Testing of Tadpole in an Oil Fired Open Vent Gravity Fed Central Heating System

Report

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1.0 Introduction

Tadpole Energy Ltd. approached the Department of Mechanical and Manufacturing Engineering in the Institute of Technology, Tralee, Co. Kerry, Ireland in late 2009 with the objective of independently testing the Tadpole Oxygen Venting product used in domestic central heating systems. The primary aim of the subsequent tests carried out was to evaluate how various output parameters particularly Dissolved Oxygen, behaved with the units installed in a typical domestic central heating system compared to the base line, i.e. no Tadpole unit in the system. The product that was tested comprised of a Tadpole unit which can be seen in in figure 1 below.

Figure 1
Tadpole Unit

In addition to Dissolved Oxygen the other output parameters that were evaluated as part of the testing process consisted of:

Outside Air Temperature
Flow Temperature
Return Temperature
Hot Water Cylinder Temperature
Radiator Temperature in Bedroom 3
Flow Rate
Boiler On Time

The test site that was chosen was a three bed roomed semi detached house in the Tralee area built circa 1900 of stone construction without wall insulation, with a 150 mm wool fibre insulation in attic areas and a mix of double glaze PVC and single glaze timber windows and external doors.

2.0 Test Site Description

The test site central heating system was fuelled by an oil fired outside boiler housed in a shed approximately 10 metres horizontally from the header tank/hot water cylinder. The house was used as a guest house and the heating system retrofitted with that in mind. The oil boiler was used to heat the hot water cylinder (which could also be heated from a separate wrap around boiler/fire place or by using an immersion heater). The boiler thermostat was set to 90 ºC the maximum and kept at that setting for the all the tests. The boiler specification was as follows.

Table 1
Boiler Specification

Make	Firebird Boiler
Model	RS Balanced Flue Popular 90
Heat Output	14 to 26 kW
Max Operating Pressure	3 bar
Max Operating Temperature	90 C
Electrical Power (Burner)	0.168 kW

The system was open vent gravity fed from a header tank located in the attic. The system was controlled by the boiler thermostat and there was no temperature control in any of the living spaces. During the tests the radiators were always in the fully on position. The system contained one Danfos pump which was located on the return beside the boiler as shown in figure 2. The system contained 8 radiators of varying sizes, 4 upstairs and 4 downstairs as detailed in Table 2.

Figure 2
Boiler and Pump Layout

Table 2
Room And Radiator Dimensions

Description	Room Size (m^2)	Radiator Size (m^2)
Sitting Room	5.3 x 3.4	1.4 x 0.49 (single)
Living Room	4.1 x 2.9	1.19 x 0.49 (double)
Dining Room	4.1 x 2.9	0.95 x 0.49 (single)
Hallway	5.6 x 1.8	1.19 x 0.51 (single)
Bedroom 1	2.7 x 1.8	0.52 x 0.51 (single)
Bedroom 2	5.3 x 3.4	1.42 x 0.51 (single)
Bedroom 3	4.1 x 3.4	1.27 x 0.51 (single)
Bathroom	2.6 x 2.5	1.42 x 0.43 (single)

A schematic of the system with positions of radiators can be seen in figure3 and the flow and return temperatures were taken just before the boiler flow and return pipes meet the hallway.

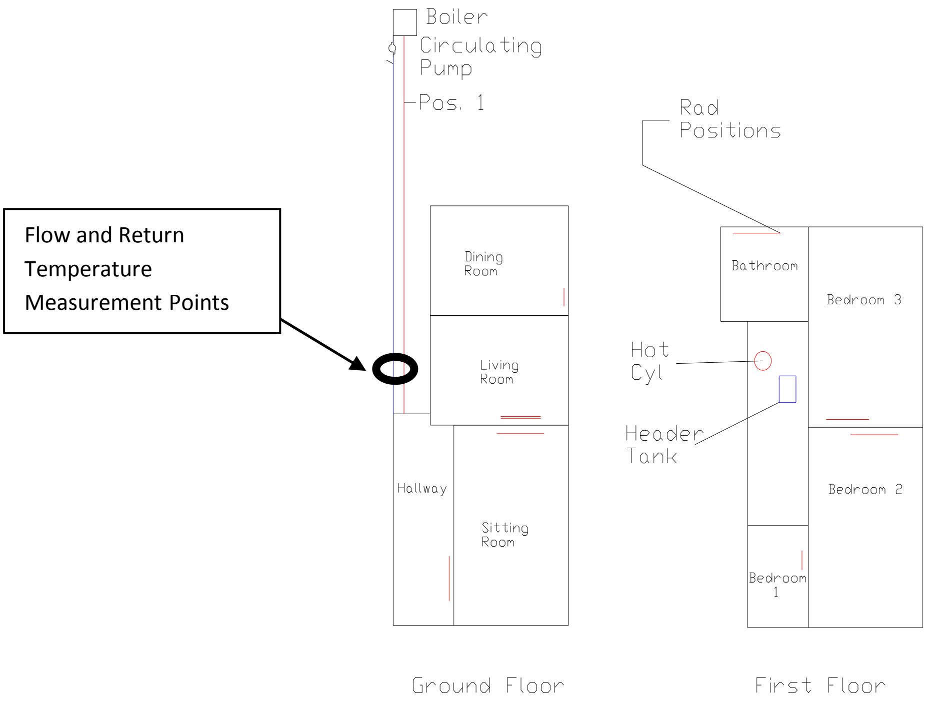

Figure 3
Schematic Of The Test Site Central Heating System.

3.0 Heating System Power up Sequence

When the heating system was switched on the system heating sequence was always the same regardless of whether or not the Tadpole was installed. The boiler and pump were wired to come on together and then the radiators in bedrooms 2 and 3 would start to heat up. This was then followed by the hot water tank and the radiators in bedroom 1 and the bathroom. The down stairs radiators then began to heat up in the following order, living room, sitting room, hallway and dining room.

4.0 Tests Conducted

In all two main tests were carried out:

Test 1: This was a baseline test (designated as BL in all the graphs). This test consisted of flushing the system and starting up without any Tadpole unit and recording the parameters outlined below.

Test 2: This test consisted of testing the system with a Tadpole (designated as TL in the graphs) unit installed as in position 1 of figure 3 above (i.e. the flow to the radiators). Again all the outlined parameters were recorded.

The primary parameter that was being evaluated in all tests was the reduction in the level of Dissolved Oxygen as the system ran. Dissolved Oxygen is regarded as one of the main factors associated with internal corrosion of system components (Appendix A). It was also decided to measure the impact the Tadpole would have on other system parameters so a suite of measurements were taken on the baseline system and with the Tadpole installed. The tests conducted involved periodic measurement and recording of the following:

a. Dissolved Oxygen (DO)
b. Outside Air Temperature
c. Flow Temperature
d. Return Temperature
e. Hot Water Cylinder Temperature
f. Radiator Temperature in Bedroom 3
g. Flow Rate
h. Boiler On Time

Prior to any testing the system was allowed to cool down for a minimum of 24 hours and all the water drained from the system at the boiler. The system was then flushed and any necessary plumbing carried out to install the Tadpole. The hot water cylinder was also flushed to ensure that the cylinder retained no heat from previous tests. The system was then refilled, the pump run on its own for 20 minutes and a cold bleed performed on the radiators.

5.0 Results

The following sections outline and discuss the results and findings obtained in the tests.

5.1 Dissolved Oxygen

The Tadpole unit was evaluated to determine the effectiveness of venting dissolved gasses from the heating system. The gas of most concern in any heating system is air as it is related to the cause of many common problems in the domestic heating system. Problems such as non uniform heating of radiators, corrosion of radiators, air pockets causing poor hot water, knocking of pipes and cavitation of pumps etc. can all be linked to systems in which air is trapped. Of the problems listed above the removal of oxygen to an inert level ($\leq 0.5PPM$) will significantly reduce the incidence of blocked pipes and radiator replacement due to corrosion residue. According to the Energy Saving Trust in the UK tests in laboratories and homes indicate that the efficiency of heating systems can fall by as much as 15% where corrosion residue is present in the system.

The Dissolved Oxygen (D.O.) was tested by taking small samples at regular intervals from the flow to the radiators and testing the water immediately using an WTW Oxy 96 D.O. meter capable of reading to 0 PPM (Parts per Million). To ensure accuracy of D.O. measurements the samples were cooled to 40 ^{0}C.

The system baseline is shown in figure 4 below and the behaviour is what would be typically expected with a rapid decline in D.O. as the temperature increased followed by a levelling off at 1.2 PPM as shown. The initial D.O. value was 7.7 ppm and this decreased rapidly as seen below when the system was heating up. The test was terminated after 1140 minutes (19 Hours) as the rate of decrease had declined significantly and it was unlikely that further testing would have yielded a further significant decrease.

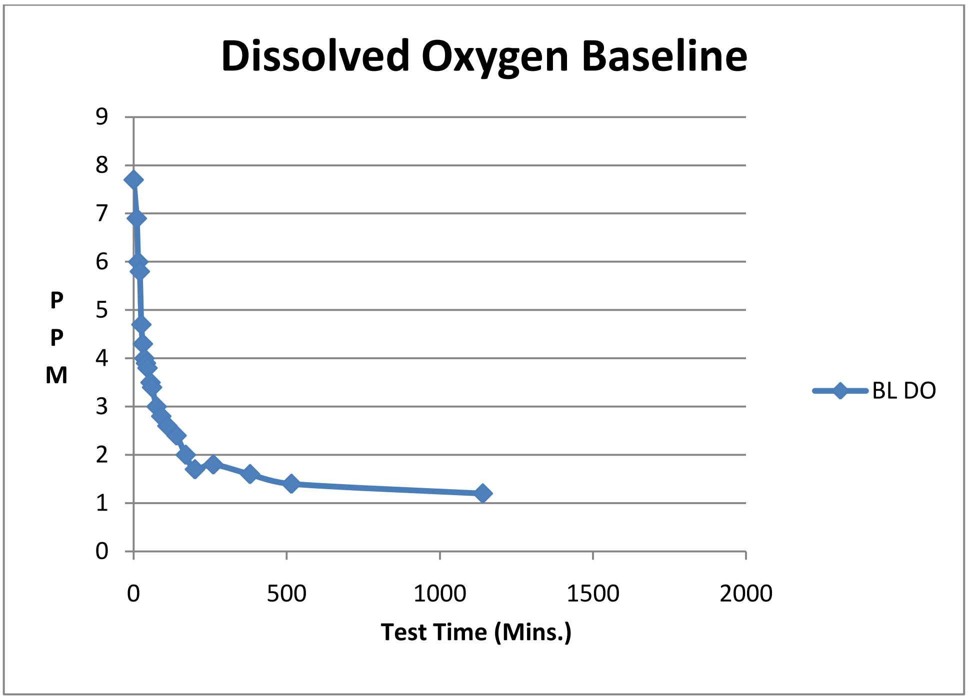

Figure 4
Baseline Dissolved Oxygen Curve

The data for the Tadpole is shown in figure 5 and again the trend is similar showing a rapid decrease initially but reducing to 0.8 PPM after 350 minutes and reaching 0.2 PPM between 350 and 1230 minutes from its initial value of 7.2 PPM.

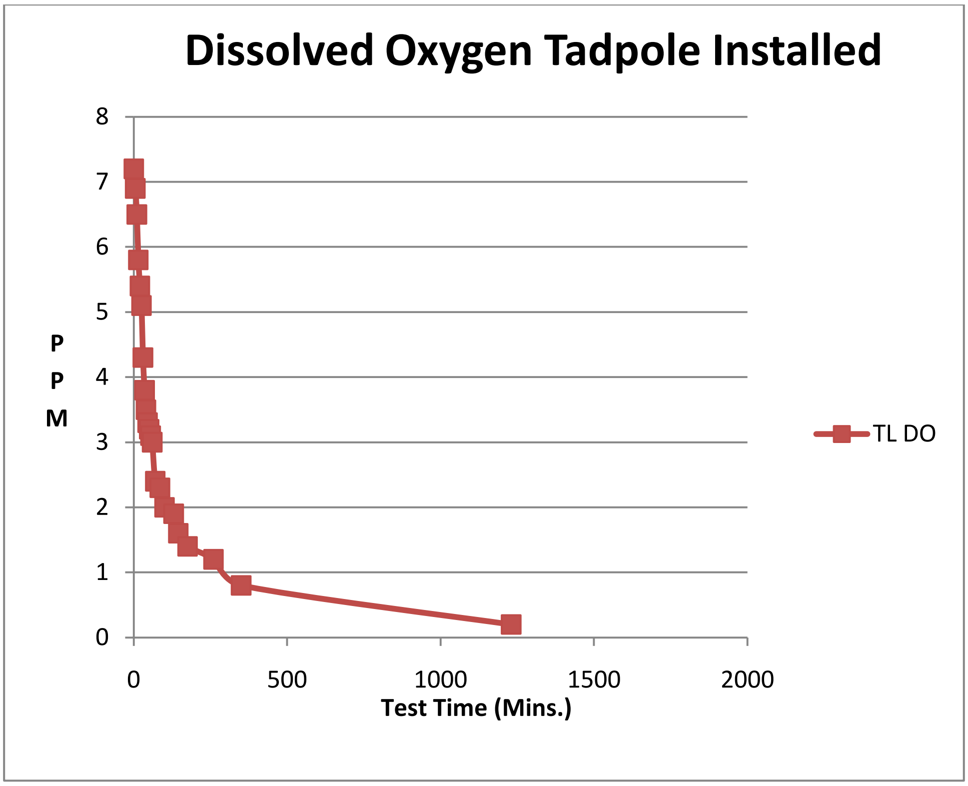

Figure 5
Tadpole Dissolved Oxygen Curve

When the 2 curves are superimposed, figure 6, on each other the rate of decrease can be seen. In a time interval of 300 minutes it can be seen that the Tadpole had the largest rate of decrease of dissolved oxygen. As the test continued the Tadpole continued to outperform the baseline and on completion of the tests the Tadpole system reached a PPM value of 0.2 as opposed to a value of 1.2 for the baseline. More importantly the rate of decrease in dissolved oxygen for the Tadpole system was greater than that achieved for the baseline which would aid in inhibiting corrosion.

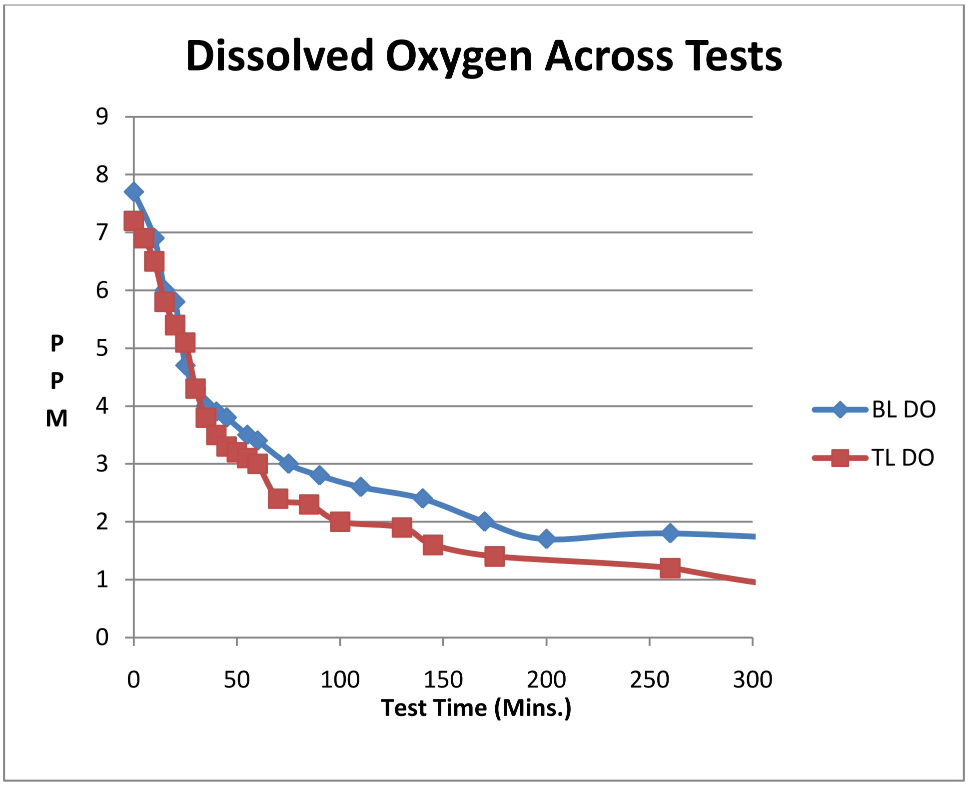

Figure 6
Dissolved Oxygen Comparison Across Tests

5.2 Outside Temperatures

The outside air temperatures are important factors to be considered when evaluating heating systems over a period of time as any fluctuations can have an effect on system performance and heating degree days are used to quantify potential consumption of energy within a system. These Heating Degree Days (HDD) are quantitative indices designed to reflect the energy required to heat a building or home and are derived from daily temperature measurements. The HDDs are defined relative to a base temperature above which the building needs no heating and this generally depends on the nature of the building, equipment it contains and the number of occupants etc. Base temperatures typically range from 15 to 18 ^{0}C and it is estimated that in a domestic building the air temperature in a building is on average 2 to 3 ^{0}C higher than the air outside. So a temperature of 18 ^{0}C indoors corresponds to an outside base temperature of about 15.5 ^{0}C. If the outside air temperature is below 15.5 ^{0}C then heating is required to maintain the temperature indoors at 18 ^{0}C. Generally a 1 ^{0}C difference from the base temperature over a 24 Hr. period is taken to be 1 degree day. The sum of the heating degree days over periods such as a year, an entire heating season, month or week are used in calculating the amount of heating required for a building over that period of time.

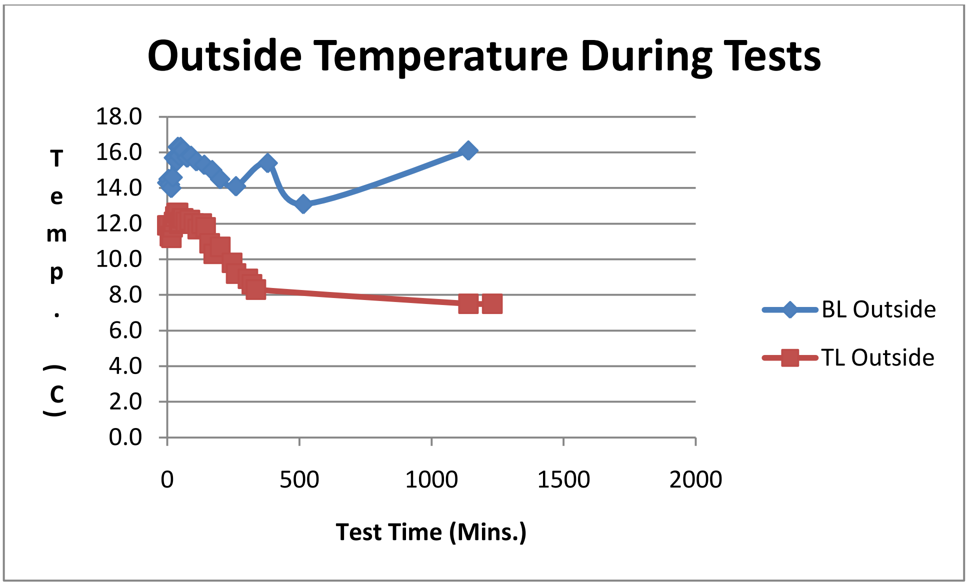

Figure 7
Outside Air Temperature For Tests

The outside air temperature was recorded away from direct sunlight on the north east side of the house. As can be seen from figure 7 there was a significant difference between the outside air temperatures at the times the Tadpole and the baseline tests were conducted.

The temperatures for tests, the HDD formulae and calculation are shown below for a given base temperature e.g. 15.5 ^{0}C, the base temperature most widely used in the U.K. In order to calculate the HDD two different formulae must be use as the maximum and minimum temperatures on the days the tests were performed were either above or below the base temperature [1, 2]. One formula was used for the Tadpole calculation while a variation of that formula had to be used for the baseline. The HDDs calculated are shown in Table 3.

$$\text{Tadpole:} \quad HDD = Tbase - (T\max + T\min)/2$$

$$\text{Baseline:} \quad HDD = (Tbase - T\min)/2 - (T\max - Tbase)/4$$

Table 3
Average Outside Air Temperatures and Heating Degree Days

	Average Temp ^{0}C	Tmax ^{0}C	Tmin ^{0}C	HDD
Baseline	15.2	16.3	13.1	1
Tadpole	11.03	12.6	7.5	5.45

5.3 Flow Temperature

The flow temperatures are shown in figures 8 through 10 for the baseline and the Tadpole unit tested. The baseline temperature during the heating up phase reached a maximum temperature of 63 ^{0}C and varied between 38 ^{0}C and 58 ^{0}C for the first 450 minutes of the testing with the variation reducing as the test time approached 500 minutes. This was as to be expected as the test progressed and the system reached temperature. The system flow temperature stabilised at approximately 50 ^{0}C. Given that the thermostat was set at 90 ^{0}C this was a relatively low value and had a subsequent effect on the radiator and domestic hot water tank temperatures. This value is consistent with the baseline return temperature which stabilised at 45 ^{0}C when the system reached maximum temperature on the radiators and the hot water tank.

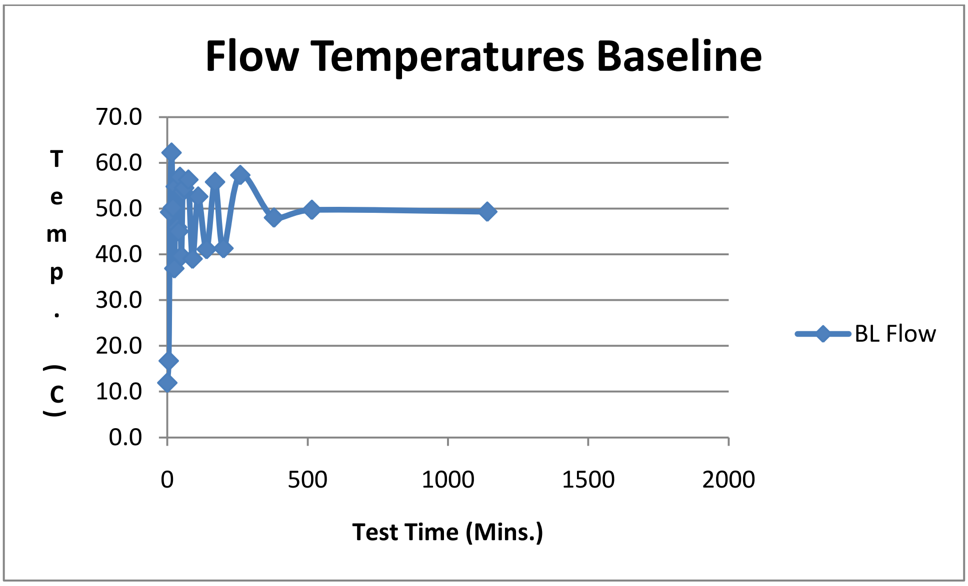

Figure 8
Baseline Flow Temperature

The flow temperature for the Tadpole is shown in figure 9. Comparing the Tadpole with the baseline of figure 8 it can be seen that with the Tadpole the temperature oscillations are larger and the system consistently reaches a higher flow temperature having started from around 8^{0}C compared to 11^{0}C for the baseline. The Tadpole system reached its stable temperature in a shorter time than the baseline and this temperature was at least 60 ^{0}C which was 10 ^{0}C above the baseline temperature. This is again consistent with the data from the other tests which show that the return temperature for the Tadpole is greater than that measured for the baseline. Similarly for the hot water tank the Tadpole measurements were better than the baseline temperatures.

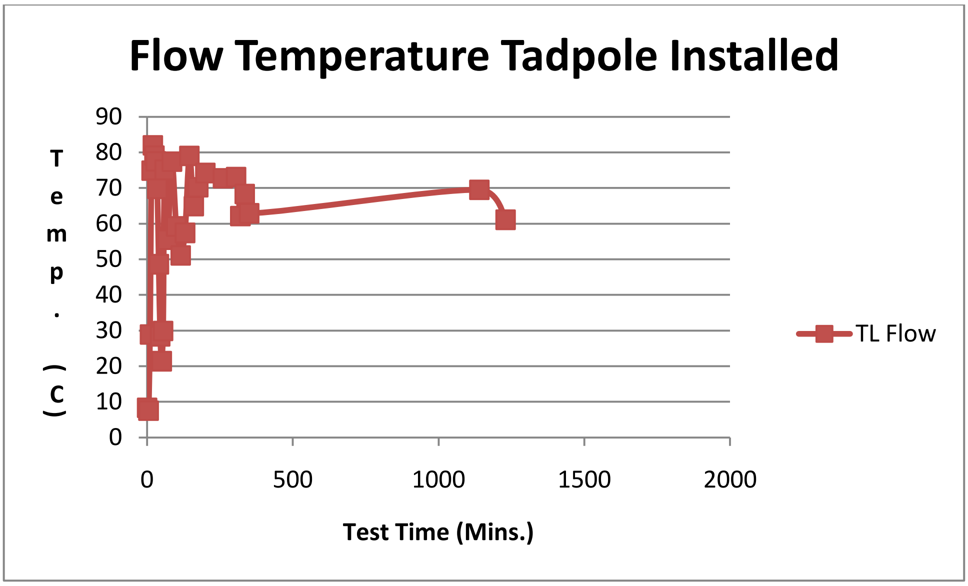

Figure 9
Tadpole Flow Temperature

Figure 10 shows clearly the improvements seen using the Tadpole in the system with Tadpole system performing better than the baseline. The Tadpole had fewer temperature oscillations and reached it maximum temperature, which was greater than the baseline, quicker than the baseline

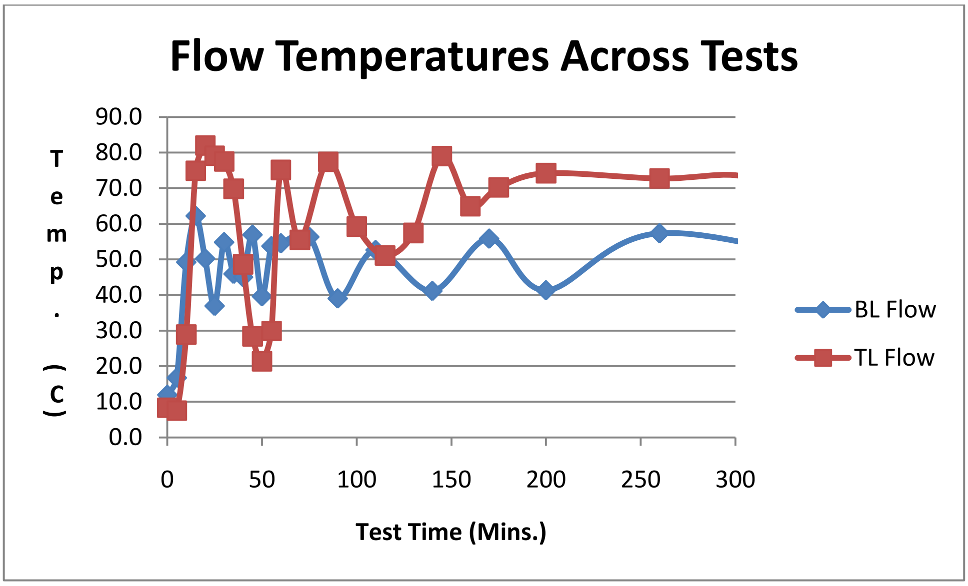

Figure 12
Flow Temperature Across Tests

The return, hot water and radiator temperatures for the other tests are shown in tabular form in table 4, (page 18) and it is clear that the data from these tests reflects the flow temperature differences seen between the baseline and the Tadpole unit.

5.4 Return Temperature

The trends seen above in the flow temperature are naturally enough mirrored in the return temperatures shown in figures 11 to 13 for the baseline and Tadpole system. In figure 11 the return temperature for the baseline produced a spike around 400 minutes. This was preceeded by a drop in the tank temperature at around 260 minutes which recovered by the next reading at 380 minutes. It is assumed that these are as a result of the system design and sequencing previously discussed and these readings in no way effect the overall results. This spike did not occur in other tests with the Tadpole installed as the Tadpole had an effect on smoothing out natural temperature variations in the flow during the heating up cycle as seen in figure 12.

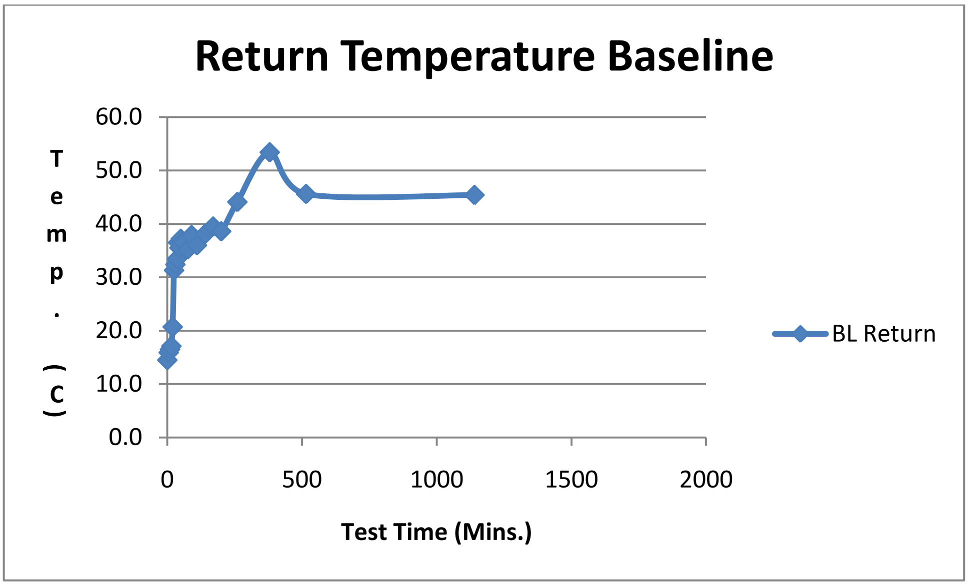

Figure 11
Baseline Return Temperature

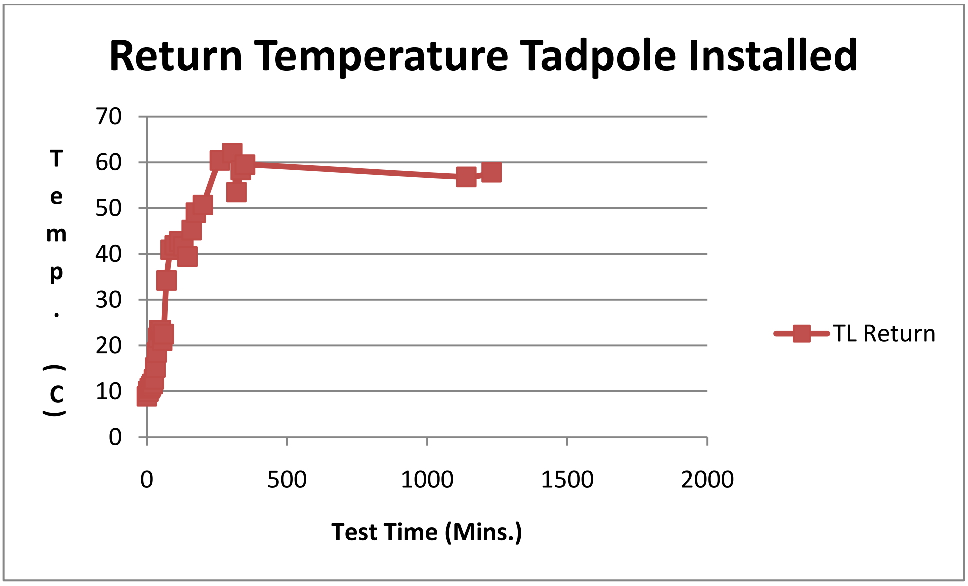

Figure 12
Return Temperature Tadpole

For the Tadpole there were no anomalies in the graphs. This is possibly due to its ability to decrease the dissolved oxygen and trapped air in the system quicker than the baseline thus smoothening out the temperature excursions seen on the baseline. The temperature rise for the Tadpole was steeper than the baseline temperature increase and the temperature stabilised at around 60 ^{0}C which was significantly higher than the baseline. The rate of increase for the Tadpole and Baseline can be appreciated from figures 11 to 13.

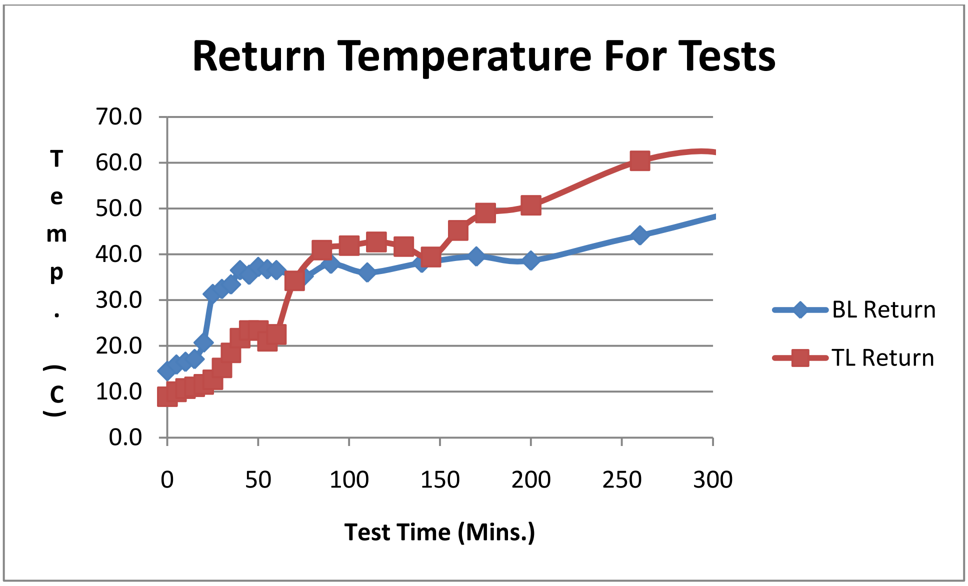

Figure 13

Return Temperatures for Baseline and Tadpole System

5.5 Tank Temperature (Hot Water Cylinder)

A common feature of any heating system is that it supplies adequate domestic hot water as well a heating. The system was designed to operate with a solid fuel back boiler and an electric immersion heater as well as the oil fired system and they would have all been used as back up to each other. When the oil fired system was used the temperature measured at the centre of the tank achieved a maximum of 30 ^{0}C as seen in figure 14. It was felt that this temperature was quite low but it must be remembered that the domestic hot water in the system would be supplemented by either the back boiler or the immersion heater. This could also be as a result of the presence of entrained air in the system which standard bleeding procedures failed to eliminate.

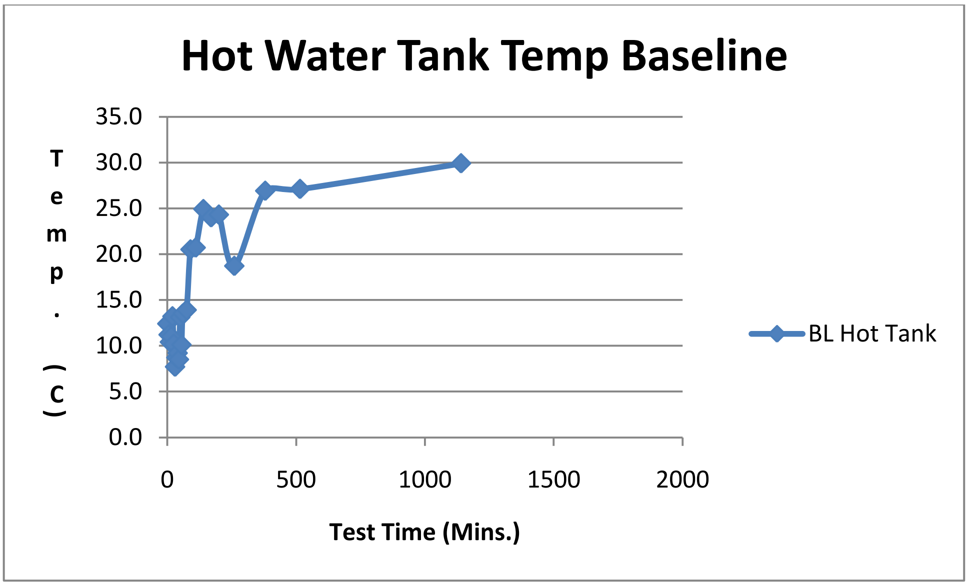

Figure 14
Baseline Hot Water Tank Temperature

When the Tadpole was introduced into the system the domestic Hot Water Tank Temperature performance improved dramatically. This can be seen from figure 15 where the highest temperatures achieved was in the region of 60 ^{0}C with the Tadpole giving not alone the highest temperature but also the largest rise in temperature achieving its maximum temperature in the shorter time.

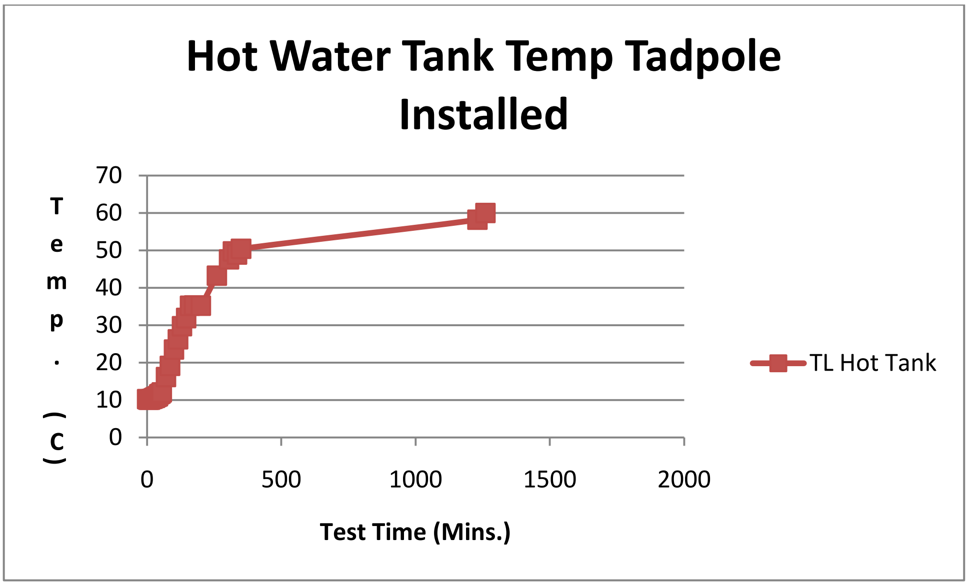

Figure 15
Tadpole Hot Water Tank Temperature

Figure 16 shows a comparison profile for the first 500 minutes for the 2 tests. From this it can be appreciated that the Tadpole system outperformed the baseline in terms of temperature achieved and the time to reach that temperature.

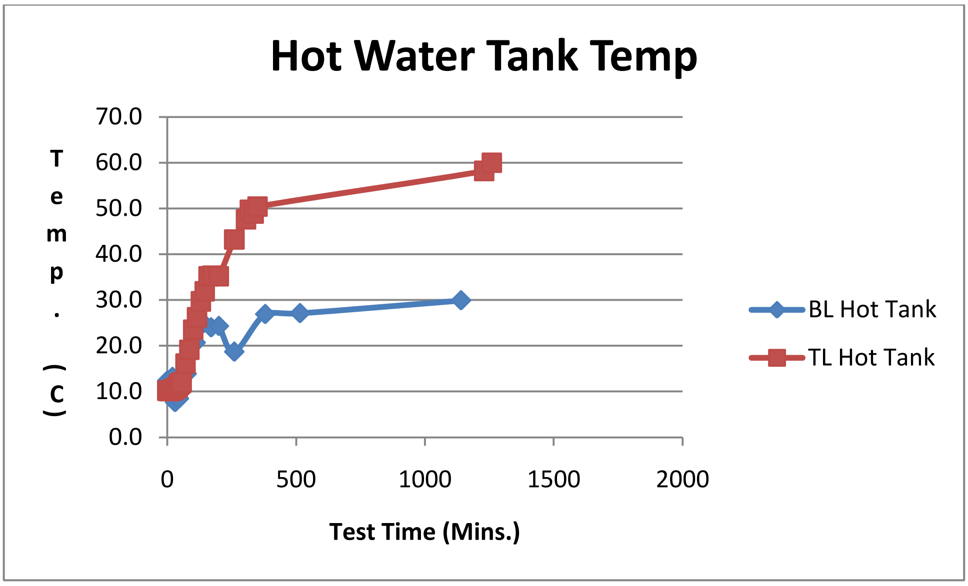

Figure 16
Hot Water Tank Temperature Across Tests

5.6 Radiator Temp

In any heating system the temperature of the radiators and the speed at which radiators attain their maximum temperature is very important. The quicker the radiators reach temperature the quicker the rooms heat to the required temperature and the more comfortable the living conditions become for the inhabitants. The radiator temperature in Bedroom 3, the first radiator to heat was monitored using a thermocouple at the top right hand side of the radiator. Again the data collected is shown in the appendices and is illustrated graphically below for the baseline test and the Tadpole. It is seen from figure 17 that the radiator temperature rises quickly to about 65 ^{0}C and starts to decrease as the loads of the other radiators and the hot water cylinder come into play. The radiator temperature for the baseline dropped to approximately 49 ^{0}C at around 400 minutes and remained at this value for the remainder of the test.

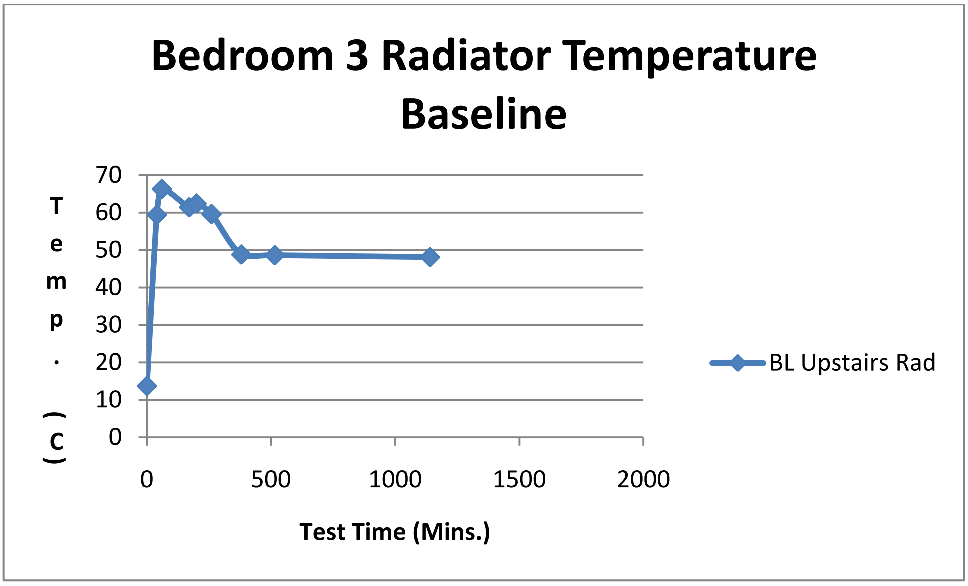

Figure 17
Baseline Radiator Temperature

When the Tadpole was installed, figure 18, the radiator temperature rise was a lot higher than the baseline and a similar decrease in radiator temperature was found when the hot water cylinder and the other radiators started to heat up. There was however a noticeable drop in the radiator temperature overnight which would be associated with the outside air temperature decreasing overnight.

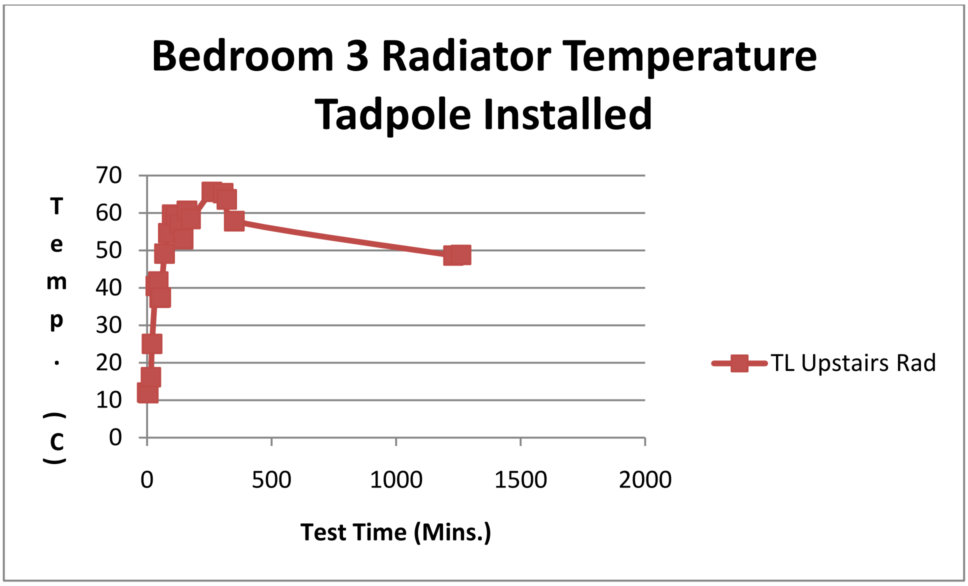

Figure 18
Tadpole Radiator Temperature

When the two profiles are examined on the one plot the trends discussed above are evident as shown in figure 19. The Tadpole reaches the same level as the baseline but takes a slightly longer time to do so. However it must be remembered that there was a significant difference between the average temperatures (approximately 4 ^{0}C) on the days the tests were conducted and heat loss through the fabric of the structure and external temperature differences during the night periods were seen as contributing factors.

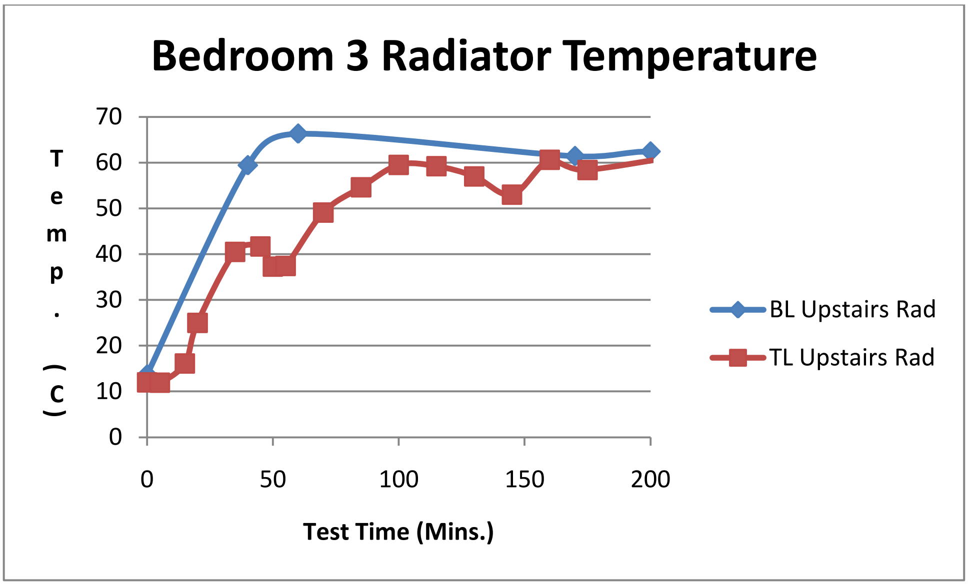

Figure 19
Comparison of the Radiator Temperatures Across Tests.

The maximum temperatures for the previous tests are summarised in Table 4 and it is evident from this that the system with the Tadpole installed gave higher maximum temperatures on the parameters measured. It must also be remembered that the radiator temperature for the baseline tests decreased to 49 ^{0}C when other sections of the system started to heat up. It is also felt that had the outside temperatures been the same the final radiator temperature with the Tadpole installed would have been greater than the baseline temperature.

Table 4
Summary of the Maximum Heating System Temps.

	Baseline	Tadpole
Flow Temp.	63	83
Return Temp.	53	62
Hot Water Tank	30	60
Radiator Temp.	66	66

5.7 Flow Rate

A critical consideration in the design of any heating system is the flow rate. The flow rate influences the return temperature of the heating liquid to the boiler. This return temperature of the heating liquid to the boiler has a bearing on the efficiency of the system (Boiler On Time) as the hotter the heating fluid is returned to the boiler the longer the boiler is off giving potential fuel savings. This is evidenced by the following formula (equ. 1) whereby the flow rate varies with the return temperature.

$$\text{Flow Rate (GPM)} = K\left(1/(T_s - T_r)\right) \qquad \text{(equ. 1)}$$

In this equation

K is a constant determined by the heating fluid and temperature
Ts is the thermostat setting
Tr is the return temperature to the boiler.

From this it is seen that the higher the flow rate the faster the system response and as a result the longer the boiler is off.

The benefits of an increased flow rate can also seen by the distance the heating fluid can be projected into the system. As the flow rate increases the hot water can go further into the system potentially heating radiators at the extremities of the system faster.

In this case the flow rate was measured at the end of each test on the flow from the boiler with the pump running and a full head of water in the header tank. Using a stop watch the time to fill completely a 6 litre container was taken. This was repeated 2 more times and the average time used to calculate the flow rate, tables 5 and 6. The flow rate is given by the volume divided by the time in liters per minute.

Table 5
Time for 6 Litre Fill

	Run 1 (secs.)	Run 2 (secs.)	Run 3 (secs.)	Average (secs.)
Baseline	45	46	45	45.33
Tadpole	49	48	50	49

These times then give the following flow rates

Table 6
Flow Rates

	Average Time (Secs.)	Flow Rate litre/min	% Difference to Baseline
Baseline	45.33	7.94	0%
Tadpole	49	7.34	-7.56%

As can be seen from table 6 there is very little difference in the flow rates with the methodology used. While the Tadpole system gave a lower flow rate the results do not indicate any negative impact of the system performance.

5.8 Boiler Cycle (On) Time

The boiler on time is measured by the amount of time the boiler is on versus the total boiler cycle in any period of time i.e. the total test time. The percentage on time could then be calculated by summing up the ON times for each cycle and dividing by the sum of the total times for each cycle.

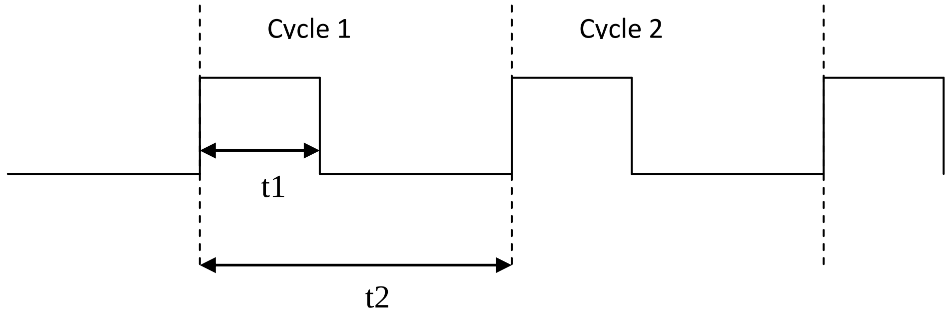

Figure 25
Boiler On Time Calculation Method

The on cycle is from the time the burner fired up until the burner stopped (t1) and the full cycle was taken as the difference between the boiler firing up on cycle 1 and then on the subsequent cycle (t2) as in figure 25. The on time was then calculated as in equation 2.

$$\%OnTime = \frac{\sum t1}{\sum t2} x100 \quad \text{-------------} \quad \text{(equ. 2)}$$

Calculating the on time in this manner allowed the overall running time to be calculated and also allowed calculation of the percentage saving on heating oil during the tests. The on time was measured by using an electronic counter accurate to 0.01 hours which accumulated the time the boiler was operational and ignored the off time. As a result t1 was the time on the counter and t2 was the total test time. The data obtained for these tests is shown in Table 7.

Table 7
Boiler On Time Per Test

	On Time (Hrs.)	Test Time (Hrs.)	Run Time (% On Time)
Baseline	7.45	19	39.21%
Tadpole	7.3	21	34.86%

The raw data indicates that the Tadpole provided a 4.35% shorter boiler on time than the baseline system even though the outside temperature was appreciably cooler on average for the test. If the previously discussed principle of Heating Degree Days are applied to these results using a base temperature of 15.5 ^{0}C as outlined in section 5.2 and the HDD calculations are applied then the potential savings to be made by using the Tadpole can be appreciated from Table 8.

Table 8
Heating Degree Days for Different Tests and Boiler On Time Savings

	HDD	Run Time % On Time	Increase Or Decrease Vs Baseline	Percentage Savings Vs Baseline
Baseline	1	39.21%	0	N/A
Tadpole	5.45	34.86%	-4.35%	-23.71%

The boiler on time savings can potentially be increased or decreased by multiplying the increase or decrease by the ratio of the degree days. For the Tadpole the ratio of the degree days is 5.45 which when multiplied by the actual decrease in run time equated to a theoretical saving of 23.71% on the baseline.

6.0 Conclusion

This test comprised of testing an oil fired central heating system in a three bed roomed semi-detached two storey house. The testing was divided into two main tests, the first test was a baseline test without any Tadpole installed (BL), the second test was with the Tadpole installed. Testing involved measuring various parameters, recording results of same and are concluded as follows.

The results of levels of Dissolved Oxygen (D.O.) in the system's water demonstrated that the system with the Tadpole was better at reducing D.O. levels than the baseline test. The Tadpole reached a level of 0.2 Parts per Million (PPM) while the base line test achieved a level of 1.2 PPM. It was also noticed that the rate of decrease of the D.O. was greater with the Tadpole installed which could greatly reduce corrosion and improve system performance and efficiency.

Measurements for Outside Temperature were also recorded periodically for the tests. The average Outside Temperature for the base line test was 15.2 ^{0}C compared to 11.03 ^{0}C for the Tadpole. It is important to note that the average test temperature externally for the Tadpole test is 4.17 ^{0}C colder than that for the base line test. Had the outside temperature for the Tadpole test been closer to the base line outside temperature it is fair to assume that the performance of the system would have been enhanced.

Temperatures were recorded for the two tests at the flow from the boiler to the heat emitting components of the system. It can be seen from results recorded that after initial ramp up the Flow Temperature of the base line oscillated between 40 ^{0}C and 60 ^{0}C and levelled off at a continuous 50 ^{0}C. The Tadpole oscillated in a band from 50 ^{0}C to 80 ^{0}C after initial ramp up and levelled off at a value between 60 ^{0}C and 70 ^{0}C for operation subsequent to that. This temperature well out performed the base line results and gave a better system performance.

The return Temperature was measured on the return to the boiler and followed a very similar pattern to the temperature at the flow. It is noted that there was a spike in the base line test and the test with the Tadpole did not demonstrate any peaks or troughs and appeared smoother overall.

Hot Tank Temperature demonstrates the availability of hot water from the system, this was recorded throughout the two tests. It can be easily seen from the test results obtained that the water in the hot tank with the Tadpole in the system was much hotter than the base line test. The temperature of the Hot Tank reached 60 ^{0}C with the Tadpole as opposed to 30 ^{0}C for the base line. Furthermore it was seen that the response time at getting to maximum temperature was much faster with the Tadpole in place.

The Radiator Temperature in room 3 was measured and recorded throughout the duration of the tests. The Tadpole performance was similar to the base line with regard to radiator temperature. This was unexpected due to the increase in other measured parameters but the likely explanation for this is that this test was conducted at colder outside temperatures (4.17 ^{0}C on average) and there would have been colder room temperatures resulting in a larger thermal draw off the radiator.

There was no appreciable difference in system Flow Rate between the two tests carried out and this was to be expected as the Tadpole did not introduce any restrictions to the system. While the Tadpole showed a decrease it is difficult to gauge the effect on the system as all measured system parameters were greater than the baseline.

The Boiler On Time is a proportional indicator of the consumption of fuel and the cost of running a central heating system. The tests that were carried out were based on running the system to maximum output in order to assess the systems full potential. Because the Tadpole test results demonstrated a much hotter system at a quicker rate to maximum heat, one would imagine that there would be a longer Boiler On Time. It was shown however that the boiler was on 34.86 % of the time for the Tadpole and 39.21 % for the base line test. The measured system parameters indicated that the Tadpole outperformed the base line test and did not consume as much energy. It is interesting to note that as the HDDs are applied in the traditional manner the potential energy savings could reach up to 23.71% with the Tadpole installed and that there may be scope for a further increase with a fully thermostatically controlled system combined with hot water usage.

Overall, the outcome from the tests carried out demonstrated that the system with the Tadpole installed resulted in a considerably hotter system which reached full heat in a quicker time frame. The Tadpole test did not consume as much energy as the base line test, provided energy savings and better system performance in colder outside temperatures than the baseline.

7.0 Recommendations

It is recommended that future testing may provide interesting results with the following test setups:

- Testing with other fuel types
- Testing with other system configurations
- Room/Internal thermostat control of system to measure the internal air temperature(s) during the test
- Hot tank thermostat control of hot water
- Zoning

8.0 References

1. http://www.met.ie/climate/data03.asp accessed 23 April 2010

2. http://en.wikipedia.org/wiki/Heating_degree_day accessed 23 April 2010

Appendix A

(Corrosion)

Corrosion occurs whenever a gas or liquid chemically attacks an exposed surface usually a metal and it is accelerated by warm temperatures. Normally corrosion products such as rust stay on the surface and can protect it from further corrosion and removing these deposits re-opens the surface and corrosion continues. Traditional heating systems consist of iron in radiators, a heating fluid, water and generally run at temperatures in excess of 45 C. so all the ingredients for corrosion are present and this generally occurs in the radiators. Corrosion or rusting has a significant economic cost. It has been estimated that the cost of corrosion is over 1% of the world's economy and that a quarter of the steel produced in the USA goes towards replacing rusted material.

The rusting process is a complex one but in its simplest form it involves the formation of a hydrated oxide such as $Fe(OH)_3$ or FeO(OH). The process requires the presence of water, oxygen and an electrolyte. If any one of these are absent then no significant amount of corrosion will occur. In air alone if the relative humidity is over 50% then sufficient amounts of water are present and corrosion can occur. If the relative humidity increases to 80% then the corrosion can be severe.

Rusting is a redox reaction involving the loss and gain of electrons between reactants. An electrochemical cell is created with impurity sites in the iron acting as cathodes for the reduction of O_2 gas and a region of the metal surface acting as the anode where the oxidation of iron occurs. The process is complex and will depend on the prevailing conditions such as the temperature, amount of impurities, quantity of oxygen in the water and a small amount of O_2 will initiate a regenerative corrosion process. The rust then forms a coating that can slow further corrosion if left undisturbed by the weather or other outside influences.

In a heating system the oxidation of the iron (corrosion) is usually localised in surface pits and crevices which would normally allow the formation of adherent rust over the surface which would slow the corrosion process down. However in a heating system the adherent rust can be swept away and further corrosion can occur in the same place in the radiator.

The removal of oxygen from the heating water to a level below 0.5 PPM, which can generally be regarded as inert, should remove the incidence of corrosion from the heating system. This would have the effect of reducing ongoing maintenance due to rusting of radiators, blocked pipes etc. According to the Energy Saving Trust in the UK tests in laboratories and homes indicate that the efficiency of heating systems can fall by as much as 15% where magnetites created by corrosion are present in the system.

Appendix B
(Raw Test Data)

Date	Time	Interval	BL DO	BL Return	BL Flow	BL Outside	BL Hot Tank	BL Rad	BL Boiler Reading
26 March	14:40	0	7.7	14.5	11.9	14.3	12.4	13.7	17122.38
26 March	14:45	5		15.9	16.7	14.5	11.2		
26 March	14:50	10	6.9	16.5	49.2	14.2	10.4		
26 March	14:55	15	6.0	17.1	62.2	14.0	11.0		
26 March	15:00	20	5.8	20.7	50.2	14.6	13.2		
26 March	15:05	25	4.7	31.3	36.9	15.7	10.2		
26 March	15:10	30	4.3	32.4	54.8	15.7	7.7		
26 March	15:15	35	4	33.4	45.9	15.5	8.7		
26 March	15:20	40	3.9	36.5	45.0	16.3	9.2	59.4	
26 March	15:25	45	3.8	35.5	56.9	15.8	8.5		
26 March	15:30	50		37.2	39.6	16.3	13.1		
26 March	15:35	55	3.5	36.7	53.7	16.1	10.1		
26 March	15:40	60	3.4	36.5	54.5	16.1	13.5	66.3	
26 March	15:55	75	3.0	35.2	56.3	15.7	13.9		
26 March	16:10	90	2.8	37.9	39.0	15.8	20.5		
26 March	16:30	110	2.6	36.0	52.6	15.5	20.7		
26 March	17:00	140	2.4	38.1	41.1	15.3	24.9		
26 March	17:30	170	2.0	39.5	55.8	15.0	24.0	61.4	
26 March	18:00	200	1.7	38.6	41.3	14.5	24.3	62.4	
26 March	19:00	260	1.8	44.1	57.3	14.1	18.7	59.6	
26 March	21:00	380	1.6	53.4	48.0	15.4	26.9	48.8	
26 March	23:15	515	1.4	45.6	49.7	13.1	27.1	48.6	
27 March	09:40	1140	1.2	45.4	49.3	16.1	29.9	48.1	17129.8

Date	Time	Interval	TL DO	TL Return	TL Flow	TL Outside	TL Hot Tank	TL Rad	TL Boiler Reading
01 April	14:50	0	7.2	8.9	8.3	11.9	10.2	12	17129.83
01 April	14:55	5	6.9	10	7.5	11.9	10.1	11.9	
01 April	15:00	10	6.5	10.7	28.9	11.3	10.1		
01 April	15:05	15	5.8	11.1	74.9	11.2	10.2	16.1	
01 April	15:10	20	5.4	11.6	82	11.8	10.3	25	
01 April	15:15	25	5.1	12.6	79.1	12.1	10.5		
01 April	15:20	30	4.3	15.2	77.5	12.4	10.6		
01 April	15:25	35	3.8	18.5	69.8	12.6	10.8	40.5	
01 April	15:30	40	3.5	21.7	48.6	12.6	11		
01 April	15:35	45	3.3	23.4	28.4	12	11.5	41.7	17129.98
01 April	15:40	50	3.2	23.4	21.4	12.1	11.7	37.3	
01 April	15:45	55	3.1	21	29.9	12.3	12	37.4	
01 April	15:50	60	3	22.5	75.1	12.3			
01 April	16:00	70	2.4	34.2	55.5	12.1	16.1	49.1	
01 April	16:15	85	2.3	40.9	77.4	12.2	19.1	54.6	17130.23
01 April	16:30	100	2	41.9	59.2	12	23.5	59.5	
01 April	16:45	115		42.7	51.1	11.7	26.2	59.2	
01 April	17:00	130	1.9	41.7	57.4	12	29.7	57	
01 April	17:15	145		39.4	79	11.8	31.9	53	17130.64
01 April	17:30	160	1.6	45.2	64.9	10.	35.2	60.6	
01 April	17:45	175	1.4	49	70.2	10.3	35.3	58.4	
01 April	18:00	200		50.7	74.2	35.2107	35.2		
01 April	19:00	260	1.2	60.4	72.7	9.8	43.2	65.6	
01 April	19:45	305		62	73.1	9.2	47.6	65.3	
01 April	20:00	320		53.5	62.1	8.9	49.7	63.6	
01 April	20:15	335		58.3	68.3	8.6	48.9		17131.72
01 April	20:30	350	0.8	59.5	62.9	8.3	50.4	57.8	
02 April	09:30	1230	0.2	56.8	69.5	7.5	58.2	48.6	
02 April	10:00	1260		57.8	61.1	7.5	60	48.8	17137.15