity demand should be examined to discern whether there are any faults in the system. The scroll compressor, highlighted on Figure 3-2 in red, is a vital component in the system. Without it, the vapour-compression refrigeration cycle would not be possible. Scroll compressors are popular due to the fact that they can tolerate conditions which other compressors cannot. Also, as the components age they tend to “wear in”, making them more efficient, as opposed to “wearing out”. Most compressors cannot tolerate any liquid entering the device, however the scroll compressor can still function under these conditions, albeit at a reduced capacity (Silberstein, 2003). Thus, if demand stays the same, yet the heat being produced is lower than required, this could be an indication that there is liquid present in the compressor.

A reduction in electricity demand could also indicate a change to the settings of the heat pump, or a breakdown in communication between the heat pump and pre-heat cylinder. Ultimately, the temperature of the pre-heat cylinder will show whether the heat pump is operating efficiently. Low temperatures could be a result of the hysteresis being set too high or of the set point temperature being set too low, among other issues.

3.2 Oil Boiler

Figure 3-3: Boiler Internal Structure

The Clyde CK10 boiler is made up of six sections and has a seasonal efficiency calculated at 84%. It has a maximum working pressure of 8 Bar and a maximum operating temperature of 110°C. The thermal efficiency (heat to water (NCV)) is equal to 88.76%. Water flow rates range from 0.63 to 1.73 litres per second, depending on the temperature rise in the water.

The presence of an oil leak could indicate a fault in the oil delivery system; this could possibly be a sign of a leak in the pipe, or it could indicate that the boiler and oil burner are misaligned or that the boiler plinth was not level.

Frequent firing occurring soon after the oil boiler has activated would indicate dry cycling. Whereas frequent activations in general would either suggest that the boiler is having to provide heat to mitigate excessive standing losses in the calorifiers, or that there was a communication or sensor error between the main DHW cylinder and the boiler. The pattern of fuel use per activation could also indicate the amount of heat being injected into the calorifier.

The BMS system software should also be examined as it contains useful information on tank and return flow temperatures, etcetera. Importantly, it should be examined against the actual conditions in the plant room, as disparities between data or temperature readings could indicate an error in system integration.

It is important to note that the factors addressed in this chapter are not exclusive, and represent only a fraction of the possible faults which could exist in the system. Nevertheless, the issues identified represent typical faults which can develop in hybrid DHW systems.

4 Initial Analysis

Understanding the past performance of the DHW system in the care home was vital if the source of the fundamental flaws in the system were to be discovered. To gain a comprehensive understanding of the operation of the system, both past and present, it was necessary to examine the care home's energy demand and water requirements. The efficiencies of the DHW heat pump and oil boiler were also assessed. The information that was available for analysis is recorded in Table 4-1 below.

Data Available	Measured Period
Utility Meter Readings (Day and Night)	31st Oct 2008 – 25th Feb 2011
Heat Pump Electrical Requirements (HP1, HP 2, HP 3)	31st Oct 2008 – 25th Feb 2011
Domestic Hot Water Usage	31st Oct 2008 – 25th Feb 2011
Oil Usage	31st Oct 2008 – 25th Feb 2011
Oil Delivery Invoices	9th May 2007 – 19th Jan 2012
Half-Hour Demand Data	1st Jan 2006 – 17th Jan 2013

Table 4-1: Care Home Data Available for Analysis

The aim of this initial analysis was to develop a comprehensive understanding of the DHW system performance, as well as to highlight any aberrations in the data which could indicate the presence (or sudden appearance) of a fault in the system. The results of this analysis were then used as an aid when developing the investigation plan for the subsequent site visit.

The analysis of the care home domestic hot water system comprised of several distinct elements;

- Demand Analysis (Section 4.1)
- Care Home Oil Use (Section 4.2)
- Oil Boiler Efficiency Study (Section 4.3)
- Water Requirements (Section 4.4)

Each subsection comprises of an account of the analysis undertaken; describing data selection, methods of analysis employed and results obtained. Any limitations of the study are also discussed, in addition to a section describing the relevance of the findings to the project as a whole.

This chapter concludes with a summary of the results obtained (Section 4.5).

4.1 Demand Analysis

Space heating and domestic hot water production often account for a large percentage of a dwellings' electricity consumption, therefore it was imperative to complete a demand analysis of the residence. Any changes or aberrations in the pattern of demand could indicate a design or operational fault in the domestic hot water system. This demand analysis comprises of a study of the care home electricity demand and relevant climate data, the heat pump contribution to demand, in addition to an investigation into typical daily, seasonal and annual demand profiles. Section 4.1.1 - Care Home Electricity Demand, determined the baseline conditions for the study and was used as a reference throughout the demand analysis.

4.1.1 Care Home Electricity Demand

Before analysis of the system could commence, the typical demand profile of the care home had to be discerned. As electricity demand is often influenced by the local climate (Clarke, 2013), the temperature values for Orkney during the measured period were also collected and recorded for comparison with the demand data.

Data collection

Half-hourly demand data was collected between the 1st of January 2006 and the 17th January 2013, which resulted in forty-eight demand readings per day over the seven year period. Demand Reading 1 corresponded to the electricity demand between 00:00 – 00:30, whilst Demand Reading 48 was a measure of the electricity demand between 23:30 – 00:00.

Temperature readings were amassed from the Met Office's online climate database. Monthly average temperature values for the North of Scotland between January 2006 and January 2013 were utilised in this analysis. Additional seasonal and annual temperature values can be found recorded in Table 10-1 in the Appendix.

Method of Calculation

The electricity demand, per day, over the measured period was calculated using the half-hourly demand data; the total daily demand was equal to the sum of Demand Readings 1 to 48. These values were then collected and plotted on a chart illustrating the electrical demand over time. A secondary axis was then added, which allowed the local climate data (monthly averages) to be included in the same figure. This allowed for a direct comparison between the climate and demand data.

Results

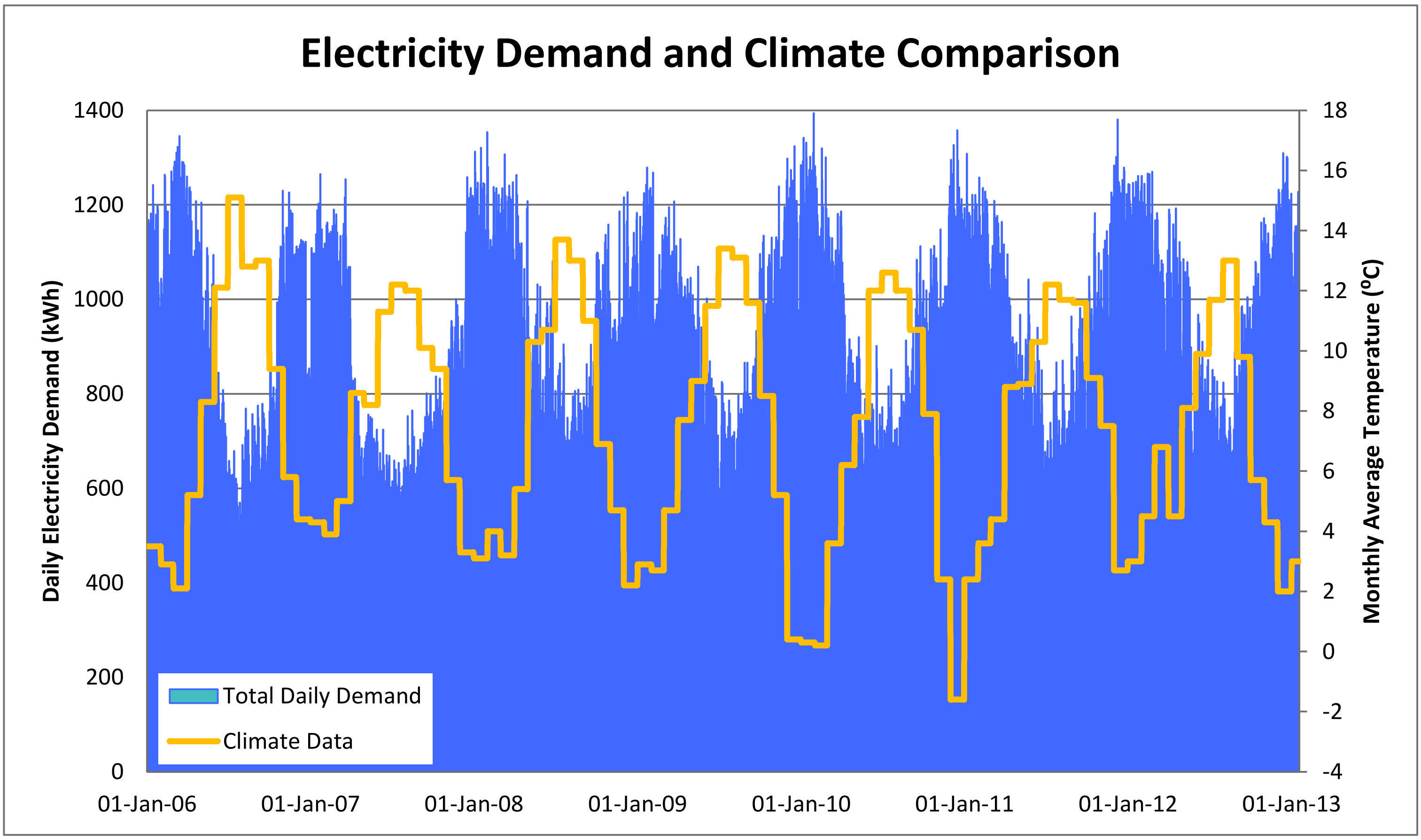


Figure 4-1: Electricity Demand and Climate Comparison

Figure 4-1 illustrates the demand profile of the care home. Generally, demand is highest during winter, and lowest in summer. The temperature comparison clearly illustrates that the level of demand increases in response to drops in temperature and vice versa. Conversely, the figure highlights a drop in demand during the winter months in 2007, with the lowest readings occurring on Christmas and New Year's Day (see Appendix: Figure 10-1). This drop in demand is likely a result of reduced occupancy, rather than evidence of a fault in the system. Demand also appears to have increased slightly over subsequent years, with the exception of 2007.

Limitations

As the climate profile displayed in Figure 4-1 is created using average monthly values it can only be considered an estimate of the local temperature, as opposed to the definitive values. Nevertheless, the profile represented in the figure is accurate enough to illustrate the correlation between local temperature and demand. It therefore acts as a useful indicator during more in-depth analysis, allowing for a quick determination of characteristic demand readings for each period.

4.1.2 Heat Pump Contribution to Electricity Demand

Now that the typical demand profile is known, the proportion directly applicable to the heat pump (HP 3), and thus the DHW system, can be analysed.

Data collection

The meter readings for the electricity use by the DHW system heat pump between the 31st of October 2008 and the 25th of February 2011 was used in collaboration with the demand data (calculated as described in 4.1.1), recorded over the same period. The meter displayed the electricity use as a cumulative total, in units of kilowatt-hours (kWh). The readings were collected over the stated time period on an irregular basis.

Method of Calculation

The demand profile calculated in 4.1.1 was amended to cover the period from the 31st of October 2008 till 25th February 2011. As the electrical demand of the heat pump was recorded as a cumulative total, measured over varying time frames, it became necessary to calculate an average value to represent the daily electrical use. First, the electricity used per measured period was calculated by subtracting the previous value from the cumulative total, and so on for each measurement. The number of days between each reading was then determined by examining the dates the measurements were collected on. Finally, an average daily rate was calculated by dividing the electrical use per period by the number of days in each period. These daily averages were then plotted against a secondary axis on the same figure as the demand profile (Figure 4-3).

The heat pump's contribution to the care home electricity demand was then calculated as follows:

$$Heat\ Pump\ Contribution\ to\ Demand\ (\%) = \left(\frac{AverageDaily\ Demand\ (HP\ 3)}{Total\ Daily\ Demand}\right) \times 100$$

The total daily demand was calculated from the half-hourly data, as described in section 4.1.1. These values were then plotted using Excel to illustrate the variation in the heat pump's contribution to total demand over time (see Figure 4-3).

As Figure 4-3 and Figure 4-4 covered a time period in excess of two years, they were annotated so that the results would be readily discernible. Both graphs were annotated according to the key shown in Figure 4-2. As illustrated in Figure 4-1, acceptable values for the total demand can be estimated based on the local climate. By illustrating where the seasons fall in the graph, any potential aberrations in the demand data will be more readily apparent.

Figure 4-2: Annotation Key

Finally, after it became obvious that the heat pump's electricity usage had decreased over time (see results below), the data was analysed to determine whether this decrease was reflected in the total demand profile. The total demand plot in Figure 4-3 was utilised and a trend line and equation describing the profile were added to the figure. A linear trend line was selected as a means to examine whether, overall, the demand was increasing or decreasing over time.

The demand profile was then expanded to include demand data beyond the measured period, now displaying a demand profile up to January 2013. The equation of the trend line describing the original measured period ($y = 0.0366x - 517.68$) was then used to calculate the expected demand for the extended period. A further trend line and equation ($y = 0.0137x + 394.69$) were then defined for the entire measured period (31st of October – January 17th 2013), representing the actual demand trend. Finally, the expected demand was compared to the actual demand and the results noted (see Figure 4-5).

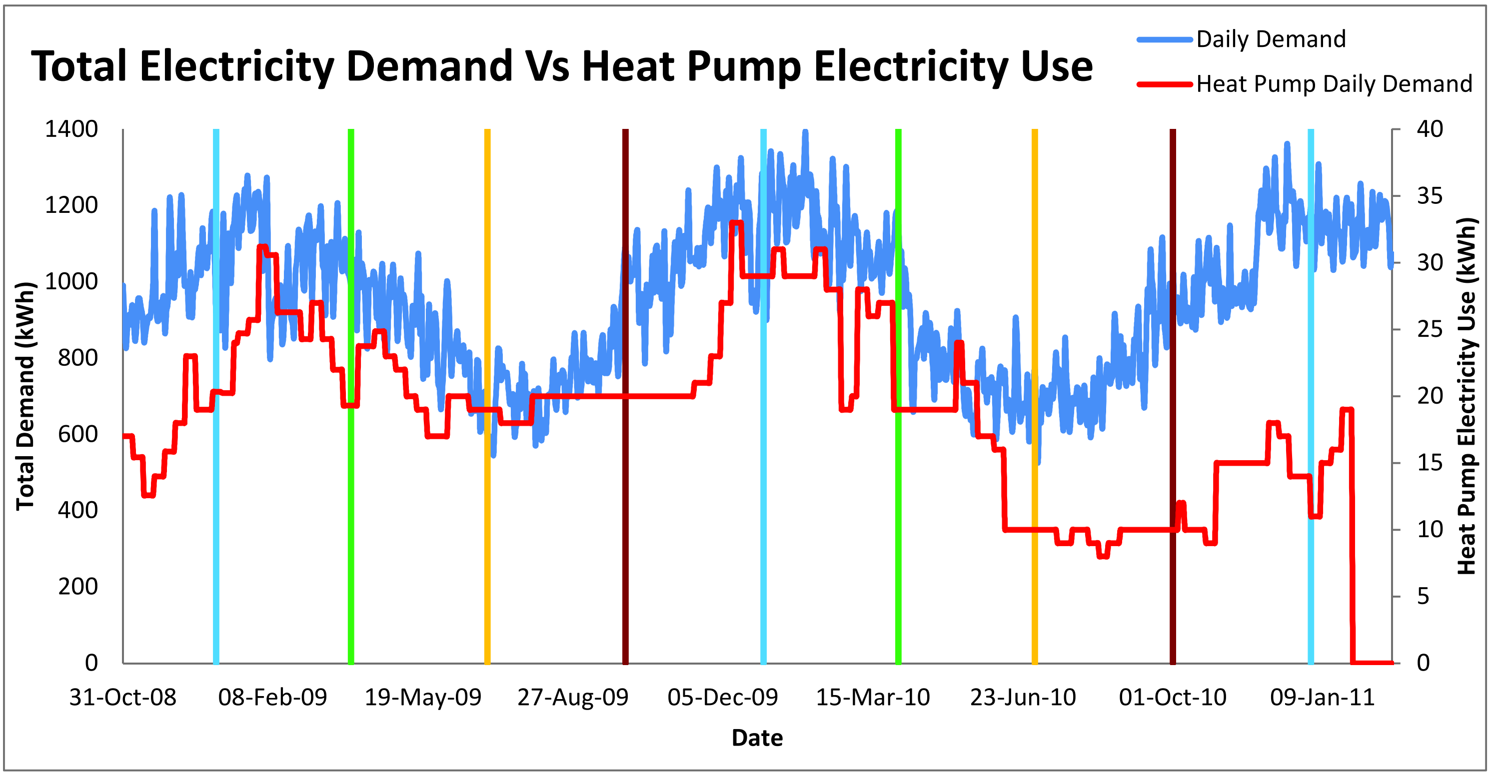


Figure 4-3: Total Electricity Demand versus Heat Pump Electricity Use

As shown Figure 4-3, the heat pump electricity demand is very similar to that exhibited by the total demand, with the heat pump demand typically ranging between 8 – 33 kWh, with an average daily demand of 20kWh. However, after the 11th of June 2010 the heat pump demand began to decrease despite the total demand remaining relatively stable. From here the profile displayed seasonal measurements approximately half the value of those registered prior to this date. After the 22nd of January 2011, the measured demand of the DHW heat pump was zero. Therefore this analysis appears to illustrate the appearance and development of a fault in the system.

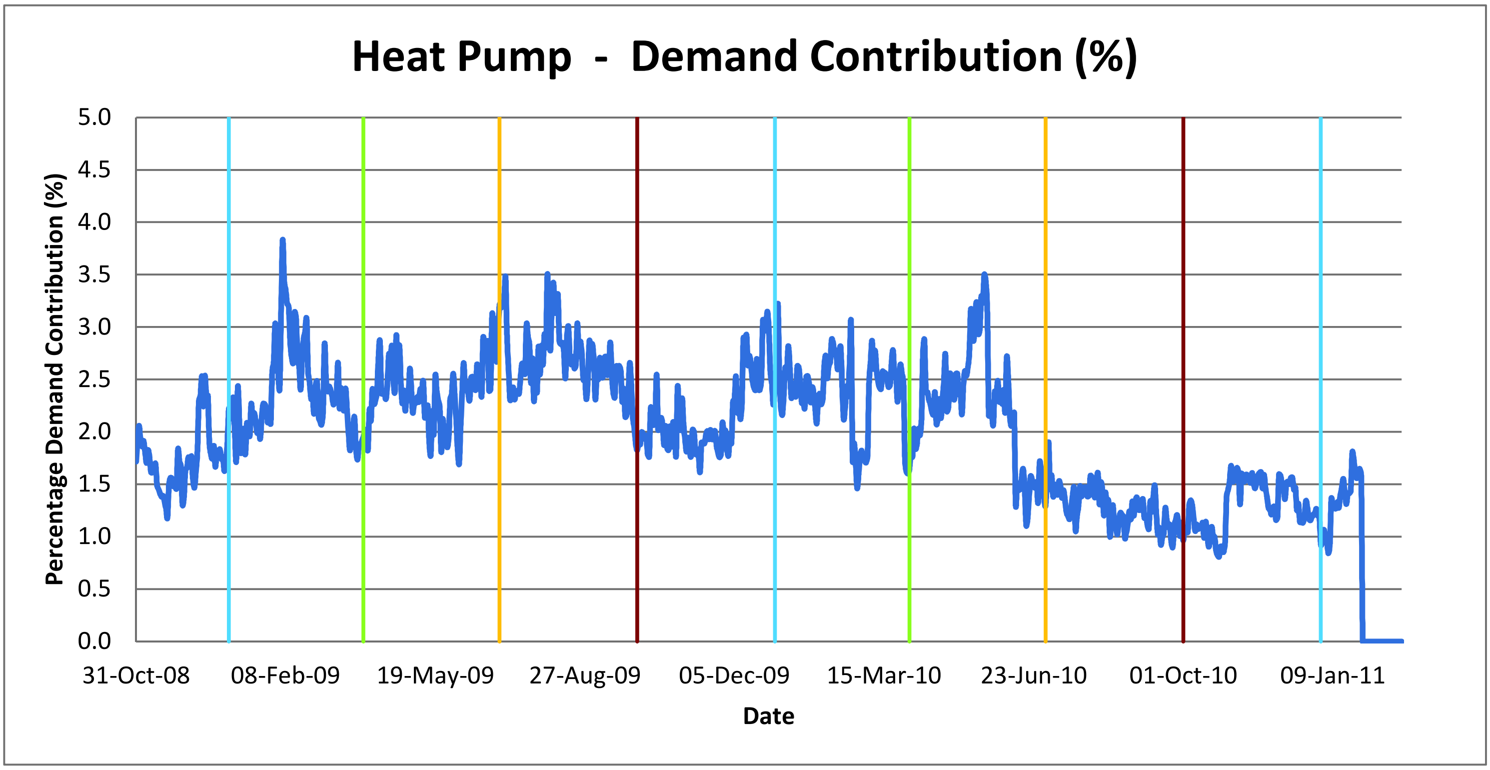


Figure 4-4: Heat Pump - Percentage Demand Contribution

Figure 4-4 shows that the heat pump was responsible for approximately 1- 4% of the electrical demand for the care home up until June 2010. Interestingly the heat pump contributed more to demand during summer than it did in colder months. This is likely a reflection of the fact that heating demand goes down in warmer months. As shown in Figure 4-3, the DHW demand reduced in summer. However so too would the demand for under floor heating and likely to a greater degree, since hot water is required year-round whilst space heating is not. Therefore, although demand has decreased, the reduction in the demand for space heating, which represents a significantly larger fraction of the total demand (approximately 35%), resulted in an increase in the heat pump contribution to the total demand.

Additionally, the figure further emphasizes the likelihood of a fault in the system since the percentage demand contribution fell, whilst all other elements of the demand profile remained consistent. This shows that it is the electrical demand of the heat pump alone that is decreasing, and not demand as a whole.

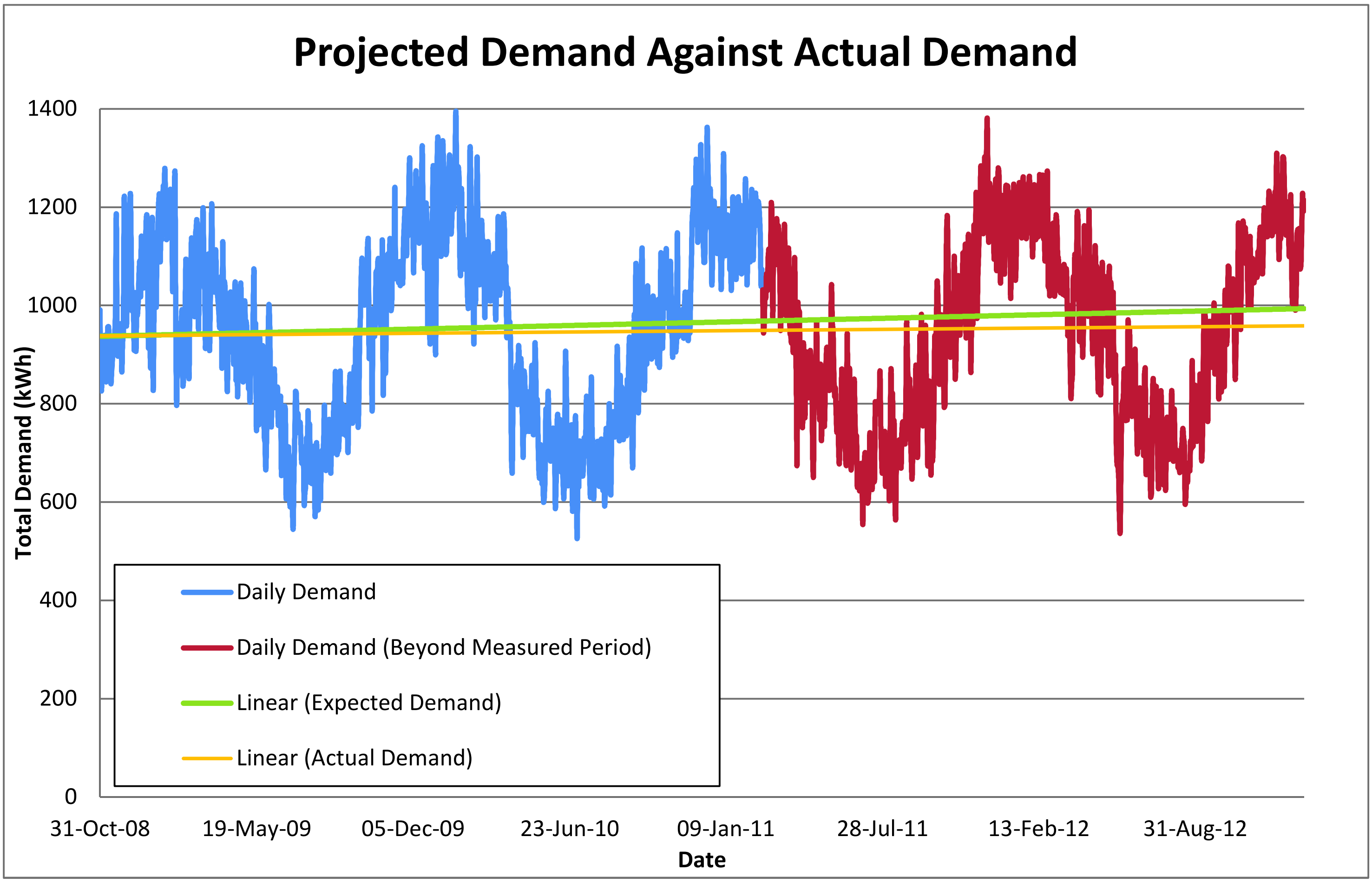


Figure 4-5: Projected Demand against Actual Demand

Figure 4-5 shows that there is a disparity between the actual demand and the expected demand calculated since the heat pump electricity usage began to decrease in June of 2010. The actual demand trend over the entire period increased at a slower rate than the expected projection. The difference between these two projections ranged in size from 17 kWh to 33 kWh with an average difference of 25 kWh. These values, though small, are significant as the average daily heat pump demand is 20kWh and ranges between 8 kWh – 33 kWh. Therefore this reduction could indicate that the heat pump had continued to operate at reduced levels since the aberration noted in June 2010. However, this evidence should be considered circumstantial as it assumes the system is operating under the same conditions over the entire period.

Limitations

The drop in heat pump electrical demand in Figure 4-3 is preceded by long flat stretches in the graph. These features are caused by a lack of data. As mentioned in the data collection section above, data on the electricity usage of the heat pump was not collected at regular intervals. The data was also displayed as a cumulative total over a period of time. This meant that an average value had to be calculated to estimate the heat pump's daily energy requirement. However, when the data was averaged over a particularly long period (108 days in one instance), the resulting profile of the graph became flattened. As the measured time period increases, the resulting level of detail and information from the graph decreases. This effect could mask the typical variation displayed by the demand profile, leading demand to appear lower than it actually was. Additionally, the days when the heat pump registered a demand of 0 kWh occurred within one month of the end of the observation period. It is possible that data collection for the heat pump simply stopped before data collection in other areas did. However, this seems unlikely, since demand readings continued to be recorded for heat pumps 1 and 2 during this timeframe. It is also feasible that the reduction in heat pump demand could have been due to planned maintenance.

As mentioned in the results section, the evidence presented in Figure 4-5 is largely circumstantial. It assumes the same conditions are present throughout the analysed period and also that the heat pump is largely responsible for the reduction in demand, when in reality it could be influenced by any number of factors.

Nevertheless, the evidence is compelling and, as this is an investigation into potential faults in the DHW system, it is important to utilise all relevant information. Therefore the data shown in Figure 4-3, Figure 4-4 and Figure 4-5 could be used in conjunction with other evidence, to diagnose the issues, if any, affecting the DHW system.

4.1.3 Daily Demand Profile

As there is now evidence which shows that the heat pump electrical requirement mimics demand, typical daily demand profiles can be analysed to determine when the heat pump in the care home is most likely to be active.

Data collection

(The following information is relevant to Sections 4.1.3 – 4.1.5)

Half-hourly data was collected between the 1st of January 2006 and the 17th January 2013, which resulted in forty-eight demand readings per day over the seven year period. Demand Reading 1 corresponded to the electricity demand between 00:00 – 00:30, whilst Demand Reading 48 was a measure of the electricity demand between 23:30 – 00:00.

Method of Calculation

The data was grouped into individual seasons according to their date. Spring time was taken to occur between the months of March to May, summer from June to August, autumn from September to November and winter from December to February (according to Met Office classifications, 2013). The demand readings for each time period were then analysed and an average value calculated across the whole season. The average values for each time period were then combined and plotted in a graph (see Figure 4-6), using the computer program Excel, to give a typical daily demand profile for each season. A further graph was created using the data for a single day in the middle of each season (see Figure 4-7). The dates chosen were: January 21st, April 21st, July 21st and October 21st. This illustrated the variation present between time periods, which were not evident on the averaged profiles illustrated in Figure 4-6.

Results

Figure 4-6 shows typical demand profiles which have been created using the average values for each half hourly time period, for each season in 2012. These profiles were indicative of daily activity, illustrating both the level and timing of periods of high and low demand.

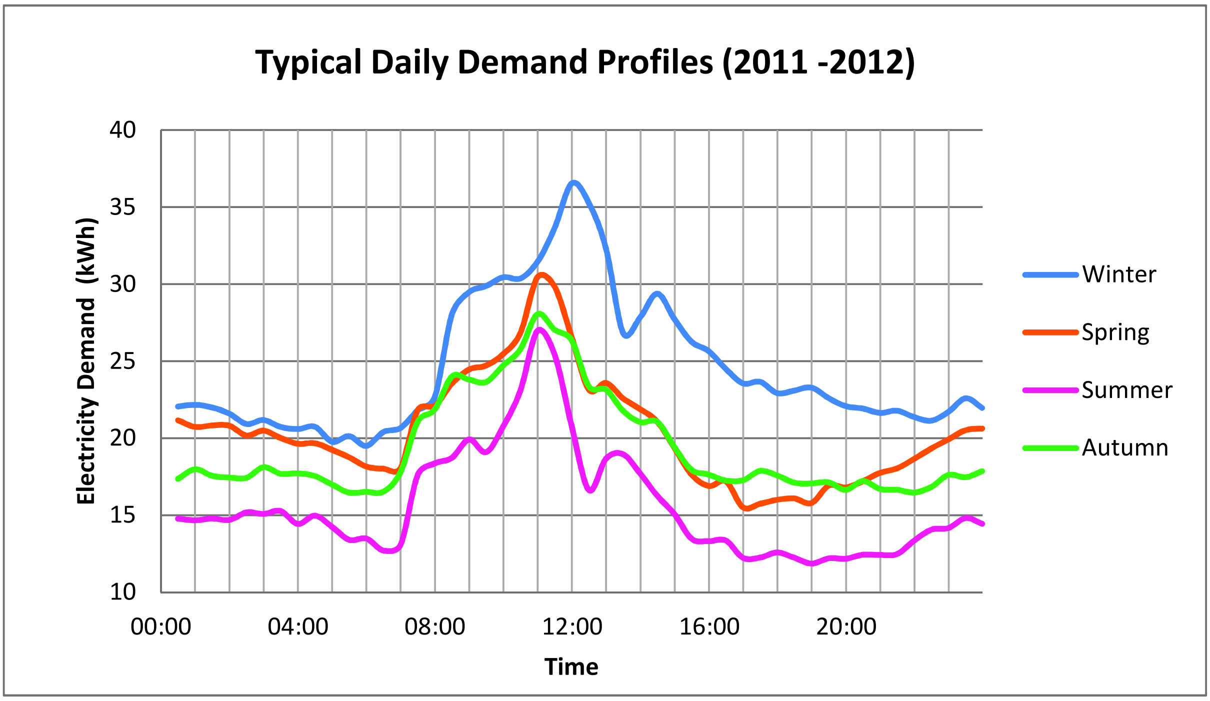


Figure 4-6: Typical Daily Demand Profiles (2011 - 2012)

As shown on Figure 4-6, demand was highest in winter and lowest in summer, with spring and autumn showing similar demand requirements. With regards to activity; spring, summer and autumn displayed very similar profiles, with an increase in demand between 08:00 to 17:00 hours. Demand was at its highest between 09:30 and 13:30, peaking at 11:00 hours. After 17:00 hours the demand levelled out until around 00:00, when there was evidence of a slight increase of approximately 2 kWh to 3 kWh. The demand then remained fairly steady until 04:00, where it dipped slightly until 08:00. Winter showed a similar, but time-shifted profile, with demand peaking at 12:00 hours. The data presented in Figure 4-6 is from 2012; however analysis of the same data from previous years yielded similar results.

As stated in the limitations discussion in Section 4.1.2, Figure 4-6 illustrates that when a profile is generated using average values the profiles appear “smoothed out”, with variation between half hourly periods not readily apparent. Therefore Figure 4-7 was generated using real values, from data obtained midway through each season, to counter this affect and illustrate the variation inherent in an actual demand profile.

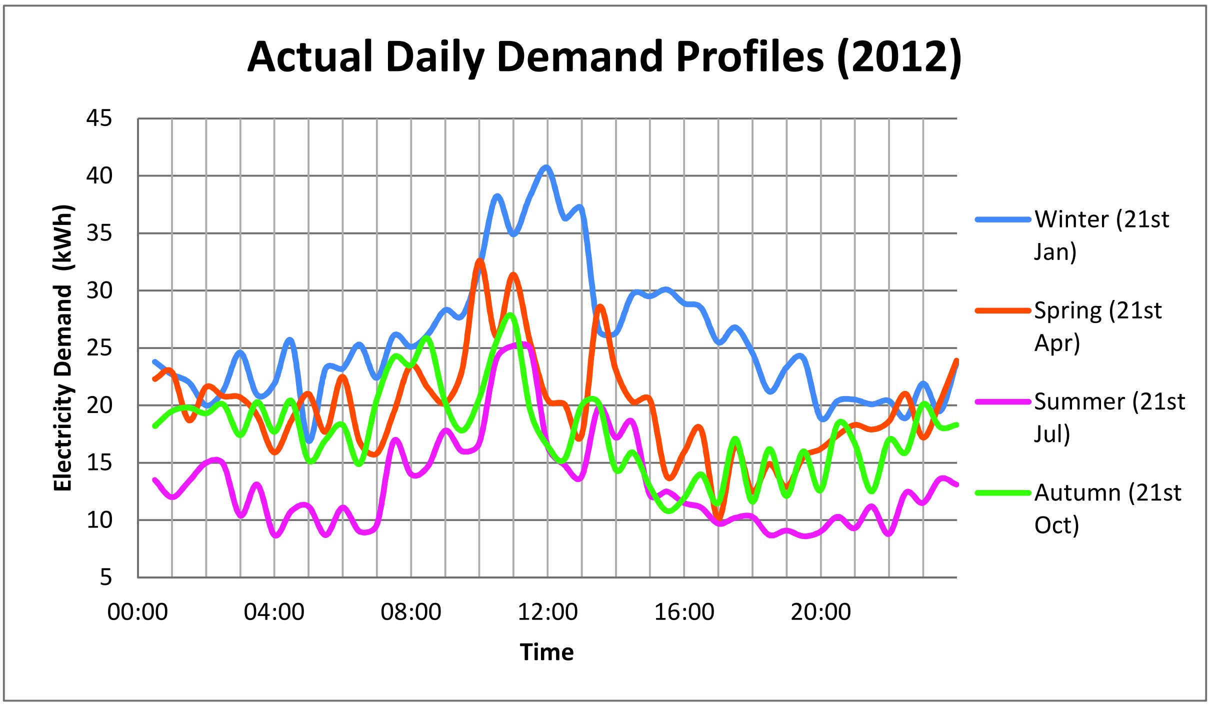


Figure 4-7: Actual Daily Demand Profiles (2012)

The profiles shown in Figure 4-7 displays a variation typically ranging from 2.5 kWh to 5kWh on a half hourly basis. This variation is more pronounced in spring and autumn than in summer or winter.

4.1.4 Seasonal Demand

As shown in Sections 4.1.1 and 4.1.2, demand has been increasing over time. Therefore to gain a better understanding of exactly when demand is increasing, the seasonal demand profiles were examined. Seasonal profiles were chosen because of the close link between demand and climate data; allowing the heat pump's most active periods throughout the year to be predicted in the same way that its daily activity was in Section 4.1.3.

Method of Calculation

The total seasonal demand was defined as the total electrical demand between the start of spring (March 1st: Met Office, 2013) until the end of winter (February 28th/ 29th on a leap year: Met Office, 2013) the following year. Therefore the data for 2006-2007 describes the total demand across the four seasons between March 2006 and February 2007. The total demand for each season was then calculated and plotted in Excel. This process was subsequently repeated for each seasonal period from 2006-2007 till 2011-2012 (see Figure 4-8: Seasonal Demand).

A further figure was plotted (Figure 4-9) to illustrate the electricity demand in full since 2006. This was achieved by plotting the total electricity demand for the entirety of the measured period, with a date midway through each season chosen for representation on the graph. The winter values were plotted on the 1st of January, spring on the 1st of April, summer on the 1st of July and autumn on the 1st of October. The figure was annotated so that the seasonal values were readily apparent upon inspection of the figure. The chosen method of annotation is shown below:

Sp represents spring
Su represents summer
A represents autumn
W represents winter.

Finally, the total seasonal demand was determined by calculating the cumulative demand recorded during the spring (March) to winter (February) cycle. This allowed for a comparison between consecutive years.

Results

Figure 4-8 illustrates the difference in total demand between each season. It comprises of profiles of seasonal cycles from 2006-2007 up until 2011-2012, to allow for a comparison between consecutive seasons.

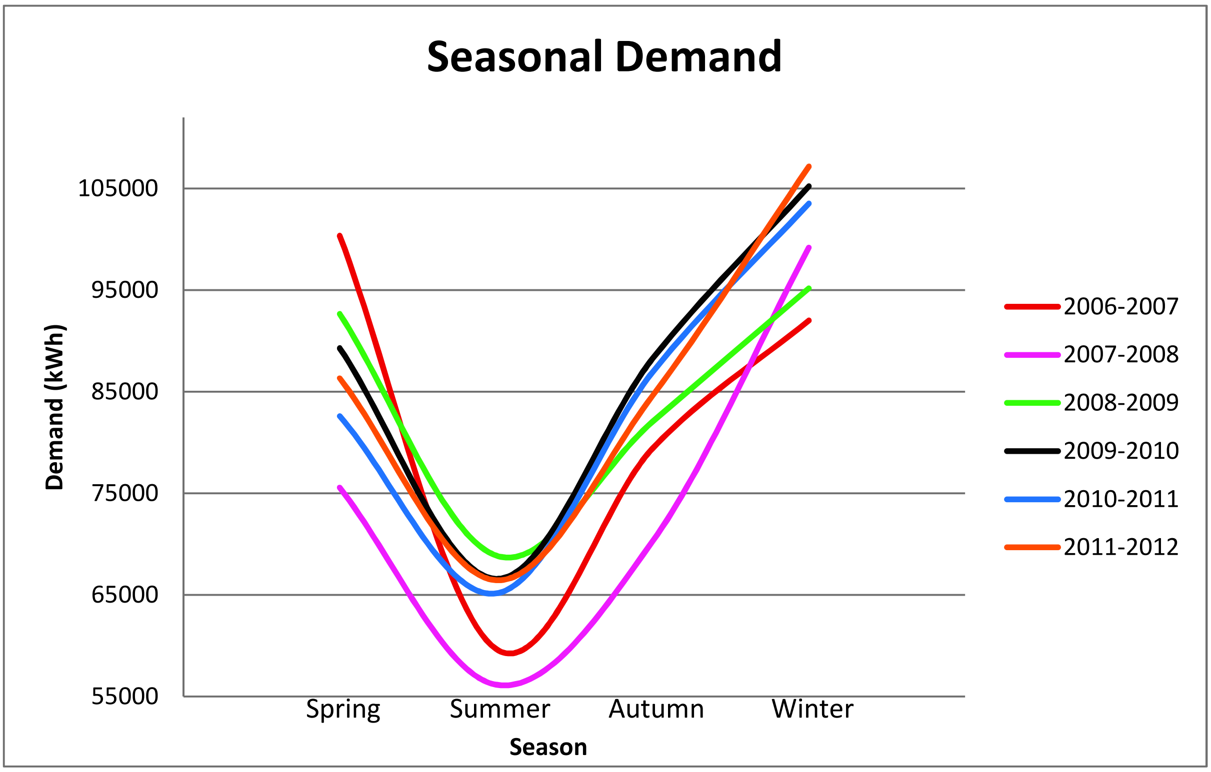


Figure 4-8: Seasonal Demand

As in Figure 4-6 and Figure 4-7, the evidence in Figure 4-8 reiterates that demand is lowest in summer, highest in winter and similar in autumn and spring. In addition, the figure also illustrates that overall; the demand had increased since the 2007-2008 seasonal cycle. The profiles for 2009-2010, 2010-2011 and 2011-2012 were also very similar. Total demand dropped sharply between spring and summer before climbing, at a similar rate, to autumn. After autumn the demand continued to rise, however, at a reduced rate. On average the demand in summer and winter had risen by approximately 5,000 kWh since 2007-2008, with an increase of greater than 10,000 kWh observed through most of spring and autumn.

Likely the new heating and domestic hot water system (operational since 2008) contributed to the increase in electrical demand. Results since 2008 have remained relatively stable; however there is prior evidence which suggests that although the demand is increasing, it is doing so at a reduced rate. There had been a small but significant decrease in the expected demand since June 2010 (see Section 4.1.2 Results). Although this evidence appears to indicate the development of a fault or a change to operational settings of the heat pump during this time period, it is still possible that any inefficiency in the system could have been present since its inception. As a result it would be useful to check whether the machine is installed per the manufacturer's instructions, in addition to examining the operational settings of the heat pump.

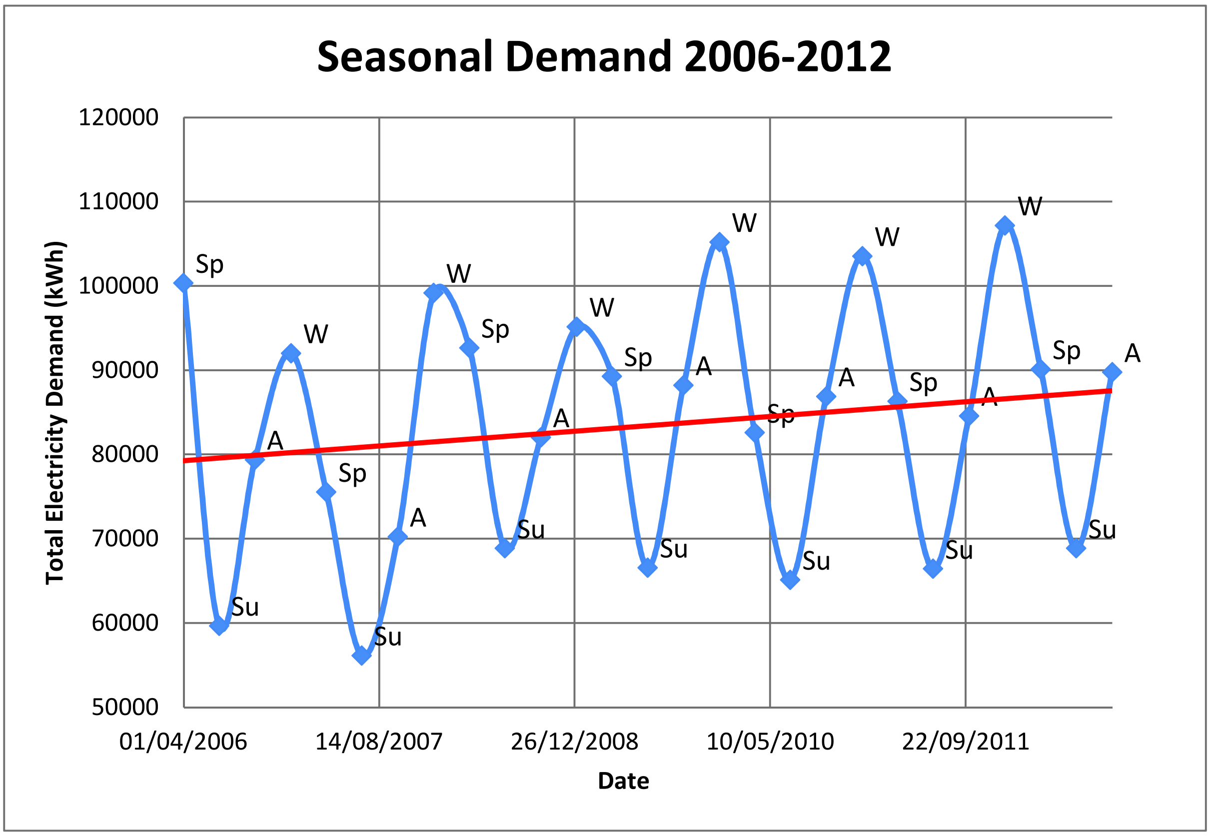


Figure 4-9: Seasonal Demand (2006-2012)

Figure 4-9 shows an annotated plot of total demand over the entire measured period. In general, the electricity demand of the care home steadily increased since 2006, illustrated by the trend line (red line). It is interesting to note that the shape of demand has changed since the summer of 2009; it has become almost uniform in appearance, whilst prior to this date there was greater variation. The graph also illustrated the slight dip in demand during the summer of 2010, which could in part represent the issue presented in Section 4.1.2. The graph also highlights the largest variation between spring and autumn demand values, which occurred between 2007 and 2008.

Finally, Figure 4-10 offers a comparison between the total demand recorded over each seasonal cycle:

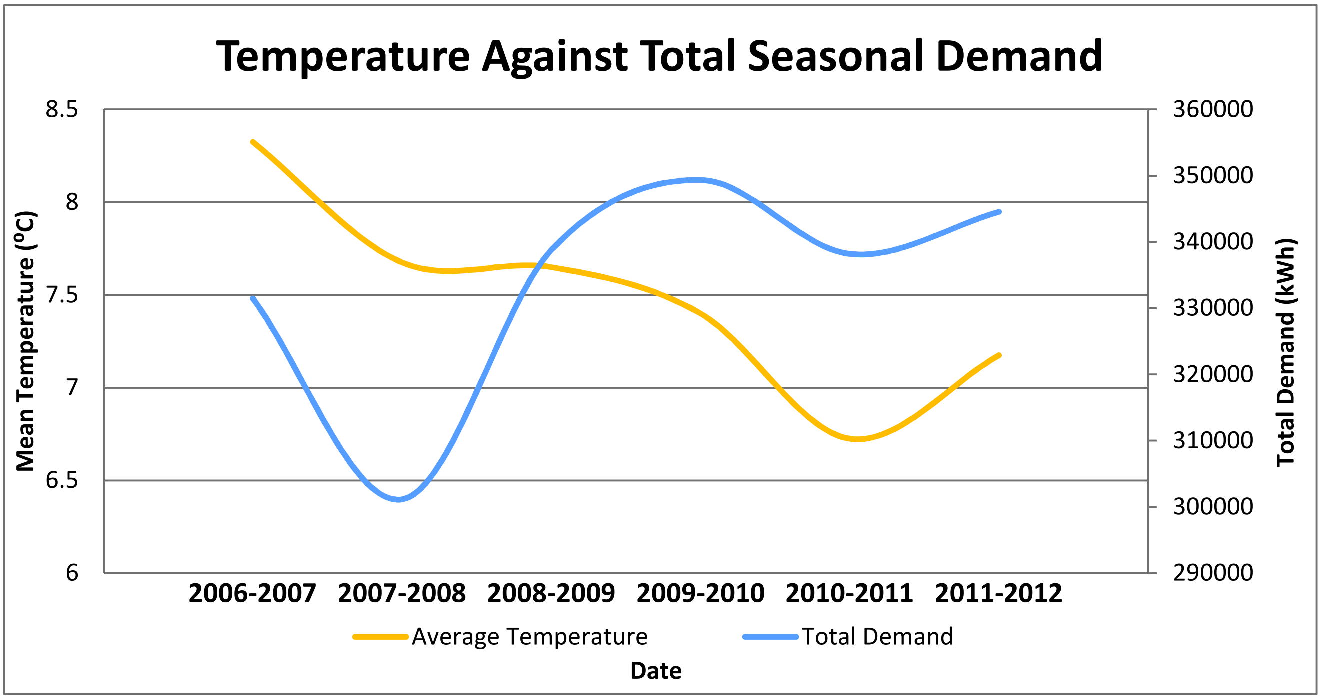


Figure 4-10: Total Seasonal Demand with Temperature Comparison

The overall seasonal demand appears to have increased since 2006-2007, with the exception of 2007-2008, which shows a 9% reduction over the previous year. This could possibly be due to the installation of the domestic hot water and heating system, which likely caused a reduction in activity in the care home whilst construction work was underway. The dip in total demand in 2010 is also clearly displayed. However, although demand has increased overall, it has not increased steadily, with consecutive years exhibiting a pattern of an increase followed by a dip, before demand increases again. As a result, it proved beneficial to examine the climate data during this period, to determine whether the local temperature was the driving force behind the fluctuating electricity demand.

As shown on the above figure, there is some correlation between the temperature and the total demand, when viewed over the entire period; As the average temperature has dropped over the years, the demand has increased (the dip in 2007-2008 can likely be discounted for the reasons stated above). However, over individual seasonal cycles the demand did not always follow this pattern. Therefore this serves as evidence that changes or aberrations in the demand profile are not necessarily linked to external factors, and should therefore be considered when analysing any potential faults in the system.

4.1.5 Annual Demand

As discussed in the previous section, electrical demand was heavily influenced by the local climate (Clarke, 2013). Nevertheless, whilst seasonal analysis offers a more comprehensive study of changes in demand, a study of the annual demand is useful in determining the performance of a system (see Chapter 7), as electricity usage and equivalent factors are often measured on an annual basis.

Method of Calculation

The yearly electrical demand was calculated through the summation of the total daily electric demand. Rather than calculating the seasonal total from spring through to winter, this analysis was completed over the traditional annual period; from January 1st until December 31st.

Results

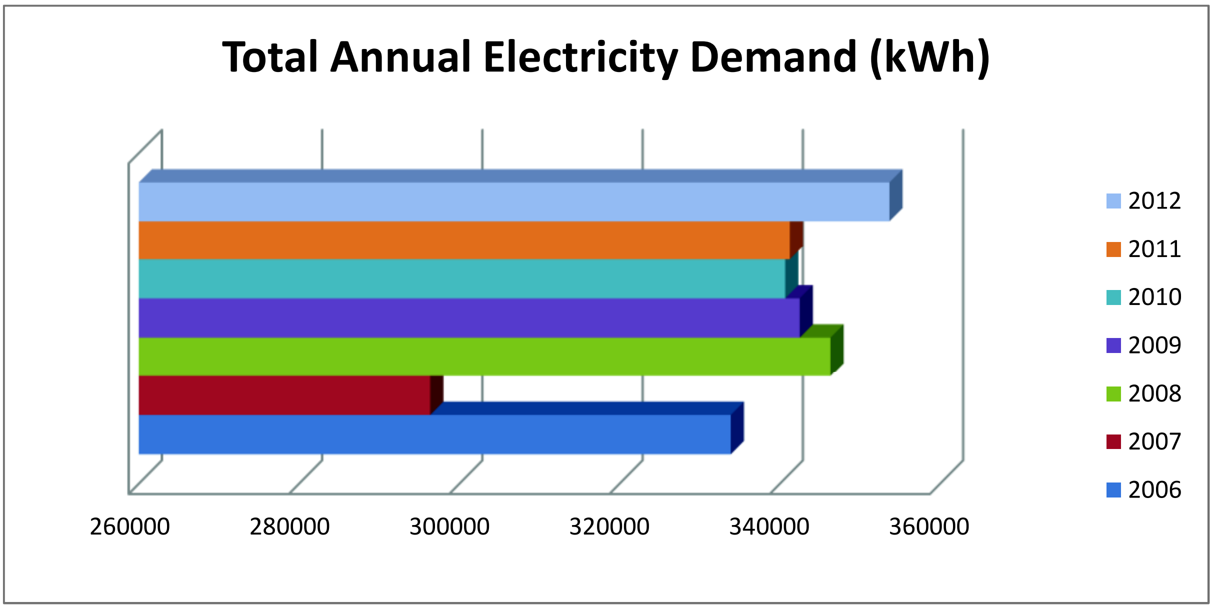


Figure 4-11: Total Annual Electricity Demand (kWh)

As in Figure 4-10, Figure 4-11 illustrates a significant decrease in demand between 2006 and 2007 (greater than 11%). Between the years 2007 to 2012 the increase in demand ranged from 6800 kWh to 19800 kWh over the 2007 value. However, the total annual demand exhibited a different pattern to the seasonal equivalent, therefore Table 4-2 has been provided to illustrate the differences observed between the annual and seasonal demand.

Seasonal Cycle	Seasonal Cycle Total (kWh)	Difference (SCT-YT) (kWh)	Yearly Total (kWh)	Year
2006-2007	331462	-2426	333888	2006
2007-2008	301149	4770	296379	2007
2008-2009	338760	-7572	346332	2008
2009-2010	349341.7	6850.6	342491.1	2009
2010-2011	338193.8	-2488	340681.8	2010
2011-2012	344545.6	3286.6	341259	2011
2012-2013	N/A	N/A	353690.9	2012

Table 4-2 : Seasonal Cycle and Annual Demand Comparison

The difference in results was due to variations in demand across January and February. For example, seasonal demand in 2006-2007 was measured from March 2006 till February 2007, whilst the corresponding annual demand was calculated from January 2006 – December 2006. As a result, the demand across the winter months of January and February determined whether the annual total was greater than its seasonal equivalent. The alternating values in the comparison table above show that the demand each winter has been increasing in an oscillating, as opposed to a linear, fashion.

4.1.6 Demand Analysis – Summary

Throughout the course of the initial analysis into the care home demand the following information was obtained:

- The magnitude of the care home demand was closely linked to the local temperature; demand was highest during colder weather. As a result, the highest demand was recorded during winter, the lowest in summer, with spring and autumn registering similar values.
- The electricity usage of the heat pump mimicked the care home demand profile, except at a reduced level.
- The calculated daily range for the heat pump was between 8 kWh – 33 kWh, with an average value of 20 kWh. This accounted for 1% - 4% of the care home's total demand.
- On June 11th 2010 the heat pump demand began to decrease, ultimately reaching 0 kWh by the 22nd January 2010 and remaining there until data collection of the heat pump's electrical usage ceased one month later.

- The care home demand data after this point registered values slightly below those predicted by the expected demand profile (calculated from data prior to the reduction in the DHW heat pump demand). Readings were found to range from 17 kWh -33 kWh below the expected value. Although small, these values were significant, as the daily heat pump demand fell within this range. This is potential evidence that the heat pump continued to operate at a reduced rate after February 2011.
- Daily demanded profiles indicated that the heat pump should theoretically be most active between 08:00 and 17:00, with activity peaking between 09:30 and 13:30.
- Seasonal Analysis illustrated that the care home demand had been increasing since the 2007-2008 period; with the total demand in summer and winter increasing by 5,000 kWh on average. The total demand in spring and autumn rose to values greater than 10,000 kWh above those recorded during the 2007-2008 period. However, although demand was increasing in general, it did not do so steadily, but largely did so in an oscillating fashion.
- Additionally, the demand profile had presented as a uniform shape since 2009. Prior to this, the shape of the demand profile had shown greater variation.
- An analysis of annual demand revealed that from 2007 to 2012 the increase in demand had ranged from 6,800 kWh to 19800kWh, depending on the season.
- The year 2007 displayed a significant reduction in demand in comparison to the previous year.

In conclusion, the demand analysis unearthed possible evidence of a fault in the DHW heat pump, which could have developed in June of 2010. Therefore it is essential that further information is collected on the heat pump during the site visit. As this fault could be due to either a mechanical, design or operational flaw it is important to examine all aspects of the heat pump's operation. The machine should be examined to determine whether it is installed correctly and whether it appears in good working order. The following information should be collected:

- The return thermostat stop temperature of the heat pump.
- The value of allowed hysteresis.
- The temperature of the pre-heat cylinder.

This data should provide information on whether the machine is working correctly, as well as whether the most efficient operational settings are selected. Additionally, the total number of hours of operation should be recorded for all three heat pumps, thus allowing for a comparison between the under floor heating and domestic hot water systems.

Any relevant alarms recorded by the machine should be noted, as well as the dates on which they occurred, to allow for a comparison with the half-hourly demand data. Furthermore, the care home management should be consulted and asked whether the heat pump underwent any maintenance and, if so, when this occurred.

4.2 Care Home Oil Use

As electrical demand data was used to evaluate the performance of the heat pump, so too could the care home oil use data be utilised to analyse the performance of the oil boiler.

Data Collection

The oil consumption data for the domestic hot water and under floor heating systems, between the 31st of October 2008 and the 25th of February 2011, was required. This data was used in collaboration with the oil delivery invoices for the period beginning 9th May 2007 till the 19th January 2012. Oil demand was measured in litres with oil being replenished as required, on an irregular basis.

Method of Calculation

The domestic hot water system's oil consumption data was examined and the number of days between subsequent readings was calculated. An estimate of the average daily oil requirement was then calculated by dividing the oil used per period over the number of days in each period. This process was repeated for each oil use reading and the resulting values were plotted on a chart displaying the average daily oil use over time (see Figure 4-12). The mean oil use over the entire period was then calculated and the resulting value added to Figure 4-12 (red line).

The care home's total oil use was then evaluated. The volumes of oil used in both the under floor heating and domestic hot water systems were combined to give a cumulative total. The total volume of oil used prior to the observed period

(31st October 2008 – 25th February 2011) was then subtracted from the cumulative total to give the care home's oil demand during the observed period. The average daily oil demand of the building was then calculated in the same fashion as the DHW system's had been.

Results

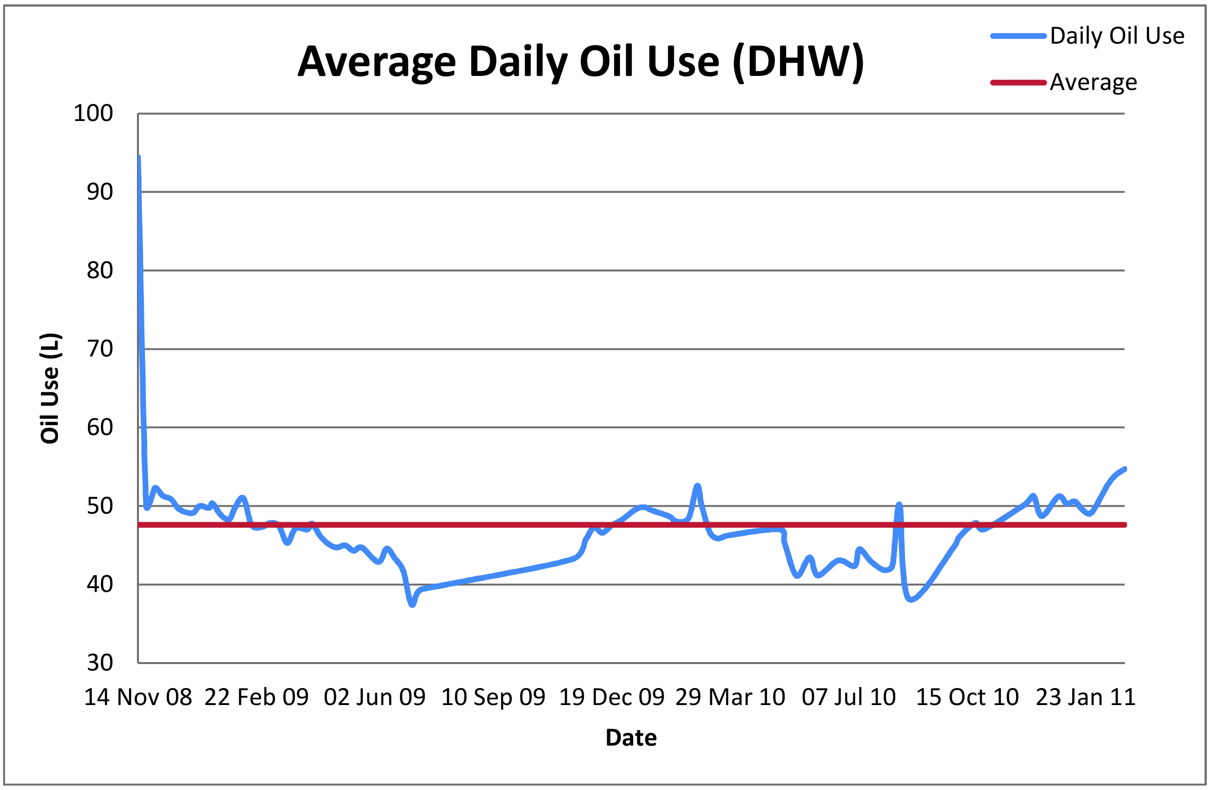


Figure 4-12: Average Daily Oil Use

As shown in Figure 5-1, the average daily oil consumption of the care home fluctuated throughout the measured period. The maximum value recorded was 94.429 litres whilst the minimum oil consumption was 37.429 litres. The average value calculated over the entire measured period (represented on the graph by a red line) was 47.59 1itres.

The total oil requirement of the care home, comprising of the oil consumption of both the domestic hot water and under floor heating systems, was measured at 7226.542 litres and the corresponding daily oil requirement was 90.317 litres.

Limitations

As before, due to the fact the oil measurements were collected as a cumulative total on an irregular basis, it was necessary to calculate average values for the DHW daily oil use, in lieu of the actual measurements. As a result, the data displayed on the chart can only be considered as approximations of the daily oil use. This data was then used to calculate the efficiency of the DHW system's oil boiler.

4.3 Oil Boiler Efficiency Study

Data Collection

The oil consumption data for the domestic hot water system between the 31st of October 2008 and the 25th of February 2011 was required. This information was used in conjunction with data on the care home hot water requirement recorded over the same period. Data on the buildings water and oil usage was collected on an irregular basis during this period.

Typical temperatures of the pre-heat cylinder attached to the heat pump were estimated from data found in the heat pumps manufacturer's guide.

Method of Calculation

As described in Chapter 3, hot water in the care home is produced by a hybrid heat pump and oil boiler system. The heat pump is responsible for the majority of the hot water heating, ideally raising the temperature in the pre-heat cylinder to around 55°C, with the oil boiler supplying the remaining heat required to raise the temperature to 60°C. Therefore, to determine whether the oil boiler is operating efficiently, the amount of heat it is injecting into the system must first be established.

If it is assumed that the heat pump is set to operate at optimum efficiency then it should be supplying heat in the region of 55°C to the water. If the allowed hysteresis is accounted for (assuming the factory set value of 2.5°C) then the heat pump should be raising the water temperature approximately between 53°C to 55°C. Therefore, to raise the temperature of the water to 60°C, the oil boiler must supply between 5°C and 7°C to the water (these values were used throughout the remainder of the calculation).

Determining an estimate for the efficiency of the oil boiler ultimately involves calculating the energy output of the process, divided by the energy available through combustion of the fuel, which in this case is Class D Oil. Firstly the energy input of the system was calculated. Using the oil consumption data, the energy used per period was derived from the cumulative total (for method see 4.2). Once these values were obtained the energy yield was calculated. Using the conversion factor: 1 litre (Class D Oil) = 11.86 kWh, which was then multiplied by the boiler thermal efficiency (heat to fuel) equal to 88.76%, gave an energy yield of 10.53 kWh per litre (The Chartered Institution of Building Services Engineers, 2007).

Once the energy supplied by the system was determined, the volume of water being heated was also calculated. Again, the water used per period was calculated from the cumulative total. The values obtained were then converted from metres cubed (m^3) into litres using the following rule:$1m^3 = 1000\ litres$. Once the water use per measured period was found, the energy required to heat it was evaluated using **Error! Reference source not found.**:

$$Q = m \times C_p \times dT$$

Equation 1

Where Q represents heat energy required in Joules, m represents the mass of the fluid in kilograms, C_p the specific heat capacity of the fluid in joules per kilogram per degree Kelvin, and dT is the temperature difference, in degrees Kelvin.

As the fluid in question was water, the specific heat capacity was equal to 4.18 kJ/kg.K and, using the fact that one degree kelvin is equal to one degree Celsius and that one litre of water is equal in mass to one kilogram, the equation became;

$$Q = (1 \times litres\ of water\ required) \times (4.18 \times 1000) \times 5$$

The amount of energy required for both a 5°C and 7°C rise in water temperature was calculated and then converted from Joules to kilowatt-hours using the following conversion factor: 1 kWh = 3,600,000 J.

The efficiency of the oil boiler in both cases was then calculated for each period by dividing the energy required to heat the water by the energy available through the combustion of the oil. These values were then plotted on a graph using Excel and an average efficiency value for each rise in temperature calculated (see Figure 4-13: Oil Boiler Efficiency).

As the resulting efficiency estimates obtained were significantly lower than expected, the oil delivery invoices were analysed to rule out a meter reading error and determine the likelihood of other possible scenarios; such as an oil leak, which could explain the low efficiency. The number of days between subsequent oil deliveries was calculated and an average daily oil use per measured period calculated. This value was then compared to the daily oil use figures calculated in Section 4.2.

Results

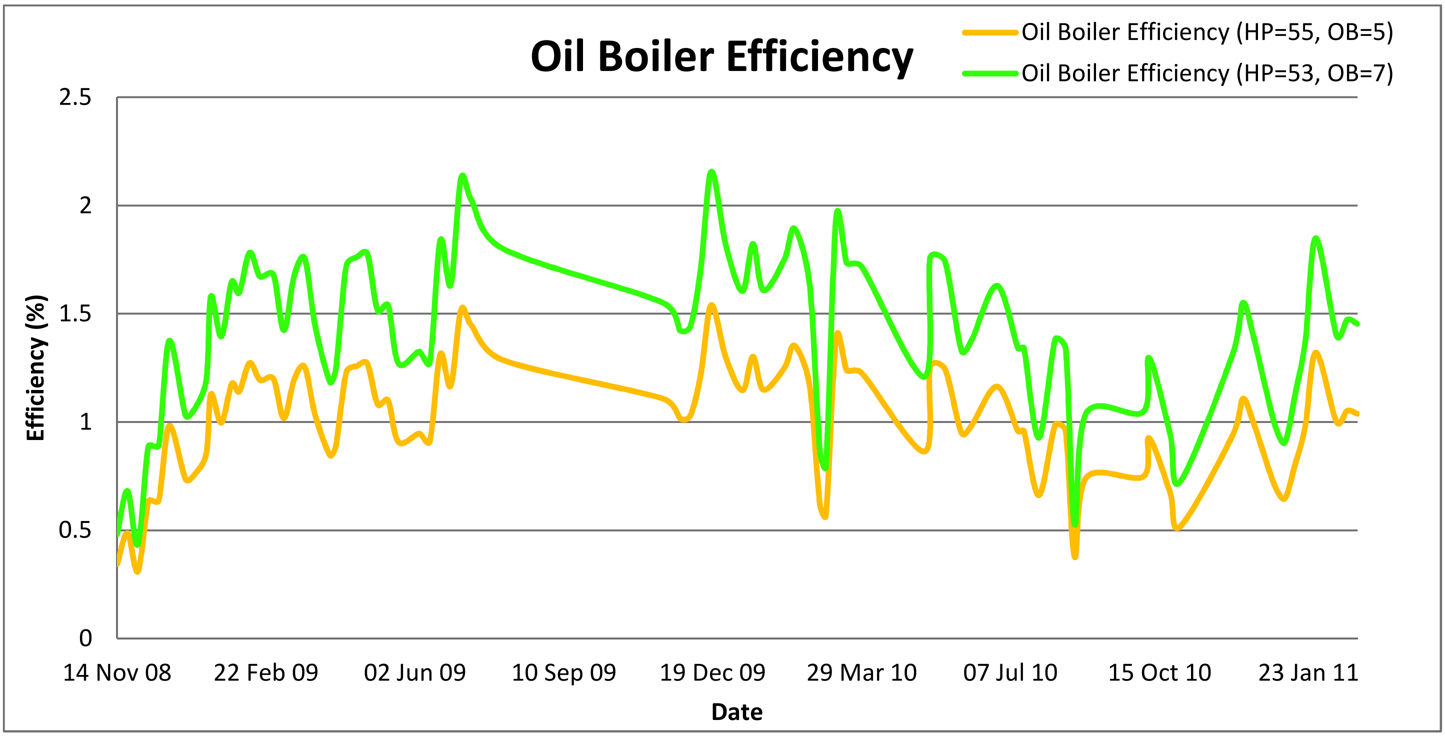


Figure 4-13: Oil Boiler Efficiency

(HP=55, OB=5 and HP=53,OB=7 in the legend entries represent the estimated heat provided, in degrees Celsius, by the heat pump and oil boiler respectively in each calculation.)

When the heat pump was assumed to be working at optimum efficiency and heating water to 55°C, with the oil boiler required to supply the remaining 5°C, the resulting oil boiler efficiency was calculated as ranging between 1.54% and 0.31%, with an average value over the entire period of 1.01%. When the heat pump was assumed to be working just below the optimum level (but still within the allowed hysteresis), heating water to 53°C, the oil boiler was required to supply the remaining

7°C. For this temperature, the oil boiler efficiency ranged between 2.16% and 0.43% with an average value over the entire period of 1.41%.

Therefore the evidence in Figure 4-13 illustrates that the oil boiler efficiency increased when it was required to produce more heat. Most importantly, it illustrates that the oil boiler is operating at an exceptionally low level of efficiency. The Clyde CK10 oil boiler installed in the care home is classed as a high efficiency boiler, with a calculated seasonal efficiency equal to 84%. If the oil boiler is working with an efficiency in the region of 1% this would represent a major flaw in the system.

Nevertheless, the above result could also indicate a fault outwith the oil boiler itself, such as an oil leak, or even a meter reading error. To determine the likelihood of these issues the oil delivery invoices were examined:

Delivery Date	Delivery Quantity	Rate	VAT Rate	Total (£)	Days Between Deliveries	Average Daily Oil Use (L)
09-May-07	7000	£36.78	17.50%	3,025.16	77	90.909
25-Jul-07	7000	£38.61	17.50%	3,175.67	76	90.909
09-Oct-07	7000	£42.09	17.50%	3,461.90	57	90.909
05-Dec-07	7000	£48.27	17.50%	3,970.21	44	90.909
18-Jan-08	7000	£49.55	17.50%	4,075.49	69	90.909
27-Mar-08	7000	£54.83	17.50%	4,509.77	117	90.909
22-Jul-08	7000	£67.69	17.50%	5,567.50	111	90.909
10-Nov-08	7000	£48.15	17.50%	3,960.34	42	90.909
22-Dec-08	7000	£40.44	15.00%	3,255.42	44	90.909
04-Feb-09	5000	£40.87	15.00%	2,350.03	69	64.935
14-Apr-09	7000	£41.99	15.00%	3,380.20	102	90.909
25-Aug-09	7000	£45.81	15.00%	3,687.71	114	90.909
17-Dec-09	6000	£47.81	15.00%	3,298.89	50	77.922
05-Feb-10	7000	£47.49	17.50%	3,906.05	75	90.909
21-Apr-10	7000	£55.41	17.50%	4,557.47	69	90.909
29-Jun-10	6000	£54.93	17.50%	3,872.57	84	77.922
21-Sep-10	5000	£53.38	17.50%	3,136.08	78	64.935
08-Dec-10	7000	£56.47	17.50%	4,644.66	77	90.909
23-Feb-11	7000	£62.32	20.00%	5,234.88	133	90.909
06-Jul-11	6800	£64.07	20.00%	5,228.11	145	88.312
28-Nov-11	7000	£68.75	20.00%	5,775.00	52	90.909
19-Jan-12	5000	£69.64	20.00%	4,178.40		
					Average	87.075

Table 4-3: Oil Delivery Invoices

Table 4-3 above gives information on the quantity, cost and frequency of oil deliveries. It also shows the average daily oil consumption calculated from this data. The average oil use over the entire measured period was estimated to be 87.075 litres. As this figure is corroborated by the value obtained in Section 4.2, of a total daily oil consumption in the care home equal to 90.317 litres, a metering error can be discounted. The low efficiency could still be a result of an oil leak, however this eventuality is unlikely, as a large leak would have to be present between the oil meter and the boiler itself, in the oil delivery pipe.

Nevertheless, this raises the likelihood that the poor efficiency of the boiler is due to a phenomenon know as dry cycling (see Chapter 2), wherein the boiler fires unnecessarily in low load conditions (U.S. Department of Energy, 2012). Therefore the oil boiler should be observed during the site visit to determine how often it is firing and in response to what conditions. The heat pump should also be examined to determine how much heat it is supplying to the water in the pre-heat cylinder, thus allowing the heating contribution of the boiler to be determined.

Limitations

There are several limitations inherent to the data reported above. Firstly, the efficiency of the oil boiler is likely slightly higher than the values obtained above. This is because the DHW system of the care home also supplies hot water to an adjoining Doctor's surgery. However, data on the water usage of this surgery was unavailable therefore, in reality, a greater volume of water would be being heated, Consequently, the energy required to heat it would be greater and the resulting efficiency of the oil boiler would be higher.

The efficiency calculation is also based on several assumptions. Chiefly, it assumes that the heat pump is working at optimum conditions when, as shown in Section 4.1, this is likely not the case. Nevertheless, optimum conditions were chosen for the calculation due to greater data availability (such as heat supplied to the pre-heat cylinder and the factory set hysteresis value) at these conditions. Additionally, only one variable can be examined at a time, therefore an evaluation of heat pump efficiency would have interfered with the results of the oil boiler efficiency study. Furthermore, it is assumed that conditions specified for the conversion rates between one variable and another, such as particular temperature and pressure values, have been satisfied.

Nevertheless, despite these limitations, the results obtained during the oil boiler efficiency study are sufficiently accurate for this investigation. A more accurate value for the boiler's efficiency will be determined when the above calculation is repeated once the necessary data has been collected during the site visit.

4.4 Water Requirements

Finally, the water requirements of the care home were evaluated to determine the electricity and oil consumption required per litre of hot water generated.

Data Collection

The cumulative DHW volume was recorded between the 31st of October 2008 and the 25th of February 2011. The number of days between subsequent readings ranged from 3 to 108, with an average of 10 days between readings. Water volume was measured in units of meters cubed (m^3). Additional data was also required on the electrical demand of the DHW system heat pump's oil usage.

Method of Calculation

The water use for each individual period was calculated from the cumulative total by subtracting the initial reading from the subsequent value and so on. The values obtained were then multiplied by 1000 to give the total in litres, since 1 m^3 of water is equal to 1000 litres of the fluid. A daily average per period was then calculated as follows:

$$Daily\ Average\ (in\ litres) = \frac{Litres\ of\ water\ used\ during\ period}{Number\ of\ days\ in\ the\ period}$$

The average daily use over the entire measured period was similarly calculated by dividing the total volume of water used by the total number of days.

As readings were not taken on a regular basis it was not possible to accurately examine the water usage during the traditional annual period from the 1st of January to the 31st of December. Therefore the annual water profile was derived from the data obtained from the 8th of January 2010 to the 7th of January 2011. During this period the total DHW usage between these dates was noted and a graph illustrating the water demand throughout the year was generated using the computer program Excel (see Figure 4-14).

To determine the electricity and oil fuel consumption per litre of hot water generated, the total electrical demand of the DHW system heat pump and the oil consumption per period were divided by the total volume of hot water produced during the period. The results were then displayed in Figure 4-16 and averages were calculated over the entire measured period. Values of minimum and maximum electricity demand and oil fuel consumption per litre of hot water generated were also noted.

Results

Between the 31st of October 2008 and the 25th of February 2011 the total domestic hot water demand amounted to 693,000 litres. During this period the average daily use ranged from 286 litres to 1286 litres. The average daily DHW requirement for the entire period was calculated as 830 litres per day. Figure 4-14 illustrates the variation in DHW demand throughout a year.

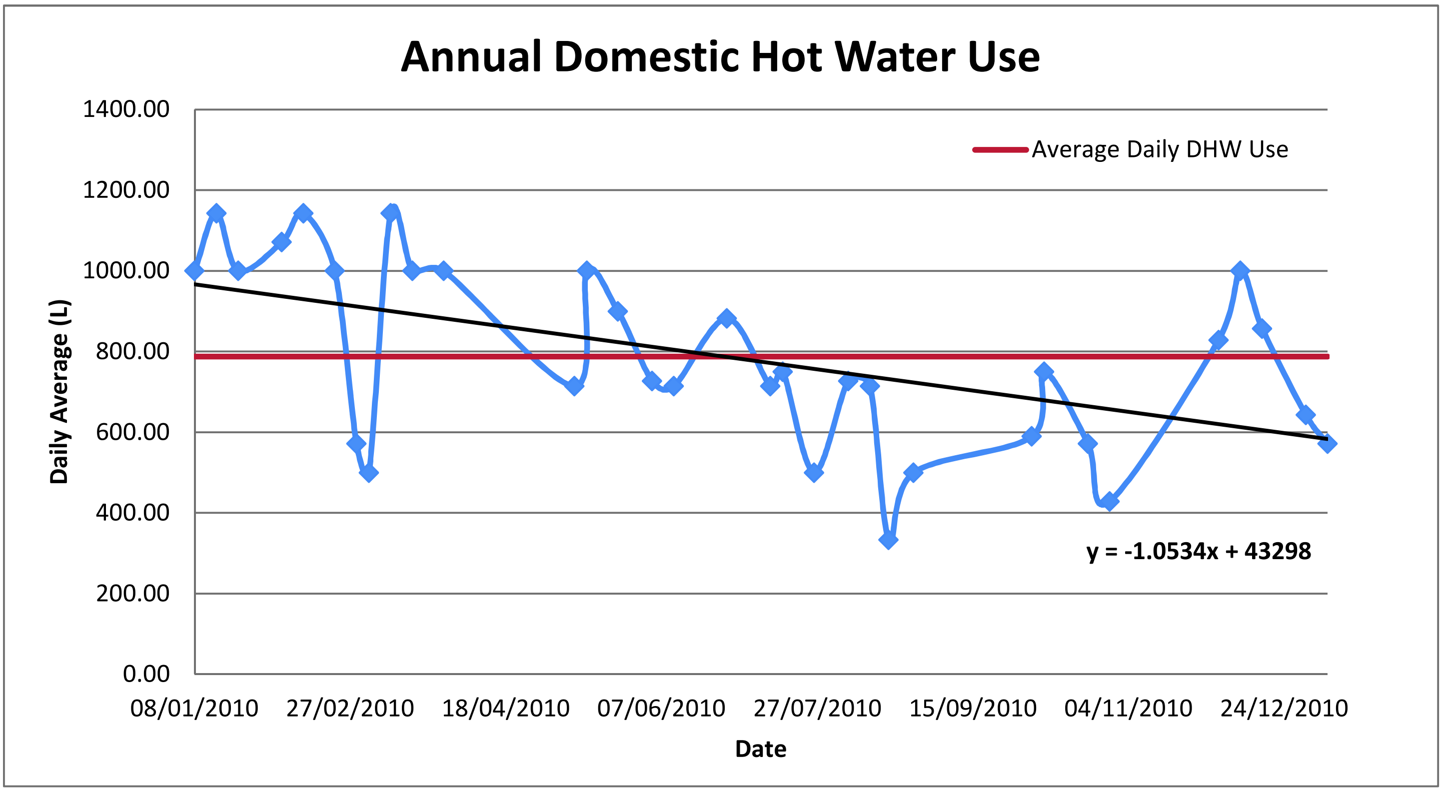


Figure 4-14: Annual Domestic Hot Water Use

Figure 4-14 illustrates the range and variation in annual DHW use. There seems to be a trend indicating greater demand for DHW in colder months, with usage peaking in February and March at a value 45% greater than the annual average. The lowest DHW usage was recorded in the period between the 13th and the 19th of August with a value 58% below average. A full table of results detailing the date of each reading, the number of days between subsequent readings, the volume of water required and calculated daily averages for each period can be found in Table 10-2 in the Appendix.

Overall, despite seasonal variations, the hot water usage appears to be decreasing at the rate described by the equation of the trend line (solid black line) on Figure 4-14. An analysis of the data over the entire measured period (31st October 2008 – 25th February 2011) supports this, however to a lesser degree (see Figure 4-15) as illustrated by the equation of the trend line on Figure 4-15.

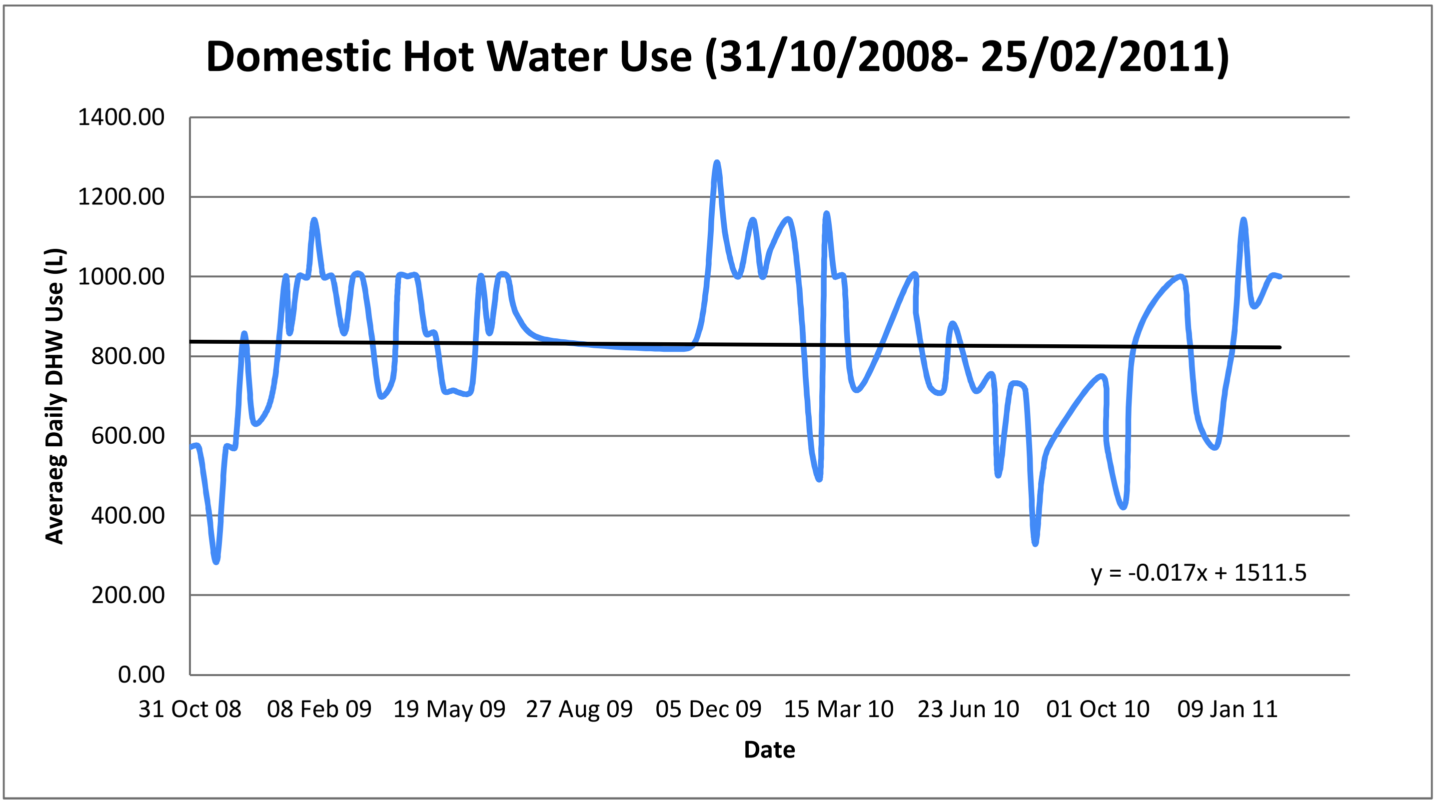


Figure 4-15: Domestic Hot Water Use (31st October 2008 - 25th February 2011)

Limitations

As subsequent water readings were taken over a range of time periods it was necessary to calculate an average value for DHW use, which allowed for an estimation of daily water requirements. Nevertheless, in reality it is likely that the DHW profile displayed significant variation over a daily basis. As a result the profiles generated in Figure 4-14 and Figure 4-15 would likely illustrate a more gradual increase/decline in water use over time. Thus, the results obtained are useful to examine the generalised use of DHW. If in the future more accurate information is required, it would be necessary to monitor and record water readings on a regular basis (daily, etcetera).

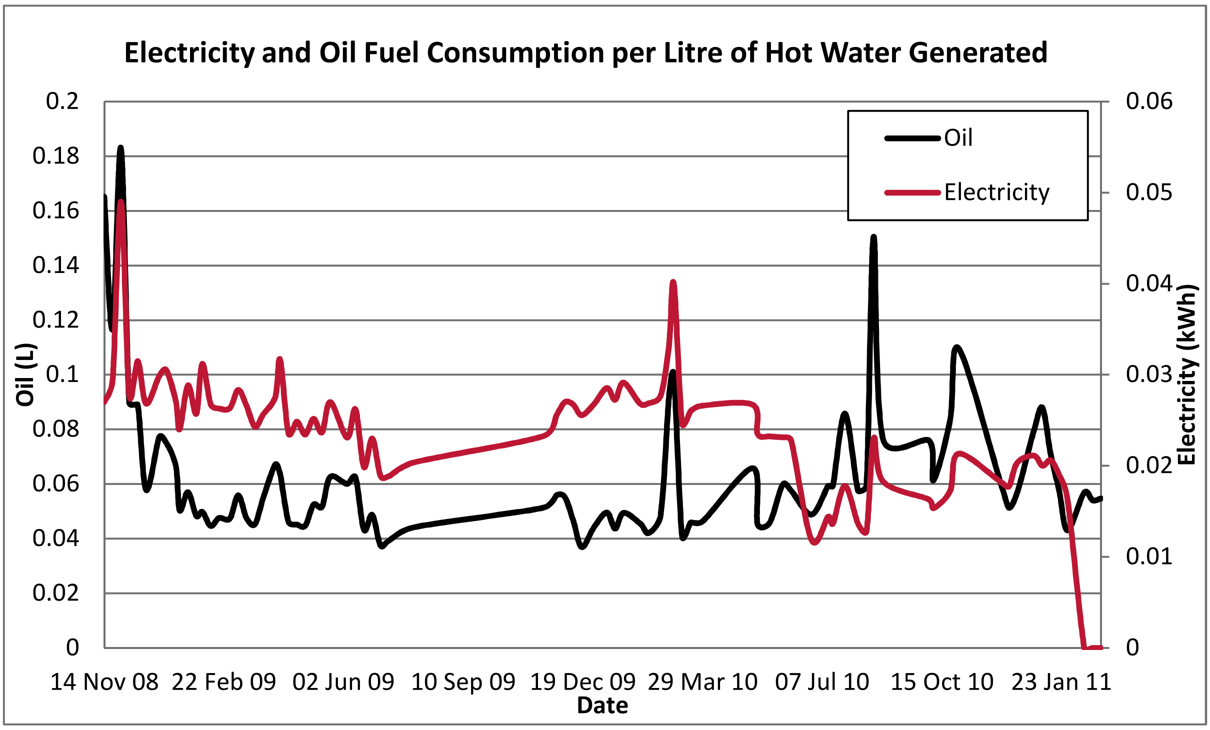


Figure 4-16: Electricity and Oil Fuel Consumption per Litre of Hot Water Generated

Figure 4-16 illustrates the fluctuation in the electricity and oil volume required to heat one litre of water over the measured period. The electricity values ranged from 0.049 kWh to 0.012 kWh, in addition to a period of time where the heat pump demand was equal to zero. The necessary oil consumption ranged from a maximum of 0.183 litres to a minimum requirement of 0.037 litres. On average 0.023 kWh of electricity and 0.063 litres of oil were required to heat one litre of water to the mandatory temperature.

Figure 4-16 also illustrates that the electricity requirement and oil consumption largely mimic each other, with both factors increasing or decreasing in response to the same stimulus. Additionally, the figure provides further evidence of a fault developing in relation to the heat pump in the summer of 2010. At this point, as the electricity levels began to fall, the oil consumption increased to compensate for the energy shortfall.

Limitations

The calculated averages are not accurate representations of the water usage in the care home, however they serve as suitable estimates.

4.5 Summary of Results

The initial analysis completed on the domestic hot water system of the care home has shown that both the heat pump and the oil boiler appear to be underperforming. The heat pump electricity usage began to decrease after June 10th 2010 and appears to have continued to operate with reduced demand outputs since this period. The calculated efficiency of the oil boiler ranged from 0.31% to 2.16% dependent on the temperature it was required to supply. The average water use for the care home was calculated at 830 litres per day, with a DHW daily oil consumption of 47.59 litres and an overall daily oil consumption of 90.317 litres.

On average, 0.023 kWh of electricity and 0.063 litres of oil were required to raise the temperature of one litre of water to the mandatory temperature of 60 °C.

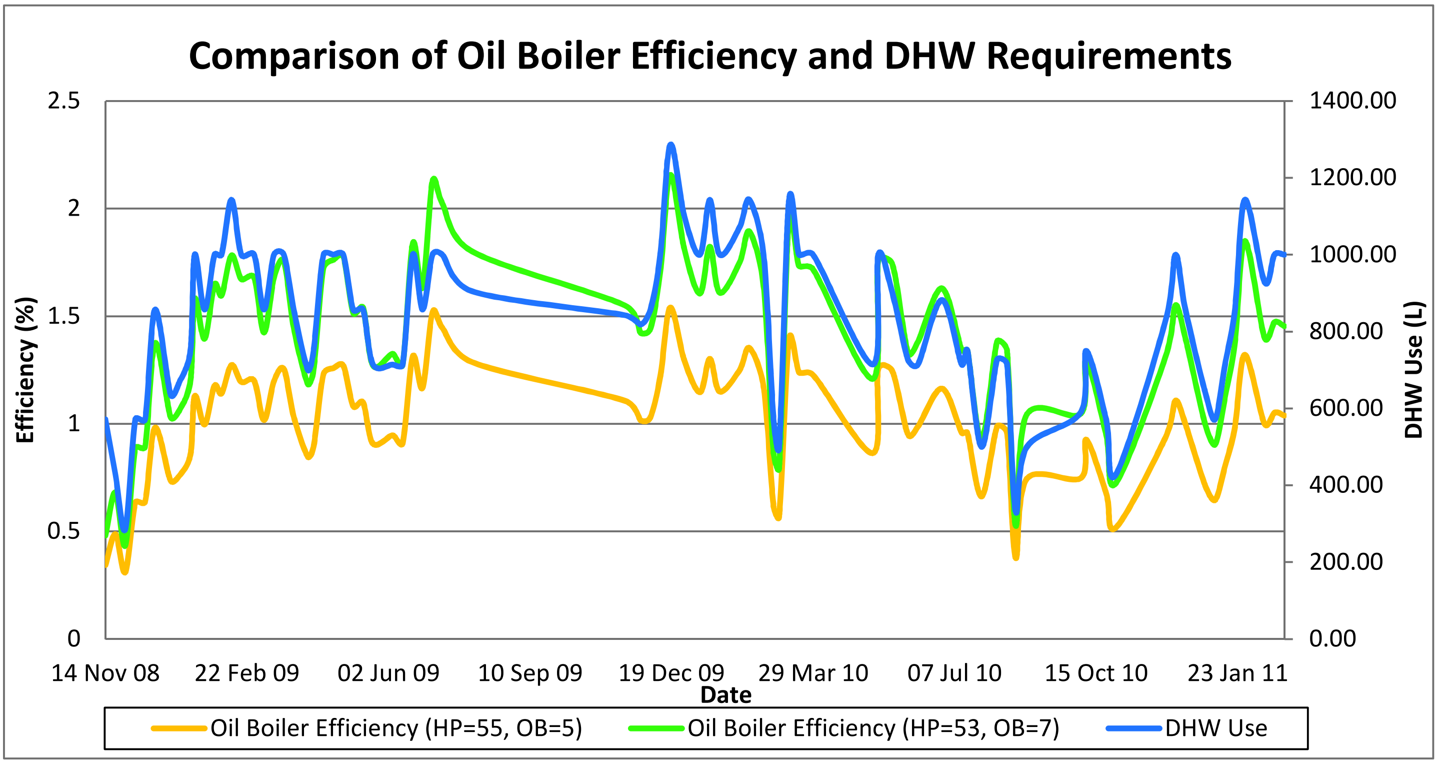


Figure 4-17: Comparison of Oil Boiler Efficiency and DHW Requirements

Figure 4-17 shows that oil boiler efficiency is closely linked to the hot water requirement and that the boiler performance increases with increasing water demand. Whilst Figure 4-18 below shows that the electricity and oil fuel consumption required per litre of hot water generated increase in response to a fall in water demand and vice versa.

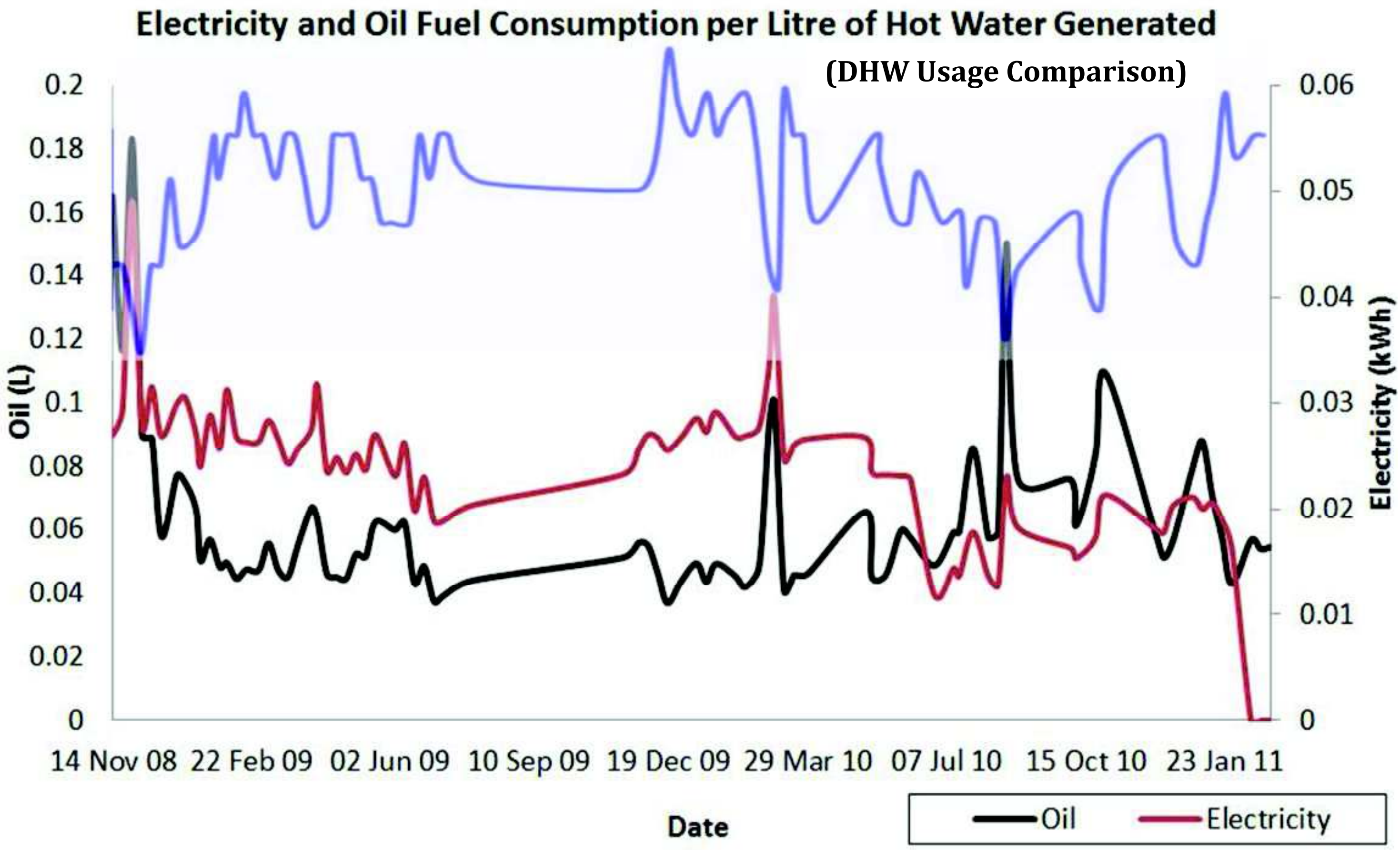


Figure 4-18: Electricity and Oil Fuel Consumption per Litre of Hot Water Generated (DHW Usage Comparison)

*(*Figure 4-18 *was created in Excel and then modified to include an overlaid image of DHW requirement using the image manipulation software GIMP 2. The DHW data (blue profile) is not to scale.)*

In conclusion, the main focus of the site visit should be to attempt to determine the cause(s) behind the inefficient operation of the heat pump and oil boiler. With regards to the heat pump; the machine should be examined to determine whether it is installed correctly and whether it appears in good working order. The following information should be collected:

- The return thermostat stop temperature of the heat pump.

- The value of allowed hysteresis.
- The temperature of the pre-heat cylinder.
- Total hours of operation for heat pumps 1, 2 and 3.

Any relevant alarms recorded by the machine should be noted and the care home management consulted and asked whether the heat pump underwent any maintenance and, if so, when it occurred.

The oil boiler should be examined to determine whether it appears in good working order and if it is installed correctly. It should be observed during the site visit to determine how often it is firing and in response to what conditions. The area should be examined for any signs of oil leaks. Additionally, there is the possibility that losses in the secondary circulation pipework are responsible for the excessive oil consumption of the care home. If the calorifiers located in each wing of the care home required additional heat on a regular basis from the oil boiler (to compernsate for losses in the pipework) then this would have a detrimental effect on the boiler performance, perhaps accounting for the low values recorded. Therefore the calorifier tanks should also be examined and water temperatures collected throughout the building; to establish whether there are significant losses in the secondary circulation pipework.

5 Investigation Plan

A site visit was necessary to fully investigate the efficiency and losses of the care home domestic hot water system. As this involved a limited time scale an investigation plan was developed prior to the site visit; to maximise the available time and to ensure all the necessary equipment could be prepared in advance. This chapter offers an overview of the completed investigative process; incorporating the main aims of the investigation, the key areas of interest, a list of all necessary equipment in addition to any necessary amendments made to the plan during the course of the investigation. The results of the on-site investigation can be found in Chapter 6: Site Visit.

5.1 Aims

Ultimately, the aim of the site visit was to attempt to ascertain the reason(s) behind the inefficiencies in the DHW system. As there are many possible scenarios which could lead to a breakdown in hybrid DHW systems, the survey undertaken during the site visit had to provide a wide range of information. The scope of the investigation was also limited by certain practical considerations; it was not possible to examine the interior of the heat pump or oil boiler etcetera, nor was it possible to examine live data due to a technical failure.

Therefore the key aims of the investigation were to;

1. Determine whether the problem was intrinsic to one machine, or the system as a whole.
2. Determine whether the DHW system could have simply been affected by human error. For example, were the machines installed correctly, were they operating on the correct settings?
3. Compare theoretical calculations, completed during the initial analysis of the system (see Chapter 4) with on-site measurements.
4. To look for any noticeable faults in the system (oil leaks, etcetera)
5. To collect additional data for further analysis.
6. To consult the management of the care home and to check if they have any additional, relevant information on the DHW system.

5.2 Identification of Key Areas

This plan was developed upon completion of the study and analysis (see Chapter 4: Initial Analysis) of the current domestic hot water system operational in the care home. It takes into consideration material obtained during a detailed literature review, as well as information contained in the manufacturer's guides for the heat pump and oil boiler.

To satisfy the objectives of the site visit, several areas were identified to serve as the focus of the investigation:

- Plant Room
- Heat Pump 3
- Oil Boiler
- Accumulator Tanks
- The Calorifier Tanks (one in each wing, five in total).
- Oil tank
- DHW Distribution System (plant room and roof spaces)

The following investigation plan is divided into several subsections, each dealing with one of the key areas identified above.

5.3 Investigation Plan

A meeting was arranged with the Energy Officer for Orkney Islands Council; Alistair Morton, for a general discussion on the DHW system for the care home in question. An initial site visit was then set up, which would precede the comprehensive site visit arranged for the following day. This allowed for a general inspection of the care home and, as a result, the inspection plan was tailored to better reflect the conditions observed during the initial visit (See section 5.3.2: Investigation Plan Amendments)

5.3.1 Day 1 – Site Visit: General Inspection

1. A brief survey was completed to become familiar with the layout of the care home and to determine whether the care home and plant room were well maintained.
2. The living spaces were also examined to ensure they were maintained at a comfortable temperature. If the rooms were too hot it could indicate heat loss from the DHW system.
3. The layout of the care home was also scrutinised, to determine whether it matched up with the plans, or if there had been any changes or alterations made to the building or the DHW system since the plans had been commissioned.
4. The plant room and surrounding area were inspected for oil leaks. Typical signs of an oil leak could be; the appearance of black stains, a strong smell, evidence of dead plants in the grounds of the care home, etcetera. The room was also examined to determine whether it smelled strongly of solvents or other cleaning products as the use of strong solvents in close proximity to a boiler can lead to poor combustion performance (Axtman. W.H, 1994).
5. Photographs were taken to document the true layout of the plant room and pipe work, in addition to illustrating the condition of the constituent parts of the DHW system.
6. The heat pump was examined to record the number of hours of operation. This data was recorded so that the reading could be repeated the following day to examine the frequency of heat pump operation.
7. Additionally, the building caretaker was consulted on several issues to determine whether the occupants had noticed any evidence of oil leaks, or complained of uncomfortably high temperatures anywhere in the building, etcetera.
8. Further information was recorded, as appropriate.

5.3.2 Investigation Plan: Amendments

After the general inspection it became apparent that there were certain elements of the original investigation plan which could be discounted. Therefore, where relevant, the words Investigation Plan Amended appears in red, next to the heading describing the affected elements, as well as an explanation for each amendment. It also became apparent that the main focus of the inspection should be centred on the plant room and the loft spaces, as well as an analysis of the water temperatures throughout the building. This encompassed the heat pump, oil boiler, distribution system and the accumulator tanks.

5.3.3 Day 2 - Site Visit: Comprehensive Site Inspection

Plant Room Inspection: Heat Pump

1. The heat pump integral to the DHW system (HP 3) was examined to determine whether it was installed correctly, according to the specifications stated in the manufacturer's guide.
2. Its position in the plant room was checked, as well as its foundations.
3. It was then examined to determine whether it was in good working order.
4. The control panel was examined (see Appendix: 10.4 Use of Heat Pump Control Panel) and the following information was obtained:
   Heat pump hours of operation, set point temperature, return thermostat stop temperature (maximum operating temperature), current temperature of the pre-heat cylinder, as well as the maximum allowed hysteresis (this value determines how far the temperature can fall below the set point before the heat pump is engaged to raise the temperature to the set value again.)

Figure 5-1: DHW Heat Pump (HP 3)

5. The alarm records were also checked, with all relevant alarms being noted. Any alarms could then be analysed and the time and date in each instance could be used in conjunction with the half hourly demand data, to determine the effects on the electrical load, if any, of each alarm.

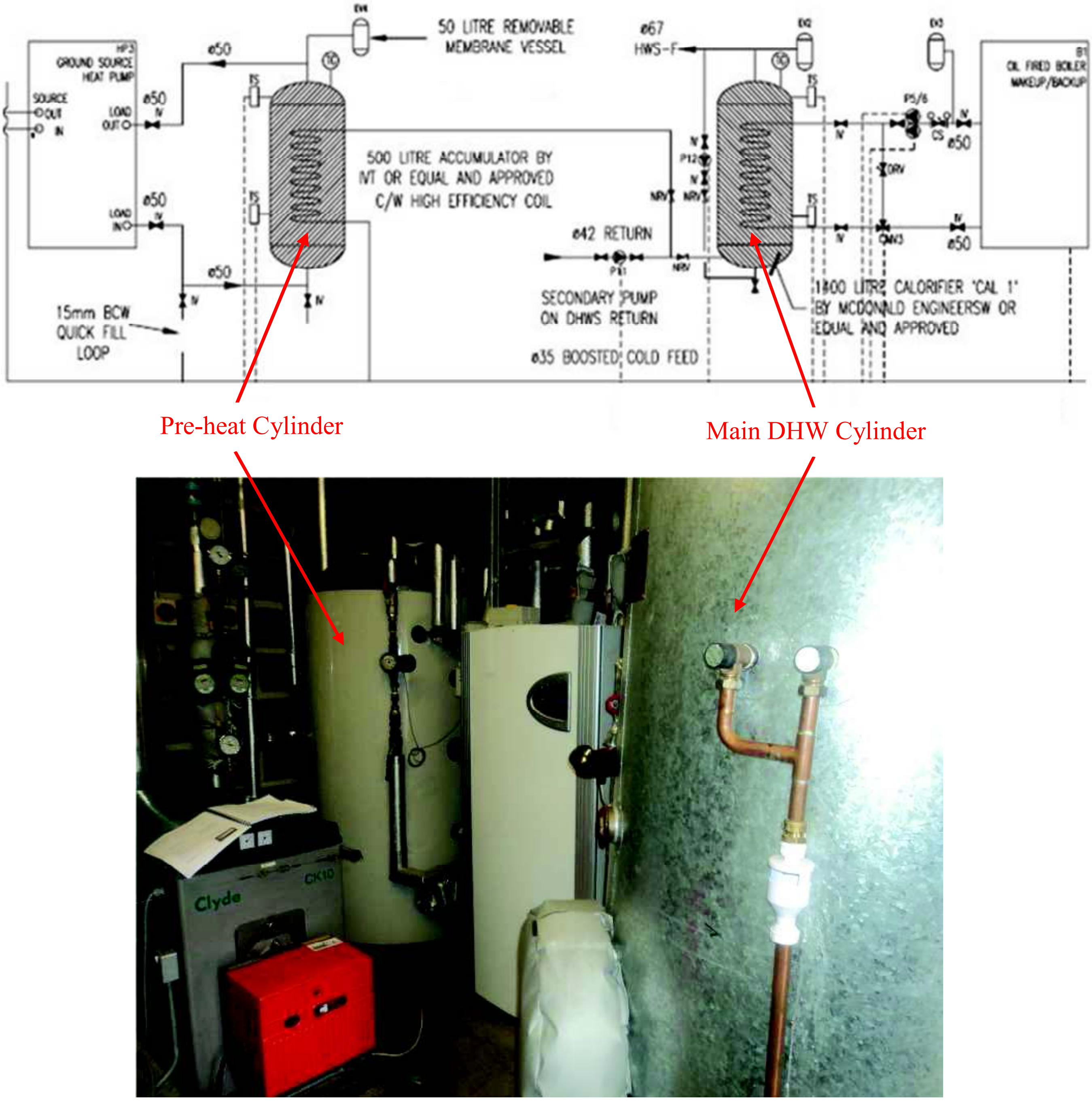
Figure 5-2: DHW Oil Boiler

Plant Room Inspection: Oil Boiler

1. The oil boiler used to raise the DHW temperature to 60°C was examined to determine whether it was installed correctly, as per the manufacturer's instruction.
2. The ceiling height of the plant room was measured to ensure there was an adequate air supply for the combustion process (Axtman, W.H, 1994).
3. The plinth was examined using a handheld laser level checker to determine if the platform was level, as an uneven platform could increase the likelihood of oil leaks.
4. The control panel was examined and the following information obtained: The boiler thermostat, the total hours of operation, the exhaust gas temperature, as well as the pump overrun temperature.
5. The control panel was also examined to ensure that none of the warning lights were activated.

6. The oil boiler was then monitored to determine how many times it switched on and off over the course of an hour. The duration of these activations were also recorded, as was the quantity of oil used on each occasion.
7. The oil delivery system and meter were examined and any potential oil leaks were documented and photographed.

Plant Room Inspection: Accumulator Tanks



Pre-heat Cylinder

Main DHW Cylinder

Figure 5-3: Accumulator Tanks

1. The accumulator tanks; both the pre-heat cylinder and the main DHW cylinder, were examined to ensure they were installed correctly and that they appeared in good working order.
2. The temperatures of the tanks were noted and utilised when analysing the boiler and heat pump performance.

Calorifier Tanks – Investigation Plan Amended

The original investigation plan involved completing an examination of these tanks, present in each wing of the care home. This process would have been similar to the one used to inspect the accumulator tanks in the plant room. Additionally, the water temperature in the surrounding area was also to be tested, to investigate potential heat losses in the system. However it became apparent during the initial, cursory, site visit that there were no calorifier tanks out with the plant room (main DHW cylinder). Where they had appeared on the plans there were now only empty rooms or storage areas. Therefore these calorifier tanks were part of one of the original designs for the care home, which were removed in later versions of the design. This proved definitively that the calorifiers (out with the plant room) were not the cause of inefficiencies in the DHW system. It also showed that the plans obtained for this investigation were out of date and contained elements of earlier, obsolete designs.

Oil Tank – Investigation Plan Amended

The original investigation plan involved determining the location of the oil tank and examining the ground above it for any signs of an oil leak (see section 5.2.1: objective number 4, for typical signs of an oil leak). However, it was observed during the general site visit that the oil meter was in close proximity to the oil boiler (see Figure 5-11) and therefore any oil spills which could account for the recorded system inefficiencies would have to occur in this area. As a result the investigation was focussed on this region, instead of the area surrounding the oil storage tank. As there were no significant discrepancies between the recorded oil use and the payment invoices examined in Section 4.3, in addition to the fact that there was no obvious evidence of oil leaks in the grounds of the care home, it was deemed unlikely that an oil spill was present. Therefore further investigation regarding this area was not pursued.

Distribution System (Plant Room and Roof Spaces)

1. The pipework was examined to check there were no signs of corrosion or leaks.
2. Any disparities between the plans and the current pipework system, due to recent redesigns, etcetera, were documented and photographed.
3. The pipes were examined to determine whether they had adequate insulation.
4. An analysis of water samples throughout the building was planned, however, due to an equipment failure it was not possible to carry out this examination. Therefore the water records, logged periodically by the building caretaker, were analysed in their place to determine the efficiency and losses on the secondary circulation pipework.

5.4 Equipment

The following equipment was deemed to be necessary for the successful completion of the on-site investigation:

- Laser level checker
- Stop Clock (or equivalent)
- Measuring Tape
- Ladder
- Torch
- Digital Camera
- Temperature probe (Unfortunately this piece of equipment stopped working midway through the site visit, hence the inability to measure water temperature readings, as discussed in the previous section)

Additionally, the manufacturer guides for both the heat pump (IVT Heat Pump Manufacturer's Guide, 2003) and the oil boiler (Clyde: Engineering Data Sheet, 2010) proved invaluable when examining their respective machines.

6 Site Visit

This chapter offers a comprehensive account of the results obtained during the site visit to the care home. As in the previous chapter, the results are grouped under the headings corresponding to those in the investigation plan (see Section 5.3). Each section offers a succinct summary of the results acquired, with further analysis available in Chapter 7.

6.1 Preliminary Meeting

The energy officer for Orkney Islands Council offered a briefing on the operation and behaviour of the DHW system in the care home. Possible reasons for inefficiencies in the system were discussed, with reference to previous analysis (see Chapter 4: Initial Analysis) and background information on the DHW system. Two key points were raised during the meeting:

1. The Energy Officer believed it was unlikely that an oil spill was the cause of the inefficiencies in the domestic hot water system due to the close proximity of the oil meter to the oil boiler. If there had been a large oil leak in this area it would be readily apparent and quickly discovered.
2. Inefficiencies due to increased heating demands by the calorifier tanks, located in each wing of the care home, also seemed unlikely, as throughout the course of repeated visits to the care home the energy officer had not observed any calorifier tanks out with the plant room.

This information was taken into consideration and as a result, determining the likelihood of each scenario became a priority of the initial site visit.

6.2 Day 1 - Site Visit: General Inspection Results

The care home appeared clean and well maintained. The plant room was easily accessible and uncluttered, whilst the living spaces were maintained at a comfortable temperature. An initial survey of the care home highlighted deficiencies in the available plans. Chief among these were the inclusion of calorifier tanks which had never been installed in the care home. It became evident that the plans

Figure 6-1: Potential Oil Leak

were of an earlier design concept and therefore did not accurately represent the current building. As a result, the original investigation plan was further refined to reflect these changes (see Section 5.2.2).

There was possible evidence of a number of small oil leaks (see Figure 6-1 above), however they were not large or numerous enough to prove significant.

The following images illustrate the machinery within the plant room:

The plant room (alternatively described as the boiler house) was too large to capture in one photograph, therefore multiple images were recorded to display the interior.

Upon entering the plant room the two heat pumps (HP 1 and HP 2), which control the under floor heating, were immediately visible to the left.

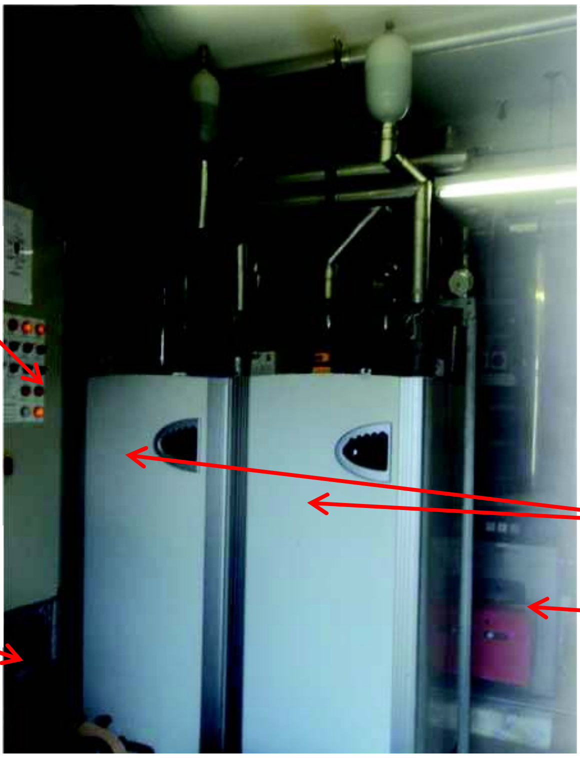


Figure 6-2: Plant Room - HP1 and HP2

Behind the two heat pumps, in the centre of the back wall, were the oil boilers - complete with orange Riello burners. The oil boiler on the left (which is also partially visible behind the heat pumps in Figure 6-2) is part of the under floor heating system. The oil boiler on the right is integral to the domestic hot water system.

Figure 6-3: Oil Boilers

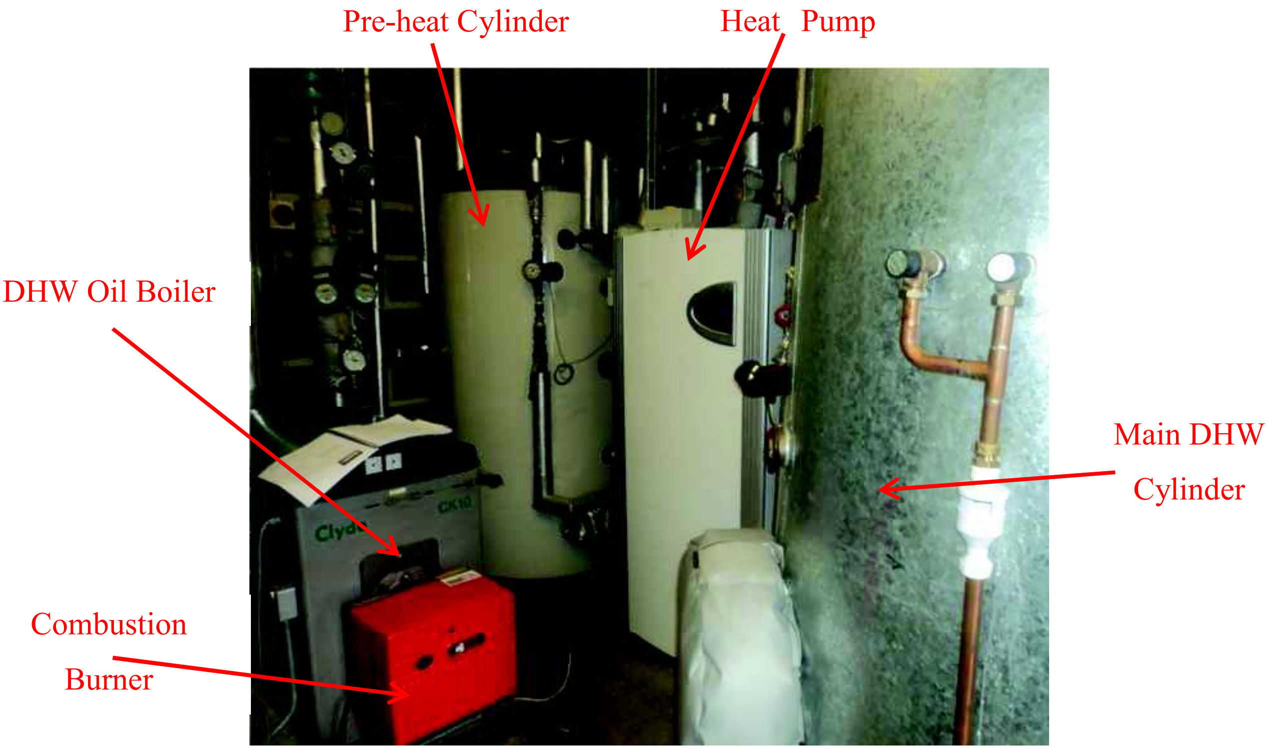


Figure 6-4: Plant Room - DHW System

The DHW system was situated along the right wall, up to and including the oil boiler at the centre of the back wall. As shown on Figure 6-4, the white accumulator tank is the pre-heat cylinder which is connected to heat pump 3. The large, silver calorifier on the right is the main DHW cylinder, which is heated by the oil boiler.

Figure 6-5: Pipework Modifications

Some of the pipework in the plant room had been redesigned (notice the double rows of pipes), however this occurred in the under floor heating system and does not directly affect the DHW system; therefore it is out with the scope of this project. However it could indicate that there have been similar errors made in the design or installation of the DHW system.

Figure 6-3 and Figure 6-4 show that the heat pump, oil boiler and accumulator tanks appear in good condition, with no apparent faults or damage to the machines.

When examined the DHW system reported 1206 total hours of operation, a much smaller figure than those reported by heat pumps 1 and 2. They recorded values of 26796 and 14135 hours of operation respectively.

Machine	Total Hours of Operation	Percentage Comparison (e.g. HP3/HP1)
HP 1	26796	4.5%
HP 2	14135	8.5%
HP 3	1206	N/A

Table 6-1: Heat Pump Hours of Operation

When consulted, the building caretaker agreed with the data shown in Table 6-1, stating that the DHW heat pump was rarely on. Additionally, no significant oil leaks had been reported, nor were there any complaints of uncomfortably high temperatures throughout the living spaces.

Importantly, it also became apparent that the system was affected by at least two faults; one involving the heat pump (1) and one involving the oil boiler (2).

(1) When examined, the pre-heat cylinder connected to the heat pump registered a low temperature, to the extent that it was cool to the touch. If the heat pump was working to maximum efficiency then this would not be the case. As it was, the tank felt close to human body temperature (37.5°C) other than the desired temperature of around 55°C.

(2) Additionally, the oil boiler was continually firing (activating) despite the temperature in the main DHW tank registering a value above the set temperature of 60°C. The oil boiler should not be heating the tank when it is above this temperature. This indicated that the oil boiler was not receiving the correct temperature information and was in fact responding to the

temperature of another cylinder, possibly the pre-heat cylinder. Therefore a malfunctioning or misplaced sensor appears to be the source of this fault.

The comprehensive site visit which took place the following day aimed to uncover further evidence in relation to the issues raised above.

6.3 Day 2 – Comprehensive Site Visit

Plant Room Inspection: Heat Pump (Results)

The heat pump appeared to be installed according to the manufacturer's instructions. An examination of the control panel yielded the following information:

- Total Hours of Operation = 1206
- Return Thermostat Stop Temperature = 43°C
- Set Point Temperature = 43°C
- Current Return Temperature = 39°C
- Hysteresis = 5°C

The machine had recorded one alarm but it was not relevant to the inefficiencies present in the DHW system.

To investigate whether the error associated with the heat pump was due to human error in the installation process, or was inherent to the machine itself, the return thermostat stop temperature of the heat pump was raised using the customisation settings on the heat pump control panel (see Appendix Section 10.4.2). The return thermostat stop temperature was increased from 43°C to 48°C. Immediately the heat pump activated and the temperature of the pre-heat cylinder and the ground loop of the heat pump began to rise. After a period of time the heat pump registered 1207 total hours of operation.

The heat pump was then returned to the original settings so that the effect of the above changes could be fully analysed at a later date (see Chapter 8: Conclusions and Recommendations).

The oil boiler was installed largely according to the manufacturer's instructions; however the space between the back wall and the boiler was shorter than recommended:

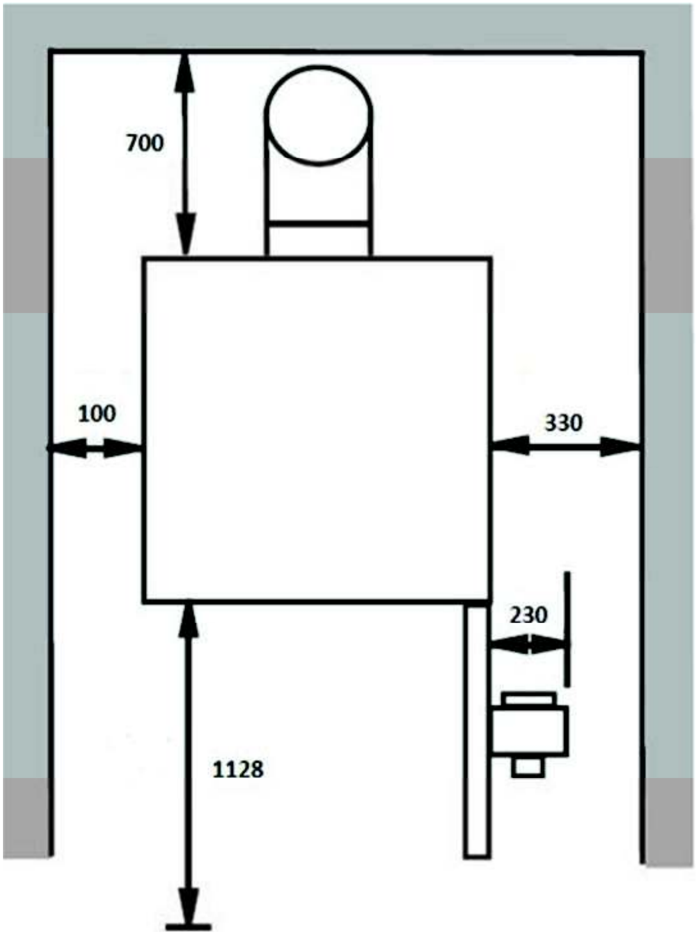


Figure 6-6: Manufacturer Installation Plan

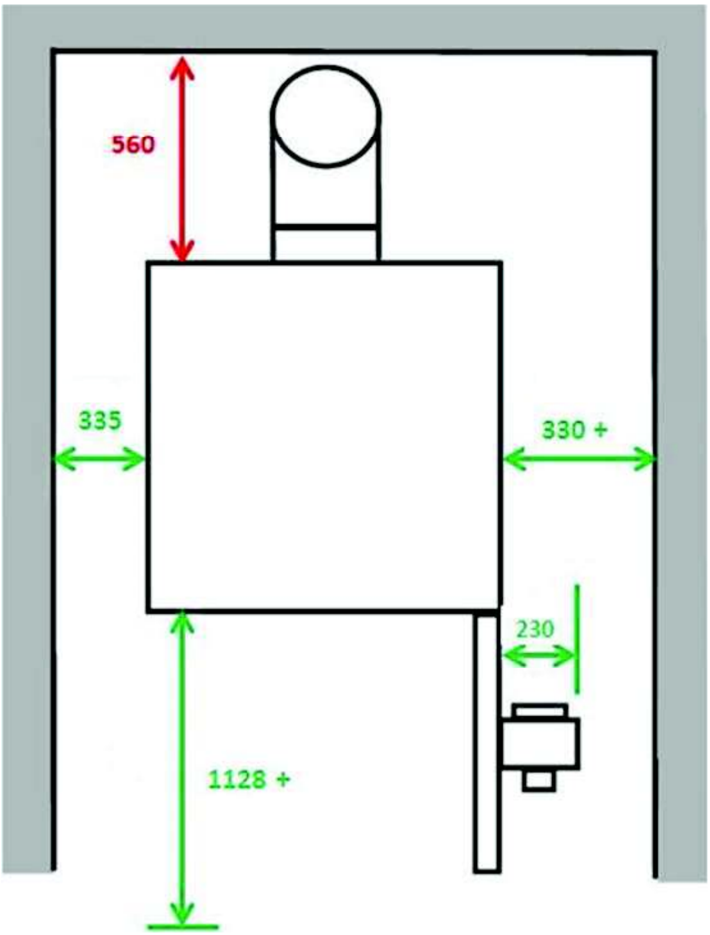


Figure 6-7: Actual Installation Plan

Figure 6-56 illustrates the minimum space required around the boiler (dimensions are in millimetres). The dimensions highlighted in green in Figure 6-57 illustrate measurements which are in accordance with the manufacturer's guidelines. Whereas the measurement highlighted in red leaves insufficient clearance between the boiler and the back wall, according to the installation specifications. The manufacturer stipulated that there should be a minimum of "700mm behind the boiler to allow 500mm of horizontal flue before any bends or tees" (Clyde: Engineering Data Sheet, 2010). This could lead to an inadequate air supply, resulting in poor combustion performance and, in worst case scenarios, a boiler furnace explosion (Axtman, W.H, 1994).

Figure 6-8: Bend in Flue above Plant Room

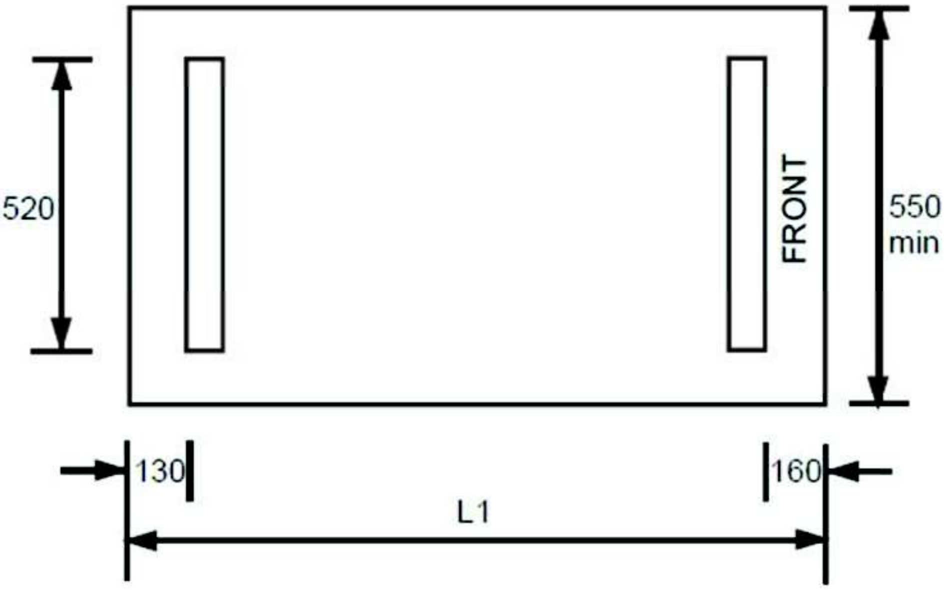


Figure 6-9: Oil Boiler Plinth Measurements

The recommended distance between the front of the boiler and the end of the plinth was 160mm. The examination showed that the plinth was made up of two pieces of concrete, with the distance to the edge of the original plinth being 90mm shorter than the required value. However, this shortfall has been compensated for with an extension of 190mm to the front of the plinth, which amounts to a total distance of 260mm between the edge of the plinth and the front of the boiler. The plinth was level, which limits the likelihood of oil spills, although there was evidence of slight damage and erosion along its edges, possibly due to maintenance work.

When the control panel was examined it was observed that none of the warning lights were activated. The following data was also recorded:

- Boiler Thermostat = 84°C
- Total Hours of Operation = 17009:86
- Exhaust Gas Temperature = 25°C
- Pump Overrun Temperature = 75°C

Figure 6-10: Oil Boiler Control Panel

At this stage it is interesting to note the disparity between the oil boilers total hours of operation, and the DHW heat pumps. The heat pump has only been operational for 7% of the time the oil boiler has. This offers further evidence indicating an underactive heat pump and an overactive oil boiler.

The oil meter was examined, as was the delivery pipe (see Figure 6-511). If the inefficiencies in the DHW system had been caused by an oil leak it would have had to have occurred in this region, otherwise the oil usage data would not concur with the oil invoices (as proven in section 4.3). Although there was evidence of a previous oil spill in this vicinity, the leak was too small to be considered significant.

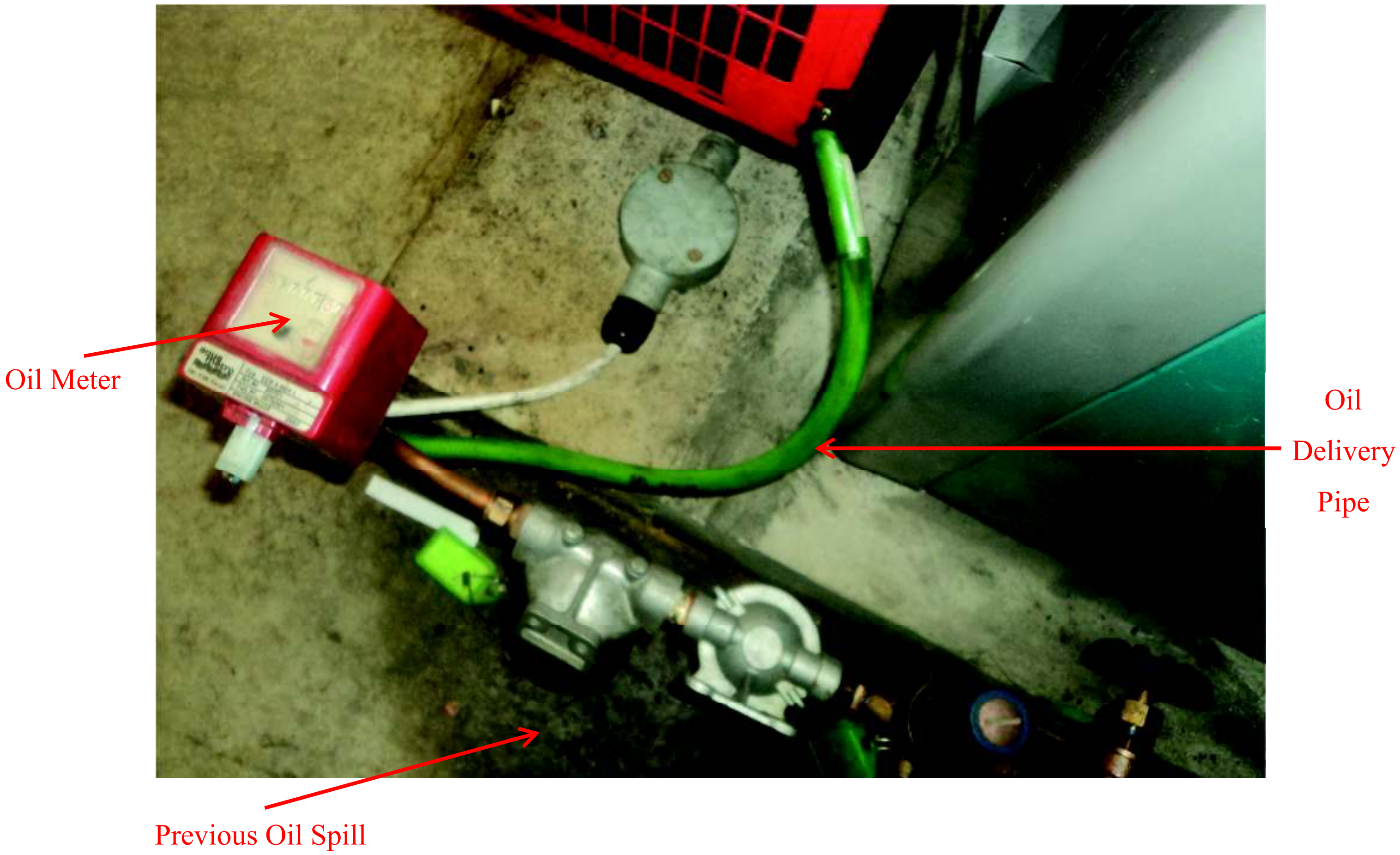


Figure 6-11: Oil Delivery System

Finally the oil boiler was monitored for an hour to gather information on how often it was active, as well as its oil consumption. The results are shown in Table 6-2 over page:

Number	**Start Time (hr:min:sec)**	**Start Time Difference (hr:min:sec)**	**Stop Time (hr:min:sec)**	**Stop Time Difference (hr:min:sec)**	**Duration (hr:min:sec)**	**Time Between Activations (hr:min:sec)**	**Oil Use (L)**
1	11:03:26	**-**	11:05:25	-	-	-	0.2
2	11:09:10	00:05:44	11:10:54	00:05:29	00:01:59	00:03:45	0.2
3	11:14:54	00:05:44	11:16:39	00:05:45	00:01:44	00:04:00	0.205
4	11:20:34	00:05:40	11:22:16	00:05:37	00:01:45	00:03:55	0.185
5	11:26:14	00:05:40	11:27:58	00:05:42	00:01:42	00:03:58	0.2
6	11:31:57	00:05:43	11:33:40	00:05:42	00:01:44	00:03:59	0.19
7	11:37:32	00:05:45	**-**	-	00:01:43	00:03:52	0.2
8	11:43:17	00:05:45	11:44:58	-	-	-	0.19
9	11:49:02	00:05:45	11:50:44	00:05:46	00:01:41	00:04:04	0.2
10	11:54:44	00:05:42	11:56:35	00:05:51	00:01:42	00:04:00	0.2
Average	-	**00:05:42**	-	**00:05:42**	**00:01:51**	**00:03:57**	**0.197**
Total	**-**	**-**	**-**	**-**	**-**	**-**	**1.97**
(+/-) Error	**00:00:05**	**00:00:05**	**00:00:05**	**00:00:05**	**00:00:05**	**00:00:05**	**0.005**

Table 6-2: Oil Boiler Observation

There were ten separate activations of the of the oil boiler during the observational period. As shown in Table 6-2, the average time between the subsequent start (and finish) time for each activation was five minutes and forty-two seconds (342 seconds), with an average duration of one minute and forty-six seconds (106 seconds). The average time between activations of the oil boiler was three minutes and fifty-seven seconds (237 seconds). The average oil use per activation was 0.197 litres of oil, amounting to a total of 1.97 litres used during the hour-long observation. The error on the time values referred to the estimated time taken to travel between the oil boiler and the stop-clock in the event of activation. The oil use error is simply the standard error for an analogue machine (+/- half the smallest division).

Plant Room Inspection: Accumulator Tanks (Results)

The accumulator tanks appeared to be installed correctly and were in good working order.

- The temperature in the pre-heat cylinder was measured at approximately 39°C.
- The temperature in the main DHW cylinder was measured as ranging between 62.5°C – 64.5°C, depending on the oil boiler activation status.

The following figure, obtained from the on-site computer, which monitors the boiler house and domestic hot water system, provided further evidence that the oil boiler was responding to the sensor in the pre-heat cylinder, as opposed to the main DHW cylinder.

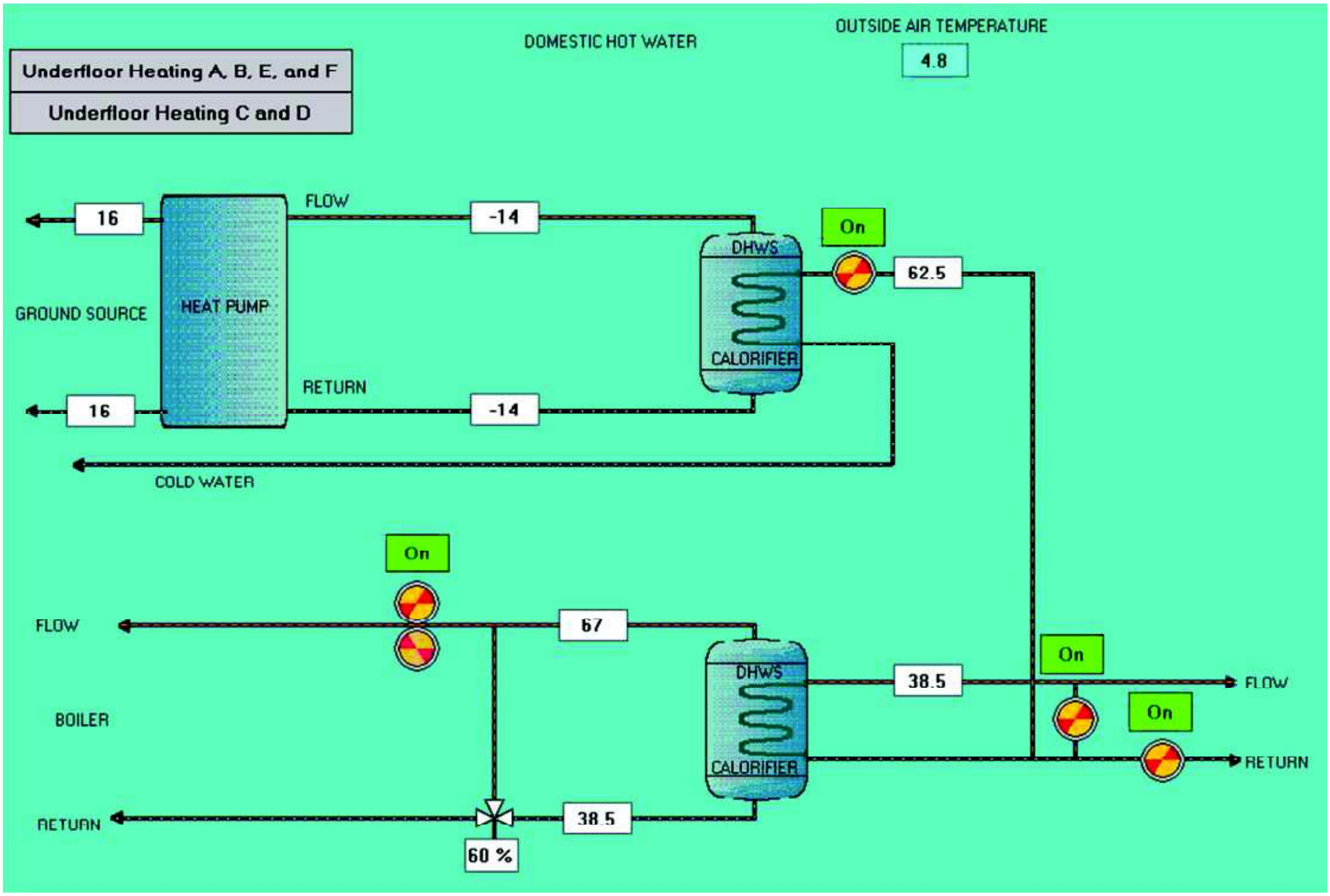


Figure 6-12: Evidence of Sensor Error

In Figure 6-12 the pre-heat cylinder is apparently sitting at 62.5°C (which is impossible given that the operating conditions of the heat pump only allow for a maximum return flow temperature of close to 55°C) whilst the main DHW cylinder is sitting at 38.5⁰C, which is more than 20⁰C below its true value. Therefore, in effect, the sensors have switched the temperature values for each accumulator tank.

Distribution System (Plant Room and Loft Spaces) Results

The pipework in the plant room and loft spaces were examined. There was no evidence of any leaks or corrosion. The pipes were clearly identified and adequately insulated, as were the loft spaces. However some of the valves were left without insulation (see Figure 6-513 below):

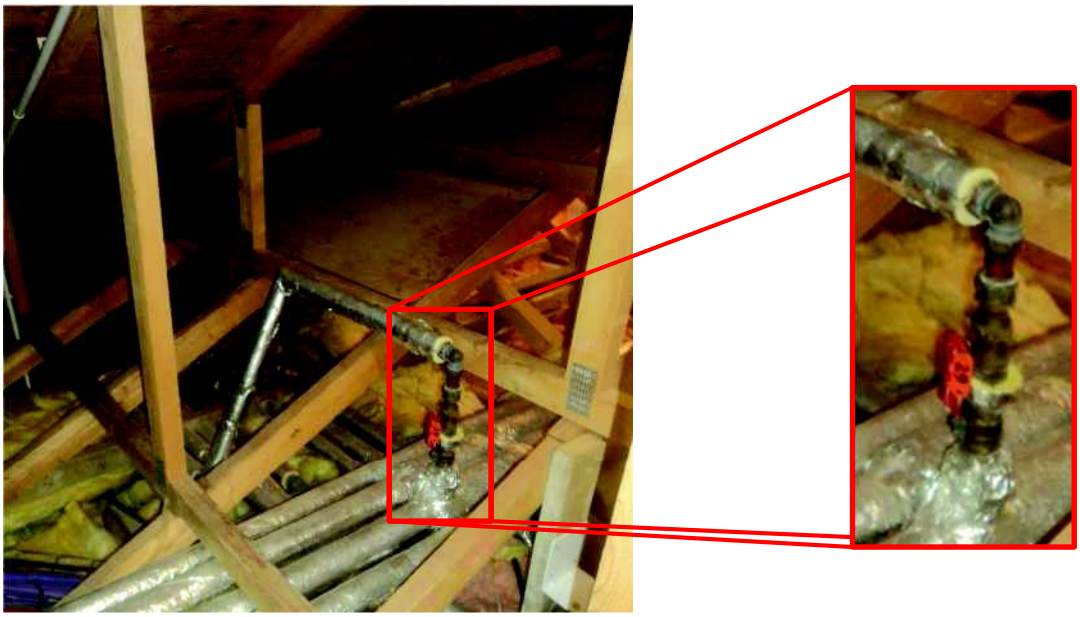


Figure 6-13: Loft Space (with Valve Inset)

As an analysis of water samples throughout the building was not possible due to an equipment failure, an analysis of the efficiency and losses on the secondary circulation pipework was completed using existing data, collected periodically by the building caretaker (see Chapter 7)

6.4 Study of Results

The study and analysis of the results covered in this chapter continue in Chapter 7: Further Analysis. The relevant conclusions are found in Chapter 8: Conclusions and Recommendations.

7 Further Analysis

To evaluate the overall performance of the care home's domestic hot water system, the data collected during the site visit (see Chapter 6) was compiled and analysed, together with the previous data (see Section 4.5), to determine the overall system efficiency and losses. The information collected during the site visit is recorded in Table 7-1 below and was used in addition to the data listed in Table 4-1, throughout the course of the analysis.

Data Available	Measured Period
Heat Pump Operational Settings	June 2013
Calorifier Temperatures	June 2013
Oil Boiler Observation Results	June 2013
Water Temperature Records	21st January 2011 – 7th June 2013
Water Services Layout Plans	Developed in 2003

Table 7-1: Data Available for Further Analysis

Further analysis was conducted to ascertain the true efficiency of the oil boiler and to determine whether there was any of evidence of significant energy losses in the secondary circulation pipework. This was accomplished through the repetition of the oil boiler efficiency study, completed during preliminary analysis (see Section 4.3). However, where conjecture on the heat pump operational settings and calorifier temperatures had previously been necessary, the true values, recorded during the site visit, could be utilised. Losses in the secondary circulation system were determined through an analysis of water and pipework temperatures throughout the building. The results of this analysis were then used to evaluate the overall system performance.

The analysis undertaken on each area can be found in the following subsections;

- Oil Boiler Efficiency Study (Section 7.1)
- Secondary Circulation Losses (Section 7.2)

Each subsection comprises an account of the analysis undertaken; describing data selection, methods of analysis employed and results obtained. Any limitations of the study are also discussed. The chapter concludes with an account of the DHW system's overall performance; detailing the energy required by the system, as well as an evaluation into the corresponding costs and carbon dioxide emissions.

7.1 Oil Boiler Efficiency Study

The previous analysis completed during the initial stages of the project was designed primarily to establish whether the oil boiler was operating efficiently. The calculated efficiency was based on several assumptions; predominantly concerning the operation of the heat pump and the temperature of the two DHW accumulator tanks. Nevertheless it was adequate to illustrate that the efficiency of the boiler did not fall within the accepted range for a machine of its type and age (expected seasonal efficiency between 70 – 85% (The Chartered Institution of Building Services Engineers, 2005), nor those quoted by the manufacturer. Therefore it established the need to gather more information on the operation of the oil boiler so that the factors responsible for the poor performance of the machine could be determined and rectified.

Data Collection

The oil consumption data for the domestic hot water system between the 31st of October 2008 and the 25th of February 2011 was required. This information was used in conjunction with data on the care home hot water requirement recorded over the same period. Data on the buildings water and oil usage was collected on an irregular basis throughout this period.

The operational settings of the heat pump and current temperatures of the two accumulator tanks, collected during the site visit, were as follows:

- Return Thermostat Stop Temperature = 43°C
- Current Return Temperature = 39°C
- Hysteresis = 5°C
- Pre-heat Cylinder Temperature = 38.5°C
- Main DHW Cylinder Temperature = 62.5°C

Method of Calculation

The same calculation method was used as in the initial oil boiler efficiency study (see Section 4.3) with the following exceptions; the geothermal heat pump set point temperature and hysteresis values were used in place of the previous assumptions; made on the basis that the heat pump was operating at, or close to, optimum efficiency. Furthermore, there was no evidence that the heat pump was supplying heat in excess of its set point temperature, as is assumed to happen in optimum conditions (For example, in previous calculations, when working at the maximum allowed set point temperature of 48^{0}C, the machine was assumed to raise the water temperature to 55^{0}C). In actual fact, when examined, the pre-heat cylinder temperature value was 0.5^{0}C below the current return temperature of the heat pump.

Thus, taking the actual settings into account, the heat pump was capable of raising the water temperature to between 38.5^{0}C and 43^{0}C in the pre-heat cylinder. Therefore, as the temperature in the main DHW tank was measured at 62.5^{0}C, the oil boiler was supplying heat between 24^{0}C and 19.5^{0}C, dependent on the corresponding heat pump contribution. When examined, the temperature of the water in the pre-heat cylinder was 38.5^{o}C, meaning the oil boiler was raising the water temperature by 24^{0}C. Therefore the values for energy requirement were altered to reflect the increased energy necessary to raise the water temperature between 19.5^{0}C to 24^{0}C, as opposed to between 5^{0}C and 7^{0}C.

Additionally, as there is no official method for calculating the effect of the dry cycling process in oil boilers, the following method was developed to estimate the effect this process has on the DHW system of the care home. The method involved utilising the calculated efficiency values to determine the amount of oil lost due to the boiler dry cycling, among other inefficient processes. First, the results of the oil boiler observation were analysed (see Table 6-2). It was assumed that the ten activations noted during the hour long observation were typical of those experienced throughout the full day; therefore it was assumed that the oil boiler fired approximately two hundred and forty times per day and the resulting oil use amounted to 47.28 litres. This value was then compared to the daily oil use average of 47.59 litres, calculated in Section 4.2. As these values were very similar it appeared that the assumption, stated above, would be suitably accurate for use in calculations.

The resultant energy yield, in kilowatt-hours, from 47.28 litres of oil was then determined, as in Section 4.2, by multiplying the oil use by 10.53. The consequent energy yield was then converted to Joules through multiplying the value, measured in kilowatt-hours, by 3,600,000. The subsequent quantity described the heat being supplied to the water over the course of the day. Equation 1 (described in section 4.2) was then rearranged to give the following equation:

$$dT = \frac{Q}{m \times C_p \times \eta_{eff}}$$

Where m was equal to 830 kilograms, having been calculated from the average daily water use in litres (830 litres) utilising the conversion factor: 1 litre = 1 kilogram. The factor η_{eff} represented the efficiency of the oil boiler. The exact efficiency value chosen (as a range of values were calculated over the entire measured period) was taken from a period with a water requirement of approximately 830 litres, to increase the accuracy of results.

The value obtained gave the calculated temperature increase experienced per litre of water, if the entirety of the oil was utilised to heat the water (Asides from the heat of the vaporisation of water from the oil, which has already been accounted for in the calculated energy yield of the oil as the net calorific value (NCV), as opposed to the gross calorific value (GCV), was used in calculations). However, since the actual temperature increase was known (24°C), the disparity between these two values was used to determine the percentage of energy lost chiefly to the "dry cycling" process in the boiler.

Results

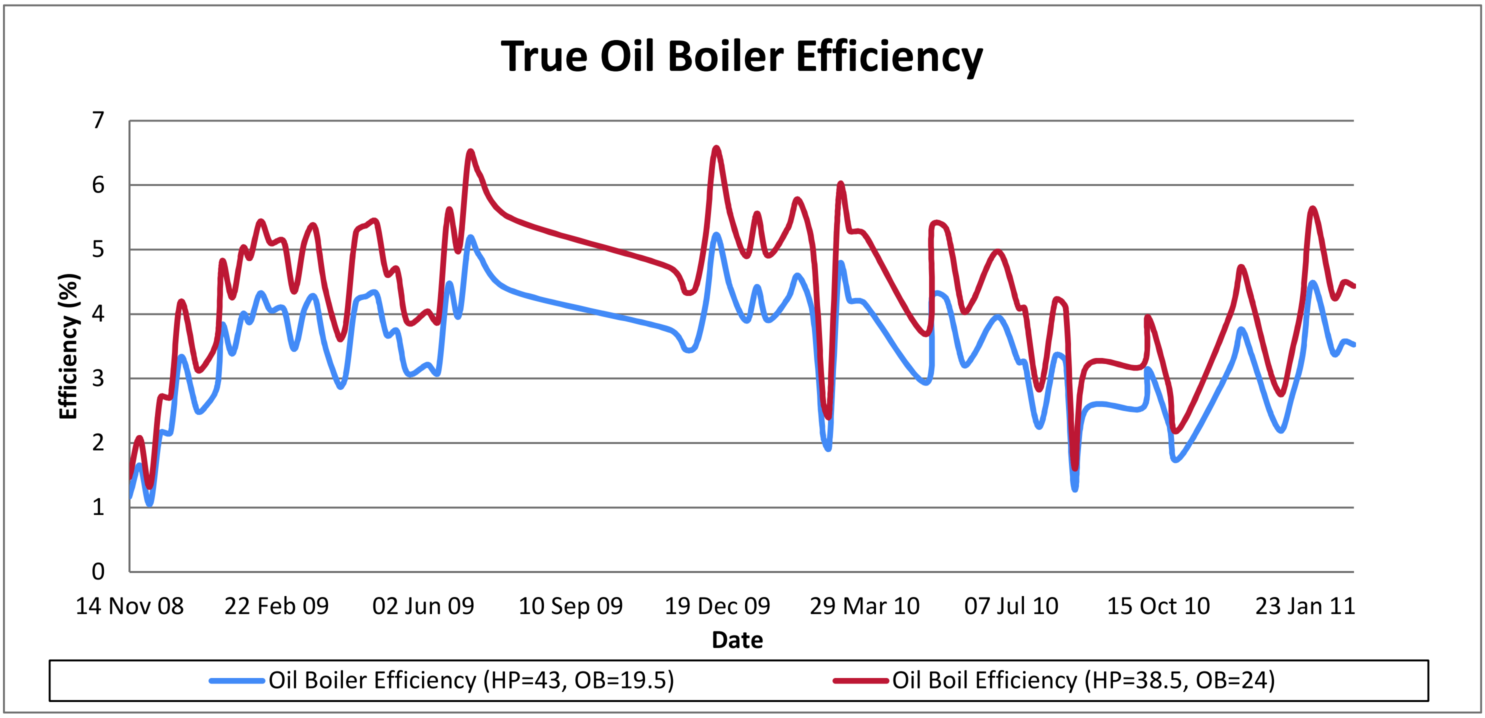


Figure 7-1: True Oil Boiler Efficiency

HP=43, OB=19.5 and HP=38.5,OB=24 in the legend entries represent the estimated heat provided, in degrees Celsius, by the heat pump and oil boiler respectively in each calculation.)

When the heat pump was assumed to be operating at the set point temperature and heating water to 43°C, with the oil boiler required to supply the remaining 19.5°C, the resulting oil boiler efficiency was calculated as ranging between 5.23% and 1.05%, with an average value over the entire period of 3.43%. When the heat pump was operating at the lowest allowed temperature (observed case), according to a hysteresis value of 5°C, and heating water to 38.5°C, the oil boiler was required to supply the remaining 24°C. For this temperature, the oil boiler efficiency ranged between 6.58% and 1.33% with an average value over the entire period of 4.31%.

As in the initial analysis, the evidence shown in Figure 7-1 illustrates that the oil boiler efficiency increased when it was required to produce more heat. Whilst the efficiency of the boiler is still very low, it is slightly higher (approximately 1.5%) than the initial estimates suggested. However this is to be expected, since the boiler is almost certainly responding to the temperature in the wrong accumulator tank.

With regards to an approximation of the fuel wasted through the dry cycling of the boiler: the calculated temperature increase experienced by the water, based on the daily volume of oil consumed, was equal to 25.5°C. When the actual temperature gain was subtracted from the calculated value, the temperature difference was found to be 1.5°C, which corresponded to approximately 6%, or 2.837 litres, of the oil consumed.

Limitations

The efficiency of the oil boiler is likely slightly higher than the values calculated, due to the lack of information regarding the adjoining doctor's surgery water requirements, as discussed in Section 4.3. Additionally, the calculation of oil boiler efficiency does not account for standing losses in the main DHW cylinder, wherein extra energy would be required to recover the heat losses. This evaluation was not included as part of this study, as due to the high activity of the oil boiler any losses would be nullified through the frequent injections of heat experienced by the calorifier every few minutes. However, this analysis has been included in the following chapter, where the improved performance of the system is estimated based on the recommended modifications suggested.

Additionally, the estimated losses experienced by the boiler due to dry cycling is dependent on several assumptions, some of which may not be correct in practice; such as oil consumption remaining the same throughout the day. However, since the volume of oil consumed per activation was the same throughout the duration of the oil boiler observation, in addition to the fact that the total daily consumption of oil was very close to the average calculated over the measured period, it was deemed sufficiently accurate enough to provide an estimate of dry cycling losses.

7.2 Secondary Circulation Pipework Evaluation

After analysis of the primary constituents of the hot water system was completed, the distribution system was examined to establish whether there was any evidence of leaks or inadequate insulation throughout the care home. During this inspection it became evident that the pipes were well maintained and adequately insulated, with the exception of valves in the loft spaces. There was only evidence of one small leak in the system, which was clearly marked and in the process of being repaired. Due to an equipment failure, it was not possible to conduct a rigorous examination of the distribution system during the site visit. However, records were available, collected as part of routine water safety checks, which contained information that could be utilised for an analysis of the distribution system.

Consequently, an examination of pipe and water temperatures throughout the building was conducted to determine whether there were any causes for concern in the distribution branch of the domestic hot water system.

Data Collection

Water (and pipe) temperature records were available from the 21st January 2011 until the 7th June 2013. Each record contained a selection of temperature readings measured throughout the care home. These water safety checks were carried out roughly to a monthly schedule and designed so that the temperature of every room would be checked periodically every few years. In total, twenty water temperature records were utilised for analysis.

Method of Calculation

The data collection process was amply suited to its purpose, however, it did not allow for a comprehensive examination of the DHW distribution system. Typically only one set of records were available containing temperature measurements for each room, which did not allow for direct comparisons between past and present data. In the absence of detailed plans, drawn to scale and utilising the same naming convention as used in the water records, it was not possible to accurately determine any energy losses due to increasing distance from the Plant Room. Additionally, some records contained more temperature results than others.

Nevertheless, there was enough data which, when analysed, could give an indication of system performance. To achieve this, the data was first examined to determine whether the temperatures recorded where within the acceptable limits (TMV hot pipe temperatures should be greater than 50^0C and water should be discharged at temperatures between 35^0C and 46^0C, as stated in the water records).

The data was then sorted into groups determined by the wing of the care home they were located in. Using Excel, a chart was plotted for each of the twenty water records used in analysis, to display the range of temperatures recorded in each wing (see Figure 10-23 to Figure 10-222 in the Appendix). These charts were then analysed to determine the variation in temperature across different wings of the care home. As there were a range of plant room temperatures recorded throughout the period, it was not possible to directly compare the results, as some would have naturally registered higher due to the elevated starting temperature. Therefore the data was evaluated through determining the frequency with which each wing recorded the lowest or highest temperature, etcetera. These results were then combined and displayed on Figure 7-3 and **Error! Reference source not found.**. Results are displayed according to the relative distance of the wing to the plant room (boiler room). The relative distances are measured along the length of pipe supplying the wing, not a direct measurement from one area to another. Figure 7-2 illustrates the layout of the major branches in the distribution system:

A selection of the readings with the same (Plant Room) starting temperature were also analysed to look for any decline in temperature values over time.

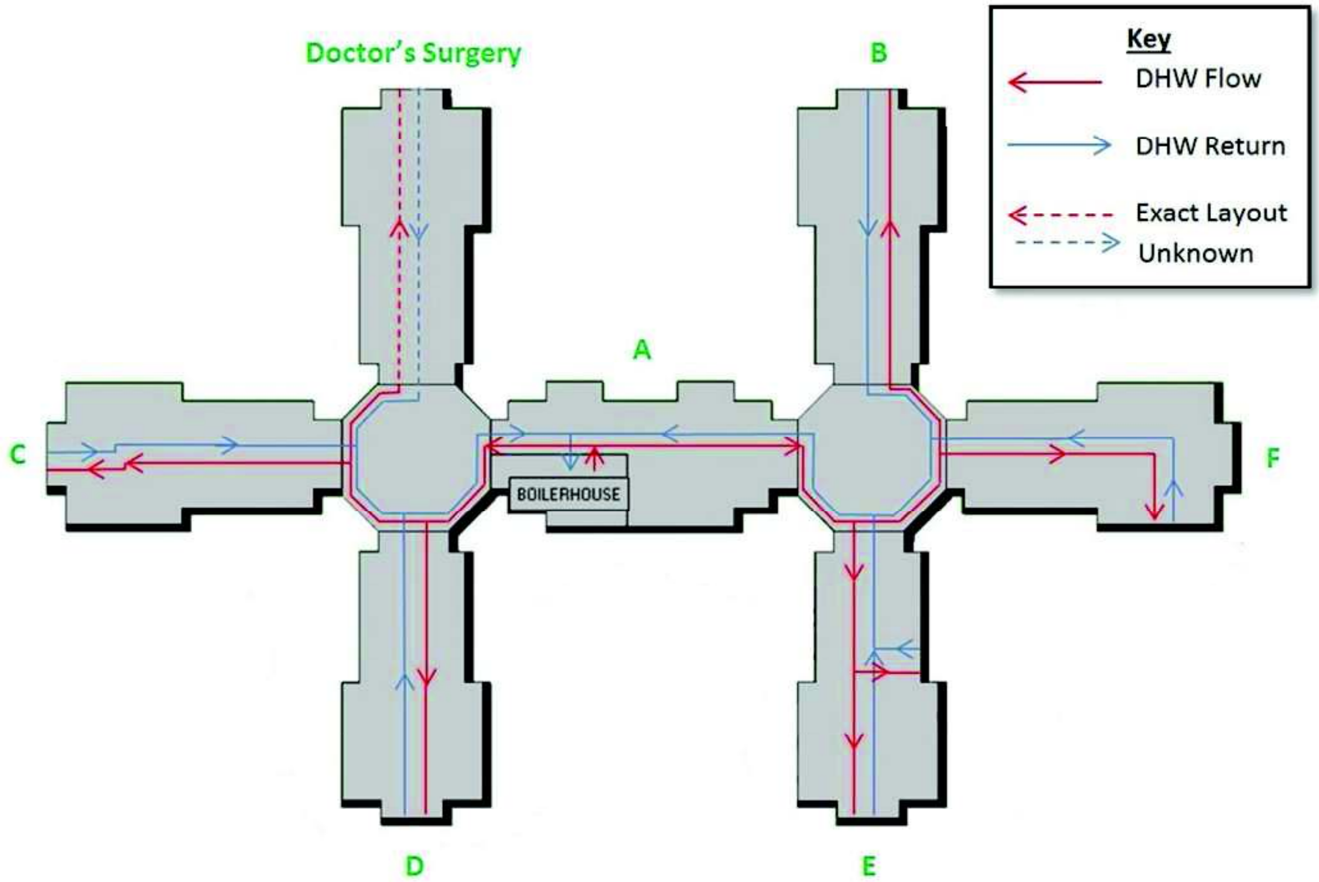


Figure 7-2: Distribution Network Layout

Results

Hot water was stored above 60ºC in accordance with World Health Organisation guidelines. Water distribution temperatures ranged from 45.4ºC to 65ºC. The recommended distribution temperatures should be in excess of 50ºC (Care Home Water Records, 2011), therefore, whilst the majority of temperatures examined did meet this requirement, there was one incidence were the measurement recorded of 45.4ºC (reading recorded on 24/12/2012) was out with these restrictions. Pipe temperatures should also be in excess of 50ºC. The vast majority of the readings met this criteria, however as with the water distribution temperature readings, there was one incidence were the value obtained was below 50ºC (a measurement of 49.5ºC, recorded on 21/11/2011).

Additionally, water should be discharged between 35ºC and 46ºC, as per the UK Health and Safety Executive recommendations; which ensure good sanitary conditions whilst minimising the risk of scalding (although there is some variation in the temperatures recommended for use with "at risk" groups compared to those in kitchen areas, etcetera). The discharge temperatures recorded in the care home ranged from 38.2ºC to 45.4ºC and therefore met this requirement.

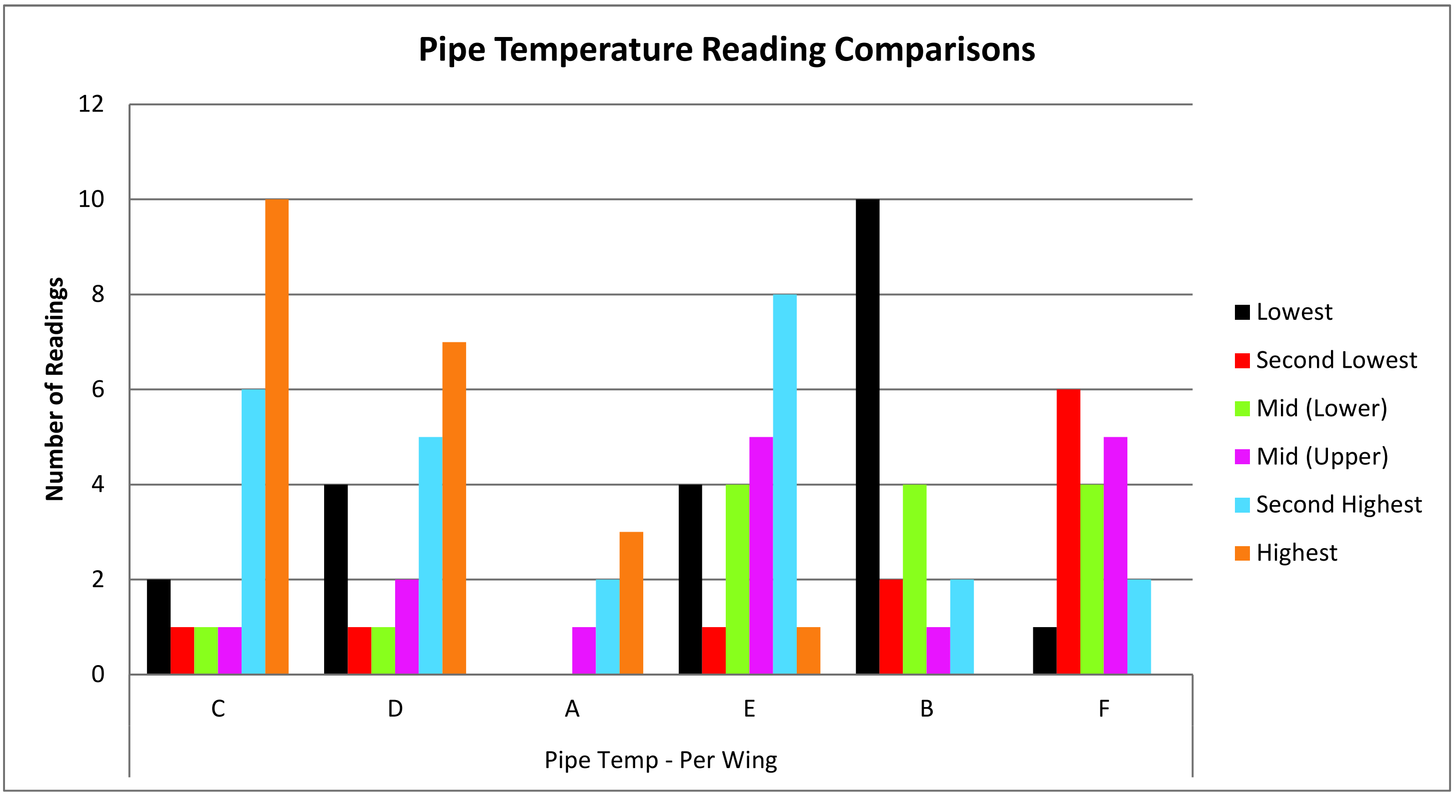


Figure 7-3: Pipe Temperature Per Wing

Figure 7-3 shows that pipe temperature measurements recorded in wings to the left of the plant room (as illustrated on Figure 7-2) were generally higher than those to the right (The plant room was located in wing A). Wings C, D and E in particular recorded higher temperatures frequently, whereas Wings B and F obtained a high proportion of the lower temperature values. Therefore it may prove beneficial to re-examine the distribution system from the branching junction at wing E and throughout wings B and F.

The results of the water temperature analysis, as shown on **Error! Reference source not found.**, were more evenly spread out between the various wings of the building. There was no obvious pattern with the lower temperatures as seen in Figure

7-3. Wing A appears to have a lower percentage of the high temperature readings; however that could be due to a lack of data.

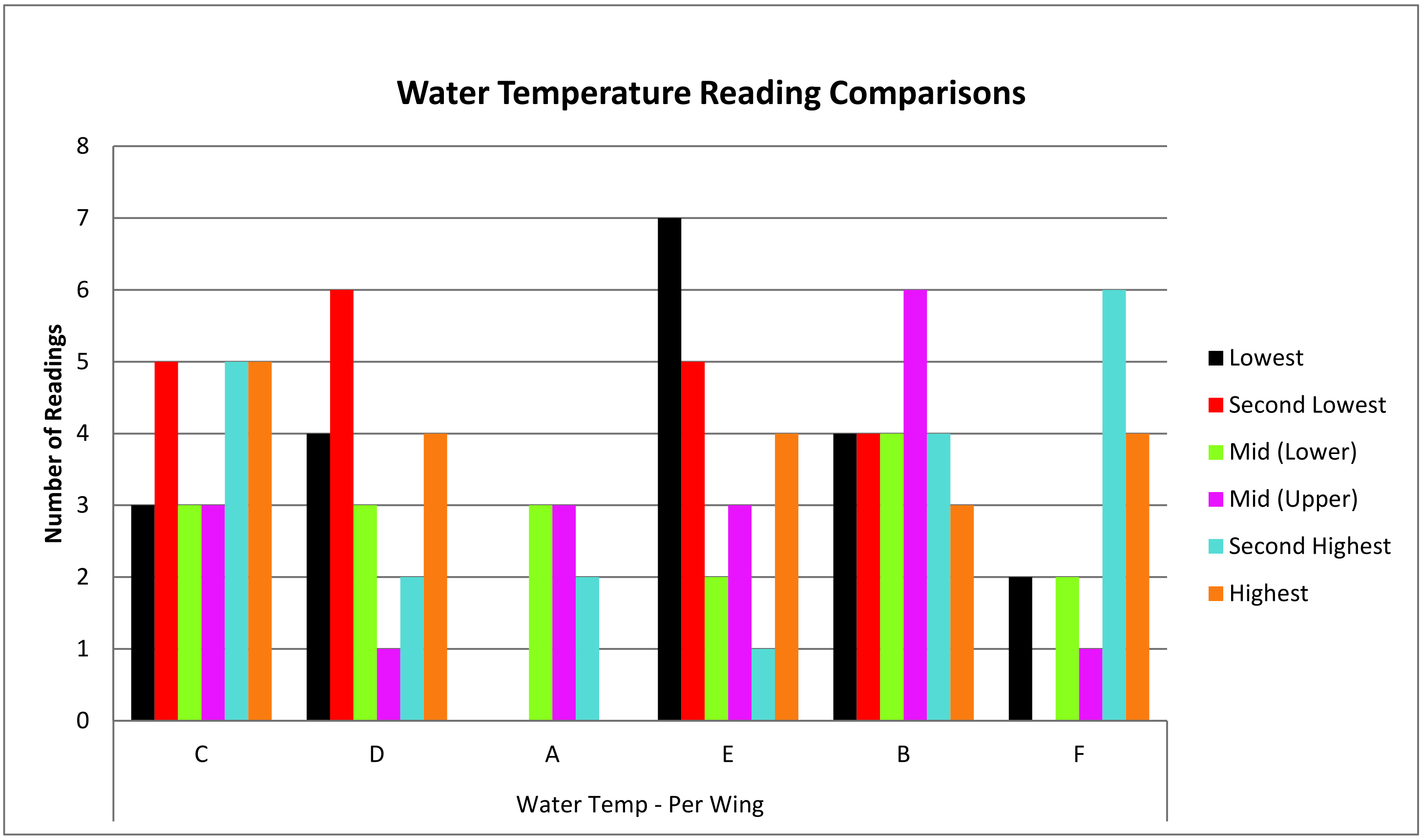


Figure 7-4: Water Temperature Per Wing

Of the twenty records available for research, there were nine which shared the same starting temperature. However, an analysis undertaken to examine whether there was evidence of a reduction in temperature over time proved inconclusive.

Where there was sufficient data to compare the pipe temperatures to the corresponding plant temperatures, variations ranging from 4.6°C to 9.2°C were recorded.

Limitations

The investigation into losses in the secondary circulation system was hampered primarily by a lack of data. Additionally, the results discussed were based around several assumptions; that the Thermostatic Mixing Valve (TMV) set temperatures had not been altered and that they were consistent throughout the building. However, as the care home houses a large kitchen block, whilst catering to occupants who would be considered at risk of scald injuries, there are likely variations in the temperature settings throughout the home. Furthermore, each wing was not evenly represented in the results; in particular, there was very little information available on Wing A. There was also variation in the number of temperature readings recorded each month.

Nevertheless, the results indicate that the distribution system between Wings F and B should be more closely examined. Additionally, it would be beneficial to examine the entire care home DHW distribution system to a more rigorous standard. This could be achieved by collecting data throughout each wing of the care home over a period of a few weeks, ensuring that the same sinks/ sluices are examined each time. **Error! Reference source not found.**5 illustrates the approximate location of suggested data collection points (represented by orange circles), based on their position and function within the care home. (Figure 7-5 should be used in collaboration with the water services drawings (see Figure 10-23 to Figure 10-28 in the Appendix):

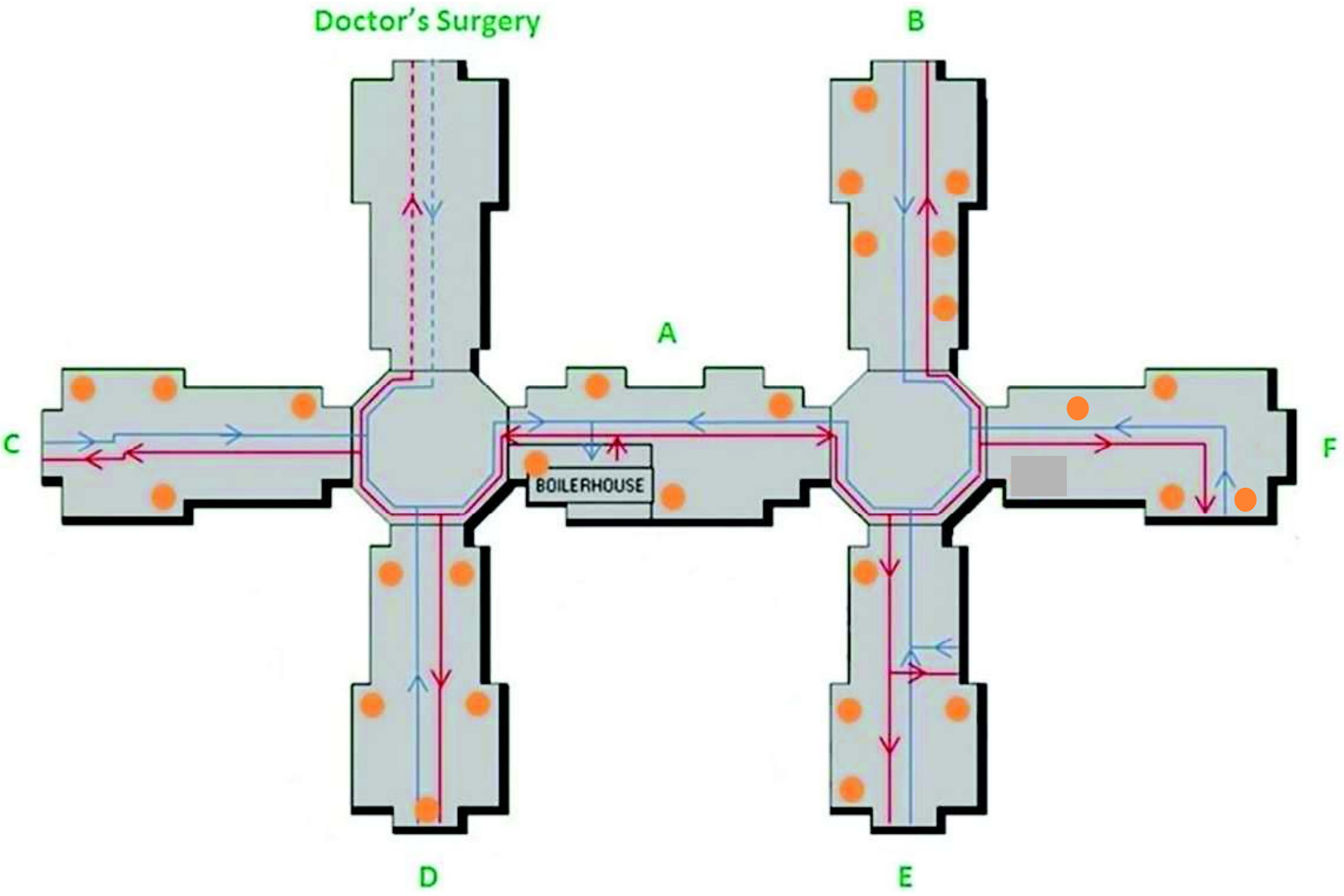


Figure 7-5: Suggested Distribution Network Data Collection Points

7.3 Evaluation of System Performance

Upon completion of the analysis of the domestic hot water system, the results were assessed, together with those obtained during the site visit, to determine the overall performance of the system. The performance was evaluated over the following areas:

- Energy Requirements
- Cost
- Carbon Dioxide Emissions

The performance values obtained were then utilised in Chapter 8: Conclusions and Recommendations, to determine the prospective improvements in performance with each suggested modification.

7.3.1 Energy Requirements

On average 0.023 kilowatt-hours of electricity and 0.063 litres of oil were required to raise the temperature of one litre of water to temperatures in excess of 60°C. Overall this equated to a total energy requirement of 0.686 kilowatt-hours per litre of water. With an average daily water requirement of 830 litres, the resulting daily energy requirement was equal to approximately 569.7 kilowatt-hours. Annually, the energy requirements of the care home amounted to over 207,940 kilowatt-hours, or approximately 750,000 Mega joules.

Table 7-2 shows a breakdown of the DHW system energy requirement, illustrating the energy used in the oil boiler and heat pump individually. The electricity supplied by the grid was calculated by dividing the heat pump energy required in kilowatt-hours by 3.2 - the heat pump coefficient of performance.

Energy Required					
	Heat Pump		Oil Boiler		Total
	Energy (kWh)	Grid Electricity (kWh)	Energy (kWh)	Oil (litres)	(kWh)
Per Litre of Hot Water Generated	0.023	0.007	0.663	0.063	0.686
Daily	19.090	5.966	550.614	52.290	569.704
Annually	6967.850	2177.453	200974.001	19085.850	207941.851

Table 7-2: DHW System Energy Requirement

Interestingly, a case study published on the care home for "Hot Winter News" quoted the entire annual heating load as equal to 530,600 kilowatt-hours. Therefore, by this estimation, the energy required by the DHW system would be equal to 39% of the energy required to heat the entire building.

7.3.2 Cost

The cost of heating water in the care home was calculated using gas oil and grid electricity rates for July 2013. They were as follows:

- Gas Oil = £0.7438 per litre
- Grid Electricity = £0.1574 per kilowatt-hour

On average it cost 5p to heat one litre of water to temperatures in excess of 60°C. This resulted in a daily sum of £39.83, with an annual total equal to £14,538.79.

Cost					
	Heat Pump		Oil Boiler		Total
	Grid Electricity (kWh)	Grid Electricity (£)	Oil (litres)	Oil (£)	(£)
Per Litre of Hot Water Generated	0.007	£0.00	0.063	£0.05	£0.05
Daily	5.966	£0.94	52.290	£38.89	£39.83
Annually	2,177.453	£342.73	19,085.850	£14,196.06	£14,538.79

Table 7-3: DHW System: Related Costs

As shown on Table 7-3, supplying a large proportion of heat to the DHW system through the oil boiler is a costly process, whereas heating water through the heat pump is more economical.

7.3.3 Carbon Dioxide Emissions

The carbon dioxide emissions from the DHW were estimated using the following conversion values (Carbon Trust, 2011):

- Gas Oil: 1 litre = 3.0595 kgCO_2e
- Grid Electricity: 1 kWh = 0.5246 kgCO_2e

On average 0.197 kg of carbon dioxide was emitted for every litre of hot water produced. This resulted in daily emissions of roughly 163 kg, with annual emissions totalling 59535 kilograms (approximately 60 metric tons.)

Carbon Dioxide Emissions					
	Heat Pump		Oil Boiler		Total
	Grid Electricity (kWh)	Grid Electricity (kgCO_2e)	Oil (litres)	Oil (kgCO_2e)	(kgCO_2e)
Per Litre of Hot Water Generated	0.007	0.004	0.063	0.193	0.197
Daily	5.966	3.130	52.29	159.981	163.111
Annually	2177.453	1142.292	19085.85	58393.158	59535.450

Table 7-4: DHW System: Carbon Dioxide Emissions

8 Conclusions and Recommendations

This chapter comprises of an account of the main conclusions drawn from the completed investigation into the efficiency and losses of the domestic hot water system of the 40-bed care home in Orkney. The modifications required to improve the DHW system efficiency are identified and a plan provided to offer guidance on implementing the necessary changes. The likely improvement on the system efficiency due to each modification was also estimated. Additionally, several suggestions are included which offer further improvements, but are not vital for the efficient operation of the system.

8.1 Conclusions

Preliminary analysis completed on the DHW system indicated that both the heat pump and the oil boiler appeared to be underperforming;

Heat Pump Performance

An analysis on the electrical demand of the heat pump registered a reduction in heat pump demand from June 10th 2010. By the 25th of January 2011 the electrical requirement had fallen to zero and remained at this level until the end of the observation period, four weeks later. The results of this analysis were reinforced by a study into the oil use over the same period which illustrated that the oil consumption had rose in response to the reduced heat pump activity, indicating that the oil boiler was forced to compensate for the reduced output of the heat pump. The results of a study which compared the projected level of demand prior to June of 2012 against the actual demand after this period, up to January 2013, offered additional evidence suggesting that the heat pump had continued to operate at a reduced rate from this period onwards.

The investigation completed during the site visit confirmed that the heat pump was supplying heat at a reduced level. An examination of the pre-heat cylinder revealed that the tank was significantly cooler than was necessary for the efficient operation of the system, whilst an examination of the heat pump itself revealed that the return thermostat stop temperature was equal to 43°C with a relatively large hysteresis value of 5°C. As a result, the heat pump was operating with an effective set point temperature of 39°C and the temperature of the water in the pre-heat cylinder was equal to 38.5°C. Consequently, the oil boiler had to supply 24 degrees of heat to the water, as opposed to the 5°C to 10°C it was typically intended to supply. Additionally, the number of hours of operation of the DHW heat pump were significantly lower than those registered by the two heat pumps responsible for the under floor heating system.

Oil Boiler Performance

The initial analysis carried out on the oil boiler showed that it was operating with an estimated efficiency of 1.54% to 0.31%, both exceptionally low values. Consequently, the oil consumption by the boiler was excessive. When the boiler was examined during the site visit it became immediately apparent that the oil boiler was operating incorrectly; as it was observed to be repeatedly firing at seemingly regular intervals, despite the fact the main DHW cylinder it was responsible for heating was already registering temperatures in excess of 60°C.

A subsequent hour-long observation of the oil boiler revealed that the boiler was firing to a regular schedule and utilising the same amount of oil each time. In total the boiler fired ten times during the hour-long period. This illustrated that the oil boiler was responding to the same apparent temperature deficit on each occasion. An examination of the BMS console revealed that the oil boiler was responding to the wrong sensor; reacting to conditions in the pre-heat cylinder connected to the heat pump, as opposed to the main DHW cylinder.

The oil boiler efficiency was recalculated using the relevant temperature data collected on-site, giving an average efficiency of 4.31%. Therefore, due to the oil boiler supplying a greater quantity of heat to the water than previously thought, the true operating efficiency was slightly higher than the initial estimation. Yet, despite this, the overall process was very inefficient.

Additionally, the boiler was noted to dry cycle as it was often observed firing twice, within 30 seconds to a minute of the initial activation of the boiler. Further analysis provided an estimate for energy losses primarily due to this process, in addition to the volume of oil wasted as a result. The average dry cycling loss was calculated at 6%, with a resulting fuel loss of 0.012 litres per activation.

Secondary Circulation System

An analysis of losses on the distribution system of the domestic hot water system proved largely inconclusive. However there was some evidence of increased heat loss across two wings of the building and an examination of the loft spaces showed that whilst the pipes were well insulated, many of the valves were not. Therefore, it may prove beneficial to examine the secondary circulation system in greater detail and to insulate any uncovered valves. As the recorded water temperatures were within the accepted values (out with two exceptions) it is not essential to fix these problems for the efficient operation of the system. Nevertheless, completing the above mentioned modifications could prevent future problems from arising. Furthermore, the two rooms which registered temperatures out with the accepted values should be retested to ensure that the water temperatures are now within safe levels.

8.2 Necessary Modifications

To improve system efficiency and raise the domestic hot water system to an acceptable standard of performance, it is vital to correct the two issues which are causing the heat pump and oil boiler to underperform. Modifications to the oil boiler should be enacted prior to those required by the heat pump, as the inefficient operation of the boiler has greater impact on the performance and fuel consumption of the system. To accomplish this, the sensor error must be corrected. Figure 8-1 shows the current sensor allocation (red box) complete with the sensor address code which must be included in the control code for the sensor to work. The value shown in the green box is the code for the correct sensor placement. Therefore the control systems specialist for Automatic Control Systems should be contacted to arrange for the software error to be corrected.

The oil consumption of the boiler should then be monitored for a period of a few weeks to determine whether the error has been amended. It would prove beneficial to repeat the hour long boiler observation to determine whether the frequency of boiler activations has decreased.

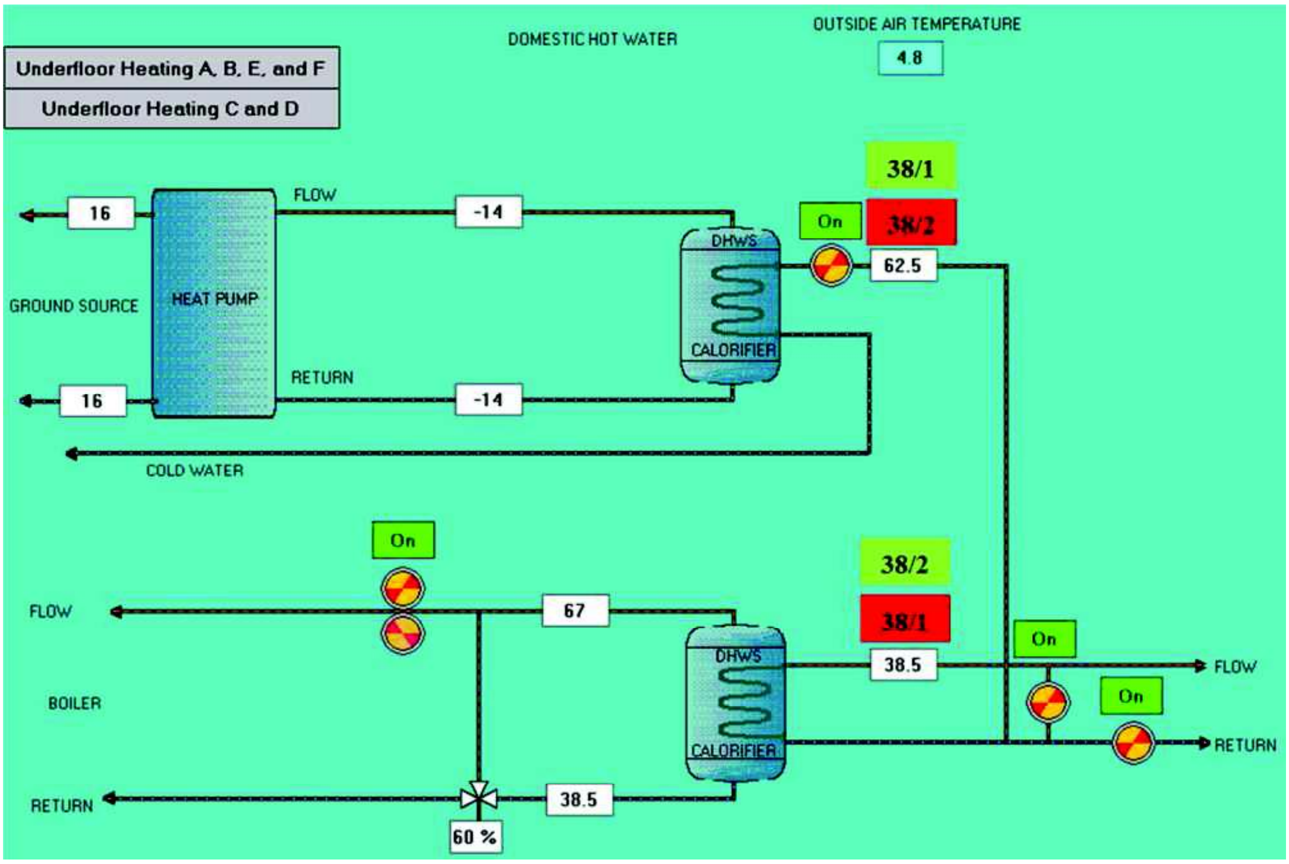


Figure 8-1: Current Sensor Allocation

Expected System Improvement

If the sensor error is corrected then the boiler should only be required to heat the water once and then replace any heat lost through standing losses in the calorifier. The standing losses were calculated using the following method devised by the Building Research Establishment (BRE) (Standard Assessment Procedure, 2009):

$$\begin{aligned} &Standing\ Loss\ (kWh/day) \\ &\qquad = Cylinder\ Volume\ \times Water\ Storage\ Loss\ Factor \\ &\qquad \times Volume\ Factor \times Temperature\ Factor \end{aligned}$$

The resulting standing loss was calculated as 4.14 kilowatt-hours per day, therefore the total energy requirement was equal to 27.269 kilowatt-hours. An additional 6% of fuel was assumed necessary to negate dry cycling losses. Therefore the daily oil consumption should amount to approximately 2.56 litres. The corresponding performance values are shown in Table 8-1 below.

	Total (kWh)	Oil (litres)	Cost (£)	CO_2Emissions (kgCO_2e)
Per Litre of Hot Water Generated	0.065	0.003	£0.01	0.026
Daily	53.585	2.755	£5.92	21.321
Annually	19558.499	1005.567	£2,159.80	7782.130

Table 8-1: Sensor Error Correction: System Performance Improvements

Once the oil boiler begins consistently operating with greater efficiency, the following heat pump settings should be modified:

- Return Thermostat Stop Temperature should be changed from 43°C to 48°C.
- Hysteresis should be changed from 5°C to 2.5°C.

Through the implementation of these changes the heat pump will provide at least 46°C to 48°C heat to the pre-heat cylinder. Under optimum conditions the heat pump contribution could be as high as 55°C.

As with the modification to the oil boiler, the heat pump should be observed over the course of a few weeks to determine how well it is operating. In particular, the number of hours of operation should be noted, and the temperature of the pre-heat cylinder recorded periodically.

Expected System Improvement

As a result of these changes the electricity demand of the heat pump should increase, however the corresponding oil consumption of the oil boiler should decrease, thereby ensuring DHW is produced in a more energy efficient and economical fashion. Table 8-2 and Table 8-3 show the expected performance improvements:

Heat Pump – Optimum Conditions (Supplying 55°C to Pre-heat Cylinder)				
	Grid Electricity (kWh)	Oil (litres)	Cost (£)	Emissions (kgCO_2e)
Per Litre of Hot Water Generated	0.015	0.001	£0.00	0.012
Daily	12.649	1.148	£2.84	10.148
Annually	4616.885	366.148	£999.04	3542.248

Table 8-2: Heat Pump (Optimum Conditions) Performance Improvements

Heat Pump (Supplying 46°C to Pre-heat Cylinder)				
	Grid Electricity (kWh)	Oil (litres)	Cost (£)	Emissions (kgCO_2e)
Per Litre of Hot Water Generated	0.012	0.002	£0.00	0.014
Daily	9.938	2.025	£3.07	11.409
Annually	3627.370	739.125	£1,120.71	4164.271

Table 8-3: Heat Pump (Pre-heat Cylinder = 46°C) Performance Improvements

In reality the improvements in system performance will likely be slightly lower than the estimates obtained, however they still represent significant improvements over the current system. Table 8-4 describes the overall performance of the care home in its current state, as well as after each proposed modification.

Annual Comparison							
	Current System	**Modification 1 – Oil Boiler Sensor Correction**		**Modification 2 – Heat Pump Operational Settings Changed.**			
		Oil Boiler Sensor Corrected	**Savings**	**Minimum Condition (Pre-heat Cylinder = 46°C)**	**Savings**	**Optimum Efficiency (Pre-heat Cylinder = 55°C)**	**Savings**
DHW Energy Requirement (kWh)	**207941.851**	19558.499	**188383.351**	19391.020	**188550.830**	19186.142	**188755.708**
Grid Electricity Required (kWh)	**2177.453**	2803.086	**-625.633**	3627.370	**-1449.917**	4616.885	**-2439.432**
Oil Consumption (litres)	**19085.9**	1005.6	**18080.3**	739.1	**18346.7**	366.1	**18719.7**
Cost (£)	**£14,538.79**	£2,159.80	**£12,378.99**	£1,120.71	**£13,418.08**	£999.04	**£13,539.75**
Carbon Emissions (kgCO2e)	**59535.4**	7782.1	**51753.3**	4164.3	**55371.2**	3542.2	**55993.2**

Table 8-4: DHW System: Overall Performance

Table 8-4 shows that if the suggested modifications are implemented; the expected Energy Requirement of the DHW system would range between 19391 kilowatt-hours to 19186 kilowatt hours which equates to a saving of over 90% on the current value. Oil use is likely to reduce to a value between 739 litres and 366 litres, a saving of approximately 96% - 98% over the present figure. Equally, savings in cost and carbon emissions are likely to be around 94% in comparison. The only factor set to increase is the grid electricity demand, which is set to become 1.6 to 2.1 times greater than the present value.

Nevertheless, despite the improvements garnered from these modifications, it would be prudent to continue to periodically monitor the care home DHW system, as other faults in the system could have easily been masked by the magnitude of the faults and inefficiencies described above.

Concluding Statement

The flaws in the domestic hot water system brought to light by this investigation have had a major impact on the finances and energy efficiency of the care home. However they are relatively straightforward and inexpensive to correct. If the recommended modifications are implemented there will be significant reductions in operating costs and carbon emissions, with vast improvements in terms of energy efficiency, thereby raising the system to an acceptable standard of performance.

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Residential Care Home Data (Orkney Islands Council, 2013):
- Mechanical Specifications
- Meter Readings (Heat Pump 1, Heat Pump 2, Heat Pump 3, Oil Use, Water Use)
- Oil Use Invoices
- Half-Hour Demand Data
- Water Temperature Records
- Tender Drawings

(5-) 001_C4	Heating Schematic
(5-) 002_C2	Equipment Schedules
(53) 001_C3	Water Services Wing A
(53) 002_C2	Water Services Wing B
(53) 004_C1	Water Services Wings C and E
(53) 005_C1	Water Services Wing F
(53) 006_C1	Water Services Schematic
(53) 007_C1	MCW and BCW Pipe Routes
(56) 002_C1	Ground Source Heat Pump Schematic

10 Appendix

10.1 Temperature Data (2006 – 2013)

Additional temperature data utilised for initial analysis in Section 4.1.1 Care Home Electricity Demand.

Time Period	2006 (^{o}C)	2007 (^{o}C)	2008 (^{o}C)	2009 (^{o}C)	2010 (^{o}C)	2011 (^{o}C)	2012 (^{o}C)	2013 (^{o}C)
Winter	5.2	7.2	6.3	7.1	5.9	7.4	6.5	N/A (2.4)
Spring	13.3	11.8	12.5	12.7	12.2	11.4	11.5	N/A
Summer	9.4	8.4	7.5	8.4	7	9.4	6.6	N/A
Autumn	3.4	4.2	3.5	2.6	0.3	1.4	3.4	N/A
January	3.5	4.3	3.1	2.9	0.3	2.4	3	N/A (3.0)
February	2.9	3.9	4	2.7	0.2	3.6	4.5	N/A
March	2.1	5	3.2	4.7	3.6	4.4	6.8	N/A
April	5.2	8.6	5.4	7.7	6.2	8.8	4.5	N/A
May	8.3	8.2	10.3	9	7.8	8.9	8.1	N/A
June	12.1	11.3	10.7	11.5	12	10.3	9.9	N/A
July	15.1	12.2	13.7	13.4	12.6	12.2	11.7	N/A
August	12.8	12	13	13.1	12	11.7	13	N/A
September	13	10.1	11	11.6	10.7	11.6	9.8	N/A
October	9.4	9.4	6.9	8.5	7.9	9.1	5.7	N/A
November	5.8	5.7	4.7	5.2	2.4	7.5	4.3	N/A
December	4.4	3.3	2.2	0.4	-1.6	2.7	2	N/A
Annual	7.9	7.8	7.4	7.6	6.2	7.8	7	N/A

Table 10-1: Climate Data

10.2 Electricity and Climate Demand (Close-Up View)

Close-up view of Figure 4-1 illustrating the drop in demand over Christmas and New Year:

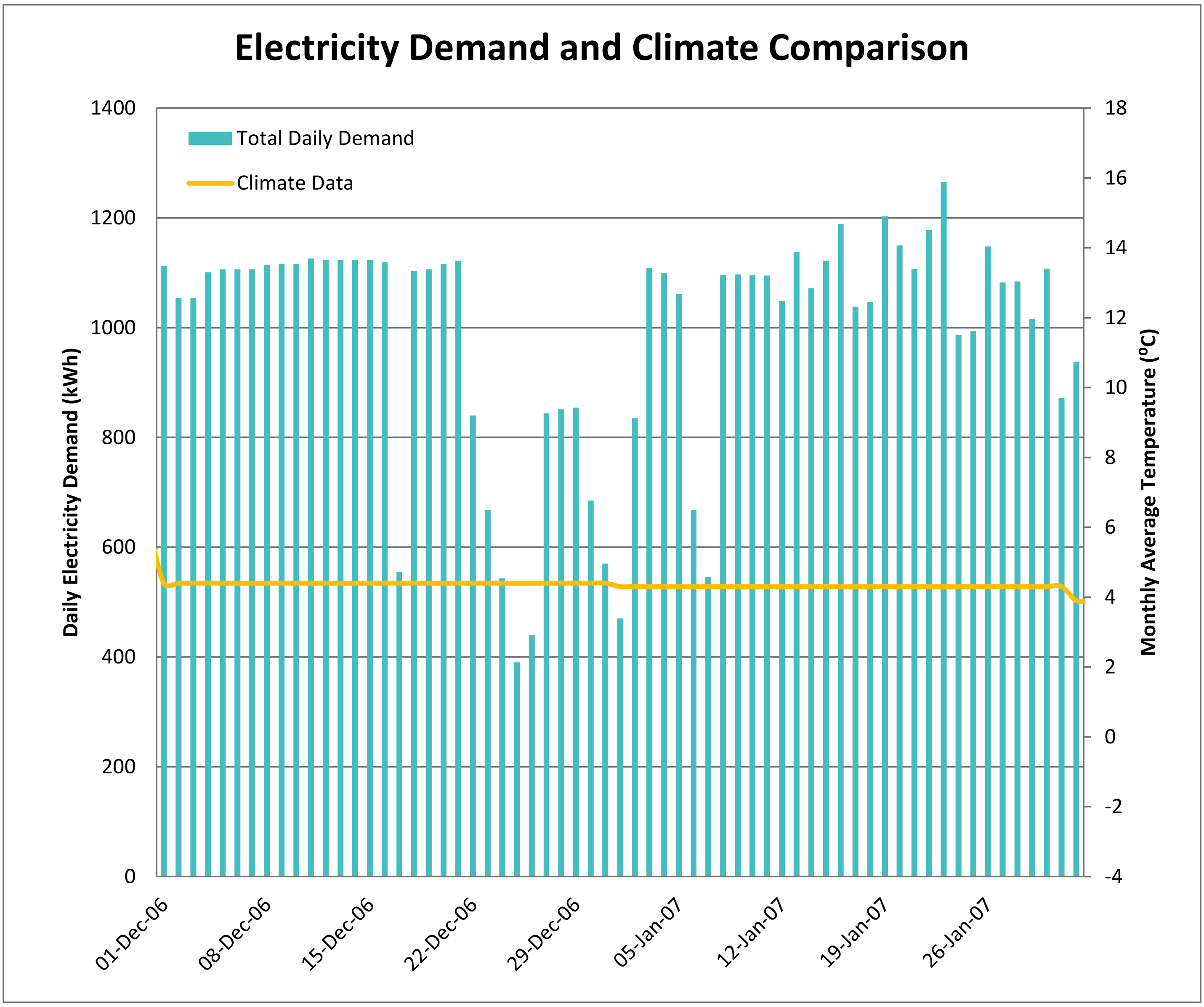


Figure 10-1: Electricity and Climate Data (Close-Up - Christmas Period 2006)

10.3 DHW Usage

Table 10-2 illustrates the full results for the care home DHW requirements. It contains information on the date of each reading, the number of days between subsequent readings, the volume of water used per period, in addition to calculated daily averages for each period.

Date	Days Between Readings	DHW Volume m^3 (Cumulative Total)	DHW Volume m^3	DHW Volume L	DHW Use Daily Average L
31 Oct 08	N/A	75	N/A	N/A	N/A
07 Nov 08	7	79	4	4000	571.43
14 Nov 08	7	83	4	4000	571.43
21 Nov 08	7	86	3	3000	428.57
28 Nov 08	7	88	2	2000	285.71
05 Dec 08	7	92	4	4000	571.43
12 Dec 08	7	96	4	4000	571.43
19 Dec 08	7	102	6	6000	857.14
30 Dec 08	11	109	7	7000	636.36
05 Jan 09	6	113	4	4000	666.67
13 Jan 09	8	119	6	6000	750.00
16 Jan 09	3	122	3	3000	1000.00
23 Jan 09	7	128	6	6000	857.14
30 Jan 09	7	135	7	7000	1000.00
04 Feb 09	5	140	5	5000	1000.00
11 Feb 09	7	148	8	8000	1142.86
18 Feb 09	7	155	7	7000	1000.00
27 Feb 09	9	164	9	9000	1000.00
06 Mar 09	7	170	6	6000	857.14
13 Mar 09	7	177	7	7000	1000.00
20 Mar 09	7	184	7	7000	1000.00
27 Mar 09	7	190	6	6000	857.14
06 Apr 09	10	197	7	7000	700.00
10 Apr 09	4	200	3	3000	750.00
17 Apr 09	7	207	7	7000	1000.00
24 Apr 09	7	214	7	7000	1000.00
01 May 09	7	221	7	7000	1000.00
08 May 09	7	227	6	6000	857.14
15 May 09	7	233	6	6000	857.14
22 May 09	7	238	5	5000	714.29
05 Jun 09	14	248	10	10000	714.29
12 Jun 09	7	253	5	5000	714.29
19 Jun 09	7	260	7	7000	1000.00
26 Jun 09	7	266	6	6000	857.14
03 Jul 09	7	273	7	7000	1000.00
10 Jul 09	7	280	7	7000	1000.00
31 Jul 09	21	299	19	19000	904.76
16 Nov 09	108	390	91	91000	842.59
27 Nov 09	11	399	9	9000	818.18
04 Dec 09	7	405	6	6000	857.14
11 Dec 09	7	412	7	7000	1000.00
18 Dec 09	7	421	9	9000	1285.71
28 Dec 09	10	432	11	11000	1100.00

08 Jan 10	11	443	11	11000	1000.00
15 Jan 10	7	451	8	8000	1142.86
22 Jan 10	7	458	7	7000	1000.00
05 Feb 10	14	473	15	15000	1071.43
12 Feb 10	7	481	8	8000	1142.86
22 Feb 10	10	491	10	10000	1000.00
01 Mar 10	7	495	4	4000	571.43
05 Mar 10	4	497	2	2000	500.00
12 Mar 10	7	505	8	8000	1142.86
19 Mar 10	7	512	7	7000	1000.00
29 Mar 10	10	522	10	10000	1000.00
10 May 10	42	552	30	30000	714.29
14 May 10	4	556	4	4000	1000.00
24 May 10	10	565	9	9000	900.00
04 Jun 10	11	573	8	8000	727.27
11 Jun 10	7	578	5	5000	714.29
28 Jun 10	17	593	15	15000	882.35
12 Jul 10	14	603	10	10000	714.29
16 Jul 10	4	606	3	3000	750.00
26 Jul 10	10	611	5	5000	500.00
06 Aug 10	11	619	8	8000	727.27
13 Aug 10	7	624	5	5000	714.29
19 Aug 10	6	626	2	2000	333.33
27 Aug 10	8	630	4	4000	500.00
04 Oct 10	39	653	23	23000	589.74
08 Oct 10	4	656	3	3000	750.00
22 Oct 10	14	664	8	8000	571.43
29 Oct 10	7	667	3	3000	428.57
03 Dec 10	35	696	29	29000	828.57
10 Dec 10	7	703	7	7000	1000.00
17 Dec 10	7	709	6	6000	857.14
31 Dec 10	14	718	9	9000	642.86
07 Jan 11	7	722	4	4000	571.43
14 Jan 11	7	727	5	5000	714.29
21 Jan 11	7	733	6	6000	857.14
28 Jan 11	7	741	8	8000	1142.86
11 Feb 11	14	754	13	13000	928.57
18 Feb 11	7	761	7	7000	1000.00
25 Feb 11	7	768	7	7000	1000.00

Table 10-2: Domestic Hot Water Usage

10.4 Use of Heat Pump Control Panel

This section describes the procedures necessary to check and modify various operational settings on the heat pump through the Rego 600 Control Panel.

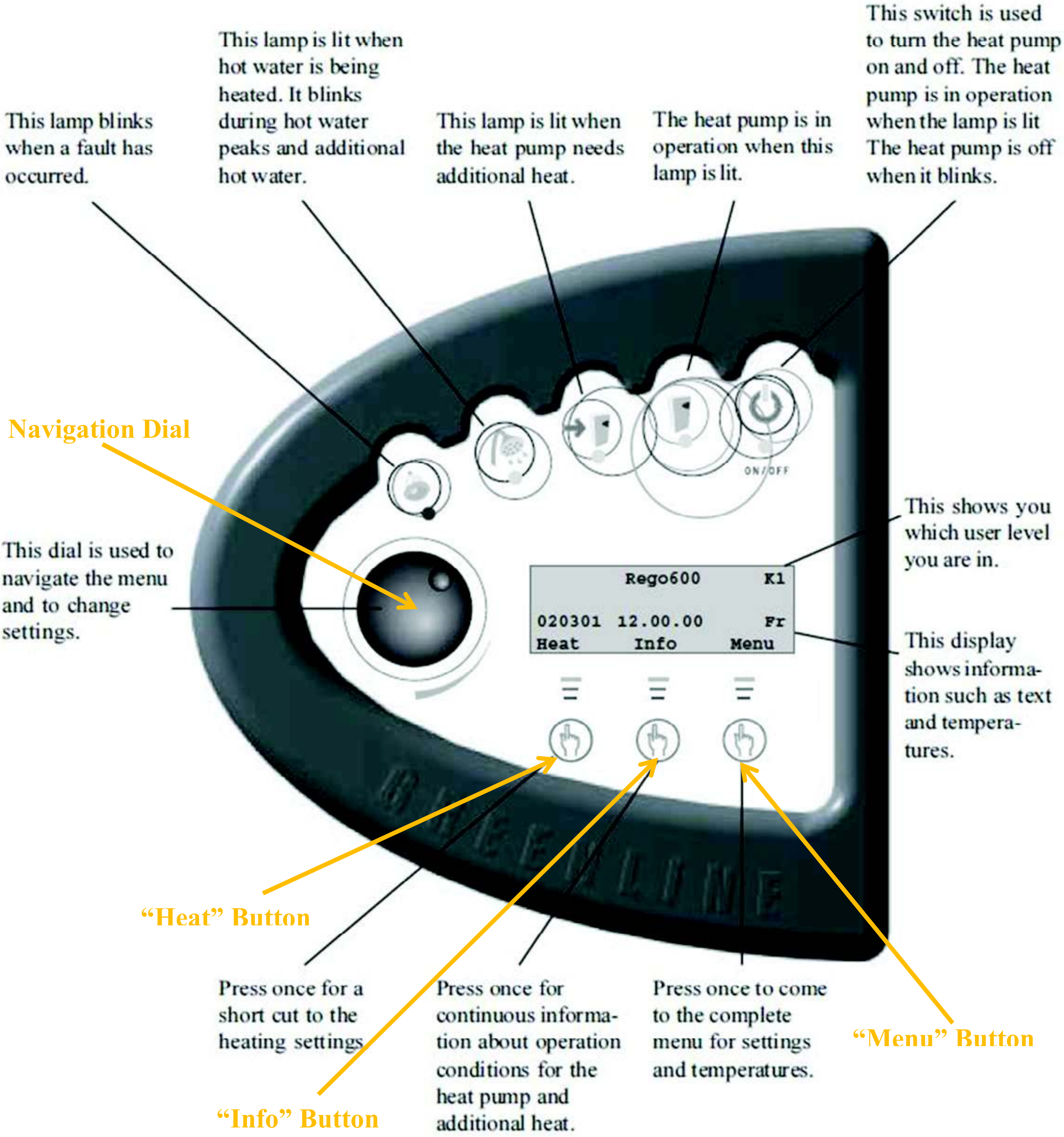


Figure 10-2: Heat Pump Control Panel

Figure 10-2 illustrates the necessary controls required to complete the observations and modifications described in Sections 10.4.1 to 10.4.4.

10.4.1 Checking the Total Number of Hours of Operation on the Heat Pump

The enhanced functions on the Rego 600 control panel must be accessed to examine the hours of operation of the heat pump:

- To enter the enhanced function settings hold the "Heat" button down for five seconds. Please note that the controls will automatically return to the normal function setting after thirty seconds of inaction.
- Use the navigation dial to scroll to menu number 7.
- The word "Select" appears in the bottom right corner of the screen and can be accessed by pressing the "Menu" button.
- Press "Select" again for menu 7.1: "Heat Pump in Operation – Number of Hours".

10.4.2 Checking and Modifying the Return Thermostat Stop Temperature

- In enhanced functions, select menu 1 (by pressing "Menu").
- Use the navigation dial to scroll to submenu 1.16 and press "Menu" to select.
- Use the dial to increase or decrease the Return Thermostat Stop Temperature as required.
- Press "Menu" to save the new temperature settings.

10.4.3 Checking and Modifying the Allowed Hysteresis

- In enhanced functions, select menu 1 (by pressing "Menu").
- Use the navigation dial to scroll to submenu 1.17 "Return Thermostat Hysteresis Set" and press "Menu" to select.
- Use the dial to increase or decrease the hysteresis as required.
- Press "Menu" to save the new temperature settings.

10.4.4 Checking Past Alarms

- Press "Info" button on control panel.
- Use dial to scroll through the menu until the "Alarms" submenu is reached.
- Use "Menu" button to select. Any previous alarms will then be displayed.
- The heat pump manufacturer's guide should then be consulted for explanations and possible causes of any alarms noted.

10.5 Water Temperature Records

The full range of water temperature values noted, in each of the twenty water records used for analysis, are displayed in Figure 10-23 to Figure 10-22.

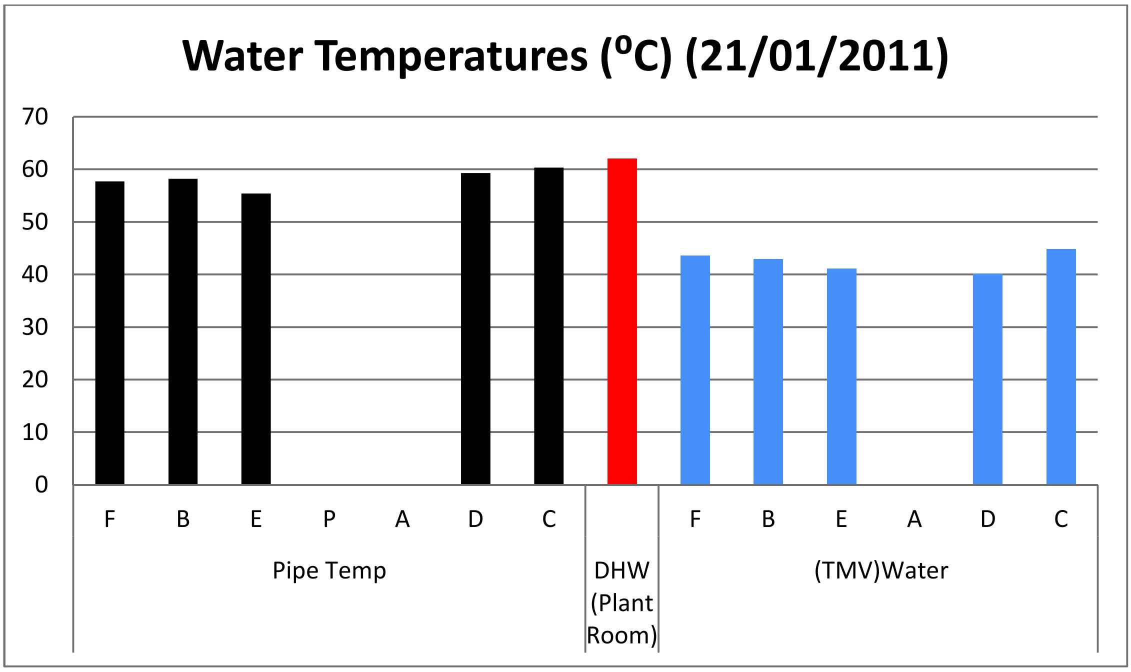


Figure 10-3: Water Temperature Record 1 (21/01/2011)

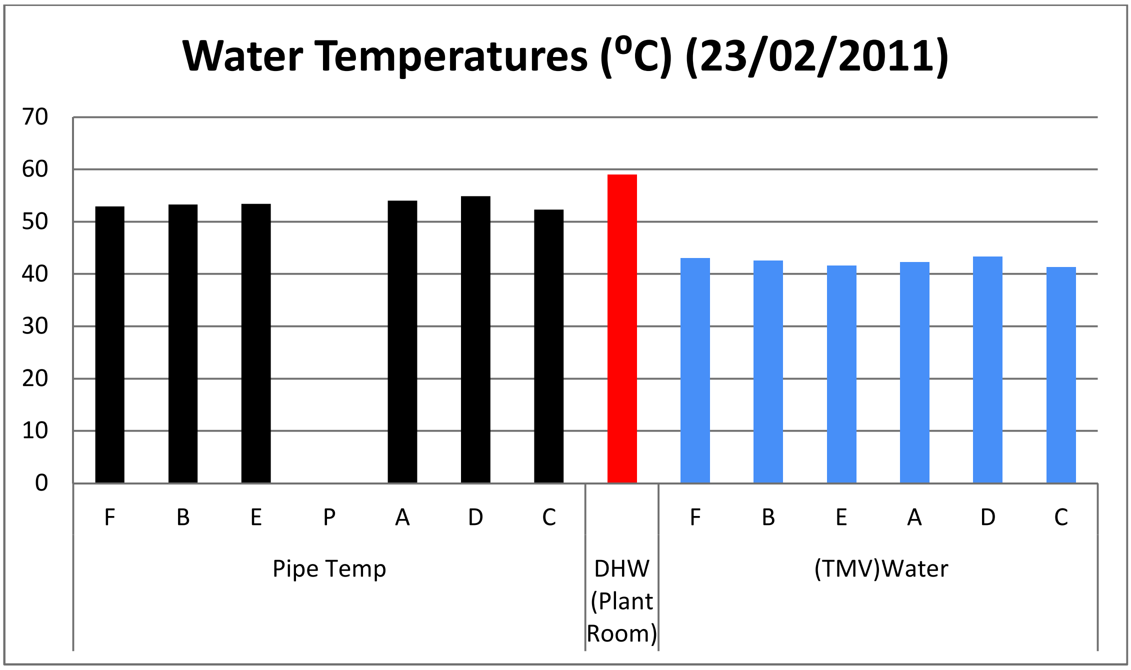


Figure 10-4: Water Temperature Record 2 (23/02/2011)

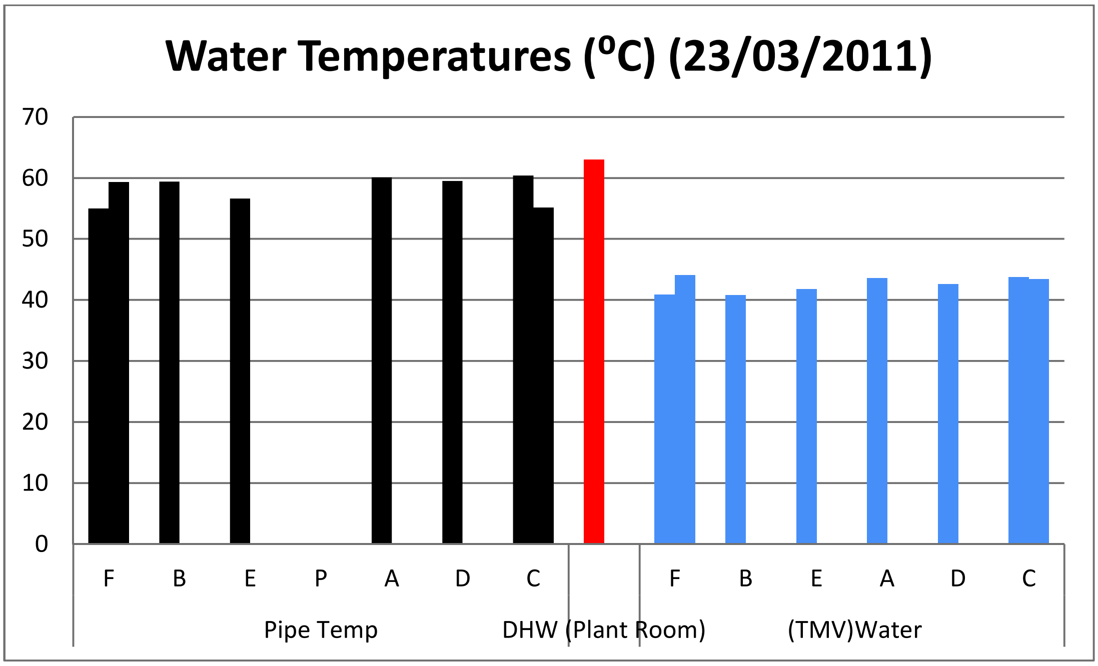


Figure 10-5: Water Temperature Record 3 (23/03/2011)

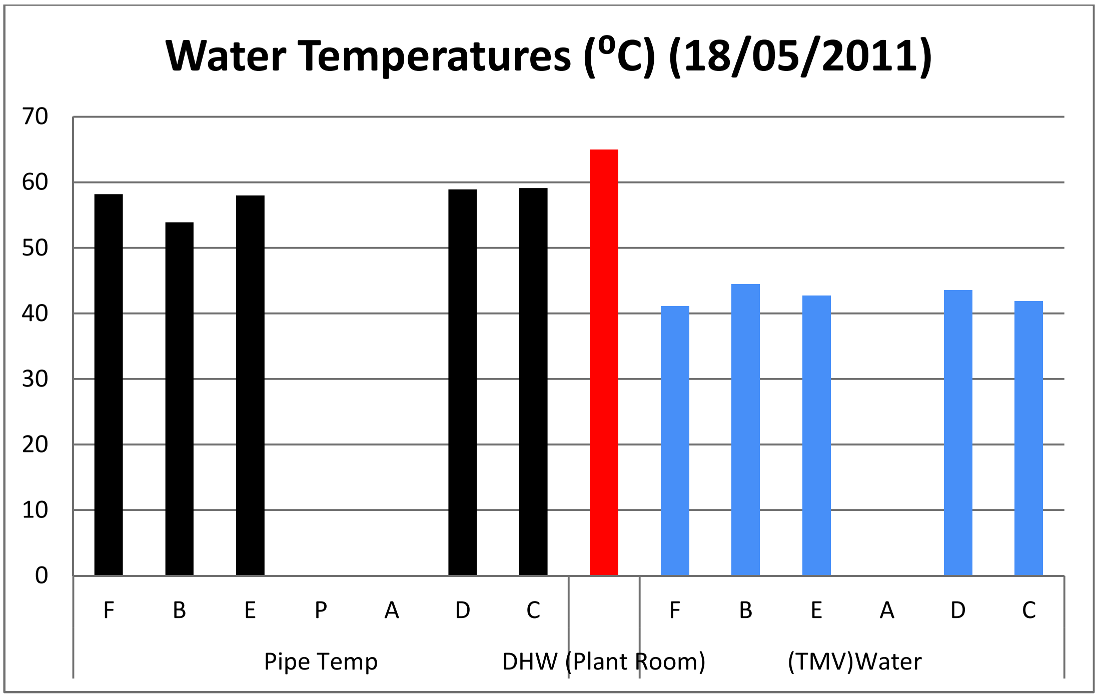


Figure 10-6: Water Temperature Record 4 (18/05/2011)

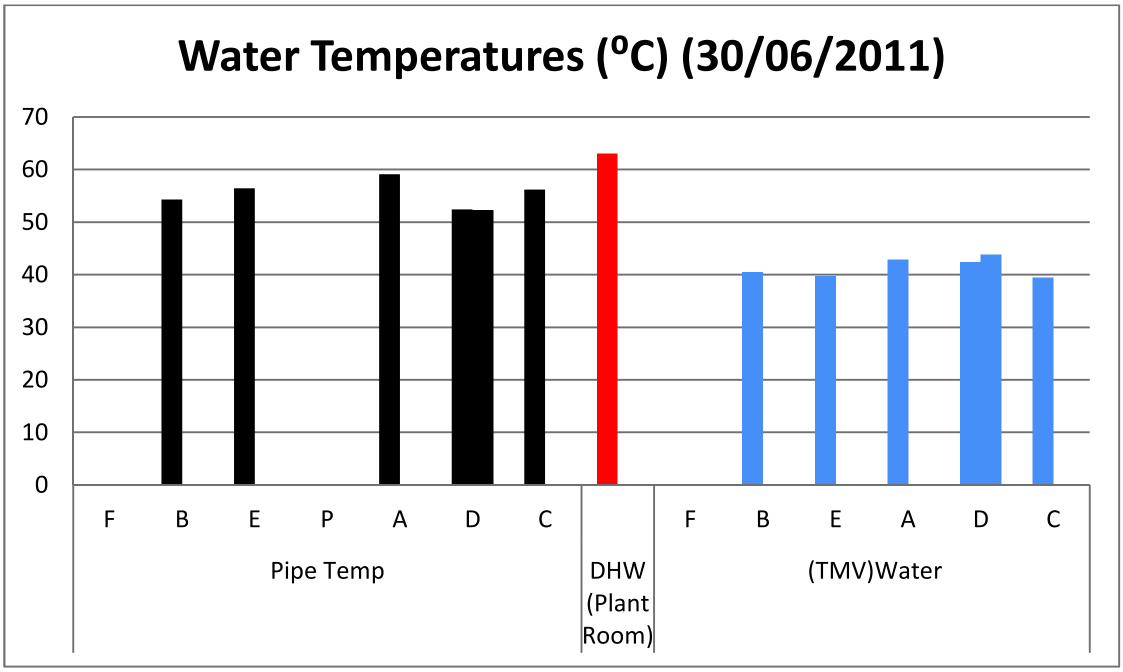


Figure 10-7: Water Temperature Record 5 (30/06/2011)

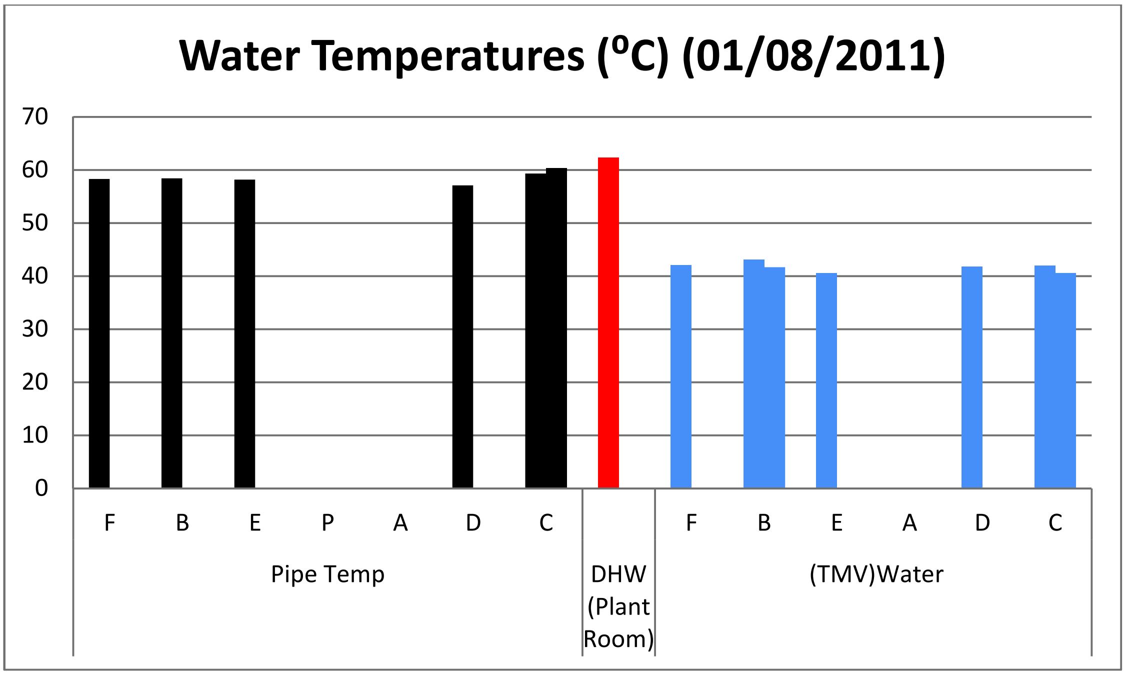


Figure 10-8: Water Temperature Record 6 (01/08/2011)

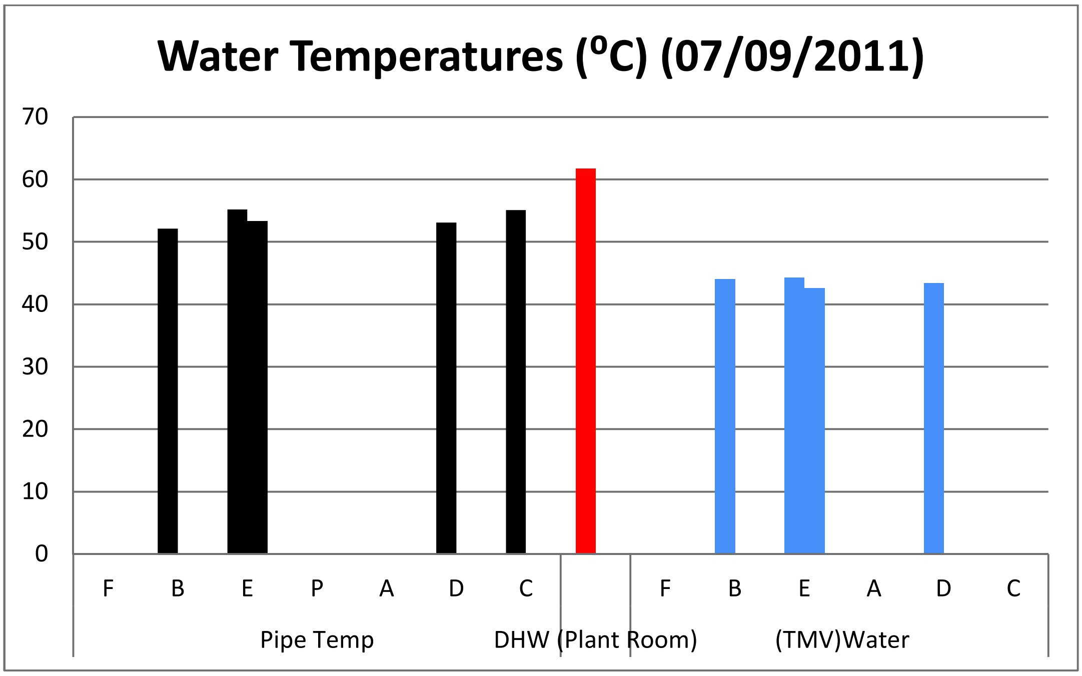


Figure 10-9: Water Temperature Record 7 (07/09/2011)

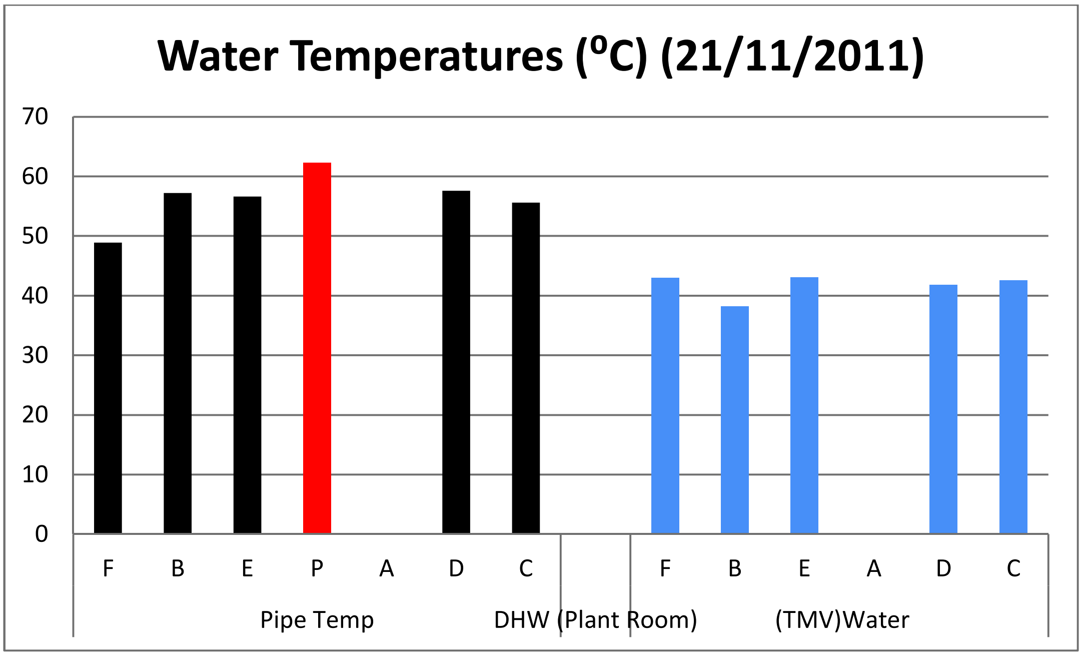


Figure 10-10: Water Temperature Record 8 (21/11/2011)

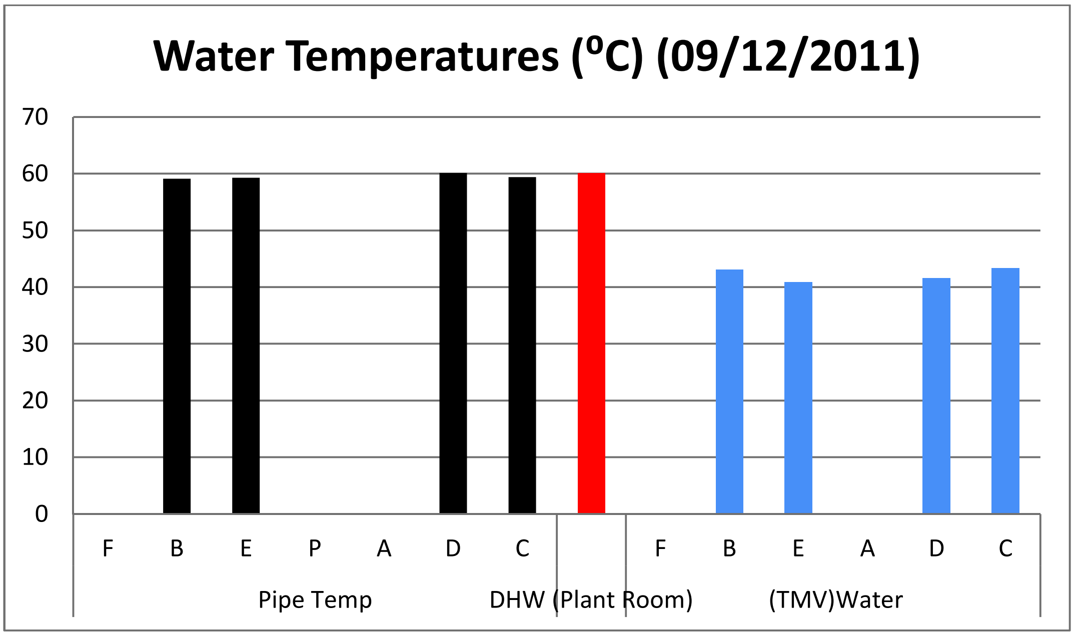


Figure 10-11: Water Temperature Record 9 (09/12/2011)

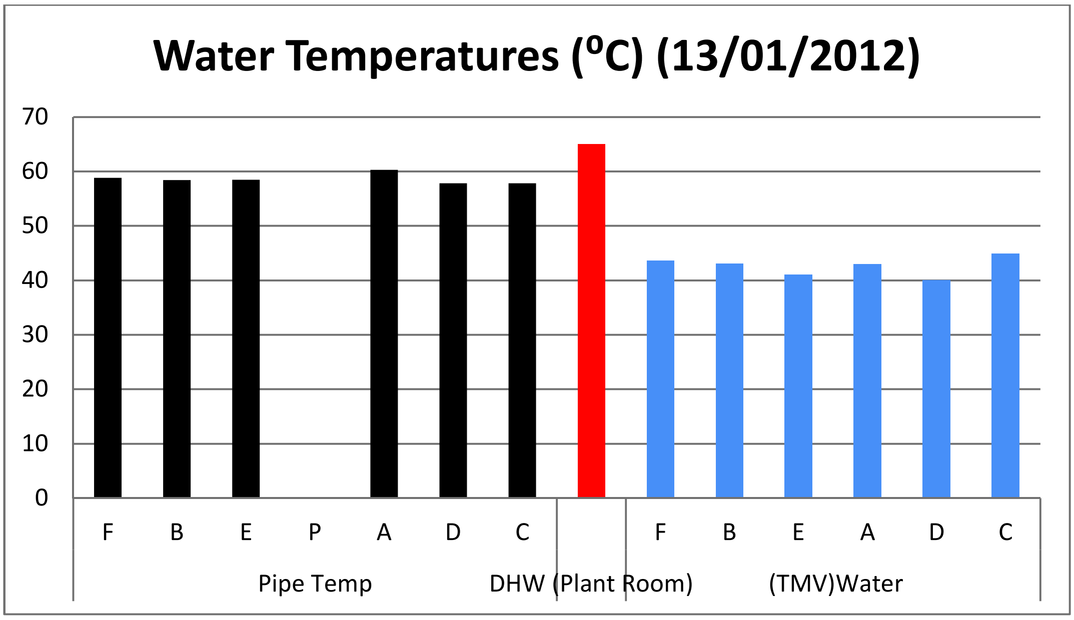


Figure 10-12: Water Temperature Record 10 (13/01/2012)

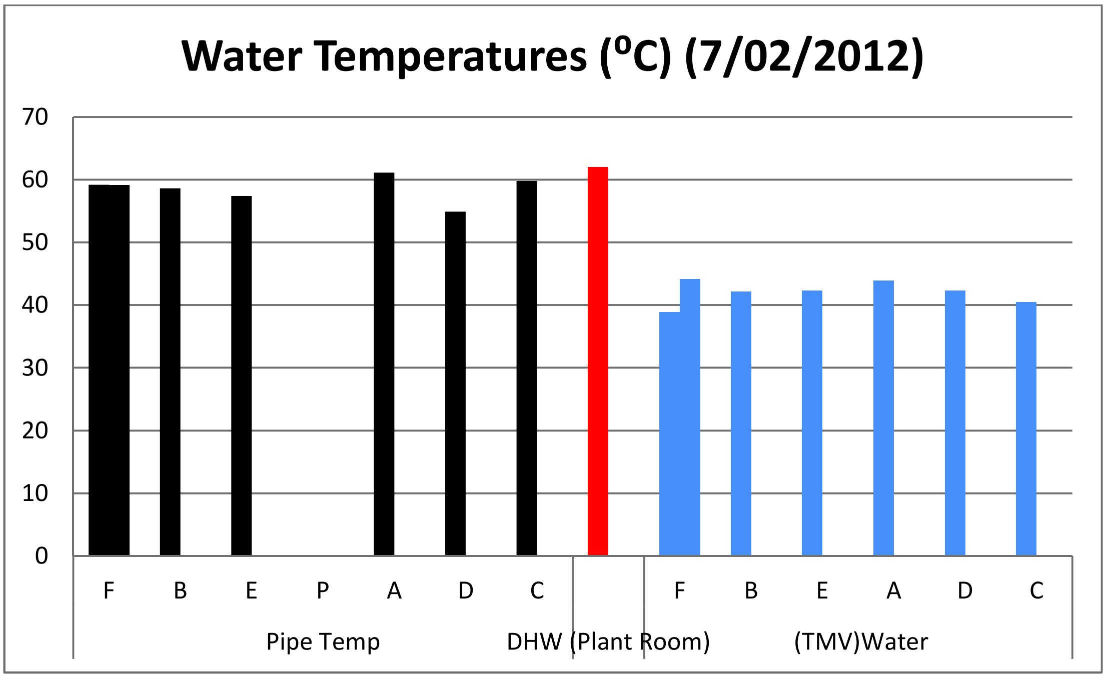


Figure 10-13: Water Temperature Record 11 (07/02/2012)

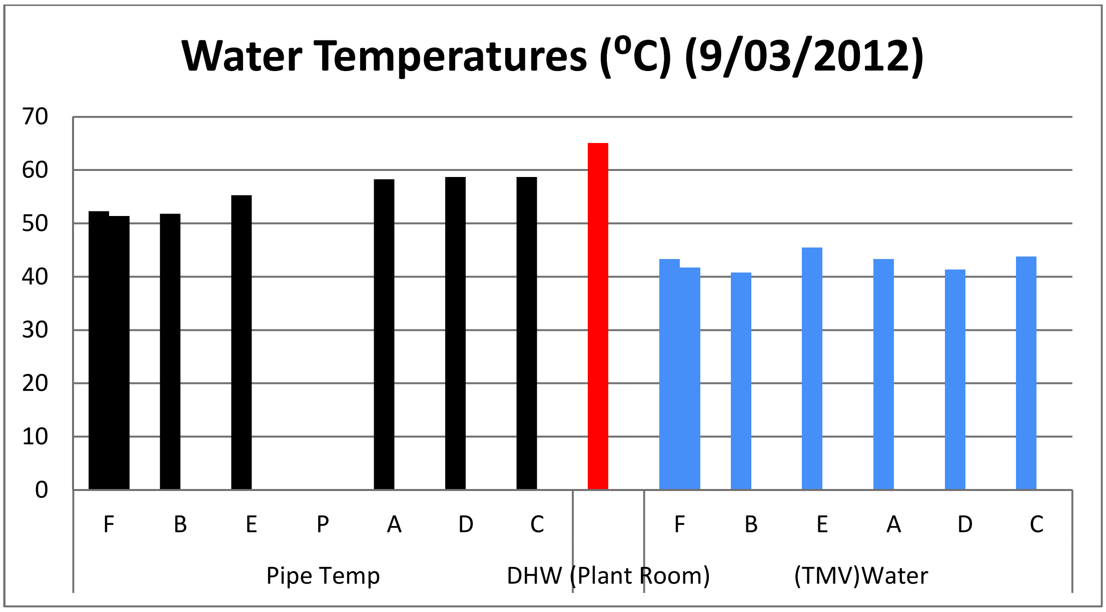


Figure 10-14: Water Temperature Record 12 (09/03/2012)

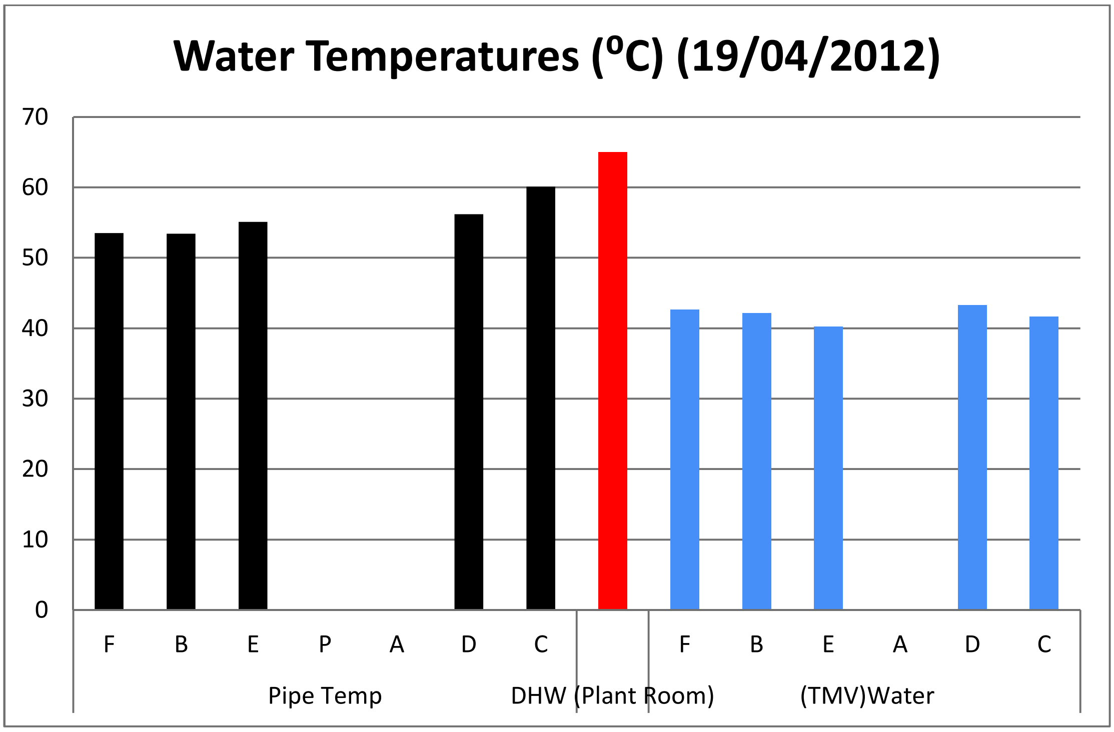


Figure 10-15: Water Temperature Record 13 (19/04/2012)

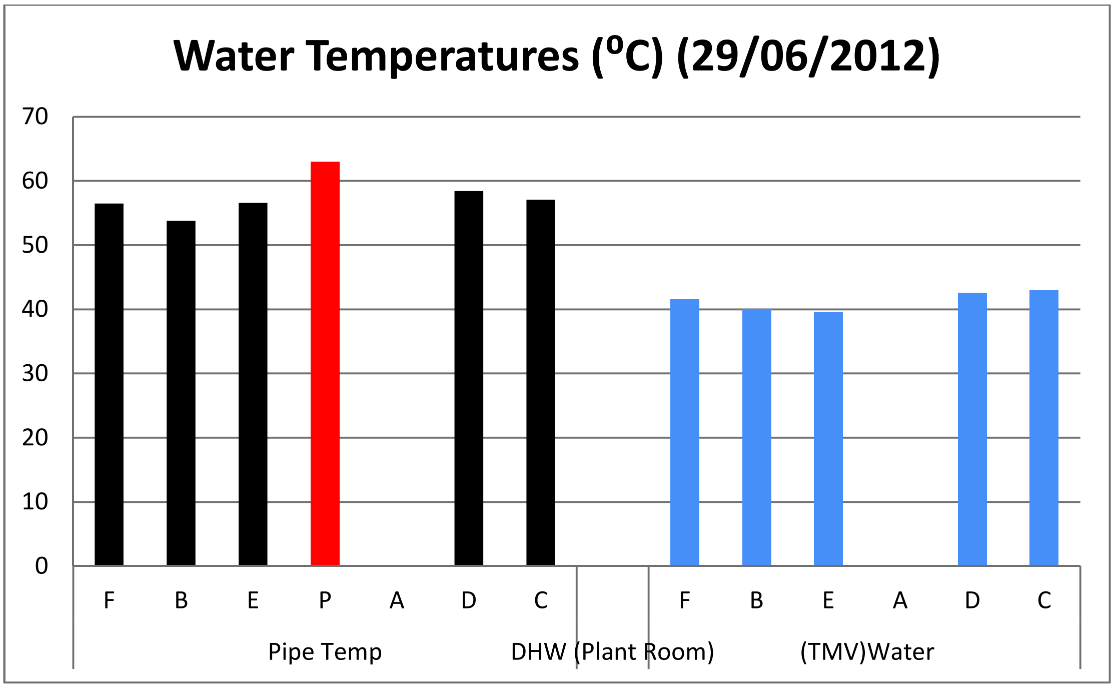


Figure 10-16: Water Temperature Record 14 (29/06/2012)

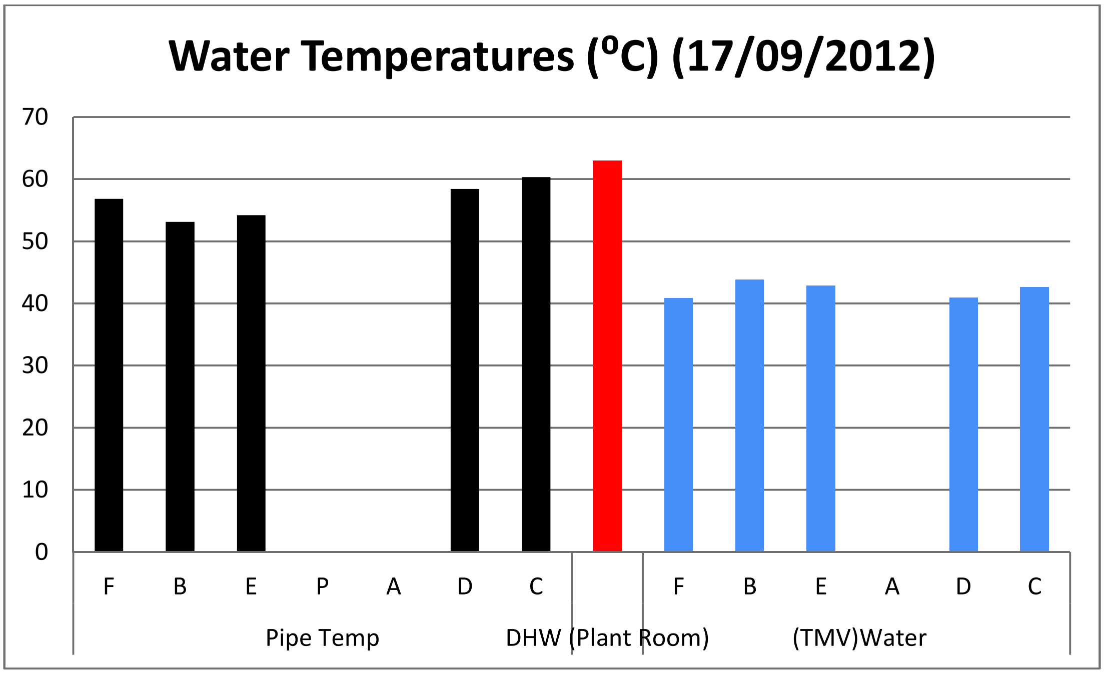


Figure 10-17: Water Temperature Record 15 (17/09/2012)

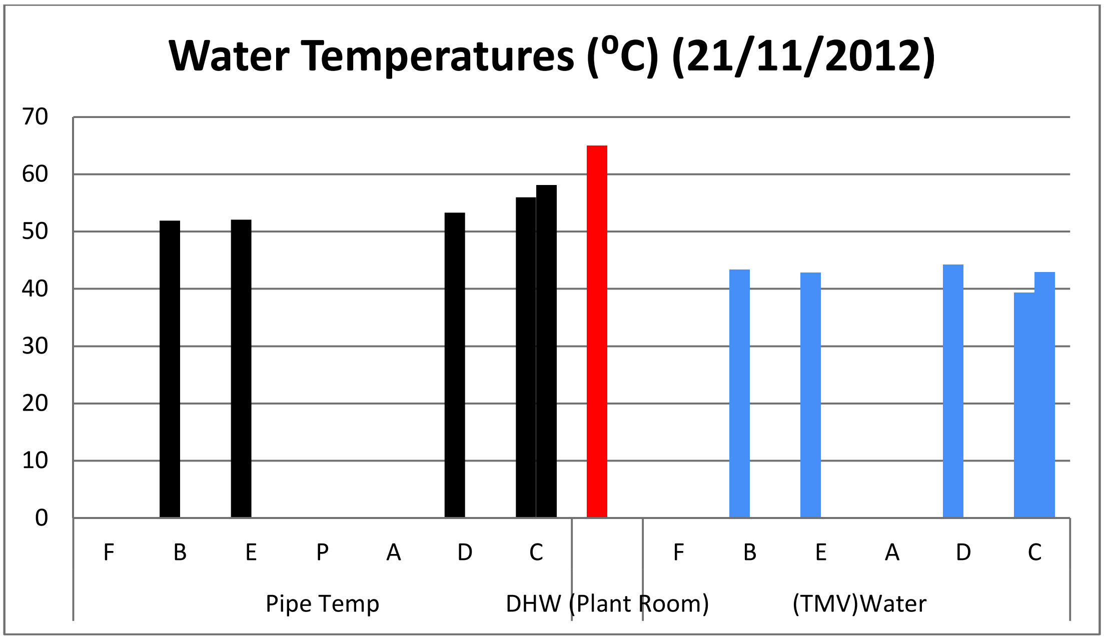


Figure 10-18: Water Temperature Record 16 (21/11/2012)

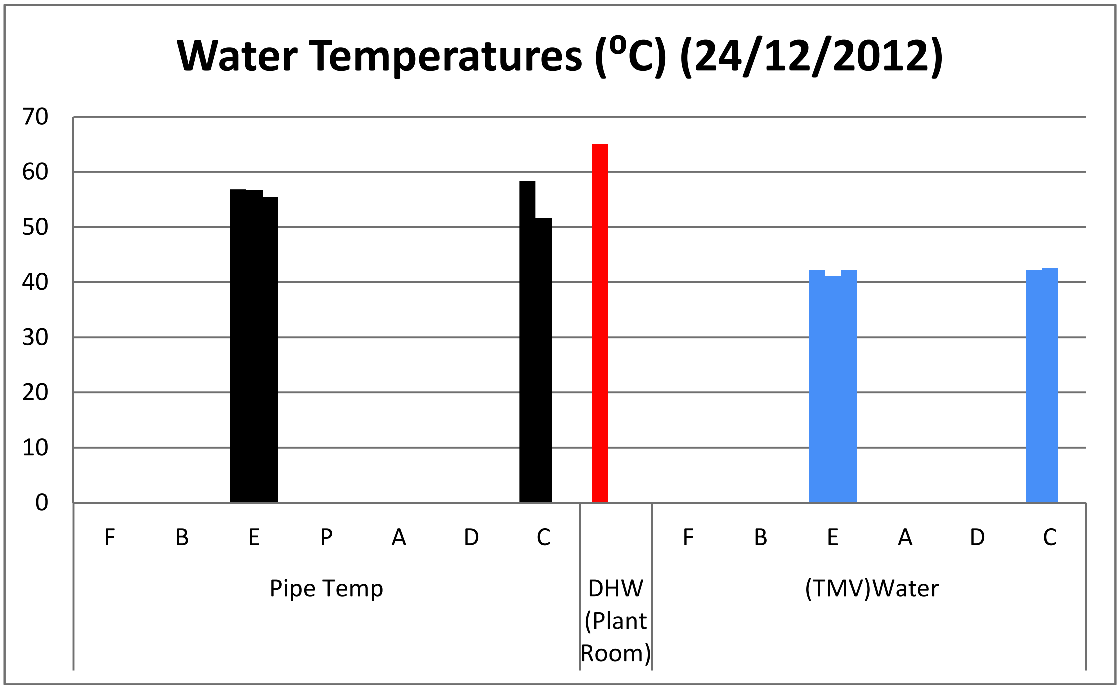


Figure 10-19: Water Temperature Record 17 (24/12/2012)

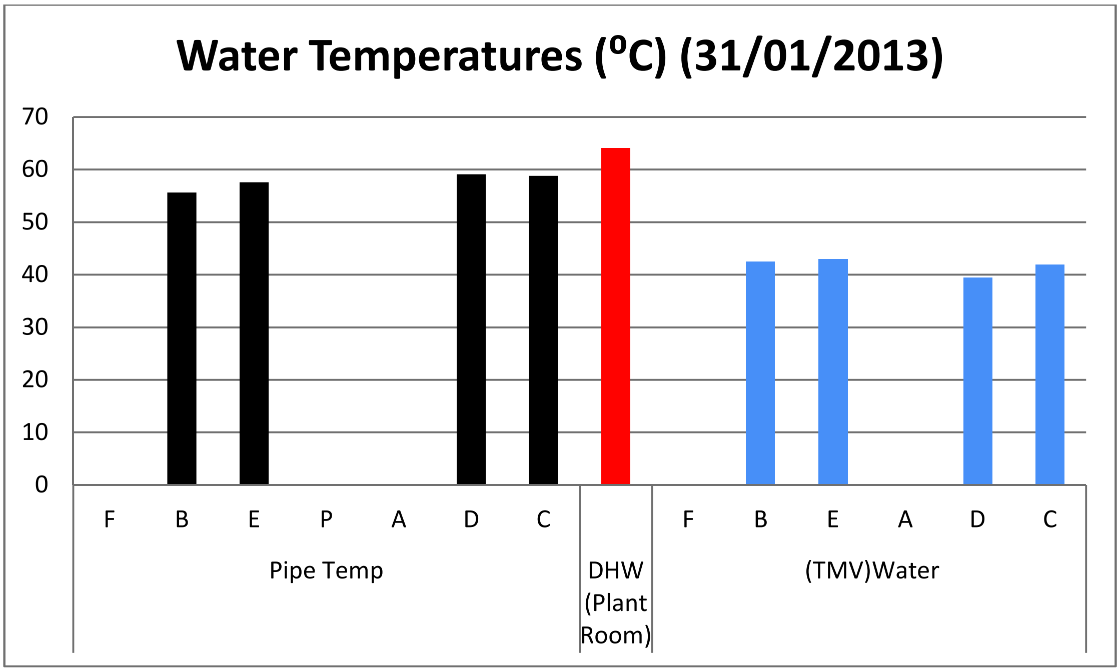


Figure 10-20: Water Temperature Record 18 (31/01/2013)

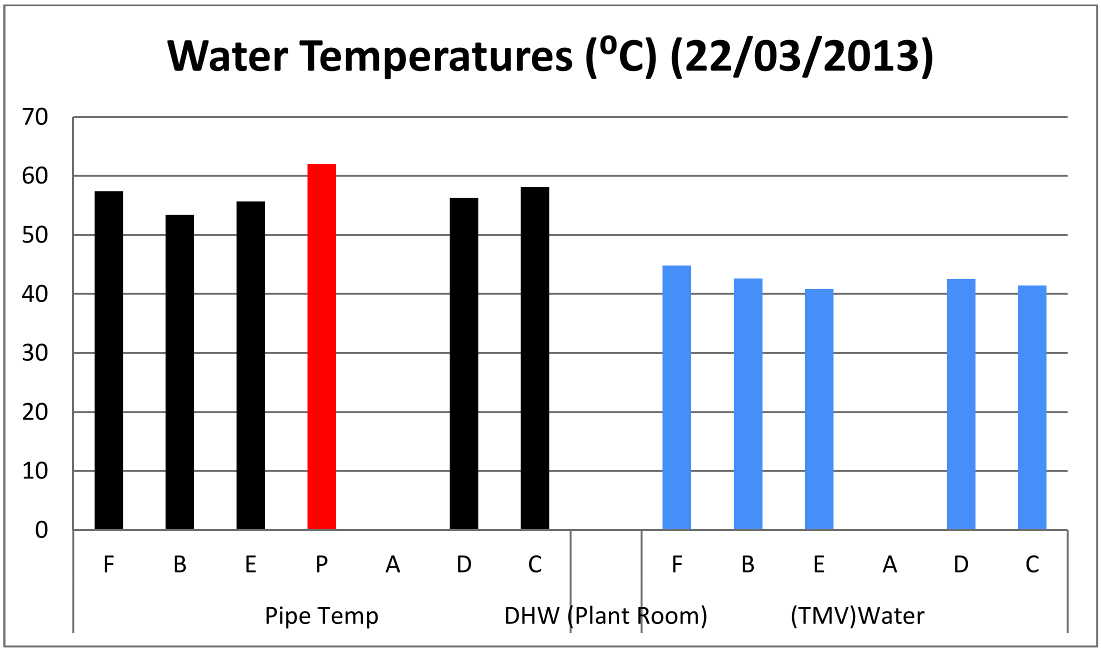


Figure 10-21: Water Temperature Record 19 (22/03/2013)

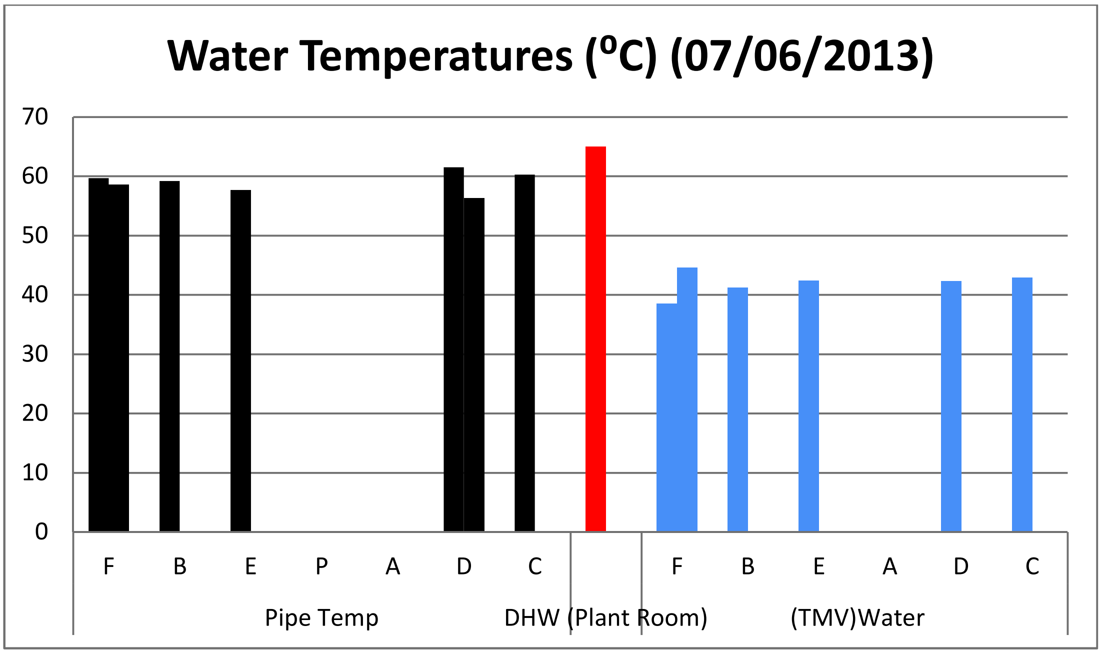
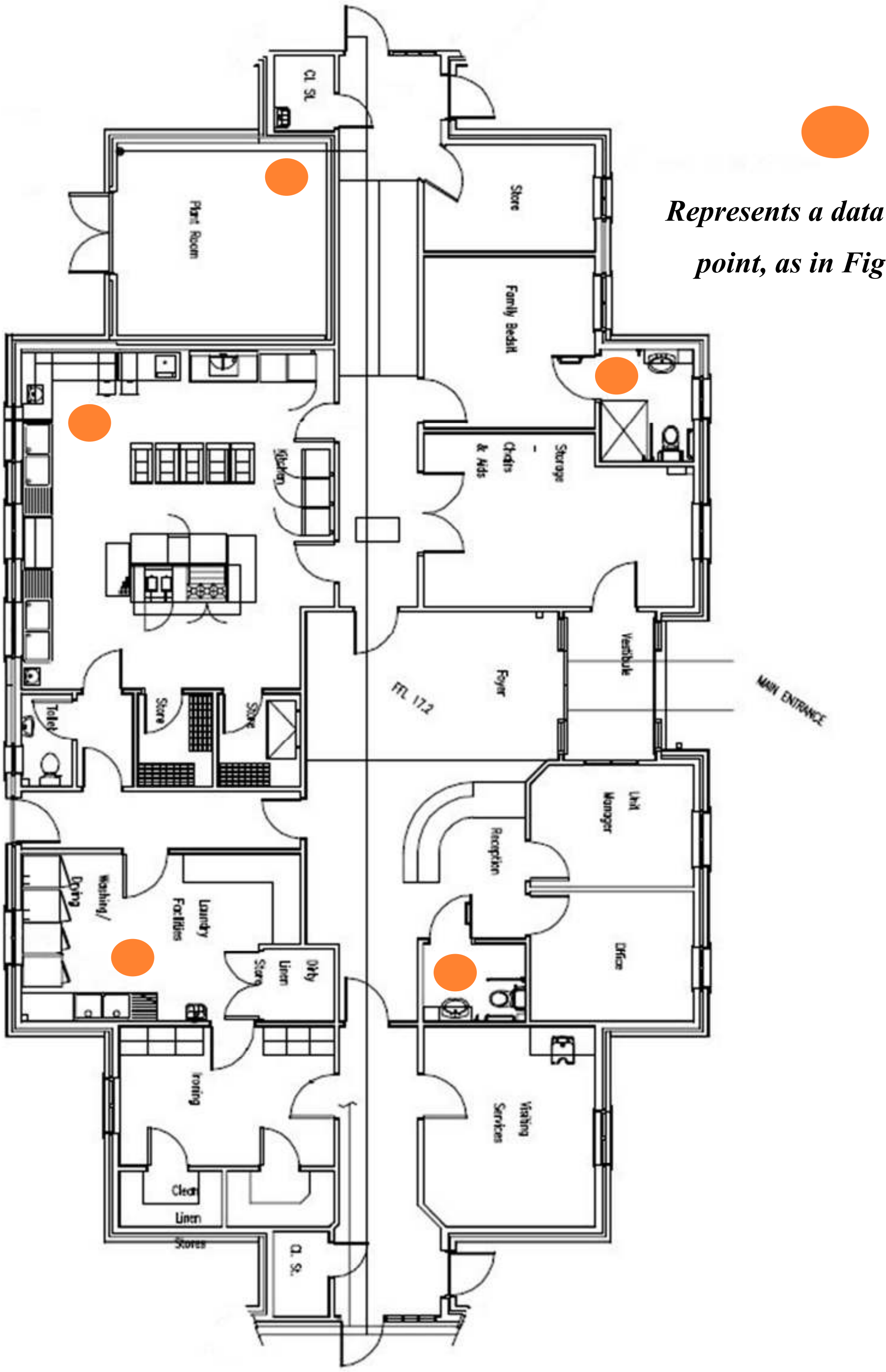


Figure 10-22: Water Temperature Record 20 (07/06/2013)

10.6 Water Service Drawings

The water service drawings contained in Figure 10-23 to Figure 10-28 should be used in collaboration with Figure 7-5 to determine the most effective locations to collect water temperature readings throughout the care home. Please note, areas of the image have been obscured for data protection.



Represents a data collection point, as in Figure 7-5.

Figure 10-23: Water Services Drawing - Wing A

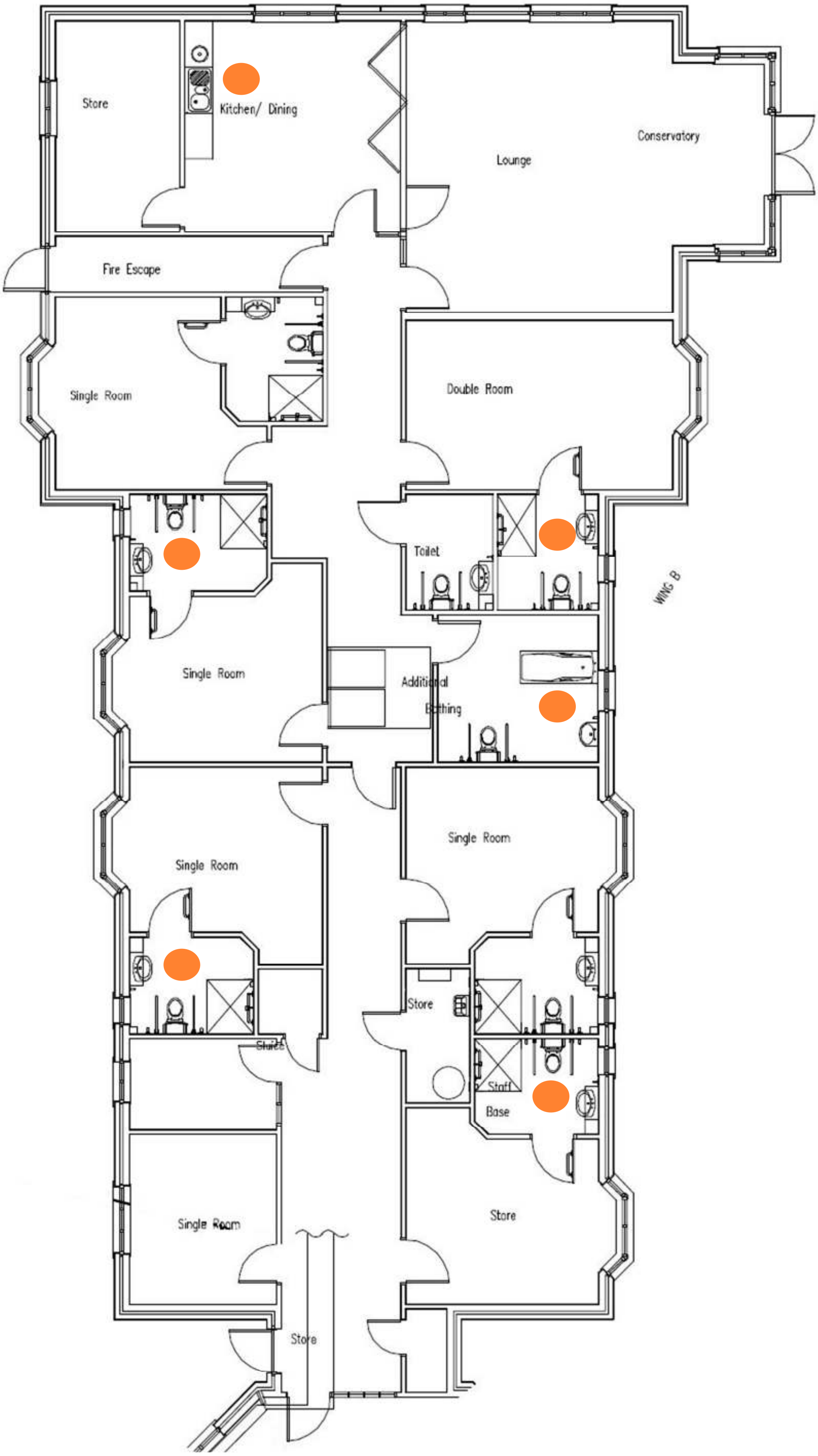


Figure 10-24: Water Services Drawing - Wing B

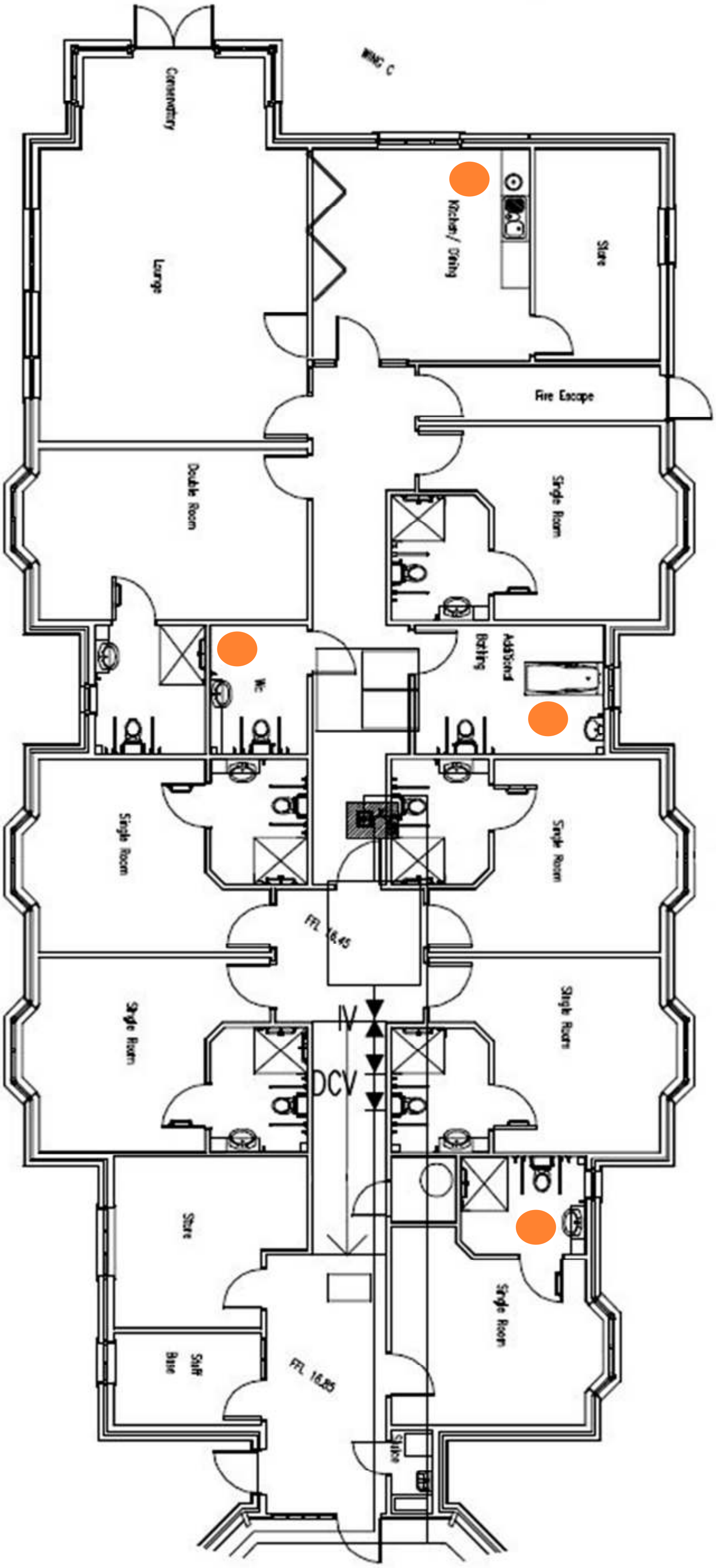


Figure 10-25: Water Services Drawing - Wing C

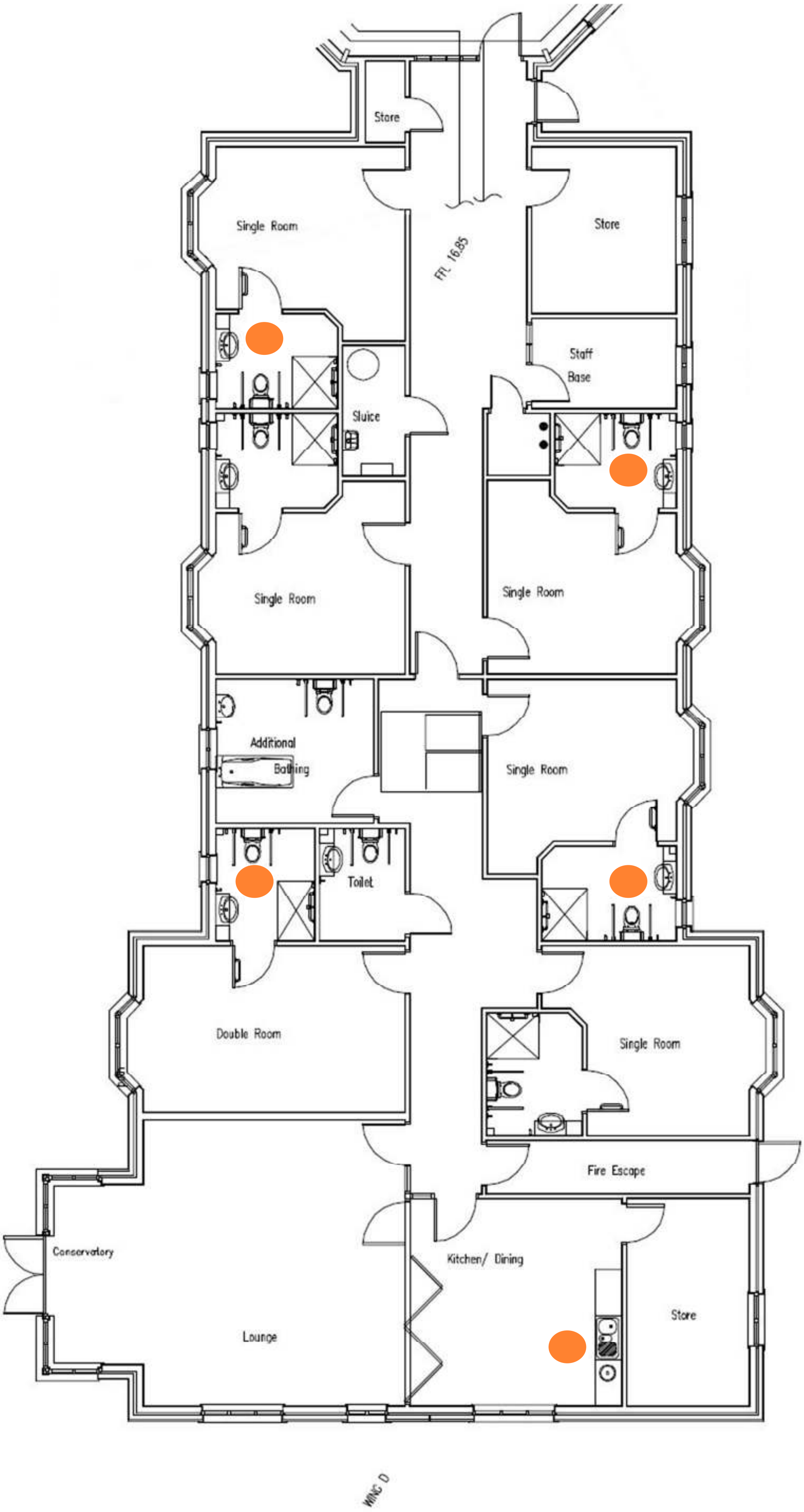


Figure 10-26: Water Services Drawing - Wing D

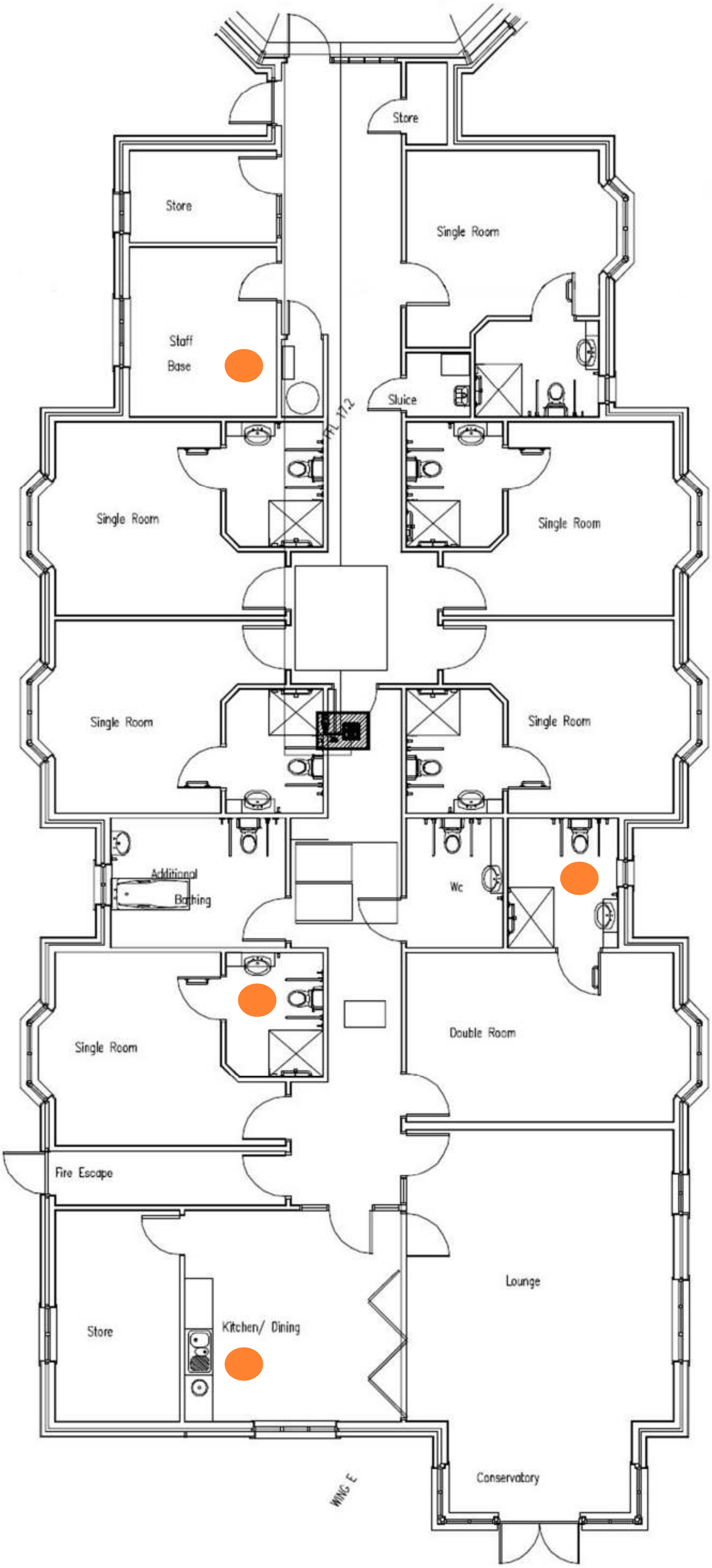


Figure 10-27: Water Services Drawing - Wing E

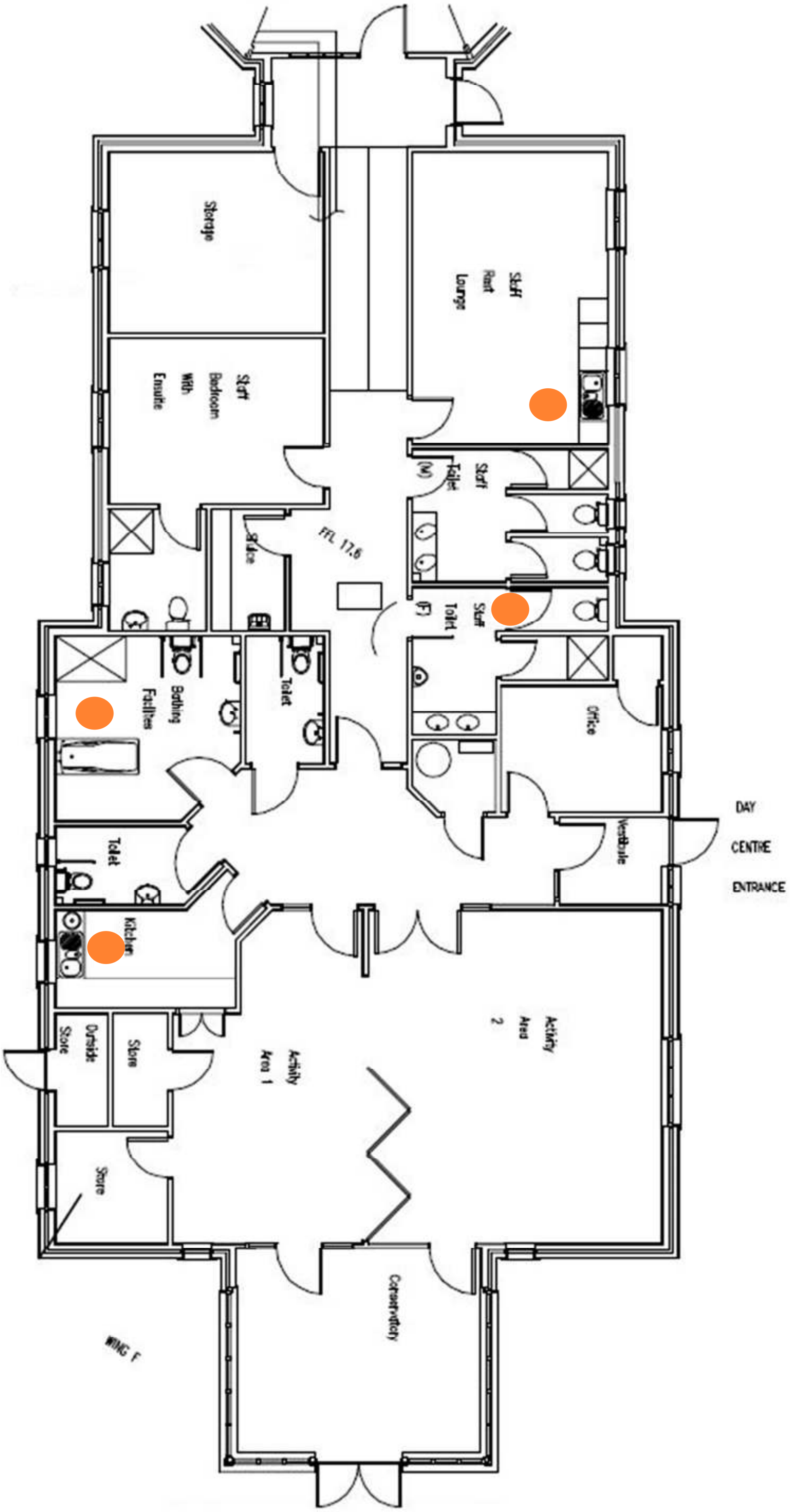


Figure 10-28: Water Services Drawing - Wing F